Maximum Transmitting Efficiency of Wireless Power Transfer System with Resonant/Non-resonant Transmitting/Receiving Elements

Qiaowei Yuan[1], Qiang Chen[2], and Kunio Sawaya[2]

[1] Sendai National College of Technology, Japan
[2] Tohoku University, Japan

Introduction

Wireless power transfer (WPT) is interested again because of its potential application to charge laptops, cell-phones, household robots, MP3 players and other portable electronics without cords [1]-[2]. The optimum load for maximum transfer efficiency of WPT system was presented when the WPT system was equivalent to a 2-ports lossy network in [3] by present authors. The maximum transfer efficiency of WPT system with resonant transmitting/receiving elements and non-resonant transmitting/receiving elements will be further analyzed and compared in this paper to investigate how the resonant characteristic of transmitting/receiving elements affects the transfer efficiency of a WPT system.

WPT Systems

Three WPT systems shown in Fig. 1 are used in this report. For type-A, a square loop D with a side length of 30 cm is used as the transmitting element and receiving element; For type-B, the same square loop D as type-A loaded with a 210 nF inductor is used as the transmitting element and receiving element; For type-C, the same square loop D with a parasitic square helical coil C is used as the transmitting element and receiving element; All transmitting or receiving elements are made of copper wire (σ=5.8 $\times$ 10^7S/m) which has radius of 2 mm. The input impedances of three WPT systems are compared in the Fig. 2. It is found that the type-A system does not resonate at the concerned frequency range, while type-B gets antiresonance and type-C gets resonance at a frequency of 19.2MHz, respectively. Frequency of 19.2MHz will be regarded as the operating frequency in this paper.

Efficiencies of WPT Systems

Generally, a WPT system can be equivalent to a 2-ports lossy network as shown in Fig. 3, where the transmitting port is defined as port 1 and the receiving port is defined as port 2. Therefore, the transfer efficiency η between port 1 and port 2 is

$$\eta = \frac{P_d}{P_{in}} = \frac{\frac{1}{2}b_2 b_2^*}{\frac{1}{2}a_1 a_1^*} = \frac{|s_{21}|^2\left(1-|\Gamma_l|^2\right)}{|1-s_{22}\Gamma_l|^2}, \quad (1)$$

where P_d and P_{in} are the receiving power of the load Z_l and the incident power at the port 1, respectively. Γ_l is the reflection coefficient related with the load impedance Z_l and defined as

$$\Gamma_l = \frac{Z_l - Z_0}{Z_l + Z_0}, \quad (2)$$

where s_{11}, s_{21}, s_{12} and s_{22} are the scattering parameters which can be obtained by MoM simulation or measurement, Z_0 is the characteristic impedance and is set to be 50 Ω. If the inner impedance of source at the transmitting port or port 1 is

