



RADIO DEPARTMENT

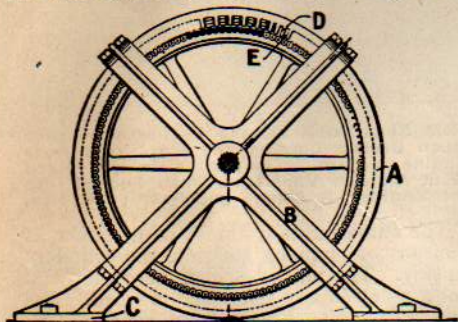


The True Wireless

By NIKOLA TESLA

Written Exclusively for The Electrical Experimenter

EVER since the announcement of Maxwell's electro-magnetic theory scientific investigators all the world over had been bent on its experimental verification. They were convinced that it would be done and lived in an atmosphere of eager expectancy, un-



Alternator of 10,000 Cycles p.s., Capacity 10 K.W., Which Was Employed by Tesla in His First Demonstrations of High Frequency Phenomena Before the American Institute of Electrical Engineers at Columbia College, May 20, 1891. Fig. 1.

usually favorable to the reception of any evidence to this end. No wonder then that the publication of Dr. Heinrich Hertz's results caused a thrill as had scarcely ever been experienced before. At that time I was in the midst of pressing work in connection with the commercial introduction of my system of power transmission, but, nevertheless, caught the fire of enthusiasm and fairly burned with desire to behold the miracle with my own eyes. Accordingly, as soon as I had freed myself of these imperative duties and resumed research work in my laboratory on Grand Street, New York, I began, parallel with high frequency alternators, the construction of several forms of apparatus with the object of exploring the field opened up by Dr. Hertz. Recognizing the limitations of the devices he had employed, I concentrated my attention on the production of a powerful induction coil but made no notable progress until a happy inspiration led me to the invention of the oscillation transformer. In the latter part of 1891 I was already so far advanced in the development of this new principle that I had at my disposal means vastly superior

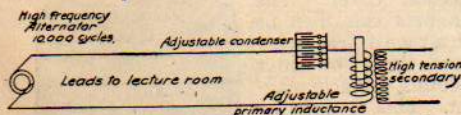


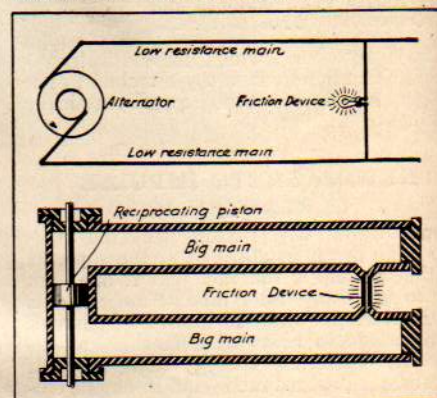
Diagram Illustrating the Circuit Connections and Tuning Devices Employed by Tesla in His Experimental Demonstrations Before the American Institute of Electrical Engineers With the High Frequency Alternator Shown in Fig. 1. Fig. 2.

to those of the German physicist. All my previous efforts with Rhumkorf coils had left me unconvinced, and in order to settle my doubts I went over the whole ground once more, very carefully, with these im-

proved appliances. Similar phenomena were noted, greatly magnified in intensity, but they were susceptible of a different and more plausible explanation. I considered this so important that in 1892 I went to Bonn, Germany, to confer with Dr. Hertz in regard to my observations. He seemed disappointed to such a degree that I regretted my trip and parted from him sorrowfully. During the succeeding years I made numerous experiments with the same object, but the results were uniformly negative. In 1900, however, after I had evolved a wireless transmitter which enabled me to obtain electro-magnetic activities of many millions of horse-power, I made a last desperate attempt to prove that the disturbances emanating from the oscillator were ether vibrations akin to those of light, but met again with utter failure. For more than eighteen years I have been reading treatises, reports of scientific transactions, and articles on Hertz-wave telegraphy, to keep myself informed, but they have always impress me like works of fiction.

The history of science shows that theories are perishable. With every new truth that is revealed we get a better understanding of Nature and our conceptions and views are modified. Dr. Hertz did not discover a new principle. He merely gave material support to a hypothesis which had

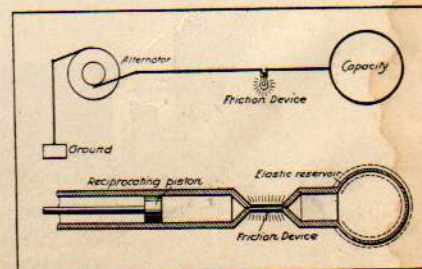
application of these radiations for the purpose was quite obvious. When Dr. Hertz was asked whether such a system would be of practical value, he did not think so, and he was correct in his forecast. The best that might have been expected was a method of communication similar to the



Electric Transmission Thru Two Wires and Hydraulic Analog. Fig. 3.

heliographic and subject to the same or even greater limitations.

In the spring of 1891 I gave my demonstrations with a high frequency machine before the American Institute of Electrical Engineers at Columbia College, which laid the foundation to a new and far more promising departure. Altho the laws of electrical resonance were well known at that time and my lamented friend, Dr. John Hopkinson, had even indicated their specific application to an alternator in the Proceedings of the Institute of Electrical Engineers, London, Nov. 13, 1889, nothing had been done towards the practical use of this knowledge and it is probable that those experiments of mine were the first public exhibition with resonant circuits, more particularly of high frequency. While the spontaneous success of my lecture was due to spectacular features, its chief import was in showing that all kinds of devices could be operated thru a single wire without return. This

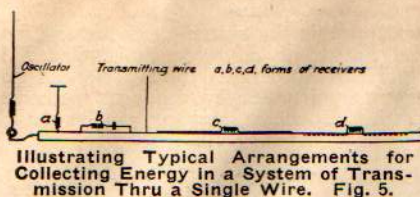


Electric Transmission Thru a Single Wire Hydraulic Analog. Fig. 4.

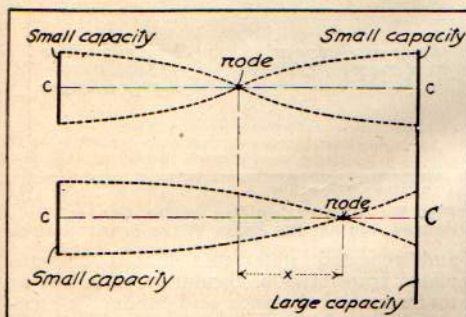
was the initial step in the evolution of my wireless system. The idea presented itself to me that it might be possible, under ob-

been long ago formulated. It was a perfectly well-established fact that a circuit, traversed by a periodic current, emitted some kind of space waves, but we were in ignorance as to their character. He apparently gave an experimental proof that they were transversal vibrations in the ether. Most people look upon this as his great accomplishment. To my mind it seems that his immortal merit was not so much in this as in the focusing of the investigators' attention on the processes taking place in the ambient medium. The Hertz-wave theory, by its fascinating hold on the imagination, has stifled creative effort in the wireless art and retarded it for twenty-five years. But, on the other hand, it is impossible to over-estimate the beneficial effects of the powerful stimulus it has given in many directions.

As regards signaling without wires, the



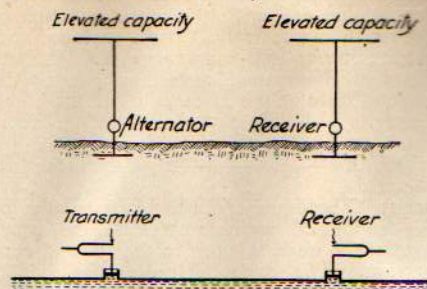
servance of proper conditions of resonance, to transmit electric energy thru the earth, thus dispensing with all artificial conductors. Anyone who might wish to examine impartially the merit of that early suggestion must not view it in the light of present day science. I only need to say that as late as 1893, when I had prepared an elaborate chapter on my wireless system, dwelling on its various instrumentalities and future prospects, Mr. Joseph Wetzler and other friends of mine emphatically protested against its publication on the ground that such idle and far-fetched speculations would injure me in the opinion of conservative business men. So it came that only a small part of what I had intended to say was embodied in my address of that year before the Franklin Institute and National Electric Light Association under the chapter "On Electrical



Resonance." This little salvage from the wreck has earned me the title of "Father of the Wireless" from many well-disposed fellow workers, rather than the invention of scores of appliances which have brought wireless transmission within the reach of every young amateur and which, in a time not distant, will lead to undertakings overshadowing in magnitude and importance all past achievements of the engineer.

The popular impression is that my wireless work was begun in 1893, but as a matter of fact I spent the two preceding years in investigations, employing forms of apparatus, some of which were almost like those of today. It was clear to me from the very start that the successful consummation could only be brought about by a

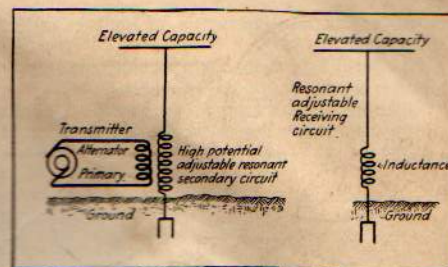
number of radical improvements. Suitable high frequency generators and electrical oscillators had first to be produced. The energy of these had to be transformed in effective transmitters and collected at a distance in proper receivers. Such a system would be manifestly circumscribed in its usefulness if all extraneous interference were not prevented and exclusiveness secured. In time, however, I recognized that devices of this kind, to be most effect-



ive and efficient, should be designed with due regard to the physical properties of this planet and the electrical conditions obtaining on the same. I will briefly touch upon the salient advances as they were made in the gradual development of the system.

The high frequency alternator employed in my first demonstrations is illustrated in Fig. 1. It comprised a field ring, with 384 pole projections and a disc armature with coils wound in one single layer which were connected in various ways according to requirements. It was an excellent machine for experimental purposes, furnishing sinusoidal currents of from 10,000 to 20,000 cycles per second. The output was comparatively large, due to the fact that as much as 30 amperes per square millimeter could be past thru the coils without injury.

The diagram in Fig. 2 shows the circuit arrangements as used in my lecture. Resonant conditions were maintained by means

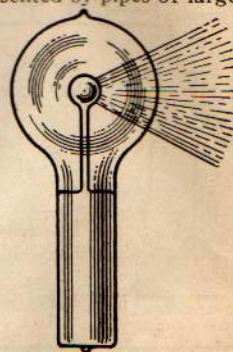


of a condenser subdivided into small sections, the finer adjustments being effected by a movable iron core within an inductance coil. Loosely linked with the latter was a high tension secondary which was tuned to the primary.

The operation of devices thru a single wire without return was puzzling at first because of its novelty, but can be readily explained by suitable analogs. For this purpose reference is made to Figs. 3 and 4.

In the former the low resistance electric conductors are represented by pipes of large

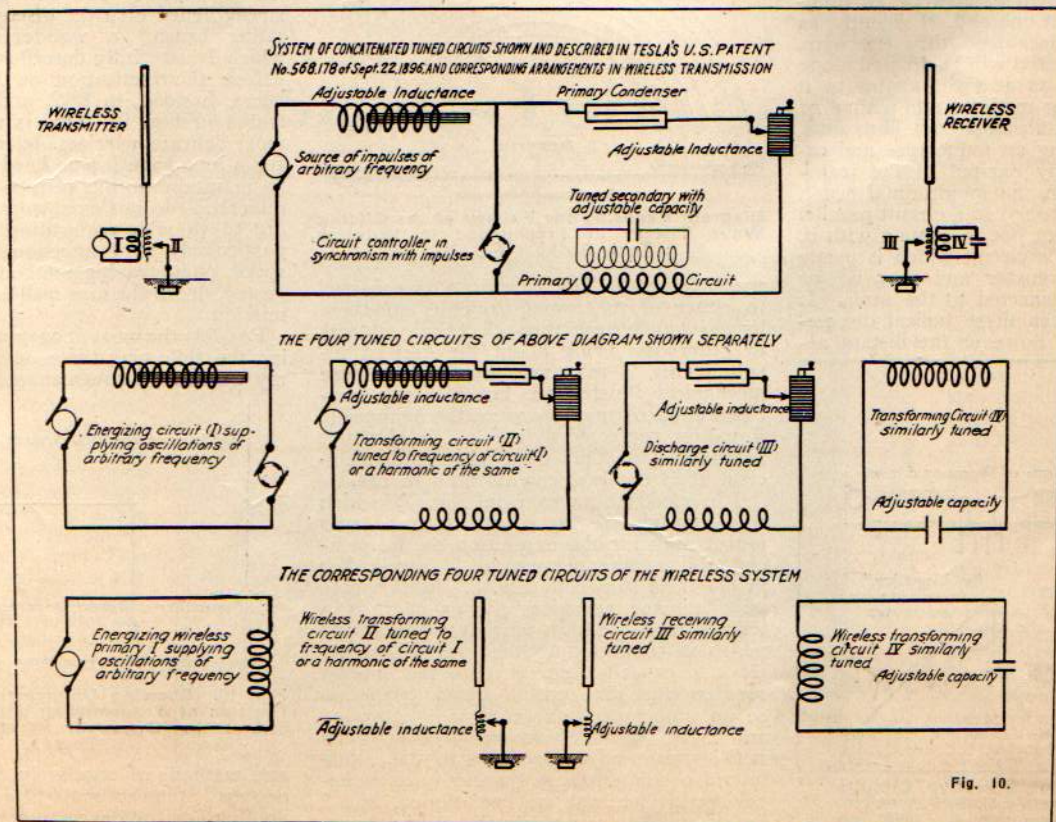
The Forerunner of the Audion—the Most Sensitive Wireless Detector Known, as Described by Tesla in His Lecture Before the Institution of Electrical Engineers, London, February, 1892. Fig. 9.



section, the alternator by an oscillating piston and the filament of an incandescent lamp by a minute channel connecting the pipes. It will be clear from a glance at the diagram that very slight excursions of the piston would cause the fluid to rush

with high velocity thru the small channel and that virtually all the energy of movement would be transformed into heat by friction, similarly to that of the electric current in the lamp filament.

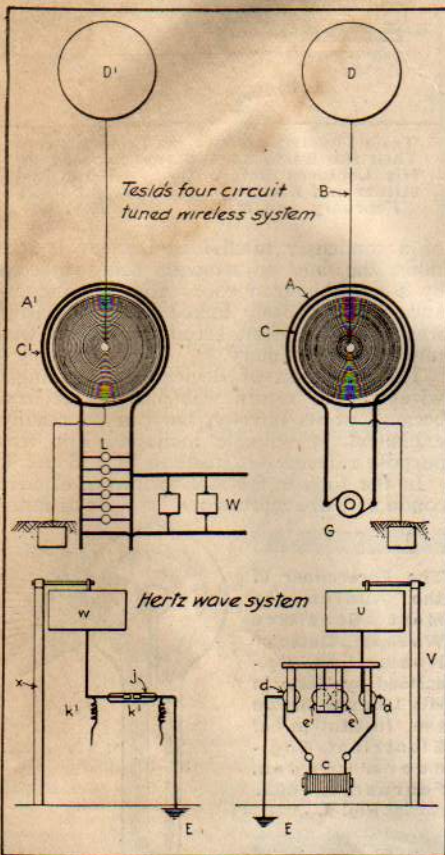
The second diagram will now be self-explanatory. Corresponding to the terminal capacity of the electric system an elastic reservoir is employed which dispenses with the necessity of a return pipe. As the piston oscillates the bag expands and contracts, and the fluid is made to surge thru the restricted passage with great speed, this



Tesla's System of Concatenated Tuned Circuits Shown and Described in U. S. Patent No. 568,178 of September 22, 1896, and Corresponding Arrangements in Wireless Transmission.

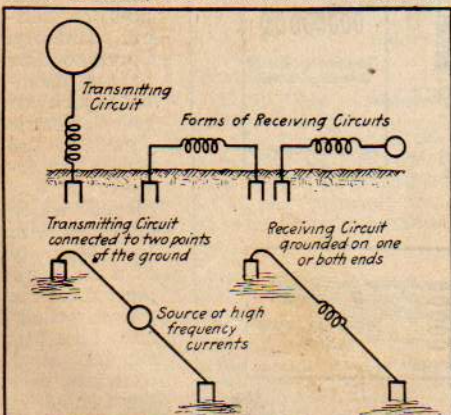
resulting in the generation of heat as in the incandescent lamp. Theoretically considered, the efficiency of conversion of energy should be the same in both cases.

Granted, then, that an economic system of power transmission thru a single wire is



Tesla's Four Circuit Tuned System Contrasted With the Contemporaneous Hertz-wave System. Fig. 11.

practicable, the question arises how to collect the energy in the receivers. With this object attention is called to Fig. 5, in which a conductor is shown excited by an oscillator joined to it at one end. Evidently, as the periodic impulses pass thru the wire, differences of potential will be created along the same as well as at right angles to it in the surrounding medium and either of these may be usefully applied. Thus at *a*, a circuit comprising an inductance and capacity is resonantly excited in the transverse, and at *b*, in the longitudinal sense. At *c*, energy is collected in a circuit parallel to the conductor but not in contact with it, and again at *d*, in a circuit which is partly sunk into the conductor and may be, or not, electrically connected to the same. It is important to keep these typical dispositions in mind, for however the distant ac-



Arrangements of Directive Circuits Described in Tesla's U. S. Patent No. 613,809 of November 8, 1898, on "Method of and Apparatus for Controlling Mechanism of Moving Vessels or Vehicles." Fig. 12.

tions of the oscillator might be modified thru the immense extent of the globe the principles involved are the same.

Consider now the effect of such a conductor of vast dimensions on a circuit exciting it. The upper diagram of Fig. 6 illustrates a familiar oscillating system comprising a straight rod of self-inductance $2L$ with small terminal capacities cc and a node in the center. In the lower diagram of the figure a large capacity C is attached to the rod at one end with the result of shifting the node to the right, thru a distance corresponding to self-inductance X . As both parts of the system on either side of the node vibrate at the same rate, we have evidently, $(L + X) \frac{C}{C - c} = (L - X) C$ from

which $X = L \frac{C - c}{C + c}$. When the capacity C becomes commensurate to that of the earth, X approximates L , in other words, the node is close to the ground connection.

The exact determination of its position is very important in the calculation of certain terrestrial electrical and geodetic data and I have devised special means with this purpose in view.

My original plan of transmitting energy without wires is shown in the upper diagram of Fig. 7, while the lower one illustrates its mechanical analog, first published in my article in the *Century Magazine* of June, 1900. An alternator, preferably of high tension, has one of its terminals connected to the ground and the other to an elevated capacity and impresses its oscillations upon the earth. At a distant point a receiving circuit, likewise connected to ground and to an elevated capacity, collects some of the energy and actuates a suitable device. I suggested a multiplication of such units in order to intensify the effects, an idea which may yet prove valuable. In the analog two tuning forks are provided, one at the sending and the other at the receiving station, each having attached to its lower prong a piston fitting in a cylinder. The two cylinders communicate with a large elastic reservoir filled with an incom-

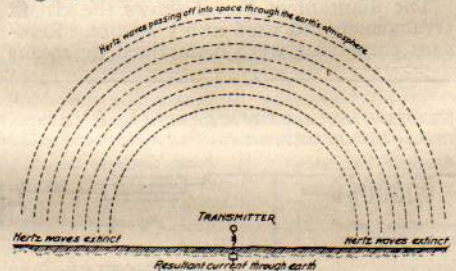


Diagram Exposing the Fallacy of the Gliding Wave Theory as Propounded in Wireless Text Books. Fig. 13.

pressible fluid. The vibrations transmitted to either of the tuning forks excite them by resonance and, thru electrical contacts or otherwise, bring about the desired result. This, I may say, was not a mere mechanical illustration, but a simple representation of my apparatus for submarine signaling, perfected by me in 1892, but not appreciated at that time, altho more efficient than the instruments now in use.

The electric diagram in Fig. 7, which was reproduced from my lecture, was meant only for the exposition of the principle. The arrangement, as I described it in detail, is shown in Fig. 8. In this case an alternator energizes the primary of a transformer, the high tension secondary of which is connected to the ground and an elevated capacity and tuned to the imprecise oscillations. The receiving circuit consists of an inductance connected to the ground and to an elevated terminal without break and is resonantly responsive to the transmitted oscillations. A specific form of receiving device was not mentioned, but I had in mind to transform the received currents and thus make their volume and tension suitable for any purpose. This, in

substance, is the system of today and I am not aware of a single authenticated instance of successful transmission at considerable distance by different instrumentalities. It might, perhaps, not be clear to

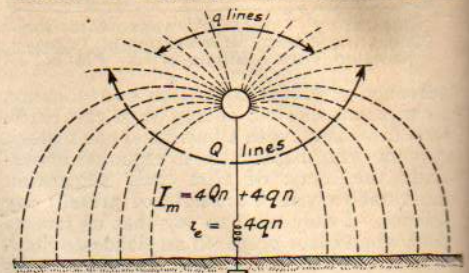


Fig. 14. Diagram Explaining the Relation Between the Effective and the Measured Current in the Antenna.

those who have perused my first description of these improvements that, besides making known new and efficient types of apparatus, I gave to the world a wireless system of potentialities far beyond anything before conceived. I made explicit

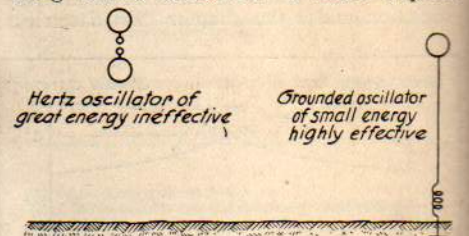


Fig. 15. Illustrating One of the General Evidences Against the Space Wave Transmission.

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.

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, 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.

Possibly the most important advances during the following three or four years were my system of concatenated tuned circuits

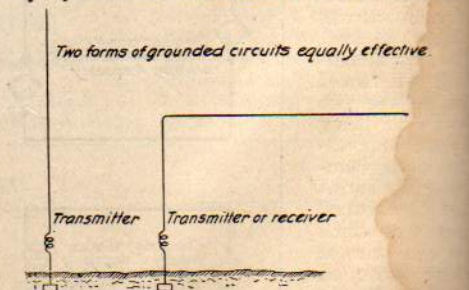


Fig. 16. Showing Unimportance of Relative Position of Transmitting and Receiving Antennae in Disproof of the Hertz-wave Theory.

and methods of regulation, now universally adopted. The intimate bearing of these inventions on the development of the wireless art will appear from Fig. 10, which illus-

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trates an arrangement described in my U. S. Patent No. 568178 of September 22, 1896, and corresponding dispositions of wireless apparatus. The captions of the individual diagrams are thought sufficiently explicit to dispense with further comment. I will merely remark that in this early record, in addition to indicating how any number of resonant circuits may be linked and regulated, I have shown the advantage of the proper timing of primary impulses and use of harmonics. In a farcical wireless suit in London, some engineers, reckless of their reputation, have claimed that my circuits were not at all attuned; in fact they asserted that I had looked upon resonance as a sort of wild and untamable beast!

It will be of interest to compare my system as first described in a Belgian patent of 1897 with the Hertz-wave system of that period. The significant differences between them will be observed at a glance. The first enables us to transmit economically energy to any distance and is of inestimable value; the latter is capable of a radius of only a few miles and is worthless. In the first there are no spark-gaps and the actions are enormously magnified by resonance. In both transmitter and receiver the currents are transformed and rendered more effective and suitable for the operation of any desired device. Properly constructed, my system is safe against static and other interference and the amount of energy which may be transmitted is *billions of times greater* than with the Hertzian which has none of these virtues, has never been used successfully and of which no trace can be found at present.

A well-advertised expert gave out a statement in 1899 that my apparatus did not work and that it would take 200 years before a message would be flashed across the Atlantic and he even accepted stolidly my congratulations on a supposed great feat. But subsequent examination of the records showed that my devices were secretly used all the time and ever since I learned of this I have treated these Borgia-Medici methods with the contempt in which they are held by all fair-minded men. The wholesale appropriation of my inventions was, however, not always without a diverting side. As an example to the point I may mention my oscillation transformer operating with an air gap. This was in turn replaced by a carbon arc, quenched gap, an atmosphere of hydrogen, argon or helium, by a mechanical break with oppositely rotating members, a mercury interrupter or some kind of a vacuum bulb and by such *tours de force* as many new "systems" have been produced. I refer to this of course, without the slightest ill-feeling, let us advance by all means. But I cannot help thinking how much better it would have been if the ingenious men, who have originated these "systems," had invented something of their own instead of depending on me altogether.

Before 1900 two most valuable improvements were made. One of these was my individualized system with transmitters emitting a wave-complex and receivers comprising separate tuned elements coöperatively associated. The underlying principle can be explained in a few words. Suppose that there are n simple vibrations suitable for use in wireless transmission, the probability that any one tune will be struck by an

extraneous disturbance is $\frac{1}{n}$. There will

then remain $n-1$ vibrations and the chance

that one of these will be excited is $\frac{1}{n-1}$,

hence the probability that two tunes would

be struck at the same time is $\frac{1}{n(n-1)}$. Similarly, for a combination of three the chance

will be $\frac{1}{n(n-1)(n-2)}$ and so on. It will be

readily seen that in this manner any desired degree of safety against the statics or other kind of disturbance can be attained provided the receiving apparatus is so designed that its operation is possible only thru the joint action of all the tuned elements. This was a difficult problem which I have successfully solved so that now *any desired number of simultaneous messages is practicable in the transmission thru the earth as well as thru artificial conductors.*

The other invention, of still greater importance, is a peculiar oscillator enabling the transmission of energy without wires in any quantity that may ever be required for industrial use, to any distance, and with very high economy. It was the outcome of years of systematic study and investigation and wonders will be achieved by its means.

The prevailing misconception of the mechanism involved in the wireless transmission has been responsible for various unwarranted announcements which have misled the public and worked harm. By keeping steadily in mind that the transmission thru the earth is in every respect identical to that thru a straight wire, one will gain a clear understanding of the phenomena and will be able to judge correctly the merits of a new scheme. Without wishing to detract from the value of any plan that has been put forward I may say that they are devoid of novelty. So for instance in Fig. 12 arrangements of transmitting and receiving circuits are illustrated, which I have described in my U. S. Patent No. 613809 of November 8, 1898 on a Method of and Apparatus for Controlling Mechanism of Moving Vessels or Vehicles, and which have been recently dished up as original discoveries. In other patents and technical publications I have suggested conductors in the ground as one of the obvious modifications indicated in Fig. 5.

For the same reason the statics are still the bane of the wireless. There is about as much virtue in the remedies recently proposed as in hair-restorers. *A small and compact apparatus has been produced which does away entirely with this trouble, at least in plants suitably remodelled.*

Nothing is more important in the present phase of development of the wireless art than to dispose of the dominating erroneous ideas. With this object I shall advance a few arguments based on my own observations *which prove that Hertz waves have little to do with the results obtained even at small distances.*

In Fig. 13 a transmitter is shown radiating space waves of considerable frequency. It is generally believed that these waves pass along the earth's surface and thus affect the receivers. I can hardly think of anything more improbable than this "gliding wave" theory and the conception of the "guided wireless" which are contrary to all laws of action and reaction. Why should these disturbances cling to a conductor where they are counteracted by induced currents, when they can propagate in all other directions unimpeded? The fact is that the radiations of the transmitter passing along the earth's surface are soon extinguished, the height of the inactive zone indicated in the diagram, being some function of the wave length, the bulk of the waves traversing freely the atmosphere. Terrestrial phenomena which I have noted conclusively show that there is no *Heaviside layer*, or if it exists, it is of no effect. It certainly would be unfortunate if the human race were thus imprisoned and forever without power to reach out into the depths of space.

The actions at a distance cannot be proportionate to the height of the antenna and the current in the same. I shall endeavor to make this clear by reference to diagram in Fig. 14. The elevated terminal charged to a high potential induces an equal and opposite charge in the earth and there are thus Q lines giving an average current $I = 4Qn$ which circulates locally and is useless except that it adds to the momentum. A relatively small number of lines q however, go off to great distance and to these corresponds a mean current of $i_e = 4qn$ to which is due the action at a distance. The total average current in the antenna is thus $I_m = 4Qn + 4qn$ and its intensity is no criterion for the performance. The

electric efficiency of the antenna is $\frac{q}{Q + q}$ and this is often a very small fraction.

Dr. L. W. Austin and Mr. J. L. Hogan have made quantitative measurements which are valuable, but far from supporting the Hertz wave theory they are evidences in disproof of the same, as will be easily perceived by taking the above facts into consideration. Dr. Austin's researches are especially useful and instructive and I regret that I cannot agree with him on this subject. I do not think that if his receiver was affected by Hertz waves he could ever establish such relations as he has found, but he would be likely to reach these results if the Hertz waves were in a large part eliminated. At great distance the space waves and the current waves are of equal energy, the former being merely an accompanying manifestation of the latter in accordance with the fundamental teachings of Maxwell.

It occurs to me here to ask the question—why have the Hertz waves been reduced from the original frequencies to those I have advocated for my system, when in so doing the activity of the transmitting apparatus has been reduced a billion fold? I can invite any expert to perform an experiment such as is illustrated in Fig. 15, which shows the classical Hertz oscillator and my grounded transmitting circuit. It is a fact which I have demonstrated that, altho we may have in the Hertz oscillator an activity thousands of times greater, the effect on the receiver is not to be compared to that of the grounded circuit. This shows that *in the transmission from an airplane we are merely working thru a condenser*, the capacity of which is a function of a logarithmic ratio between the length of the conductor and the distance from the ground. The receiver is affected in exactly the same manner as from an ordinary transmitter, the only difference being that there is a certain modification of the action which can be predetermined from the electrical constants. It is not at all difficult to maintain communication between an airplane and a station on the ground, on the contrary, the feat is very easy.

To mention another experiment in support of my view, I may refer to Fig. 16 in which two grounded circuits are shown excited by oscillations of the Hertzian order. It will be found that the antennas can be put out of parallelism without noticeable change in the action on the receiver, this proving that it is due to currents propagated thru the ground and not to space waves.

Particularly significant are the results obtained in cases illustrated in Figures 17 and 18. In the former an obstacle is shown in the path of the waves but unless the receiver is within the effective *electrostatic* influence of the mountain range, the signals are not appreciably weakened by the presence of the latter, because the currents pass under it and excite the circuit in the same way as if it were attached to an energized wire. If, as in Fig. 18, a second range happens to be beyond the receiver, it could only strengthen the Hertz wave effect by reflection, but as a matter of fact it detracts

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greatly from the intensity of the received impulses because the electric niveau between the mountains is raised, as I have explained in connection with my lightning protector in the EXPERIMENTER of February.

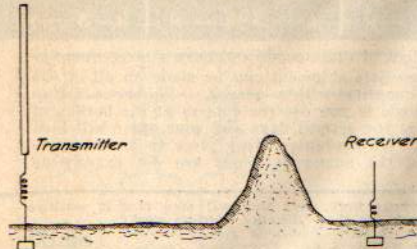


Fig. 17. Illustrating Influence of Obstacle in the Path of Transmission as Evidence Against the Hertz-wave Theory.

Again in Fig. 19 two transmitting circuits, one grounded directly and the other thru an air gap, are shown. It is a common observation that the former is far

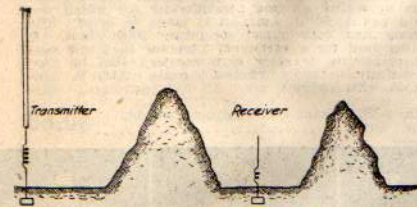


Fig. 18. Showing Effect of Two Hills as Further Proof Against the Hertz-wave Theory.

more effective, which could not be the case in a transmission with Hertz radiations. In like manner if two grounded circuits are

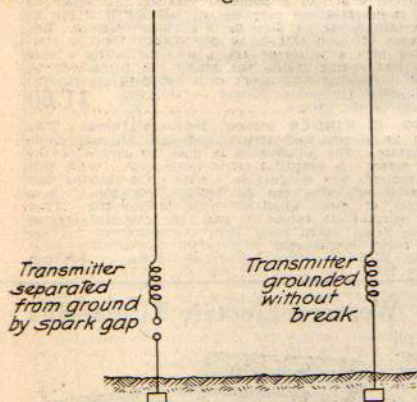
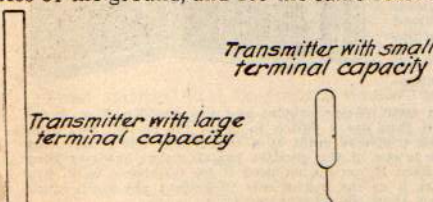


Fig. 19. Comparing the Actions of Two Forms of Transmitter as Bearing Out the Fallacy of the Hertz-wave Theory.

observed from day to day the effect is found to increase greatly with the dampness of the ground, and for the same reason



also the transmission thru sea-water is more efficient.

An illuminating experiment is indicated in Fig. 20 in which two grounded transmitters are shown, one with a large and the other with a small terminal capacity. Suppose that the latter be 1/10 of the former but that it is charged to 10 times the potential and let the frequency of the two circuits and therefore the currents in both antennas be exactly the same. The circuit with the smaller capacity will then have 10 times the energy of the other but the effects on the receiver will be in no wise proportionate.

The same conclusions will be reached by transmitting and receiving circuits with wires buried underground. In each case the actions carefully investigated will be found to be due to *earth currents*. Numerous other proofs might be cited which can be easily verified. So for example *oscillations of low frequency* are ever so much more effective in the transmission which is inconsistent with the prevailing idea. My observations in 1900 and the recent transmissions of signals to very great distances are another emphatic disproof.

The Hertz wave theory of wireless transmission may be kept up for a while, but I do not hesitate to say that in a short time it will be recognized as one of the most remarkable and inexplicable aberrations of the scientific mind which has ever been recorded in history.

TO ALL RADIO AMATEURS

We have received many thousands of communications from radio amateurs for the past few months asking us about the status of their radio stations, and when they will be allowed to operate them again.

Inasmuch as there has been no official information as to the reopening of amateur stations, during the armistice, we can only say that in all likelihood, amateurs will not be allowed to operate until actual peace has been signed. In his executive order of April the 6th, 1917, President Wilson closed all radio stations in the United States by an act approved in the Radio Law of August 13, 1912.

Such a measure, according to law, is only for the duration of the war, there being at present no legislation which prevents any station, amateur or otherwise, from operating after peace has actually been declared. Therefore, the minute newspapers announce that peace between the United States and the Central Powers has been signed, *all amateur stations automatically revert to their former status*, and amateurs need not wait for permission to operate their stations, once peace has been declared.

EDITOR.

TESLA ON GLOBAL WIRELESS ENERGY TRANSMISSION FOR TELECOMMUNICATIONS AND OTHER PURPOSES

With Additional Comments by Henry Bradford and Gary Peterson

Atmospheric Conduction Method

Energy Transmission By Means of a Spherical Conductor Transmission Line With an Upper Half-space Return Circuit.

Tesla's ideas about electrical conduction through the "natural media" fall into two categories: closed circuit and open circuit. [Henry Bradford]

In 1932 journalist John J. O'Neill conducted an interview with Tesla in which he talked about the difference between the wireless transmission of electric energy using what Mr. Bradford describes as either "closed circuit" or "open circuit" principles.

I also asked him if he is still at work on the project which he inaugurated in the '90's of transmitting power wirelessly anywhere on earth. He is at work on it, he said, and it could be put into operation. . . . He at that time announced two principles which could be used in this project. In one the ionizing of the upper air would make it as good a conductor of electricity as a metal. In the other the power is transmitted by creating "standing waves" in the earth by charging the earth with a giant electrical oscillator that would make the earth vibrate electrically in the same way a bell vibrates mechanically when it is struck with a hammer. "I do not use the plan involving the conductivity of the upper strata of the air," he said, "but I use the conductivity of the earth itself, and in this I need no wires to send electrical energy to any part of the globe." ["Tesla Cosmic Ray Motor May Transmit Power 'Round' Earth," Brooklyn Eagle, July 10, 1932.]

The closed circuit system consists of a large Tesla coil transmitter, an ionized path connecting the transmitter to the upper atmosphere, the upper atmosphere, a second ionized path connecting the upper atmosphere back down to a receiving location, and the receiver itself. The circuit back to the transmitter is completed through the earth. The upper atmosphere, like any low-pressure gas, is not an ohmic conductor, but will conduct electricity if broken down; i.e., ionized. The portion of the upper atmosphere between the transmitter and the receiver would then conduct current like a neon tube of planetary proportions. It would require a certain amount of energy to maintain the electrical discharge through it.

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, Twenty First Century Books, 1992, pp. 129-130.]

In operation, the electrical energy flowing through the atmospheric conductor is characterized by its high voltage and low current, and through the terrestrial conductor by its high current and low voltage. For any given power level, the loss in the atmospheric plasma transmission line is proportional to the value of the resistance (R) of the ionized path between the two stations, and inversely proportional to the amount of current (I) flowing along this path. The voltage drop (E) across R is given by Ohm's law, $E = IR$. There is an inverse relationship between voltage and current, so for any given load, increasing the transmission line voltage reduces the current. Looking at this relationship a different way, real power in a transmission line is dissipated as heat due to the resistive element R impeding the flow of electrons. Decreasing the current or rate of flow of electrons through the conductor results in fewer electron 'collisions' resulting in less energy dissipation in the form of heat. Thus, for any given load with a constant transmission-line resistance, reducing the current that flows through the transmission line also reduces the voltage drop. This reduction in end-to-end voltage drop equates to greater transmission-line efficiency. [See [I² R, Double Proportion of Resistance to Power](#).]

In Tesla's words,

. . . by such means as have been described practically any potential that is desired may be obtained, the currents through the air strata may be rendered very small, whereby the loss in the transmission may be reduced. [SYSTEM OF TRANSMISSION OF ELECTRICAL ENERGY, Sept. 2, 1897, U.S. Patent No. 645,576, Mar. 20, 1900.]

Tesla's wireless transmitter-receiver station was designed to develop extremely high potentials on the elevated terminal in order to minimize the loss due to the atmospheric plasma transmission line resistance. Another characteristic of the Tesla apparatus is that a high current flows in the conductor that connects the oscillator to the earth. Looking at an entire atmospheric conduction system, each of the transmitter-receiver stations serves, in a sense, as a lever and a fulcrum that impedance matches the heavy-current power flowing through the terrestrial ground path with the high-voltage power flowing through the atmospheric path. [Kenneth L. Corum and James F. Corum]

An independent power source is required at the receiving location to sustain the conducting path to the upper atmosphere. Both the transmitter and the receiver have to be capable of ionizing the upper atmosphere out to some distance, in much the same way that a corona discharge ionizes the air out to a radius at which its electric field falls below the breakdown value for air, or the leader in a lightning discharge ionizes the air ahead of the bolt.

Tesla described the ionization process like this:

For example, a conductor or terminal, to which impulses such as those here considered are supplied, but which is otherwise insulated in space and is remote from any conducting-bodies, is surrounded by a luminous flame-like brush or discharge often covering many hundreds or even as much as several thousands of square feet of surface, this striking phenomenon clearly attesting the high degree of conductivity which the atmosphere attains under the influence of the immense electrical stresses to which it is subjected. This influence is however, not confined to that portion of the atmosphere which is discernible by the eye as luminous and which, as has been the case in some instances actually observed, may fill the space within a spherical or cylindrical envelop of a diameter of sixty feet or more, but reaches out to far remote regions, the insulating qualities of the air being, as I have ascertained, still sensibly impaired at a distance many hundred times that through which the luminous discharge projects from the terminal and in all probability much farther. [SYSTEM OF TRANSMISSION OF ELECTRICAL ENERGY, Sept. 2, 1897, U.S. Patent No. 645,576, Mar. 20, 1900.]

Both wireless stations would be individually capable of ionizing the upper atmosphere in their vicinities out to distance that is based upon four physical parameters. Tesla identified these as the “electromotive force” of the transmitted impulses, the atmospheric density, the height of the elevated terminal above the ground, “and also, apparently, in slight measure, . . . the degree of moisture contained in the air.” By using a vertical ionizing beam of ultraviolet radiation the requirement for very tall towers is reduced.

I have also found it practicable to transmit notable amounts of energy through air strata not in direct contact with the transmitting and receiving terminals, but remote from them, the action of the impulses, in rendering conducting air of a density at which it normally behaves as an insulator, extending, as before remarked, to a considerable distance. . . . [Ibid.]

The region from the upper troposphere and upward, located between the transmitter and the receiver, would become available as a conductor by inducing the plasma state within that region. This is the “aurora” effect described by Tesla in the 1916 interview.

I have constructed and patented a form of apparatus which, with a moderate elevation of a few hundred feet, can break the air stratum down. You will then see something like an aurora borealis across the sky, and the energy will go to the distant place.” [Nikola Tesla On His Work With Alternating Currents and

Their Application to Wireless Telegraphy, Telephony, and Transmission of Power, 1992, p. 110.]

Tesla also spoke about instances in which the connection between the elevated terminals is, in part, by electrostatic induction.

In some cases when small amounts of energy are required the high elevation of the terminals, and more particularly of the receiving – terminal D, may not be necessary, since, especially when the frequency of the currents is very high, a sufficient amount of energy may be collected at that terminal by electrostatic induction from the upper air strata, which are rendered conducting by the active terminal of the transmitter or through which the currents from the same are conveyed. [SYSTEM OF TRANSMISSION OF ELECTRICAL ENERGY, Sept. 2, 1897, U.S. Patent No. 645,576, Mar. 20, 1900.]

This means that a wholly conductive path between the transmitting and the receiving stations is not an absolute requirement. A portion the transmitter's energy can be collected at the receiver by electrostatic induction alone. This also suggests that a flow of energy may occur between the two high-altitude ionized regions by means of electrostatic induction, that is to say, by so-called displacement current. Once the initial station-to-upper-atmosphere connections are established by the means of displacement current and electrical conduction through the vertical ionized paths, each high-altitude ionized region grows in size in the direction of its counterparts with the passage of time,

I have likewise observed that this region of decidedly-noticeable influence continuously enlarges as time goes on, and the discharge is allowed to pass not unlike a conflagration which slowly spreads, this being possibly due to the gradual electrification or ionization of the air or to the formation of less insulating gaseous compounds. [Ibid.]

To accomplish this would be a stupendous undertaking. It strikes me that Tesla's concept of transmitting electric power wirelessly via electrical conduction through a closed circuit consisting of the earth and the atmosphere is not promising from a practical viewpoint. This is because of the enormous voltages needed to reach to useful distances from the transmitter through the atmosphere, and the power requirements for maintaining the air path in an ionized state.

Wireless power transmission by means of the atmospheric method appears to be feasible. It can be accomplished exactly as Tesla said it could without violating the known laws of physics. Perhaps it has not been adopted for economic reasons, and because certain basic engineering challenges that Tesla addressed while developing the system have not been revisited. Perhaps the point-to point atmospheric conduction method is simply impractical.

I [have] contemplated the possibility of transmitting . . . high tension currents [on the order of twenty million volts] over a narrow beam of radiant energy ionizing the air and rendering it, in measure, conductive. After preliminary laboratory

experiments, I made tests on a large scale with the transmitter referred to [in Colorado Springs] and a beam of ultra-violet rays of great energy in an attempt to conduct the current to the high rarefied strata of the air and thus create an auroral such as might be utilized for illumination, especially of oceans at night. I found that there was some virtue in the principal but the results did not justify the hope of important practical applications. [The New Art of Projecting Concentrated Non-dispersive Energy Through Natural Media.]

Tesla spoke about the commercial establishment of a wireless system in which the transmitted energy is utilized in at least three different ways—high-frequency lighting, turning electric motors, and wireless telecommunications.

Wireless communications is not as demanding as the transmission of power. Tesla seems to have favoured carrier frequencies in the range of tens of kilohertz or so, which would be reasonable for transmission of information at a useful rate. He had in mind transmitters and receivers as those shown in his patent drawings, communicating through the earth via current from the ground terminal of the transmitter and the partially or wholly ionized path described above. This raises the question of whether the current from the ground terminal of a Tesla transmitter, which definitely would exist, would have a range comparable to or greater than that of a radio wave from a radio transmitter of the same power and frequency, and the induced earth current that would accompany it.

The principal difference between Tesla's system, either closed or open circuit, and open circuit low frequency radio systems is that a radio transmitter is designed primarily to emit energy in the form of electromagnetic radiation from its antenna, whereas the Tesla communications transmitter is designed primarily to inject an electrical current into the earth at its ground terminal. The mode of propagation for both systems appears to me to be the same; i.e., earth currents and surface charge coupled to a vertical electric field in the Earth-ionosphere cavity.

Mr. Bradford describes the mode of propagation for both the Tesla system and LF radio systems as, "earth currents and surface charge coupled to a vertical electric field in the Earth-ionosphere cavity." While this is not a description of space wave electromagnetic radiation, it is, however, consistent with the definition of the electromagnetic field associated with an electrical current flowing through a transmission line. Of course there is also a space wave component associated with the emissions of an LF radio transmitter in the form of electromagnetic radiation launched from its antenna. Tesla argued the emissions from the great low frequency AM radio transmitters of the early 20th century were, predominantly, in the form of transmission line surface waves.

The principal difference between the Tesla-produced and radio-produced disturbances appears to be the difference in the configuration of currents and fields close to the transmitter.

The basic idea is that the earth currents and charge-coupled electromagnetic field associated with Tesla coil transmissions gradually decouple from the

associated charge carriers and become ordinary radio waves as a function of the distance from the transmitter. Mr. Bradford states,

I do not believe that the theory for it has been worked out, but in principle it is a straightforward application of electromagnetic theory.

An alternative hypothesis is one in which the configuration of the electromagnetic field associated with an ordinary radio antenna changes as it moves out of the near-field zone, as described by presently accepted antenna and propagation theory, while the configuration of the electromagnetic field associated with a Tesla coil transmitter remains essentially unchanged as it moves out beyond the near-field zone, through the far-field zone, all the way to a well grounded phase-conjugate or synchronized Tesla coil receiver.

There are two distinctly different forms of electromagnetic-wave propagation. The first is by means of electromagnetic radiation or ordinary radio waves, such as emitted by an ordinary dipole radio antenna. The second is by ordinary electrical conduction, such as takes place when a current flows through a transmission-line accompanied by a charge-coupled electromagnetic field.

There are two types of transmitter-antenna excited propagation modes. The first is by means of an ordinary radio wave launched by a dipole antenna in the form of electromagnetic radiation. The second is by means of a charge-coupled transmission-line wave launched by a high voltage, pulse-driven, top loaded helical resonator in the form of earth currents and a charge-coupled electromagnetic field. A small radio-wave component might also be present, but this is viewed as an energy loss. What might be called a hybrid propagation mode is a combination of the radio wave and the charge-coupled electromagnetic transmission-line wave launched by a grounded or counterpoise monopole antenna, i.e., the Marconi-type antenna, the emissions of which more or less predominate as electromagnetic radiation plus an electromagnetic transmission-line wave component. In addition to space waves, Marconi antennas also appear to launch the type of transmission-line or surface wave described by Arnold Sommerfeld and Johann Zenneck. This surface wave is different from the well-known Norton Surface Wave that is the result of the interaction of the ground wave part of a radio antenna's radiated space wave with the earth's surface. There may be an interaction between the Zenneck and Norton surface waves which occurs along the interface between the two half-spaces resulting in the creation of an interference pattern extending outward around the launching structure.

My guess is that at very large distances from the transmitter, the two disturbances would be indistinguishable.

If, as predicted, the disturbances produced by the two launching structures are distinctly different then the effects at a distance will be very much distinguishable. In fact, the emissions of a refined Tesla coil transmitter in the far-field zone should be practically undetectable when using an ungrounded radio receiver with a balanced magnetic loop antenna; quo erat demonstratum.

So it would boil down to which method of producing the disturbance is the most efficient and cost effective. One disadvantage of very long distance radio is that VLF transmitting antennas tend to be very large and inefficient, which is one reason why long distance communications mostly switched from long wave to short wave in the 1930's. One thing bothers me. If the Tesla earth currents propagate to long distances at low frequencies, why don't the earth currents from the ground terminals of low frequency radio transmitters do likewise, or do they?

According to Tesla they do. Some portion of the earth current associated with the excitation of a well-grounded LF radio-transmitting antenna propagates to great distances.

Counsel

You say radio engineers put too much energy into the radiating part. What, as a matter of fact, according to your conception, is the part of the energy that is received in the receivers in the present system? . . . To illustrate my question, take for instance the energy used at Sayville [Long Island, New York] and the reception of that at Nauen [Germany]. I want to know whether it is your idea that the reception there is due to the earth currents that you have described or to the radiated energy.

Tesla

It is far more due to the earth currents than to the radiated energy. I believe, indeed, that the radiated energy alone could not possibly produce the effect across the Atlantic. It is simply because they are incidentally sending a current through the globe—which they think is their current—that the receiver is affected. The current produces variations of potential at the earth's surface in Germany; these fluctuations of potential energize the circuit, and by resonance they increase the potential there and operate the receiver. But I do not mean that it is absolutely impossible to use my apparatus and operate with electromagnetic waves across the Atlantic or Pacific. I only say that according to calculations, for instance, which I have made of the Sayville plant, the radiated energy is very small and cannot be operative. I have also calculated the distribution of the charge on the antenna. I am told that the Sayville antenna is without abrupt changes of capacity. It is impossible. There are changes even in a cylindrical antenna; but particularly in that form at Sayville—there are very abrupt changes. [Nikola Tesla On His Work With Alternating Currents and Their Application to Wireless Telegraphy, Telephony, and Transmission of Power, p. 142.]

A grounded radio transmitter generates an earth current, and observations of it might help to answer questions about the range of earth currents. However, distinguishing current from the ground terminal from earth current induced by the radio wave (or part of the wave, depending on how you look at it) might be difficult. The two types of earth current might be distinguishable because earth current from the ground terminal of a radio transmitter should be free from the variations in the strength of the radio wave (e.g., day-night) caused by the ionosphere. I am not aware of such observations. On the other hand, VLF to MF radio transmitters often use some sort of counterpoise instead of a ground

connection, and do not produce an earth current directly. The most reliable answers would come from a computer analysis.

Freely speculating for a moment, perhaps a powerful Tesla coil earth resonance transmitter operated at a non-earth-resonance frequency might result in the creation of radio waves somewhat as predicted by Mr. Bradford. In the operation of a Tesla coil transmitter, earth resonance results from the constructive interference of outgoing Tesla waves with the reflection of preceding Tesla waves returning from the antipode. If the transmission frequency were to be adjusted away from being purely constructive, then radio waves might result. Going out on a limb even further, rather than a gradual transition from Tesla waves to Hertz waves with an increase in distance from the transmitter, the radio wave emissions might be global in nature and ubiquitous.

"The chief engineer shook his head slowly, "all radio stations went off the air at seven-fifty-one, and nobody can discover why. We've called the electronic laboratory of the State Science Institute. They said it looks like radio waves, but of a frequency never produced before, never observed anywhere, never discovered by anybody. It looks like a wall of radio waves jamming the air, and we can't get through it, we can't touch it, we can't break it. What's more, we can't locate its source, not by any of our usual methods. Those waves seem to come from a transmitter that makes any known to us look like a child's toy! That's it, Dr. Stadler, it can't be possible, it shouldn't be possible, but there it is."
[\[Atlas Shrugged\]](#)

Ionospheric effects like the day-night variations indicate that the radio signal received is mainly accounted for by radio waves. Is it that low frequency radio transmitters generally use counterpoises rather than actual earth connections? Is it that the currents from the ground terminals of the transmitters (as opposed to induced currents in the electrical disturbance in the Earth-ionosphere cavity; see the next section) do not propagate to a significant distance? Once again, the answers to these questions, like all the other questions, could be found theoretically by straightforward computations made on a realistic model of the transmitter, receiver, and intervening medium.

Construction and operation of full-size Tesla transmitting and receiving apparatus, as described in his patents and elsewhere, will also facilitate this computer analysis. The creation of a realistic model demands the collection of empirical data related to the performance of actual functioning Tesla coil transmitters, and active and passive Tesla coil receivers. At the same time these data were being collected it can also be shown that radio waves are not involved with the transfer of electrical energy between the Tesla transmitting and receiving stations. This can be done using a radio receiver with a balanced magnetic loop antenna, tunable to the Tesla coil transmitter's operating frequency. The radio receiver's antenna can be configured in such a way so it interacts more efficiently with radio waves than with the non-radiating emissions of the Tesla coil transmitter. Grounded monopole and low-counterpoise radio antennas cannot be used. Even the vertical 1/2-wave dipole antenna, with or

without loading coils and suspended high above the ground to minimize capacitive coupling to the earth would be compromised in its performance.

The Schumann Cavity Resonance Hypothesis

Proposed Energy Transmission By Means of a Concentric Spherical Shell Waveguide

Tesla spoke about the wireless transmission of electric energy utilizing some type of terrestrial resonance mode. Three different forms of terrestrial resonance have been identified. These are the "single-wire transmission line" resonances (for lack of a better term), the transverse cavity resonances, and the Schumann cavity resonances. As their names suggest, the latter two are resonances that can be excited in the concentric spherical shell waveguide formed from the earth and the ionosphere. Of these three, only transmission systems utilizing the transmission line resonances and the Schumann resonances are under consideration for power transmission. Both mechanisms fall under Mr. Bradford's so-called "open circuit" category.

Natural lightning excites the Schumann resonances. They are observed at the lowest few resonance frequencies (about 8 Hertz and multiples of that). Their measured Q's of order 5 - 10 suggest that the electrical disturbances produced by lightning make a few circuits of the Earth before damping out, and create a fairly definite terrestrial standing wave of a few cycles duration. What is wanted for wireless transmission of power is for the electrical load connected to the receiver to draw power from the transmitter via the standing wave. I.e., when the load is switched on, the transmitter should "feel" the load, as it would in a closed circuit, and respond by providing more power via the standing wave. According to my estimates, this would require an Earth-ionosphere cavity Q of order $\sim 10^6$ or 10^7 at the lowest Schumann resonance frequencies, whereas it appears the actual value is more like 5 or 10. Cavity Q is defined here as the ratio of the electric field energy stored in the Earth-ionosphere cavity per cycle of the oscillation to the average power input to the cavity from the transmitter.

This estimate of the required Q is based on the requirement that the current induced in the input impedance of the receiver should reciprocally induce power in the output impedance of the transmitter similar to the power that was transmitted initially. This is a way of expressing the coupling between the transmitter and receiver required for the transmitter to "feel" the load on the receiver. The Q in my estimate is the value that produces an electric field in the cavity strong enough to induce the required current in the input impedance of the receiver. At higher frequencies, the required Q is larger, but I expect that the Q of the Earth-ionosphere cavity probably decreases because propagation losses in the Earth and ionosphere increase. So my opinion is that Schumann electrical oscillations would not allow efficient transfer of power from the transmitter to the receiver over long distances.

Conclusions

The concept of transferring power with small losses in this manner will not work because the standing wave would occur in the Earth-ionosphere cavity, which is too lossy (Q too small) to enable a standing wave of sufficient amplitude to be generated. This limitation is independent of the power of the transmitter. In order for the transmitter to feed power to the receiver as efficiently as it would in a closed low-loss circuit, the power transferred to the receiver should be able to transfer power of the same order of magnitude reciprocally to the transmitter. This is a necessary condition for the transmitter to "feel" the load connected to the receiver, and to supply power to it via the standing wave. In order to do this, the required Q of the Earth-ionosphere cavity is of the order of 10^6 or so at the lowest Earth-ionosphere cavity Schumann resonant frequency of about 8 Hz, according to my estimates, whereas measurements based on the spectrum of natural electrical radio noise yield a Q of only about 5 to 10. I believe that the situation only gets worse at higher frequencies because of increasing energy losses in the earth and ionosphere, as is the case in radio transmission.

In my opinion the reason Tesla believed that he could generate very high Q whole-earth oscillations was that he did not know about the existence of the ionosphere and its damping effect. He also dismissed the practicality of long-range radio because he was unaware of the ionosphere and its reflecting properties.

On the other hand, it has been pointed out that wireless energy transmission using the concentric spherical shell model, as discussed above, is not consistent with the Tesla type transmitter.

The conceptual difficulty with this model is that, at the very low frequencies that Tesla said that he employed (1-50 kHz), earth-ionosphere waveguide excitation, now well understood, would seem to be impossible with either the Colorado Springs or the Long Island apparatus (at least with the apparatus that is visible in the photographs of these facilities). ["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. 10.]

The maximum recommended operating frequencies of 25 kHz as specified by Tesla is far above the highest easily observable Schumann resonance mode (the 9th overtone) that exists at approximately 66.4 Hz. Tesla's selection of 25 kHz is wholly inconsistent with the operation of a system that is based upon the *direct* excitation of a Schumann resonance mode.

Another terrestrial propagation mode is far more promising.

The Earth Resonance Method

Energy Transmission By Means of a Spherical Conductor "Single-wire" Surface Wave Transmission Line

The type of transmitter used to excite this propagation mode is described and illustrated in Tesla's patent ART OF TRANSMITTING ELECTRICAL ENERGY THROUGH THE NATURAL MEDIUMS, May 16, 1900, U.S. Patent No. 787,412, Apr. 18, 1905 and elsewhere. It is essentially the same as the transmitter used for the atmospheric conduction method, connected to the ground and to an elevated terminal, with the elevated terminal having the modified spherical shape seen in a number of photographs and artistic renderings of the Wardenclyffe wireless station prototype. A similar rendering of a Wardenclyffe-type structure appears in the specifications of Tesla's APPARATUS FOR TRANSMITTING ELECTRICAL ENERGY, Jan. 18, 1902, U.S. Patent 1,119,732, Dec. 1, 1914 in which this terminal is drawn as a modified torus.

It is apparent from documents on file at the U.S. Patent Office pertaining to U.S. Patent No. 787,412 that Tesla collected actual performance data. In response to a question from U.S. Patent Examiner G.C. Dean regarding three stated requirements that, "seem essential to the establishment of the resonating condition" Tesla's attorneys responded,

These three requirements, as stated are in agreement with his numerous experimental observations. . . . we would point out that the specification does not deal with theories, **but with facts which applicant has experimentally observed and demonstrated again and again**, and in the commercial exploitation of which he is engaged. ["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. 3n.]

Tesla determined that the time required for a transmitted pulse or wave train to travel from the transmitter to the antipode and back again is .08484 seconds. This equates to a fundamental earth resonance frequency of 11.786892 Hz. He believed that by incorporating a portion of the earth as part of a powerful earth-resonance Tesla coil transmitter an electrical disturbance could be impressed upon the earth and detected, "at great distance, or even all over the surface of the globe."

Tesla also made an assumption that Earth is a charged body floating in space.

A point of great importance would be first to know what is the capacity of the earth? and what charge does it contain if electrified? Though we have no positive evidence of a charged body existing in space without other oppositely electrified bodies being near, there is a fair probability that the earth is such a body, for by whatever process it was separated from other bodies—and this is the accepted view of its origin—it must have retained a charge, as occurs in all processes of mechanical separation. [ON LIGHT AND OTHER HIGH

FREQUENCY PHENOMENA , Nikola Tesla, Inventions, Researches and Writings of Nikola Tesla, 1894, pp. 294-373.]

Tesla was familiar with demonstrations that involved the charging of Leiden jar capacitors and isolated metal spheres with electrostatic influence machines. By bringing these elements into close proximity with each other, and also by making direct contact followed by their separation the charge can be manipulated. He surely had this in mind in the creation of his mental image, not being able to know that the model of Earth's origin was inaccurate. The presently accepted model of planetary origin is one of accretion and collision.

If it be a charged body insulated in space its capacity should be extremely small, less than one-thousandth of a farad. [Ibid.]

We now know that Earth *is* in fact a charged body relative to the uppermost atmospheric strata, made so by processes—at least in part—related to an interaction of Earth's magnetosphere with the continuous stream of negatively charged particles called the solar wind, flowing outward from the center of our solar system.

But the upper strata of the air are conducting, and so, perhaps, is the medium in free space beyond the atmosphere, and these may contain an opposite charge. Then the capacity might be incomparably greater. [Ibid.]

We also know one of the upper strata of Earth's atmosphere, the ionosphere, is conducting.

In any case it is of the greatest importance to get an idea of what quantity of electricity the earth contains. [Ibid.]

Earth possesses a naturally existing negative charge with respect to the conducting region of the atmosphere beginning at an elevation of about 50 kilometers. The potential difference between the earth and this region is on the order of 400,000 volts. Near the earth's surface there is a ubiquitous downward directed E-field of about 100 V/m. In LIGHTNING PROTECTOR, May 6, 1916, U.S. Patent 1,266,175, May 14, 1918 Tesla referred to this charge as the "electric niveau" or electric level.

It is difficult to say whether we shall ever acquire this necessary knowledge, but there is hope that we may, and that is, by means of electrical resonance. If ever we can ascertain at what period the earth's charge, when disturbed, oscillates with respect to an oppositely electrified system or known circuit, we shall know a fact possibly of the greatest importance to the welfare of the human race. I propose to seek for the period by means of an electrical oscillator, or a source of alternating electric currents. . . . [Ibid.]

A Tesla coil earth resonance transmitter creates a local disturbance in the earth's charge that manifests itself as an annular deviation in the density of the background electric field. This disturbance propagates away from the transmitter and diminishes in intensity as the distance from the transmitter

increases. A sufficiently powerful transmitter produces a field distortion that propagates all the way to the antipode, at which point the energy is reflected back towards its point of origin. The transmission of electrical energy across the entire globe and its reflection all the way back to its source is the basis of Tesla's earth resonance method.

While the atmospheric conduction method requires that both transmitting and receiving apparatus be placed into operation, a properly tuned and sufficiently powerful earth resonance transmitter, on the other hand, can be made to operate exactly as intended without any man-made Tesla-type receivers being activated. The earth itself fulfills the *requirement* that a synchronized receiver be present.

Conclusion

Long-distance wireless transmission by means of the Atmospheric Conduction Method is feasible, defying none of the known laws of physics, but a power transmission system based upon this method may not be practicable. The hypothesized Schumann Cavity Resonance Method, *unto itself*, is unworkable. Wireless transmission by means of the Earth Resonance Method may be possible, a feasibility study using a sufficiently powerful and properly tuned Tesla coil earth-resonance transmitter being called for.

Research of Nikola Tesla in Long Island Laboratory

by Aleksandar Marinčić, Ph.D.

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1. INTRODUCTION

After completing grandiose research in Colorado Springs Nikola Tesla returned to New York and started to look for money and the place where to build a new laboratory. This time he wanted to make a commercial plant--the "World System" power plant--as he called it. About the time he returned to New York Tesla wrote a long article in the Century magazine about his experiments in Colorado Springs. The editor of the magazine tried to persuade Tesla to write a more understandable paper, but his efforts were not very successful. In the end Tesla wrote something that looked more like an essay rather than a typical scientific paper. The length of the paper was also unusual--it was as long as his lectures that he delivered earlier before various scientific gatherings. After "Colorado Springs Notes 1899-1900" were published in 1978, a new material was put forward to researchers, and many queries from the Century article became clarified. However, a veil of unknown remained, especially in connection with Tesla's later research in Long Island Laboratory. For a long time we have studied Tesla's notes which he wrote in the period 1900-1906 and in this paper we want to present some of the findings that will help to understand Tesla's research in this period.

2. LONG ISLAND NOTES IN NIKOLA TESLA MUSEUM

In contrast to Colorado Springs Notes that were neatly assembled by Nikola Tesla himself, Long Island Notes were scattered through his scientific papers. It will be some time before all Notes are collected together, but it is clear that there will be no great change as to the amount of dated notes in comparison to what we have already found.

Some Long Island Notes are written by pencil, some by ink. The sizes of notes vary considerably. Sometimes there are only few lines or few formulae, or some calculations. Less than one third of the notes are neatly finished similar to the Colorado Springs Notes.

In 1900 Tesla's notes contain only 8 leaves. That number increases to 141 in 1901, 196 in 1902, 272 in 1903, drops rapidly in 1904 to 13 only, there are no notes in 1905 and then there is a jump to 50 leaves in January 1906, only. With the title "Notes to Long Island Plant," written by Tesla on the folder we found 73 leaves without dates. On the following pages we have given a Table showing

the number of leaves written on the specified dates. Later we will discuss the content of the Notes.

The Notes in 1901 are written by ink (except few that are written by pencil) in a similar fashion to the Colorado Springs Notes. The handwriting can be read without much difficulty, typical page being like the one shown (May 19, 1901). The rest of the notes are written by pencil. Some of the notes are difficult to read, especially those written later.

LONG ISLAND NOTES

[illegible]

Date	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	
1903																
January									2	1	1	2	5	7		
February			2	1	2	2		4	1	4	1	5				
March		3	1			2	1	4	2	4		3	2	5	4	2
April	3	4	5	8	3	4	3	1	2	8	4	3	2	2		1
May	1	4	1				1	1	1	2	5	9	1	1	3	2
June	12	4	2	4	2	2	1	3	2	1				1		1
July			2	2												
August																
September					1				1							
October							1	1	1	1	2	3				1
November	1			1					2				2	3	2	1
December	5		2													
1904																
June																3
July				1	1	1	2			1	1					
August										3						
1906																
January						4	11		3	14		1	1		2	4

Remark: undated notes have not been included.

Source: Nikola Tesla Museum, Belgrade

3. SUMMARY OF RESEARCH TOPICS IN DATED NOTES 1900-1906

Dated notes, as explained in chapter 2, contained over 600 leaves and it is not an easy task to cover even main topics created in the Notes. It should not be expected that all important thoughts or results (experimental or theoretical) will be given. We have read most of the material trying to discover interesting topics in the Notes. However, Tesla's handwriting is not easy to read and further efforts are needed to "decode" all the Notes and make them prepared for detailed study.

3.1. Notes written in 1900

As mentioned earlier there are only 8 leaves as the record of four days of work. At the very beginning of 1900 Tesla was in Colorado Springs for at least a week (last date in the Colorado Springs Notes was January 7, 1900). First notes written in the Colorado Springs Notes were dated June 2, 1900 and refer to

insulating conductors by freezing. In late November, 1900, there were four pages that deal with new plant problems.

3.2. Notes written in 1901

In 1901 Tesla began to look for "approximate theoretical estimate of constants determining wavelength of electrical disturbance through Earth." The capacitance of the Earth he calculated as the capacitance of a metal sphere of the globe size. Then he calculated the radius of an equivalent cylindrical conductor, r , which have the same capacitance as the considered sphere. From the equality of the sphere capacitance and the capacitance of equivalent cylindrical conductor of length l (Tesla neglected the edge effects), he obtained r and C from the equation:

$$C = D/2 = 0.5 \cdot D / (\log_e (D/r)).$$

To calculate inductance of the Earth Tesla assumed that it is equal to the inductance of the equivalent cylindrical conductor, L :

$$L = 2 \cdot D \cdot (\log_e (D/r) - 0.75),$$

where for the equivalent conductor he calculated inductance ignoring "magnetic influence." For the Earth diameter he assumed to be 7914 miles so that,

--total capacitance of the cylinder $707.5 \text{ uF} = C = c \cdot D$

--total inductance of the cylinder $2.40377 \text{ H} = L = 1 \cdot D$

From the above values capacitance per mile and inductance per mile were calculated (the length of conductor was assumed to be 7914 miles, the Earth diameter). From the calculated c and 1 , Tesla obtained the relationship between frequency and the wavelength along the cylindrical conductor (Long Island Notes, January 29, 1901):

$$\text{wavelength (miles)} = 1/(f \cdot lc) = 192,300/f \text{ (Hz)}.$$

The idea behind this relationship is based on the following statement from the insert of February 2, 1901 notes (citation):

"In many experiments with electrical oscillators of very high frequency curious spark discharges were observed which for long time could not be accounted for. Finally I found that they were due to exceptional rise by resonant action of the electromotive force. Further investigation led me to the discovery of fact that long conductor, say a straight telegraphy line, cable etc., has a definite frequency at which the capacity just counteracts the inductance and when worked with currents of that frequency the conductor is capable of transmitting energy condition exceptionally favorable. . . ."

Developing Long Island plant Tesla considered mainly the transmitting tower, oscillators for production of HF currents, choice of operating frequency, design of various coils, arrangements of terminals, etc. His propagation theory was

based on the charge redistribution along the globe. As he did not consider only the static case, for higher frequencies (in this case frequencies above few Hz) he assumed that the zones of a half wavelength extent contain alternatively positive and negative electric charge. He considered transmitter frequencies as low as 4 Hz, but he devoted more attention to 60 Hz. On June 8, 1901, he wrote:

Assume frequency of dynamo on plant under process of construction, 60 c/s, and capacity C of terminal insulated 10000 cm. With full steam-pressure on one of the boilers I can easily get 150 HP This will be only half of actual output. To use the power to the full extent we must charge the terminal to a pressure P given by equation:

$C \cdot p^2 = 150\,746$, from which . . . $P = 409700\text{ V}$. . ."

Continuing further his consideration along these lines, Tesla came around with figures that with 100,000 cm capacity terminal on the polar cap (a point on the opposite side of the globe to the transmitter location), one could get about 2 HP, which, in his opinion ". . . is enough to demonstrate practicability of power transmission."

An interesting summary appeared on October 13, 1901 (citation):

"The following are important facts to bear in mind in connection with my system of energy transmission through the globe:

a) The strength of current passed into the ground by transmitting circuit determines the e.m.f. obtainable at any point of Earth in a receiving circuit connected either on one or two points or more. The e.m.f. is proportional to: a) current strength, b) frequency, conversely proportionate to distance from transmitting ground connection.

b) The energy at any point is proportional to actual energy delivered by transmitter and inversely to square distance from same up to equatorial zone.

c) Beyond equatorial zone the energy is increasing as the square of distance from opposite pole."

3.3. Notes written in 1902

The Notes are scattered throughout the year but there are two peaks--one smaller in March--and the other in October-November. In March period he dealt with experimental matters: he measured some coils, capacitances and frequency of laboratory oscillators. In October, a number of new considerations regarding his theory of current propagation through the Earth appeared. On October 8, 1902, he wrote in his notes:

"All facts now agree with the theory that velocity of propagation as measured along a line passing from transmitter through center of the Earth, is perfectly

constant. The velocity is very high at the poles and much smaller in the middle of the equatorial region."

For Tesla the Earth was nothing else but a metal ball, so it is natural that he tried to verify his theory of current propagation through the Earth by measurements on a metal ball. In October, 1902, he proposed a number of experiments to test his theory. The idea was to make a cage in the form of a sphere and pass very high frequency current through such structure (taking product of sphere diameter and operating frequency the same in the two cases). He expected to find that the wavelength change along the sphere cage, (imagining it as a conductor of variable cross-section) indicating that the velocity of propagation is constant along the axis of the sphere. Experimentally he tried to measure inductance of the sphere by replacing it with a straight conductor which inductance could be calculated. He also wanted to measure capacitance of "zones"--spherical rings. In a substitution sphere-straight conductor, in one measurement on November 3, 1902, Tesla found that "the induction of sphere 38.1 cm radius would be 45 cm. . ."

In November Tesla measured extensively various capacitances using balanced bridges. Occasionally he would return again to his theory of current propagation.

3.4. Notes written in 1903

For about half a year in 1903 Tesla wrote many pages of his Notes. Between January and May he performed many measurements of ground resistance and insulation resistance of the tower. He was careful ground resistance as can be seen from numerous calculations of power losses due to this resistance, and heavy current he wanted to use. The currents he considered varied between 2000-3000 A and obviously even 1 ohm of ground resistance would cause a great loss. He even calculated temperature rise caused by ground losses. He considered grounding by the use of a large metal sphere, metal pipes, and spreading of salty water around the grounding. Another important aspect of losses was in connection with the tower leakage. Tesla measured resistance between tower and grounding in various weather conditions, and in various times of the day and night.

In May, 1903, Tesla again turned more intensively to his theory of propagation. This time, and this is rather rare in all Tesla's notes, he refers to names. On May 21, 1903, he wrote:

"Consider radiation whether sphere uniformly charged or alternatively in positive and negative zones the radiation loss would be the same with due allowances. Now according to Maxwell, energy per unit volume is proportional to the square of P . We may therefore approximate result by taking Earth as a Hertzian vibrator uniformly charged and applying Maxwell's theory also making allowances. The loss would be simply proportional to the square of charge."

On May 24, 1903 he began his discussion on radiation from the Earth by quoting a formula from Maxwell's book for the radiation of sphere charged to a

potential P. Later he tried to make use of the same principle in calculation of radiated power by non-uniformly charged sphere.

3.5. Notes written between 1904-1906

There are few notes written in this period. They refer again to some earlier considered matters: oscillator design, maximum performance of electrical machinery (1904), some aspects of his theory (1906).

4. DISCUSSIONS AND CONCLUSIONS

The ideas which were developed, and the results of research which Tesla carried after his return from Colorado Springs in January 1900 were not fully disclosed in Tesla's papers which he published after 1900. Something was disclosed in [1] in 1904. Here Tesla explained his intelligence transmission "World Telegraphy" plant at Long Island. However, very little is said about technical details, most of statements are prediction-like types. From technical point of view, more interesting things had been disclosed in 1912 paper [2]. Another description of Tesla's system is found in a handbook [3]. Tesla's claim that "his" system is different from "Hertz's" is based on the fact that at low frequencies, and with small antenna l in terms of wavelength, radiation of Hertzian type electromagnetic wave is small. "Tesla's waves," if we are allowed to use such a name, are in fact surface waves in modern terminology (as known, this type of waves are significant in the range of long waves) or the Earth cavity waves, known better as ELF (extremely low frequency) waves. In "pure Hertzian" wave (in Tesla's terminology) there is no induced current in the Earth, except on reflection region which is not essential for the discussion. In contrast to the latter, guided surface or ELF waves do not exist without current in the Earth crust. Having this in mind, we can conclude that there is a truth in Tesla's statements about specific behavior of low frequency, guided to the Earth 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.

5. REFERENCES

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Worldwide Wireless Power Prospects

Kurt VanVoorhies, Ph.D., P.E.

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ABSTRACT

Worldwide wireless power began as a concept with the pioneering work of Nikola Tesla about 100 years ago. His principal approach is summarized. The viability of such a system must still be demonstrated and many questions remain. Potentially, a wireless system can transfer power more efficiently and flexibly, especially to and from remote regions. The principal elements of worldwide wireless power transfer include: 1) the source: an oscillator/transmitter, 2) the path: the cavity bounded by the earth and the ionosphere and 3) the receiver: a means of extracting power from the path. The system transfers and stores energy via the resonance modes of the cavity. The key challenges facing demonstration of technical feasibility are in finding an efficient means of coupling power into and out of the earth-ionosphere cavity, and in devising a feasible receiver that is both small and efficient. Along with demonstrating technical feasibility, new research must consider safety, environmental impact, susceptibility to weather, and effects on weather.

INTRODUCTION

Nikola Tesla pioneered the concept of worldwide wireless power transfer about 100 years ago, beginning with work on high voltage, high frequency single electrode lighting systems, and following with development of the Tesla Coil, The Magnifying Transmitter, and the single electrode x-ray tube. The Tesla Wireless system and concepts leading thereto are documented in Tesla's notes [1,2] patents [3,4], lectures [4-8] and published articles [4, 5, 9-11] and described by Tesla's biographers [12,13] and others [14, 15]. Following the death of Tesla in 1943, the concept lay dormant until referenced by Wait in 1974 [16,17] in conjunction with extremely low frequency communications, followed by Marincic's illuminating review in 1982 [18] and subsequent technical analysis by Corum and Corum [19-24], Golka [25,26] replicated the oscillator used in Tesla's Colorado Springs experiments for studying ball lightning and plasma containment for nuclear fusion, Corum and Corum [27-31] have also replicated Tesla's ball lightning experiments but with smaller scale equipment. However, Tesla's worldwide wireless power concept remains unverified.

PRINCIPLES OF WORLDWIDE WIRELESS POWER TRANSFER

Consider the earth as a large spherical capacitor or cavity resonator, comprising the terra firma as the inner conductor, the lower atmosphere as the insulating dielectric, and the upper atmosphere (electrosphere) and ionosphere as the outer conductor. Power is coupled into the cavity via either direct conduction/displacement, or radiation, with high power RF oscillators or transmitters tuned to the cavity's resonant frequency. A remote receiver, also tuned to this resonant frequency, then extracts this power wirelessly. The propagation loss in the earth-ionosphere cavity increases with frequency but, at the fundamental frequency, is about 11% less than the equivalent loss on a 200KV power line. The wireless concept described here differs from that used in microwave wireless power transmission in that the latter beams power along a line of sight path, normally from outer space to earth [32]

PROMISES OF WORLDWIDE WIRELESS POWER TRANSFER

The benefits of wireless power transfer have not changed since originally described by Tesla in 1900 [9] and 1904 [10]. A cheap, efficient means of distributing energy would revolutionize development and improve access to new energy sources. Energy could be coupled into the cavity at the source, eliminating the need for the costly and time-consuming process of constructing and maintaining power transmission lines. The system would enable better utilization of remote sources of energy and would facilitate power transfer to remote users worldwide. While Tesla primarily proposed supplying power for lighting in conjunction with his high frequency single electrode lighting systems, he also envisioned "...energy of a waterfall made available for supplying light, heat and motive power anywhere - on sea, or land or high in the air..."[10]. Of course, the economic viability of such a system depends upon either 1) a technical means for controlling/measuring the supply and use of wireless power around the world, or 2) a very low cost source energy.

Nikola Tesla

Nikola Tesla was a prolific inventor best known for the AC induction motor and AC polyphase distribution system which are the basis for our present AC power system. His other inventions include the Tesla coil, high frequency generators, the Tesla Magnifying Transmitter, key elements of radio, single electrode high frequency, the single electrode x-ray tube, a viscous turbine, and remote control. Following his developments in low frequency AC machines and power distribution systems, Tesla experimented with single electrode, high frequency, high voltage lamps utilizing rarefied gases, the forerunner of present fluorescent lights. Initially he utilized patented high frequency alternators with 384 poles to produce the necessary 20 KHz power, but subsequently invented the disruptive discharge high voltage transformer, a.k.a. Tesla Coil, in 1891 [33].

In a Tesla Coil, low frequency AC power is amplified in voltage with a conventional transformer. The output of this transformer feeds the Tesla Coils' resonant LC primary circuit through a spark gap. The spark gap creates a broad spectrum of energy, components which resonate the primary and secondary circuits of the Tesla coil. The secondary of the Tesla Coil is tuned to be electrically $1/4$ wavelength long, with one terminal grounded, and acts as a "slow wave" device to resonantly amplify the voltage further.

Tesla found that the high frequency output from the Tesla coil could readily power lights and motors utilizing a single wire with a ground return. Tesla presented these results in this lecture to the IEE in London in 1892[7]. Following the work of Kelvin and Crookes, Tesla also noted that slightly rarefied gases were excellent conductors, leading him to propose a system for "... transmitting intelligence or perhaps power, to any distance through the earth or environing medium". [34] In February 1893, at his lecture on high frequency currents before the Franklin Institute of Philadelphia (repeated in March in St Louis.) Tesla proposed to determine the capacitance of the earth and the period of oscillations resulting from a disturbance of the earth's charge. After subsequent patented improvements to the Tesla Coil Tesla patented the single wire power distribution system in March., 1897, [35] and patented the wireless power distribution 6 month later [36,37]. In the wireless system, the single wire conductor was replaced by a conductive path through a slightly rarefied gas coupled to bodies of large surface area, or open capacitors, connected to the high tension terminals of the transmitter and receiver, thus forming an open resonator circuit between the body and

the earth. In his patent, Tesla claimed the use of the conductive layers in the upper atmosphere as the conductive path.

in the 1892 lecture in London, Tesla noted that " It is quite possible, however, that such 'no wire' motors, as they might be called, could be operated by conduction through the rarefied air at considerable distances. Alternate currents, especially of high frequencies, pass with astonishing freedom through even slightly rarefied gases. The upper strata of the air are of difficulties of a merely mechanical nature. There is no doubt that with the enormous potential is obtainable by the use of high frequencies and oil insulation, luminous discharges might be passed through many miles of rarefied air, and that by thus directing the energy of many hundreds of thousands of horsepower, motors or lamps might be operated at considerable distances from stationary sources. But such schemes are mentioned merely as possibilities. We shall have no need to transmit powers in this way. We shall have no need to transmit powers at all. Ere many generations pass, our machinery will be driven by a power obtainable at any point of the universe..."[38] Tesla demonstrated plasma conduction in a glass tube with rarefied air surrounding a central axial platinum electrode, he observed that the wire was heated only at the ends, and not in the middle. He also observed that the pressure at which the gas becomes conducting is directly related to the applied voltage. Colorado Springs Laboratory Tesla moved to Colorado Springs in May 1899, after reaching the limits of his New York Laboratory with Tesla Coils operating at 4 million volts. The dry, electrostatic filled air at the 2000 m facility in Colorado Springs facilitated his developments. His primary and secondary coils were 51 ft. in diameter, and it was here that he developed the concept of an extra coil placed in series with the secondary but with loose inductive coupling so as to enable large resonant amplification of voltage. In addition to the development and improvement of the high power Tesla coil, Tesla concentrated on the development of sensitive receivers necessary for detecting communication signals. On July 3, 1899, using these devices, Tesla monitored the progression of a passing thunderstorm, observing electrical standing waves which he attributed to the storm's disturbance of the earth's electrical charge and a corresponding propagation of this disturbance around the conductive globe. Tesla also experimented with his single electrode x-ray tubes. The oscillator reportedly operated at frequencies between 45KHz and 150 KHz, at voltages between 12 MV and 18MV, and with secondary currents as high as 1100A [1,12,12,39].

Wardenclyffe Laboratory

Funded principally by J.P. Morgan, Tesla proceeded with the construction of a system of "World Telegraphy" at Wardenclyffe on Long Island upon his return from Colorado Springs in 1900 [12,13]. While he intended to use the facility publicly for communications, Tesla's secret aim was to implement wireless power transfer. The facility featured a 187 ft. wooden tower designed to support a 68 ft. diameter copper hemisphere, which was not completed because of Tesla's difficulty in obtaining funding following Marconi's success in demonstrating transoceanic wireless communication with much simpler equipment (albeit using Tesla's patents in the process) The transmitter was to have operated at 30 MV, which Tesla claimed was sufficient for worldwide power distribution; however, the transmitter was designed to handle up to 100MV. Aside from its toroidal elevated capacitor, patent 1,119,732 [40] filed in 1902 shows the Wardenclyffe configuration of the transmitter, which incorporated the 'extra coil' from the Colorado Springs experiments.

TESLA'S Concept of Worldwide Wireless Power Transfer

Tesla outlined the requirements for wireless power distribution in patent 787.412, describing the earth as "...behaving 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"[41]. He described reflections of signals from antipodes, the points on the globe diametrically opposite from the transmitter, as being similar to those from the end of a conducting wire, thus creating stationary waves on the conductive surface. He provided three requirements for resonance: 1) the earth's diameter should be equal to an odd number of quarter wavelengths, 2) the frequency should be less than 20 KHz to minimize

Hertzian radiation; and 3) most critical, the wave train should continue for a minimal period which he estimates to be 1/12 second, and which represents the period of time for a wave to propagate from and return to the source at a mean speed of 471,240 Km/sec. Tesla conceived

the wave as propagating through the earth along a straight line path, the effect on the outside surface being that of concentric rings expanding to the equator and then contracting until reaching the opposite pole. Tesla also applied a fluid analogy to the earth and the water level representing the earth's state of charge at any given point. While his earlier work emphasized ground currents as the mechanism for transferring power, he later indicated that he had conclusively demonstrated that "... with two terminals maintained at an elevation of not more than thirty thousand to thirty five thousand feet above sea level, and with an electrical pressure

of fifteen to twenty million volts, the energy of thousand of horse-power can be transmitted over distances which may be hundreds, and, if necessary, thousands of miles. I am hopeful, however that I may be able to reduce very considerably the elevation of the terminals now required..."[42].

Summary of Tesla's Proof of Concept

Tesla claimed to have observed the effects of the Colorado Springs transmitter at a distance of up to 600 miles. An advertising brochure for the World Telegraphy system claims the transmission of power around the globe in sufficient quantity to light incandescent lamps (50watts). Others report that a bank of 200 watt lamps, 50 watts each, were lit at a distance of 26 miles [12,13]. The article in Century magazine shows photographs of an isolated extra coil powering and incandescent lamp as evidence of "...electrical vibrations transmitted to it through the ground from the oscillator..." [43]. However, this extra coil was most likely within the inductive field of primary transmitter, with the ground serving as a return path.

Rationale for a Renewed Interest in Wireless Power Transfer

Given Tesla's firm and unending belief in the feasibility of wireless power transfer, yet his inability, after considerable expenditure of time and money, to conclusively demonstrate its viability, the reader may question why there is a renewed interest in demonstrating the feasibility of wireless power transfer. Aside from the benefits outlined initially, the best reason probably lies in both 1) the legacy of Tesla himself, and 2) the fact that because of insufficient funding, Tesla was never able to test a facility that had been developed strictly for power transfer, and thus his wireless power transfer concept remains to be proven.

The legacy of Tesla speaks for itself in terms of his many and varied significant inventions, his insightful pioneering understanding of physics and electrical engineering, his tremendous drive and creative energy enabling him to constructively work long hours on a protracted basis guided by a keen sense of vision, his ability to visualize and test concepts in his mind enabling him to achieve good results with little trial and error, and his genuine

concern for improving the condition of humanity. The breath of his accomplishments at Colorado Springs with less than 8 months exemplifies these. The Colorado Springs experiments focused primarily in the development of wireless communications, i.e., radio rather than wireless power transfer. As indicated by Marincic [18], 56% of his time was spent

in developing the Tesla Coil, 21% on receivers for small signals, 16% on measuring the capacity of the vertical antenna, and 6% on miscellaneous other research, including fireballs. Wireless power transmission experiments were limited to small distances.

Tesla shared much with the world in the form of his patents, publications, lectures, he was also a very secretive person, and never fully documented his intended configuration for the wireless power system, even though he was confident there would be a workable solution. He believed that his Magnifying Transmitter (Tesla Coil w/extra coil designed to excite the earth) would ultimately be recognized as his greatest invention [11], and felt that there would be no problem in wireless disturbing the earth's energy. He also believed the universe to be so full of energy that, ultimately, wireless distribution would not be necessary. Modern day researchers attempting to follow his path, must also be part detective. Tesla's belief and confidence in wireless power transfer is clear, however, so too was Edison's belief in magnetic ore separation, which, like Tesla's experience with Wardenclyffe, left him in deep financial debt. [44]

Recent Developments

In recent years, there has been a renewed interest in Tesla's work on high voltage, high frequency phenomena. Beginning in 1968, R. Golka formed Project Tesla to measure, under Air Force Contract, aircraft susceptibility to lightning discharge and to repeat Tesla's ball lightning experiments for application to laser fusion, in the process, he replicated Tesla's Colorado Springs transmitter and succeeded in operating it at twice Tesla's original power levels [25,26]. In 1986, Golka and Grotz proposed the application of this device to artificially resonating the earth-ionosphere waveguide [45].

Cheney reports on wireless power projects that had been planned and some partially implemented circa 1977-1980 in Canada, Central Minnesota and Southern California. [13] Wait indicated how Tesla's early wireless experiments were the forerunner of modern developments in ELF. He observed that Tesla's fluid analogy for the process is faulty in its assumption that all of the signal energy would propagate through the fluid medium, i.e. the earth. Also faulty was Tesla's notion that energy propagates to the antipode via the center of the earth, although it is not known if Tesla had viewed this as a conceptual model as opposed to a physical model as presently interpreted.

Marincic, in his annotations of Tesla's Colorado Springs Notes [1,2] and his excellent review of Tesla's wireless work [18] applies results from recent ELF experimental data to show that the transfer of power via ELF radiation would be extremely inefficient. He indicates that for a typical gridded ELF antenna, 106 m. total length, that the antenna operating efficiency would be only 0.026% and for both receiving and transmitting antennas, the total efficiency would be (0.026%), not to mention the path losses, which are as low as 0.25 dB/Mm at 10Hz and 0.8dB/Mm at 50Hz. For a fixed size antenna, efficiency increases with operating frequency, but so do path losses, so that for long distance power transfer, the overall efficiency of a radiation-based system will be low.

Corum and Corum [27-31] also replicated some of Tesla's Colorado Springs fireball experiments but with much smaller scale equipment. This work extended to a critical engineering evaluation of Tesla's wireless power concept. [20-23], showing how the current

moment in the tower of Tesla's transmitter could be used to excite the Schumann resonances in the earth-ionosphere cavity. They also hypothesized that Tesla intended to use a single electrode x-ray to both ionize a current path to the sphere of elevated capacitance and to rectify the RF energy enabling the sphere to be electrostatically charged at RF rates [20,21]

The sphere would then be discharged to ground, either naturally or via a second x-ray device, at a Schumann resonance frequency. Corum and Corum have also verified that Tesla's electrical measurements such as the attenuation constant, phase velocity, cavity resonant frequency and Q are consistent with modern measurements [23] and that the losses due to glow discharge around the transmitter would be small [21].

J. F. Corum patented a toroidal helical antenna [46,47] one of whose applications could be a waveguide probe for either ELF communications or wireless power transfer. This antenna is physically small while reportedly possessing good radiating efficiencies with vertical polarization. Since the propagating Schumann modes are primarily vertically polarized, a vertically polarized antenna would have a distinct advantage over the horizontally polarized example presented by Marincic. However, in applying Corum's design formula to the 8 Hz example presented in his patent, one finds that an antenna with a 6 Km major radius (0.0002)

free space wavelengths) would require a virtual continuum of 43,200 semicircular loops each 600 m in diameter, with a total conductor length equivalent to half the circumference of the earth.

The Q of the earth-ionosphere cavity is generally reported to be about 6-8 but Corum and Spaniol [48] indicate that a low Q cavity does not necessarily limit the practicability of wireless power. However, Sutton and Spaniol [49] found that the previously measured Q values were limited by instrument noise and using modern equipment they measured levels as high as 1000, which they say were also confirmed by others. [50].

In 1986-1988, Nash, Smith, Craven and Corum of WVU utilized a 1/4 wave coaxial resonator to develop a high frequency "Tesla Coil" and proposed coupling this device to a Tesla single electrode x-ray tube to generate ionizing radiation with possible application to wireless power transfer [53].

THE KEY ELEMENTS OF WORLDWIDE WIRELESS POWER TRANSFER

The key elements of worldwide wireless power transfer consist of:

1. source/transmitter
2. path
3. receiver
4. system considerations
5. environmental impact
6. economic viability

Each of these will now be explained in more detail, along with their subgroups.

Source/Transmitter

The source/transmitter, consisting of Tesla's Magnifying Transmitter is the most highly developed elements of the system, as evidenced by the standard terminology of "wireless power transmission". In this paper, the term "transfer" emphasizes the importance of other system elements as well. The Tesla Coil is a remarkable efficient power processing element, and Corum and Corum have shown that Tesla's Colorado Springs Transmitter operated at power levels high by even modern standards, with peak average power levels some four

orders or magnitude higher than those of the Stanford Linear Accelerator. [21]

Earth-Electrosphere/Ionosphere Cavity with Dielectric Atmosphere

The path comprises the earth (ground) and the atmosphere. The ground is a good conductor at lower frequencies, conductivity decreasing with frequency due to the skin effect. The lower atmosphere is normally a good insulator. At higher altitudes the air becomes conductive due to ionization caused by cosmic rays. The conductive layer, termed the electrosphere, [54] provides an electrostatic shield and an equipotential surface due to its high conductivity relative to the ambient currents. Lord Kelvin, in 1860 [55] originally postulated the existence of such a conductive layer based upon the fact that rarefied gases act as good conductors, and he thus postulated that this conductive layer together with the earth and intervening insulating atmosphere forms a capacitor. The potential of the electrosphere is about 300 KV. The ionosphere, located above the electrosphere, is caused by ionizing solar radiation, different ionospheric layers (D,E,F) being attributed to different components of the radiation. The ionosphere is that part of the earth's atmosphere which reflects radio waves [54,56]. The properties of the path are normally measured under conditions (voltage, current, frequency) quite different from those expected for wireless power transfer, and this should be considered before drawing conclusions on the suitability of the path for such purposes. Also, the effects of weather on conductivity and the effects of magnetic storms must be considered.

Spherical Cavity Modes

The spherical cavity between the ground and the ionosphere resonates at specific modes as predicted by Schumann [57,58] and discussed by Wait[59] and Galejs[60]. The transverse electric field mode (TE) is cutoff below 1.5 KHz, so for the ELF frequencies normally considered for wireless power transfer, the cavity will only support transverse magnetic TM waves, [61]. The first seven Schumann resonances are naturally excited by lightning and this fact has been used to track lightning strikes around the globe. [61-67]. The polarization and ellipticity of the waves vary diurnally. Waves propagating in the cavity are attenuated with distance due to the finite conductiveness of the conductive and dielectric layers, and the attenuation increases exponentially with frequency, increasing from 0.25 dB/Mm at 10 Hz to 20 dB/Mm at 1 KHz. (compared with 1.15 dB/Mm for a conventional 200KV power line [24]. Tesla has indicated that very little power is required to maintain a state of resonance in the cavity [21].

Waveguide Coupling

The key issue in wireless power transfer is how to couple power into and out of the cavity with minimal, or at least acceptable loss. Corum and Corum have indicated that Tesla more likely created the necessary current moments to excite the cavity by electrostatically charging an isolated capacitance at RF rates via a single electrode x-ray tube and then suddenly discharging this capacitance at a resonant frequency of the cavity [20-21]. They reported that the currents measured by Tesla would have been sufficient to generate relatively weak ELF global field strengths. Tesla noted that the discharge tended to pass upward away from ground, which he attributed to either electrostatic repulsion, or convection of the heated air.

