Analysis on Transmission Efficiency of Magnetic Resonance Based Wireless Energy Transmission Resonator

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Abstract

In this paper, a high-efficiency wireless energy transmission via magnetic resonance is experimentally implemented in a resonator with the various sizes of transmitting and receiving coils and the receiving coil having two shapes of rectangular and circular types. The transmission efficiency is analyzed by varying the transmission distance. The resonance between the transmitting and receiving coils is achieved with lumped capacitors terminating the coils. The transmission efficiency of the resonator consisted of the circular transmitting coil with the diameter of 60 cm and rectangular receiving coil with the length of one side of 10 cm is about 80 % at the transmission distance of 20 cm.

Keywords : Wireless Energy Transmission Magnetic Resonance Resonator High-Efficiency Transmission Distance

1. Introduction

In recent years, there has been increasing interest in the research and development of wireless energy transmission technology to eliminate the “last cable” due to its wide range of applications in charging ubiquitous electronic devices such as MP3 players, PDA, tablet PC, mobile phones, and household robots without a cord. The portable devices are still constrained to the use of batteries or some other form of energy storage. Even with advances in the reduction of power consumption, the batteries are typically the largest and heaviest component in modern portable devices. The wireless energy transmission can enable the creation of ambient power, where the devices send and receive the power to each other [1], [2].

The most popular wireless energy transmission technologies are the electromagnetic induction and microwave energy transmission. However, the electromagnetic induction has a short range and, and the microwave energy transmission has a low efficiency as it uses radiation. Recently, a highly efficient mid-range wireless energy transmission technology using magnetic resonance coupling has been proposed by WiTricity. It makes wirelessly transmitting the energy as high efficiency at the mid-range. However, this wireless energy transmission technology has used the large transmitting and receiving coils. Therefore, it has not been used to charge wirelessly the small-sized ubiquitous electronic devices due to the large size of receiving coil [3]-[6].

In this paper, we have simulated and measured the wireless energy transmission resonators consisted of the various sizes of transmitting and receiving coils and the receiving coil having two shapes of rectangular and circular types.

2. Comparison on Transmission Efficiency Between Circular and Rectangular Wireless Energy Transmission Resonators

As shown in Fig. 1, the wireless energy transmission resonator having the large transmitting and small receiving coils has been simulated by varying the transmission distance. The transmitting and receiving coils have the circular shape. The diameters (D_{Tx1}, D_{Tx2}) of coupling and resonance loops in the transmitting coil are 40 cm and 60 cm, and the diameters (D_{Rx1}, D_{Rx2}) of coupling and resonance loops in the receiving coil are 10 cm. The widths (W_{Tx}, W_{Rx}) of transmitting and receiving coils are 3 cm and 0.5 cm. The separation (S_{Tx}) of transmitting coil varies as the transmission distance for the impedance matching. The separation (S_{Rx}) of receiving coil is 0.5 cm. The capacitors (C_{Tx1}, C_{Rx3}) terminating the resonance loops in the transmitting and receiving coils generate the between the transmitting and receiving coils. The capacitors (C_{Rx1}, C_{Rx2}) consisting of the coupling loop in the receiving coil have been used for 50 Ω matching network. As shown in Fig. 2, the wireless energy transmission resonator having the large circular transmitting and small rectangular receiving coils has been simulated by varying the transmission distance. The diameters (D_{Tx1}, D_{Tx2}) of coupling and resonance loops in the transmitting coil are 40 cm and 60 cm, and the lengths (D_{Rx1}, D_{Rx2}) of one side of coupling and resonance loops in the receiving coil are 10 cm. The widths (W_{Tx}, W_{Rx}) of transmitting and receiving coils are 3 cm and 0.5 cm. The separation (S_{Tx}) of transmitting coil varies as the transmission distance for the impedance matching. The separation (S_{Rx}) of receiving coil is 0.5 cm. The capacitors (C_{Tx1}, C_{Rx3}) terminating the resonance loops in the transmitting and receiving coils generate the resonance between the transmitting and receiving coils. The capacitors (C_{Rx1}, C_{Rx2}) consisting of the coupling loop in the receiving coil have been used for 50 Ω matching network.

