

Wireless Energy Transmission

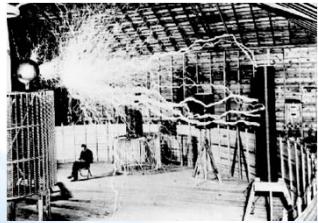
Nicola Tesla “UNPLUGGED”

by

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OBJECTIVE

By staying within the framework of the accepted governing physics laws:

- Attempt to arrive to an understanding of how Tesla conceived and planned
- WIRELESS Energy Transmission at his Shoreham Experimental Station
- In particular try to understand the Principles & his Methods
- The objective is NOT to prove or disprove his ideas BUT rather to understand what he was after
- Aim is to **steer clear** from convoluted concepts which, after all have hurt rather than helped N. Tesla's scientific contributions and reputation

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Resonance and N.TESLA (a cornerstone of his work)

Heraclitus: “τα παντα ρει ...”
or “everything is in motion”

and **Tesla** understood that “everything oscillates”
earth
fields (electric, mechanical, etc.)

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Finally, N. Tesla in the company of pioneers and immortal scientists



Figure 1.1: The pioneers of electromagnetic theory. From left to right: André-Marie Ampère (1775–1836), French physicist. Michael Faraday (1791–1867), English chemist and physicist. James Clark Maxwell (1831–1879), Scottish physicist and mathematician.

Gerhard Kristensson 2012, Lund, January 30, 2012



Figure 1.2: Immortal scientists of electromagnetic theory. From left to right: Jean-Baptiste Biot (1774–1862), French physicist, astronomer, and mathematician. Heinrich Rudolf Hertz (1857–1894), German physicist. Hendrik Antoon Lorentz (1853–1928), Dutch physicist. Nikola Tesla (1856–1943), Serbian inventor, mechanical engineer, and electrical engineer.

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Some Background

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Maxwell Equations and TESLA

While these form the basis of our understanding of electromagnetism we also accept that inconsistencies (both mathematical and physical) MAY EXIST in them

Stemming from Abrupt changes or DISCONTINUITIES (not everything is smooth)

In an effort to understand what Tesla had in mind, resorting to some mathematical formulations and Maxwell Equation solutions **will unavoidable**
(Kept to a minimum but necessary as a matter of record)

In all, we will NOT DEVIATE from the **Maxwell Equations Domain** (no new physics)

Try to explain everything starting every time from the universally accepted Maxwell governing relations

Maxwell Equations?

What are they ?

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Maxwell's Equations: Ingenious way of explaining the connection between electric and magnetic fields (electric field E and magnetic field B)

$$\nabla \times E = -\mu \frac{\partial B}{\partial t} \text{ (Faraday's Law)}$$

$$\nabla \times B = J + \epsilon \frac{\partial E}{\partial t} \text{ (Ampere's Law)}$$

$$\nabla \cdot E = \frac{\rho_v}{\epsilon} \text{ (Gauss's Law)}$$

$$\nabla \cdot B = 0 \text{ (Gauss's Law of Magnetism)}$$

ρ_v is volume electric charge density,
 J is the electric current density (ϵ is the
 permittivity and
 μ is the permeability)

All is smooth and easy UNTIL one gets close to abrupt electric and magnetic sources

Classical Maxwell equations are supposed to be satisfied point-wise at any instant of time.

Therefore, discontinuous or diverging solutions are not allowed, BUT

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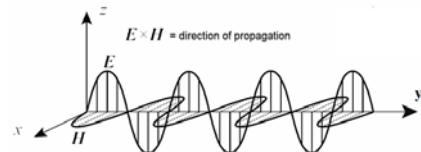
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When electromagnetic fields vary with time, we can re-arrange and decouple these relations and express them in forms that describe propagation of waves

$$\Delta E(r,t) - \epsilon \mu \frac{\partial^2 E(r,t)}{\partial t^2} = \frac{1}{\epsilon} \nabla \rho(r,t) + \mu \frac{\partial J(r,t)}{\partial t}$$

$$\Delta B(r,t) - \epsilon \mu \frac{\partial^2 B(r,t)}{\partial t^2} = -\mu \nabla \times J(r,t)$$



Transverse waves (Hertz type)

An antenna radiates high frequency transverse electromagnetic waves as shown

But is it all Hertz-type? Not necessarily!

Can other types of waves be generated and propagated?

Longitudinal waves? Tesla bet on it → will revisit the point

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To understand how Tesla, while remaining true to the Maxwell governing principles, conceptualized and pursued his goals, we need to go back and start at **Colorado Springs**

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Tesla at Colorado Springs

Pre-cursor to Wardenclyffe

What did he do there?

What did he observe?

How relevant to his work in Wardenclyffe (Shoreham)?

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What did he do there?

