Experiments to proof the evidence of scalar waves

Tests with a Tesla reproduction by Prof. Konstantin Meyl

H. Weidner, E. Zentgraf, T. Senkel, T. Junker, P. Winkels,

Institut für Gravitationsforschung (IGF), Am Heerbach 5, D-63857 Waldaschaff
http://www.gravitation.org

September 2001

Summary

In this article we represent measurements, carried out on an unscaled replica of Nikola Tesla's, wireless energy transmission, the replica was designed by Professor Konstantin Meyl. He claims that with the replica, substantial observations made by Nikola Tesla, can be reproduced, among other things, the existence of scalar waves and over unity - effect.
For the time being, the effects described by Professor Meyl could be reproduced at the IGF. However close investigation of the arrangement, especially the analysis of the interference and error sources and the following realization of our own experiments revealed, that the transmission effects are within the scope of the classical electrodynamics, and can be explained through transmittance of transversal electromagnetic waves. An over unity effect was not observed. A precise description of the experimental studies conducted, as well as further examinations, are presented in this article and published in [7]

Table of contents

1 Introduction

According to Professor Meyl is his experimental kit, an unscaled smaller replica of Nikola Tesla’s assembly, Meyl distributes the kit commercially. At the beginning of the 20th century, Tesla allegedly succeeded with his assembly a wireless and very efficient energy and information transmission. Tesla’s assembly, on which the experimental kit of Professor Meyl is based upon, is described in US patent [3]. This patent was Tesla’s result of extensive work to transfer energy. In patent [1] he describes a assembly, in which he used a grounding connection as well as line interfacing. In further developments, illustrated in figure 1 below (taken from [2] he used instead of wire an air filled glass tube; the air pressure is extremely reduced. Subsequently he registered the patent [3,] as wireless transfer of energy, which exclusively gets by with a ground connection. The assembly is displayed in figure 2. Tesla used in all these assemblies resonant circuits of high quality, to produce high frequency voltage.

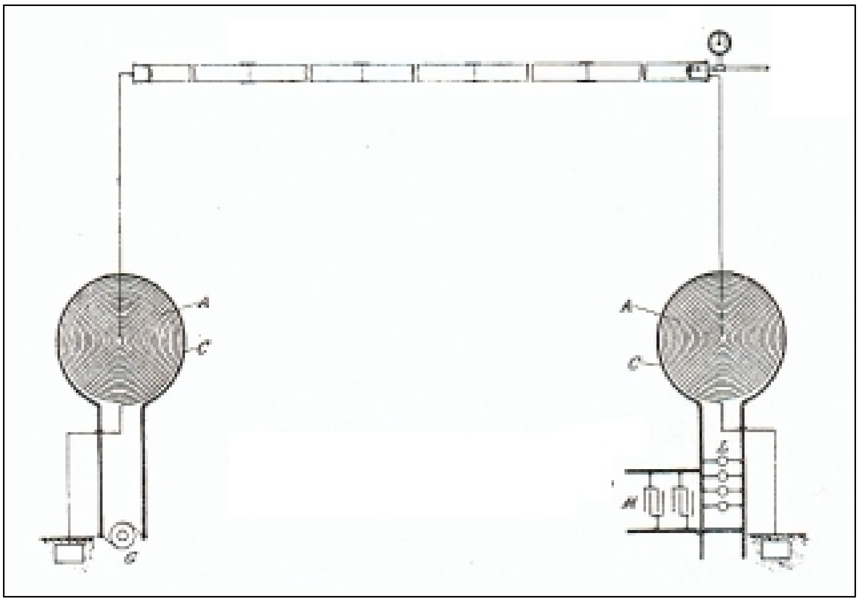


Illustration 1: Assembly for energy transmission through an air filled glass tube were the air pressure is extremely reduced.
(Reference: N. Tesla *Colorado Spring Notes 1899-1900*)

Temporarily, Tesla assumed, that the air is responsible for the transfer of energy, which in high altitude and under low pressure becomes conductive, see patent [3] and patent [4]. He contradicts however partly this theory in patent [5] wireless energy transmission. There he assumes, the transfer of energy takes place also through earth, by means of longitudinal waves. A summary of Tesla’s work, the transfer of energy, can be referred in essay [6] by André Waser.

At least until 1900 Tesla assumed in his work, that the energy transfer, enabled through his assemblies, require a material medium such as air or earth.
At this point Professor Meyl continues a decisive step further. He claims that the transfer of energy is not bound to wave broadening, which require a material medium.
According to Meyl are electromagnetic longitudinal waves responsible for the transmittance. These longitudinal waves consist, according to Prof. Meyl, of electric potential vortexes. Electric potential vortexes, which after the classic electro dynamic, basis on the Maxwell-Equation, do not exist. Explained in detail in book [8], [9], [10] and [11] by Prof. Meyl.

