

Selective Wireless Power Transfer Using Two Transmission Coils Sandwiching Reception Coils

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Abstract—In this paper, a selective wireless power transfer system using two transmission coils is proposed. In this system, a magnetic resonant coupling between two transmission coils and two reception coils aligned on a line is used. By applying the phase difference to the two transmission coils, the power transferred to the two reception coils can be controlled. The mechanism of the proposed system is described using an equivalent circuit and the feasibility of the system is experimentally demonstrated. The maximum power transfer efficiency of 69% is obtained at the phase difference of 90 degrees where the power transfer to another reception coil is 10%.

Keywords—WPT; selective wireless power transfer; magnetic resonant coupling.

I. INTRODUCTION

Wireless power transfer systems based on an electromagnetic resonant coupling have been actively studied since the proposal by MIT in 2006 [1]. In order to extend the power transfer range, repeater coils placed between transmitter and receiver are also proposed [2]. Simultaneous information transfer is also studied [3]. The feature of the electromagnetic resonant coupling technology is using a resonant phenomenon of resonators. Hence, when the resonant frequencies of the transmission coil and reception coil are the same, it is possible to transfer the power in a middle range (several centimeters to several meters) with high efficiency. Furthermore, a transmitter sends power to all of reception coils near the transmission coil due to the long transfer range. This feature is an advantage to send power to multiple receivers at the same time. On the other hand, this feature also becomes a disadvantage to suppress undesired power transfer. Therefore a selective wireless power transfer technology is required. To transfer the power to only the desired devices, a resonant frequency switching technique was studied [4]. It is easy to implement, and simple to apply. But since the frequency band is the finite resource, it is not able to use a wide frequency band.

In this paper, we propose a new selective wireless power transfer system which effectively uses the characteristics of the coupled magnetic resonances. The proposed system consists of two transmission coils and two reception coils placed in a line. The power is fed to the two transmission coils with a phase difference. The basic behavior and experimental result are also discussed. In Section II, the principle of the proposed system is explained using an equivalent circuit. Simulation and

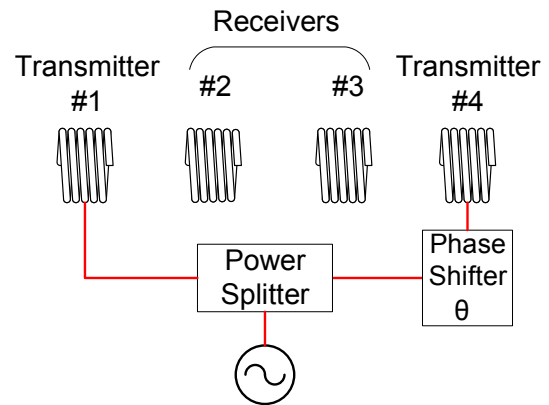


Fig. 1. Configuration of the proposed wireless power transfer system.

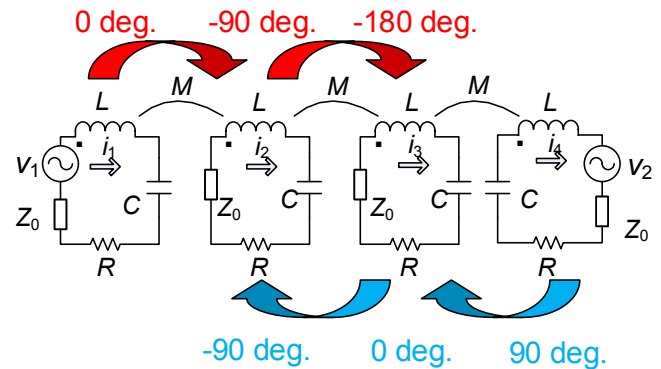


Fig. 2. Equivalent circuit and schematic of phase differences.

experimental results to confirm the feasibility of the proposed system are demonstrated in Section III. Finally, Section IV concludes the paper.

II. BASIC PRINCIPLE OF THE PROPOSED SYSTEM

Fig. 1 shows the configuration of the proposed selective wireless power transfer system. Two transmission coils (#1 and #4) and two reception coils (#2 and #3) are aligned in a line. A power source is connected to the two transmission coils with the phase difference θ .

Fig. 2 shows an equivalent circuit of the proposed system [4]. In this figure, L and M are the inductance of each resonator

coil and mutual inductance between adjacent coils, respectively. C and R are the parasitic elements of the coils. Z_0 is the source impedance or load impedance. With the reference to Fig. 2, the closed circuit equations are expressed as follows:

$$v_1 = Z_r i_1 + j\omega M i_2 \quad (1)$$

$$0 = j\omega M i_1 + Z_r i_2 + j\omega M i_3 \quad (2)$$

$$0 = j\omega M i_2 + Z_r i_3 + j\omega M i_4 \quad (3)$$

$$0 = j\omega M i_3 + Z_r i_4 \quad (4)$$

where Z_r is $j\omega L + 1/j\omega C + R + Z_0$. Therefore, i_2 and i_3 can be expressed in the following equations:

$$i_2 = \frac{-j\omega M \{Z_r^2 + (\omega M)^2\}}{Z_r \{Z_r^2 + 2(\omega M)^2\}} i_1 \quad (5)$$

$$i_3 = \frac{-(\omega M)^2}{Z_r^2 + 2(\omega M)^2} i_1 \quad (6)$$

When ω is equal to the resonant frequency ω_0 , Z_r becomes a real number. Thus phase shift from i_1 to i_2 is -90 deg. On the other hand, phase shift from i_1 to i_3 is -180 deg. As a result, the phases at the coils #2 and #3 become in-phase and anti-phase, respectively when the phase of #4 is advanced 90 degrees from #1 as shown in Fig. 2. This fact results in a selective wireless power transfer system.

