Design of a compact Resonator for Wireless Power Transfer based on Magnetic Resonance

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Abstract

In this paper, wireless power transfer via strongly coupled magnetic resonances is experiment tally demonstrated. The proposed compact resonator is applicable to a tablet PC and wireless power transfer is validated by LED lighting test. The resonance between source and load coils is generated by using the multi-turn Litz wire to reduce the skin effect. The measured transfer efficiency is 66 %.
Keywords : Wireless power transfer, magnetic resonance, resonator

1. Introduction

The wireless power transfer becomes one of the most fascinating technologies since research group at MIT first investigated magnetic resonance based on wireless power transfer. They lighted a 60W bulb by transmitting the electrical power wirelessly from the source 1M apart using a helical coil of high Q and the power transfer efficiency was 60%. The basic principle of this technology is that the two separate coils with the same resonant frequency can form a resonant system based on high frequency magnetic coupling and exchange power in a high efficiency, while the coupling effect is weak between those objects with different resonant frequency. The medium of power transfer is an alternating magnetic field. This technology can be used to provide power for electrical equipments wirelessly in a certain distance[1,2] and can also be used to provide power wirelessly for mobile device charging. It will be a convenient and rapid method in the future. If one can make further improvement on the power transfer efficiency, this technology will have a wider application prospect such as mobile, laptop charging, LCD TV and industrial robot. In this paper, the compact resonator applicable to a tablet PC is proposed.

2. Theoretical model of self-resonant coils

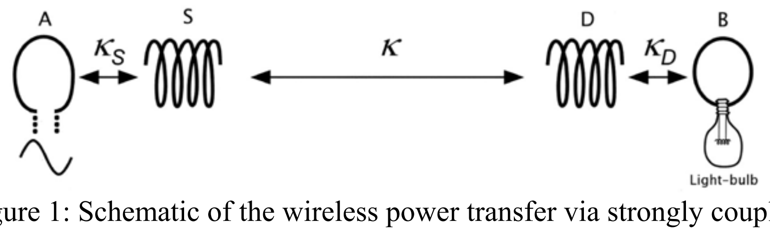


Figure 1: Schematic of the wireless power transfer via strongly coupled magnetic resonance[1].

The experimental realization of power transfer scheme achieved by MIT research group consists of two self-resonant coil. As shown in Fig. 1, one coil(S: the source resonant coil) is coupled inductively to an oscillating circuit; the other (D: the device resonant coil) is coupled inductively to a resistive load. Self resonant coils count on the interplay between distributed inductance and distributed capacitance to achieve resonance. The effective inductance 'L' and effective capacitance 'C' for each coil is defined as

$$L = \frac{\mu_0}{4\pi |I_0|^2} \iint dr dr' \frac{J(\mathrm{r}) \cdot J(r')}{|r - r'|}$$

$$\frac{1}{C} = \frac{1}{4\pi\varepsilon_0 |q_0|^2} \iint dr dr' \frac{\rho(\mathrm{r}) \cdot \rho(r')}{|r - r'|}$$

where J(r) is spatial current density, $\rho(r)$ is charge density, current I_o is current flowing through coil at initial condition and q_o is the total charge at current $I = 0$. The energy U contained in the coil is given by

$$U = \frac{1}{2} L |I_0|^2 = \frac{1}{2C} |q_0|^2$$

Given this relation and equation of continuity, the resulting resonance frequency is

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

The efficiency of power transfer depends only on 'Γ', the intrinsic decay rate of magnetic transfer (due to radiated losses and absorption by other objects), and 'κ', the coupling coefficient that describes the strength of resonance between the two resonating coils. Both κ and Γ are functions of distance between resonating objects and resonant frequency.
The parameters κ for the transfer path and Γ for the two coils were experimentally adjusted to achieve strong coupling. The experimental power transfer efficiency of the coupled coils decayed with distance, as expected from the theory. The power transferred from source to device coil is given by

$$P_{DS} = -i\omega M I_S I_D$$

where M is the effective mutual inductance[1,2].

3. Simulated Results

As shown in Fig. 2, A is a single cooper loop of radius 95mm that is a source of driving resonator. S and D are resonator which consists of source and device resonant coils. B is device coil attached to the load. Distance between the source and device resonant coils is 80 mm. The design of the proposed resonator was performed using Ansys HFSS[3].

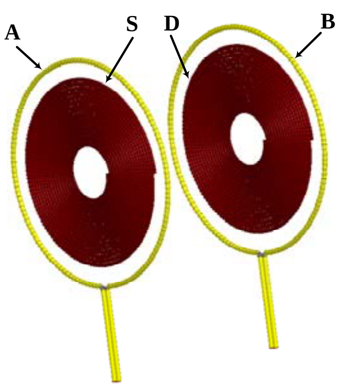


Figure 2 : Geometry of the resonator structure for wireless power transfer.

Fig. 3 shows the simulated results of the transfer and reflection properties of the proposed resonator. As shown in Fig. 3, S_{21}(the transfer efficiency) is -0.82 dB(82.8%). In addition, the input and output matching characteristics (S_{11} and S_{22}) reveal that the designed resonator has

7.8 dB I/O return losses at 13.16 MHz.