However, with such an electrically short tower, radiation into the cavity at cavity resonant frequencies would not be sufficiently efficient for technical or commercial viability. And while a resonating cavity would have purely reactive fields, and hence zero point radiation resistance together with non-stationary fields would be required for power transfer within the cavity. A radiative coupling approach appears to be infeasible for reasons stated above by Marincic.

Transmission Line Coupling

A second method for coupling power into the cavity would be via direct conduction/displacement with the conductive surfaces of the waveguide, which appears to be Tesla's original concept dating back to 1892. Several mechanisms could be considered as follows: 1) Recall that, in 1900, he proposed using balloons at 30-35 thousand feet of elevation. Conceivably the power could be conducted to these via an ionization path, created by a single electrode x-ray tube driven by the transmitter. 2) The conducting path formed by ionizing radiation might be used to couple directly into the electro sphere without the elevated conductive sphere. 3) An approach might also be borrowed from those used in present ionospheric modifications experiments [68]. 4) Perhaps with the extremely high operating voltages that Tesla had proposed, the displacement coupling with the atmospheric conduction path would be direct, as apparent from an artist's rendition of wireless power distribution from Tesla's Wardenclyffe facility [69], Tesla originally indicated that the atmosphere could be made conductive at lower elevations with either high voltage or high frequency so this should be studied further. . With such a direct coupling approach, the power transfer mechanism would then be a spherical "transmission line", rather than a spherical wave guide.

Ground Currents

The ground currents in Tesla's Colorado Springs experiments were reported to have caused sparks within the ground, and to have shocked horses through their metal shoes within 1/2 mile from his transmitter. [70]. As an aside, ground currents were separately exploited for communications during WW I, when conversations over the then prevalent single wire telephone systems were susceptible to enemy interception by differentially amplifying the signals extracted from two separate and displaced ground plates. The phenomenon of magnetospheric plasma whistler waves was first noticed with these receivers, but was not identified until later [71].

Power Loss

Power loss can occur in all elements of the path, which have finite conductivity: the ground, the dielectric lower atmosphere, and the conductive upper atmosphere. Elaborate and extensive ground planes are often constructed with antenna systems in order to minimize resistive power loss to the ground. Since the ground is an intrinsic conductive element, losses are inevitable, but can be reduced by operating at lower frequencies and/or establishing distributed area contacts at the transmitter and receiver sites. The poor conductivity of the Colorado Springs soil appears to have caused Tesla some difficulty [1]. At Wardenclyffe, Tesla was planning to use saltwater filled viaducts under the transmitter to establish a good ground connection. Similar to the ground, atmospheric losses can be reduced by operating at lower frequencies. This appears to conflict with Tesla's notion that

gases conduct better at high frequencies, but could be explained by higher dielectric losses. One important feature to the wireless system is the possibility of storing power in the resonating fields within the earth-ionosphere cavity, however, the feasibility of doing this will be dependent upon the Q of the cavity and upon the relative amount of excess power being stored therein. As Tesla had indicated, the power losses are reduced with higher operating voltage since power would then be distributed at lower current levels. Precipitation can dramatically change the conductivity of the atmosphere, and the effects of this on power coupling need to be considered further.

Receiver

The receiver is the least understood element of the system, and one that is most crucial to the system's success. For system using a radiative coupling mechanism, an antenna's efficiency and size both benefit from higher operating frequencies which, as noted above, increased the system's path losses. A transmission line approach would require conductive/displacement coupling into the electrosphere, which requires invention and development.

Tesla expressed confidence in being able to extract power for both individual and home use as well as for powering ground and air transportation vehicles, as illustrated in an artist's rendition [69]. He indicated in patent 649,621: "Obviously the receiving coils, transformer, or other apparatus may be movable - at, for instance, when they are carried by a vessel floating in the air or by a ship at sea. In the former case the connection of one terminal of the receiving apparatus to the ground might not be permanent, but might be intermittently or inductively established without departing from the spirit of my invention. IT is to be noted here that the phenomenon here involved in the transmission of electrical energy is one of true conduction and is not to be confounded with the phenomenon of electrical radiation which have heretofore been observed and which from the very nature and mode of propagation would render practically impossible the transmission of any appreciable amount of energy to such distances as are of practical importance [36].

Tesla separately described the utilization of energy from ionized air, in connection with his description of the art of telautomatics; "Most generally I employed receiving circuits in the form of loops, including condensers, because the discharges of my high-tension transmitter, ionized the air in the hall so that even a very small aerial would draw electricity from the surrounding atmosphere for hours. Just to give an idea, I found for instance, that a bulb 12 inches in diameter, highly exhausted, and with one single terminal to which a short wire was attached, would deliver well on to one thousand successive flashes before all charge of the air in the laboratory was neutralized..." [72]

Systems Considerations

A wireless system would entail a multiplicity of transmitters and receivers each coupling into a common propagation and storage cavity, each requiring proper phasing and balance.

Safety

A wireless power system would expose the entire biosphere to ELF fields of varying intensity. The 78 Hz Seafarer/Sanguine/ELF submarine communication system provoked health concerns, as do high-tension power lines. The fields of wireless and wire-based power transmission systems need to be compared for equivalent power levels. There is much

speculation about the adverse effects of magnetic fields on health. However, recent reports from PACE indicate that ELF energy at the lower Schuman resonance frequencies constitute a natural biological clock [71]. The first four Schuman resonance frequencies are within the range of brain wave activity. The fundamental mode is coincident with the theta wave spectrum, which ranges from 4 to 8 Hz, and is attributed to a normally unconscious state with enhanced mental energy and a high level of creativity. [72] The next three Schuma modes are coincident with the beta wave spectrum which ranges from 13 to 26 Hz, and is associated with the normal conscious state.

Environmental Impact

Operating at high voltages and surrounded by a glow discharge, the transmitter could be a source of pollutants, including ozone, NO and nitric acid, as reported by Tesla during his experiments and steps would have to be taken to mitigate any such hazards if they exist. Electromagnetic Interference (EMI) and Radio Frequency Interference (RFI) The operating frequencies of a wireless system could be expected to be low enough so as to not interfere with present communications of electronic systems. The FCC does not make frequency allocations below 9Khz and Tesla had predicted the operating frequency to be below 20 Khz. Circuit interrupters in conventional Tesla coils could be expected to create a significant amount of wide-band EMI; however, modern transmitters could be expected to utilize more advanced switching devices which, together with shielding, could minimize radiated EMI/RFI. The glow discharge surrounding the high transmitter could also be a source of EMI/RFI.

Weather Modification

Since the potential of the electrosphere is about 300 KV relative to the earth, and the wireless system as proposed by Tesla was designed to operate at 30-100MV, there is a significant potential for electrically disturbing the atmosphere. It is not know whether this would be beneficial or harmful. Vonnegut [75] has suggested that the destructive effects of tornadoes may result from atmospheric electrical effects; however, Wilkins [76] concluded from laboratory model vortex experiments that the electrical effects were the effect, rather than the cause, of tornadoes.

Economic Viability

Given technical feasibility and safety, the wireless power transfer system must still be economically viable in order to succeed. Multiple transmitter could conceivably be phased to control the location of antinodes from which power could be extracted, however, this could be at best, a short term solution, unless wireless is constrained to a relatively few large scale facilities that will be expensive and technically difficult to construct. The worldwide regulation and control of wireless power distribution will be difficult if physically constrained to operate at selected resonant frequencies.

CONCLUSION

Times have changed since Tesla's initial investigations of wireless power. Tesla originally envisioned a distributed network of relatively low level suppliers and users of wireless power,

and thought it would benefit remote users the most, although he also envisioned large scale power distribution. Our power needs have dramatically increased over the past 100 years, as have their complexity. Tesla expressed great confidence in the viability of wireless power distribution, yet was unable to see its fruition after nearly 50 years of effort. The fulfillment of his vision was undoubtedly impeded by limitation on funds and resources. Tesla demonstrated that the earth can be electrically resonated. The key challenge to feasible worldwide wireless power distribution is whether a means can be found for efficiently coupling power into and out of the cavity formed by the earth, the atmosphere, and the electrosphere/ionosphere.

Radiative coupling does not appear to be viable. A conductive approach is proposed which is consistent with Tesla's original wireless concepts; this requires, however, further invention and development. The receiver is the element requiring the most development to make wireless power transfer feasible.

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Kurt Van Voorhies holds patents #5,442,369, and #6,239,760 and can be reached at Vortekx, Inc., DeTour Village, MI, vortekx@sault.com

Operating Principles of the Wardenclyffe Apparatus

Can you explain, within accepted laws of physics, what was Tesla was trying to accomplish at Colorado Springs and on Long Island?

This appeared in the Electrical Review - N. Y., Nov, 30, 1898, pp. 344, 345, "TESLA DESCRIBES HIS EFFORTS IN VARIOUS FIELDS OF WORK"

. . . Starting from two facts that the earth was a conductor insulated in space, and that a body cannot be charged without causing an equivalent displacement of electricity in the earth, I undertook to construct a machine suited for creating as large a displacement as possible of the earth—s electricity.

This machine was simply to charge and discharge in rapid succession a body insulated in space, thus altering periodically the amount of electricity in the earth and consequently the pressure all over its surface. It was nothing but what in mechanics is a pump, forcing water from a large reservoir into a small one and back again. Primarily I contemplated only the sending of messages to great distances in this manner, and I described the scheme in detail, pointing out on that occasion the importance of ascertaining certain electrical conditions of the earth. The attractive feature of this plan was that the intensity of the signals should diminish very little with the distance, and, in fact, should not diminish at all, if it were not for certain losses occurring, chiefly in the atmosphere. As all my previous ideas, this one, too, received the treatment of [Marsyas](#), but it forms, nevertheless, the basis of what is now known as — wireless telegraphy.— This statement will bear rigorous examination, but it is not made with the intent of detracting from the merit of others. On the contrary, it is with great pleasure that I acknowledge the early work of Dr. Lodge, the brilliant experiments of Marconi, and of a later experimenter in this line, Dr. Slaby, of Berlin. . . .

In 1899 Tesla arrived at the conclusion that he could periodically alter "the pressure all over [the earth's] surface." This could not have been an idle prediction. Real-world observations involving operating experimental apparatus must have played a significant role in the process.

I've read that,

in 1907 Jonathan Zenneck formulated a special surface wave solution to Maxwell's equations ["Über die Fortpflanzung ebener elektro-magnetischer Wellen langs einer ebenen Leiterfläche und ihre Beziehung zur drahtlosen Telegraphie," Annalen der Physik, Vol. 23, September 20, 1907, pp. 846-866 and "Über die Wirkungsweise der Sender für gerichtete drahtlose Telegraphie," Physik. Zeitschrift, Vol. 9, 1908, pp. 50 and 553-556] that was fundamentally different from the free-space waves studied by Hertz in 1887. [Corum, K. L. and J. F. Corum, "The Zenneck Surface Wave," Appendix II of "Nikola Tesla, Lightning Observations, and Stationary Waves," 1994.]

And, in the 1916 interview Tesla said, ". . . the mathematical treatise of [Arnold] Sommerfeld, . . . shows that my theory is correct, that I was right in my

explanations of the phenomena. . . ." The paper, "Über die Ausbreitung der Wellen in der drahtlosen Telegraphie," ["Propagation of Waves in Wireless Telegraphy," *Annalen der Physik*, Vol. 28, March, 1909, pp. 665-736] contained a formal analytical solution for the radiation from a short vertical monopole over a finitely conducting ground, and was written within the context of Zenneck's 1907 formulation. It posits,

Two contrasting concepts arise which may be designated by the terms 'space waves' and 'surface waves.' The Hertzian electrodynamic waves are [space waves]. Electrodynamic waves on wires are typical surface waves. . . .

Then Sommerfeld goes on to ask,

With which type are the waves utilized in wireless telegraphy to be identified? Are they like Hertzian waves in air or electrodynamic waves on wires?

In his review of this paper the late James R. Wait points out that,

Sommerfeld obtained exact expressions for the field components in the form of integrals which were then evaluated asymptotically. . . . In an attempt to explain the physical nature of his solution, he divided the expressions for the field into a 'space wave' and a 'surface wave'. Both parts, according to Sommerfeld, are necessary in order to satisfy Maxwell's equations and the appropriate boundary conditions. He found that the 'surface wave' part of the solution had almost identical properties to the plane Zenneck surface wave. The field amplitudes varied inversely as the square root of the horizontal distance from the source dipole. Furthermore it was a fast wave and it decayed exponentially with height above the interface. ["Electromagnetic Surface Waves," in *Advances in Radio Research*. J.A Saxton, editor, Academic Press, Vol. 1, 1964, pp. 157-217. (See *Corrections in Radio Science*, Vol. 69D, #.1, 1965, pp. 969-975.)]

Analytically, the issue arose as follows:

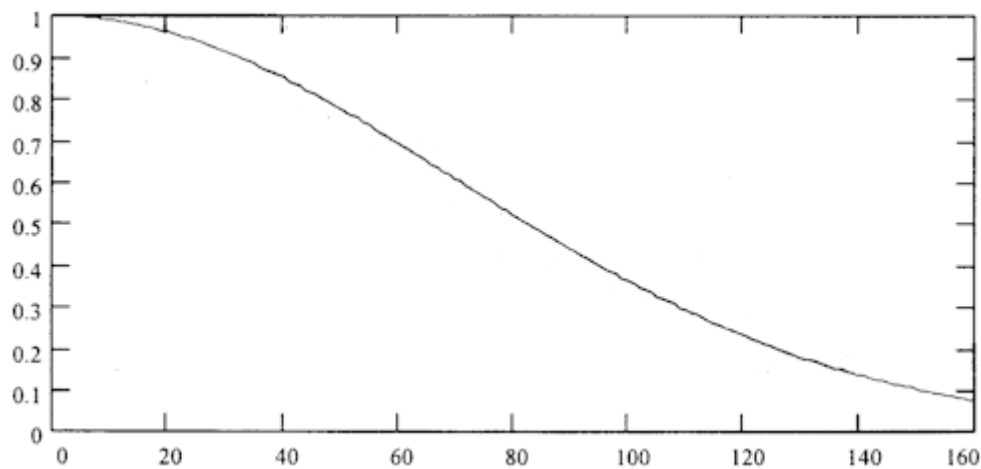
After Sommerfeld formulated the wave function for a vertical infinitesimal dipole as an infinite integral and noted that the integral around the pole of the integrand is the wave function for a surface wave, which at great distances is identical with the Zenneck wave, no one questioned the reality of Zenneck's surface wave. [Wise, W.H, "The Physical Reality of Zenneck's Surface Wave," *Bell System Technical Journal*, Vol. 16, January, 1937, pp. 35-44.] [Corum and Corum, 1994, loc cit.]

Getting back the original "mathematical treatise," Sommerfeld concluded,

Zenneck surface waves appear as an important and occasionally predominant component of the electromagnetic field accompanied by space waves, which on their part predominate under certain other conditions.

How might the surface-wave be made to predominate? For one, significant presence of this component appears to be very much frequency dependent.

Tesla asserted, "I only used low [frequency] alternations, and I produced 90 percent in current energy and only 10 percent in electromagnetic waves . . . and that is why I got my results."



Zenneck wave field strength decrease for around-the-world propagation as a function of frequency in kHz.

Another condition is the physical geometry of the launching structure. After a series of experiments performed in 1937, Charles Burrows of Bell Labs concluded, "The surface wave component of Sommerfeld is not set up by simple [monopole] antennas on the surface of the earth. . . ." such as modeled by Sommerfeld in his analysis. [Burrows, C.R, "The Surface Waves in Radio Propagation Over Plane Earth," Proceedings of the IRE, Vol. 25, No.2, February, 1937, pp. 219-229].

A paper by Yu. V. Kistovich, "Possibility of Observing Zenneck Surface Waves in Radiation from a Source with a Small Vertical Aperture" [Soviet Physics Technical Physics, Vol. 34, No.4, April, 1989, pp. 391-394] appears to shed further light on what an appropriate geometry for launching the Zenneck surface wave might be.

Kistovich notes that it is known that the asymptotic expansion of the field of a vertical electric dipole does not manifest a Zenneck wave, ". . . and it is inferred from this result that a Zenneck surface wave is never generated by sources with a small vertical aperture. This opinion is widely held in radiophysics at the present time." However, he and his colleagues have found, both analytically and experimentally, that it is possible to use small "resonators" to excite a Zenneck wave that is observed to be 10-20 dB stronger than radiation fields. They also found that both traveling and standing Zenneck waves can be excited. [Schelkunoff and Friis clearly delineate the distinction between a quarter wave resonator and a quarter wave radiator in terms of the in-phase "feed current" (which supplies the radiated power) and the "quadrature current" (which supplies the resonant oscillations of the structure) [Schelkunoff, S., and H.T. Friis, Antennas: Theory and Practice, Wiley, 1952, pp. 352-353]. Without the "feed current" component, the base impedance of an ideal lossless series-resonant quarter wave monopole would drop to zero at resonance despite the

fact that the reactive "quadrature current" would be infinite [Schelkunoff and Friis, *ibid*, pg. 252.]]. . .

As it turns out, the Zenneck wave is generally difficult to excite with a realistic source because it has a rather slow decay with height above the earth's surface. But there is still an open question whether other types of sources may not be more favorable. . . . An infinite vertical aperture with a height variation corresponding to that of the Zenneck wave will excite only the Zenneck surface wave with no radiation field. . . . The infinite Zenneck aperture excites no radiation field and the pure Zenneck surface wave is the expected result. . . ."

[Hill, D. and J.R Wait, "Excitation of the Zenneck Surface Wave by a Vertical Aperture," *Radio Science*, Vol. 13, No.6, November-December, 1978, pp. 969-977.] This analysis examined the fields produced by a vertical sheet of horizontally directed magnetic current with an exponential variation in [a] vertical aperture. . . called an 'infinite Zenneck aperture,' and such a source truly "excites a pure Zenneck wave with no radiation field." [Corum and Corum, 1994, *loc cit.*]

Furthermore, it should be remembered that in Colorado Springs Tesla was at times using frequencies in the area of 5 kHz and below, well below those to be expected from any realistically sized helical resonator by itself. The extra coil of his large 1899 oscillator vibrated at about 100 kHz which suggests that Tesla had developed a technique for producing a very low frequency (VLF) output from this low frequency (LF) machine.

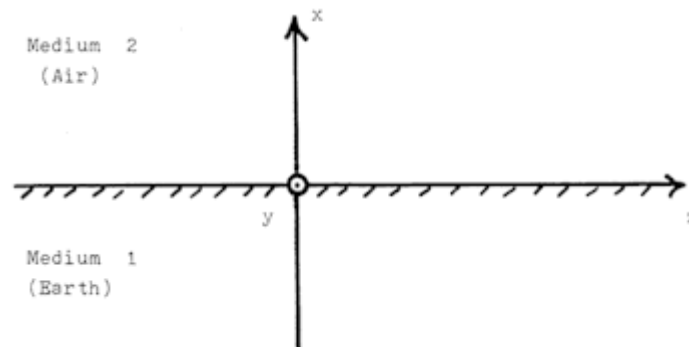
REDISCOVERING THE ZENNECK SURFACE WAVE

by Gary Peterson

In 1916 while speaking of his system for global transmission, Nikola Tesla cited the analysis of mathematician Arnold N. Sommerfeld as verification of his explanations of observed radio phenomena. Tesla was referring to his system in which, he claimed, 90% to 95% of the electrical energy was manifested at the transmitters output as "current waves" with the remainder existing as dissipating electromagnetic radiation (see [Antenna Theory](#)). In 1909 another investigator by the name of Johann Zenneck, while working to explain Marconi's trans-oceanic results, showed that a unique type of surface wave could travel along the interface between the ground and the air. In the words of James Corum,

"The distinguishing feature of the Zenneck wave was that the propagating energy didn't spread like radiation, but was concentrated near the guiding surface. Sommerfeld had shown that an electromagnetic wave could be guided along a wire of finite conductivity, and Zenneck conceived that the earth's *surface* would perform in a manner similar to a *single conducting wire*." [see ["Operating Principles of the Wardencliff Apparatus"](#)]

In commenting on Sommerfeld's analysis of the surface wave, James R. Wait states that "The field amplitude varies inversely *as the square root* of the horizontal distance from the source. . . ." It's interesting to note that Sommerfeld made a point of distinguishing between the "electrodynamic" surface wave and its Hertzian counterpart the space wave, believing that both components could be present in varying proportion in the wave complex. It was Tesla's assertion that the exact composition of the emissions was dependent upon the design of the transmitter.



Geometry for Zenneck wave propagation.

According to James Corum's mathematical analysis of the Zenneck wave,

"The resulting wave is a surface guided (single conductor) *transmission line* mode which attenuates exponentially along the guide. . . . There is no *inverse square* spreading or diffraction, as with Hertzian waves. . . . 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."

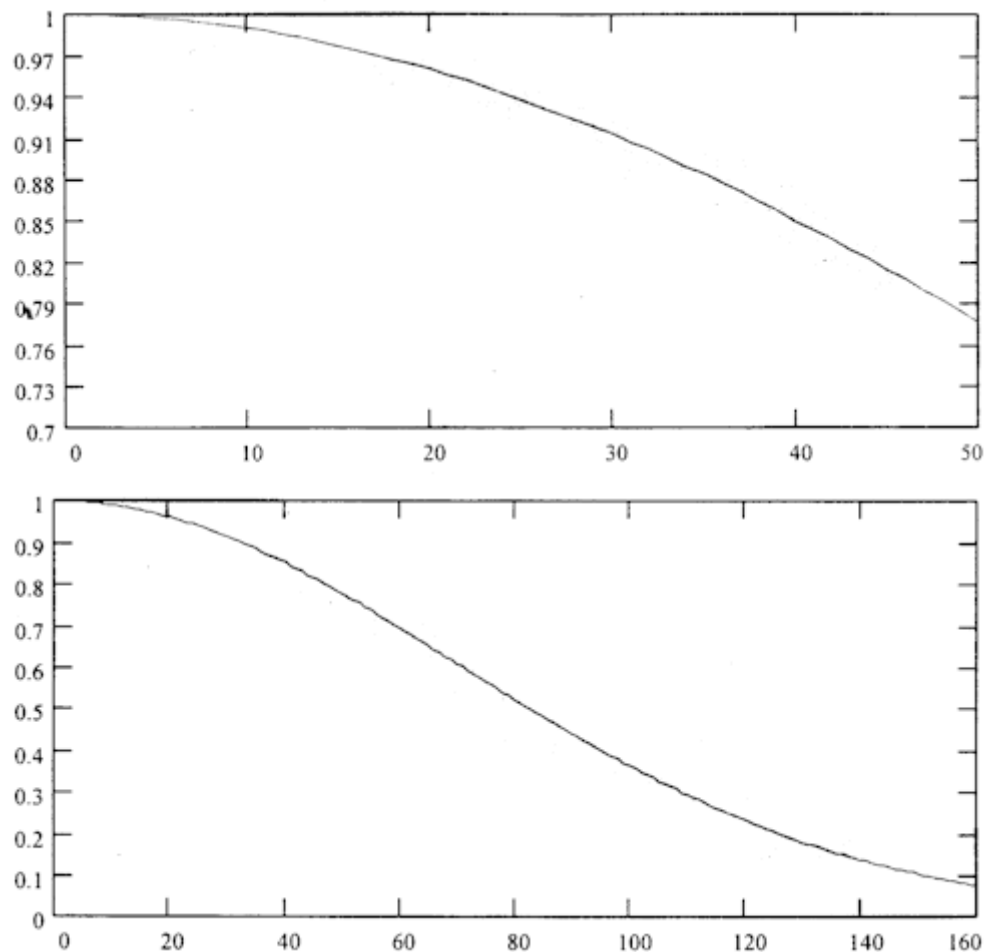
As the study of radio propagation progressed and certain mathematical analyses excluded it, some question as to the existence of Zenneck surface waves began to develop. In 1937 limited support was given to these doubts after tests showed *simple antennas* driven at 150 mHz produced 100 times lower field strength than predicted. More recent investigations show evidence that Zenneck waves can, indeed, be generated. The lower the frequency, the lower are the propagation losses. It is also apparent that they are not a major contributor to the field produced by an electric dipole or a quarter wave *radiator*, however they might be excited by an energetic quarter wave *resonator*. To quote Hill and Wait,

"As it turns out, the Zenneck wave is generally difficult to excite with a realistic source because it has a rather slow decay with height above the earth's surface. But there is still an open question whether other types of sources may not be more favorable. . . . An infinite vertical aperture with height variation corresponding to that of the Zenneck wave will excite only the Zenneck surface wave with no radiation field. . . ." [Hill, D. and J.R. Wait, "Excitation of the Zenneck Surface Wave by a vertical Aperture," Radio Science, Vol. 13, No. 6, November-December, 1978, pp. 969-977.]

And to once again quote Dr. Corum,

"The 1978 analysis provided by Hill and Wait examined the fields produced by a vertical sheet of horizontally directed magnetic current with an *exponential variation* in an 'infinite Zenneck' aperture. . . . The analysis . . . showed that this field has no intrinsic merit at 1 to 10 MHz, and we certainly agree. One wonders, however (and this is pure conjecture at this point), if the disposition of Tesla's Colorado Springs high voltage (10-20 Mv) VLF resonator did, in fact, possess an effective vertical distribution of magnetic current which could launch a similar Zenneck Surface Wave. . . ."

Plots of field strength vs. frequency indicate that a Zenneck wave propagates best at ELF and VLF frequencies up to about 35 kHz and begins to lose its advantage as frequency rises above this point.



Predicted Zenneck wave field strength decrease for around-the-world propagation as a function of frequency in kHz.

$$\beta_z = \frac{2\pi}{\lambda_o} \sqrt{\frac{n^2}{1+n^2}} = \frac{2\pi}{\lambda_o} \sqrt{\frac{\epsilon_{gr} - j60\lambda_o\sigma}{(\epsilon_{gr} + 1) - j60\lambda_o\sigma}}$$

The complex longitudinal propagation phase constant along the Earth's surface for the Zenneck surface wave.

The Zenneck Surface Wave vs. the Norton Surface Wave

A 1/2-wave dipole antenna in free space--the Hertz antenna--approaches an ideal source of electromagnetic radiation emitted in the form of space waves. These space waves can reach the receiver either by sky-wave propagation or by ground-wave propagation, the latter being the portion of the radiated space wave that propagates close to the earth's surface. The ground wave has both direct-wave and ground-reflected components, and under certain conditions a tropospheric ducting component. The direct-wave is limited only by the distance to the horizon from the transmitter plus a small distance added by atmospheric diffraction around the curvature of the earth. The ground-reflected

portion of the radiated wave reaches the receiving antenna after being reflected from the earth's surface.

There is also an induced ground-hugging [surface-wave](#) component known as the Norton surface wave. This wave is the result of electrical currents induced in the ground by refraction of a portion of the reflected-wave component at the earth-atmosphere interface. Upon reflection from the Earth's surface the reflected wave undergoes a 180deg phase reversal. When both transmitting and receiving antennas are on, or close to, the ground, and the distance between them becomes great, the direct and reflected components tend to cancel out, and the resulting field intensity is principally that of this surface wave. Because part of its energy is absorbed by the ground, the electrical intensity of the surface wave is attenuated at a much greater rate than inversely as the distance. It is the conductivity of the underlying terrain that determines the attenuation of the surface-wave field intensity as a function of distance. The ground currents of a vertically polarized surface wave do not short-circuit a given electric field but rather serve to restore part of the used energy to the following field. The better the conducting surface layer, the more energy returned and the less energy absorbed. [Antennas and Radio Propagation, TM 11-666, Dept. of the Army, Feb. 1953, pp. 17-23.]

It is useful here to consider two additional forms of wireless telecommunications antennas or launching structures, the Marconi antenna, a vertical 1/4-wave monopole antenna element and the Tesla antenna, a vertical high aspect-ratio 1/4-wave helical resonator with large capacitive top loading and small overall height, compared to the electrical 1/4 wavelength. In both cases the structure is base fed, and a ground connection is used.

The Marconi antenna is a modified 1/2-wave Hertz antenna adapted to the real-world conditions encountered in the construction of medium and low frequency transmitters. These adaptations are imposed by the wavelength involved and the resulting physical dimensions required of the antenna. The dipole antenna is modified in that its lower half, 1/4 wavelength long, exists only as a mirror image of its upper counterpart. The resulting 1/4-wave vertical monopole antenna takes advantage of the fact that at lower frequencies the ground acts as a mirror for the radiated energy. The ground reflects a large amount of the energy that is radiated downward from the antenna mounted over it. In the physical construction of the ground connection is important to have as high a conductivity as possible. The object is to provide the best possible reflecting surface for the energy radiated downward from the antenna. The ground consists of a number of bare conductors arranged radially and connected, 1/2 wavelength long, buried a short distance beneath the earth's surface. In practice these conductors may act as part of the reflecting surface as well as making the connection to ground itself. An alternative type of ground is the counterpoise. It is a wire structure erected a short distance above the ground, and insulated from the ground. The counterpoise operates by virtue of its capacitance to the ground. Not unlike the Hertz antenna, the Marconi antenna is a source electromagnetic radiation in the form of space waves.

The Tesla antenna is a form of wireless antenna or wave launching structure developed by Nikola Tesla in which the transmitted energy propagates or is carried to the receiver by a combination of electrical current flowing through the earth, electrostatic induction and electrical conduction through plasma with an embedded magnetic field. Of course it is also part of an electric dipole, consisting of the elevated capacitance, the helical resonator and master oscillator plus connections, and the Earth itself. The above-ground structure is not intended as a source of electromagnetic radiation, rather, it is designed to minimize the production of electromagnetic radiation. The principle that the ground acts as a mirror, which reflects electromagnetic energy radiated downward by the antenna mounted over it, is not applicable.

In operation, the Tesla launching structure induces an electrical current in the earth between the transmitting and receiving stations, along with an associated surface wave, that propagate the transmitted energy. A conducting path is also established through the rarified upper level atmosphere between the transmitting and receiving stations elevated high voltage terminals, leading Tesla to coin the term "disturbed charge of ground and air method." He stated that this method involves electrical conduction and that energy escapes from the system in the form of electromagnetic radiation. The conducting media are the earth and the atmosphere above 5 miles elevation. While the region from 5 miles up to the ionosphere is not an ohmic conductor, the density or pressure is sufficiently reduced to so that, according to Tesla's theory, the atmosphere's insulating properties can be easily impaired allowing an electric current to flow. His theory further suggests that the conducting region is developed through the process of atmospheric ionization, shifting the effected portions thereof to a plasma state. A magnetic field is developed by each plant's helical resonator, meaning that an embedded magnetic field is also involved. The atmosphere below 5 miles is also viewed as a propagating medium for a portion of the above ground circuit, and being an insulating medium, electrostatic induction or —displacement current— would be involved rather than true electrical conduction. Tesla felt that with a sufficiently high electrical potential on the elevated terminal the practical limitation imposed upon its height could be overcome. He anticipated that a highly energetic transmitter would charge the elevated terminal to the point where the atmosphere around and above it would break down and become ionized, leading to a flow of true conduction currents between the two terminals through the troposphere path connection.

Now, Sommerfeld described an electrodynamic wave that is guided along a wire of finite conductivity and Zenneck expanded upon this description, asserting that the earth's surface performs in a manner similar to a conducting wire. And, while the Norton Surface Wave is the result of electrical currents induced in the ground by refraction of a portion of the reflected-wave component of the ground-wave at the earth-atmosphere interface, the surface wave associated with Tesla's apparatus is the result of electrical ground currents flowing between two discrete points on the earth's surface. Unlike the lossy Norton surface-wave that is excited by a conventional AM radio transmitter it would seem that Tesla's surface wave would not diminish quite as significantly as the distance from the source facility increases. [See "[A Comparison of the Tesla and Marconi LF Wireless Systems](#)"]

[This piece is derived from "The Zenneck Surface Wave," Appendix II of the paper entitled "Nikola Tesla, Lightning Observations and Stationary Waves" by K. L. Corum and J. F. Corum, Ph.D. 1994., presented at the 1994 Colorado Springs Tesla Symposium. This and other papers are available through PV Scientific Instruments' [Tesla Reprint Page](#). See also [The Purpose of the Wardencllyffe Tower](#).]

A Comparison of the Tesla and Marconi Low-Frequency Wireless Systems

What is the difference between present day low-frequency wireless transmitters and Tesla's system? When used as a wireless transmitter how does the performance/efficiency and characteristics of an electrical oscillator change when working with a sphere capacitor antenna, rather than working with a conventional monopole antenna?

In answering this question, three basic forms of wireless telecommunications antennas or launching structures are considered. All three consist of an electric dipole excited with an identical impedance matched high voltage radio frequency power supply. The first is the Hertz antenna, a vertical $1/2$ -wave dipole antenna, center fed, positioned $1/2$ wavelength above the ground. Needless to say, this is not a practical configuration at low frequencies. Next is the Marconi antenna, a vertical $1/4$ -wave monopole antenna element with its lower end at ground level. A vertical conductor with no loading coil and no capacitive top loading is assumed. It is fed at its base by the standard RF power supply plus an appropriate matching section, with the opposing terminal grounded. Third is the Tesla launching structure, a vertical high aspect-ratio $1/4$ -wave helical resonator with large capacitive top loading and small overall height as compared to the electrical $1/4$ wavelength. The $1/4$ -wave resonator is base fed by the standard RF power supply plus an appropriate matching section, with the opposing terminal grounded. In the second and third cases a ground connection is used, and this must be constructed in such a way as to introduce the least possible resistance to ground.

Comparing these three configurations it is assumed the Hertz antenna, a physical embodiment of an electric dipole in free space, approaches an ideal source of electromagnetic radiation emitted in the form of space waves. These space waves can reach the receiver either by ground-wave propagation or by reflection from the ionosphere, known as sky-wave propagation. Sky-wave propagation will not be discussed here.

The Marconi antenna is a modified $1/2$ -wave Hertz antenna. It is adapted to the real-world conditions encountered in the construction of low frequency transmitters. These adaptations are imposed by the wavelength involved and the resulting physical dimensions required of the antenna. The dipole antenna is modified in that its lower half, $1/4$ wavelength long, exists only as a mirror image of its upper counterpart. The resulting $1/4$ -wave vertical monopole antenna takes advantage of the fact that at low frequencies the ground acts as a mirror for the radiated energy. The ground reflects a large amount of the energy that is radiated downward from the antenna mounted over it. In the physical construction of the ground connection is important to have as high a conductivity as possible. The object is to provide the best possible reflecting surface for the downward radiated energy from the antenna. The ground consists of a number of bare conductors arranged radially and connected, $1/2$ wavelength long, buried a short distance beneath the earth's surface. In practice these conductors may act as part of the reflecting surface as well as

making the connection to ground itself. An alternative type of ground is the counterpoise. It is a wire structure erected a short distance above the ground, and insulated from the ground. The counterpoise operates by virtue of its capacitance to the ground. Not unlike the Hertz antenna, the Marconi antenna is a source electromagnetic radiation in the form of space waves. Typically, these waves, that is to say the ground waves, take a direct or reflected path from the transmitter to the receiver. They may also be guided by the earth's surface as a ground-hugging Norton surface wave. The direct-wave component of the ground wave is limited only by the distance to the horizon from the transmitter plus a small distance added by atmospheric diffraction around the curvature of the earth. The ground-reflected component is the portion of the radiated wave that reaches the receiving antenna after being reflected from the Earth's surface. Prevailing wave propagation theory teaches that the surface-wave component is wholly the result of electrical currents induced in the ground by refraction of a portion of the reflected-wave component. Upon reflection from the Earth's surface the reflected wave undergoes a 180deg phase reversal. When both transmitting and receiving antennas are on, or close to, the ground, and the distance between them approaches the above-described limit, the direct and reflected components tend to cancel out, and the resulting distant field intensity is principally that of the surface wave. Because part of its energy is absorbed by the ground, the electrical intensity of the surface wave is attenuated at a much greater rate than inversely as the distance. It is the conductivity of the underlying terrain that determines the attenuation of the surface-wave field intensity as a function of distance. The ground currents of a vertically polarized surface wave do not short-circuit a given electric field but rather serve to restore part of the used energy to the following field. The better the conducting surface, the more energy returned and the less energy absorbed. [Antennas and Radio Propagation, TM 11-666, Dept. of the Army, Feb. 1953, pp. 17-23.]

Of course the Tesla launching structure is also part of an electric dipole, consisting of the elevated capacitance, the helical resonator plus connections, and the Earth itself. The above-ground portion is not intended as a source of electromagnetic radiation, rather, it is designed to minimize the production of electromagnetic radiation. [The working of the structure's helical resonator may be associated with a transverse magnetic wave. [Corum and Corum] and with an interaction with the Earth's magnetic field [Papadopoulos.] The principle that the ground acts as a mirror, which reflects electromagnetic energy radiated downward by the antenna mounted over it, is not applicable. In operation, the Tesla launching structure induces ground currents in the earth along with an associated surface wave (this may be similar to the [Zenneck surface wave](#)) which propagate the transmitted energy. At the [Wardencllyffe facility](#) the ground connection consisted of a 300-foot long vertical pipe driven downward from the bottom of a 120-foot deep shaft, placing the maximum depth of the installation beneath the earth's surface at 420 feet. A conducting path is also establish through the rarified upper level atmosphere between the transmitting and receiving stations elevated high voltage terminals, leading to the name "air-ground system." Tesla clearly stated that his system used conduction and that energy escapes from the system in the form of electromagnetic radiation. The conducting media are the earth below and the atmosphere above 5 miles

elevation. While the region from 5 miles up to the ionosphere is not an ohmic conductor, the density or pressure is sufficiently reduced to so that, according to Tesla's theory, the atmosphere's insulating properties can be easily impaired allowing an electric current to flow. His theory further suggests that the conducting region is developed through the process of atmospheric ionization, shifting the effected portions thereof to a plasma state. A magnetic field is developed by each plant's helical resonator, meaning that an embedded magnetic field is also involved. The atmosphere below 5 miles is also viewed as a propagating medium for a portion of the above ground circuit, and being an insulating medium, electrostatic induction or so called — displacement currents— would be involved rather than true electrical conduction. Tesla felt that with a sufficiently high electrical potential on the elevated terminal the practical limitation imposed upon its height could be overcome. He anticipated that a highly energetic transmitter, as was intended at Wardenclyffe, would charge the elevated terminal to the point where the atmosphere around and above it would break down and become ionized, (see U.S. Patent No. 645,576, —System of Transmission of Electrical Energy—) leading to a flow of true conduction currents between the two terminals through the troposphere path connection.

Assuming individually optimized RF power supplies and grounding systems, the only other difference between the Marconi antenna and the above-ground portion of the Tesla launching structure is in the geometry. Using a frequency of, say, 25 kHz, a idealized quarter-wave Marconi-type antenna would consist of a vertical conductor extending about 9,750 feet above the earth's surface. A [Tesla-type launching structure](#) for the same frequency would be much shorter, the bottom third or so consisting of a helical resonator followed by a relatively large conducting cylinder connected to a spherical or torriod-shaped terminal of large surface area.

The problem is to characterize the performance of these two different structures in response to the application of the rapidly varying alternating current. In the first case, antenna theory indicates that with proper coupling between the transmission line and the antenna, the structure will be an efficient radiator of electromagnetic energy. Because the velocity of the electric current in the conductor is finite, it takes some time for the applied charge to build up on the antenna. The electric field follows the charges moving along the monopole antenna and the lines tend to spread out toward the position they would occupy under static charge conditions. During the next quarter cycle, the monopole is discharged and some of the field lines break away to form closed loops. Energy continues to propagate out into space as long as there is excitation. The implication here is that energy is irretrievably lost from the monopole. This lost energy exists in the form of electromagnetic radiation, that is to say, radio waves. Along with the field energy lost or radiated by the monopole, a certain fraction of the energy returns to the vertical conductor during each RF cycle. Consequently, it might be said that the fields near the antenna represent both energy storage and radiation components, with the storage component falling off as the distance increases. [[The Radio Amateurs Handbook](#), ARRL, 1978, Chapter 21 -- Radiation and Antennas, p. 588]

In the case of the Tesla-type launching structure it appears the delay effect responsible for the dissipating radiation of energy, such as manifested with a quarter-wave monopole, is reduced and the stored-energy component of the electric field is increased. While the amount of time expended to charge the structure remains the same as with the Marconi antenna, the overall distance between the bottom feed-point and the structure's upper extremity is much smaller. For example, if the structure were to be 500 feet in height, when compared with the monopole the greatest overall distance the wave disturbance or a point of charge could move would be in the order of 5 percent. The field throughout space would follow the charge movements more efficiently. This implies that once the polarity of the RF source reversed a greater proportion of the energy in the field would return to the transmitting element and electromagnetic radiation would be suppressed. Much of the RF energy, which in the case of the Marconi antenna is dissipated in the form of electromagnetic radiation, is physically retained within the oscillating system.

A considerable expenditure might be expected for the complete antenna structure of a conventional long wave wireless facility—if it is to perform efficiently. Installing the grounding system would not be much of a problem. Somewhat the opposite would be the case in the construction of a proper magnifying transmitter. Here is a little of what Tesla had to say about this:

"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. . . ."

In conclusion, it appears fundamentally identical electrical oscillators consisting of an RF power supply, an elevated conductor and a robust ground connection can be configured in ways which are conducive to the production of two different types of surface wave. It is proposed that low frequency wireless communications can be accomplished by the production of either electromagnetic radiation in the form of space wave induced ground currents and an accompanying electromagnetic wave called the [Norton surface wave](#), or the generation of a pulsed magnetic field and production of ground currents flowing between the transmitter and the receiver resulting in an accompanying trapped electromagnetic surface-wave bearing a resemblance to the [Zenneck surface wave](#). Once again to quote Tesla,

"From my circuit you can get either electromagnetic waves, 90 percent of electromagnetic waves if you like, and 10 percent in the current energy that passes through the earth. Or, you can reverse the process and get 10 percent of the energy in electromagnetic waves and 90 percent in energy of the current that passes through the earth.

"It is just like this: I have invented a knife. The knife can cut with the sharp edge. I tell the man who applies my invention, you must cut with the sharp edge. I know perfectly well you can cut butter with the blunt edge, but my knife

is not intended for this. You must not make the antenna give off 90 percent in electromagnetic and 10 percent in current waves, because the electromagnetic waves are lost by the time you are a few arcs around the planet, while the current travels to the uttermost distance of the globe and can be recovered.

"This view, by the way, is now confirmed. Note, for instance, the mathematical treatise of Sommerfeld, ["Propagation of Waves in Wireless Telegraphy," Arnold N. Sommerfeld, Ann. Phys. (Leipzig), 28, 1909, pp. 665-737.] who shows that my theory is correct, that I was right in my explanations of the phenomena, and that the profession was completely misled. This is the reason why these followers of mine in high frequency currents have made a mistake. They wanted to make high frequency alternators of 200,000 cycles with the idea that they would produce electromagnetic waves, 90 percent in electromagnetic waves and the rest in current energy. ***I only used low alternations, and I produced 90 percent in current energy and only 10 percent in electromagnetic waves, which are wasted, and that is why I got my results.*** ([Nikola Tesla On His Work With Alternating Currents and Their Application to Wireless Telegraphy, Telephony and Transmission of Power](#))

Nikola Tesla's Investigation of High Frequency Phenomena and Radio Communication (Part III)

Donald Mitchell

Pelican Rapids, Minnesota, 1972

The World Broadcast System

When Tesla's work in Colorado was completed, he returned to New York in mid January of 1900 [58]. He immediately applied for a patent on the wireless telegraphy system that he had been perfecting in Colorado; however, the patent was not granted until 1905 [59]. This patent described the stationary wave theory and stated that three conditions had to be met before the system would work. First, the frequency had to be such that the diameter of the earth would be an odd multiple of the quarter wavelength of that frequency. Tesla believed that the current for the transmitter traveled directly through the center of the earth, but more likely, it travels around the circumference. If this were so, then the distance from pole to pole along the surface of the earth would have to be used instead of the diameter, for calculating the frequency. The second condition was that the frequency should, for ideal results, not exceed 20 KHz, or radiation loss would impair the action of the transmitter. The third condition was that the wave train of the oscillator must last at least $1/12$ of a second. That is the time that it took for the signal to go to the other side of the earth and return.

Along with this, the patent also contains a receiving circuit that uses a synchronous rotary rectifier to detect signals. This circuit bears close resemblance to the "tickers" or tone wheels used a few years later with the Poulson Arc transmitters. In the tone wheel, a rapidly spinning wheel interrupts the radio signal from the antenna and heterodynes with it to produce a shrill whistle that could be heard easily with headphones. Tesla's device would be for lower frequencies so he planned to have it more carefully synchronized to produce almost pure direct current. For the detection of signals that were too faint for headphones, Tesla proposed using a device he had invented in 1891 to respond to the direct current from the rectifier. This device consisted of an evacuated glass bulb with an electrode in the center. When this was connected to a high voltage transformer powered by an alternator (of high frequency), an electron "brush" was formed. This brush was so sensitive to electric and magnetic fields that a one-inch horseshoe magnet at six feet would cause it to be deflected.

After succeeding in sending signals 600 miles in Colorado, Tesla felt that his long wave system was ready for full scale use. He set out immediately to design and build a giant Magnifying Transmitter on Long Island that would be able to send signals across the Atlantic to England. Beyond just replacing the underwater telegraph cables, Tesla conceived of a much more ambitious plan. Up to that time, most scientists were only interested in using radio for point-to-point transmission. Tesla, however, saw that wide range broadcasting was possible.

Tesla was not sure if a single transmitter could be picked up all over the world (he had not tested his vacuum bulbs yet), so he suggested that a global network of relay stations might be required. He called this idea the "World System" and in 1902, he published an article explaining some of the points of the plan. This was printed during the construction of the transmitter.

1. Interconnection of the existing telegraph exchanges or offices all over the world;
2. Establishment of a secret and non-interferable government telegraph service;
3. Interconnection of all the present telephone exchanges or offices all over the globe;
4. Universal distribution of general news, by telegraph or telephone in connection with the Press;
5. Establishment of a World System of intelligence transmission for exclusive private use;
6. Interconnection and operation of all stock tickers of the world;
7. Establishment of a world system of musical distribution, etc.;
8. Universal registration of time by cheap clocks indicating the time with astronomical precision and requiring no attention whatever;
9. Facsimile transmission of typed or handwritten characters, letters, checks, etc.;
10. Establishment of a universal marine service enabling navigators of all ships to steer perfectly without compass, to determine the exact location, hour and speed, to prevent collisions and disasters, etc;
11. Inauguration of a system of world printing on land and sea;
12. Reproduction anywhere in the world of photographic pictures and all kinds of drawings or records; [60]

To help accomplish these things, Tesla was involved in the development of a number of new inventions. He was doing experiments with Selenium to see if pictures could be transmitted [61]. This was the same approach that John Logie Baird used twenty years later when he invented television. Another invention was a technique to allow more careful individualization of signals. Tesla could already tune his transmitters, but with very sensitive receivers at great distances, he had difficulty with static. In this new system, two transmitters of different frequencies were used. They were arranged to emit their impulses simultaneously and would both send the same telegraph message. The receiver was also made up of two circuits, each tuned to one of the broadcast frequencies. The signal coming into each of the circuits would operate a relay, and the two relays would be connected in a logic "and" circuit, which would reject any impulse that did not come from both receivers at the same time. This ingenious system would have solved the difficulty of signal interference that was a problem to all experimenters of that time. Although Tesla could tune his equipment with much greater success than other more primitive systems, he was looking to the time when many stations would be operating within close limits of each other.

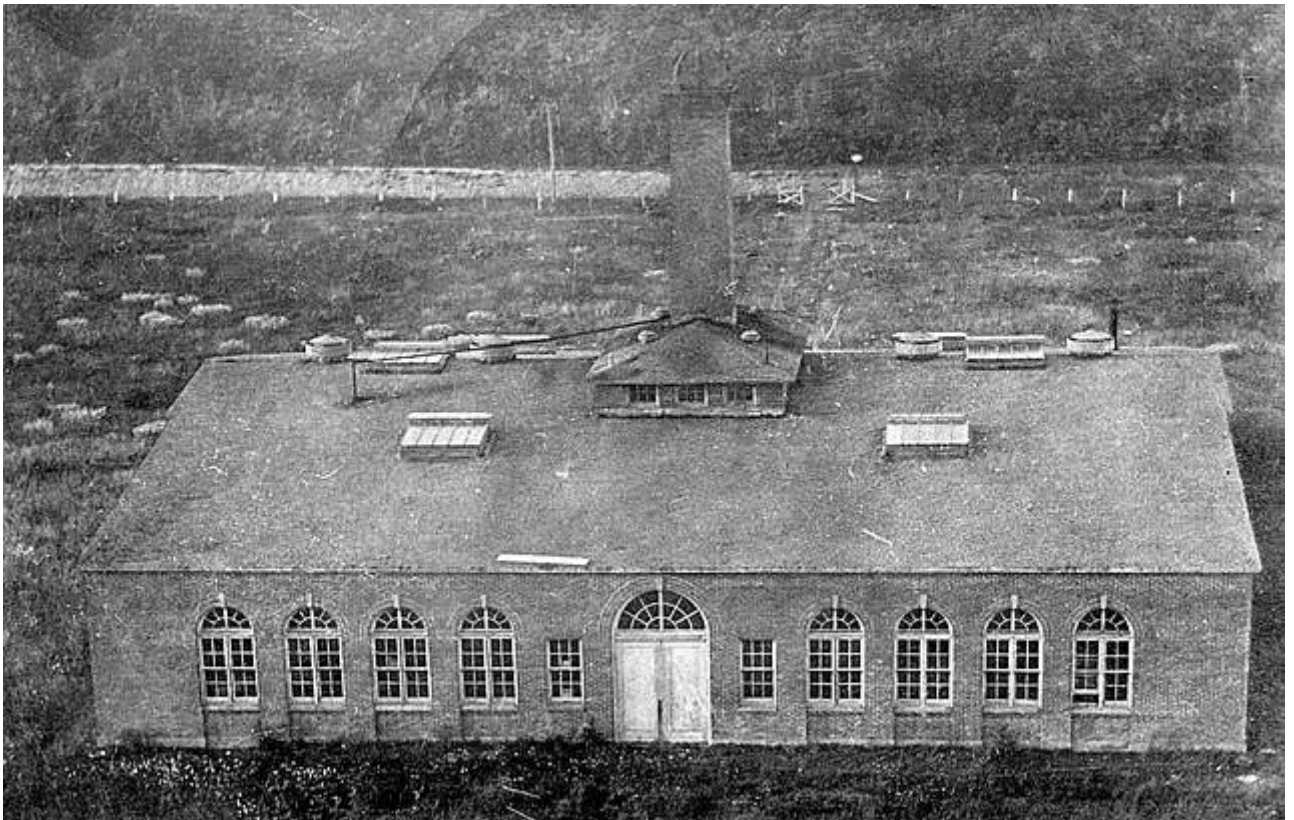
Tesla did not want to build a separate Magnifying Transmitter for each frequency (at least not for telegraphy transmission), so he developed a way for one transmitter to send signals on many frequencies at the same time, thus creating a wave complex. Naturally it is not easy to make a circuit oscillate at different frequencies, but Tesla invented a means of allowing the transmitter to send impulses in a rapid succession of changing frequencies. This would have been done with a complex system of rotary breaks and tuning coils. This could still be used in the double circuit system just described because

the impulses would be separated by an insignificant amount of time (thousand of pulses per second would probably have been used). It would be logical to assume that at least three or four frequencies could be sent in this manner by one station, and as many as ten might have been possible.

As far as the secret transmissions that Tesla spoke of, we can only speculate. It would not have been difficult to send two meaningless sounding signals in which those impulses common to both signals contain the message. It is indeed unfortunate that more is not known about Tesla's plans. He was a very great thinker, and he was hard at work to develop wireless to its highest potential.

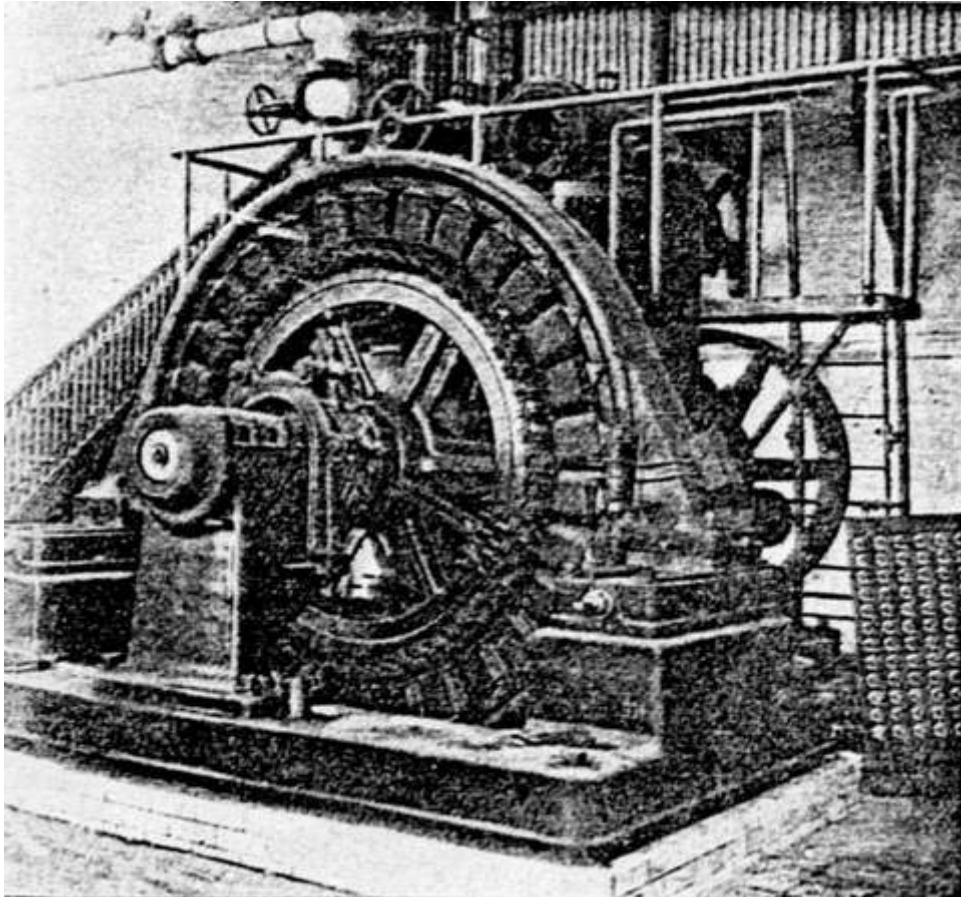
The Shoreham Transmitter

In the fall of 1900, Tesla received \$150,000 from J.P. Morgan to build his transmitting station [62]. Along with \$50,000 from other wealthy friends, Tesla began work on the construction of an oscillator of incredible size and power.



On March 21 of 1901, Tesla arranged for the Westinghouse Electric Company in Pittsburgh to make the transformers and generators that he needed to power the oscillator [63]. During the entire project, Tesla worked closely with the engineers at Westinghouse Co. in designing apparatus. He had chosen a site on Long Island near the city of Shoreham for the transmitter. 200 acres of land were bought from James Warden, the manager and director of the Suffolk County Land Company (This area near Shoreham was then called Wardencllyffe). Twenty acres of the wooded property were cleared for building, and Tesla hoped to purchase an additional 2000 acres in the future of the "Radio City" which he hoped to start there [64].

Tesla employed about fifty people in this new project, including guards to keep people away from the area. Tesla feared that someone might steal some of his inventions (many of which he never patented), and he wished to keep things quiet until he was finished. The famed architect, Stanford White, who was a personal friend of Tesla's, designed a laboratory building (seen above) that would house the power plant and oscillator [65]. Five or six other buildings were to be built later on. Tesla may have planned to build a number of transmitters at that site as his company expanded.



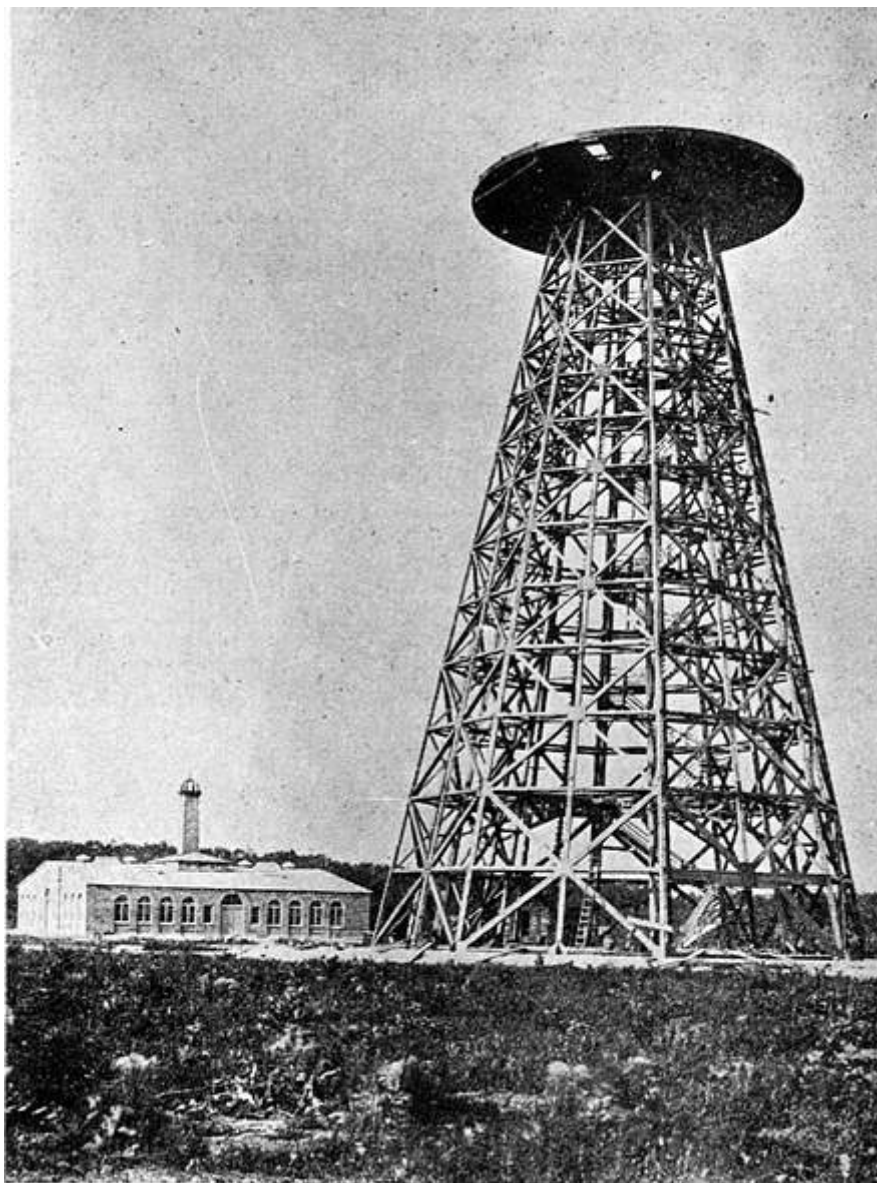
The laboratory was a brick building about 100 feet square and as tall as a two-story building. It was completed in a few months, and the concrete footings for a huge tower were laid 250 feet south of the building. Tesla had ordered a couple of 100 horsepower steam engines and they were installed in the power plant in November of 1901. A 300-kilowatt Westinghouse Alternator (above) was installed later. The laboratory building was divided into four parts: the boiler room, the engine and dynamo room, a workshop containing eight metal lathes, and a laboratory. The building also houses offices and a small library.

The oscillator, for what would have been the largest Tesla Coil ever built, was contained in the building and would be connected to the primary of the Magnifying Transmitter by underground cable [66]. Four seven-foot high steel tanks filled with oil were to contain the high voltage transformer. Seven more tanks would house the condenser bank, and one special tank was to be filled with a system of coils and regulating apparatus for controlling the frequency and power of the oscillations. Not all of this equipment was installed, but even when not finished, the inside of the lab was an impressive sight. Its

huge tanks and giant pieces of machinery made contemporary efforts at wireless transmission seem very pitiful.

In December of 1901, Marconi made history by transmitting the letter "S" across the Atlantic [67]. The equipment that he used was a crude single circuit transmitter (as opposed to Tesla's primary-secondary type) contained in a small building and operated by a heavy wooden lever. Although Marconi's achievement was great, Tesla was far ahead of him. Some of Tesla's agents were already searching for a suitable area in Britain for a major receiver and relay station.

In June of 1902, Tesla moved out of his laboratory on Houston Street and into the Wardenclyffe building [68]. The laboratory section was soon filled with lecture equipment, coils, X-ray machinery and other devices. In the workshop, glass blowers were busy making the electron bulbs that Tesla hoped to use in his receivers.



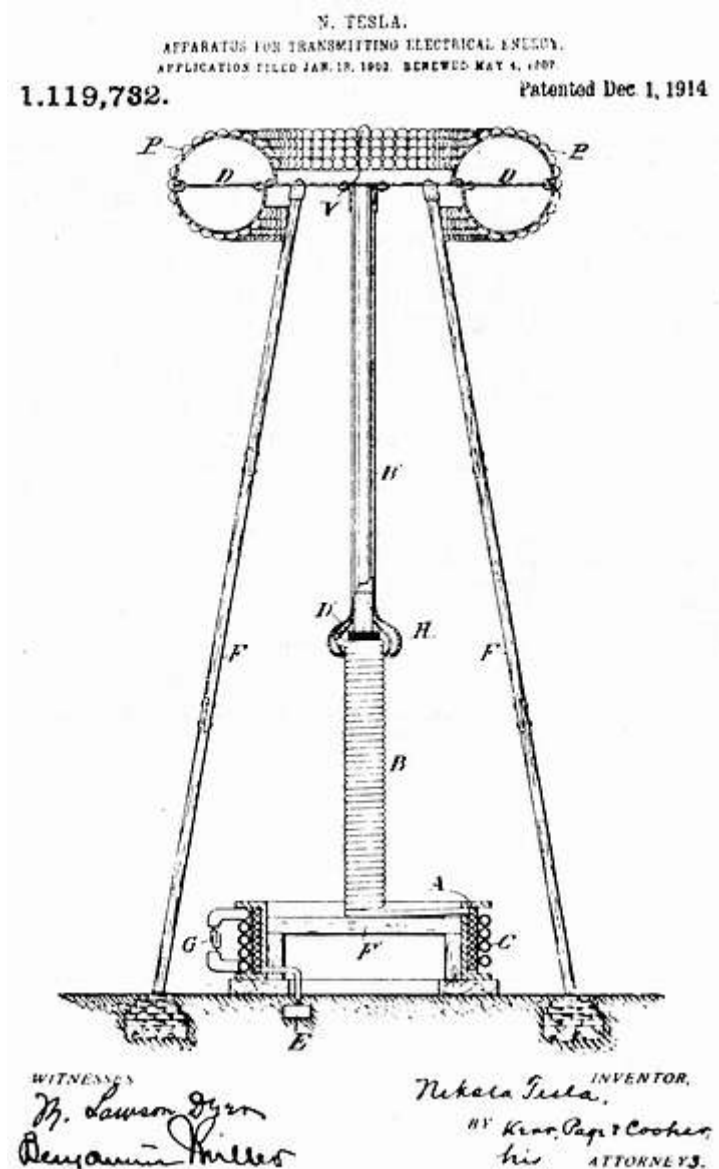
The most striking object at this site was the strange tower that was being constructed there (above). This was to be the actual Tesla Coil or Magnifying Transmitter. The

tower was made out of large wooden beams joined together with copper gussets and bronze bolts. No ferrous metals were used anywhere in the structure because of magnetic hysteresis which would cause heating and power loss. The sections were constructed on the ground and later hoisted into place with cranes. When completed, it was a pyramid shaped tower having eight sides. The smallest dimension across the base was 95 feet, and it stood 154 feet high [69].



By the early part of 1903, a 55 ton copper mesh dome was placed on the top of the tower. This dome was 66 feet in diameter and was to have been covered with copper sheeting to form a giant copper electrode elevated above the ground by the insulating wooden tower. With dome, the tower stood 187 feet tall (above).

Beneath the tower a copper pipe was driven 150 feet into the ground to make a good earth connection. Local rumors told that pits and underground tunnels were being constructed, but these do not appear to be true. Years later, there was reported to be well 12 feet wide and 100 feet deep at the site of the tower.



The exact plan of the Magnifying Transmitter is not known because it was never finished. However, from what is contained in interviews with Tesla for newspapers, it is known that it would have resembled diagrams in one of Tesla's patents (No. 1,119,732). This patent (above) deals mainly with methods of handling very high voltage. In the diagram, "C" is the primary coil of a Magnifying Transmitter. "G" is the oscillator, "A" and "B" are two sections of the secondary coil, and "D" is the elevated terminal, a torus shaped electrode, in this case. The bumps on the terminal ("P") are to prevent the freely

resonating circuit from getting out of hand. If the voltage gets too high, it would arc from one of these bumps instead of some part of the circuit nearer the ground. With energy that would have dwarfed the Colorado transmitter, this station could destroy itself by such an accident.

The reasons for not completing the Wardenclyffe station were numerous. In the fall of 1903, J.P. Morgan withdrew his support of the project and a number of other financiers quickly followed him [71]. Tesla was sued several times from Colorado Springs for unpaid bills and even had to appear in court out there on September 6 of 1905 [72]. To get money, Tesla ordered the Colorado Springs lab sold, and in 1906 some of his equipment was put up for auction there. To top all this off, Tesla's AC motor patents in Europe expired and left him without any income from royalties.

In 1905, Tesla had set up a temporary factory in the Wardenclyffe building and began to manufacture Tesla Coils for medical and industrial use [73]. He also invented a new type of turbine that operated without blades [74]. This machine worked very well, but no one seemed interested in it.

In spite of all the financial troubles Tesla had, it may have been his health that forced him to abandon the Wardenclyffe building in 1906. He had suffered from several serious nervous breakdowns brought about from over work (Tesla slept about five hours a night and the rest of the day was filled with work) during the past two decades before then. Local people reported seeing Tesla collapse from exhaustion while taking a walk by the sea.



In 1912, Westinghouse removed their equipment, which had not been paid for, and in 1915 Tesla was forced to turn over the mortgages to the property to Waldorf Astoria [75]. In July of 1917, they had the tower torn down and sold for scrap. The building was sold in 1938 to Peerless Photos Products Inc. who transformed it into a factory for making light sensitive paper [76].

After leaving Wardenclyffe, Tesla opened up an office at 165 Broadway in New York [77]. By this time, Tesla did not have enough money to carry on much research, and he became more and more of a recluse. In 1915, he became involved in a law suite with Marconi [78]. Tesla claimed that Marconi's patents were in violation of his own patents No. 645,576 and 649,621. Tesla lost this suit, but in 1943, Marconi's key patents were invalidated by the Supreme Court [79].

In the years after Wardenclyffe, Tesla wrote a number of articles in which some of the details of his earlier experiments were revealed. Many facts about Tesla's work may never be known, however. His laboratory in Colorado Springs was destroyed so completely that today no one seems to know the exact place where it was located (the city of Colorado Springs expanded out over the area). On May 23, 1966, an historical marker was placed near the site [80]. The detailed plans for Tesla's fabulous Wardenclyffe broadcasting plant appear to be lost (Peerless Photos has made an extensive search for the plans, but the building firms, libraries and historical societies in that area have no idea what became of them).

Tesla's greatest misfortune seems to be that he was twenty years ahead of his time. Few people understood Tesla's ideas, and Tesla did not go to great lengths to make them clear. It is indeed ironic that only two miles from Tesla's lost Wardenclyffe plant, the Radio Corporation of America years later established at Rocky Point, one of the most powerful broadcasting stations in the world [81].

Acknowledgements

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Notes for Part III

58. Leland I. Anderson, "Wardenclyffe--A Forfeited Dream", *Long Island Forum*, August 1968, p 146.

59. Patent NO. 787,412, "Transmitting Electrical Energy Through the Natural Mediums", April 18, 1905, p 1.

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70. *Ibid.*, supplement.
71. O' Neill, *Op. Cit.*, p 198.
72. *Colorado Springs Gazette*, September 6, 1905, p 5.
73. Leland I. Anderson, "Wardenclyffe--A Forfeited Dream (part 2)", *Long Island Forum*, September 1968, p 169.
74. *Ibid.*, p 170 and O' Neill, *Op. Cit.*, pp 218-228.
75. Anderson, *Op. Cit.*, p 171.
76. *Ibid.*, p 172.
77. O' Neill, *Op. Cit.*, p 214.
78. "Tesla Sues Marconi on Wireless Patent", *Electrical Review*, August 14, 1915, p 297.
79. Leland I. Anderson, "Nikola Tesla", *Collier's Encyclopedia*, 1964, XXII, p 181.
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The Wardenclyffe laboratory & the World Wireless System



Intro

Wikipedia: **Wardenclyffe Tower** (1901–1917) also known as the **Tesla Tower**, was an early [wireless](#) transmission tower designed by [Nikola Tesla](#) and intended for commercial trans-Atlantic [wireless telephony](#), broadcasting, and proof-of-concept demonstrations of [wireless power transmission](#). It was never fully operational, and the tower was demolished in 1917.

<http://www.teslasociety.com/teslatower.htm>

J.P. Morgan, the richest and most powerful man of that time, was a financier of the Tesla Broadcasting system. The Tower was designed as a world communications center and Nikola Tesla added to the project in that the tower would also be used for transmitting electrical energy without wires to the entire globe. Tesla wanted to saturate

the globe with electricity as a dynamo so that everyone on the surface of the globe could obtain electrical light just by sticking wires into the soil and a electrical bulb would light. When J.P. Morgan heard about the Tesla project, he was asked: "How can we get money from the electricity which Tesla is supplying to every part of the world?" After that Morgan cut the funds and the Tower was never finished.

Nikola Tesla, 1919:

“The tower was destroyed two years ago but my projects are being developed and another one, improved in some features, will be constructed. My project was retarded by laws of nature. The world was not prepared for it. It was too far ahead of time, but the same laws will prevail in the end and make it a triumphal success.”



"The World-System makes possible the instantaneous and precise wireless transmission of any kind of signals, messages or characters, to all parts of the world. By its means a telephone subscriber here may call up and talk to any other subscriber on the Globe. An inexpensive receiver, not bigger than a watch, will enable him to listen anywhere, on land or sea, to a speech delivered or music played in some other place, however distant.

"I also proposed to make demonstrations in the wireless transmission of power. A plant was built on Long Island with a tower 187 feet high, having a spherical terminal about 68 feet in diameter. These dimensions were adequate for the transmission of virtually any amount of energy. The transmitter was to emit a wave complex of special characteristics and I had devised a unique method of telephonic control of any amount of energy."

My Inventions, Nikola Tesla, p. 87-90



Fig. 2 (Click on to enlarge)

<http://blog.world-mysteries.com/science/incredible-inventions-of-nikola-tesla/>

In December of 1901, Marconi made history by transmitting the letter “S” across the Atlantic [67]. The equipment that he used was a crude single circuit transmitter (as opposed to Tesla’s primary-secondary type) contained in a small building and operated by a heavy wooden lever. Although Marconi’s achievement was great, Tesla was far ahead of him. Some of Tesla’s agents were already searching for a suitable area in Britain for a major receiver and relay station.

In June of 1902, Tesla moved out of his laboratory on Houston Street and into the Wardenclyffe building [68]. The laboratory section was soon filled with lecture equipment, coils, X-ray machinery and other devices. In the workshop, glass blowers were busy making the electron bulbs that Tesla hoped to use in his receivers.

<http://www.teslaradio.com/pages/wardenclyffe.htm>

Near the North Shore Long Island community of Shoreham, New York there exists a sturdy 94 by 94 foot red brick structure that is another, no less significant reminder of this great man's work. Its importance lays not so much in the technology that it represents or in the engineering clues that remain buried there. It is in the fact that the Wardenclyffe Power Plant / Office Building, designed by the well renowned architect Stanford White, is the last of Dr. Tesla's own work places to remain standing anywhere in the world. The saga of the building's history, from its construction in 1902 alongside a 187-foot companion tower to house the various components of a prototype world broadcasting and telecommunications facility to later less glamorous uses, is a story yet to be fully told. And, there is history in the making as well. For a movement is underway which, if successful, will result in the establishment of the Tesla Science

Center at Wardenclyffe—a permanent monument to this great creative genius and his work.



<http://www.teslaradio.com/pages/wardenclyffe.htm>

The Wardenclyffe World Wireless facility as envisioned by Tesla was to have been quite different from radio broadcasting stations, as they presently exist. While there was to be a great similarity in the apparatus employed, the method in which it was to be utilized would have been radically different. Conventional transmitters are designed so as to maximize the amount of electromagnetic radiation emitted by the antenna structure.

For long-range communications such equipment must process tremendous amounts of power in order to counteract the loss in field strength ($P = 1/R^2$) encountered as the signal radiates outward from its point of origin.

The transmitter at Wardenclyffe was configured so as to minimize the radiated power. The energy of Tesla's steam driven Westinghouse 200 kW alternator was to be channeled instead into an underground structure consisting of iron pipes driven from a point 120 feet beneath the tower's base. This was to be accomplished by combining an extremely low frequency signal (ELF) along with the higher frequency current coursing between the earth and the transmitter's elevated terminal [through the master oscillator and helical resonator]. The low frequency current in the presence of an enveloping corona-induced plasma of free charge carriers would have "pumped" the earth's charge. It is believed the resulting ground current and its associated wave complex would have

allowed the propagation of wireless transmissions to any distance on the earth's surface with as little as 5% loss due to electromagnetic radiation.

The terrestrial transmission line modes so excited would have supported a system with the following technical capabilities:

1. Establishment of a multi-channel global broadcasting system with programming including news, music, et cetera;
2. Interconnection of the world's telephone and telegraph exchanges, and stock tickers;
3. Transmission of written and printed matter, and data;
4. World wide reproduction of photographic images;
5. Establishment of a universal marine navigation and location system, including a means for the synchronization of precision timepieces;
6. Establishment of secure wireless communications services (**non-interferable government telegraph service**). Additional World System capabilities and related technologies include,..
7. Remote control and propulsion of UAV "atmospheric satellites" in long duration flight (**World System of intelligence transmission for exclusive private use**).
8. Wireless transmission of electrical energy for propulsion of aerial and other vehicles, and industrial purposes.
9. Geophysical exploration [Waite]
10. Weather control, artificial rain; climate control
11. Macroscopic charged particle beam projection
12. Electrical projection of explosive energy
13. Electrotherapeutics
14. Electronic logic gate and digital computing allow,
 - a) Software defined radio
 - b) Digital world-system broadcasting and terrestrial network backbone
 - b) Artificial intelligence
15. Interplanetary Communications providing a stable, high-capacity interplanetary network backbone supporting high-speed Internet protocols.

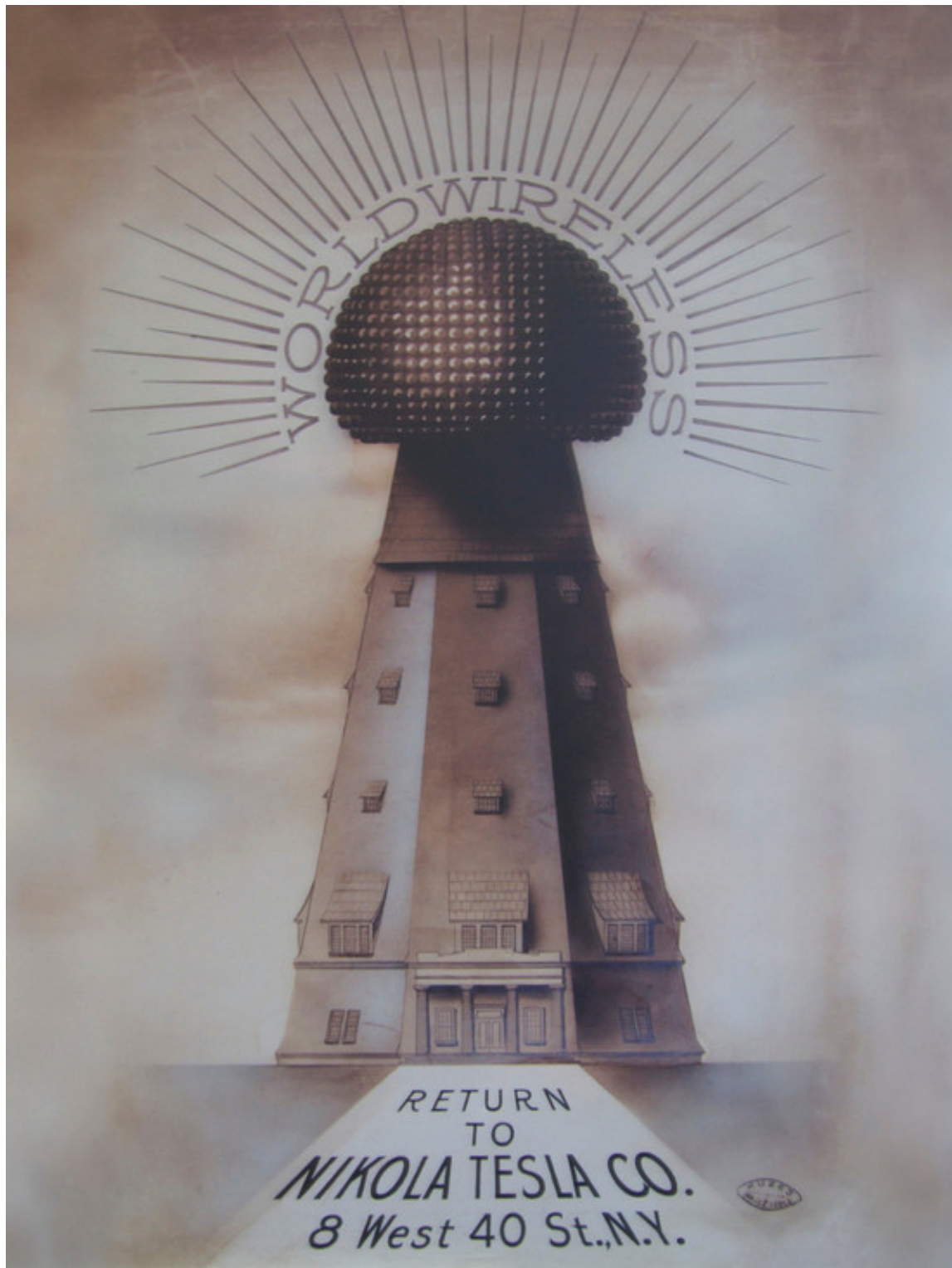


Fig. 1 (Click on to enlarge)

<http://blog.world-mysteries.com/science/incredible-inventions-of-nikola-tesla/>

When Tesla's work in Colorado was completed, he returned to New York in mid January of 1900 [58]. He immediately applied for a patent on the wireless telegraphy system that he had been perfecting in Colorado; however, the patent was not granted until 1905 [59]. This patent described the stationary wave theory and stated that three conditions had to be met before the system would work. First, the frequency had to be such that the diameter of the earth would be an odd multiple of the quarter wavelength of that frequency. Tesla believed that the current for the transmitter traveled directly through the center of the earth, but more likely, it travels around the circumference. If this were so, then the distance from pole to pole along the surface of the earth would have to be used instead of the diameter, for calculating the frequency. The second condition was that the frequency should, for ideal results, not exceed 20 KHz, or radiation loss would impair the action of the transmitter. The third condition was that the wave train of the oscillator must last at least $1/12$ of a second. That is the time that it took for the signal to go to the other side of the earth and return.

Along with this, the patent also contains a receiving circuit that uses a synchronous rotary rectifier to detect signals. This circuit bears close resemblance to the "tickers" or tone wheels used a few years later with the Poulson Arc transmitters. In the tone wheel, a rapidly spinning wheel interrupts the radio signal from the antenna and heterodynes with it to produce a shrill whistle that could be heard easily with headphones. Tesla's device would be for lower frequencies so he planned to have it more carefully synchronized to produce almost pure direct current. For the detection of signals that were too faint for headphones, Tesla proposed using a device he had invented in 1891 to respond to the direct current from the rectifier. This device consisted of an evacuated glass bulb with an electrode in the center. When this was connected to a high voltage transformer powered by an alternator (of high frequency), an electron "brush" was formed. This brush was so sensitive to electric and magnetic fields that a one-inch horseshoe magnet at six feet would cause it to be deflected.

After succeeding in sending signals 600 miles in Colorado, Tesla felt that his long wave system was ready for full scale use. He set out immediately to design and build a giant Magnifying Transmitter on Long Island that would be able to send signals across the Atlantic to England. Beyond just replacing the underwater telegraph cables, Tesla conceived of a much more ambitious plan. Up to that time, most scientists were only interested in using radio for point-to-point transmission. Tesla, however, saw that wide range broadcasting was possible.

Tesla was not sure if a single transmitter could be picked up all over the world (he had not tested his vacuum bulbs yet), so he suggested that a global network of relay stations might be required. He called this idea the "World System" and in 1902, he published an article explaining some of the points of the plan.

Tesla was involved in the development of a number of new inventions. He was doing experiments with Selenium to see if pictures could be transmitted [61]. This was the same approach that John Logie Baird used twenty years later when he invented television.

Another invention was a technique to allow more careful individualization of signals. Tesla could already tune his transmitters, but with very sensitive receivers at great distances, he had difficulty with static. In this new system, two transmitters of different frequencies were used. They were arranged to emit their impulses simultaneously and would both send the same telegraph message. The receiver was also made up of two circuits, each tuned to one of the broadcast frequencies. The signal coming into each of the circuits would operate a relay, and the two relays would be connected in a logic “and” circuit, which would reject any impulse that did not come from both receivers at the same time. This ingenious system would have solved the difficulty of signal interference that was a problem to all experimenters of that time. Although Tesla could tune his equipment with much greater success than other more primitive systems, he was looking to the time when many stations would be operating within close limits of each other.

Tesla did not want to build a separate Magnifying Transmitter for each frequency (at least not for telegraphy transmission), so he developed a way for one transmitter to send signals on many frequencies at the same time, thus creating a wave complex. Naturally it is not easy to make a circuit oscillate at different frequencies, but Tesla invented a means of allowing the transmitter to send impulses in a rapid succession of changing frequencies. This would have been done with a complex system of rotary breaks and tuning coils. This could still be used in the double circuit system just described because the impulses would be separated by an insignificant amount of time (thousand of pulses per second would probably have been used). It would be logical to assume that at least three or four frequencies could be sent in this manner by one station, and as many as ten might have been possible.

As far as the secret transmissions that Tesla spoke of, we can only speculate. It would not have been difficult to send two meaningless sounding signals in which those impulses common to both signals contain the message. It is indeed unfortunate that more is not known about Tesla’s plans. He was a very great thinker, and he was hard at work to develop wireless to its highest potential.

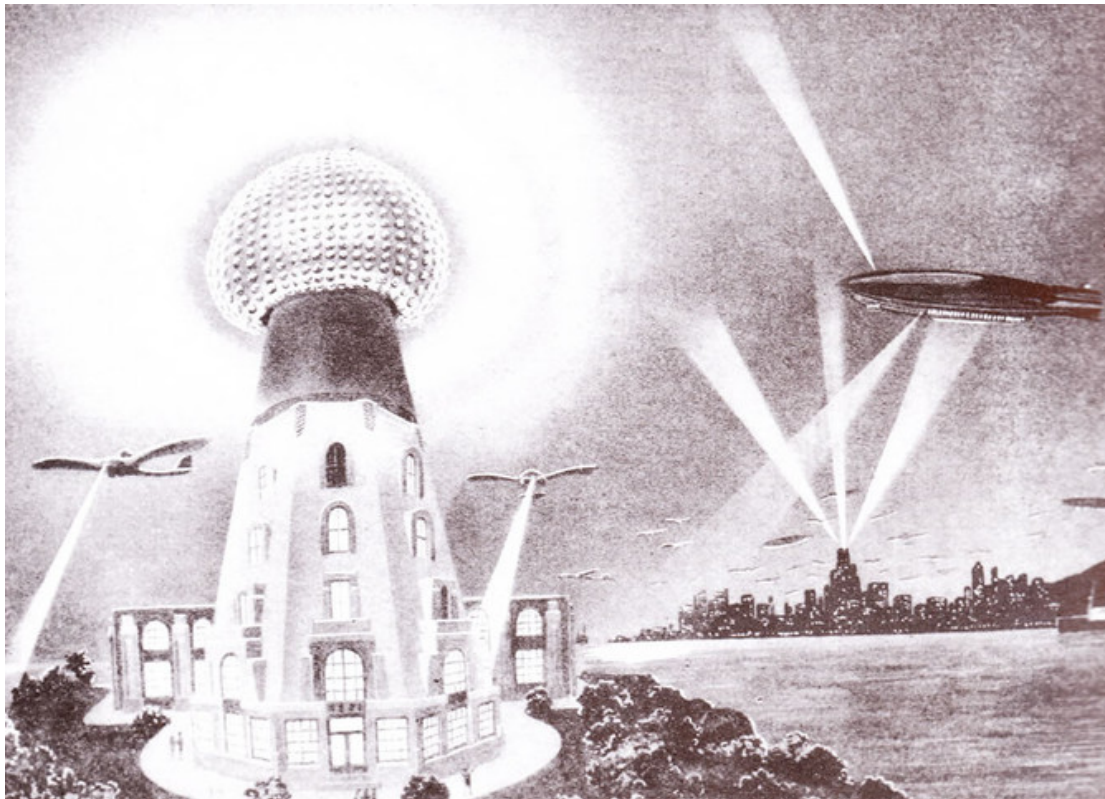


Fig. 3 (Click on to enlarge)

Tesla Tower in Long Island, New York, transmitting electrical power to aircraft in flight. Tesla's inventions in electrical generation and power transmission resulted in the development of alternating current, the form of electricity used today to provide power to homes and businesses. In honor of the Croatian-born inventor, this issue of The Trumpeter is dedicated in honor of the genius who ushered in the power age.

<http://www.teslaradio.com/pages/wardenclyffe.htm>

Nikola Tesla:

"Much has already been done towards making my system commercially available, in the transmission of energy in small amounts for specific purposes, as well as on an industrial scale. The results attained by me have made my scheme of intelligence transmission, for which the name of "World Telegraphy" has been suggested, easily realizable. It constitutes, I believe, in its principle of operation, means employed and capacities of application, a radical and fruitful departure from what has been done heretofore. I have no doubt that it will prove very efficient in enlightening the masses, particularly in still uncivilized countries and less accessible regions, and that it will add materially to general safety, comfort and convenience, and maintenance of peaceful relations."

"It involves the employment of a number of plants, all of which are capable of transmitting individualized signals to the uttermost confines of the earth. Each of them will be preferably located near some important center of civilization and the news it receives through any channel will be flashed to all points of the globe. A cheap and simple device, which might be carried in one's pocket, may then be set up somewhere on sea or land, and it will record the world's news or such special messages as may be

intended for it. Thus the entire earth will be converted into a huge brain, as it were, capable of response in every one of its parts. Since a single plant of but one hundred horsepower can operate hundreds of millions of instruments, the system will have a virtually infinite working capacity, and it must needs immensely facilitate and cheapen the transmission of intelligence."

"The first of these central plants would have been already completed had it not been for unforeseen delays which, fortunately, have nothing to do with its purely technical features. But this loss of time, while vexatious, may, after all, prove to be a blessing in disguise. The best design of which I know has been adopted, and the transmitter will emit a wave complex of a total maximum activity of 10,000,000 horsepower, one percent of which is amply sufficient to "girdle the globe." This enormous rate of energy delivery, approximately twice that of the combined falls of Niagara, is obtainable only by the use of certain artifices, which I shall make known in due course."

"For a large part of the work which I have done so far I am indebted to the noble generosity of Mr. J. Pierpont Morgan, which was all the more welcome and stimulating, as it was extended at a time when those, who have since promised most, were the greatest of doubters. I have also to thank my friend Stanford White, for much unselfish and valuable assistance. This work is now far advanced, and though the results may be tardy, they are sure to come. Meanwhile, the transmission of energy on an industrial scale is not being neglected. The Canadian Niagara Power Company have offered me a splendid inducement, and next to achieving success for the sake of the art, it will give me the greatest satisfaction to make their concession financially profitable to them. In this first power plant, which I have been designing for a long time, I propose to distribute 10,000 horsepower under a tension of 10,000,000 volts, which I am now able to produce and handle with safety."

"This energy will be collected all over the globe preferably in small amounts, ranging from a fraction of one to a few horsepower. One of the chief uses will be the illumination of isolated homes. It takes very little power to light a dwelling with vacuum tubes operated by high frequency currents and in each instance a terminal a little above the roof will be sufficient. Another valuable application will be the driving of clocks and other such apparatus. These clocks will be exceedingly simple, will require absolutely no attention and will indicate rigorously correct time. The idea of impressing upon the earth American time is fascinating and very likely to become popular."

"There are innumerable devices of all kinds which are either now employed or can be supplied and by operating them in this manner I may be able to offer a great convenience to the whole world with a plant of no more than 10,000 horsepower. The introduction of this system will give opportunities for invention and manufacture such as have never presented themselves before. Knowing the far reaching importance of this first attempt and its effect upon future development, I shall proceed slowly and carefully. Experience has taught me not to assign a term to enterprises the consummation of which is not wholly dependent on my own abilities and exertions. But I am hopeful that these great realizations are not far off and I know that when this first work is completed they will follow with mathematical certitude."

"When the great truth, accidentally revealed and experimentally confirmed, is fully

recognized, that this planet, with all its appalling immensity, is to electric currents virtually no more than a small metal ball and that by virtue of this fact many possibilities, each baffling imagination and of incalculable consequence, are rendered absolutely sure of accomplishment; when the first plant is inaugurated and it is shown that a telegraphic message, almost as secret and non-interferable as a thought, can be transmitted to any terrestrial distance, the sound of the human voice, with all its intonations and inflections faithfully and instantly reproduced at any other point of the globe, the energy of a waterfall made available for supplying light, heat or motive power, anywhere...on sea, or land, or high in the air...humanity will be like an ant heap stirred up with a stick.

See the excitement coming!"



Fig. 4 Tesla's 1904 resume advertising his services and those of the Wardenclyffe facility (Click on to enlarge)

TESLA READY FOR BUSINESS.

**HE HAS BOUGHT THE LAND FOR HIS
WIRELESS TELEGRAPHY STATION
AND LET THE CONTRACTS FOR
THE BUILDINGS.**

Nikola Tesla's plans for a transatlantic wireless telegraphic system are now so well in hand that he has bought a site for the station on the Long Island shore, and has agents looking for a suitable place for a station on the British coast. The station in this country will be at Wardencllyffe, on the Sound, nine miles east of Port Jefferson. Mr. Tesla has purchased two hundred acres of land in that vicinity, and closed contracts yesterday for the necessary buildings.

Five or six buildings will be erected on different parts of the tract, the largest of which is to be one hundred feet square and several stories high. It will contain, Mr. Tesla says, one of the most complete electrical plants that can be purchased. Three hundred and fifty horsepower will be developed, and the total cost will be nearly \$150,000. The other buildings will be used for the electrical experiments with which Mr. Tesla is now engaged, including a system of lighting by diffused light. He will probably give up his present laboratory, at No. 46 East Houston-st., and make his headquarters at Wardencllyffe.

Mr. Tesla has been working for several years with his system of wireless telegraphy, and believes that he has advanced far enough to warrant a change from the experimental to the commercial stage. He says it will not be long before he will be transmitting commercial messages between Wardencllyffe and Europe without the use of wires or cables.

When seen at the Waldorf-Astoria Hotel last night Mr. Tesla said:

"I would have been sending messages across the ocean without the use of wires by this time if the public were not so hard to convince that it could be done. It takes time to assure people of the truth of new discoveries. It was six or eight years before people believed in my system of transmitting electric power. Now it is used everywhere. I cannot tell you just how far I have advanced in the perfection of my system of telegraphy, but I hope soon to be able to show most convincing results."

-Wireless transmission concept



Tesla made the following statement regarding his theory and technique of energy transmission.

"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."

