Investigation of adaptive matching method for wireless power transfer system operating at fixed frequency

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Abstract

Adaptive matching methods for a wireless power transfer system (WPTS) are investigated. The effect of load impedance on the power transfer efficiency (PTE) is analyzed. It is found that efficient WPTS can be achieved by using the proposed method which has better performance compared to other methods.

Keywords : wireless power transfer Near-field coupling Adaptive matching

1. Introduction

Wireless power transfer has been studied for a long time [1]-[7]. One of issues reported by many researchers concerns the adaptive matching method for a wireless power transfer system (WPTS). As such, it is known that the optimum source and the load impedance vary drastically with the coupling distance and the orientation of the antennas [6]. It is difficult to control the source and the load impedance, simultaneously. In order to achieve efficient power transfer in the near-field region, it is important to utilize an adaptive matching system when the coupling between the antennas is changed. Some researchers recommend the frequency tracking method for adaptive matching [8]-[11]. This method controls the source frequency according to the coupling between the antennas. By only controlling the source frequency, this method achieves an almost simultaneous matching condition in the strongly coupling region. However, this approach has limitations when applied to the WPTS since it must use a frequency range and it may be difficult to control the frequency regulation. In this paper, we investigate the matching problem associated with WPTS when the operating frequency is fixed and the coupling between the antennas is varied. We suggest a new, simpler method to achieve the adaptive matching when the distance of the resonators is changed. In this paper, we suggest a new method that only controls the source impedance for fixed load impedance and we investigate the effect of the load impedance to find the optimum load impedance condition according to the resistance and coupling of the antennas.

2. The Effect of Load Impedance

The suggested adaptive matching method for WPTS is investigated using simulation. FEKO is used as a simulator. In this paper, we used a helix-type loop antenna, as shown in Fig. 1. The antenna is made of 1 mm copper wire. The height and the radius of the antenna are 6 mm and 5 cm, respectively. We force the antenna to resonate at 12.3 MHz using the capacitor. The resistance of the isolated antenna is approximately 1 ohm. Fig. 2 represents the equivalent circuit of the WPTS. If the resistance of the antennas is infinitesimal, we can achieve very high PTE, such as can be found in a lossless network. The condition that makes WPTS similar to a quasi-lossless network is represented as:

$$
\begin{aligned}
&R_{Load} \gg R_{Rx} \\
&\frac{(X_{21})^2}{R_{Load}} \gg R_{Tx} \\
&R_{Rx} \ll R_{Load} \ll \frac{(X_{21})^2}{R_{Tx}}
\end{aligned} \tag{1}
$$

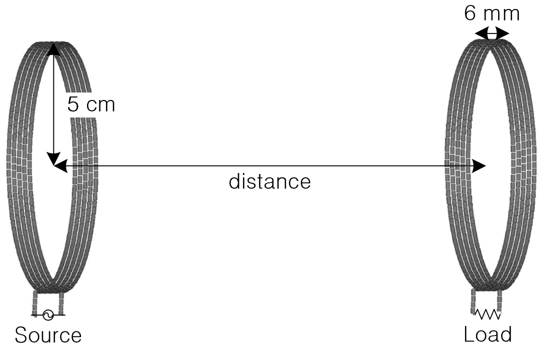

Figure 1: Helix type loop antenna (radius = 5 cm, height = 6 mm, wire thickness = 1 mm, 5 turns, forced resonant frequency = 12.3 MHz).

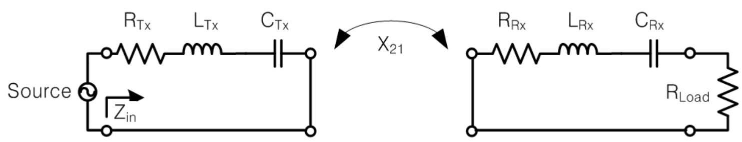

Figure 2: Equivalent circuit of wireless power transfer system.

