PURSUING TESLA'S VISION

Gary Peterson

PURSUING TESLA'S VISION Creation of a Tesla Curriculum

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Preface

In the children's game 'Pass it Along,' a group of kids line up and the first one whispers a message to the next and so on down the line until the last player announces the received message to the entire group. "Errors typically accumulate in the retellings, so the statement announced by the last player differs significantly, and often amusingly, from the one uttered by the first. Reasons for changes include anxiousness or impatience, erroneous corrections, and that some players may deliberately alter what is being said to guarantee a changed message by the end of the line." [Wikipedia]

Over the last one-hundred or so years, the largely word-of-mouth recounting of Tesla's engineering legacy has, in certain aspects, resembled this game. Some facts have been obscured and errors have entered into picture that is being drawn of this pioneering inventor's work. Faced with the large volume of material now available, particularly on the Internet, it's becoming more and more difficult to distinguish between truth and that which is only hearsay, having no scientific basis in fact.

Teachers must have adequate tools at their disposal to counteract this phenomenon. This is the primary goal of the proposed Tesla Curriculum; to harness the student's eagerness, to foster deliberation and critical thinking, to encourage rigor and attention to detail, and goodness and honesty in all that they seek to do throughout their adult lives.

The following presentation is intended specifically for educators who wish to use the example of Nikola Tesla in guiding their students who are thinking about a career in the physical sciences, and the fields of mechanical and electrical engineering.

Introduction

Tesla's fundamental design for an AC power system evolved over the years. Having stood the test of time, the result has been an improvement of the human condition. The same holds true for his four-tuned-circuit wireless transmission-reception system, and other innovations that are described in Part 1 of this presentation. This being said, it's also worthwhile to pay some attention to those discoveries that have received only limited consideration as to their practicality and or usefulness.

What can be done to expedite a Tesla-technology based industrial renaissance?

Tesla is known to have said,

If you are desirous of hastening the accomplishment of still greater and further-reaching wonders you can do no better than by emphatically opposing any measure tending to interfere with the free commercial exploitation of water power and the wireless art. [1]

What are the political hurdles associated with pursuit of the yet-to-be-adopted portions of Tesla's engineering legacy?

So absolutely does human progress depend on the development of [water power and the wireless art] that the smallest impediment, particularly through the legislative bodies of this country, may set back civilization and the cause of peace for centuries. [1]

What does the future hold for wireless telecommunications?

The following words were written about the World Wireless system in 1905.

It is not a dream, it is a simple feat of scientific electrical engineering, only expensive—blind, faint-hearted, doubting world! [2]

And, this was written in 1908.

Nothing could be further from my thought than to call wireless telephony around the world "the greatest achievement of humanity" as reported. This is a feat which, however stupifying, can be readily performed by any expert. I have myself constructed a plant for this very purpose. The wireless wonders are only seeming, not results of exceptional skill, as popularly believed. The truth is the electrician has been put in possession of a veritable lamp of Aladdin. All he has to do is to rub it. Now, to rub the lamp of Aladdin is no achievement. [1]

What are the risks associated with Tesla technology?

As with the harnessing of nuclear reactions for the generation of electrical energy and for other useful purposes, the development of World Wireless carries with it certain hazards to life and human welfare. Perhaps the greatest of these is the potential for weaponization,

Even now wireless power plants could be constructed by which any region of the globe might be rendered uninhabitable without subjecting the population of other parts to serious danger or inconvenience. [1]

There are also legitimate concerns that implementation of World Wireless system technology at a significant power level might have adverse environmental impacts.

The same as with any other enterprise that deals with high energy levels, there are other potential dangers. The possibility of an industrial accident is ever-present, so the apparatus must be designed and operated with safety in mind.

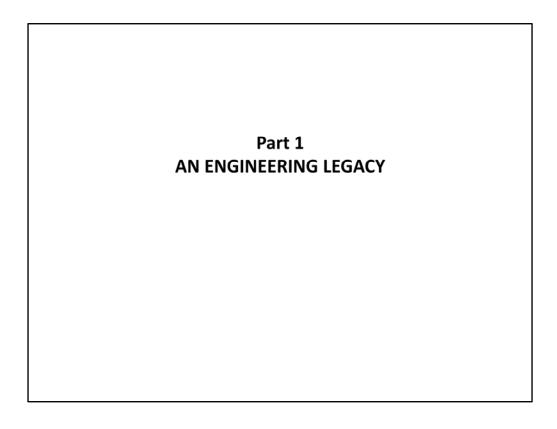
Is the Tesla wireless system an invention whose time has come?

While there might be some local and regional advantages associated with its implementation, assuming the basic principles can be rigorously validated, the greatest benefit will accrue if the system is adopted globally. In any case, problems such as fresh water resource management, food and energy production, climate change and managing the risks associated with unforeseen natural disasters must eventually be addressed with resolute action on a global scale.

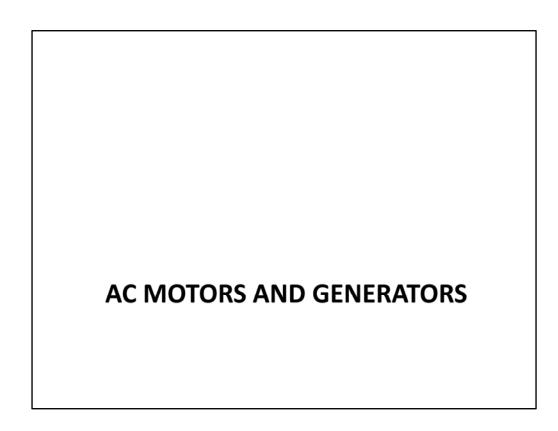
Tesla dedicated his entire adult life to the design and improvement of instruments for "the service of mankind," forming in his mind an image of a world in which all work is performed in an efficient and harmonious manner. AC power, broadcasting, wireless telecommunications, personal computing, high-efficiency fluorescent lighting, X-ray diagnostics and, more recently, WiTricity charging stations are now components of life on Earth that serve to fulfill this vision. While these innovations have changed our world for the better, there are unused Tesla inventions still waiting in the wings that may have the capacity to be of an equivalent and possibly greater value to society. To paraphrase Marshall McLuhan, 'Firstly, we must learn and then we must teach these things in all their subtle details and abundances.'

References

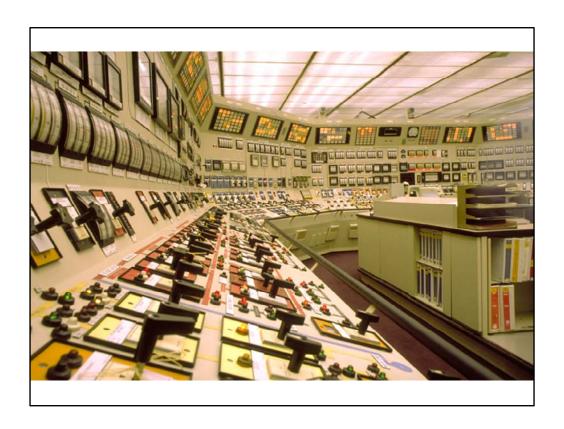
- 1. Tesla, Nikola, "Mr. Tesla's Vision," Letter to the Editor, *New York Times*, April 21, 1908, p. 5, col. 6.
- 2. Tesla, Nikola, "The Transmission of Electrical Energy without Wires as a Means for Furthering Peace," *Electrical World and Engineer*, January 7, 1905.



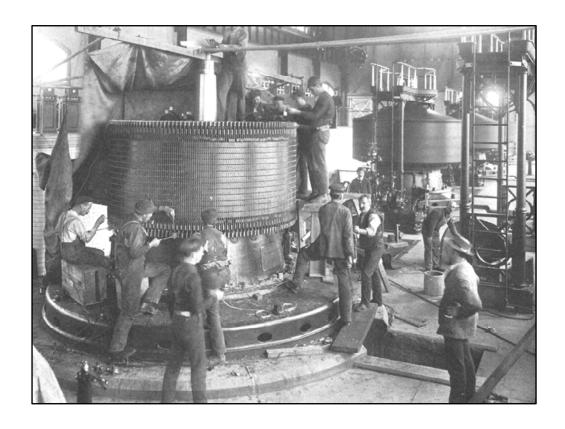
Let's begin by taking a look at those engineering marvels of years gone by as they presently exist in the Modern Era.



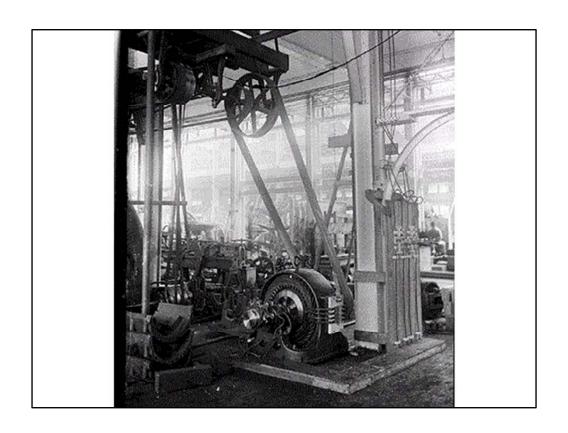
We'll start with low-frequency, heavy current electric power generation, transmission and utilization.



This is the control room of the Watts Bar nuclear power plant near Spring City, Tennessee. This station alone produces 1,200 megawatts of electricity—enough to power 250,000 homes.



Here is an interior shot of the Edward Dean Adams Power Station at Niagara Falls during its construction in 1896. We see the armature of a 5000 H.P. Westinghouse Generator in the process of being assembled. Notice the two generators already spinning in the background.

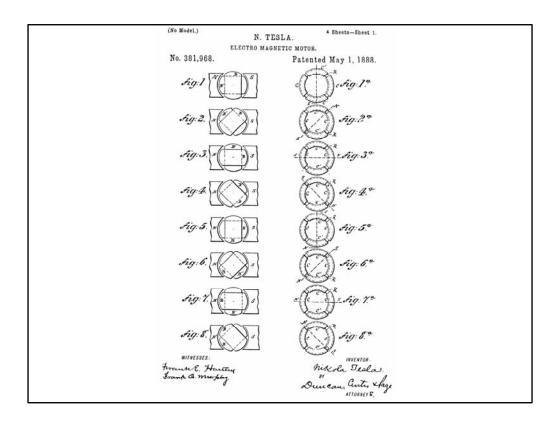


This shows a 40 H.P. 2-phase induction motor ready to drive some factory machinery.



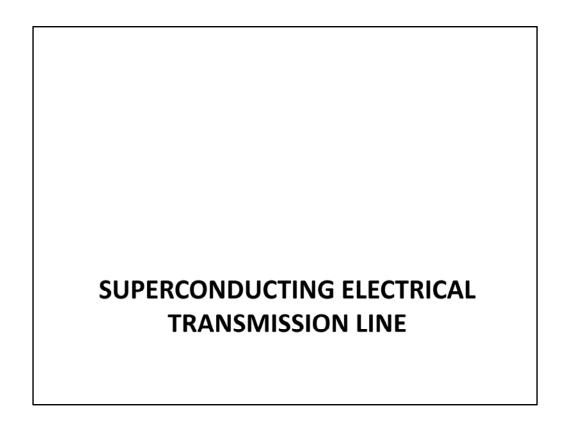
Here is Tesla with an array of poly-phase AC induction motors that embody his rotating magnetic field concept.

[Nikola Tesla Photograph Archive.]



This is a drawing from one of Tesla's original patents related to the poly-phase AC power system.

A motor is employed in which there are two or more independent circuits through which alternate currents are passed at proper intervals, in the manner hereinafter described, for the purpose of effecting a progressive shifting of the magnetism or of the "lines of force" in accordance with the well-known theory, and a consequent action of the motor. It is obvious that a proper progressive shifting of the lines of force may be utilized to set up a movement or rotation of either element of the motor, the armature, or the field-magnet, and that if the currents directed through the several circuits of the motor are in the proper direction no commutator for the motor will be required; but to avoid all the usual commutating appliances in the system I prefer to connect the motor-circuits directly with those of a suitable alternate-current generator. The practical results of such a system, its economical advantages, and the mode of its construction and operation will be described more in detail by reference to the accompanying diagrams and drawings. — U.S. Patent No. 381,968, ELECTRO-MAGNETIC MOTOR, May 1, 1888. Application filed October 12, 1887.

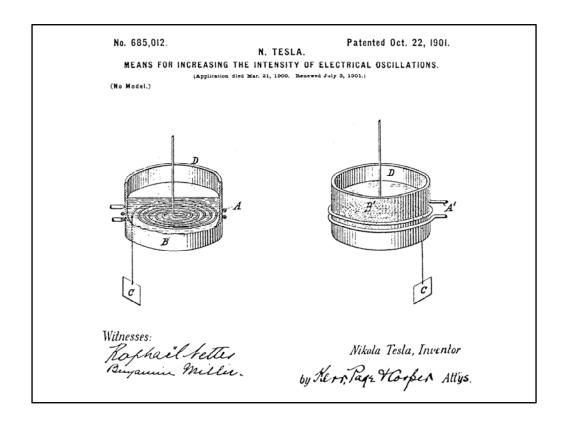


Tesla patented a means for reducing the resistance of electrical conductors by cooling conventional wires with liquid air.



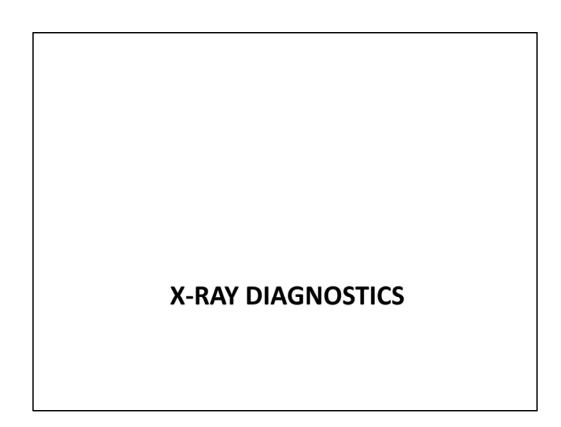
Electric utility companies are presently researching electrical transmission lines constructed of sophisticated high-temperature superconducting cable that delivers more power with greater voltage control and current density. By "high temperature" we mean superconductivity at the temperature of liquid nitrogen. Under normal atmospheric pressure the boiling point of liquid air is approximately 78 K (-319°F) and that of liquid nitrogen approximately 77.2 K (-320.44°F).

The use of superconducting cable will help utilities meet increasing demands without building additional transmission towers or installing new underground rights-of-way under crowded city streets.



The related Tesla patent is associated with his work in the area of radio-frequency (RF) power processing.

High-temperature superconductor technology can be applied by researchers who are reproducing Tesla's original wireless work.

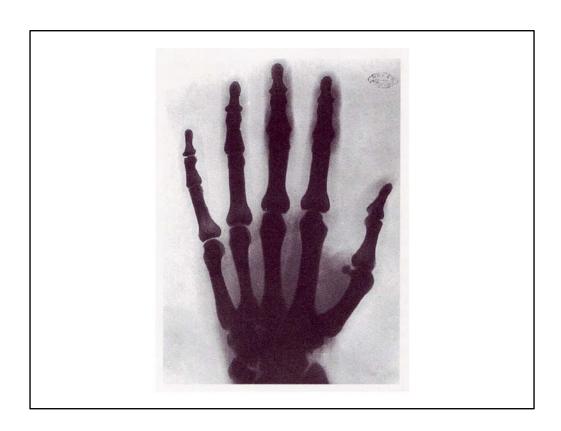


Tesla's researches in the area of RF power processing went hand-in-hand with experiments in which high voltage vacuum discharge tubes were used for the production of X rays.



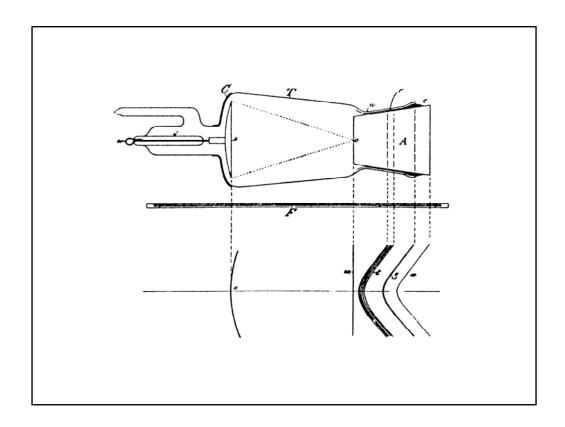
This is a modern radiology suite in which X-ray imaging is used to both diagnose and assist in the treatment of diseases and injuries visualized within the human body. The X rays penetrate the portion of the body to be examined and by controlling the energy and the length of exposure, a high contrast image is formed on silver-impregnated film or a plate of sensors that converts the signals generated into digital information, which is transmitted and converted into an image displayed on a computer screen.

