

A Consideration of Electric and Magnetic Coupling Coefficient of Spiral Antenna for Wireless Power Transfer

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1. Introduction

Wireless power transfer technologies are now getting large interests. Coupled resonant wireless power transfer proposed by MIT [1] has an advantage of high efficiency and middle range transfer distance. For a practical use, design criteria of high efficiency antennas should be established.

We have investigated open-end and short-end helical antennas [2]. Recently, it has been found that coupling between transmitting and receiving antennas become stronger by arranging spiral antennas in reverse direction [3]. In this report, open-end and short-end spiral antennas with normal and reverse arrangement are investigated from the viewpoints of coupling coefficient and transmission efficiency. We have found that transmission distance is improved by arranging antenna in reverse direction. Effect of reverse arrangement of the open-end model is larger than the short-end model because both electric and magnetic fields are dominant in the open-end model.

2. Analysis model

Consideration model of the open-end spiral antenna is shown in Fig. 1. This antenna has a self-resonant frequency of 36.7MHz. Transfer distance between transmitting antenna and receiving antenna is D . Figure 2 shows short-end spiral model. In this model, series capacitor of 2.54pF is connected to the port1 and the port2 to resonate at 25MHz. Thus, the input impedance of the short-end model is inductive. Figures 1(a) and 2(a) are the normal arranged model whereas Figs. 1(b) and 2(b) are the reverse arranged models.

To confirm difference between the open-end and the short-end models, logarithmic relative spatial impedance (LRSI) is calculated. LRSI is defined by (1),

$$\zeta = 20 \log_{10} \left(\frac{1}{\eta_0} \frac{|\mathbf{E}|}{|\mathbf{H}|} \right) \quad (1)$$

where η_0 is wave impedance of a uniform plane wave in vacuum, and \mathbf{E} and \mathbf{H} show electric and magnetic field vector, respectively. Positive value of LRSI shows that electric field is dominant, and negative value of LRSI shows that magnetic field is dominant. Figure 3 shows LRSI of the open-end model and short-end model. From this result, electric field coupling of the open-end model is stronger than the short-end model.

S parameters are calculated by using method of moment (MoM). Voltage source with output impedance 50Ω is connected to the transmitting antenna. Load impedance 50Ω is connected to the receiving antenna. Perfect electric conductor is assumed for the spiral wire.

3. Simulation Results

3.1 Frequency characteristics of S parameter

S_{21} of the consideration models are shown in Fig. 4 in which distance D is set to 0.1m. It is confirmed that the frequency separation of the low-frequency mode resonance and the high-frequency