978-1-4244-4968-2/10/$25.00 ©2010 IEEE

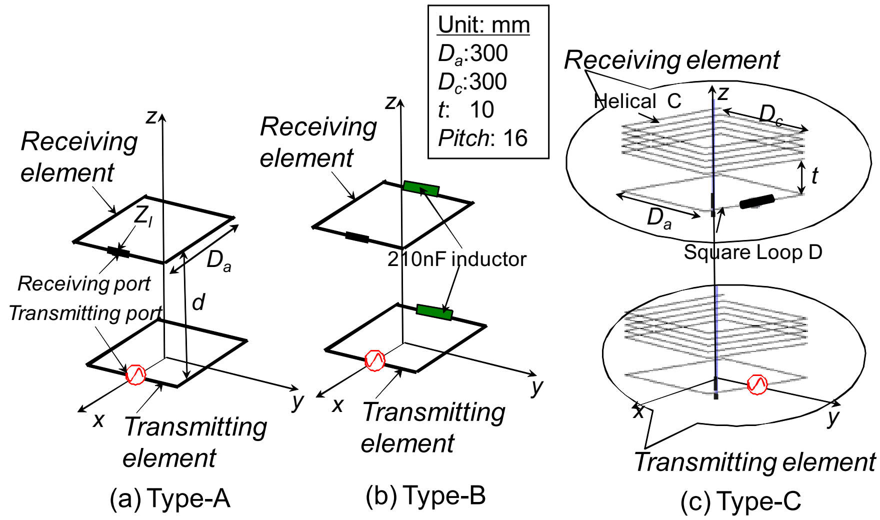


Figure 1: Three WPT systems

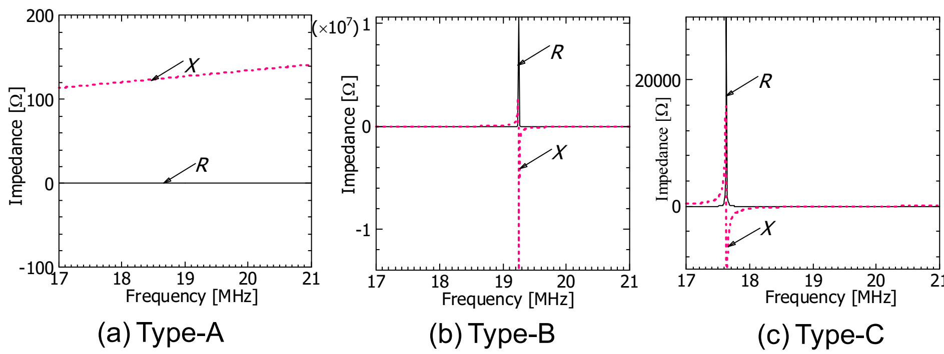


Figure 2: Input impedances of three WPT systems

equivalent to Z_0, the maximum transfer efficiency can be achieved when the load is satisfied with the following matching condition,

$$\Gamma_l = s_{22}^*. \tag{3}$$

The load satisfied the above condition is so-called the optimum load for the maximum transfer efficiency.

The transfer efficiencies of three WPT systems when the loads are satisfied with their matching condition (3) respectively are shown in Fig. 4, where all s-parameters are calculated by FEKO soft and the transfer efficiency is calculated by using (1). From Fig. 4, it can be found that, no matter how the resonance situation the transmitting/receiving element of the WPT system is, all of the maximum transfer efficiencies of three WPT systems are greater than 90 % when the distance d between transmitting element and receiving element is equivalent to 10 cm. However, when the distance d is increased to 30 cm, the transfer efficiency of type-A and type-B drop to about 25 %, 18 %, respectively, while that of type-C still keeps the efficiency as high as 90 % when the frequency is less than 19.5 MHz. Therefore it

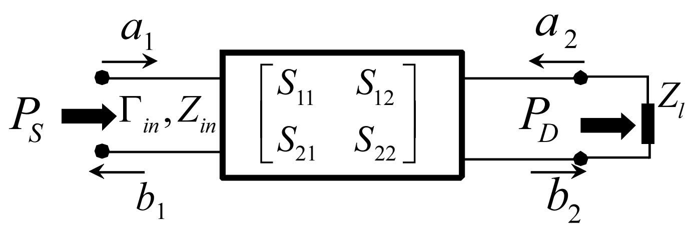


Figure 3: equivalent circuit

can be concluded that the resonant situation of the transmitting/receiving element doesn't affect the transfer efficiency when the receiving element is very close to the transmitting element, however resonant situation of transmitting/receiving elements give an impact on the maximum transfer efficiency when the receiving element is relatively far from transmitting one, the high transfer efficiency can only be achieved when the transmitting and receiving element get resonance mutually.

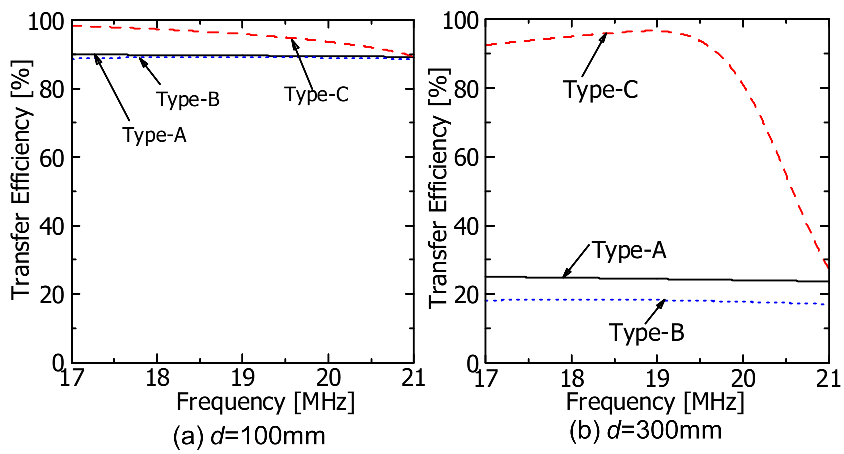


Figure 4: Transfer efficiencies of three WPT systems

The incident power P_{in} of the transmitting port can be divided into three parts as expressed

