

TESLA'S CONTRIBUTION TO RADIO WAVE PROPAGATION

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Abstract In this paper we describe a review of the Tesla's contribution to radio wave propagation and wireless power transmission.

Tesla's patents, published and unpublished notes about radio wave propagation and wireless power transmission are less known, and if known to some extent, they are usually wrongly interpreted.

Keywords – Radio wave propagation, wireless power transmission, Nikola Tesla.

I. INTRODUCTION

Radio waves have been propagating through the universe for billions of years, take or give a few nanoseconds. However, radio waves propagating purposefully are less than 120 years old by about seven years, if Hertz in 1888 was first, i.e., if another Hertz on another planet in another solar system did not precede him. Radio wave propagation and the wireless communication revolution it spawned, however, are products of the twentieth century and the question "who invented the radio" has no straightforward answer in a form of a single name. In various papers we find names as Faraday, Maxwell, Hertz, Branly, Tesla, Popov, Lodge, and so on. Undoubtedly, all mentioned made great contribution to the development of wireless communications. Most often exposed single person is Marconi, who, inspired by Hertz, set the pace with his bold experiment perhaps in part based on Nikola Tesla's conjecture of a high reflecting layer in the atmosphereas indicated by William Gordon [1] who suggests that Marconi's famous transatlantic wireless communication experiment in December 1901 was a verification of an already predicted phenomenon, "perhaps in part based on Tesla's conjecture of a high reflecting layer in the atmosphere". This statement was criticised by Probir Bondyopadhyay [2] who stated that "Nikola Tesla never predicted the reflection of Hertzian waves by a high reflecting layer in the atmosphere and the consequent possibility of the transatlantic wireless transmission. Neither did he ever predict the existence of such a reflecting layer in the atmosphere". The fact is that Tesla's attempts to formulate a theory of wireless energy transmission proved wrong, but his apparatus built for this purpose was sound and correct, as well as his choice of operating frequencies for early global communications. It is interesting that this facts were taken into consideration in proving the invalidation of USA Marcony's patent No.763772, issued in 1900 [3], because it was preceded by Tesla's patent on the four tuned circuits issued on 1897 [4] and some other elements of Marcony's apparatus earlier filed in patents of Stone and Lodge.

Nikola Tesla, well known for his contributions to the present day alternating current system, and less known for his important discoveries in high frequency field, devoted nearly fifty years to developing ideas of wireless power transmission.

When he began to think about it, some time in 1890-1891, only a few facts were known about electromagnetic waves, following the publication of Hertz's work in 1888, which provided confirmation of J.C. Maxwell's dynamic theory of the electromagnetic field of 1865, scientists become more and more convinced that electromagnetic waves behaved like light waves, propagating in straight lines. Transmission along the globe could not be explained on the basis of diffraction theory, and in that period Tesla proposed a conduction wireless scheme in Tesla's own words [4]

The invention which forms the subject of my present application comprises a transmitting coil or conductor in which electrical currents or oscillations are produced and which is arranged to cause such currents or oscillations to be propagated by conduction through the natural medium from one point to another remote therefrom and a receiving coil or conductor at such distant point adapted to be excited by the oscillations or currents propagated from the transmitter.

In fact, prior to Marconi's famous transatlantic wireless experiment in Dec. 1901, that is what Tesla had to say about the Hertzian waves reflectomagnetic radiation.

It is interesting to note that in 1898 Tesla patented and ingenious radio control system for vessels (Fig. 1) often regarded as the first practical use of radio [5]. From May 1899 through January 1900, Tesla was in Colorado Springs [6] conducting further high-voltage, high-frequency experiments.

II. EARLY EXPERIMENTS OF RADIO WAVE PROPAGATION

Heinrich Hertz carried out his experiment in 1887-8 on power transmission by radio waves and demonstrated electromagnetic wave propagation in free space by using a complete system with a spark gap to generate high-frequency power and to detect it at the receiving end.

In 1881 Nikola Tesla invented the high frequency, high voltage transformer known since that time as "The Tesla Coil." [7]. This transformer contained little or no iron and still could easily, and with a high efficiency, produce extremely high voltages. With this transformer, and with a number of other inventions, at the turn of the century Nikola Tesla carried out his experiments on power transmission by radio waves. In his system Tesla used resonance to increase efficiency of the transmission of energy without wires.