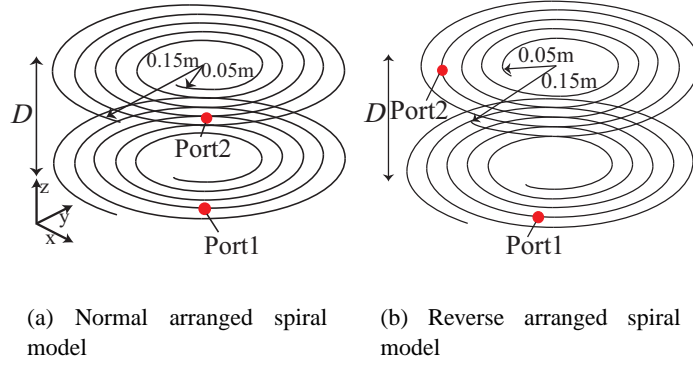


Figure 1: Open-end model

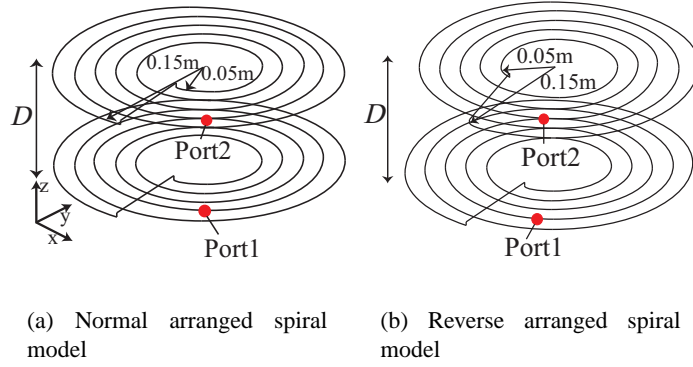


Figure 2: Short-end model

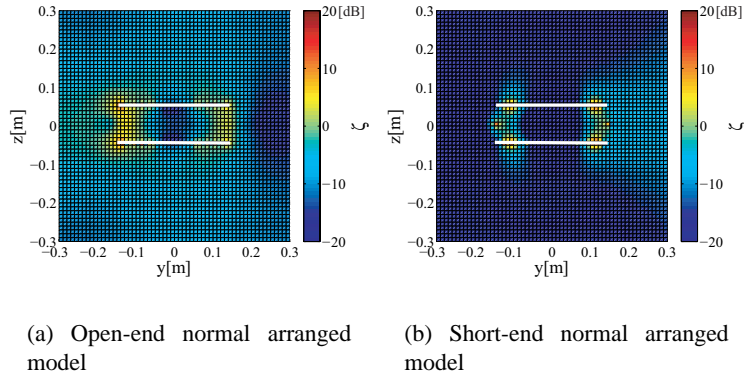


Figure 3: Logarithmic relative spatial impedance

mode resonance is increased by using reverse arranged model. Coupling coefficient k is obtained from (2).

$$k = \frac{f_h^2 - f_l^2}{f_h^2 + f_l^2} \quad (2)$$

The f_l is a resonant frequency of the low-frequency mode and f_h is a resonant frequency of the high-frequency mode. Table 1 and 2 show the coupling coefficients obtained from (2) for the transfer distance D of 0.1m. It is confirmed that the coupling coefficients of the open-end and the short-end model were 129% and 8.9% increased by using the reverse arranged model, respectively.

3.2 Distance characteristics of coupling coefficient

Distance characteristics of coupling coefficient obtained from (2) are shown in Fig. 5. Since the (2) can be used only in the transmitting distance where resonant frequency is divided into high-frequency mode and low-frequency mode, coupling coefficient is set to 0 in the distance beyond it. As shown in

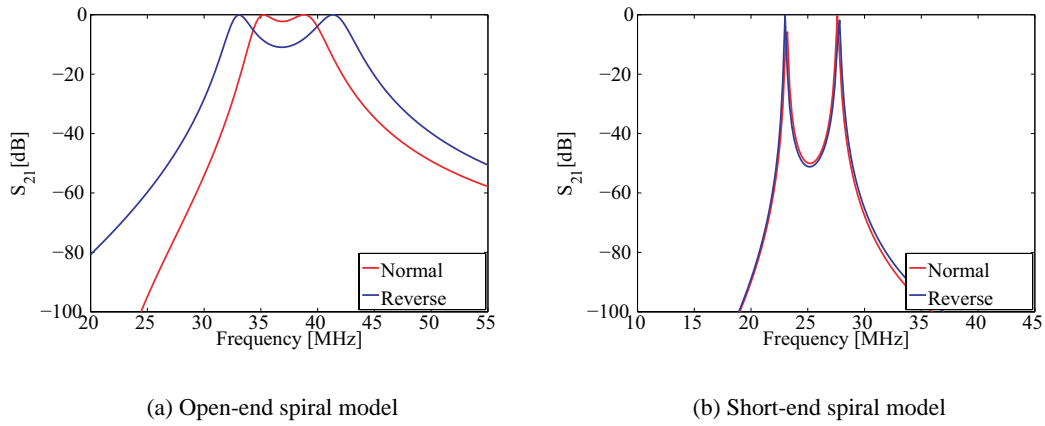


Figure 4: Frequency characteristics of S_{21}

Table 1: Coupling coefficient of open-end spiral model

	Normal arranged	Reverse arranged
k	0.0971	0.2230

Table 2: Coupling coefficient of short-end spiral model

	Normal arranged	Reverse arranged
k	0.17193	0.1873

Fig. 5, coupling coefficient is increased by using reverse arranged model. Effect of reverse arrangement for the open-end model is larger than the short-end model because electric field of the open-end model is stronger than the short-end model.

