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A study on Relay Effect via Magnetic Resonant Coupling for Wireless Power Transfer

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Abstract. Wireless power transfer (WPT) transmits electrical energy from a power source to an electrical load wirelessly or without any conductors. The capability of WPT to transmit the energy is limited. Therefore, a relay was introduced to increase the distance of the WPT capabilities. The effect of the relay has been investigated to extend the energy transfer distance. The effect of relay was demonstrated by placing a relay coil between transmitter and receiver, relay biased to transmitter and placing two relay coils in the designed system. Experimental results are provided to prove the concept of the relay effect. The power transmission efficiency can be achieved up to 75% at 1 meter distance.

1 Introduction

The concept of Wireless Power Transfer (WPT) has been introduced over the century and now this technology is gaining more advances in wireless charging especially in portable consumer electronic devices, medical and industrial devices. The concept of transmitting power wirelessly has been proposed by Nikola Tesla, a pioneer electrical engineer in WPT by introducing a large scale wireless power distribution [1].

The capability of transmission power distance in WPT system is relatively short due to the effect of magnetic resonance coupling. The magnetic coupling decreases as the distance increases. Consequently, the capability of the WPT needs to be improvedto extend the distance in power transmission system. The transmission power at a longer distance can be enhanced by placing a relay coil (resonator) between the transmitter (Tx) and receiver (Rx). The resonator will receive magnetic field from the transmitter and then sending the magnetic field to the receiver. This concept is able to enhance the transmission power at a longer distance [2].

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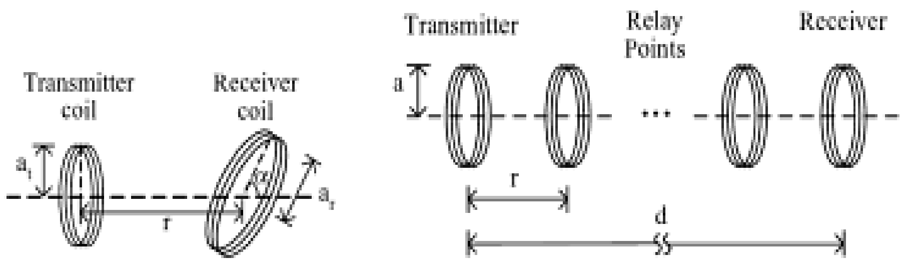
In a previous research work [3], the researchers managed to transfer power with a little radiated loss and approximately 40% to 50% of the power source has been delivered to the load when using the resonance at both the transmitter and receiver ports.

In magnetic coupling principle, the Rx coil is not sufficient to capture the magnetic flux linkage for the power delivery process from source to the load if the coupling distance is large [4]. Therefore, by placing a relay coil between Tx and Rx coils, longer distance for the power transmission process can be achieved [5], [6]. In [7], the relay effect in the magnetic resonance coupling has been reviewed. The relay coil was designed in spiral form to reduce the volume and high Q-capacitors were placed to alter the resonant frequency. The function of the relay coil was studied in [8]. The setting of an optimal position to place the relay coil has been recommended to achieve maximum power transmission. However, the relay coil can sometimes decrease the efficiency when the coupling distance is equal between Tx and Rx coils.



(a) (b)

Fig. 1. (a) The typical WPT system and (b) WPT with relay coils.

In this paper, the effect of relay coil has been investigated. The relay resonator is proposed to enhance the transmission distance and improve the power efficiency to increase the performance of the WPT system. The relay effect was examined by placing one relay coil between the Tx and Rx, placing the relay coil very close to the transmitter and inserting the two relay coils between Tx and Rx. Comparison is then made between each methods that has been proposed with the typical WPT system.

2 Basic principles for mid-range WPT

2.1 The mutual coupling strength

Mutual coupling can be defined as the electromagnetic interaction between the system elements in an array. The analysis of the mutual coupling between two resonant circuits has been discussed in [1]. Mutual inductance was described as:

$$M = k\sqrt{L_1 * L_2} \tag{1}$$

where k is the coupling coefficient that is represented by the distance of the Tx and Rx coils. It can be defined as:

$$k_{xy} = \frac{M_{xy}}{\sqrt{L_{xy}}} \tag{2}$$

For the model represented by the four-coil system as depicted in Fig. 9, th e coupling coefficients were determined by k_{12}, k_{23} and k_{34}. M_{xy} is a mutual inductance between coil *x* and coil *y*.

