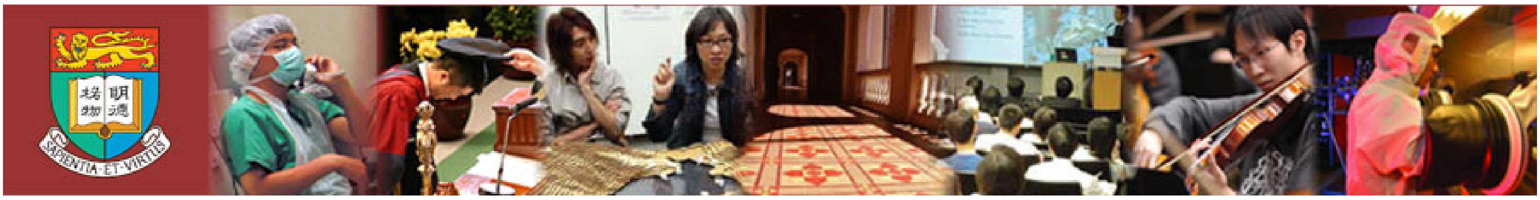

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Study of Wireless Power Transfer Link with Metallic Plates

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***Abstract* — In this paper, the wireless power transfer link with metallic plates is studied. By enforcing the boundary conditions along metallic surface, the magnetic fields are well confined between two plates and its flux focusing can be also improved. Meanwhile, the large metallic plates can also help to achieve higher transfer efficiency of the wireless power transfer link. Based on the filter theory, these enhanced field intensity effectively enlarge the dynamic range of coupling degree, thus improving the efficiency of the energy transmission. Finally, a 40.68MHz wireless transfer link with the highest measured efficiency of 86.56% is obtained and demonstrated.**

***Index Terms* — Wireless power transfer, metallic plates, transmission efficiency, magnetic-coupled resonators.**

I. INTRODUCTION

Recently, the research and development in wireless power transfer technologies have attracted an increasing attention in various fundamental and application fields, especially for contactless charging systems such as for the desk-based portable devices [1], telephones [2], as well as biomedical implantable devices [3]. As the most important parameter, the transmission efficiency depends on not only the physical configuration of the resonators, but also the surrounding environment. In [4], a four-coil symmetric system was experimentally demonstrated by varying the coupling factor between the source (load) and the internal resonators. As a result, the maximum efficiency of wireless power transfer link can achieve 92.5% at 6.7MHz. By optimizing the external and internal coupling coefficients, the optimized transmission links in free space can be obtained [5]-[8].

On the other hand, the placement of additional elements can also enhance the transmission links, such as metamaterials [9] and metallic planes [10]. The idea of using metamaterials was proposed to enhance the evanescent wave coupling and improve the transmission efficiency of a wireless power transfer system [9]. By placing two metallic planes at two sides symmetrically, the transfer efficiency of the coil systems with large capacitive patches can be improved from 95.4% to 97% [10].

In this work, we investigate the influences of metallic plates on the printed circuit boards (PCB) based wireless power transfer links. As shown in Fig. 1, two rectangular metallic plates are placed in parallel behind source and receiver loops, respectively, while two spiral resonators are designed at 40.68 MHz. Different from the coil-based system in free space [10], the whole system is fully based on PCB technology and the compact open-circuited spiral topologies are employed as resonators. By varying the distance from the existing system and changing the size of the metallic plates, we found that the magnetic field can be well confined between two metallic plates, thus improving magnetic flux focusing. Based on both simulated and experimental results, the transfer efficiency of the system is further improved.

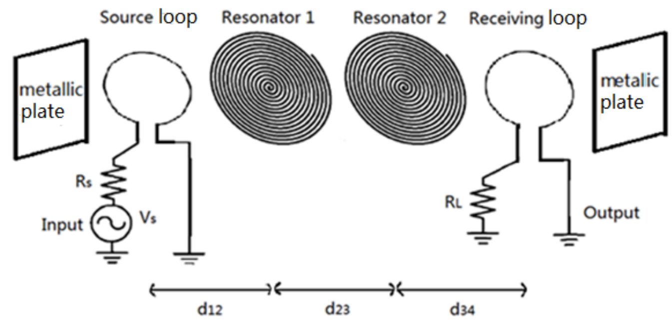

Fig. 1. Schematic of wireless power transfer link with metallic plates.