3.3 Distance characteristics of electric and magnetic coupling coefficient

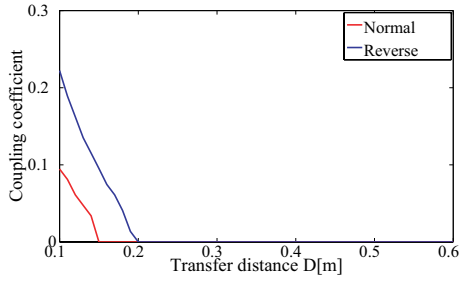
To understand a difference of coupling coefficient between the open-end model and the short-end model, electric and magnetic coupling coefficients are calculated through an equivalent circuit analysis [4]. Distance characteristics of electric and magnetic coupling coefficients are shown in Fig. 6. It is confirmed that reverse arrangement makes the electric coupling coefficient negative because direction of electric field vector changes by using reverse arrangement. Moreover, it turns out that the electric coupling coefficient of the open-end model is larger than the short-end model because electric field of the open-end model is stronger than the short-end model.

3.4 Distance characteristics of S parameter

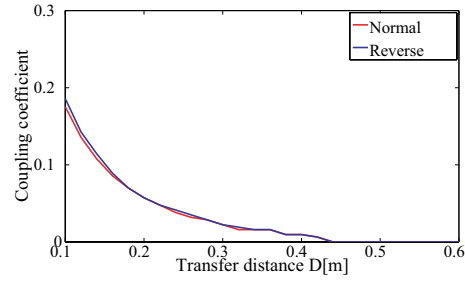
Distance characteristics of S parameters are shown in Fig. 7. Since the resonant frequency varies according to the transfer distance, value of S_{21} at the resonant frequency of each position is used in this graph. As shown in Fig. 7(a), transfer distance of the open-end model was improved by 35mm (25.0%). On the other hands, transfer distance of the short-end model was improved by 8.5mm (1.8%). Effect of reverse arrangement on transfer distance for the open-end model is larger than the short-end model because electric field of the open-end model is stronger than the short-end model.

4. Conclusion

Effect of reverse arrangement of spiral antenna for the open-end and the short-end models was discussed. Reverse arrangement makes the electric coupling coefficient negative. As a result, transfer distance is extended. Moreover, effect of reverse arrangement on transfer distance for the open-end model is larger than the short-end model because of the electric field coupling.

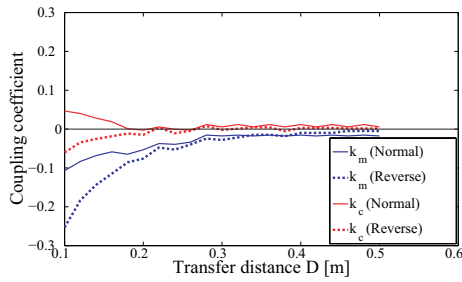


(a) Open-end spiral model

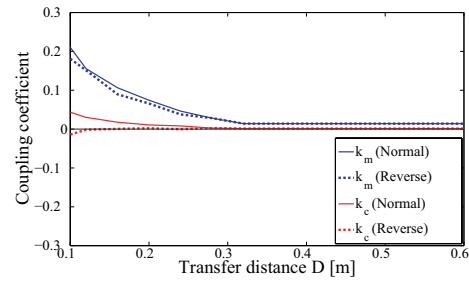


(b) Short-end spiral model

Figure 5: Distance characteristics of coupling coefficient

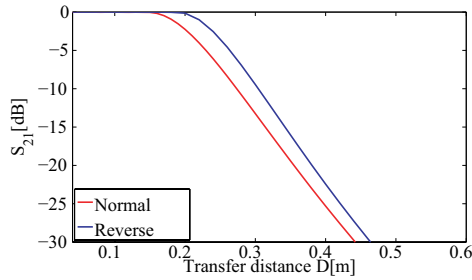


(a) Open-end spiral model

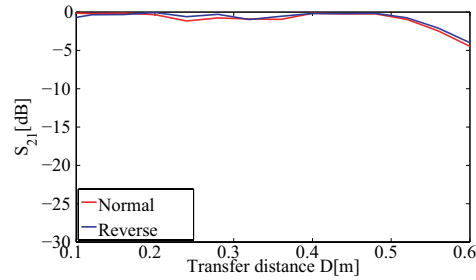


(b) Short-end spiral model

Figure 6: Distance characteristics of electric and magnetic coupling coefficient



(a) Open-end spiral model



(b) Short-end spiral model

Figure 7: Distance characteristics of S parameter

References

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