2.2 Power transfer efficiency

The power transfer efficiency (PTE) is interrelated with the scattering S-parameter that is represented by S_{21}sincethe WPT model system contains a two-port network. The two-port network is represented as input fed at the source while the other as output fed at the load. As for the S-parameter, the PTE can be defined as $\eta = |S_{21}|^2$when the network matches at both ports [9].

PTE is an important element of the Q-factor of primary coil (Q_p) and secondary coil (Q_s). The mutual coupling of both primary and secondary coils reacts to the function alignment and distance between the coils. Thus, the power efficiency can be defined as:

$$\eta = \frac{k^2\, Q_P\, Q_S}{1 + k^2\, Q_P\, Q_S} \tag{3}$$

The parameter of S_{21} can be defined as the ratio of signal exiting at output port to the signal incident at input port and this can be expressed as:

$$S_{21} = 2\frac{V_L}{V_S}\sqrt{\frac{R_S}{R_L}} \tag{4}$$

S_{11} represents the reflection coefficient of port 1 and S_{21} is the transmission coefficient from port 2 to port 1 of the WPT system and expressed as:

$$S_{11}(dB) = 20\log S_{11} \tag{5}$$

$$S_{21}(dB) = 20\log S_{21} \tag{6}$$

Therefore, based on the equation in (5), the ratio of power reflection, η_{11} can be expressed as:

$$\eta_{11} = |s_{11}|^2 x100\% \tag{7}$$

and the PTE of the system is represented by η_{21}as the following:

$$\eta_{21} = |s_{21}|^2 x100\% \tag{8}$$

3 Results and discussion

Modelling and analysis of the WPT system was implemented using Computer Simulation Technology (CST) Microwave Studio simulation software. The coil for this WPT system has been constructed as shown in Fig. 2 using planar hexagon spiral shape.

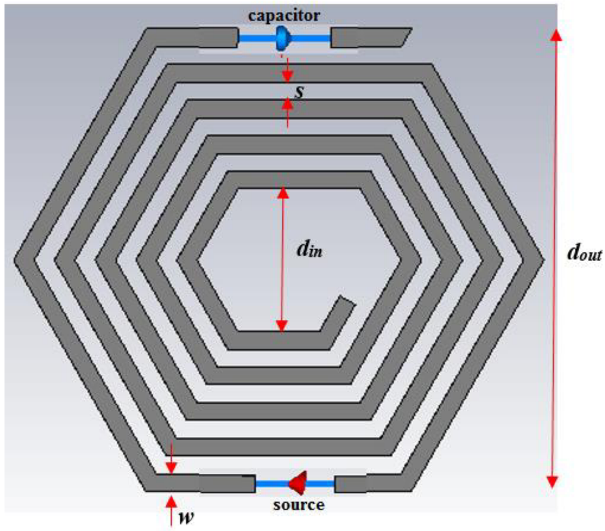


Fig. 2. Layout for LC resonator.

The coil was designed with 4.75 turns of coil, with an inner diameter (d_{in}), outer diameter (d_{out}), width (w) and turn spacing (s) of 8cm, 26cm, 1cm and 2cm respectively. The capacitance was set at 17.31pF to perform at resonant frequency of interest. Thus, making this WPT system to be well resonant at the operating frequency. The size of this model is similar for both transmitting (Tx) and receiving (Rx) inductive coils for a distance of 1 m. The design and optimization of the effect of relay coil and number of turns have been conducted for this investigation.

Fig. 3 shows the design of the Tx and Rx inductive coils at 1m distance. The system model of WPT in Fig. 3 is considered as two port network system. Therefore, the S-parameters i.e. S_{11} and S_{21} were determined to analyze this network system. S-parameter refers to the voltage travelling waves of the system which describe the relationship of the input-output between ports in the system model. S_{11} parameter can be defined as the power reflection coefficient by determining how much of the supplied power is reflected back from the system terminal, while S_{21} parameter represents the transferred power that indicates the vector of the ratio of signal exiting at output port to the incident signal at the input port.