II. DESIGN OF WPT LINK WITH FILTER THEORY

As detailed in [8], a general wireless power transfer system based magnetic-coupled resonators can be considered as a filtering system. Hence, the transfer efficiency can be modeled by filter theory in terms of the amplitude of transmission coefficient

$$\eta = \left|S_{21}\right|^2 \tag{1}$$

Recalling the coupling matrix in the filter design [11], we have

$$S_{21} = 2\frac{1}{\sqrt{q_{e1}\cdot q_{e4}}}\left[\bar{Z}\right]_{41}^{-1} \tag{2}$$

where q_{e1} and q_{e4} are the scaled external quality factors, and the normalized impedance matrix $[\bar{Z}]$ can be written as

$$[\bar{Z}] = \begin{bmatrix} \frac{1}{q_{e1}}+p & -jm_{12} & \cdots & -jm_{14} \\ -jm_{21} & p & \cdots & -jm_{24} \\ \vdots & \vdots & \vdots & \vdots \\ -jm_{41} & -jm_{42} & \cdots & \frac{1}{q_{e4}}+p \end{bmatrix} \tag{3}$$

where m_{ij} denotes the so-called normalized mutual coupling coefficient, and p is the complex lowpass frequency variable. Mathematically, the confined magnetic field in-between the two metallic plates can effectively enlarge the realizable range of external quality factors and coupling coefficient.

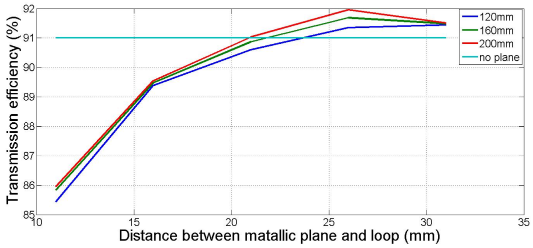

Fig. 2. Simulated transmission efficiency versus the distance between metallic plates and loops.

III. Results and Discussion

As shown in Fig. 1, a wireless power transfer link with two spiral resonators and feeding loops is designed at 40.68 MHz in this work. Resonator 1 and 2 can be regarded as the repeaters to help transmitting energy. For simplification, the source loop and resonator 1 are placed on two substrates, so that the distance in-between can further be adjusted, while the resonator 2 and receiving loop are placed on the two sides of one substrate. By increasing the distance between the loops and metallic plates (120 mm $\times$ 120 mm) from 11 mm to 32 mm, the transmission efficiency increases from 85.5 % to 91.5%. If the side length of the metallic plates increases from 120, 160 to 200 *mm*, the transfer efficiency reaches its maximum, which is higher than 91% without plates as shown in Fig. 2. Obviously, large metallic plates can help achieve higher transmission efficiency. At the distance of 26 *mm*, the system with 200 *mm* side length metallic plates can transmit 91.96% energy from source to receiver, while the system with smaller si de lengths of metallic plates could only receive 91.69% and 91.35% energy from source, respectively. Fig. 3 shows the amplitudes of magnetic fields in the longitudinal cross-section. It is important to notice that the metallic plates can help to confine the fields between two plates, while the intensity around the resonators is enhanced due to the magnetic flux focusing.

Fig. 4 shows the measured transfer efficiency of the system with 120 *mm* $\times$ 120 *mm* metallic plates. As expected, the efficiency gradually increases as the distance between metallic plates and loops gets larger. When the distance exceeds 25.5 *mm*, the system achieves higher transmission efficiency than that without metallic plates. Difference between measured results and simulated results may be caused by the actual loss of SMA connectors and fabrication tolerance.

IV. Conclusion

We have studied the influence of two metallic plates installed behind feeding loops of wireless power transfer system. Because of the enforced boundary conditions, the magnetic field can be effectively confined between the two metallic plates. As a result, the external and internal coupling degree can be enhanced, while the transmission efficiency can be further optimized.