– http://en.wikipedia.org/wiki/Radiology



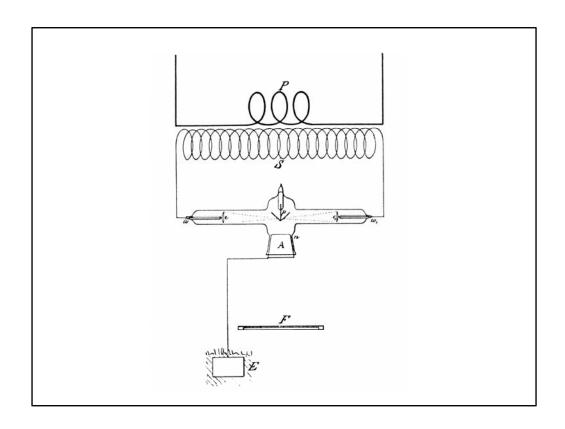
Wilhelm Conrad Röntgen discovered the X ray in 1895 and received the first Nobel Prize in Physics for their discovery in 1901. In 1895 Tesla was also observing X-ray related effects in that exposed photographic plates documenting his work were being inexplicably spoiled. His follow-up investigations in this area were significantly delayed when the South 5th Avenue laboratory was destroyed by fire.

This is an example of an X-ray image or "radiograph" created by Tesla.

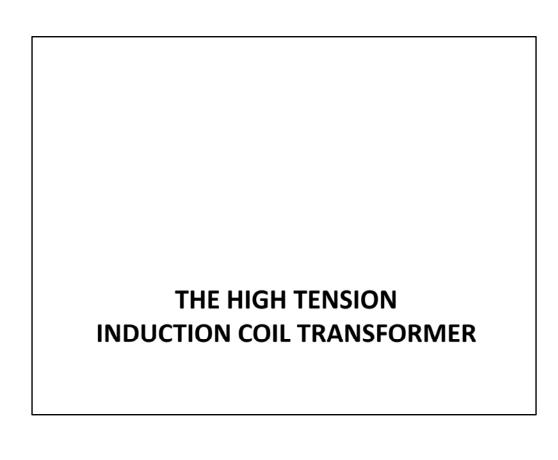


This is an illustration of a tube used in investigations performed to determine the X ray's exact point of origin, the conditions necessary for it's production, and matters associated with secondary emission.

The diagram shows a Lenard tube of improved design, consisting of a tube T of thick glass tapering towards the open end, or neck n, into which is fitted an aluminum cap A, and a spherical cathode e, supported on a glass stem s, and platinum wire w sealed in the opposite end of the tube as usual. The aluminum cap A, as will be observed, is not in actual contact with the ground glass wall, being held at a small distance from the latter by a narrow and continuous ring of tinfoil r. The outer space between the glass and the cap A is filled with cement c, in a manner which I shall later describe. c is a Roentgen screen such as is ordinarily used in making the observations. — Nikola Tesla: Lecture Before the New York Academy of Sciences — April 6, 1897, pp. 96-99.

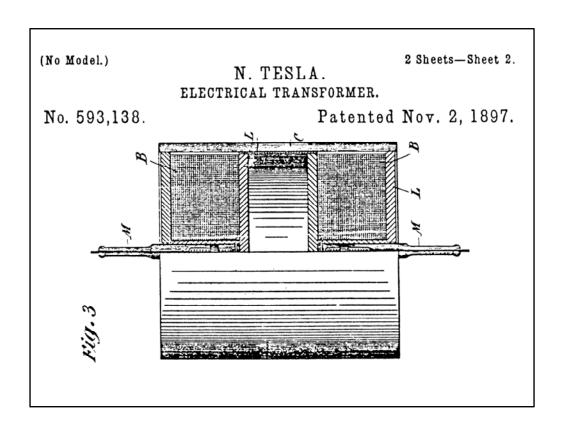


Tesla's independent discovery of X-Rays, unlike Roentgen's, was primarily based on sources which produced X-Rays by vacuum high field emission and the process now known as bremsstrahlung. While Roentgen employed a gaseous discharge tube utilizing electron avalanche, Tesla's cold cathode tubes worked best with high vacuum. Tesla's distinctive approach presaged the way for high energy particle accelerators, permitting the utilization of megavolt potentials, single electrode tubes, atmospheric bremsstrahlung, and a variety of intense beam techniques. As usual, he was years ahead with his inventions: Fowler and Nordheim's quantum mechanical considerations, necessary to understand Tesla's sources, were not available for another 32 years! By then Tesla was developing a macroscopic charged particle beam. – Kenneth and James Corum, 1994

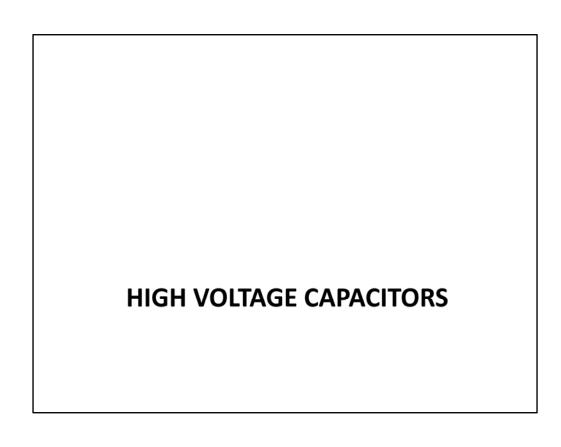




"Inductorium" is an archaic term for the commercial iron-core induction coil transformer, common during Tesla's time. The induction coil transformer was used up to and through the 1890s for high-voltage research. Tesla improved upon the "commercial coil" creating what is known as the "high tension induction coil." A present-day form of induction coil is found in the automobile ignition system.

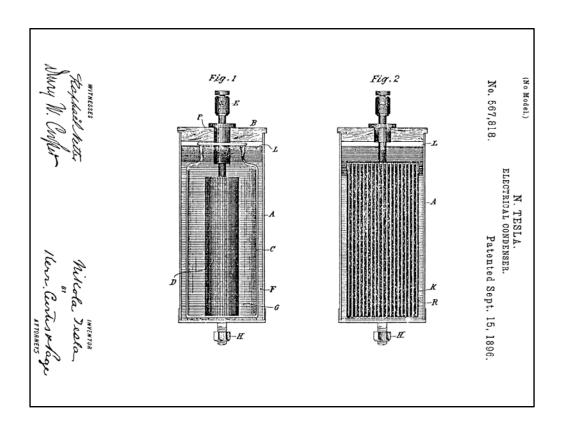


Here is a patent drawing of Tesla's high-tension induction coil, also known as the "Tesla coil."





This is a present-day high voltage capacitor.



Here are two of Tesla's capacitor designs, used as a component of his high power wireless transmitter.

(A word on nomenclature. What Tesla referred to as a "condenser" is, in modern terms, a "capacitor.")

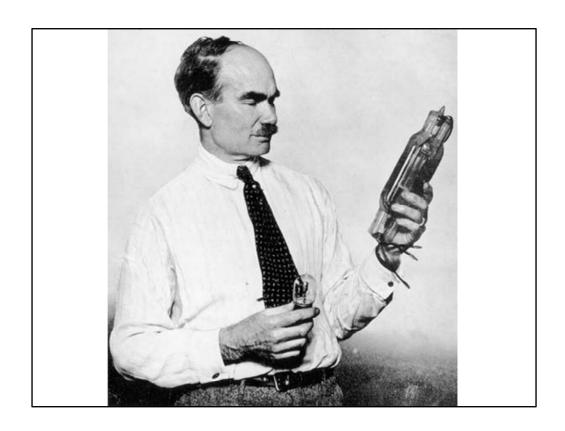


Tesla devoted considerable time and effort to the design and construction of high speed circuit controllers.



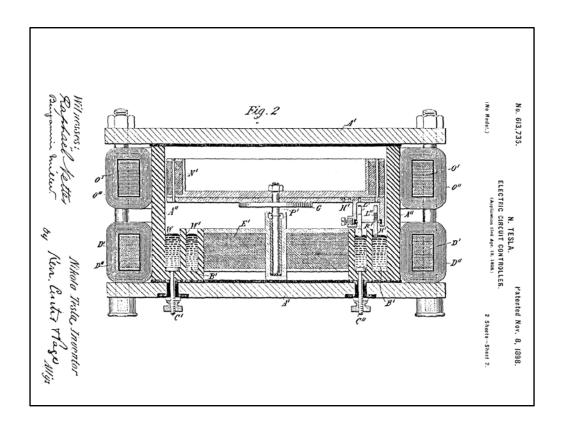
The <u>insulated-gate bipolar transistor (IGBT)</u> is a three-terminal power semiconductor device primarily used as an electronic switch and in newer devices is noted for combining high efficiency and fast switching. It switches electric power in many modern appliances: Variable-Frequency Drives (VFDs), electric cars, trains, variable speed refrigerators, air-conditioners and even stereo systems with switching amplifiers. Since it is designed to turn on and off rapidly, amplifiers that use it often synthesize complex waveforms with pulse width modulation and low-pass filters. In switching applications modern devices boast pulse repetition rates well into the ultrasonic range—frequencies which are at least ten times the highest audio frequency handled by the device when used as an analog audio amplifier. – http://en.wikipedia.org/wiki/Insulated-gate_bipolar_transistor

The <u>metal-oxide-semiconductor field-effect transistor (MOSFET, MOS-FET, or MOS FET)</u> is a transistor used for amplifying or switching electronic signals. Although the MOSFET is a four-terminal device with source (S), gate (G), drain (D), and body (B) terminals,[1] the body (or substrate) of the MOSFET often is connected to the source terminal, making it a three-terminal device like other field-effect transistors. Because these two terminals are normally connected to each other (short-circuited) internally, only three terminals appear in electrical diagrams. The MOSFET is by far the most common transistor in both digital and analog circuits, though the bipolar junction transistor was at one time much more common. – http://en.wikipedia.org/wiki/MOSFET



In 1922, the Institute of Radio Engineers (IRE) selected Lee de Forest as the fifth recipient of its Medal of Honor. He was cited for "his major contributions to the communications arts and sciences, as particularly exemplified by his invention of that outstandingly significant device: the three-electrode vacuum tube, and his work in the fields of radio telephonic transmission and reception." He served a term as president of the IRE in 1930. He also received the Edison Medal of the American Institute of Electrical Engineers (AIEE) in 1946, becoming one of only seven to receive both the Medal of Honor and the Edison Medal prior to 1962. He became known for having a rather flamboyant personality and was a very prolific inventor, receiving more than 300 patents during his career.

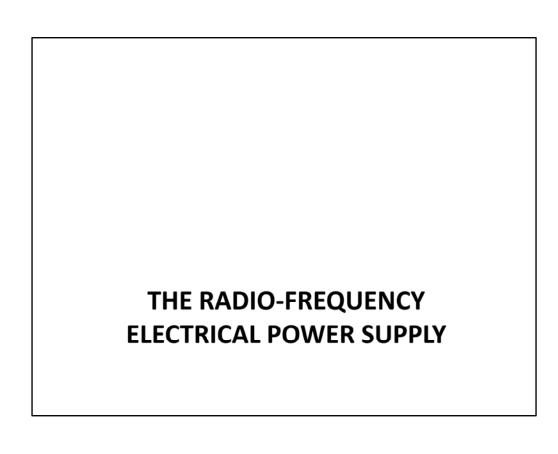
- http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=1369709

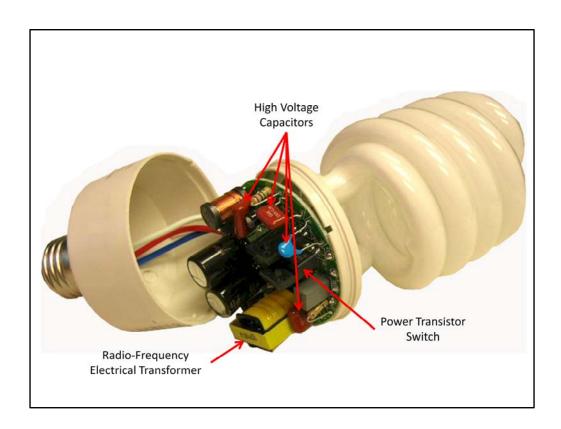


Here is one of Tesla's high speed switches, also known as a "circuit controller" or "break." His pioneering advances in the area of radio-frequency power processing would have been impossible without these sophisticated devices.

In some of the forms of apparatus which I have heretofore devised for carrying out this invention I have employed a mechanism for making and breaking an electric circuit or branch thereof for the purpose of charging and discharging the condenser, and my present application is based upon a novel and improved form of device for this purpose, which may be generally styled a "circuit-controller."

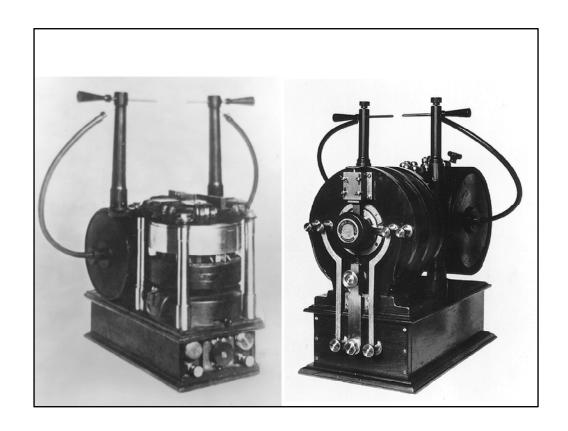
U.S. Patent No. 609,251, ELECTRIC-CIRCUIT CONTROLLER, August 16, 1898.
 Application filed June 8, 1897. Renewed June 15, 1898.



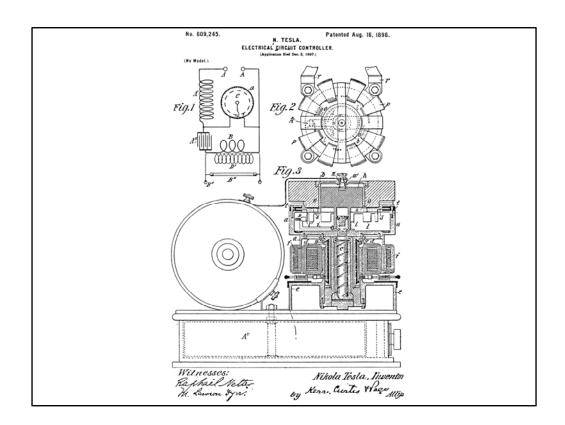


Present-day high efficiency fluorescent lighting systems depend upon a transistorized radio-frequency power supply to energize the lamp. A common example of such a system is the Compact Fluorescent Lamp (CFL).

The CFL's internal circuit board carries all of the components present in Tesla's original high voltage RF power supply, in miniaturized form.



While initially designed for high frequency lighting, Tesla also used his high voltage resonance transformer—the Tesla coil—for wireless propagation experiments.



This circuit controller patent drawing also shows the layout of the primary capacitor and RF transformer along with a circuit diagram, including an external electrode fluorescent lamp.

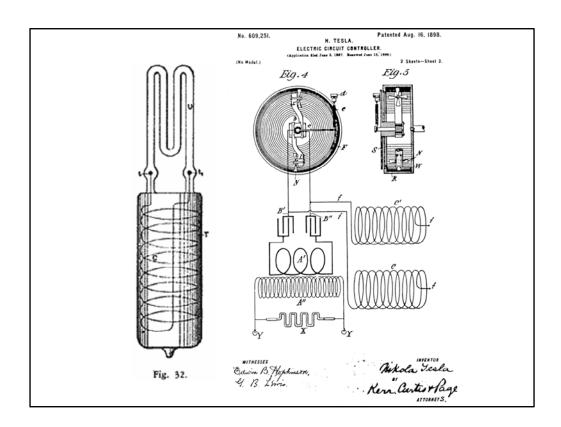


Tesla experimented with what he called "phosphorescent" lamps, but it was French physicist Alexandre-Edmond Becquerel (1820-1891) who first conceived the idea of placing a fluorescent coating on the inner surface of a high voltage gas discharge tube.

