Experiment About Wireless Energy Transfer

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***Abstract* — This work presents an experiment for wireless energy transfer by using the inductive resonant coupling (also known as resonant energy transfer) phenomenon. The basic principles will be presented about this physical phenomenom, the experiment design, and the results obtained for the measurements performed on the system. The parameters measured were the efficiency of the power transfer, and the angle between emitter and receiver.**

I. INTRODUCTION

Early in the 19th century the physicist Nikola Tesla performed several experiments [17] in-volving the wireless energy transfer obtaining astonishing results by that time. Nevertheless, the experiments did not transcend due to the skepticism of the people and the low efficiency of the energy transfer. In recent times various researchers have been trying to transfer energy by wireless means using diverse mechanisms like:

- Laser beam. The laser beam is a coherent light beam capable to transport very high en-ergies, that makes it an efficient mechanism to transfer energy point to point using a line of sight. The NASA [14] presented in 2003 an unmanned aircraft energized wirelessly by a laser beam and a photovoltaic cell in-frared sensitive acting as the energy collec-tor. In fact, NASA is proposing such scheme to power satellites and wireless power trans-mision where no ther mechanism could be viable [14].
- Piezoelectric principle [8]. It has been demonstrated that it is possible to transfer energy by wireless means using piezoelec-tric transducers capable to emit and receive vibrational waves.
- Radio waves and Microwaves. In [6] can be seen an scheme to transmit high power energy through long distances using Microwaves. Besides, there is a whole research field in the rectenna area [16][1][9][15] which are antennas capable to collect energy from radio waves.
- Inductive coupling [13][5][12][2]. The induc-tive coupling works on the resonant coupling effect between the coils of two LC circuits. Maximum efficiency can only be reached when the transmitter and the receiver are placed in a very short distance.
- ”Strong” electromagnetic resonance. In [10] and [11] a wireless energy transfer method was introduced, this method uses the ”strong” electromagnetic resonance phe-nomenon, achieving energy transfer in an efficient way through several tens of cen-timeters.

II. HEALTH EFFECTS DUE TO THE ELECTROMAGNETIC WAVES

Since the loom of telecommunications, the radio frequencies use have been increased to broadcast wireless telephony, radio, Morse code, public and satellite television, WiFi networks, Bluetooth, among the most common. The result of these radio frequencies flowing everywhere is the dispersion of the electromagnetic waves. People is getting more concerned about the effects caused by the electromagnetic radiation generated every day. To this concern one more effect should be added by the wireless energy transfer mechanism, because it is based on elec-tromagnetic waves.

Several studies have been performed [4][7] on the effects of the electromagnetic waves, in particular the cellular phone waves, verifying that on the fringe of the international safety values certain effects on the genes are noticed. In [18] ensures that it is not yet possible to establish health effects in the short or long term due to the electromagnetic waves exposure like the ones generated by broadcasting stations and cellu-lar phone stations. Nevertheless, in [3] a study carried out in US Marines working in ranges of 10 meters from broadcasting stations or radar

stations, it was noticed a decrease of the fertility, which was concordant with another study that established that semen quality decreases by occupational reasons (electricians, technicians, welders, among others) are exposed to constant electromagnetic radiation including microwaves. Some studies reveal that there are harmful ef-fects on humans, but these effects occur on high frequencies (**>** 800Mhz), therefore there are no health concerns for the experiment since it will be performed under the 2MHz frequency range.

III. ELECTRIC RESONANCE

Electromagnetic radiation has been used, typ-ically, for information broadcasting. But that is not the only possible application, however. It is possible to transfer power using electromag-netic radiation. In particular, using microwaves the energy can be directed to an specific point. Although the mehtod is efficient, it has two draw-backs: requires a sight line and it is a dangerous mechanism for live beings.