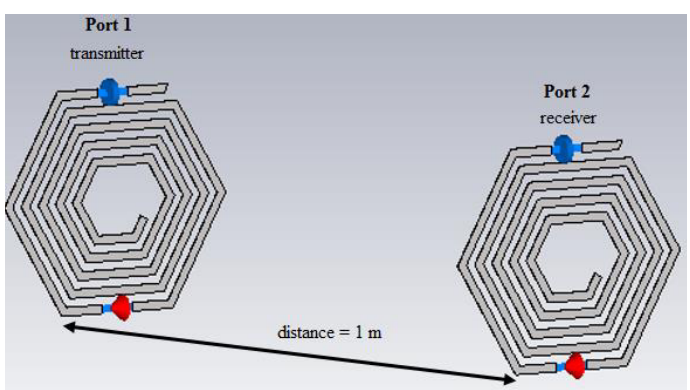


Fig. 3. Transmitter and receiver coils of atypical WPT system.

Fig. 4 shows the simulation result based on the designed system in Fig. 3. The simulation result was determined by S_{11} and S_{21}. Based on the S-parameters results in Fig. 3, the S_{11} parameter is -0.37 dB while the S_{21} parameter is -26.68 dB at the operating frequency of 38.58 MHz. The power transfer efficiency (PTE) that has been indicated with this parameter value is 4.6 % which is very low to transfer the power in the WPT system. Low efficiency will affect tthe performance of the WPT system. Therefore, such modelled system is not appropriate for the power transmission at a distance of 1m.

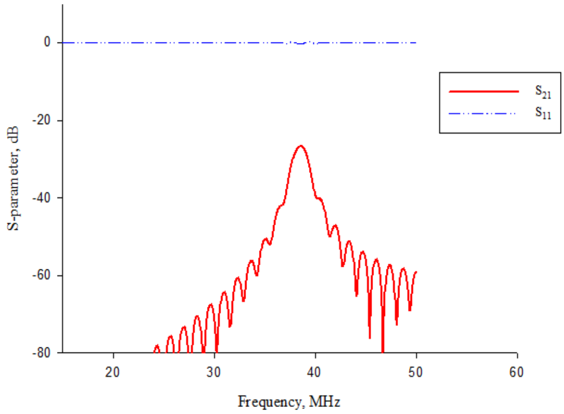


Fig. 4. Simulation results of S_{11} and S_{21} for a typical WPT system.

To overcome this issue, the relay coil was placed in between the Tx and Rx coils to be able to transfer the power for a distance of 1m. Consequently, the transmission efficiency can also be improved for a better performance. The magnetic coupling can be enhanced at a longer distance by placing the intermediate relay coil. The relay coil receives the magnetic field from the Tx and then relays the field to the Rx. Fig. 5 shows a WPT system with a resonator i.e. relay coil.

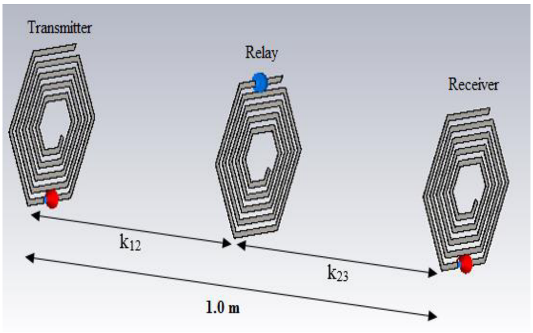


Fig. 5. WPT system with a relay coil.

The k_{12} and k_{23} represent the coupling coefficient of the system design. Coupling coefficient is referred as a dimensionless value for the coils that connects each other via magnetic field. This system was designed in a spiral form using hexagon shape. The coil in spiral shape is able to reduce the volume and a high-Q capacitor was inserted to tune the resonant frequency.

Based on the S-parameters results in Fig. 6, the S_{11} parameter is -1.90 dB while the S_{21} parameter is -13.30 dB at the operating frequency of 38.25 MHz. The PTE that has been

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indicated with this parameter value is 21.4 %. This result shows almost 16.8% increment of the power efficiency when inserting the relay coil compared with the typical WPT system.

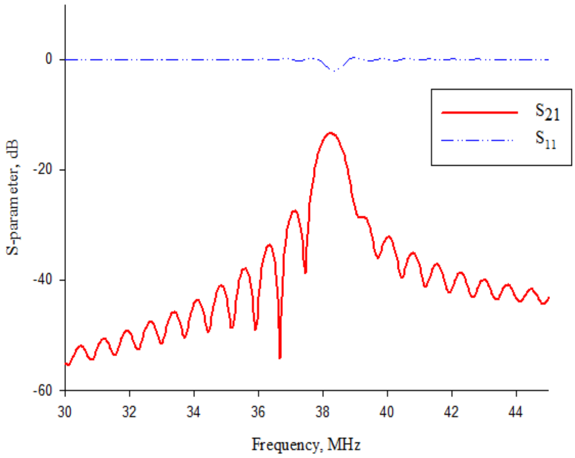

Fig. 6. Simulation results of S_{11} and S_{21} parameters with a relay coil.