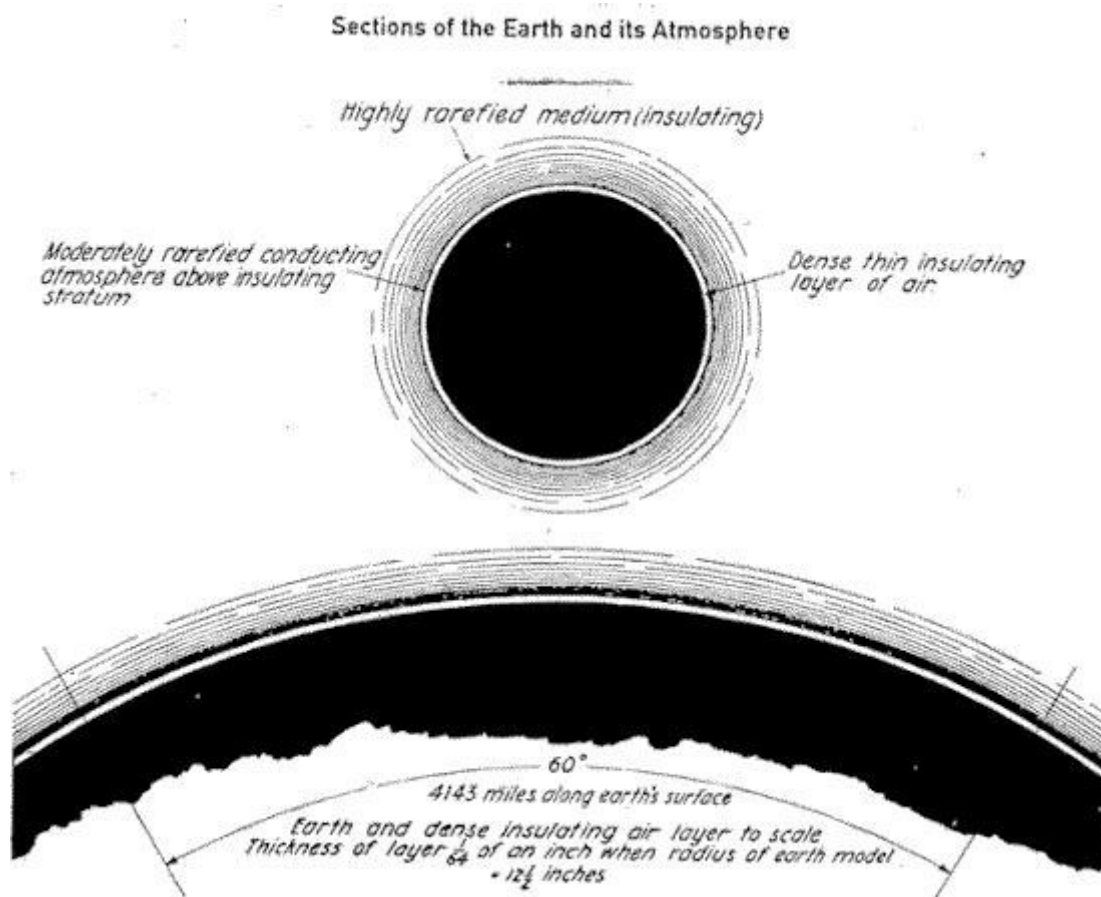


Figure 32

Tesla's diagram explanatory of the transmission of electrical energy by the ground air method. This was first put before Lord Kelvin in the Houston Street laboratory in September 1897.

It should be noted that in describing the "atmosphere above" as being conducting he roughly predicted the existence of the ionosphere and the earth-ionosphere cavity.

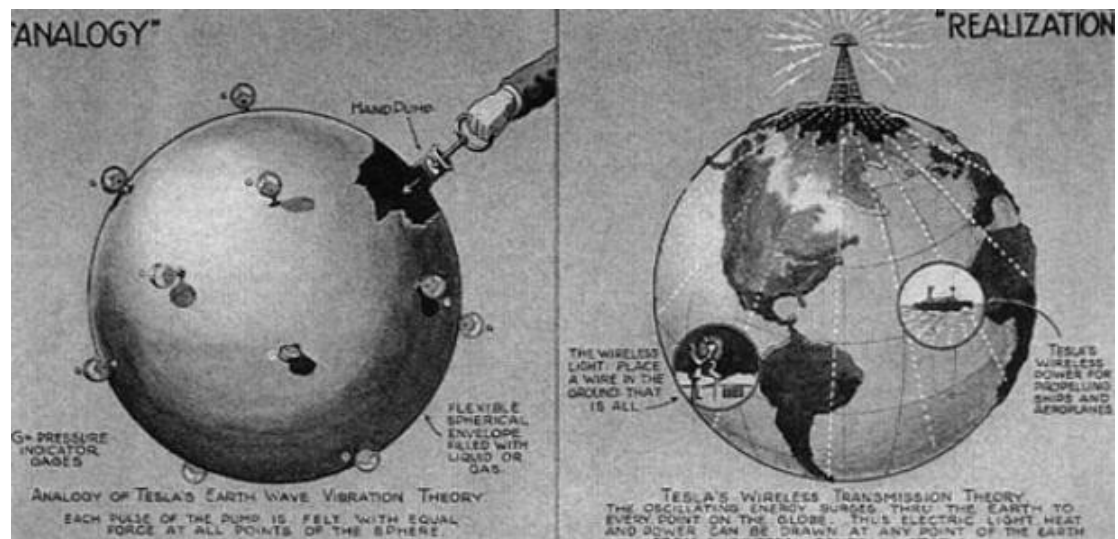


Figure 33

"Application of Ether Longitudinal Waves for Telecommunication Systems"

by Alexander V. Frolov

Scientific Expert of the Russian Physical Society

P.O.Box 37, 193024, St.-Petersburg, Russia

Tel: 7-812-2747877

Email: frolov@mail.dux.ru

By the ether concept, space is a physical substance that has a known (electric constant ϵ and magnet constant m) and unknown, as of yet, properties. In any substance can be created so called longitudinal waves. In a general case, these are oscillations of the energy density in the direction of the wave spreading.

In Alexander Chernetsky's paper "On the Physical Nature of Bioenergy Phenomenons and on their modeling", published in 1989, is described the properties of longitudinal waves which are created in so called "working bodies" (superconducting metal, plasma (electric discharge) and biological plasma). The theory of 1960, named as the "charge equivalent theory" was proposed by V.I.Dokutchayev, Russia (1932 - 1990). Relative motion of charges, according to Lorentz scale transformations, make the change of distance between charges of a moving frame of reference equivalent to an increase in charge density of the current. In a moving system there is created an additional equivalent charge:

$$q = (q_0 / 2) (u^2 / c^2) \text{ by Dokutchayev}$$

where q_0 is the charge in a motionless system, u is the velocity of the system and c is the velocity of light.

Dokutchayev's dissertation of 1970 described some experiments: superconductors were placed in an electromagnetically screened box (Faraday cage) but some signal was detected outside of the box when current was created in superconductor. The main conclusion is: longitudinal waves can be created in space (in vacuum) by means of electric energy and such sort waves is not screened by metal screens.

Alexander Chernetsky also described some experiments in which longitudinal waves were created. In his version "the working body" is an electric discharge. There is a known pinch - effect (interaction between the electric current and magnetic field of this current) that leads to high frequency oscillations of the plasma. Radial components of the density current oscillations is responsible for longitudinal waves which are spreading in radial direction also [1].

More than 60 years ago Nikola Tesla wrote: " I showed that the universal medium is a gaseous body in which only longitudinal pulses can be propagated, involving alternating compressions and expansions similar to those produced by sound waves in the air. Thus, a wireless transmitter does not produce Hertz waves, which are a myth, but sound waves in the ether, behaving in every respect like those in the air, except that, owing to the great elastic force and extremely small density of the medium, their speed is that of light." It is part of N.Tesla's article "Pioneer Radio Engineer Gives Views on Power", published in New York Herald Tribune, Sept. 11, 1932, [2, p.94].

American scientist Thomas E. Bearden explained this statement of Tesla in this way: An ordinary receiver uses so called "precession of electrons" a phenomenon that is result of interaction between the electron gas of antenna metal wires and longitudinal waves [2]. Tesla wrote about a great mistake of modern science: "The Hertz wave theory of wireless transmission may be kept up for a while, but I do not hesitate to say that in a short time it will be recognized as one of most remarkable and inexplicable aberrations of

the scientific mind which has ever been recorded in history", article "The True Wireless" [2, p.95].

The technology of Tesla requires high potential sources (up to millions of Volts) that produce high frequency oscillations. The terminals that creates the longitudinal waves are spherical metal surfaces (sphere capacitor). The synthesis of Tesla's scheme and Dokutchaev's concept allows us to make the conclusion: longitudinal waves are generated by means of a changing energy density (electric charge density). Let's call it the function $r(t)$. In a Hertz transmitter there is a changing energy density also, but it is linear density $r_1(t)$: the density of electric current in the wire of the antenna. It is a one-dimensional density of energy. In Tesla's sphere capacitor there is a change of charge value that is placed on the surface of the capacitor. So, it is a two-dimensional density of energy $r_2(t)$.

N.Kozyrev [3] created so called "**waves of density of time**" by means of non-electrical methods: rotation plus axial vibrations of a gyroscope, deformation of a material body, diffusion and dissolving or crystallization of the matter, fading of plants and so on. Different detectors for such sort waves were used: the electrical component of the was were detected by means of a galvanometer, the gravitational component of the wave was detected by means of the weighing-machine, the chrontal component of the wave was detected by means of an electronic scheme that used so called "Winston bridge" since electrical properties of the electronics components are changing in the wave area. These three methods showed the next: any type of change of matter structure that can be presented as $r(t)$ (i.e. a change of density of energy) is the method for generation of the longitudinal wave. For example, if it is a change of volume density of matter, we can write the three-dimensional density function $r_3(t)$. It is connected with the well-known Poisson equation for gravitation.

There are more complex methods for longitudinal wave creation. R. Ziolkovsky, Physical Review A, vol.39, p.2005, wrote in the paper "Localized Transmission of Electromagnetic Energy" about his experiments. Before the electromagnetic version, R. Ziolkovsky created an analogy in liquid to study the properties of wave and to create an optimum antenna system.

What method of the energy density modulation is the best for telecommunication systems? Some experiments prove the possibility that living biosystem create longitudinal waves [1 , p. 50]. By this analogy there is the possibility for creation of a technical system.

References:

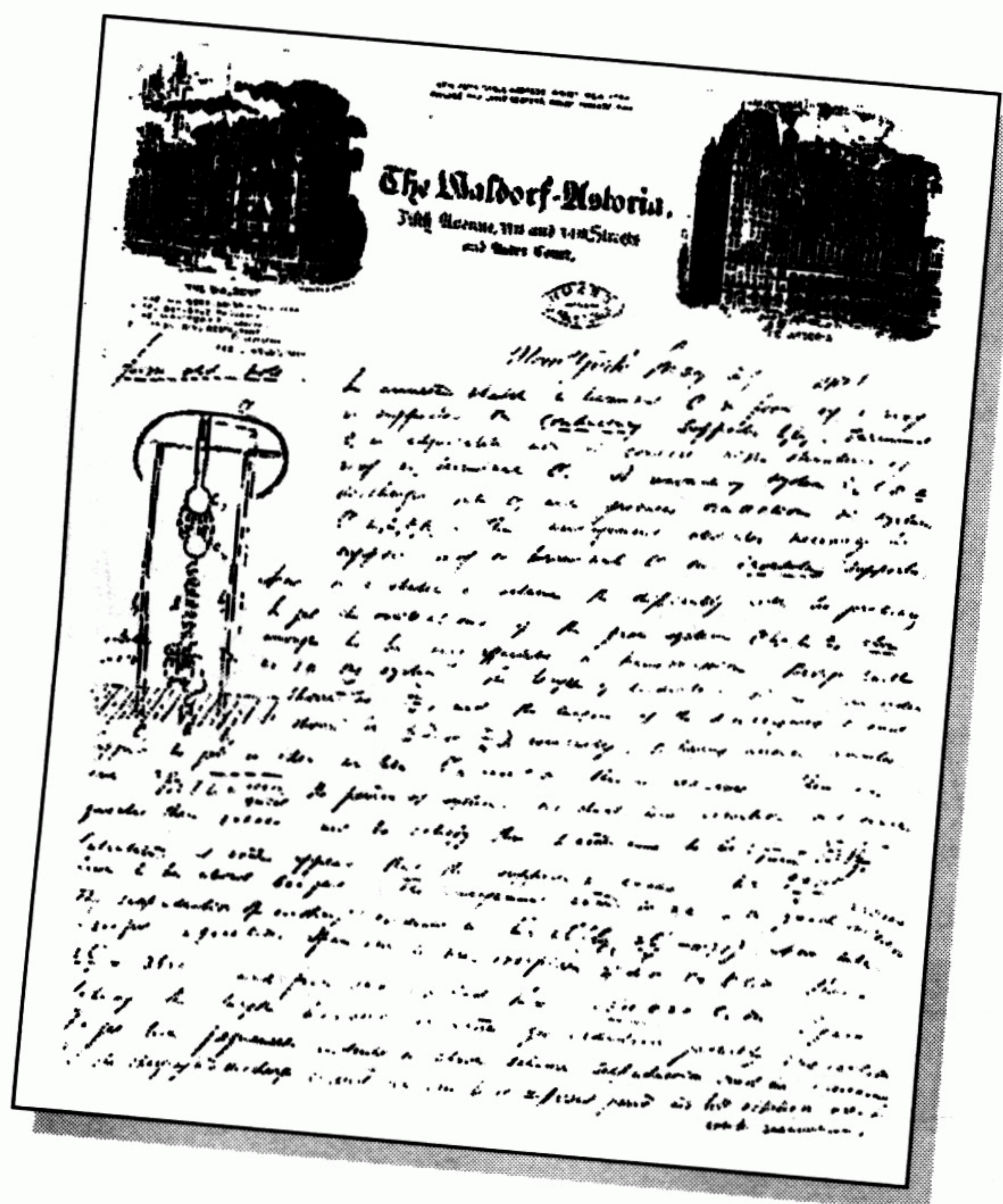
1. Alexander Chernetsky, "On The Physical Nature of Bioenergy Phenomenons and on Their Modeling", published in 1989 by Moscow Polytechnical Institute.
2. T.E. Bearden, Gravitobiology, 1991, published by Tesla Book Company, P.O. Box 121873, Chula Vista, CA 91912, USA.
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Rare notes from Tesla on Wardenclyffe

LELAND ANDERSON HAS KINDLY PROVIDED COPIES OF RARE DOCUMENTS FROM THE TESLA MUSEUM IN BELGRADE. THE PAPERS REPRODUCED IN THIS REPORT SUPPLY INFORMATION ABOUT THE WARDENCLYFFE TOWER, AND SHOW THAT THE DESIGN PROCESS WASN'T AS AUTOMATIC AS LEGEND LEADS US TO BELIEVE.

Tesla's tower at Wardenclyffe is perhaps as enigmatic as the prodigal genius was himself. (Figs. 1-3 show in part a conceptual evolution of the tower.) While Tesla aficionados have scraped the archives and haggled with politicians to obtain even the minutest revelations on how this device might have actually been capable of transmitting energy worldwide, nobody seems to know how this was to be effected. In what follows, the contents of some practically-uncirculated papers, that Leland Anderson managed to obtain, are reproduced in full.

The first note, written on Waldorf-Astoria letterhead, discloses Tesla's reasoning behind some of the dimensional specifications required in an early design for the tower which he claimed would be capable of transmitting electricity worldwide by means of earth resonance. The letters reprinted here were all written in 1901. Actual construction of the tower did not start until December 12, 1901.



New York May 29, 1901

from old note

In annexed sketch [See Fig. 4.] a terminal C in form of a roof is supported on conducting supports $L_1 L_2$. Terminal C_1 is adjustable and in contact with structure of roof, or terminal C_2 . A resonating system $C_2 L_2 E_2 E_1$ discharges with C_1 and produces oscillations in system $C L_1 L_2 E_2 E_1$. This arrangement obviates necessity to support roof or terminal C on insulated supports.

Now in a sketch or scheme the difficulty will be probably to get the oscillations of the free system $C L_1 L_2 E_2 E_1$ slow enough to be very effective in transmission through earth as in my system. The length of conductors in the free system should be $\lambda/4$, and the length of the discharging current should be $3/4 \lambda$ or $n/4 \lambda$ eventually, n being uneven number.

Suppose, to get an idea, we take $C = 10,000$ cm. This is realizable. Then we have

$$\frac{2\pi}{10^3} \sqrt{L \times \frac{10,000}{9 \times 10^5}}$$

the period of the system. We should have vibration not much quicker than 100,000 and to satisfy this L would have to be:

$$\frac{1}{100,000} = \frac{2\pi}{10^3} \sqrt{\frac{L}{90}}$$

$L = 9 \times 10^5 / 4 = 225,000$ cm. Calculated it would appear that the supports L would have to be about 600 feet. The arrangement would be OK with quick oscillation. The self-induction of a straight conductor is $L' = 2l' [\log_e (2l'/r) - 0.75]$. Now, take $l' = 300$ ft = 9000 cm. If we want to use iron pipes 4" diam. $r = 5$ cm. Then $2l'/r = 3600$ and from this I find $L' = 134,000$ cm. Again taking the length 600 ft we would get inductance probably 268,000 cm. To get lower frequencies, evidently in above scheme self-induction must be increased.

P. S. The charging and discharge current may even be of different period and both vibrations used to excite receiver.

RARE NOTES FROM TESLA ON WARDENCLYFFE

The person who proofread the decipherer's notes found fault with Tesla's analysis, stating that in order to limit the induction to 225,000 cm, the tower would need to be nearly three times taller than Tesla anticipated, or 1,404 feet high.

As it was, the Wardenclyffe Tower project was very large, and involved numerous construction crews. The following note was sent to Margaret Cheney, while she was writing Tesla's biography.

Wardenclyffe Project

Reference has been made by O'Neill and contemporary newspaper accounts of the large crew that Tesla had working for him at Wardenclyffe. Instead of just referring to the "large crew" as such, it might be a good idea to sprinkle in a few names of Tesla's direct assistants. They were:

Willie Eppersteiner

Hartmann

Johnnison

Lindeke

Meyer

Alfred Peters

Seibel

Mr. Uhlman (815 N. 12th St., St. Joseph, MO)

Wagner (Tesla's glass blower)

LETTERS

The next three letters illustrate, to a small degree, the breadth of the concerns Tesla had while overseeing the building of his tower. The first two are written to the architect, Stanford White; the third is to the company that was to furnish the building's boilers.

New York, Aug. 28th, 1901

46 & 48 East Houston Str.

Mr. Stanford White

160 Fifth Ave.

New York City

My Dear Stanford:

I have seen the American Bridge people today to ascertain whether they will be able to construct the cupola of my building without much delay. As this item will consume the longest time, it is necessary to take all the preliminary steps so that the work may begin just as soon as you have passed upon the plans. I believe that the American Bridge Company is the best concern to deal with in this matter, but I beg you not to pay any attention to my suggestion, if you think otherwise.

The Bethlehem Steel Company will furnish me the sheets, but I cannot give the order until we have agreed upon all details.

With kind regards,

Yours very sincerely,

N. Tesla

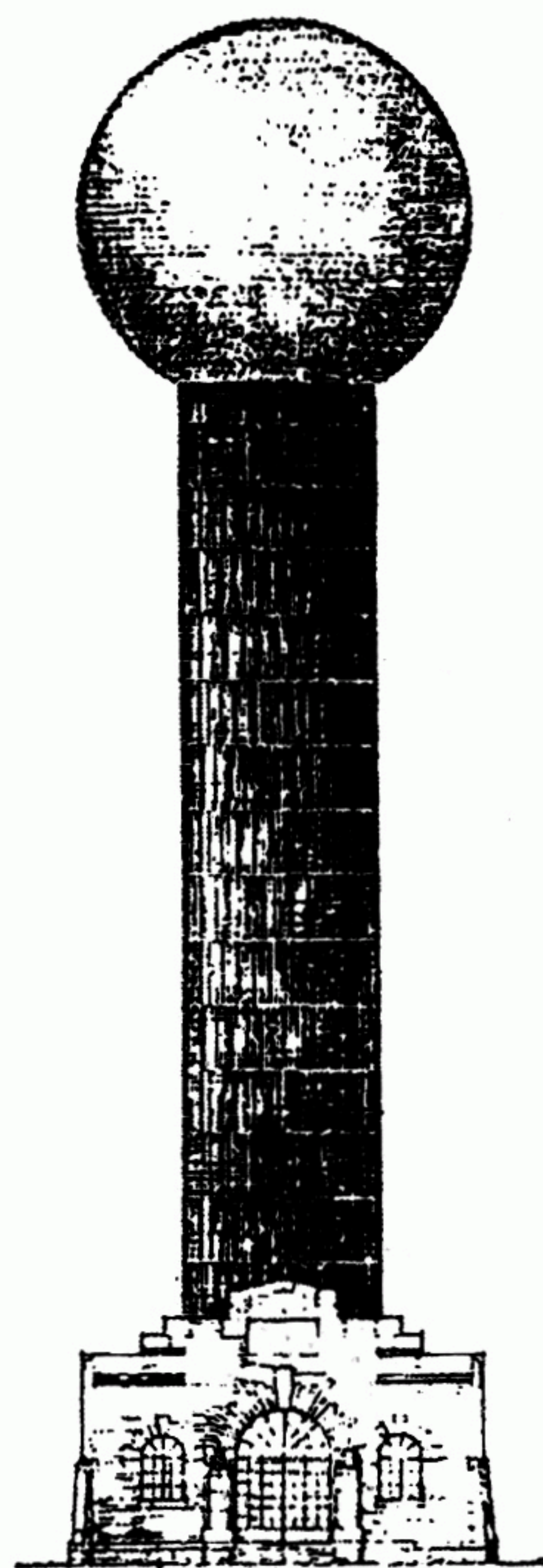


Fig. 1

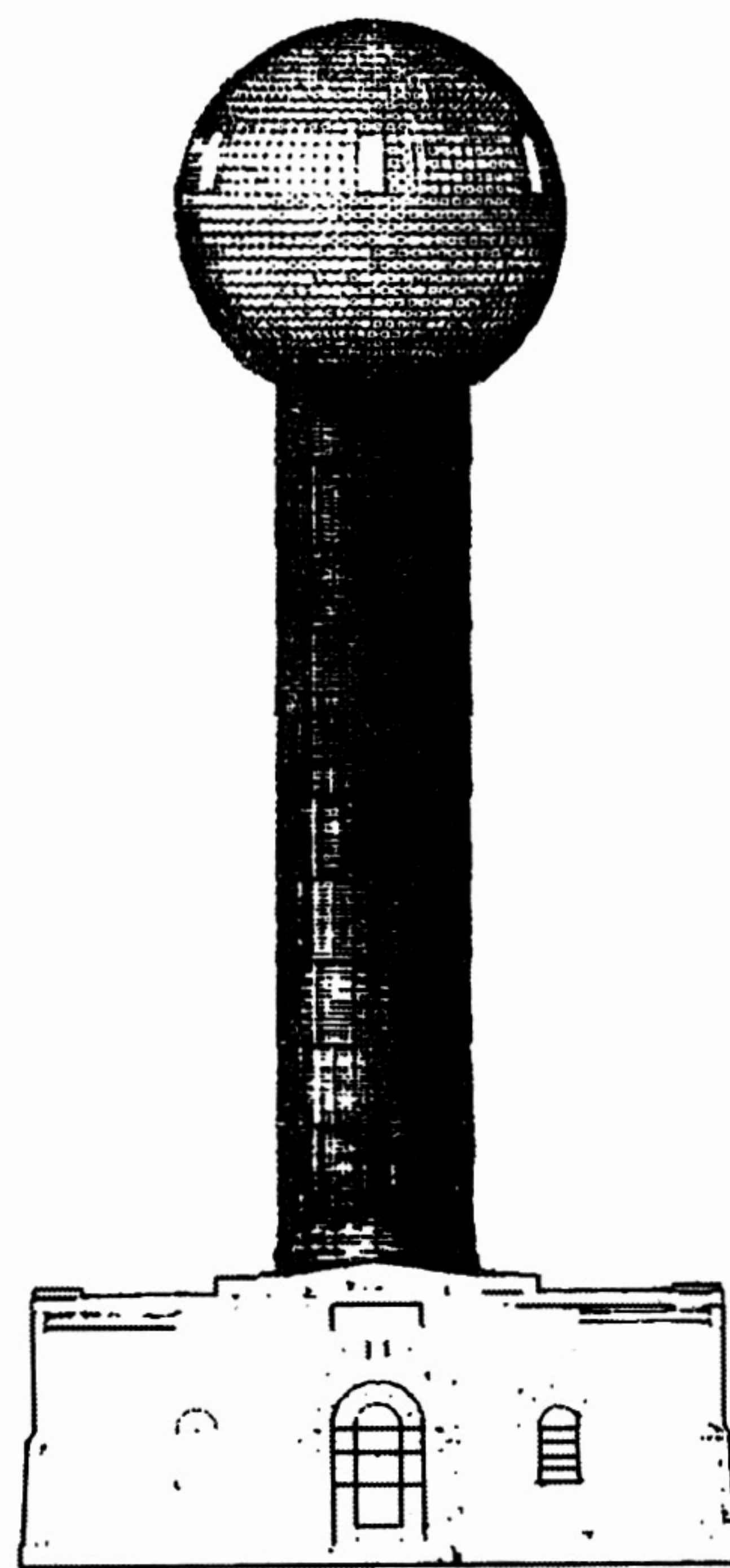


Fig. 2

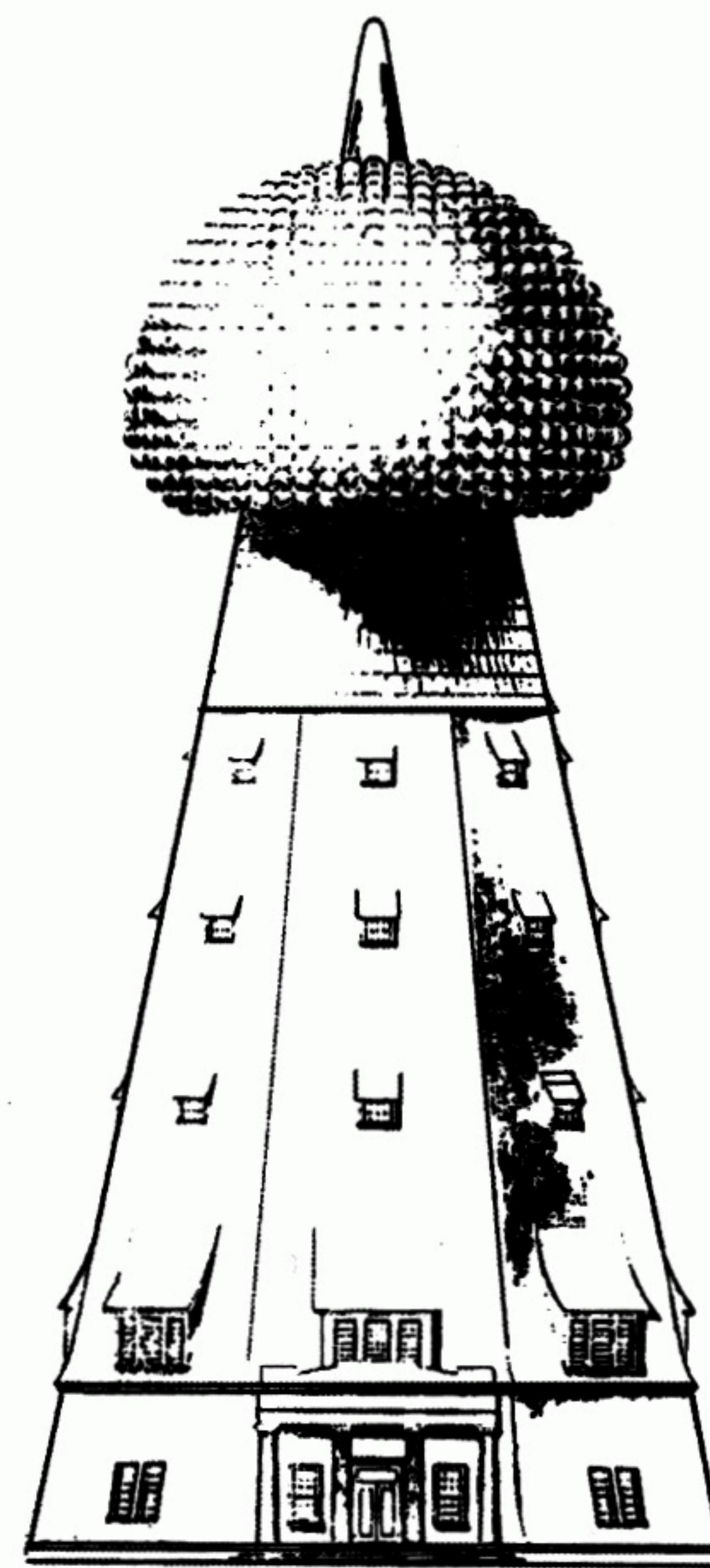


Fig. 3

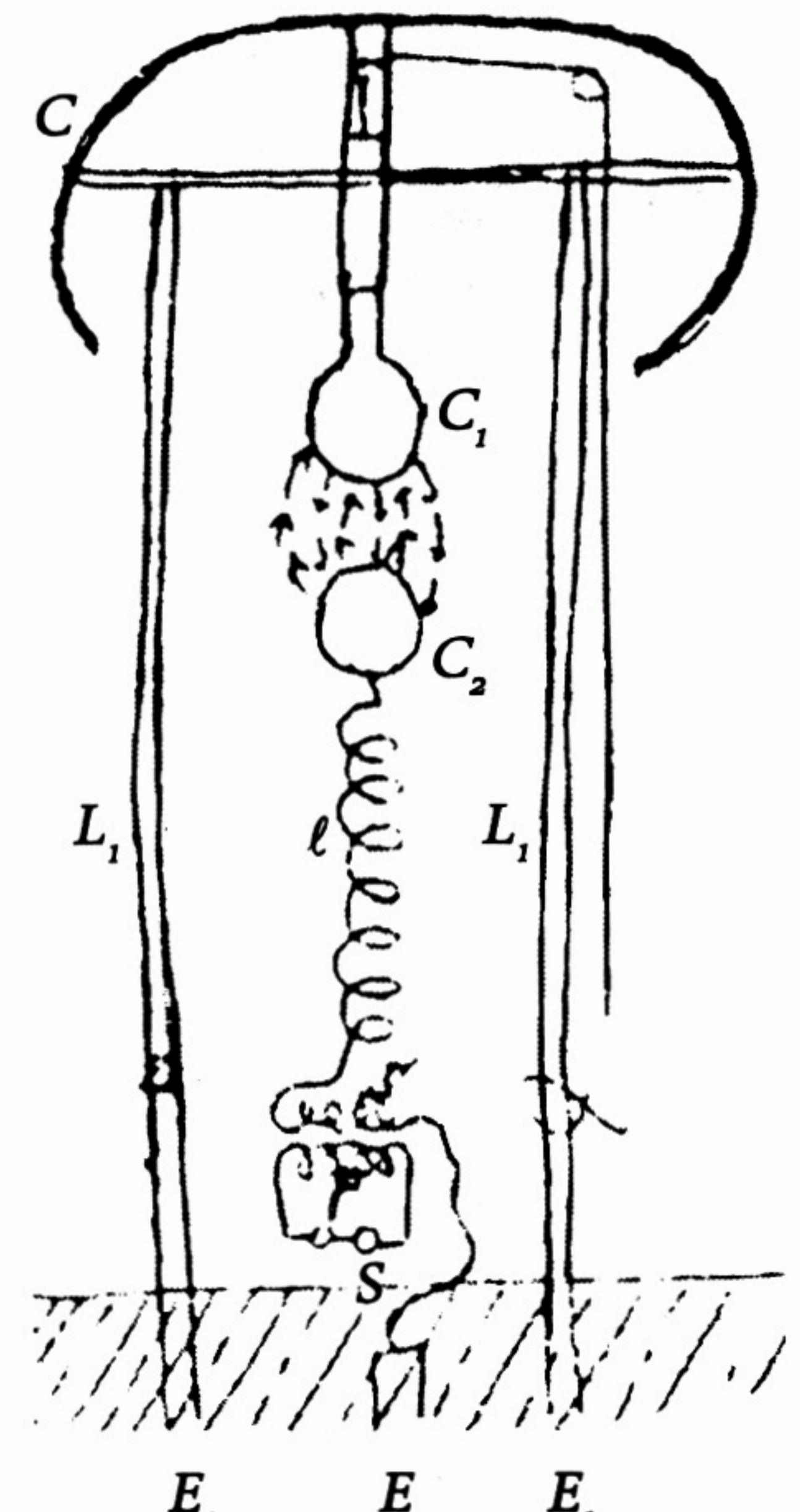


Fig. 4

RARE NOTES FROM TESLA ON WARDENCLYFFE

New York, Aug. 30th, 1901

46 & 48 East Houston Str.

Mr. Stanford White

160 Fifth Ave.

New York City

My Dear Stanford:

Many thanks for your suggestions. I am writing to Mr. Powell today. Perhaps he will be able to clear the land altogether.

I want you to understand that I went to the American Bridge Company simply because of my anxiety to have the work pushed through as fast as practicable. I am only too glad to follow your advice and beg you to consider yourself absolutely free in your choice and arrangements regarding this work.

Yours very sincerely,

N. Tesla

New York, Sep. 12th, 1901

46 & 48 East Houston Str.

Babcock & Wilcox Co.

85 Liberty Street

New York City

Gentlemen:

Under enclosure I forward sketch showing your two boilers as they will be placed in my building and their position relative to and exact distance from the chimney. The scale is $\frac{1}{2}$ inch to a foot.

You will greatly oblige me by furnishing the drawings of the flues leading to the chimney and the position of the breech, as the builder cannot proceed without this information.

Yours very truly,

Encl.

Anyone familiar with the Wardenclyffe Tower knows it to have been a colossal structure. Yet, few realize that it was supposed to have been even larger. Although the exact figures are not revealed, Tesla must have drastically underestimated the cost of building his structure as is evidenced by the following response to White.

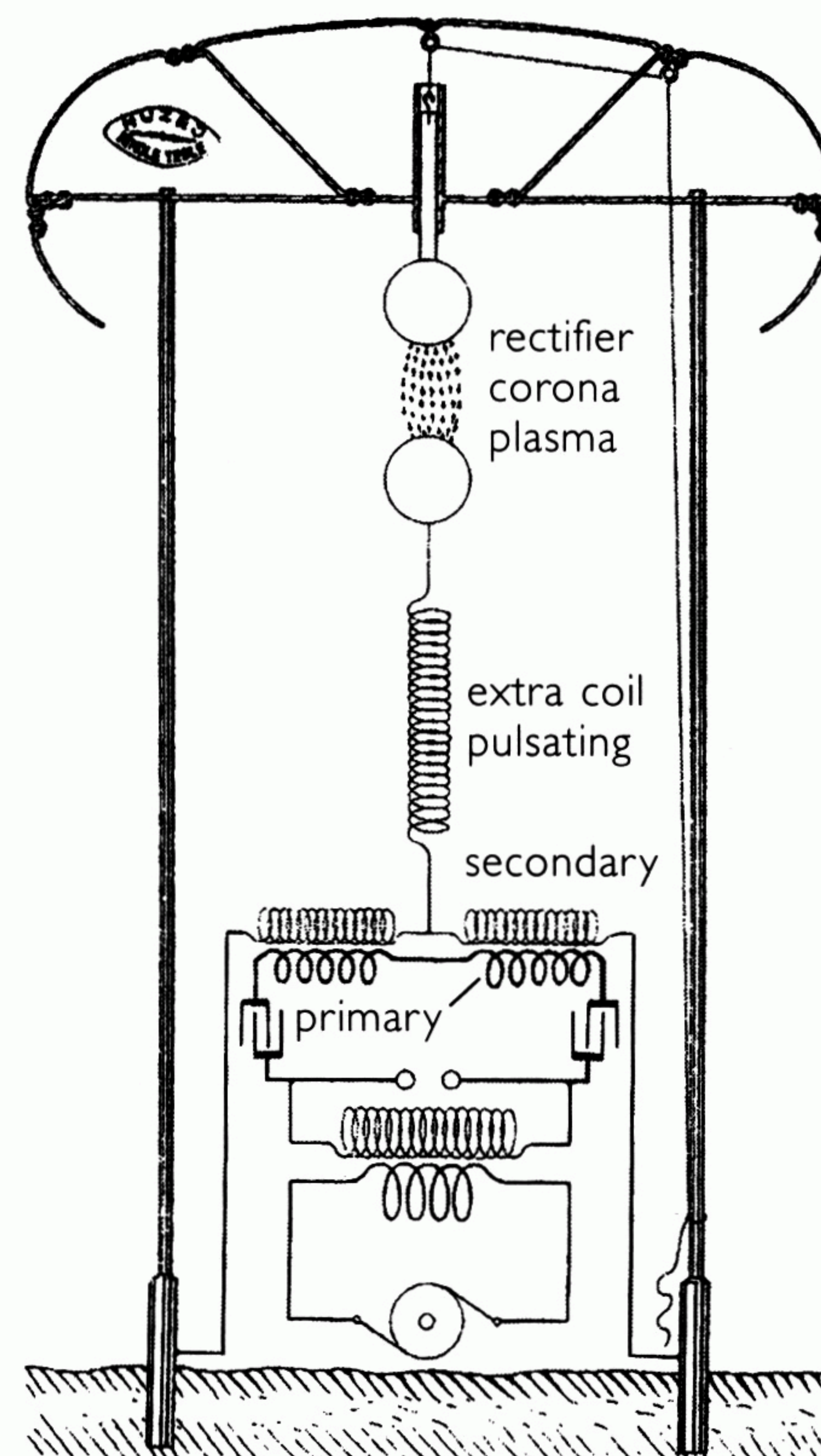


Fig. 5 Oscillating statically charged terminal.

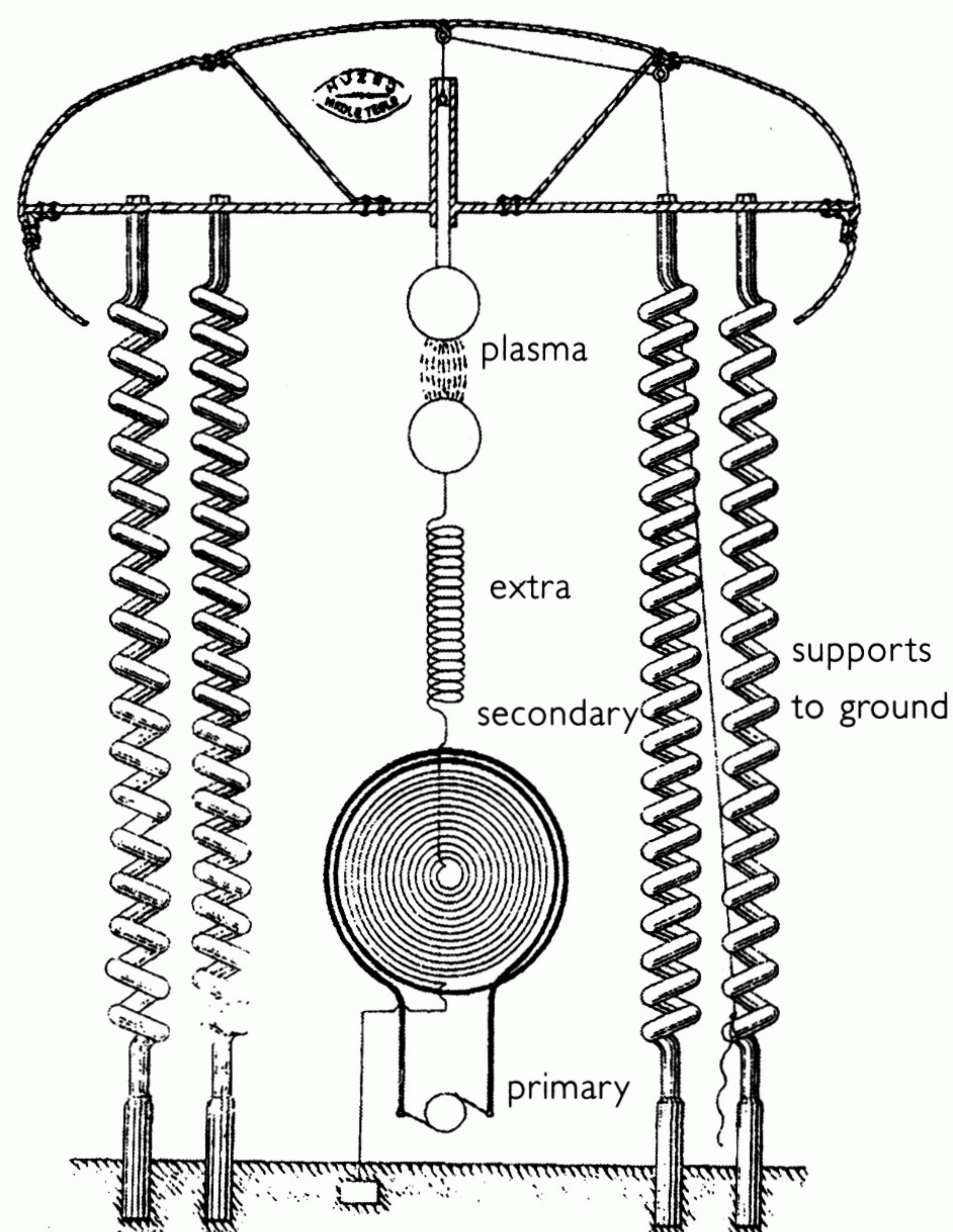


Fig. 6 Oscillating electrostatically charged dome.

RARE NOTES FROM TESLA ON WARDENCLYFFE

New York, Sep. 13th, 1901

46 & 48 East Houston Street

Mr. Stanford White

160 Fifth Ave.

New York City

My Dear Stanford:

I have not been half as dumbfounded by the news of the shooting of the President as I have by the estimates submitted to you, which, together with your kind letter of yesterday, I received last night.

One thing is certain: We cannot build that tower as outlined.

I cannot tell you how sorry I am, for my calculations show, that with such a structure I could reach across the Pacific. Since last night, I have thought carefully over the matter and have come to the conclusion that the best plan will be to fall back on an older design which I have made, involving the use of two and possibly three towers, but much smaller. We would keep the design of the tower the same and would only reduce the dimensions. It will probably be best to adopt a design with two towers and a low central part for the machinery. I shall make some calculations today and will see how far I can reduce the height without impairing materially the efficiency of the apparatus, and will communicate with you as soon as practicable.

Thanking you heartily for your friendly interest and efforts on my behalf, I remain,

Yours very sincerely,

N. Tesla

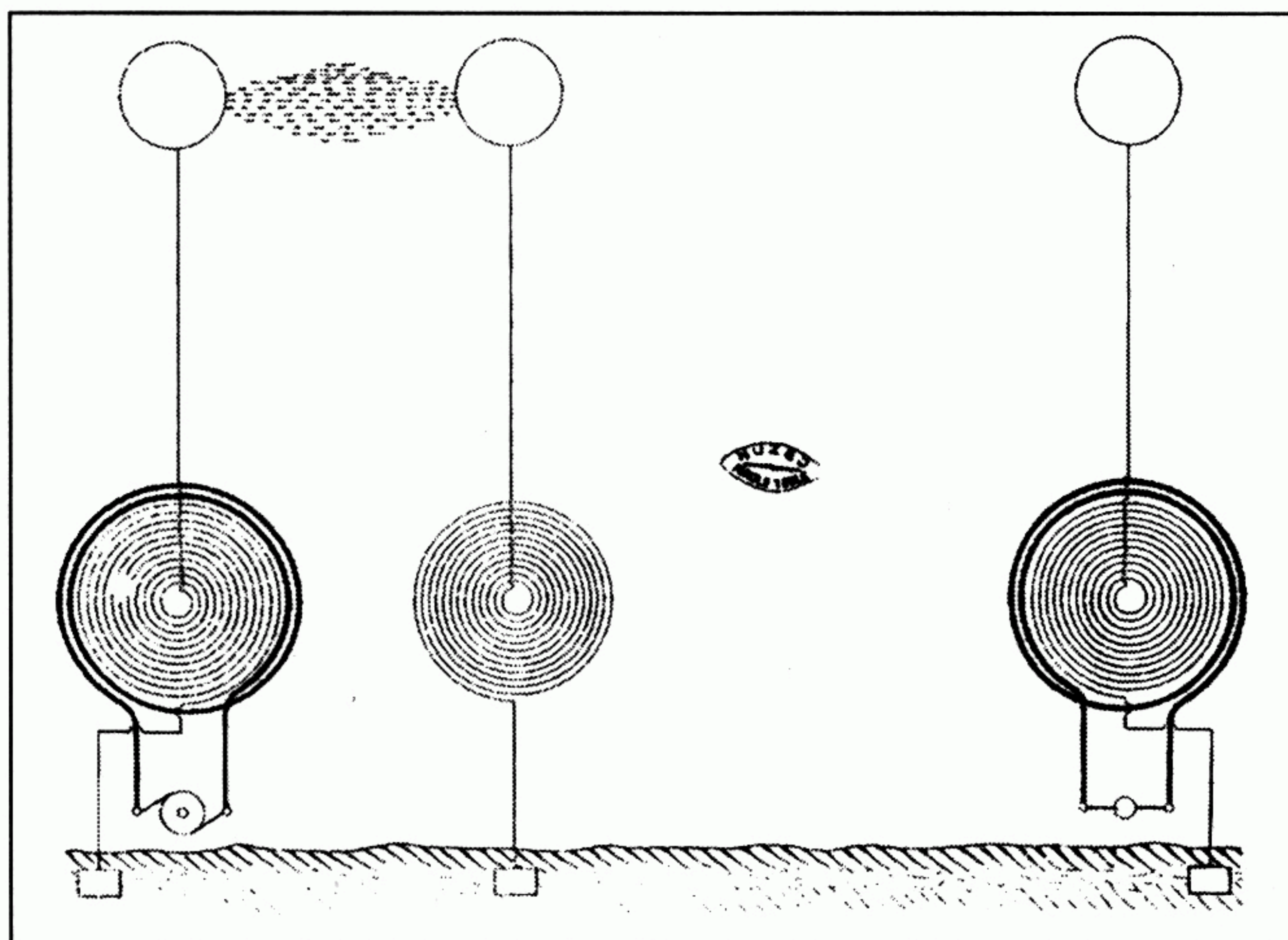


Fig. 7

In less than a week after receiving news of the exorbitant construction bids, Tesla had a new design, but he could only provide a rough estimate of what its capacitance would be. (Figs. 5-8 show somewhat the conceptual evolution of the electrical apparatus which was to build a capacitance sufficiently large to power the globe via earth resonance.)

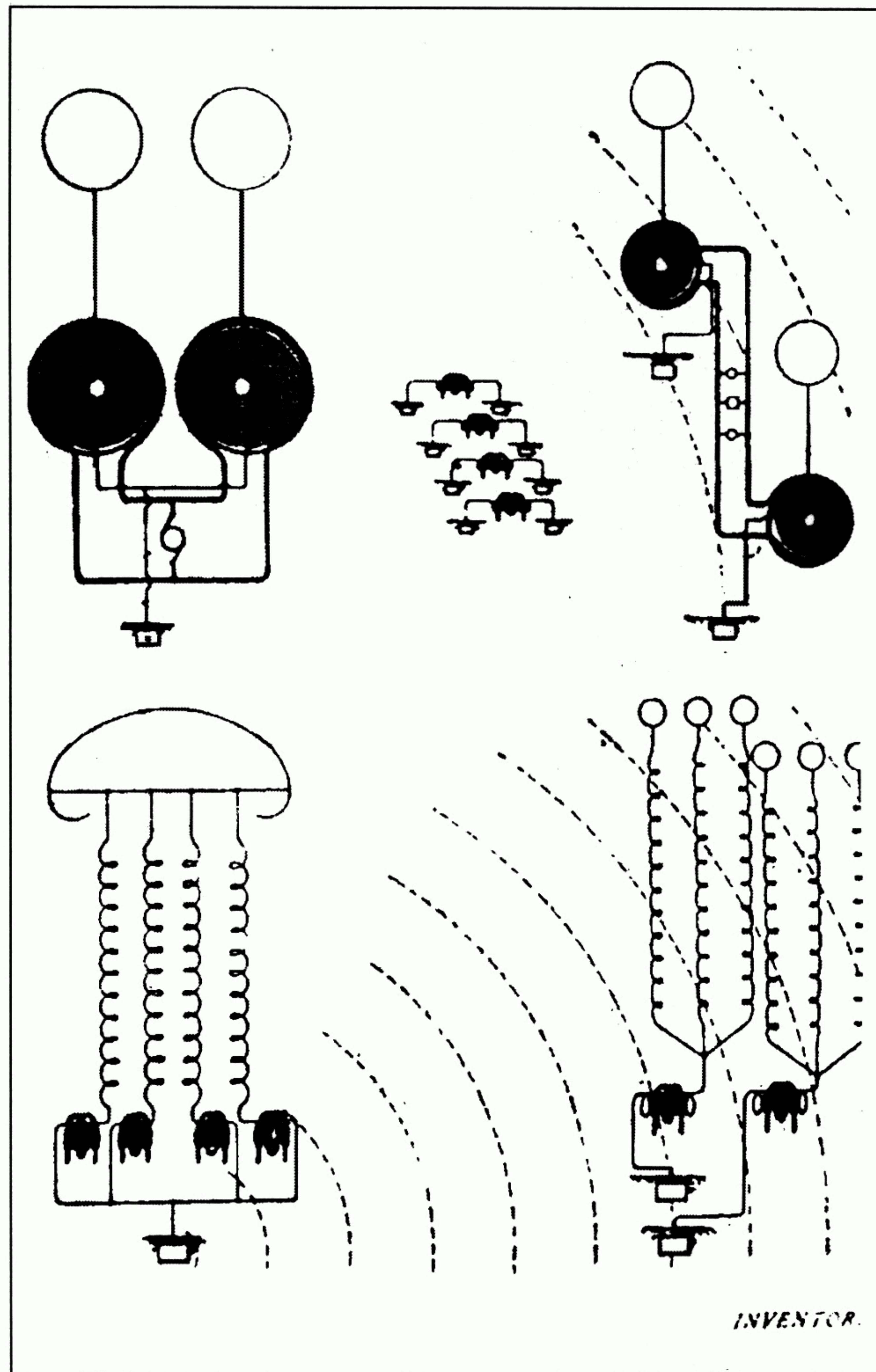


Fig. 8

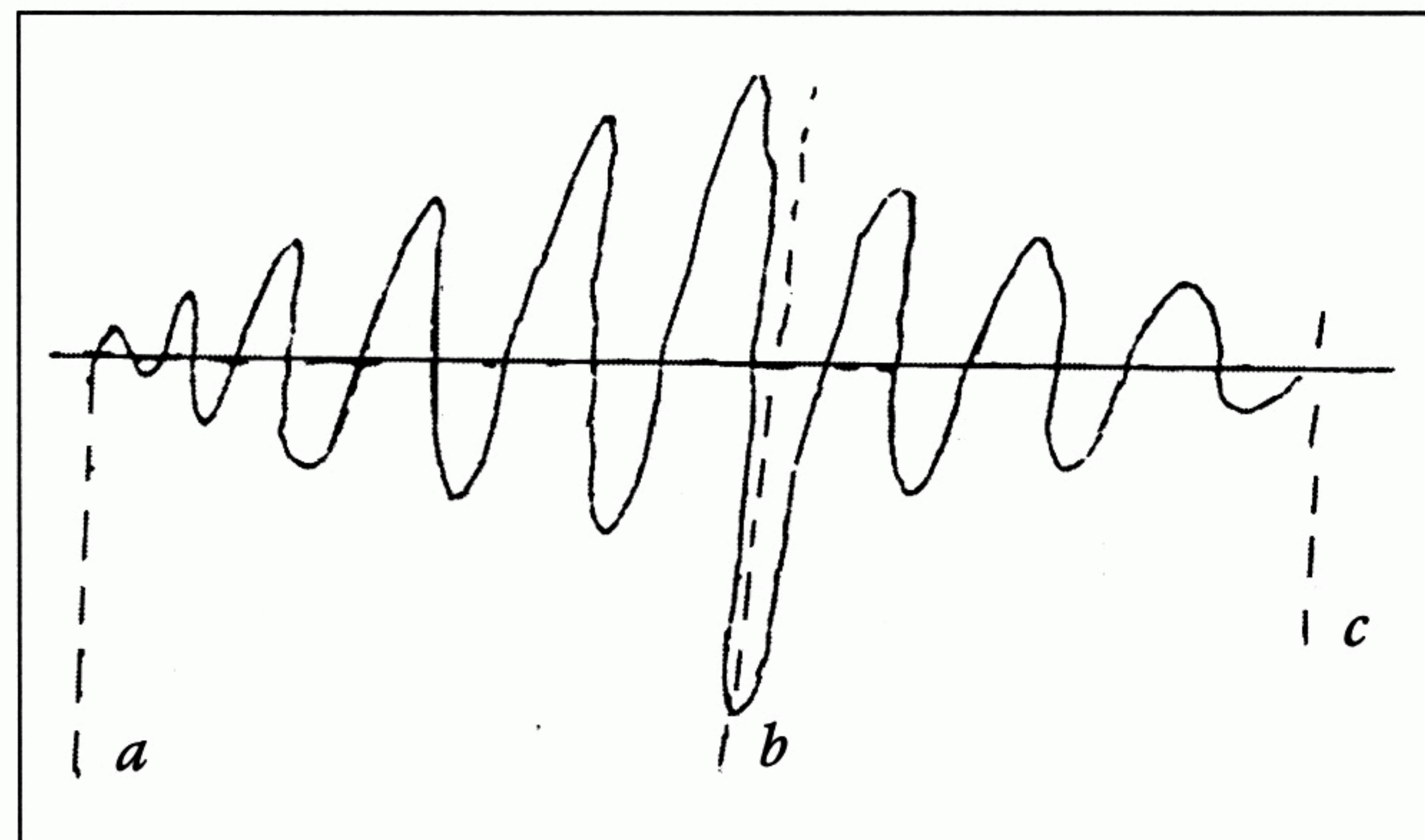


Fig. 9

RARE NOTES FROM TESLA ON WARDENCLYFFE

Sept. 18, 1901

Following results may be confidently expected with smaller tower 200 feet and terminal roof of cheap construction as last designed. The roof will comprise a single platform with spherical bodies of large curvature on rim.

The construction of latter will be given in detail. The platform 20 meters diameter, 15 round surfaces on top and 15 on the bottom as shown in sketch below.

It is difficult to estimate in advance the capacity of the structure with precision, but an approximate idea may be obtained. The spherical bodies will be each of a capacity of 200 cm. This would give $30 \times 200 = 6000$ cm without taking elevation into consideration. But owing to proximity capacity will be much smaller. Estimates place the minimum value at or less than 1000 cm (elevation not considered). This means, say, that of each spherical body only 1/6 of surface is fully active.

Now, surface of one spherical body will be $\pi \times 400^2$. Calling σ density, we would have on 1/6 of surface

$$\frac{\pi \times 400^2 \sigma}{6 \times 3 \times 10^9} \text{ Coul. of electricity.}$$

We can safely make $\sigma = 10$ minimum. This would give on the whole structure

$$\frac{\pi \times 400^2 \times 10 \times 30}{6 \times 3 \times 10^9}$$

= roughly at least $8/10^3$ Coulombs. Now, if we put capacity as 1000 cm we would have

$$\frac{8}{10^3} = \frac{1000}{9 \times 10^{11}} \cdot V$$

and

$$V = \frac{9 \times 8 \times 10^{11}}{10^6} = 7,200,000 \text{ volts.}$$

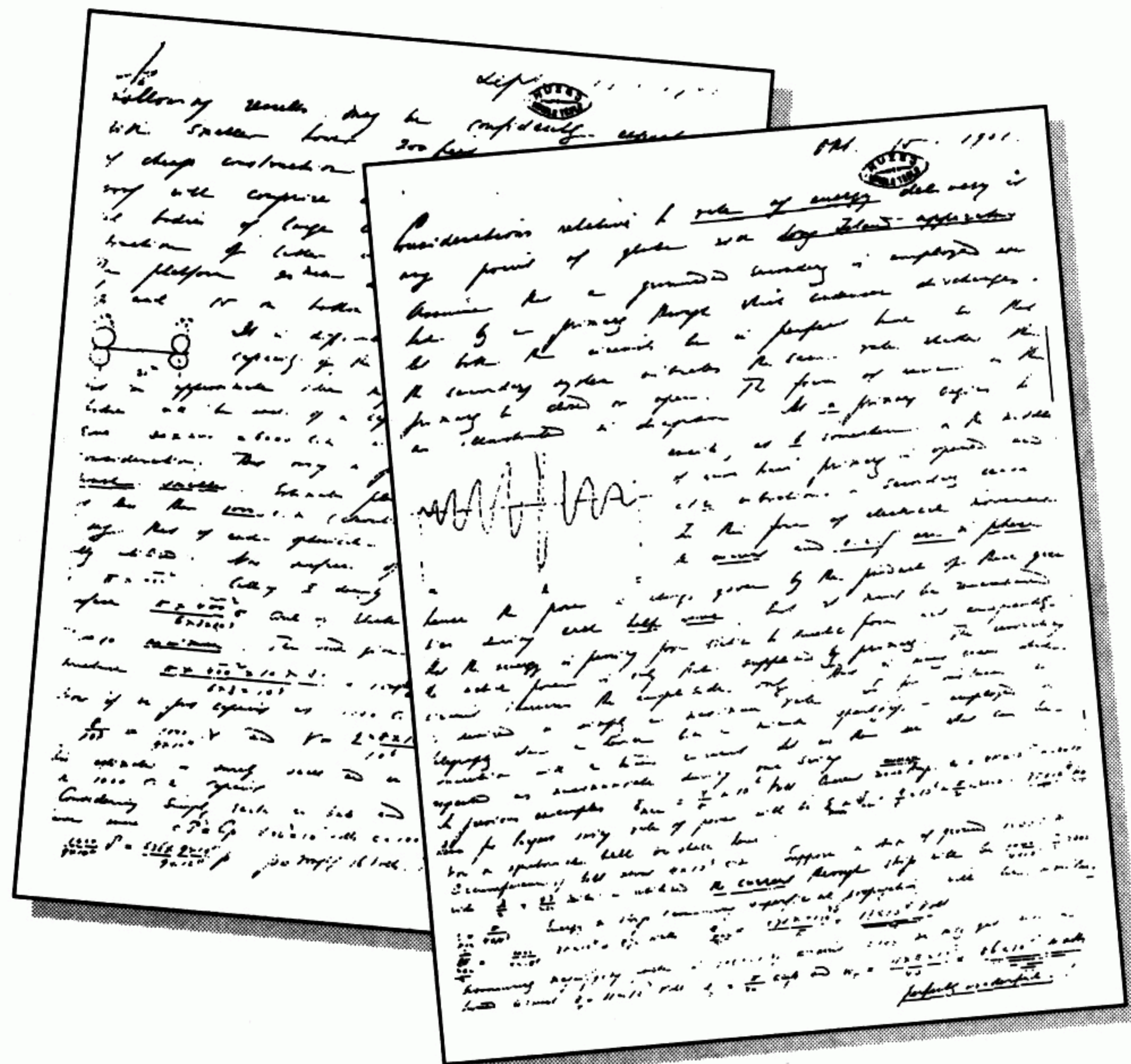
This estimate is surely small and we may take safely 10,000,000 volts for 1000 cm capacity.

Considering simply earth as ball and leaving out short waves, we have since $cP = Cp$; $V = P = 10^7$ volts; $c = 1000$ cm.

$C =$ capacity of earth $= 636 \times 9 \times 10^5$

$$\frac{1000}{9 \times 10^{11}} \times P = \frac{636 \times 9 \times 10^5}{9 \times 10^{11}} \times p;$$

$p =$ simply 16 volts. This means variation of $2p = 32$ volts all over globe.



DECIPHERER'S NOTES

Again, the decipherer's proofreader took issue. Using 636×10^6 cm as the value for earth's capacitance, he arrived at the conclusion that p should equal 11 and not 16 volts.

By October, Tesla was quite pleased with his projections for the new tower's output. The decipherer's proofreader had no objections, either.

Oct. 15, 1901

Consideration relative to rate of energy delivery at any point of globe with Long Island apparatus.

Assume that a grounded secondary is employed excited by a primary through which condenser discharges and let both the circuits be in perfect tune so that the secondary system vibrates the same rate whether the primary be closed or open. The form of wave is then as illustrated in diagram. [See Fig. 9.] At a primary begins to excite, at b somewhere in the middle of wave train primary is opened and at c vibrations in secondary cease. In this form of electrical movement the current and emf are in phase, hence the power is always given by the product of these quantities during each half wave, but it must be remembered that the energy is passing from static to kinetic form and consequently the actual power is only that supplied by primary. The secondary circuit increases the amplitude only. But in many cases what is desired is simply a maximum rate. So for instance in telegraphy when a device like a minute spark gap is employed in connection with a tuned circuit. Let us then see what can be expected as reasonable during one swing.

RARE NOTES FROM TESLA ON WARDENCLYFFE

In previous examples, $E_{max} = 9/8 \times 10^6$ volt.

$$\text{Current} = \frac{\text{average}}{2000 \text{ amp}}$$

$\omega = 4\pi \times 10^5 \text{ M} = 2 \times 10^5$. Hence for largest swing rate of power will be $E_{max} \times J_{max} = 9/8 \times 10^6 \times \pi/2 \times 2000 = 35 \times 10^8$ WG. Now on equatorial belt we shall have:

Circumference of belt about 4×10^9 cm. Suppose a strip of ground 1000cm wide $\lambda/2 = 93/200$ miles is utilized. The current through the strip will be

$$\frac{1000}{4 \times 10^9} \times \frac{\pi}{2} \times 2000 = i_{max} = \frac{\pi}{4 \times 10^3}.$$

Energy in strip considering superficial propagation will be similarly

$$W_{max} = \frac{1000}{4 \times 10^9} \times 35 \times 10^8 = 875 \text{ watts.}$$

$e_{max} = 875 \times 4 \times 10^3/\pi = 11 \times 10^5$ volt. Assuming magnifying factor in receiving circuit = 100 we may get with a tuned circuit $e_r = 11 \times 10^7$ volt, $i_r = \pi/40$ amp and $W_r = 11\pi \times 10^7/40 = 86 \times 10^5$ watts. Perfectly wonderful!

SOLID STATE TESLA COIL

by

Dr. Gary L. Johnson
Manhattan, Kansas

Some years ago I developed an interest in Tesla coils. I was teaching a senior elective course at Kansas State University where we talked about power MOSFETs and topics related to high voltages and currents. I decided to use a Tesla coil as a class project. We would talk about design aspects, then design, build, and test a coil. The best description of the results of that plan was fiasco, or maybe disaster. We had some sparks, but none where they belonged. That was one of the most humiliating experiences of my career.

I learned several things from that experience. One is that the Tesla coil is more complex than I had thought. Another was that there seemed to be a mismatch between theory and experiment. At that time, at least, people would go through pages of high powered mathematics and quit without giving an example of how to use all the formulas. Experimentalists would sometimes make fun of the theorists, and give rules-of-thumb on how to make long sparks. It was like I was hearing a debate on whether the best cooks use recipes or not. My mother never used a recipe and I always enjoyed her cooking. However, my own talents are such that if I am to cook anything fit to eat, I need a recipe.

This book is written for people like me, challenged when faced with doing something without a recipe or complete set of instructions. I will throw in things learned from other Tesla coil builders, but will quickly admit that when it comes to making long sparks, there are many who are far better than I.

I started asking questions about Tesla coils that any electrical engineer would ask. These include:

1. What is the input impedance?
2. What are the fractions of input power that are dissipated in the spark itself, in electromagnetic radiation, the coil wire, the coil form, the toroid, the spark gap, and other

circuit components?

3. Are there circuit models that allow these questions to be answered on the computer before building and testing devices in open air?
4. What are the differences between Tesla coils driven by or through spark gaps, vacuum tubes, or solid state devices?
5. What are the important factors in producing long sparks (energy per bang, power input at spark inception, rate of change of power, the coil, the toroid, etc.)?

One would expect the answers to these questions to come from a mix of theory and experiment. One would develop a theory or model and then go to the laboratory to measure parameters and check performance. The theory would then be adjusted to reflect experimental observations.

We now review a little Tesla coil history and look at the ‘simplest’ model, the lumped circuit element model.

1 History

Nikola Tesla (1856 - 1943) was one of the most important inventors in human history. He had 112 U.S. patents and a similar number of patents outside the United States, including 30 in Germany, 14 in Australia, 13 in France, and 11 in Italy. He held patents in 23 countries, including Cuba, India, Japan, Mexico, Rhodesia, and Transvaal. He invented the induction motor and our present system of three-phase power in 1888 [20]. He invented the Tesla coil, a resonant air-core transformer, in 1891. Then in 1893, he invented a system of wireless transmission of intelligence. Although Marconi is commonly credited with the invention of radio, the U.S. Supreme Court decided in 1943 that the Tesla Oscillator patented in 1900 had priority over Marconi’s patent which had been issued in 1904 [15]. Therefore Tesla did the fundamental work in both power and communications, the major areas of electrical engineering. These inventions have truly changed the course of human history.

After Tesla had invented three-phase power systems and wireless radio, he turned his attention to further development of the Tesla coil. He built a large laboratory in Colorado Springs in 1899 for this purpose. The Tesla secondary was about 51 feet in diameter. It was in a wooden building in which no ferrous metals were used in construction [15]. There was a massive 80-foot wooden tower, topped by a 200-foot mast on which perched a large copper ball which he used as a transmitting antenna. The coil worked well. There are claims of bolts of artificial lightning over a hundred feet long, although Richard Hull asserts that from Tesla’s notes, he never claimed a distance greater than 43 feet. From photographic evidence, the maximum may have been closer to 22 feet [12].

Tesla then abandoned the Colorado Springs Laboratory early in 1900, having learned what he needed from that facility, and also having become somewhat unpopular as a result of frequently knocking the local sub-station off line.

Since that time, it appears that no one has built a Tesla coil of both the size and performance of the Colorado Springs coil. Apparently the only coil of that size was built by Robert Golka at Wendover Air Force Base in Utah [8] and later moved to a facility near Leadville, Colorado [9, 19]. The original purpose of this coil was to produce artificial lightning for testing the effects of lightning striking aircraft in flight. Golka determined that the average voltage produced in Utah was about 10 MV, with the highest voltage observed being 25 MV. Operation was spectacular, even if not quite at the level of the Colorado Springs coil.

When Golka's coil was moved to Leadville, however, it performed very poorly. Golka and his associates were basically unable to properly tune the coil. There has been considerable speculation over the reasons for the difference in performance, but one problem seems to be that we did not have adequate theoretical models for the design and operation of Tesla coils. What appeared to be minor differences in location and construction caused a major decrease in performance. The number of variables was simply too large to allow for a purely experimental optimization of performance before the coil was dismantled and moved early in 1990.

Some work on theoretical models has been performed by high energy physicists [6, 10, 1, 17, 18]. They are interested in high voltage capacitor discharges for research in plasma physics and in the production of pulsed particle or radiation beams. The most common way of producing such high voltage discharges is the Marx circuit, in which capacitors are charged in parallel to a lower voltage and then discharged in series through a number of airgaps. The Marx circuit requires the capacitor bank to be divided into sub-banks well-insulated from each other and from ground. A Tesla coil offers an alternative method of charging the high voltage capacitors. Discharges are reported in the range of 100 kA at 1 MV, with one report of 2.5 MV [10]. These models are all lumped parameter models.

There are a number of experimenters who build Tesla coils as a hobby. The Tesla Coil Builders Association has several hundred members and a quarterly newsletter published by Harry Goldman [7]. Harry has announced plans to stop publishing the newsletter at the end of 2001. The Tesla Coil Builders of Richmond has been a very active local group [11], although their leader Richard Hull has recently become interested in other activities. A number of manuals are available on how to build coils [16, 4, 5]. The one by Lee [16] is especially well illustrated with pictures of capacitors and other components that might be needed for a moderate sized Tesla coil. There is an Internet listserv (www.pupman.com) that has about 700 subscribers, which has been very helpful to me.

The brothers James and Kenneth Corum have done considerable work on distributed models of Tesla coils in the past few years [2, 3]. They argue that lumped parameter models are not adequate for all situations. Sometimes a distributed circuit analysis must be made. In this case, the Tesla coil secondary and another component called the extra coil are considered

as sections of transmission lines. This explains some of the effects in an elegant manner. They have written a sophisticated computer program, TCTUTOR, to analyze Tesla coils. They have also performed considerable historical research into Tesla's notes made on his facility in Colorado Springs [21].

The Tesla coil community is divided over the issue of lumped versus distributed models. A majority favors the lumped model approach. Some are outspoken in their belief that distributed models are useless at best and just plain wrong on important issues. I confess to being somewhere in the middle on this controversy. James Corum and I both have our Ph.D.s in electromagnetic theory, so I can mostly understand what he says, and I therefore have a natural orientation to the distributed approach. In my eyes, I am like a Baptist pastor of a 50 person congregation and James is like Billy Graham. That is, I hold him in awe. I have heard the Corums speak several times, and have gotten caught up in their knowledge and excitement.

On the other hand, I cannot honestly say that TCTUTOR has been helpful to me in building and understanding Tesla coils. I can see significant problems with distributed models, which will be discussed later. And James, like many bright people, has a tendency to talk down to us slow ones. This puts some people off, of course.

In this book we will look at both lumped and distributed models. We will point out difficulties with both. We will look at some data, and ask which approach does best in describing reality.

2 Classical Tesla Coil

A classical Tesla coil contains two stages of voltage increase. The first is a conventional iron core transformer that steps up the available line voltage to a voltage in the range of 12 to 50 kV, 60 Hz. The second is a resonant air core transformer (the Tesla coil itself) which steps up the voltage to the range of 200 kV to 1 MV. The high voltage output is at a frequency much higher than 60 Hz, perhaps 500 kHz for the small units and 80 kHz (or less) for the very large units.

The lumped circuit model for the classical Tesla coil is shown in Fig. 1. The primary capacitor C_1 is a low loss ac capacitor, rated at perhaps 20 kV, and often made from mica or polyethylene. The primary coil L_1 is usually made of 4 to 15 turns for the small coils and 1 to 5 turns for the large coils. The secondary coil L_2 consists of perhaps 50 to 400 turns for the large coils and as many as 400 to 1000 turns for the small coils. The secondary capacitance C_2 is not a discrete commercial capacitor but rather is the distributed capacitance between the windings of L_2 and the voltage grading structure at the top of the coil (a toroid or sphere) and ground. This capacitance changes with the volume charge density around the secondary, increasing somewhat when the sparks start. It also changes with the surroundings of the coil, increasing as the coil is moved closer to a metal wall. This may have been one of the reasons

that Golka's coil worked better in Utah than in Colorado, because the metal walls were closer to the coil in Colorado.

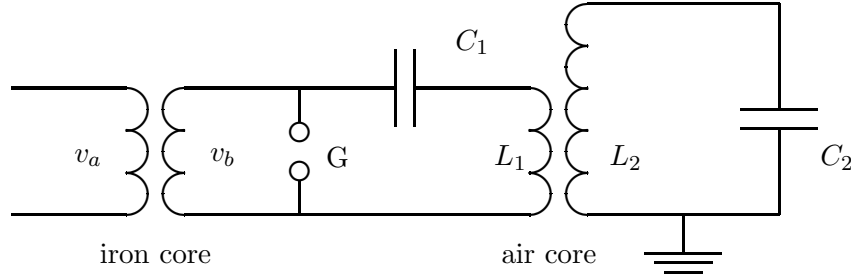


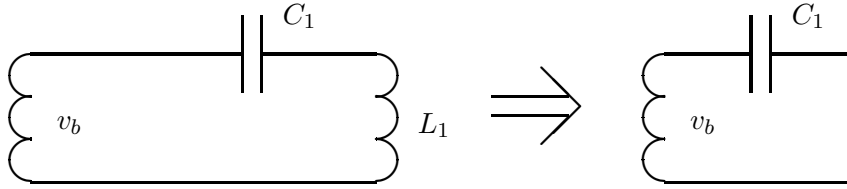
Figure 1: The Classical Tesla Coil

The symbol G represents a spark gap, a device which will arc over at a sufficiently high voltage. The simplest version is just two metal spheres in air, separated by a small air gap. It acts as a voltage controlled switch in this circuit. The open circuit impedance of the gap is very high. The impedance during conduction depends on the geometry of the gap and the type of gas (usually air), and is a nonlinear function of the current density. This impedance is not negligible. A considerable fraction of the total input power goes into the production of light, heat, and chemical products at the spark gap. In any complete analysis for efficiency, an equivalent gap resistance R_{gap} could be defined such that $i^2 R_{gap}$ would represent the power loss in the gap. This would have rather limited usefulness because of the mathematical difficulty of describing the arc.

The arc in the spark gap is similar to that of an electric arc welder in visual intensity. That is, one should not stare at the arc because of possible damage to the eyes. At most displays of classical Tesla coils, the spark gap makes more noise and produces more light than the electrical display at the top of the coil.

When the gap is not conducting, the capacitor C_1 is being charged in the circuit shown in Fig. 2, where just the central part of Fig. 1 is shown. The inductive reactance is much smaller than the capacitive reactance at 60 Hz, so L_1 appears as a short at 60 Hz and the capacitor is being charged by the iron core transformer secondary.

A common type of iron core transformer used for small Tesla coils is the neon sign transformer (NST). Secondary ratings are typically 9, 12, or 15 kV and 30 or 60 mA. An NST has a large number of turns on the secondary and a very high inductance. This inductance will limit the current into a short circuit at about the rated value. An operating neon sign has a low impedance, so current limiting is important to long transformer life. However, in Tesla coil use, the NST inductance will resonate with C_1 . The NST may supply two or three times the NST rated current in this application. Overloading the NST produces longer sparks, but

Figure 2: C_1 Being Charged With The Gap Open

may also cause premature failure.

When the voltage across the capacitor and gap reaches a given value, the gap arcs over, resulting in the circuit in Fig. 3. We are not interested in efficiency in this introduction so we will model the arc as a short circuit. The shorted gap splits the circuit into two halves, with the iron core transformer operating at 60 Hz and the circuit to the right of the gap operating at a frequency (or frequencies) determined by C_1 , L_1 , L_2 , and C_2 . It should be noted that the output voltage of the iron core transformer drops to (approximately) zero while the input voltage remains the same, as long as the arc exists. The current through the transformer is limited by the transformer equivalent series impedance shown as $R_s + jX_s$ in Fig. 3. As mentioned, this operating mode is not a problem for the NST. However, the large Tesla coils use conventional transformers with per unit impedances in the range of 0.05 to 0.1. A transformer with a per unit impedance of 0.1 will experience a current of ten times rated while the output is shorted. Most transformers do not survive very long under such conditions. Golka was not alone in burning out some of his transformers. The solution is to include additional reactance in the input circuit.

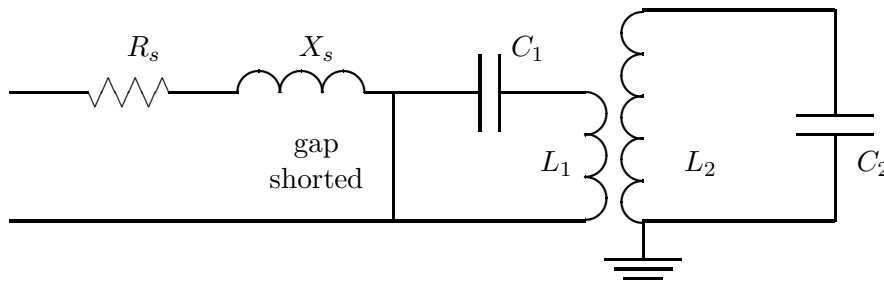


Figure 3: Tesla Circuit With Gap Shorted.

The equivalent lumped circuit model of the Tesla coil while the gap is shorted is shown in Fig. 4. R_1 and R_2 are the effective resistances of the air cored transformer primary and secondary, respectively. The mutual inductance between the primary and secondary is shown

by the symbol M . The coefficient of coupling is well under unity for an air cored transformer, so the ideal transformer model used for an iron cored transformer that electrical engineering students study in the first course on energy conversion does not apply here.

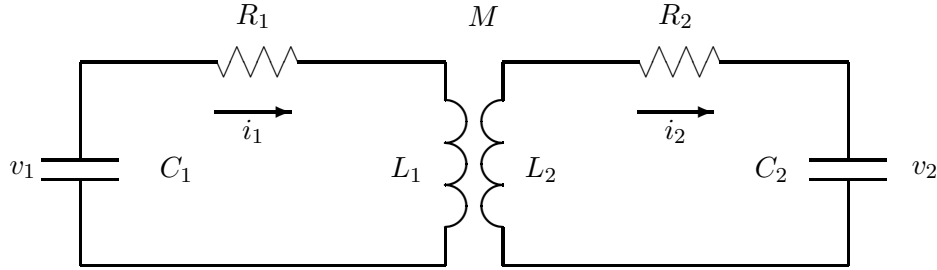


Figure 4: Lumped Circuit Model Of A Tesla Coil, arc on.

At the time the gap arcs over, all the energy is stored in C_1 . As time increases, energy is shared among C_1 , L_1 , C_2 , L_2 , and M . The total energy in the circuit decreases with time because of losses in the resistances R_1 and R_2 . There are four energy storage devices so a fourth order differential equation must be solved. The initial conditions are some initial voltage v_1 , and $i_1 = i_2 = v_2 = 0$. If the arc starts again before all the energy from the previous arc has been dissipated, then the initial conditions must be changed appropriately.

The Corums present the necessary solution technique in their manual [3] and also the computer code. The voltages and currents are not single frequency sinusoids. Rather there is a frequency spectrum with one hump for M small and two humps for M large. This is fascinating material for lovers of circuit theory, but is of somewhat limited usefulness in suggesting design changes for better performance.

It appears to this author that the time domain solution is more useful than the frequency domain. We simply examine v_1 , v_2 , i_1 , and i_2 as time increases, either graphically or in some sort of tabular printout. We then change one or more of the energy storage device values and do it again. It is also helpful to calculate the energy stored in each device. If the total energy stored in the circuit is decreasing monotonically with time, at the rate power is being absorbed by R_1 and R_2 , then one can be reasonably confident that the computer code is working correctly.

The time domain solution resembles a drunken walk in that it is difficult to predict what a given value will do next. Energy is moving among storage devices like cannon balls rolling around on the deck of an old sailing ship. Patterns can be changed readily by changing component values. We need a strategy for evaluating each solution for movement toward or away from some optimum. This strategy is developed by recognizing the following facts. After a small number of half cycles of i_1 , the arc will dissipate and the spark gap will again become an open circuit. At this point we want as much energy as possible stored in the secondary, either as $i_2^2 L_2 / 2$ or $v_2^2 C_2 / 2$. Any energy stored in C_1 when the gap opens is not available to

produce the desired high voltages on C_2 .

With proper design (proper values of C_1 , L_1 , C_2 , L_2 , and M) it is possible to have all the energy in C_1 transferred to the secondary at some time t_1 . That is, at t_1 there is no voltage across C_1 and no current through L_1 . If the gap can be opened at t_1 , then there is no way for energy to get back into the primary. No current can flow, so no energy can be stored in L_1 , and without current the capacitor cannot be charged. The secondary then becomes a separate RLC circuit with nonzero initial conditions for both C_2 and L_2 , as shown in Fig. 5. This circuit will then oscillate or “ring” at a resonant frequency determined by C_2 and L_2 . With the gap open, the Tesla coil secondary is simply an RLC circuit, described in any text on circuit theory. The output voltage is a damped sinusoid.

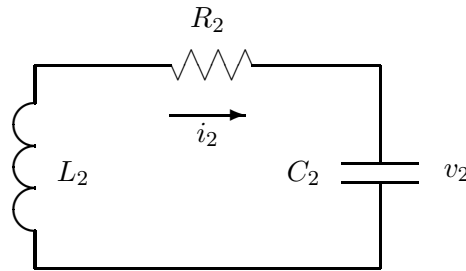


Figure 5: Lumped Circuit Model Of A Tesla Coil, arc off.

Finding a peak value for v_2 given some initial value for v_1 thus requires a two step solution process. We first solve a fourth order differential equation to find i_2 and v_2 as a function of time. At some time t_1 the circuit changes to the one shown in Fig. 5, which is described by a second order differential equation. The initial conditions are the values of i_2 and v_2 determined from the previous solution at time t_1 . The resulting solution then gives the desired peak values for voltage and current. The process is tedious, but can readily be done on a computer. It yields some good insights as to the effects of parameter variation. It helps establish a benchmark for optimum performance and also helps identify parameter values that are at least of the correct order of magnitude. However, there are several limitations to the process which must be kept in mind.

First, as we have mentioned, the arc is very difficult to characterize accurately in this model. The equivalent R_1 will change, perhaps by an order of magnitude, with factors like i_1 , ambient humidity, and the condition, geometry, and temperature of the electrode materials. This introduces a very significant error into the results.

Second, the arc is not readily turned off at a precise instant of time. The space between electrodes must be cleared of the hot conducting plasma (the current carrying ions and electrons) before the spark gap can return to its open circuit mode. Otherwise, when energy starts to bounce back from the secondary, a voltage will appear across the spark gap, and

current will start to flow again, after the optimum time t_1 has passed. With fixed electrodes, the plasma is dissipated by thermal and chemical processes that require tens of microseconds to function. When we consider that the optimum t_1 may be $2\ \mu\text{s}$, a problem is obvious. This dissipation time can be decreased significantly by putting a fan on the electrodes to blow the plasma away. This also has the benefit of cooling the electrodes. For more powerful systems, however, the most common method is a rotating spark gap. A circular disc with several electrodes mounted on it is driven by a motor. An arc is established when a moving electrode passes by a stationary electrode, but the arc is immediately stretched out by the movement of the disc. During the time around a current zero, the resistance of the arc can increase to where the arc cannot be reestablished by the following increase in voltage.

The rotary spark gap still has limitations on the minimum arc time. Suppose we consider a disc with a radius of 0.2 m and a rotational speed of 400 rad/sec (slightly above 3600 rpm). The edge of the disc is moving at a linear velocity of $r\omega = 80\ \text{m/s}$. Suppose also that an arc cannot be sustained with arc lengths above 2 cm. It requires $0.02/80 = 25\ \mu\text{s}$ for the disc to turn this distance. This time can be shortened by making the disc larger or by turning it at a higher rate of speed, but in both cases we worry about the stress limits of the disc. Nobody wants fragments of a failed disc flying around the room. The practical lower limit of arc length seems to be about $10\ \mu\text{s}$. With larger coils this may be reasonably close to the optimum value.

The third reason for concern about the above calculations is that the Tesla coil secondary has features that cannot be precisely modeled by a lumped circuit. One such feature is ringing at ‘harmonic’ frequencies. Neither the distributed or lumped models do a particularly good job of predicting these frequencies. Data will be presented later for a medium sized secondary (operated as an extra coil, explained in the next section), with a high Q resonance at about 160 kHz. When applied power is switched off, the coil usually rings down at 160 kHz. Sometimes, however, it will ring down at $3.5(160) = 560\ \text{kHz}$. A third harmonic appears in many electrical circuits and has plausible explanations. A 3.5 ‘harmonic’ is another story entirely.

These three reasons explain why we never see a paper giving a complete Tesla coil design with experimental data verifying the theoretical design. We get started with theory, but at some point have to move to an experimental optimization. The saying is, “Tune for most smoke”, which Harry Goldman attributes to Bill Wysock and Gary Legel. It is a tribute to the experimentalists that we have coils in existence with names like “Nemesis” that can produce sparks fifteen feet long [11].

3 Magnifier

As mentioned above, the classical Tesla coil uses two stages of voltage increase. Some coilers get a third stage of voltage increase by adding a magnifier coil, also called an extra coil, to their classical Tesla coil. This is illustrated in Fig. 6.

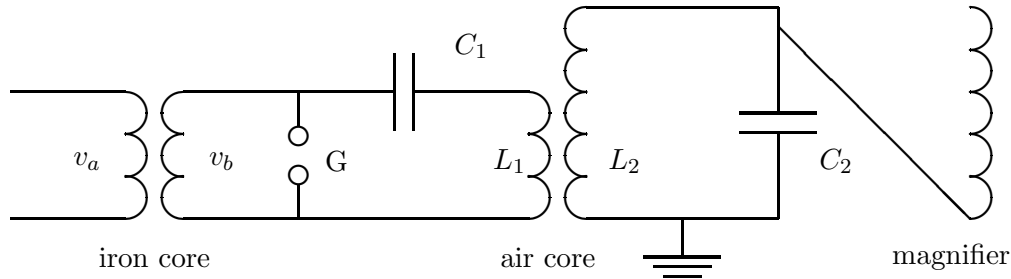


Figure 6: The Classical Tesla Coil With Extra Coil

The extra coil and the air core transformer are not magnetically coupled. The output (top) of the classical coil is electrically connected to the input (bottom) of the extra coil with a section of copper water pipe of large enough diameter that corona is not a major problem. A separation of 2 or 3 meters is typical.

Voltage increase on the extra coil is by transmission line action, rather than the transformer action of the iron core transformer. Voltage increase on the air core transformer is partly by transformer action and partly by transmission line action. When optimized for extra coil operation, the air core transformer looks more like a transformer (greater coupling, shorter secondary) than when optimized for classical Tesla coil operation.

The lumped circuit enthusiast would say that voltage rise is by RLC resonance. Both camps agree that voltage rise in the secondary and especially in the extra coil are not by transformer action.

Although not shown in Fig. 6 the extra coil depends on ground for the return path of current flow. The capacitance from each turn of the extra coil and from the top terminal to ground is necessary for operation. Impedance matching from the Tesla coil secondary to the extra coil is necessary for proper operation. If the extra coil were fabricated with the same size coil form and wire size as the secondary, the secondary and extra coil tend to operate as a long secondary, probably with inferior performance to that of the secondary alone. There are guidelines for making the coil diameters and wire sizes different for the two coils, but optimization seems to require a significant amount of trial and error.

In my quest for a better description of Tesla coil operation, I decided that the extra coil was the appropriate place to start. It looks like a vertical antenna above a ground plane, so there is some prior art to draw from. While the classical Tesla coil makes an excellent driver to produce long sparks, it is not very good for instrumentation and measurement purposes. There are just too many variables. The spark gap may be the best high voltage switch available today, but inability to start and stop on command, plus heating effects, make it difficult to use when collecting data.

I therefore decided to build a solid state driver. Vacuum tube drivers have been used for many years and several researchers have developed drivers using power MOSFETs, so this was not entirely new territory. It turned out to be a long term project. At the beginning, I had little idea about the input impedance of a coil above a ground plane, or how much power would be required to get significant sparks (say, half a meter in length or more). There have been many iterations, but I finally produced a design that would make sparks. Two major disadvantages are that it requires a digital oscilloscope with deep memory for tuning purposes, and one can make longer sparks using a standard spark gap. These disadvantages make it unlikely to sweep the Tesla coil community. There might be situations, however, where this approach would be useful. One is a museum installation, for example, where sparks of 0.5 to 1 meter are acceptable, and long life and low maintenance are critical factors.

The remainder of this document is a collection of my notes on this project, including some deadends. There are discussions on

1. Capacitance
2. Inductance and Transformers
3. Gate Driver and Inverter
4. Lumped Model
5. Experimental Results

Capacitance appears in many different places in the Tesla coil system, in the power supply, the controller, the driver, the coil body itself, and the top toroid or sphere. It therefore gets a lengthy treatment. Other items get a somewhat lesser treatment.

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Nikola TESLA's Wireless Systems

André Waser*

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After his inventions about the polyphase powering systems Nikola TESLA has focused himself more to experiments with high voltages, high currents and high frequencies. One of his goals was to transmit electrical energy without a power network directly from a central plant to the different consumers. In New York TESLA has done his first trials for this new technology. Then at the change of the century 1899-1900 TESLA moved to the high lands of Colorado Springs. There he has executed so many experiments, which has not been repeated in all its details and specialties until these days. Now, exactly one hundred years after a review about this impressive and important experiments may be of a particularly interest.

Introduction

It is surprising how little information can be found in literary about the work of the famous Serbian experimenter Nikola TESLA. In the contrary his antagonist Thomas EDISON, which mainly promoted the direct current systems, is mentioned where ever one looks. But it was Nikola TESLA who invented the today used polyphase power system in all its part of generation, transmission and consumption. It was Tesla, not EDISON, who has made the world-wide use of electricity even become possible.

And today almost all publications about TESLA's work are looking at his high frequency and high voltage transformers, known under the summary term „Tesla-Coil“. From time to time some papers has been published about this specific topic; for example for a repetition of some experiments^{[3],[7],[16]}, about applications of this transformers^{[1],[9],[17]}, about the measurement on such devices^[49] or about some theoretical considerations^{[2],[4]}.

Very special arrangements of the TESLA coils are the power transmitting and receiving devices of Tesla. Konstantin MEYL has recently published many papers about this topic. MEYL^{[10]-a,[11]-a} has used the same speculative explanation hypothesis as the author^[44] has used at an earlier time and which are – as suggested now – not necessary anymore.

It is typical for an experimental explorer that he discovers unexpected results and finds new facts only because he makes some leading experiments on the basis of speculative models. And because of this TESLA was far ahead of the theoretical knowledge of that time with his experimental practices. Therefore a communication with the established science was not always easy for him, what could be a reason (beneath of commercial interests) that Tesla has more or less stopped his publications in scientific journals after the year 1899 and since then only published in popular daily or weekly newsletters.

* André Waser, Birchli 35, CH-8840 Einsiedeln, Switzerland

Wireless transmission of electrical energy

In the years 1884-1889 TESLA got different patents for his alternating polyphase technology, which has been a substantial breakthrough at that time against the direct current technology. But leading economists and companies in Europe didn't understand TESLA's visions and he was forced to emigrant in the USA. Together with George WESTINGHOUSE TESLA made it possible to build the first alternating power station of a large scale at the Niagara Falls in 1893. But the first patent^[19], which reveals the landmark thoughts TESLA's, was filed in the year 1891 and is a fully description of a high frequency lighting system. The specific feature of this system is the use of only one supplying single wire to the particularly build and patented single terminal carbon lamps without a return wire. (The patent has been granted in the record time of only two months.)

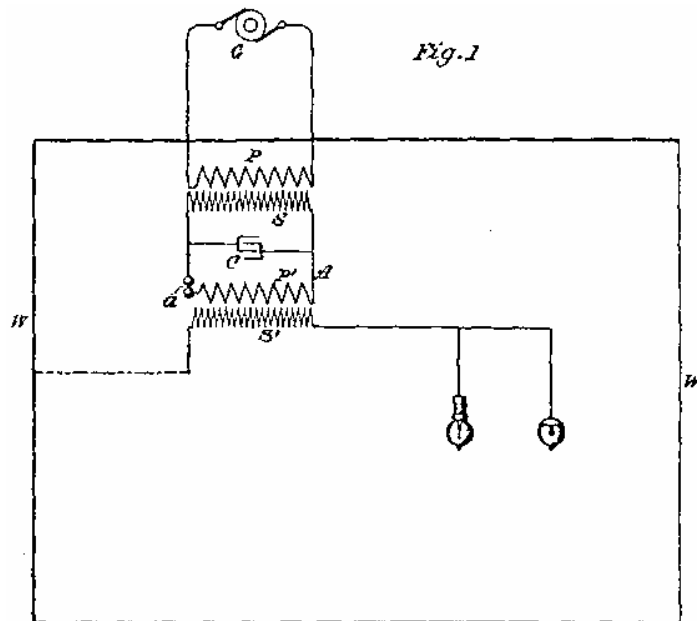


Figure 1: US-Patent 454,622 „System of Electric Lighting“ issued on June 23rd, 1891^[19]

With the first transformer P-S the alternating voltage of generator G (about 5 kHz) is transformed to high voltage. The resonance circuit S-C is then vastly discharged along the spark gap. As a result there are high current peaks in the primary winding P' of the second transformer. With this second transformation the high frequency part of this current peaks is again transformed upwards and feeds the load circuit. One end of the second secondary S' is connected to a long wire or wire grid W positioned along the room walls. The other end is connected to TESLA's invented single terminal lamps. In opposite to the lamps used today this lamps have only one connector. And this connection leads to an electrode – mostly made from carbon – inside the fully or partly evacuated glass bulb. On different occasions TESLA^{[18],[20],[22]} has demonstrated, that this high frequency currents and voltages do not cause immediate injury to the experimenter (himself) or the audience.

This patent shows all characteristics of the high frequency circuits with high voltage and high currents as used by TESLA. In the following steps TESLA optimized the technology of generation and utilization of high frequency and high voltage apparatus, which he mostly applied to lighting systems with different kinds of bulbs. In the year 1897 he applied for three patents about the transmission of electrical energy. The first patent^[23] he registered on March 20th about a high frequency transformer with high power capabilities. Besides a common ground connection this transmission method needs only one transmission wire.

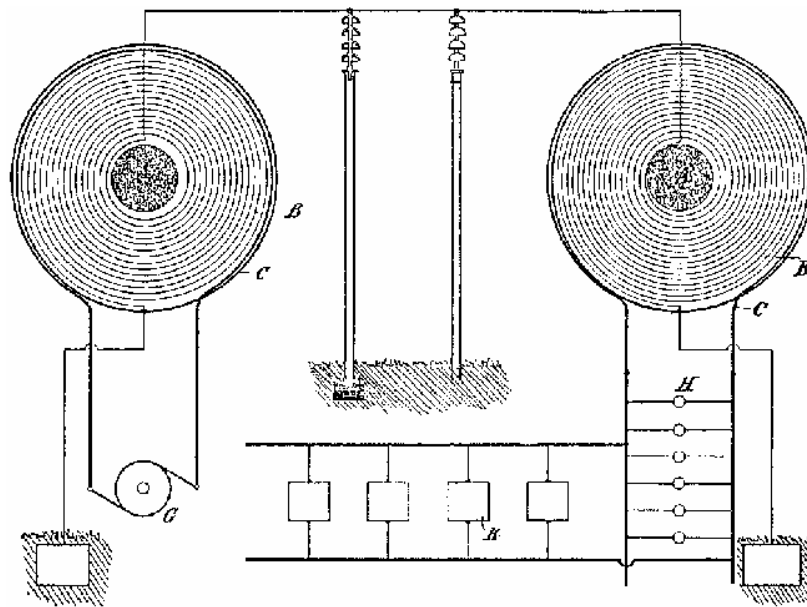


Figure 2: US-Patent 593,138 „Electrical Transformer“ issued on November 2nd, 1897

The generator G supplies the primary of the flat coil C. This simplified diagram does not come very close to the real experimental setup^[27]. Then as previously shown with the patent about the lighting system an intermediate step-up transformation with a spark gap and a high voltage transformer is necessary to achieve a resonant frequency of some million cycles per second. With some advantages it is also possible to use this step-up transformation after the flat secondary coil B. This flat coil TESLA^[21] has extra patented because of its excellent performance with high voltage and high frequency signals. On one end the secondary B is connected to ground and on the other end to the transmission wire which is connected to a receiving device with a flat coil B' of a symmetrical form. With a step-down transformation with the coil C' the electrical energy is finally transmitted from the generator G to the load L with only one conducting wire.