Mechanical resonance is well known, it works applying a vibratory action on an object. The vibration period match the frequency in which the object reach the highest energy absorption rate. Such frequency is known as resonance frequency. This phenomenon well known on me-chanics is also perceived in electricity and it is known as electric resonance. Such phenomenon can be used to transfer energy in a wireless fashion with two main benefits: the maximum absorption energy rate is guaranteed and it is possible to work using low frequencies (not so harmuful to the human being). When two objects have the same resonant frequency, they can be coupled in a resonant way that one object can transfer energy (in an efficient way) to the other. In electricity there are two kinds of resonant coupling: ”inductive” [13] and ”strong” [10].

The inductive coupling is the resonant cou-pling between the coils of two LC circuits with the same resonant frequency, transferring energy from one coil to the other as seen in figure 1. The disadvantage of this technique is that the efficiency degrades sharply as coils separate. In fact, there is a commercial product that recharge mobile devices that requires to place the device right over the transmitter, it means that maximum efficiency can be reached only at 0 cm.

The ”strong” coupling is achieved using self-resonant coils. These are placed in a scheme like the one shown in figure 2. It can be seen on the transmitter circuit that the self-resonant coil (B) is not physically connected to the circuit but electromagnetically coupled with a single spiral coil (A) (same radius r') connected to the energy

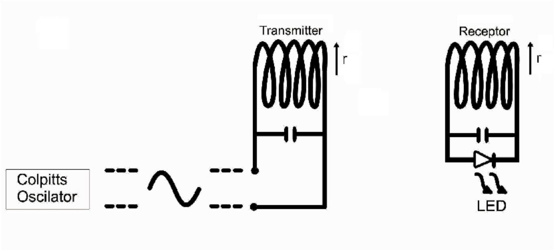


Fig. 1. Inductive coupling for energy transfer.

source, which oscillates (Colpitts oscillator) at the self-resonant frequency. There is a second self-resonant coil (C) of the same frequency as coil B, which allows the coupling of both coils transferring energy from transmitter coil B to the receiving C. The receiving coil is not directly connected to the load, it is coupled with a single spiral coil (D) and it also has the same radius (r'), which is connected to the load. This scheme has two drawbacks:

- The self-resonant frequency is a coil that de-pends on its parasite capacitance, this cause that such frequency be high (in the range of GHz). Therefore, to achieve a low sel-resonant frequency (**<** 10Mhz) is necessary to employ thick copper wire and be placed in such a way to achieve a high parasite capac-itance reducing the self-resonant frequency to the megahertz range. In fact, in [10][11] it is reported an experiment using cable with radius of 3 cm.
- Efficiency on the power transfer sharply de-clines as the separation between coils in-crease, then it is necessary to employ big coils in order to achieve longer separation distances. This is the reason why the re-ported experiments in [10][11] the coils have radius of about 30 cm.

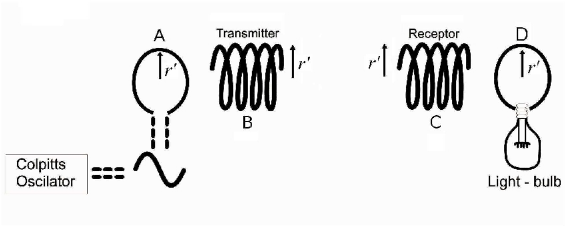


Fig. 2. ”Strong” resonant coupling for energy transfer.

The ”strong” resonant coupling has de ad-vantage over the inductive coupling to achieve longer distances of separation between coils with a relative good efficiency. Nevertheless, the coils for the ”strong” coupling should be big although it is not necessary for the inductive coupling. That is the reason that this work focus to experiment with the inductive coupling in order to better understand the phenomenon, thus it would be possible to propose an improvement. Besides, it is possible to think on the inductive coupling as a previous step on the experimental complex compared to the the ”strong” coupling. Then, performing experiments on the inductive coupling will serve as base for subsequent experiments on the ”strong” couling, which will serve to compare both phenomena.

IV. OSCILLATOR CIRCUIT

The Colpitts oscillator [17][18][19] is an im-plementation of a sinusoidal oscillator with just one transistor, which is broadly employed in electronic devices and communication systems. It has as operational frequency a range that spans few hertz up to gigahertz, it depends on the implementation. Therefore, this characteristic makes it attractive to implement the oscillator that simultaneously supplies the power for the wireless energy transmission. Figure 3 shows the oscillator with the selected values for the components. The oscillation frequency employed is about the same as the resonance for the LC circuit.