Fig. 3 shows the fabrications and measured s-parameters of the wireless energy transmission resonators using the large circular transmitting and small circular receiving coils and the large circular transmitting and small rectangular receiving coils at the transmission distance of 20 cm. The wireless energy transmission resonators have been fabricated on the copper pipes with the widths of 3 cm and 0.5 cm. As shown in the measured results, the transmission efficiencies of the wireless energy transmission resonators using the large circular transmitting and small circular receiving coils and the large circular transmitting and small rectangular receiving coils are 78.2 % and 79.6 % at the transmission distance of 20 cm. The resonance frequency is 13.56 MHz. The impedance matching is perfectly implemented by adjusting the separation between the coupling and resonance loops of the transmitting coil and by the matching circuit on the coupling loop of the receiving coil in two wireless energy transmission resonators. Fig. 4 shows the comparison on the transmission efficiency between the wireless energy transmission resonators using the small circular and rectangular receiving coils as increasing the transmission distance. As shown in these results, the transmission efficiency of the wireless energy transmission resonator having the circular transmitting coil with the resonance loop of the diameter of 60 cm and the rectangular receiving coil with the resonance loop of the length of one side of 10 cm is superior to that of the wireless energy transmission resonator having the circular transmitting coil with the resonance loop of the diameter of 60 cm and the circular receiving coil with the resonance loop of the diameter of 10 cm. It is because the length of the resonance loop of the rectangular receiving coil is longer than that of the resonance loop of the circular receiving coil in the same area. Namely, the inductance of the resonance loop of the rectangular receiving coil is larger than that of the resonance loop of the circular receiving coil in the same area. Therefore, the capacitance of the capacitor terminating the resonance loop in the rectangular receiving coil is smaller than that of the capacitor terminating the resonance loop in the circular receiving coil.

3. Analysis on Transmission Efficiency of Various Sizes of Wireless Energy Transmission Resonators

As shown in Fig. 5, the wireless energy transmission resonators having the various-sized circular transmitting and receiving coils have been fabricated and measured at the transmission distance of 20 cm. In first case, the diameters (D_{Tx1}, D_{Tx2}) of coupling and resonance loops in the transmitting coil are 40 cm, and diameters (D_{Rx1}, D_{Rx2}) of coupling and resonance loops in the receiving coil are 10 cm. In second case, the diameters (D_{Tx1}, D_{Tx2}) of coupling and resonance loops in the transmitting coil are 20 cm, and diameters (D_{Rx1}, D_{Rx2}) of coupling and resonance loops in the receiving coil are 10 cm. In third case, the diameters (D_{Tx1}, D_{Tx2}, D_{Rx1}, D_{Rx2}) of coupling and resonance loops in the transmitting and receiving coils are 10 cm. In all cases, the widths (W_{Tx}, W_{Rx}) of transmitting and receiving coils are 0.5 cm. The separations (S_{Tx}, S_{Rx}) of transmitting and receiving coils are 0.5 cm. The capacitors (C_{Tx3}, C_{Rx3}) terminating the resonance loops in the transmitting and receiving coils generate the resonance between the transmitting and receiving coils. The capacitors (C_{Tx1}, C_{Tx2}, C_{Rx1}, C_{Rx2}) consisting of the coupling loops in the transmitting and receiving coils have been used for 50 Ω matching network.

