Wireless Power Transfer Using Resonance Coupling Method for Implantable Applications

Jingchen Wang, Mark Leach, Eng Gee Lim, Zhao Wang
Department of Electrical and Electronics Engineering
Xi'an-jiaotong Liverpool University
Suzhou, China
jingchen.wang@xjtlu.edu.cn, mark.leach@xjtlu.edu.cn, enggee.lim@xjtlu.edu.cn, zhao.wang@xjtlu.edu.cn

Yi Huang
Department of Electrical Engineering and Electronics
University of Liverpool
Liverpool, UK
Yi. Huang@liv.ac.uk

***Abstract*—This paper presents a physically small wireless power transfer (WPT) system that is able to provide a high power transfer efficiency using the resonance coupling method for implantable applications. The resonant circuit topologies used at the transmitter and receiver are Series and Parallel respectively (referred to as an SP topology). The circuits utilize loop antennas and are designed to operate at 403 MHz and the power transfer efficiency can reach 85.66%. The effects of varying power transfer distance and load impedance on the system performance are inspected via software simulation.**

Keywords—wireless power transmission; loop antenna, resonance coupling; implantable applications; inductive coupling.

I. INTRODUCTION

Wireless power transfer (WPT), is a promising and innovative technology that allows the user to avoid the hassle of using wires to deliver energy to appliances. Recently, WPT technologies have been applied to charge consumer devices such as mobile phones and electric/hybrid vehicles [1-2], as well as other battery-operated items such as medically implanted devices [3-4], where battery replacement is not convenient. Importantly, the resonance coupling method of WPT has become the main focus as it can offer higher power transfer efficiency over larger distances than other methods [5].

In this work, a physically small resonance coupling based WPT system, with high power transfer efficiency, for use in charging implantable devices is proposed in Section II. Section III shows simulation results describing the influence of some important factors (distance and load resistance) on power transfer efficiency. Conclusions and ideas for future work are provided in Section IV.

II. WPT SYSTEM FOR IMPLATABLE APPLICATIONS

Firstly, the WPT power transfer performance depends on the equivalent impedance of the secondary circuit to the primary circuit at the resonant frequency [6]. Secondly, a primary circuit with a parallel topology looks like an open circuit at resonance, which means low current will be supplied for power transfer. Consequently, a series primary topology and a parallel secondary topology are chosen (as shown in Fig. 1).

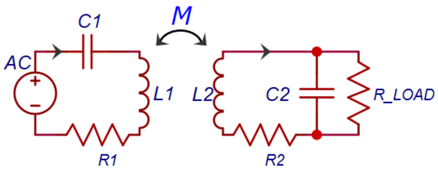


Fig. 1. Schematic of a SP compensated cicuit for implantable WPT.

The WPT system is designed to operate at 403 MHz in the MedRadio band. Planar loop antennas (as shown in Fig. 2) have been designed on FR4 substrate with dimensions of 12 mm×10 mm×1.5 mm to form the two inductors required ($L1$ and $L2$). The simulated inductance of the loop at 403 MHz is $L1=L2=112$ nH. Capacitances for the primary ($C1$) and secondary ($C2$) circuits were then calculated to form resonance at 403 MHz, $C1=1.4$ pF and $C2=1.39$ pF.

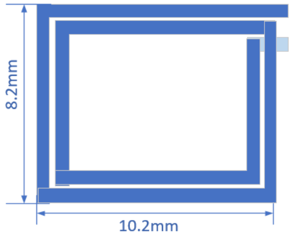
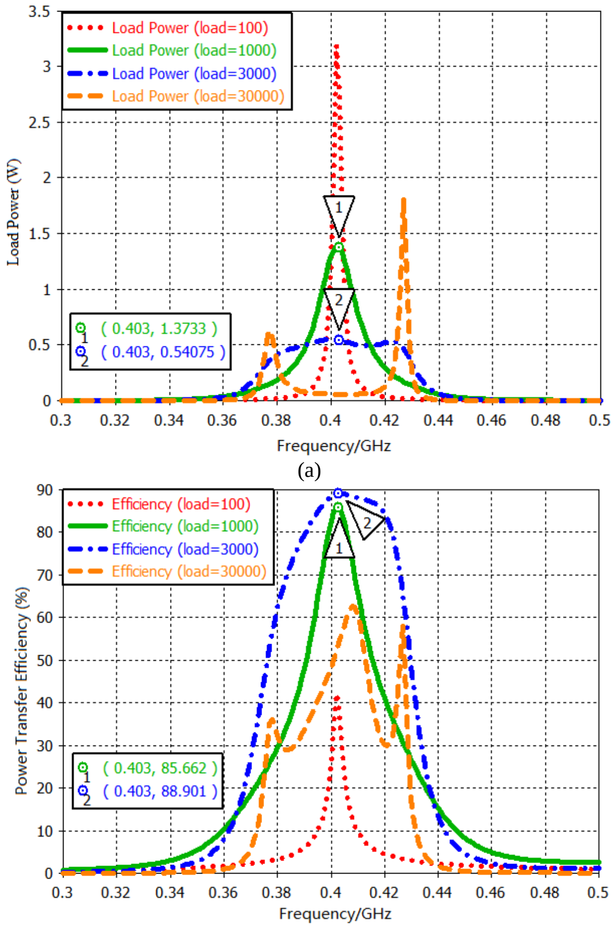


Fig. 2. Geometry of the designed loop antenna.