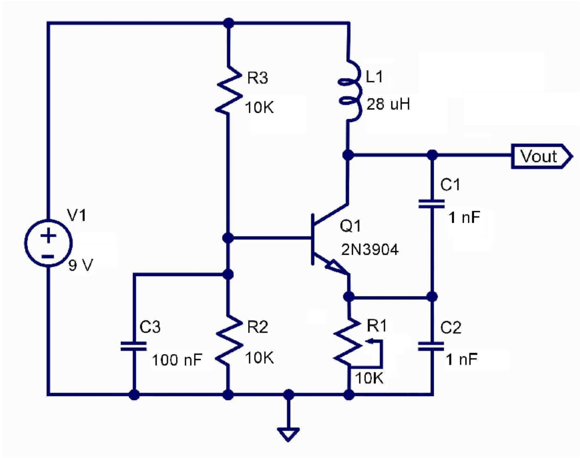


Fig. 3. Colpitts oscillator.

V. EXPERIMENTATION

In order to know the distribution of the elec-tromagnetic wave around the generating coil the first experiment is designed, it consists in using the receiving coil to measure and graph the space energy distribution. In this experiment the generating coil was kept in a fixed position while the receiving coil take samples of the electromag-netic field, around the generating coil, at a fixed

distance and with constant angular displacement completing 360 degrees(figure 4).

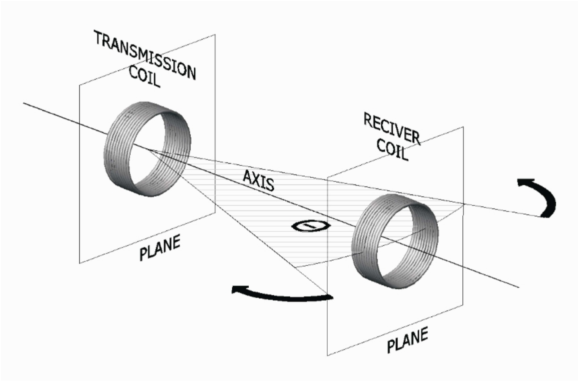


Fig. 4. Radiation pattern of the experiment.

On the following graphs (figure 5) the radiation patterns for the generating coil are shown.

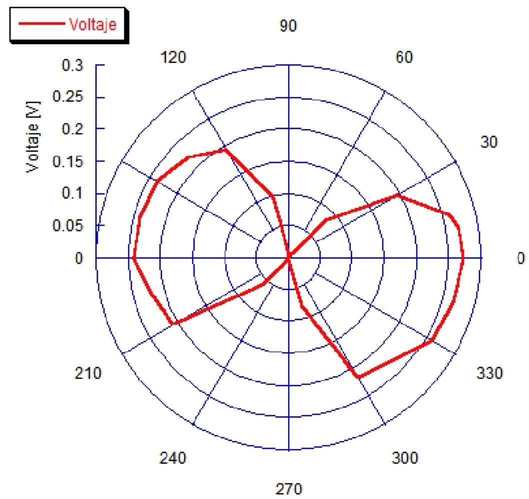
From this experiment can be seen that the produced energy by the generating coil spreads at 90° in front of the generating coil and at 90° behind the same coil. This result becomes interesting because the next experiment will be designed taking into account the radiation pattern in order to send the highest forward energy and take account of the rear for further experiments. It can also be seen that the highest radiation level is located at 345° and at 165° (due to the configuration and experiment conditions, the receiving coil had a displacement of about 15° to the x-axis), that is, just in front and back of the generating coil. The fact to have a bidirectional pattern has an important effect on the gain cal-culation of the system, given the fact that energy depends on the directivity of the coil. Thus, the efficiency will be affected by the shape of the radiation pattern.