- A. Wirelessly transmitted electric pulses to large distances
- B. Observed the undiminished return of an electric pulse (which he speculated traveled to the antipode and back)

There has been speculation that what Tesla did he excited was resonances of the **Schumann Cavity**, but did he?

in his words:

"This mode of conveying electrical energy to a distance is not 'wireless' in the popular sense, but a transmission through a conductor, and one which is incomparably more perfect than any artificial one.

All impediments of conduction arise from confinement of the electric and magnetic fluxes to narrow channels. The globe is free of such cramping and impediments....."

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Some Background on the Cavity

Earth and Ionosphere (both conducting, **capacitor-like** or a cavity that can resonate)

Plenty is happening in the space between:

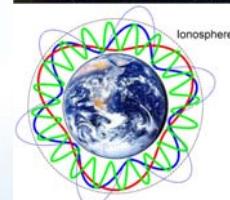
Electric field between this spherical capacitor exhibits characteristic modes when excited

Electrical discharges can excite them (lightning is a broadband or white noise excitation exciting all the modes in the cavity)

BUT why is it important?

It proves that certain electromagnetic types EXIST

i.e. longitudinal ELF and VLF waves

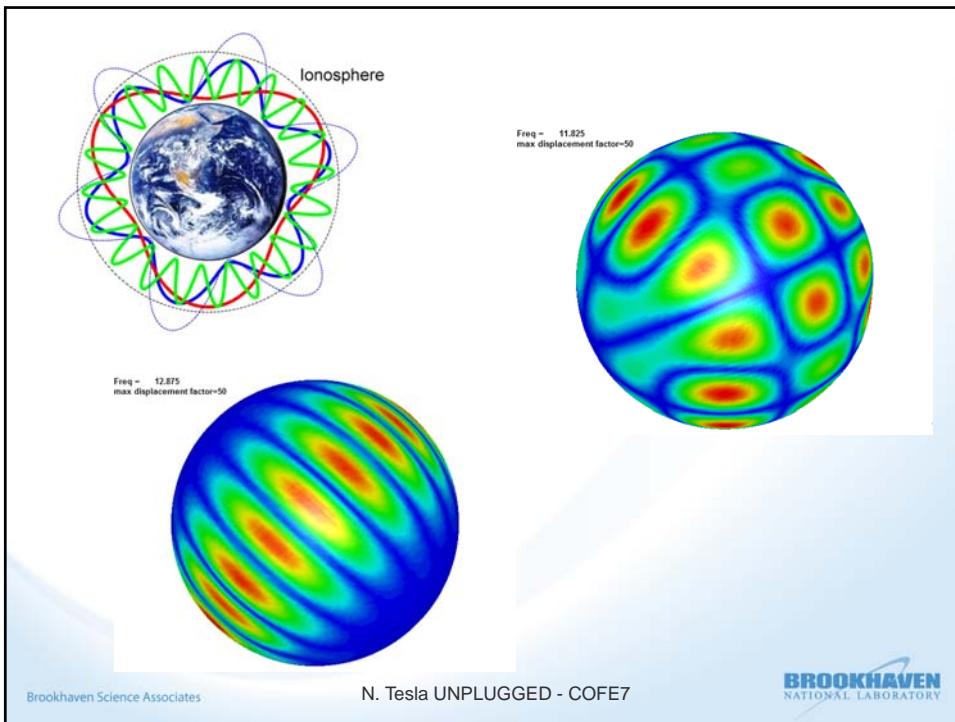


Source: Wikipedia

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Schumann Resonances – “Earth Breathing”

STANDING waves (modes-like) are formed in the cavity which functions like a **wave guide**

Solving the CLASSICAL Maxwell Equations one can arrive at the conclusion that both

Longitudinal and Transverse Modes (or standing waves) are present in the cavity

Longitudinal	~ Cavity mean radius
Transverse	~ Cavity height

2 orders of magnitude difference between eigenfrequencies

ELF (0-100 Hz) and **VLF (0-10 kHz)** waves or resonances develop.
These are considered **LONGITUDINAL Modes**

Lightning (or man-made) discharges can EXCITE these modes and especially those considered Extremely Low Frequency (ELF) – **including the 7.83 Hz mode**

Prof. O. Schumann around 1952 mathematically estimated the 7.83 Hz mode that was soon after (1954) confirmed with measurements

But wait a second

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According to Wikipedia:

The first documented observations of global electromagnetic resonance were made by Nikola Tesla at his Colorado Springs laboratory in 1899. The observations led to certain conclusions about the electrical properties of the Earth, and which made the basis for his idea of wireless energy transmission.

Tesla researched ways to transfer power wirelessly over long distances (via transverse and longitudinal waves) transmitting ELF through the earth and as well as between the Earth's surface and the Kennelly-Heaviside layer (standing waves).

Making calculations based on the experiments, Tesla discovered that the resonant frequency of the Earth was ~8 Hz. In the 1950's researchers confirmed that the resonant frequency of the Earth's ionospheric cavity was in that range ([later named the Schumann resonance](#))

Quote:

Physicist Nikola Tesla back in 1890's was FIRST to experiment with the CAVITY, powerful discharges emulating lightning and exciting ELF waves based on which he "discovered" the resonance frequency of the earth at 8 Hz.