Some months later TESLA^[27] has shown that the transmission wire can be dropped completely and can be replaced by a glass tube filled with air of low pressure.

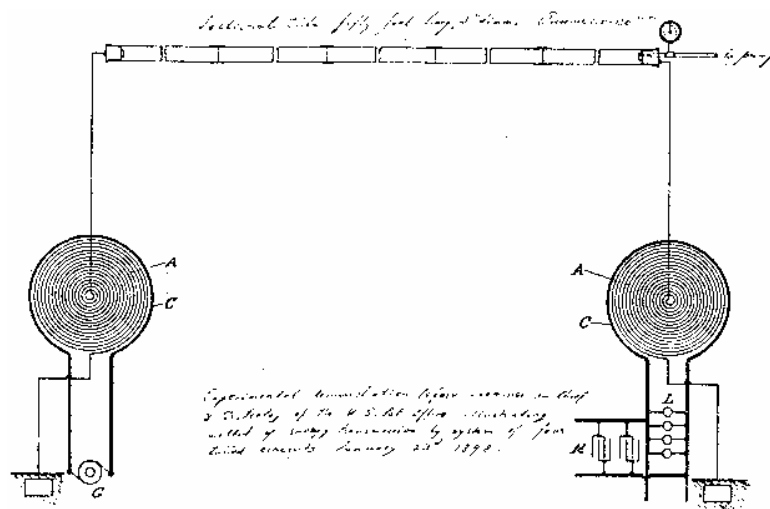


Figure 3: Slide of Nikola TESLA^[27] about the energy transmission through a partly evacuated glass tube; dated of January 23rd 1898.

In figure 3 the arrangement of figure 2 can be found again. With this discovery of the good electrical conductivity of air of low pressure the path was free for further developments.

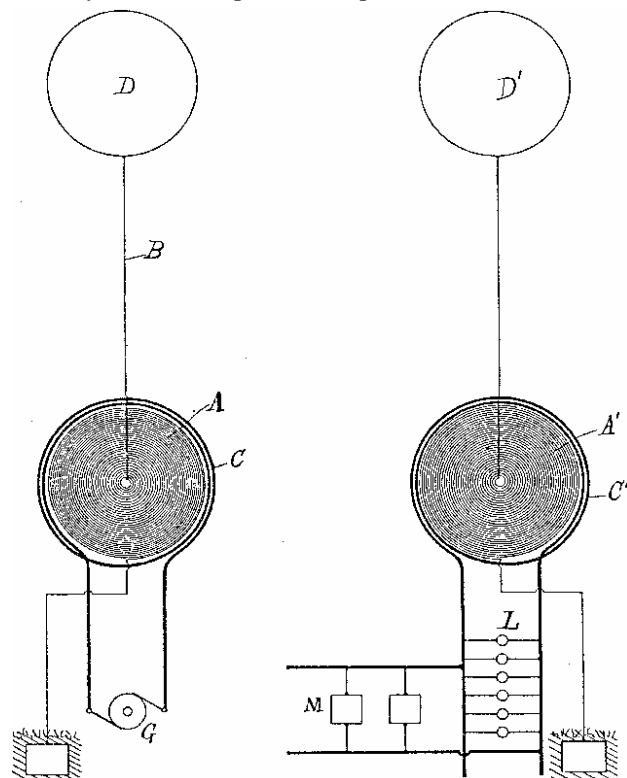


Figure 4: US-Patent 645,576 „System of Transmission of Electrical Energy“ filed on September 2nd 1897, issued on March 20th, 1900

Then on September 1897 TESLA^{[24],[25]} has filed two other patents for the transmission of electrical energy (figure 4). But the granting of this patent has been made dependent of the experimental success as a corresponding part in the patent shows (Pat. 645'576, p. 3, col. 2).

In this patents TESLA writes of a grounded high frequency emitter with a highly elevated ball electrode which was in resonant connection with a symmetrical, grounded resonant circuit (receiver) to enable the energy transmission through the upper atmosphere, which in great heights becomes more and more conductive for electrical currents.

The *Electrical Review*^[24] of London published on May 1899 a summary of articles about the work of Nikola TESLA previously published by their New York colleges. Here TESLA stated that the air will have a sufficient conductivity for his experiments, if the ball electrodes are placed in a height of four miles (~6.5 km). This could probably be done by balloons, TESLA suggested.

Trained with many experiments TESLA left New York on May 11th 1899 to the highlands of Colorado Springs (2000 m about sea level) where he experimented^[27] with several systems for the transmission for electrical energy until the turn of the century on January 11th 1900. One of the goals was to prove by experiment the feasibility of his patent applications of 1897. As a result of his experiments he got his second patent^[24] on March 20th 1900 and his third patent^[25] on May 15th 1900. And only one day after he got this third patent he filed an other, very important patent^[32]. In this patent he describes for the first time in detail the energy transmission through the earth and gives more information about signal detection (figure 5).

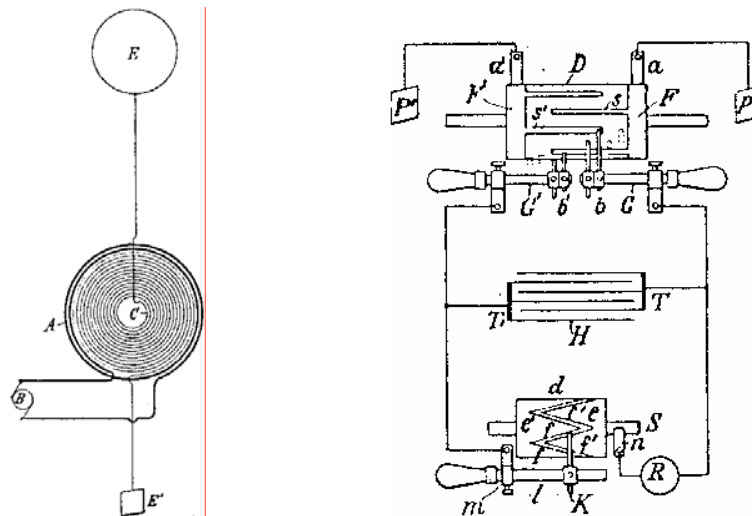


Figure 5: US-Patent 787,412 - „Art of Transmitting Electrical Energy Through the Natural Mediums“ filed on May 16th 1900, issued on April 18th 1905.

Obviously he was only able to file this patent after the other two patents from 1887 has been granted. And this is because the older patents and this new one does contradict each other in the description of the method of the energy transmission in essential points! The results of the Colorado Springs experiments has motivated TESLA to replace his previous patents – based on his New York experiments – with a newer and accurate one.

Almost during his work in Colorado Springs TESLA^[28] to ^[31] filed continuously some patents which report his experimental progress in detail but which are mainly focused on the receiving devices only and not on the full system of transmitter and receiver.

The topic of signal transmission through the earth has engaged Tesla further and two months later he again filed a patent^[39] which shows some different methods for signaling with and without the use of transmitting wires.

All his efforts culminated in a project for the transmission of electrical power of 10MW in Wardencliffe^[1], USA, which has never been completed probably because of low fundings. The basic arrangement for the large scale power transmission was published in his last patent^[40] file of this kind.

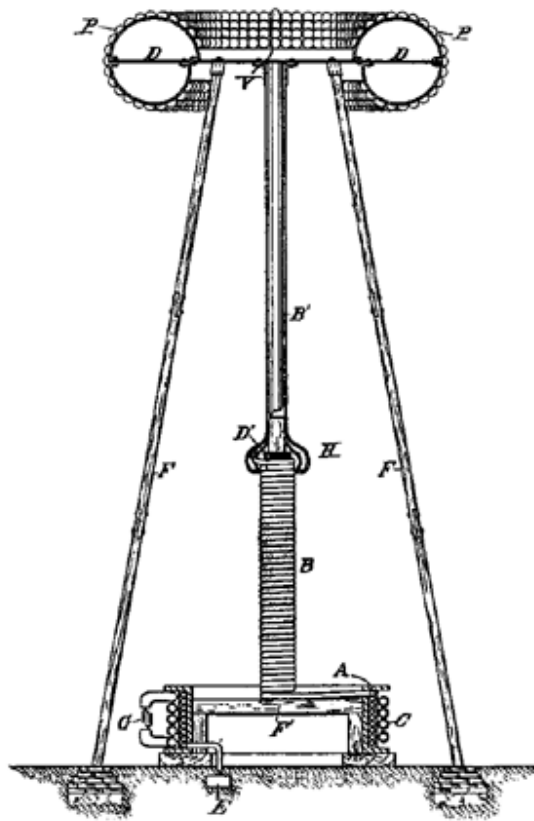


Figure 6: US-Patent 1,119,732 - „Apparatus for Transmitting Electrical Energy“ filed on January 18th 1902, issued on December 1st 1914.

This enormous work TESLA's, which has not – or only perfunctory – been published in the scientific publications of that time, is worth to be reconsidered at least partly on the basis of today's knowledge and theories.

On the first glance to the series of figure 2 to 4 one supposes that the energy transmission finally occurs through the air by the means of an increasing electric conductivity of the upper atmosphere. Actually TESLA^{[24],[25]} has written in his first patents that this is the case. But with

a closer look at his drawings there can be recognized that all his circuits has – beneath the high voltage transformers – an other common thing: the ground connection. In later publications TESLA^{[32],[36],[32]} has mentioned explicitly that the really conductor of the power transmission is the Earth itself. The Earth acts like a giant reservoir for electrical charges which can be set into oscillation by his powerful equipment. Is now a very sensitive resonant circuit (receiver) placed on an other place on Earth, which is tuned to the transmitter's frequency, then the receiver couples to this oscillations and gains its signals due to resonance.

This electrical excitement of the Earth TESLA^{[27]-S.61, [36]} has discovered in a stormy night from July 03rd to 04th 1899 in Colorado Springs. To his great surprise he detected standing waves on the Earth surface after heavy lightning. With his sensible equipment he was able to record that the signals first diminished when the storm passes away but then again increased and later on diminished again and so fourth. Of a special interest for Tesla was the fact that the different maximum readings almost increased the more the storm was moved away from the receiver, and this to an estimated distance of about 200 miles.

The receiver must be constructed according to figure 4 by enabling powerful oscillations between Earth and the elevated charge terminal D', if it is used for energy transmission. If only signals are to be detected, then it is sufficient to have a receiving device according to figure 5, which only detects and demodulates electrical signals on Earth's surface.

After his discovery on July 3rd 1899 TESLA obviously has done further measurements, which he has not published in great detail, but on which he has made some insinuations^[32] after his time in Colorado Springs. Beneath some distortions due to lightning and other influences due to sun eruptions and aurora borealis he also discovered a week periodic signal. He was only able to speculate about the origin of this signal, which he recorded with his very sensitive devices.

Today we can assume with great certain that TESLA has detected radio signals from pulsars, from which he erroneously thought^[35] they are signals from intelligence of civilizations on other planets. Since 1967 the radio signals of pulsars has not been detected again by science. The team of Antony HEWISH^[6] in the Cavendish-Labor of Cambridge has re-discovered this signals, for which HEWISH received 1974 the Nobel price of physics, which really had been admitted to TESLA. It is typical for the awarding of this Nobel price, that Jocelyn BELL-BURNELL, who has worked in HEWISH's team and who first has noticed the absolutely unknown and curious peaks of a period of $1\frac{1}{3}$ seconds on the recorded signals, also not has been nominated .

TESLA intended to transmit huge amount of electricity through the atmosphere and discovered with his experiments in Colorado Springs^[27] the surprising fact of Earth's electric conductivity. By using the whole planet as a receiving device Tesla had the biggest radio telescope ever used on Earth to detect signals from outer space. He was not able to determine the exact direction of the incoming signals but the sensitiveness of his receiving equipment was so extremely high (for that time), that he was able to detect this signals from which we know today that they come from pulsars and magnetars. This is – beneath the discovery of the X-rays (later named by Roentgen) – his second missed Nobel price.

Analysis

The force of an oscillating HERTZ dipole on a stationary charge is well known. This can also be described as a sum of forces between relatively resting, moving and accelerating charges as the author^[45] has shown for the case of large distances to the HERTZ dipole. A transmission of electrical energy from one point to another is certainly possible with a HERTZ dipole, too. But with increasing distance r from the transmitter the energy density diminishes rapidly. This law of distance can be undergone when instead of air under normal pressure a conducting medium (electrical wire) is used. An almost frictionless transmission of electrical energy between two points on Earth without wires only can be done by using some sort of a 'connecting wire', a voltage or current source and a load. This connecting wire is the Earth. The voltage or current source is the transmitter and the receiver is the load.

The elevated terminals D and D' function as a charge reservoir (electric capacitor), but they do not act as the transmitting terminal itself, whereas the energy is given off to the air. If no transmission through air is planned, it is preferred to insulate these terminals so that no charges are lost to the atmosphere. This has been sometime described by TESLA. For a simpler construction TESLA could have placed the capacitor terminals D and D' beneath the transformers A-C and A'-C' respectively. But obviously the specific arrangement of the terminals D and the supply wire B as shown in all patent drawings is very important for the correct function of the apparatus.

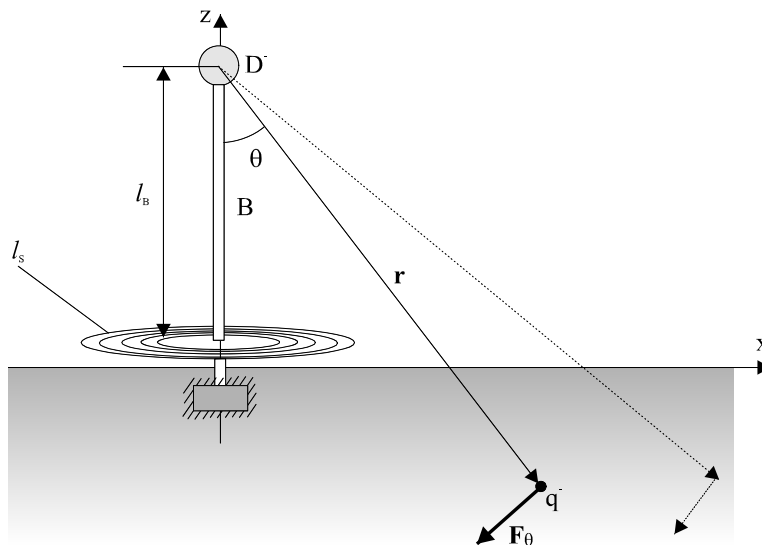


Figure 7: Accelerating dependent forces of a TESLA transmitter on negative charges in the Earth.

TESLA has operated the Earth as a ball capacitor. The transmitter "pumps" with a frequency between 20...250kHz^{[24],[32]} electrons between the Earth and the elevated terminal back and fourth. To minimize the HERTZ radiation losses this frequency has to be as low as possible, as TESLA has mentioned explicitly. To achieve an optimal effect it is necessary to use high voltages. Tesla has tuned the whole conductor length consisting of the secondary coil A and of the conductor B to the wave length of the resonant frequency of the secondary.

With this tuning the voltage between ground and terminal rised up to more than four Million Volts. To produce such high voltages a resonant circuit with high efficiency (low damping) is requested, as TESLA mentioned many times. For that he sometimes used his flat spiral coil. The main goal is to move as many charges as possible in a short time from the terminal down to the usually bad conducting ground and back to the terminal again.

If we look at the transmitter oscillating with the resonant frequency ω then the equation of the force between resting, moving and accelerating charges ^{[45],[46]} can be applied. At the considered time the terminal D should be fully charged with electrons.

The conductor part l_B is much shorter than the conductor l_S used in the coil S as arranged in the TESLA experiments. So we can assume with high accuracy that the current is not a function of the direction z. Then, for example, on a distance $r \gg l_B$ the acceleration dependent force^[45] acts on charges in the vicinity of the transmitter proportional to $1/r$:

$$\frac{\mathbf{F}}{q} = \frac{I l_B}{4\pi\epsilon_0} \frac{i\omega}{c^2 r} \sin\theta \mathbf{r}_\theta^0 \quad (0.1)$$

That means, the electrons previously sitting in D are not only locally pressed into ground but in addition there acts a force \mathbf{F}_θ on every ,free‘ charge in the Earth (and atmosphere), which is inverse proportional to the distance to the transmitter. This force pushes (or pulls) the negative charges in the Earth down to deeper layers (or up again to the transmitter). Additionally there acts also a force proportional $1/r^2$ to on every charge in the ground around the transmitter. Only the simple “injection” of electrons into ground has a much smaller effect than the forces of the moving and accelerating charges in the wire element B.

With this explanation it is clear why Tesla used such high voltages or why he always intended to use as much charges as possible in his circuits. The effects of the moving and accelerating charges in the wire B depends directly on the number of involved electrons and of the frequency of the apparatus. The acceleration can not be made higher in ordinary conductors but the number of electrons can be increased with higher voltages. And the increasing of the voltage was always TESLA’s intention.

The energy of the transmitter is used for the acceleration of the free charges in Earth, which in turn again accelerate more distant charges in the ground. The result is a longitudinal wave of oscillating electrons across the Earth’s diameter. And exactly this is what TESLA^[32] always has claimed to do. If the Earth would be a body of unlimited size, the impressed wave would be dissipated as well as the involved energy. But because of the finite size of the Earth the longitudinal wave soon approaches the borderline to the atmosphere where it will be reflected similar to sound waves. The really astonishing fact is, that the longitudinal wave through the Earth is close to the speed of light in vacuum as can be calculated form TESLA’s patent information.

If the Earth is electrically struck – for example by lightning – there will always be at least two basically different resonances. The main resonance between Earth and atmosphere is known as SCHUMANN resonance^{[14],[15]} and has a frequency of about 7.9 Hz, whereas the TESLA resonance is 11.8 Hz. Both different resonances are again presented in figure 8.

The Earth behaves like a perfect electrical conductor: „...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.“ This wave is concentrated and reflected exactly at the opposite pole of the planet as Charles YOST^[49] and HARTHUN et. al.^[5] has shown. TESLA describes in one^[32] his patents the velocity of the

surface wave along the Earth's circumference from pole to pole in words as to be $v_0 = 471'0240 \text{ km/s}$. This means, the wave velocity through the Earth along the diameter $2r_E$ is close to the speed of light in vacuum, then it is:

$$\frac{v_0}{c} = \frac{l_0}{2r_E} = \frac{\pi}{2} \rightarrow v_0 = c \frac{\pi}{2} \quad (0.2)$$

So the speed of the longitudinal wave through the Earth is close to c . The main longitudinal resonance is 11.79 Hz . With this longitudinal wave of free electrons in the ground the whole Earth is set in resonance. The Earth diameter must be an odd multiple of a quarter wavelength of the transmitter. Then, to produce a forward and backward wave front, the signal must be applied at least for 0.085 seconds to achieve a standing wave. And exactly all this numbers are given in TESLA's patent^[32].

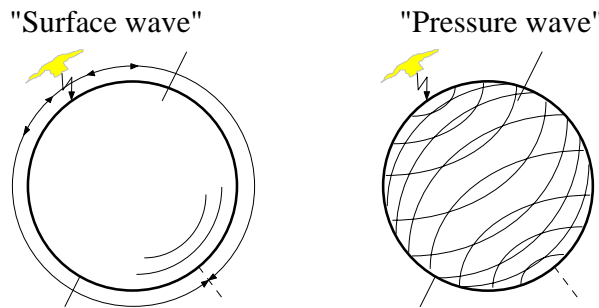


Figure 8: Difference of SCHUMANN (left) and TESLA (right) resonance

Once there are built such standing waves it is possible to produce on different places on the globe wave knots, where the excitation is a maximum and places where no oscillation can be measured. Preferably on the places of maximum oscillations a receiver is placed. This receiver is built symmetrically to the transmitter. Because of its low OHM'ic losses the receiver gains its amplitude due to resonance. Then the receiver becomes a transmitter, too. The receiver also builds a standing wave in strong synchrony with the transmitter and as a result the energy transmission can be started, if a load is placed on the receiver as shown in figure 4. Principally this energy transmission is possible in both directions.

First the transmitter must supply the energy to build up the standing wave in Earth and the to build up the receiver's oscillations. This does not require a high energy throughput. Then, as Tesla states, if this standing waves are established in perfect synchrony an energy transmission can be done without heavy losses. The energy consumed by the receiver (and the losses) out of the standing waves must be supplied by the transmitter to hold the oscillating system through the Earth alive. According to TESLA^[2] the requested energy transmission can be made with an efficiency of 99.5% .

The assumption^{[10]-b}, that TESLA has received more energy than transmitted – and therefore gave his system the name „Magnifying Transmitter“ – can neither be definitively confirmed nor rejected with the presented analysis. There exists a text passage^[4] that may support this assumption, but in most other original publications TESLA^{[2],[3],[3]} always claims of an efficiency of about 99% .

If only the receiving of signals is requested, the receiver can be built much cheaper, because it has not to induce also a standing wave into Earth. Also the transmitter does not necessarily have to produce a standing wave in Earth so that every desired frequency can be

used. According to figure 5 (right side) the receiver can detect the potential difference between two distant points on the Earth surface. It is possible to receive signals around the globe as well as under water with this method.

TESLA has used high voltages and high currents, as he often said. The noise of his experiments in Colorado Springs was detectable many miles. Despite the fact, that he doesn't involve such large amounts of energy as assumed to be released in thunderstorms, the analogy to lightning is allowed. So the Earth's longitudinal resonance should be detectable if lightning strikes the Earth surface. Actually it can be seen by eyes that the lightning brightness appears to flicker. It is known^[8], that with ground lightning the flash strikes two to four times the same location within a time duration between each stroke between 40...80 milliseconds. This corresponds to the propagation time of a forward and backward wave through Earth close to the speed of light in vacuum.

Up to this point the transmitter and receiving devices are described in its basic functionality. It is desirable that this particular TESLA devices would be reconstructed in fully detail as done hundred years ago in Colorado Springs to get an even better understanding what has happened.

TESLA has made much more progress after his experiments with the transmission of electrical energy as mentioned above. Over 30 years he has made much more discoveries, which he has published only partly or even nothing. But in his later years he always mentioned a new energy source he already has found in the years, where he worked with the wireless systems. About this part of TESLA's work an other paper^[48] will be published.

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Figure 9: TESLA in his New York laboratory. Has for example be published 1897 in *Electrical Review* (New York and London).

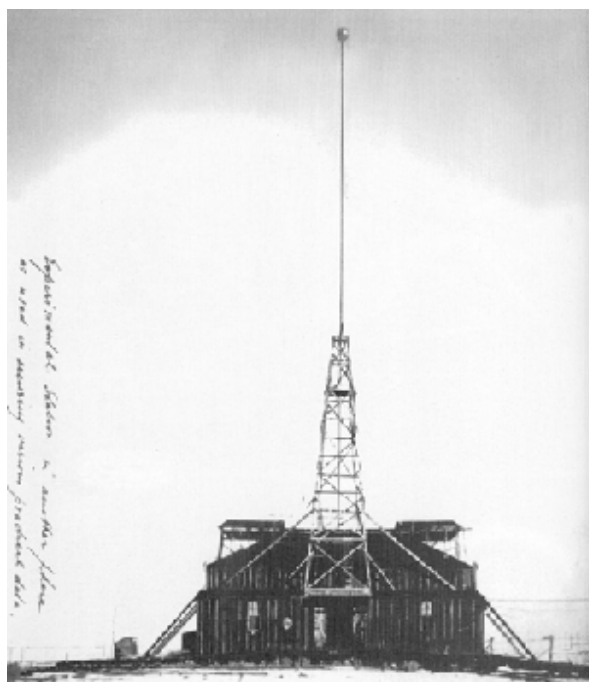


Figure 10: TESLA's Colorado Springs experiment in 1899. The metal ball (~75cm diameter) can be moved in height up to 50 meter about ground.



Figure 11: The skillet of the first TESLA plant (constructed ~1901-1903) for the transmission of energy and broadcasting signals in Wardencliffe, Long Islands, New York. It was never completed.

SUMMARY NOTES ON TESLA COILS

K.L. Corum and J.F. Corum, Ph.D.

“The apparatus is practically the lamp of Aladdin.” Nikola Tesla (1916)¹

A. The Lumped-Element Regime

1. Transients (finite energy signals)². The lumped element Tesla coil (lumped element, coupled, tuned circuits) was demonstrated at Columbia University and patented in 1891.^{3,4,5,6} Initially, the primary capacitor is charged up by the power mains transformer. When the break conducts, the initial stored energy discharges into the RF primary. During the time that the primary spark is conducting, the system operates in the Lumped Element regime (Fig. 1). Writing the coupled second order circuit differential equations (including resistive losses) results in the following interplaying damped oscillations, which fritter away the energy.^{7,8,9,10} $x_{1,2}(t) = A_U e^{-\alpha_U t} \cos(\omega_U t + \varphi) + A_L e^{-\alpha_L t} \cos(\omega_L t + \psi)$ (The analysis is in our references.)

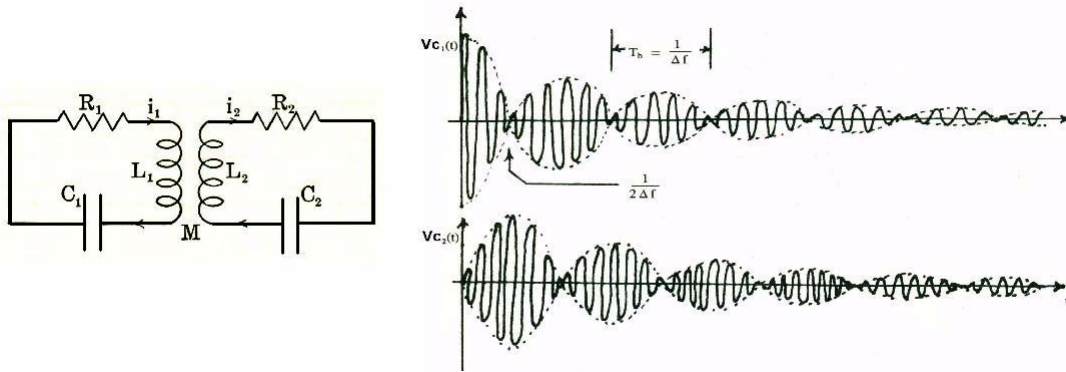


Fig. 1 (a) Coupled oscillators (lumped): infinite duration primary spark. (b) Transient oscillations.

Unlike Hertz, who did not use C_1 , *Tesla's stroke of genius*^{11,12,13,14,15} was to move the energy storage capacitance to the primary side (where it could be huge by comparison to C_2) and use it to tune the primary. [Incidentally, the last 2 references copied these remarks without source attribution. When we were kids, ... in the days before Doris Kerns Goodwin, this used to be called plagiarism. We were stunned that a Cantabrigian of such stature would openly bootleg from us in an IEEE paper and a Wiley textbook.] The highest voltage step-up *possible* from a properly tuned, lossless, lumped-element coupled circuit is, by Kelvin's conservation of energy principle,¹⁶ the square root of the primary-to-secondary capacitance ratio:¹⁷

$$W = \frac{1}{2} C_1 V_1^2 = \frac{1}{2} C_2 V_2^2 \quad \Rightarrow \quad V_2 = \sqrt{\frac{C_1}{C_2}} V_1$$

2. Spectra. The Fourier magnitude-spectrum of the voltage across the secondary capacitor is a double-hump, characteristic of a tightly coupled IF transformer or a Double Side-Band oscillation:¹⁸

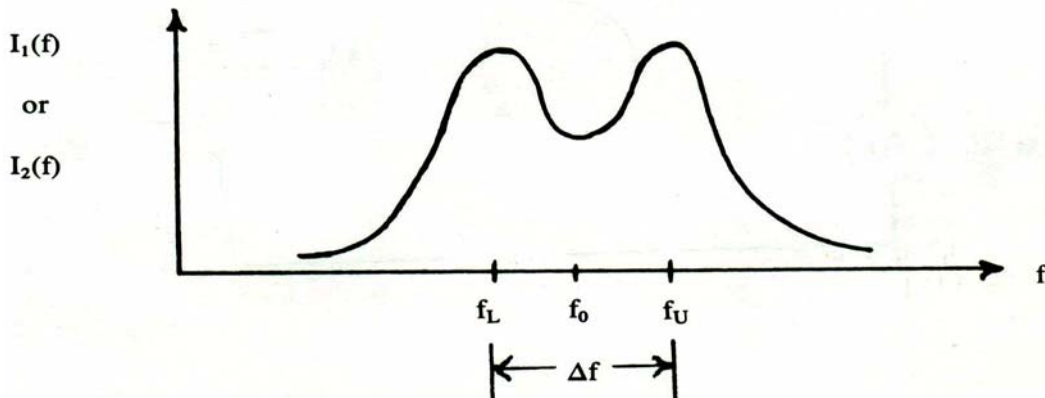


Fig. 2. Fourier spectrum of the time-domain waveforms in Fig. 1(b). The beat period is $T_b = 1/(\Delta f)$.

For low-loss circuits with $L_1C_1 = L_2C_2$, or $f_1 = f_2 = f_0$, formal analysis gives the two frequencies (appearing in each mesh) as

$$f_{L,U} \approx \frac{f_0}{\sqrt{1 \pm k}} \quad \text{or} \quad \Delta f = f_U - f_L \approx k f_0$$

where we have separately resonated the isolated tuned circuits at f_0 , and k is defined in Figure 3.

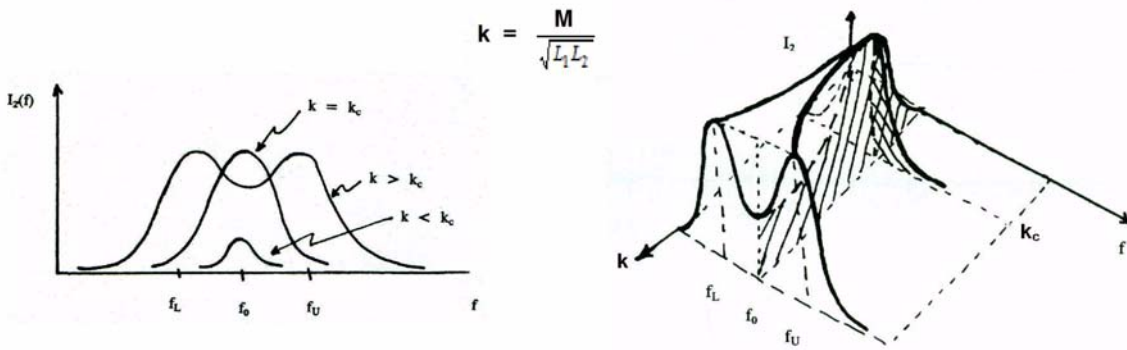


Fig. 3. (a) Line splitting due to coupling. (b) Three dimensional plot as the coupling is tightened.¹⁹

As the magnetic coupling between primary and secondary is increased, the upper and lower spectral prominences split and move further apart. (See Tesla's comments.)²⁰ However, they coalesce into one component when $\omega M = (R_1 R_2)^{1/2}$ giving $k = k_c = 1/\sqrt{(Q_1 Q_2)}$, which is called "critical coupling". (Maximum power transfer occurs at *critical coupling*, "The resistance which the secondary couples into the primary at critical coupling is equal to the primary resistance."²¹ But, the efficiency of the machine then drops to only 50%.) Radio engineers will recognize the impulse response of an IF "can" in Figures 1 and 3.

3. Importance of Dwell (Spark Duration). From Figure 1(b), the time for the primary energy to be transferred to the secondary is $\frac{1}{2} T_b$ (half the beat period) which is $1/(2\Delta f)$. If the coupling is looser the spread Δf is smaller and energy transfer will take longer. At critical coupling or less $\Delta f \rightarrow 0$ and the required transfer time (the primary spark duration) $t_s \rightarrow \infty$. If the coupling is tighter, the spread between spectral peaks widens and the energy transfers more rapidly, *requiring very short primary spark durations*. The rate of transfer of energy from the primary to the secondary depends upon the tightness of coupling. Fig. 4 is a plot of normalized secondary voltage as a function of primary spark duration for two values of coupling, k . Clearly, tight coupling (and the associated short t_s) is desirable. (Easy to attain with IGBT's.)

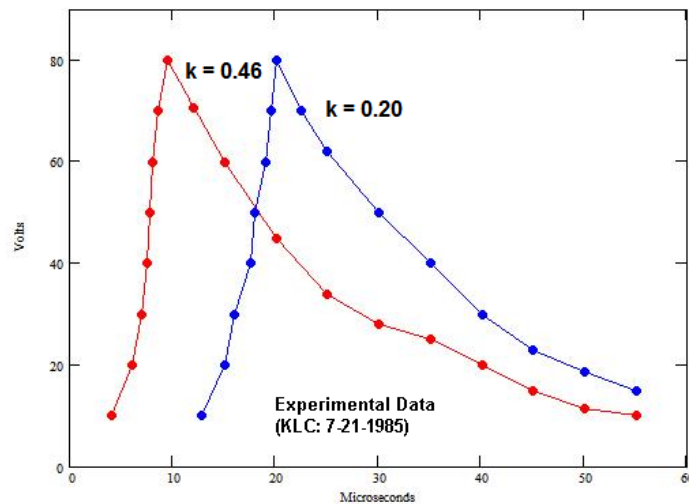


Fig. 4. Measured $|V_2|$ for fixed k , V_1 , C_1 and C_2 as primary spark duration, t_{pss} , is varied. Note the dramatic advantage for operating with a commensurate coupling and spark duration.^{22,23,24}

Skilling gives the physical reason for energy transfer between coupled oscillators:

“As long as the current in the primary is inducing a voltage in the secondary that has a component in phase with i_2 , there will be energy added to the secondary. At the same time the voltage being induced in the primary by i_2 has a component in opposition to i_1 and energy is being removed from the primary.”²⁵

It can be shown that the time required for $V_{C2}(t)$ to reach its first maximum, which is when you would like the primary spark to break, is given by: $\Delta T = 1/(2\Delta f)$.²⁶ The voltages would then look like Figure 5. But, this is *not* what is observed for *distributed-resonator* machines. (See Fig. 7, below.)

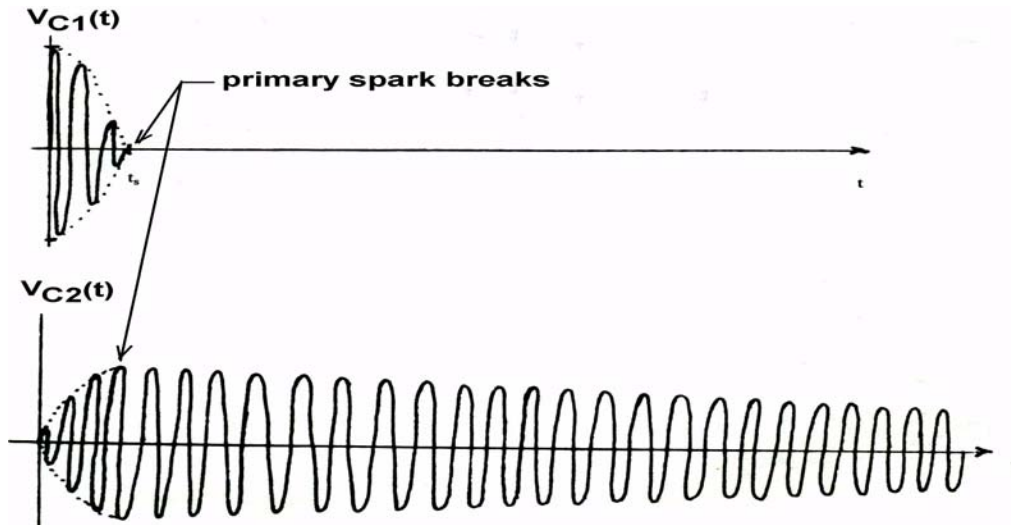


Figure 5. A perfectly timed rotary break. (Note the decay of V_2 after the primary spark breaks.)

4. Lord Kelvin's Logarithmic Decrement.²⁷ The exponentially damped RF wave shown in Figure 6, $[V(t) = e^{-\alpha t} \sin(\omega_0 t)]$ where $\alpha = \pi f/Q$, has successive, but decreasing, peaks at $t = nT = n/f_0$. Consequently $X(t)/X(t+T) = e^{\alpha T} = e^{\delta}$. The logarithm of the ratio falls by δ during each complete oscillation (cycle), which is the product of the damping coefficient and the period, and is called the logarithmic decrement: $\delta = \alpha T = \alpha/f = \pi/Q$. (The more damping, the bigger the decrement, and the broader the signal.)

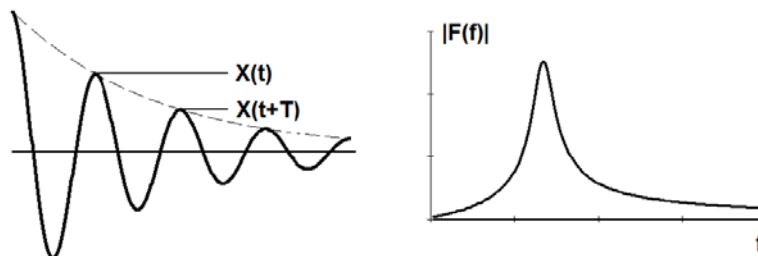


Fig. 6. Damped wave, decrement and spectrum.

5. Finkelstein's 'Optimum Coupling' for Lumped Operation. When the open circuit resonances are equal ($f_1 = f_2 = f_0$), David Finkelstein²⁸ found an optimum magnetic coupling of $k = 3/5$ (which is significantly greater than *critical* coupling) for total energy transfer with only 1 primary voltage reversal. (See Fig. 7.) This makes $f_U = 2f_L$. However, this *also* requires the break's spark duration to be $t_s = 1/(2\Delta f)$ which can be a challenge to obtain mechanically. (Tesla at Colorado Springs had $f_0 \approx 100$ kHz, and the required spark duration would be about $t_s = 8$ μ s.) Otherwise, there will be a beat wave. Furthermore, the lumped circuit analysis is valid *only during the primary spark duration*, while the primary and secondary are mutually bathed in magnetic flux and no standing waves are set up yet on the secondary (resonator).

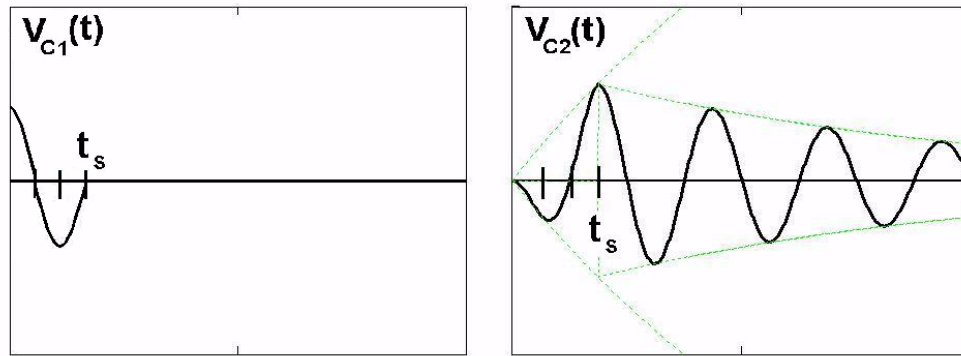


Fig. 7. (a) Complete transfer of energy with only one voltage reversal. (b) Ring up/down.

B. The Distributed-Element Epoch

6. **Fleming & Dyke.** As observed via wave-meter measurements long ago, Fleming & Dyke²⁹ noted that the spectrum of the induced voltage has *3 humps, not two*.³⁰

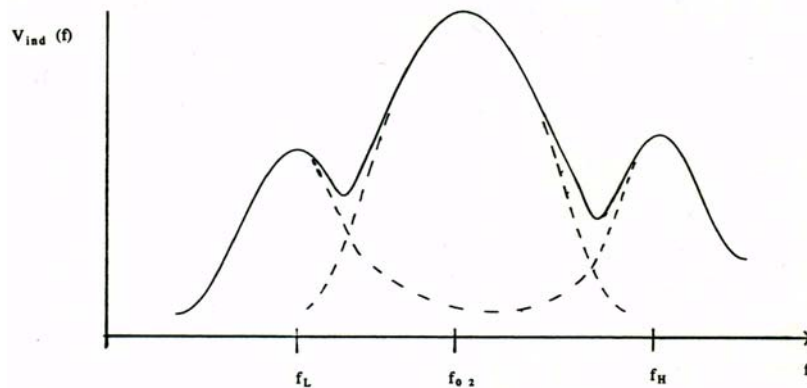


Fig. 8. Fleming & Dyke's observed spectrum.

What's going on? Fleming & Dyke wrote, "The frequency corresponding to the middle hump is the natural free period frequency of the secondary circuit. The frequencies of the other two maxima on either side correspond to the two oscillations which are created between the primary and secondary circuits."³¹ Eccles concurred, "The fact that Dr. Fleming's curves show, for *some degrees of coupling*, three humps instead of two, indicates that the pair of circuits does not remain a double system throughout the oscillation. One circuit disappears at a more or less *early stage* of the process, that is to say, the primary spark goes out and virtually removes the primary circuit from the combination, so that *thereafter the secondary circuit vibrates alone*."³² An actual oscillogram of the time-domain voltage on C_2 , showing this effect, is shown below.³³

During the time that the primary spark is conducting, the "*early time*" system response is that of a coupled circuit, producing beats and a double-humped spectrum. If the primary spark breaks when all the energy is trapped in the secondary, the secondary circuit rings-upward toward a maximum and then fritters down, giving the single-humped spectrum as the "*late-time*" response.* The secondary oscillations are growing after the spark has broken, which is different from what is occurring in Figure 5!!

Figure 9 permits a clear interpretation of the Fleming, Dyke and Eccles phenomenon. At the moment the primary spark breaks the magnetic flux trapped in the secondary (now a top-loaded, stand-alone, helical resonator) can't get back to the primary (an open circuit high-impedance) and collapses, forming quasi-monochromatic forward and backward traveling waves on the top-loaded helical transmission line resonator. During this "*transition epoch*" these waves set up an interference pattern (a standing wave).

* This is identical to the early-time and late-time backscatter response of an extended radar target (where pspice fails). In the early-time you're looking at backscatter while the target is still being illuminated. In the late-time the illumination pulse is over and the target itself (as a resonator) is responding with its own characteristic frequencies.

How long does it take for the trapped energy to set up the wave interference pattern (standing wave) now forming on the isolated resonator stage?

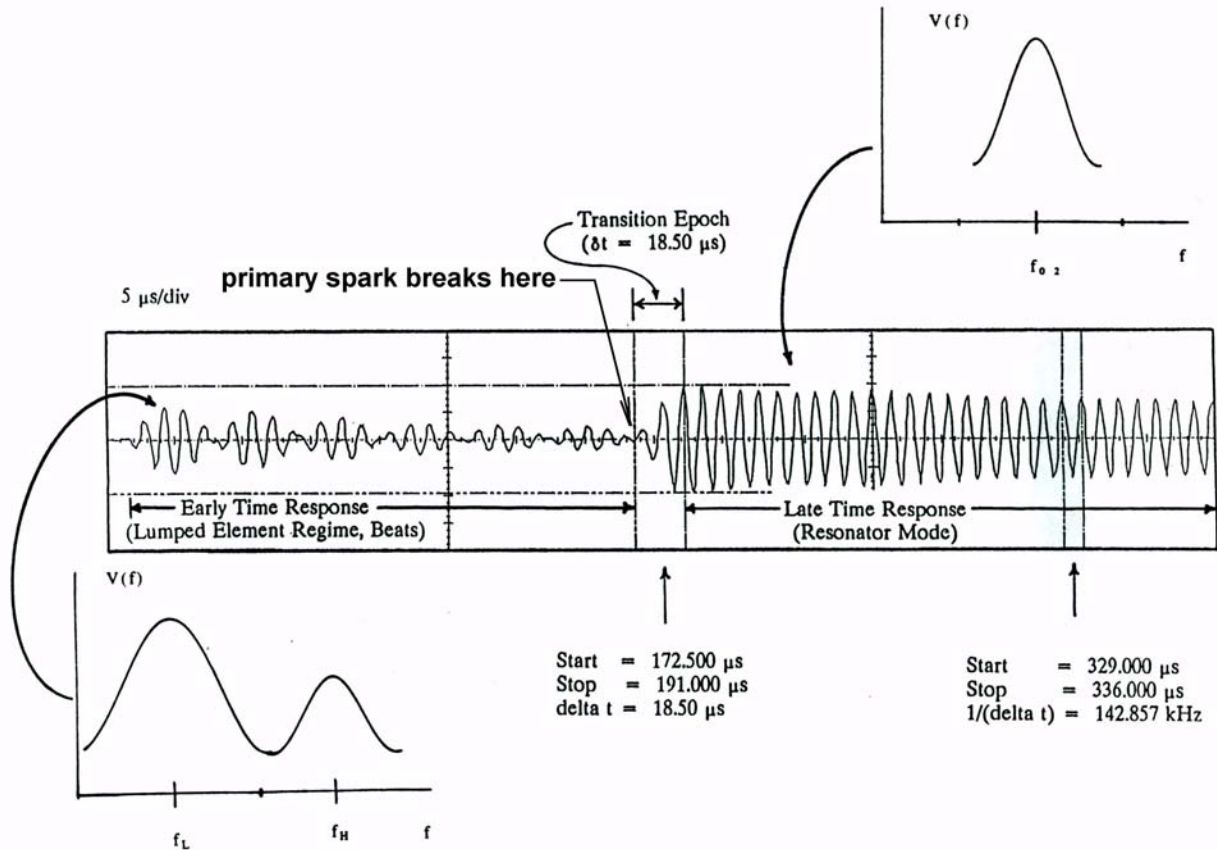


Fig. 9. Measured secondary voltage. Note that the spark conducts only during the early-time response, giving beats. Unlike Fig. 5(b), V_2 grows after the primary spark breaks! (See Fig. 12 below.)

Goldman³⁴ has observed that the build-up transient time of a tuned transmission line must be inversely related to the spectral width of the resonator, δf . We note that the time taken for the waves to build up from initial uniform energy storage (at the spark quenching instant) is related to the resonator bandwidth by the Fourier reciprocity relation $\delta t \cdot \delta f \geq 1/4\pi$, where δf is related to the selectivity, Q , as $Q = f_0/\delta f$, and δt is a quantity often called the coherence time, τ_{coh} , (for optical fields).^{35,36} In optics, temporal, or self-coherence (at a point in space) is the ability of a light beam to interfere with a time-delayed sample of itself.

C. Steady-State Analysis (Power Signals³⁷)

[To avoid having to solve the problem of transients on anisotropic waveguides, we'll pass to finite power signals and do the helix boundary value problem in the sinusoidal steady state. The approach is acceptable for describing wave interference provided the spectral width of the oscillations is reasonably narrow: $\delta f \ll f_0$, i.e. – slowly decaying exponential modulation of a time-harmonic carrier. It is a matter of partial coherence and spectral purity. (In the parlance of the physicist we've assumed "adiabatic invariants".³⁸)]

7. Helix mode (a boundary value problem). In our publications it has been our hypothesis that, during this later time, the secondary behaves as a slow wave helical resonator and that voltage rise is by standing waves: $V_{\text{max}} = S V_{\text{min}}$,³⁹ which exceeds the usual lumped-element response. A post-1894 Tesla coil is a velocity inhibited quarter wave resonator with the V_{min} induced at the base stepped up by VSWR, which then rings down and dies out exponentially due to resonator losses (assuming no breakdown at the top of the resonator). The ring-up operation takes place over several cycles and power is the conserved quantity.

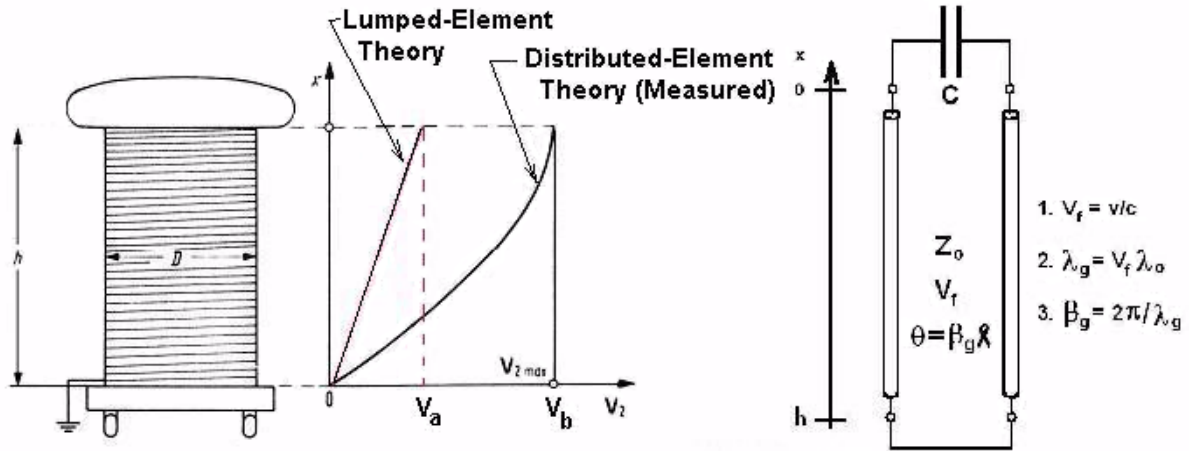


Fig. 10. (a) Fundamental mode voltage distribution prior to a discharge. (Heise)⁴⁰
 (b) Slow-wave transmission line equivalent.^{41,42,43}

A boundary value solution of Maxwell's equations gives the surface wave characteristic impedance^{44,45}

$$Z_o \approx \frac{60}{V_f} \left[\ln \left(\frac{4h}{D} \right) - 1.027 \right]$$

(which is a more rigorous form of Schelkunoff's "average characteristic impedance"⁴⁶), and the surface-wave velocity factor $V_f = v/c$ and guide attenuation are given by⁴⁷

$$V_f = \frac{v}{c} = \frac{1}{\sqrt{1 + 20 \left(\frac{D}{s} \right)^{2.5} \left(\frac{D}{\lambda_o} \right)^{0.5}}} \quad \text{and} \quad \alpha h = \frac{7.8125 (h/D)^{1/5}}{d_w Z_o \sqrt{f \text{ MHz}}}$$

(s = turn-to-turn spacing, D = helix diameter, and d_w = wire diameter in inches). The "voltage" is then distributed along the line as the *interference pattern of the forward and backward traveling wave pair* that are solutions of the transmission line wave equation and are, for the present, assumed to be monochromatic and coherent. The voltage distribution along a lossy transmission line is given by the familiar expression

$$V(x) = V_L \cosh \gamma x + (I_L Z_o) \sinh \gamma x \approx V_L \left[(1 + (Z_o/Z_L) \alpha x) \cos \beta_g x + j((Z_o/Z_L) + \alpha x) \sin \beta_g x \right]$$

where the distance x is measured backward from the load, V_L is the load voltage, I_L is the load current and α is the attenuation constant. For the dominant mode on a low loss quarter wave line ($\beta_g h = \pi/2$) which is open circuited at the load end ($Z_L = \infty$), these give the voltage step-up ratio (or *magnification factor*^{48,49,50,51,52}) between the top and bottom of the resonator as^{53,54,55,56}

$$\frac{V_L}{V(-h)} = -j \left(\frac{1}{\alpha h} \right)$$

where $V(-h)$ is the induced driving voltage referred to the base of the structure. Tesla was aware of this distinctive phenomenon (even with spiral resonators) and wrote, "With such coils, I found that there was *practically no limit to the tension available*."⁵⁷ This is a Tesla coil resonance transformer.^{58,59} (Obviously, the load may be a capacitive electrode (sphere, toroid, etc), which has the dual role of electrically shortening the required structure for system resonance and holding off high voltage discharges until a desired potential is attained. Tesla wrote,

"... these 'extra coils' with one of the terminals free, enable the attainment of practically any EMF, the limits being so far remote that I would not hesitate in undertaking to produce sparks of

Incidentally, the Smith chart shown in Figure 11 is for Tesla's "Extra Coil" appearing in his Colorado Springs Notes for November 1, 1899 and shown in Photos XII (p. 336), XIV (p. 338) and XXVII (p. 358).

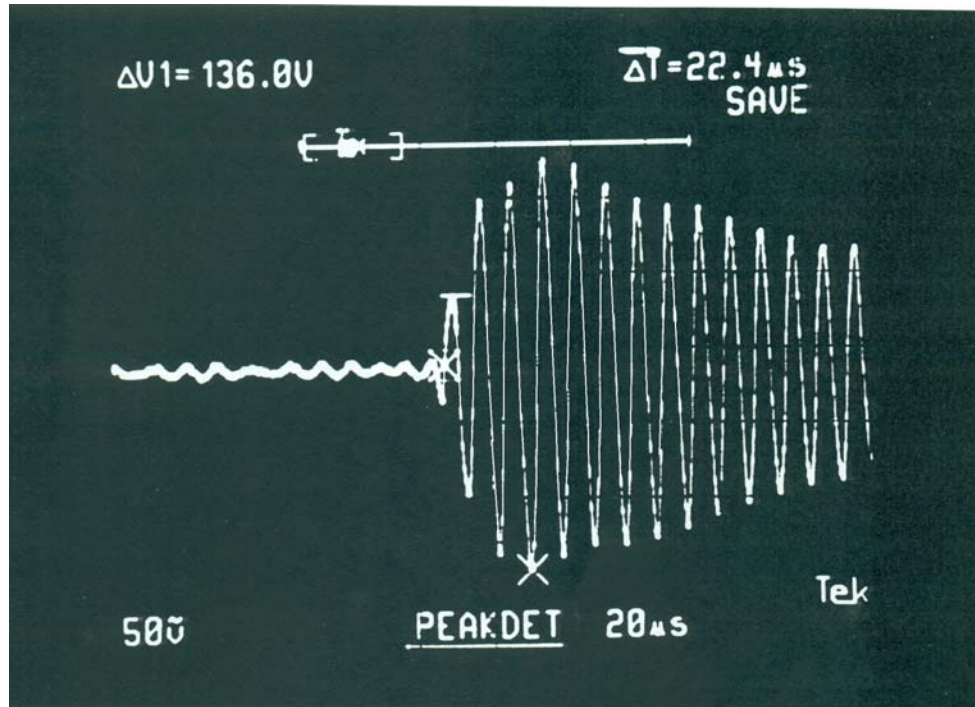


Figure 12. Photographic documentation of the coherence time phenomenon for magnification. The switch opens at the first x, and the resonator voltage rises thereafter (!) to the peak at the second x. This is NOT the same as the phenomenon shown in Fig. 5(b) above.⁶⁹

During the primary spark, the secondary field exhibits the phenomenon of beats shown on the left. When the spark breaks, however, the energy is trapped in the resonator and the voltage distribution is *observed to build up* (by a factor of 18 times the lumped element voltage at the switching instant), during the duration of the coherence interval. This is different than the exchange shown in Figure 5 above! (No overlap of i_1 and i_2 during build-up.) Build-up is due to wave interference and the formation of a standing wave over the coil. (*This magnification does not occur if operating in the lumped element regime!*) The standing wave, in turn, rang down with a logarithmic decrement of $\pi/Q = 0.09$. The resonator frequency was 122 kHz and the measured $Q = 34.9$, giving $\delta f = 3.495$ kHz, $\delta t = 22.8$ μ s and an error of 1.8%. The documentation was taken at Battelle (Columbus) on a Tesla Technology Research Model 10 (now residing in the Power Engineering Lab at Ohio State), which was top loaded and the coil was approximately 73° tall. This Tesla coil phenomenon was first observed in 1988 and reported in 1990 in Figures 4 and 5 of an old paper⁷⁰. The above photograph was taken in 1991 at Battelle.

9. What about Conservation of Energy? Back in section 1 we reported that the maximum step-up for lumped circuits was the square-root of the primary-to-secondary capacitor ratio, but in section 7 we showed that the maximum step-up for a transmission line resonator was the VSWR times the induced voltage referred to the base. Aren't we violating "conservation of energy"? Isn't the magnification greater than $(C_1/C_2)^{1/2}$? No and no. For the dominant mode on a low loss quarter wave line that is open circuited at the load end ($Z_L = \infty$, i.e. $C_2 = 0$), the voltage step-up is $1/\alpha l$, not ∞ as the C-ratio would assert. The fundamental limit is the propagation attenuation constant, which when approaching zero (the lossless case) permits extreme VSWR and voltage magnification.

10. Vacuum Tube Excited Coils. For the same resonator and the same input power, why do rotary break and IGBT excitation produce more spectacular displays than vacuum tube coils? John Wiesner found that by adjusting the time constant of the grid-leak RC he could optimize the spark length, but it upset the grid bias.⁷¹ Even though a class C vacuum tube oscillator can have a relatively small conduction angle⁷² (analogous to spark-duration), the effective "spark rep rate" is too high for oscillations to coherently build up in the resonator over several cycles. (The output of the tube oscillator is CW rather than pulsed power.)

With CW the output is proportional to the average input power (a relatively long duty cycle). With a spark driven coil, the duty cycle is very small but the output is high peak power. (Additionally, the tube plate resistance acts as a load during the conduction time, which dampens the coherent build-up in the resonator.) Two kW average in a vacuum tube coil produces 1 or 2 foot sparks ... but two kW *average* in a rotary gap coil can produce twenty to fifty kW (or more) of *peak power* and an 8 foot spark, depending on primary spark duration (dwell). [However, a tube can be forced to be cut-off for many cycles and behave similar to a lossy circuit with a low duty-cycle rotary break machine driving the resonator. (An SCR on the cathode.)]

11. Oudin Coils and Seibt's Experiment. Since any magnetically coupled circuit (transformer) is equivalent to a T-circuit,⁷³ instead of operating with link-coupled coils (a transformer with a primary and a secondary) as shown in Figure 1(a), one may excite a portion of the secondary resonator circuit directly⁷⁴ as a tapped coil, autotransformer, or tapped resonator worked against ground (like a gamma match on a quarter-wave tower). This version of the Tesla coil, "invented" by P.M. Oudin in 1899, was actually widely published from both Tesla's 1891 Columbia University lecture/demonstration⁷⁵ and his 1893 lectures in Philadelphia and St Louis.^{76,77} Sometimes one end of the primary and one end of the secondary are just tied together and to ground and tuned (Fig. 13 on the left). The unwarranted attribution to Oudin (who merely popularized the circuit in early 20th century medical research) once again illustrates ignorance of the physical phenomenon of voltage magnification on resonators by standing waves. **Seibt's Experiments.** Seibt^{78,79,80} not only demonstrated the effect of sweeping the frequency of single-wire, base-driven helical resonators through their resonant frequencies (also from Tesla's 1893 lecture) but also *demonstrated* the existence of standing waves (and their nodes and antinodes) on helical resonators (Tesla coils).

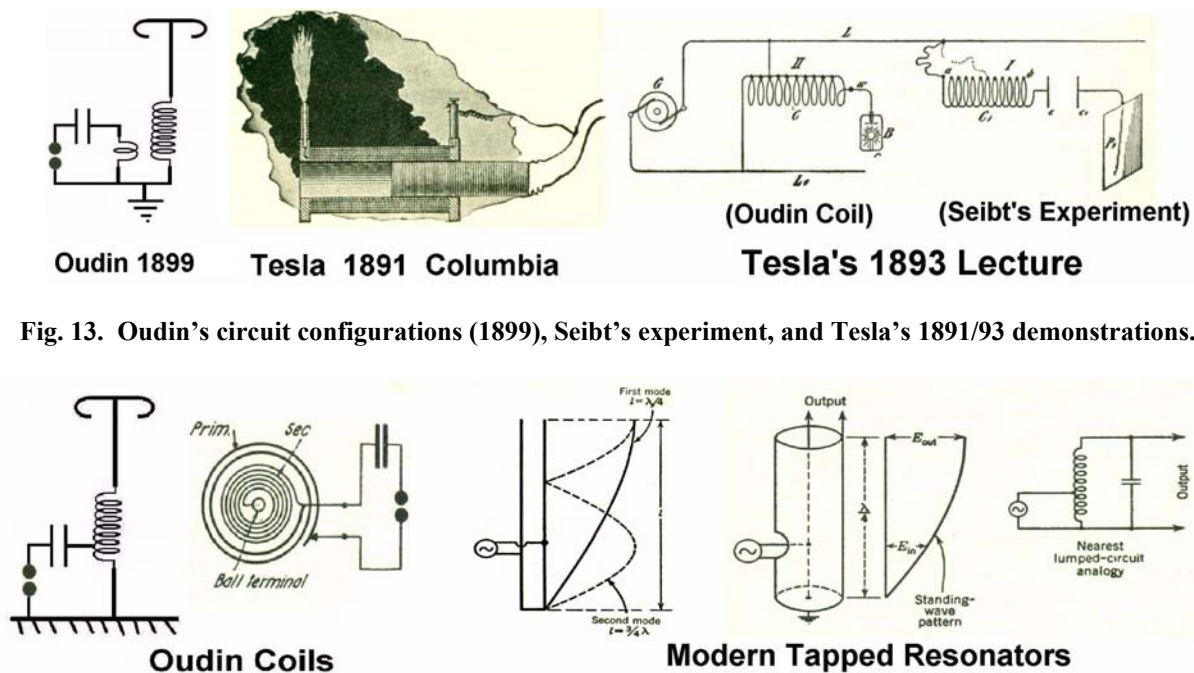


Fig. 13. Oudin's circuit configurations (1899), Seibt's experiment, and Tesla's 1891/93 demonstrations.

Fig. 14. Tesla's 1891 circuit (predates Oudin) - left. Tapped resonators (VHF/UHF 'Oudin coils') right.⁸¹

12. Breakdown. Finally, we should mention that what limits the maximum attainable voltage is the power driving the resonator and the breakdown potential of the load geometry (which depends upon the radius of curvature of the load, and arises from the onset of cold field emission from the electrode's surface: the rapid evolution of the discharge from cold field emission to Trichel pulses to avalanche to arc/spark). Tesla asserted that the RF breakdown potential of a smooth spherical electrode in air at sea level can be approximated by the expression: $V_{bk} = 7.5 \times a \times 10^6$, where "a" is the radius of the sphere in meters and V_{bk} is called the "*disruptive potential*".⁸² During the discharge, the load electrode passes from a linear capacitor to a nonlinear low impedance dissipative load, shifting the system resonator frequency. (Tesla asserted that the spectacular discharges with which his name has become synonymous, "...while wonderful are worthless"!⁸³)

13. Finish. The primitive lumped-element version of the “Tesla coil” was invented in 1891. Today, virtually all high performance Tesla coils are velocity inhibited, distributed-element,[†] slow wave transmission line helical or spiral resonators. (Note that the latter should be operated in the vertical plane.) Distributed resonator voltage-magnification by standing waves was patented by Tesla in 1897.⁸⁴ (The cavity resonator evolved from this notion.^{85,86}) Incidentally, Tesla said that he discovered this striking nature of RF coils experimentally in 1894, “*That was the first single step toward ... my magnifying transmitter.*”⁸⁷ He was aware of the distributed element nature of Tesla coils in the mid 1890’s, and his work at Colorado Springs was intended to experimentally determine *terrestrial propagation phenomena*, not reinvent the Tesla coil.^{88,89,90} (The analytical problem was not solved until 1909,⁹¹ and has endured a century of controversy.^{92,93}) It is ignorant people that have turned Tesla into a caricature of the mad scientist. See a prior note⁹⁴ to grasp the esteem in which Tesla was held by Einstein, Lord Kelvin (“Tesla has contributed more to electrical science than any man up to his time.”^{95,96}), Helmholtz (“Helmholtz was convinced from the very beginning that I could do it. It took argumentation and experiments to convince Lord Kelvin.”⁹⁷ But when Kelvin witnessed Tesla’s experiments, he said with tears in his eyes, “I am sure you will do it.”⁹⁸), Bohr, Millikan, Compton, Chadwick, Rutherford, Crooks, Lord Rayleigh, ... His nomination for an *undivided* Nobel Prize in Physics in 1937 is now documented.⁹⁹ For more on Tesla’s background and professional credentials see our review papers^{100,101,102} and his obituary.¹⁰³

D. Conclusions:

Assuming you have followed all the usual good engineering construction practices for RF (high Q, etc.), also consider these:

- (a) The switch duration of your break device (whether IGBT, rotary or quenched gap) sets the requirement for primary-to-secondary coupling. Note that:
 - (1) Spectral spread is proportional to coupling: $\Delta f \sim k$
 - (2) The time required for energy transfer = $\frac{1}{2} T_b$
 - (3) Except for IGBT’s, your break device has a given t_s that you’re stuck with.
 - (4) Therefore, to make $\frac{1}{2} T_b = t_s$, adjust k to make t_s and $1/(2\Delta f)$ equal: $t_s = 1/(2\Delta f)$.
- (b) The size of your secondary electrode (C_2) sets the hold-off voltage of the resonator. Hold off breakdown as long as you can.
- (c) The primary power = $N \times \frac{1}{2} C_1 V_1^2$.
- (d) $V_{\max} = S V_{\min} \approx [1/(\alpha \ell)] V_{\text{induced}}$ (Make the VSWR on the resonator as large as possible!)
- (e) **We call special attention to Figures 4, 9 and 12, and to the voltage distributions in Fig. 10(a).**

The lessons to be learned are: (1) operating in the *distributed element* regime has a substantial advantage over lumped element operation; (2) if you have a long spark duration (say, $t_s \sim 100 \mu\text{s}$) then, as a compromise, use critical coupling (which is fairly loose). This at least gives the resonator a sine wave at f_0 . And, (3) if you have control over the spark duration go for as tight a coupling (fast energy transfer) as you can. In any case do whatever is necessary to cut the spark duration way down (use IGBT’s if you can) and then tighten up the coupling. [Consider running **Test II** of the TCBA paper¹⁰⁴ on your machine.]

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[†] Even Hertz understood the distinction between the *lumped-element* regime (in which his antenna’s structural capacitance was charged from a low frequency buzzer) and the *distributed-element* regime (in which the structure’s high frequency common-mode natural oscillations *radiated* damped waves). And, Seibt clearly demonstrated the distributed nature of helical resonators in his 1902 dissertation at Rostock.

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Class Notes: Tesla Coils and the Failure of Lumped-Element Circuit Theory

by

Kenneth L. Corum and James F. Corum, Ph.D.

"The working [of the Extra Coil] was excellent with 1/4 wave-length." Nikola Tesla, September 18, 1899

I. Introduction. Can one model the physical operation of a Tesla coil appropriately with only lumped-element circuits? If not, why not? It was pointed out long ago that, *at its operating frequency*, a Tesla coil is **not** a lumped-element induction coil. Forget the quest for "many turns of fine wire". In fact, a Tesla coil has more in common with a cavity resonator than it does with a conventional inductor. [See TCTUTOR, Corum, 1988, pp. 56-58; "Extra Coil as a Slow Wave Resonator," Proc. 1986 ITS Symposium, pp. 2:1-2:24; Industrial Electron Accelerators, by E.A. Abramyan, Hemisphere, 1988, p. 94.] With a real Tesla coil, voltage rise is **neither** by lumped-element transformer action ($E_2 = NE_1$), **nor** by induction ($E_2 = M di/dt$), **nor** by simple lumped-element coupled resonance [$V_2 = V_1 \times (L_2/L_1)^{1/2}$]. In all of those circuit models the *current* is analytically presupposed to be *uniformly* distributed along the wire in the coil (it's in the Neumann integral definition of inductance - see any elementary electromagnetics text) and the voltage will rise proportional to N , the turns along the coil. There are no standing waves on a lumped element circuit component. (In fact, lumped-element circuit theory inherently employs the cosmological presupposition that the speed of light is infinite, as every EE sophomore should know. See, e.g., - Electric Circuits, by J.W. Nilsson, Addison-Wesley, 1983, p. 3.)

However, a true Tesla coil (circa 1894) is a velocity inhibited slow-wave helical *transmission line resonator*: $V_{max} = S \times V_{min}$, where S is the standing wave ratio. *Voltage magnification is by standing waves*. Period. No such voltages, even in the remotest degree, can be obtained by either lumped element transformers or by lumped element LC resonating circuits. This behavior of all quarter-wave resonators is well known. [See "Resonant Lines and Radio Circuits," by F.E. Terman, Trans. AIEE, July, 1934, pp. 1046-1053; Hyper and Ultra High Frequency Engineering, by R. Sarbacher and E.W. Edson, Wiley, 1943, p. 353; Networks, Lines and Fields, by J.D. Ryder, Prentice-Hall, 1949, p. 285; Electromagnetic Waves & Radiating Systems, by E.C. Jordan and K. Balmain, Prentice-Hall, 1968, pp. 227, 231.] In the following note, we will show why one needs transmission line analysis (or **Maxwell's equations**) to model these electrically distributed structures. Lumped circuit theory fails because it's a *theory* whose presuppositions are inadequate. Every EE in the world was warned of this in their first sophomore circuits course. (A pre-discharge, linear operating regime is being assumed for both lumped and distributed operation, of course.)

It makes no difference whether the coil is a cylindrical helix, a conical frustum, or a flat spiral. Tesla clearly understood the velocity-inhibited nature of spiral and helical resonators and taught that, "The length of the wire coil in each transformer should be approximately one-quarter of the wave length of the electric disturbance in the circuit, this estimate being *based on the velocity of propagation of the disturbance through the coil itself*." [US Patent 645,576; Applied for Sept. 2, 1897] It's not the physical length of the wire but rather the velocity inhibited *electrical length* of the helical coil which must be quarter-wave resonant (i.e., have forward and reflected wave-interference producing a standing quarter-wave resonance). This was recognized by Tesla, and this is the meaning of the phrase "...this estimate being *based on the velocity of propagation of the disturbance through the coil itself*." (The consideration could not exist for a lumped element, obviously.) Berkeley physicist David Sloan, ("An RF High Voltage Generator," Phys. Rev., Vol. 47, 1935, pp. 62-70), did not know how to mathematically handle the inhibited velocity of propagation on the helical resonator, and a suitable engineering analysis was provided only a decade ago.

Is there any question that Tesla is speaking of a distributed transmission-line resonator? Well, if so, listen to his correspondence to the US Patent Examiner on November 15, 1897. He is explaining what happens if the resonator excitation-frequency is raised (i.e., the wavelength shortened). As every electrical engineer knows, a grounded quarter-wave transmission-line resonator possesses a V_{min} at the base and a V_{max} at the top. If the frequency is lowered, the structure is too short for quarter-wave resonance, and if the frequency is raised, then V_{max} positions form down in the resonator. The same is true for both helical coils and spiral coils. Concerning the latter, Tesla wrote,

"If the transmitting and receiving coil were made longer than the quarter of the wave-length of the electrical disturbance in the wire, then the points of highest potential would not fall at the inner ends of the coils ... as required, but nodal points would form, as the case may be, somewhere in the middle of the coils ..." [Dr. Nikola Tesla - Selected Patent Wrappers, compiled by J.T. Ratzlaff, Tesla Book Company, 1980, Vol. 1, p. 150.]

This phenomenon is decisive. It occurs only on *distributed* resonators: it is impossible with any lumped circuit element! (The *current* has the same value at every point along a lumped-element.) To understand what is happening, consider a cylindrical helical coil of height H . The base is always forced to be a voltage node (it's grounded). The top is always a relative voltage loop at the odd quarter-wave resonances and a voltage node at the even (half-wave) resonances. These boundary conditions constrain the mode patterns on the structure (called spatial harmonics). We assert that velocity inhibited *partially coherent* forward and reflected RF traveling waves form interference patterns on the coil.

II. Physical Description. At the fundamental (quarter-wave) resonant frequency there is a V_{min} at the base and the V_{max} appears at H (the top). At the next mode there's a V_{min} at the base, a V_{max} appears at $1/3 H$, then there's another V_{min} at $2/3 H$, and, finally, a V_{max} at the top. (The structure is 3 quarter-wavelengths tall.) At the next resonant mode there are voltage nodes at the base, $2/5 H$, and $4/5 H$; and a V_{max} appears at $1/5 H$, $3/5 H$, and at the top. (The structure is 5 quarter-wavelengths tall.) To see the nodes sharply, you have to be at the resonant frequencies. (The impedance is following a circle around the Smith chart and the voltage is varying accordingly.) We will number the modes in terms of the number of quarter-waves on the structure: $n = 4H/\lambda_g$. [The resonant frequencies are called "overtones" instead of "harmonics". Only overtones that are integer multiples of the fundamental are called harmonics. For a *nondispersive* resonator the fundamental is called the first harmonic, the first overtone is the second harmonic, the second overtone is the third harmonic, etc. However, a *helix is a frequency*

dispersive resonator - the velocity factor is *not* a linear function of frequency and, therefore, the overtones of the resonator are *not* integer multiples of the fundamental.] At the next overtone, the voltage nodes are at the base, $2/7 H$, $4/7 H$, and $6/7 H$. The V_{max} are at $1/7 H$, $3/7 H$, $5/7 H$ and the top. Sketch a vertical line with 7 equidistant tick marks. Sketch heavy dots (nodes) at 0, 2, 4, and 6. Sketch in loops with maxima at 1, 3, 5 and the top. (The structure is 7 quarter-wavelengths tall.) The magnitude distribution of the spatial interference pattern is called a standing wave. At all the odd resonant overtones, there is always a V_{max} at the top and a V_{min} at the base. The pipe organ, trombone, violin, harp, guitar, xylophone, ... (even a flag pole) ... are all transmission line resonators. No wonder Helmholtz and Lord Kelvin were so entranced by Tesla's wonderful coil: it's a musical instrument whose very soul has been tuned for creating an electrical fountain of celestial fire. One can write analytical expressions for all this, of course. (They're in Appendix VI of our book Vacuum Tube Tesla Coils.)

III. An Experimental Test. In spite of the fact that Tesla, himself, concurs, all the above are just assertions until an experiment is conducted. Well, here is a **simple test** to see if *your* Tesla Coil is operating as a lumped circuit or a distributed circuit, i.e. - to see if it's possible to use lumped circuit theory to analytically model your coil. Stand your resonator up (in monopole fashion), connect a signal generator between its base and ground (you could connect the base directly to ground and link couple the generator to the coil), and sweep the oscillator up through the resonant frequencies. Hold an oscilloscope probe near the top and make a note of the frequencies (resonances) that show a V_{max} . If other loop (V_{max}) and node (V_{min}) positions form down the coil at the higher resonant frequencies - congratulations. You're beholding a transmission line resonator. You'll see the voltage loop and node positions move down as the frequency is raised. (You could, if so disposed, measure the current along the coil. There will be a current *maximum* at the base and a current *minimum* at the top of a distributed resonator: **the current entering one end of a tuned transmission line resonator is not equal to that exiting at the other end** - this isn't DC!) If either the current diminishes at the top of the coil or the loops and nodes migrate down the coil, then you have a *distributed element*, and *lumped circuit modeling fails*. Period. Lumped circuit theory isn't absolute truth, it's only an analytical *theory* - and in these resonators we have the case where this sophomore *theory* fails *experimentally*. The engineer must either use Maxwell's equations or distributed elements to model reality. (If lumped analysis describes your coil, cheer up - modify its operation to an open resonator and you'll see what Tesla called, on July 11, 1899, "a beautiful advance in the art"! Helical resonators of this genre are common knowledge in the engineering community. Top loading by a sphere or toroid will foreshorten the resonator in a predictable way. (TCTUTOR, p. 50) The procedure given by Tesla is to select a top loading (toroid or sphere) that is *physically* large enough to prevent discharge prior to reaching the desired potential, and then design the resonator to operate with this load reactance at a frequency that brings the top-loaded system into resonance at the desired potential. (CSN, July 11, 1899) This is different than designing resonant lumped element systems, where currents are uniform along coils and voltage rises are *much* smaller. It was documented (analytically *and* experimentally) over a decade ago, and it's astonishing that it's still disputed seriously by some Tesla aficionados.

As with all experiments, be careful to control stray effects such as the mutual capacitance between the scope probe leads and the resonator. (You're looking for spatial variations in a geometrically compact field distribution.) Even the experimenter's body will modify the resonator's voltage distribution. We constructed a sliding coax-fed E-field probe. (It's a variation of the conventional *slotted-line* experiment so familiar to undergraduate EEs.) This simple probe samples the resonator's external E-field (proportional to the voltage distribution along the coil) without seriously perturbing the fields, and it avoids errors that would arise from the experimenter waving his arms near the coil. (An H-field probe could be used, if desired.) A simple procedure (we'll call it **Test I**) to observe transmission line modes on a Tesla Coil is:

1. Tune to the fundamental frequency and observe the V_{max} at the top and the V_{min} at the base.
2. With an oscilloscope probe (or even a neon bulb) near the top, tune to the first *overtone* (the next frequency where the V_{max} at the top again reappears sharply). Then move the probe downward along the coil. You will see a V_{min} (near the $2/3 H$ point) and a V_{max} (near the $1/3 H$ point). And then, of course, a V_{min} again at the base. [*Lumped element coils can't do this.*]
3. To convince yourself that the transmission line resonator theory is *really* gospel, tune to the 5th V_{max} observed at the top (counting the fundamental as 1). The structure is then 9 quarter-wavelengths tall. There will be 5 V_{max} s, with a guide quarter-wavelength equal to the coil length divided by 9. You can either move the probe up and down the coil to find the 5 separate voltage maxima, or you can place the probe $1/9$ up and swing through the V_{max} . (Place the probe $2/9$ up and you'll sweep through a voltage null at the same frequency.)

[There is even enchantment for the analytically minded. If you solve Maxwell's equations on a helix for the interior and exterior fields, and match the boundary conditions radially across the helix, you will be led to a transcendental equation which must be solved iteratively for the guide phase constant from which the all important inhibited velocity factor may be determined. (It will be on the order of $1/1000$ or less for a Tesla helix.) The spatial "wavelength compression factor" for the helical transmission line resonator then follows, as do the *predicted resonant frequencies* and the V_{max} positions. This all sounds complicated, but it's not, really. And, no - there is no violation of the equation of continuity (i.e., conservation of charge) on helical resonators - even though the *current* is **different** at the two ends (the base and the top).]

We ran the experiment on the coil shown in Photo 1, below. The geometrical parameters of the coil were as follows: $N = 317$ turns, $D = 24.3"$, $H = 55.4"$, #10 gauge stranded copper (1 kV insulation), $d_w = 0.1019"$, $s = 0.175"$. The predictions and measured data were:

Mode	Predicted V_{max} Position	Measured V_{max} Position	Predicted f_0 (kHz)	Measured f (kHz)	Error ($\Delta f/f_0$)
1	55.4"	Top (55.4")	180	175	2.8%
3	18.5"	18.0"	455	435	4.4%
5	11.1"	11.0"	677	645	4.7%
7	7.9"	8.0"	903	860	4.8%

The normalized measured voltage wave interference patterns for the first three resonant frequencies were plotted alongside the coil as shown in Photo 1. The experiment was also conducted on a small helical coil with the following parameters: $N = 532$ turns, $D = 6.3"$, $H = 25"$, #18 gauge enameled, $d_w = .0403$, $s = .047"$. The data are tabulated below and provide added confirmation of the transmission line resonator theory.

Mode	Predicted Vmax Position	Measured Vmax Position	Predicted f_0 (kHz)	Measured f (kHz)	Error ($\Delta f/f_0$)
1	25"	Top (25")	540	520	3.7%
3	8.33"	8.0"	1,210	1,240	2.5%
5	5.0"	5.0"	1,753	1,800	2.7%
7	3.6"	3.5"	2,250	2,350	4.4%
9	2.78"	2.75"	2,750	2,800	1.8%

The theory and experiment agree to within 5%, which is acceptable engineering accuracy. Anybody should be able to obtain similar results.

IV. What's Going On? All those handbook formulas that people use for inductance, L , inherently *assume* applications at frequencies so low that the current distribution along the coil is uniform. (They were all derived from the Neumann integral with an assumed *uniform* current, which, historically, is an attempt to *geometrically* characterize a coil in terms of a ratio of magnetic flux linkage to impressed current.) The real issue is that migrating voltage nodes and loops *are not a property of lumped-circuit elements* - they are the directly observable consequence of velocity inhibited wave *interference* on the self-resonant coil. Lumped element representations for coils **require** that the current is uniformly distributed along the coil - no wave interference and no standing waves can be present on lumped elements. The problem has been that many experimenters working with self-resonant helices have *pursued the concept of coil self-capacitance without really understanding where the notion comes from or why it was ever invoked by engineers*. For that, they will have to go read R.W.P. King's wonderful old book Electromagnetic Engineering, McGraw-Hill, 1945. (See pp. 418-422, 461-466.) On pg. 465, the Harvard Professor points out that, for coils whose **wire length** exceeds $1/6$ wavelength (as is the case for the secondary of authentic Tesla coils), **"an adequate representation of the reactance of a coil with a nonuniformly distributed current is not possible in terms of a coil with a uniform current [a lumped-element inductance] connected in parallel with a lumped capacitance."** Period. Resonant *fields* present surprises to engineers with limited training.

V. Discussion. Figure 1 shows an actual physical system and two candidate models: (1) a transmission line (distributed element) model (that allows one to include the effect of a spatially varying current distribution); and (2) a lumped-element model. Depending upon whether you're operating at a frequency where the current is sinusoidally distributed along the coil or operating at a low enough frequency so that the current is uniformly distributed along the coil, either model may be appropriate. (*Distributed theory encompasses lumped circuits and always applies.*)

In the **transmission line resonator model**, the ball on the top serves as a load reactance conjugate to the transmission line back impedance to bring the system, of electrical length $\theta = \beta_g \ell$, into resonance at the operating frequency and, assuming no discharges, the voltage rise is proportional to the VSWR on the resonator. Smith charts are the easiest way to work with distributed circuits. For a resonant system, enter the chart at the capacitive load and proceed along a VSWR circle to the V_{min} at the input end. When the losses go to zero in the distributed resonator mode, $S \rightarrow \infty$ and the voltage magnification is limited only by the avalanche breakdown around the top electrode. The goal is to make the structure's losses small and, therefore, keep the VSWR as high as possible - just the opposite of what RF engineers usually want to do with VSWR! The voltage magnification can be truly stunning for distributed resonance. (*"There is sweet music here."* - Tennyson)

In the **lumped element model**, the sphere serves as a conjugate reactance, equal and opposite to $2\pi f_0 L$, where L is the self inductance of the coil measured at (or calculated for) *frequencies so low that the current distribution on the coil is uniform*. A thorough analytical investigation of such *tuned* coupled lumped resonance was given in TCTUTOR (p.16-44). In the lossless case, the voltage across the secondary is given by the conservation of energy expression $V_2 = V_1 \times (L_2/L_1)^{1/2} = V_1 \times (C_1/C_2)^{1/2}$, RF magic which Tesla had discovered at his Grand St. Laboratory in 1891 and disclosed to Hertz at Bonn in 1892. (See Vacuum Tube Tesla Coils, Appendix X.) This is the most lumped can give - even if the coil has no resistance whatsoever! When real world losses in the coil are included the voltage step-up is even smaller than this optimistic $(C_1/C_2)^{1/2}$ expression. The voltage magnification in coupled tuned coils is nowhere near what is possible from a simple distributed resonator with standing waves.

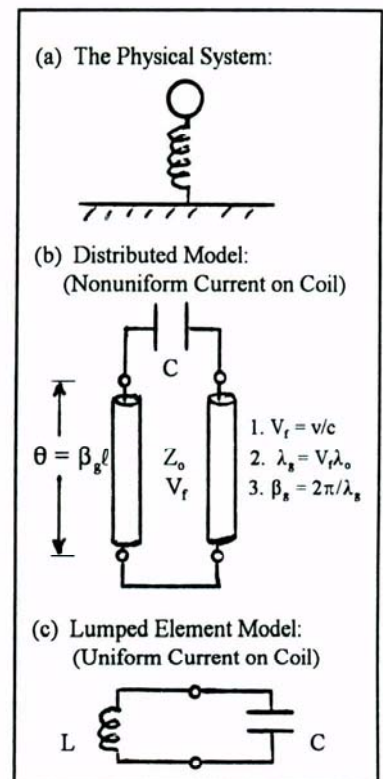


Fig. 1 Physical system and models.

VI. Operating Regimes. How can you tell whether your Tesla coil is operating in Tesla's pre-1894 tuned lumped element regime or in his post-1894 distributed resonator regime? You could just look at the field distributions, as described in the test above. Here's a decisive set of quantitative measurements to see *how bad* the lumped-element model really is. Do the experiment on your Tesla coil. We'll call it **Test II**.

- Step 1. With the sphere (or toroid) attached on the top of your coil and a ground connected to its base, link couple a signal generator into the bottom of the coil and hold up an oscilloscope probe in the vicinity of the sphere - but not so close as to interfere with the experiment. Sweep the signal generator until the first Vmax is observed. Call this the system resonant frequency, f_0 .
- Step 2. With the coil disconnected, but the top capacitor supported at the same height above ground as when it's on the coil, measure C.
- Step 3. Calculate the capacitive reactance of the top capacitor at the measured system resonant frequency f_0 : $X_C(f_0) = 1/(2\pi f_0 C)$.
- Step 4. With L and C still disconnected, measure the self inductance of the coil (without the top capacitor) with an LCR bridge at 1 kHz (i.e., at a frequency so low that the current on the coil will be uniformly distributed). Call this value L.
- Step 5. Calculate the frequency at which the lumped-element inductance has the same reactance as the actual capacitive reactance in steps 1 and 3. That is, $f = X_C(f_0)/(2\pi L)$. If $f \approx f_0$ then the coil in step 1 was operating in the lumped-element regime.

Well . . . What frequency did you get in step 5? Is it the same as f_0 ? Is the difference within engineering accuracy, i.e. is $|f - f_0|/f_0 \times 100\%$ less than 5%? If the answer is yes, then you may confidently use lumped-element modeling. However, if the answer is no, then, from the halls of Valhalla, old Wotan, *himself*, is thundering out over the battlements, "#*&%!! . . . Thor, you dum dum! You *can't* use lumped circuit modeling! . . ." [The coil has standing waves and is behaving as a distributed resonator.] Now, which model describes the operation of *your* coil? We took the coil shown in Photo 1 and top-loaded it with a 25 pF (22" by 8") toroid and performed **Test II**. The results were:

- | | |
|---------|---|
| Step 1. | $f_0 = 135$ kHz (The toroid load lowered the resonant frequency and foreshortened the helical resonator to $\theta = 65.7^\circ$.) |
| Step 2. | $C = 25.6$ pF (measured at an elevation of 70") |
| Step 3. | $X_C(f_0) = 46,052$ ohms |
| Step 4. | $L = 0.022$ H (measured with a BK Precision LCR meter, model 875A) |
| Step 5. | $f = 333.155$ kHz (So, $ f - f_0 /f_0 \times 100\% = 146.8\%$ error. . . Not even close to being a lumped-element circuit!) |

By the way, **TCTUTOR** predicts that, for $C = 25.6$ pF, the operating frequency will be at $f = 140$ kHz, and the error is only 3.7%.

About a decade ago, while one of the authors was serving as a Senior Research Scientist at the Battelle Memorial Institute's Columbus, Ohio Laboratories, he had the opportunity to acquire Bill Wysock's **Tesla Technology Research Model-10** commercial Tesla Coil. (See TCBA, 1983 Vol. 2, #3, p. 21, and the TTR website at <http://www.ttr.com>) We have the coil's parameters and measured data before us: $N = 342$ turns, $D = 2.0'$, $H = 97.8"$, $d_w = 0.102"$ (silver stranded #10), $s = 0.286"$. The Model-10 is capped with a large 4 foot diameter spun aluminum toroid. (See Photo 2.) The results of **Test II**, to determine the appropriateness of "lumped-element" coil modeling, are as follows:

- | | | | |
|---------|--|---------|--|
| Step 1. | $f_0 = 140$ kHz (measured) | Step 4. | $L = 16.3$ mH (measured with an HP-4262A bridge at 1kHz) |
| Step 2. | $C = 48$ pF (measured) The 4 foot diameter toroid is supported 13 feet above ground. | Step 5. | $f = 231.25$ kHz The "lumped-element assumption" has $ f - f_0 /f_0 \times 100\% = 65.2\%$ error. . . (Lumped circuits? . . . Not even close.) |
| Step 3. | $X_C(f_0) = 23,684$ ohms | | |

Transmission line modeling of this coil predicts that, for $C = 48$ pF, the operating frequency will be $f = 133$ kHz. The "distributed-element" model's error is only 5%. (Maxwell's equations win again!)

Photo 2 is a 1990 snapshot when we first turned the coil on. We were limited by the fact that the lab (the old foundry), though several hundred feet in length, was only 50' wide and 25' high. (The discharges hit the walls and ceiling.) The Model-10 has a professionally constructed system control panel housed in a 7' mobile relay rack cabinet, with all kinds of instrumentation, heavy duty switching components, safety interlocks, remote control, etc. The safety protected 35 kV power transformer was modestly rated at 25 kVA and the coil (with appropriate loading) was advertised as capable of 6 megavolt peaks. We routinely used it (at half throttle) for 30 foot directed discharges. (At night the flash and echo were awesome!) When the author left Battelle, this marvelous machine was rescued by the Ohio State University's Electrical and Computer Engineering Department, and, since 1995, it has been prominently displayed in the Department's modern High Voltage Lab facility adjacent to Dreese Lab, where it continues to be used in high voltage research at OSU. (Go Bucks!)

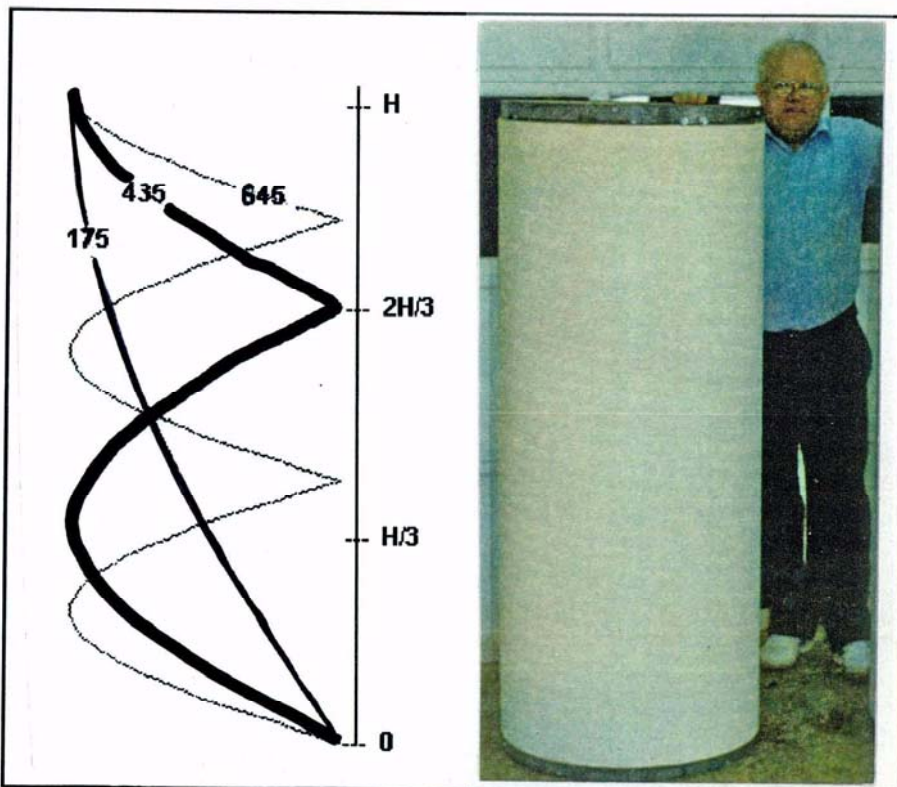


Photo 1. Coil and normalized *measured* voltage distributions at $f = 175, 435$, and 645 kHz.

The OSU High Voltage Lab web page can be found at <http://eewww.eng.ohio-state.edu/~sebo/hvlab.html>. In May, 1999, the authors were pleased to visit at Ohio State with Professor Stephen Sebo, the Lab's Director, and operate the coil once again. We digress. The conclusion to be drawn from Test II is that modeling with lumped circuits is of marginal utility (it's a naive swindle!) for really comprehending any modern Tesla coil or understanding Tesla's post 1894 research.

