

# WARDENCLYFFE

## How does Tesla's World Wireless tower work?

By Gary Peterson<sup>1</sup>

An electric current flowing through a conductor carries electrical energy. Earth is an electrical conductor, nearly spherical in shape, insulated in space. It possesses an electric charge relative to the upper atmosphere beginning at about 31 miles or 50 kilometers elevation. When a second body, directly adjacent to Earth, is charged and discharged in rapid succession this causes an equivalent variation of its electrostatic charge resulting in the passage of electric current through the ground. The Tesla coil magnifying transmitter is an electrical machine specifically designed to create as large a displacement as possible of Earth's natural electric charge. It does this by alternately charging and discharging the oscillator's elevated terminal capacitance at a specific frequency, periodically altering the electrostatic charge of the earth, and consequently, with sufficient power, the pressure over its entire surface.

A connection to earth, either directly or through a condenser is essential. – The Disturbing Influence of Solar Radiation on the Wireless Transmission of Energy," *Electrical Review and Western Electrician*, July 6, 1912.

The placement of a grounded Tesla coil receiver tuned to the same frequency as the transmitter at another point on the surface results in the flow of electric current through the earth between the two, "while an equivalent electric displacement occurs in the atmosphere." The electrical displacement takes place predominantly by electrical conduction through the oceans, and metallic ore bodies and similar subsurface structures. The electrical displacement may also be by means of electrostatic induction through the more dielectric regions such as quartz deposits and other non-conducting minerals.

There is no appreciable radiation and the receiver is energized through the earth while an equivalent electric displacement occurs in the atmosphere. – The Disturbing Influence of Solar Radiation on the Wireless Transmission of Energy," *Electrical Review and Western Electrician*, July 6, 1912.

This current can be used at the receiver to drive an electrical load, which in the case of an individual World Wireless Telecommunications System receiver is a sensitive device using only a small amount of energy. This energy transfer technique is suitable for wireless broadband telecommunications in conjunction with low level energy harvesting for battery charging, and possibly for transmission of electrical power in industrial quantities.

### ***What was the intended purpose of the Long Island Wardencllyffe tower and the additional towers to be built around the world?***

The Wardencllyffe Tower facility was a commercial venture designed for trans-Atlantic wireless telecommunications, broadcasting and for proof-of-concept demonstrations of global wireless power transmission. These applications were mentioned in 1923 in the Wardencllyffe Foreclosure Proceedings.

Well, the primary purpose of the tower, your Honor, was to telephone, to send the human voice and likeness around the globe through the instrumentality of the earth. That was my discovery that I announced in 1893, and now all the wireless plants are doing that. There is no other system being used. And the idea was to reproduce this apparatus and then connect it just with a central station and telephone office, so that you may pick up your telephone and if you wanted to talk to a telephone subscriber in Australia you would simply call up that plant and the plant would connect immediately with that subscriber, no matter where in the world, and you could talk to him. And I had contemplated to have press messages, stock quotations, pictures for the press and these reproductions of signatures, checks and everything transmitted from there throughout the world. The tower was so designed that I could apply to it any amount of power and I was planning to give a demonstration in the transmission of power which I have so perfected that power can be transmitted clear across the globe with a loss of not more than five per cent, and that plant was to serve as a practical demonstration. And then I was going to interest people in a larger project and the Niagara people had given me 10,000-horse power. – Nikola Tesla On His Work With Alternating Currents and Their Application to Wireless Telegraphy, Telephony, and Transmission of Power, Leland I. Anderson, Editor, 21<sup>st</sup> Century Books, 1992.

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Earlier Tesla had stated,

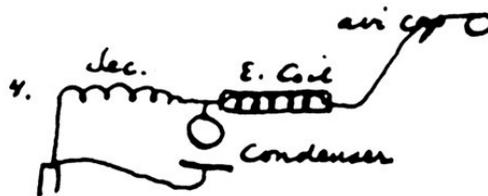
It is intended to give practical demonstrations of these principles with the plant illustrated. As soon as completed, it will be possible for a business man in New York to dictate instructions, and have them instantly appear in type at his office in London or elsewhere. He will be able to call up, from his desk, and talk to any telephone subscriber on the globe, without any change whatever in the existing equipment. An inexpensive instrument, not bigger than a watch, will enable its bearer to hear anywhere, on sea or land, music or song, the speech of a political leader, the address of an eminent man of science, or the sermon of an eloquent clergyman, delivered in some other place, however distant. In the same manner any picture, character, drawing, or print can be transferred from one to another place. Millions of such instruments can be operated from but one plant of this kind. More important than all of this, however, will be the transmission of power, without wires, which will be shown on a scale large enough to carry conviction. These few indications will be sufficient to show that the wireless art offers greater possibilities than any invention or discovery heretofore made, and if the conditions are favorable, we can expect with certitude that in the next few years wonders will be wrought by its application." – "The Future of the Wireless Art," Wireless Telegraphy & Telephony, Walter W. Massie & Charles R. Underhill, 1908, pp. 67-71.

Tesla intended to use a 200 kilowatt Westinghouse generator for the Wardencllyffe transmitter power supply. Factoring in an estimated 100 H.P. or 75 kilowatt terrestrial transmission-line loss, this leaves around 125 kW to work with. When demonstrating wireless power transfer the plant could have run the equivalent of about 100 modern-day toaster ovens. Stated another way, the facility would have been capable of powering the heaters, lighting and appliances of a little more than a single all-electric residential house when demonstrating wireless power transmission.