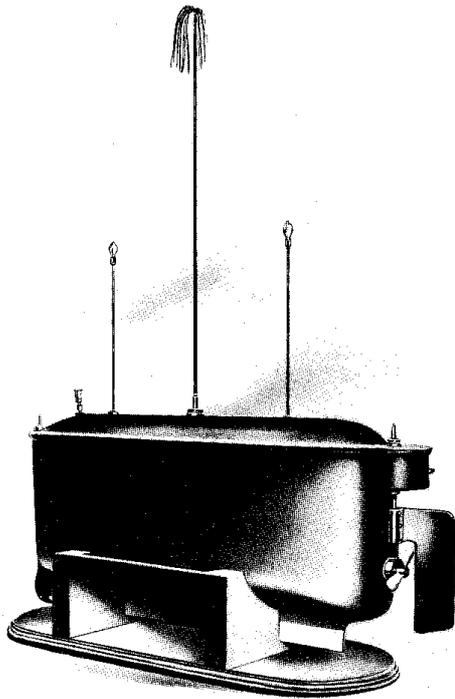


Figure 1. Wireless radio controlled vessel, 1898.

Figure 2. shows the first attempt to transmit power without wires using a high voltage transformer, conduction through a rarefied air and tuned step-down receiver transformer. The slide shown was found among Tesla's belonging in Nikola Tesla Museum in Belgrade.

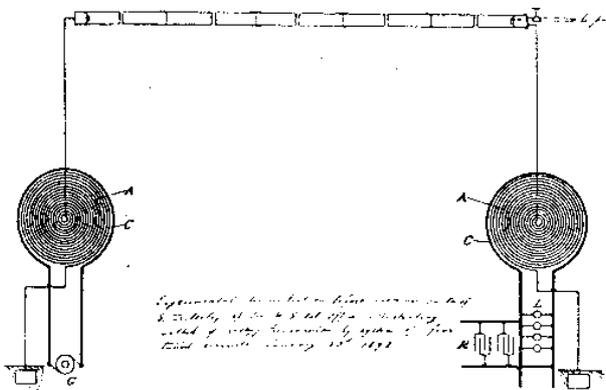


Figure 2. Diagram of apparatus demonstrating transmission of electric power through rarefied gas

In the East Huston Street Laboratory in New York (Fig.3), Tesla made several high voltage Tesla coils but the space was limited there, and in 1898 he began looking for a site for a new laboratory.

In New York he experimented with short-distance energy transmission for lighting lamps and driving receivers.



Figure 3. New York laboratory (1896-98)

III. COLORADO SPRINGS LABORATORY

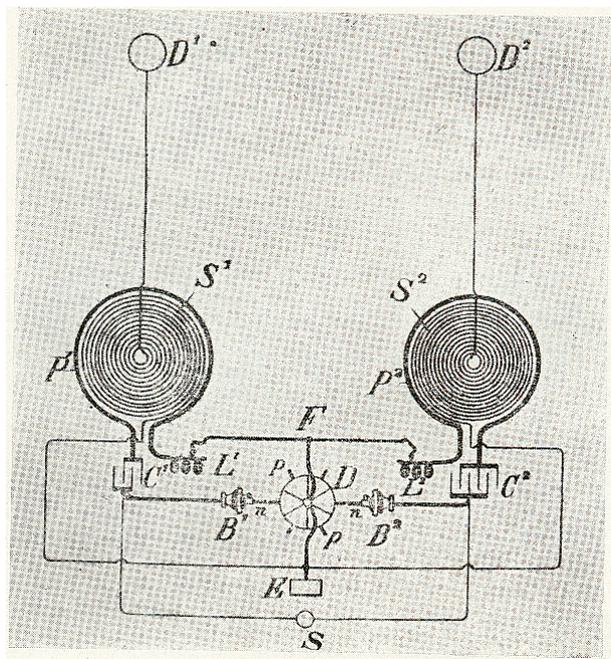
Under a \$30,000 grant from Colonel John Jacob Astor, owner of the Waldorf-Astoria Hotel in New York City, in mid-1899 Tesla finally decided on Colorado Springs, a plateau about 2000 m above sea level, where he erected a shed large enough to house a high-frequency transformer with a coil diameter of 15 meters. This gigantic coil was placed in a large square shed over which rose a 200-ft (61 m) mast with a 3-ft (91.4 cm) diameter copper ball positioned at the top.