"Unfortunately Tesla was before his time and his discoveries were not taken seriously"

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Wireless Transmission with “Schumann Resonances?

Not quite FEASIBLE, here is why:

- Spherical waves in Cavity or Modes
- Small Q-factor (ratio electric field energy stored in cavity per cycle/average power input)

While Tesla understood the Cavity effect and assessed its fundamental resonance, he did not ride these resonances to wirelessly transfer electric pulses.

So, what did Tesla excite at Colorado Springs?

He disturbed the earth's electric field (or blanket) with extreme electric discharges

- Electrically excite receivers at great distances
- Observed the undiminished electric pulses return from antipode

Determined a **DIFFERENT frequency** (not the 8 Hz Schumann fundamental resonance) which will guide his wireless transmission concepts

Determined that time required for transmitted pulse to travel to the antipode and back is .08484 seconds → fundamental earth resonance frequency of 11.786892 Hz)

→ Electromagnetic waves at these frequencies!!! → ELF & VLF shown in Schumann Cavity

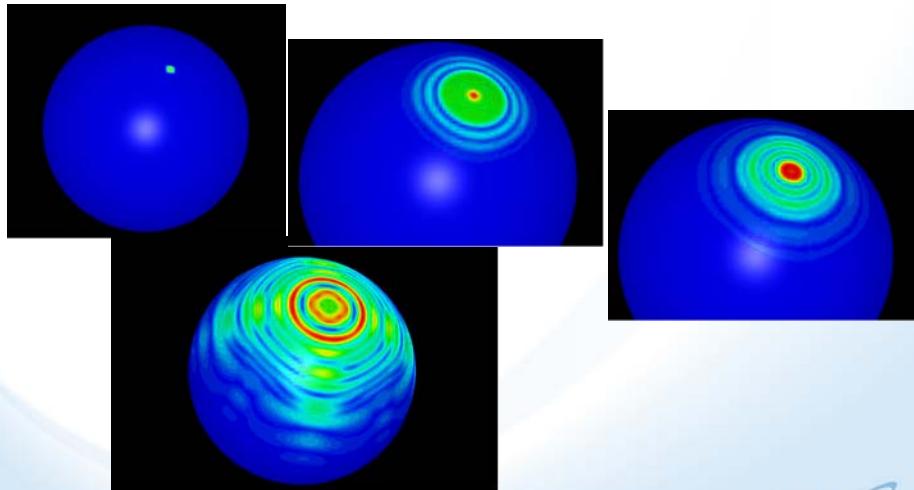
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Tesla quoting:

*Power would be transmitted by creating "standing waves" in the earth by **charging the earth with a giant electrical oscillator** that would make the earth vibrate electrically in the same way a bell vibrates mechanically when it is struck with a hammer. . . ."*

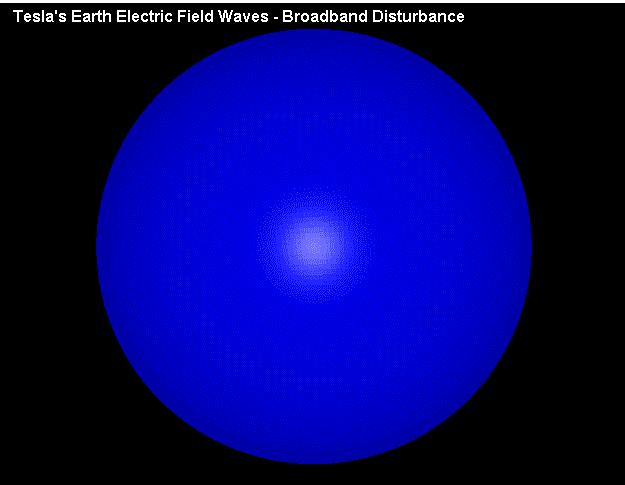


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Tesla's Earth Electric Field Waves - Broadband Disturbance



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Tesla at Shoreham

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Wireless power transmission From Colorado Springs to Shoreham

Fundamental principles underlying Tesla's wireless energy transmission:
(what he counted on)

1. **Low frequency alternating current can be transmitted through the earth with low loss**
(net resistance between earth's antipodes <1 ohm)
2. **Low frequency, high voltage alternating current** via electric displacements by
a) electrostatic induction, b) electrical conduction, or a combination of the two
3. **Earth's naturally existing electrostatic potential (electrostatic field)**
400,000 V potential with ionosphere
Downward directed **E-field of about 100 V/m** near surface
ability to create disturbances in this charge as annular distortion of the
background electric field

AIMED AT TWO (2) Methods, or Circuit Types, namely

- **OPEN CIRCUIT** → Earth Resonance
- **CLOSED Circuit** → Atmospheric Conduction

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How do his two concepts work?

