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Enabling Multiple Loads through Wireless Power Transfer

Hema Ramachandran
Department of Electrical Engineering,
College of Engineering,
Trivandrum, Kerala, India

Dr. Bindu G.R.
Department of Electrical Engineering,
College of Engineering,
Trivandrum, Kerala, India

***Abstract*—Magnetic Resonance coupling using non-radiative mode of transmission is a cutting edge technology which can possibly replace the connecting cords of all portable electronic devices. A magnetic resonance coupling arrangement in which a single transmitter antenna coil powering multiple loads is demonstrated with an overall efficiency of 20%**

Keywords: Magnetic resonance coupling, WiTricity, Multiple loads

I. INTRODUCTION

In the 1890's wireless energy transmission was demonstrated by Nikola Tesla using his demonstration on resonant transformers called Tesla coils. Since these coils had undesirable electric fields which radiated energy in all directions, the efforts made by Tesla made little success. Various technologies for wireless power transfer like capacitive coupling, microwave and laser method have been proposed involving far fields. However it is the technology using magnetic resonance coupling has been found to be a viable technology for midrange energy transfer. Further, this means of energy transfer uses non-radiative mode of transmission and offers the use of connector free devices and is an alternative to the use of hazardous disposable batteries. Wireless energy transfer or WiTricity is currently extending its applications to medical implants saving patients from undergoing operations to replace the lithium ion batteries used for pacemakers. Magnetic resonance is also being used for charging of electric vehicles while driving on a highway. Since this technology can work even in water, powering of under- water cameras can be done reliably.

In this paper the powering of multiple loads from a single transmitter coil has been designed using magnetic resonance coupling. The loads are powered at a distance of 10 cm from the transmitter coil with an overall efficiency of 20%.

II. RESONANT COUPLED SYSTEM OVERVIEW

The resonant coupled system is formulated on the basis of coupled mode theory [1]. A high frequency power source drives power through a transmitting antenna. The transmitting antenna sends power wirelessly using electromagnetic resonance coupling to the receiving antennas. Near field coupling using evanescent field drives the receiving antennas. The distance of transmission can be increased using coupled source antennas which work as resonators [2]. This allows the transmission to follow a curved transmission path in space. The resonant coupled system with a source antenna coil delivering power to two receiving loads is shown in Fig.1.

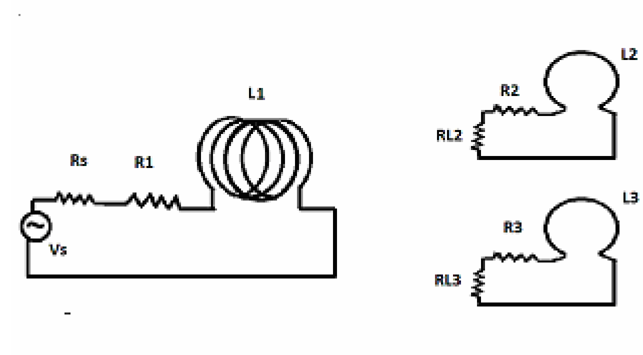

Fig.1. Schematic of the resonant coupled system

III. COMPARISON WITH INDUCTIVE COUPLING

Traditional inductive coupling methods have limited transmission distance due to weak coupling between the source and loads. This occurs in the charging of conventional electric toothbrushes. The tooth brush with the receiving coil is placed on the source cradle for getting charged. The efficiency is as low as 1-2%. Using magnetic resonance the transmitting source coil frequency exactly matches the frequency of the receiving coils at resonance. Since the energy transfer is maximum at resonance, magnetic resonance coupling is found to have an efficiency of about 45% as has been demonstrated by the MIT team [3].

