Magnetic Resonance Type Selective Wireless Power Transfer Using Two Transmission Resonators with Phase Difference

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***Abstract*—Recently, a magnetic resonant wireless power transfer technology has attracted much attention due to its superior power transfer performance in a middle distance. As the technology utilizes the resonance phenomenon of a magnetic field, unintentional resonators with the same resonant frequency cause a power leak. In this study, a new selective wireless power transfer system using two transmission resonators with a phase difference is proposed and experimentally examined. The proposed concept was found to be feasible.**

***Keywords*—magnetic resonance coupling; selective wireless power transfer; phase difference feeding.**

I. Introduction

In recent years, mobile devices such as a cell phone are widely used. These devices allow us to exchange information anywhere and anytime. If electric power is also wirelessly supplied, it will give the mobile devices a new vista. A magnetic resonant type wireless power transfer technology has attracted much attention since the proposal by MIT [1]. It provides high efficiency power transfer in a middle distance by utilizing the resonance phenomenon of a magnetic field. It is also robust for the resonator positions. Toward the commercialization of the wireless power transfer systems, several approaches have been studied to improve the performance. For example, efficiency improvement of the resonators [2], interference preventing coil [3] and dual-band coil [4]. However, undesired power leak to unintentional resonators is worried the due to its long transfer distance.

In this paper, a selective wireless power transfer system using two transmission resonators is proposed. The proposed system effectively suppresses the unintentional power leak to undesired resonators by applying the source power to the two transmission resonators with a phase difference. The proposed system is experimentally evaluated to show the feasibility of the concept.

The rest of the paper is organized as follows. The basic concept and mechanism of the proposed system is introduced in Section II. Section III shows experimental results and demonstrates the feasibility. Section IV concludes the paper.

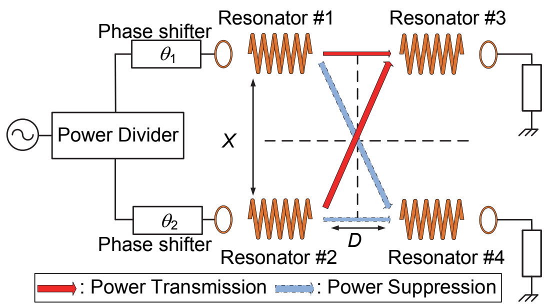

Fig. 1. Basic concept of the proposed selective wireless power transfer system.

II. Concept of the Proposed Selective Wireless Power Transfer System

Fig. 1 shows the basic concept of the proposed selective wireless power transfer system. The proposed system consists of two transmission resonators #1 and #2 and a reception resonator #3. Resonator #4 is an undesired resonator which power transfer is not intended to. The phase shifters are used to give a phase difference to the resonators #1 and #2.

The purpose of the proposed system is to transfer power only to the reception resonator #3 and not the undesired resonator #4. The configuration shown in Fig. 1 can be considered as a 4-port microwave circuit constructed with the coupling of the four resonators. When the four resonators are placed at double symmetric positions as shown in Fig. 1, the 4-port circuit acts as a 90° hybrid. Assuming the circuit is an ideal lossless 4-port circuit, its S matrix becomes unitaly. When all ports are perfectly matched and it has isolations between Port 1 and 2, and between Port 3 and 4, the S matrix is expressed in following expression.

$$S = \begin{bmatrix} 0 & 0 & S_{13} & S_{14} \\ 0 & 0 & S_{23} & S_{24} \\ S_{31} & S_{32} & 0 & 0 \\ S_{41} & S_{42} & 0 & 0 \end{bmatrix} \quad (1)$$

Considering the double-symmetry condition, the S parameters are as follows.

$$S_{31} = S_{42} = S_{13} = S_{24} = f \quad (2)$$

$$S_{41} = S_{32} = S_{14} = S_{23} = g \quad (3)$$

By applying the unitary condition

$$\sum_{k=1}^{n} S_{ki}^{*} S_{kj} = 0 \text{,} \quad (4)$$

following relation is obtained.

$$f^{*} g + g^{*} f = 0 \quad (5)$$

By using the complex notation of f and g, i.e.,

$$f = |f| e^{j\Theta}, g = |g| e^{j\psi} \text{,} \quad (6)$$

(5) results in

$$\cos(\Theta - \psi) = 0 \quad (7)$$

$$\Theta - \psi = \pm \frac{\pi}{2} \text{.} \quad (8)$$

As a result, the 4-port circuit constructed with four resonators acts as a 90° hybrid when the resonators are placed at the double symmetric positions [5, 6]. Hence, the transmission power is selectively transferred to a desired resonator only by giving 90° phase difference to the two transmission resonators.

III. Simulation and Experimental Results

Fig. 2 shows an experimental setup of the proposed system. Each resonator is formed by using a 2-mmϕ copper wire and the coil dimensions are 24.5-cm diameter and 7-cm long. The number of turn is 10. The resonant frequency of each coil is designed to be around 12 MHz.