III. SIMULATION AND EXPERIMENT RESULTS

Electromagnetic field simulation and experiment are conducted to confirm the feasibility of the proposed selective wireless power transfer system. Keysight Technologies' EMPro is used for the simulation.

Fig. 3 shows an experimental setup. Every self-resonant coil is made of 2-mm ϕ copper wire and the number of turn is 10. The radius and length of each coil are 12.25 cm and 7 cm, respectively. Each self-resonant coil is coupled to a loop coil for input and output. Every separation between the self-resonant coils is set to 200 mm in this experiment. Each of the separation between the self-resonant coil and loop coil is adjusted to achieve an impedance matching to the sources and loads.

Power transfer efficiencies to the reception coil #2 and #3 are defined in the following formulas:

$$\eta_2 = \frac{|S_{21} + S_{24}e^{j\theta}|^2}{2} \times 100 [\%] \quad (7)$$

$$\eta_3 = \frac{|S_{31} + S_{34}e^{j\theta}|^2}{2} \times 100 [\%] \quad (8)$$

where S_{ij} are S parameters of the circuit constructed with 4 coils and i and j are the number of coils shown in Fig. 1. In the experiment, S parameters are measured between one of the reception coils and the input port of the power divider which equally divides input power to the two transmission coils.

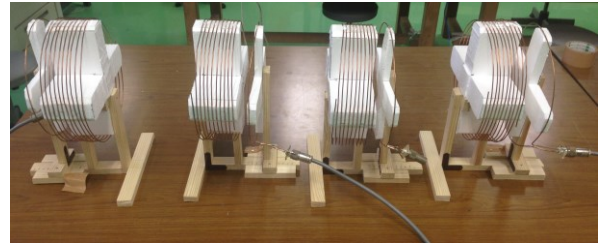


Fig. 3. Experimental setup.

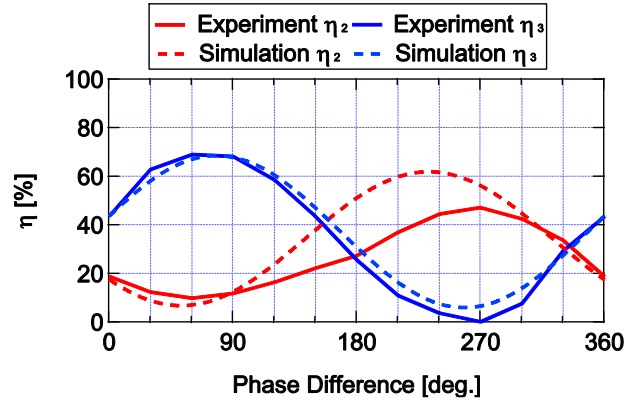


Fig. 4. Simulated and measured power transfer efficiency to the two reception coils (Simulation: $f = 11.88$ MHz, Experiment: $f = 11.75$ MHz).

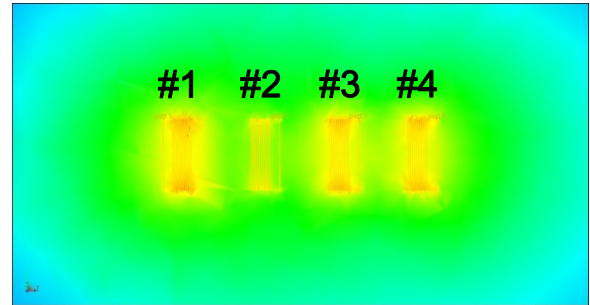


Fig. 5. Simulated magnetic field ($\theta = 90$ deg., $f = 11.85$ MHz).

Fig. 4 shows the simulation and experiment results. Simulated and experiment frequencies were determined from the frequency when S_{11} becomes minimum. They are 11.88 MHz and 11.75 MHz for simulation and experiment, respectively. According to the results, the reception coil #2 receives maximum power and coil #3 receives minimum power around the phase difference of 270 deg., and reverse characteristic is obtained around 90 deg. In the experiment results, the minimum value of η_2 is less than 1% at $\theta = 270$ deg., and the minimum value of η_3 is 10% at $\theta = 90$ deg. Thus, enough suppression is achieved at the phase differences of 90 deg. or 270 deg. according to the simulation and experiment results. In addition, the maximum transfer efficiencies to the resonators #2 and #3 reach 69% at $\theta = 90$ deg. and 47% at 270 deg. at the coil separation of 200 mm, respectively. The measured and simulated results become asymmetry because each coil is fed from different side by a loop coil.

Fig. 5 shows the simulated magnetic field ($\theta = 90$ deg.). Red area shows the strong magnetic field, and green area shows the weak magnetic field. Because the intensity of the magnetic field around #2 is less than that around #3, this figure means suppression is clearly occurred at #2.

IV. CONCLUSION

In this paper, a new selective wireless power transfer system based on the coupling magnetic resonances is proposed. The proposed system is consists of two transmission coils with a phase difference and two reception coils sandwiched by the transmission coils. The basic characteristics of the proposed system are evaluated by simulation and experiment. Selective power transfer is achieved with the phase differences of 90 deg. and 270 deg. The maximum transfer efficiency of 69% was obtained with the undesired transfer of 10% for 200-mm transfer. The proposed concept is found to be feasible.

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