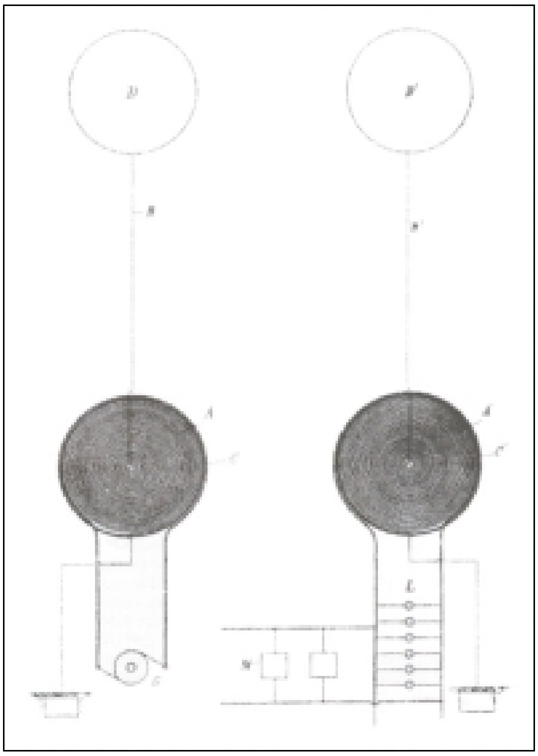


Illustration 1: Assembly for wireless energy transmission – grounding is essential
(Reference: N. Tesla *Collected German and American Patents*)

So far our short theoretical pre considerations. The emphasis of this article is however not the theory of the wireless transfer of energy developed by Nikola Tesla, but those experiments executed with Prof. Meyl's replica. With his assembly, Prof. Meyl states, it is possible, to experimentally verify following assertions.

1. The verification of standing electromagnetic longitudinal waves is achievable with this assembly

2. The assembly shows a so called overunity effect, if it is operated in a certain working position.

Besides experiments to test these two main-hypothesis which effect fundamental physical theories, Prof. Meyl described a further interesting experiment. He claims, that during the transmission between the transmitter and receiver the Faraday cage is effect less.

In our IGF laboratory we reviewed these two main hypotheses as well as the Faraday cage experiment. These results are defined in the following chapters.

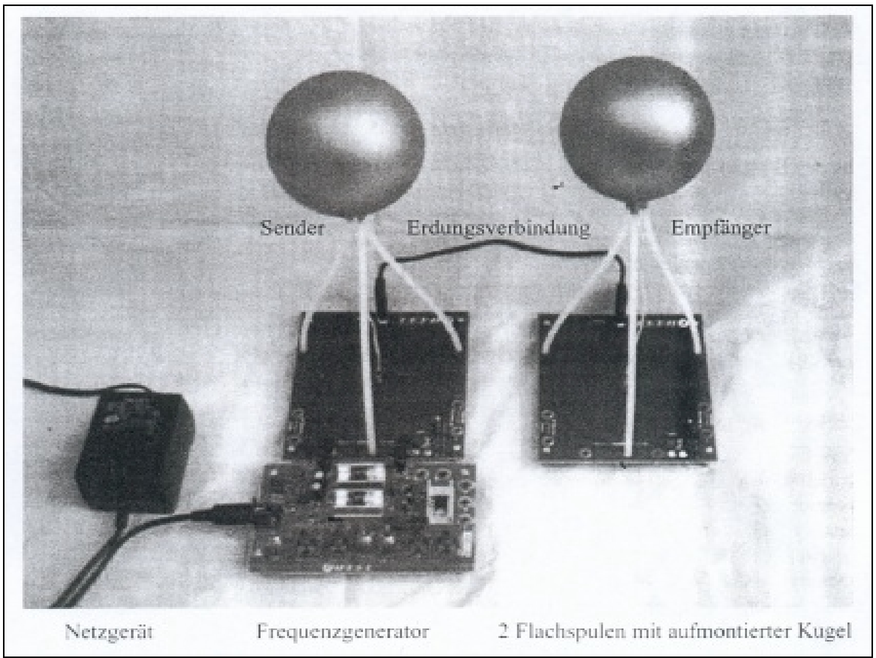
2. The experimental kit and measuring equipment

2.1 Complexity of the experimental kit

The experimental kit includes a total of 6 each Tesla flat coils with different wire lengths, 2 sphere electrodes, a frequency generator and a frequency counter. On each of the Tesla flat coils a sphere electrode can be attached. Furthermore can each of the flat coils, with attached sphere electrodes, be operated as transmitter or as receiver.

The power consumption (input) is displayed qualitative through the intensity of reflection of the two light-emitting diodes on each of the coil. To carry out the experiment, the transmitting and the receiving coil must be connected to each other by with a single wire connection
This connection simulates the mass connection, described in Tesla's assembly.
In the experiments described by Prof. Meyl, arrangements have to be operated from different resonance points.

These resonance points are adjusted through regulation of the frequency on the frequency generator. Illustration 3 shows a typical assembly that can be realized with the experimental kit. The theory of Prof. Meyl as well as suggestions on experiments with the experimental kit are specified in [12].