The power transfer efficiency to the resonator #3 and #4 are defined in

$$\eta_3 = \frac{|s_{31} e^{j\theta_1} + s_{32} e^{j\theta_2}|^2}{2} \times 100\,[\%] \quad (9)$$

$$\eta_4 = \frac{|s_{41} e^{j\theta_1} + s_{42} e^{j\theta_2}|^2}{2} \times 100\,[\%] \quad (10)$$

where θ_1 and θ_2 are the phase shift values shown in Fig. 1. Measurement was conducted at the input port of the power splitter and the reception resonator #3 or the undesired resonator #4. The insertion loss of the power splitter is calibrated. Keysight Technologies' EMPro is used for simulation.

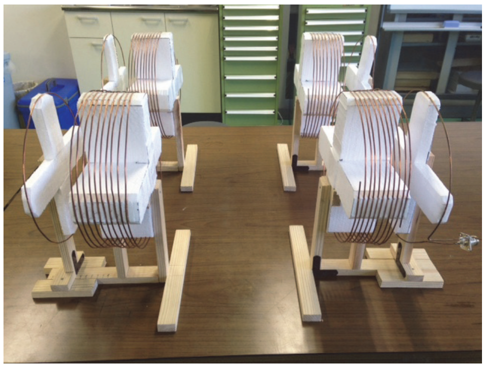

Fig. 2. Experimental setup of the proposed system.

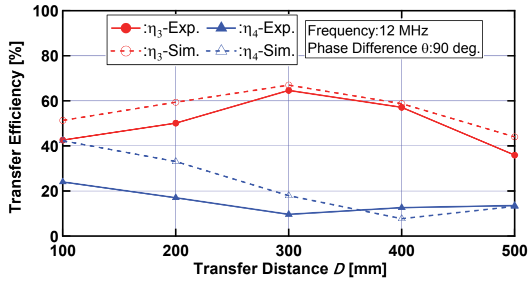

Fig. 3. Transfer efficiency with respect to the transfer distance (f = 12 MHz, X = 255 mm, D = 300 mm).

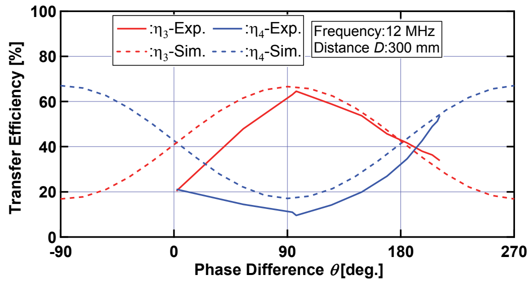

Fig. 4. The transfer efficiency with respect to the phase difference (f = 12 MHz, X = 255 mm, D = 300 mm).

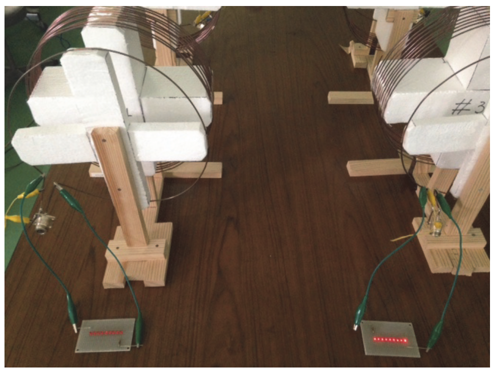

Fig. 5. Demonstration using LED lights (θ = 90°, f = 12 MHz, X = 255 mm, D = 300 mm).

Fig. 3 shows the simulated and measured transfer efficiency η_3 and power leak ratio η_4 with respect to the transfer distance *D* defined in Fig. 1. The transmission resonator separation *X* is set to 255 mm. In the range of *D* = 300 to 400 mm, good selectivity is obtained where the measured transfer efficiency η_3 and the leak power ratio η_4 are about 60% and 11%, respectively. In the case of *D* = 100 mm, the selectivity becomes low. This is because of the coupling between the transmission and reception resonators facing each other.

Fig. 4 shows the transfer efficiency with respect to the phase difference. Here, the transfer distance *D* and the separation of the two transmission resonators *X* are fixed to 255 mm and 300 mm, respectively. As shown in the results of the electromagnetic field simulation, the transfer efficiency changes like a sine function. Hence, reception resonators can be switched by changing the phase difference between the two transmission resonators. According to the experimental results, power is transferred to #3 only with the phase difference from 0° to 197° and transferred to #4 only with the phase difference from 197° to 211°.

Fig. 5 shows a demonstration of the proposed system using LED lights. The LED lights are connected to the output loop coils of the resonator #3 and #4. In this experiment, the transfer distance *D* and transmission resonator separation *X* are 300 mm and 255 mm, respectively again. The phase difference is set to 90°. Only the LED lights connected to the resonator #3 turn on. This result confirms the feasibility of the proposed selective wireless power transfer system.

IV. Conclusion

In this paper, a new selective wireless power transfer system is proposed. In this system, transmitting power is fed to the two transmission resonators with the phase difference of 90°. The proposed system is found to be feasible by the experimental results.

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