III. THE PERFORMANCE OF DESIGNED WPT LOOPS

The simulated loop antennas can be imported into CST-DS (Design Studio) to conduct analysis of the WPT circuit. The distance between the two loops is set to 5 mm and the input voltage to 5 V. In this case, the trends of load power and power transfer efficiency for different load impedances (100 Ω, 1 kΩ, 3 kΩ, and 30 kΩ) are shown in Fig. 3. The power transfer efficiency can be expressed by (1):

$$\eta=\frac{\mathbf{P}_{load}}{\mathbf{P}_{in}}\times 100\% \qquad (1)$$



(a)

(b)

Fig. 3. (a) Output power against frequency for various load impedances; (b) Power transfer efficiency against frequency for various load impedances.

From Fig. 3, the power transfer efficiency reaches a maximum of 88.90% for a load of 3 kΩ but the load power is only 0.54 W, resulting from the phenomenon of frequency splitting. However, when the load impedance is 1 kΩ, the output power is at its highest at around 1.37 W at 403 MHz and the power transfer efficiency reaches 85.66%, which is close to the maximum. So the optimized load impedance is 1 kΩ.

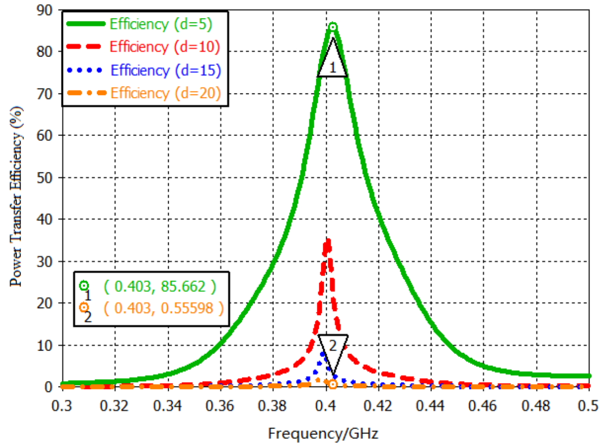


Fig. 4. Power transfer efficiency against frequency for various distances.

To investigate the influence of the distance between the loops, the distance is varied from 5 mm to 20 mm in 5 mm steps. The load impedance is fixed at 1 kΩ, and the input voltage is fixed at 5 V. The trend of power transfer efficiency against frequency for each distance is shown in Fig. 4. Fig. 4 demonstrates that as the distance becomes larger, the power transfer efficiency drops greatly from 85.66% to 0.56%. But for implantable applications such as devices located just under the skin, 5 mm is enough to conduct power transfer.

IV. CONCLUSIONS AND FUTURE WORK

In this paper, a physically small loop antenna was proposed with a simulated inductance of 112 nH. Simulations involving two identical loop antennas were used to obtain the mutual inductance for different distances using the CST software. A model of the proposed loops has been imported directly into CST-DS allowing an SP compensated circuit for WPT to be constructed. In this case, the influence of load impedance and distance on the power transfer and power transfer efficiency has been investigated using the CST models.

The load impedance was optimized up to 1 kΩ, which maximises output power at a power transfer efficiency of 85.66% at 403 MHz for a distance of 5 mm. Even though resonance coupling-based WPT has been shown to be a promising solution with relatively high power transfer efficiency, the circuit theory of this method needs further consideration. Factors including distance, load impedance, and inductance have been seen to have an effect on output power, power transfer efficiency and the consistency between maximum output power and maximum power transfer efficiency. Larger distances have been seen to significantly reduce the power transfer efficiency. This is a key issue for further research into the charging of implanted devices operating in the UHF band.

REFERENCES

[1] K. N. Bocan, M. H. Mickle and E. Sejdic, “Tissue variablitlity and antennas for power transfer to wireless implantable medical devices,” Wearable Sensors and Health Monitoring System, vol.5, pp. 2017

[2] R. Das and H. Yoo, “A multiband antenna associating wireless monitoring and noleaky wireless power transfer system for biomedical implants,” IEEE Transactions on Microwave Theory and Techniques, vol.65, no. 7, pp. 2485-2495, July, 2017

[3] Duc. Hung. Tran, Van. Binh. Vu and Woojin. Choi, “Design of a high-efficiency wireless power transfer system with intermediate loops for the on-board chargers of electric vehicles,” in IEEE transactions on power electronics. vol. 33, no. 1, pp. 175-187, Jan. 2018

[4] Mariusz. Bojarski, Erdem. Asa, Kerim. Colak and Dariusz. Czarkowski, “Analysis and control of multiphase inductively coupled resonant converter for wireless electric vehicle charger application,” IEEE transactions on transportation electrification, vol. 3, no.2, pp. 312-320, June, 2017.

[5] K. Agarwal, T. jegadeesan, Y. X. Guo and N. W. Thankor, “Wireless power transfer strategies for implantable bioelectronics: methodological review.” IEEE Reviews in Biomedical Engineering, vol. 10, pp. 1-28, 2017.

[6] Jiejian Dai, Daniel C. Ludois. A survey of Wireless Power Transfer and a Critical Comparison of Inductive and Capacitive Coupling for Small Gap Application., IEEE transaction on Power Electronics, vol.30, no.11, pp.6017-6029. 2015.