$$P_{in} = P_{ref} + P_d + P_{loss} \tag{4}$$

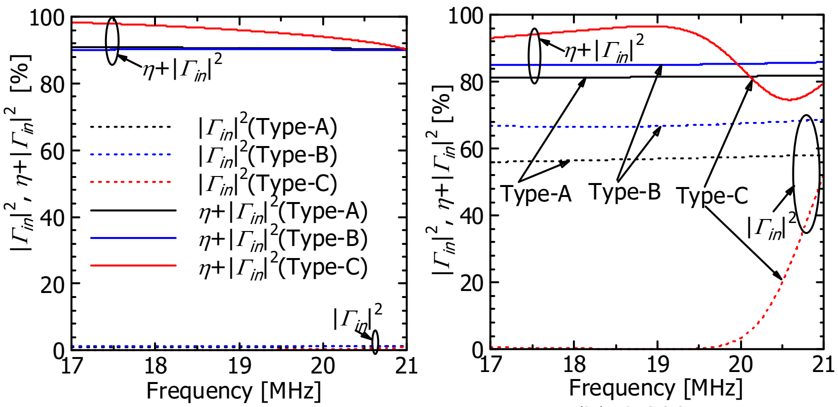
where P_{loss} denotes the lost power due to the transmitting path, finite conductivity and the radiation of transmitting/receiving elements. P_{ref} represents the reflected power at the transmitting port, can be expressed

$$P_{ref} = |\Gamma_{in}|^2 P_{in} \tag{5}$$

Therefore, the ratio of the reflected power P_{ref} to the incident power P_{in} can be expressed by $|\Gamma_{in}|^2$. Γ_{in} is

$$\Gamma_{in} = s_{11} + \frac{s_{12}s_{21}\Gamma_l}{1 - s_{22}\Gamma_l}. \tag{6}$$

The ratio of the sum of P_{ref} and P_d to P_{in} can be expressed by $\eta + \Gamma_{in}^2$.



(a) d=100mm (b) d=300mm

Figure 5: $\eta + \Gamma_{in}^2$ and Γ_{in}^2 of three WPT systems

$\eta + |\Gamma_{in}|^2$ and $|\Gamma_{in}|^2$ of three WPT systems are compared in Fig. 5. It is found that P_{ref} and P_d occupy more than 80 % of the incident power when the distance d = 10 cm and 30 cm. The ratio of the reflected power is less than 2 % when d=10 cm for all WPT systems, resulting more than 90 % transfer efficiency is achieved in this case. However, when d=30 cm, the ratios of the reflected power for type-A and type-B are greater than 50 %, making the transfer efficiencies of these WPT systems decrease significantly, while the transfer efficiency of type-C still has more than 90 % due to small $|\Gamma_{in}|^2$ when the frequency is less than 19.5 MHz.

Conclusion

The maximum transfer efficiency of WPT system with resonant transmitting/receiving elements and non-resonant transmitting/receiving elements has been analyzed and compared in this paper. It has been observed that the resonant characteristic of transmitting/receiving elements gives little impact on the maximum transfer efficiency when the receiving element is close to the transmitting element, but affects the maximum transfer efficiency greatly when the receiving element is far from the transmitting element.

References

[1] Kurs, Aristeidis Karakis, Robert Moffatt, J. D. Joannopoulos, Peter Fisher, Marin Soljacic,"Wireless Power transmission via Strongly Coupled Magnetic Resonances," *SCIENCE*, Vol.317, pp. 83-86, July 2007.

[2] Qiaowei Yuan, Qiang Chen and Kunio Sawaya, "Effect of Human Body on Near-Field Resonant Coupling Wireless Power Transmission System," *EMC09*, Kyoto, July 2009.

[3] Qiaowei Yuan, Qiang Chen, Takanori Iwaki, Kazuhiro Ozawa, Kunio Sawaya, "Efficiency Improvement of Wireless Power Transfer System Using Resonant Near-Field Coupling," *IEICE Technical Report*, vol. 109, AP2009-87, no. 183, pp. 47-52, Sep. 2009.