Several years ago, a numerically modeled transient analysis of coupled lumped-element coils was published in the AJP ("A Solid-State Low Voltage Tesla Coil Demonstrator," by D. Bruns, American Journal of Physics, Vol. 60, 1992, pp. 797-803). An *exact* mathematical analysis of the same circuitry, *including losses*, had been given in TCTUTOR back in 1988 when we pointed out that a lumped analysis is appropriate only during the duration of the primary spark (while the coupled flux is uniform throughout the resonator), and we indicated the great importance of controlling the primary switching epoch. (Finkelstein's optimum $k = 0.6$ criteria is valid only if the spark duration is roughly $1/(2\Delta f)$ where Δf is the line splitting passband broadening of the over-coupled circuit.) **That the coupled-coil, lumped-element model of Tesla coils is physically fallacious** (it doesn't predict the three-humped spectrum that is actually observed when the spark duration is finite) **has been known since the 1911 experimental observations of Dr. Fleming.** ("Some Resonance Curves taken with Impact and Spark-Ball Discharges," by J.A. Fleming and G.B. Dyke, Proc. of the Physical Soc., London, Vol. 23, 1911, pp. 136-146 (see comments by Dr. Eccles and Prof. Howe, p. 144); Also see "100 Years of Cavity Resonator Development," by J.F. Corum and K.L. Corum, Proc. 1990 ITS Symposium, pp. 2:1-18, Figs. 3, 4.) Needless to say, the 1992 AJP article is little more than the simulated impulse response of an IF can - the kind of tuned lumped coupled circuit Tesla was using before his splendid discovery of 1894.

On the other hand, *if you* have been able to model *your* coil with a lumped-element inductance, L , with less than 5% error, then you've been working with a lumped, tuned, coupled-circuit (like a radio receiver IF can) just as Tesla was doing *prior* to 1894, before he discovered the true Tesla coil. [If you've got a huge capacitance on the top then the length of wire in the secondary may be less than $\lambda_o/(2\pi)$ and, as voiced by Professor King, the current distribution could be *uniform enough* so that you can represent the transmission line as a lumped element. But, as Tesla once told his attorney, **"A large capacity and a small self inductance is the poorest kind of circuit which can be constructed."**] The good news is: there's a whole new realm waiting for you to explore. *"Oh brave new world that has such creatures in it!"* (Tempest, V.1)

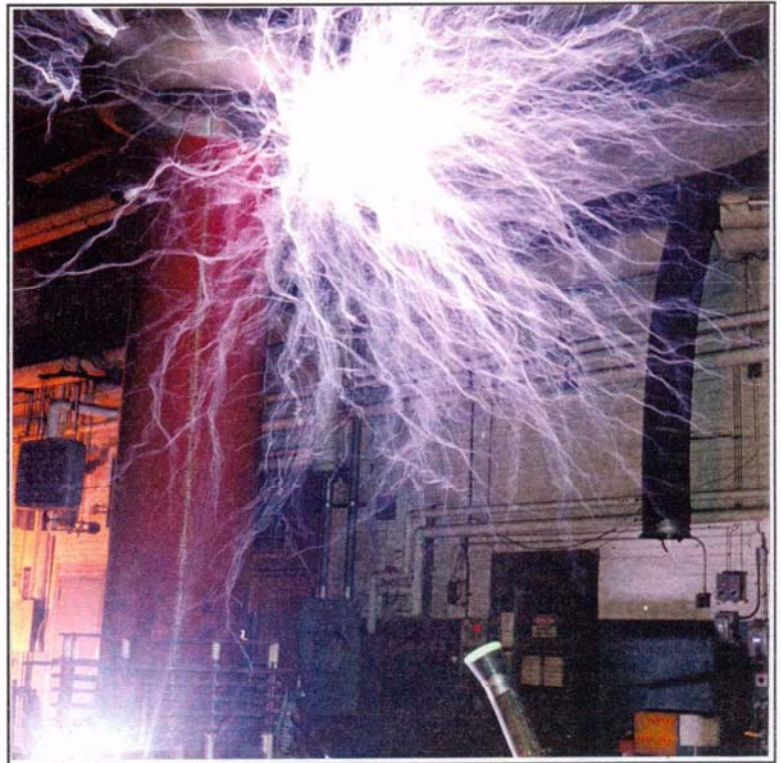


Photo 2. Bill Wysock's TTR Model-10 as initially set up at Battelle.

VII. Closing Thoughts. There is nothing sacred about using a sine wave generator (a finite power signal) to perform the above tests. The more sophisticated experimenter might want to repeat **Test II** with a broadband white noise (stochastic) source coupled to the resonator with an untuned link. Fundamental and overtone resonances can be observed with a calibrated receiver or a spectrum analyzer. Those with a knowledge of modern optics will easily recognize even richer phenomena occurring. (It can be shown that the ultimate limit in voltage rise on the coil is set by the degree of coherence of the up and back resonator waves.) While this may shatter the egos of some coilers, contrary to popular myth, the **key performance parameter** for a high voltage Tesla coil is *not the length of the discharge* (which is a function of things like input energy and primary spark duration) but, rather, the **VSWR** on the resonator coil - *the higher the better!* [It's related to the fringe "Visibility Function" for quasimonochromatic, partially coherent optical beams. (Principles of Optics, by Born and Wolf, 5th ed., p. 506.)]

The tests above are experiments that EEs have commonly performed since the '30's in undergraduate courses associated with RF electronics, and they are easily replicated with trifling effort. Concerning idealized circuit elements, Prof. Ron Scott has written that students shouldn't be "disappointed to learn that **circuit theory is not real engineering.**" (Linear Circuits, Addison-Wesley, 1960, p. 2.) Finally, we point out that virtually *all modern Tesla Coils* are velocity inhibited, distributed-element, slow wave transmission line resonators. Those asserting the contrary simply have not done their homework. Tesla said that he discovered this striking nature of coils in 1894, "That was the *first single step* toward ... my magnifying transmitter." [Tesla on His Work with AC, edited by L. Anderson, Sun Publishing, 1992, p. 72.]

Perform steps 1-5 of **Test II** on your coil. And then do **Test I**, mapping the voltage distributions at the fundamental and overtones. Now go back and reread Tesla's 1897 patent application comment, above. His remarks also apply in the case when "the impressed oscillations are more rapid than the free oscillations" (Patent # 1,119,732), but that's about electric fire-balls and is enchantment for another time.

Jim Hardesty has made many of the Corum papers on Tesla coils available through the PV Scientific Instruments web page at www.arcsandsparks.com

The Tesla Longitudinal Wave

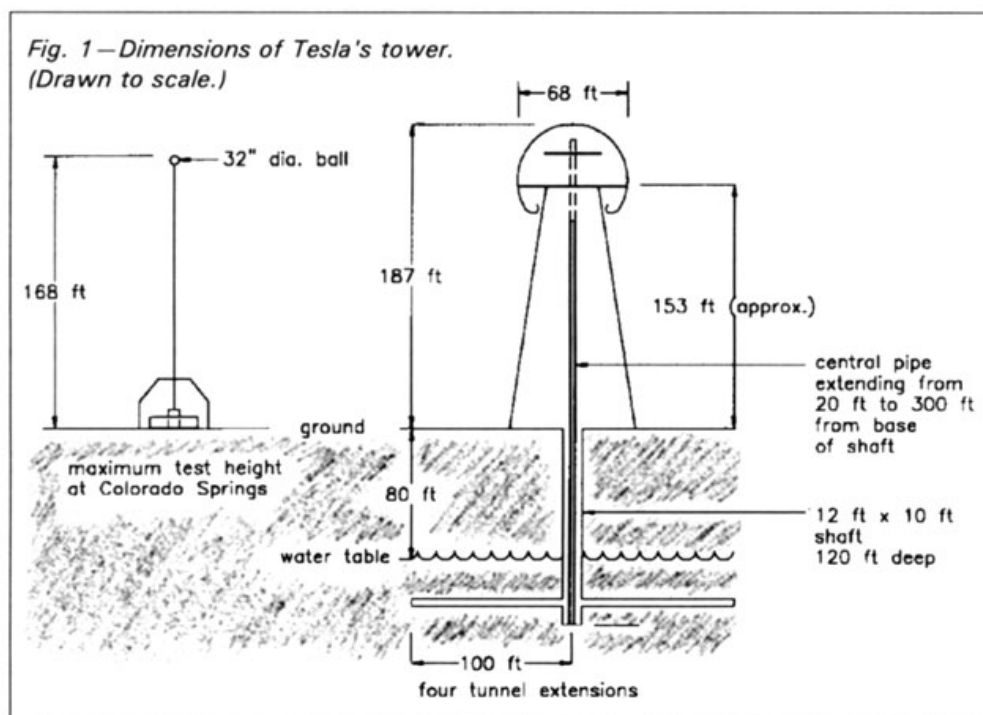
George W. Damm

George W. Damm suggests that Nikola Tesla incorporated acoustic resonant criteria in the design and modulation of his tower at Shoreham, Long Island. At first, this seems a bit farfetched, but a pause to check the dimensions of the tower's components and their acoustic resonant frequencies reveals that they are well-matched to the earth's electrical resonant frequencies. Tesla's sensitivity to sound, vibration and light, and his early work with compressed air oscillator frequency control may have been combined in his last major project.

When reading this report, do so with the physics of acoustic vibrations in mind; that is, ordinary sound waves in air. Sound waves are longitudinal in nature and propagate in the form of compression and rarefaction in a medium, at the speed of sound. The speed of sound in standard air is 340 meters/sec (1115 feet/sec). Nikola Tesla insisted his electrical transmissions were longitudinal in nature, and thus similar to sound waves. Whereas sound waves have compression (-) and rarefaction (+), electrical waves have positive and negative charge polarity.

In order to show how Tesla may have incorporated actual acoustic vibration into the tower's design, some descriptions and dimensions of the tower will be helpful.¹ These are shown in Figure 1.

By Tesla's own testimony¹, the tower was 187 feet tall from the ground to the top of the dome. The shaft into the ground was 10 x 12 feet square and 120 feet deep. The water table was reached at a depth of 80 feet. Other sources² state that four smaller diameter shafts were bored below water level at the base of the main shaft, each with a length of 100 feet and perpen-



dicular to each other. These provided an intimate electrical contact to the earth.

The dome on top of the tower is given to have a diameter of 68 feet. The dome framework was constructed completely of steel. It sat on top of the tower truss structure which was made entirely of pine timbers and steel plates at the joints. A segmented steel pipe telescoped to extend up to 300 feet from the base of the underground shaft. There were about 16 telescoping sections. The variable heights were used to determine the nodal points for electrical vibrations. Tesla said he could measure any distance on earth with an accuracy of \pm four feet, including the earth's size.¹

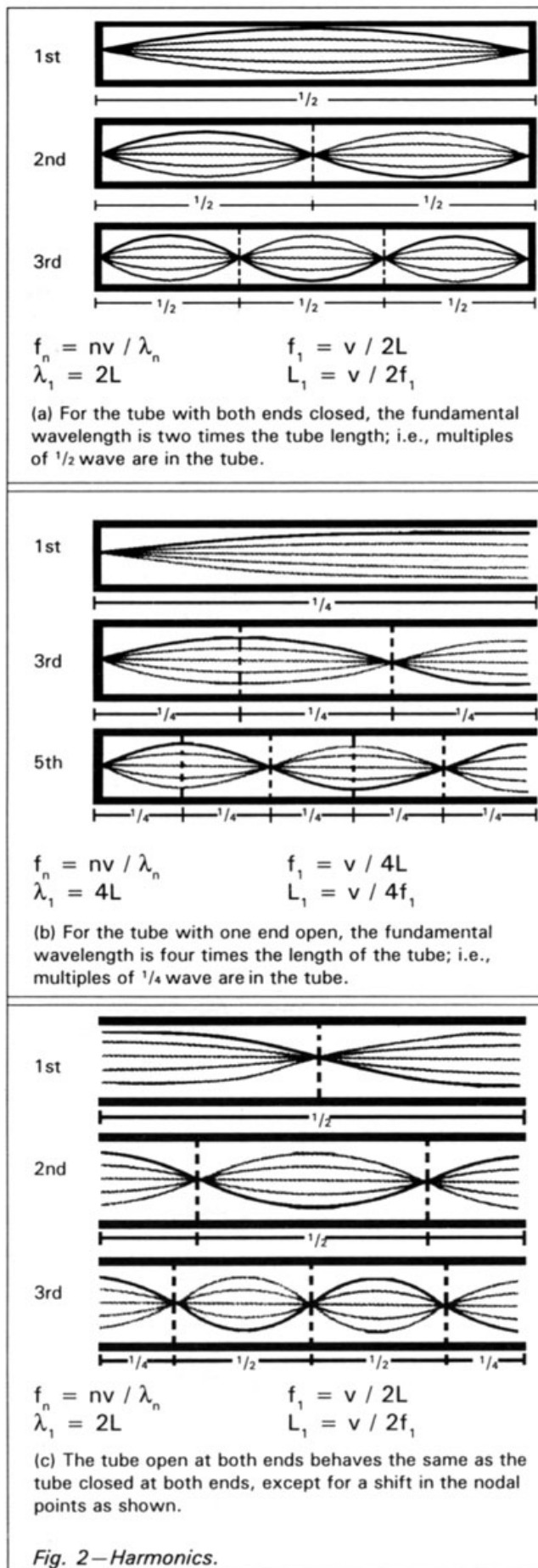
For the dimensions of the tower given in Figure 1, it is possible to calculate various fundamental acoustic frequencies and their harmonics. Key dimensions of the tower are shown in Table 1.

Dome diameter	68 ft	20.7 m
Tower height to dome top	187 ft	57.0 m
Tower height to mid-dome	153 ft	46.6 m
Shaft depth	120 ft	36.6 m
Telescoping tube length	up to 300 ft	up to 91.5 m
Depth to water table	80 ft	24.4 m

Table 1—Dimensions of Tesla's tower.

The acoustic resonant frequency and nodal points for pipes differ somewhat depending on whether the pipe is closed at both ends, has one end open, or is open at both ends. The manner in which this varies is shown in Figure 2.³

Given the various dimensions (L) of the tower design and the velocity of sound ($v = 340$ m/sec = 1115 ft/sec), it is possible to calculate various acoustic fundamental and harmonic resonant frequencies. Upon doing this, it is evident that the air acoustic resonant frequencies of the tower fall in the same range as the earth electrical resonant frequencies. For example, the telescoping tube length (L) can be calculated for a couple of earth electrical resonant frequencies that have been mentioned on occasion. One resonant frequency mentioned is 7.5 Hz. The fundamental frequency (f_1) is given by:



$$f_1 = v / \lambda_1 . \quad (1)$$

The fundamental wavelength (λ_1) is therefore given by:

$$\lambda_1 = v / f_1 . \quad (2)$$

If Tesla used a closed telescoping tube, in order to adjust to the first fundamental wavelength node, it would need to be extended to a length (L):

$$L = v / 2f_1 . \quad (3)$$

$$\begin{aligned} L &= v / 2f_1 = (340\text{m/sec}) / (2 \times 7.5 \text{ cyc/sec}) \\ &= 22.7\text{m} = 74.3 \text{ ft.} \end{aligned}$$

This is the node-to-node half wavelength of the fundamental frequency illustrated in Figure 2a.

If the telescoping tube were open at one end, the first fundamental node-to-node length (L) would be:

$$L = v / 4f_1 . \quad (4)$$

$$L = 340 / (4 \times 7.5) = 11.3\text{m} = 37.2 \text{ ft.}$$

The acoustic wavelength (λ_1) is 4L or 148.7 ft. This is shown in Figure 2b.

Tesla mentions the period of 0.08484 seconds for an electric pulse to travel the earth's diameter and back. This is approximately an 11.79 Hz pulse rate.

For the closed tube, the fundamental tube length (L) for an 11.79 Hz pulse rate would be:

$$\begin{aligned} L &= 340 / (2 \times 11.79) = 14.4\text{m} = 47.3 \text{ ft,} \\ \lambda &= 2L = 94.6 \text{ ft.} \end{aligned}$$

For the telescopic tube open on one end, the fundamental length (L) would be:

$$\begin{aligned} L &= 340 / (4 \times 11.79) = 7.2\text{m} = 23.7 \text{ ft,} \\ \lambda &= 4L = 94.6 \text{ ft.} \end{aligned}$$

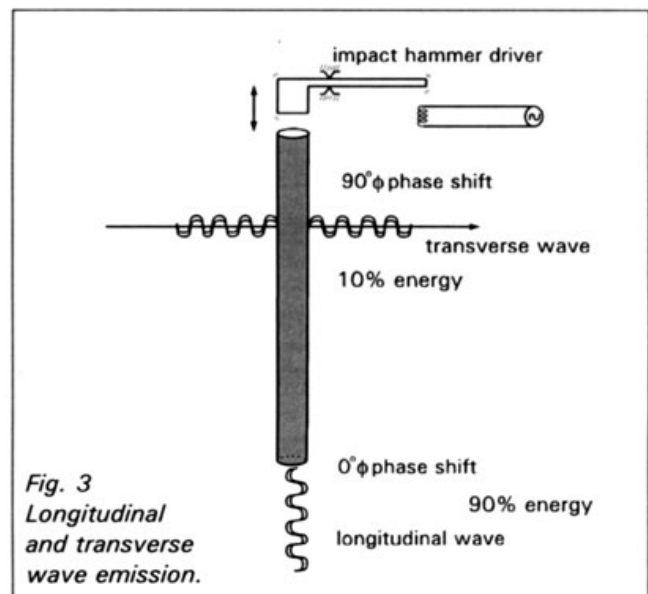
The higher harmonics all require longer tube lengths, which are readily allowed with the telescoping tube's ability to extend 300 feet.

The similarity of the numerical values for acoustic and electrical resonant frequencies provides a basis for the argument that Tesla may have incorporated acoustic compression and rarefaction techniques into the process of modulating the electrical waves propagated and received at the dome.

I think that Tesla used the term ϕ phase not in relation to time, but rather to polarity. The term ϕ phase may therefore be used in reference to negative polarity (-) for compression and positive polarity (+) for rarefaction. Perhaps when Tesla talked about frequency it was in relation to impulses per second and not sine wave cycles. This translates to (electrostatic and kinetic) pressure for negative impulses on molecules for compression, or a vacuum for positive impulses on molecules for rarefaction.

I think what Tesla intended was conversion from electrical to vibrational acoustic resonance and resonators (as indicated in Figure 3). His coils and towers were not only electrical, but also acoustic and vibrational. In my opinion, he had learned how to convert transverse waves to longitudinal waves and vice versa.

The hole in the ground was perhaps not only a ground-plane, but an organ pipe tuned to a beat frequency of 12 cycles per second. By changing the beat frequency he was able to shift the ϕ phase between compression and rarefaction.

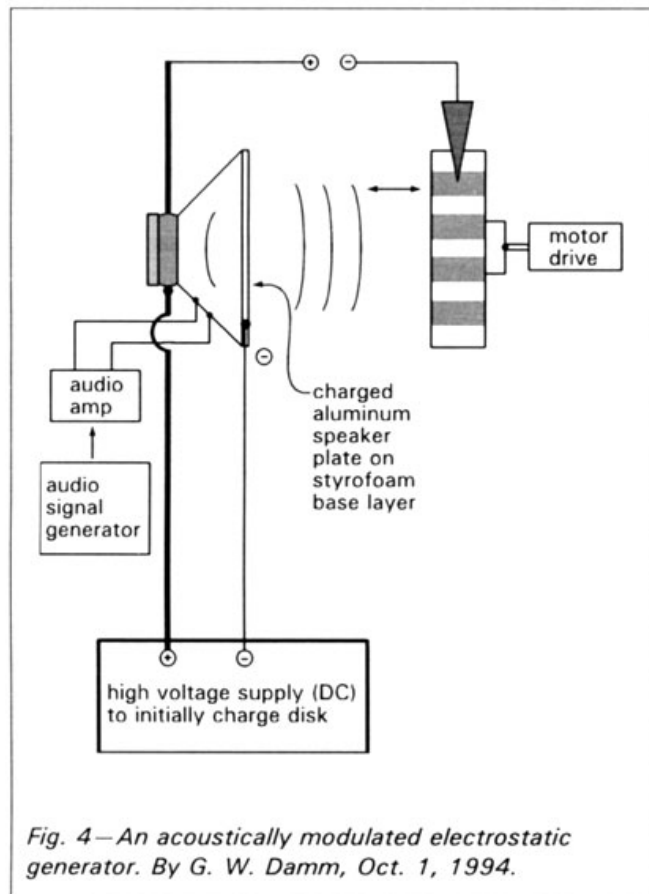


*Fig. 3
Longitudinal
and transverse
wave emission.*

When he was in Colorado, I think Tesla was trying to tune in to the resonance of the earth's magnetic field, which is connected to a natural static charge existing in the atmosphere. Perhaps he acoustically modulated this earth capacitance such that it would magnify all effects. Therefore, his hole in the ground and telescoping pipe at Shoreham were used as an acoustic resonator, like an organ pipe.

When two charged bodies are separated, the work of separating them increases the difference in their potential. I believe that Tesla used acoustic modulation to produce such voltage increases. Such induction may represent a principle source of charge separation in clouds.

Figure 4 shows my idea of an acoustically modulated electrostatic charge.



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George Damm is currently retired with an active focus of interest relating to Tesla's work, magnetic imaging, plasma, magnetics and electrostatics. He has worked as a technician in radio, TV, radar, electronic sensors and magnetic imaging. He has spent much of his research activity with the RCA tube division, Rockefeller Institute, Princeton Plasma Physics Lab, Tokomak, General Instruments and the State University of New York at Stony Brook. Damm lives near the Shoreham, Long Island site of Tesla's Wardenclyffe Tower.

Scalar waves

Advanced Concepts for Wireless Energy Transfer

by:

Prof. Dr.-Ing. Konstantin Meyl

Introduction

It will be shown that scalar waves, normally remaining unnoticed, are very interesting in practical use for information and energy technology for reason of their special attributes. The mathematical and physical derivations are supported by practical experiments. The demonstration will show:

1. the wireless transmission of electrical energy,
2. the reaction of the receiver to the transmitter,
3. free energy with an over-unity-effect of about 3,
4. transmission of scalar waves with 1.5 times the speed of light,
5. the inefficiency of a Faraday cage to shield scalar waves.

Tesla radiation

Here is shown extraordinary science, five experiments, which are incompatible with textbook physics. Following my short lecture I will present you the transmission of longitudinal electric waves.

It is a historical experiment, because already 100 years ago the famous experimental physicist Nikola Tesla has measured the same wave properties, as me. From him stems a patent concerning the wireless transmission of energy (1900)¹. Since he also had to find out that at the receiver arrives very much more energy, than the transmitter takes up, he spoke of a „Magnifying Transmitter“.

By the effect back on the transmitter Tesla sees, if he has found the resonance of the earth and that lies according to his measurement at 12 Hz. Since the Schumann resonance of a wave, which goes with the speed of light, however lies at 7.8 Hz, Tesla comes to the conclusion, that his wave has 1.5 times the speed of light².

As founder of the diathermy Tesla already has pointed to the biological effectiveness and to the possible use in medicine. The diathermy of today has nothing to do with the Tesla radiation; it uses the wrong wave and as a consequence hardly has a medical importance.

The discovery of the Tesla radiation is denied and isn't mentioned in the textbooks anymore. For that there are two reasons:

1. No high school ever has rebuilt a „Magnifying Transmitter“. The technology simply was too costly and too expensive. In that way the results have not been reproduced, as it is imperative for an acknowledgement. I have solved this problem by the use of modern electronics, by replacing the spark gap generator with a function generator and the operation with high-tension with 2-4 Volts low-tension. I sell the experiment as a demonstration-set so that it is reproduced as often as possible. It fits in a case and has been sold more than 200 times. Some universities already could confirm the effects. The measured degrees of effectiveness lie between 140 and 1000 percent.

2. The other reason, why this important discovery could fall into oblivion, is to be seen in the missing of a suitable field description. The Maxwell equations in any case only describe transverse waves, for which the field pointers oscillate perpendicular to the direction of propagation, as I have just explained.

Vortex model

The Tesla experiment and my historical rebuild however show more. Such longitudinal waves obviously exist even without plasma in the air and even in vacuum. The question thus is asked, what the divergence \mathbf{E} describes in this case? How is the impulse passed on, so that a longitudinal standing wave can form? How should a shock wave come about, if there are no particles which can push each other?

I have solved this question, by extending Maxwell's field theory for vortices of the electric field. These so-called potential vortices are able to form structure and they propagate in space for reason of their particle nature as a longitudinal shock wave. The model concept bases on the ring vortex model of Hermann von Helmholtz, which Lord Kelvin did make popular. In my books³ the mathematical and physical derivation is described.

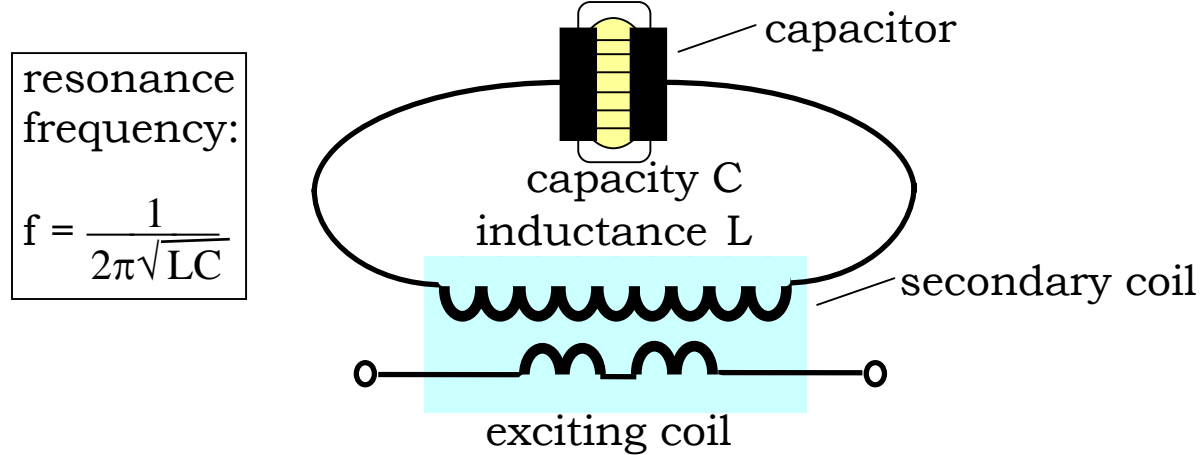
In spite of the field theoretical set of difficulties every physicist at first will seek for a conventional explanation. He will try two approaches:

Resonant circuit interpretation

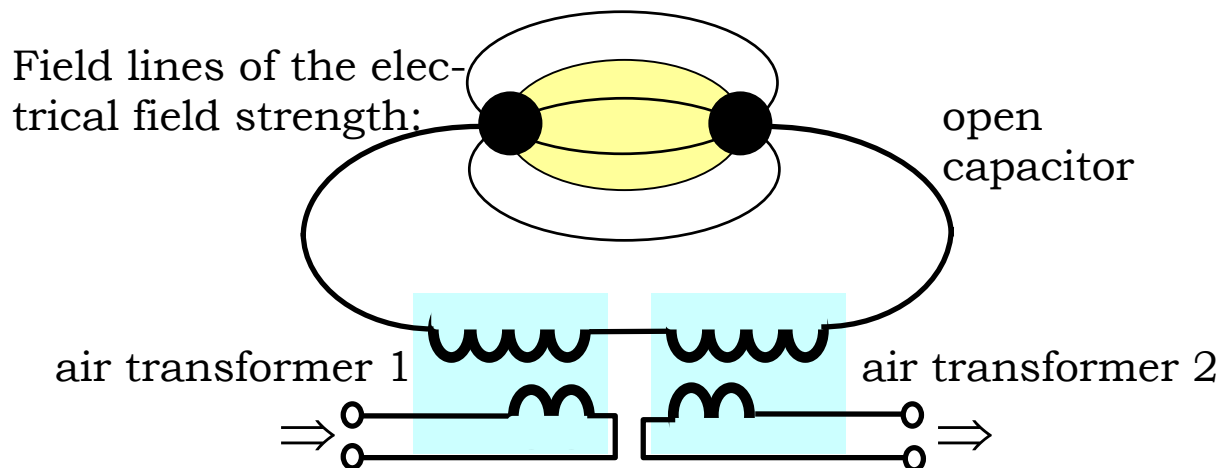
Tesla had presented his experiment among others to Lord Kelvin and he already 100 years ago has spoken of a vortex transmission. In the opinion of Kelvin it however by no means concerns a wave but radiation. He had recognized clearly, that every radio technical interpretation had to fail, because alone the course of the field lines is a completely different one.

It presents itself to assume a resonant circuit, consisting of a capacitor and an inductance.

1. *closed resonant circuit*



2. *separating the resonant circuit*



3. *resonant circuit with open capacitor*

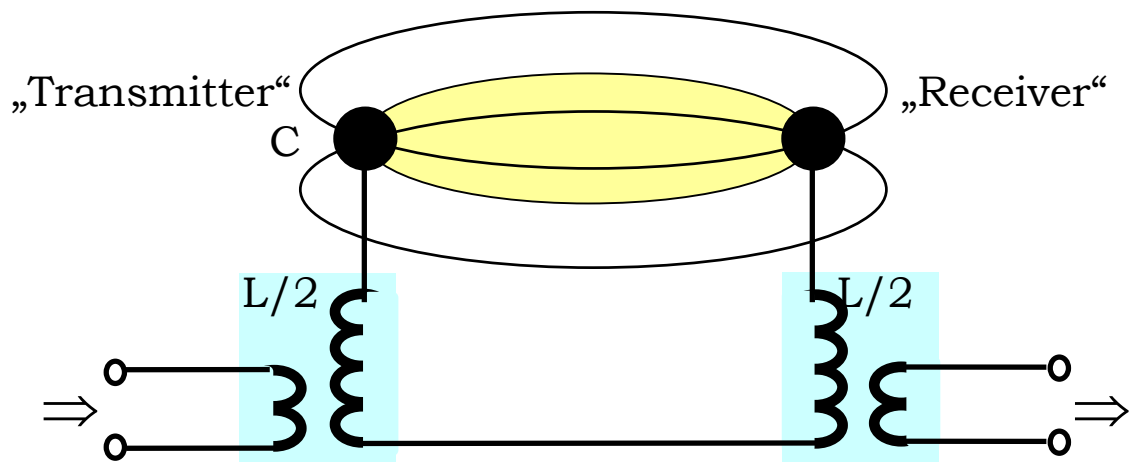


Figure 1: Interpretation as an open resonant circuit

If both electrodes of the capacitor are pulled apart, then between both is stretching an electric field. The field lines start at one sphere, the transmitter, and they bundle up again at the receiver. In that way a higher degree of effectiveness and a very tight coupling can be expected. In this manner without doubt some of the effects can be explained, but not all.

The inductance is split up in two air transformers, which are wound completely identical. If a fed in sinusoidal tension voltage is transformed up in the transmitter, then it is again transformed down at the receiver. The output voltage should be smaller or at maximum equal the input voltage– but it is substantially bigger!

There can be drawn and calculated an alternative wiring diagram, but in no case the measurable result comes out, that light-emitting diodes at the receiver glow brightly ($U > 2\text{Volt}$), whereas at the same time the corresponding light-emitting diodes at the transmitter go out ($U < 2\text{Volt}$)! To check this both coils are exchanged.

The measured degree of effectiveness lies despite the exchange at more than 100 percent. If the law of conservation of energy should not be violated, then only one interpretation is left: The open capacitor withdraws field energy from its environment. Without consideration of this circumstance does the error deviation of every conventional model calculation lie at more than 90 percent. There one rather should do without the calculation.

It will concern oscillating fields, because the spherical electrodes are changing in polarity with a frequency of approx. 7 MHz. They are operated in resonance. The condition for resonance reads: identical frequency and opposite phase. The transmitter obviously modulates the field in its environment, while the receiver collects everything what fulfils the condition for resonance.

Also in the open question for the transmission velocity of the signal the resonant circuit interpretation fails. But the HF-technician still has another explanation at the tip of his tongue:

Near field interpretation

In the near field of an antenna effects are measured, which on the one hand go as inexplicable, because they evade the normally used field theory, which on the other hand come the by me shown scalar wave effects very close. Everyone knows a practical application: e.g. at the entrance of department stores, where the customer has to go through in between of scalar wave detectors.

New problems will occur to the HF-specialist, when in my experiment the distance between the transmitter and the receiver is 10-times more than the near zone.

Students of the TU-Berlin have shown and proofed this. Tesla as well had demonstrated a power transmission over 30 miles, whereas his near field was less than half a mile. I have shown how vortices are forming and how they come off the dipole, that the fields in the near zone of a Hertzian dipole are longitudinal scalar wave fields. But the scalar waves of Tesla and of my experiment show even more.

The vortex decay however depends on the velocity of propagation. Calculated at the speed of light the vortices already have decayed within half the wavelength. The faster the velocity, the more stable they get, to remain stable above 1.6 times the velocity. These very fast vortices contract in the dimensions. They now can tunnel. Therefore speed faster than light occurs at the tunnel effect. Therefore no Faraday cage is able to shield fast vortices.

Since these field vortices with particle nature following the high-frequency oscillation permanently change their polarity from positive to negative and back, they do not have a charge on the average over time. As a result they almost unhindered penetrate solids. Particles with this property are called neutrinos in physics. The field energy which is collected in my experiment, according to that stems from the neutrino radiation which surrounds us. Because the source of this radiation, all the same if the origin is artificial or natural, is far away of my receiver, every attempt of a near field interpretation goes wrong.

Experiment

At the function generator I adjust frequency and amplitude of the sinusoidal signal, with which the transmitter is operated. At the frequency regulator I turn so long, till the light-emitting diodes at the receiver glow brightly, whereas those at the transmitter go out. Now an energy transmission takes place.

If the amplitude is reduced so far, till it is guaranteed that no surplus energy is radiated, then in addition a gain of energy takes place by energy amplification.

If I take down the receiver by pulling out the earthing, then the lighting up of the LED's signals the mentioned effect back on the transmitter. The transmitter thus feels, if its signal is received.

The self-resonance of the Tesla coils, according to the frequency counter, lies at 7 MHz. Now the frequency is ran down and see there, at approx. 4.7 MHz the receiver again glows, but less bright, easily shieldable and without discernible effect back on the transmitter. Now we unambiguously are dealing with the transmission of the Hertzian part and that goes with the speed of light. Since the wavelength was not changed, does the proportion of the frequencies determine the proportion of the velocities of propagation. The scalar wave according to that goes with $(7/4.7=)$ 1.5 times the speed of light!

If I put the transmitter into the aluminium case and close the door, then nothing should arrive at the receiver. Expert laboratories for electromagnetic compatibility in this case indeed cannot detect anything and that, although in spite of that the receiver lamps glow! By turning of the receiver coil it can be verified that an electric and not a magnetic coupling is present although the Faraday cage should shield electric fields. The scalar wave obviously overcomes the cage with a speed faster than light, by tunnelling!

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(information about the books, see: <http://www.k-meyl.de>).

Address

Prof. Dr.-Ing. Konstantin Meyl, 1.TZS
Leopoldstraße 1,
D-78112 St. Georgen/Schwarzwald (Germany)
Tel.: +49-7724-1770, Fax.: +49-7724-9486720
Email: meyl@k-meyl.de
Internet: <http://www.k-meyl.de>

Scalar Waves: Theory and Experiments¹

KONSTANTIN MEYL

*Transferzentrum der Steinbeis-Stiftung,
Leopoldstrasse 1, D-78112 St. Georgen/Schwarzwald,
Germany
e-mail: meyl@k-meyl.de*

(TRANSLATION BY BEN JANSEN)

Abstract—It will be shown that scalar waves, which normally remain unnoticed, are very interesting in terms of their practical use for information and energy technology because of their special attributes. The mathematical and physical derivations are supported by practical experiments. The demonstration will show the following: (1) the wireless transmission of electrical energy, (2) the reaction of the receiver to the transmitter, (3) free energy with an over-unity-effect of about 10, (4) transmission of scalar waves with 1.5 times the speed of light, and (5) the inefficiency of using a Faraday cage to shield scalar waves.

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Maxwell equations (rot \equiv curl):

$$\text{rot } \mathbf{E} = -\delta \mathbf{B} / \delta t \quad \text{rot } \mathbf{H} = \mathbf{j} + \delta \mathbf{D} / \delta t$$

$$\mathbf{B} = \mu \cdot \mathbf{H} \quad \mathbf{j} = 0 \quad \mathbf{D} = \epsilon \cdot \mathbf{E}$$

$$\text{rot rot } \mathbf{E} = -\mu \cdot \delta(\text{rot } \mathbf{H}) / \delta t = -\mu \cdot \epsilon \cdot \delta^2 \mathbf{E} / \delta t^2$$

$$\mu \cdot \epsilon = 1/c^2$$

wave equation:

$$\Delta \mathbf{E} = \underbrace{\text{grad div } \mathbf{E}}_{?} - \text{rot rot } \mathbf{E} = \frac{1}{c^2} \frac{\delta^2 \mathbf{E}}{\delta t^2}$$

Fig. 1. The vectorial part of the wave equation (derived from the Maxwell equations).

perative to an acknowledgement of Tesla radiation. I have solved this problem by the use of modern electronics by replacing the spark gap generator with a function generator and the operation with high tension with 2 to 4 Volts low tension. I sell the experiment as a demonstration-set so that it is reproduced as often as possible. The experimental kit fits in a case and has been sold 50 times in the last 4 weeks. Some universities can already confirm the effects. The measured degrees of effectiveness lie between 500 and 1000%. (2) The other reason why this important discovery could fall into oblivion is seen in the absence of a suitable field description. The Maxwell equations in any case only describe transverse waves, for which the field pointers oscillate perpendicular to the direction of propagation.

Wave Equation

By using the Laplace operator, the well-known wave equation, according to the rules of vector analysis, can be taken apart in two parts: in the vectorial part (rot rot \mathbf{E} ; Figure 1), which results from the Maxwell equations, and in a scalar part (grad div \mathbf{E} ; Figure 2), according to which the divergence of a field pointer is a scalar. We have to ask ourselves, "Which properties have this wave part, which founds a scalar wave?"

If we derive the field vector from a scalar potential ϕ , then this approach immediately leads to an inhomogeneous wave equation, which is called plasma wave. Solutions are known, like the electron plasma waves, which are longitudinal oscillations of the electron density (Langmuir waves).

Wave equation:

Laplace-operator	$\text{rot } \mathbf{E} = 0$ longitudinal wave	$\text{div } \mathbf{E} = 0$ transverse wave	$c =$ speed of light
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$$\Delta \mathbf{E} = \text{grad div } \mathbf{E} - \text{rot rot } \mathbf{E} = \frac{1}{c^2} \frac{\delta^2 \mathbf{E}}{\delta t^2}$$

$\text{Div } \mathbf{E} \neq 0$ is a scalar \Rightarrow **scalar wave !**

$\mathbf{E} = -\text{grad } \phi :$

$$\begin{cases} (1) \text{ grad div } \mathbf{E} = -\text{grad } \frac{1}{c^2} \frac{\delta^2 \phi}{\delta t^2} \\ (2) \text{ div } \mathbf{E} = -\text{div grad } \phi \end{cases}$$

$\text{div } \mathbf{D} = \rho :$

$$(3) \text{ div } \mathbf{E} = \frac{\rho}{\epsilon}$$

plasma wave:

$$\Delta \phi = \frac{1}{c^2} \frac{\delta^2 \phi}{\delta t^2} - \frac{\rho}{\epsilon}$$

i.e. = longitudinal Langmuir-wave
or: = longitudinal electric wave (vortex)

Fig. 2. The scalar part of the wave equation describes longitudinal electric waves (derivation of plasma waves).

Vortex Model

The Tesla experiment and my historical rebuild, however, show more solutions. Such longitudinal waves obviously exist even without plasma in the air and even in vacuum. Thus, the question is asked, "What does the divergence \mathbf{E} describe in this case?" How is the impulse passed on, so that a longitudinal standing wave can form? How should a shock wave come about, if there are no particles which can push each other?

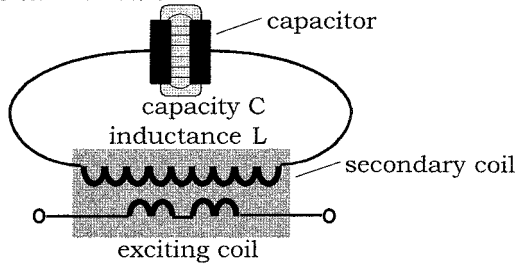
I have answered this question by extending Maxwell's field theory for vortices of the electric field. These so-called potential vortices are able to form structures, and they propagate in space because of their particle nature as a longitudinal shock wave. The model concept is based on the ring vortex model of Hermann von Helmholtz, which Lord Kelvin made popular. In my books (Meyl, 1996, 1998, 1999, 2002), the mathematical and physical derivations are described.

In spite of the field theoretical set of difficulties, every physicist will initially seek a conventional explanation. He will try the following two approaches.

1. **closed resonant circuit**

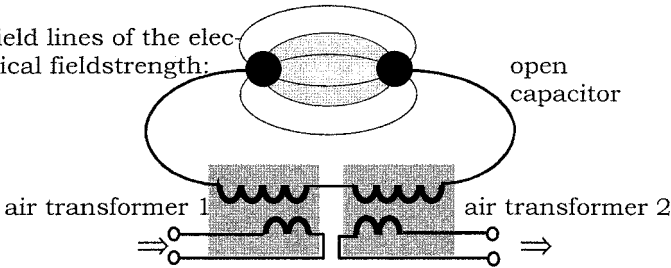
resonance
frequency:

$$f = \frac{1}{2\pi\sqrt{LC}}$$



2. **separating the resonant circuit**

Field lines of the electrical field strength:



3. **resonant circuit with open capacitor**

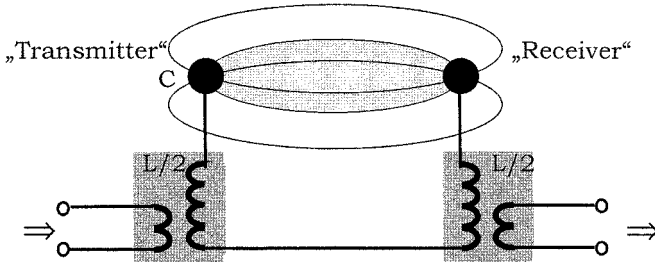


Fig. 3. Interpretation as an open resonant circuit.

Resonant Circuit Interpretation

Tesla had presented his experiment among to, among others, Lord Kelvin, and 100 years ago, Tesla had spoken of a vortex transmission. In the opinion of Kelvin, however, vortex transmission by no means concerns a wave but rather radiation. Kelvin had recognized clearly that every radio-technical interpretation had to fail, because alone the course of the field lines is a completely different one.

It presents itself to assume a resonant circuit, consisting of a capacitor and an inductance (Figure 3). If both electrodes of the capacitor are pulled apart, then between both stretches an electric field. The field lines start at one sphere, the transmitter, and they bundle up again at the receiver. In this manner, a high-

er degree of effectiveness and a very tight coupling can be expected. In this manner, without doubt some, but not all, of the effects can be explained.

The inductance is split up in two air transformers, which are wound in a completely identical fashion. If a fed in sinusoidal tension voltage is transformed up in the transmitter, then it is again transformed down at the receiver. The output voltage should be smaller or, at most, equal to the input voltage—but it is substantially bigger!

An alternative wiring diagram can be drawn and calculated, but in no case does the measurable result that light-emitting diodes at the receiver glow brightly ($U > 2$ Volts) occur, whereas at the same time, the corresponding light-emitting diodes at the transmitter go out ($U < 2$ Volts)! To check this result, both coils are exchanged.

The measured degree of effectiveness lies despite the exchange at 1000%. If the law of conservation of energy is not to be violated, then only one interpretation is left: The open capacitor withdraws field energy from its environment. Without consideration of this circumstance, the error deviation of every conventional model calculation lies at more than 90%. In this case, one should do without the calculation.

The calculation will concern oscillating fields, because the spherical electrodes are changing in polarity with a frequency of approximately 7 MHz. They are operated in resonance. The condition for resonance reads as follows: identical frequency and opposite phase. The transmitter obviously modulates the field in its environment, while the receiver collects everything that fulfills the condition for resonance.

Also, in the open question regarding the transmission velocity of the signal, the resonant circuit interpretation fails. But the HF-technician still has another explanation on the tip of his tongue, as follows.

Near Field Interpretation

In the near field of an antenna, effects are measured, which on the one hand are inexplicable, because they evade the normally used field theory, and which on the other hand come, by the scalar wave effects I have shown, very close. Everyone knows of a practical application (e.g., at the entrance of department stores, where the customer has to go through in between scalar wave detectors).

In my experiment, the transmitter is situated in the mysterious near zone. Also, Tesla always worked in the near zone. But he who asks for the reasons will discover that the near field effect is nothing but the scalar wave part of the wave equation. My explanation is as follows: The charge carriers which oscillate with high frequency in an antenna rod form longitudinal standing waves. As a result, the fields in the near zone of a Hertzian dipole are also longitudinal scalar wave fields. Figure 4 shows clearly how vortices are forming and how they come off the dipole.

As is the case for the charge carriers in the antenna rod, the phase angle be-

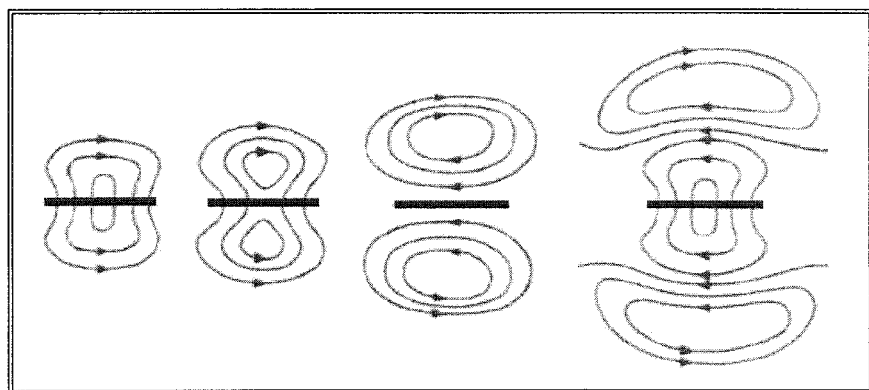


Fig. 4. The coming off of the electric field lines of the dipole.

tween current and tension voltage amounts to 90 degrees and occurs in the near field; also, the electric and the magnetic field phase shifted 90 degrees. In the far field, however, the phase angle is zero degrees. In my interpretation, the vortices are breaking up, they decay, and transverse radio waves are formed.

Vortex Interpretation

The vortex decay, however, depends on the velocity of propagation. Calculated at the speed of light, the vortices have already decayed within half the wavelength. The faster the velocity, the more stable they get, to remain stable above 1.6 times the velocity. These very fast vortices contract in the dimensions. They now can tunnel. Therefore, speed faster than light occurs at the tunnel effect. Therefore, no Faraday cage is able to shield fast vortices.

Since these field vortices with particle nature following the high-frequency oscillation permanently change their polarity from positive to negative and back, they don't have a charge, on the average, over time. As a result, they are able to penetrate solids in an almost unhindered manner. Particles with this property are called neutrinos in physics. The field energy which is collected in my experiment, according to that property, stems from the neutrino radiation which surrounds us. Because the source of this radiation, all the same if the origin is artificial or natural, is far away from my receiver, every attempt at near field interpretation goes wrong. After all, does the transmitter installed in the near field zone supply less than 10% of the received power? However, the 90% which it concerns here cannot stem from the near field zone!

Experiment

At the function generator I adjust the frequency and amplitude of the sinusoidal signal, with which the transmitter is operated. At the frequency regulator I turn significantly, until the light-emitting diodes at the receiver glow

brightly, whereas those at the transmitter go out. At this point, an energy transmission takes place.

If the amplitude is reduced so far that it is guaranteed that no surplus energy is radiated, then a gain of energy also takes place by energy amplification. If I take down the receiver by pulling out the earthing, then the lighting up of the LED signals the mentioned effect back on the transmitter. The transmitter thus feels as if its signal is received.

The self-resonance of the Tesla coils, according to the frequency counter, lies at 7 MHz. Now the frequency is run down and there, at approximately 4.7 MHz, the receiver again glows, but less brightly, and is easily shieldable and without discernible effect back on the transmitter. Now we unambiguously are dealing with the transmission of the Hertzian part and that goes with the speed of light. Since the wavelength was not changed, does the proportion of the frequencies determine the proportion of the velocities of propagation? The scalar wave, according to this theory, goes with $(7/4.7 =) 1.5$ times the speed of light!

If I put the transmitter into the aluminium case and close the door, then nothing should arrive at the receiver. Expert laboratories for electromagnetic compatibility in this case indeed cannot detect anything, and, in spite of this fact, the receiver lamps glow! By turning the receiver coil it can be verified that an electric and not a magnetic coupling is present, although the Faraday cage should shield electric fields. The scalar wave obviously overcomes the cage with a speed faster than light, by tunneling!

Note

¹This paper is based on a presentation made by the author at the Amsterdam conference of the Society for Scientific Exploration, October 2000.

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Nikola Tesla and Future of Electric Power Engineering

Dmitry S. Strebkov¹

Abstract –If an electric engineer* had studied classical electrotechnics during three semesters and works in the field of high-power electric networks, it is rather difficult for him to accept, that an alternative electrotechnics exists, which is characterized by the following features: A closed circuit containing two conductors between the generator and the load is not necessary to obtain an electric current flow.

The current can flow through a single-wire circuit, like the water flows through a pipe from the upper basin to the lower one, or like the heat flows from a hot end of a metal bar to its cold end. (W. Thomson was first to point to the analogy between thermal conduction and electrostatics, while J. Maxwell was first to show the analogy between hydrodynamics and electrodynamics).

In a coil containing a single-layer wire winding, the phase velocity of the electromagnetic wave along the coil axes can be hundreds times lower, than in an overhead transmission line (or than the light speed in the free space).

The current varies along the line length, in different winds of a coil, or in different sections of a single-conductor line, it can have any local value, including zero. Furthermore, the current in different segments of a single-wire circuit can flow in opposite directions.

Keywords – Nikola Tesla, high-power electric networks, Tesla's coil

¹Dmitry S. Strebkov All-Russian Research Institute for Electrification of Agriculture VIESH, 1-st. Veschnyakovsky proezd, 2, Moscow, 109456, Russia, www.viesh.ru, E-mail: viesh@dol.ru

* The author, electric engineer, graduated from the Moscow State Agricultural Engineering University in 1959. After delivering lectures during 15 years, he has received the academic status of professor at the Open University, Chair of Fundamentals of Radiotechnics and Television. The author is grateful to professor V.M. Svistov (Chair holder of Fundamentals of Radiotechnics and Television from 1972 to 1987) for discussing waveguide systems for power transmission, to academician of the Russian Academy of Sciences Ya.B. Danilevich and to Corresponding Member of the Russian Academy of Sciences N.S. Lidorenko for fruitful discussions, recommendations and support of the work.

I. INTRODUCTION

However, such exotic behavior of the current (from the viewpoint of a classical electric engineer) does not seem strange to a radio engineer, because a beam antenna and a single-conductor waveguide are classical examples of single-conductor lines for him [1–3]. Standing waves and traveling waves of the current (and voltage) exist in such lines, and the circuit is closed by displacement currents in the space surrounding the single-conductor line. J. Maxwell wrote: “Extraordinary difficulty of coordinating the electromagnetism laws with the existence of unclosed electric currents is one of the reasons (among many other), why we must admit the existence of currents created by displacement variation”. At a high frequency, the single-layer electric coil is transformed from a classical induction coil (in different application conditions) to a slow-wave structure or electromagnetic-wave delay line, to a helical waveguide, helical antenna or electric resonator with distributed parameters, which can not be determined using the classical electric circuit theory.

All the considered phenomena in a single-conductor line and in a spiral coils exist also at frequencies of 1 to 100 kHz, and they can be used for electric power transmission. Furthermore, the specified frequency range is most suitable for electric power transmission along a single-conductor waveguide in connection with limitations imposed by the radiation loss caused by the antenna effect. Unfortunately, the radio engineers have little interest in this frequency range, while the electric engineers are insufficiently prepared for working at the interface of electrotechnics and radiotechnics.

The electric power transmission along a single-conductor line at a higher frequency has been first proposed and realized by N. Tesla more than 100 years ago [4]. N. Tesla considered a resonant single-conductor system for electric power transmission as an alternative to a dc power transmission system proposed by T. Edison. The competition between dc and ac power transmission systems continues at present, however it takes place in the context of classical single-phase (double-wire) and three-phase (triple-wire) closed transmission lines.

We have shown experimentally, that a single-conductor line with a high-frequency resonant Tesla transformer at the line end can transmit electric power at any frequency, including zero frequency (i.e. using rectified current). The

single-conductor resonant systems (see Fig.1, 2) offer possibilities for designing super-long cable lines and replacing (in future) the existing overhead lines with cable single-conductor lines [5]. In this way one of major electrification problems: increasing the reliability of electric power supply will be solved.

The open-ended line shown in Fig. 1, whose length is $l = (2n + 1) \lambda/4$, $n = 0, 1, 2, 3, \dots$, has a current loop and a voltage node at the generator terminals; in case of $l = n \lambda/2$, it is a voltage loop and a current node. In both cases the line is equivalent to a resonant oscillatory circuit.

The standing waves in the open-ended single-conductor line (see Fig. 3) arise as a result of superposing the incident and the reflected waves having equal amplitudes. The voltage and current phase values demonstrate no displacement along the line, while the phase shift between the current and the voltage is equal to 90° . The line cross-sections with voltage loops contain current nodes, while voltage nodes correspond to current loops. The mean power delivered by the generator into the open-ended single-conductor lossless line (or into a line, loaded with a capacitor) is equal to zero [2].

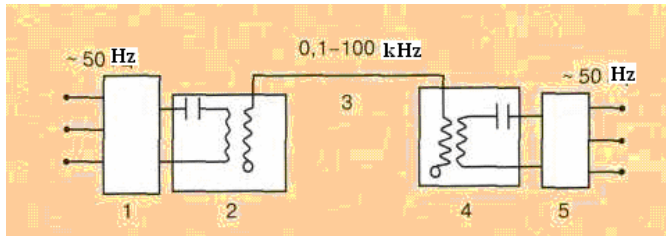


Fig. 1. Resonant system for electric power transmission 1 – generator, 50 Hz (1 to 100 kHz); 2 – frequency converter 50 Hz / 1 to 100 kHz (absent, if the generator frequency is 1 to 100 kHz); 3 – high-frequency step-up transformer 0.4 kV / 10 to 500 kV; 4 – single-conductor line 10 to 500 kV; 5 – high-frequency step-down transformer 10 to 500 kV / 0.4 kV; 6 – inverter 1 to 100 kHz / 50 Hz

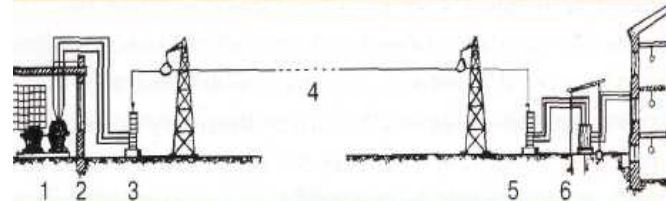


Fig. 2. Single-conductor resonant power transmission system 1 – electric generator, 50 Hz (1 to 100 kHz); 2 – frequency converter 50 Hz / 1 to 100 kHz (absent, if the generator frequency is 1 to 100 kHz); 3 – high-frequency step-up transformer 0.4 kV / 10 to 500 kV; 4 – single-conductor line 10 to 500 kV; 5 – high-frequency step-down transformer 10 to 500 kV / 0.4 kV; 6 – inverter 1 to 100 kHz / 50 Hz

If the line operates in the standing-wave regime, its input impedance is reactive. If the line is lossy, a certain traveling wave from the generator compensates for the loss. If traveling and standing waves are present in the line, its input impedance contains both reactive and active components.

The single-conductor resonant line, open at the load end (or loaded with a capacitor) is shown in Fig. 4,a; the current and voltage distribution for the open-ended line is plotted in Fig. 4,b [2, 6].

$$n = 0; f = 5 \text{ kHz}; \lambda = 60 \text{ km}; l = \lambda/4 = 15 \text{ km}$$

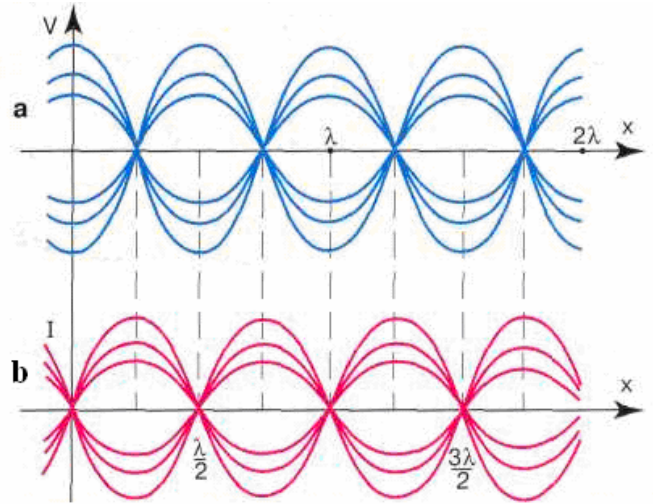


Fig. 3. Standing waves in an open-ended line at various time points

a – voltage; b – current

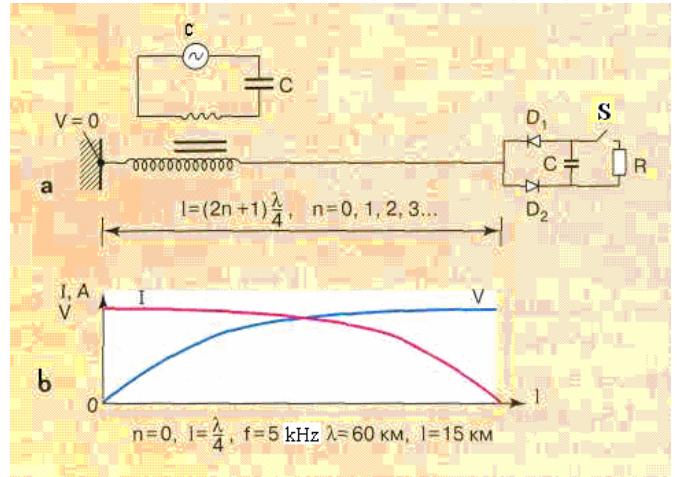


Fig.4. Circuit representation for a single-conductor resonant line, open at the load end or loaded with a capacitor (a); current and voltage distribution (b)

G – generator; C_0 – capacitance of the resonant circuit; D_1 and D_2 – diode unit;

C – load capacitance; S – electronic switch; R – load resistance

$$n = 1; f = 10 \text{ kHz}; \lambda = 30 \text{ km}; l = \lambda/2 = 15 \text{ km}$$

The current and voltage distribution in a single-conductor line shorted to the ground at both ends is shown in Fig.5 [5]. The classical electric engineer (mentioned at the beginning of this section) would say, looking at Fig.5,a,b, that it is a closed double-conductor transmission line using the ground as the second conductor, with the conductance current in the closed circuit. The radio engineer would give a correct explanation: it is a conventional waveguide characterized by 90° phase shift between the current and the voltage, fastened to grounded metal supports, which are connected to the line at the voltage

node points. The line grounding at the voltage node points does not change the waveguide parameters and does not effect the transmitted power value.

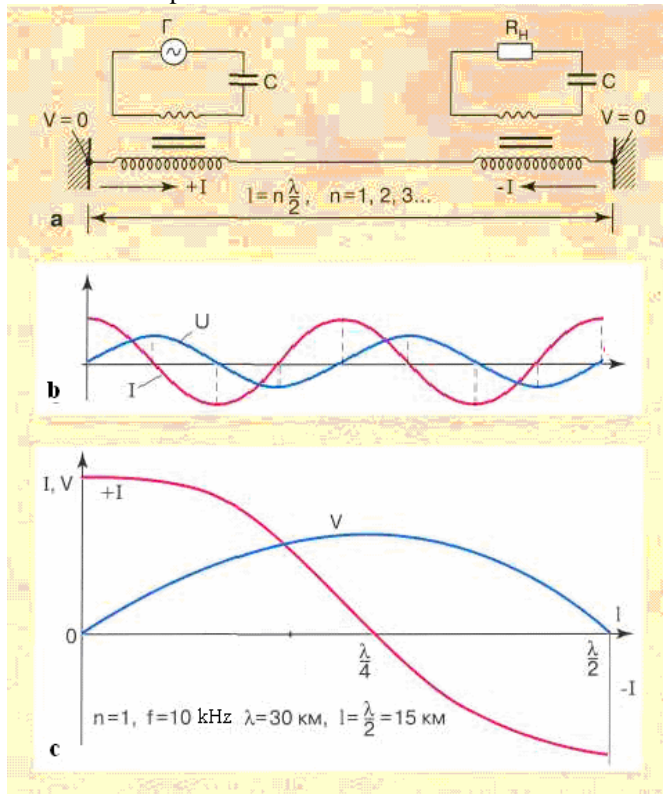


Fig.5. Current and voltage distribution in a single-conductor line shorted to the ground at both ends

a – circuit representation (G – high-frequency generator, R_L –load resistance, C – capacitance of the resonant circuit);
b – current and voltage standing wave distribution along a single-conductor line;
c – current and voltage distribution in a half-wave single-conductor line

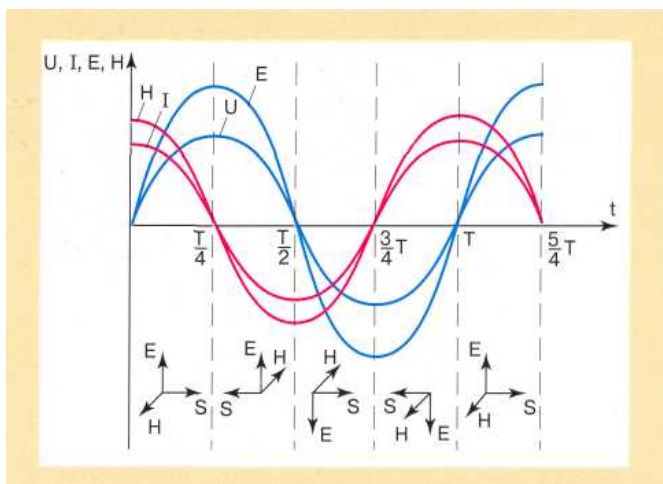


Fig.6. Direction of the Poynting vector \vec{S} along the single-conductor line in the standing-wave regime I, H – waves of the current and the magnetic field strength; V, E – waves of the voltage and the electric field strength

When the line operates in the standing-wave regime, the direction of the Poynting vector \vec{S} is inverted every quarter of the time period: it is directed from the generator to the load or back (see Fig.6). This phenomenon is explained in the following way. The phase shift between the voltage and the current in the line (and consequently between the values of the electric and magnetic field strength) is equal to 90° ; as a result, the direction of one of the vectors: \vec{E} or \vec{H} is inverted every quarter of the period. This consideration confirms, that the generator spends no energy to produce standing waves in the line [2].

For the electric engineer, the stationary or standing waves shown in Fig.6 illustrate a phenomenon, which has no real physical basis, because the length of transmission lines does not usually exceed 1000 km, while the current and voltage wavelength at a frequency of 50 Hz equals to 6000 km. A half-wave line (see Fig.5,c), 1000 km in length, can be obtained at a frequency of 150 Hz, and in this case even a conventional single-phase or three-phase line will transmit considerably more power, than at a frequency of 50 Hz. However conventional transmission lines reveal resonant properties only in an emergency condition (for example, in case of line break at the consumer). In order to understand N. Tesla works and develop his ideas on resonant electrotechnics, the classical course for electric engineers shall be supplemented by a special course containing information on high-frequency resonant lines, principles of single-conductor and helical waveguides, methods for designing electric circuits with distributed components, main scientific and practical results in the field of resonant electric technologies and prospects for their application.

Several application fields for resonant single-conductor electric systems are considered below.

A 20-kW, 1-kHz resonant transmission line based on a single-conductor cable, 1.2 km in length, has been successfully developed and tested at the VIESH (Fig. 7) [6].



Fig.7. 20 kW, 1 kHz resonant electric power transmission system

Application of various conducting mediums in the resonant systems for transmitting electric power has been illustrated using an electric boat model, which receives electric power from a water basin with alive fish (Fig 8, 9).

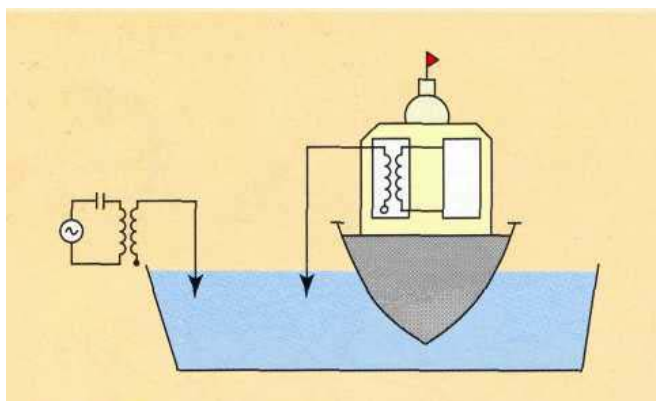


Fig. 8. Electric power transmission using water as conducting media

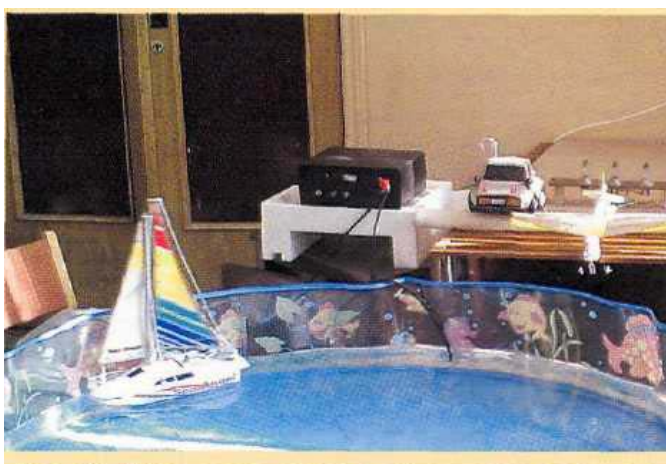


Fig. 9. Electric boat model receiving electric power through the water

A wind power station, a solar battery, etc can be used as a source of electric power in a resonant electric system.

Another global application for resonant single-conductor electric power transmission systems consists in the opportunity of developing noncontact high-frequency electric transport. The well-known noncontact method for transmitting electric power to a vehicle through an air-core transformer (using the electromagnetic induction method and conventional single-phase power transmission lines) has basic limitations on the transmitted power level, the transmission efficiency and the line length; therefore, it is not used at present [7].

An experimental model of a small electric vehicle developed at the VIESH receives electric power from an isolated single-conductor cable line laid inside the roadway covering (see Fig.10). The works on increasing the noncontact drive power and developing a commercial project of a resonant electric transport system are being carried out now. It is possible to imagine in future a big green city, full of flowers, without exhaust gases and smog. A cable transmission line will be laid in this city under each driving row along main roads, and each vehicle has an electric motor and a noncontact trolley in addition to the combustion engine. The traffic along big highways between cities can be organized in the same way, including possible use of automated vehicles controlled by robots and computers.

Use of an electric noncontact drive in the agricultural energetics opens the prospects for substantial fuel saving and developing pilotless automatic robots controlled by computers with satellite navigation, intended for tillage, cultivation and harvesting agricultural products. In this case the agricultural plants will turn to field factories organized according to the principles of automated industrial enterprises. Thus, three present-day electrification problems can be solved: energy saving, reducing harmful gas ejection and automation of agricultural production process.



Fig. 10. Contactless high frequency electric vehicle

The third application field for resonant single-conductor systems are plasma medical and technological facilities. They differ from conventional plasmotrons in having not two, but a single electrode, which is the beginning of a resonant single-conductor line, while the capacitance of any body or treated substance is used as a load. A new resonant coagulator developed at the VIESH (see Fig.11) is used in medicine, in veterinary technique and in cosmetology [6]. Technological single-electrode plasmotrons can have pulsed power up to 10^{10} W and continuous power up to 20 MW. They can be used to eliminate weeds (instead of pesticides), to produce liquid biofuel from organic raw material, to manufacture and purify solar-grade silicon, to generate plasma in physical experiments (for example, producing artificial ball lightning [8]).

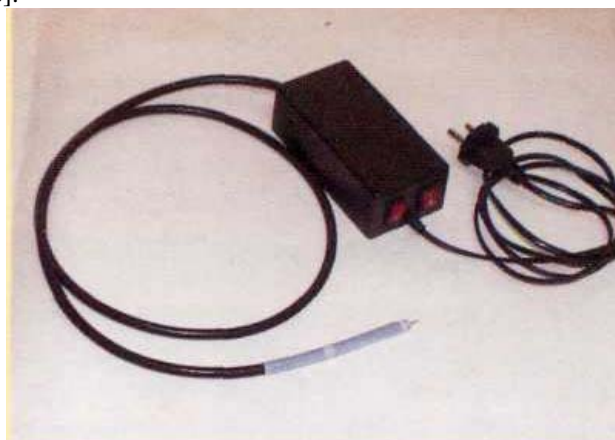


Fig.11. Resonant cold-plasma coagulator developed by Cand. Sci. (Tech.) Veryutin V.I. (VIESH)

The fourth application field for resonant systems is creating global and local information communicating systems using single-conductor lines. Many works by N. Tesla are devoted to this application. The first devices transmitting information signals has been developed by N. Tesla in 1899, they were patented in 1901. In 1943, the Supreme Court of the USA has recognized N. Tesla priority disputed by R. Marconi in long-distant transmission of electric signals.

Each single-conductor line has several resonant waves. Therefore, the single-conductor line (as well as a fiber-optic line) may be used to transmit simultaneous different information to several users. A specialized line screening technique allows to reduce the loss in signal amplitude and quality, when it is transmitted over a long distance. N. Tesla has proposed original methods for encoding the information and protecting it against unauthorized access. The information communicating systems and power transmission systems based on modern technologies are now key factors for the social development of the country and progress in the agricultural production.

N. Tesla was an ingenious scientist, who had foreseen the development of the electrotechnics and energetics for hundreds of years. He has produced a voltage of 100 million volts using simple facilities; he has transmitted electric power over tens kilometers, using the ground as the conducting medium; he has tested a boat controlled through the water medium; he has invented the asynchronous electromotor, the multiple-phase current and has made many other inventions. N. Tesla was a brilliant designer of mechanical systems. Magnificent drawings of different mechanisms designed by N. Tesla are stored in Tesla museum in Belgrade. Some of his non-electric inventions are of interest till now: a combustion engine without a piston and a crankshaft, steam and hydraulic turbines without blades, and a mechanical analog for the electric diode (device allowing to a gas or fluid stream to flow in one direction only). In this valveless device, the hydraulic resistance values in the direct and reverse direction differ by factor of 300. Now we can fully repeat and develop Tesla resonant techniques in the field of electric power transmission using single-conductor lines and conducting mediums.

There is little information on N. Tesla works in the field of wireless power transmission methods. His last invention in this field "Device for electric power transmission" has been written in 1902, revised in 1907 and patented in 1914. At a session of the American Institute of Electric Engineers on May 18, 1917, N. Tesla received a reward named after T. Edison. His speech at the session contained the following statement:

"As to power transmission through the space, it is a project, which I consider absolutely successful for a long time. Years ago I could transmit power without wires to any distance without limitation, which was imposed by the physical dimensions of the Earth. In my system, the distance value is of no importance. The transmission efficiency can reach 96 or 97 percents, and there are practically no loss, except for the component, which is inevitable for the device operation. If there is no receiver, there is no power consumption anywhere...

When there is no receivers, the station consumes only a few horsepowers, which is necessary to maintain the electromagnetic oscillations; it is idling, like the Edison station, when the lamps and the motors are switched off..."

The high transmission efficiency may be easily explained, considering the standing waves in the conducting channel (see Fig.6). The journal "Time" wrote on July 23, 1934: "Last week doctor Tesla announced a combination of four inventions, which would make the war absurd. The essence of his idea is connected with deadly rays: a concentrated beam of submicron particles moving with a speed, close to the light speed. According to Tesla, the beam, will defeat the army during flight, causing airplane squadrons to fall down at a distance of 250 miles (400 km). The inventor will launch the rays by using the following: device for reducing the particle delay in the atmosphere to zero; method for producing high potential; procedure for amplifying this potential up to 50 million volts; producing tremendous acting electric force".

II. CONCLUSION

N. Tesla died on January 7, 1943 in hotel "New Yorker" in Manhattan, in the room 3327 on the 33-rd floor. Immediately after his death, his scientific works disappeared from the room; they were never found. A part of those materials contained an information on the techniques, which could be used for wireless power transmission. Methods for generating and amplifying high potential have been fully described by N. Tesla in [4]. Taking into account the present-day level of the scientific knowledge and progress in electrotechnics, N. Tesla works on resonant methods for electric power transmission give new opportunities for the development of electroenergetics, electric technologies, electric transport and communications.

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(Extract from TCBA NEWS, volume 8, #3, 1989) TESLA'S PRODUCTION OF ELECTRIC FIREBALLS by Kenneth L. Corum and James F. Corum Corum & Associates, Inc. 8551 State Troute 534 Windsor, Ohio 44099 "I have succeeded in determining the mode of their formation and producing them artificially." Nikola Tesla [ELECTRICAL WORLD AND ENGINEER, March 5, 1904]

INTRODUCTION

Although there have been numerous articles, publications, and seminars on the phenomenon of ball lightning and fireballs, only a very few have ever reported on the actual production of fireballs. Yet even fewer of these handful have ever actually produced fireballs under conditions that, even remotely, could be considered similar to nature. As with General Relativity, the number of theoretical publications exceeds the number of experimental papers by several orders of magnitude.

Our laboratory in Ohio (which is noted for slow wave helical antenna research) has developed equipment that will produce electric fireballs that will last after the external power is removed. We have been able to produce electric fireballs that will fit the conditions and circumstances that are frequently seen in nature (i.e., fireballs passing through windows, inside airplanes, traveling along fences, etc.).

Last summer, during the 3rd International Tesla Symposium at Colorado Springs, while walking around Tesla's Laboratory site and Prospect Lake in nearby Memorial Park, Leland Anderson made the comment, "I don't understand why we don't all see fireballs. The way Tesla described them, they just seemed to bubble from his machine." (See Photograph 4). We had been discussing the "missing" chapter 34 that Harry Goldman had just published in TCBA NEWS (Volume 7, #3, 1988 pp. 13-15). Its import may be gotten from this brief quote attributed to Tesla:

stray "...it became apparent that the fireballs resulted from the interaction of two frequencies, a
higher frequency wave imposed on the lower frequency oscillations of the main circuit....

wave This condition acts as a trigger which may cause the total energy of the powerful longer
tremendously to be discharged in an infinitesimally small interval of time and the proportionately
released great rate of energy movement which cannot confine itself to the metal circuit and is
into surrounding space with inconceivable violence.

lower It is but a step, from the learning how a high frequency current can explosively discharge a
be frequency current, to using the principle to design a system in which these explosions can
produced by intent." -N. Tesla

It was a puzzle to us. While flying back to Cleveland, we continued to compare Chapter 34 with the photographs in Tesla's published notes. And then it struck us. We just weren't using the circuit configuration which Tesla shows to us. When we got back, we arranged our apparatus as shown in Figure 1.

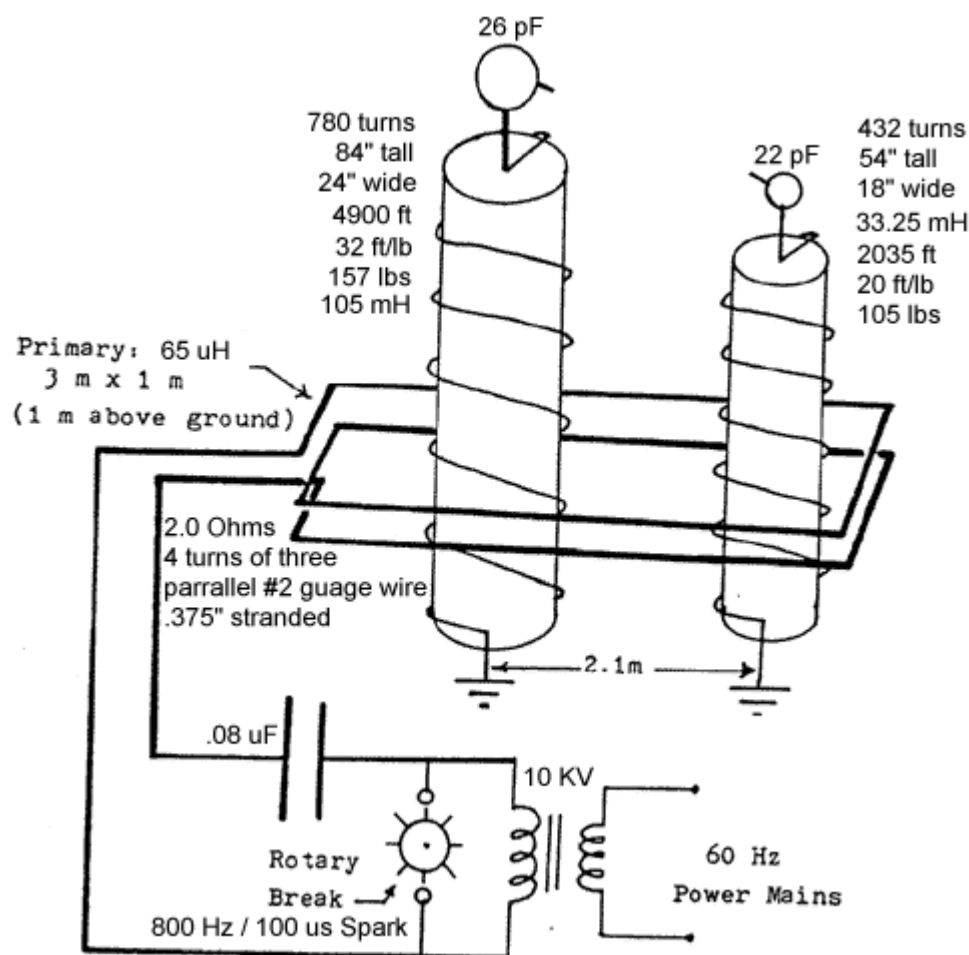


figure 1.

APPARATUS

Following Tesla's instructions, we rewired our apparatus as two synchronously pulsed high power RF oscillators, the first at a frequency of 67 KHz and the second at 156 KHz (The exact frequencies aren't critical). The basis for the apparatus was first conceived and patented in 1897 by Nikola Tesla. The idea of using two oscillators in synchronism was also used by Tesla at the turn of the century in a patented primitive spread spectrum communication system. The apparatus can be seen in dozens of photographs and circuit diagrams in Tesla's Colorado Springs Notes (referred to as CSN below).

There have been many descriptions and analyses of Tesla's oscillators. The classic being the Oberbeck in 1895. However, all of these scientific and engineering descriptions fall short of a true description. It wasn't until we applied slow wave transmission line theory and partial coherence to Tesla's oscillator that we were able to accurately predict the operation of the oscillator and the subsequent production of fireballs.

The apparatus consists primarily of two one-quarter wavelength, slow wave helical resonators above a conducting ground plane. Both of the resonators were magnetically coupled by a common link to a spark gap oscillator, of high peak power (approximately 70 KW), operating at a frequency of 67 KHz. The actual average power being delivered to the high voltage electrode was on the order of 3.2 KW (2.4 megavolts RF). Tesla, of course, was running about 100 times the power which we could produce with our rather modest equipment.

OPERATION

The spark gap oscillator was set to 800 pulses per second and the duration was 100 microseconds. The low frequency coil had a coherence time of 72 microseconds. This means that the induced incoherent oscillations on the resonator took 72 microseconds to build up a standing wave (or interference pattern), and show up as a high voltage on the top end of the resonator: $V_{\max} = S V_{\min}$ (where S is the VSWR) [The theory is developed in great detail in References 5,6,7. Reference 8 even provides a computer assisted tutorial.] The high frequency coil had a coherence time of 30 microseconds.

#1. Using the high frequency coil to arc to the low frequency coil, the low frequency coil would then release its energy rapidly, in a burst. The burst of energy released manifests itself in the shape of a ball or "bubble." Due to the faster voltage rise on the high frequency coil and the subsequent short duration arc to the low frequency coil, the low frequency now sees a low impedance where it would normally see a high impedance. the energy trapped in the coil when the oscillator was on must now be dissipated very quickly at this lower impedance point, hence the burst. (See CSN page 114, bottom paragraph. Tesla's use of lumped circuit Q is somewhat misleading, but his physics is substantially correct. Circuit 4 on page 115 and the one on the top of page 174 are virtually the same as Figure 1.)

#2. A second method of fireball production includes the use of microscopic vaporized metal or carbon particles. We used the low frequency coil alone and deposited a thin film of carbon particles on the high voltage electrode. When the voltage began to rise on the end of the resonator, streamers began to form on the electrode. The current passing through the carbon film tended to rapidly heat the carbon particles. This dissipation of power also tends to quickly reduce the impedance and subsequently release all the power rapidly into this heated micron size "resistor." The same results may be gotten by using "the tip of rubber covered cable or wire #10" to "facilitate the pumping of the spark." (CSN page 173-174) Old fashioned rubber is loaded with soot.

Experimentally, we have determined the ideal set of conditions for producing electric fireballs. They are:

1. Generate a lot of carbon or vaporized metal particles in a small region of space.
2. Create large electric fields in the same vicinity (on the order of 1 to 2 MV/m).
3. Rapidly elevate the temperature of the particles.

Video tape easily documents the results of meeting these three conditions. From this, fireball lifetimes are deduced to be 1 to 2 seconds and dimensions are 1 to 3 centimeters in diameter. Also, these are in agreement with Tesla's observations and conclusions. For example, in one place he attributes fireballs to the presence of resistively heated material in the air. (CSN page 333)

This mechanism is consistent with Zaitsev's relatively recent theory in which the resistive heating of particles creates a glowing region or fire ball: "the current of the preleader stages of the discharge from the seed [cloud of fine particles (metal, soot, or ash)] flowing through the structure drives it to thermal explosion." (ref. 1) The fire balls disappear either when the particles burn up or when a thermal explosion occurs. we have observed both.

RESULTS

Using these methods for producing the fireballs, we then set about creating conditions as described by observers of ball lightning. By having the streamers, produced by the two resonators operating together, strike a windowpane surrounded by a wooden frame, we produced conditions normally found in nature.

(see refs 2 & 3) What was observed by the operator of our apparatus was astounding! "the streamers went from the high voltage terminal and struck the windowpane. There were many fire balls present between the electrode and the window. But where the streamers hit the glass, there were many fireballs emanating from the opposite side of the glass. The fireballs would then travel slowly horizontally 12 inches or so and flare up. Some would travel out a bit farther and explode." What was captured on video tape can be seen in the sequence of photos 1, 2, and 3. These results are reproducible on demand. Try it!

Powell and Finkelstein have described a mechanism for how fire balls may appear to pass through a glass window intact.



"initially electric lines of force pass freely through glass. Positive ions from the ball follow force lines and pile up on one side of the glass while electrons from the room accumulate on the other. When the ball approaches, the glass is heated or broken down enough to become slightly conducting. It then becomes an electrode, and a ball is formed inside the room; the ball then floats away from the window." (Ref. 3)

The actual physics may be somewhat different, but the sequence of photographs 1, 2, and 3 support the general idea.

The relative ease of electric fireball generation by high voltage discharges in the presence of carbon films, smoke, ash, and dust is consistent with its frequent natural observation in and around chimneys, where carbon is deposited in great profusion.

[Readers familiar with Michael Faraday's famous Christmas Lecture, "The Chemical history of a Candle" ("There is not a law under which any part of this universe is governed which does not come into play."), will recall his glowing remarks about the presence of smoke and solid carbon particles in a brilliant candle flame - they give us glorious colors and beautiful light. Imagine what would have resulted if Faraday and Tesla had met! If you can't get the 1 or 2 MV that Zaitsev requires as necessary and which we observed under condition 2 above, you can place a wire wrapped plumber's candle on the side of your small Tesla coil and get an idea of what can be seen on a larger machine. Again, video taping the experiment, adjusting the power levels and reviewing the tape, frame by frame, will be quite a

revealing experience. Faraday noted that if you put a strainer or a glass tube down in a candle flame, you will see an incredible amount of soot particles bubbling up. This is what gives candle flame its color and luminosity.]

we were able to produce other interesting features. Often we had pulsating fireballs. These would appear and then shrink. When they were hit by streamers, they would grow in size then shrink again. This would occur a number of times and then they would fade away. Another feature was that some had the appearance of a doughnut; bright circles with darkened centers. Others appeared to the observer as white, red, green, yellow, blue-white, and purple. See photo 4. Many other color photographs and a historical discussion are given in Reference 9.

CONCLUSION

We believe the phenomenon that manifests itself when the coherence time is cut short could indeed be the same phenomenon that occurs in nature. Instead of having a short helical resonator being the transmission line, the natural lightning stroke could be a full quarter-wave transmission line with its own coherence time shortened by small streamers at one end of the lightning stroke. According to lightning specialists, most of these small streamers occur at the top end of the lightning stroke. This would account for the infrequency of ball lightning on the ground side of the stroke. Dust, soot, ashes, and other pollutants in the air near lightning strikes would, of course, produce similar results.

Our conclusion is that these fireballs are primarily RF in origin, and not nuclear phenomena. Consistent with Tesla's observations, they can be produced either by high current dump into hot air ["I am satisfied that the phenomenon of the fireball is produced by the sudden heating, to a high incandescence of a mass of air or other gas as the case may be, by the passage of a powerful discharge." CSN page 368] or by the presence of resistively heated material particles ["I attribute them (fire balls) to the presence of material in the air at that particular spot which is of such nature, that when heated, it increases the luminosity." CSN page 333] The latter would account for the "engine room fire balls" produced by high current switches and relays. Finkelstein and Rubenstein once made a remarkable statement: "If this model is appropriate, then ball lightning has no relevance to controlled-fusion plasma research." (Ref. 4) It should now be apparent that this position can be experimentally supported.

In our literature research on the topic over the past 26 years, we have read through hundreds of technical articles, papers, reports, and books. It would be impossible to cite and discuss all of them in this communication. But we believe that Tesla's is the only apparatus that has been developed that can address and reproduce on demand the many descriptions of ball lightning in nature. Now a host of experimenters may carry out fire ball generation and experimentation under their own controlled conditions. Best of all, the required apparatus is not only inexpensive, it is readily available in thousands of homes and existing laboratories around the world.

What would have transpired if Faraday and Tesla had met? Why, high power RF oscillators and candle chemistry would have combined to reign brilliant electric fireballs - of course!

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1978, pp.111, 330-333, 368-370, 372, 379-384, 431-433, (CSN above)

TESLA'S COLORADO SPRINGS LIGHTNING OBSERVATIONS

by Gary Peterson

As seen from a present day perspective, the time which Nikola Tesla invested into his 1899 Colorado "expedition" appears to have been some of his most productive. This might be because he had considered the previous ten years of research as practice for the work that was being conducted at the now well-known Experimental Station. Or perhaps it is from the many recorded observations dating from this period and the group of important patents would appear over the next few years. In fact, work on the applications for these fundamental radio patents began while Tesla was still in Colorado. One major account that is related in the *Colorado Springs Notes* and in an article titled "The Transmission of Electrical Energy Without Wires," has to do with an unusual natural radio phenomenon that Tesla observed during and after an intense thunder storm which passed close by his Colorado lab.

The receiver that he used appears to have built around an oscillatory transformer similar to the type employed for high frequency lighting. (See *Nikola Tesla: Lecture Before the New York Academy of Sciences — April 6, 1897* for details about these devices.) Located on the primary side of the transformer were a sensitive device known as a rotating coherer and a mica condenser both connected to an elevated terminal and to ground. The primary side of the circuit also included a battery for placing a small dc voltage across the coherer and a mechanical switch known as a "break." During normal operation the make-and-break device would open and close about 72 times per second. In the secondary side of the circuit was another coherer and battery plus a delicate relay which responded by closing every time a lightning discharge occurred in the general vicinity. This type of receiver was extremely sensitive, being capable of recording effects as distant as an estimated 500 miles.

On July 4 Tesla writes that his observations began as the storm was approaching and still at a distance of 80 to 100 miles. The relay on the elegantly simple receiver must have begun to chatter practically as soon as all the connections were made. As the storm came closer, the relay continued to respond even as it was adjusted to its least sensitive setting. As the storm continued on past the lab is when, in Tesla's word's, "the most interesting and valuable observation was made." The relay was once again adjusted to be more sensitive and it continued to respond for a while and then stopped. After an unspecified time had passed the relay again responded for a while and then once again ceased to play. As recorded by Tesla this on-again off-again action continued to repeat itself with a period of about 30 minutes, at the very least six or seven times, on into the evening. He writes, "most of the horizon was clear by that time."

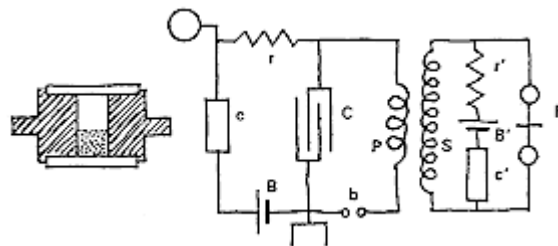
A number of people have speculated as to what, exactly, Tesla had seen that summer long ago. One proposal, put forth in the *Proceedings of the Tesla Centennial Symposium*, is that mechanical vibrations were being detected which were the result of terrestrial piezoelectric interactions associated with the lightning strikes. Another theory has it that the varying ground currents were the result of stationary waves created by reflections off the Pikes Peak mountain range. Tesla himself considered two other possibilities for the creation of what he believed were stationary waves anchored to their moving point of origin. The first and, at the time, to him least probable, was that they were the result of reflections from the point of the earth's surface diametrically opposite to the storm. More likely, in his mind, was that they resulted from reflections which took place within the storm itself, at a point very close to the origin of the initial wave packets.

In 1994 a new premise was set forth by Kenneth and James Corum in a paper presented at the biennial Tesla Symposium in Colorado Springs. The proposed model is an adaptation of waveguide theory and draws upon a method of treating radiation sources in a waveguide that calls for the existence of "images" which mirror an assumed dipole source. These images in combination with the source itself can be said to form what appears to be broadside array of radiating elements. Furthermore, the radiation from these sources, being coherent, can interfere and cast side lobes that appear as maxima and nulls along the waveguide walls.

It is proposed that rather than registering the existence of stationary waves, Tesla might have been seeing a wave interference phenomenon similar to that described above. The nodes and antinodes which passed by his point of observation might have been due to the superposition of partially coherent lightning induced VLF waves radiating from the primary source and an adjacent image and propagating down along the earth-ionosphere waveguide. This model bears more than passing resemblance to Tesla's preferred scenario that did not call for the reflection of waves from the antipodes. At the same time it is important to note that in the specifications for his Patent No. 787,412, *Art of Transmitting Electrical Energy Through Natural Media* Tesla stated that the lightning produced waves provided "unmistakable evidence that the disturbances created had been conducted from their origin to the most remote portions of the globe and had been thence reflected..." In the ten short months between July 4, 1899 and the May 16, 1900 application date what had caused this tremendous shift of opinion to where he now believed and practically recorded as fact what before had been assigned the lesser probability? Tesla himself gave us the answer in 1929 when he wrote:

"The chief discovery which satisfied me thoroughly as to the practicability of my plan was made in 1899 in Colorado Springs, where I carried on tests with a generator of 1500 KW capacity and ascertained that under certain conditions the current was capable of passing across the entire globe and returning from the antipodes to its origin undiminished in strength. It was a result so unbelievable that the revelation at first almost stunned me."

The Corums' 1994 analysis provides us with a highly plausible physical model to explain Tesla's lightning related observations during the stormy summer of 1899. It is also quite apparent that that year's ground breaking experiments with a specially designed high power electrical oscillator thoroughly convinced Tesla that he was seeing indications of electrical earth resonance. This raises the question: while in he was in Colorado Springs did Tesla ever observe any indications of interference between the outgoing waves that were induced by his experimental VLF transmitter and incoming waves reflected from the antipode?

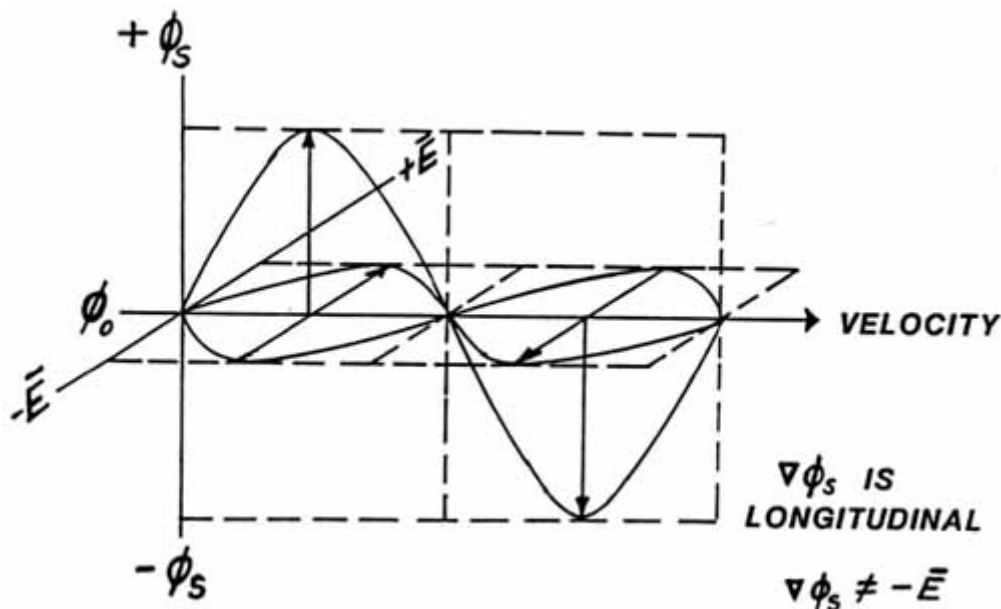


The rotating coherer and associated circuitry

Tesla's VLF receiver must have been very similar to the circuit illustrated here. Each of the two coherers *c* and *c'* were constructed from a short section of 3/8 inch I.D. glass tubing capped with two brass plugs. The intervening space was partially filled with coarse nickel chips. The two adjacent batteries *B* and *B'* were adjusted with resistors *r* and *r'* to strain the devices to a point where they were just about to break down and become conducting. An incoming signal would drive the potential across the device beyond its threshold causing a much stronger battery current to flow. A clockwork drive mechanism was used to continuously rotate the small glass cylinders thus decohering the chips after each received impulse. It is now believed that coherers are uniquely suited to detect the particular type of natural radio phenomenon that Tesla observed in 1899.