To improve the power efficiency by more than 21.4 %, the relay coil is then placed very close to the transmitter as shown in Fig. 7. The experimental result is shown in Fig. 8.

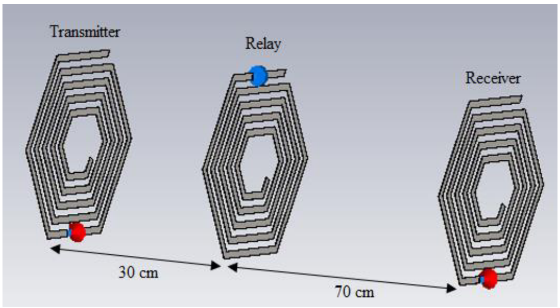

Fig. 7. Relay coil being placed very close to the transmitter.

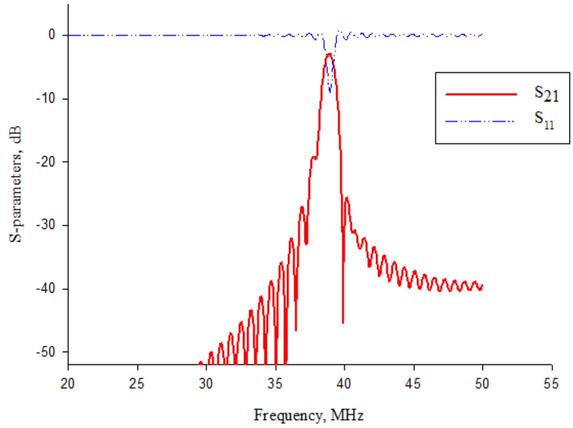

Fig. 8. Simulation results of S_{11} and S_{21} parameters when relay is biased to the transmitter.

Based on the S-parameters results in Fig. 8, the S_{11} parameter is -8.95 dB while the S_{21} parameter is -2.92 dB at the operating frequency of 38.91 MHz. The PTE that has been indicated with this parameter value is 71.4 %. This result shows almost 50 % increment of the power efficiency when placing the relay coil biased to the transmitter compared with the relay coil placed with equal distance in between the Tx and Rx of the WPT system. The relay effect in wireless power transfer can be improved with higher performance by more than 71 % improvement when inserting two relay coils between the Tx and Rx as shown in Fig. 9. The simulation result is shown in Fig. 10.

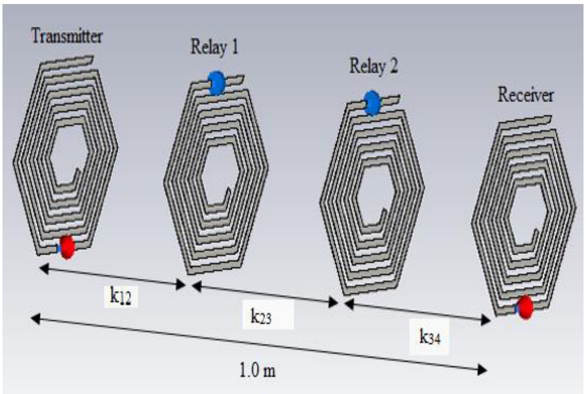

Fig. 9. The WPT system with 2 relay coils.

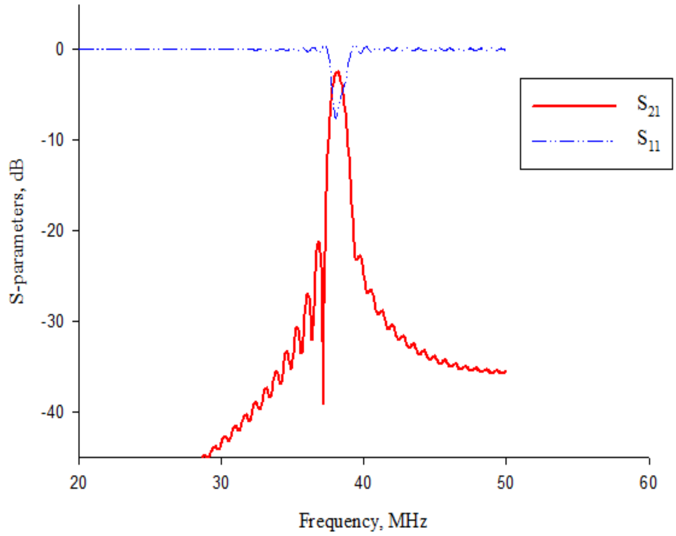

Fig. 10. Simulation results of S_{11} and S_{21} parameters when inserting 2 relay coils.