Acknowledgement

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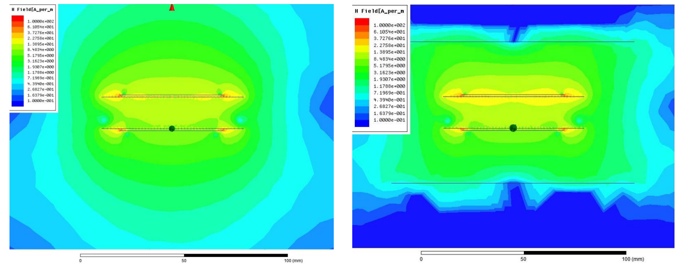

(a) (b)

Fig. 3. Amplitudes of magnetic fields in the longitudinal cross-section. (a) Without metallic plates; (b) With metallic plates.

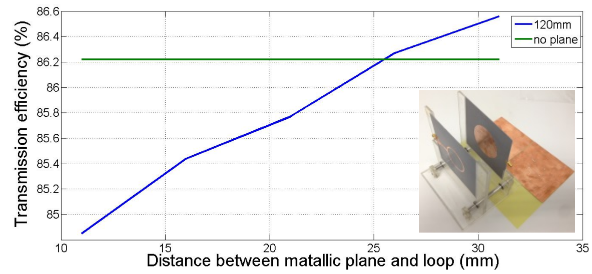

Fig. 4. Measured transmission efficiency versus the distance between metallic plates and loops. Inset: Photograph of experimental setup.

References

[1] K. Hatanaka, F. Sato, H. Matsuki, S. Kikuchi, J. Murakami, M. Kawase, and T. Satoh, “Power transmission of a desk with a cord-free power supply,” *IEEE Trans. Magn.*, vol. 38, no. 5, pp. 3329-3331, Sep.2002.

[2] J. Yungtaek and M. M. Jovanovic, “A contactless electrical energy transmission system for portable-telephone battery chargers,” *IEEE Trans. Ind. Electron.*, vol. 50, no. 3, pp. 520-527, Jun. 2003.

[3] A. K. RamRakhyani, S. Mirabbasi, and M. Chiao, “Design and optimization of resonance-based efficient wireless power delivery systems for biomedical implants,” *IEEE Trans. Biomed. Circuits Syst.*, vol.5, no. 1, pp. 48-63, Feb. 2011.

[4] T. P. Duong, and J. W. Lee, “Experimental results of high-efficiency resonant coupling wireless power transfer using a variable coupling method,” *IEEE Microw. Wireless Comp. lett.*, vol. 21, no. 8, pp. 442-444, Aug. 2011

[5] A. Karalis, J. D. Joannopoulos, and M. Soljacic, “Efficient wireless non-radiative mid-range energy transfer,” *Ann. Phys.* 323, pp. 34-48, 2008.

[6] R. E. Hamam, A. Karalis, J. Joannopoulos, and M. Soljacic, “Efficient weakly-radiative wireless energy transfer: An EIT-like approach,” *Ann. Phys.* 324, pp. 1783-1795, 2009.

[7] A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, and M. Soljacic, “Wireless power transfer via strongly coupled magnetic resonances,” *Science*, vol. 317, no. 5834, pp. 83-86, 2007.

[8] S. Sun, D. T. Xu, Q. S. Liu, and F. J. Lin, "From filter to mid-range wireless power transfer system," in *IEEE Int. Symp. on Radio Freq. Integration Tech.*, pp. 125-127, November 2012.

[9] B. Wang, K. H. Teo, T. Nishino, W. Yerazunis, J. Barnwell and J. Zhang, “Experiments on wireless power transfer with metamaterials,” *Appl. Phs. Lett.* 98, 254101, 2011.

[10] X. Yu, S. Sandhu, S Beiker, R. Sassoon, and S. Fan, “Wireless energy transfer with the presence of metallic planes,” *Appl. Phs. Lett.* 99, 214102, 2011.

[11] J. –S. Hong and M. J. Lancaster, *Microstrip filters for RF/microwave applications*, John Wiley & Sons, Inc., 2001.