IV. CIRCUIT ANALYSIS

The analysis of the circuit was done using the application of Kirchhoff's voltage law for the source coil and the coupling load coils. The source antenna coil is supplied from a high frequency signal generator having an input voltage V_s. The internal resistance of the source is R_s. The source antenna coil having a resistance R_1 is represented by the equation (1).

$$V_s = I_s(R_s + R_1) + j\omega L_1 \quad (1)$$

The load coils with internal resistances R_2 and R_3 along with load resistances R_{L1} and R_{L2} and the associated inductances L_2 and L_3 are shown in terms of circuit equation(2) and equation (3) respectively. The current through the load coils are I_{L1} and I_{L2}.

$$0 = I_{L1}(R_{L1} + R_2) + j\omega L_2 \quad (2)$$

$$0 = I_{L2}(R_{L2} + R_3) + j\omega L_3 \quad (3)$$

The determination of inductances of the source coil and the loads was arrived at using the Wheeler's inductance formula for air-cored helical coil [4]. The inductance L for a single layer helical coil is found as per equation (4).

$$L = \frac{a^2 N^2}{9a + 10l} \text{ micro henries} \quad (4)$$

where a is the radius of the coil in inches, N is the number of turns and l is the height of the coil in inches. The interplay of distributed inductance and distributed capacitance at high frequencies determine the resonance of the transmitter and receiver coils. The modeling of the above circuit has been carried out according to the condition that efficiency is influenced by air gaps, mutual inductance and impedance of the receiving antenna [5]. The transmission efficiency is calculated by the formula as in equation (5), where M is the mutual inductance between the source and load coils, ω is the angular frequency of resonance, and R_r and R_L are the receiver coil resistance and load resistance respectively.

$$\eta = \frac{(\omega M)^2 R_L}{(R_r + R_L)[R_r(R_r + R_L) + (\omega M)]^2} \quad (5)$$

The mutual inductance M between the two antennas is a function of the coupling between the coils which is calculated as per equation (6), where L_1, L_2, L_3 are the self inductances of the source and load coils.

$$M = k\sqrt{L_1}L_2 = k\sqrt{L_1}L_3 \quad (6)$$

It is clear from equation (5) and (6) that the transmission efficiency increases as the mutual inductance increases.

V. SIMULATION

Based on the empirical modeling three helical coils made of copper wire were selected to resonate at a frequency of 400 KHz. The inductance of the source driving coils for a coil radius r of 0.5 cm has been simulated in MATLAB environment. The source coil is made of a 4 turn helical coil and the two load coils are helical coils of 15 turns each. The source coil is wound around the edge of a cane table of diameter 1m. The load coils are wound as helices of diameter 25cm. The variation of inductance of the source coil with having 4 turns for different radius of coils are as shown in Fig.2.

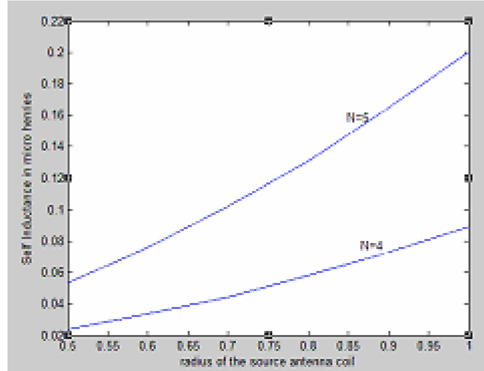

Fig.2. Self Inductance of the source coil for different radius of coils.

VI. EXPERIMENTATION

An experimental set up of the magnetic resonant coupled system with a source antenna coil powering two receiver antenna coils is shown in Fig. 3. The source coil wound around the edge of a 1m diameter cane table is supplied power from a standard Colpitts oscillator. The output of the Colpitts oscillator is amplified using a Class AB power amplifier to drive the receiving coils. The load coils which are helices of 25 cm diameter, one of which is wound with 15 turns each is made to resonate with the source coil. At 400 KHz, the source coil is found to resonate with the two load coils. The driving voltage at the input of the source coil is 13.4V and the current input to the source coil is 0.5A. The output current through the receiving coils is 0.2 A. The efficiency as calculated from equation (5) is 20%. The receiving coils are found to pick up power at a distance of 10 cm from the source coil.

Fig.3. Multiple loads (LEDs) powered by Magnetic Resonance produced on a table top.