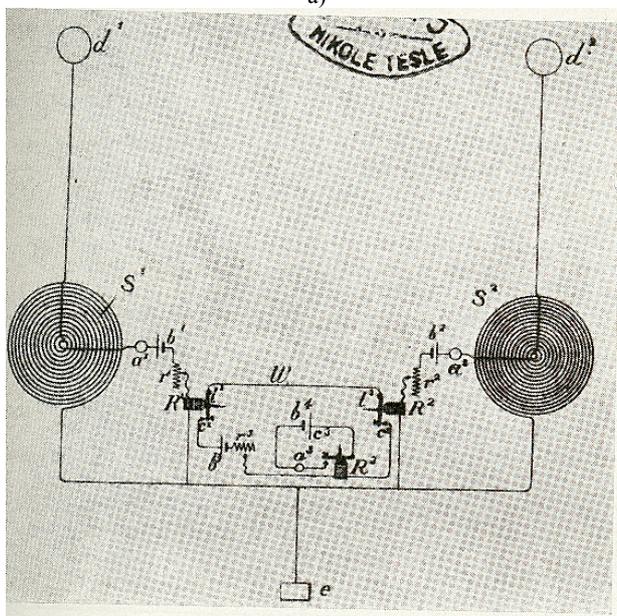
Figure 4. Colorado Springs laboratory (1899-1900)

In his article “The transmission of electric energy without wires,” [8] written in 1904 in the *Electrical World and Engineer*, Tesla writes that he came to Colorado Springs with the following goals:

- a) to develop a transmitter of great power
- b) to perfect means for individualising and isolating the energy transmitted.
- c) to ascertain the law of propagation of currents through the earth and the atmosphere.



a)



b)

Figure 5. Tesla double circuit selective space-telegraph system: a) transmitter; b) receiver

In Colorado Springs Tesla certainly thought a lot about his wireless transmission of energy but did not write much about it in his diary. He described some wireless energy transmission but all one could see in the diary points to

transmission over short distances [6]. Tesla himself claimed to have succeeded in transmitting a small amount of wireless power and setting up electrical waves with high-voltage discharges from the Tesla coil. He also experimented with a sophisticated construction of multicarrier transmitter with a special receiver tuned to all carriers (Fig. 5). It is stated in [9] that “*this invention consists in generating two or more kinds or classes of disturbances or impulses of distinctive character with respect to their effect upon a receiving circuit and operating thereby a distant receiver which comprises two or more circuits, each of which is tuned to respond exclusively to the disturbances or impulses of one kind or class and so arranged that the operation of the receiver is dependent upon their conjoint or resultant action*”.

Tesla double circuit system is in a way predecessor of modern spread spectrum radio system.

IV. LONG ISLAND LABORATORY

Nikola Tesla took energetic steps to get backing for the implementation of a system of “World Telegraphy” after returning to New York from Colorado Springs laboratory.



Figure 6. Long Island laboratory (1900-1917).

In a letter to his sponsor J. P. Morgan early in 1902 [10], Tesla explained in details his research aims in developing system for transmission of electrical energy. He envisaged three “steps to be made:

- a) the transmission of minute amounts of energy and the production of feeble effects, barely perceptible by sensitive devices;
- b) the transmission of notable amounts of energy dispensing with the necessity of sensitive devices and enabling the positive operation of any kind of apparatus requiring a small amount of power; and

c) the transmission of power in amounts of industrial significance.. With the completion of my present undertaking the first step will be made”.

For the experiments with transmission of large power he envisaged the construction of a plant at Niagara to generate about 100 million volts. In 1904 he wrote to Morgan that “The Canadian Niagara Co. will agree in witting to furnish me 10000 horse power, for twenty years without charge, if I put up a plant there to transmit this power without wires to other parts of the world..” [10].

In searching, through the archives of the Nikola Tesla Museum in Belgrade, many notes have been found relative to his long Island research. There are a few notes in 1901, more numerous in 1901 to 1903 and again a few in 1904, and hardly any in 1905 and 1906. In 1900 he prepared to work in the new laboratory (Fig. 6) and had to complete several patent applications. Among these patents is the one submitted on May 16, 1900 which is closely related to his wireless transmission plans. It was renewed June 17, 1902, but issued on April 18, 1905, under the title “Art of transmitting electrical energy through the natural mediums” (No. 787 412). Many of Tesla’s complicated explanations in this patent become more clear and even more acceptable, if his Long Island notes are studied, for example, when he states that “the rate of radiation of energy in the form of hertzian or electromagnetic waves is very small,” one may think that this is a nonsense, but when one read in his notes that he tried to select the operating frequency in such a way that the dipole formed by the globe and the judgment and think in terms of ELF propagation phenomena [11]. Tesla made calculations for operating frequencies 4, 6, 60 Hz, and at somewhat higher frequencies of 15 and 20 KHz. Particularly at the lower frequencies he expected the resonance of the earth to occur.