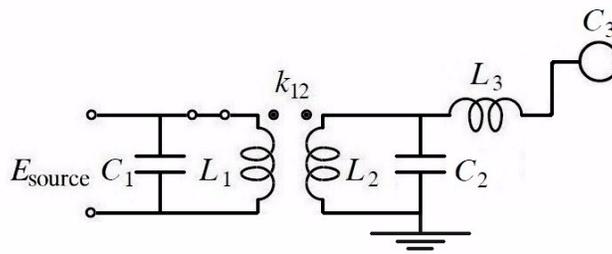
The Wardencllyffe facility was erected in 1901 at Wardencllyffe-On-Sound (now Shoreham) on Long Island, New York. Built entirely of wood, except for spar junction plates and the 55-ton skeleton spheroid at the top, the tower was designed so that every piece of framing could be taken out at any time and replaced if necessary. It was to be the first of many wireless installations constructed near population centers around the world. If plans had moved forward without interruption, the Long Island prototype would have been followed by a second plant built in the British Isles, on the west coast of Scotland near Glasgow. Each facility would include a magnifying transmitter of a design loosely based upon the apparatus assembled at the Colorado Springs Experimental Station in 1899.

The plant in Colorado was merely designed in the same sense as a naval constructor designs first a small model to ascertain all, the quantities before he embarks on the construction of a big vessel. I had already planned most of the details of the commercial plant, subsequently put up at Long Island, except that at that time the location was not settled upon. The Colorado plant I have used in determining the construction of the various parts, and the experiments which were carried on there were for the practical purpose of enabling me to design the transmitters and receivers which I was to employ in the large commercial plant subsequently erected. – Nikola Tesla On His Work With Alternating Currents and Their Application to Wireless Telegraphy, Telephony, and Transmission of Power, Leland I. Anderson, Editor, 21<sup>st</sup> Century Books, 1992, p. 170.

This is a wiring diagram of the preferred wireless magnifying transmitter design developed at the Colorado Springs Experimental Station. The oscillator's primary LC circuit is not shown.



The schematic is redrawn below with standardized labeling of the various components.



Primary capacitor C1 and primary inductor L1, and secondary capacitor C2 and secondary inductor L2 comprise the primary and secondary tuned LC circuits of what is called the master oscillator transformer. Extra coil inductor L3 and elevated terminal capacitance C3 comprise the transmitting element that is connected through the tuned secondary lumped LC driver circuit to a robust ground terminal connection.

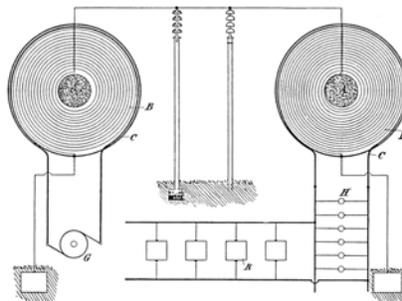
### *How did Tesla envision energy transmission by means of his system?*

Between 1897 and 1902 Tesla applied for ten patents directly related to his wireless system. They describe two different propagation modes that he claimed can be excited by means of his wireless system apparatus. The first involves electrical conduction through the upper atmosphere with a return circuit through Earth. The second depends upon the transmission of sufficient alternating current energy into Earth so it responds by vibrating electrically. In 1932 journalist John J. O'Neill conducted an interview with Tesla in which he talked about these two different methods of using his wireless system apparatus for the transmission of electrical energy.

I also asked him if he is still at work on the project which he inaugurated in the '90's of transmitting power wirelessly anywhere on earth. He is at work on it, he said, and it could be put into operation. . . . He at that time announced two principles which could be used in this project. In one the ionizing of the upper air would make it as good a conductor of electricity as a metal. In the other the power is transmitted by creating "standing waves" in the earth by charging the earth with a giant electrical oscillator that would make the earth vibrate electrically in the same way a bell vibrates mechanically when it is struck with a hammer. . . ." – "Tesla Cosmic Ray Motor May Transmit Power 'Round' Earth," Brooklyn Eagle, July 10, 1932.

### **The Terrestrial Transmission Line with Atmospheric Return Method.**

Present day earth return AC electrical power transmission systems rely on current flowing through the earth plus a single wire insulated from the earth to complete the circuit. In emergencies high-voltage direct current power transmission systems can also operate in the 'single wire with earth return' mode. Elimination of the raised insulated wire, and transmission of high-potential alternating current through the earth with an atmospheric return circuit is the basis of the atmospheric conduction method of wireless electrical power transmission.



**A pair of Tesla coils can be used to transmit and receive electrical energy using the earth as a conductor. The one-wire with ground return electrical power transmission system shown here relies on current flowing through a single elevated wire plus current flowing through the earth to complete the circuit.**

The process is essentially the same as transmitting electricity by conduction through a wire. The earth itself is one of the conducting media involved in this implementation of "the disturbed charge of ground and air system." The other medium is the atmosphere above approximately 3 miles (4.8 km) elevation. While not an ohmic conductor, in this region of the troposphere and upwards, the density or pressure is sufficiently reduced to so that, according to Tesla's theory, the atmosphere's insulating properties can be easily impaired thus allowing an electric current to flow. Theory further asserts that the conducting region is developed through the process of atmospheric ionization in which the affected portions thereof are changed to plasma. The presence of the magnetic fields developed by each plant's helical resonator suggests that an embedded magnetic field and flux linkage might also be involved, with flux linkage with Earth's natural magnetic field being a possibility. The atmosphere below 3 miles is also a propagating medium for a portion of the above-ground circuit. Being an insulating medium, electrostatic induction would be involved rather than true electrical conduction.