Tesla's investigations in the area of high-voltage RF power processing did result in the very first high efficiency, high frequency lighting ballasts. His seminal lectures on the topic of high frequency lighting are, Experiments With Alternate Currents of Very High Frequency and Their Application to Methods of Artificial Illumination, Experiments with Alternating Currents of High Potential and High Frequency and On Light and Other High Frequency Phenomena. The world's first commercial fluorescent lamps, introduced by the Westinghouse Electric Company at the 1939 New York World's Fair, were of the low-voltage 50-60 Hz hot cathode type still in common use today. Only since the late 1980s have efficient high frequency lighting systems gained wider acceptance.

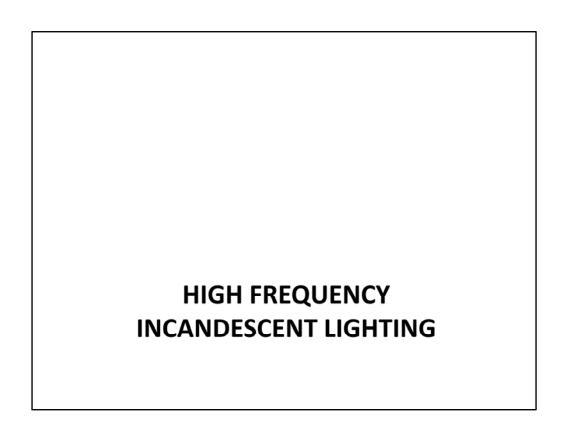


While Tesla did not invent the fluorescent lamp, it seems he was the first person to conceive of the idea of bending the tube back upon itself in order to make the lamp more compact.

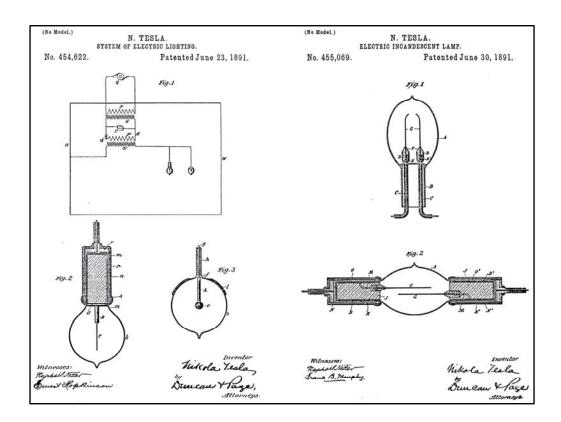


In Fig. 32 a wide tube T was sealed to a smaller W-shaped tube U, of phosphorescent glass. In the tube T was placed a coil C of aluminium wire, the ends of which were provided with small spheres t and t1 of aluminium, and reached into the U tube. The tube T was slipped into a socket containing a primary coil through which usually the discharges of Leyden jars were directed, and the rarefied gas in the small U tube was excited to strong luminosity by the high-tension currents induced in the coil C. — Experiments with Alternate Currents of High Potential and High Frequency, IEE Address, London, February 1892.

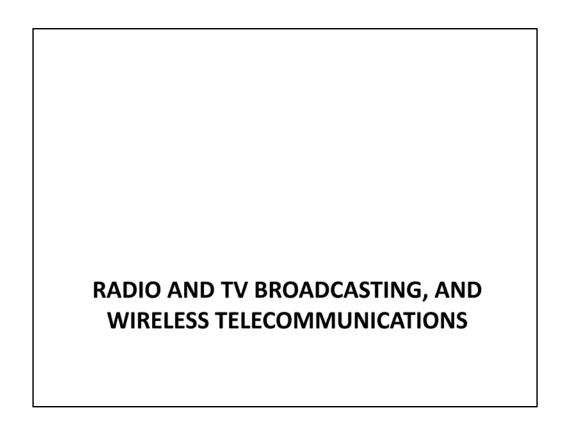
In previous patents granted to me I have shown and described methods and apparatus for the conversion and *utilization of electrical current* of very high frequency based upon the principle of charging a condenser or a circuit possessing capacity and discharging the same generally through the primary of a transformer, the secondary of which constituted the source of working current and under such conditions as to yield a vibrating or rapidly-intermittent current. – U.S. Patent No. 609,251, ELECTRIC-CIRCUIT CONTROLLER, August 16, 1898. Application filed June 8, 1897. Renewed June 15, 1898.



The possibilities of high frequency incandescent lighting are yet to be developed. It seems electrical engineers have not even scratched the surface of this technology.



Single and dual electrode incandescent lamps require a more energetic RF power supply than the fluorescent lamp. This may start to explain the lack of attention these high-efficiency lamp designs have received.

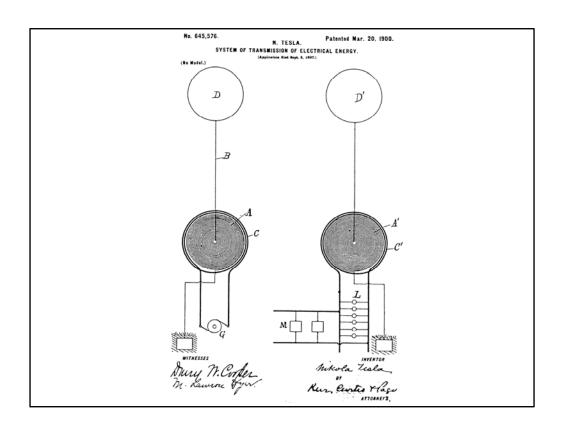


The fields of wireless telecommunications and broadcasting owe their existence to Tesla's numerous pioneering inventions in the area of radio-frequency power processing.

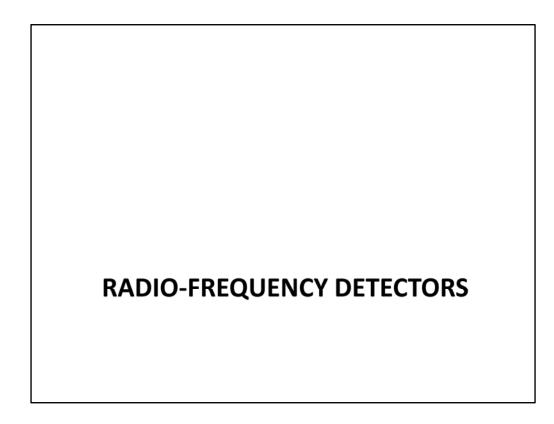


Tesla is known for having developed the world's first practical radio transmitter. His high-power transmitter was based upon his high power, high voltage, high frequency power supply, originally intended for lighting purposes.

This is the Armstrong Tower, also known as Alpine Tower, a 129.5-meter lattice structure built by Edwin Armstrong in 1938 at Alpine, New Jersey and used for his transmission experiments that led to modern FM radio. – http://en.wikipedia.org/wiki/Armstrong_Tower



Tesla pioneered practical wireless transmission by means of electromagnetic radiation. He is credited with the radio telecommunications transmission-reception system consisting of four tuned circuits, two at the transmitter and two at the receiver. Other early participants in the field of wireless telecommunications and broadcasting include Oliver Lodge, Guglielmo Marconi, Ferdinand Braun, Alexander Popov, Adolf Slaby, Georg von Arco, Reginald Fessenden, Jostein Pedersen, Julio Cervera Baviera, Charles "Doc" Herrold, Valdemar Poulsen, Mihajlo Pupin, Fritz Lowenstein, Edwin H. Armstrong, and David Sarnoff.



Speaking about his wireless system Tesla said,

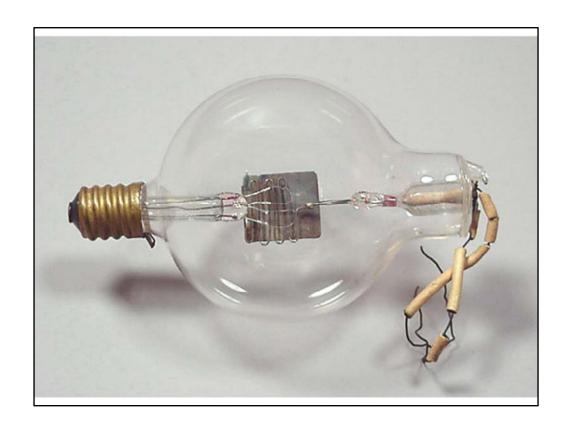
If you take this fourth circuit entirely away, and leave only that circuit here, the antenna and the ground connection, then that is the ideal condition for the flow of the current in this receiving circuit. Any other circuit you bring near to that excited circuit with the antenna will draw energy from it and tend to pull down the oscillation in the latter circuit and diminish the resonant rise. No matter what you link to the antenna circuit, and how you link it, the energy you take away from that circuit will always tend, being frictional, to diminish the resonant rise.

Now the art consists in reducing as much as possible the energy necessary for the signal, and in that regard the evolution of detectors as the audion of Dr. De Forest, and of other such devices, is in the proper direction, rational, and good. But the ideal condition requires that you should have here a device which only requires pressure and no current; and once you have a device which does not need any current but merely acts by pressure and has no internal capacity, so that there will be no capacity current in the circuit, then that is the ideal receiver. — Nikola Tesla On His Work With Alternating Currents and Their Application to Wireless Telegraphy, Telephony, and Transmission of Power, Tesla Presents Series Part 1, Nikola Tesla; Leland I. Anderson, Editor, pp. 99-100.



The field-effect transistor (FET) is a transistor that uses an electric field to control the shape and hence the conductivity of a channel of one type of charge carrier in a semiconductor material. FETs are unipolar transistors as they involve single-carrier-type operation. The concept of the FET predates the bipolar junction transistor (BJT), though it was not physically implemented until after BJTs due to the limitations of semiconductor materials and the relative ease of manufacturing BJTs compared to FETs at the time.

– http://en.wikipedia.org/wiki/Field-effect_transistor



The Audion was an electronic amplifying vacuum tube invented by American electrical engineer Lee De Forest in 1906. It was the first triode, consisting of a partially evacuated glass tube containing three electrodes; a heated filament, a grid, and a plate. It is important in the history of technology because it was the first widely used tube which could amplify; a small electrical signal applied to the grid could control a larger current flowing from the filament to plate.

Unlike later vacuum tubes, the primitive Audion had a small amount of gas in the tube, thought to be necessary by De Forest, which limited the dynamic range and gave it nonlinear characteristics and erratic performance. Originally invented as a radio receiver detector by adding a grid electrode to the Fleming valve, it found little use until its amplifying ability was recognized around 1912 by several researchers, who used it to build the first amplifying radio receivers and electronic oscillators. The many practical applications for amplification motivated its rapid development, and the original Audion was superseded within a few years by improved versions with higher vacuum, developed by Irving Langmuir at GE and others. These were the first modern "hard vacuum" triodes.

– http://en.wikipedia.org/wiki/Audion

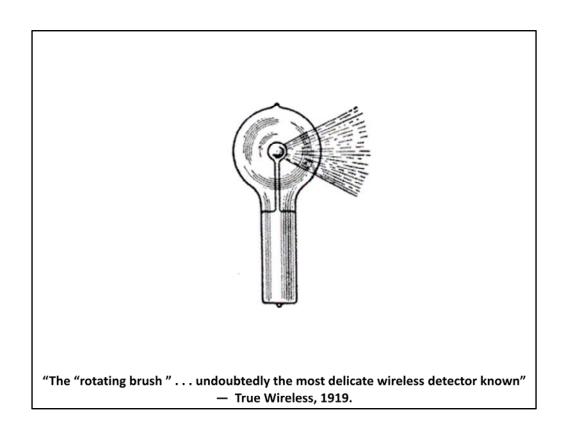
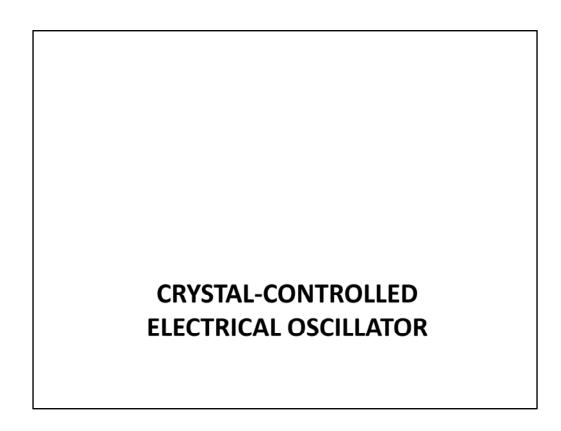
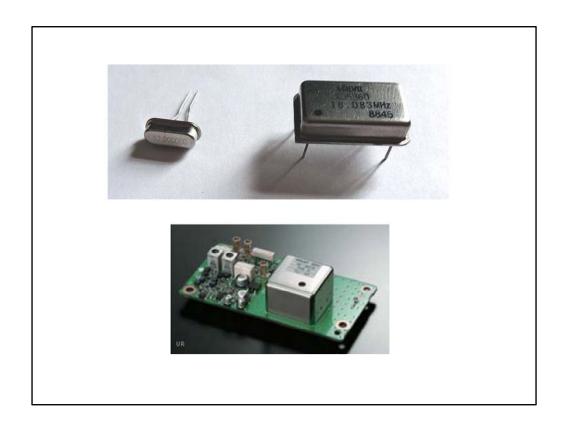


Figure 9 of <u>The True Wireless</u> is captioned, "The Forerunner of the Audion-the Most Sensitive Wireless Detector Known, as Described by Tesla In His Lecture Before the Institution of Electrical Engineers, London, February, 1892."

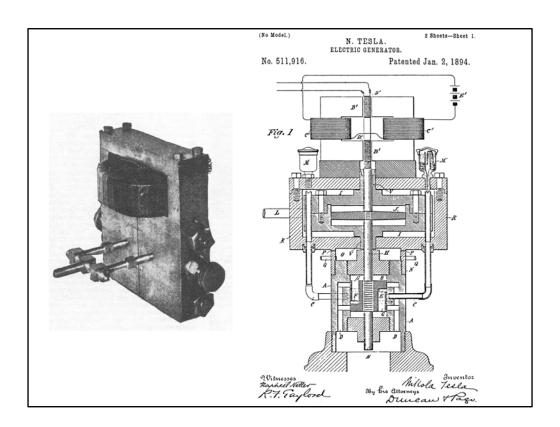
My confidence that a signal could be easily flashed around the globe was strengthened thru the discovery of the "rotating brush," a wonderful phenomenon which I have fully described in my address before the Institution of Electrical Engineers, London, in 1892 [Experiments with Alternate Currents of High Potential and High Frequency], and which is illustrated in Fig. 9. This is undoubtedly the most delicate wireless detector known, but for a long time it was hard to produce and to maintain in the sensitive state. These difficulties do not exist now and I am looking to valuable applications of this device, particularly in connection with the high-speed photographic method, which I suggested, in wireless, as well as in wire, transmission. – The True Wireless, *Electrical Experimenter*, May 1919.



A little-known Tesla contribution to the field of wireless telecommunications and radio-frequency power processing is the isochronous electro-mechanical oscillator.

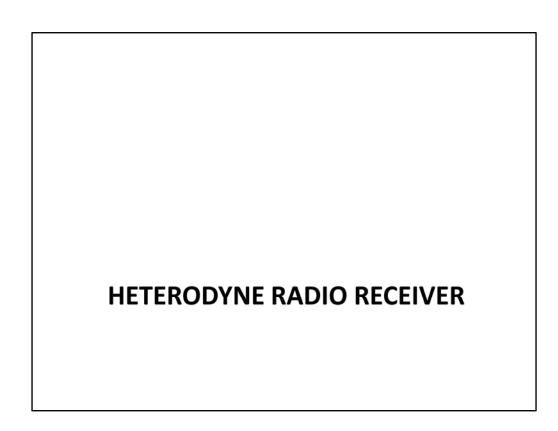


The crystal-controlled electrical oscillator is used in wireless transmitters and receivers, along with numerous electronics devices such as personal computers, digital clocks and various scientific instruments.



These are illustrations of Tesla's original isochronous electromechanical oscillator.