Transmitter – Sender   Maß connection – Erdungsverbindung   Receiver – Empfänger
Power Supply – Netzgerät   Frequency generator - Frequenzgenerator
2 flat coils with sphere electrodes – 2 Flachspulen mit aufmontierter Kugel

Illustration 2: typical assembly, which can be realized with Meyl's experimental kit.

2.2 Used measuring equipment in the IGF

During the replication of Meyl's experiments and realization of our own experiments with Meyl'ss experimental kit we used following measuring equipment:

> Digital table multimeter *Fluke 45*
> Digital table multimeter *Fluke 85-4*
> Digital oscilloscope, 4 channel, range 500 MHz *Tektronix TDS 3054*
> Antenna measuring equipment *Kathrein MFK 55*
> Signal generator *Fluke 6062 A*
> Spectrum analyser *Hewlett Packard 8594 EM*
> RCL meter *Fluke PM 6304*

3 Exact reproduction of experiments

Our first step was the exact reproduction of Prof. Meyl'ss suggested experiment. specified in above-mentioned hypothesis. Experiments are described in documentations accompanying the experimental kit. The results were reproduced as well.

To our estimation however, these results have no particular high relevance, because in the documentation there is no indication of analysing the disturbances and the error sources. Our work however, consisted to a great extend in the analyses of the error sources, followed by exact reproduction of Meyl's results.

4 Our performed test with the experimental kit

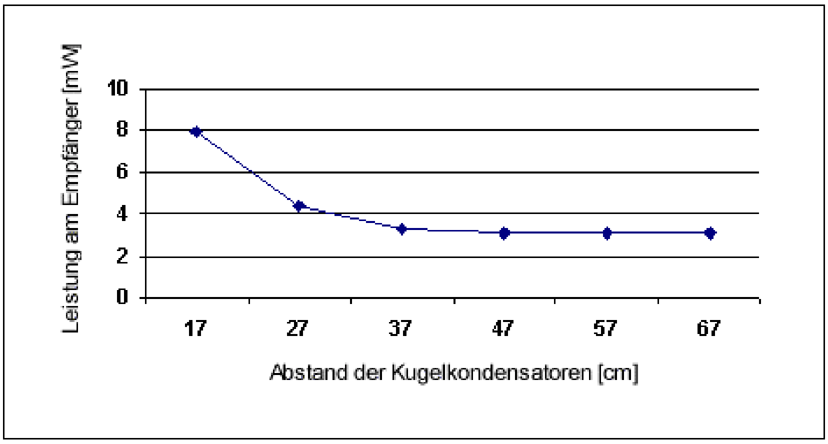
4.1 Eliminating disturbance and error sources

Our first step, for time being, was to minimize the well-known possible error sources that occur on measurements within the HF field.

> The use of short cables, to avoid antenna effects.

> Galvanic separation of equipment from the 230V alternating-current supply The separation was realized by using accumulators. After we noticed that the inverter used, had an interfering radiation in the vicinity of 6MHz, we converted the equipment to operate with direct current voltage.

> The measurements, after removing the error sources however, revealed a distance dependency, measured on the receiver's performance. The result is described in illustration 3. This was the first clear indication, that the energy transmission between transmitter und receiving module does not take place on the basis of scalar waves.



Measured power of the receiver – Leistung am Empfänger
Distance of the sphere condenser – Abstand der Kugelkondensatoren
Illustration 3: distance dependency measured on the performance of the receiver

4.2 Operational hypothesis Lecher line

The plainest explanation on the behaviour of the assembly is the assumption, that on the mainline of the assembly a standing wave occurs. Professor Meyl's has, until now, always denied, that the performance of his assembly can easily be explained. His explanatory statement was, that the wavelength of the fundamental frequency is noticeable larger as the overall length of the line. The basic frequency according to our measurements runs in the range of (5,35±) MHz. The wavelength is calculated by the following equation.

$$\lambda = \frac{c_{Cu}}{\nu} \approx \frac{c}{\nu} = \frac{3 \cdot 10^8 m/s}{5,35 \cdot 10^6 Hz} = 56,07m$$

A calculation of the total length of the assembly leads to 18,9 m (see paragraph 4.4.2).) Following we will justify, under which circumstances, on a line in the length of 18,9 m a standing wave, with above specified frequency of (5,35±0,1) mc/s can expand. The length of the line is calculated by the distance of the highest point of one sphere condenser to the highest point of the other sphere condenser.

4.2.1 Standing waves on a Lecher line

The classic form of the Lecher lines (called after the physicist Lecher 1856-1926) are long, approximately at a 10 mm distance parallel strained copper wires, connected at the beginning. Inductive energy is linked. The end is either connected or ends open, influencing the resonant frequency.
In this chapter we always imply on an oscillator with a short-circuited beginning and an open line end (right) (see illustration 5), the reason for doing so is that the results are easily transferable to Meyl's's Tesla short-circuit. Furthermore should the assembly be operated in air ($\varepsilon_r = 1$) and no ferromagnetic material near by.