The earth is 4,000 miles radius. Around this conducting earth is an atmosphere. The earth is a conductor; the atmosphere above is a conductor, only there is a little stratum between the conducting atmosphere and the conducting earth which is insulating. Now, you realize right away that if you set up differences of potential at one point, say, you will create in the

media corresponding fluctuations of potential. But, since the distance from the earth's surface to the conducting atmosphere is minute, as compared with the distance of the receiver at 4,000 miles, say, you can readily see that the energy cannot travel along this curve and get there, but will be immediately transformed into conduction currents, and these currents will travel like currents over a wire with a return. The energy will be recovered in the circuit, not by a beam that passes along this curve and is reflected and absorbed, . . . but it will travel by conduction and will be recovered in this way. – Nikola Tesla On His Work With Alternating Currents and Their Application to Wireless Telegraphy, Telephony, and Transmission of Power, Leland I. Anderson, Editor, 21<sup>st</sup> Century Books, 1992, pp. 129-130.

Tesla believed the practical construction limitation imposed upon the height of the elevated terminals could be overcome by charging them to a sufficiently high electrical potential. With a highly energetic transmitter, as was intended at Wardenclyffe, the elevated terminal would be charged to the point where the atmosphere around and above the facility would become strongly ionized. This would lead to a flow of true conduction currents between the two terminals by a path up to and through the upper atmosphere, and back down to the other facility. He believed the ionization of the atmosphere above a plant's elevated terminal might be facilitated by the use of a vertical ionizing beam of ultraviolet radiation to form what might be called a high-voltage plasma transmission line. Upon further investigation he found this idea not to be practical.

I mastered the technique of high potentials sufficiently for enabling me to construct and operate, in 1899, a wireless transmitter developing up to twenty million volts. Some time before I contemplated the possibility of transmitting such high tension currents over a narrow beam of radiant energy ionizing the air and rendering it, in measure, conductive. After preliminary laboratory experiments, I made tests on a large scale with the transmitter referred to and a beam of ultra-violet rays of great energy in an attempt to conduct the current to the high rarefied strata of the air and thus create an auroral such as might be utilized for illumination, especially of oceans at night. I found that there was some virtue in the principal but the results did not justify the hope of important practical applications. . . . – “The New Art of Projecting Concentrated Non-dispersive Energy Through Natural Media System of Particle Acceleration for Use in National Defense,” circa May 16, 1935. (Reprinted as part of Nikola Tesla's Teleforce & Telegeodynamics Proposals, edited by Leland I. Anderson, 21<sup>st</sup> Century Books, 1998, pp. 11-33.]

### **The Terrestrial Transmission Line Zenneck Surface Wave Method.**

Given the apparent impracticality of atmospheric conduction method, Tesla directed his attention to the second technique that involves Earth's conductivity and the excitation of a non-radiating guided wave propagation mode known as the Zenneck surface wave.

The Zenneck wave was first identified in 1907, when Jonathan Zenneck described an electromagnetic wave that travels over a flat surface bounding two homogeneous media of different conductivity and dielectric constants, which exists as an exact solution to Maxwell's equations. [J. Zenneck, “Über die Fortpflanzung ebener elektromagnetischer Wellen längs einer ebenen Leiterfläche und ihre Beziehung zur drahtlosen Telegraphie” (“On the propagation of plane electromagnetic waves along a planar conductor surface and its relation to wireless telegraphy”), *Ann. Physik* [4] 23, 846 (1907).] The Zenneck wave has a phase velocity greater than that of light and its field strength falls off exponentially at a rate of  $e^{-\alpha d}/\sqrt{d}$  in the direction of propagation along the interface, where  $\alpha$  is a frequency-dependent attenuation constant. As the wavelength is increased the propagation attenuation decreases and the fields extend over a greater distance. The field intensity of the wave is at a maximum at the bounding surface, has a small attenuation in the direction along the interface, and high attenuation with height above the surface. In 1909 Arnold Sommerfeld performed a theoretical analysis of the propagation of radio waves around the earth, solving for the problem of a vertical dipole over a finitely conducting homogeneous ground.<sup>2</sup> He divided the expression for the resulting field into “space wave” and “surface wave” components. The surface wave part had nearly identical properties to the unique plane surface wave solution to Maxwell's equations that had been identified by Jonathan Zenneck two years previously. The field amplitudes varied inversely as the square root of the horizontal distance from the source and decayed exponentially with height above the interface. [Sommerfeld, Arnold N., “Über die Ausbreitung der Wellen in der drahtlosen Telegraphie,” *Annalen der Physik*, March 16, 1909 (Vol. 28, No. 4), pp. 665-736.]

Tesla was clear on the point that his wireless system did not depend upon the production of electromagnetic radiation or radio waves, also known as the Hertz wave.

There is no radiation in this case. You see, the apparatus which I devised was an apparatus enabling one to produce tremendous differences of potential and currents in an antenna circuit. These requirements must be fulfilled, whether you transmit by currents of conduction, or whether you transmit by electromagnetic [space] waves. You want high potential currents, you want a great amount of vibratory energy; but you can graduate this vibratory energy. By proper design and

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<sup>2</sup> See the chapter “Bell Labs and the Radio Surface Wave Propagation Experiment” by James and Kenneth Corum, elsewhere in this book, for a history of radio-wave propagation theory development as it relates to the physical reality of the Zenneck surface wave.

choice of wave lengths, you can arrange it so that you get, for instance, 5 percent in these electromagnetic waves and 95 percent in the current that goes through the earth. That is what I am doing. Or, you can get, as these radio men, 95 percent in the energy of electromagnetic waves and only 5 percent in the energy of the current. . . . The apparatus is suitable for one or the other method. I am not producing radiation in my system; I am suppressing electromagnetic waves. But, on the other hand, my apparatus can be used effectively with electromagnetic waves. The apparatus has nothing to do with this new method except that it is the only means to practice it. So that in my system, you should free yourself of the idea that there is radiation, that energy is radiated. It is not radiated; it is conserved.