To ignore the loss at the receiving antenna, the load resistance should be significantly larger than the resistance of the receiving antenna. Furthermore, if the resistance of the transmitting antenna is somewhat smaller than the effective resistance of the load impedance converted by mutual coupling network, we can ignore the loss at the transmitting antenna. The condition of load resistance is presented at (1). When the load resistance is high, the first condition is easily satisfied. However, it is difficult to satisfy the second condition because fairly strong coupling is needed to satisfy the second condition. Therefore, we choose the proper load resistance for an efficient WPTS. Fig. 3 shows the mutual reactance between the antennas. The PTE of the three types of load resistance is compared in Fig. 4. We define the PTE as dissipated power at the load resistance over the input power entering the transmitting antenna. Because the resistance of the isolated antenna is approximately 1 ohm, when the load resistance is 1 ohm, the first condition is violated. Consequently, the PTE is low even if the distance between the antennas is very close, as shown in Fig. 4. The 100 ohm case is apt to violate the second condition. Considering the information shown in Fig. 3, the PTE of the 100 ohm case is sharply decreased, although the distance between the antennas is very close (see Fig. 4). In the lower 20 cm, only the 10 ohm case satisfies both conditions.

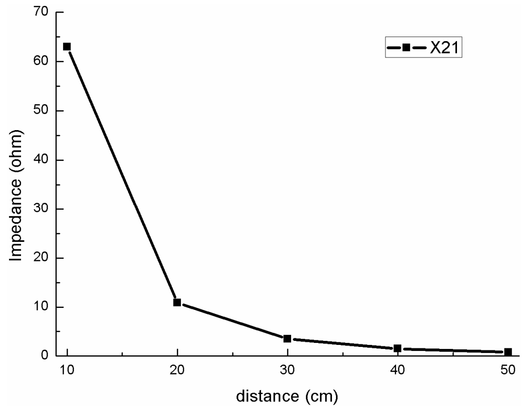

Figure 3: Mutual impedance against distance.

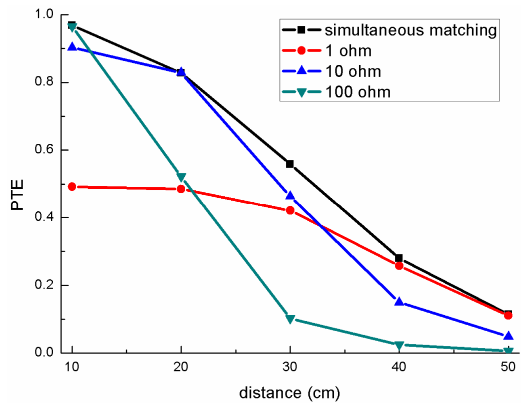

Figure 4: Effect of load resistance on the input efficiency against distance.

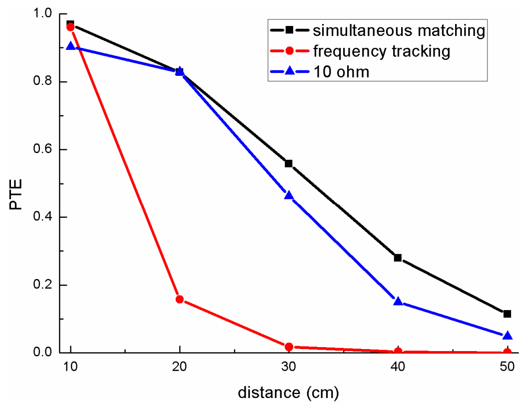

Figure 5: Comparison of the input efficiency with frequency tracking method.

In Fig. 5, the proposed method is compared with other methods. Maximum PTE of the WPTS can be achieved by simultaneous matching. However, it is difficult to implement this method when the distance between the antennas is varied. The frequency tracking method can achieve almost maximum PTE in the strongly coupling region, but this method requires the use of some frequency range. When the operating frequency of the WPTS is fixed, this method is apt to violate the frequency regulation. The proposed method can achieve high PTE in the close distance at the fixed operating frequency, but an issue remains with regard to how to implement the proposed method. When the proposed method is used for WPTS, the input impedance at the transmitting antenna is varied. Therefore, we need to use an additional variable transformer for adaptive matching or voltage/current power sources to avoid the matching problem.

3. Conclusion

For this study, we suggest the adaptive matching method with a fixed operating frequency for wireless power transfer. We compared PTE, using the suggested method, with PTE using other methods. It was found that almost maximum PTE is achieved in the strongly coupling region using the suggested method.

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