CENTRAL to Tesla's concepts is the Capacitor Principle

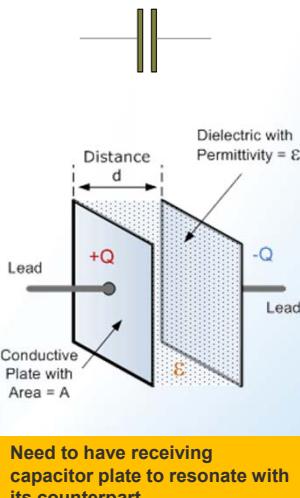
He is envisioning however a capacitor of enormous proportions

In a typical capacitor (energy indeed transfers wirelessly across the two plates through the dielectric) AC current jumps the gap that is between 1/6-1/2 wavelength.

Because AC frequencies are high → wavelengths are small so GAP is small

In Tesla's model the two distant elevated terminals are electrically coupled together in a manner similar to the transfer of electrical energy between two closely spaced capacitor plates **but at distances greatly exceeding 1/6 - 1/2 wavelength**

His concept/model, at first glance, considered to be inconsistent with mainstream physics UNLESS different types of waves between the plates can be excited!!!!

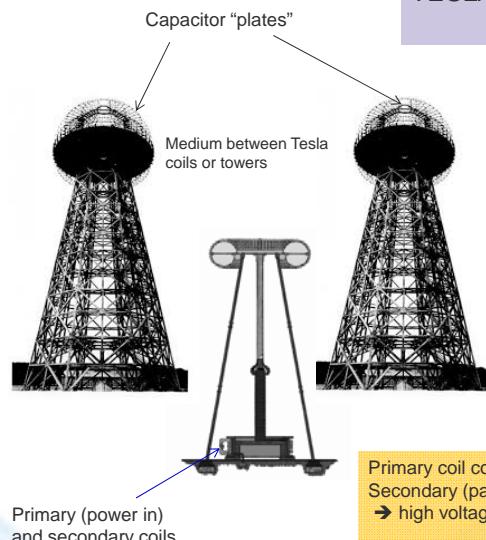


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TESLA Coil and System: What is it? A capacitor and some other stuff!!!



The wireless system is comprised of two sympathetically tuned electrical oscillators

RF power supply connected to a **grounded top-loaded helical resonator**

Distance apart many wavelength's (unlike capacitor !!!)

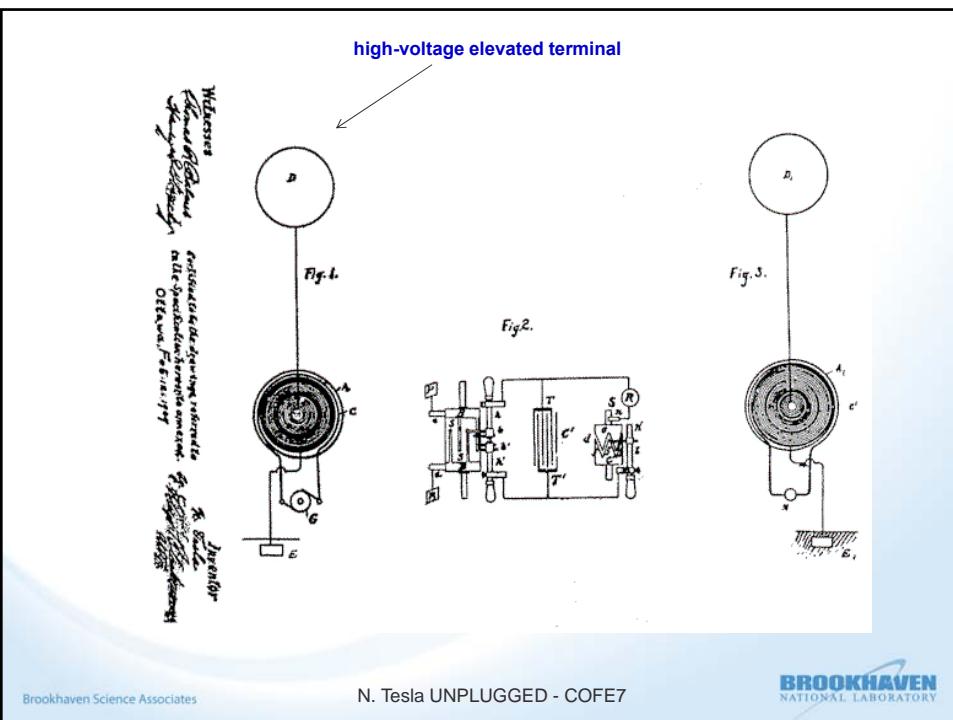
Primary coil connected to power source
Secondary (pancake) coil and connector to capacitor plate:
→ high voltage and **selected frequency (harmonic of 11.78 Hz)**

Ionization of air between capacitor plates:
→ excitation of LF longitudinal modes or waves