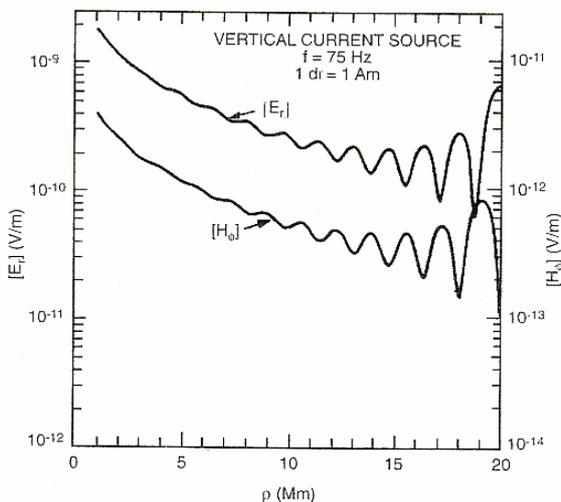


Figure 7. Principal fields in the Earth-Ionosphere waveguide radiated by a vertical electric current source.

Tesla assumed that the earth behaves like a solid conducting ball with current passing through the centre. Although this model was oversimplification, it let Tesla to correct conclusion that the standing wave over the earth surface will be established. Tesla’s claim about ELF earth

standing wave is illustrated in Figure 7 that is based on a correct model of earth ionosphere waveguide [12].

To illustrate Tesla’s assumptions about low attenuation of ELF waves, in Table 1. various experimental approximate values of attenuation at several frequencies of interest are given [12].

TABLE 1.

Frequency (Hz)	10	50	100	300	1000
Attenuation dB/Mm	0.25	0.80	1.00	3.00	20.00

If the antenna size is specified, it would be possible to calculate the overall efficiency of ELF system as function of distance and frequency.

Such a calculation is hardly necessary if a large distance system is required. The antenna efficiency of reasonable size is high enough at about 20 KHz, where the attenuation of the wave in propagation is too high. For example, an antenna that is made in the form of two umbrella shaped top loaded monopoles, each of 2 km in diameter and some 250 m high, with the grounding system of some 3000 km of copper, wire, has 86% efficiency at 20 KHz and only 0.1% at 100 Hz [12].

Hence, it is possible that the efficiency of the system may vary with frequency and distance but it will be always very low. Thus, at present, ELF system are used in communication with objects under the sea, where one can make use of the property of ELF waves to penetrate to deeply submerged receiving antennas.

Unfortunately, even today, the radiation systems at ELF are very inefficient due mainly to small electrical dimensions of antennas. It is interesting that Tesla was aware about that when he suggested using a vertical monopole (24 km long or so) or two metal plates buried some distance apart. Some latter Tesla’s development in antenna ELF design is shown in Figure 8, probably prepared for a patent application which was not accepted.

V. CONCLUSION

Tesla’s contribution to radio wave propagation and wireless power transmission was described in Tesla’s patents, published and unpublished notes. For many years Tesla tried to realise wireless transmission of energy on a large scale. He was convinced that at sufficiently low frequencies, low attenuation and standing wave characterised the behaviour of his transmission system. He also predicted that at very low frequency the earth resonances could be set. His concept of energy flow (through the earth!) was misleading. Tesla did not manage to produce practical system or persuade others to follow his ideas, but some of his statements and visions were proved much later when the research into ELF propagation phenomena began about half century later.

He patented a number of interesting receivers and complex transmission systems using more carriers which are early stages of sophisticated modern spread spectrum radio systems.

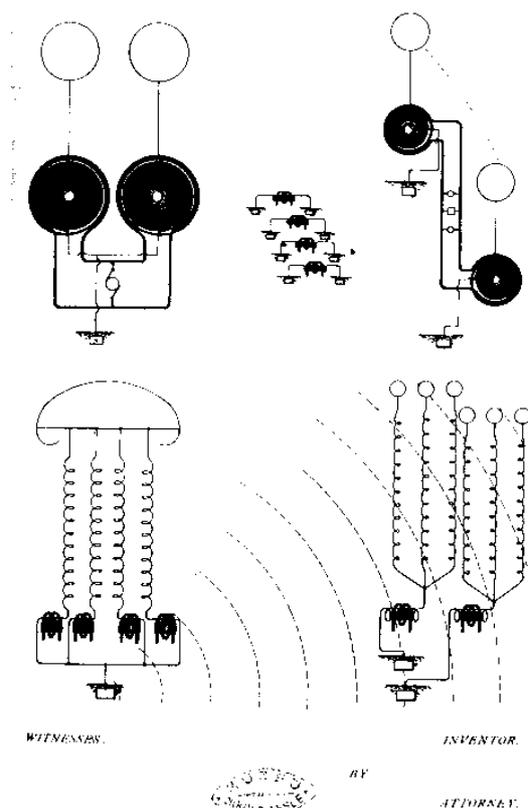


Figure 8. Arrangements of Tesla's antennas. The drawings were, probably, prepared for a patent application (Nikola Tesla Museum, Belgrade).

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