VII CONCLUSION

Wireless power transfer has a potential impact in a society of wireless devices like mobile phones, laptops and house hold robots. The experimental study has shown that multiple loads can be simultaneously powered by wireless electricity. Based on the circuit analysis, the efficiency of transmission has been obtained and its correctness has been verified by experiment. The losses due to skin effect and proximity effect at high frequencies are factors which can influence the efficiency of power transfer. The influence of the above parameters on the power system needs to be probed. Also an analysis of transmission efficiency with distance and driving frequency can be carried out. Increasing distance and efficiency of transmission needs to be further investigated.

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REFERENCES

[1] A. Karalis, J. D. Joannopoulos and M. Soljacic " Efficient wireless non radiative mid-range energy transfer," *Ann. Phys.*vol..323, no.1, pp.34-48. Jan.2008.

[2] Fei Zhang, Hackworth, S.A.; Weinong Fu; Mingui Sun; " Relay effect on wireless power transfer using WiTricity," Biennial Conference on Electromagnetic Field Computation, pp.1-1,May 2010.

[3] A. Kurs, A.Karalis, R. Moffat, J. D. Joannopoulos, P. Fischer and M. Soljacic, " Wireless power transfer via strongly coupled resonances," *Science,* vol.317, pp.83-86, Jul6, 2007.

[4] Harold A. Wheeler, "Simple Inductance Formulas for Radio Coils," in *Proc. I.R.E,* vol.16, no.10, Oct. 1928.

[5] Takehiro Imura and Yoichi Hori, "Maximizing Air Gap and Effeciency of Magnetic Coupling for wireless Power TransferUsing Equivalent Circuit and Neumann Formula," *IEEE Transactions on Industrial Electronics,* vol.8, no.10, pp 4746-4751, Feb.2004.

[6] C.S. Wang, G.A. Covic and O.H. Stileau," Power transfer capability and bifurcation phenomena of loosely coupled inductive power transfer systems," *IEEE Transactions on Industrial Electronics,* vol.1, no.1, pp 148-157, Feb.2004.

[7] Qiaowei Yuan, Qiang Chen, Long Li and Kunio Sawaya. "Numerical Analysis on Transmission Efficiency of Evanescent Resonant Coupling Wireless Power Transfer system,"*IEEE Transactions on Antennas and Propogation,* vol.58, No.5, pp.1751-1758, May 2010.

[8] Nikola Tesla. "Experiments with Alternate Currents of High Potential and High Frequency," Fredonia Books Amsterdam, the Netherlands, 2002.

[9] H. Matsumoto."Research on solar power satellites and microwave power transmission in Japan," *IEEE Transactions on Magnetics,* vol.3, no.4, pp.36-45, Feb.2004..

[10] Murakami, F. Sato, T. Watanabe, H.Matsuki, s. Kikuchi, K. Harakaiwa, and T. Satoh, "Consideration on cordless power station-Contactless power transmission system," *IEEE Transactions on Magnetcs,* vol.317, pp.83-86, July2007

[11] C. A. Balanis, *Antenna Theory Analysis and Design,* 3ed. Hoboken, NJ:wiley, 2005 , ch3.

AUTHORS PROFILE

Hema Ramachandran is a Speed-IT Research Fellow at the College of Engineering,Trivandrum, Kerala, India. She has taught in NSS College of Engineering, Palakkad and University College of Engineering, Trivandrum where she also seved as Principal for a brief period. She also had a brief stint in software industry at Technopark, Trivandum. She is currently into full time research in WiTricity systems.

Dr. Bindu G. R was born in Kerala, India, on February 03, 1967. She took her M Tech Degree in 1992 and PhD in 2006 from University of Kerala. She worked as an Engineer in KERAFED and also as a Faculty in various Engineering Colleges in Kerala. At present she is Associate Professor in the Department of Electrical Engineering, College of Engineering Trivandrum. Her areas of special interest are electromagnetic field theory, control and condition–monitoring of electric drives.