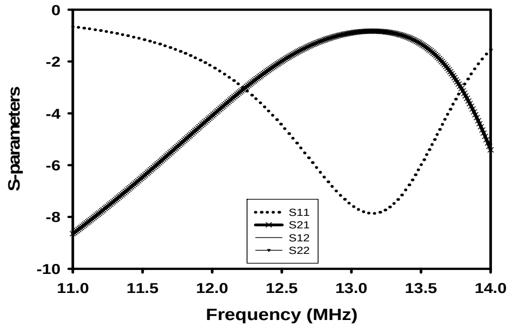
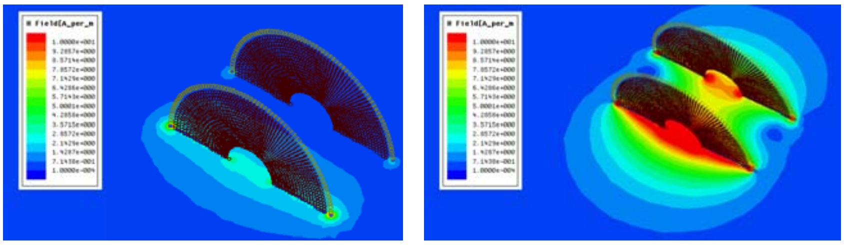


Figure 3: Simulated results of transfer and reflection properties.



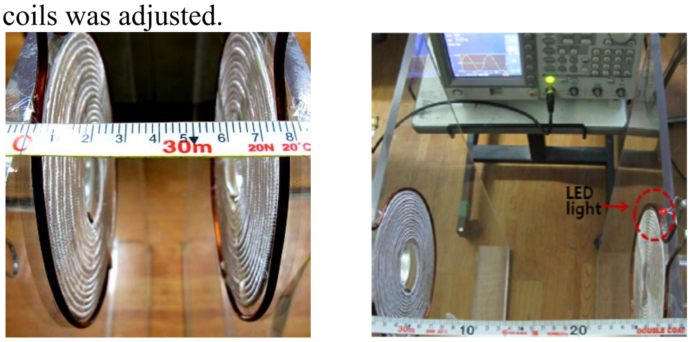
(a) (b)

Figure 4: Simulated magnetic field of the resonator.
(a) Without coupled magnetic resonance. (b) With coupled magnetic resonance.

Fig. 4 shows the simulated magnetic field of the resonator without and with coupled magnetic resonance. Unlike the case without coupled magnetic resonance, the magnetic field between the source and receiving devices with coupled magnetic resonance is strongly focused to the receiving device.

4. Fabrication and Measured Results

Fig. 5 shows the experimental setup. As shown in Fig. 5.(a), reflection coefficient (S_{11}, S_{22}) and transfer efficiency (S_{21}) were measured by the vector network analyzer (VNA). The diameter of source and device coils is 170 mm and the number of turn for resonant coils is 16. Distance between the source and device resonant coils is 80 mm and the resonance between source and load coils is generated by using the multi-turn Litz wire to reduce the skin effect that can occur at resonant frequency. Since the difference between the simulated and measured results was mainly due to manufacturing tolerance and an error due to the connector used in the measurement, the diameter of source and device coils was adjusted.



(a) (b)

Figure 5: The experimental setup.
(a) S-parameter measurement. (b) LED lighting test setup.

As shown in Fig. 5.(b), to validate the wireless power transfer, the LED light was connected attached device coil using a function generator. As shown in Fig. 6, S_{21} (the transfer efficiency) is

-1.8 dB (66%). In addition, the input and output matching characteristics (S_{11} and S_{22}) reveal that the designed resonator has sufficient 23 dB and 10 dB I/O return losses at 13.25 MHz, respectively. Fig. 7 shows the proposed resonator on a tablet PC (iPAD) for wireless power transfer.

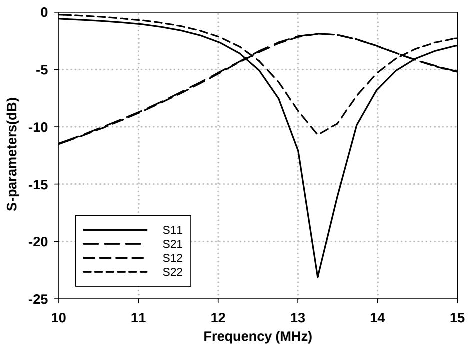


Figure 6: Measured S-parameters. Figure 7: The proposed resonator on the tablet PC.

5. Conclusions

In this paper, a compact resonator for wireless power transfer is proposed. It has a compact size applicable to a tablet PC and mobile devices. The power transfer efficiency between receiver and transmitter is 66 % (-1.8 dB). The diameter of source and device coils 160 mm and the number of turns for resonant coils is 16. Based on the experimental result and analysis, it is proved that wireless power transfer can be achieved using the coupled magnetic resonance technique. Nevertheless, the efficiency improvement and further experimental work need to be done to make this technology more practical.

Acknowledgments

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References

[1] Andre kurs, Aristeidis karalis, Robert Moffatt, J.D. Joannopoulos, Peter Fisher, Marin Soljacic, “Wireless Power Transfer via Strongly Coupled Magnetic Resonances,” *Science*, vol-317, pp.83-85, July,2007.

[2] Anand A.Trikolikar, Dr. Sanjay L. Nalbalwar, Lt. Milind P. Bhagat, “Review of Wireless Power Transmission by Using Strongly Coupled Magnetic Resonance,” *International Journal of Advanced Engineering & Applications,* Vol. 1, pp. 157-161, Jan. 2010.

[3] HFSS: High frequency structure simulator based on the Finite Element Method, v.13, Ansys Corporation.