Fig. 6 shows the fabrication of the wireless energy transmission resonators having the various-sized circular transmitting and receiving coils. Fig. 7 shows the measured s-parameters of the wireless energy transmission resonator having the various-sized circular transmitting and receiving coils. As shown in Fig. 7 (a), the transmission efficiency of the wireless energy transmission resonator having the circular transmitting coil with the coupling and resonance loops of the diameter of 40 cm and the circular receiving coil with the coupling and resonance loops of the diameter of 10 cm is about 75.86 % at the transmission distance of 20 cm. As shown in Fig. 7 (b), the transmission efficiency of the wireless energy transmission resonator having the circular transmitting coil with the coupling and resonance loops of the diameter of 20 cm and the circular receiving coil with the coupling and resonance loops of the diameter of 10 cm is about 68.03 % at the transmission distance of 20 cm. As shown in Fig. 7 (c), the transmission efficiency of the wireless energy transmission resonator having the circular transmitting and receiving coils with the coupling and resonance loops of the diameter of 10 cm is about 52.73 % at the transmission distance of 20 cm. Fig. 8 shows the variation on the transmission efficiency of the wireless energy transmission resonator as increasing the diameter of the transmitting coil at the transmission distance of 20 cm. As shown in the result, when the diameter of the transmitting coil increases above a certain threshold, it is expected that the contribution of the increase of the transmitting coil size is progressively less significant. It is evident that increasing the diameter of the transmitting coil above a certain threshold does not produce any further improvement of the transmission efficiency in the short range. Therefore, the diameter of the coil must be selected by considering the transmission efficiency, transmission distance, and resonator size for preventing the unnecessary increase of the coil size.

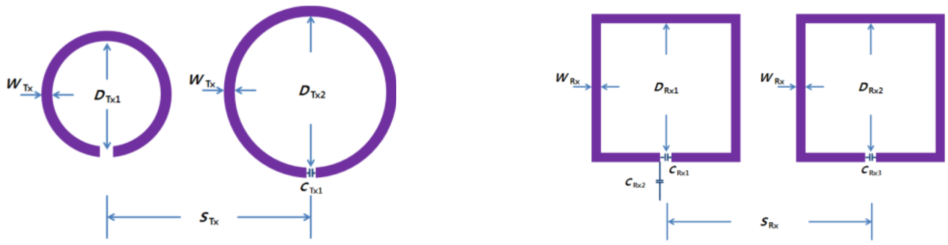
4. Conclusions

A high-efficiency wireless energy transmission via magnetic resonance is experimentally implemented in a resonator with the various sizes of transmitting and receiving coils and the receiving coil having two shapes of rectangular and circular types. The transmission efficiency is analyzed by varying the transmission distance. The resonance between the transmitting and receiving coils is achieved with lumped capacitors terminating the coils. The transmission efficiency of the wireless energy transmission resonator with the rectangular receiving coil is superior to that of the wireless energy transmission resonator with the circular receiving coil. Increasing the diameter of the transmitting coil above a certain threshold does not produce any further improvement of the transmission efficiency in the short range. The diameter of the coil must be selected by considering the transmission efficiency, transmission distance, and resonator size for preventing the unnecessary increase of the coil size.

5. Figures and Tables

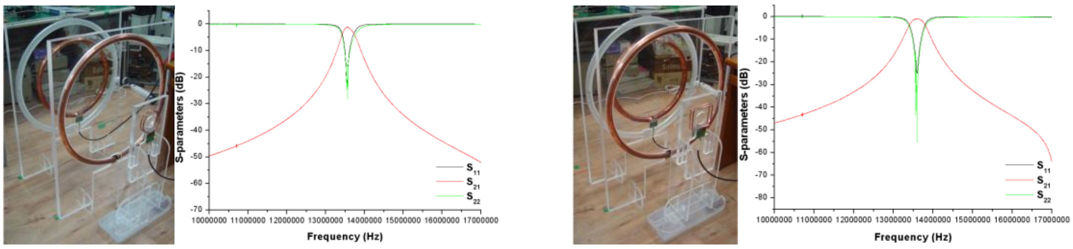
(a) (b)

Figure 1: Wireless energy transmission resonator having large circular transmitting and small circular receiving coils (a) Transmitting coil, (b) Receiving coil.