That oscillator [left] was one of high frequency for isochronous work, and I used it in many ways. The machine, you see, comprised a magnetic frame. The energizing coil . . . produced a strong magnetic field in this region. I calculated the dimensions of the field to make it as intense as possible. There was a powerful tongue of steel which carried a conductor at the extreme end. When it was vibrated, it generated oscillations in the wire. The tongue was so rigid that a special arrangement was provided for giving it a blow; then it would start, and the air pressure would keep it The vibrating mechanical system would fall into synchronism with the electrical, and I would get isochronous currents from it. That was a machine of high frequency that emitted a note about like a mosquito. It was something like 4,000 or 5,000. It gave a pitch nearly that of my [RF] alternator. . . . This device was not intended for a big output, but simply to give me, when operating in connection with receiving circuits, isochronous currents. The excursions of the tongue were so small that one could not see it oscillate, but when the finger was pressed against it the vibration was felt. - Nikola Tesla On His Work With Alternating Currents and Their Application to Wireless Telegraphy, Telephony, and Transmission of Power, Tesla Presents Series Part 1, Nikola Tesla; Leland I. Anderson, Editor, p. 45.

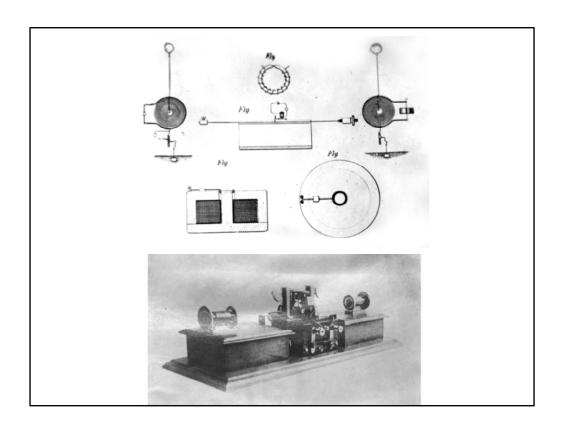


Another little known Tesla invention is the direct-conversion heterodyne wireless telegraph receiver.



This is an example of a state-of-the-art super heterodyne radio receiver, the front-end circuitry design of which can be traced back to Tesla's "beat receptor."

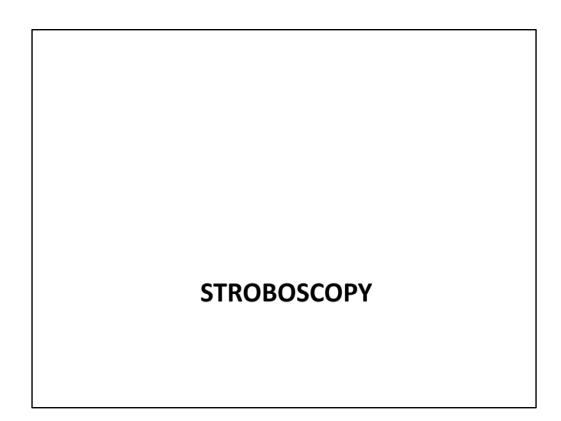
"The Icom IC-R9500-02 . . . features an Oven Control Crystal Oscillator to achieve impressive ± 0.05 ppm frequency stability."



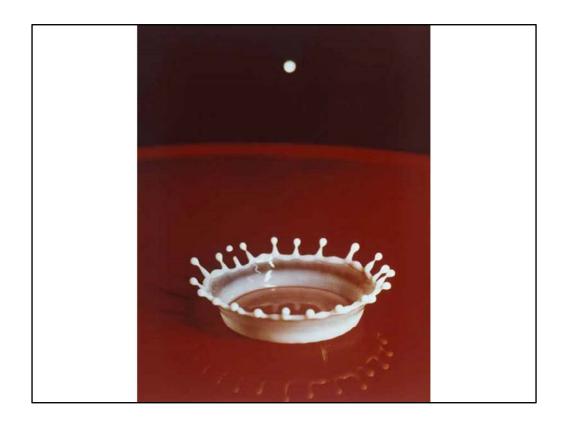
Tesla's beat receptor for radio-telegraphy is a direct-conversion heterodyne receiver consisting of an isochronous electro-mechanical local oscillator and a mixer. Reginald Fessenden also experimented with the heterodyne technique.

- http://en.wikipedia.org/wiki/Beat_receptor

See also, Cohen, Samuel, <u>Dr. Nikola Tesla and His Achievements</u>, *The Electrical Experimenter*, February 1917, "Unique Alternating Current Generator for Exciting Tesla's Early "Beat" Receptor. Actuated by Compressed Air or Steam Which Vibrates a Special Diaphragm-Coil." – http://en.wikisource.org/wiki/Dr._Nikola_Tesla_and_His_Achievements



Tesla's electro-mechanical instrument for the measurement of frequency and phase of alternating electric currents, the "tikker," incorporated the stop-motion principle of stroboscopy.



Harold Eugene "Doc" Edgerton (April 6, 1903 – January 4, 1990) was a professor of electrical engineering at the Massachusetts Institute of Technology. He is largely credited with transforming the stroboscope from Tesla's obscure laboratory instrument into a common device.

Falling drop of milk, illuminated by using a strobe light, photographed by Harold E. Edgerton, c. 1938.

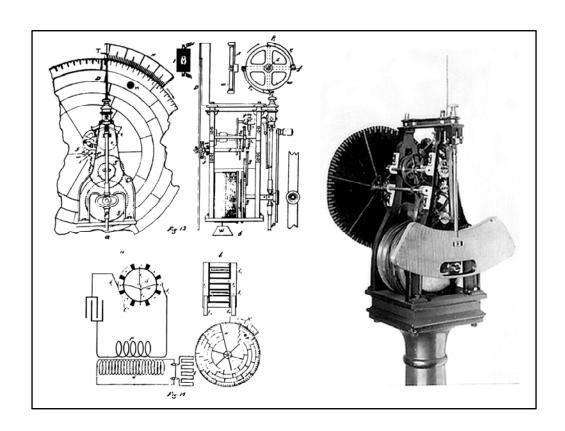
Credit: © The Harold E. Edgerton 1992 Trust
- https://alum.mit.edu/pages/sliceofmit/2009/12/21/doc-edgerton/



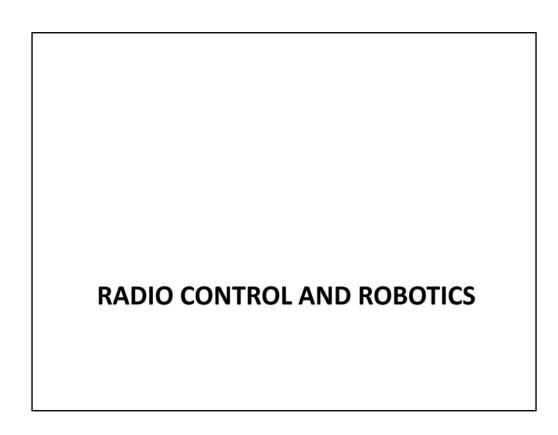
The Edgerton stroboscope is widely used for stop-motion photography and other purposes.



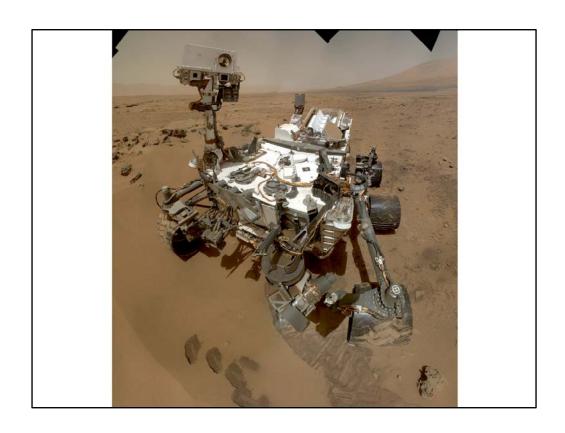
The Stroboscopic Card is for calibrating the speed of rotation of record turntables in order to assure accurate reproduction of musical pitch.



This is Tesla's electro-mechanical instrument for the measurement of frequency and phase of alternating electric currents, popularly known as the "tikker." It incorporates a mechanical clockwork mechanism that turns, at a constant speed, a disk that is marked with a side-by-side pattern of equally spaced lines. Frequency measurements are obtained by connecting a gas-discharge-type light source to the apparatus under test and illuminating the rotating disk. The stop-motion effect combined with knowledge of the speed of rotation of the calibrated disk allows for calculation of the frequency. Phase determination might be achieved using two light sources and measuring the angular displacement between a single line as it appears to the observer. — Nikola Tesla: Lecture Before the New York Academy of Sciences — April 6, 1897, pp. 61-69.



In addition to the poly-phase AC power system, Tesla is fairly well known for his work in the areas of radio control and robotics.



The arrival on Mars of the Pathfinder robotic planetary exploration vehicle with it's diminutive rover Sojourner on July 4, 1997 was a landmark event in the history of wireless remote control. After nearly 100 years of development, a technology with roots in an instrument of war had begun to fulfill what may be its greatest potential—helping mankind to establish a virtual presence on other worlds. For the first time ever, a person on Earth could visit an object on a distant planet and by reaching out through the medium of radio, touch it.

This slide shows Curiosity, a car-sized robotic rover now exploring Gale Crater on Mars as part of NASA's Mars Science Laboratory mission (MSL). It was launched from Cape Canaveral on November 26, 2011 aboard the MSL spacecraft and successfully landed on Aeolis Palus in Gale Crater on Mars on August 6, 2012, 05:17 UTC. The Bradbury Landing site was less than 2.4 km from the center of the rover's touchdown target after a 563,000,000 km journey. The rover's goals include: investigation of the Martian climate and geology; assessment of whether the selected field site inside Gale Crater has ever offered environmental conditions favorable for microbial life, including investigation of the role of water; and planetary habitability studies in preparation for future human exploration. In December 2012, Curiosity's two-year mission was extended indefinitely. In April and early May 2013, Curiosity went into an autonomous operation mode for approximately 25 days during Earth–Mars solar conjunction. During this time, the rover continued to monitor atmospheric and radiation data, but did not move on the Martian surface. – http://en.wikipedia.org/wiki/Curiosity_(rover)



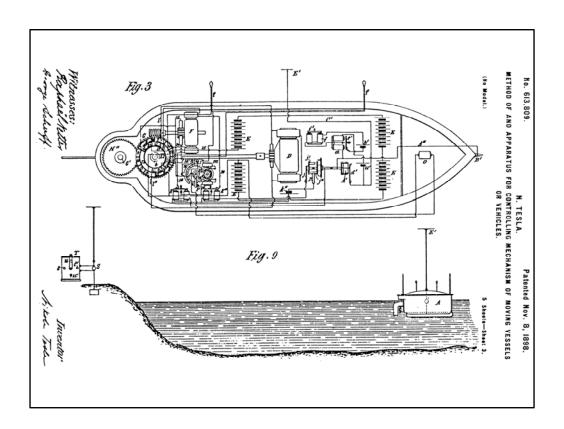
During wartime there was much research under way toward reducing the Tesla concept of the guided weapon in various laboratories. . . . So far as I know, the credit for the concept rests entirely with him. – Edwin H. Armstrong

The Tomahawk is an all-weather submarine or ship-launched land-attack cruise missile deployed by the U.S. Navy in 1983. It can self-navigate to a target by comparing the terrain beneath missile's flight path with a contour map stored in an onboard computer. After launch, a solid propellant propels the missile until a small turbofan engine takes over for the cruise portion of flight. Tomahawk is a highly survivable weapon. Radar detection is difficult because of the missile's small cross-section and low altitude flight. Similarly, infrared detection is difficult because the turbofan engine emits little heat. Systems include Global Positioning System (GPS) receiver; an upgrade of the optical Digital Scene Matching Area Correlation (DSMAC) system; Time of Arrival (TOA) control, and improved 402 turbo engines. – http://www.fas.org/man/dod-101/sys/smart/bgm-109.htm

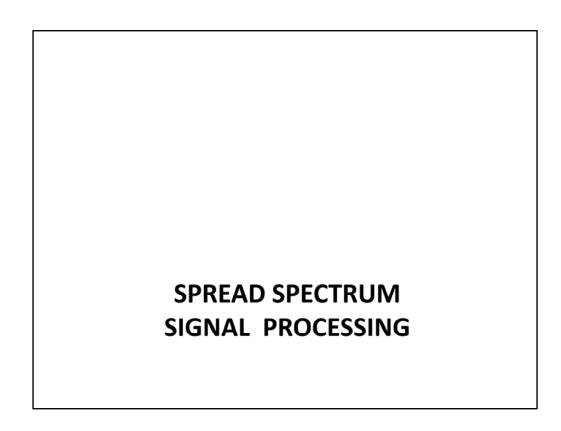


This propeller-driven radio controlled boat, designed and built by Tesla in 1898, is the original prototype of all modern-day uninhabited aerial vehicles (the UAV) and precision guided weapons—in fact, all remotely operated vehicles—air, land or sea. Powered by lead-acid batteries and an electric drive motor, the vessel was designed to be maneuvered alongside a target using instructions received from a wireless remote-control transmitter. Once in position, a command would be sent to detonate an explosive charge contained within the boat's forward compartment.

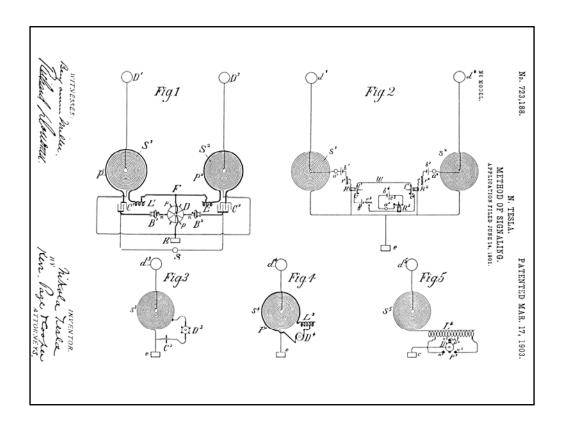
[Nikola Tesla Photograph Archive.]



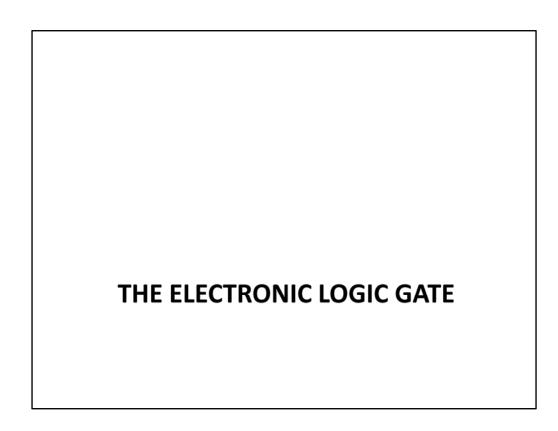
The weapon's guidance system incorporated a secure communications link between the pilot's controller and the surface-running torpedo in an effort to assure that control could be maintained even in the presence of electronic countermeasures.



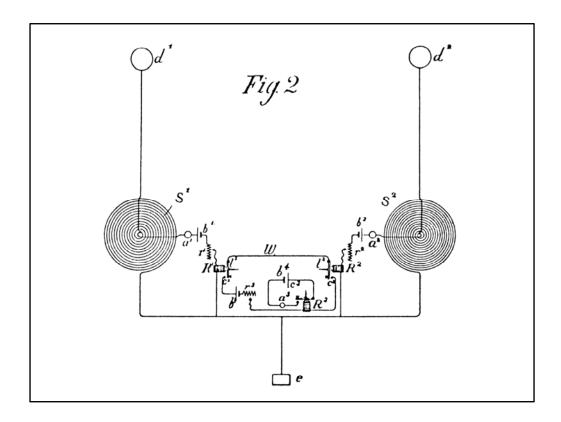
Tesla work in the area of wireless remote control went hand in hand with a critical interest in secure wireless telecommunications.



An important feature of every system for wireless remote control is its immunity to interference. In order to achieve this Tesla developed a method for selectively activating the vehicle's wireless receiver. He called this "the art of individualization." In its most basic form he would transmit the control signals using only a single frequency. If greater security was needed, he used a wireless signal produced on a multiple of frequencies—the transmitter worked at a number of separate wave lengths, like a pipe organ playing a musical chord or, alternatively, a specific sequence of notes. On the receiver side each one of the individual frequency components had to be tuned in, in order for the control circuitry to respond. These are the basic principles of the frequency-division multiplexing frequency-hopping spread spectrum techniques for secure telecommunications. - U.S. Patent No. 723,188, METHOD OF SIGNALING, March 17, 1903, application filed July 16, 1900, and U.S. Patent No. 725,605, "SYSTEM OF SIGNALING, April 14, 1903, application filed July 16, 1900.



It's a little known fact that Tesla is the acknowledged inventor of the electronic logic gate circuit, a critical element of every digital computer.



