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A Feedback Circuit of Effective Wireless Power Transfer for Low Power System

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Abstract

Wireless power transfer (WPT) is the technology that forces the power to transmit electromagnetic field to an electrical load through an air gap without interconnecting wires. This technology is widely used for the applications from low power smartphone to high power electric railroad. In this paper, the model of wireless power transfer circuit for the low power system is designed for a resonant frequency of 13.45 MHz. Also, a feedback WPT circuit to improve the power transfer efficiency is proposed and shown better performance than the original open WPT circuit, and the methodology for power efficiency improvement is studied as the coupling coefficient increases above 0.01, at which the split frequency is made.

Key words: wireless power transfer, coupling coefficient, wireless resonant frequency, power efficiency, magnetic resonance

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I. Introduction

Wireless power transfer (WPT) [1] is the transmitting without the use of wires. There are two ways of transmitting the source power to the output load. One is inductive method and another is magnetic resonance method. At the beginning of the 20th century, Nikola Tesla developed a technique for a large scale wireless power distribution. For the past two decades, major developments were made in the field of microwave transmission. In 1946, William C. Brown invented wireless power transmission by using a rectenna, a rectifying antenna, converting microwave energy into direct current electricity.

The inductive method for a short charging distance is applied, but the magnetic resonance method was introduced at MIT in 2007 to transmit the 60 W power up to a medium distance of 2m.

II. Design of Wireless Power Transfer Circuit

The equivalent circuit for the magnetic resonant circuit is shown in Fig. 1, which has the additional magnetic resonant coil to the original inductive circuit [2]. As shown in Fig. 2, the effective transmission depends on the high Q factor and coupling coefficient of k

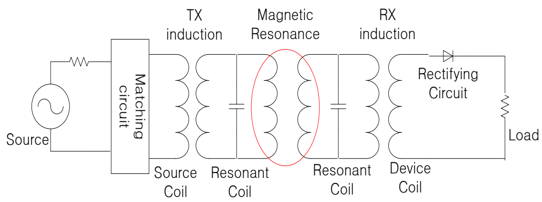

Fig. 1. A scheme for wireless power transmission using resonant coil.

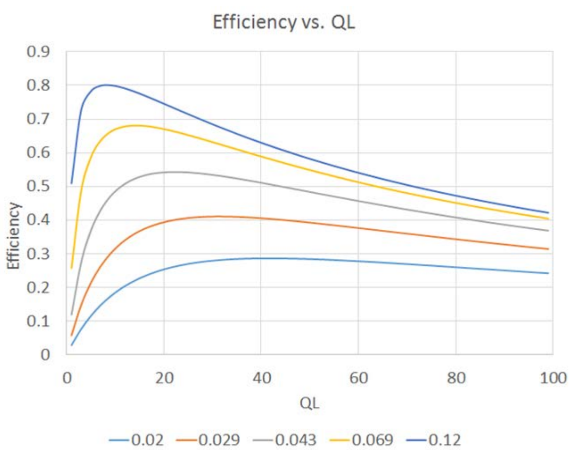

Fig. 2 The efficiency vs. the quality factor (Q_L).

The value of k is ranged from 0.01 to 0.12. Increasing the coupling coefficient leads to enhancing the transmission efficiency.

III. Simulation

The coupling coefficient has the range of 0 to 1. If the microwave produced at the source is all transmitted to the load, then the efficiency is 1. The efficiency is 0 for not transmitting it at all. The coupling coefficient [3] is defined by eq. (1).

$$k_{xy} = \frac{M_{xy}}{\sqrt{L_x L_y}} \quad (1)$$

where Mxy indicates mutual inductance between coil 'x' and coil 'y', Lx and Ly are inductances of coil 'x' and coil 'y', respectively, and the range of kxy is from 0 to 1. The relationship between the voltage and the current in Fig. 3 by using KVL is represented by eq. (2).

$$\begin{bmatrix} V_S \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} Z_1 & jwM_{12} & 0 & 0 \\ jwM_{12} & Z_2 & -jwM_{23} & 0 \\ 0 & -jwM_{23} & Z_3 & jwM_{34} \\ 0 & 0 & jwM_{34} & Z_4 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \\ i_4 \end{bmatrix} \quad (2)$$

