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Relation Analysis between Feeding Structures and Effect of Shield for Coils in Wireless Power Transfer with Magnetically Coupled Resonance

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1. Introduction

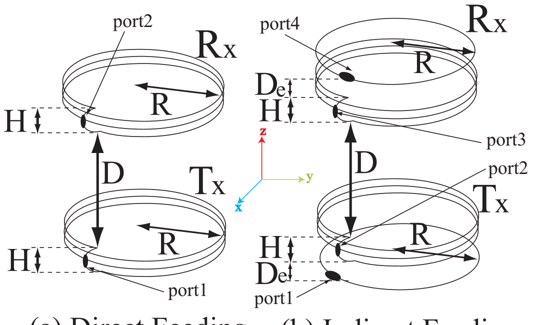
Recently, the technology of supplying the electric power by the wireless attracts our attention for use in household electric appliances and electric vehicles. Particularly, the research of wireless power transfer with magnetically coupled resonance proposed by MIT is actively pursued [1]- [2]. This is because it satisfies the demand of long distance transmission, high robustness against misalignment between transmitting and receiving equipments, and low unwanted radiation. However, the influence on human bodies and other electric devices is felt uneasy because this technology has the problem of leaked electromagnetic field generated by transmitting and receiving equipments [3]. Therefore, for the practical use, decreasing the leaked electromagnetic field is inevitable.

In this paper, we examined basically the difference between direct feeding and indirect feeding (electromagnetic induction feeding) in the effect of shield for decreasing leaked electromagnetic field. As the evaluation measures, transmitting efficiency and leaked magnetic field are used in the computer simulation.

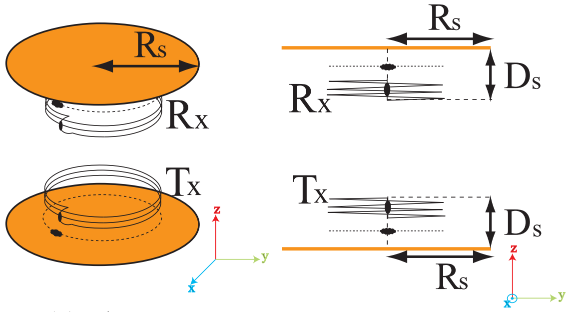
2. Analysis Model

Firstly, Figure 1 shows the coil shape of two types of feeding structure used in this paper. Specific values of size parameters of the transmitting (T_x) and receiving (R_x) coils are written in Table 1. Transmitting and receiving coils have three turns in both feeding structures. Loaded circuit elements on each port are shown in Tables 3 and 4. The loaded capacitor C is determined to cancel the inductance of a single resonant coil at the frequency of 10MHz for both feeding structures. Section radius of conducting wire is 1mm. Material of conducting wire is copper($\sigma = 5.8 \times 10^7$).

Next, Figure 2 shows the shape and placement of the shields. Each shield is disk-shaped as shown in Fig.2(a). In addition, when viewed in the y-z plane, the shields are placed at a distance of D_s from the top of each resonant coil of T_x and R_x for both feeding structures as shown in Fig.2(b). Specific values of size parameters of the shield are given in Table 2. Material of the shield is aluminium($\sigma = 3.8 \times 10^7$).



(a) Direct Feeding (b) Indirect Feeding
Figure 1: Shape of transmitting and receiving coils.



(a) Shape (b) Placement
Figure 2: Shape and placement of the shields.

Table 1: Size parameters of the transmitting and receiving coils.

	R	D	H	D_e
mm	300	500	90	50

Table 2: Size parameters of the shield disk.

	R_s	D_s
mm	500	200

Table 3: Loaded circuit elements on each port(Direct Feeding).

port1	Voltage Source	1[V]
	Loaded Capacitor	15.4[pF]
	Internal Resistance	50[Ω]
port2	Loaded Capacitor	15.4[pF]
	Loaded Resistance	50[Ω]

Table 4: Loaded circuit elements on each port(Indirect Feeding).

port1	Voltage Source	1[V]
	Internal Resistance	50[Ω]
port2	Loaded Capacitor	15.4[pF]
port3	Loaded Capacitor	15.4[pF]
port4	Loaded Resistance	50[Ω]

3. Consideration by Computer Simulation

3.1 Evaluation of Transmitting Efficiency

Firstly, transmitting efficiency is evaluated by using the Method of Moments (FEKO). The transmitting efficiency is calculated from the scattering parameter S_{21}. Frequency characteristics of transmitting efficiency of both feeding structures are shown in Figs.3 and 4, respectively. These figures indicate that resonant frequencies get higher from f_1 to f_2 in direct feeding of Fig.3, and from f_3 to f_4 in indirect feeding of Fig.4, by placing the shields. In addition, you can find that the transmitting efficiency at the shifted resonant frequencies is degraded by about 1.61dB in direct feeding, and degraded by about 0.47dB in indirect feeding.