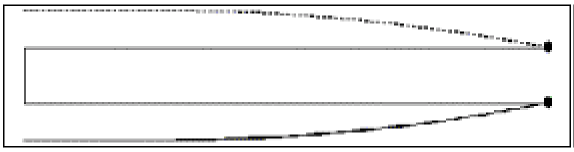


Illustration 4

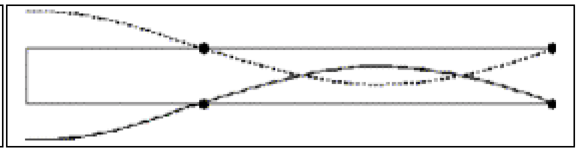


Illustration 5

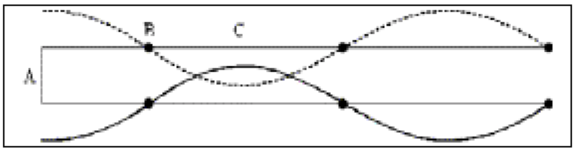


Illustration 7

A 60 cm double line, that is short circuited on the left end (total wire length 120 cm, in all illustrations marked as thin lines) is the longest resonance wavelength 240 cm, equivalent to a frequency of 125 MHz. The current distribution (thick line) shows on the left side of the connection of the parallel wires, only one electric current maximum, that can be verified with an inductive coupled electric bulb. On the open right wire ends, the voltage must be zero. (Current node).

The same line for instance, can also reach a resonance of 375MHz with the current distribution shown above. (see illustration 56). Thick points mark all four current minimums, their mutual distance is $\lambda/2$ of the resonance wavelength. Exactly between two points, at the current maximum, can the line be grounded, without (at this frequency!) modifying the electrical characteristics of the system. At this point, the magnet field is especially strong and at the same time the current is zero.

The next resonance is located at 625 MHz, with current distribution shown in illustration 7. On each of the two wires there are three current nodes. With the current maximum at the short circuit left end, a total of five current antinodes exist. It applies in general, that the resonant frequencies are always odd multiples of the deepest frequency.

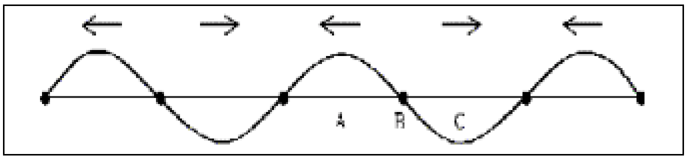


Illustration 8

Picture the wire as a straight bend up line (see figure 8). This changes – compared to the proceeding illustration – neither the current distribution nor the resonance frequency of (625 MHZ). The Lecher circuit however starts to radiate energy because the long range compensation of the magnet fields are missing. Common applications are tuned dipoles antennas used to transmit and receive.

4.2.1.1 Changes caused by winding

If the wire is wrapped in a spiral manner, as shown in Meyl'ss experimental kit, two effects lead to a decline of the resonance frequency: Magnet fields of neighbouring coils boost, the stored magnetic energy increases. Causing an effect like an enlarged inductivity. Also after winding
wires are laying close together, at stretched dipoles they are far apart. This enlarges the coils self-capacitance. The $\varepsilon_r > 1$ of the platinum material increases that tendency. Increasing the inductivity and self-capacitance leads to a decline of the resonance frequency