The 1903 "System of Signaling" and "Method of Signaling" patents explain more than the basic principles of frequency-hopping and frequency-division multiplexing spread spectrum techniques for secure wireless telecommunications. They also describe the electronic AND-gate logic circuit, a fundamental element of all present day digital computers.

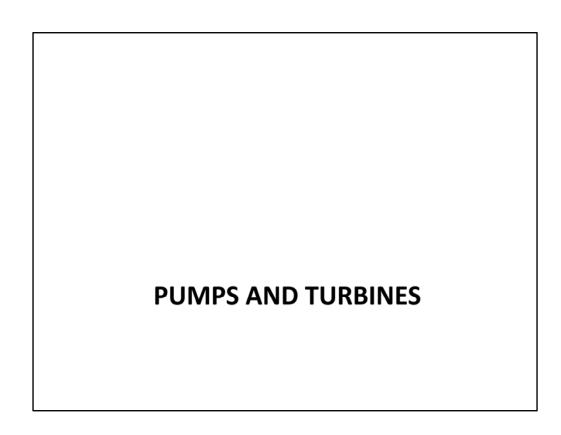
In the mid 1890s Tesla's work was focused on the development of an independent remotely-controlled device—the "telautomaton." These efforts led him to devise methods for selectively activating any of several wireless receivers that involved multiple transmissions on separate frequencies. At the receiving end, each one of the individual frequency components had to be tuned in, in order for the receiver to respond—the AND logic function. In 1899 Tesla established an experimental station at Colorado Springs where he continued his studies. Realizing the importance of his ground-breaking techniques he gave instructions upon his return to New York that patent applications be prepared and submitted. During the review period, the Patent Office told Tesla that another patent application for a similar concept had been received from Reginald Fessenden, and in 1902 a U.S. Patent Interference investigation was conducted concerning Tesla's wireless communications system. In the end, Tesla's claims were supported and he was granted protection under the "System of Signaling" and "Method of Signaling" patents—both describing the AND-gate circuit.

After World War II when computer hardware manufacturers attempted to patent digital logic gates in general, the U.S. Patent Office asserted Tesla's turn-of-the-century priority in their electrical implementation. These same patents describe essential features of the spread-spectrum wireless communications techniques known as frequency-hopping and frequency-division multiplexing.



This is a photograph of the "Spirit" super computer at Wright-Patterson Air Force base. In addition to, perhaps, containing everything that anyone might possibly want to know about Tesla's work in the areas of mechanical and electrical engineering, its circuitry is rooted in one of his designs from 1900, the electronic logic gate.

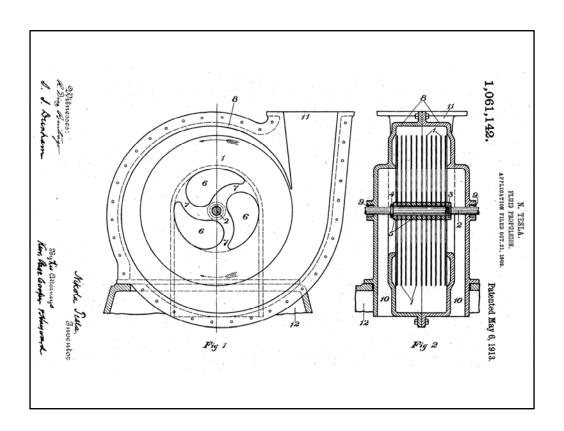
This government computer is tasked with simulated experiments that are too risky to be undertaken by personnel. Calculating at 1,500 trillion calculations a second makes it the 7th most powerful computer in the world. Dubbed "Spirit," this highly-dense supercomputer sits on 9,000 square feet and weighs more than 30 tons. The price tag is \$25 million. A specialized water-circulation system was created to cool the computer off and prevent over-heating in the thousands of miles of copper wiring that encompasses its fiber optic cables. Spirit tests weapons systems, simulates bomb detonations and projects how cargo in aircraft can be parachuted to land where necessary and safely. Scientific research is also a function of Spirit, with a focus on everything from subatomic particles to hurricane forecasting.



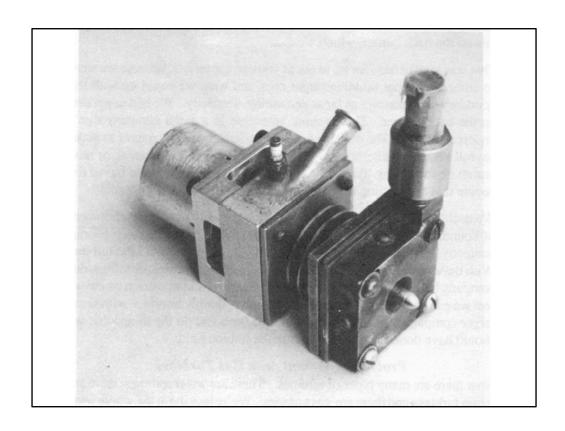


This photo accompanies a case history published by a manufacturer of the Tesla disk pump.

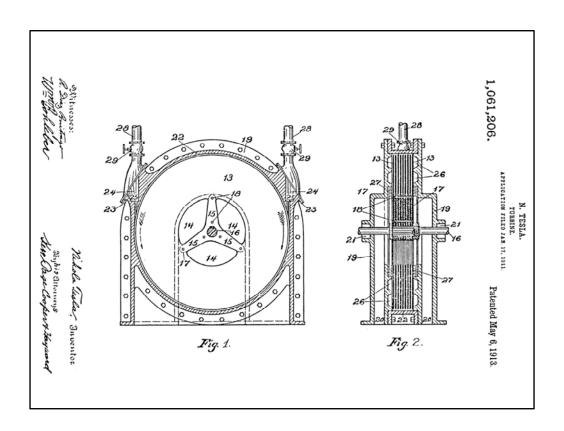
The UK paper industry's first DiscFlo pump has reduced downtime in pumping paper stock to almost zero and has cut machine downtime by 12 hours a month, which yields savings of approximately \$150,000 a year. The paper stock, which includes recycled deinked stock, is around 4% consistency and contains 5-7% entrained air. The pump feeds stock to the paper machine and if it fails, the entire paper machine goes down. The previous pump, a centrifugal type commonly used for stock pumping, suffered frequent breakdown and cavitations problems, due to the high level of entrained air. The mill engineering manager is delighted with the disc pump's performance: "Since start up, the DiscFlo pump has performed 100%."



The Tesla disk pump-blower design has gained some acceptance by industry for specialized applications where it is necessary to move viscous fluids and those containing solids. In addition, due to an absence of lifting surfaces, i.e., blades or impellers, its decreased susceptibility to impingement-related corrosion and internal cavitations allows it to better handle abrasive-containing fluids and two-phase flows, such as boiling water. – U.S. Patent No. 1,061,142, FLUID PROPULSION, May 6, 1913, application filed October 21, 1909.



This is a miniaturized Tesla turbo generator, prototyped for the U.S. Navy by C. R. Possell around 1954. It consists of a two stage disk compressor, a one-inch disk turbine and a two pole 180-watt generator, all mounted on a common shaft.

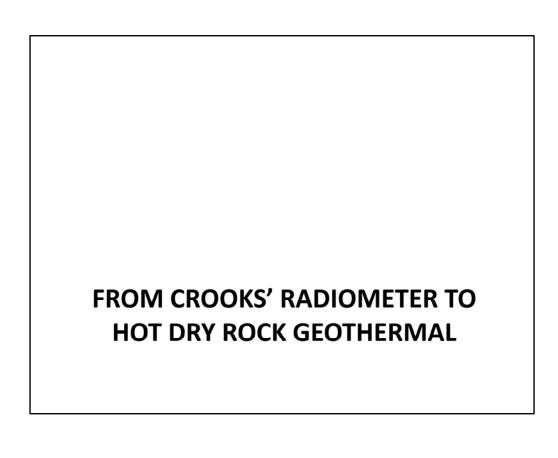


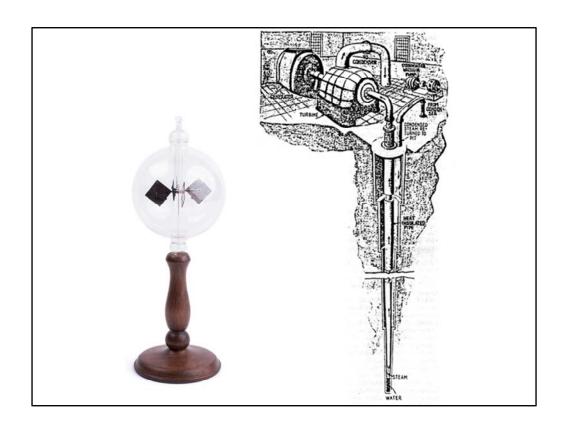
While a number of researchers have investigated the design, the Tesla disk turbine is not readily available for use by the public. — U.S. Patent No. 1.061,206, TURBINE, May 6, 1913, original application filed October 21, 1909; divided and this application filed January 17, 1911.

Part 2 FREE ENERGY

In 1892 Tesla wrote,

Ere many generations pass, our machinery will be driven by a power obtainable at any point of the universe. This idea is not novel. Men have been led to it long ago by instinct or reason. It has been expressed in many ways, and in many places, in the history of old and new. We find it in the delightful myth of Antheus, who derives power from the earth; we find it among the subtle speculations of one of your splendid mathematicians, and in many hints and statements of thinkers of the present time. Throughout space there is energy. Is this energy static or kinetic? If static our hopes are in vain; if kinetic—and this we know it is, for certain—then it is a mere question of time when men will succeed in attaching their machinery to the very wheelwork of nature. Of all, living or dead, Crookes came nearest to doing it. His radiometer will turn in the light of day and in the darkness of the night; it will turn everywhere where there is heat, and heat is everywhere. But, unfortunately, this beautiful little machine, while it goes down to posterity as the most interesting, must likewise be put on record as the most inefficient machine ever invented! -Experiments with Alternate Currents of High Potential and High Frequency, IEE Address, London, February 1892.

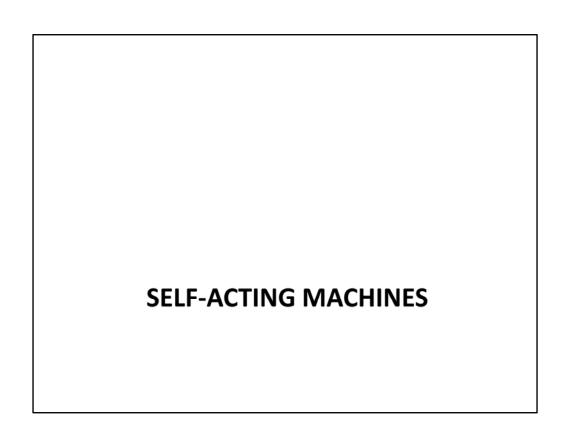




Tesla recognized that Crooks' radiometer held little promise as a device for extracting significant energy from the "ambient medium." He was far more optimistic about the possibility of hot dry rock geothermal electric power generation.

"It is a well-known fact that the interior portions of the globe are very hot, the temperature rising, as observations show, with the approach to the center at the rate of approximately 1deg C. for every hundred feet of depth." – The Problem of Increasing Human Energy, 1901.

"All that is necessary to open up unlimited resources of power throughout the world is to find some economic and speedy way of sinking deep shafts." – Our Future Motive Power, 1931.



POSSIBILITY OF A "SELF-ACTING" ENGINE OR MACHINE CAPABLE OF DERIVING ENERGY FROM THE MEDIUM—THE IDEAL WAY OF OBTAINING MOTIVE POWER.

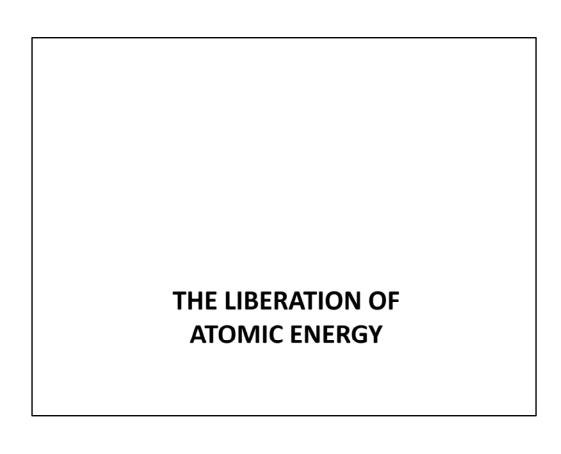
"When I began the investigation of the subject under consideration . . . a survey of the various ways of utilizing the energy of the medium convinced me . . . That to arrive at a thoroughly satisfactory practical solution a radical departure from the methods then known had to be made. The windmill, the solar engine, the engine driven by terrestrial heat, had their limitations in the amount of power obtainable. . . . There was enough heat-energy in the medium, but only a small part of it was available for the operation of an engine in the ways then known. . . . The problem was to discover some new method which would make it possible both to utilize more of the heat energy of the medium and also to draw it away from the same at a more rapid rate. . . .

"Evidently a living being could do this very thing, and since the experiences of my early life . . . had convinced me that a living being is . . . a "self-acting-engine," I came to the conclusion that it was possible to construct a machine which would do the same. . . . I finally conceived a combination of apparatus which should make possible the obtaining of power from the medium by a process of continuous cooling of atmospheric air. . . . In the process . . . there were five essential elements in combination. . . .

"The mechanical oscillator was the first element of this combination, and having perfected this, I turned to the next, which was an air-compressor of a design in certain respects resembling that of the mechanical oscillator. . . . At the close of 1894 I had completed these two elements of the combination. . . . I was just beginning work on the third element, which together with the first two would give a refrigerating machine of exceptional efficiency and simplicity, when a misfortune befell me in the burning of my laboratory, which crippled my labors and delayed me.

"Much of this task on which I have labored so long remains to be done. A number of mechanical details are still to be perfected and some difficulties of a different nature to be mastered, and I cannot hope to produce a self-acting machine deriving energy from the ambient medium for a long time yet, even if all my expectations should materialize. Many circumstances have occurred which have retarded my work of late, but for several reasons the delay was beneficial.

"One of these reasons was that I had ample time to consider what the ultimate possibilities of this development might be. I worked for a long time fully convinced that the practical realization of this method of obtaining energy from the sun would be of incalculable industrial value, but the continued study of the subject revealed the fact that while it will be commercially profitable if my expectations are well founded, it will not be so to an extraordinary degree." – The Problem of Increasing Human Energy, 1901.



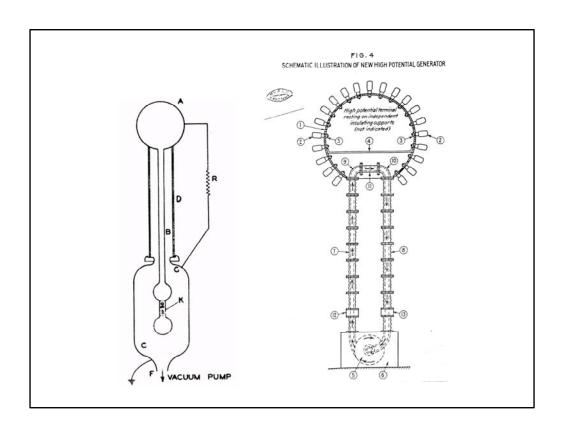
In 1932 Tesla stated, "All of my investigations seem to point to the conclusion that [cosmic rays] are small particles, <u>each carrying so small a charge that we are justified in calling them neutrons.</u>" – <u>Tesla Cosmic Ray Motor May Transmit Power 'Round Earth</u>, *Brooklyn Eagle*, July 10, 1932.

Writing about radioactivity and radioactive materials a few months later Tesla said, "According to experimental findings and deductions of positive science, any material substance (cooled down to the absolute zero of temperature) should be devoid of an internal movement and energy. . . . I was struck by the thought that if there is energy within the substance it can only come from without. . . . I expressed it in the following axiom: "There is no energy in matter except that absorbed from the medium." . . . If all energy is supplied to matter from without then this all important function must be performed by the medium.