Here, we consider the factors of reducing the transmitting efficiency. Increases in the reflected power, radiated power and the conductor loss are considered as the factors that reduce the transmitting efficiency. Therefore, to examine the factors, frequency characteristics of reflection coefficient, radiation efficiency and conductor loss in each feeding structure are shown in Figs.5 and 6. Also, values of reflection coefficient, radiation efficiency and conductor loss at resonant frequencies are listed in Tables 5 and 6. From Table 5, the shields increase reflection coefficient and conductor loss, and reduces radiation efficiency at the resonant frequency in direct feeding. In particular, the reflection coefficient is high when the shields are placed. That is why the reflection power is supposed to be the main factor of reducing the transmitting efficiency in direct feeding. From Table 6, the shields increase reflection coefficient and conductor loss, and reduces radiation efficiency at the resonant frequency in indirect feeding in the same tendency as direct feeding. However, the reflection coefficient is suppressed enough with shields unlike direct feeding. Alternatively, the conductor loss is high when the shields are placed. That is why the conductor loss is the main factor of reducing transmitting efficiency in indirect feeding.

As mentioned above, it is confirmed that the resonant frequency gets higher by placing the shield in both feeding structures, and that indirect feeding has less degradation of transmitting efficiency than direct feeding.

Table 5: Values of the factors that reduce transmitting efficiency at the resonant frequency(Direct Feeding).

	Without Shield[dB]	With Shield[dB]
Reflection Coefficient	-38.52	-5.91
Radiation Efficiency	-27.65	-31.34
Conductor Loss	-12.21	-10.21

Table 6: Values of the factors that reduce transmitting efficiency at the resonant frequency(Indirect Feeding).

	Without Shield[dB]	With Shield[dB]
Reflection Coefficient	-29.78	-20.12
Radiation Efficiency	-27.46	-34.65
Conductor Loss	-10.61	-7.47

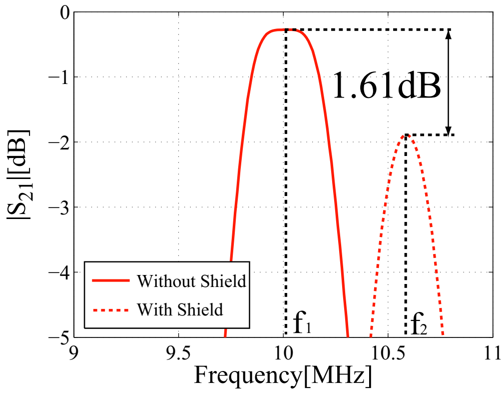


Figure 3: Frequency characteristics of transmitting efficiency(Direct Feeding).

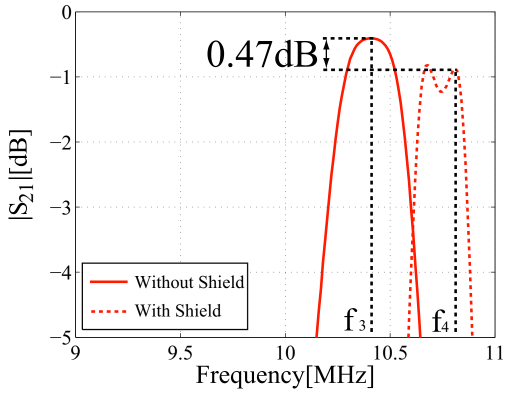


Figure 4: Frequency characteristics of transmitting efficiency(Indirect Feeding).

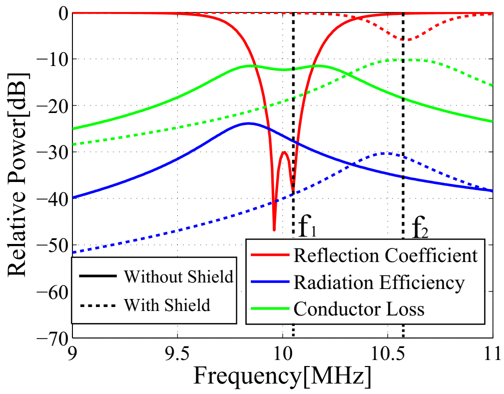


Figure 5: Frequency characteristics of the factors that reduce transmitting efficiency(Direct Feeding).

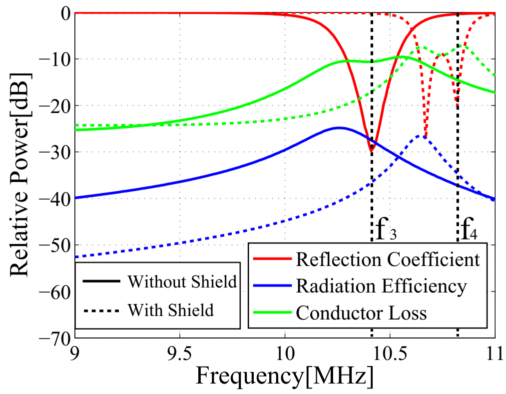


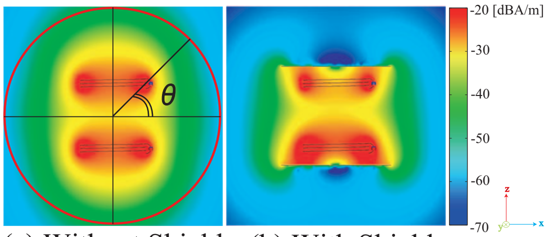
Figure 6: Frequency characteristics of the factors that reduce transmitting efficiency(Indirect Feeding).