Then, the load current of i_4 is obtained by eq. (3).

$$i_4 = \frac{-V_3 jwM_{12}(w^2 M_{23} M_{34})}{Z_1 Z_2 (Z_3 Z_4 + w^2 M_{34}^2) + w^2 M_{12}^2 (Z_3 Z_4 + w^2 M_{34}^2)} \quad (3)$$

Then, the load voltage of V_L becomes $V_L = -i_4 R_4$ and the power transmission efficiency of S_{21} is represented by eq. (4).

$$S_{21} = 2\frac{V_L}{V_S}\left(\frac{R_S}{R_L}\right)^{\frac{1}{2}} \quad (4)$$

The magnitude of S_{21} is determined by the coupling coefficient of k_{23} and the frequency, and the k_{23} is affected by the distance between the transmitting coil and the receiving coil. The mutual inductance decreases as the distance increases, in which the phenomena make the transmission efficiency be reduced and result in mismatching two coils.

In this paper, the equivalent open circuit of Fig. 3 [4] for wireless power transfer system is modeled, and the study of efficiency improvement is carried out.

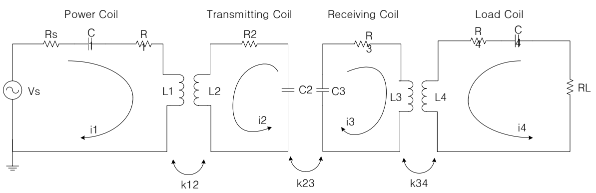

Fig. 3 The equivalent open circuit of wireless power transfer.

The power transferred to the load resistance of R_L is changed when k_{23} is changed. For the feedback circuit (Fig. 5), the k_{25} is obtained through the coupling L_5 for sensing the voltage across L_2.

The resonant frequency for WPT circuit is calculated using,

$$f_o = \frac{1}{2\pi\sqrt{LC}}\ \mathrm{Hz} \tag{5}$$

The resonant frequency for each inductance and capacitance is computed as 13.45 MHz. The inductance and the capacitance are 0.5 μH and 280 pF, respectively. The power transmission efficiency of S_{21} shown in Fig. 4 is calculated from 0.0001 to 0.1 by log sweep. S_{21} increases as the coupling coefficient of k_{23} increases at the center of the resonant frequency of fo, which is 13.45 MHz, but the width of frequency is expanded and the frequency is split from the coupling coefficient of greater than 0.01. For the coupling coefficient of less than 0.01, the resonant phenomenon occurs at the center of the single frequency. It is estimated that increasing k, namely the strongly coupling, can produce rather the reduction of efficiency for the short distance between two coils.

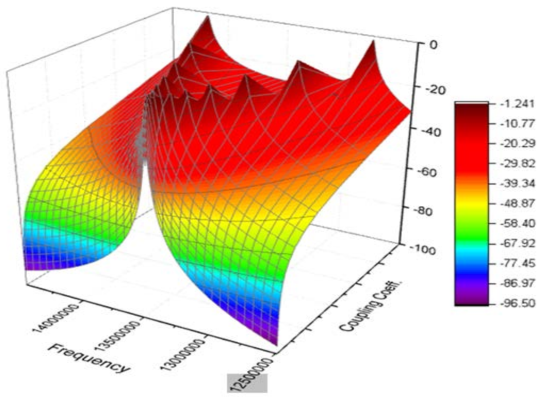

Fig. 4. The power transmission efficiency of S_{21}.

In Fig. 5, the value of k_{23} is estimated after measurement of V_{L2}. The variance of k_{23} affects the voltage of V_{L2}, having the corresponding resonant frequency fo±Δf. The oscillating frequency of the source voltage is adjusted to a new frequency of fo±Δf to make the circuit have a resonant condition in order to improve the power transfer efficiency for strongly coupled coefficient within the maximum allowed frequency of regulation. A new adjusted frequency for making the improved power transfer efficiency is created by the corresponding voltage for the feedback sensor inductor at the bottom part in Fig. 5.