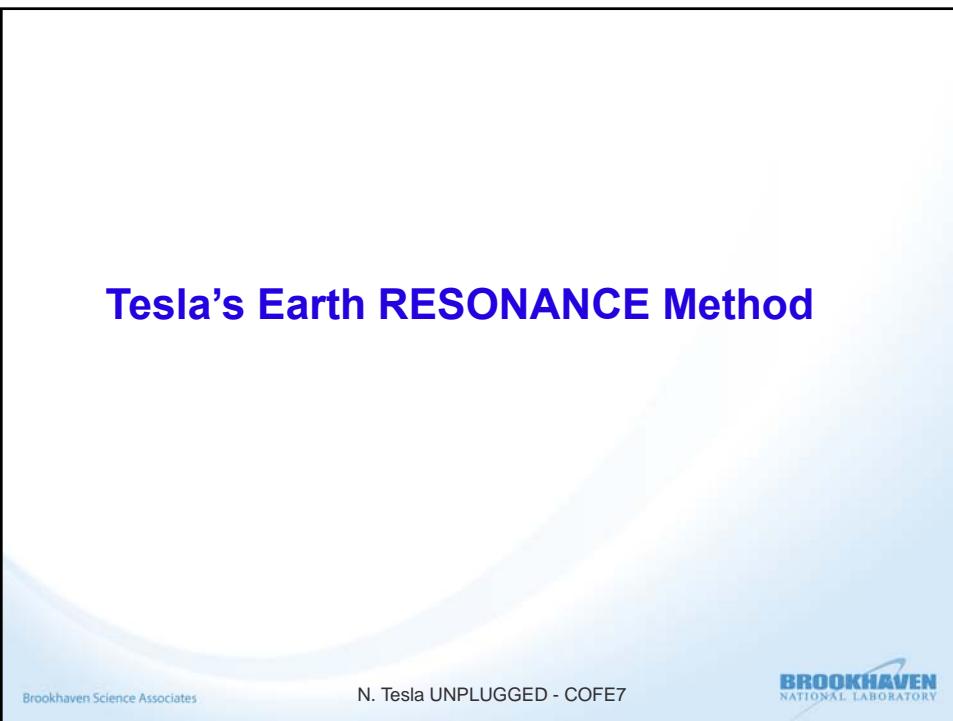
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Tesla's Earth RESONANCE Method



Open Circuit working principle – Earth Resonance Method

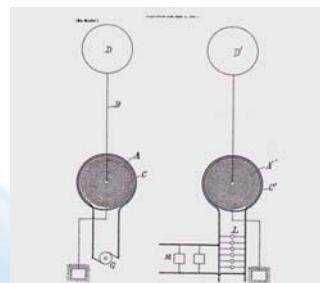
A Tesla coil earth resonance transmitter creates a local disturbance in the earth's charge

He is now zooming-in to not simply excite the earth's electric field with a broadband source BUT with a source that operates at some harmonic of the earth field-resonance (~11.78Hz)

Such source is the basis of Tesla's earth resonance method.

The receiver (from the two Tesla coils) is **Passive**

Earth's electric field resonance will provide the synchronization of the receiver!!!



Recall that Tesla estimated that the fundamental earth resonance frequency is of the order 11.786892 Hz.

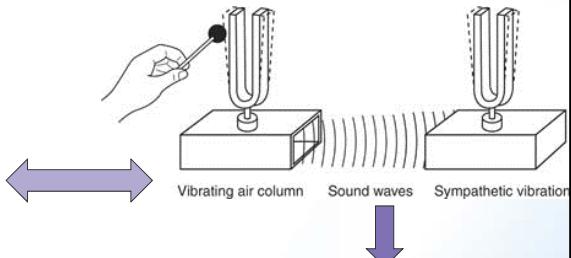
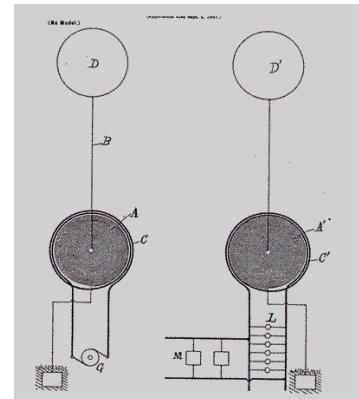
That came from his Colorado Springs work! So, there is the connection!

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Governing Principles in Resonance Method



Medium between tuning forks (transmitter and receiver) is AIR

Sound (**compression**) waves propagate in the medium

Energy transfers between transmitter and receiver

If the characteristic tone of fork **B** is different than **A** NOTHING happens!!!

Medium between similar coils (transmitter and receiver)?