The maximum efficiency of the system is a datum that provides more complete information because it allows to know how much energy is being collected by the receiving coil. Even though the efficiency definition would be a relationship between powers or gain and directivity, in the first stages of the experiment only the output volt-ages values for the receiving coil are known with respect to the input voltage for the generating coil, using these values the voltage gain for the system was calculated.

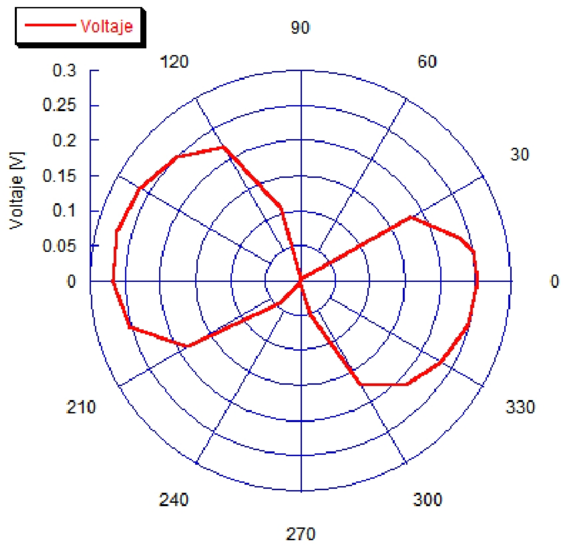
To measure the voltage gain both coils were placed facing each other and the receiving coil was moved away at a constant rate from the generating coil. Since the generating coil has constant voltage, the voltage measurement was only performed at the receiving coil after each displacement.

Once the voltage were measured, the ratio between them was graph and is shown in figure 6. In this graph can be seen that when both coils are together all the energy is sent to the front by the generating coil which is taken by the receicing coil. This is noticed when the voltage gain is 50%. Keep in mind that the other half of energy is sent to the back of the generating coil.

Figure 7 shows that, beyond the 8 cm distance, the system voltage gain falls bellow the -30dB range. In future works it is pretended to rise this distance in laboratory tests.



A)



B)

Fig. 5. Radiation pattern of the generating coil.

The figure 8(a) shows the complete working experiment and in 8(b) a close-up of the oscilloscope showing the input and output signals. In figure 9 can be seen the coil lighting up a LED in a way to show visually the energy transfer.

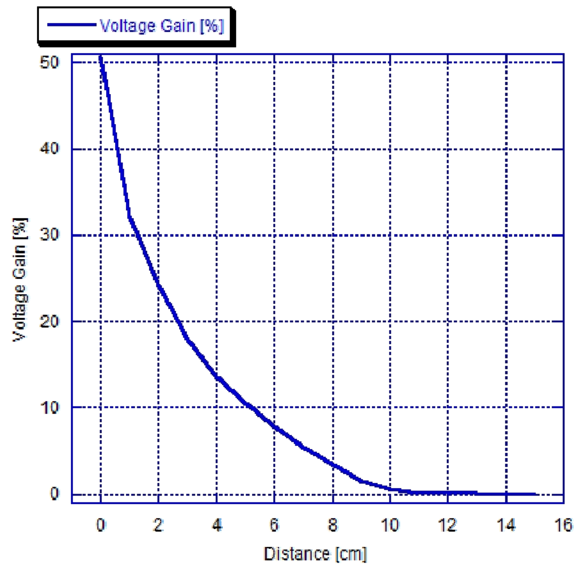


Fig. 6. Percentage voltage gain of the system with respect of voltage ratio.