Tesla further wrote, "When radio-active rays were discovered their investigators believed them to be due to liberation of atomic energy in the form of waves. This being impossible in the light of the preceding I concluded that [radio-active rays] were produced by some external disturbance and composed of electrified particles. . . . Suppose that bullets are fired against a wall. Where a missile strikes the material is crushed and spatters in all directions radial from the place of impact. In this example it is perfectly clear that the energy of the flying pieces can only be derived from that of the bullets. But in manifestation of radio-activity no such proof could be advanced and it was, therefore, of the first importance to demonstrate experimentally the existence of this miraculous disturbance in the medium. I was rewarded in these efforts with quick success largely because of the efficient method I adopted which consisted in deriving from a great mass of air, ionized by the disturbance, a current, storing its energy in a condenser and discharging the same through an indicating device." — The Eternal Source of Energy of the Universe, Origin and Intensity of Cosmic Rays, October 13, 1932, New York, reprinted in Tesliana, Special Edition, Belgrade, Yugoslavia, 1995, p. 56 - 59.

In 1933 a reporter with the Philadelphia Public Ledger wrote of Tesla's work, "This principle, which taps a source of power described as "everywhere present in unlimited quantities" and which may be transmitted by wire or wireless from central plants to any part of the globe, will eliminate the need of coal, oil, gas or any other of the common fuels." – Tesla 'Harnesses' Cosmic Energy, Philadelphia Public Ledger, November 2, 1933.

Taken together these words suggest that in tapping a source described as "everywhere present in unlimited quantities" Tesla was speaking of the liberation of atomic energy from radioactive material, possibly by the process of static accumulation, and in writing about "central plants" the reporter is referring to nuclear power plants of a novel design based upon Tesla's research from which energy would be distributed in the form of electricity.



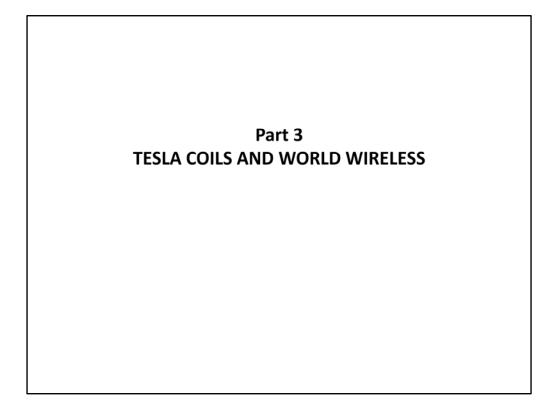
The Static Accumulation nuclear battery (left) was developed in the early 1950's by Linder, Rappaport and Loferski. Using a radioactive source of 25 Ci Sr-90 (located at K) the device developed a DC potential of 365 kV at about 1 nA, for a continuous power output of about 0.2 mW. D is an electrical insulator. Chamber C is evacuated.

Tesla's description of his initial demonstration experiments suggests that he may have been doing something along the same lines as the 1950's static accumulation nuclear battery.

I was rewarded in these efforts with quick success largely because of the efficient method I adopted which consisted in deriving from a great mass of air, ionized by the disturbance, a current, storing its energy in a condenser and discharging the same through an indicating device.

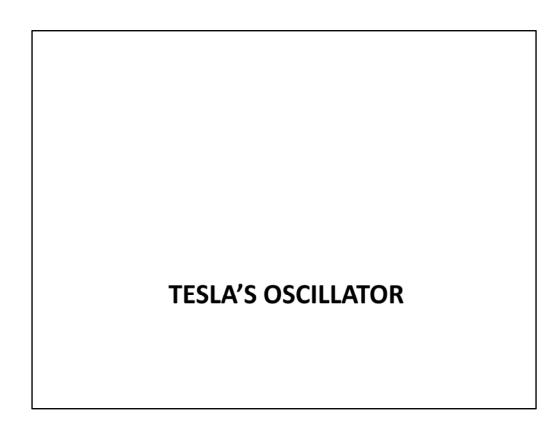
It is assumed from the phrase, "rewarded with quick success" that no sophisticated apparatus was required. The phrase, "consisted in deriving from a great mass of air" brings to mind Tesla's disk blower, and an electrostatic generator (right) designed for the 1935 particle beam projector and disclosed in The New Art of Projecting Concentrated Non-dispersive Energy Through Natural Media — System of Particle Acceleration for Use in National Defense. It may be the two designs have some features in common.

Perhaps there are documents at the Nikola Tesla Museum in Belgrade that might shed some light on this obscure subject.



Another invention that has yet to enter into the public domain is Tesla's advanced system for the wireless transmission of electrical energy.

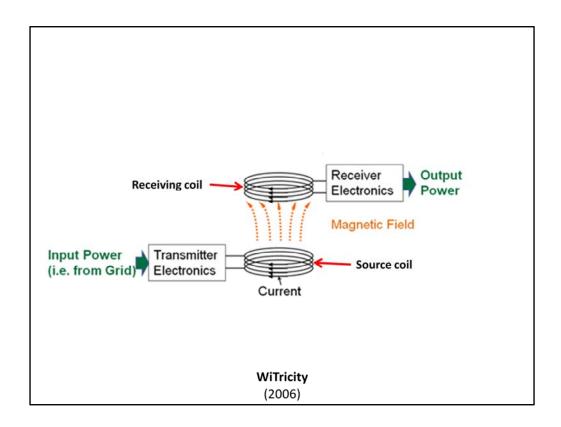
In this section we will learn more about the Tesla coil and then look beyond the convenience of induction coil charging pads to describe and possibly expand upon Tesla's world-wireless vision.



The Tesla coil is intended for radio-frequency (RF) power processing.

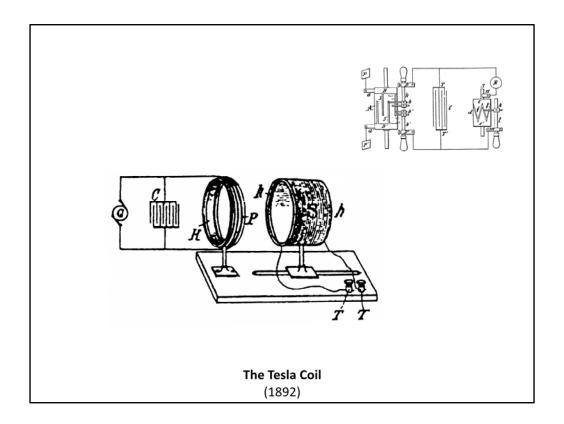


This WiTricity induction coil charging pad is a minor fulfillment of Tesla's wireless vision.



The WiTricity transmitter's electronics includes an RF oscillator and a power amplifier to drive a tuned primary LC circuit.

A rectifier is included in the identically tuned WiTricity receiver circuit. It changes the induced RF current to DC current, suitable for battery charging.

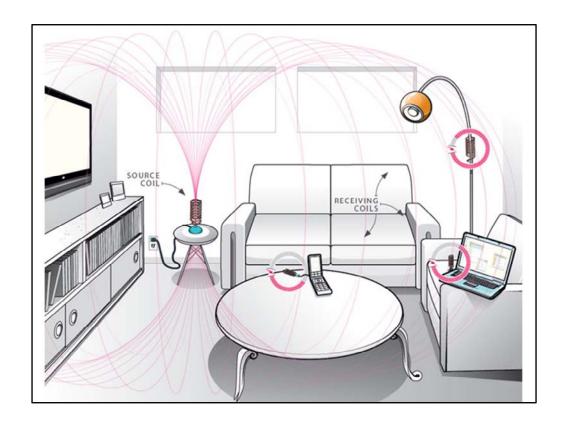


The same apparatus was constructed by Tesla, as seen in this drawing from his 1898 lecture <u>High Frequency Oscillators for Electro-therapeutic and Other Purposes</u>.

G is a special high-frequency alternator designed for the specific purpose of driving a tuned Tesla coil primary LC circuit.

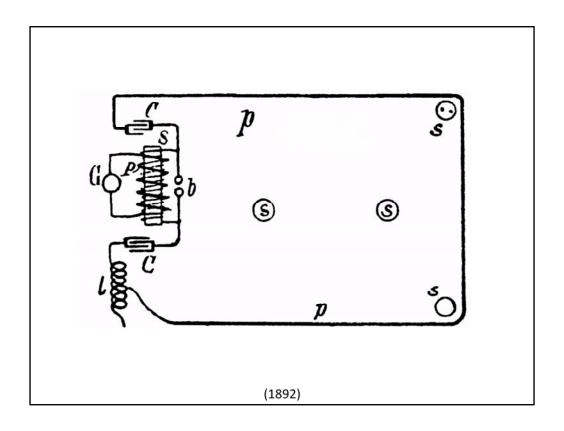
Inductor **P** (L) and capacitor **C** (C) constitute the tuned primary "LC circuit." Secondary inductor **S** is the "receiving coil." The inset shows a mechanical rectifier and a mechanical pulse-width modulator, both designed by Tesla in 1899.

When it is desired to use small currents of high tension, a secondary coil is resorted to, as illustrated in Fig. 2. I have found it from the outset convenient to make a departure from the ordinary ways of winding the coils with a considerable number of small turns. For many reasons the physician will find it better to provide a large hoop H of not less than, say three feet in diameter and preferably more, and to wind upon it a few turns of stout cable P. The secondary coil S is easily prepared by taking two wooden hoops h h and joining them with stiff cardboard. One single layer of ordinary magnet wire, and not too thin at that, will be generally sufficient, the number of turns necessary for the particular use for which the coil is intended being easily ascertained by a few trials. Two plates of large surface, forming an adjustable condenser, may be used for the purpose of synchronizing the secondary with the primary circuit, but this is generally not necessary. In this manner a cheap coil is obtained, and one which cannot be easily injured. Additional advantages, however, will be found in the perfect regulation which is effected merely by altering the distance between the primary and secondary, for which adjustment provision should be made, and, furthermore, in the occurrence of harmonics which are more pronounced in such large coils of thick wire, situated at some distance from the primary. - High Frequency Oscillators for Electrotherapeutic and Other Purposes, *Electrical Engineer*, November 17, 1898.



Computer Science undergrad and writer Shashank Bhardwaj came up with this fanciful illustration of Witricity.

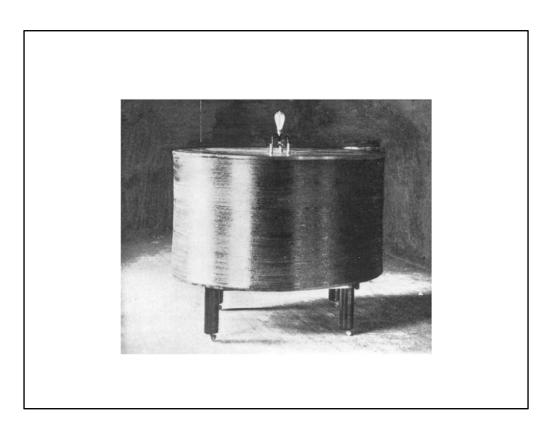
[Bhardwaj, Shashank, <u>The Future of Wireless Charging</u>, Geek Insider, March 15, 2013; www.geekinsider.com/the-future-of-wireless-charging/]



This is Tesla's own WiTricity setup, constructed more than 120 years ago as a scientific tool and used to entertain visitors at his South 5th Avenue laboratory.

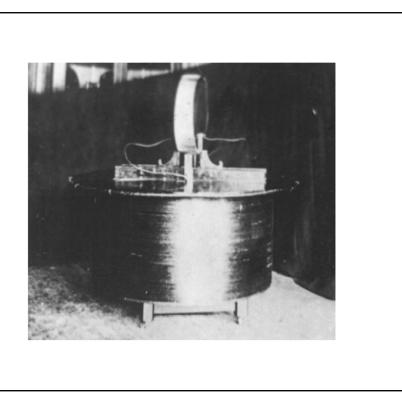
The "WiTricity Source Coil" is labeled **P** for "primary." Instead of being a small coil of wire sitting on an end table, it consists of a single electrical cable that, "passes all around the hall."

Multiple WiTricity "Receiving Coils" are labeled **S** for "secondary."



This is a "coil table" WiTricity secondary receiver with an incandescent electric lamp attached.

The wireless connection to the surrounding primary cable is by electromagnetic induction.

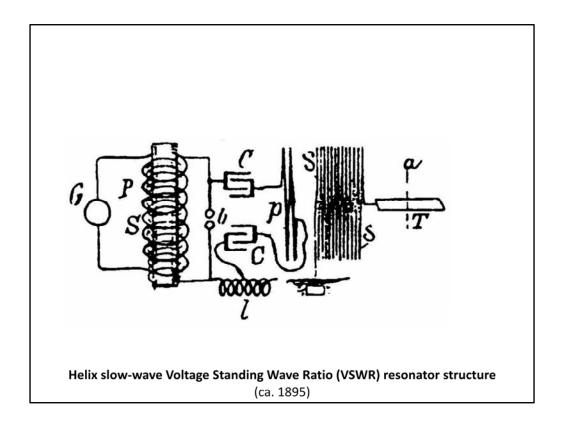


This slide shows another secondary coil table with sparks jumping between two vertical metal plates mounted on top of it. It's also known as a "tuning table."

A few experiments performed in Mr. Tesla's laboratory work shop afford an idea of the flexibility of the methods by which powerful electrostatic effects are produced across many feet of intervening space. The workshop is a room about forty by eighty feet, and ten or twelve feet high. A circuit of small cable is carried around it from the terminals of the oscillator. In the center of the clear, open space is placed a coil, wound drum fashion, three or four feet high, and unconnected with the current source save through the medium of the atmosphere. The coil is provided, as shown in the picture, with two condenser plates for adjustment, standing up like cymbals. The plates act after the manner of a spring, and the coil is comparable to an electromagnetic weight. The system of apparatus in the middle of the room has therefore a certain period of vibration, just as though it were a tuning-fork, or a sheet of thin resonant glass. Around the room, over the cable, there are sent from the oscillator electrical current vibrations. By carefully adjusting the condenser plates so that the periodicity or swing of the induced current is brought into step with that of the cable currents, powerful sparks are made to pour across between the plates in the dense streams shown in Fig. 9. In this manner it is easy to reach tensions as high as 200,000 and 300,000 volts. - Tesla's Oscillator and Other Inventions, Century Illustrated Magazine, April 1895.

The circuit connections as usually made are illustrated schematically. . . . The condensers C C, connected in series, are preferably charged by a step-up transformer, but a. high frequency alternator, static machine, or a direct current generator, if it be of sufficiently high tension to enable the use of small condensers, may be used with more or less success. The primary p, through which the high frequency discharges of the condensers are passed, consists of very few turns of cable of as low resistance as possible, and the secondary s, preferably at some distance from the primary to facilitate free oscillation, has one of its ends--that is the one which is nearer to the primary--connected to the ground, while the other end leads to an insulated terminal T. . . . It is of importance in this case to establish synchronism between the oscillations in the primary and secondary circuits p and s respectively. This will be as a rule best effected by varying the self-induction of the circuit including the primary loop or coil p, for which purpose an adjustable self-induction e is provided. . . .

The primary and secondary oscillations being in close synchronism, the points of highest potential will be on a part of terminal T, and the consumption of energy will occur chiefly there. . . . The synchronism being perfect and the length of the secondary coil just equal to one-quarter of the wave length, these points will be exactly on the free end of terminal T, that is, the one situated farthest from the end of the wire attached to the terminal. If this be so and if now the period of the oscillations in the primary be shortened, the points of highest potential will recede towards the secondary coil, since the wave-length is reduced and since the attachment of one end of the secondary coil to the ground determines the position of the nodal points, that is, the points of least potential. Thus, by varying the period of vibration of the primary circuit in any manner, the points of highest potential may be shifted accordingly along the terminal T, which has been shown, designedly, long to illustrate this feature. — High Frequency Oscillators for Electro-therapeutic and Other Purposes, *Electrical Engineer*, November 17, 1898.



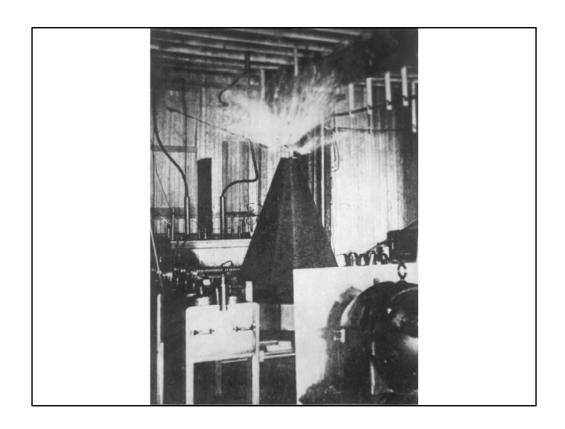
In the previous slides the inductive coupling between the primary and the secondary coils is quite loose.

With the tighter coupling shown here the transfer of energy into the secondary is more efficient; more energy is extracted from the primary circuit during each cycle.