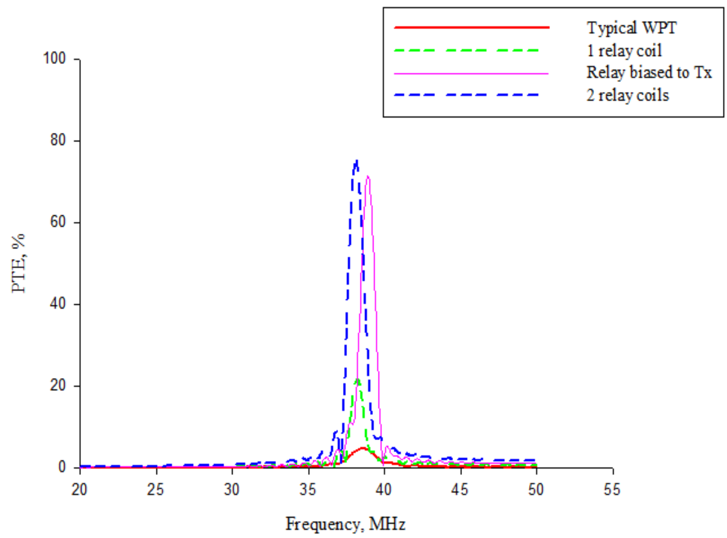

Fig. 11. Comparison of power efficiencies influenced by relay effect.

Based on the S-parameters results in Fig. 10, the S_{11} parameter is -6.98 dB while the S_{21} parameter is -2.45 dB at operating frequency of 38.15 MHz. The PTE that has been indicated with this parameter value is 75.4 %. This result shows almost 4 % increment of the power efficiency when placing the two relay coils between the Tx and Rx of the WPT system. Fig. 11 shows the comparison of the power efficiencies in WPT system that has been influenced by the relay coil effect. The power efficiency in WPT system increases when the number of relay increases.

5 Conclusions

The mid-range WPT system was designed to be applied in small device applications. The power efficiency of a typical WPT system has poor performance to transmit energy at 1 meter distance which can only reach up to 4.6 % power efficiency. Therefore, relay coil was inserted between Tx and Rx coils to extend the power transfer distance of the system. After placing the relay coil resonator, the power efficiency has shown an improvement up to 50 % increment compared to the system without relay coil. The effect of relay coil has been furtherinvestigated to increase the efficiency by positioning the relay coil close to the transmitter port. When the relay coil was placed closer to the Tx, result shows about 50 % increment of power efficiency.. In addition, by adding two relay coils between the Tx and Rx, the power efficiency was able to be increased up to 75 % at 1 meter distance of the WPT system. Thus, the relay effect is one of the solutions to enhance the distance for wireless power transmission.

References

1. S.Y.R. Hui, W. Zhong, C.K. Lee, IEEE Trans. Power Electron., **29**, 4500 (2014)
2. D. Ahn, S. Hong, IEEE Trans. Ind. Electron., **60**, 360 (2012)
3. B.L. Cannon, J.F. Hoburg, D.D. Stancil, S.C. Goldstein, IEEE Trans. Power Electron., **24**, 1819 (2009)

4. S.R. Barman, A.W. Reza, N. Kumar, M.E. Karim, A.B. Munir, Renew. Sust. Energ. Rev., **51**, 1525 (2015)
5. F. Zhang, S.A. Hackworth, W. Fu, C. Li, Z. Mao, M. Sun, IEEE Trans. Magnetics, **47**, 1478 (2011)
6. M. Kiani, U.M. Jow, M. Ghovanloo, IEEE Trans. Biomed. Circuits Syst., **5**, 579 (2011)
7. J.W. Kim, H.C. Son, K.H. Kim, Y.J. Park, IEEE Antennas Wireless Propag. Lett., **10**, 389 (2011)
8. X. Zhang, S.L. Ho, W.N. Fu, IEEE Trans. Magnetics, **48**, 4026 (2012)
9. L. Chen, S. Liu, Y.C. Zhou, T.J. Cui, IEEE Trans. Ind. Electron., **60**, 339 (2013)