SCALAR STRESS WAVE - TESLA WAVE

Tom Bearden



On this slide we now show a simple way to make a scalar, zero-vector wave -- the kind of wave originally discovered by Nikola Tesla.

It's simple. We just believe that a sum-zero vector substructure makes a scalar quantity, and we MAKE some scalars that way.

We also understand that a zero-gradient of a scalar is a zero vector, so that the scalar itself may be taken to be a zero vector.

The simplest explanation of this wave is as follows:

First, in physics we have two competing, mutually exclusive theories as to the nature of electromagnetic energy: the wave theory and the particle theory. Physicists argued for decades over these theories, for some experiments support one and some support the other. They never solved the problem; they just agreed to quit arguing. They formulated the "duality" principle to allow the saving of face to both sides.

Briefly, the duality principle implies that, whatever the nature of electromagnetic energy is before an interaction, in the interaction you can get it to act as a wave or as a particle. In other words, AS IT EXISTS, BEFORE THE INTERACTION, it is implicitly both particle and wave, joined together in some fashion, without being explicitly either one.

With the fourth law of logic, this becomes perfectly clear. With three-law Aristotlean logic, the problem is unresolvable.

Let us use this idea of "explicit duality without implicit duality" to analyze the wave shown on the slide.

First, from a wave aspect, the E-fields and the B-fields of the two waves do superpose and vectorially add. Since the waves are 180 degrees out of phase, the exterior resultant wave has a zero electric field and a zero magnetic field. Therefore it is a "zero-vector" wave, or "scalar" wave. It's a wave of pure stress in spacetime.

However, this scalar wave has a precisely determined substructure, consisting_of

two ordinary sine waves, each of which comprises an ordinary E-H vector EM wave.

Now we apply the photon consideration (remember, before we interact with the wave, it must implicitly possess BOTH wave and particle natures combined, and we have so far only examined the implication of the wave nature.

The theory of photons' states that they are monocular critters. Photons pass right through other photons without interaction, in a linear situation. Therefore they can coexist without interaction, which is what we show here.

One photon, by the way, is one wavelength .

The photon theory requires that both substructure waves continue to exist as independent photons. Therefore we are assured that our substructure is intact.

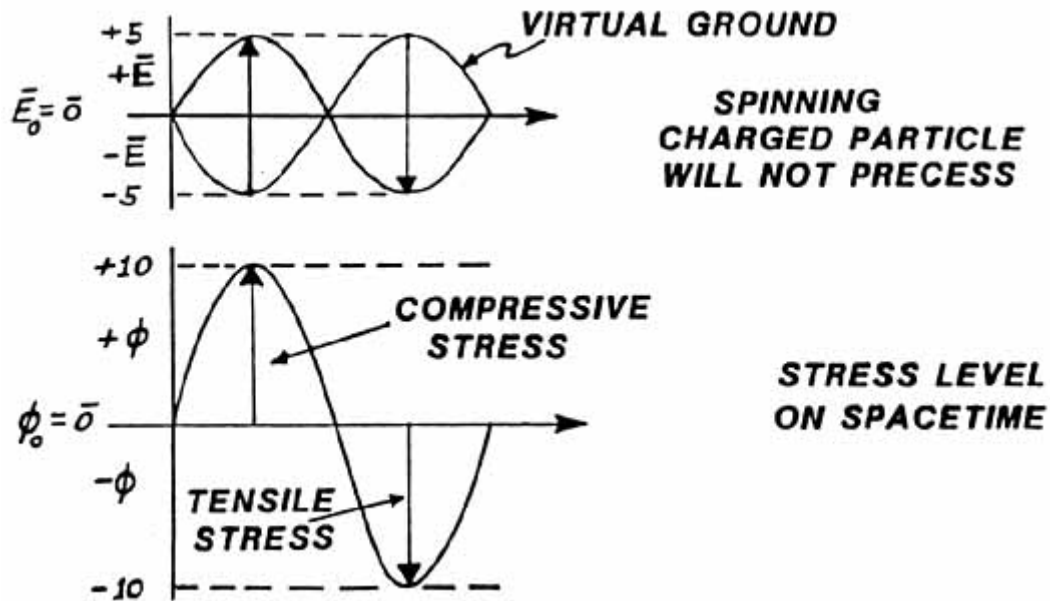
However, notice that the totality of the two waves stresses spacetime. In other words, we have twice the stress on spacetime now as we would have from either wave separately.

This wave is therefore just a pure stress wave in spacetime itself.

This thing oscillates time, oscillates the relativity of the situation, and can affect energy, time flow rate, inertia, gravity, etc. aspects of an absorbing system.

Note that we have a rhythmic oscillation in phi (\emptyset), and we have a longitudinal stress wave, very similar to a sound wave. The MEDIUM for this wave is the virtual particle flux that identically comprises vacuum spacetime itself.

SCALAR WAVE PRODUCTION



On this slide we show how to regard the magnitude of the stress, by using one wave envelope as "virtual ground." In the top diagram, the original E-field stress of each wave has a magnitude of 5, and the composite stress wave now has a magnitude of 10, in whatever units we choose to express them.

We show in the bottom diagram that during one half cycle we have compressive stress in the virtual particle vacuum flux, and during the second half cycle we have tensile stress.

This shows the wave is like a sound wave in the gaseous molecules of the air.

However, this wave has one difference. It also oscillates time, and thus has at least one additional degree of freedom, compared to ordinary EM waves.

In fact, this wave can be made n-dimensional and hyperspatial.

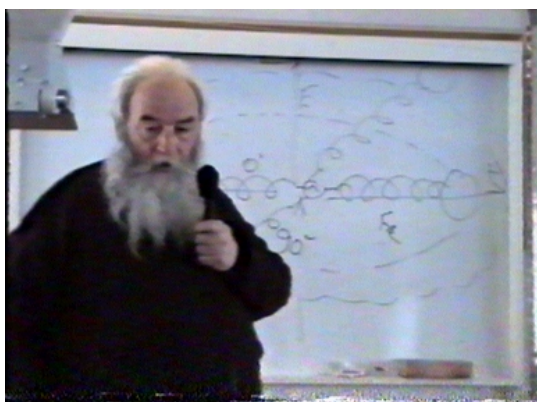
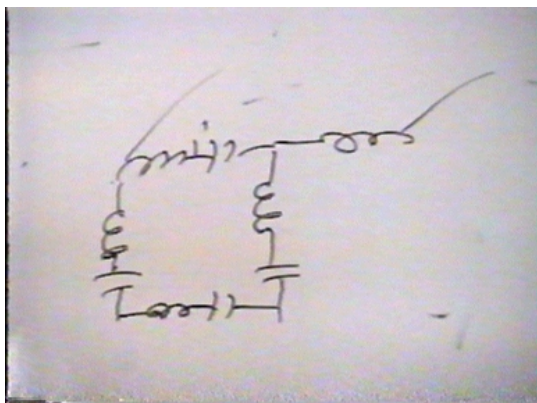
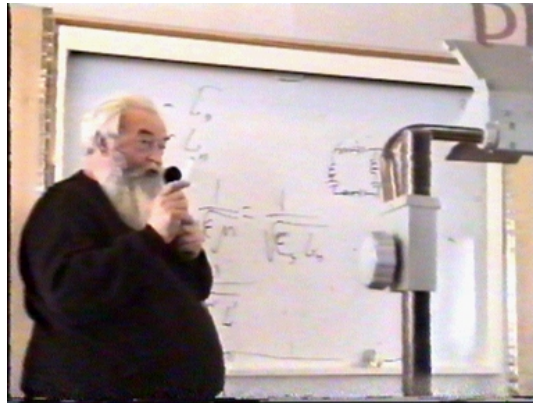
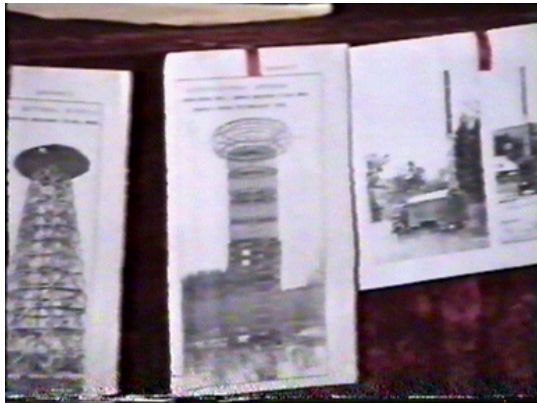
As a first order approximation, we can treat such a wave in a spatial fashion, if the wave is not too great in magnitude and the relativistic oscillation of time and inertia is not too large.

N.Tesla's Unique Experiments in Colorado

Academician Gennady F. Ignatyev

Kurchatov Str., 9 b, apt. 70, Krasnoyarsk, 660041, Russia

tel: 7-3912-452476; 7-3912-494803



N.Tesla's experiments in Colorado (those he made in 1880-1889) are not deliberate to all over the end and it is not repeated up to present time. Some people consider these experiments as something that is not quite correct, and other think that the experiments are wonder and only Tesla himself can made it [1].

It is necessary to pay attention to some peculiarities of experiments in Colorado. These experiments produced round scientific technical branch that is the high frequency

electrophysics and they are interesting as a basis for designing and using for high-frequency high-voltage exciters (HHE). Check up some principal qualities of his experiments:

operational frequency - 160 kHz
generative power - 250 kW
operational voltage - 10×10^6 V
fixed voltage - 100×10^6 V

Now after 100 years these figures get in surprise. But if we make analyze for the facts more deeply, we'll see that there are no any wonders here and N.Tesla was real designer-scientist who could use all achievements of science and techniques for his time. Just a combination of these quantities: a genius designer and a brilliant scientist - allowed him to reach these outstanding results.

Tesla's tank in a sparking generator electric circuit was about 3 m diameter and 5 m high ($D=3$ m; $h=5$ m). Then the first stage had factor of merit (Q) more that 103. A low frequency transformator (60 Hz) with voltage about 3 kV was a feed source for arc discharges. Tesla used combined circuit and by means of second step resonance he increased voltage up to 10×10^6 V. He used a ferrous mast as a capacitor of the second step circuit that allow to provide surely such sort operational voltage. The mast was 60 m high ($h=60$ m) and it was loaded on a cooper sphere of 1 m diameter ($D=1$ m).

Telsa explained the second resonance with an assistance of stationary waves, which the transmitter exited. He considered that stationary waves go round the Earth and come back to the point of radiation so voltage of antenna is increasing; such explanation is doubtful because waves propagate for a long distance and that why they can't comeback without damp.

It can be proposed another explanation of the second resonance. Suppose the second resonance is provided of the sphere electro-resilient properties. The sphere can resound and parametrically pump up the power. Consider feature of on adjustment (agreement) of the electro-resilient parametrical resonance. When a sphere has a high voltage, some force $F=1/8$ acts on its sides. This force strives to increase the diameter of the sphere. The electroresilient properties of a hollow cooper sphere provide the parametrical resonance with double-frequency [2].

N.Tesla fixed the second resonance in a few minutes. It means that the parametrical resonance has high factor of merit ($Q \ 10^6$). Only crystals (quartz) have such resonance. The main difficulty to reach this resonance is the adjustment (agreement), because these properties can be displayed when an oscillation energy comes through a high-reactive resistor. The ferrous mast was this adjustment (agreement) element. It had the magnetic permeability and considerable inductive resistance that made it in some original throttle. When its magnetic permeability m is about 104, its inductance L is about 1 Hn.

N.Tesla created an artificial lightning when he made his experiments. Its rumbles were heard at a distance of 16 miles.

The author of this paper created a high-frequency arc in his laboratory (1986) and this arc branched and closed on to environment (Fig.1a,b,c,d). On the Fig.2 the single

discharge is shown between a couple of capacitors: one of them is a sphere and other is a toroid.



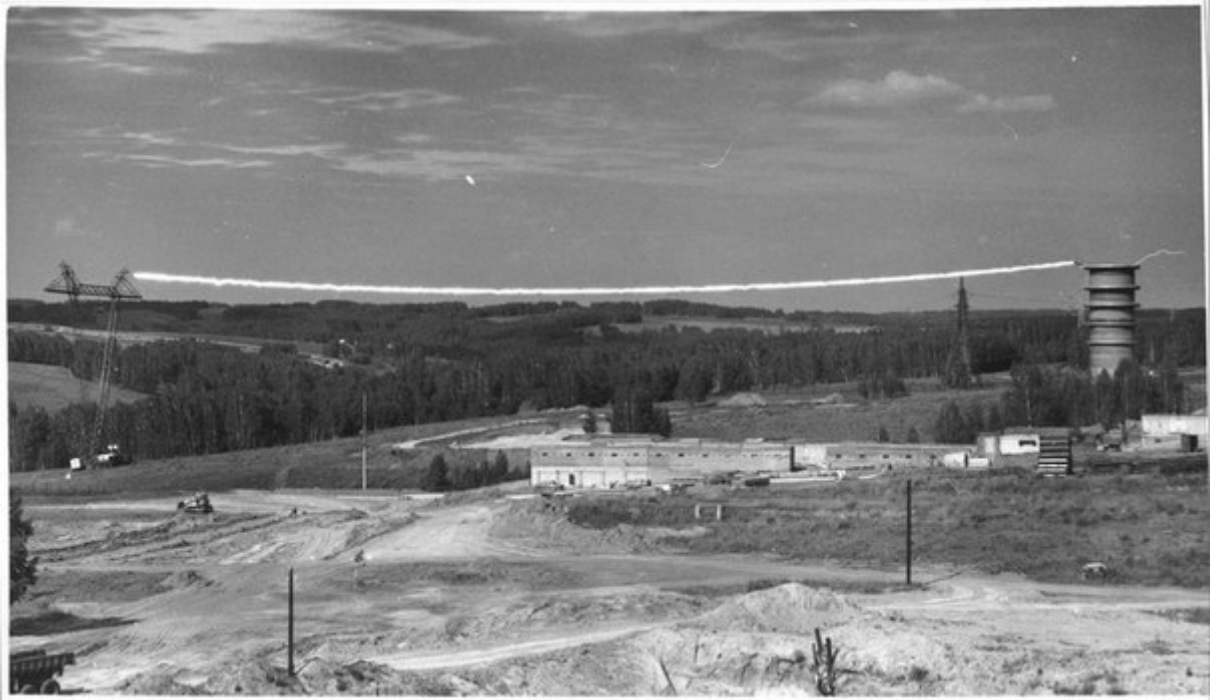
Solution for a problem for high-voltage potential creation allow to produce the wireless energy transmission for a long distance. N.Tesla designed and began to construct a HHE of electric field (Fig.3) but unfortunately this idea was not realized to all over the end. In 1992 the author of this paper tried to carry out this idea also (Fig.4) but it was wrecked, because the woods are surrounding the exiter absorbed its radiation. Results were unstable, because electric conditions of trees depends on a season (winter-summer) and on a weather (dry - wet). In some cases trees spontaneously flared up. But idea of wireless energy transmission has the practical sense in the individual cases.



On the basis of this idea it was made an experiment for determination of a signal transmission velocity by the vector of the electric density (D). The experiment consist in the following. HHE that includes step up transformer by patent N 2033651 creates quasi static electric field that has intensity about 0.4×10^6 V. The signal was received at two points: $A=50$ m and $B=400$ m on the frequency 135 kHz. Supporting signal was transmitted by glass fiber (fiberoptic line), and a phase shift was measured to determine the signal transmission velocity. In both cases the length of the glass fiber remained a constant. Then fixed velocity was more than velocity of light on 16%.

Sure, it's necessary to develop and to repeat this experiment because "purely" electric component and electromagnetic component that is determined by vertical current in HHE are transmitted simultaneously.

There is a new theory for matter of free space, it is theory which the N.Tesla's experiments bring for us. This theory was proposed by authors L. Gutenmacher, P.Krasnooshkin and V. Kessenikh [3]. By this theory the electric (ϵ) and magnetic (μ) permeabilities change on corresponding specific capacity (C_s) and the specific inductivity (L_s). Then an equation for the velocity of light is



Such sort interpretation can explain many physical phenomenons of macrocosm and in particular it can explain the change of light velocity. For example, the velocity of light changes near the Earth surface because specific capacity C near the surface is increasing and then the velocity of light is decreasing.

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ФИЗИЧЕСКИЙ ВАКУУМ, ТОРСИОННЫЕ ПОЛЯ, КВАНТОВАЯ МЕХАНИКА И ЭКСПЕРИМЕНТЫ Н.ТЕСЛА

Г.И.Шипов

Введение

Почти 100 лет назад Н.Тесла продемонстрировал миру и запатентовал свои беспрецедентные эксперименты по беспроводной и однопроводной передаче электроэнергии [8,10]. Однако до сих пор официальная теоретическая физика, включая стандартную модель и теорию суперструн, не в состоянии объяснить наблюдаемые (аномальные с точки зрения электродинамики Максвелла-Лоренца) электродинамические процессы, официально зарегистрированные в многочисленных патентах Н. Тесла. Поэтому «серьезные теоретики» либо ничего не знают об этих экспериментах, либо сознательно умалчивают об их существовании, поскольку не в состоянии объяснить их.

Еще одной загадкой, не решенной официальной наукой до сих пор, является квантовая механика с ее многочисленными парадоксами и противоречиями. Одно только замечание П.Дирака о том, что основные уравнения квантовой электродинамики (уравнения Дирака) неверны и требуют принципиального изменения, говорит о глубоком кризисе в понимании изучаемой нами реальности. Стандартная модель и теория суперструн не касаются основ современной физики, а, наоборот, используют старые представления о квантовой теории, развитые в 30-50 годах прошлого столетия.

В настоящей работе показано, что теория физического вакуума, основные принципы и уравнения которой были созданы автором в 1988 г. [3], дает принципиально новое описание квантовой теории. Волновая функция в новой квантовой теории связана с торсионным полем, интерпретируемым как поле инерции (гравитационной, электромагнитной...).

В теории физического вакуума квантовая механика рассматривается как обычная классическая теория, которая описывает динамику полей инерции в микро и макро масштабах. Оказалось, например, что эксперименты Н. Тесла (а так же эксперименты по сверхпроводимости и сверхтекучести) представляют собой разновидность макроквантовых явлений, в которых квантовые (в смысле старой теории) и классические процессы описываются универсальными уравнениями физического вакуума.

Решение уравнений физического вакуума для источника с переменной массой (или зарядом) описывает монополярное излучение источника, которое, с одной стороны, порождает скалярные гравитационные (или электромагнитные) поля, а с другой, позволяют вводить в «классические» уравнения движения волновую функцию (поле инерции) «квантовой» теории. Н.Тесла первый экспериментально обнаружил монополярное излучение системы зарядов и сопровождающее его скалярное электромагнитное поле. В работе приведены результаты экспериментов, подобных экспериментом Н.Тесла, подтверждающие существование скалярного электромагнитного поля.

1. Квантовая жидкость Маделунга

Со времени создания квантовой механики физика находится в кризисном состоянии, поскольку до сих пор между вдумчивыми теоретиками идут споры о физической природе квантовых явлений. Уже в 1927 году ведущие теоретики разделились на две группы во главе с А.Эйнштейном и Н.Бором (см. рис.1).

Кризис в Физике

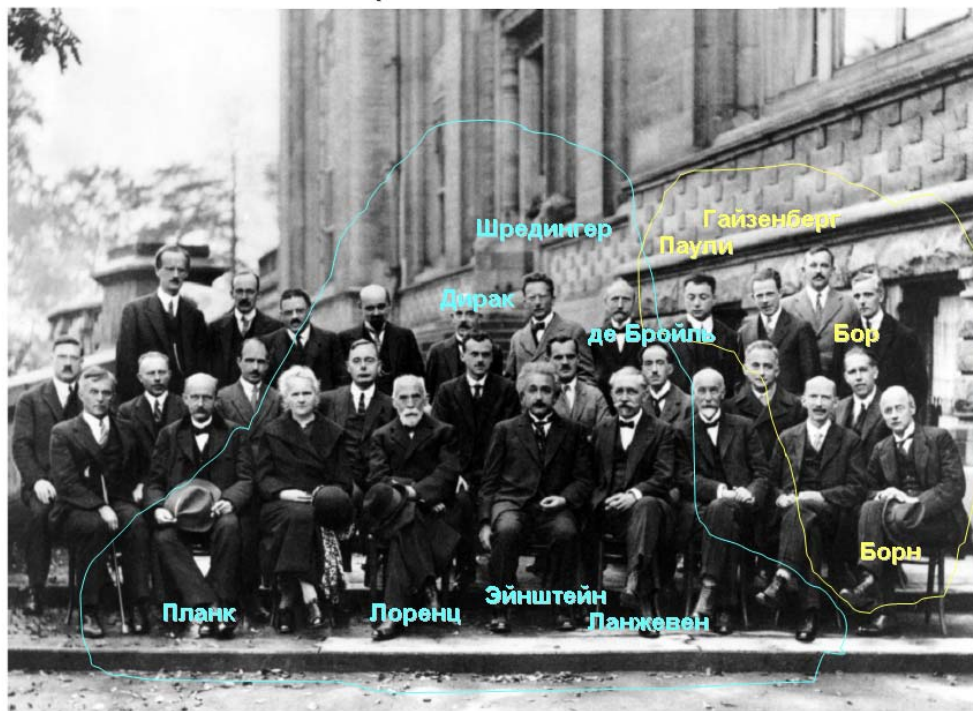


Рис.1 Участники 5-го Солвейского конгресса в 1927.

Точка зрения Эйнштейна сводилась к тому, что квантовая механика в современном ее состоянии не является фундаментальной теорией, поскольку в ней потеряно образное мышление, так необходимое для понимания природы и, кроме того, она не согласуется с общим принципом относительности. Поэтому квантовая механика не может служить отправной точкой для дальнейшего развития физики. Есть просто физика и существующее разделение ее на квантовую и классическую носит временных характер.

Существуют различные подходы рассматривать квантовую физику как часть классической теории. Среди них наибольшее распространение получила гидродинамическая модель Маделунга [1], вдохновившая Л. де Бройля и Д.Бома на поиски детерминистической квантовой теории. В модели Маделунга уравнение Шредингера

$$i\hbar \frac{\partial}{\partial t} \psi + \frac{\hbar^2}{2m} \nabla^2 \psi - U\psi = 0, \quad (*)$$

после подстановки волновой функции, записанной в виде $\psi = \sqrt{\rho} \exp(iS/\hbar)$,

и приравнивания реальной и мнимых частей полученного уравнения к нулю, может быть представлено в виде уравнения непрерывности и уравнений Гамильтона-Якоби

$$\frac{\partial \rho}{\partial t} + \nabla \left(\frac{\rho \nabla S}{m} \right) = 0, \quad (**)$$

$$\frac{\partial S}{\partial t} + \frac{(\nabla S)^2}{2m} + U + Q = 0, \quad (***)$$

где S - механическое действие, $Q = -\hbar^2 \nabla^2 \sqrt{\rho} / 2m \sqrt{\rho} = -\hbar^2 \nabla^2 |\psi| / 2m |\psi|$ - квантовый потенциал и $\rho = |\psi|^2$. Таким образом, в модели Маделунга одно линейное по ψ уравнение (*) эквивалентно двум нелинейным (**) и (***). Скорость частицы в уравнениях Гамильтона-Якоби (***), (**) представляется как $\vec{v} = \nabla S / m$, поэтому можно записать систему (**), (***) как

$$\begin{aligned} \frac{\partial \rho}{\partial t} + \nabla(\rho \vec{v}) &= 0, \\ m \left(\frac{\partial \vec{v}}{\partial t} + \vec{v} \nabla \vec{v} \right) &= m \frac{d\vec{v}}{dt} = -\nabla(U + Q) \end{aligned}$$

или в виде уравнений гидродинамики [1]

$$\frac{\partial \rho}{\partial t} + \nabla(\rho \vec{v}) = 0, \quad (1)$$

$$\rho \frac{d\vec{v}}{dt} = -\frac{\rho}{m} \nabla U - \frac{\rho}{m} \nabla Q, \quad (2)$$

где $\rho = m \psi^* \psi$ - плотность жидкости и $Q = -2s^2 \nabla^2 |\psi| / m |\psi|$ - квантовый потенциал, записанный через спин электрона $s = \hbar / 2$. Уравнения (2) переходят в классические уравнения гидродинамики Эйлера в пределе, когда $s = \hbar / 2 \rightarrow 0$ поэтому квантовые уравнения (1) и (2) можно интерпретировать как движение классической капли жидкости с собственным моментом вращения s .

Уравнения (1) и (2) можно использовать для описания любых квантовых систем, например, для атома водорода, при этом получаются такие же результаты, как и при вычислении с помощью уравнения Шредингера [2]. Из (2) следует, что центр масс капли квантовой жидкости движется согласно уравнениям

$$m \frac{d\vec{v}}{dt} = -\nabla(U + Q),$$

где \vec{v} - скорость центра масс. При $s = \hbar / 2 \rightarrow 0$ эти уравнения переходят в уравнения механики Ньютона.

2. Квантовая механика, следующая из уравнений физического вакуума

Физический вакуум можно рассматривать как спиновую жидкость, при этом рожденные из вакуума частицы со спином, представляют собой капли вакуумной жидкости, обладающие собственным моментом вращения. Уравнения вакуума представляют собой самосогласованную систему нелинейных спинорных уравнений, в которую входят полностью геометризированные (включая источники) уравнения, подобные уравнениям Гейзенберга [3]

$$\begin{aligned} \nabla_{\beta\dot{\chi}} l_{\alpha} = & \nu o_{\alpha} o_{\beta} \bar{o}_{\dot{\chi}} - \lambda o_{\alpha} o_{\beta} \bar{l}_{\dot{\chi}} - \mu o_{\alpha} l_{\beta} \bar{o}_{\dot{\chi}} + \pi o_{\alpha} l_{\beta} \bar{l}_{\dot{\chi}} - \\ & - \gamma l_{\alpha} o_{\beta} \bar{o}_{\dot{\chi}} + \alpha l_{\alpha} o_{\beta} \bar{l}_{\dot{\chi}} + \beta l_{\alpha} l_{\beta} \bar{o}_{\dot{\chi}} - \varepsilon l_{\alpha} l_{\beta} \bar{l}_{\dot{\chi}}, \end{aligned} \quad (A_{s^+}^+ .1)$$

$$\begin{aligned} \nabla_{\beta\dot{\chi}} o_{\alpha} = & \gamma o_{\alpha} o_{\beta} \bar{o}_{\dot{\chi}} - \alpha o_{\alpha} o_{\beta} \bar{l}_{\dot{\chi}} - \beta o_{\alpha} l_{\beta} \bar{o}_{\dot{\chi}} + \varepsilon o_{\alpha} l_{\beta} \bar{l}_{\dot{\chi}} - \\ & - \tau l_{\alpha} o_{\beta} \bar{o}_{\dot{\chi}} + \rho l_{\alpha} o_{\beta} \bar{l}_{\dot{\chi}} + \sigma l_{\alpha} l_{\beta} \bar{o}_{\dot{\chi}} - \kappa l_{\alpha} l_{\beta} \bar{l}_{\dot{\chi}}, \end{aligned} \quad (A_{s^+}^+ .2)$$

$$\alpha, \beta \dots = 0, 1, \quad \dot{\chi}, \dot{\gamma} \dots = \dot{0}, \dot{1},$$

Эйнштейна

$$2\Phi_{AB\dot{C}\dot{D}} + \Lambda \varepsilon_{AB} \varepsilon_{\dot{C}\dot{D}} = \nu T_{A\dot{C}B\dot{D}}, \quad (B_{s^+}^+ .1)$$

и Янга-Миллса

$$\begin{aligned} C_{A\dot{B}C\dot{D}} - \partial_{C\dot{D}} T_{A\dot{B}} + \partial_{A\dot{B}} T_{C\dot{D}} + (T_{C\dot{D}})^F_A T_{F\dot{B}} + (T^{+\dot{D}C})^{\dot{F}}_{\dot{B}} T_{A\dot{F}} - \\ - (T_{A\dot{B}})^F_C T_{F\dot{D}} - (T^{+\dot{B}A})^{\dot{F}}_{\dot{D}} T_{C\dot{F}} - [T_{A\dot{B}} T_{C\dot{D}}] = -\nu J_{A\dot{C}B\dot{D}}, \end{aligned} \quad (B_{s^+}^+ .2)$$

$$A, B \dots = 0, 1, \quad \dot{B}, \dot{D} \dots = \dot{0}, \dot{1}$$

При исследовании проблемы движения материи в уравнениях Эйнштейна с полностью геометризированным тензором энергии-импульса $T_{A\dot{C}B\dot{D}}$, из уравнений физического вакуума (А), (В) следуют обобщенные уравнения гидродинамики для несжимаемой жидкости [3]

$$\nabla_j(\rho u^j) = \partial_j(\rho u^j) + \rho u^k \Gamma_{kj}^j = 0, \quad (3)$$

$$\rho \frac{du^m}{ds} + \rho \Gamma_{kn}^m u^k u^n = 0, \quad (4)$$

$$i, j, k \dots = 0, 1, 2, 3,$$

где $\rho = -\frac{1}{\nu c^2} \mu_{A\dot{B}} \mu^{A\dot{B}} > 0$ - спинорная плотность материи, $\mu_{A\dot{B}}$ - спинор,

подобный спинору Дирака [3], Γ_{kn}^m - символы Кристоффеля, ν - множитель, зависящий от типа взаимодействий частиц, рожденных из вакуума.

Важно отметить, что спинор $\mu_{A\dot{B}}$ является одной (из трех) неприводимой компонентой торсионного поля $T_{A\dot{B}}$, которое физически интерпретируется как поле инерции [3]. Поэтому уравнения (3) и (4), а так же следующие из них уравнения квантовой механики, описывают динамику полей инерции.

Существует несколько способов представить связь нерелятивистских уравнений (3) и (4) с уравнениями Шредингера для ψ и ψ^* .

1. **Нормируем спинорное поле** материи $\mu_{A\dot{B}}$ в уравнениях (3) и (4) на единицу, записав плотность материи ρ как

$$\frac{\rho}{m} = \int \psi^* \psi dV = 1, \quad (5)$$

где ψ - дираковский спинор. Представляя в нерелятивистском пределе поле ψ в виде плоской волны де Бройля, можно записать нелинейное относительно ψ уравнение (3) в виде двух линейных уравнений Шредингера для ψ и ψ^* [4]. Этот прием, предложенный Э.

Маделунгом, сделан без использования квантового потенциала Q , поскольку не учитывает уравнения (2).

2. **Используем решение уравнений вакуума** со спинирующим источником (типа решения Керра) поля (массой или зарядом) и создающим потенциальную энергию вида [3]

$$U^* = -\frac{mc^2}{2} \frac{\Psi^0 r}{r^2 + a^2 \cos^2 \theta}, \quad (6)$$

где $\Psi^0 = \text{const}$ - функция источника, a - параметр Керра [3], описывающий вращение источника, θ - угол наклона оси вращения к оси z . На больших расстояниях ($r \gg a$) и при $\theta = 0$ потенциальную энергию (6) можно представить в виде суммы

$$U^* = U + Q = -\frac{mc^2}{2} \frac{\Psi^0}{r} + \frac{mc^2}{2} \frac{\Psi^0}{r} \frac{a^2}{r^2}, \quad (7)$$

В этом случае нерелятивистские уравнения (3) и (4) для капли вакуумной жидкости с собственным вращением принимают вид уравнений (1) и (2), если параметр Керра совпадает с комптоновской длиной волны квантовой частицы $a = \lambda = \hbar/mc$, а $|\psi|$ удовлетворяет уравнению

$$\left(\nabla^2 - \frac{2U}{mc^2 r^2} \right) |\psi| = 0. \quad (8)$$

3. Решение вакуумных уравнений (A),(B) с функцией источника Ψ^0
 может быть представлено в виде нелинейных спинорных уравнений Гейзенберга $(A_{s^+}^+ .1)$ и $(A_{s^+}^+ .2)$ в виде

$$\left(\nabla_{\beta\dot{\chi}} - \frac{\Psi^0}{2r^2} o_{\beta} \bar{o}_{\dot{\chi}} \right) o_{\alpha} = -\frac{1}{r} \iota_{\alpha} \bar{\iota}_{\dot{\chi}} o_{\beta}, \quad (9)$$

$$\left(\nabla_{\beta\dot{\chi}} + \frac{\Psi^0}{2r^2} o_{\beta} \bar{o}_{\dot{\chi}} \right) \iota_{\alpha} = -\left(\frac{2\Psi^0 - r}{2r^2} \right) o_{\alpha} \bar{o}_{\dot{\chi}} \iota_{\beta}, \quad (10)$$

$$\alpha, \beta, \dots = 0, 1, \quad \dot{\chi}, \dot{\tau}, \dots = 0, \dot{1}.$$

где o_{β} и ι_{α} - двухкомпонентные спиноры, образующие обобщенные матрицы Паули, уже содержат информацию о спине. Это позволяет представить функцию источника как

$$\Psi^0 = \alpha \frac{\hbar}{mc} = \alpha \frac{2s}{mc}, \quad (11)$$

где α - безразмерная константа, характеризующая взаимодействие вакуумной жидкости. Например, для вакуумной частицы с гравитационным взаимодействием [3] $\Psi^0 = mG/c^2 = \alpha_g \hbar/mc$, откуда

$$\alpha_g = \frac{m^2 G}{\hbar c}. \quad (12)$$

Соответственно, для электрон-позитронного вакуума мы имеем [3]

$$\Psi^0 = \frac{e^2}{mc^2} = \alpha_e \frac{\hbar}{mc}, \quad \alpha_e = \frac{e^2}{\hbar c}. \quad (13)$$

Если заряд e равен нулю в уравнениях (9) и (10), то эти уравнения описывают распространение только спина, т.е. становятся уравнениями поля нейтрино.

3. Квантовая гидродинамика с переменной функцией источника

Закон сохранения массы и заряда является одним из основных законов сохранения современной теории поля. Однако, эксперименты с элементарными частицами, в которых происходит рождение частиц из вакуума или их взаимное превращение, показывают, что этот закон не всегда выполняется. В теоретическом плане нарушение закона сохранения массы или заряда означает, что не выполняется уравнение непрерывности (1). В вакуумной гидродинамике, как это следует из уравнения (3), (в общем случае), мы имеем дело с переменными массами и зарядами.

Используем решение уравнений вакуума с переменным сферически-симметричным источником поля (массой или зарядом) [3]. В этом случае нерелятивистские уравнения (3) и (4) для капли вакуумной жидкости с переменной массой (зарядом) принимают вид

$$\nabla_j(\rho u^j) = \partial_j(\rho u^j) + \rho \frac{1}{rc} \frac{\partial \Psi^0}{\partial t} = 0, \quad (14)$$

$$\rho \frac{dv^\alpha}{dt} = \rho c^2 \frac{\Psi^0}{r^3} x^\alpha - \rho c^2 \frac{1}{rc} \frac{\partial \Psi^0(t)}{\partial t} \frac{dx^\alpha}{cdt}, \quad (15)$$

$$\alpha = 1, 2, 3,$$

где $\Psi^0(t) = m(t)G/c^2$ - функция источника с переменной массой $m(t)$ или $\Psi^0(t) = eq(t)/mc^2$ - функция источника с переменным зарядом $q(t)$. Из уравнения (6) видно, что для переменной массы (заряда) обычное уравнение непрерывности (или закон сохранения массы (заряда)) не выполняется.

Для решения с переменной функцией источника тензор Риччи R_{ik} отличен от нуля и плотность сферически-симметричной капли жидкости имеет вид [3]

$$\rho(t) = -\frac{2}{\nu c^2 r^2} \frac{\partial \Psi^0(t)}{c \partial t} > 0. \quad (16)$$

В пределе, когда $\Psi^0(t) \rightarrow \Psi^0 = const$, плотность источника (16), с учетом (5), может быть представлена как $\rho = 8\pi\Psi^0\delta(\vec{r})/\nu c^2 = m\psi^*\psi$, при этом $\nu = 8\pi G/c^4$. Соответственно, для заряженной жидкости в предел, мы имеем

$$\rho_e = q\psi^*\psi = q\delta(\vec{r}), \quad (17)$$

при этом $\nu_e = 8\pi e/mc^4$.

Для распределения заряда близкого к точечному уравнения (15) приближенно можно представить как

$$\rho \frac{d\vec{v}}{dt} = -\frac{\rho}{m} \nabla U - \frac{\rho}{m} S \frac{e}{c} \frac{d\vec{x}}{dt}, \quad (18)$$

где $U = eq(t)/r$ - потенциальная энергия взаимодействия зарядов e и $q(t)$, $S = 1/rc \cdot \partial q(t)/\partial t$ - скалярное поле, порожденное переменным зарядом $q(t)$ (монопольное излучение заряда).

С другой стороны, из (16) и (17) следует

$$S \approx -4\pi q(t)\psi^*\psi, \quad (19)$$

Поэтому (18) можно записать как

$$\rho \frac{d\vec{v}}{dt} \approx -\frac{\rho}{m} \nabla U + 4\pi e r \frac{\rho}{m} q\psi^*\psi \frac{d\vec{x}}{cdt}, \quad (20)$$

где $\psi(t)$ - волновая функция заряда $q(t)$. Соответственно, уравнения движения центра масс заряженной капли квантовой жидкости в поле переменного заряда $q(t)$, имеют вид

$$m \frac{d\vec{v}}{dt} = -\nabla U - S \frac{e}{c} \frac{d\vec{x}}{dt}, \quad (21)$$

$$m \frac{d\vec{v}}{dt} = -\nabla U + 4\pi e r q\psi^*\psi \frac{d\vec{x}}{cdt}. \quad (22)$$

Из этих уравнений видно, что волновая функция источника с переменным зарядом входит в классические уравнения движения подобно тому, как это имеет место в уравнениях (2). Похожие уравнения можно написать для квантовой жидкости с переменной массой $m(t)$.

В общей теории относительности для описания переменной массы $m(t)$ используется конформная метрика [5,6], при этом квантовый потенциал Q

появляется в классических уравнениях в результате конформных флуктуаций метрики плоского пространства.

4. Связь скалярного электромагнитного поля с экспериментами Тесла

Уравнения (21) и (22) не следуют из уравнений электродинамики Максвелла-Лоренца, поскольку в ней выполняется закон сохранения заряда и монопольное излучение отсутствует. Поэтому, для экспериментального исследования уравнений (21) и (22), необходимо создать физические условия, в которых уравнение непрерывности (1) не выполняется, т.е. существует монопольное излучение заряда. В макром мире это можно сделать не для одного заряда, а для системы зарядов. Действительно, пусть мы имеем заряженную сферу (рис.1)

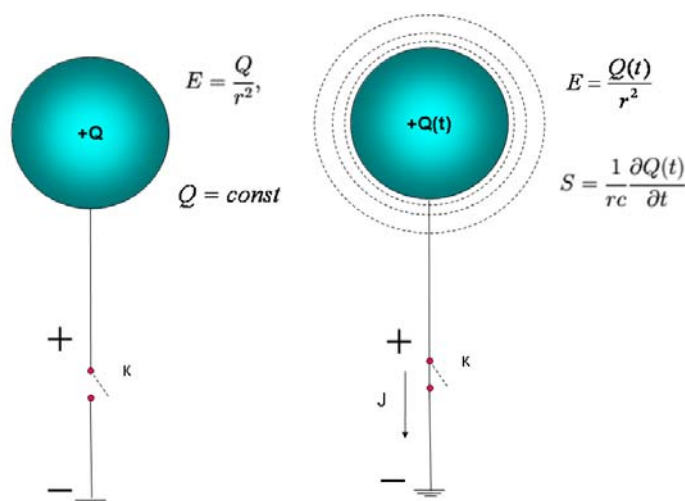


Рис.1

и пусть заряд сферы равен $+Q$. Если замкнуть ключ k , заряд сферы будет меняться и в результате, как это следует из уравнений (21), вне сферы появиться скалярное электромагнитное поле $S = 1/rc \cdot \partial Q(t)/\partial t$. Заряд e с массой m будет двигаться в этом поле согласно уравнениям (21). Предварительные эксперименты по обнаружению скалярного электромагнитного поля были проделаны в работе [7]. В результате экспериментов было обнаружено аномальное, с точки зрения электродинамики Максвелла-Лоренца, вращение

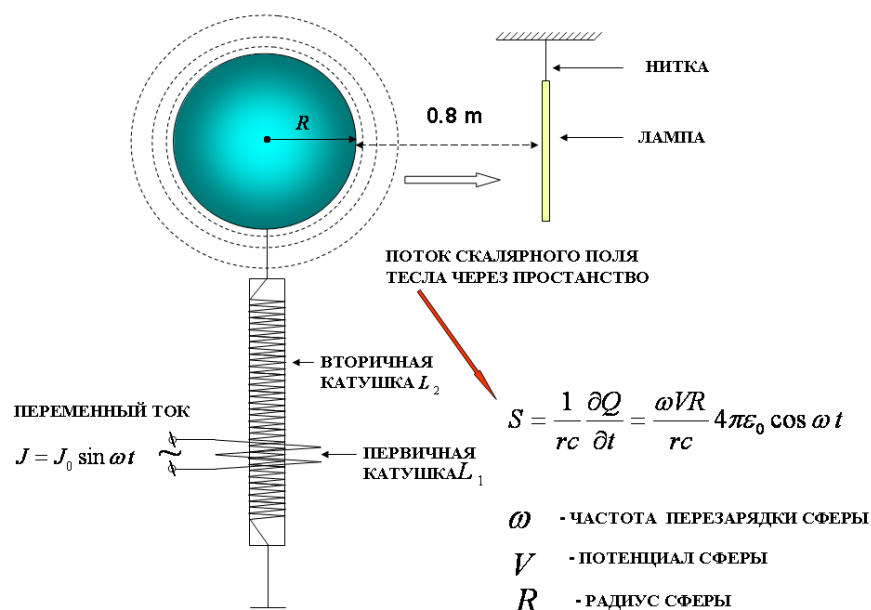


Рис.2 Беспроводная передача электроэнергии скалярным полем S

латунного кольца, подвешенного в плоскости экватора сферы.

На следующем этапе экспериментов мы использовали для заряда и разряда сферы трансформатор Тесла, состоящий из первичной катушки толстого ($d=5\text{ мм}$) алюминиевого провода (6 витков) и вторичной катушки, которую образуют 1500 витком медного провода ($d=0.35\text{ мм}$), намотанные на полиэтиленовую трубу ($d=50\text{ мм}$). На первичную обмотку (см. рис.2) подавались импульсы с амплитудой $V=17.5$ вольт с частотой порядка 10 МГц от генератора Бровина <http://rutube.ru/tracks/1889979.html?v=e617cdbf946eb042b0ce89074b0faac1>, схема которого представлена на рис. 3. Во вторичной обмотке (за счет резонансных свойств системы) мы получали синусоидальное напряжение с амплитудой 5000 вольт.

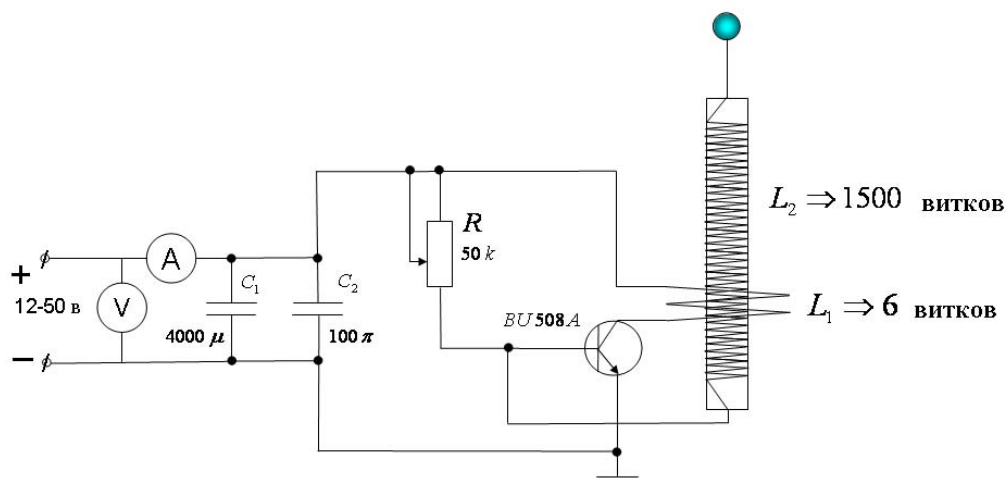


Рис.3

Если заряд сферы меняется по закону $Q = Q_0 \sin \omega t$, то излученное скалярное поле сферы меняется по закону

$$S = \frac{1}{rc} \frac{\partial Q}{\partial t} = \frac{\omega V}{rc} 4\pi\epsilon_0 R \cos \omega t. \quad (23)$$

Если в поле монопольного излучения (23) находится лампа дневного света (см. рис. 2), то она светиться, причем яркость свечения увеличивается с увеличением либо частоты ω , либо с увеличением напряжения V .

Впервые опыты по передаче электроэнергии с использованием монопольного излучения были проделаны Н.Тесла в 1919 г [8]. Он первым, на основе многочисленных опытов, установил, что эффективность беспроводной передачи электроэнергии возрастает с увеличением частоты и напряжения сигнала на передающей антенне. Поэтому справедливо назвать монопольное скалярное излучение (23) полем Тесла. На рис. 4 приведены фотографии, на которых



Рис.4. Лабораторные эксперименты по беспроводной передаче электроэнергии

демонстрируется передача энергии с помощью скалярного поля (23) (или монопольного электромагнитного излучения). Из формулы (19) следует, что скалярное электромагнитное поле – бозон, который можно интерпретировать как пару фермионов с противоположными спинами, подобно куперовским парам в теории сверхпроводимости [9].

С учетом скалярного поля уравнения Лоренца принимают вид

$$m \frac{d\vec{v}}{dt} = e\vec{E} + \frac{e}{c} \{[\vec{v}\vec{H}] - S\vec{v}\} = e\vec{E} + \frac{e}{c} \{[\vec{v}\vec{H}] + 4\pi Q\psi^* \psi \vec{v}\}. \quad (24)$$

Отсюда видно, что поле S по своей природе ближе к магнитному поля \vec{H} , поэтому его можно называть также скалярным магнитным полем. Одновременно это поле - монопольное излучение источника поля Q ,

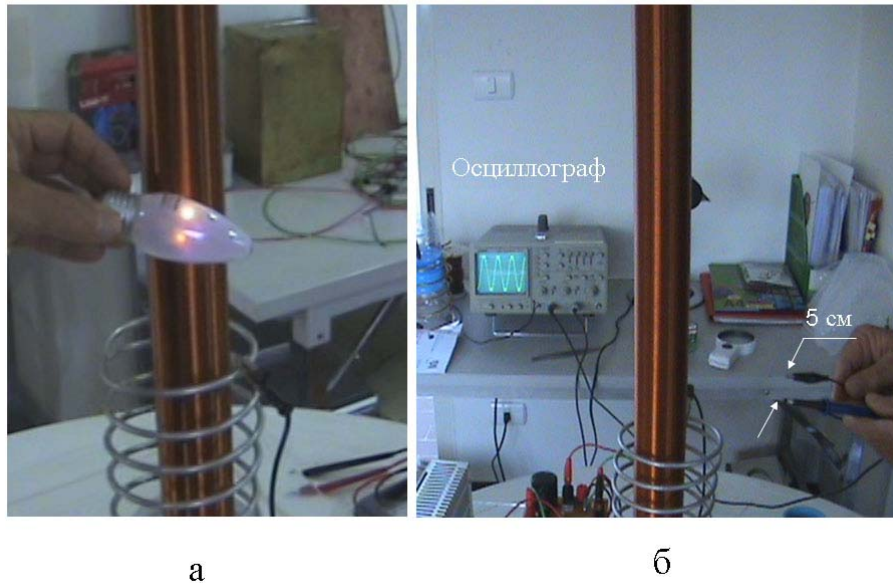


Рис.5. а) свечение лампы накаливания 220 вольт 40 ватт в поле S в руках исследователя; б) осциллограф показывает напряжение, созданное полем S , при этом концы щупа осциллографа разнесены в пространстве на 5 см

выраженное через квадрат нормированного поля электромагнитной инерции ψ . Когда Н.Тесла спросили, какое поле он излучает и принимает своими приборами, он ответил, что его поля – это не электромагнитные волны Герца. На рис.5 представлены эксперименты, которые показывают, что Н.Тесла был прав. Например, на рис.5 б) в цепи щупа осциллографа возникает электрический ток, хотя цепь не замкнута. Объяснить замкнутость цепи обычным током смещения $\partial\vec{H}/c\partial t$ не удастся из-за большого емкостного сопротивления цепи. Сам Н.Тесла считал, что вторичная катушка трансформатора поляризует физический вакуум вблизи ее. Такая интерпретация вполне согласуется с представлением о монопольном электромагнитном излучении, переносимом скалярным полем S . Если напряженность поля S значительна, то вокруг свободного конца вторичной обмотки возникает коронный разряд, природу которого объясняют последующие эксперименты. Скорее всего, это (спаренные) электроны, излучаемые (и поглощаемые) концом вторичной обмотки.

5. Торсионная яма и спаривание электронов

Потенциальная энергия (6), (7) при $a = \hbar/mc$ описывает спиновые свойства источника. График потенциальной энергии (7) для двух электронов

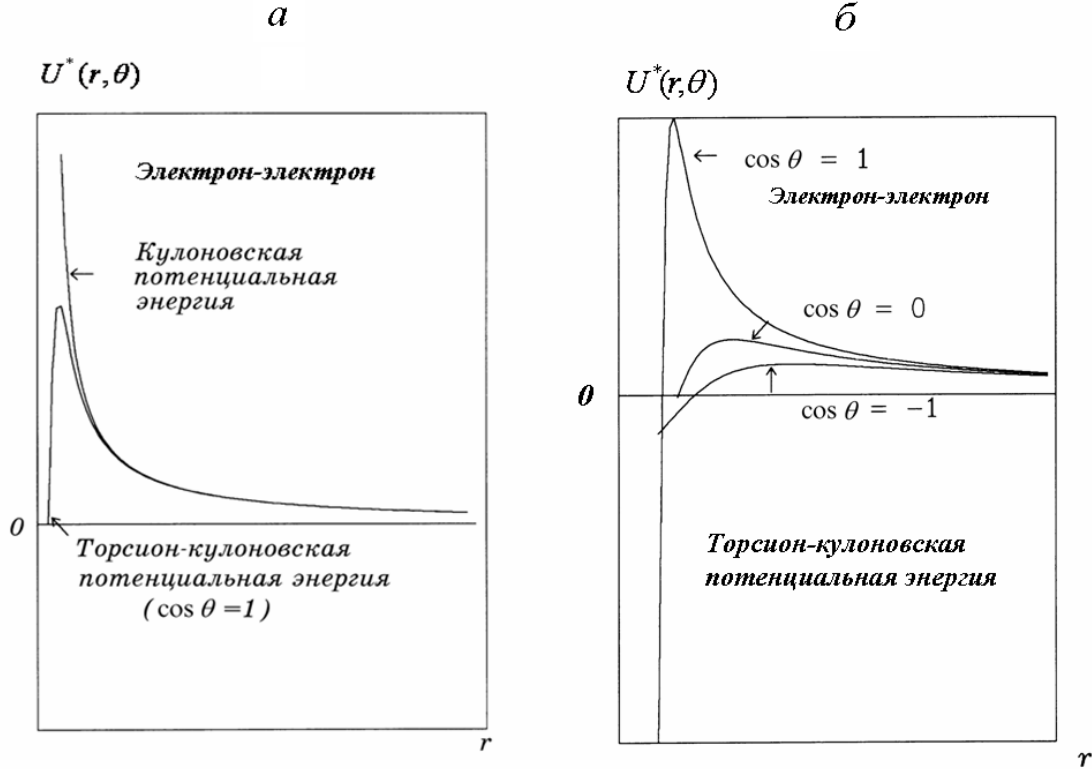


Рис. 6. Потенциальная энергия взаимодействия двух электронов при $|\Psi^0|/a = 3/2$ и при различных ориентациях спина источника

представлен на рис. 6. Поскольку для электронов $2|\Psi^0| = 2e^2/mc^2$ и $a = \hbar/mc$, то из этого графика следует, что при $\cos \theta = 1$ на расстоянии порядка $10^{-11} - 10^{-12}$ см между электронами возникает притяжение за счет торсионного (спинового) взаимодействия (рис.1а). Если же $\cos \theta = 0$ или $\cos \theta = -1$, то кулоновский барьер отталкивания значительно понижается и торсионное притяжение может возникнуть на расстояниях $10^{-5} - 10^{-4}$ см.

Подобные результаты можно получить, решая уравнения квантовой механики для взаимодействия частиц со спином [10]. Полученное решение показывает, что основное состояние (вакуум) сверхпроводящей электронной жидкости является конденсатом двух сортов пар Купера с двумя различными энергетическими щелями, Δ_α , $\alpha = 1, 2$, причем пары Купера каждого сорта содержат лишь электроны с одной заданной спиральностью (проекцией спина на импульс): $+1/2$ или $-1/2$, т.е. электроны с одной и той же спиральностью

(но с противоположными импульсами) спариваются. Вывод о существовании двух энергетических щелей находится в качественном согласии с экспериментальным обнаружением двух температур сверхпроводящего фазового перехода [11].

6. Передача электроэнергии по одному проводу и резонансы скалярного поля S

На рис. 7. представлена схема передачи электроэнергии по одному проводу, аналогичная запатентованной Н.Тесла еще в 1897 г.[11]!

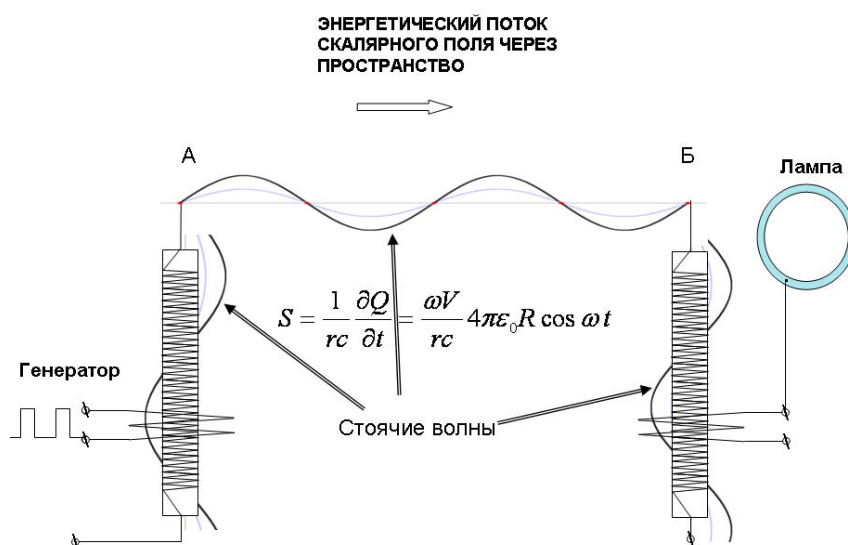


Рис.7. Передача электроэнергии полем S по одному проводу из точки А в точку Б, а, затем, через трансформатор на лампу. Второй конец катушки Б и понижающей катушки висят в воздухе.

При измерении распределения поля S вдоль катушек и однопроводной линии было обнаружено, стоячие волны поля S , т.е. стоячие волны зарядов, излученных источником. На рис. 8 а) представлена экспериментальная однопроводная линия, передающая электроэнергию на расстояние 2 метра, собранная по схеме на рис. 7.

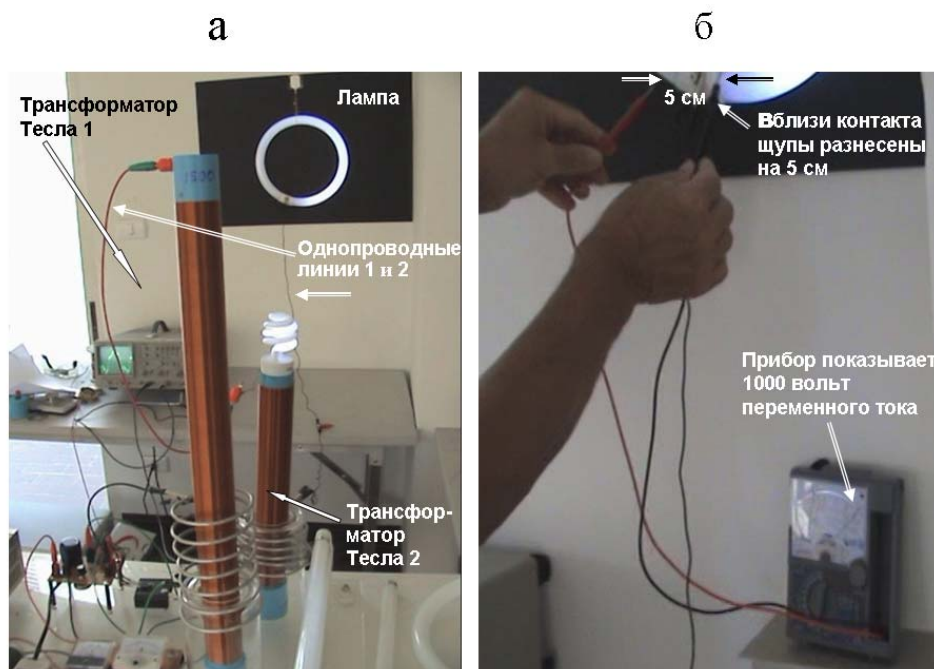


Рис. 8. а) экспериментальная однопроводная линия; б) в месте контакта одного провода с лампой прибор показывает 1000 вольт при разомкнутых на 5 см щупах без соприкосновения с проводом.

Наблюдаемый способ передачи электроэнергии невозможно описать уравнениями векторной электродинамики Максвелла-Лоренца. Именно по этой причине эксперименты Н.Тесла не были восприняты научной общественностью в начале прошлого века. Тем не менее, в 1931 г., когда Н.Тесла продемонстрировал журналистам автомобиль, работающий на энергии физического вакуума, восхищенный А.Эйнштейн поздравил его с семидесятипятилетием. Видимо, гения может признать только гений.

В настоящее время ситуация изменилась, поскольку создана теория физического вакуума, дающая ключ к научному обоснованию восхитительных экспериментов Тесла. Как и предполагал ранее великий изобретатель, его эксперименты доказывают связь электромагнитных явлений с физикой вакуума, т.е. со структурой пространства.

Заключение

Простейшие эксперименты, повторяющие пионерские работы Н.Тесла, указывают на уравнения электродинамики, обобщающие электродинамику Максвелла-Лоренца-Дирака. Как было показано выше, из уравнений физического вакуума (А) и (В) следует вакуумная электродинамика, способная описать наблюдаемые эксперименты по монополю излучению системы зарядов и связать квантовые и классические явления в электродинамике. Это удастся сделать благодаря тому, что волновая функция в детерминированной квантовой теории представляет собой поле инерции – универсальное поле, связывающее все физические процессы, и по праву названное Единым Полем. Два гения – А.Эйнштейн и Н.Тесла, каждый по-своему, пытались обнаружить и

описать это поле, но только, примерно, через 70 лет были найдены уравнения физического вакуума, позволяющие объединить их усилия.

Основная цель настоящей работы – обратить внимание научной общественности на электродинамические работы Н.Тесла и на предсказательную силу уравнений физического вакуума.

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ЭЛЕКТРОДИНАМИКА ТЕСЛА

В ТЕОРИИ ФИЗИЧЕСКОГО ВАКУУМА

Шипов Г.И.

Введение

Никола Тесла был 8^{ми} летним подростком, когда Максвелл написал свои знаменитые уравнения электродинамики, а через 25 лет осуществил однопроводную передачу электроэнергии [1], физические основы которой до сих пор остаются неопределенными. По данным из разных источников, Н. Тесла, в течение своей творческой жизни, зарегистрировал от 800 до 1000 патентов. При создании патентов, он использовал особый метод, ко-



Сербский гений Никола Тесла
(1856-1943)

1. Получил 800-1000 патентов
2. Отказался от Нобелевской
3. Спонсировался Морганом
4. Высокие частоты
5. Высокие напряжения
6. Электрические резонансы
7. Связь Тесла и Эйнштейна



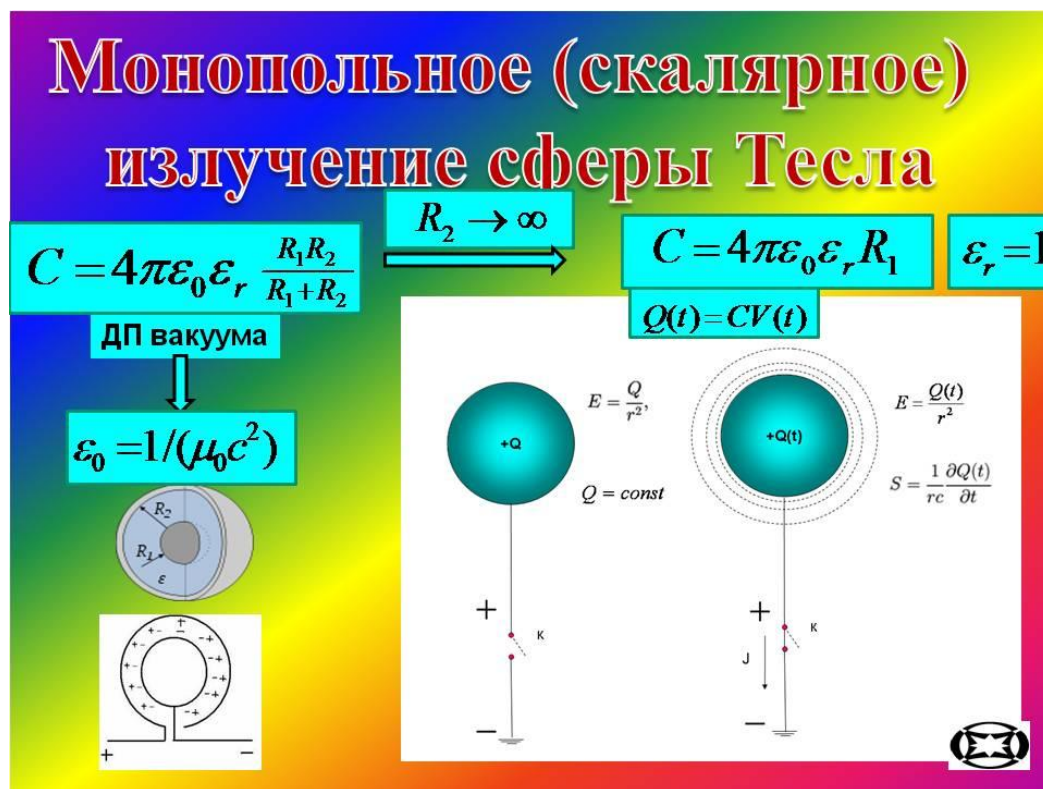
Слайд 1

торый мы сейчас определяем как «мысленный эксперимент». Обладая незаурядной интуицией, он мысленно создавал будущее устройство, мысленно экспериментировал с ним и, затем, переносил воображаемое устройство на бумагу. При этом воплощенное в «железе» устройство работало именно так, как представлял себе Н.Тесла. В интернете существуют источники, которые сообщают, что Н.Тесла был выдвинут на Нобелевскую премию, но отказался от неё. Научно-технические проекты Н.Тесла в основном финансировались американским multimillionerом Морганом, который прекратил финансирование после экспериментов по беспроводной резонансной передаче электроэнергии большой мощно-

сти с помощью башни, построенной в Колорадо Спрингс. В отличие от других исследователей начала 20^{го} века, Н.Тесла работал с устройствами, в которых он использовал экстремально высокие напряжения (миллионы вольт), высокие частоты (десятки МГц) и явление электромагнитного резонанса О.Хивисайда. По официальным документам два гения - Н.Тесла и А.Эйнштейн никогда не сотрудничали вместе. Более того, Н.Тесла протестовал против отказа А.Эйнштейна в 1905 г. от эфира (физического вакуума), считая это ошибкой. Со своей стороны, А.Эйнштейн поздравил Н.Тесла с 75^м летним Юбилеем, когда Н.Тесла продемонстрировал журналистам в 1931 г.автомобиль, который использовал для своего передвижения энергию эфира (вакуума).

1. Монопольное (скалярное) излучение сферы и катушка Тесла

Наибольший интерес для физики в экспериментах Н.Тесла представляет сферичес-



Слайд 2

кий конденсатор (слайд 2), емкость которого вычисляется по формуле $C = 4\pi\epsilon_0\epsilon_r R_1 R_2 / (R_1 + R_2)$. В этой формуле R_1 - радиус внутренней обкладки, R_2 - радиус внешней обкладки, ϵ_0 - диэлектрическая проницаемость вакуума (эфира во времена Тесла), ϵ_r - диэлектрическая проницаемость среды между обкладками. Из этой формулы в пределе $R_2 \rightarrow \infty$ следует емкость сферы $C = 4\pi\epsilon_0\epsilon_r R_1$. Соответственно, заряд сфе-

ры Q вычисляется по формуле $Q = CV = 4\pi\epsilon_0\epsilon_r R_1 V$, где V - напряжение между обкладками. Если заряженная сфера разряжается, то вне радиуса сферы должно наблюдаться векторное поле $\vec{E}(t) = Q(t)\vec{r} / r^2 |\vec{r}|$ (уравнения Максвелла) и скалярное поле Тесла $S(t) = 1/rc \cdot \partial Q(t) / \partial t$ (уравнения Физического Вакуума [2-4]). Скалярное излучение S

Монопольное (скалярное) излучение сферы Тесла

$$m \frac{d\vec{v}}{dt} = e\vec{E} + \frac{e}{c}[\vec{v}\vec{H}] - \frac{e}{c}S\vec{v} + \frac{2e^2}{3c^3}\ddot{\vec{v}}$$

МОНОПОЛЬНОЕ ИЗЛУЧЕНИЕ

ПЕРЕМЕННЫЙ ТОК $J = J_0 \sin \omega t$

ВТОРИЧНАЯ КАТУШКА L_2

ПЕРВИЧНАЯ КАТУШКА L_1

ПОТОК СКАЛЯРНОГО ПОЛЯ ТЕСЛА ЧЕРЕЗ ПРОСТРАНСТВО

НИТКА

ЛАМПА

0.8 m

R

$S = \frac{1}{rc} \frac{\partial Q}{\partial t} = \frac{\omega VR}{rc} 4\pi\epsilon_0 \cos \omega t$

ω - ЧАСТОТА ПЕРЕЗАРЯДКИ СФЕРЫ

V - ПОТЕНЦИАЛ СФЕРЫ

R - РАДИУС СФЕРЫ

Слайд 3

отсутствует в электродинамике Максвелла-Лоренца. Это монопольное излучение системы зарядов следует из решения уравнений Физического Вакуума (слайд 7) [2]. В вакуумной электродинамике нерелятивистские уравнения движения излучающего заряда e с массой m имеет вид

$$m \frac{d\vec{v}}{dt} = e\vec{E} + \frac{e}{c}[\vec{v}\vec{H}] - \frac{e}{c}S\vec{v} + \frac{2e^2}{3c^3}\ddot{\vec{v}}.$$

Здесь $eS\vec{v}/c$ - монопольное излучение источника поля (например, сферы Тесла) и $2e^2\ddot{\vec{v}}/3c^3$ - дипольное излучение ускоренно движущегося заряда. На слайде 3 представлена схема эксперимента Тесла по беспроводной передаче энергии [14], в котором используется скалярное поле Тесла S . На первичную обмотку трансформатора Тесла подается переменный ток с частотой ω . Один конец вторичной обмотки заземлен, а второй присоединен к сфере с радиусом R . В этом случае скалярное поле Тесла определяется формулой $S = 4\pi\epsilon_0\omega VR \cos \omega t / rc$. Поток скалярного поля распространяется от поверхности сферы в окружающее пространство и производит эффекты, которые не объясняются

уравнениями Максвелла-Лоренца. Например, поле S вызывает свечение ламп дневного света вблизи катушки Тесла (слайд 4).

2. Беспроводная передача электроэнергии и Тесла-Куперовские пары

Монопольное поле S представляет собой поток заряженных частиц – электронов,

Слайд 4

при этом поле можно представить в виде

$$S = -4\pi Q(t) \psi^* \psi = -4\pi Q(t) |\psi|^2 = -4\pi \rho_{rad}(t), \quad (1)$$

где ψ - волновая функция излученных заряженных частиц. Соотношение (1) интересно тем, что описывает «спаренные электроны», подобные куперовским парам в БКШ теории сверхпроводимости [5-7] (см. Слайд 5). Надо отметить, что «спаривание» электронов, обладающих кулоновским отталкиванием, не имеет фундаментального описания ни в теории Гинзбурга-Ландау [8], ни в теории БКШ [5-7]. Иное положение дел мы имеем в теории Физического Вакуума [2,3]. На слайде 5 представлена потенциальная энергия [3]

$$U = -\frac{mc^2}{2} \frac{-\alpha_e \lambda r}{r^2 + \lambda^2 \cos^2 \theta}, \quad \alpha_e = \frac{e^2}{\hbar c}, \quad \lambda = \frac{\hbar}{mc}$$

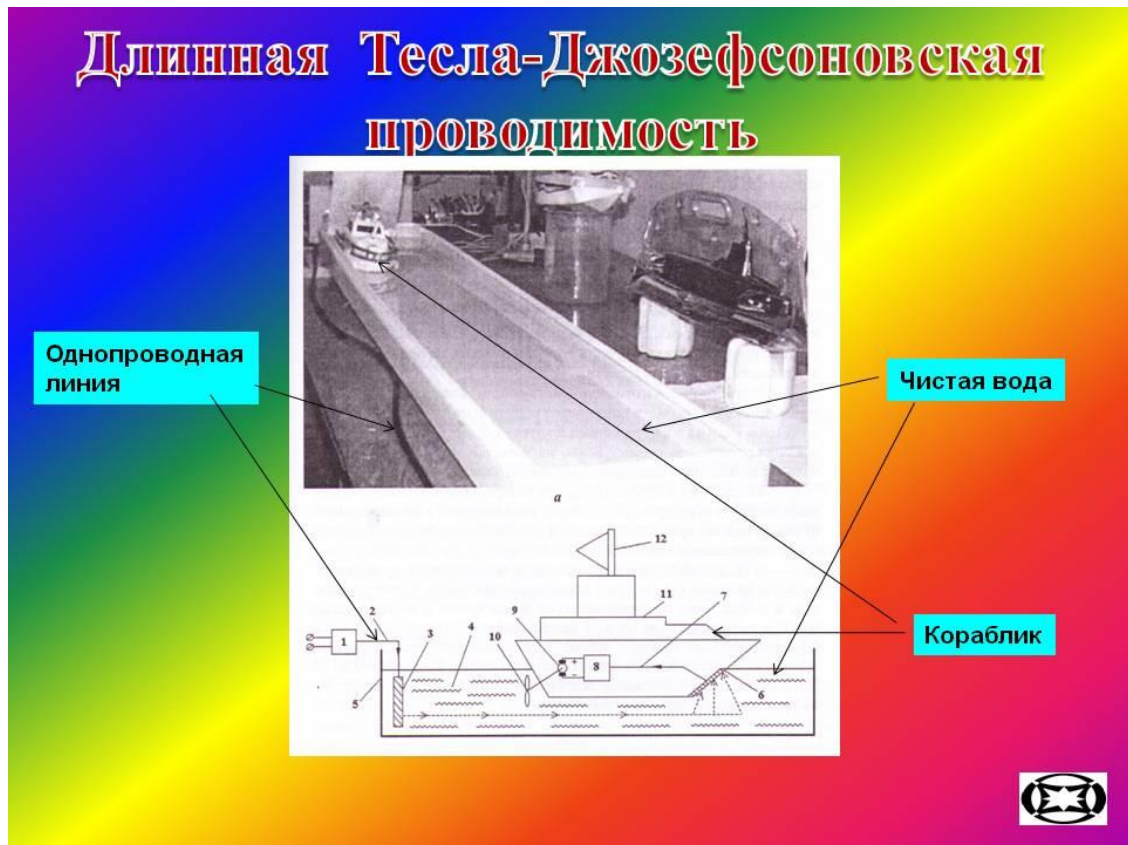
взаимодействия двух электронов с массами m и зарядами e , один из которых имеет спин $s = \hbar/2$. Эта энергия была получена из точного решения уравнений Физического Вакуума (слайд 7). Согласно полученной формуле, энергия кулоновского отталкивания электронов преодолевается торсионной энергией притяжения на расстояниях $\alpha_e \lambda \leq r \leq \lambda$ или $2.8 \cdot 10^{-13} \text{ см} \leq r < 10^{-11} \text{ см}$. Следовательно, по формулам теории Физического Вакуума, размер куперовской пары не должен превышать 10^{-11} см . Наблюдать извивающийся поток куперовских пар в режиме реального времени можно с помощью «Волшебного шара», представленного на слайде 4 слева и справа от формулы.



Слайд 5

Эксперименты со скалярным излучением Тесла показывают, что скалярный ток сверхпроводимости возникает не только в проводниках, но и в диэлектриках, причем не только при низких температурах, но и при комнатной температуре. На слайде 5 слева внизу представлена фотография эксперимента, когда ток сверхпроводимости течет по одному проводу, при этом участок длиной 8 см представляет собой чистая вода. На фотографии видно как слева горят две лампы, подключенные к вторичной обмотке левого трансформатора Тесла, первичная обмотка которого питается от одного провода. Это очень похоже на эффект Джозефсона [9] в теории сверхпроводимости, когда между двумя проводниками помещается диэлектрик, но сверхпроводящий ток все равно проходит. Длинная джозефсоновская проводимость наблюдается в экспериментах с трансформатором Тесла достаточно давно [10], но ее теоретическое обоснование в рамках традиционной квантовой теории отсутствует. На слайде 6 представлен эксперимент группы Д.С. Стребкова по однопроводной передаче электроэнергии, в котором длина диэлектрического водного промежутка состав-

ляет величину от 0.1 до 2 метров [9]. Эксперимент включает в себя трансформатор Тесла 1, из которого выходит один провод (Слайд 6). На конце провода, опущенного в воду, расположен излучатель 3 электронных пар Тесла-Купера. Поток спаренных электронов проходит через воду, попадает на приемный электрод 6 и по одному проводу подается на выпрямитель 8. После выпрямителя постоянный ток подается на электродвигатель постоянного тока 9, вращающего гребной винт 10.



Слайд 6

3. Уравнения Физического Вакуума

Основными полями в теории Физического Вакуума оказываются торсионные поля с разнообразными физическими свойствами. Эти поля как предмет изучения в науке возникли в конце 19 века в работах итальянского математика Г.Риччи. Существует огромное количество математических работ проведенных Картаном, Схоутеном и др. математиками по исследованию свойств торсионных полей, но только в конце 20 века в России ученым удалось обнаружить связь этих полей с физическими экспериментами. В работе [11] в 1984 г. были впервые опубликованы уравнения Физического Вакуума, а в 1988 г. мной была завершена программа Всеобщей относительности и окончательно представлены уравнения Вакуума (А) и (В) (слайд 2) как новые фундаментальные уравнения физики.

Торсионные поля T^i_{jk} в уравнениях Физического Вакуума играют роль того самого Единого Поля, на поиски которого А.Эйнштейн потратил более 30 лет.

10 D

Уравнения Физического Вакуума

(Шипов 1988)

$$\nabla_{[k} e^a_{j]} + T^i_{[k j]} e^a_i = 0, \quad (A)$$

$$R^a_m - \frac{1}{2} g^a_m R = \nu T^a_m, \quad (B.1)$$

$$C^a_{bkm} + 2\nabla_{[k} T^a_{|b|m]} + 2T^a_{c[k} T^c_{|b|m]} = -\nu J^a_{bkm} \quad (B.2)$$

T^i_{jk} — ТОРСИОННОЕ ПОЛЕ ОБРАЗУЕТ
 ИСТОЧНИКИ В УРАВНЕНИЯХ ЭЙНШТЕЙНА (B.1)
 И ЯНГА – МИЛЛСА (B.2)



Слайд 7

Уравнения (А) представляют собой торсионные уравнения, поскольку содержат торсионное поле T^i_{jk} и вектора e^a_k четырехмерной произвольно ускоренной системы отсчета. Уравнения (В) распадаются на полностью геометризованные (включая правую часть) уравнения Эйнштейна (В.1) и полностью геометризованные уравнения Янга-Миллса (В.2). Тензор энергии-импульса T^a_m в уравнениях (В.1) и тензор тока J^a_{bkm} определяются через квадратичные комбинации торсионного поля T^i_{jk} и их производные. Поэтому торсионное поле в уравнениях Физического Вакуума играет роль *поля материи*. Значение константы (или функции) ν в уравнениях (В.1) и (В.2) определяется после того, как найдено решение этих уравнений, которое затем сравнивается с решением одного из фундаментальных уравнений физики.

Полностью геометризованное уравнение Эйнштейна (В.1) предсказывает новые представления о структуре пространства-времени. Согласно этим представлениям мы живеем в 10 мерном координатном пространстве, которое включает в себя 4 трансляционных координаты x, y, z, ct и 6 вращательных координат $\varphi_1, \varphi_2, \varphi_3, \theta_1, \theta_2, \theta_3$. Именно

6 вращательных координат определяют торсионные поля T^i_{jk} . В нерелятивистском приближении и в (квази)инерциальных системах отсчета плотность материи ρ любого объекта, рожденного из вакуума, определяется как $\rho = \hbar \omega \psi^* \psi$, где ψ - нормированное на единицу поле инерции (торсионное поле), удовлетворяющее геометризованному уравнению Шредингера, \hbar - квантовая константа для данного объекта, ω - частота торсионного поля. Таким образом, торсионное поле имеет квантовую природу, что указывает на квантовую природу 10 мерного пространства, в котором мы живем. Доказательством этого служит квантовый эффект Джанибекова (слайд 8). На слайде представлены 5 кадров движения вращающейся гайки, которая квантовым образом меняет направление оси вращения через каждые 40 см. пройденного пути в состоянии невесомости. Это можно увидеть в динамике в фильме http://www.youtube.com/watch?v=dL6Pt1O_gSE&NR=1 снятом в кабине космического корабля. Наблюдаемый эффект не объясняется теорией гравитации Эйнштейна. Макроквантовая структура пространства наблюдается и в квантовании средних расстояний от Солнца до планет и в наклоне осей вращения планет к плоскости экватора Солнца.



Слайд 8

На слайде 8 внизу слева показан эксперимент по квантованию направления оси вращения гироскопа при изменении частоты его вращения.

Основные статьи и книги по теории Физического Вакуума и Торсионных полей

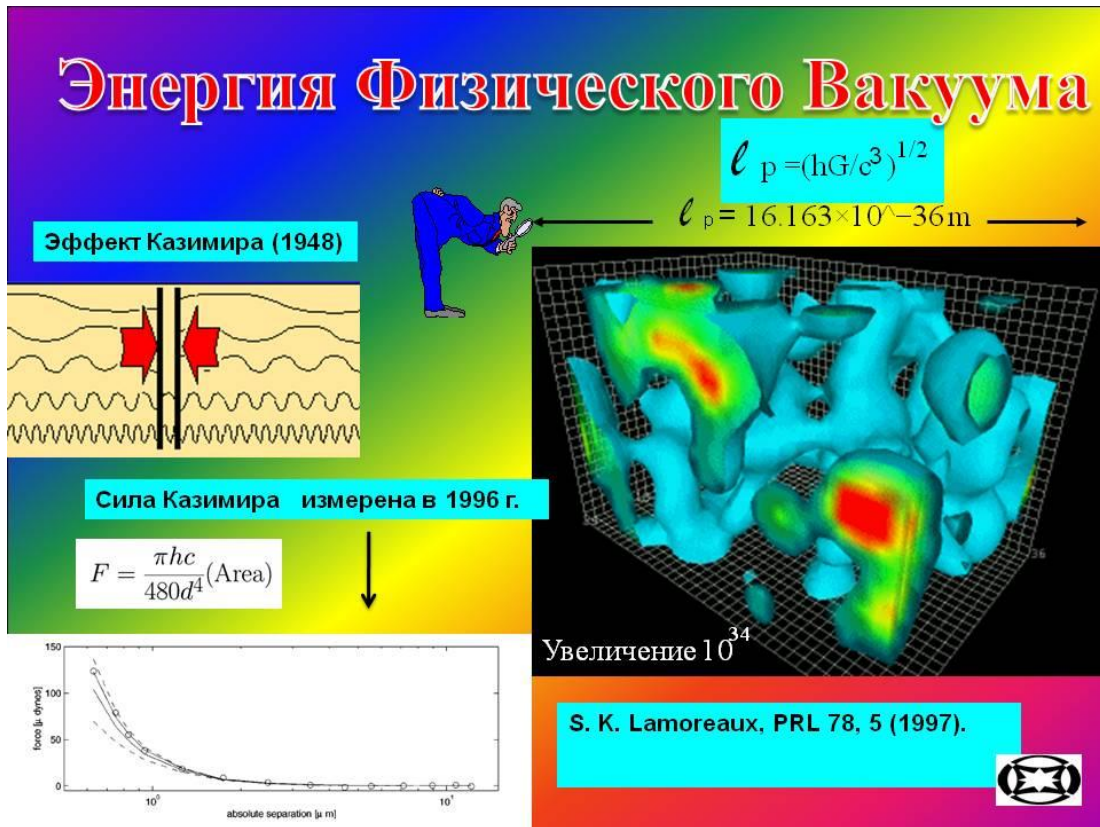


Слайд 9

На слайде 9 представлены основные опубликованные статьи и монографии по теории Физического Вакуума. Более оперативно и подробно можно познакомиться с работами по теории Вакуума на сайтах www.shipov.com и www.trinitas.ru. На этих сайтах расположены статьи автора, написанные в последние 10-12 лет и трудно доступные в других источниках информации. В книге моего последователя Е.А.Губарева «Теория реальной относительности» достаточно подробно изложены основы Всеобщей относительности, которая использует вращательные координаты $\varphi_1, \varphi_2, \varphi_3, \theta_1, \theta_2, \theta_3$ как элементы 10 мерного пространства-времени.

3. Энергия Физического Вакуума и генераторы свободной энергии

Из современной квантовой теории следует, что Физический Вакуум, будучи основным состоянием всех видов материи, в среднем обладает нулевыми физическими характеристиками. Тем не менее, Вакуум обладает бесконечной энергией нулевых колебаний.



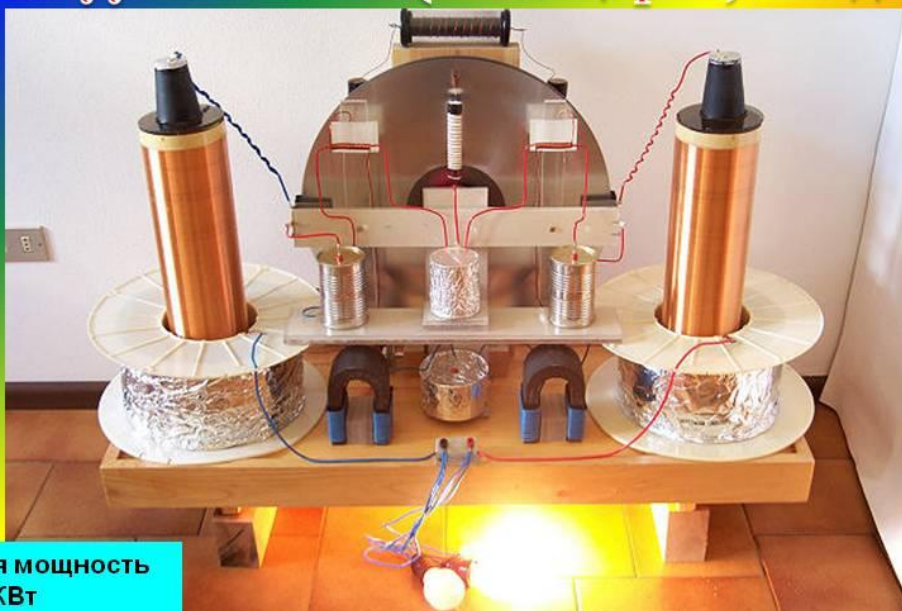
Слайд 10

Эта энергия способна действовать как на атомные уровни (лембовский сдвиг [12]), так и на макрообъекты (эффект Казимира [13]). На слайде 10 справа вверху представлены нулевые колебания энергии Вакуума, которые можно увидеть на расстояниях порядка длины Планка $\ell_p = (\hbar G / c^3)^{1/2} = 1.6 \cdot 10^{-35} \text{ m}$. Если бы мы имели прибор с увеличением 10^{34} , то мы бы увидели динамическую картину, представленную на слайде 9. В 1948 г. Х.Казимир предсказал существование силы притяжения между двумя незаряженными пластинками (см. слайд 9) в зависимости от площади пластин и расстояния между ними. В 1996 г. это предсказание было подтверждено экспериментально. Этот макроквантовый эксперимент показывает, что существует принципиальная возможность построить макроприбор, который будет преобразовывать недетерминированную вакуумную энергию в обычную детерминированную энергию. Во многих лабораториях мира вот уже несколько десятков лет ученые пытаются превратить эту «недетерминированную» энергию в энергию детерминированную, которую можно использовать для пользы людей. Однако Природа любит пошутить над ученым миром, преподнося ему, время от времени, неожиданные открытия, сделанные людьми, далекими от науки. Примером машины, которая получает энергию из вакуума является Тестатика Пауля Баумана.

2. ТОРСИОННАЯ ЭНЕРГЕТИКА

$$\rho = \sum \hbar \omega \Psi^* \Psi$$

Генератор П.Баумана качает энергию из вакуума с 1980 г. (Швейцария, Линден)



Суммарная мощность
740 КВт

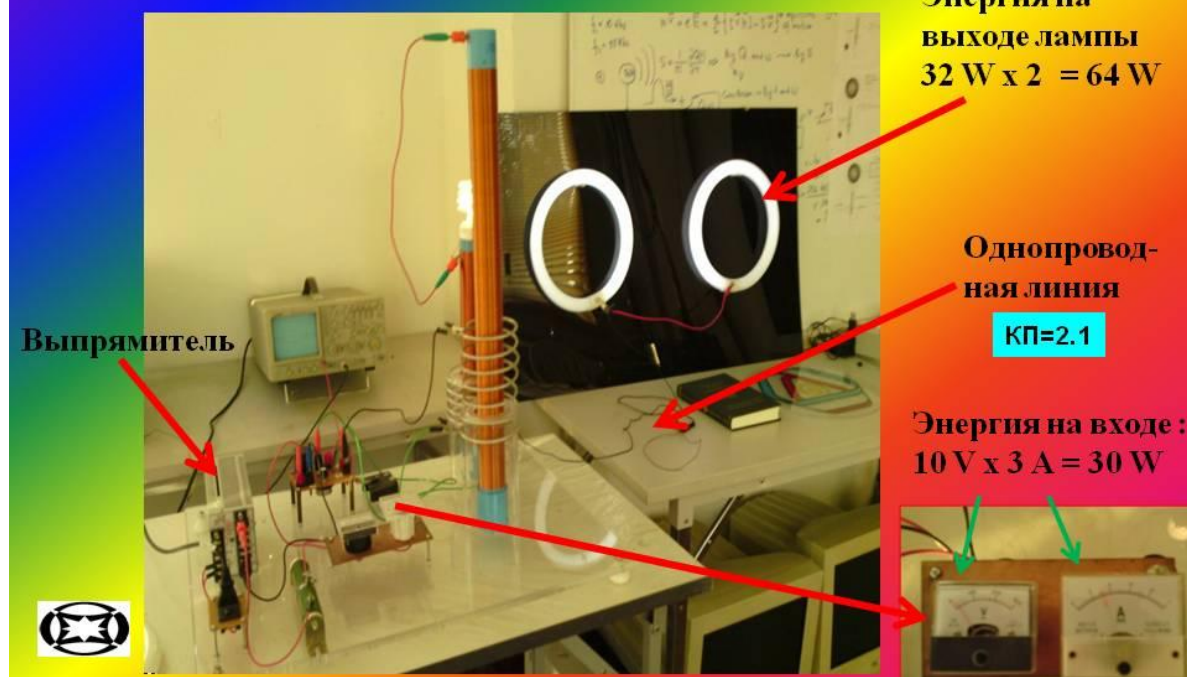


Слайд 11

Генератор Тестатика был создан в 1978 г. и смастерил его часовых дел мастер Пауль Бауман на четвертом году заключения в швейцарской тюрьме из консервных банок, которые выполняли роль конденсаторов, обрывков проводов и деталей, собранных из хлама в тюремной мастерской. В созданной им христианско-религиозной коммуне «Метернита» в Швейцарии с 1980-х годов работают устройства, генерирующие от 200 Вт. до 30 КВт электроэнергии для бытовых нужд поселка. Суммарная мощность всех систем составляет уже более 750 Киловатт (слайд 11). Таким образом, в 1980 году в мире появился населенный пункт, который раз и навсегда решил энергетические проблемы. Его жители (будучи дилетантами в науке) отказались от традиционных видов топлива и разрушили мифы об угрожающем нам «энергетическом кризисе». Секрет генератора коммуной не раскрывается по причине неверия членов коммуны в мирное использование человечеством нового источника энергии. Фильм о работе генератора Тестатика можно посмотреть на сайте <http://www.youtube.com/watch?v=AJqMSjGo3Ig> .

Тестатика является первой в мире машиной, производящей «свободную энергию» из Физического Вакуума, флуктуации которого, по представлениям современной науки, обладают бесконечным количеством энергии.

Передача электроэнергии по одному проводу



Слайд 12

114 лет тому назад Н.Тесла предложил однопроводную передачу электроэнергии [15]. На слайде 12 эксперимент Тесла по однопроводной передаче электроэнергии представлен в миниатюре. Эксперименты показали, что при такой передаче электроэнергии не работают:

- 1) закон Ома для двухпроводной линии;
- 2) законы Кирхгофа для двухпроводной линии;
- 3) закон сохранения электрической энергии.

На слайде 12 катушка Тесла потребляет 30 ватт электроэнергии, а к однопроводной линии подключены 2 лампы дневного света, потребляющие 64 ватта электроэнергии. При подключении дополнительных источников энергии потребление энергии катушкой Тесла остается тем же самым. Выходит, что в установке происходит преобразование электроэнергии с коэффициентом преобразования (КП) больше единицы. На слайде 14 КП=2.1, хотя другие конструкции катушки Тесла позволяют получить гораздо больший коэффициент преобразования.

Нарушение закона сохранения энергии в катушке Тесла



Слайд 13

На слайде 13 представлена катушка Тесла, генератор импульсов которой питается батарейкой. Потребляемая генератором мощность всего 1.7 Вт. В скалярном поле S катушки Тесла горят две лампы с общей мощностью 50 Вт. Слева лампа в руке исследователя является обычной лампой накаливания 110 v и мощностью 25 Вт. Справа на столе лежит лампа дневного света, мощностью 25 Вт. У этой установки КП=29.4. Фильм об эксперименте можно посмотреть на сайте <http://www.youtube.com/watch?v=ozGwb0glcXg>

Невольно напрашивается вопрос, а почему бы после запуска системы не взять часть избыточной энергии, генерируемой катушкой Тесла, и направить ее на вход, исключив пусковую батарейку? В этом случае система должна генерировать свободную энергию сама по себе, наподобие Тестатики Пауля Баумана.

Генератор Тесла-Капанадзе

Установка Капанадзе 5 КВт



Заземление

1.2 КВт



Слайд 14

Эта идея была реализована Н.Тесла еще в 1931 г., когда Н.Тесла поставил энергетическую установку на автомобиль и использовал полученную электрическую энергию для передвижения автомобиля с помощью электромотора.

В наше время подобная установка была предложена Таризлем Капанадзе (мощность от 5 КВт до 100 КВт) и, затем, повторена другими исследователями. На слайде 14 справа представлена энергетическая установка Капанадзе мощностью 1.2 КВт, созданная Жаном-Луи Нодином. Установка имеет один внешний провод, идущий на заземление. В качестве нагрузки использованы 6 ламп накаливания мощностью 150 Вт напряжением 220 вольт. В интернете можно найти несколько реплик установки Капанадзе <http://www.youtube.com/watch?v=uxQ99R4gOWY&feature=related> смотри, например,

<http://www.youtube.com/watch?v=PqorIWlkhWI&feature=related>

В результате неприятия этих явлений академической наукой, процесс развития идет в таком направлении, что каждый нуждающийся в энергии будет вынужден покупать детали установки на рынке и самостоятельно по схемам, предлагаемым в интернете, создавать нужной мощности источники электрической энергии. Энергетические установки, сделанные Капанадзе, имеют мощность от 3 до 100 КВт и это далеко не предел. По мнению

Н.Тесла эти установки, как и машина П.Баумана, используют энергию эфира (Физического Вакуума), превращая ее в электрическую энергию.