(a) (b)

Figure 2: Wireless energy transmission resonator having large circular transmitting and small rectangular receiving coils (a) Transmitting coil, (b) Receiving coil.



(a) (b)

Figure 3: Fabrications and measured s-parameters of wireless energy transmission resonators at transmission distance of 20 cm (a) Large circular transmitting and small circular receiving coils, (b) Large circular transmitting and small rectangular receiving coils.

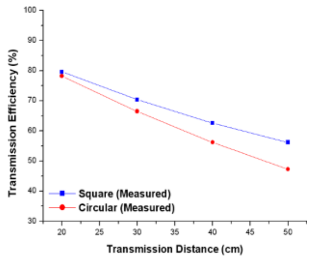
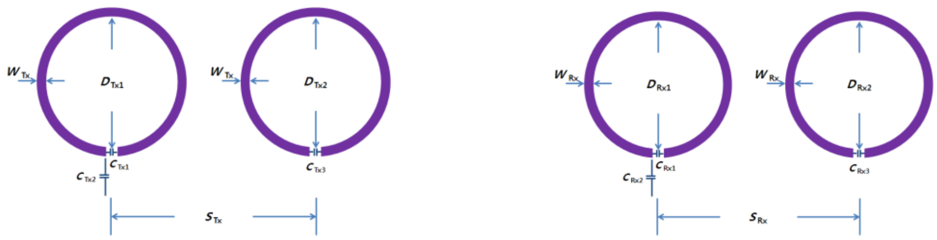


Figure 4: Comparison on transmission efficiency between wireless energy transmission resonators using small circular and rectangular receiving coils.

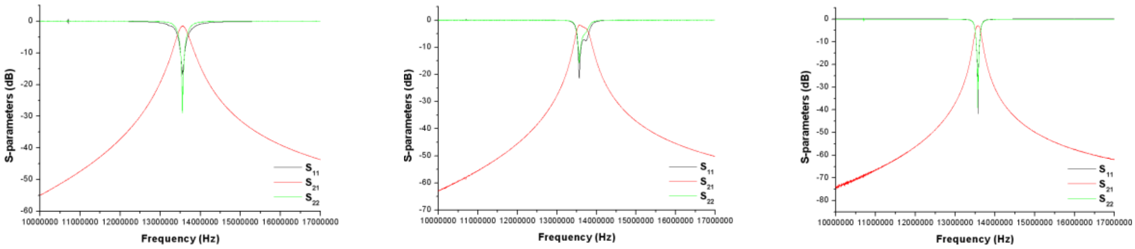


(a) (b)

Figure 5: Wireless energy transmission resonators having various-sized circular transmitting and receiving coils (a) Transmitting coil, (b) Receiving coil.

(a) (b) (c)

Figure 6: Fabrication of wireless energy transmission resonators having various-sized circular transmitting and receiving coils (a) D_{Tx1}, D_{Tx2} = 40 cm, (b) D_{Tx1}, D_{Tx2} = 20 cm, (c) D_{Tx1}, D_{Tx2} = 10 cm.



(a) (b) (c)

Figure 7: Measured s-parameters of wireless energy transmission resonators having various-sized circular transmitting and receiving coils at transmission distance of 20 cm (a) D_{Tx1}, D_{Tx2} = 40 cm, (b) D_{Tx1}, D_{Tx2} = 20 cm, (c) D_{Tx1}, D_{Tx2} = 10 cm.

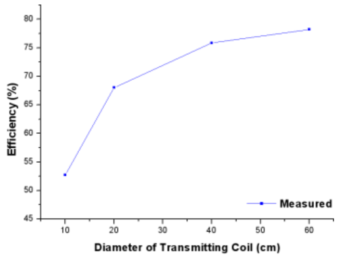


Figure 8: Variation on transmission efficiency of wireless energy transmission resonator as increasing diameter of transmitting coil at transmission distance of 20 cm.

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