Types of waves it can support (VLF, ELF)

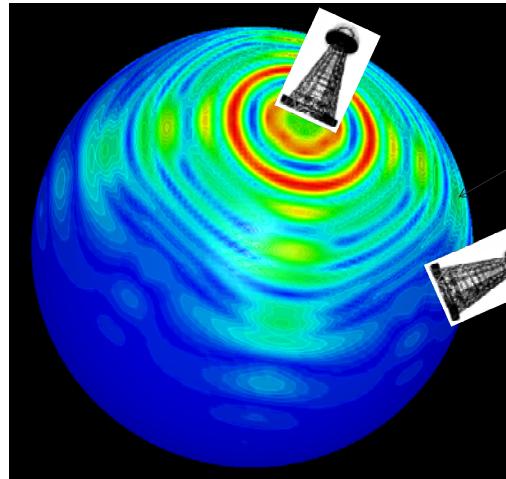
Longitudinal waves ??? (not Hertzian) ➔ debate

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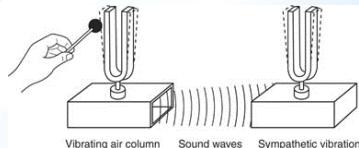
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How will Tesla's Resonance System look like?



Receiver will be tuned transmitter and will be excited by the field distortion, itself excited by the transmitter at the same frequency



Same thing, only electrically

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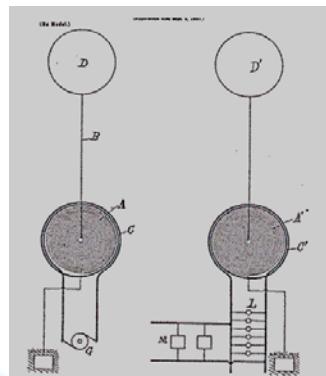
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Open Circuit working principle – Earth Resonance Method (continued)

System **MUST** operate at some harmonic of the earth-resonance frequency (~11.78Hz)

Receiver waiting to be SYMPATHETICALLY activated, once it does, NEEDS to draw load (transfer of energy).



Success of the method rides on the ability of the transmitter to excite and induce waves in the medium between them **OTHER** than of the Hertz-type

Let's go back to Maxwell's Equations and take a closer look

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Longitudinal and Transverse Waves

START from the fact that any vector field (finite, uniform, continuous) can split into longitudinal and transverse fields

$$F = F_{\perp} + F_{\parallel}$$

$\nabla \times F_{\parallel} = 0$
 $\nabla \bullet F_{\perp} = 0$

$$\nabla \bullet D_{\parallel} = \rho(r, t)$$

D_{\parallel} = longitudinal electric excitation
 E_{\parallel} = longitudinal electric field

Maxwell equation for the long. part of electric displacement field

Which after some mathematical manipulations leads to:

$$D_{\parallel}(r, t) = \frac{1}{4\pi} \int \rho(r', t) \frac{r - r'}{|r - r'|^3} d^3 r'$$

$$E_{\parallel}(r, t) = \frac{1}{4\pi\epsilon} \int \rho(r', t) \frac{r - r'}{|r - r'|^3} d^3 r'$$

(Source: J. Nitsch, et al, Equivalent Circuit Method)

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Longitudinal and Transverse Waves

$$E_{\parallel}(r, t) = \frac{1}{4\pi\epsilon} \int \rho(r', t) \frac{r - r'}{|r - r'|^3} d^3 r'$$

Above is an interesting finding which says that the longitudinal electric displacement D_{\parallel} and electric strength E_{\parallel} are **fully coupled** to **the instantaneous Coulomb charge !!!**

$$E_{\parallel}(r, t) \longleftrightarrow \rho(r', t)$$

Or, whatever the SOURCE is doing at (r', t) the field is doing at (r, t) :

That is CRUCIAL !!!!

If the source is oscillating with a frequency f so will any point on the domain → receiver will oscillate sympathetically at the same frequency (which is made to be identical to that of the transmitter)

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Parenthesis

Attempt to see if the types of waves Tesla was counting on can be generated

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$$\Delta E(r,t) - \epsilon\mu \frac{\partial^2 E(r,t)}{\partial t^2} = \frac{1}{\epsilon} \nabla \rho(r,t) + \mu \frac{\partial J}{\partial t}(r,t)$$

$$\Delta B(r,t) - \epsilon\mu \frac{\partial^2 B(r,t)}{\partial t^2} = -\mu \nabla \times J(r,t)$$

Interesting solutions due to charge/current singularities

Consider one of the “wave-like” equations

Laplace transform on τ

$$c^2 \Delta E(r,t) - \frac{\partial^2 E(r,t)}{\partial t^2} = \delta(\xi-x, \eta-y, \zeta-z, \tau-t)$$

$$(r\bar{E})_{rr} - (s/c)^2(r\bar{E}) = (r/c^2)\delta(\xi-x, \eta-y, \zeta-z)$$

$$\bar{E} = -e^{-i\tau(r/c)} / 4\pi \cdot c^2 \cdot r$$

In 3-D space

$$E = -\delta[\tau-t-(r/c)] / 4\pi \cdot c^2 \cdot r$$

In 2-D space

$$E = \begin{cases} 0 & r > d(\tau-t) \\ \frac{1}{2\pi\sqrt{c^2(\tau-t)^2 - r^2}} & r < d(\tau-t) \end{cases}$$