Заключение

Однажды Ньютон сказал такие слова: «Либо не надо говорить ничего нового, либо всю жизнь надо потратить на защиту своего открытия». На защиту от кого? От завистников? От конкурентов? От дураков? Но ведь открытия такого класса, как электродинамика Тесла, генераторы Баумана или Капандзе дают человечеству невероятные возможности. И, видимо, именно это является основным препятствием к их внедрению.

Во времена Джордано Бруно за открытия людей сжигали на кострах, во времена Галилея их судили, а Н.Тесла в начале XX века за его невероятные изобретения обвиняли в связи с нечистой силой! Во второй половине XX В. Толчина посадили в сумасшедший дом за изобретение и демонстрацию инерциоидов. Борьба велась и ведется против отдельных творцов науки всеми, кто управляет нашим сознанием - церковью, академиями и правительствами некоторых государств.

Сейчас дело борьбы с новаторами науки принимает качественно новый оборот. Борются уже не с отдельными личностями, а с целыми направлениями, например, так было с генетикой и кибернетикой. Дурак платит дважды, а завистливый дурак – трижды, поэтому Сколково создается в России на 50 лет позже Силиконовой Долины в Америке.

Вот и теория Физического Вакуума, а также связанные с ней экспериментальные и технологические наработки, развиваемые сотнями людей, почти 20 лет «гнобятся» Российской академией наук с молчаливого согласия Российского государства. Сон разума рождает чудовищ, и уже скоро мы увидим, чем закончится это «ментальное мракобесие».

11.03.2011.

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Nikola TESLA's Radiations and the Cosmic Rays

André Waser*

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Without doubt Nikola TESLA was one of the greatest experimenters in the field of electricity. With his inventions of the alternating and polyphase current with all his components for generation, transmission and consumption devices TESLA has become famous around the world. TESLA was not much interested in the world of business. He rather continued experimenting for many years after his success with the alternating current systems, while his experimental capabilities has only be restricted by his always tight funds. Especially in his second part of life TESLA has elaborated and realized experiments which have not been reconstructed until these days. Some of them seems to be very promising to overcome the increasing challenges of our society in a better way. By studying many original papers of TESLA this essay tries to reconstruct the visions and conclusions he has got from his experiments.

Introduction

It is astonishing how little can be found in literary about the work of the world-wide known Serbian inventor and experimenter. And this is even more astonishing because all the today used electricity polyphase power systems has been invented in its basic characteristics by Nikola TESLA at a time, whereas the whole world only did know the expensive and very limited direct current systems of Thomas EDISON.

But after this inventions of alternating current systems TESLA has published many, many papers, which are almost forgotten. This papers will be summarized and analyzed. It is shown very impressive that TESLA with his experimental knowledge in physics was far ahead of the theoretical physics of his time. Still today many phrases in this papers have never been understood, has seldom be commented and some have become a mystery.

Almost all publication of the modern world only look at TESLA's work with high frequency and high voltage transformers, better known with the summary term „TESLA coil“. But after his successful work with the magnetic rotary field TESLA has discovered a new kind of rays which he called *radiations*.

It is characteristic for an experimental discoverer that he finds unexpected and new facts and results due to measurements and experiments based on some new conceptual ideas. Because TESLA's practical know-how was so far ahead of the theoretical know-how, the communication to the established science was almost impossible. They didn't simply understand! Probably because of this and also because of financial interests TESLA almost stopped his publications in scientific newsletters since 1899 and since then he only published some material in popular weekly or daily newspapers. Only in the patents some deeper information can be found.

* André Waser, Birchli 35, CH-8840 Einsiedeln; Switzerland

The Radiations

TESLA has used the term *radiations* for more than 40 years. From different statements and interviews with TESLA always some pieces of information can be found about that, what has kept him busy for the whole second part of his life. From the publications listed in the appendix the following summary about the nature of the radiations can be given:

1. They are small particles of „*infinitesimal*“ size [57], [58].
2. They carry a small, positive charge, which is only a fragment of the elementary charge [58], [65], [66].
3. They penetrate through substance almost without interactions [57], [62], [66].
4. They could achieve a speed far above of the speed of light [57], [58], [66]. This velocity is only limited by the mass to charge ration of the particles [66].
5. They are the cause of radioactivity because they're bombarding and destabilizing the nucleus of the atoms [54], [57].
6. They arrive the Earth form all directions [57], [66].
7. They are emitted form all the stars, therefore also form the sun. This is why this radiation during day is a little bit higher than during night [57], [60], [66].
8. A small fraction of this radiation is absorbed by celestial bodies which causes them to increase in masse and volume continuously [66].
9. They can be proved with vacuum tube experiments [57].

Later TESLA^[54] himself has mentioned 1897 as the year of discovery of the *radiations*. When exactly Tesla was convinced to measure this *radiations* is not precisely known, but should be between the years 1896-1897. What can be said for sure is that TESLA has filed two patents^{[41],[42]} where he describes the utilization of this *radiations* in a crude way.

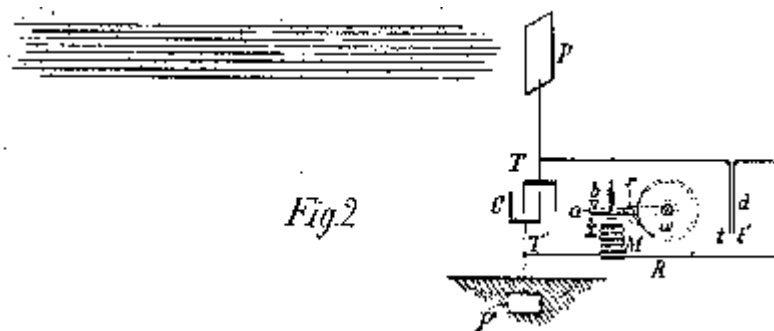


Figure 1: Nikola TESLA, „Apparatus for the Utilization of Radiant Energy“, US-Patent 685,957, issued on November 05,1901, Fig. 2

Also known is, that TESLA presented in his speech before the Institution of Electrical Engineers in London – where he explained many experiments he has done with some special kind of bulbs –an experiment where radiant matter is emitted form a single electrode within a partly evacuated glass bulb (Figure 2).

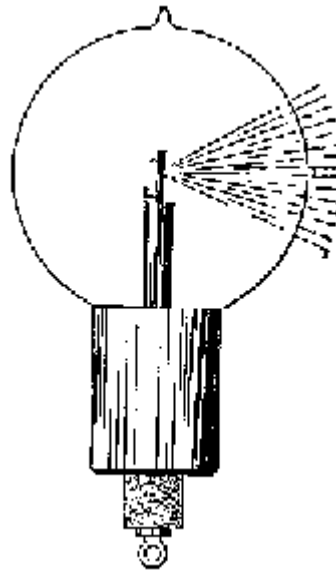


Figure 2: Nikola TESLA, „Experiments with Alternate Currents of High Potential and High Frequency“, February 03/04, 1982

Then Tesla mentioned not only the cormic space as the source of this radiation but also a glass tube with one single electrode^{[41]-Fig.4}.

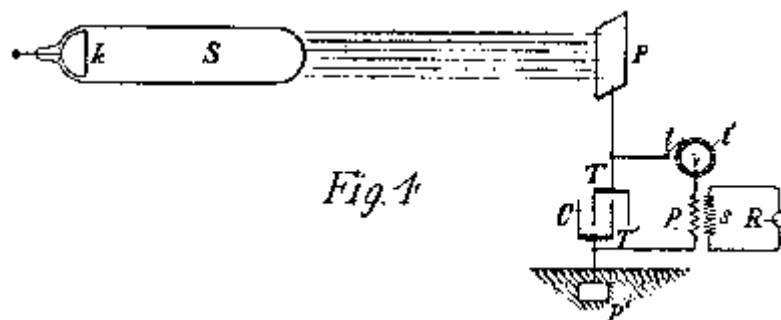


Figure 3: Nikola TESLA, „Apparatus for the Utilization of Radiant Energy“, US-Patent 685,957, issued on November 05, 1901, Fig. 4

Consequently TESLA experimented for decades with vacuum tubes. In his Colorado Springs Notes^{[36]- p.29} three drawings can be found about a simple connected tube with different surrounding constructions (reflectors). This note carries the title „*Arrangements with single terminal tube for production of powerful rays.*“. The purpose of this experiments can be found in the last sentence: „*The capacity would be such as to bring about maximum rise of e.m.f. on the free terminal.*“

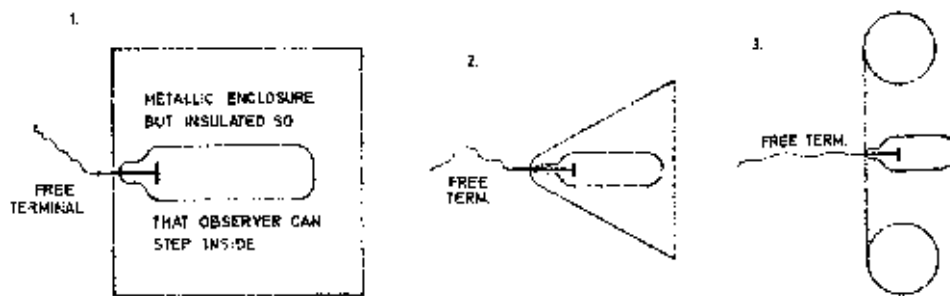


Figure 4: Nikola TESLA, „Colorado Springs Notes“; page 29, June 06, 1899.

37 years later (July 11th, 1937, *New York Times*, page 13) he still writes about the successful construction of a powerful tube with supplementary circuitry which can be operated with voltages far above 100'000'000 volts.

Obviously the key to TESLA's *radiations* lies in his earlier experiments with high frequency currents and voltages. Therefore this passages of his papers, which could probably bring more light on this enigma, should now be examined more closely.

In his first lecture^[18] before the American Institute of Electrical Engineers on May 20th 1891 TESLA describes merely his inventions and discoveries with partly evacuated glass bulbs. He describes the fascinating properties of Professor CROOKES's radiometer. He founds, that the bombardment of the residing charges within the glass bulbs cause the heat production at the spherical single electrode of his spherical bulbs. Until these days he has perfected the production of high frequency generation with high voltages to examine leading experiments with cathode rays.

One must remember this area at the beginning of the last century full of new discoveries. The atom was totally unknown except that it can not be decomposed into smaller parts. The constituents of an „electric flux“ (LENARD rays, named after Philip LENARD 1862-1947) in a vacuum tube was totally unknown. Then in August 1874 George Johnstone STONEY^[16] has postulated with his examinations of electrolytic liquids a certain small amount of electricity E_r , which he named in October 1894 with the name „electron“. William CROOKES^{[2],[4]} published 1878 and 1879 his experiments with cathode rays. Wilhelm Conrad ROENTGEN^[15] discovered new penetrating rays on November 08, 1895. And some months later Antoine Henri BECQUEREL^[1] speaks on February 24th, 1896 before the French Academy of Science about a new radiation emitted from phosphorescent materials. Then in October 1897 Joseph John THOMSON^[70] has first confirmed the existence of the electron.

Different experiments with vacuum tubes and photographic plates has characterized this time of discoveries. With his high frequency lighting system TESLA already has had a broad experimental experience with vacuum tubes and high voltage equipment. Obviously TESLA has forced his experiments to higher and higher frequencies and voltages. The original lamp more and more transformed into electron tubes which has later on be built by TESLA in hundreds of variants. With the use of his high voltage systems TESLA was able to accelerate electrons to extremely high velocities.

TESLA has produced many photographs with his powerful electron tubes but despite of some sharp shadows on his photo plates he did not recognize the new kind of X-rays, which later has been reported by ROENTGEN. Then with the announcement of ROENTGEN the main focus of TESLA was directed away from electron rays toward the discovery of new rays. Probably TESLA did not firstly report of this new kind of rays because of the fire in March 13 1896 in his New York laboratory which has destroyed almost all

apparatus and papers totally. So the official discovery of the X-rays has been done by ROENTGEN. This was TESLA's first missed Nobel price.

In the year 1896 TESLA published a remarkable series of articles in the *New York Electrical Review* about his work with ROENTGEN rays. Soon on March 11, 1896 he presented his first Roentgen pictures which he has produced with his high frequency coils and vacuum tubes. Obviously the peculiar construction of his vacuum tube with only one single electrode is very important. TESLA writes about it^[20]: »Clearly, if we put two electrodes in a bulb ..., we limit the potential, for the presence not only of the anode but to any conducting object has the effect of reducing the practicable potential on the cathode.«

A week later on March 18, 1896 TESLA^[21] describes that he can produce radiographs at a distance up to 40 feet. At that time this was an enormous distance for the transmission of Roentgen rays through air.

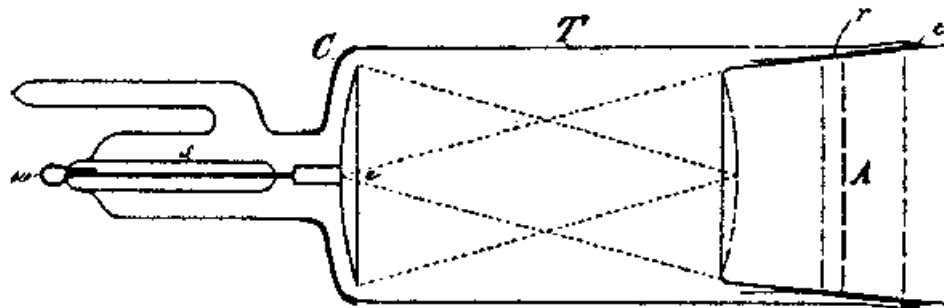


Figure 5: One of Tesla's Roentgen tubes with one single electrode (from [30]).

On the 1st of April TESLA^[23] shows that ROENTGEN rays can be reflected. He made his experiments not only with conducting reflectors. According to TESLA the insulator Ebonite has the same reflection index as copper. This shows, that besides the ordinary reflection of ROENTGEN radiation TESLA has produced a secondary effect today known as Back Scattering Electrons (BSE). This BSE effects depends solely of the reflector's density and not on its conductivity. And this was also mentioned by TESLA. Then TESLA reports that he did not succeed with the deflection of ROENTGEN rays despite the fact he has used many different kinds of glass lenses.

On April 8th he reports more on the impossibility of the deflection of ROENTGEN rays and also writes about experiments^[24] with multi-layered metal reflectors. But despite of a great effort it was not possible to reflect more that a few percent of the incoming rays.

On April 22nd TESLA^[25] believes that the LENARD and ROENTGEN rays are almost identical, except that the ROENTGEN rays do have a much higher velocity. In addition he postulated that the order of the reflecting metals due to their reflection capabilities are equal to the series of voltage elements according to Alessandro VOLTA. From this TESLA concluded that the ROENTGEN rays are made of the same agent as that, what is responsible for the different voltages between two metals. With this he was partly correct and partly not, as we know today. Obviously he mixed the ROENTGEN radiation (electromagnetic waves or high energy photons) with the electrons, but he recognized correctly, that the reflected particles (BSE electrons) are identical to the particles (valence electrons) which cause the voltage between different metals.

This publication^[25] of TESLA is also of a particularly interest in connection with his later statements^{[61], [65]} about the sun.

On June 08th TESLA describes the source of the ROENTGEN rays as this place, where the LENARD rays impact the first time on an obstacle. This obstacle could be the glass wall of the vacuum tube or a metal plate placed within the tube. Today this radiation is well known as bremsstrahlung, but at the time of TESLA's experiments and years later this was not known in theoretical science.

On August 12th 1896 TESLA^[27] is absolutely sure about the corpuscular nature of the ROENTGEN rays and presents eleven reasons for this. The ROENTGEN rays consists of the same but much faster particles than the LENARD rays. Also TESLA reports the exposure of photo plates up to a distance of 30 meters.

On December 02nd 1896 TESLA^[28] describes the particle nature of the ROENTGEN rays in more details. Now he distinguished the ROENTGEN rays clearly between the LENARD rays and he compares the ROENTGEN rays similar to the disassociation process of Lord KELVIN's aether atoms^[71]. This particles of a „primordial form“ are created after the impact of Lenard rays on an obstacle and then they have different intensities and velocities.

On April 06th 1897 TESLA gave a lecture before the New York Academy of Sciences entitled with *The Streams of Lenard and Roentgen and Novel Apparatus for Their Production*, which has never been published by him in a written form. A reconstruction of this lecture has been done by Leland ANDERSON^[30]. In this lecture TESLA has made a very astonishing claim, then he said, that he has succeeded to deflect the LENARD rays as well as the X-rays with a magnet. This has been published by the *Electrical Engineer*^[31] in a short notice on April 14th 1897 as well as by the *Electrical Review* with the same date^[32] and again on August 09th 1897^[34].

On May 05th 1897 TESLA^[33] assigned a small electric charge to the particles of the ROENTGEN rays and states, that this rays are able to transmit a huge amount of electricity.

Then on August 11th 1897 TESLA^[34] confirms again his statements in the lecture of April 06th about the deflection of ROENTGEN rays with magnetic fields and promises to publish this experiments to a later time. But unfortunately a publication about this very important experiments has never been done, as far as the author knows. In opposite, from this time on TESLA's publications has been dried up for decades. One reason for this was certainly the protection for further patent applications for the utilization of this rays, then a mayor part of TESLA's financial income was derived from (sometime only hoped) patent license fees.

Analysis

Many things points to the fact, that TESLA has observed the classical ROENTGEN rays as an effect of the Bremsstrahlung. His particle theory was as correct as the wave theory, then today we know of the quatisized nature of the electromagnetic radiation and it is common to describe light with photons. It seems as TESLA has recognized the particle character of electromagnetic radiation correctly. TESLA has used the following causal chain for the description of the production and effects of ROENTGEN rays:

1. The LENARD rays consists of sub-atomic particles analogue to the KELVIN's aether vortexes, which travel with a velocity between hundred and several thousands kilometers per second.
2. If this particles of the LENARD rays impact on an obstacle then this particles are disassociated and the result of the impact are much smaller particles, which now travels with higher speed than the particles of the LENARD rays.

3. Not all particles of the LENARD rays are disassociated on the first obstacle. The thicker the obstacle the intense are the resulting ROENTGEN rays.
4. This smaller particles correspond to the ROENTGEN radiation. It is not possible to deflect ROENTGEN radiations with glass lenses but they can be reflected on conducting surfaces.
5. This granular ROENTGEN rays are capable to charge distant ball capacitors positively. Therefore the particles of the ROENTGEN rays are charged positively. Thus the rays of LENARD and ROENTGEN are very similar in nature.
6. If the ROENTGEN rays are composed of electric positive and fast particles, it must be possible to deflect this rays with magnets. According to TESLA this can be proved with a sensitive measuring device.

Now we try to translate TESLA's causal chain into the terminology of today's physics:

1. The LENARD rays consists of electrons, which can travel close to the speed of light if the accelerating voltage is high enough.
2. If this electrons impact on an obstacle they are highly accelerated. The result of the impact are emitted high energy photons (bremsstrahlung) which now travels wit the speed of light.
3. Not all electrons are absorbed in the first obstacle. The thicker the obstacle is made the longer is the (negative) acceleration of the electrons and the intense is the resulting ROENTGEN radiation.
4. This high energy photons correspond to the ROENTGEN rays. The frequency range of this photons is far above visible light. Therefore ROENTGEN radiation can be deflected with optimized crystal lenses (1912 discovered by Max von LAUE) but not by ordinary glass lenses. They also can be reflected on metallic surfaces.
5. This high energy photons are able to knock out electrons form distant conductors so that this conductor is charged positively.
6. Electromagnetic waves, and therefore also the photons, can not be deflected with magnetic fields. But a rotation of the light's polarity can be done (known as FARADAY effect).

Except the last point all of TESLA's statements are well known today and can be explained by known physical models. The decisive question lies in the deflection of such rays which TESLA called ROENTGEN rays with magnetic fields.

Only once TESLA^[25] gives probably a hint about a possible experimental device. There he references to a ball-shaped vacuum tube developed by him without a metallic anode or cathode, which he has presented^[20] in 1892 on the first time (figure 6).

If the tube is exited with his high frequency coils for a certain time between some hours and a few weeks, a thin sensible light can be observed in this tube which can be compared best with a brush. This week light stream is never in rest but is always moving. The positions of this light reacts very sensitive on external magnetic fields. If, for example, the bulb hangs down straight to the Earth's center, the Earth's magnetic field forces the light brush to rotate clockwise.

If TESLA really has used such sensitive devices for the measurement of the deflection is not known for certain. Also a text passage of his lecture held on April 06th 1897 which was reprinted in the *Electrical Engineer*^[31] does not gives more help. Then it is also possible that TESLA has deflected electrons or ions with a magnetic field, which then has charged a distant capacitor.

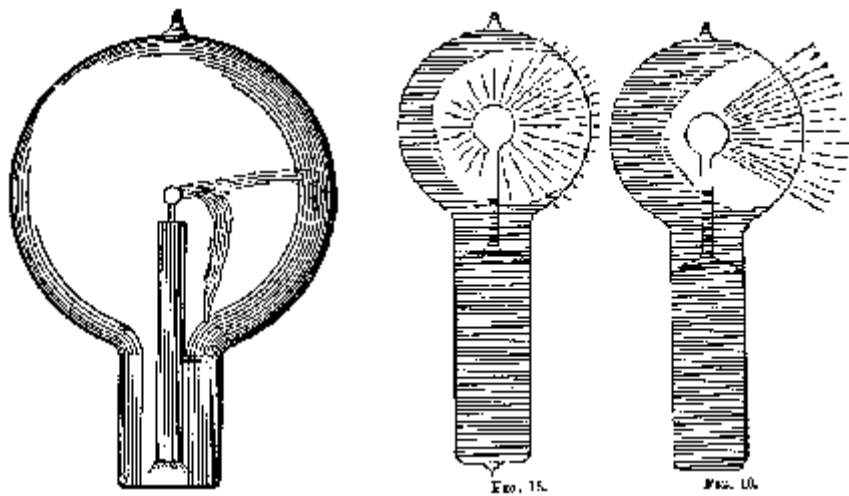


Figure 6: Nikola Tesla, „Experiments with Alternate Currents of High Potential and High Frequency“, February ¾, 1882; the rotating brush bulbs

If TESLA's observations are correct, then he has produced at least two different effects outside his vacuum tube under high voltage pressure. One effect was the high frequency ROENTGEN radiation and the other effect was of a corpuscular nature. Then the corpuscular effects are only detectable for very high accelerating voltages for the electrons in the vacuum tubes, if this electrons impact at the end of the tube with high energy and not release the whole energy into the ROENTGEN radiation due to bremsstrahlung. The simultaneous appearing of two different effects could explain many inconsistencies of TESLA's statements. Once the fresh discovered Roentgen rays can be deflected by a magnet, an other time not. Once a photographic plate can be exposed at a distance of over 30 meter through air without problems^[27], an other time this is only possible for close plates. Later TESLA recognized this parallel effects and has decided to proceed further with the particle ray model only which does not diminish with the $1/r$ law as known from electromagnetic radiations. This particle rays can be focused so that they are able to transmit large amounts of energy without losses^[63]. We can suppose that TESLA^[75] was able to make such transmissions with voltages of 4 million volts at his New York laboratory already in the year 1898.

Some phenomena of this TESLA experiments can be explained with today's knowledge. The main difficulty for a further analysis is the mixing in his original papers of the effects of electromagnetic waves and of the effects of particle beams. As long as not more information is available we only can speculate now which particles represent TESLA's *radiations*.

Which particles TESLA has generated and transmitted from one point to an other? When looking at his enormous voltages it is clear that TESLA has worked with some kind of a linear accelerator for electrical charges which was able to accelerate electrons up to energies of 2.4MeV. Later TESLA has worked with voltages of 10MV, what makes even higher electron energies possible. And if the particles are electrically charged, there is the next problem, then TESLA claimed, that the charge of such a particle is only a fraction of the elementary charge (of an electron). Beneath the quarks no elementary particles with a smaller charge than the elementary charges are known.

There has been the suggestions^{[72], [11]} that TESLA's *radiations* can be interpreted as neutrinos but also other particles are possible candidates for this *radiations*. Then neutrinos doesn't have an electrical charge and only a small rest mass (energy). Despite to the

fact that neutrinos do fit well to most characteristics of the radiations listed in the first section of this chapter it is not very likely that they constitute the main part of TESLA's *radiations*.

It is still not possible to say exactly how TESLA has found his statements about the corpuscular nature of the radiations. If, for example, we compare a statement TESLA's^[68] about the conservation of electrical charge, then it is also possible to interpret this statement in an other way. There TESLA has claimed that the electric charge is growing with increasing velocity and that the velocity of such charges easily can exceed the speed of light. The author^[73] has shown, that this view of TESLA can be interpreted from a conventional standpoint and that therefore this statement TESLA's should not be weighed to much.

And finally on one occasion TESLA^[62] describes the *radiations* similar to small ball lightning or, in modern words, as *high-density charge clusters* known from Kenneth SHOULDERS^[16].

It can be concluded from the above analysis the TESLA's *radiations* are particle rays consisting of minute charges and do not have many in common with an electromagnetic wave or photons. But this is all what can definitively be said about the nature of the *radiations*. Probably an other discipline of physics about the *cosmic rays*, which are very close connected to Tesla's radiations, can provide more information.

The Cosmic Rays

These *radiations* – which reach the Earth from all directions from outer space – are the fundament on which TESLA has founded his ideas for the utilization of a new and ecological energy source since the year 1900. Again TESLA was ahead of his time then only in 1912 Viktor Franz HESS^[7] has succeeded to prove to existence of cosmic rays with balloon experiments by rising balloons carrying electrometers in board on an altitude of about 17'500 feet and later up to 28'000 feet. For this investigations HESS has been nominated for Nobel price of physics in 1936. This is the third missed Nobel price for TESLA.

The source of this cosmic rays, as this rays are called today in science, are at least for its high energy constituents still in discussion^[5], the measuring methods too. The cosmic rays close to Earth are measured with balloons or satellites and with a more indirect method by the measurement of its secondary radiations in the atmosphere.

The composition of this cosmic rays is complex. In terms of numbers there predominate the photons and neutrinos as well as the lighter particles as electrons or positrons but also protons and alpha particles. But also much heavier nucleus as for example iron can be found. Outside of the Earth's atmosphere the particles of the cosmic rays travel close to the speed of light and therefore some of them have a very high kinetic energy. But still today it is not known in detail what is the cause for the propelling force which drives the cosmic rays.

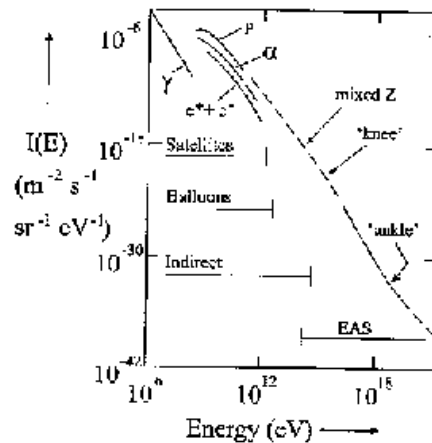


Figure 7: Energy spectra (intensity) of cosmic rays on measured Earth surface; from ERLYKIN A. D and A. W. WOLFENDALE, „The origin of cosmic rays“, *European Journal of Physics* **20** (1999) p410

The very high particles with much more kinetic energy than the main part of the cosmic rays can be seen clearly (please note the logarithmic scales in figure 7). The distribution of the different particles relative to the numbers of Silicium is shown in figure 8.

Now, due to the Earth's magnetic field the electrons are deflected far away from the Earth and do either pass the Earth or do come in more in the polar regions (aurora borealis). If the cosmic rays in outer space may be electrically neutral in average, as it is commonly suggested, then it is even possible that the heavier particles really reaching wide areas of the Earth (i.e. not polar areas) and there a net positive electrical charge can be measured in atmosphere.

This has been observed by TESLA^[66]. Therefore he suggested the sun and other stars are charged positively and they continuously emit positive charges into space. This charges are then absorbed by the relatively negative charged planets. According to TESLA^[65] the sun would have an electrical charge of $5.0 \cdot 10^{19}$ COULOMBS whereas the relative charge of the sun against the Earth is „only“ $216 \cdot 10^9$ COULOMB's. The question how he has determined this values he has never answered.

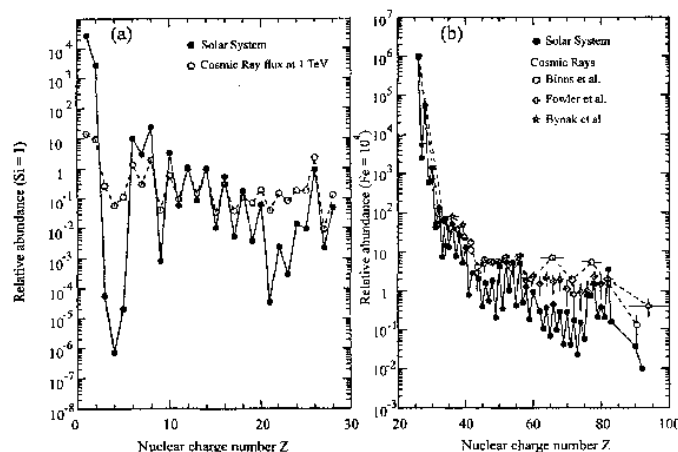


Figure 8: Relative distribution of the positive ions of cosmic rays on Earth's surface; from ERLYKIN A. D and A. W. WOLFENDALE, „The origin of cosmic rays“, *European Journal of Physics* **20** (1999) p411

Probably TESLA^[39] has determined this values with an experiment he reported in January 1901. Here he writes about a remarkable property of elevated ball capacitors. According to his publication the capacity increases with its height about ground with $\sim 0.5\%$ per feet. But this is not all. In addition it is possible to measure a seasonal and a daily variation of the capacity. The seasonal variation shows a maximum in summer and a minimum in winter and the daily variation has its maximum during night. With this experiments TESLA didn't measure the capacity C of the elevated sphere directly. He has always measured the resonance frequency of the sphere capacity together with his coil arrangement^{[36]-14.09.1899}. If he rised the sphere he has in turn needed to remove some windings of one of his coils to establish the same resonant frequency as before. The dependency of the capacity from the relative position to the sun is interesting. Because there are no more data available the author can only assume that TESLA has determined the charge of Earth and sun with this measurings.

TESLA's assumed the potential difference between sun and Earth (and also between the sun and other planets) is the cause for an electric current of positive particles. TESLA^[68] has then taken an analogy of this electric current through space to Earth with one of his patents^[19] about a lighting system with only one supplying wire. And according to his thoughts this energy should not fall on Earth without a technical use. Merely this cosmic particle rays should somehow be collected – for example with apparatus described in a patent^[41] – and infused to Earth through a transformer to obtain electrical energy to drive machinery.

Because of the ionizing characteristic of the incoming high energy proton radiation many decay by-products are built when the protons collide with gas molecules of the upper atmosphere. From this incoming rays the atmosphere is finally charged slightly positive whereas the Earth has a slightly (relative) negative charge. Because of this on the Earth surface there always are some free electrons available which play an important role in nature.

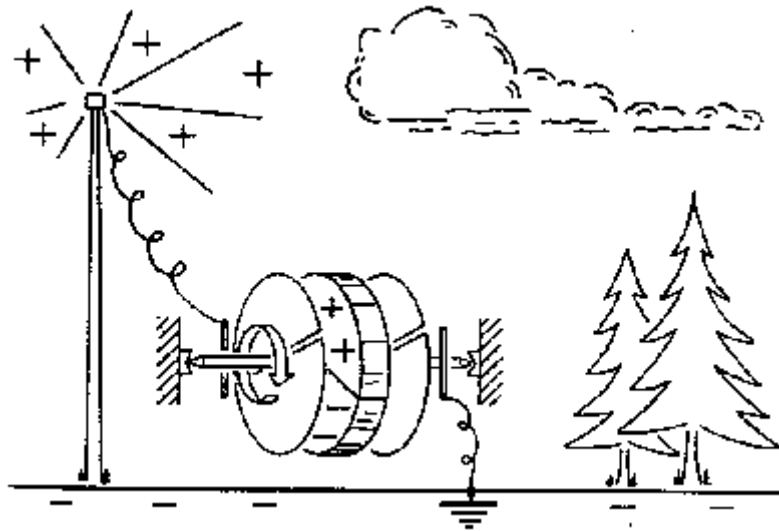


Figure 9: Driving an electrostatic motor wit the positive electric field of the atmosphere; from JEFIMENKO Oleg D., *American Journal of Physics* **39** (July 1971) p.777

With an abstract formulation the solar wind can be regarded as a superimposition of positive and negative direct currents from which a small fraction is available on Earth's surface. If we check this model with the method described in TESLA's patent^[42] to receive the radiations, it is clear, that with this solar wind alone not energy is available. Oleg

JEFIMENKO^[9] (figure 9) has shown with a particular rotating device that the simple collection of electrons in the near-Earth atmosphere can be done by using electretes (the electric analogy to the permanent magnet). With this rotating machine it was possible to draw the atmosphere's electrical energy directly into mechanical motion with a maximum power output of about 100 watts.

But a real analogy to TESLA's lighting patent^[19] is only given, when not the direct current feature of the solar wind is used, but instead a novel, not recognized and from TESLA^[68] postulated alternating current capability of the cosmic rays would be imagined. Then not the transport of charges to Earth itself is important but merely their longitudinal oscillations between sun and Earth. Then in analogy to TESLA's patent^[19] the solar wind is considered as the required oscillating medium (air). This now would be a real longitudinal wave consisting of oscillating charges.

Then the primary force does not act with a constant push but as an alternating source. About the frequency of this oscillation TESLA didn't not give further information. Shortly before his death he has made the following statement^[68]: *»The effects at great elevations are due to waves of extremely small lengths produced by the sun in a certain region of the atmosphere. This is the discovery I wish to make known.«* Today we know that the atmosphere has two 'windows' which can be passed well by electromagnetic radiation. The best known window lies in the range of the visible light and encloses a side window which covers a part of the infrared spectra. The second window lies in the short wave and ultra-short wave frequency range of 3MHz up to 3GHz. According to the patent^[38] TESLA's experiments in Colorado Springs has also been executed with frequencies of about 5MHz. This is just in the second window. But this is only a weak declaration then the searched longitudinal waves could also use other windows not suitable for electromagnetic radiation. For the search of the frequency one statement may be of interest, then TESLA^[61] mentioned that in the year 1900 – this is during the experiments in Colorado Springs – he has worked with wave lengths of one or two millimeters which corresponds to an average frequency of about 300GHz.

If such longitudinal waves between the celestial bodies really exists then every planet would be in contact with other planets and with other stars with this waves. Such a model is compliant with some older models of natural science – for example with astrology – but is not known in today's science. On the other hand the author does not know any measurements on the cosmic rays where superimposed high frequency oscillations have been searched.

Primary and Secondary Cosmic Rays

TESLA^[61] explains his model about the cosmic rays in two steps. If the primary rays collide with particles and atoms in space in-between sun and Earth a secondary radiation is created. According to Tesla this unknown primary rays are the cause of the ordinary cosmic rays for example reported by BOTHE and KOHLHÖRSTER^[2]. In addition TESLA^[61] says that this primary rays are the cause of radioactivity.

Accordingly the candidates for this arriving cosmic rays are high energy positively charged ions and atom nucleus which then causes the secondary radiation observed close to Earth's surface. The cause for this high energy cosmic rays is not known exactly still today. FRIEDLANDER^[6] for example describes the wide uncertainty as follows: *»No model yet satisfactorily encompasses all of our knowledge. The changing views of partisans in this long-running debate provide a fascinating insight into the swings of fashion and consensus. What I outline here is the model that now has wide support; it provides a framework within which to plan further observations and to judge the significance of each piece of evidence. ... Supernovas are now generally considered to be the best candidates for Cosmic Ray sources, either directly or indirectly. The evidence is circumstantial but persuasive, comprehensive but not yet compelling.«*

And still today in the year 2000 the source of this high energy rays is not known better. Some time ago there has been popped up the idea^{[72],[11]} that TESLA's described characteristics of the radiations could be covered completely with the neutrino. The propelling force of the cosmic particle rays can at least partly be explained with interactions with also emitted neutrinos. This could help to explain the cause of the cosmic particle acceleration. Then in terms of TESLA the neutrinos could be the energy source (primary rays) of the steady accelerated particles (secondary rays). According to actual models^[10] the energy radiated away by the sun consists of about 97% of photons and particles. The remaining three percent are radiated with the kinetic energy of neutrinos. But actually only 50..70% of the expected neutrinos seems to reach the Earth^[10], the others get somehow "lost" during their journey through space.

With a world-wide great effort the neutrino flux through Earth is measured with different detectors since over thirty years. If we now imagine that they interact with other matter in space during their flight and gives off more and of their kinetic energy away to this matter, it can probably be explained why on Earth less neutrinos are detected than expected by physical models. At least in a qualitative way the problem of missing solar neutrinos can be explained with the absorption of cosmic particles.

In this way the neutrinos may deliver a part of the propelling energy to the high energy cosmic rays, which has traveled a long way until they reach the Earth. A direct coupling to this neutrino flux seems to be a theoretical possibility to tap a new source of energy^{[72],[11]}, but this is extremely difficult to do with the technology available today. And because it is expected that the neutrino flux represents only about 3% of the total solar energy output, they stand not in first line as candidates for tapping the cosmic rays.

Longitudinal Wave Coupling to the Cosmic Rays

A coupling on the herein postulated longitudinal oscillations of the cosmic rays could rather be done than a coupling to the neutrino flux. And probably it was this what TESLA^[50] intended to do with his project "*Magnifying Transmitter*" in Wardencliffe.

To sum it up it can be said the following assumption: If TESLA speaks of electric longitudinal waves similar to sound waves then he really means a longitudinal oscillation of charged particles, which are the transport medium for energy transmission. At least this is the case with his experiments about a conductor-less (wireless) transmission of energy^[37] or of the system of electric lighting^[19] using only a one-wire supply. In all these cases the involved charges of the Earth, the atmosphere or even in his partly evacuated tubes oscillate in a longitudinal direction. Therefore not a new longitudinal electric field with a high range must be searched but merely longitudinal forces with a short range, namely to reach the next charge. So each receiving charge in turn becomes to a transmitting charge (similar to HUYGEN's principle^[8] of wave propagation in a medium). In opposite to the models of radio wave technology over large distances a TESLA wave needs matter (i.e. charges) for an optimal expansion. Therefore in an absolute vacuum no longitudinal waves are possible, or the range of this wave becomes very short. And this oscillating matter for TESLA's longitudinal waves are the cosmic rays itself.

The formula of a longitudinal effect of a moving and accelerating charge on an other free charge are known^{[73],[74]}. This effect diminishes with a spherical radiation if there are no more charges in-between. But if it is somehow arranged that the longitudinal oscillations are aligned and focussed in a certain direction the whole energy of the transmitter oscillations is transported to a receiver without mayor losses and without diminishing with the distance. If TESLA^{[62],[63]} intended to drive his death rays^[69] with such longitudinal waves is not known for certain.

On this point a new consideration of figure 2 and 3 can be done. It can be imagined that TESLA didn't only collect the static available charges of the atmosphere and draws them through a linear load as for example done by JEFIMENKO. He has operated his

radiations receiver as an oscillator with interrupter circuitry. And if one is only interested to collect free charges one does not continuously break the (direct) current flow. This alternating oscillation induction in the receiver does only make sense if one is interested in resonance coupling!

A coupling to a new and clean cosmic energy source, as TESLA^{[18],[20]} has mentioned over decades, means a coupling to the hypothetical longitudinal oscillations of the cosmic rays which reach the Earth day and night from all directions. If this oscillations really exists is not known. But if they exist, then the author is convinced, that they can be used to tap a new energy source on Earth as well as in outer space. Only with detailed and strongly focussed measurement on Earth (or in space) more information can be obtained about the feasibility of TESLA's visions.

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Appendix: Chronological Selection of important Statements of Nikola TESLA about *Radiations* and *Cosmic Rays*

It may be helpful for the reader, if he does not have to search all the referenced publications and quotations of TESLA with troublesome work. For this a condensed selection of important original passages of his publications are reprinted here. They are not complete but the author hopes they may animate the reader to read more original papers of TESLA. Then, the reader will soon recognize that some texts do correspond, some not. This is the reason why an exact interpretation and translation into today's knowledge is very difficult.

§1 20. Mai 1891^[18]: » *We are whirling through endless space, with an inconceivable speed, all around us everything is spinning, everything is moving, everywhere there is energy. There must be some way of availing ourselves of this energy more directly. Then, with the light obtained from the medium, with the power derived from it, with every form of energy obtained without effort, from the store forever inexhaustible, humanity will advance with giant strides. The mere contemplation of these magnificent possibilities expands our minds, strengthens our hopes and fills our hearts with supreme delight.*«

§2 03/04 February 1892^[20]: »*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.*«

§3 18 March 1896^[22]: »*“I state this merely for the sake of correctness of my communication, but, as far as the general truth of the fact of taking such a shadow at the distance given is concerned, your caption might as well stand, for I am producing strong shadows at distances of 40 feet. I repeat, 40 feet and even more. Nor is this all. So strong are the actions on the film that provisions must be made to guard the plates in my photographic department, located on the floor above, a distance of fully 60 feet, from being spoiled by long exposure to the stray rays.” ... »We have to deal here, evidently, with a radiation of astonishing power, and the inquiry into its nature becomes more and more interesting and important.*« ... »*In my attempts to contribute my humble share to the knowledge of the Roentgen phenomena, I am finding more and more evidence in support of the theory of moving material particles. It is not my intention, however, to advance at present any view as to the bearing of such a fact upon the present theory of light, but I merely seek to establish the fact of the existence of such material streams in so far as these isolated effects are concerned. I have already a great many indications of a bombardment occurring outside of the bulb, and I am arranging some crucial test which, I hope, will be successful. The calculated velocities fully account for actions at distances of as much as 100 feet from the bulb, and that the projection through the glass takes place seems evident from the process of exhaustion, which I have described in my previous communication. An experiment which is illustrative in this respect, and which I intended to mention, is the following: If we attach a fairly exhausted bulb containing an electrode to the terminal of a disruptive coil, we observe small streamers breaking through the side of the glass. Usually such a streamer will break*

through the seal and crack the bulb, whereupon the vacuum is impaired; but, if the seal is placed above the terminal, or if some other provision is made to prevent the streamer from passing through the glass at that point, it often occurs that the stream breaks out through the side of the bulb, producing a fine hole. Now, the extraordinary thing is that, in spite of the connection to the outer atmosphere, the air can not rush into the bulb as long as the hole is very small. The glass at the place where the rupture has occurred may grow very hot – so such a degree to soften; but it will not collapse, but rather bulge out, showing that a pressure from the inside greater than that of the atmosphere exists. On frequent occasions I have observed that the glass bulges out and the hole, through which the streamer rushes out, becomes so large as to be perfectly discernible to the eye. As the matter is expelled from the bulb the rarefaction increases and the streamer becomes less and less intense, whereupon the glass closes again, hermetically sealing the opening. The process of rarefaction, nevertheless, continues, streamers being still visible on the heated place until the highest degree of exhaustion is reached, whereupon they may disappear. Here, then, we have a positive evidence that matter is being expelled through the walls of the glass.«

§4 22 April 1896^[25]: *»...we shall be justified to draw the following conclusions: first, the highly exhausted bulb emits material streams which, impinging on a metallic surface, are reflected; second, these streams are formed of matter in some primary or elementary condition; third, these material stream are probably the same agent which is the cause of the electromotive tension between metals in close proximity or actual contact, and they may possibly, to some extent, determine the energy of combination of the metals with oxygen; fourth, every metal or conductor is more or less a source of such streams; fifth, these streams or radiations must be produced by some radiations which exist in the medium; and sixth, streams resembling the cathodic must be emitted by the sun and probably also by other sources of radiant energy, such as an arc light or Bunsen burner.«*

§5 March 1897^[29]: *»But we shall not satisfy ourselves simply with improving steam and explosive engines or inventing new batteries; we have something much better to work for, a greater task to fulfill. We have to evolve means for obtaining energy from stores which are forever inexhaustible, to perfect methods which do not imply consumption and waste of any material whatever. Upon this great possibility, upon this great problem, the practical solution of which means so much for humanity, I have myself concentrated my efforts for a number of years, and a few happy ideas which came to me have inspired me to attempt the most difficult, and given me strength and courage in adversity. Nearly six years ago my confidence had become strong enough to prompt me to an expression of hope in the ultimate solution of this all-dominating problem. I have made progress since, and have passed the stage of mere conviction such as is derived from a diligent study of known facts, conclusions and calculations. I now feel sure that the realization of that idea is not far off. But precisely for this reason I feel impelled to point out here an important fact, which I hope will be remembered.«*

§6 14 April 1897^[31]: Mr. Tesla stated, that he had also succeeded in deflecting the Roentgen rays by a magnet. He had proved this by deflecting the rays into a condenser placed a long distance from the source of the rays, and which in 5 seconds was charged sufficiently to throw a galvanometer needle off the scale.

§7 14 April 1897^[32]: Mr. Tesla announced two important discoveries relating to the Roentgen rays. First, he said he had discovered a new and powerful source of the rays in an electric arc formed under peculiar conditions. The second discovery was the deflection of the Roentgen rays by means of a magnet. This

discovery is particularly important in establishing the identity of the Roentgen rays, and those discovered by Lenard in 1891, and is, therefore, one of the most valuable contributions to our knowledge of these rays. ... To a few interested scientific men Mr. Tesla showed a great number of diagrams illustrating experiments he had performed which tended to prove the correctness of the views he holds in regard to the Roentgen phenomena being caused by material particles projected with great velocity.

§8 05 May 1987^[33]: *»We have absolute experimental evidence that particles or rays, to express myself generally, convey an immense amount of electricity, and I have even found a way of how to estimate and measure that amount.«.*

§9 11 August 1897^[34]: *“I did, however, on that occasion [6. April 1897 vor der New York Academy of Science, Anm. d. Autors] illustrate and describe experiments in which was shown the deflectibility of the Roentgen rays by a magnet, which establishes a still closer relationship, if not identity of the rays named after these two discoverers.”*

§10 30 November 1898^[35]: *»As to the idea of rendering the energy of the sun available for industrial purposes, it fascinated me early but I must admit it was only long after I discovered the rotating magnetic field that it took a firm hold upon my mind. In assailing the problem I found two possible ways of solving it. Either power was to be developed on the spot by converting the energy of the sun's radiations or the energy of vast reservoirs was to be transmitted economically to any distance. Though there were other possible sources of economical power, only the two solutions mentioned offer the ideal feature of power being obtained without any consumption of material. After long thought I finally arrived at two solutions, but on the first of these, namely, that referring to the development of power in any locality from the sun's radiations, I can not dwell at present.« ... »I, namely, at once observed that the air, which is a perfect insulator for currents produced by ordinary apparatus, was easily traversed by currents furnished by my improved machine, giving a tension of something like 2,500,000 volts. A further investigation in this direction led to another valuable fact; namely, that the conductivity of the air for these currents increased very rapidly with its degree of rarefaction, and at once the transmission of energy through the upper strata of air, which, without such results as I have obtained, would be nothing more than a dream became easily realizable. This appears all the more certain, as I found it quite practicable to transmit, under conditions such as exist in highest well explored, electrical energy in large amounts.«*

§11 30 January 1901^[39]: *Ever since everything has been known about electricity, scientific men have taken for granted that the capacity of an electrical conductor is constant. When Tesla was experimenting in Colorado Springs he found out that this capacity is not constant – but variable. ... »The capacity is increased as the conducting surface was elevated, in open space, from one-half to three-quarters of 1 per cent per foot of elevation. In buildings, however, or near large structures, this increase often amounted to 50 per cent per foot of elevation. ... Far more interesting, however, for men of science is the fact I observed later, that the capacity undergoes an annual variation with a maximum in summer, and a minimum in Winter. ... Furthermore I observed that there was a diurnal variation with a maximum during the night. Further, I found that sunlight causes a slight increase in capacity. The moon also produces an effect, but I do not attribute it to its light. ... I find that this variation of the capacity and consequently of the vibration period is evidently dependent, first, on the absolute height above sea level, though in a smaller degree; second, on the relative height of the conducting surface or capacity with respect to*

the bodies surrounding it; third, on the distance of the earth from the sun, and fourth, on the relative change of the circuit with respect to the sun, caused by the diurnal rotation of the earth.»

§12 02 February 1901^[40]: *«The process of light production is, according to my views, as follows: The street current is passed through a machine which is an electrical oscillator of peculiar construction and transforms the supply current, be it direct or alternating, into electrical oscillations of very high frequency. These oscillations, coming to the metallic-coated ends of the glass tube, produce in the interior corresponding electrical oscillations, which set the molecules and atoms of the inclosed rarefied gases into violent commotion, causing them to vibrate at enormous rates and emit those radiations which we know as light. The gases are not rendered incandescent in the ordinary sense, for if it were so, they would be hot, like an incandescent filament. As a matter of fact, there is very little heat noticeable, which speaks well for the economy of the light, since all heat would be loss.» ... »It is a remarkable feature of the light that during the day it can scarcely be seen, whereas at night the whole room is brilliantly illuminated. When the eye becomes used to the light of these tubes, an ordinary incandescent lamp or gas burner produces a violent pain in the eye when it is turned on, showing in a striking manner to what a degree these concentrated sources of light which we now use are detrimental to the eye. I have found that in almost all its actions the light produces the same effects as sunlight, and this makes me hopeful that its introduction into dwellings will have the effect of improving, in a measure now impossible to estimate, the hygienic conditions. Since sunlight is a very powerful curative agent, and since this light makes it possible to have sunlight, so to speak, of any desired intensity, day and night in our homes, it stands to reason that the development of germs will be checked and many disease, as consumption, for instance, successfully combated by continually exposing the patients to the rays of these lamps.»*

§13 21 March 1901: *«The sun, as well as other sources of radiant energy throw off minute particles of matter positively electrified, which, impinging upon the upper plate, communicate continuously an electrical charge to the same. The opposite terminal of the condenser being connected to ground, which may be considered as a vast reservoir of negative electricity, a feeble current flows continuously into the condenser and inasmuch as the particles are charged to a very high potential, this charging of the condenser may continue, as I have actually observed, almost indefinitely, even to the point of rupturing the dielectric. «*

§14 07 January 1905^[43]: *«This invention, which I have described in technical publications, attempts to initiate, in a very crude way, the nervous system in the human body.» ... »That electrical energy can be economically transmitted without wires to any terrestrial distance, I have unmistakably established in numerous observations, experiments and measurements, qualitative and quantitative. These have demonstrated that it is practicable to distribute power from a central plant in unlimited amounts, with loss not exceeding a small fraction of one per cent in the transmission, even to the greatest distance, twelve thousands miles – to the opposite end of the globe. This seemingly impossible feat can now be readily performed by any electrician familiar with the design and construction of my “high-potential magnifying transmitter”, the most marvelous electrical apparatus of which I have knowledge, enabling the production of effects of unlimited intensities in the earth and its ambient atmosphere. « ... »But the fact, that stationary waves are producible in the earth is of special and, in many ways, still greater significance in the intellectual development of humanity. Popularly explained, such a wave is a phenomenon generically akin to an echo – a result of reflection. It affords a positive and uncontrollable experimental evidence that the electric current, after passing into the earth*

travels to the diametrically opposite region of the same and rebounding from there, returns to its point of departure with virtually undiminished force. The outgoing and returning currents clash and form nodes and loops similar to those observable on a vibrating chord.«

§15 19 May 1907^[44]: *»It would not be difficult to convey to one of our liners, say, 50'000 horsepower from a plant located at Niagara, Victoria or other waterfall, absolutely irrespective of location. In fact, there would not be a difference of more than a small fraction of one per cent, whether the source of energy be in the vicinity of the vessel or 12'000 miles away, at the antipodes.«*

§16 21 April 1908^[45]: *»According to an adopted theory, every ponderable atom is differentiated from a tenuous fluid, filling all space merely by spinning motion, as a whirl of water in a calm lake. By being set in movement this fluid, the ether, becomes gross matter. Its movement arrested, the primary substance reverts to its normal state. It appears, then, possible for man through harnessed energy of the medium and suitable agencies for starting and stopping ether whirls to cause matter to form and disappear.«*

§17 18 May 1917^[46]: *»Years ago I was in the position to transmit wireless power to any distance without limit other than that imposed by the physical dimensions of the globe. In my system it makes no difference what the distance is. The efficiency of the transmission can be as high as 96 or 97 per cent, and there are practically no losses except such as are inevitable in the running of the machinery. When there is no receiver there is no energy consumption anywhere. When the receiver is put on, it draws power. That is the exact opposite of the Hertz-wave system. In that case, if you have a plant of 1,000 horsepower, it is radiating all the time whether the energy is received or not; but in my system no power is lost.«*

§18 August 1917^[47]: *»At the time of those test I succeeded in producing the most powerful X-rays ever seen. I could stand at a distance of 100 feet from X-ray apparatus and see the bones of the hand clearly wit the aid of a fluoroscope screen; and I could have easily seen them at a distance several times this by utilizing suitable power. In fact, I could not then produce X-ray generators to handle even a small fraction of the power I had available. But I now have apparatus designed whereby this tremendous energy of hundreds of kilowatts can be successfully transformed into X-rays.«*

§19 February 1919^[48]: *»In the summer of 1897 Lord Kelvin happened to pass through New York and honored me by a visit to my laboratory where I entertained him with demonstrations in support of my wireless theory. He was fairly carried away with what he saw but, nevertheless, condemned my project in emphatic terms, qualifying it as something impossible, ' an illusion and a snare'. I had expected his approval and was pained and surprised. But the next day he returned and gave me a better opportunity for explanation of the advances I had made and of the true principles underlying the system I had evolved. Suddenly he remarked with evident astonishment: 'Then you are not making use of Hertz waves?' Certainly not, I replied, these are radiations. No energy could be economically transmitted to a distance by any such agencies. In my system the process is one of true conduction which, theoretically, can be effected at the greatest distance without appreciable loss.«*

§20 June 1919^[50]: *»In a more restricted meaning this wireless transmitter is one in which the Hertz-wave radiation is an entirely negligible quantity as compared with the whole energy, under which condition the damping factor is extremely small and an enormous charge is stored in the elevated capacity. Such a circuit may*

then be excited with impulses of any kind, even of low frequency and it will yield sinusoidal and continuous oscillations like those of an alternator. Taken in the narrowest significance of the term, however, it is a resonant transformer which, besides possessing these qualities, is accurately proportioned to fit the globe and its electrical constants and properties, by virtue of which design it becomes highly efficient and effective in the wireless transmission of energy. Distance is absolutely eliminated, there being no diminution in the intensity of the transmitted impulses. It is even possible to make the actions increase with the distance from the plant according to an exact mathematical law.« ... »On this occasion I would contradict the widely circulated report that the structure was demolished by the Government which owing to war conditions.« ... »I would add further, in view of various rumors which have reached me, that Mr. J. Pierpont Morgan did not interest himself with me in a business way but in the same large spirit in which he has assisted many other pioneers. He carried out his generous promise to the letter and it would have been most unreasonable to expect from him anything more.« ... »My project was retarded by laws of nature. The world was not prepared for it. It was too far ahead of time. But the same laws will prevail in the end and make it a triumphal success.«

§21 25 February 1923^[51]: *»I had perfected a wireless receiver of extraordinary sensitiveness, far beyond anything known, and I caught signals with I interpreted as meaning 1—2—3—4.«*

§22 16 October 1927^[52]: *»Notwithstanding my repeated explanations experts do not seem to realize that no concentration of energy such as I attain in my wireless power system can or will ever be achieved through the instrumentality of reflectors, for in transmitting energy in this manner the receiver can collect only an amount proportionate to the area exposed to the rays, while in my system it draws the energy from an immense reservoir in ever so much greater quantity.«*

§23 22 September 1929^[53]: *»Up to 1896, however, I did not succeed in obtaining a positive experimental proof of the existence of such a medium. But in that year I brought out a new form of vacuum tube capable of being charged to any desired potential, and operated it with effective pressures of about 4,000,000 volts. I produced cathodic and other rays of transcending intensity. The effects, according to my view, were due to minute particles of matter carrying enormous electrical charges, which, for want of a better name, I designated as matter not further decomposable. Subsequently those particles were called electrons.«*

§24 April 1930^[54]: He holds that radio-activity is due, not to forces in the substances themselves, but to a cosmic ray, the discovery of which he announced in 1897. In other words, an element like Radium emits radiations merely because the cosmic ray impinges upon it, producing these secondary effects. The element itself has no such energy, it all comes from the cosmic ray. Tesla says, that he has proved the existence of this rays by mathematical analysis and experiment, finding both in perfect agreement. It would seem to follow, from Tesla's theory, that the radiation from radium, or similar bodies, would change from place to place on the globe; and this has recently proved to be an actual fact, as determined by a Russian investigator. Tesla assured the writer in a recent interview, that through a new discovery he has perfected rays of tremendous power, penetrating through miles of solid substances, will become available shortly, by the use of his high potential cathode tube, without a target.

§25 July 1931: *Time*, pp27-28: *»I'm working to develop a new source of power. When I say a new source, I mean that I have turned for power to a source which no previous scientist has turned, to the best of my knowledge. The conception, the idea when it first burst upon me was a tremendous shock. It will throw light on*

many puzzling phenomena of the cosmos, and may prove also of great industrial value, particularly in creating a new and virtually unlimited market for steel.« Tesla said it will come from an entirely new and unsuspected source, and will be for all practical purposes constant day and night, and at all times of the year.

§26 07. November 1931^[55]: Tesla disagreed with the part of the Einstein Theory which states that the mass of an object increases with its speed. The mass of a body is unalterable, contended Dr. Tesla, according to the article, *»otherwise energy could be produced from nothing, since the kinetic energy acquired in the fall of a body would be greater than that necessary to lift it at a small velocity.*«

§27 December 1931^[56]: *»It was clear to me many years ago that a new and better source of power had to be discovered to meet the ever increasing demands of mankind. In a lecture delivered before the American Institute of Electrical Engineers at Columbia University May 20, 1891, I said: "We are whirling through endless space with inconceivable speed, all around us everything is spinning, everything is moving, everywhere is energy. There must be some way of availing ourselves of this energy more directly. Then, with the light obtained from the medium, with the power delivered from it, with every form of energy obtained without effort, from the store forever inexhaustible humanity will advance with giant strides." I have thought and worked with this object in view unremittingly and am glad to say that I have sufficient theoretical and experimental evidence, that my efforts of years will be rewarded and that we shall have at our disposal a new source of power, superior to the hydro-electric, which may be obtained by means of simple apparatus everywhere and in almost constant and unlimited amount.*«

§28 06 February 1932^[57]: *»When radioactivity was discovered, it was thought to be an entirely new manifestation of energy limited to a few substances. I obtained sufficient evidence to convince me that such actions were general and in nature the same as those exhibited by my tubes. In these, minute corpuscles, regarding which we are still in doubt, are shot from a highly electrified terminal against a target where they generate Roentgen or other rays by impact. Now, according to my theory, a radioactive body is simply a target which is continuously bombarded by infinitesimal bullets projected from all parts of the universe, and if this, then unknown, cosmic radiation could be wholly intercepted, radioactivity would cease. I made some progress in solving the mystery until in 1899 I obtained mathematical and experimental proofs that the sun and other heavenly bodies similarly conditioned emit rays of great energy which consist of inconceivably small particles animated by velocities vastly exceeding that of light. So great is the penetrative power of these rays that they can traverse thousands of miles of solid matter with but slight diminution of velocity. In passing through space, which is filled with cosmic dust, they generated a secondary radiation of constant intensity, day and night, and pouring upon the earth equally from all directions. As the primary rays projected from the suns and stars can pass through distances measured in light-years without great diminution of velocity, it follows that whether a secondary ray is generated near a sun or at any distance from it, however great, its intensity is the same. Consequently, if our sun, or any other, would be snuffed out of existence, it would have no appreciable effect on the secondary radiation. The latter is not very penetrative and is partly absorbed by the atmosphere. According to my determinations, its intensity beyond the atmosphere is about 50 per cent greater than at sea level. The whole atmosphere being equivalent to about 36 inches of lead, it is easy to determine the intensity of this radiation by making a measurement of the penetration at any known altitude. This theory is borne out strictly in experiments with my vacuum tubes, but even if I did not have such proofs I would consider it plausible.*«

§29 10 July 1932^[58]: *»I have harnessed the cosmic rays and caused them to operate a motive device«,* declared Nikola Tesla, famous scientist, in an interview last evening on the eve of his 76th birthday. *»Cosmic ray investigation is a subject that is very close to me. I was the first to discover these rays and I naturally feel toward them as I would toward my own flesh and blood.«,* said Dr. Tesla. ... Dr. Tesla stated that the amount of power he was able to develop in the device was insignificant. I asked him if its power output was of the same magnitude as that of Crookes' radiometer, the device with four vanes in a glass tube that are rotated by sunlight, and which is often seen in jewelers' windows. He stated that the power output was many thousand times that of a Crookes' radiometer. *»The attractive features of the Cosmic rays is their constancy. They shower down on us throughout the whole 24 hours, and if a plant is developed to use their power it will not require devices for storing energy as would be necessary with devices using wind, tide or sunlight. All of my investigations seem to point to the conclusion that they are small particles, each carrying so small a charge that we are justified in calling them neutrons. They move with great velocity, exceeding that of light. More than 25 years ago I began my efforts to harness the cosmic rays and I can now state that I have succeeded in operating a motive device by means of them.«* I was able to prevail upon Dr. Tesla to give me some idea of the principle upon which his cosmic ray motor works. *»I will tell you in the most general way«,* he said. *»The cosmic ray ionizes the air, setting free many charges – ions and electrons. These charges are captured in a condenser which is made to discharge through the circuit of the motor.«*

§30 10 September 1933^[59]: *»My first and most important discovery concerns the harnessing of a new source of power, hitherto unavailable, to be developed through fundamentally novel machines of my invention. ... My power generator will be of the simplest kind – just a big mass of steel, copper and aluminum, comprising a stationary and rotating part, peculiarly assembled. ... Such a source of power obtainable everywhere will solve many problems with which the human race is confronted.«*

§31 02 November 1933^[60]: A principle by which power for driving the machinery of the world may be derived from the cosmic energy which operates the universe, has been discovered by Nikola Tesla, noted physicist and inventor of scientific devices, he announced today. 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, he said. ... The central source of cosmic energy for the earth is the sun, Dr. Tesla said, but *»night will not interrupt the flow of the new power supply«.*

§32 July 1934^[61]: *»Some years ago I urged the experts engaged in the commercial application of the wireless art to employ very short waves, but for a long time my suggestions were not heeded. Eventually, though, this was done, and gradually the wave lengths were reduced to but a few meters. Invariably it was found that these waves, just as those in the air, follow the curvature of the earth and bend around obstacles, a peculiarity exhibited to a much lesser degree by transverse vibrations in a solid. Recently, however, ultra-short waves have been experimented with and the fact that they also have the same property was hailed as a great discovery, offering the stupendous promise of making wireless transmission infinitely simpler and cheaper. It is of interest to know what wireless experts have expected, knowing that waves a few meters long are transmitted clear to antipodes. Is there any reason that they should behave radically different when their length is reduced to about half of one meter? As the knowledge of this subject seems very limited, I*

may state that even waves one or two millimeters long, which I produced thirty-four years ago, provided that they carry sufficient energy, can be transmitted around the globe. This is not so much due to refraction and reflection as to the properties of a gaseous medium and certain peculiar action.« ... »I have disintegrated atoms in my experiments with a high potential vacuum tube I brought out in 1896 which I consider one of my best inventions. I have operated it with pressures ranging from 4,000,000 to 18,000,000 volts. More recently I have designed an apparatus for 50,000,000 volts which should produce many results of general scientific importance.« ... »And as for the cosmic ray: I called attention to this radiation while investigating Roentgen rays and radioactivity. In 1899 I erected a broadcasting plant at Colorado Springs, the first and only wireless plant in existence at that time, and there confirmed my theory by actual observation.« ... »I have satisfied myself that the rays are not generated by the formation of new matter in space, a process which would be like water running up hill. According to my observations, they come from all the suns of the universe and in such abundance that the part contributed to our sun is very insignificant by percentage. Some of these rays are of such terrific power that they can traverse through thousands of miles of solid matter. They have, furthermore, other extraordinary properties. This ray, which I call the primary solar ray, gives rise to a secondary radiation by impact against the air and the cosmic dust scattered through space. It is now commonly called the cosmic ray, and comes, of course, equally from all directions in space. If radium could be screened effectively against this ray it would cease to be radioactive.«

§33 11 July 1934^[62]: The beam of force itself, as Dr. Tesla described it, is a concentrated current – it need be no thicker than a pencil – of microscopic particles moving at several hundred times the speed of artillery projectiles. The machine into which Dr. Tesla combines his four devices is, in reality, a sort of electrical gun. He illustrated the sort of thing that the particles will be by recalling an incident that occurred often enough when he was experimenting with a cathode tube. Then, sometimes, a particle larger than an electron, but still very tiny, would break off from the cathode, pass out of the tube and hit him. He said he could feel a sharp, stinging pain where it entered his body, and again at the place where it passed out. The particles in the beam of force, ammunition which the operators of the generating machine will have to supply, will travel far faster than such particles as broke off from the cathode, and they will travel in concentrations, he said. ... Such beams or rays of particles now known to science are composed always of fragments of atoms, whereas, according to Dr. Tesla, his would be of microscopic dust of a suitable sort. The chief differentiation between his and the present rays would appear to be, however, that his are produced in free air instead of in a vacuum tube. The vacuum tube rays have been projected out into the air, but there they travel only a few inches, and they are capable only of causing burns or slight disintegration of objects which they strike. ... He had, he said, detected *»certain motions in the medium that fills space, and measured the effects of this motions«*. The results of the experiments had led his *»inescapably«* to the conclusion that such bodies as the sun are taking on mass more rapidly than they are dissipating it by the dissipation of energy in heat and light. He pointed out that his theory means a future for the earth as different from the general belief as the future of the sun. It is generally held that life on the earth will cease when the sun grows so cold that the earth temperature drops to a point where life can no longer be supported. Dr. Tesla prophesies that life on the earth will cease because the planet will grow too warm to support life, and he believes that life will then begin on outer planets now too cold.

§34 February 1935^[63]: *»I want to state explicitly that this invention of mine does not contemplate the use of any so-called ‘death rays’. Rays are not applicable because they cannot be produced in requisite quantities and diminish rapidly in*

intensity with distance. All the energy of New York City (approximately two million horsepower) transformed into rays and projected twenty miles, could not kill a human being, because, according to a well known law of physics, it would disperse to such an extent as to be ineffectual. My apparatus projects particles which may be relatively large or of microscopic dimensions, enabling us to convey to a small area at a great distance trillions of times more energy than is possible with rays of any kind. Many thousands of horsepower can thus be transmitted by a stream thinner than a hair, so that nothing can resist. This wonderful feature will make it possible, among other things, to achieve undreamed-of results in television, for there will be almost no limit to the intensity of illumination, the size of a picture, or distance projection.»

§35 03 March 1935^[64]: *»There exists, however, an element of incertitude which in itself is sufficient to invalidate completely the results obtained and of which Dr. Kolhoerster[†] does not seem to have thought. Light is a wave motion of definite velocity, determined by the elastic force and density of the medium. Cosmic rays are particles of matter, the speed of which depends on the propelling force and mass and may be much smaller or greater than that of light. Consequently, there can be no concordance in the phases of the two disturbances at the place of observation. The cosmic rays, generated during the maximum brightness of the star, may reach the place many centuries sooner or later than the light, according to their speed.«*

§36 11 July 1935^[65]: *Cosmic rays, he asserted, he found are produced by the force of »electrostatic repulsion«; they consist of powerfully charged positive particles which come to us from the sun and other suns in the universe. He determined, »after experimentation«, he added, that the sun is charged »with an electric potential of approximately 215,000,000,000 volts, while the electric charge stored in the sun amounted to approximately 50,000,000,000,000,000 electrostatic units.«*

§37 18 August 1935^[66]: *»Condensation of the primary substance is going on continuously, this being in a measure proved, for I have established by experiments which admit of no doubt that the sun and other celestial bodies steadily increase in mass and energy and ultimately must explode, reverting to the primary substance. ...I finally ascertained with a reasonable degree of certitude, and to my amazement, that the sun was at a constant positive potential of about 216,000,000,000 volts. Thus the secret of the cosmic rays was revealed. Owing to its immense charge, the sun imparts to minute positively electrified particles prodigious velocities which are governed only by the ratio between the quantity of free electricity carried by the particles and their mass, some attaining a speed exceeding fifty times that of light.« ... »The greatest mistake is made in the appraisal of the energy of cosmic rays. In most cases the ionizing action is used as a criterion, which is useless, for the most powerful cosmic rays virtually do not ionize at all and leave no trace of their passage through the instrument. I have resorted to different means and methods and have found that the energy of the cosmic radiations impinging upon the earth from all sides is stupendous, such that if all of it were converted into heat the globe quickly would be melted and volatilized. Since expressing, in 1896, my ideas on the origin and character of cosmic rays and of the cause of radioactivity, all my views have been confirmed by my own findings and those others, while numerous theories advanced have been proved false or inadequate.«*

[†] TESLA probably points to the references below:

KOLHÖRSTER W, *Physikalische Zeitschrift* **26** (1925) 654

BOTHE W. und KOLHÖRSTER W. „Das Wesen der Höhenstrahlung“, *Zeitschrift für Physik* **56** (1929) 751-777

§38 12 July 1937^[67]: *»My most important invention from a practical point of view is a new form of tube with apparatus for its operation. In 1896 I brought out a high potential targetless tube which I operated successfully with potentials up to 4 million volts from '96 to '98.« ... »At a later period I managed to produce very much higher potentials up to 18 million volts, and then I encountered insurmountable difficulties which convinced me that it was necessary to invent an entirely different form of tube in order to carry out successfully certain ideas I had conceived. This task I found far more difficult than I had expected, not so much in the construction as in the operation of the tube. For many years I was baffled in my efforts, although I made a steady slow progress. Finally though, I was rewarded with complete success and I produced a tube which it will be hard to improve further. It is of ideal simplicity, not subject to wear and can be operated at any potential, however high, that can be produced. It will carry heavy currents, transform any amount of energy within practical limits, and it permits easy control and regulation of the same. I expect that this invention, when it becomes known, will be universally adopted in preference to other forms of tubes, and that it will enable the production of cheap radium substitutes in any desired quantity and will be, in general, immensely more effective in the smashing of atoms and the transmutation of matter. However, this tube will not open up a way to utilize atomic or subatomic energy for power purposes. It will cheapen radium so, that it will be just a cheap – well, it will get down to \$1 a pound, in any quantity.«* Expressing annoyance that some newspapers had indicated he would 'give a full description' of his atom-smashing tube at yesterday's luncheon, Dr. Tesla said he was bound by financial obligations 'involving vast sums of money' against releasing this information. *»But it is not an experiment. I have built, demonstrated and used it. Only a little time will pass before I can give it to the world.«*

§39 22 August 1937^[68]: *»While the origin and character of the rays observed near the earth's surface had thus been sufficiently well ascertained, the so-called cosmic rays observed at great altitudes presented a riddle for more than twenty-six years, chiefly because it was found they increased with the height at a rapid rate. My investigations brought out the astonishing fact that the effects at high altitude are of an entirely different nature, having no relation whatever to cosmic rays. These are particles from celestial bodies at very high temperatures and charged to enormous electrical potentials.«* It might be remarked parenthetically that Dr. Tesla does not accept the concept of the electron presented by physicists as an elementary unit and carrying a unit charge of electricity. He holds that the electron in a well-exhausted tube operated at high potential carries many multiples of this unit charge. The ignorance of this fact is responsible for many errors and fallacies in various scientific investigations. *»The effects at great elevations«,* Dr. Tesla continued, *»are due to waves of extremely small lengths produced by the sun in a certain region of the atmosphere. This is the discovery I wish to make known. The process involved in the generation of the waves is the following: The sun projects charged particles constituting an electric current which passes through a conducting stratum of the atmosphere approximately ten kilometers (six miles) thick enveloping the earth. This is a transmission of electrical energy exactly as I illustrated in my experimental lecture in which one end of a wire is connected to an electric generator of high potential, its other end being free. In this case the generator is represented by the sun and the wire by the conducting air. The passage of the solar current involves the transference of electrical charges from particle to particle with the speed of light, resulting in the production of extremely short and penetrating waves. As the air stratum mentioned is the source of the waves it follows that the so-called cosmic rays observed at great altitude must increase as this stratum is approached.«*

Famous Scientific Illusions

By NIKOLA TESLA

Written specially for the Electrical Experimenter

In this original and revolutionizing discussion, Nikola Tesla gives us something really new to think about. First—Does the moon rotate on its axis? Second—Is the Franklin pointed lightning rod correct in theory and operation? Third—Do wireless signals fly thru space by means of so-called Hertzian waves in the ether, or are they propagated thru the earth at prodigious velocity by means of earth-bound oscillations? World-famous conundrums these—questions which have been answered in many ways by some of the greatest scientists. Dr. Tesla explains these three predominant scientific fallacies in a masterly way, so that everyone can understand them.

THE human brain, with all its wonderful capabilities and power, is far from being a faultless apparatus. Most of its parts may be in perfect working order, but some are atrophied, undeveloped or missing altogether. Great men of all classes and pro-

electric current according to a childish simple rule. The writer, who was known to recite entire volumes by heart, has never been able to retain in memory and recapitulate in their proper order the words designating the colors of the rainbow, and can only ascertain them after long and la-

reality. The greatest triumphs of man were those in which his mind had to free itself from the influence of delusive appearances. Such was the revelation of Buddha that self is an illusion caused by the persistence and continuity of mental images; the discovery of Copernicus that,

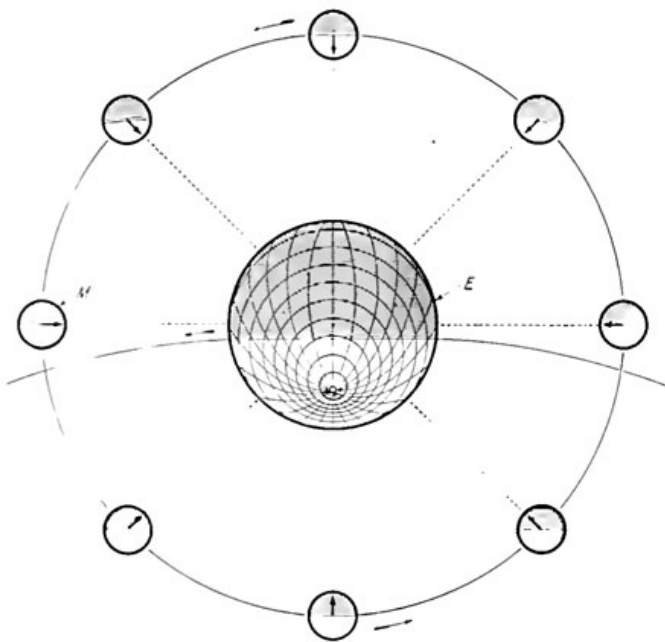


Fig. 1

It is Well Known That the Moon, *M*, Always Turns the Same Face Toward the Earth, *E*, as the Black Arrows Indicate. The Parallel Rays From the Sun Illuminate the Moon in Its Successive Orbital Positions as the Unshaded Semi-circles Indicate. Bearing This in Mind, Do You Believe That the Moon Rotates on Its Own Axis?

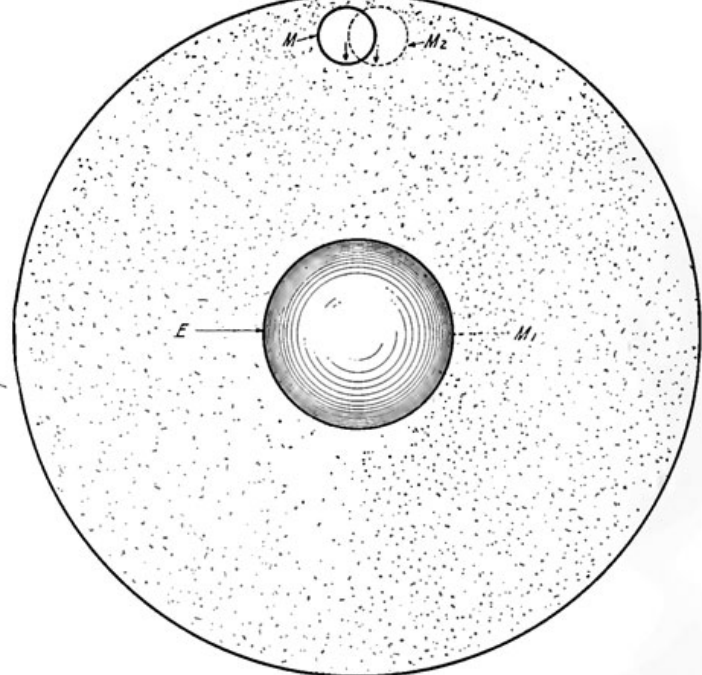


Fig. 2.—Tesla's Conception of the Rotation of the Moon, *M*, Around the Earth, *E*; the Moon, in This Demonstration Hypothesis, Being Considered as Embedded in a Solid Mass, *M*. If, As Commonly Believed, the Moon Rotates, This Would Be Equally True For a Portion of the Mass *M*, and the Part Common to Both Bodies Would Turn Simultaneously in "Opposite" Directions.

fessions—scientists, inventors, and hard-headed financiers—have placed themselves on record with impossible theories, inoperative devices, and unrealizable schemes. It is doubtful that there could be found a single work of any one individual free of error. There is no such thing as an infallible brain. Invariably, some cells or fibers are wanting or unresponsive, with the result of impairing judgment, sense of proportion, or some other faculty. A man of genius eminently practical, whose name is a household word, has wasted the best years of his life in a visionary undertaking. A celebrated physicist was incapable of tracing the direction of an

aborious thought, strange as it may seem.

Our organs of reception, too, are deficient and deceptive. As a semblance of life is produced by a rapid succession of inanimate pictures, so many of our perceptions are but trickery of the senses, devoid of

contrary to all observation, this planet rotates around the sun; the recognition of Descartes that the human being is an automaton, governed by external influence and the idea that the earth is spherical, which led Columbus to the finding of this

continent. And tho the minds of individuals supplement one another and science and experience are continually eliminating fallacies and misconceptions, much of our present knowledge is still incomplete and unreliable. We have sophisms in mathematics which cannot be disproved. Even in pure reasoning, free of the shortcomings of symbolic processes, we are often arrested by doubt which the strong-

FOR over a century and a half the whole world, educated and otherwise, thought that the moon revolved around its axis. Nikola Tesla in the present highly instructive article disproves that theory and will convince scientists and all others alike that the moon does no such thing.

For thousands of years it was thought that the sun and stars revolved around the earth and all kinds of experimental proofs were furnished to substantiate this theory. The illustrious Galileo thought different, and everyone today knows that the earth revolves around the sun.

So it is with Tesla's discovery. Tesla also, in the second part of the present paper, shows us that the ancient and time-worn theory advanced by Benjamin Franklin as to the lightning conductor is not substantially correct as viewed by latter day science. It will come as a shock even to our professors that the lightning rod actually aids the lightning in hitting the building. The reason is that the lightning rod helps in ionizing (making conductive) the surrounding air.

Mr. Tesla has devised a lightning conductor with no points, and there is no doubt whatsoever that his theory is right. Scientists the world over will acknowledge this very shortly.

In a third section of the same paper Tesla explodes still another popular delusion, viz., that wireless waves follow the curvature of the earth when messages are transmitted, let us say from a point in the United States to a point in Europe. In his revolutionary arguments, supported by facts as well as by logic, Tesla shows why the currents do not travel around the earth but directly thru it. In other words, Tesla maintains that wireless communication is accomplished ONLY thru the medium of the earth itself. His contention seems very sound. If it were not so, let every wireless station, commercial or otherwise, do away with its ground connection. None could then operate as is well known, except perhaps over very limited distances.

Mr. Tesla's present article will arouse world-wide comment due to the revolutionary philosophy contained therein. We are sure our readers will appreciate Mr. Tesla's most timely and illuminating article on this but little understood subject.

est intelligences have been unable to dispel. Experimental science itself, most positive of all, is not unfailing.

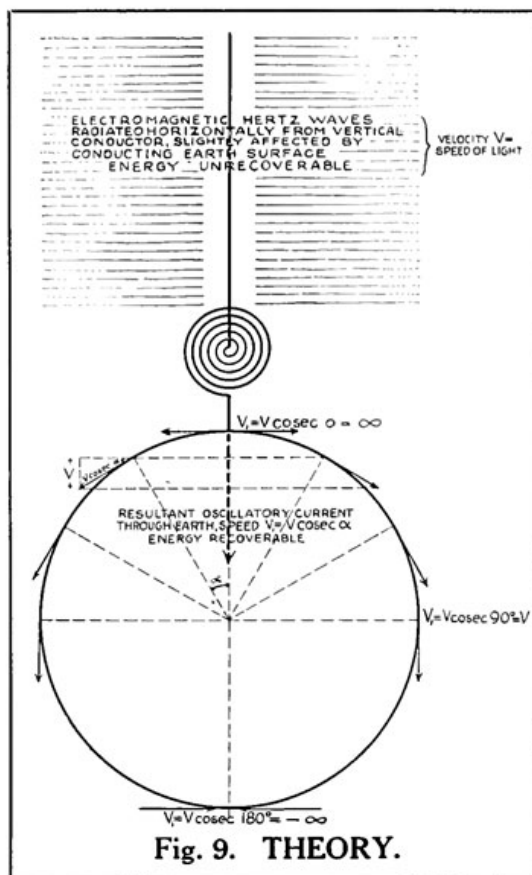
In the following I shall consider three exceptionally interesting errors in the interpretation and application of physical phenomena which have for years dominated the minds of experts and men of science.

I. The Illusion of the Axial Rotation of the Moon.

It is well known since the discovery of Galileo that the moon, in travelling thru space, always turns the same face towards the earth. This is explained by stating that, while passing once around its mother-planet the lunar globe performs just one revolution on its axis. The spinning motion of a heavenly body must necessarily undergo modifications in the course of time, being either retarded by resistances internal or external, or accelerated owing to shrinkage and other causes. An unalterable rotational velocity thru all phases of planetary evolution is manifestly impossible. What wonder, then, that at this very instant of its long existence our satellite should revolve exactly so, and not faster or slower. But many astronomers have accepted as a physical fact that such rotation takes place. It does not, but only appears so; it is an illusion, a most surprising one, too.

I will endeavor to make this clear by reference to Fig. 1, in which E represents the earth and M the moon. The movement thru space is such that the arrow, firmly attached to the latter, always occupies the position indicated with reference to the earth. If one imagines himself as looking down on the orbital plane and follows the motion he will become convinced that the moon *does* turn on its axis as it travels around. But in this very act the observer will have deceived himself. To make the delusion complete let him take a washer similarly marked and supporting it rotatably in the center, carry it around a stationary object, constantly keeping the arrow pointing towards the latter. Tho to his bodily

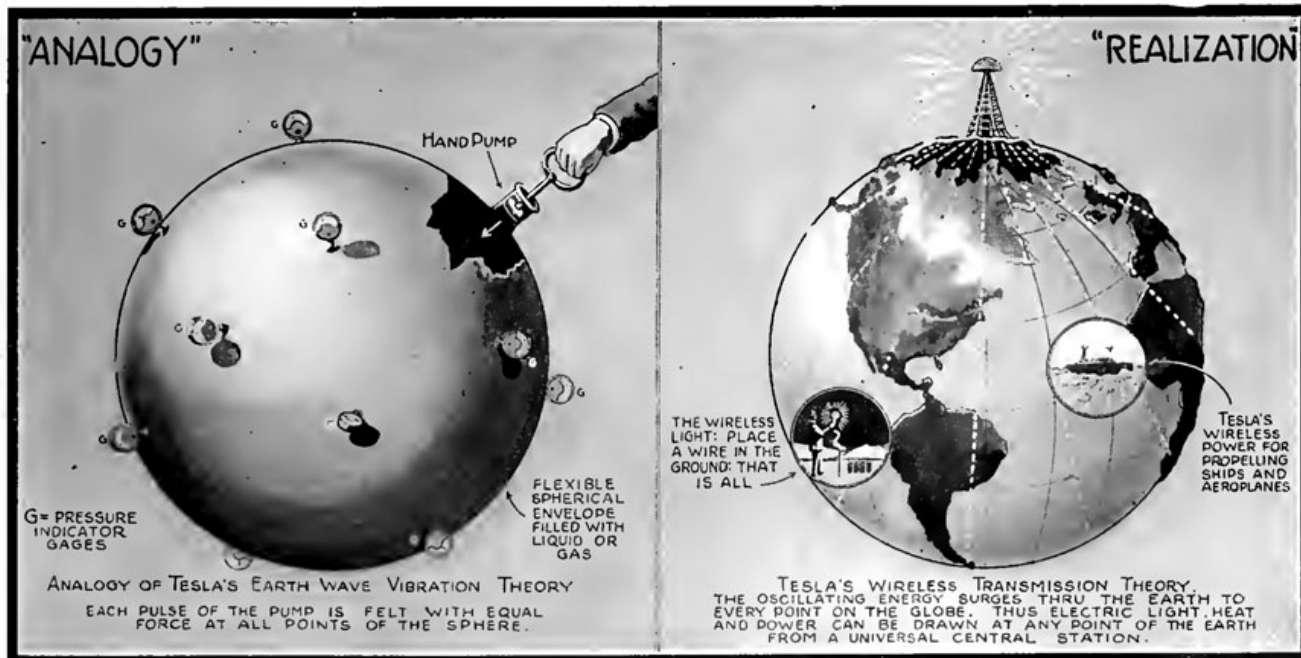
vision the disk will revolve on its axis, such movement does not exist. He can dispel the illusion at once by holding the washer fixedly while going around. He will now readily see that the supposed axial rotation is only apparent, the impression being produced by successive changes of position in space.



But more convincing proofs can be given that the moon does not, and cannot revolve on its axis. With this object in view attention is called to Fig. 2, in which both the satellite, M, and earth, E, are shown embedded in a solid mass, M₁ (indicated by stippling) and supposed to rotate so as to impart to the moon its normal translatory velocity. Evidently, if the lunar globe could rotate as commonly believed, this would be equally true of any other portion of mass M₁, as the sphere M₂, shown in dotted lines, and then the part common to both bodies would have to turn *simultaneously in opposite directions*. This can be experimentally illustrated in the manner suggested by using instead of one, two overlapping rotatable washers, as may be conveniently represented by circles M and M₂, and carrying them around a center as E, so that the plain and dotted arrows are always pointing towards the same center. No further argument is needed to demonstrate that the two gyrations cannot co-exist or even be pictured in the imagination and reconciled in a purely abstract sense.

The truth is, the so-called "axial rotation" of the moon is a phenomenon deceptive alike to the eye and mind and devoid of physical meaning. It has nothing in common with real mass revolution characterized by effects positive and unmistakable. Volumes have been written on the subject and many erroneous arguments advanced in support of the notion. Thus, it is reasoned, that if the planet did *not* turn on its axis it would expose the whole surface to terrestrial view; as only one-half is visible, it *must* revolve. The first statement is true but the logic of the second is defective, for it admits of only one alternative. The conclusion is not justified as the same appearance can also be produced in another way. The moon does rotate, not on its own, but about an axis passing thru the center of the earth, the true and only one.

The unflinching test of the spinning of a mass is, however, the existence of



Tesla's World-Wide Wireless Transmission of Electrical Signals, As Well As Light and Power, Is Here Illustrated in Theory, Analogy and Realization. Tesla's Experiments With 100 Foot Discharges At Potentials of Millions of Volts Have Demonstrated That the Hertz Waves Are Infinitesimal In Effect and Unrecoverable; the Recoverable Ground Waves of Tesla Fly "Thru the Earth". Radio Engineers Are Gradually Beginning to See the Light and That the Laws of Propagation Laid Down by Tesla Over a Quarter of a Century Ago Form the Real and True Basis of All Wireless Transmission To-Day.

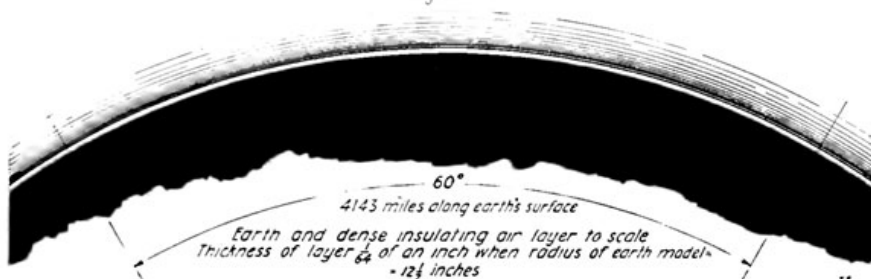
energy of motion. The moon is not posses of such *vis viva*. If it were the case then a revolving body as M_1 would contain mechanical energy other than that of which

tion of the latter immediately stiffens, being at the same time deformed by gravitational pull. The shape becomes permanent upon cooling and solidification and the smaller

Fig 5
Highly rarefied medium (insulating).—



Fig 6



A Section of the Earth and Its Atmospheric Envelope Drawn to Scale. It Is Obvious That the Hertzian Rays Cannot Traverse So Thin a Crack Between Two Conducting Surfaces For Any Considerable Distance, Without Being Absorbed, Says Dr. Tesla, in Discussing the Ether Space Wave Theory.

we have experimental evidence. Irrespective of this so exact a coincidence between the axial and orbital periods is, in itself, immensely improbable for this is not the permanent condition towards which the system is tending. Any axial rotation of a mass left to itself, retarded by forces external or internal, must cease. Even admitting its perfect control by tides the coincidence would still be miraculous. But when we remember that most of the satellites exhibit this peculiarity, the probability becomes infinitesimal.

Three theories have been advanced for the origin of the moon. According to the oldest suggested by the great German philosopher Kant, and developed by Laplace in his monumental treatise "Mécanique Céleste", the planets have been thrown off from larger central masses by centrifugal force. Nearly forty years ago Prof. George H. Darwin in a masterful essay on tidal friction furnished mathematical proofs, deemed unrefutable, that the moon had separated from the earth. Recently this established theory has been attacked by Prof. T. J. J. See in a remarkable work on the "Evolution of the Stellar Systems", in which he propounds the view that centrifugal force was altogether inadequate to bring about the separation and that all planets, including the moon, have come from the depths of space and have been captured. Still a third hypothesis of unknown origin exists which has been examined and commented upon by Prof. W. H. Pickering in "Popular Astronomy of 1907", and according to which the moon was torn from the earth when the latter was partially solidified, this accounting for the continents which might not have been formed otherwise.

Undoubtedly planets and satellites have originated in both ways and, in my opinion, it is not difficult to ascertain the character of their birth. The following conclusions can be safely drawn:

1. A heavenly body thrown off from a larger one cannot rotate on its axis. The mass, rendered fluid by the combined action of heat and pressure, upon the reduc-

tion of the latter immediately stiffens, being at the same time deformed by gravitational pull. The shape becomes permanent upon cooling and solidification and the smaller

show any measurable flattening in form.

2. If a planetary body in its orbital movement turns the same side towards the central mass this is a positive proof that it has been separated from the latter and is a true satellite.

3. A planet revolving on its axis in its passage around another cannot have been thrown off from the same but must have been captured.

II. The Fallacy of Franklin's Pointed Lightning-Rod.

The display of atmospheric electricity has since ages been one of the most marvelous spectacles afforded to the sight of man. Its grandeur and power filled him with fear and superstition. For centuries he attributed lightning to agents god-like and supernatural and its purpose in the scheme of this universe remained unknown to him. Now we have learned that the waters of the ocean are raised by the sun and maintained in the atmosphere delicately suspended, that they are wafted to distant regions of the globe where electric forces assert themselves in upsetting the sensitive balance and causing precipitation, thus sustaining all organic life. There is every reason to hope that man will soon be able to control this life-giving flow of water and thereby solve many pressing problems of his existence.

Atmospheric electricity became of special scientific interest in Franklin's time. Faraday had not yet announced his epochal discoveries in magnetic induction but static frictional machines were already generally used in physical laboratories. Franklin's powerful mind at once leaped to the conclusion that frictional and atmospheric electricity were identical. To our present view this inference appears obvious, but in his time the mere thought of it was little short of blasphemy. He investigated the phenomena and argued that if they were of the same nature then the clouds could be drained of their charge exactly as the ball of a static machine, and in 1749 he indicated in a published memoir how this could be done by the use of pointed metal rods.