Ideally, all of the available energy is taken out of the primary LC circuit and put into the secondary circuit in a single cycle or less, but this is difficult to achieve with the two coil configuration.

Here is our first example a Tesla coil secondary configured as a one-quarter wavelength helical resonator. The end closest to the primary is grounded and the coil's opposite end is connected to a terminal capacitance or isotropic capacitance; the "top-load" in Tesla coil builder's jargon.

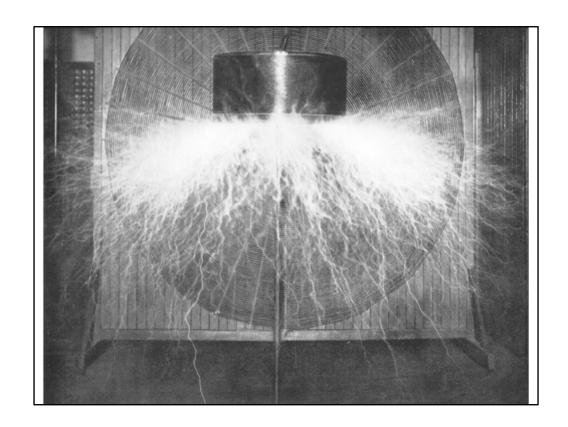
The slow wave helical resonator was a major engineering breakthrough in radio-frequency power processing that has yet to achieve its full potential in terms of applied technology.



This an early conical Tesla coil helix slow-wave VSWR resonator structure at the South 5th Avenue laboratory, circa 1895.

Notice the primary cable fastened to struts projecting down from ceiling. A power supply transformer and capacitor banks can also be seen.

This illustrates the first step in the evolution of the magnifying transmitter.



Here's a photo of a three coil magnifier system taken at the Houston Street laboratory, circa 1896.

A two turn primary cable is wound on a wooden frame hidden behind the flat spiral secondary.

The coil in the foreground from which streamers are issuing is called the "extra coil."

[Nikola Tesla Photograph Archive.]

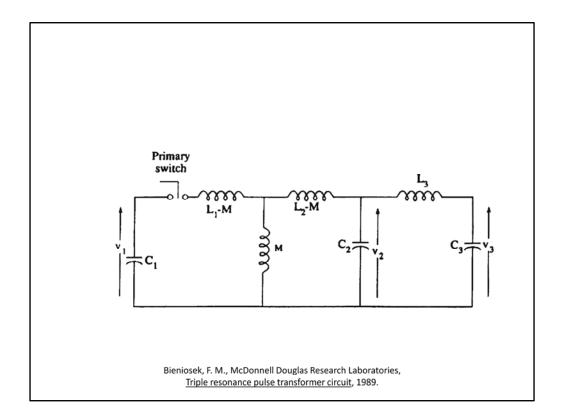
Here Tesla describes the operation of his oscillator as used to investigate methods of frequency-division multiplexing.

Referring to the apparatus which I often employed for convenience in practicing the invention, the transmitter comprised a high tension transformer, giving about 50 kilovolts pressure, which charged several sets of condensers. These condensers were automatically discharged so that a number of oscillations, two, three or more, in extremely rapid succession were passed through a cable laid around the room. When I used arrangements of circuits, such as illustrated in my patents on the transmission of energy, I most frequently directed the oscillatory discharges of the condensers through primaries placed in inductive relation to the circuits which were grounded or, generally speaking, connected to the medium which served as a means of transmission, which in some cases was wire. . . .

This coil I excited by a primary so proportioned that when the latter was closed by the make-and-break disk which discharged the condensers, the oscillation in the secondary was quickened to much above the rate which the secondary or spiral coil vibrated when the primary was opened. In this way I obtained two oscillations, which I regulated and controlled in a number of ways, and by means of which I excited two tuned circuits, each adjusted to respond to one of the oscillations which were impressed upon the ground in rapid succession by the transmitting coil described....

The primary was wound on a wooden frame and comprised two turns of very heavy cable. The coil to which I refer was placed on rollers so that it could be put at any desired distance from the exciting primary, in this way permitting me go graduate the effects and to produce the two vibrations required....

It was in regular use for a number of years prior to my going to Colorado, having been constructed, if I remember rightly, sometime in 1895, but it was not used in the manner described to produce two oscillations until a much later date, I think sometime in 1898. – Nikola Tesla: Guided Weapons & Computer Technology, Tesla Presents Series Part 3, Nikola Tesla, et al; Leland I. Anderson, Editor, 21^{st} Century Books, 1998, pp. 10-13.

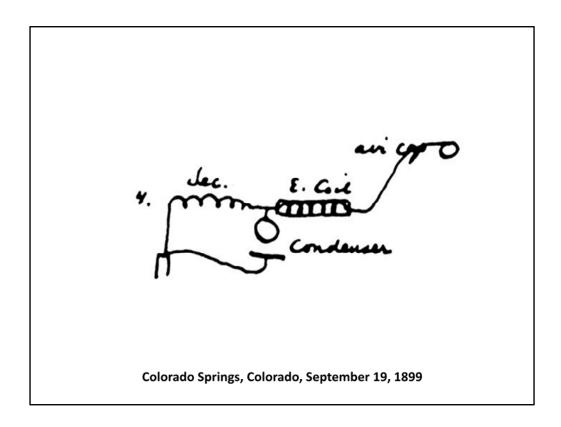


This is a Tesla coil equivalent circuit diagram by Bieniosek. The diagram represents both the three-inductor magnifier and the classic two-inductor configurations. In the latter case, inductances **L2** and **L3** are contiguous, and discrete capacitor element **C2** is eliminated. The remaining 'internal capacitance' represented by **C2** is negligible.

A shortcoming of the classic Tesla coil is that loose primary-to-secondary coupling , usually about k = 0.25, does not allow full energy transfer in a single RF cycle. This places a limit on the rate at which energy can leave the primary circuit, enter into the secondary and go on to the oscillation transformer output.

Efficiency can be increased by dividing the secondary inductor into two sections consisting of L2, which is kept close to primary inductor L1, and L3 which is moved farther away. This allows the coefficient of coupling between L1 and L2 to be increased to k = 0.6 or more, thus increasing the rate at which energy can flow into secondary L2. In a three-coil system, the L1L2 assembly is called the "master oscillator transformer."

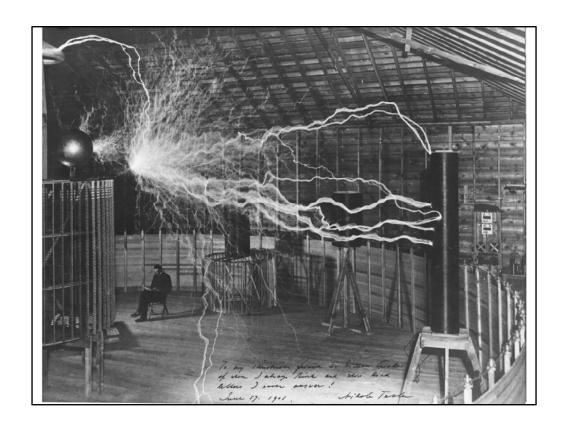
The design objective of the triple resonance circuit is to maximize the flow of energy through the circuit, from the input current that charges **C1**, to the output in the form of a high potential on elevated terminal **C3** relative to the ground plane beneath the oscillator. Maximum elevated terminal potential is achieved when the rate at which energy leaves master oscillator primary circuit **L1C1** and enters into master oscillator secondary circuit **L2C2** is the same as the rate at which energy leaves **L2C2** and enters into VSWR resonator circuit **L3C3**.



At the Colorado Springs Experimental Station Tesla tested various concepts in preparation for the construction of Wardenclyffe, that was planned as the first station in a worldwide network of wireless telecommunications facilities.

In Colorado I erected a plant for the practical purpose of arriving at accurate data for the construction of a large plant which I have termed a universal relay, or some such words. 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, p. 170.

In this drawing of the Colorado Springs magnifying transmitter the primary circuit **L1C1** has been omitted for the sake of simplicity. The accompanying text in the <u>Colorado Springs Notes</u> reads, "In all cases it has been found important to have the two systems vibrate in synchronism." The "two systems" are the secondary LC circuit and the extra coil plus the elevated air terminal.



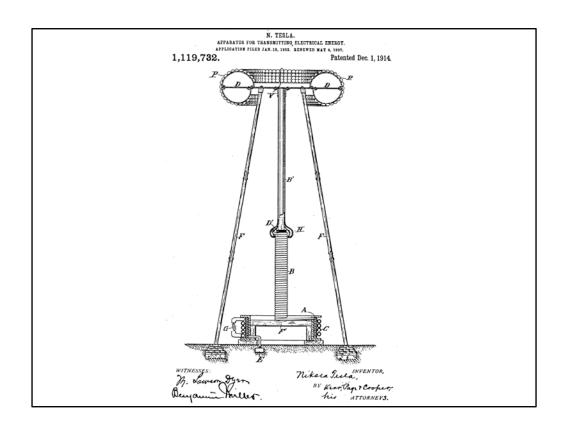
This is the Colorado Springs Magnifying Transmitter of 1899.

The three-coil oscillator design allows tighter inductive coupling and more rapid energy transfer between the primary and secondary. With the k = 0.6, transient, lumped coupled excitation mode, full energy transfer takes place in exactly one cycle. With tighter coupling full energy transfer can be achieved in less than one cycle. [Dr. James Corum]

The sparking Tesla coil incorporates a local ground plane. This can be either a local ground connection made up of buried wires or a ground rod driven near the base of the machine. Alternatively, a conducting surface, such as a large metal sheet or screen is positioned directly under the apparatus.

With the refined Tesla coil magnifying transmitter, on the other hand, close attention must be paid to electrical isolation of the ground terminal electrode from the oscillator in order to avoid a partial 'short-circuit' of the elevated terminal with the surrounding terrain.

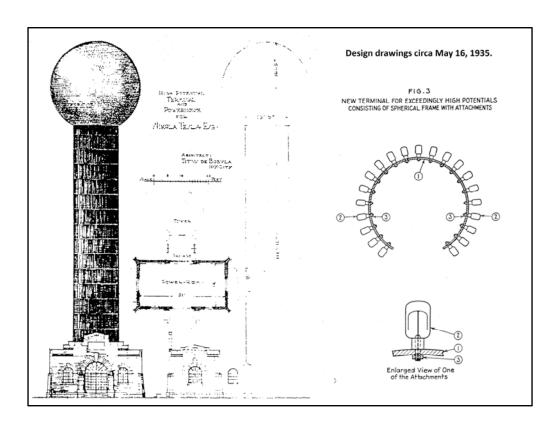
[Nikola Tesla Photograph Archive.]



Tesla discovered a number of problems with the Colorado Springs magnifying transmitter design. The solutions for these are found in the 1914 patent "Apparatus for Transmitting Electrical Energy" and other patents applied for between 1900 and 1902.

The maximum elevated terminal potential is increased by the prevention of streamers. The 1914 patent drawing shows an improved terminal that can be charged to a higher potential than previously possible. Tesla achieved this by modifying the earlier terminal's smooth surface with closely spaced hemispherical attachments.

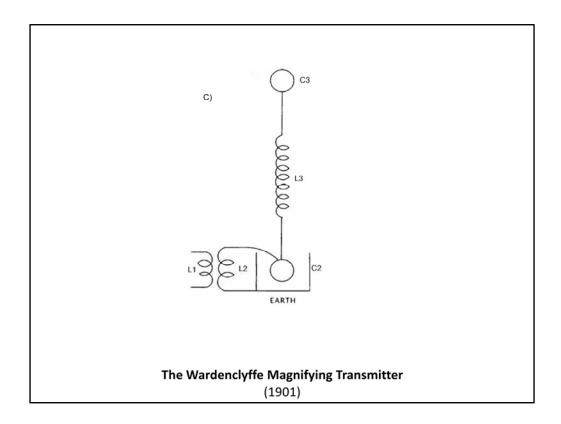
Shown are the closely coupled primary **C** and secondary **A** of the master oscillator transformer. The lower end of the tertiary or helix extra coil VSWR resonator is connected to the upper end of the relatively low impedance secondary. The lower end of the transformer secondary is connected to a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



An even more advanced elevated terminal than the 1902 version is revealed in 1935 in, <u>The New Art of Projecting Concentrated Non-dispersive Energy Through Natural Media – System of Particle Acceleration for Use in National Defense.</u>

- 1) Spherical frame.
- 2) Insulating bulb with an electrode of thin sheet metal suitably rounded and a metallic socket.
- 3) Nut fastener.

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 on inestimable value for practical purposes as well as scientific research.

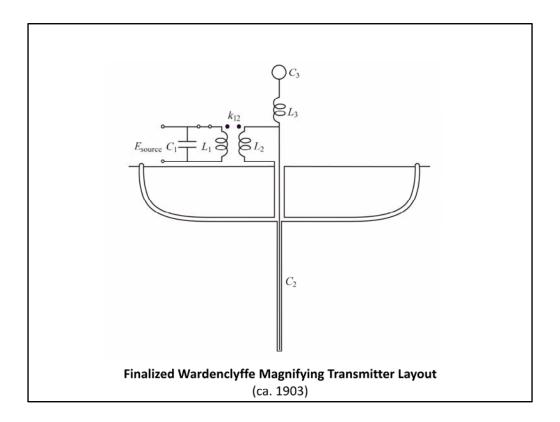


Another area of investigation directed toward perfection of the magnifying transmitter design was the oscillator-to-earth ground terminal electrode. Shown here is a magnifying transmitter design dated May 19, 1901, placing it at Wardenclyffe.

Included are, **L1**, **L2**, **C2**, **L3**, **C3**. Notice how the master oscillator secondary capacitor **C2** and the ground terminal electrode are placed together as a single unit.

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. — <u>Nikola Tesla - From Colorado to Long Island: Research Notes - Colorado Springs 1899-1900 - New York 1900-1901.</u>

In fig. C the most effective plan is illustrated. Here the secondary is joined to the condenser [C2]. – Nikola Tesla - From Colorado to Long Island: Research Notes - Colorado Springs 1899-1900 - New York 1900-1901.



As best we can tell, this is the basic Tesla magnifying transmitter schematic. Shown are the earth terminal electrode assembly and also the legendary Wardenclyffe tunnels.

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..

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, <u>Wizard: The Life and Times of Nikola Tesla</u>, Chapter 33, p. 291.

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. — <u>Cloudborn Electric Wavelets To Encircle the Globe</u>, *New York Times*, March 27, 1904.

A sump pump is placed into continuous operation for the water drainage system to be effective. **C2** is oil filled; the upper seal is not shown.

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.

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.

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.

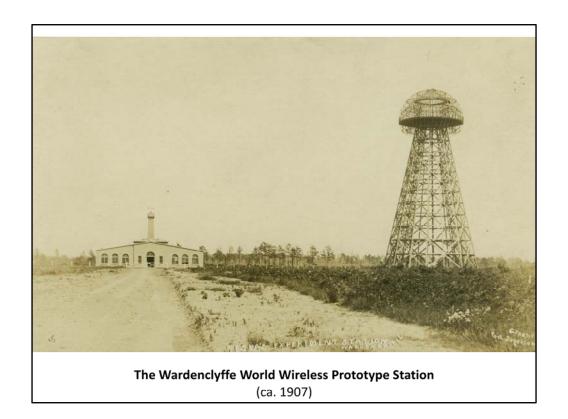
By Mr. Fordham:

Q. Was the hole really one hundred and twenty feet deep, did you say?

A. Yes, you see the ground water on that place is about one hundred and twenty feet. We are above the ground water about one hundred and twenty feet. In the well we struck water at about eighty feet.

By the Referee:

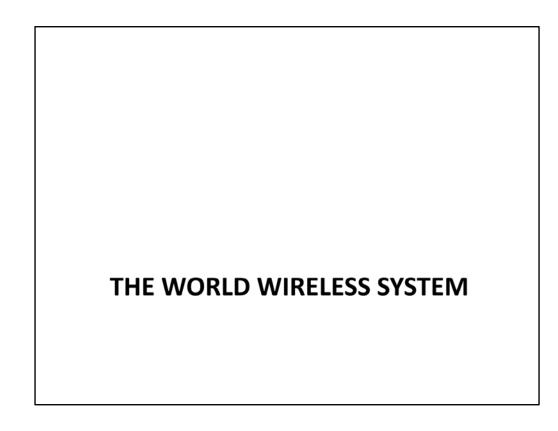
- Q. What you call the main water table?
- A. Yes the main well we struck at eighty feet, but there we had to go deeper.
- Nikola Tesla On His Work with Alternating Currents and Their Application to wireless Telegraphy, Telephony, and Transmission of Power, pp. 203-204.