4.2.2 Changes through end-capacitance

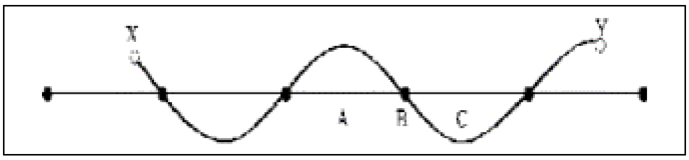


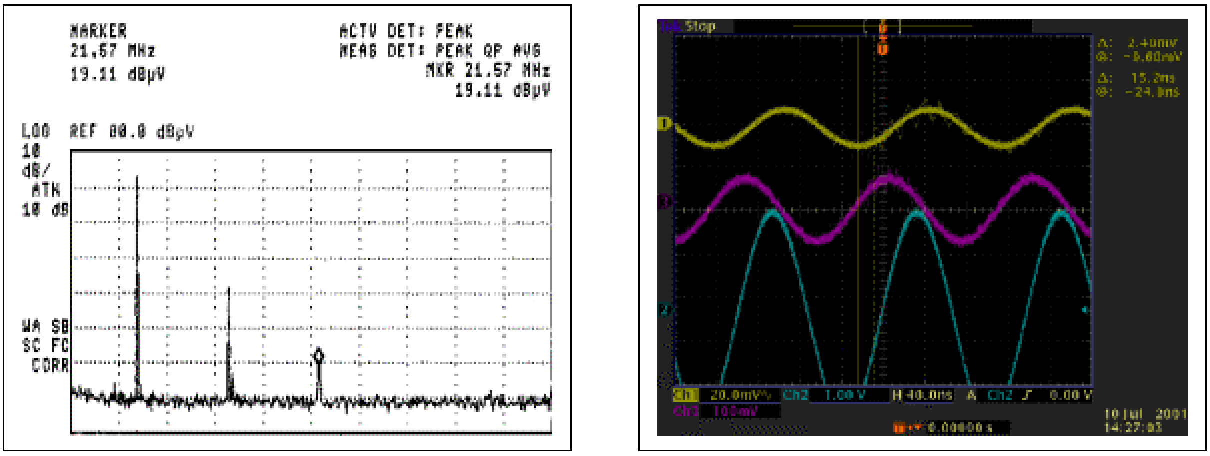
Illustration 9

Figure 9 shows in comparison, how the uneven condenser, X and Y (Tesla-spheres) shorten the outer segments (wire pieces between two current minimum).
The larger capacity X is able to absorb more electrons and substituting a longer piece of wire. Similar to the environment of the coupling transformer.
The segment length can be influenced in its capacity, if there is no current node**.** A condenser at B would shorten both neighboring segments. Condenser at A and C however are effect less. Meyl's Tesla resonant circuit has only some intervals between current nodes shortened, therefore the position of the current maximum is not evenly spread. Accordingly are the higher resonance frequencies **no integer multiple** of the fundamental frequency.

4.3 Arranging our own measurements

4.3.1 Side effects of light-emitting diode

Meyl's recommends these LED's, they are low-priced "Power-measuring equipment." But keep in mind, the information content of a simple brightness meter is extremely limited. Especially with LED's you can not analyse electric procedures within the Tesla resonant circuit



Illustr. 10: circuit without LED's

Yellow curve induced current obove the coupling transformer of the receiver board;
Blue curve: oscillator current on the coupling transformer of the transmitter board;
Violet curve: Voltage at 5 Ω-resistance within the interconnecting line oscillator - coupling transformer

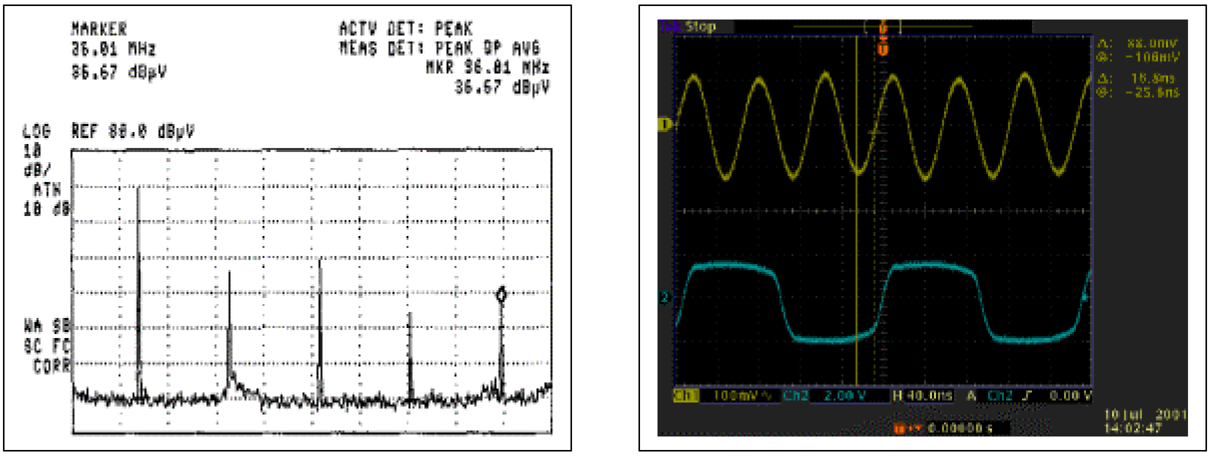


Illustration 11: LED only on transmitting board

Yellow curve: induced current above the coupling transformer of the transmitter board
Blue curve: oscillator current at the coupling transformer of the transmitter board