He goes on to say,

It is just like this: I have invented a knife. The knife can cut with the sharp edge. I tell the man who applies my invention, you must cut with the sharp edge. I know perfectly well you can cut butter with the blunt edge, but my knife is not intended for this. You must not make the antenna give off 90 percent in electromagnetic and 10 percent in current waves, because the electromagnetic waves are lost by the time you are a few arcs around the planet, while the current travels to the uttermost distance of the globe and can be recovered. This view, by the way, is now confirmed. Note, for instance, the mathematical treatise of Sommerfeld, who shows that my theory is correct, that I was right in my explanations of the phenomena. – Nikola Tesla On His Work With Alternating Currents and Their Application to Wireless Telegraphy, Telephony, and Transmission of Power, Leland I. Anderson, Editor, 21<sup>st</sup> Century Books, 1992, p. 75.

A basic difference between those transmitters designed to excite radio space waves and those designed to excite Zenneck surface waves is in the geometry of the launching structure. In the case of a simple monopole radio wave antenna for example, the vertical height would be close to one-quarter of a wavelength of the operating frequency. The launching structure of a Tesla coil transmitter designed to operate at the same frequency would have a vertical height that is only a small fraction of one-quarter wavelength.

Tesla's claim that "his" system is different from "Hertz's" is based on the fact that at low frequencies, and with small antenna in terms of wavelength, radiation of Hertzian type electromagnetic wave is small. "Tesla's waves," if we are allowed to use such a name, are in fact surface waves in modern terminology (as known, this type of waves are significant in the range of long waves) or the Earth cavity waves, known better as ELF (extremely low frequency) waves. In "pure Hertzian" wave (in Tesla's terminology) there is no induced current in the Earth, except on reflection region which is not essential for the discussion. In contrast to the latter, guided surface or ELF waves do not exist without current in the Earth crust. Having this in mind, we can conclude that there is a truth in Tesla's statements about specific behavior of low frequency, guided to the Earth [surface] waves. – Marinčić, Aleksandar (1990). "Research of Nikola Tesla in Long Island Laboratory," Energy and Development at the International Scientific Conference in Honor of the 130th Anniversary of the Birth of Nikola Tesla". *The Tesla Journal, An International Review of the Sciences and the Humanities* (Tesla Memorial Society, Inc.) (Numbers 6 & 7): 25-28.

## Earth Resonance

With a sufficiently powerful magnifying transmitter operating at a frequency at or below 25 kHz, Tesla believed its emissions would reach to the opposite side of the earth and be reflected back, thus creating stationary terrestrial waves. He explained that Earth has self-inductance and also capacitance, the latter which is relative to the conducting region of the upper atmosphere. This natural electrical system behaves as a resonant LC circuit when it is electrically excited at a harmonic of the 11.78 Hz fundamental earth resonance frequency. The operating frequencies used at Wardenclyffe ranged from 1,000 Hz to 100 kHz, and those up to about 25 kHz were found "to be most economical."

At present it may be sufficient, for the guidance of experts, to state that the waste of energy is proportional to the product of the square of the electric density induced by the transmitter at the earth's surface and the frequency of the currents. Expressed in this manner it may not appear of very great practical significance. But remembering that the surface density increases with the frequency it may also be stated that the loss is proportional to the cube of the frequency. With waves 300 meters in length [1 MHz] economic transmission of energy is out of the question, the loss being too great. When using wave-lengths of 6,000 meters [50 kHz] it is still noticeable though not a serious drawback. With wave-lengths of 12,000 meters [25 kHz] it becomes quite insignificant and on this fortunate fact rests the future of wireless transmission of energy. – "The Disturbing Influence of Solar Radiation On the Wireless Transmission of Energy," *Electrical Review and Western Electrician*, July 6, 1912.

In describing his work he speaks of the Earth resonance principle over and over again. Following an experiment at Colorado Springs in which sufficient energy was transmitted through the ground to cause sparking on the oscillator's lightning arresters, he wrote,

This is certainly extraordinary for it shows more and more clearly that the earth behaves simply as an ordinary conductor and that it will be possible, with powerful apparatus, to produce the stationary waves which I have already observed in the displays of atmospheric electricity. – Marincic, Aleksandar (1978). Nikola Tesla Colorado Springs Notes 1899–1900. Nolit. p. 103; July 24, 1899.

In the patent *Art of Transmitting Electrical Energy Through the Natural Mediums* he described some of the necessary requirements to achieving earth resonance.

The powerful electrical oscillations in the system E C D being communicated to the ground cause corresponding vibrations to be propagated to distant parts of the globe, whence they are reflected and by interference with the outgoing vibrations produce stationary waves the crests and hollows of which lie in parallel circles relatively to which the ground-plate E may be considered to be the pole. Stated otherwise, the terrestrial conductor is thrown into resonance with the oscillations impressed upon it just like a wire.

Three requirements seem to be essential to the establishment of the resonating condition.