Wardenclyffe was the first of two stations to be used for trans-Atlantic wireless telecommunications, global broadcasting and small-scale demonstrations of wireless power transmission. It was erected in 1901 at Wardenclyffe-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.

A minimum of two Wardenclyffe-type stations are required for a multi-channel, bidirectional full duplex World Wireless telecommunications system. The Long Island prototype was to be followed by a second plant, probably on the west coast of Scotland near Glasgow. Both facilities were to include a magnifying transmitter of the design shown in APPARATUS FOR TRANSMITTING ELECTRICAL ENERGY, U.S. Patent 1,119,732, December 1, 1914, application filed January 18, 1902.

[Nikola Tesla Photograph Archive.]

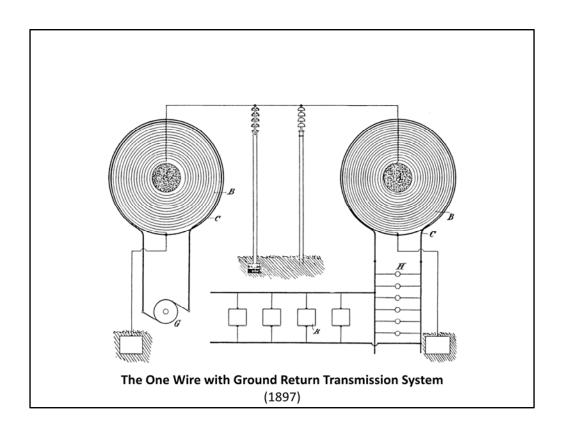


An electric current flowing through a conductor carries electrical energy. Earth is an electrical conductor, nearly spherical in shape, insulated in space. It possesses an electric charge relative to the upper atmosphere beginning at about 50 kilometers elevation. When a second body, directly adjacent to Earth, is charged and discharged in rapid succession this causes an equivalent variation of Earth's electrostatic charge resulting in the passage of electric current through the ground.

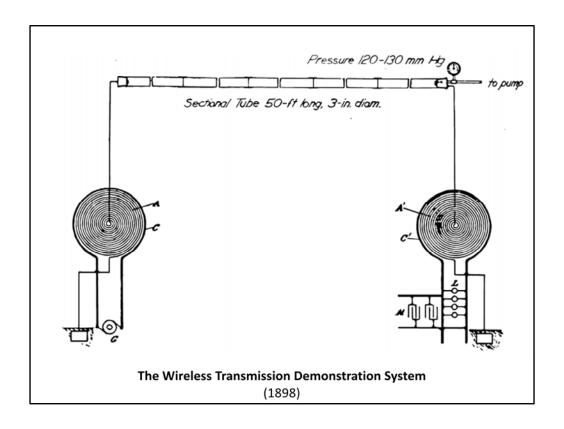
The Tesla coil magnifying transmitter, both the single and dual tower forms, is an electrical machine specifically designed to create as large a displacement as possible of Earth's electric charge. It does this by alternately charging and discharging the oscillator's elevated terminal capacitance at 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. — <u>The Disturbing Influence of Solar Radiation On the Wireless Transmission of Energy, Electrical Review and Western Electrician</u>, 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." 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.

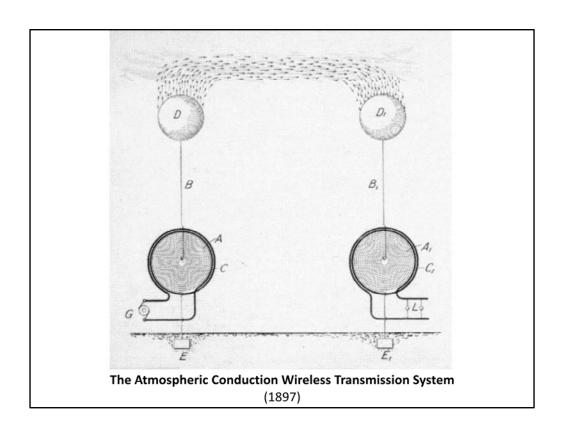


A pair of Tesla coils can be used to transmit and receive electrical energy using the earth as a conductor. The one-wire with ground return electrical power transmission system shown here relies on current flowing through a single elevated wire plus current flowing through the earth to complete the circuit.



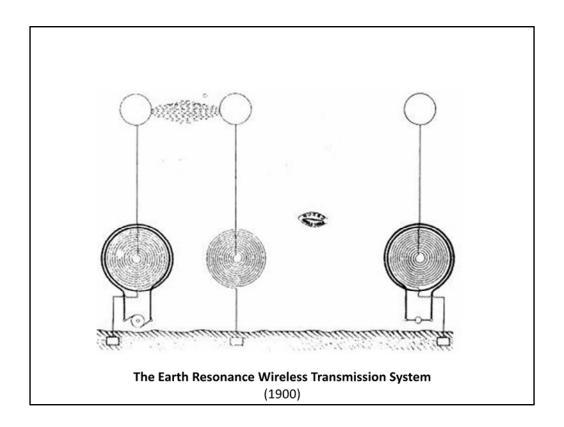
The elevated wire can be replaced by an ionized path connecting the Tesla coil transmitter to the Tesla coil receiver. This drawing shows a demonstration of this principle for an examiner with the U.S. Patent Office. 120 to 130 mmHg is the atmospheric pressure corresponding to about 8 miles elevation.

I came to the conviction that it would be ultimately possible, without any elevated antenna—with very small elevation—to break down the upper stratum of the air and transmit the current by conduction. Having discovered that, I established conditions under which I might operate in putting up a practical commercial plant. When the matter came up in the patents before the Examiner, I arranged this experiment for him in my Houston Street laboratory. I took a tube 50 feet long, in which I established conditions such as would exist in the atmosphere at a height of about 4 1/2 miles, a height which could be reached in a commercial enterprise, because we have mountains that are 5 miles high; and, furthermore, in the mountainous regions we have often great water power, so that the project of transmitting it, if the plan was rational, would be practicable. – Nikola Tesla On His Work With Alternating Currents and Their Application to Wireless Telegraphy, Telephony, and Transmission of Power, p. 126.



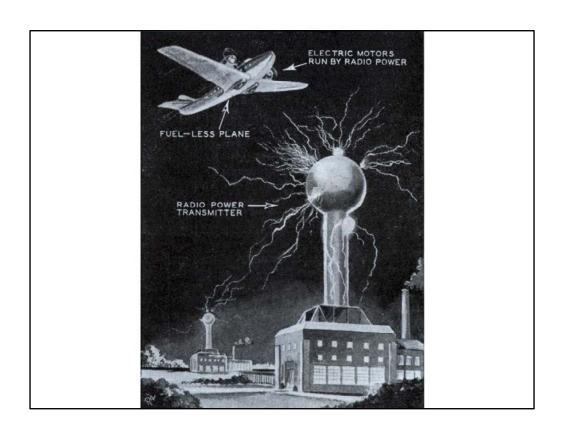
This is the basic Tesla wireless system showing the individual ground and elevated terminals. The circuit consists of an ionized path connecting a transmitter-receiver station to the upper atmosphere beginning at an elevation of five to eight miles, the upper atmosphere, and a second ionized path connecting the upper atmosphere back down to a second transmitter-receiver station. For lower power operation the paths connecting the two transmitter-receiver stations to the upper atmosphere take the form displacement current. In both cases, the return path is established through the earth.

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, 21st Century Books, 1992, pp. 129-130.



This is the basic earth-resonance transmitter configuration as incorporated into the initial Wardenclyffe design. To the right is a Tesla coil receiver. [Leland Anderson, "Rare Notes from Tesla on Wardenclyffe," Electric Spacecraft, Issue 26, Apr/May/Jun 1997.]

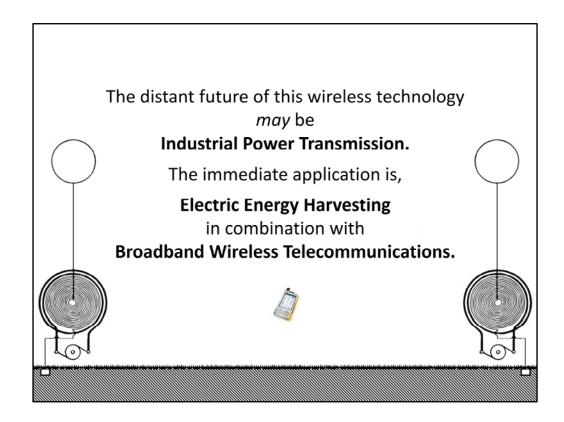
I shall typically illustrate the manner of applying my discovery by describing one of the specific uses of the same - namely, the transmission of intelligible signals or messages between distant points. . . . For the present it will be sufficient to state that the planet behaves like a perfectly smooth 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, Apr. 17, 1906, Canadian Patent No. 142,352, Aug. 13, 1912.



This is a similar earth-resonance transmitter. In this case the two side-by-side synchronized resonator structures are energized by separate power plants.

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 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."



Great possibilities might be easy achieved. Here are some suggested services that could become available by means of basic World Wireless system technology:

- 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 compliment middle-mile and last-mile fiber-optic infrastructure;
- Global synchronization of precision timepieces;
- Enhanced Deep Space Network.

"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, altho 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.

Part 4 A THEORETICAL FOUNDATION

Further development of the existing theoretical foundation supporting Tesla's wireless work.

"From my circuit you can get 90% of electromagnetic waves if you like . . . or, you can reverse the process. . . . By proper design and choice of wavelengths you can get 5 percent in these electro-magnetic waves and 95 percent in the current that goes through the earth.

"That is what I am doing." — Tesla, 1916

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.

He then mentions Arnold Sommerfeld.

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, p. 75

Arnold Sommerfeld described an electrodynamic wave that is guided along a wire of *finite* conductivity and Jonathan Zenneck expanded upon this description, asserting that the earth's surface behaves in a manner similar to a conducting wire. This is the **Sommerfeld-Zenneck Surface Wave.**

The *free electron model* for the behavior of valence electrons in a conductor was developed principally by Arnold Sommerfeld. The valence electrons are assumed to be completely detached from their ions, forming an *electron gas*.

"Because of its low resistance the *global spherical transmission line* may be modeled as an *electron qas*."

— J. Corum, 1996

The free electron model is a simple model for the behavior of valence electrons in a metallic solid.

On the cosmological scale, non-gaseous planets like Earth are spoken of as "metals."

The free electron model was developed principally by Arnold Sommerfeld who combined the classical Drude model with quantum mechanical Fermi-Dirac statistics and hence it is also known as the Drude–Sommerfeld model.

- http://en.wikipedia.org/wiki/Free electron model

"Spherical Transmission Lines and Global Propagation, An Analysis of Tesla's Experimentally Determined Propagation Model," K. L. Corum, J. F. Corum, Ph.D., and J. F. X. Daum, Ph.D. 1996, p. 24, Appendix I. "Plasmons, Longitudinal Waves, and the World as an Electron Gas."

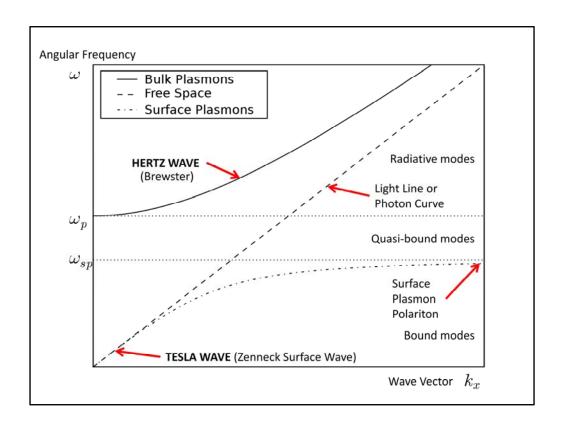
An *oscillating electric field* applied to a conductor causes the free electrons to accelerate resulting in an *harmonic plasma oscillation*.

This is either a **bulk plasmon** or a **surface plasmon**, depending upon the **oscillation frequency** (ω) and the **plasma frequency** (ω_p).

The "conductor" can be either a ½ wavelength dipole in free space over the terrestrial ground plane or the earth itself.

Bulk plasmons are associated with pure electromagnetic space waves, with the electric and magnetic fields being modeled as perpendicular to the direction of propagation.

Surface plasmons are associated with longitudinal charge density waves along the earthatmosphere interface, earth being a conductor and the lower atmosphere being a dielectric.



A motivated student could easily invest their entire career toward an investigation of the concepts represented here. There are researchers presently doing just this in the fields of quantum physics, plasmonics and nano-technology.

The <u>bulk plasmon dispersion curve</u> relates the time variation of the radiating electromagnetic space wave (given by its angular frequency ω) to the spatial variation of the wave (given by its wave vector k_x). Bulk plasmons can only exist for $\omega > \omega_p$, where ω_p is the plasma frequency, the resonant frequency of free electrons or electron gas in response to an electrical excitation.

The <u>surface plasmon dispersion curve</u> relates the time-variation of the electromagnetic transmission-line wave (also given by its angular frequency ω) to the spatial variation of the wave (given by its wave vector k_x). Surface plasmons exist for $\omega < \omega_p$, in which the wave-vector for bulk plasmons becomes imaginary. The electrical excitation gives rise to a longitudinal electron density wave along with a bound-mode electromagnetic wave, decaying exponentially away from the conductor-dielectric interface.

- <u>Surface Plasmon Polaritons</u>, Justin White, March 19, 2007 (Submitted as coursework for AP272, Stanford University, Winter 2007).
- <u>Introduction to Surface Plasmon Theory</u>, Jean-Jacques Greffet, Institut d'Optique Graduate School, ca. 2009.
- Nanophotonics lecture series, Prof. Albert Polman, Utrecht University, 2010-2011, Class 2: "Surface plasmon polaritons."

Zenneck waves may be excited by bombarding the surface with "fast electrons [Powel, C.J. and J.B. Swan, Physical Review, Vol. 118, 1960, p. 640]. This bears a striking resemblance to Tesla's experiments. . . . These plasma waves behave like real surface waves. — "Spherical Transmission Lines and Global Propagation, An Analysis of Tesla's Experimentally Determined Propagation Model," K. L. Corum, J. F. Corum, Ph.D., and J. F. X. Daum, Ph.D. 1996, p. 24, Appendix I. "Plasmons, Longitudinal Waves, and the World as an Electron Gas."

While the Norton Surface Wave (excited by a vertical dipole in free space over a conducting ground plane) is the result of electrical currents induced in the earth by refraction of a portion of the reflected-wave component of the ground-wave component of the space wave at the earth-atmosphere interface, the 'Zenneck-like' surface wave associated with Tesla's apparatus is the result of fast electron bombardment at each station resulting in terrestrial current flowing between discrete points of electrical connection to the earth's subsurface.

"A *pure Zenneck wave* would seem to hold out the promise of guided propagation with *no radiation field* to waste energy."

James Corum, 1994

Dr. Corum also writes,

There will exist the possibility of long-range coulomb interactions, which engender longitudinal 'compressional' electric waves propagating over the surface of the earth and bear a striking similarity to the Zenneck waves propagating over the surface of the earth. — Corum, J. F., et al, "Plasmons, Longitudinal Waves, and the World as an Electron Gas," 1996.

With appropriate constitutive parameters, a pure Zenneck wave would seem to hold out the promise of guided propagation with no radiation field to waste energy. – Corum, K. L. and J. F. Corum, "Nikola Tesla, Lightning Observations and Stationary Waves," Appendix II, "The Zenneck Surface Wave," 1994.

"As regards correctness of [Tesla's] approach to the propagation theory based on outlined assumptions, more study is needed and we hope that it will be done in the future."

— Aleksandar Marinčić, 1986

Tesla's approach is to employ longitudinal charge density waves while at the same time suppressing electromagnetic radiation.

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. . . . 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 . . . 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 waves. As regards correctness of his approach to the propagation theory based on outlined assumptions, more study is needed and we hope that it will be done in the future. – Marinčić, Aleksandar, "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*, Numbers 6 & 7, Tesla Memorial Society, 1990, pp. 25-28.

"The wonder is that, with the present state of knowledge and the experiences gained, no attempt is being made to disturb the electrostatic or magnetic condition of the earth, and transmit, if nothing else, intelligence."

— Nikola Tesla, 1892