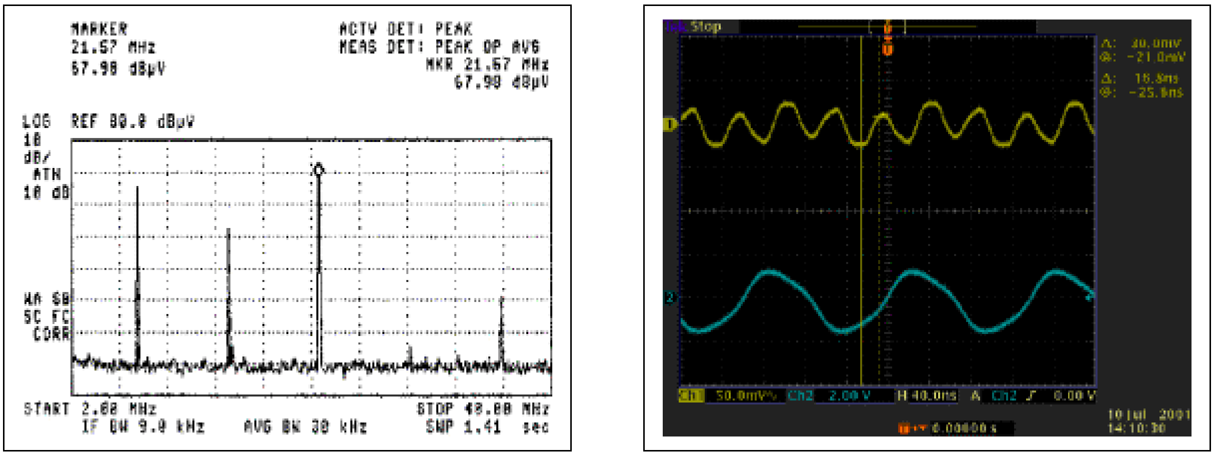


Illustration 12: LED only on receiver board

Yellow curve: induced circuit above the coupling transformer of the transmitter board
Blue curve: oscillator current at the coupling transformer of the transmitter board

Furthermore does the tight on the resonant circuit coupled, anti parallel switched LED, influence the circuit very strong. According to there limited voltage of approx 1,7 V, they are non-linear components, changing therefore the previous sinus voltage of the oscillator to a almost rectangular form developing a strong harmonic wave. The influence of the non-linearity toward the behaviour of the circuit is unpredictable, therefore we examined it extensively.

Illustration 10 shows the harmonic content of the signal generator used. (f=7,2 MHz). The second harmonic is located at 14,4 MHz, the 3rd harmonic, highlighted by marker at 21,6 MHz. Higher frequencies can be neglected.
The oscillator shows no noticeable divergence of the sinusoidal. As shown in illustr. 11 the spectrum changes compared to the previous picture drastically as soon as the jumper for the LED is inserted into the transmitting board. The symmetric limiting of the LED generates strong harmonics, where as the odd parts harmonize with the Fourier analysis predominantly. On the oscillogram is a almost rectangle curve visible.

On our next attempt the LED’s on the transmitter plate were again switched off and the LED’s on the receiver plate switched on (see illustration 11). The inductive sensor remains unchanged above the couple coil of the receiver plate. The basic frequency is 7.2 MHz. The 2. harmonic wave at 14.4 MHz is weaker on or about factor 4.5. 3. The harmonic wave at 21.6 MHz is stronger on or about factor 1.4 (!) than the basic frequency. The 4. harmonic wave at 28.8 MHz is weaker and hardly noticeable on or about factor 280. The 5. harmonic wave at 36 MHz has the level of 31 dBμV and still surprisingly strong. The relative strength of the harmonic waves and the shape of the curve strongly depend on the position of the inductive sensor, caused by the different positions of the current antinodes along the wire spiral of the Tesla resonant circuit.

4.3.2 Capacitive and inductive sensor

We realized, that an actual ground connection with some resonance’s (especially with 3. and 5. harmonic wave) has no influence on the electrical behavior of the circuit, on others however (for example 4. or 6. harmonic wave) the disturbance is very strong. This depends on the order of each harmonic wave measured and can be explained without any problem on the position of the voltage maxima along the wire. In order of not falsifying the measurement results, we did not use any conductive connection of the plates within the environment. We have also done without connecting the oscillograph housing with it’s large capacity of 130 pF.

To avoid grounding problems, we used an inductive and a capacitive sensor, with it we determined contact free the position of the current and voltage maxima.

The inductive sensor consists of a coil with 4 windings of 0.6 mm thick painted copper wire, with an inside diameter of 12 mm attached to the oscillograph with 100 cm long coaxial cable. Its own resonance lies scarcely over 40 MHz. The capacitive sensor was manufactured, by removing the last 2 cm of the external braid from the 100 cm coaxial cables. The insulated inner conductor which stuck out, was used as a capacitive antenna.

4.3.3. Current transformer

Both circuit boards with top mounted spheres are, according to instructions connected by a wire, which replaces the grounding connection in the structure described by Tesla, there length obviously lies somewhere between 20 cm and 600 cm. We asked our self: Does this wire have a current flow or not? What value does it have? The current sensing was conducted with a current transformer, which is a ferrite ring of approximately 15 mm outside diameter, wound with 20 torus-like turns. This type of current sensing has minimum disturbance on the circuit. The resonant frequencies of the entire arrangement is maximal affected by 1.6%.

4.4 Our measurements on the resonant circuit

Based on the hypothesis that Meyl's's circuit is a wounded and capacitive shortened Lecher line, measurements have been conduct to prove this hypothesis. The measurements described here and further measurements are published in [7].

4.4.1 Determining the basic frequency

At first the deepest resonant frequency is determined. At this frequency the current has a relative maximum from the oscillator to the transmitter plate. Voltage maximum is measured at the wire ends (sphere). There is only one voltage maximum, that can be verified, which is in the vicinity of the connecting wire (grounding) and on the outer windings of the Tesla coil. Furthermore decrease the induced current above the spiral monotonously from the **outside** toward center.