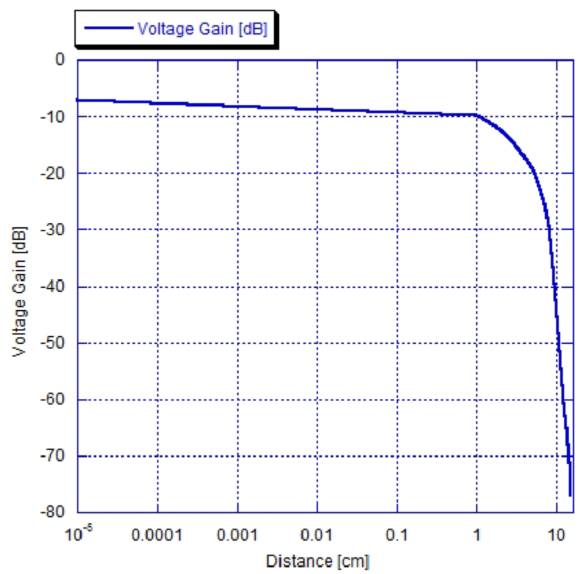
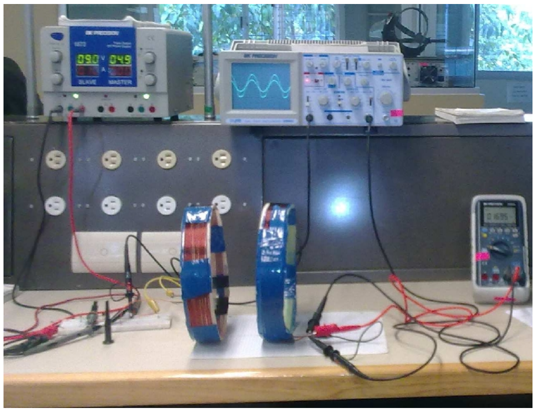


Fig. 7. System voltage gain with respect of voltage ratio.

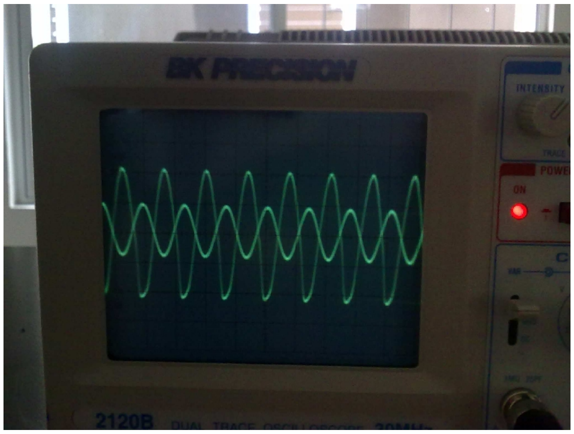
VI. CONCLUSIONS

This work shows an experiment of wireless energy transfer at distances between 0 cm. and 8 cm.(-30 dB) by means of inductive coupling. It was verified that the distance between the coils centers play an important role on the efficiency of the power transfer, decreasing as the centers are moved away and reaching its maximimum at 0 cm. Besides, the relative angle between planes of each coil also affect the efficiency, establishing in experiment that the planes should be placed in parallel fashion over the same axe. The work due to complete is to perform tests using reflecting surfaces to direct energy and

design the experiment of wireless energy transfer using the ”strong” resonan coupling phenomenon in order to compare both schemes.



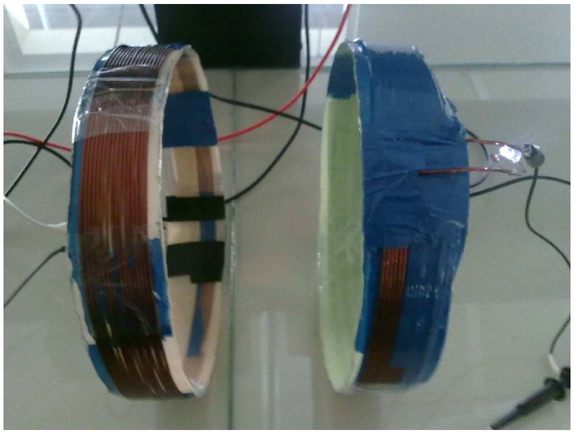
A)



B)

Fig. 8. a) Complete experiment for wireless energy transfer. b) Photo showing oscilloscope screen comparing input and output signals

A)



B)

Fig. 9. a) y b) Experiment based on the shown in figure 1, the LED is the load.