First. The earth's diameter passing through the pole should be an odd multiple of the quarter wave length--that is, of the ratio between the velocity of light--and four times the frequency of the currents.

Second. It is necessary to employ oscillations in which the rate of radiation of energy into space in the form of hertzian or electromagnetic waves is very small . . . say smaller than twenty thousand per second, though shorter waves might be practicable. The lowest frequency would appear to be six per second, in which case there will be but one node, at or near the ground-plate.

Third. Irrespective of frequency the wave or wave-train should continue for a certain interval of time, estimated to be not less than one-twelfth or probably 0.08484 of a second [11.78 Hz] and which is taken in passing to and returning from the region diametrically opposite the pole. – *Art of Transmitting Electrical Energy Through the Natural Mediums*, May 16, 1900, U.S. Patent No. 787,412, Apr. 18, 1905.

In response to objections raised by U.S. Patent Examiner G.C. Dean regarding these three requirements, Tesla's attorneys responded,

These three requirements, as stated are in agreement with his numerous experimental observations. . . . We would point out that the specification does not deal with theories, but with facts which applicant has experimentally observed and demonstrated again and again, and in the commercial exploitation of which he is engaged. – Corum, J. F.; Corum, K. L.; Daum, J. F. X. (1987). "Spherical Transmission Lines and Global Propagation, An Analysis of Tesla's Experimentally Determined Propagation Model." CPG Communications. p. 3n.

In the article *The Problem of Increasing Human Energy* he writes of an observation made at Colorado Springs, convincing himself that Earth can be electrically resonated.

That communication without wires to any point of the globe is practicable with such apparatus would need no demonstration, but through a discovery which I made I obtained absolute certitude. Popularly explained, it is exactly this: When we raise the voice and hear an echo in reply, we know that the sound of the voice must have reached a distant wall, or boundary, and must have been reflected from the same. Exactly as the sound, so an electrical wave is reflected, and the same evidence which is afforded by an echo is offered by an electrical phenomenon known as a "stationary" wave — that is, a wave with fixed nodal and ventral regions. Instead of sending sound-vibrations toward a distant wall, I have sent electrical vibrations toward the remote boundaries of the earth, and instead of the wall the earth has replied. In place of an echo I have obtained a stationary electrical wave, a wave reflected from afar. – "The Problem of Increasing Human Energy," *Century Magazine*, June 1900]

In 1905 he wrote of the challenge he encountered in developing an oscillator capable of exciting Earth resonance.

This problem was rendered extremely difficult, owing to the immense dimensions of the planet . . . but by gradual and continuous improvements of a generator of electrical oscillations . . . I finally succeeded in reaching electrical movements or rates of delivery of electrical energy not only approximately, but, as shown in comparative tests and measurements, actually surpassing those of lightning discharges. . . . By the use of such a generator of stationary waves and receiving apparatus properly placed and adjusted in any other locality, however remote, it is practicable to transmit intelligible signals, or to control or actuate at will any one apparatus for many other important and valuable purposes. – "Tesla's Reply to Edison," *English Mechanic and World of Science*, July 14, 1905, p. 515.

And, in 1908 he summarized this achievement and describe some of the ramifications.

When the earth is struck mechanically, as is the case in some powerful terrestrial upheaval, it vibrates like a bell, its period being measured in hours. When it is struck electrically, the charge oscillates, approximately, twelve times a second. By impressing upon it current waves of certain lengths, definitely related to its diameter, the globe is thrown into resonant vibration like a wire, stationary waves forming, the nodal and ventral regions of which can be located with mathematical precision. Owing to this fact and the spheroidal shape of the earth, numerous geodetically and other data, very accurate and of the greatest scientific and practical value, can be readily secured. Through the observation of these astonishing phenomena we shall soon be able to determine the exact diameter of the planet, its configuration and volume, the extent of its elevations and depressions, and to measure, with great precision and with nothing more than an electrical device, all terrestrial distances.

In the densest fog or darkness of night, without a compass or other instruments of orientation, or a timepiece, it will be possible to guide a vessel along the shortest or orthorhombic path, to instantly read the latitude and longitude, the hour, the distance from any point, and the true speed and direction of movement. By proper use of such disturbances a wave may be made to travel over the earth's surface with any velocity desired, and an electrical effect produced at any spot which can be selected at will and the geographical position of which can be closely ascertained from simple rules of trigonometry.

This mode of conveying electrical energy to a distance is not 'wireless' in the popular sense, but a transmission through a conductor, and one which is incomparably more perfect than any artificial one. All impediments of conduction arise from confinement of the electric and magnetic fluxes to narrow channels. The globe is free of such cramping and hinderment. It is an ideal conductor because of its immensity, isolation in space, and geometrical form. Its singleness is only an apparent limitation, for by impressing upon it numerous non-interfering vibrations, the flow of energy may be directed through any number of paths which, though bodily connected, are yet perfectly distinct and separate like ever so many cables. Any apparatus, then, which can be operated through one or more wires, at distances obviously limited, can likewise be worked without artificial conductors, and with the same facility and precision, at distances without limit other than that imposed by the physical dimensions of the globe. – “The Future of the Wireless Art,” Wireless Telegraphy & Telephony, Walter W. Massie & Charles R. Underhill, 1908, pp. 67-71.