The detected frequency for the following test is not very interesting, the reading is at (5,35±0,1) MHz, this corresponds to a vacuum wavelength of 44,4m.
A flat half - wave dipole must be 22.2 m long. The over all length of the circuit (the distance from the highest point of the sphere condenser to the highest point of the second sphere condenser) amounts to only 18.8 m. The reason for the reduction has already been discussed (see sections 0 and 4,2,2).

4.4.2 Harmonic

Next point was to look for higher resonant frequencies. We already discussed this in (chapter 4.2.2) they do not have to be integral multiples of the basic frequency. Several frequencies were found using the inductive sensor. The resonant frequency of 29.5 MHz was examined closely by using the sensor on the turns of the two Tesla coils, on which the induced voltage minimum existed (no magnetic field) respectively maximum (strong magnetic field). Table 1 shows the result.

The first column indicates the number of turns. The second column indicates whether the induced voltage with this number of windings has a relative minimum (= current nods) or maximum (= current antinodes). Column 3.shows the induced voltage, which with each zero function relocates by 180^0. The fourth column shows the wire lengths from the center of the 20 cm grounding; starting from turn 47 we add the distance between the board and the highest point of the sphere (317 mm) because the current flow ends at this point the last column shows the wire lengths. Dx between successive zero functions of the current antinodes. Resulting in 188.74 cm.

Above measurement shows clearly the geometrical influence of the Tesla coil on the location of the current nodes. With a straight-line wire the current nodes were measured within a distance of 508 cm. The spiral winding of the Tesla coil reduces the distance of the current node to (402±6) cm, if no auxiliary capacities are available. (see section 4.4.2). The auxiliary capacity reduces the length of the outer two l/2- section to 140 cm (see section 4.2.2).

The values were controlled with a capacitive probe. The result corresponds to the classical line theory: Between two current maxima there is always exactly one voltage maximum! Before and after each current node the phase position changes by 180 degrees.
There is no doubt: The Tesla resonant circuit is a shortened, winded dipole antenna on which, with higher frequencies, standing waves can be activated

winding	induced current	Phase	wirelenght[mm]	Δx[mm]
(47)	no measuring possible		9120+317 ± 74	
remark a)	exists	+	-	1402 ± 141
31 ± 0,5	0		8035 ± 67	-
20 ± 2	rel. Maximum	-	(6100)	3950 ± 210
12 ± 0,5	0		4085 ± 143	-
8 ± 2	rel. Maximum	+	(2885)	4085 ± 143
0	0		100	(receiver board)
			200 (GROUND)	
0	0		100	(transmitter board)
8 ± 2	rel. Maximum	-	(2885)	4085 ± 143
12 ± 0,5	0		4085 ± 143	-
20 ± 2	rel. Maximum	+	(6100)	3950 ± 210
31 ± 0,5	0		8035 ± 67	-
remark a)	exists	-	-	1402 ± 141
(47)	No measuring possible		9120+317 ± 74	

Table 1: Minimal induced voltage(no magnetfield) respect. maximal induced voltage (strong magnetfield) on Tesla-coil’s.
(Quote a: Second line and before last line there is no winding number, because there is no relative maximum existing.
In this area there is only voltage.

4.4.3 Measurement of the current within the conductor

The current transformer described in 4.3.3 gives evidence of whether and how much current flows through the ground line. According to Professor Meyl’s it should be always at zero, allegedly will the energy only transmit from one sphere to the next. We however always determined considerable currents, 3,4 mA_{eff}. represent 28% of the current delivered by the oscillator. On the other hand we found a reproducible arrangement, despite of the missing transmitter sphere, the LED’s on the receiver plate shine considerable brighter as on the transmitter board – according to Meyl’s that’s impossible! This case reveals, that it is possible to measure the current on the transmitting line, this supports our theory of the winded Lecher circuit.

4.5 Meyl’s experiment

In the manual, included in the experimental set, Prof. Meyl’s suggested 5 tests that point out, that the Tesla-replication cannot be explained with conventional classical electrodynamics. We now will discuss each test on the background of these results described above.

4.5.1 The Experiment “ Reaction “

The construction is carried out as described, increasing the frequency from approx. 5 MHz to 7,2 MHz, the transmitter LED fade out and the receiver LED beginning to shine. -

Meyl interprets this observation as a reaction from the receiver to the transmitter. The transmitter supposedly "notices" that he looses energy through the receiver.

Following measurements describe however, that the behavior of the circuit can be explained with classical electrodynamics. The inductive sensor is fixed above the 6. winding of the transmitter board. At this point, right above the coupling transformer the basic frequency is at 7.2 MHz remarkably weak, the third harmonic at 21.6 MHz is with factor 5,6 stronger. The harmonic extracts, due to resonance, a lot of energy from the oscillator. The current of the oscillator breaks down to less than 1.7 V_s and the parallel-connected transmitter LED's stops shining.