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“Near-field” a and “wave-zone” effects

Hertzian Oscillator – Dipole Antenna

At point P with a stationary positive charge $+e$ and an oscillating negative charge $-e$ (about P) forming a dipole

➔ “Hertzian Oscillator” ➔ generate what we know as Hertzian waves

The field produced (omit derivation from Maxwell's equations)

$$E = \frac{e}{4\pi R^2} (R_i - r_i) + \frac{f[R_i, \ddot{p}]}{4 \cdot \pi \cdot c^2 \cdot R}$$

Near-field Wave-zone

So, even an oscillating dipole induces a near field !!!!

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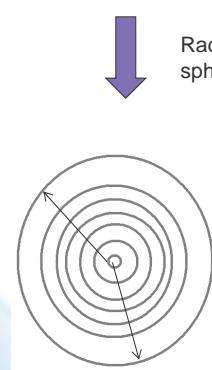
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Let's revisit the solution from a discharge that Tesla was doing in Colorado Springs

$$E = -\delta[\tau - t - (r/c)] / 4\pi \cdot c^2 \cdot r$$

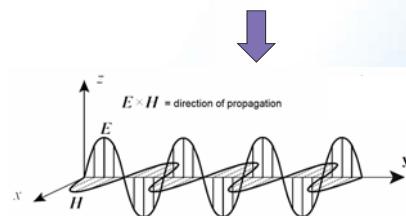
From singular discharge



Radially expanding thin spherical shell

$$E = \frac{e}{4\pi R^2} (R_i - r_i) + \frac{f[R_i, \ddot{p}]}{4 \cdot \pi \cdot c^2 \cdot R}$$

From oscillating dipole



Well, what is under debate is how far from the source inducing the electromagnetic waves **the two types** separate

It can be said that it depends on the disturbance, or source-type

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RECEIVER Responding INSTANTLY?

It can only happen if the Transmitter EXCITES a mode of the field (standing wave)

ONLY then the field will be disturbed instantly!!!

and Tesla AIMED at exactly that:

Hence, RIDE the fundamental mode of the earth electric charge field OR
a multiple harmonic of it

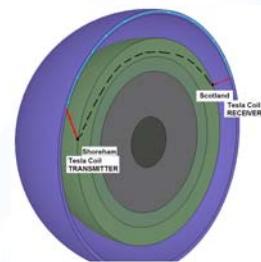
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Tesla's ATMOSPHERIC CONDUCTION Method

Closed Circuit Method



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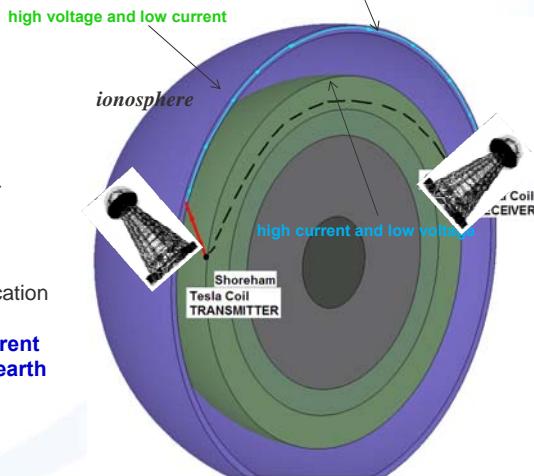
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Atmospheric Conduction

electrostatic induction instead of true conduction

Electrical displacement or the passage of electrical energy through space other than the application of voltage potential



What will the system look-like:

- **Tesla coil transmitter**
- Ionized path connecting the transmitter upper atmosphere
- Ionosphere
- Ionized path connecting the upper atmosphere back down to receiving location
- Tesla Coil (receiver)
- **Closed circuit is completed with current back to the transmitter through the earth**

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DETAILS of the Atmospheric Conduction Method

An oscillating electric field is induced by High Potential RF current applied to the HELICAL Resonator of a Tesla coil (oscillating magnetic field → oscillating electric field)

A plasma state is formed in the High Voltage Terminal (capacitor plate) making it conductive

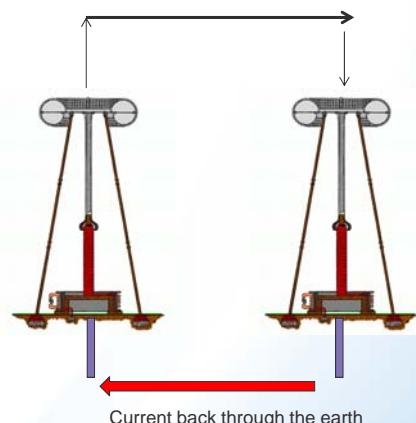
Current is pushed in the 10,000,000 to 12,000,000 volts line created to the upper strata (high voltage will minimize loss due to plasma transmission-line resistance)