*What is the function of the tunnels below the tower and its mushroom-shaped dome?*

### **The Ground Terminal Electrode**

Electrical energy can be transmitted through inhomogeneous Earth with low loss because the net resistance between Earth antipodes is less than one ohm, as analytically demonstrated by James Corum in *Spherical Transmission Lines and Global Propagation, An Analysis of Tesla's Experimentally Determined Propagation Model*. The resistance of Earth is negligible due to its immense cross-sectional area and relative shortness as compared to its diameter. The greatest losses are apt to occur at the points where the transmitting-receiving plants and dedicated receiving stations are connected with the ground. The key to good performance is a robust ground connection. This is why Tesla stated:

You see the underground work is one of the most expensive parts of the tower. In this system that I have invented it is necessary for the machine to get a grip of the Earth, otherwise it cannot shake the Earth. It has to have a grip on the Earth so that the whole of this globe can quiver, and to do that it is necessary to carry out a very expensive construction. – Nikola Tesla On His Work With Alternating Currents and Their Application to Wireless Telegraphy, Telephony, and Transmission of Power, Leland I. Anderson, Editor, 21<sup>st</sup> Century Books, 1992, p. 203.

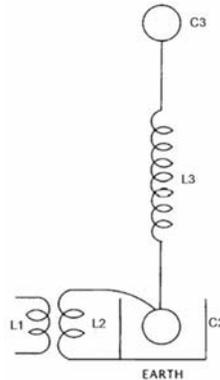
And again,

However surprising, it is a fact that a sphere of the size of a little marble offers a greater impediment to the passage of a current than the whole earth. Every experiment, then, which can be performed with such a small sphere, can likewise be carried out, and much more perfectly, with the immense globe on which we live. This is not merely a theory, but a truth established in numerous and carefully conducted experiments. – “The Future of the Wireless Art,” Wireless Telegraphy & Telephony, Walter W. Massie & Charles R. Underhill, 1908, pp. 67-71.

On Long Island, Tesla continued to refine the magnifying transmitter with a focus on designing the underground portion of the tower that served as a massive ground terminal electrode connecting the transmitter to Earth. Describing one of his critical scientific observations he stated,

In many instances when working with an oscillatory system transmitting its vibrations upon the ground I observed that the effects produced were stronger when the oscillating system was connected to earth through a condenser. This may have been due to some secondary causes but theoretically there are reasons for expecting such a result. – Nikola Tesla - From Colorado to Long Island: Research Notes - Colorado Springs 1899-1900 - New York 1900-1901, Nikola Tesla Museum, Belgrade.

As a further improvement, the master oscillator secondary shunt capacitor C2 was combined with the ground terminal electrode.



Shown here is a magnifying transmitter design dated May 19, 1901, placing it at Wardenclyffe. Included are, L1, L2, C2, L3, C3. Notice how the master oscillator secondary capacitor C2 and the ground terminal electrode are combined as a single unit. – Credit: Nikola Tesla - From Colorado to Long Island: Research Notes - Colorado Springs 1899-1900 - New York 1900-1901, Nikola Tesla Museum, Belgrade. Long Island, N.Y.

Some additional ground terminal construction details were provided by Tesla during the 1923 foreclosure proceedings:

A. *Yes. You see the underground work is one of the most expensive parts of the tower. In this system that I have invented it is necessary for the machine to get a grip of the earth; otherwise it cannot shake the earth. It has to have a grip on the earth so that the whole of this globe can quiver, and to do that it is necessary to carry out a very expensive construction. I had in fact invented special machines. But I want to say this underground work belongs to the tower.*

By Mr. Hawkins:

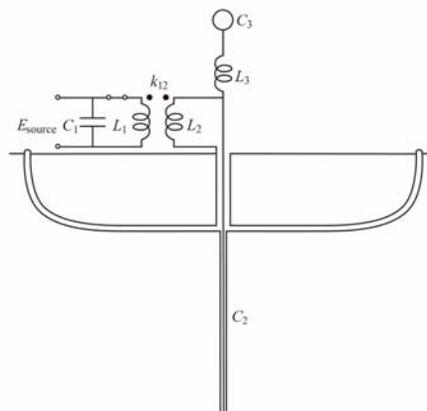
Q. Anything that was there, tell us about it.

A. *There was, as your Honor states, a big shaft about ten by twelve feet goes down about one hundred and twenty feet and this was first covered with timber and the inside with steel and in the center of this there was a winding stairs going down and in the center of the stairs there was a big shaft again through which the current was to pass, and this shaft was so figured in order to tell exactly where the nodal point is, so that I could calculate every point of distance. For instance I could calculate exactly the size of the earth or the diameter of the earth and measure it exactly within four feet with that machine.*

Q. And that was a necessary appurtenance to your tower?

A. *Absolutely necessary. And then the real expensive work was to connect that central part with the earth, and there I had special machines rigged up which would push the iron pipe, one length after another, and I pushed these iron pipes, I think sixteen of them, three hundred feet, and then the current through these pipes takes hold of the earth. Now that was a very expensive part of the work, but it does not show on the tower, but it belongs to the tower.*

Based upon available drawings and descriptions of the underground work the following simplified schematic may be a fair representation of the Long Island facility.



Shown are the earth terminal electrode assembly and also the legendary Wardenclyffe tunnels. The cylindrical subterranean chamber with its insulated central electrode, comprising capacitor C2, would have been oil-filled. According to George Scherff the brick-lined passages starting at the bottom of the 120-foot deep vertical and curving up to the surface are for ground water drainage. They serve to keep the earth around the tower dry, thus reducing capacitive coupling of the elevated terminal with the surrounding terrestrial ground plane and mitigating as much as possible the partial short circuit. A sump pump would have been placed into continuous operation for the water drainage system to be effective.