The inductive sensor is fixed above the 10. winding of the transmitter board. The harmonic is even 10 times higher as the fundamantal mode, which can be lead back to the non-linearity of the LED. Further measurements revealed, that at this point a voltage node / current antinode exists, that makes a particularly good inductive coupling possible – consequently the LED's shine.

The experiment can be easely explained by the presence of harmonics and by uncoupling of energy from these harmonics.

4.5.2 The "distance square “and the test with the Faraday cage

Prof. Meyl claims, that the energy transfer between transmitter and receiver is independent from the distance between transmitter and receiver and that a Faraday cage cannot screen the transmitted scalar waves.

This phenomenon needs also no explanation by means of scalar waves. The energy transfer takes place by electron movements. This is caused by standing waves which are within the circuit, therefore developing also a earth connection. In this case the distance between transmitter and receiver is insignificant.

Of course can the ineffectiveness of a Faraday cage be explained in the same manner. Due to the developing standing waves, will the energy be transported through the “ground ” connection into the Faraday cage, or out.

4.5.3 “ Proof ” of free energy

Meyl's conclusion is, that the different brightness of the LED's cause, that " more power is received as the transmitter releases ". Opposed, we also measured with Tektronix gauges, less than 50% efficiency of the Tesla resonant circuit --. For a rough calculation withdrawn from the oscillogram in illustration 13 (blue curve) (: current, violet curve: proportional to current), that oscillator current and current are almost sinusoidal and hardly out of phase. The oscillator output is roughly calculated by $P = U_{eff} \cdot I_{eff} = 1{,}2\ V \cdot 16\ mA = 19$ mW.

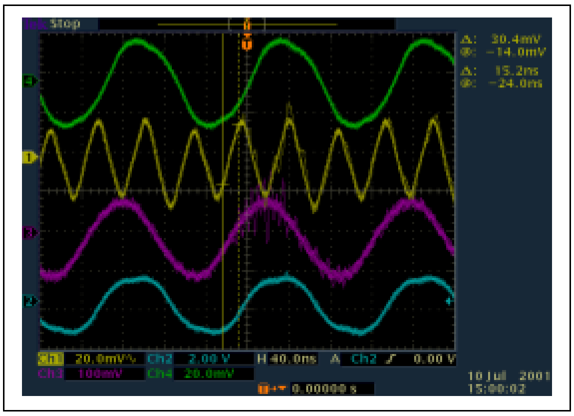


Illustration 13: test measureing „Free energie“
Yellow curve: induced voltage above coupling transformer of the transmitter board;
Blue curve oscillator current at the coupling transformer of the transmitter board
Violet curve: Voltage at 5 Ω-resistance within the interconnecting line oscillator - coupling transformer
Green curve: Current oncurrent transformer on the interconnecting linehen between transmitter and receiver board

If a LED is hardly shining red, the output is only 60 µW (micro watts!). If power of 4 mW is supplied, then the LED’s shine very bright. In comparison, two identical type LED’s of 8,5 mW received direct current and were held next to the LED’s of the receiver board. All LED’s were evenly bright.This value is noticeable smaller as the given output of approx. 19mW from the signal generator
Taken into consideration that two LED’s are always switched paralell, a efficiency of 8,5 mW/19 mW = 45%. Till η=100% or even 500% is still a long path away.

4.5.4 “Superluminal velocity”

On this experiment Prof. Meyl writes: If the frequency regulator is turned to the left, additional value exists on the turned on amplitude regulator , and the receiver lamps shine . The following assertion, " the spool length and with that the wavelength hasn’t been changed" is wrong: Because of the additional capacities (spheres) there isn't any simple connection between wire and wavelength, in particular one can not assert, that the wave lenght hasn't changed. It is not clear at all which wavelength Meyl actually means.

We have measured a fundamental frequency of 5.35 MHz with a vacuum wavelength of 44.4 m. The examined harmonic of 29.5 MHz (only one of more possible) has a vacuum wavelength of 10.2 m! What is "the wavelength" that Meyl means and which allegedly hasn't changed? Due to the fact that he dosent clearly indicate, is his “derivation” of the superluminal velocity not traceable.

5. Final conclusion

We can **not** confirm even one of the hypothesis, which can according to Prof. Meyl experimentally be veryfied with the experimental kit. The effects, which Professor Meyl describes, can be explained within the context of the classical electrodynamics by standing waves on a Lecher line.
The experiments carried out at the IGF, as well as other examinations revealed, that with the Meyl assembly the effects, which Tesla describes in his patents, are not reproduceable.There is a serious difference between Teslas assembly and Meyls reproduction, especially concerning the geometrical size as well as the power handling capacity. In general it can not be considered as a replication.

Out of the results on Meyl's assembly, no conclusion can be made, that Teslas assembly, documented in patent [1] and [2] to [5], would also reveal no results. So far the Tesla experiments were not exactly reconstructed yet, because of lack of funds. It is our opinion, that it is urgently necessary to reconstruct Teslas experiments and assemblies to finally really measure the content of his work. Tesla ranks among the most unusual and most capable inventors in the electricity field.

Literature

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