Sensing the voltage across L_4 after coupling between L_2 and L_5 coils, and measuring the average voltage enables to change the input source voltage for the Feedback WPT circuit. The blue line in Fig. 7 indicates the power transfer efficiency for the open WPT circuit and yellow line shows that for the feedback WPT circuit of S_{21} in terms of the coupling coefficient.

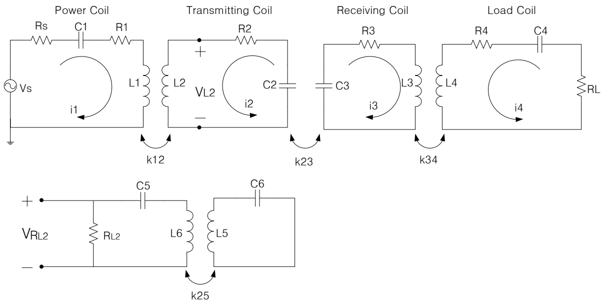

Fig. 5. The proposed feedback WPT circuit

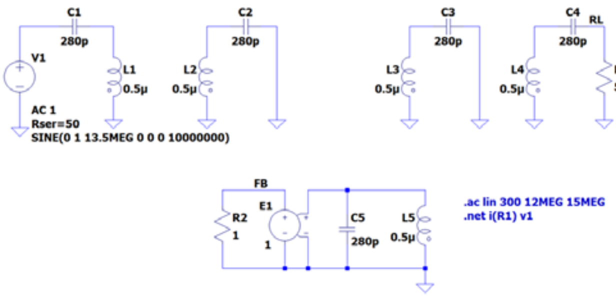

Fig. 6. A simulation circuit for WPT and feedback WPT

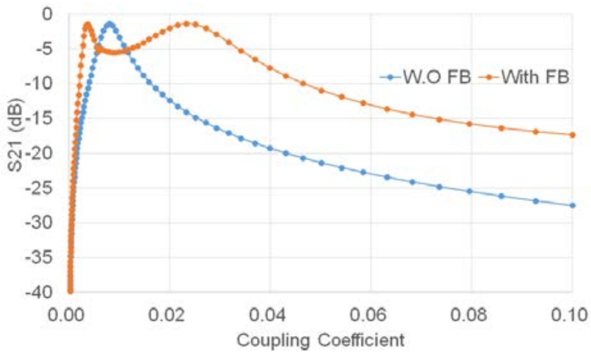

Fig. 7. S_{21} for the open and the feedback WPT circuit vs. coupling coefficient k_{23}.

It is confirmed that the efficiency improvement of maximum 15dB of S_{21} is accomplished for the feedback WPT circuit, compared with the open WPT circuit.

IV. Conclusions

The feedback WPT circuit is designed, and the relationship between the coupling coefficient and the power transmission efficiency is analyzed. It is estimated that this study can contribute to efficiency improvement for charging low power electronic devices. The hardware implementation for applying WPT system in real time is needed in the future work.

References

[1] Homepage of Wireless Power Consortium, http://www.wirelesspowerconsortium.com.

[2] Dong-Wook Seo, Jae-Ho Lee, and Hyung Soo Lee, "Study on Two-Coil and Four-Coil Wireless Power Transfer Systems Using Z-Parameter Approach," *ETRI Journal*, Volume 38, Number 3, June 2016.

[3] Junfeng Chen, Zhixia Ding, Zhaoyang Hu, Shengming Wang, Yongzhi Cheng, Minghai Liu, Bin Wei, and Songcen Wang, "Metamaterial-Based High-Efficiency Wireless Power Transfer System at 13.56 MHz for Low Power Applications," *Progress In Electromagnetics Research B*, Vol. 72, 17-30, 2017.

[4] Hoang Minh Huy, "Efficiency Improvement of Wireless Power Transfer by using of Adaptive Circuit," *Journal of The Institute of Electronics Engineers of Korea*, Vol. 38, NO. 10, Oct. 2011 (in Korean).