(Continued on page 728)

MODE OF PROPAGATION OF THE CURRENT FROM THE TRANSMITTER THRU THE EARTH

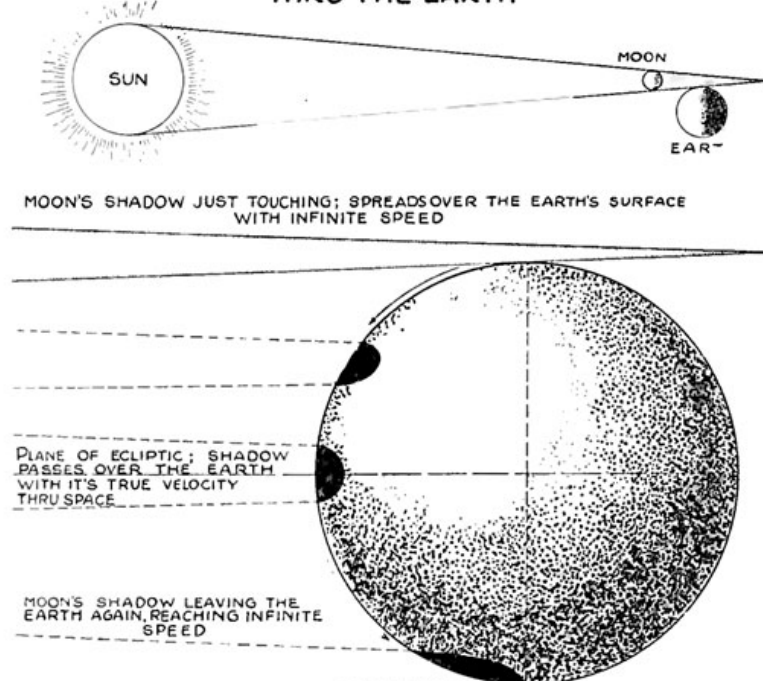


Fig. 8.—This Diagram Illustrates How, During a Solar Eclipse, the Moon's Shadow Passes Over the Earth With Changing Velocity, and Should Be Studied in Connection With Fig. 9. The Shadow Moves Downward With Infinite Velocity at First, Then With Its True Velocity Thru Space, and Finally With Infinite Velocity Again.



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Famous Scientific Illusions

(Continued from page 694)

The earliest trials were made by Dalibrand in France, but Franklin himself was the first to obtain a spark by using a kite, in June, 1752. When these atmospheric discharges manifest themselves today in our wireless station we feel annoyed and wish that they would stop, but to the man who discovered them they brought tears of joy.

latter has the property of quickly dissipating the accumulated charge into the air. To examine this action in the light of present knowledge we may liken electric potential to temperature. Imagine that sphere s is heated to T degrees and that the pin or metal bar is a perfect conductor of heat so that its extreme end is at the same tem-

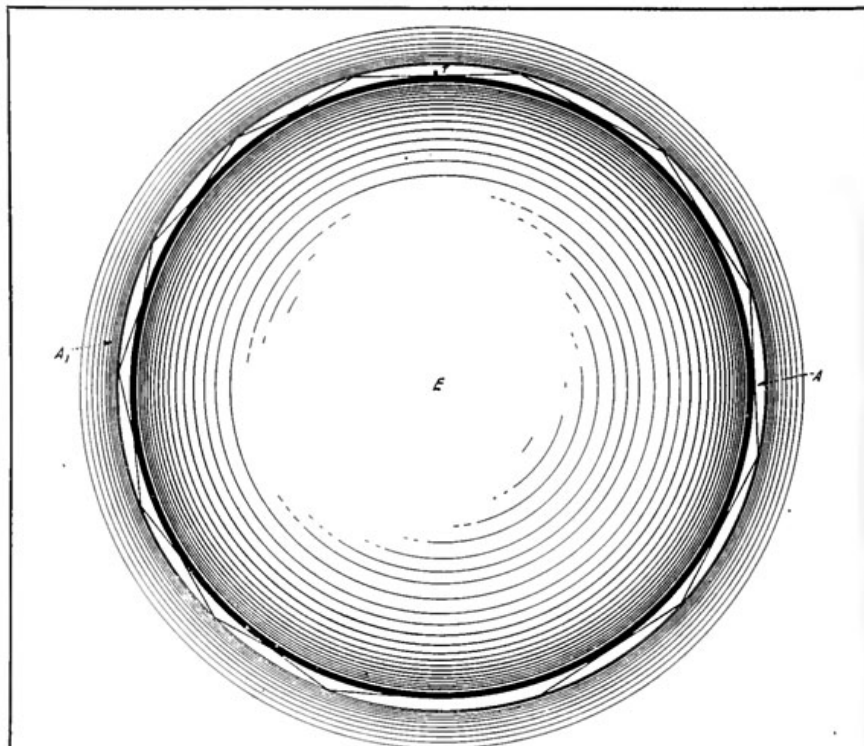


Fig. 7

The Theory Has Been Seriously Advanced and Taught that the Radio Ether Wave Oscillations Pass Around the Earth by Successive Reflections, as Here Shown. The Efficiency of Such a Reflector Cannot be more than 25 Per Cent; the Amount of Energy Recoverable in a 12,000-mile Transmission being but One Hundred and Fifteen Billionth Part of One Watt, with 1,000 Kilowatts at the Transmitter.

The lightning conductor in its classical form was invented by Benjamin Franklin in 1755 and immediately upon its adoption proved a success to a degree. As usual, however, its virtues were often exaggerated. So, for instance, it was seriously claimed that in the city of Pietermaritzburg (capital of Natal, South Africa) no lightning strokes occurred after the pointed rods were installed, altho the storms were as frequent as before. Experience has shown that just the opposite is true. A modern city like New York, presenting innumerable sharp points and projections in good contact with the earth, is struck much more often than equivalent area of land. Statistical records, carefully compiled and published from time to time, demonstrate that the danger from lightning to property and life has been reduced to a small percentage by Franklin's invention, but the damage by fire amounts, nevertheless, to several million dollars annually. It is astonishing that this device, which has been in universal use for more than one century and a half, should be found to involve a gross fallacy in design and construction which impairs its usefulness and may even render its employment hazardous under certain conditions.

For explanation of this curious fact I may first refer to Fig. 3, in which s is a metallic sphere of radius r , such as the capacity terminal of a static machine, provided with a sharply pointed pin of length h , as indicated. It is well known that the

perature T . Then if another sphere of larger radius, s_1 , is drawn about the first and the temperature along this boundary is T_1 , it is evident that there will be between the end of the bar and its surrounding a difference of temperature $T - T_1$, which will determine the outflow of heat. Obviously, if the adjacent medium was not affected by the hot sphere this temperature difference would be greater and more heat would be given off. Exactly so in the electric system. Let q be the quantity of the charge, then the sphere—and owing to its great conductivity also the pin—will be at

the potential $\frac{q}{r}$. The medium around the point of the pin will be at the potential $\frac{q}{r+h}$ and, consequently, the difference $\frac{q}{r} - \frac{q}{r+h} = \frac{qh}{r(r+h)}$. Suppose now that a sphere S of much larger radius $R = nr$ is employed containing a charge Q this difference of potential will be, analogously $\frac{Qh}{R(R+h)}$. According to elementary

principles of electro-statics the potentials of the two spheres s and S will be equal if $Q = nq$ in which case $\frac{Qh}{R(R+h)} = \frac{qh}{r(r+h)}$

(Continued on page 730)

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FAMOUS SCIENTIFIC ILLUSIONS.

(Continued from page 728)

$\frac{nqh}{nr(nr+h)} = \frac{qh}{r(nr+h)}$. Thus the difference of potential between the point of the pin and the medium around the same

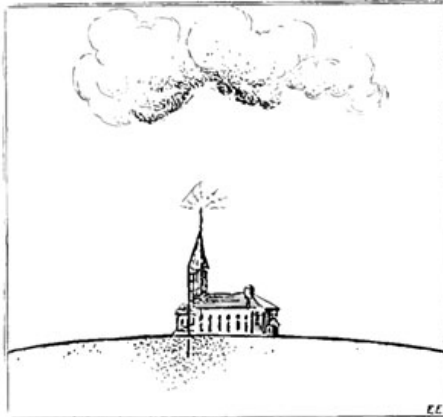


Fig. 4. Tesla Explains the Fallacy of the Franklin Pointed Lightning Rod, Here Illustrated, and Shows that Usually Such a Rod Could Not Draw Off the Electricity in a Single Cloud in Many Years. The Density of the Dots Indicates the Intensity of the Charges.

will be smaller in the ratio $\frac{r+h}{nr+h}$ when

the large sphere is used. In many scientific tests and experiments this important observation has been disregarded with the result of causing serious errors. Its significance is that the behavior of the pointed rod entirely depends on the linear dimensions of the electrified body. Its quality to give off the charge may be entirely lost if the latter is very large. For this reason, all points or projections on the surface of a conductor of such vast dimensions as the earth would be quite ineffective were it not for other influences. These will be elucidated with reference to Fig. 4, in which our artist of the Impressionist school has emphasized Franklin's notion that his rod was drawing electricity from the clouds. If the earth were not surrounded by an atmosphere which is generally oppositely charged it would behave, despite all its irregularities of surface, like a polished sphere. But owing to the electrified masses of air and cloud the distribution is greatly modified. Thus in Fig. 4,

the positive charge of the cloud induces in the earth an equivalent *opposite* charge, the density at the surface of the latter diminishing with the cube of the distance from the static center of the cloud. A brush discharge is then formed at the point of the rod and the action Franklin anticipated takes place. In addition, the surrounding air is ionized and rendered conducting and, eventually, a bolt may hit the building or some other object in the vicinity. The virtue of the pointed end to dissipate the charge, which was uppermost in Franklin's mind is, however, infinitesimal. Careful measurements show that it would take many years before the electricity stored in a single cloud of moderate size would be drawn off or neutralized thru such a lightning conductor. The grounded rod has the quality of rendering harmless most of the strokes it receives, tho occasionally the charge is diverted with damaging results. But, what is very important to note, it invites danger and hazard on account of the fallacy involved in its design. The sharp point which was thought advantageous and indispensable to its operation, is really a defect detracting considerably from the practical value of the device. I have produced a much improved form of lightning protector characterized by the employment of a terminal of considerable area and large radius of curvature which makes impossible undue density of the charge and ionization of the air.* These protectors act as quasi-repellents and so far have never been struck tho exposed a long time. Their safety is experimentally demonstrated to greatly exceed that invented by Franklin. By their use property worth millions of dollars which is now annually lost, can be saved.

III. The Singular Misconception of the Wireless.

To the popular mind this sensational advance conveys the impression of a single invention but in reality it is an art, the successful practise of which involves the employment of a great many discoveries and improvements. I viewed it as such when I undertook to solve wireless problems and it is due to this fact that my insight into its underlying principles was clear from their very inception.

In the course of development of my induction motors it became desirable to operate them at high speeds and for this purpose I constructed alternators of relatively

*Refer to the October, 1918, issue of this journal wherein Dr. Tesla's new form of non-pointed lightning rod was fully described and illustrated.

(Continued on page 732)

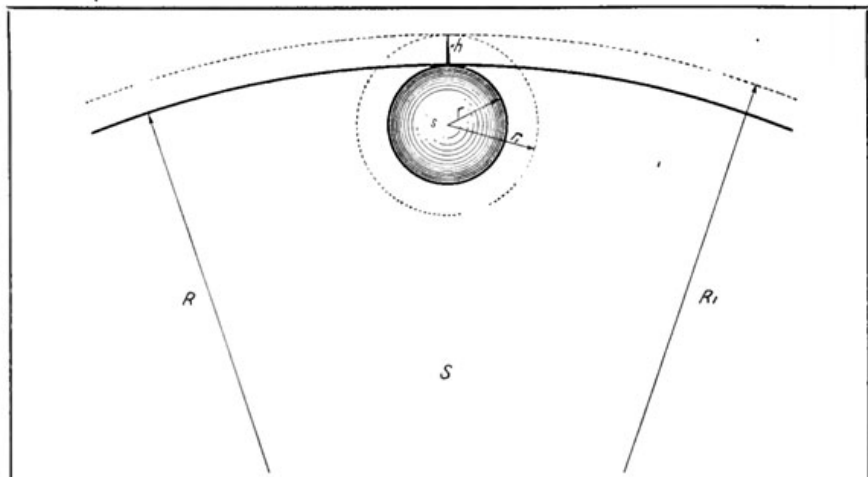


Fig. 3

Diagram Used to Explain the Fallacy of the Franklin Pointed Lightning Rod, and an Analogy Whereby the Author Shows in a Clear Manner How the Charged Sphere May for Illustration be Considered as Heated to a High Degree, and the Heat Allowed to Escape at a Known Rate

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FAMOUS SCIENTIFIC ILLUSIONS

(Continued from page 730)

high frequencies. The striking behavior of the currents soon captivated my attention and in 1889 I started a systematic investigation of their properties and the possibilities of practical application. The first gratifying result of my efforts in this direction was the transmission of electrical energy thru *one wire* without return, of which I gave demonstrations in my lectures and addresses before several scientific bodies here and abroad in 1891 and 1892. During that period, while working with my oscillation transformers and dynamos of frequencies up to 200,000 cycles per second, the idea gradually took hold of me that the earth might be used in place of the wire, thus dispensing with artificial conductors altogether. The immensity of the globe seemed an unsurmountable obstacle but after a prolonged study of the subject I became satisfied that the undertaking was rational, and in my lectures before the Franklin Institute and National Electric Light Association early in 1893 I gave the outline of the system I had conceived. In the latter part of that year, at the Chicago World's Fair, I had the good fortune of meeting Prof. Helmholtz to whom I explained my plan, illustrating it with experiments. On that occasion I asked the cele-

brated physicist for an expression of opinion on the feasibility of the scheme. He stated unhesitatingly that it was practicable, provided I could perfect apparatus capable of putting it into effect but this, he anticipated, would be extremely difficult to accomplish.

I resumed the work very much encouraged and from that date to 1896 advanced slowly but steadily, making a number of improvements the chief of which was my system of *concatenated tuned circuits* and method of regulation, now universally adopted. In the summer of 1897 Lord Kelvin happened to pass thru New York and honored me by a visit to my laboratory where I entertained him with demonstrations in support of my wireless theory. He was fairly carried away with what he saw but, nevertheless, condemned my project in emphatic terms, qualifying it as something impossible, "an illusion and a snare." I had expected his approval and was pained and surprised. But the next day he returned and gave me a better opportunity for explanation of the advances I had made and of the true principles underlying the system I had evolved. Suddenly he remarked with evident astonishment: "Then you are not making use of Hertz waves?" "Certainly not," I replied, "these are *radiations*. No energy could be economically transmitted to a distance by any such agency. In my system the process is one of *true conduction* which, theoretically, can be effected at the greatest distance without appreciable loss." I can never forget the magic change that came over the illustrious philosopher the moment he freed himself from that erroneous impression. The skeptic who would not believe was suddenly transformed into the warmest of supporters. He parted from me not only thoroughly convinced of the scientific soundness of the idea but strongly express his confidence in its success. In my exposition to him I resorted to the following mechanical analogues of my own and the Hertz wave system.

Imagine the earth to be a bag of rubber filled with water, a small quantity of which is periodically forced in and out of the same by means of a reciprocating pump, as illustrated. If the strokes of the latter are effected in intervals of more than one hour and forty-eight minutes, sufficient for the transmission of the impulse thru the whole mass, the entire bag will expand and contract and corresponding movements will be imparted to pressure gauges or movable pistons with the same intensity, irrespective of distance. By working the pump faster, shorter waves will be produced which, on reaching the opposite end of the bag, may be reflected and give rise to stationary nodes and loops, but in any case, the fluid being incompressible, its inclosure perfectly elastic, and the frequency of oscillations not very high, the energy will be economically transmitted and very little power consumed so long as no work is done in the receivers. This is a crude but correct representation of my wireless system in which, however, I resort to various refinements. Thus, for instance, the pump is made part of a resonant system of great inertia, enormously magnifying the force of the impress impulses. The receiving devices are similarly conditioned and in this manner the amount of energy collected in them vastly increased.

The Hertz wave system is in many respects the very opposite of this. To explain it by analogy, the piston of the pump is assumed to vibrate to and fro at a terrific rate and the orifice thru which the fluid passes in and out of the cylinder is reduced to a small hole. There is scarcely any movement of the fluid and almost the whole work performed results in the production of radiant heat, of which an infinitesimal part is recovered in a remote locality. However incredible, it is true that



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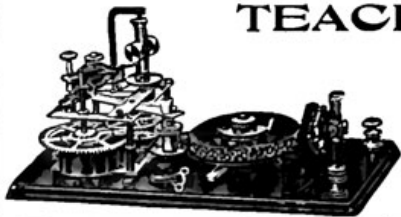
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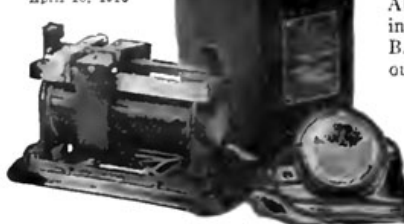
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the minds of some of the ablest experts have been from the beginning, and still are, obsessed by this monstrous idea, and so it comes that the true wireless art, to which I laid the foundation in 1893, has been retarded in its development for twenty years. This is the reason why the "statics" have proved unconquerable, why the wireless shares are of little value and why the Government has been compelled to interfere.

We are living on a planet of well-nigh inconceivable dimensions, surrounded by a layer of insulating air above which is a rarefied and conducting atmosphere (Fig. 5). This is providential, for if all the air were conducting the transmission of electrical energy thru the natural media would be impossible. My early experiments have shown that currents of high frequency and great tension readily pass thru an atmosphere but moderately rarefied, so that the insulating stratum is reduced to a small thickness as will be evident by inspection of Fig. 6, in which a part of the earth and its gaseous envelope is shown to scale. If the radius of the sphere is $12\frac{1}{2}$ ", then the non-conducting layer is only $1/64$ " thick and it will be obvious that the Hertzian rays cannot traverse so thin a crack between two conducting surfaces for any considerable distance, without being absorbed. The theory has been seriously advanced that these radiations pass around the globe by successive reflections, but to show the absurdity of this suggestion reference is made to Fig. 7 in which this process is diagrammatically indicated. Assuming that there is no refraction, the rays, as shown on the right, would travel along the sides of a polygon drawn around the solid, and inscribed into the conducting gaseous boundary in which case the length of the side would be about 400 miles. As one-half the circumference of the earth is approximately 12,000 miles long there will be, roughly, thirty deviations. The efficiency of such a reflector cannot be more than 25 per cent, so that if none of the energy of the transmitter were lost in other ways, the part recovered would be measured by the fraction $(\frac{1}{4})^{30}$. Let the transmitter radiate Hertz waves at the rate of 1,000 kilowatts. Then about one hundred and fifteen billionth part of one watt is all that would be collected in a perfect receiver. In truth, the reflections would be much more numerous as shown on the left of the figure, and owing to this and other reasons, on which it is unnecessary to dwell, the amount recovered would be a vanishing quantity.

Consider now the process taking place in the transmission by the instrumentalities and methods of my invention. For this purpose attention is called to Fig. 8, which gives an idea of the mode of propagation of the current waves and is largely self-explanatory. The drawing represents a solar eclipse with the shadow of the moon just touching the surface of the earth at a point where the transmitter is located. As the shadow moves downward it will spread over the earth's surface, first with infinite and then gradually diminishing velocity until at a distance of about 6,000 miles it will attain its true speed in space. From there on it will proceed with increasing velocity, reaching infinite value at the opposite point of the globe. It hardly need be stated that this is merely an illustration and not an accurate representation in the astronomical sense.

The exact law will be readily understood by reference to Fig. 9, in which a transmitting circuit is shown connected to earth and to an antenna. The transmitter being in action, two effects are produced: Hertz waves pass thru the air, and a current traverses the earth. The former propagate with the speed of light and their energy is unrecoverable in the circuit. The latter proceeds with the speed varying as the cosecant of the angle which a radius drawn from any point under consideration forms

Increase Your Will Power In One Hour

Author of This Article Tells How He Quickly Acquired a Dominating Will Power That Earns Him Between \$50,000 and \$70,000 a Year

FOUR YEARS ago a man offered me a wonderful bargain. He was hard up for money and wanted to sell me some shares in a young, growing company for \$1,000. Based on the earnings of the Company the stock offered me was easily worth \$5,000—in fact, the man who finally bought the shares sold them again in five months at a profit of \$4,300.

The reason I didn't buy the shares was that I could no more raise a thousand dollars than I could hop, skip, and jump across the Atlantic Ocean. A thousand dollars! And my income only twenty-five a week.

The second chapter in my life began a few months later, when another opportunity came to me. It required an investment of \$20,000 during the first year. I raised the money easily, paid back every penny I borrowed, and had \$30,000 left at the end of the first year! To date, in less than four years, my business has paid me a clear profit of over \$200,000 and is now earning between \$50,000 and \$70,000 a year. Yet for twelve years before, the company had been losing money every year!

The natural question for my reader to ask is, "How could you borrow \$20,000 to invest in a business which had previously been a failure, after being unable to borrow \$1,000 for an investment that seemed secure?" It is a fair question. And the answer can be given in two little words—WILL POWER.

When the first proposition came to me I passed it by simply because I didn't have the money and couldn't borrow it. I went from one friend to the next and all turned me down. Several refused to talk business with me at all. They all liked me personally, and they asked me about the kiddies, but when it came to money matters I hadn't a chance. I was scared stiff every time I talked to one of them. I pleaded with them, almost begged them. But everybody had their "money all tied up in other investments." It was an old excuse, but I accepted it meekly. I called it hard luck. But I know today that it was nothing in the world except my lack of Will Power, or rather my weak Will Power, which kept me from getting what I wanted.

When I heard that the man sold those shares at a profit of \$4,300, it seemed that my sorrow could not be greater. That profit was just about what my salary amounted to for four years! But instead of grieving over my "hard luck," I decided to find out why I was so easily beaten in everything I tried to accomplish. It must be that there was something vital that made the difference between success and failure. It wasn't lack of education, for many illiterate men become wealthy. What was this vital spark? What was this one thing which successful men had and which I did not have?

I began to read books about psychology and mental power. But everything I read was too general. There was nothing definite—nothing that told me what to do.

After several months of discouraging effort, I finally encountered a book called "Power of Will," by Frank Channing Haddock. The very title came to me as a shock. When I opened the book I was amazed. I realized that will power was the vital spark—the one thing that I lacked.

And here in this book were the very rules, lessons and exercises through which anyone could increase their will power. Eagerly I read page after page; including such articles as: The Law of Great Thinking; How to Develop Analytical Power; How to Concentrate Perfectly; How to Guard Against Errors in Thought; How to Develop Fearlessness; How to Acquire a Dominating Personality.

An hour after I opened the book I felt like a new person. My sluggish will power was beginning to awaken. There was a new light in my eye, a new spring in my step, a new determination in my soul. I began to see, in my past, the many mistakes I had made, and I knew I would never make them again.

I practiced some of the simple exercises. They were more fascinating than any game of cards or any sport.

Then came an opportunity to acquire the business which had lost money for twelve years, and which I turned into a \$50,000 a year money maker. Instead of cringing before the moneyed people, I won them over by my sheer force of will. I would not be denied. And my every act and word since then has been the result of my training in will power.

I am convinced that every man has within himself every essential quality of success except a strong will. Any man who doubts that statement need only analyze the successful men he knows, and he will find himself their equal, or their superior, in every way except in will power. Without a strong will, education counts for little, money counts for nothing, opportunities are useless.

I earnestly recommend Prof. Haddock's great work, "Power of Will," to those who feel that success is just out of reach—to those who lack that something which they cannot define, yet which holds them down to the grind of a small salary.

Never before have business men and women needed this help so badly as in these trying times. Hundreds of real and imaginary obstacles confront us every day, and only those who are masters of themselves and who hold their heads up will succeed. "Power of Will" as never before is an absolute necessity—an investment in self-culture which no one can afford to deny himself.

I am authorized to say that any reader who cares to examine "Power of Will" for five days may do so without sending any money in advance. If after one hour you do not feel that your will power has increased, and if after a week's reading you do not feel that this great book supplies that one faculty you need most to win success, return it and you will owe nothing. Otherwise send only \$3, the small sum asked.

Some few doubters will scoff at the idea of will power being the fountainhead of wealth, position and everything we are striving for, but the great mass of intelligent men and women will at least investigate for themselves by sending for the book at the publisher's risk. I am sure that any book that has done for me—and for thousands of others—what "Power of Will" has done—is well worth investigating. It is interesting to note that among the 250,000 owners of "Power of Will" are such prominent men as Supreme Court Justice Parker; Wu Ting Fang, Ex-U. S. Chinese Ambassador; Gov. McKelvie, of Nebraska; Assistant Postmaster-General Britt; General Manager Christenson, of Wells-Fargo Express Co.; E. St. Elmo Lewis; Senator Arthur Capper of Kansas and thousands of others. In fact, today "Power of Will" is just as important, and as necessary to a man's or woman's equipment for success, as a dictionary. To try to succeed without Power of Will is like trying to do business without a telephone.

As your first step in will training, I suggest immediate action in this matter before you. It is not even necessary to write a letter. Use the form below, if you prefer, addressing it to the Pelton Publishing Company, 30-B Wilcox Block, Meriden, Conn., and the book will come by return mail. You hold in your hand, this very minute, the beginning of a new era in your life. Over a million dollars has been paid for "Power of Will" by people who sent for it on free examination. Can you, in justice to yourself, hesitate about sending in the coupon? Can you doubt, blindly, when you can see, without a penny deposit, this wonder-book that will increase your will power in one hour.

The cost of paper, printing and binding has almost doubled during the past three years, in spite of which "Power of Will" has not been increased in price. The publisher feels that so great a work should be kept as low-priced as possible, but in view of the enormous increase in the cost of every manufacturing item, the present edition will be the last sold at the present price. The next edition will cost more. I urge you to send in the coupon now.

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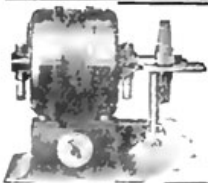
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with the axis of symmetry of the waves. At the origin the speed is infinite but gradually diminishes until a quadrant is traversed, when the velocity is that of light. From there on it again increases, becoming infinite at the antipole. Theoretically the energy of this current is recoverable in its entirety, in properly attuned receivers.

Some experts, whom I have credited with better knowledge, have for years contended that my proposals to transmit power without wires are sheer nonsense but I note that they are growing more cautious every day. The latest objection to my system is found in the cheapness of gasoline. These men labor under the impression that the energy flows in all directions and that, therefore, only a minute amount can be recovered in any individual receiver. But this is far from being so. The power is conveyed in only one direction, from the transmitter to the receiver, and none of it is lost elsewhere. It is perfectly practicable to recover at any point of the globe energy enough for driving an airplane, or a pleasure boat or for lighting a dwelling. I am especially sanguine in regard to the lighting of isolated places and believe that a more economical and convenient method can hardly be devised. The future will show whether my foresight is as accurate now as it has proved heretofore.

SHIP RADIO OPERATORS ASK INCREASED WAGES.

Increased wages and the fixing of a standard wage scale for radio operators on vessels operating under Government direction was asked of the Shipping Board recently by a delegation representing the Marconi Radio Telegraphers' Association. The radio operators included in the request made of the Board are those on vessels operating in transatlantic and Gulf waters. Assurances were given the radio representatives by Board officials that their request would be taken under advisement for immediate consideration.

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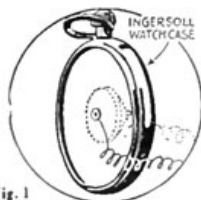


Fig. 1



Fig. 2

THE SKINDERVIKEN TRANSMITTER BUTTON presents the latest advance in microphones and marks a revolution in transmitter construction. It works on an entirely new principle, takes up practically no room, and marks

with surprising clarity. Fig. 3 illustrates the same arrangement placed on the chest as shown. In this position the transmitter will talk clearly and loudly. Fig. 4 shows an arrangement whereby the Skinderviken button is attached on a thin wood board at the preacher's pulpit. His voice is clearly transmitted so that people hard of hearing can readily hear the sermon. Fig. 5 shows an interesting stunt, whereby a hole is drilled in the side of a thin glass water-tumbler; the sides of the glass thus acting as a diaphragm, the voice is clearly transmitted. Fig. 6 shows a simple match box Detectophone. The Skinderviken button is concealed inside of the box, only the small brass nut showing on the outside. This can be camouflaged as well. This device talks well. Fig. 7 shows how to transmit phonograph music at a distance merely by drilling a small hole in the phonograph arm and attaching the Skinderviken button; a very favorite experiment with all experimenters. Fig. 8 shows how a very sensitive Detectophone can be made by placing one of the buttons in the center of a lithographed cardboard picture, so that only the small brass nut shows. The large surface of the picture acts as a big diaphragm, and the voice is well reproduced.



Fig. 3



Fig. 4

the end of all telephone transmitter troubles. The **SKINDERVIKEN TRANSMITTER BUTTON** can be placed in any position and it will talk loudly and distinctly and is at the same time extraordinarily sensitive. It was primarily designed to replace the old damaged or burnt out transmitter. Simply unscrew and remove the telephone transmitter front, disconnect the two inside wires, unscrew and remove the bridge and the old electrode. There remains only the diaphragm. These wires are then connected with the Skinderviken button, the latter screwed to the diaphragm, and after screwing the old transmitter housing together again, the telephone is ready for work.

ELECTRICAL EXPERIMENTER readers will be particularly interested in all the different experiments that can be performed with the Skinderviken Button. Fig. 1 shows the Skinderviken button attached to the back of an Ingersoll watch case. When speaking towards the inside of the case, it will be found that the



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Fig. 5

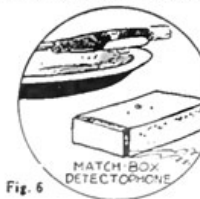


Fig. 6

voice is reproduced clearly and loudly. Fig. 2 shows another interesting stunt. By attaching the button to a tin diaphragm about the size of half a dollar, and by holding the diaphragm at the side of the throat, as shown, speech can be transmitted

(\$1.00) for which we will mail one button prepaid. If you do not wish to keep it, return it within five days and your money will be refunded. Boys! send stamp for booklet No. 3. It gives diagrams and experiments using the Skinderviken Transmitter Button, and prices of telephone equipment.

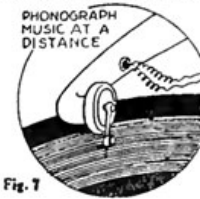


Fig. 7



Fig. 8

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South Atlantic magnetic anomaly ionization: A review and a new focus on electrodynamic effects in the equatorial ionosphere

M.A. Abdu*, I.S. Batista, A.J. Carrasco, C.G.M. Brum

Instituto Nacional de Pesquisas Espaciais-INPE, 12245 970 São Jose dos Campos, SP, Brazil

Available online 2 November 2005

Abstract

Satellite observations of enhanced energetic particle fluxes in the South Atlantic Magnetic Anomaly (SAMA) region have been supported by ground-based observations of enhanced ionization induced by particle precipitation in the ionosphere over this region. Past observations using a variety of instruments such as vertical sounding ionosondes, riometers and VLF receivers have provided evidences of the enhanced ionization due to energetic particle precipitation in the ionosphere over Brazil. The extra ionization at E-layer heights could produce enhanced ionospheric conductivity within and around the SAMA region. The energetic particle ionization source that is operative even under “quiet” conditions can undergo significant enhancements during magnetospheric storm disturbances, when the geographic region of enhanced ionospheric conductivity can extend to magnetic latitudes closer to the equator where the magnetic field line coupling of the E and F regions plays a key role in the electrodynamics of the equatorial ionosphere. Of particular interest are the sunset electrodynamic processes responsible for equatorial spread F/plasma bubble irregularity generation and related dynamics (zonal and vertical drifts, etc.). The SAMA represents a source of significant longitudinal variability in the global description of the equatorial spread F irregularity phenomenon. Recent results from digital ionosondes operated at Fortaleza and Cachoeira Paulista have provided evidence that enhanced ionization due to particle precipitation associated with magnetic disturbances, in the SAMA region, can indeed significantly influence the equatorial electrodynamic processes leading to plasma irregularity generation and dynamics. Disturbance magnetospheric electric fields that penetrate the equatorial latitudes during storm events seem to be intensified in the SAMA region based on ground-based and satellite-borne measurements. This paper will review our current understanding of the influence of SAMA on the equatorial electrodynamic processes from the perspective outlined above.

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1. Introduction

The existence of large longitudinal variations in the major phenomena of the equatorial ionosphere has been verified in the past by various types of observations,

both ground based and satellite based. They reflect a corresponding variation in the electrodynamic processes that control those phenomena. A major source of such variations could reside in the well-known longitudinal variations in the geomagnetic field intensity and declination angle. A possibly significant role of the South Atlantic Magnetic Anomaly (SAMA) in contributing to such longitudinal variations has not been addressed so far. In this paper, we focus on this question.

*Corresponding author. Tel.: +55 12 3945 7149;
fax: +55 12 3945 6990.

E-mail address: abdu@dae.inpe.br (M.A. Abdu).

Based on ionosonde and radar data it was shown that ionospheric dynamo electric field enhancement in the evening hours, and the consequent ESF/plasma bubble irregularity generation and dynamics, present significant longitudinal/seasonal difference between the west and east coast of South America, (i.e., between Peru and Brazil–Atlantic longitude sectors), which could be attributed to the large longitudinal variation in the magnetic declination angle that characterize this sector (Abdu et al., 1983; Batista et al., 1986). Longitudinal/seasonal variation in ionospheric scintillation occurrence at VHF on global scales has been attributed to the associated variation of the magnetic declination angle (Tsunoda, 1985). Magnetospheric electric fields that penetrate the equatorial latitudes during disturbed/storm conditions also seem to exhibit significant longitudinal variations in this longitude sector (Abdu, 1994; Basu et al., 2001). Enhanced ionospheric conductivity over the SAMA region could result from precipitation of energetic particles from the inner radiation belt on a spatial scale that may extend several degrees in longitude and latitude around the central region of the anomaly. The presence of enhanced ionization at E-layer heights under magnetically quiet conditions has been verified from analysis of ionosonde data over Cachoeira Paulista located inside the SAMA region (Abdu and Batista, 1977), and this could signify a corresponding background pattern of enhanced conductivity structure in the region. Such quiet-time/background conductivity distributions can become significantly enhanced under magnetospherically disturbed conditions (Abdu et al., 1998, 2003a, b). As a result, the electrodynamic coupling processes of the equatorial region in the SAMA longitude sector undergo significant modification. The quiet and disturbed electric fields, plasma irregularity development and dynamics (related to equatorial spread F processes) over the longitude sector of the SAMA do seem to differ from those of other longitudes (especially those in the immediate vicinity of the SAMA). In this paper, we will first present a brief review of the evidence available, based on different observational databases, for enhanced ionization by energetic particle precipitation in the SAMA region under quiet and disturbed conditions (see for example, Abdu et al., 1973, 1979, 1981a; Gledhill and Torr, 1966; Paulikas, 1975; Nishino et al., 2002). We will then consider the effect of such enhanced ionization in causing enhanced ionospheric conductivity that in turn could modify the electrodynamic conditions for plasma irregularity development and plasma drifts of the post-sunset equatorial ionosphere in the SAMA longitude sector.

2. Sama magnetic field configuration and particle precipitation

Fig. 1 shows the configuration of the geomagnetic field total intensity distribution over the globe, in which

the lowest value of the total magnetic field intensity defines the position of the center of the SAMA. Its present location in the southern part of Brazil resulted from the steady and secular westward drift of the SAMA from its location in the South Atlantic Ocean a few years ago. An associated aspect/characteristic of the SAMA field configuration is the large magnetic declination angle, and the associated feature of the dip equator crossing the geographic equator and extending deeper down to the South American continent to $\sim 12^\circ\text{S}$ over Jicamarca in Peru. As a result, the magnetic declination angle over the eastern part of Brazil attains $\sim 21^\circ\text{W}$ whereas it reverts to $\sim 4^\circ\text{E}$ over the Peruvian longitude sector as shown in Fig. 2.

The trapped and azimuthally drifting energetic particles, bouncing between hemispheres, come deeper down into the atmosphere owing to the low field intensity over SAMA (in conservation of its second adiabatic invariant), thereby interacting with the dense atmosphere resulting in ionization production. Other processes, such as wave–particle interaction leading to an enhanced loss cone of the drifting particles has also been suggested as a mechanism for the loss of inner radiation belt particles in the SAMA region. Evidence of enhanced energetic particle populations in the SAMA region has come from early Russian COSMOS satellite observations. Contours of constant omni-directional flux of fission electrons, detected at 0.29 MeV energy at altitudes 320 ± 450 km by one of the COSMOS satellites in the South Atlantic Anomaly region are shown in Fig. 3 (Vernov et al., 1967). The region of maximum particle flux close to the Brazilian South Atlantic coast can be noted. With westward secular drift of the SAMA, the center region of maximum particle flux should have moved well into the Brazilian land mass.

Evidence of enhanced ionization in the D region over SAMA due to the precipitation of inner radiation belt energetic particles azimuthally drifting eastward was first obtained during the great storm of August 1972, from spaced antenna riometer measurements by Abdu et al. (1973). Subsequent measurements by ionospheric vertical sounding by ionosondes and measurement of very low frequency (VLF) phase in earth-ionosphere wave guide mode propagation path, monitored by ground-based VLF receivers, have verified the occurrence of significant ionization enhancement in the ionospheric D and E regions (~ 70 – 120 km) over the SAMA. Interesting aspects of the spatial structure and dynamics of the particle precipitation regions in the lower ionosphere, associated with a magnetic storm event, have recently been investigated by Nishino et al. (2002) using an imaging riometer operated in southern Brazil. An example of simultaneous observation of energetic particle precipitation, as manifested in enhanced sporadic E-layer intensity over Cachoeira Paulista (22.6°S , 315°E ; dip angle: 28°) and phase

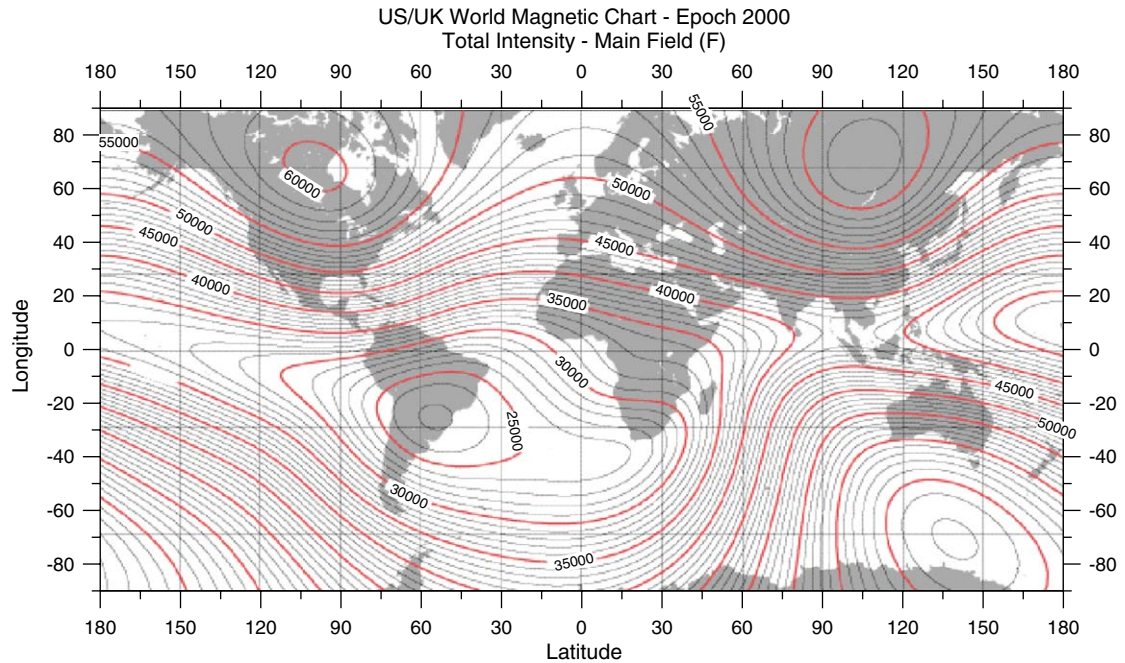


Fig. 1. The geomagnetic field total intensity distribution, represented by iso-intensity lines over the globe in which the lowest value of the total magnetic field intensity situated in South Brazil defines the position of the center of the SAMA (South Atlantic Magnetic Anomaly), which was located in the South Atlantic several years ago. The unit is in nanoTesla (nT), and the contour interval is 2000 nT.

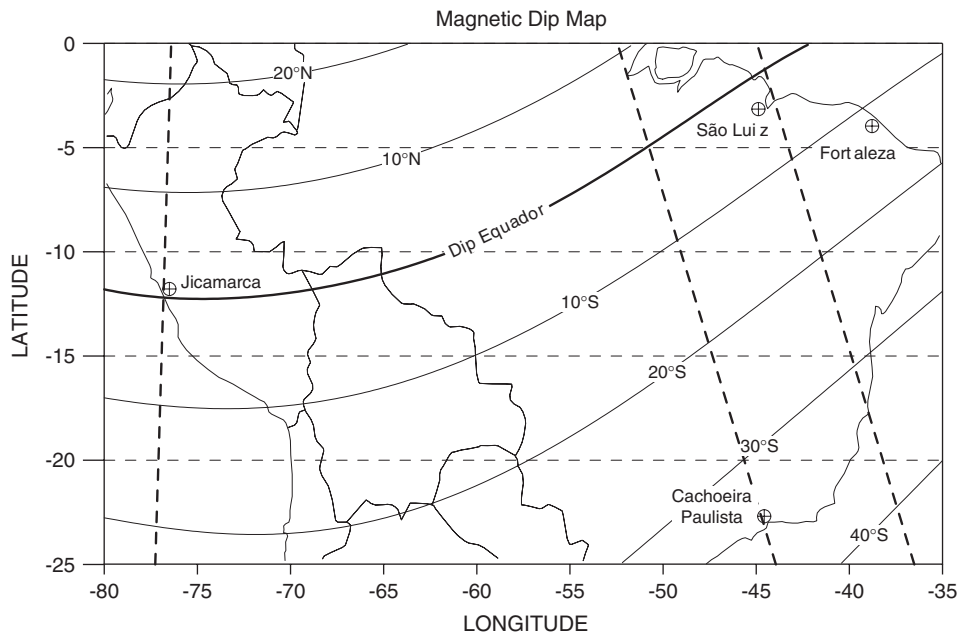


Fig. 2. Magnetic declination angles over Peru and Brazil. The declination angle is $\sim 21^\circ\text{W}$ over Fortaleza (FZ), Brazil, and $\sim 4^\circ\text{E}$ over Jicamarca (JIC), Peru.

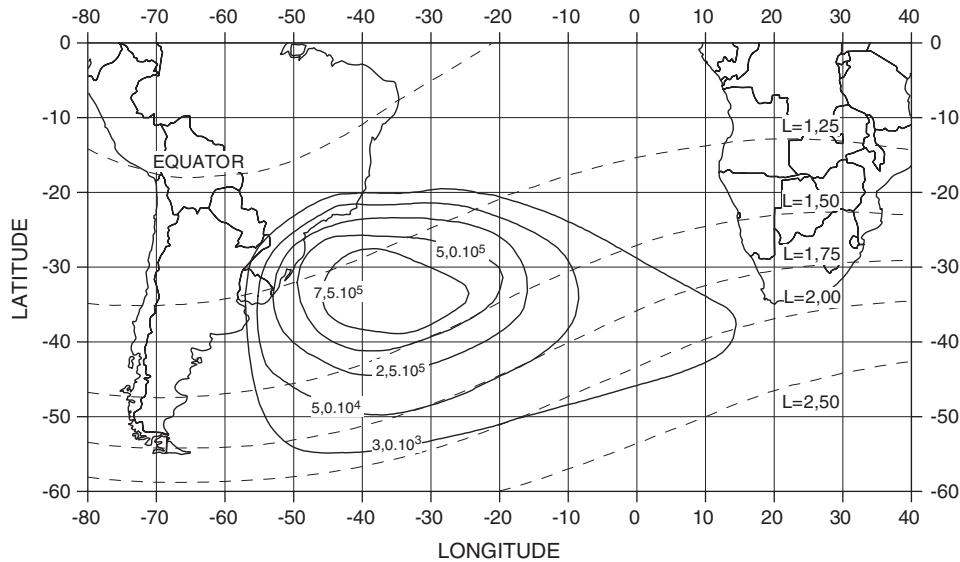


Fig. 3. Contours of constant omni-directional flux of fission electrons ($\text{cm}^{-2}\text{s}^{-1}$) at 0.29 MeV energy for altitudes 320 ± 45 km as observed by a COSMOS satellite. Due to the secular westward drift of the SAMA, the region of maximum flux has moved over to the Brazilian land mass during the course of years since this measurement was made in the 1960s.

advance of VLF signals received at Atibaia (23°S, 45°W, dip angle: 28°) are shown in Fig. 4 (Abdu et al., 1981a). Increases in sporadic E-layer frequencies, the f_{Es} (the top frequency backscattered by the layer) and the f_{bEs} (the blanketing frequency which indicates the plasma frequency of the reflecting layer) occur in events of a few hours duration during enhanced magnetic activity indicated by large Kp values, which suggested a corresponding increase in the E-layer ionization. Oscillatory variation in the intensity of the Es layer can be noted especially on the night of 3–4 May 1978. Their occurrence during night hours suggests particle precipitation in the E region as the source of the enhanced ionization needed to produce them. Simultaneous increase of D region ionization is indicated by the VLF phase decrease, (relative to the reference curve shown by the broken line) in events of varying intensity, that fluctuates at the same rate as that of the Es layer. In fact, significant lowering of the VLF reflection height (phase decrease) during the entire night with respect to the quiet-time reflection height of ~ 90 km persists on many nights in the examples shown in this figure. The effect seems to last even after Kp has decreased to its “quiet”-time values. Modulation of the precipitating particle flux intensity on time scales of several minutes to a few hours is indicated in these results.

Extensive analysis of the sporadic E-layer characteristics over Cachoeira Paulista has established that the occurrence, as well as the intensity of this layer, exhibits significant enhancements during magnetically disturbed conditions (Batista and Abdu, 1977; Abdu et al., 2003a). The plasma frequency of the layer at such times becomes

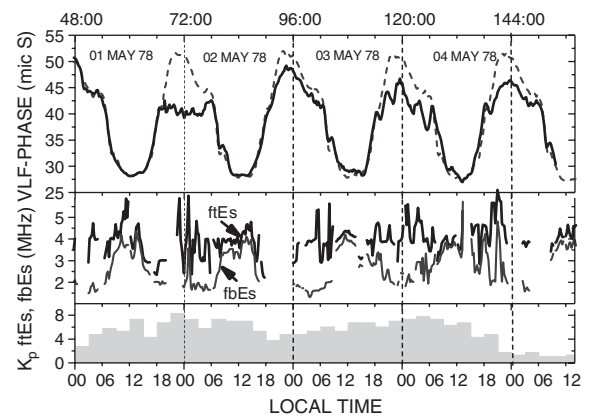


Fig. 4. Variation of the VLF signal phase, received at Atibaia, SP, (top panel) plotted during the intensely disturbed period of 01–04 May 1978. The VLF phase represents the reflection height of the VLF signals propagating in earth-ionosphere wave-guide, with the upper boundary nominally considered to be at 90 km during the night, and 70 km during the day. A decrease (advance) in phase indicates lowering of the VLF reflection height due to ionization increase below the normal reflection height. The dotted curve is a reference phase variation for quiet conditions. The middle panel shows the top frequency f_{Es} reflected by the sporadic E-layer whose plasma frequency is indicated by the blanketing frequency f_{bEs} . The Kp variations are shown in the bottom panel (Abdu et al., 1981a).

comparable to, or even exceed, the daytime E-layer peak densities. Furthermore, as shown in the example of Fig. 5, such Es layers are identified by traces of range spreading echoes similar to those of auroral-type

sporadic E layers that are well known to be produced by auroral-zone particle precipitation. Our analysis of Es layers over Cachoeira Paulista under magnetically quiet conditions has revealed that their regular occurrence during night hours could only be explained by a nighttime source of ionization that could be attributed to particle precipitation in the SAMA region (Abdu and Batista, 1977). Thus, there is accumulating evidence that energetic particle-induced ionization is a regular feature of the ionosphere over the SAMA even under magnetically quiet conditions that should result in a correspondingly modified/enhanced ionospheric conductivity distribution over this region, and that significant enhancement of the conductivity distribution pattern could occur during magnetic disturbances.

3. Electrodynamic effects due to the SAMA

The influence of the SAMA on the equatorial ionospheric electrodynamic processes could operate mainly in two ways: (1) via the influence of the magnetic declination angle that controls the F layer dynamo development in the evening hours, which is a regular quiet-time feature and (2) through the enhanced ioniza-

tion by particle precipitation with enhanced conductivity adding to the background conductivity distribution in the ionosphere over the SAMA region under quiet conditions, and additional enhancements of the ionization and the conductivities with their modified spatial distributions that could dominate during magnetic disturbances.

3.1. Magnetic declination effect on the evening equatorial electrodynamic

Significant differences in the evening electrodynamic processes that control the conditions for equatorial spread F development have been noted between the Peruvian and Brazilian longitude sectors and attributed to the significant variation of the magnetic declination angle between the two longitude sectors (Abdu et al., 1981b). The longitudinal variation of the magnetic declination angle in the south American sector is a part of the SAMA magnetic field configuration, and it varies drastically between the west and east coasts of South America, as shown in Fig. 2. The associated effects on the sunset electrodynamic processes can be explained as follows. The F layer undergoes rapid uplift in the evening hours, which is a pre-requisite for the post-sunset spread F/plasma bubble irregularity development under the Rayleigh–Taylor instability mechanism. The layer uplift/vertical plasma drift is caused by an enhanced zonal electric field known as the pre-reversal electric-field enhancement (PRE), produced by the F-layer dynamo. The PRE develops under the combined action of an eastward thermospheric wind and the longitudinal gradient in the field line integrated Pedersen conductivity that exists across the sunset terminator (Rishbeth, 1971). This integrated conductivity gradient has a major contribution from conjugate E layers, and therefore attains its largest values when the sunset terminator moves parallel to (aligned with) the magnetic meridian, which corresponds to near-simultaneous sunset at conjugate E layers. This condition leads to the generation of PRE with largest intensity as was pointed out by Abdu et al. (1981b). The large westward declination angle ($\sim 21^\circ\text{W}$) in the Brazilian Atlantic sector causes this condition to prevail during a period close to December, when, therefore, a seasonal maximum occurs in the intensity of the PRE (F-region vertical drift) and hence in the spread F irregularity (ESF) occurrence. In the Peruvian sector, where the magnetic declination angle is small (and eastward), such propitious condition for seasonal maxima (i.e., alignment of the magnetic meridian and sunset terminator) occurs during equinoctial months. Thus, while a broad seasonal maximum in ESF irregularities occurs around December over Brazil, two equinoctial maxima occur over Peru as shown in Fig. 6. In Fig. 6, the left-hand panel shows a plot of monthly mean percentage

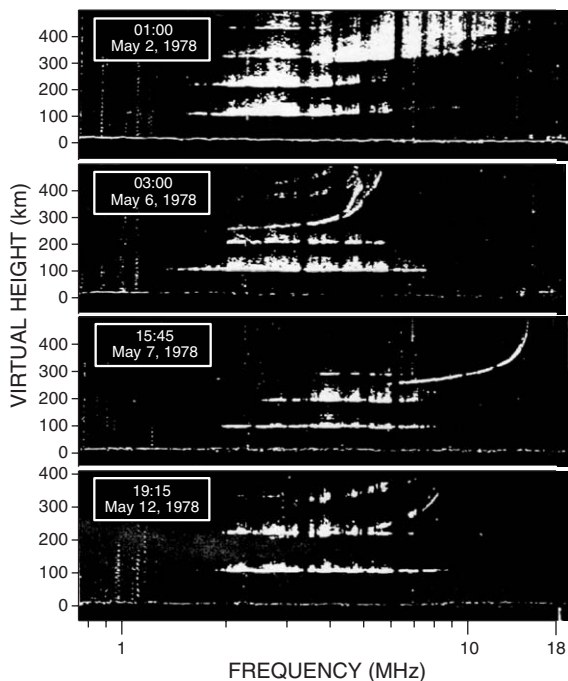


Fig. 5. Examples of sporadic E layers over Cachoeira Paulista during magnetically disturbed conditions. The range spreading of the trace is similar to that which is characteristic of auroral Es layers produced by particle precipitation. Ionospheric absorption of the radio waves causes range spreading less marked during the day (Batista and Abdu, 1977).

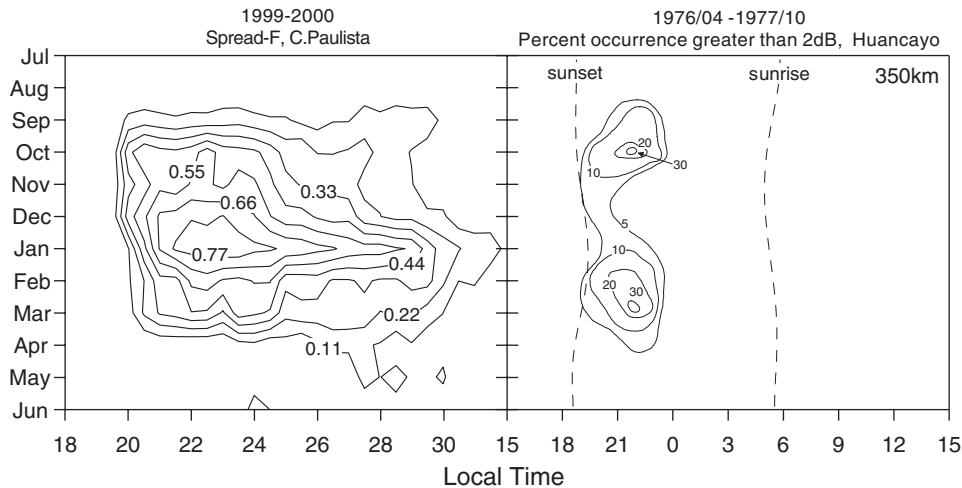


Fig. 6. Left panel: Month versus local time variation of equatorial spread F occurrence (in monthly mean percentage occurrence values) over Cachoeira Paulista showing a broad summer maximum. Right panel: UHF (1.6 GHz) scintillation occurrences over Huancayo, Peru, showing two equinoctial maxima (taken from Basu et al., 1980).

occurrence of ESF over Cachoeira Paulista in month versus local time format. It should be noted that the bottomside spread F statistics over Cachoeira Paulista in fact represent the statistics of well-developed flux tube-aligned plasma bubbles extending from their equatorial apex height to the F-region bottomside over this station (Abdu et al., 1983). A seasonal maximum centered in December–January is a well-defined feature here. The right panel presenting similar statistical plots of UHF scintillation over Peru (Basu et al., 1980) shows two equinoctial maxima as expected.

3.2. SAMA-associated conductivity longitudinal gradient and the enhancement of the quiet-time PRE

Besides the difference in the seasonal pattern of the PRE between the east and west coast of South America (brought about by the difference in the magnetic declination angle) just explained above, there is also a significant and systematic difference in the amplitude of the PRE between the two sectors; the amplitude in the Brazilian sector being generally higher than in the Peruvian sector. Monthly mean vertical drift velocities obtained as the time rate of change of plasma frequency heights measured by Digisondes (Reinisch, 1996) over Sao Luis (Brazil) and Jicamarca (Peru) are compared in Fig. 7 for the four seasons, i.e., two equinoctial and two solstice months. The monthly average solar flux (F10.7) units are indicated in the figure. Only the vertical drift velocities around the evening PRE maximum are of interest here. The V_z values obtained from digisondes at other local times, when generally the F-layer bottomside height is less than 300 km, can differ significantly from the real drift velocities owing to photochemical/recom-

binations effects as explained by Bittencourt and Abdu (1981) (see also, Abdu, et al., 2004). Seasonal as well as solar flux dependence of the PRE amplitude (in agreement with the results of Fejer et al., 1991) can be noted in the figure. The PRE amplitude over Jicamarca, even during its expected seasonal maxima, in March and September, is smaller than that over Sao Luis. The difference becomes more marked when the seasonal maximum of V_z occurs over Sao Luis during December. Thus, the PRE amplitude over the eastern longitude sector of South America tends to be always higher than that over the western sector. An explanation for this difference can be sought in terms of the possible difference in the evening ionospheric conductivity longitudinal/local time variations over the two sectors arising from the proximity of the SAMA to the eastern longitude sector, as follows:

Thermospheric zonal winds produce, by dynamo action, a vertical polarization field in the F region whose magnitude is dependent upon field-line-integrated conductivities and current flow between E and F regions. The associated E–F-region electrical coupling processes leading to the generation of the PRE was first modeled by Heelis et al. (1974) (see also, Farley et al., 1986; Batista et al., 1986; Crain et al., 1993). As explained in Abdu et al. (2003b) the vertical electric field can be written as: $E_v = U_y B_0 [\Sigma_F / (\Sigma_F + \Sigma_E)]$, where Σ_F is the field-line-integrated conductivity of the F region and Σ_E is that of the conjugate E-regions, U_y is the thermospheric zonal wind and B_0 is the magnetic-field intensity. During post-sunset hours Σ_E decays faster than Σ_F , thus, contributing to the development of a vertical electric field whose intensity increases towards the night side (i.e., across the sunset terminator). The

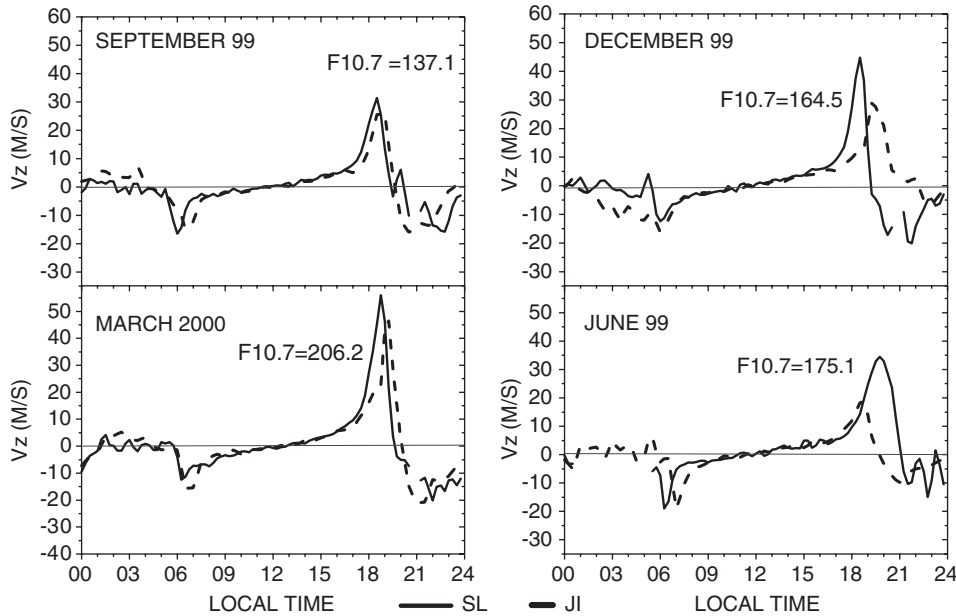


Fig. 7. F-region vertical drift over Sao Luis (solid line) and Jicamarca (dashed line) obtained from Digisonde data, plotted as monthly mean values representing 4 months: March 2000, June, September and December 1999.

application of the curl-free condition to such an electric field variation could result in the enhanced evening zonal electric field, the PRE, as suggested by Rishbeth (1971) and recently modeled by Eccles (1998). The local time variation of the E_v arises largely from that of the conductivity local time/longitude gradient.

In considering the difference in PRE amplitude between the west and east coast of South America, we need to consider the possible role of the thermospheric zonal wind as well as that of the conductivity longitudinal gradient ($\Delta\Sigma$). While there is no strong reason for the U_y amplitude to differ significantly within a relatively short longitude span, we have strong reason to expect that $\Delta\Sigma$ could be significantly different between the western and eastern longitude sectors due to the proximity of the SAMA to the latter. In order to examine the control of the evening E-layer conductivity/density variation on the PRE, we carried out a simulation of the vertical drift (PRE) variation using the E- and F-region electrodynamics coupling model of Batista et al. (1986) that was based on the original model of Heelis et al. (1974). The results are presented in Fig. 8 (see also, Abdu et al., 2004). This figure shows, in the lower panel, the E-layer critical frequency (f_oE) (which corresponds to the layer peak density, N_mE) as a function of local time during daytime as observed over Fortaleza, and its extrapolation to possible different nighttime values. Each of these model curves identified as mod1, mod2, etc., in the figure represents a different

conductivity local-time gradient around sunset that produces different amplitudes of the pre-reversal vertical drift enhancement shown in the upper panel. It can be noticed that the steeper the gradient in f_oE (i.e., E-layer Pederson conductivity), in the transition from day to night, the higher the peak amplitude, V_{zp} , of the evening V_z variation (i.e., PRE).

Fig. 9 shows a sketch of how an enhanced conductivity distribution, with the conductivity decreasing from a hypothetical location of maximum intensity of E-region particle precipitation in southern Brazil, could result in a westward gradient in Σ that can add to the normal $\Delta\Sigma$ across the sunset terminator that is also directed westward. The consequence of the resulting enhanced $\Delta\Sigma$ will be to produce larger PRE according to the model simulation result of Fig. 8. Thus, a possible enhancement of the conductivity gradient due to quiet time particle precipitation in the SAMA could contribute to an increase in the post-sunset V_{zp} in the Brazilian sector. The significantly larger V_{zp} over Brazil as compared to the V_{zp} over Jicamarca in Fig. 7 can be accounted for in this way. We should point out that for a given electric-field intensity, the vertical drift (E/B) should be obviously larger for a weaker magnetic-field intensity. However, it is difficult to evaluate any possible contribution from this factor to the vertical drifts at the two longitude sectors due to the lack of direct and simultaneous measurements of electric fields at these places and due to the wind dynamo (from $U \times B_0$

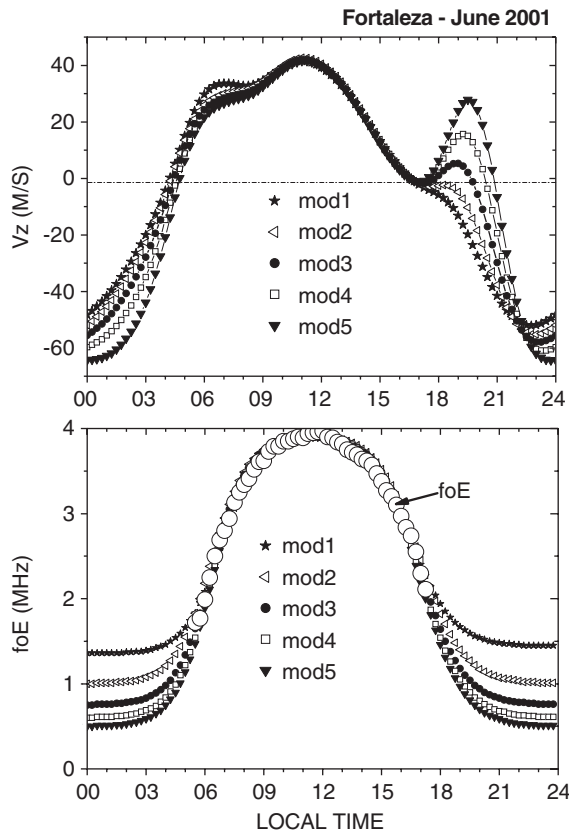


Fig. 8. Results of simulation using an E-F-region electrical coupling model showing that a higher local time gradient at sunset in the E-layer Pedersen conductivity produces higher amplitude of the PRE. The E-layer critical frequency f_oE is plotted in the figure to represent the shape of the conductivity variations. The curves identified as mod 1 and mod 5 correspond to the lowest and highest conductivity gradients at sunset (lower panel) and correspondingly the PRE has lowest and highest amplitudes (upper panel).

forcing) required to produce the E_V mentioned before (see also further considerations on this point in the discussion session).

3.3. Effect of storm-associated enhanced conductivities on the post-sunset plasma drifts

During magnetic disturbances, intense particle precipitation can cover a wider geographical area. DMSP satellite measurements of energetic particles, at ~ 840 km, during the great magnetic storm of March 1989, show that the geographic region affected by particle precipitation in the South American longitude sector could extend equatorward up to the latitude of Fortaleza as shown in Fig. 10 (Greenspan et al., 1991). Under such conditions, the combined effects of magne-

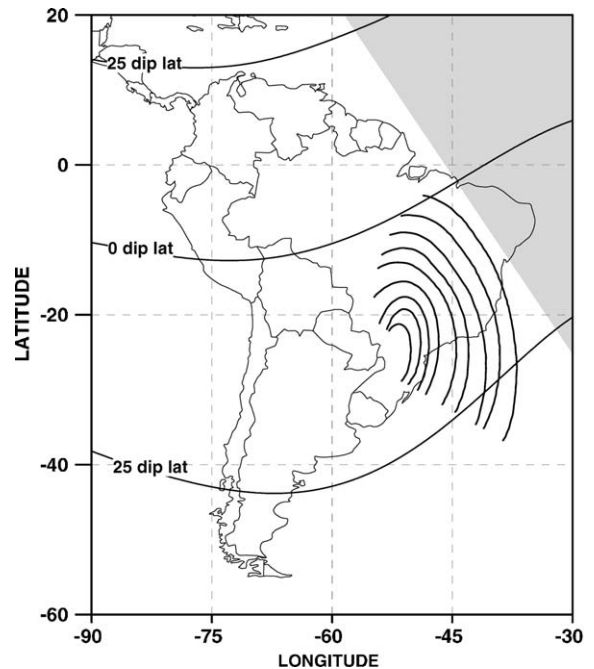


Fig. 9. A cartoon of the sunset terminator and the possible background ionization/conductivity pattern in the SAMA. The contours are drawn to represent conductivity decreasing with increasing distance from a hypothetical location of maximum conductivity region inside the innermost contour line near the center of the SAMA. This conductivity gradient due to ionization from quiet time particle precipitation in the SAMA contributes to an increase in $\Delta\Sigma$ across the sunset terminator that results in enhanced V_z (PRE) in the Brazilian sector.

tospheric electric field penetration to low/equatorial latitudes and the enhanced ionospheric conductivity due to energetic particle precipitation in the SAMA region could cause a complex response of the ionosphere over this region. The disturbance zonal electric field that penetrates to low latitudes could govern the electrodynamics of the equatorial ionospheric response in two ways: (1) through a direct effect on vertical plasma drift, by which an eastward penetration electric field occurring at sunset hours could cause uplifting of the F-region plasma that could be in phase with (and therefore add to) the normal vertical drift due to PRE, thus helping trigger the development of spread F/plasma bubble irregularities even during the season of their normal non-occurrence (Abdu et al., 2003a; Sastri et al., 1997), or causing a more intense bubble event during the season of its normal occurrence (Abdu et al., 1988; Hysell et al., 1990) and (2) through electric fields, generated by Hall conduction and divergence-free current flow in regions of conductivity spatial gradients produced by enhanced particle precipitation, under the action of the primary disturbance (penetrating) electric

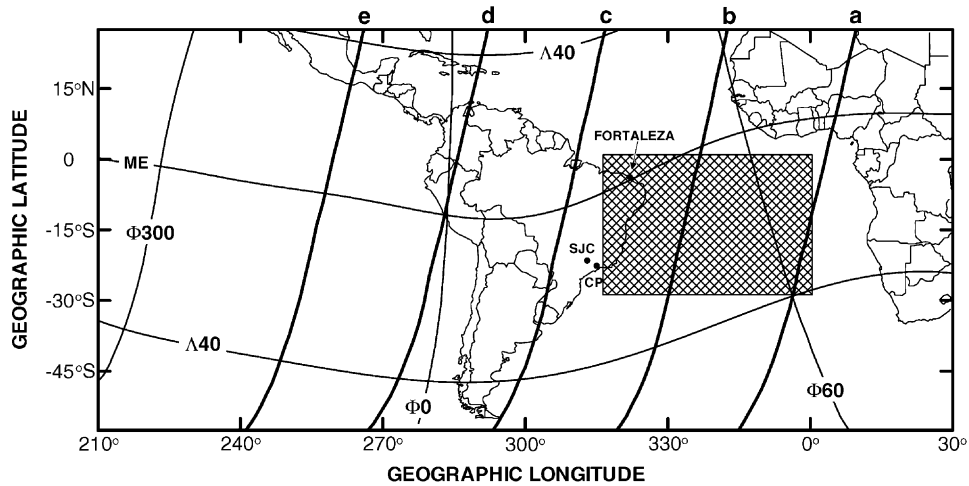


Fig. 10. Map showing the DMSP F9 satellite ground track, locations of Fortaleza and Cachoeira Paulista ionosondes. The symbols Λ and Φ designate the invariant latitude and magnetic longitude at 1000 km. The line labeled ME is the magnetic equator. The shaded area indicates the region of enhanced 30–80 keV protons in the South Atlantic Magnetic Anomaly during the main phase of the great magnetic storm of March 1989 (from Greenspan et al., 1991).

field (Abdu et al., 1998, 2003a). As regards the sunset and nighttime effects, while the ionospheric response due to the first process (direct effect of vertical plasma drift) can be observed in all longitude sectors, that due to the second should be observable only, or at least primarily, in the longitude sector of the SAMA. As far as the daytime effects are concerned, the responses arising from conductivity features, similar to those giving rise to the second process, but not necessarily caused by particle precipitation, should of course be observable in varying degrees at all longitudes, as are the effects from the first process.

Fig. 11 shows F-layer bottomside irregularity vertical drift velocity (middle panel) measured by a digital ionosonde (CADI—Canadian Advanced Digital Ionosonde) at Fortaleza, during a magnetically disturbed night in November 1994 as represented by the auroral activity indices shown in the top panel (Abdu et al., 1998). Oscillations in the vertical drift that are coherent, but somewhat shifted in phase, relative to the fluctuations in AE index, are out of phase with those in the zonal drift velocity (plotted in the bottom panel). Frequent cases of such “anti-correlated” vertical and zonal drift variations have been observed during magnetic disturbances, as shown by another example, in terms of the scatter plots, presented in Fig. 12. Such an “anti-correlation” between the vertical and zonal velocities can be understood based on a simple equation connecting the zonal and vertical electric fields, in which the current divergence effects are ignored for simplicity, and Hall conduction and neutral wind dynamo terms are included (see Haerendel et al., 1992; Abdu et al.,

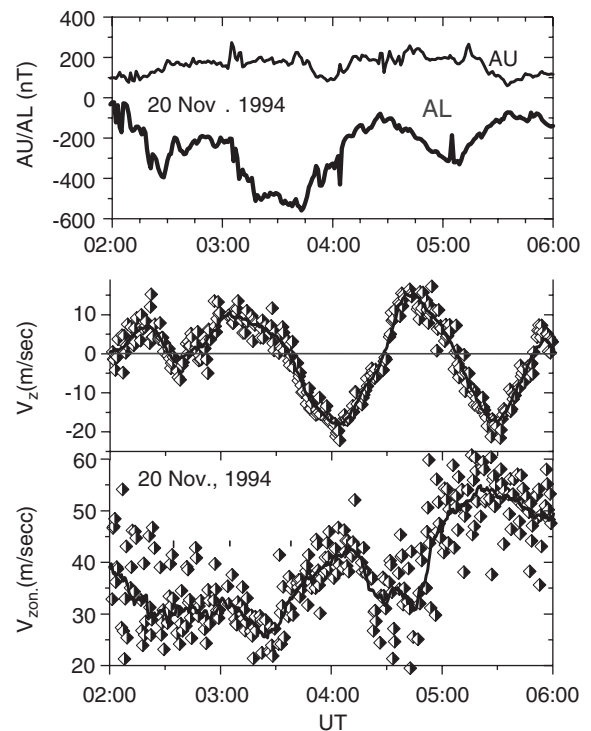


Fig. 11. Top panel: Auroral electrojet activity index AU and AL during a magnetic disturbance on 20 November 1994. Middle and bottom panels: vertical and zonal irregularity drift velocities, respectively, as measured by a CADI (Canadian Advanced Digital Ionosonde) over Fortaleza in the height region of 300 km.

1998, 2003a):

$$E_v \cong -BU_{EW}^P + E_{EW}[\Sigma_H/\Sigma_P], \quad (1)$$

where E_{EW} and E_v are the zonal and vertical electric fields, respectively. The first term on the right side represents the neutral wind dynamo, and U_{EW}^P is field-line-integrated conductivity weighted zonal wind. The term inside the bracket is the Hall conduction term, with Σ_H and Σ_P representing the field-line-integrated Hall and Pedersen conductivities, respectively. This equation clearly shows that the degree of “anti-correlation” between the two velocities, as shown in Fig. 12, is highly dependent on the variability in the neutral wind dynamo. Thus, these results do demonstrate the generation of a Hall vertical electric field due to a primary disturbance zonal electric field penetrating to the equatorial latitudes, under the presence of enhanced conductivity produced by particle precipitation in the nighttime ionosphere over the SAMA as was shown by Abdu et al. (1998). The influence of Hall conduction on daytime F-region plasma drifts as observed by the Jicamarca Radar has been shown by Fejer and Emmert (2003) for the case of a penetration electric field event associated with a solar wind pressure surge event. Their results are presented in Fig. 13. An increase in the solar wind pressure was responsible for the disturbance penetrating zonal electric field over the equator that

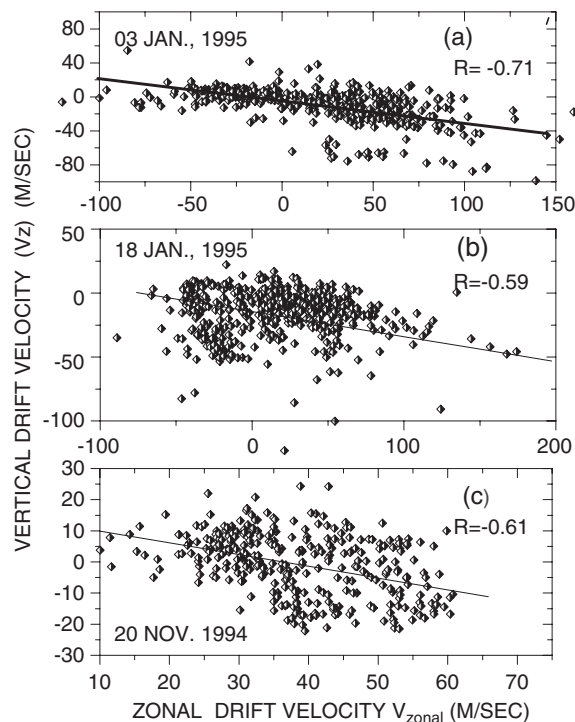


Fig. 12. Scatter plots of V_z versus V_x for three cases of disturbance electric field events.

caused vertical plasma drift and associated westward plasma drift very similar to the results in Figs. 11 and 12. These results were obtained during daytime over Jicamarca when the ratio Σ_H/Σ_P is large. Our results over Fortaleza correspond to night conditions when normally (under quiet conditions) the conductivity ratio, Σ_H/Σ_P , is not sufficient to produce the degree of Hall conduction observed in the results of Figs. 11 and 12. It seems to be clear therefore that an extra ionization enhancement and an associated conductivity enhancement, due to particle precipitation during magnetic disturbances, should be invoked to explain the large zonal velocity fluctuations that are anti-correlated with the vertical drift fluctuations seen in Figs. 11 and 12. No cases of “anti-correlated” vertical and zonal plasma drifts such as that present in Fig. 13 have been reported over Jicamarca under nighttime conditions. This point

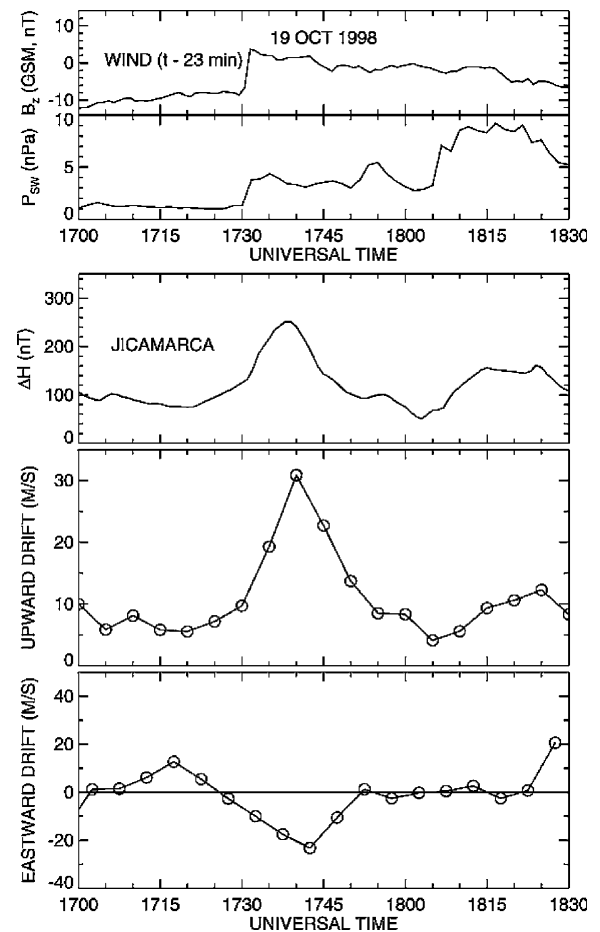


Fig. 13. Top panel: IMF, north–south magnetic field component and solar wind dynamic pressure measured by the WIND satellite and shifted by 23 min. Lower panels: Jicamarca horizontal magnetic field and plasma drifts observations near 1730 UT, on 19 October 1998.

highlights the uniqueness of the nighttime results over the Brazilian longitude sector and supports the contention that the SAMA-associated enhanced nighttime conductivity was indeed a necessary condition for the generation of vertical electric field /zonal plasma drift perturbations observed during magnetically disturbed periods.

4. Discussion and conclusions

Energetic particle precipitation in the SAMA region is a well-established phenomenon. The aeronomical effects in terms of enhanced ionization in the E and D region of the ionosphere that are caused by energetic particles of relatively lower energy range (electrons of < 100 keV and protons of a few MeV), are now well established based on the diverse results presented above. Furthermore, balloon-born X-ray measurements have detected energetic electron precipitation at stratospheric heights during magnetic disturbances (e.g., Pinto and Gonzalez, 1986; Jayanthi et al., 1997). More recent results from the radiation detector on board SAC-C satellite show the energetic proton flux over the SAMA region extending to equatorial latitudes. As its main focus, this paper addresses the question concerning the influence of enhanced particle precipitation in the SAMA on the electro-dynamical processes of the equatorial ionosphere arising from the modified ionospheric conductivity distributions, under quiet as well as disturbed conditions, a field of research that has not received any attention by the scientific community so far. On the other hand, this problem has great impact/implication on the currently important questions of longitudinal/seasonal variability of equatorial electrodynamic processes at sunset and associated spread F/ plasma bubble irregularity development conditions. In this context, the significant difference in the amplitude of the PRE between the east and west coast of South America in its monthly mean values calls for our special attention. The difference is real and significant since the same technique by similar instruments was used to obtain the vertical drift velocities at the two sites. Any significant/major role of thermospheric zonal wind in the evening hours in causing the observed larger V_p over Sao Luis, as compared to Jicamarca, seems unlikely on the basis of the following reasoning.

The two magnetic equatorial stations have different latitudinal separation from the geographic equator (in their respective longitude sectors), Sao Luis at 2.33°S being closer to it and Jicamarca at 12°S being farther from it. While this different separation from the geographic equator can cause different seasonal variations in the evening thermospheric zonal wind at the two locations, such a difference does not seem to be sufficient to account for the observed difference in the

PRE amplitudes. For example, in March, due to the proximity of the sub-solar point to Sao Luis, the evening zonal wind amplitude over this location can be larger than over Jicamarca, whereas the (solar radiation dependent) $\Delta\Sigma$ value is larger for the latter station where solar terminator and magnetic meridian alignment occurs in this month. We note, in Fig. 7, that the amplitude of the PRE is larger over Sao Luis (SL) during March, which might suggest that an expected larger zonal wind effect over SL might have overcome the expected increase of PRE due to a larger $\Delta\Sigma$ over Jicamarca. The situation reverses in December, when the magnetic meridian is better aligned with the sunset terminator, with $\Delta\Sigma$ being larger, over SL, whereas Jicamarca can be subjected to larger zonal wind. Yet the PRE over SL is again significantly larger than over Jicamarca. Thus, irrespective of the season-dependent zonal wind intensity variations over the two stations, the PRE amplitude is always higher over SL, as though one of the major control parameters for the PRE has a systematically larger amplitude (in all seasons) over SL. The situation can be explained if we include an extra $\Delta\Sigma$, with a westward increase of conductivity in the eastern sector of Brazil attributed to the SAMA-induced particle precipitation (as sketched in Fig. 9) that is superposed on the normal sunset $\Delta\Sigma$ which is also westward, so that the net enhanced $\Delta\Sigma$ could be a deciding factor in the generally larger PRE amplitude in nearly all of the seasons observed over SL. Further, we may point out that in view of the well-known westward secular drift of the SAMA, one would expect that the difference in the evening vertical drift velocities between the east and west coast of South America, as the present data set show, should continue to increase in the coming years.

Thus, the large-scale spatial gradients in conductivity arising from particle precipitation in the SAMA region seem to produce longitudinal electric field structure that is superimposed, in phase, on the pre-reversal zonal electric field enhancement in the sunset sector. The resulting longitudinal variation in the ESF/plasma bubble development and intensity, as has been clearly verified between the longitudes of Peru and Brazil, could constitute a significant component of the global-scale longitudinal variability of the phenomenon. A recent study by Burke et al. (2004) on the longitudinal distribution of the plasma depletions at 840 km using an extensive DMSP database, sought to verify the expected dependences of the plasma bubble development conditions on factors such as the terminator-magnetic meridian alignment and the magnetic field intensity over the equator (B_{eq}). Their results on the yearly distribution statistics of the plasma bubbles for different longitude sectors showed that the maximum occurrence rate generally corresponded to periods of the terminator-magnetic meridian alignment, which is in good agreement with the earlier such statistical results

based on global scintillation data presented by Tsunoda (1985). Thus, the magnetic declination control was found to be a generally valid first-order explanation (Abdu et al., 1981a,b; Tsunoda, 1985; Batista et al., 1986) for the seasonal/longitude dependence of ESF occurrence probability. The bubble distribution statistics presented by Burke et al. (2004) showed the largest rate of plasma bubble occurrence in the Atlantic sector, including the Eastern longitudes of South America that cover the SAMA region of lowest magnetic field intensity. They sought to associate the largest bubble occurrence rate to the weakest magnetic field intensity based on a previous suggestion by Huang et al. (2001) of a possible negative correlation between the two parameters. Such a negative correlation was expected on the premise that a longitudinally uniform electric field could produce larger vertical (E/B) drift in the evening hours (PRE) in regions of weaker magnetic field intensity. However, a clear association between the ESF occurrence and the magnetic field intensity was not forthcoming in their results, which is understandable in view of the expectation that the zonal electric field responsible for the vertical plasma drift itself results from the action of a wind dynamo (driven by the $U \times B$ forcing) so that a weaker electric field is not unexpected by virtue of a weaker magnetic field. Thus, a stronger vertical drift in the evening, leading to larger ESF/plasma bubble development (and hence larger occurrence probability), may not be entirely or necessarily related to a weaker magnetic field. The ESF occurrence rate increasing with eastward longitude in South America (to reach a global maximum in the Atlantic sector) as seen in the results of Burke et al., (their Fig. 2) is consistent with the generally larger PRE amplitudes observed by us over Sao Luis as compared to those of Jicamarca (Fig. 7). We have shown on the basis of the modeling results of Fig. 8 that larger PRE amplitude over São Luis could result from an expected larger longitudinal/local time gradient in the integrated E-layer Pedersen conductivity in the evening hours which can arise from the superposition of a westward gradient in the E-layer conductivity produced by the SAMA particle precipitation effect on the background westward gradient that exists across the terminator (as explained before).

The situation under magnetic disturbances becomes highly complex due to the disturbance magnetospheric electric fields that penetrate the equatorial latitudes and their interaction with the enhanced conductivity structure of the ionosphere over SAMA. Results presented in Figs. 11 and 12 for moderate magnetic disturbances showed that the vertical electric field resulting from Hall conduction induced by the interaction of the disturbance zonal electric field with the enhanced conductivity governs the dynamics of the spread F plasma irregularities over Fortaleza (as was explained by Abdu et al., 1998, 2003a). A possible effect of the enhanced

conductivity on the zonal electric field could not be clearly identified in these events. However, it is expected that the divergence-free conditions for the Pederson/Hall current driven by a disturbance electric field that is primarily zonal in regions of large-scale conductivity spatial gradients could lead to local generation of enhanced zonal electric field as well. Some evidence for such enhanced zonal electric fields seems to be available in the equatorial ionospheric response to very intense storms. An example of ionospheric F-layer height response to the great storm of 13–14 March 1989, at a number of equatorial low- and mid-latitude stations, distributed at different longitudes of the earth, taken from Abdu (1994) is presented in Fig. 14a (left panel). Here, the top panel shows the AE activity index variations during 12, 13 and 14 March and lower panel shows the virtual height of the F-layer base ($h'F$) for different stations including Fortaleza and Cachoeira Paulista in Brazil, and Dakar and Ouagadougou in West Africa, approximately 1 h in local time ahead of the Brazilian stations. Associated with the intense substorm activity around 21 UT of 13 March, i.e., in the evening sector (~ 18 LT) in Brazil, a drastic increase in $h'F$ occurred over both Fortaleza and Cachoeira Paulista. As explained by Batista et al. (1991) this corresponded to a penetrating disturbance eastward electric field of > 2 mV/m. In fact, the F layer disappeared for about 1 h from the 1000 km height range of the ionograms over Fortaleza and Cachoeira Paulista, and the spectacular height rise lasted past local midnight. In comparison to this, over the West African stations, also in the evening sector, but some 20° eastward, only a modest response (smaller height increase) was observed. This appears to be clear evidence of a strong longitudinal effect, in the equatorial/low latitude response to intense magnetic storms, with significantly enhanced disturbance zonal electric field intensity in the SAMA longitude sector. Another example of what looks like an enhancement of the penetrating zonal electric field in the SAMA longitude sector is shown in Fig. 14b (right panel), taken from Basu et al. (2001). DMSP passes over Fortaleza and Ascension Island during the great storm of 15–16 July 2000 are shown in the upper panel. The corresponding latitudinal cuts of ion densities as observed by the F14 and F15 satellites over Fortaleza and Ascension Island are presented, in the left and right panels respectively. The large bite out of the ion densities around the magnetic equator is similar to that observed, also in the evening sector, during the March 1989 storm by the DMSP F8 and F9 satellites, as reported by Greenspan et al. (1991), and is caused by the equatorial F layer rising to well above the ~ 840 km DMSP orbits, as a result of the large penetrating eastward disturbance electric field associated with the storm. We note that the width and (probably) the depth of the ion density depletion are significantly larger along

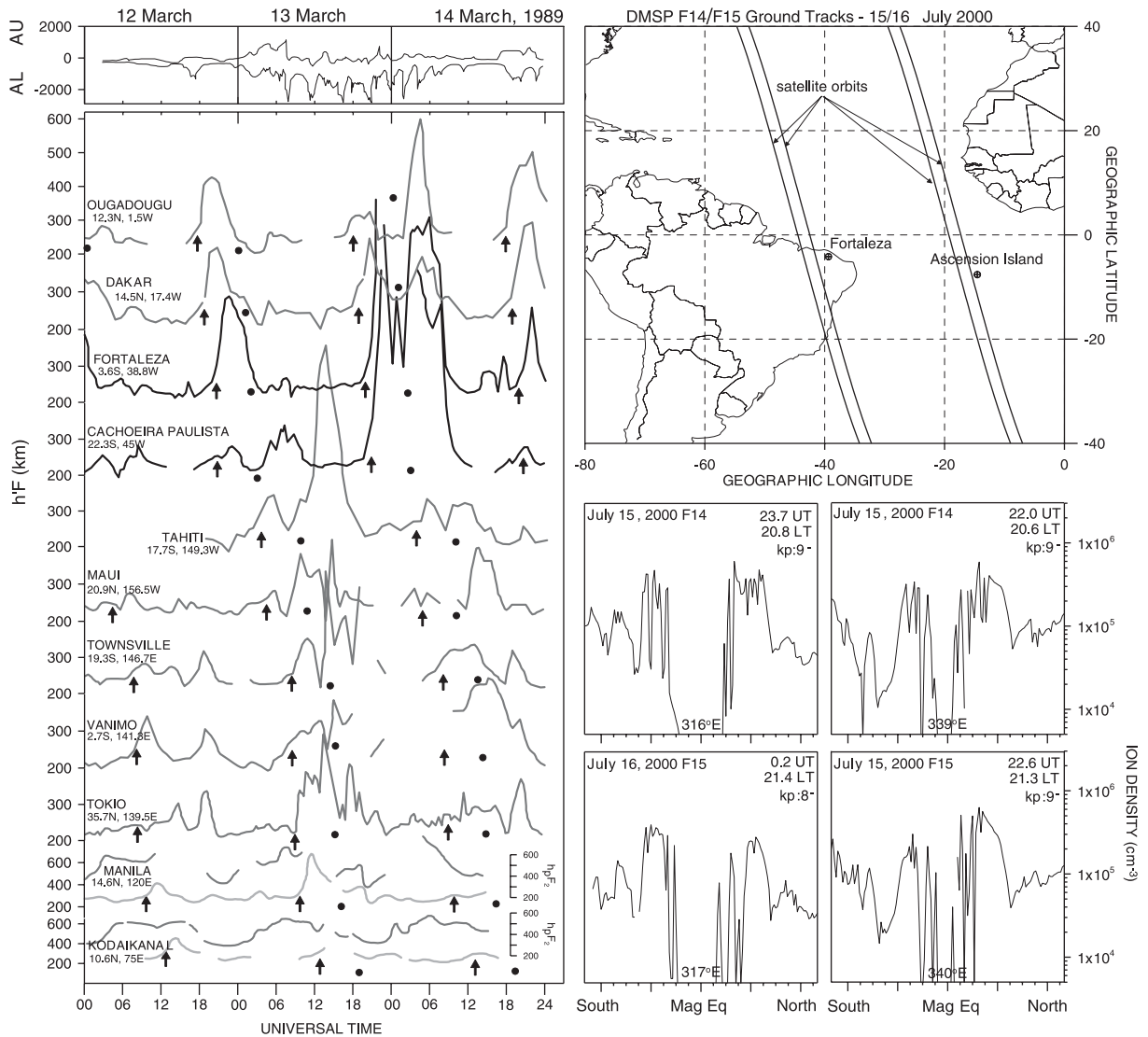


Fig. 14. $h'F$ variations over longitudinally distributed stations during the great storms of March 1989 are shown in the left panel (Abdu, 1994). Note the large increase of F-layer height over Fortaleza and Cachoeira Paulista (plotted in thick lines). The DMSP ion densities on the passes in the Atlantic sector between Brazil and Africa during the great storm of July 2000 are shown in the right panel (Basu et al., 2001).

the passes over Fortaleza than along those over Ascension Island, located only ~ 1.5 h in local time ahead of the former. Basu et al. (2001) have attributed this difference to the influence of the SAMA, which is most effective at the longitude of Fortaleza, decreasing with increasing longitudinal separation from there. Although the DMSP passes over the two stations, in Fig. 14b, are separated by ~ 1.6 h in UT, the significant longitudinal difference in the intensity of the disturbance eastward electric field between the two nearby longitudes is very similar to the results in Fig. 14a. In the latter case, the F-layer height rise (due to penetrating eastward electric field intensity) over Fortaleza was also signifi-

cantly larger than over the West African stations. Thus, there is important evidence to the effect that amplification/local generation of electric field takes place in the SAMA region under magnetically disturbed conditions. ROCSAT measurements in the SAMA region during the intense storm of July 2000 as presented by Lin and Yeh (2005) also suggest possible amplification of the disturbance penetrating electric field due to conductivity enhancement in the region. Further detailed analysis of this problem needs to be undertaken.

The present study leads to the following conclusions: energetic particle precipitation causing enhanced ionization in the ionosphere is a regular feature over the

SAMA, which is responsible for a modified background ionospheric conductivity distribution in the region. Such a conductivity spatial distribution seems to modify the conductivity longitudinal/local time gradients at sunset hours to a degree capable of affecting the quiet time sunset electrodynamic processes, and hence the development of the pre-reversal electric field enhancement in the evening hours that is known to control the conditions for equatorial spread F/plasma bubble irregularity development. The generally larger evening F-layer vertical drift over the eastern sector as compared to the western sector of South America seems to be caused by the proximity of the SAMA to the former. Significant intensification of particle precipitation and associated enhanced ionization modify drastically the ionosphere over SAMA during magnetospheric disturbances. The electrodynamic processes under such disturbed conditions are controlled by the interaction of the disturbance penetrating electric field with the enhanced conductivities and their spatial gradients. As a result, local generation of vertical electric field (zonal plasma drift) seems to take place during disturbances of moderate intensity. Significant enhancement in zonal electric field (vertical plasma drift) also seems to occur in the SAMA during intense magnetic storms. Thus, the particle precipitation in the SAMA region does seem to play a significant role in the equatorial ionospheric electrodynamics under quiet as well as disturbed conditions. This leads to important questions as to the role of the SAMA in influencing the longitudinal variability of equatorial spread F and in the equatorial ionospheric response to magnetospheric disturbances. More quantitative studies need to be undertaken to provide more detailed answers to these questions.

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