An ionizing beam of ultraviolet radiation will also form a high-voltage plasma transmission line

If a plasma state is induced in the upper troposphere (part of the scheme) then that becomes a conductor

End result is a flow of true conduction currents between transmitter and receiver

The process relies on **plasma waves** developing in the ionized region between the two terminals (**electrostatic waves or magneto-hydrodynamic waves**)



One can see a purely conduction method and a hybrid one (part conductive part inductive)

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Longitudinal Waves and Maxwell Equations

Electrostatic or magneto-hydrodynamic plasma wave model

Electrostatic Waves (K. T. McDonald, An Electrostatic Wave)

Assertion: A time-varying purely ELECTRIC field $E(r,t)$ can exist and propagate as a longitudinal wave WITHOUT coupling to a time-varying magnetic field

$$\nabla \times E = 0 \quad \frac{\partial B}{\partial t} = 0$$

But under the Conditions:

Electric Displacement D is zero in a plasma medium0

These **Longitudinal electric waves** can coexist with background electrostatic and magneto-static fields

$$E = E_x \hat{x} e^{i(kx-\omega t)}$$

$$E = -\nabla V \quad \Rightarrow \quad \nabla \times E = -\frac{1}{c} \frac{\partial B}{\partial t} = 0$$

$$V = i \frac{E_x}{k} e^{i(kx-\omega t)}$$

$$\rho = -\nabla P$$

Maxwell Equations

$$\nabla \cdot E = 4\pi\rho$$

$$P = -\frac{E}{4\pi}$$

$$\text{Condition: } D = E + 4\pi P = 0$$

P = volume density of electric moments
D = Electric Displacement of Long. Wave
ρ = charge density

Further analysis reveals that the longitudinal waves can only have the plasma frequencies!

We did observe the same in the separation of transverse and longitudinal waves of Maxwell's equations

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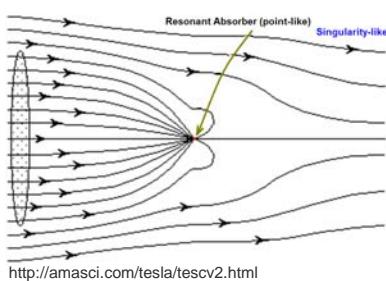
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So, what happens at the receiving end

COUPLED Transmitter and Receiver → Transmitter "feels" the load in the receiver



ENERGY SUCKING ANTENNAS and TESLA

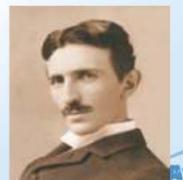
Parallelism with ATOMS (1 Am) strongly interacting with LIGHT (5000 Am wavelength)

Flood the atmosphere with standing waves (ionosphere keeps most of this EM energy from escaping into space) then a small resonator can grab significant wattage right out of the air (effective disk in figure)

A **small resonator** can produce an extensive and intense AC field of its own, and can act as an "**EM funnel**"
(simple desktop experiments demonstrated it !!!)

This is "**circuitry**", where wavelength is huge, and circuits are small

As one said: "This is probably the concept that put that "Mona Lisa grin" on photographs of old Nikola. And that twinkle in his eye..."



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How Feasible or Workable is Tesla's Concepts?

Resonance or Open Circuit Method:

Tesla's model involves two very distant, electrically coupled elevated terminals (capacitor plates) in a manner similar to the transfer of electrical energy between two closely spaced capacitor plates in a typical AC circuit, **but at distances greatly exceeding 1/6 - 1/2 wavelength**

This model considered to be inconsistent with a basic tenet of mainstream physics (related to the scalar derivatives of the electromagnetic potentials)

So we thought, BUT "Witricity" is proving to be otherwise

- ➔ MIT tests and Resonant Inductive Coupling ➔ distances > $\frac{1}{4}$ wavelength
maybe not the distances Tesla envisioned BUT much greater than what was thought as the threshold of a capacitor

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Atmospheric Conduction or Closed Circuit Method:

Model has no inconsistencies

It also involves two very distant, electrically coupled elevated terminals (capacitor plates) that are both active and rely on in electrostatic induction alone

It also involves the ionization of the space between the two "capacitor" plates which in turn (being in a state of plasma) will permit ELF and VLF waves

While consistent, it may be impractical for its size. Maybe!

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In his own words

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Let the future tell the truth, and evaluate each one according to his work and accomplishments.

The present is theirs; the future, for which I have really worked, is mine.

Nikola Tesla

It is possible then that our future already lies in our past

..... all we need to do is continue connecting the dots

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Links and Resources

www.teslasciencecenter.org – TESLA Science Center at Wardenclyffe

www.teslasociety.org – Tesla Society of USA and Canada

www.teslaradio.com

J. Nitsch, F. Gronwald, G. Wollenberg, "Equivalent Circuit Method", Wiley

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