REFERENCES

[1] Mohammod Ali, G. Yang, and R. Dougal, A new circu-larly polarized rectenna for wireless power transmission and data communication, IEEE Antennas and Wireless Propagation Letters **4** (2005), 205–208.

[2] Philippe Basset, Andreas Kaiser, Bernard Legrand, Do-minique Collard, and Lionel Buchaillot, Complete system for wireless powering and remote control of electrostatic actuators by inductive coupling, IEEE/ASME Transac-tions on Mechatronics **12** (2007), no. 1, 23–31.

[3] Valborg Baste, Trond Riise, and Bente E. Moe, Ra-diofrequency electromagnetic fields; male infertility and sex ratio of offspring, Springer, European Journal of Environmental Epidemiology (2008), 369–377.

[4] Jurgen Breckenkamp, Gabriele Berg-Beckhoff, Eva Munster, Joachim Schuz, Brigitte Schlehofer, Jurgen Wahrendorft, and Maria Blettner, Feasibility of a cohort study on health risks caused by occupational exposure to radiofrequency electromagnetic fields , BioMed Cen-tral Environmental Health (2009).

[5] Jianbo Gao, Traveling magnetic field for homogeneous wireless power transmission, IEEE Transactions on Power Delivery **22** (2007), no. 1, 507–514.

[6] Peter E. Glaser, Method and apparatus for converting solar radiation to electrical power, U.S.A Patent (1973).

[7] Riadh W. Y. Habash, J. Mark Elwood, Daniel Krewski, W. Gregory Lotz, James P. McNamee, and Frank S. Prato, Recent advances in research on radiofrequency fields and health: 2004-2007 , Journal of Toxicology and Environmental Health, Part B (2009), 250–288.

[8] Hongping

[9] Ji Wang, A system of two piezoelectric transducers and a storage circuit for wireless energy transmission through a thin metal wall, IEEE Transactions on Ultra-sonics, Ferroelectrics, and Frequency Control 55 (2008), no. 10, 2312–2319.

[9] G. J. N. Doodeman J. A. G. Akkermans, M. C. van Beur-den and H. J. Visser, Analytical models for low-power rectenna design, IEEE Antennas and Wireless Propa-gation Letters **4** (2005), 187–190.

[10] Aristeidis Karalis, J.D. Joannopoulos, and Marin Sol-jacic, Efficient wireless non-radiative mid-range energy transfer, Elsevier Annals of Physics (2008), no. 323, 34– 48.

[11] Andre´ Kurs, Power transfer through strongly coupled resonances, Massachusetts Institute of Technology, Master of Science in Physics Thesis (2007).

[12] Zhen Ning Low, Raul Andres Chinga, Ryan Tseng, and Jenshan Lin, Design and test of a high-power high-efficiency loosely coupled planar wireless power transfer system, IEEE Transactions on Industrial Electronics **56** (2009), no. 5, 1801–1812.

[13] H. Mansor, M.A.A. Halim, M.Y. Mashor, and M.A. Rahim, Application on wireless power transmission for biomedical implantable organ, Springer-Verlag Biomed 2008 proceedings 21 (2008), 40–43.

[14] NASA, Beamed laser power for uavs, Dryden Flight Research Center (2003).

[15] Yu-Jiun Ren and Kai Chang, 5.8-ghz circularly polarized dual-diode rectenna and rectenna array for microwave power transmission, IEEE Transactions on Microwave Theory and Techniques **54** (2006), no. 4, 1495–1502.

[16] Khan M. Z. Shams and Mohammod Ali, Wireless power transmission to a buried sensor in concrete, IEEE Sen-sors Journal **7** (2007), no. 12, 1573–1577.

[17] Nikola Tesla, Apparatus for transmitting electrical en-ergy, USA Patent 1119732 (1914).

[18] Peter A. Valberg, T. Emilie van Deventer, and Michael H. Repacholi, Workgroup report: Base stations and wire-less network radiofrequency (rf) exposures and health consequences, Environmental Health Perspectives **115** (2007), no. 3.