3.2 Evaluation of Leaked Magnetic Field

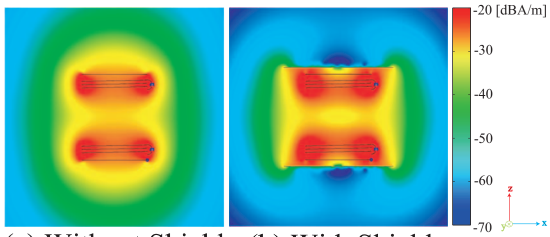
Next, leaked magnetic fields around the coils are evaluated. In Figs.7 and 8, the intension of leaked magnetic field by transmitting and receiving coils are illustrated. The leaked magnetic field is evaluated at the resonant frequency. Also, if there are two resonant frequencies, we use the higher frequency which gives lower radiation [4]. The specific frequencies when evaluating the leaked magnetic field are shown in Table 7.

From Figs.7 and 8, it is confirmed that the leaked magnetic field is reduced especially in the vertical direction (axial direction z) by placing the shields in both feeding structures. Furthermore, in order to evaluate the leaked magnetic field quantitatively, intensions of magnetic field on the circle of 1m radius from the center of Figs.7 and 8 are compared. Angle characteristics of leaked magnetic field are shown in Figs.9 and 10. Here, θ is taken from the x-axis toward the z axis as depicted in Fig.7(a). Moreover, to specify the difference between the presence and absence of the shields, angular averages of leaked magnetic field strength are shown in Table 8. From Figs.9 and 10, it is found that the leaked magnetic field is reduced over all angles by placing the shields in both feeding structures. Additionally, from Table 8, it is confirmed that the magnetic field is reduced by 8.5dB on the circle of 1m radius by placing the shields in case of direct feeding. Also, in case of indirect feeding, it is found that the shields can reduce the leaked magnetic field by 8.3dB.

As mentioned above, it is shown that direct feeding can reduce a little more leaked magnetic field than indirect feeding. However, the difference between both feeding structures is only 0.2dB in angular average. Therefore, it is said that the shields can suppress leaked magnetic field enough for both feeding structures.



(a) Without Shield (b) With Shield
Figure 7: Leaked magnetic field by the transmitting and receiving coils(Direct Feeding).



(a) Without Shield (b) With Shield
Figure 8: Leaked magnetic field by the transmitting and receiving coils(Indirect Feeding).

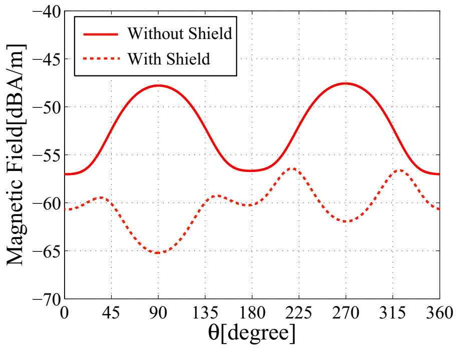


Figure 9: Angle characteristic of leaked magnetic field(Direct Feeding).

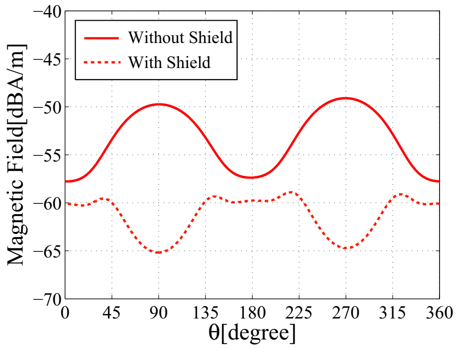


Figure 10: Angle characteristic of leaked magnetic field(Indirect Feeding).

Table 7: Frequencies at which evaluation of leaked magnetic field is performed.

	Direct Feeding [dBA/m]	Indirect Feeding [dBA/m]
Without Shield	10.05	10.41
With Shield	10.59	10.82

Table 8: Angular average of leaked magnetic field.

	Direct Feeding [dBA/m]	Indirect Feeding [dBA/m]
Without Shield	-51.6	-52.8
With Shield	-60.1	-61.1

4. Conclusion

In this paper, we made a comparison between direct feeding and indirect feeding for the effect of shield to reduce the leaked magnetic field in the wireless power transfer with magnetically coupled resonance. As a result of the computer simulation, it is confirmed that the shields can suppress leaked magnetic field enough for both feeding structures. Particularly, it is observed that direct feeding can reduce a little more the leaked magnetic field than indirect feeding. On the other hand, it is found that indirect feeding is less susceptible by the shields than direct feeding in transmitting efficiency.

For the future works, it is considered that analysis results in this paper are verified by experiments using actual equipments.

References

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