Mr. Scherff, the private secretary of the inventor, told an inquirer that the companionway led to a small drainage passage built for the purpose of keeping the ground about the tower dry. – “Cloudborn Electric Wavelets To Encircle the Globe,” *New York Times*, March 27, 1904.

In the well were four stone-lined tunnels, each of which gradually rose back to the surface. Large enough for a man to crawl through, they emerged like isolated, igloo-shaped brick ovens three hundred feet from the base of the tower. – Seifer, Marc, *Wizard : The Life and Times of Nikola Tesla*, Chapter 33, p. 291.

### The Elevated Air Terminal Electrode

It appears that Tesla discovered some problems with the Colorado Springs magnifying transmitter design. And, when he began operational testing of the Wardenclyffe plant in July 1903 he was not satisfied with its performance. Experiments with the 1899 through 1901 transmitter configuration led him to write his financial underwriter J.P. Morgan on November 5, 1903,

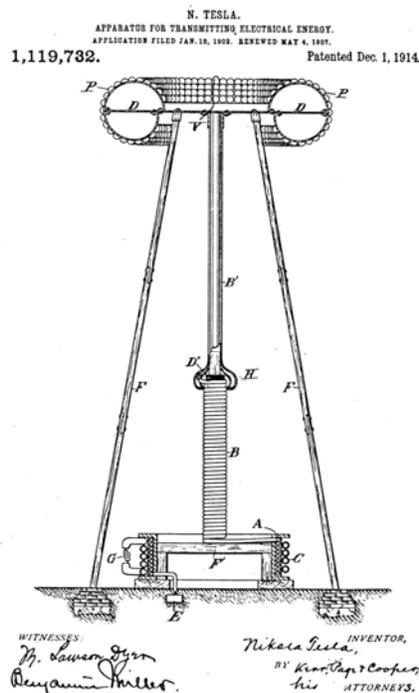
Dear Mr. Morgan:-

The enclosed bears out my statement made to you over a year and a half ago. The old plant has never worked beyond a few hundred miles. Apart of imperfections of the apparatus design there were four defects, each of which was fatal to success. It does not seem probable that the new plant will do much better, for these faults were of a widely different nature and difficult to discover.

As to the remedies, I have protected myself in applications filed 1900-1902, still in the office.

Yours faithfully,  
N. Tesla

The "old plant" probably refers to the Colorado Springs Experimental Station. As for the "remedies" protected in applications filed between 1900 and 1902, and "still in the office," the only patented invention meeting these criteria is “Apparatus for Transmitting Electrical Energy,” No. 1,119,732, issued on December 1, 1914.

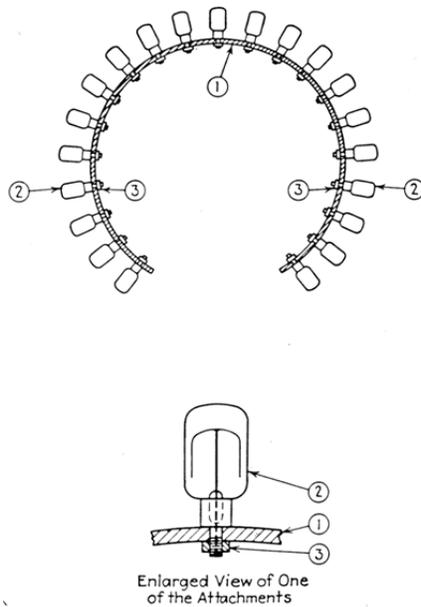


Shown are the closely coupled primary C and secondary A of the master oscillator transformer. The lower end of the tertiary or helix extra coil resonator is connected to the upper end of the relatively low impedance secondary. The lower end of the transformer secondary is connected to a substantial ground terminal set in the bulk composite material that is Earth as described above. The upper end of the extra coil is connected to the elevated terminal insulated in space on non-conducting supports.

Comparing the Colorado Springs apparatus with the Wardencllyffe design, one obvious difference is in the geometry of the elevated terminal electrode, which is now greatly enlarged and covered with closely spaced hemispherical attachments. This modification allowed the air terminal to be charged to a much higher potential than was previously possible, due to the prevention of streamers.

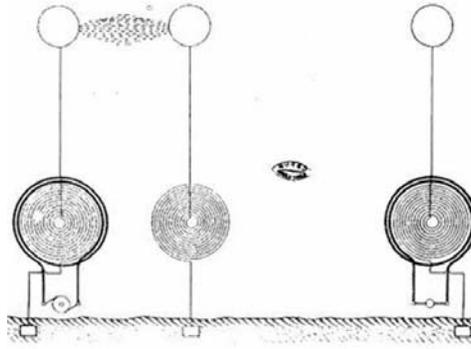
The design of an even more advanced elevated terminal than the 1902 version was published in 1935 in, *The New Art of Projecting Concentrated Non-dispersive Energy Through Natural Media – System of Particle Acceleration for Use in National Defense*.

FIG. 3  
NEW TERMINAL FOR EXCEEDINGLY HIGH POTENTIALS  
CONSISTING OF SPHERICAL FRAME WITH ATTACHMENTS



As will appear from the inspection of the drawing, the spherical frame of the terminal is equipped with devices, one of which is shown in the enlarged view below and comprises a bulb 2, of glass or other insulating material and an electrode of thin sheet suitable rounded. The latter is joined by a supporting wire to a metallic socket adapted for fastening to the frame 1, by means of nut 3. The bulb is exhausted to the very highest vacuum obtainable and the electrode can be charged to an immense density. Thus, it is made possible to raise the potential of the terminal to any value desired, so to speak, without limit, and the usual losses are avoided. I am confident that as much as one hundred million volts will be reached with such a transmitter providing a tool of inestimable value for practical purposes as well as scientific research. – “The New Art of Projecting Concentrated Non-dispersive Energy Through Natural Media – System of Particle Acceleration for Use in National Defense,” circa May 16, 1935. (Reprinted as part of Nikola Tesla's Teleforce & Telegeodynamics Proposals, edited by Leland I. Anderson, 21<sup>st</sup> Century Books, 1998, pp. 11-33.)

This is the basic earth-resonance transmitter configuration as incorporated into the initial Wardencllyffe design. To the right is a Tesla coil receiver. – Leland Anderson, “Rare Notes from Tesla on Wardencllyffe,” *Electric Spacecraft*, Issue 26, Apr/May/June 1997.



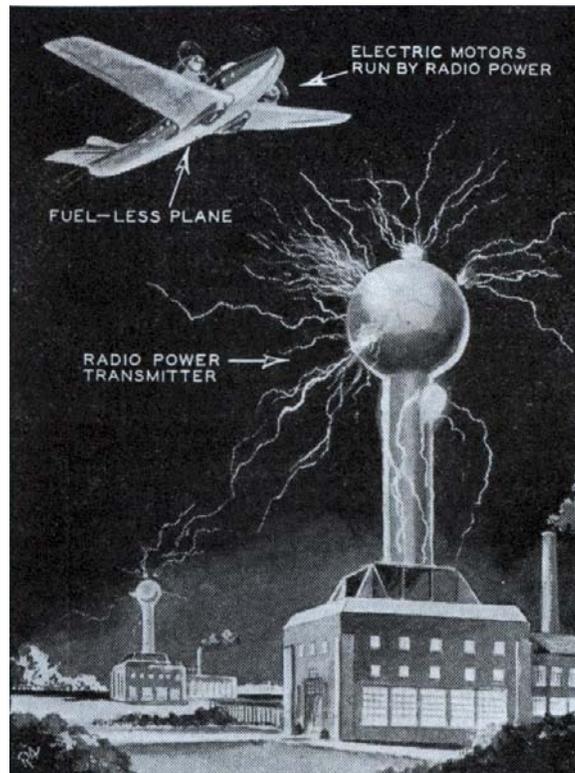
Tesla described this configuration in a 1906 patent.

I shall typically illustrate the manner of applying my discovery by describing one of the specific uses of the same - namely, the transmission of intelligible signals or messages between distant points. . . . For the present it will be sufficient to state that the planet behaves like a perfectly smooth or polished conductor of inappreciable resistance with capacity and self-induction uniformly distributed along the axis of symmetry of wave propagation and transmitting slow electrical oscillations without sensible distortion and attenuation. . . . The specific plan of producing the stationary waves, here-in described, might be departed from. For example, the circuit which impresses the powerful oscillations upon the earth might be connected to the latter at two points. . . . In collecting the energy of these disturbances in any terrestrial region at a distance from their source, for any purpose and, more especially, in appreciable amounts, the most economical results will be generally secured by the employment of my synchronized receiving transformer. – Art of Transmitting Electrical Energy Through the Natural Mediums, April 17, 1906, Canadian Patent No. 142,352, August 13, 1912.

These words harken back to a statement made in 1893.

Now, it is quite certain that at any point within a certain radius of the source S a properly adjusted self-induction and capacity device can be set in action by resonance. But not only can this be done, but another source S1 . . . similar to S . . . can be set to work in synchronism with the latter, and the vibration thus intensified and spread over a large area. . . . – “On Light and Other High Frequency Phenomena,” Franklin Institute, Philadelphia and National Electric Light Association, St. Louis, 1893.

The following drawing shows a similar earth-resonance transmitter. In this case the two side-by-side synchronized resonator structures are both energized by separate power plants. The drawing is from Modern Mechanix, July 1934, *Radio Power will Revolutionize the World* as told by Tesla to Alfred Albelli. The illustration is captioned, “We are on the threshold of a gigantic revolution, based on the commercialization of the wireless transmission of power.”



While the distant future of Tesla World Wireless system technology may be industrial power transmission, one immediate application is the harvesting of electrical energy in combination with broadband wireless telecommunications. Great possibilities may be easily achieved. Here are some suggested services that might become available:

- Enhanced emergency alert and response resources, including global 911 services and passive transponder-type locator beacons;
- Emergency battery trickle charging for mobile devices;
- Global common-carrier wireless telecom services with no 'dead' zones;
- Global multi-channel broadcasting (digital radio and television);
- Global broadband wireless Internet backbone to complement middle-mile and last-mile fiber-optic infrastructure;
- Global synchronization of precision timekeepers;
- Enhanced Deep Space Network.

All of Tesla's achievements in the area of wireless transmission have been formally validated through replication by others, with the exception of the earth resonance principle. Given the fact that, to date, all of his other patented inventions in this area have been demonstrated as fully functional and reproducible, one cannot help but look forward to the day when empirical evidence is presented that fills in this one missing piece of the puzzle. Closing with Tesla's own words,

I gave to the world a wireless system of potentialities far beyond anything before conceived. I made explicit and repeated statements that I contemplated transmission, absolutely unlimited as to terrestrial distance and amount of energy. But, although I have overcome all obstacles which seemed in the beginning unsurmountable and found elegant solutions of all the problems which confronted me, yet, even at this very day, the majority of experts are still blind to the possibilities which are within easy attainment. – "The True Wireless," *Electrical Experimenter*, May 1919.