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초전도 공진 코일의 효율성을 높이기 위한 차폐 재질에 따른 무선전력전송 효율비교 분석

Characteristics of Wireless Power Transmission Using Superconductor Coil to Improve the Efficiency According to the Shielding Materials

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Abstract - The magnetic resonance method requires high quality factor(Q-factor) of resonators. Superconductor coils were used in this study to increase the Q-factor of wireless power transfer(WPT) systems in the magnetic resonance method. The results showed better transfer efficiency compared to copper coils. However, as superconducting coils should be cooled below critical temperatures, they require cooling containers. In this viewpoint, shielding materials for the cooling containers were applied for the analysis of the WPT characteristics. The shielding materials were applied at both ends of the transmitter and receiver coils. Iron, aluminum, and plastic were used for shielding. The electric field distribution and S-parameters (S11, S21) of superconducting coils were compared and analyzed according to the shield materials. As a result, plastic shielding showed better transfer efficiency, while iron and aluminum had less efficiency. Also, the maximum magnetic field distribution of the coils according to the shielding materials was analyzed. It was found that plastic shielding had 5 times bigger power transfer rate than iron or aluminum. It is suggested that the reliability of superconducting WPT systems can be secured if plastic is used for the cooling containers of superconducting resonance coils.

Key Words : Superconductor coil, Wireless power transfer(WPT), Shielding materials

1. Introduction

Wireless power transfer (WPT) is the technology that sends energy without any connection to other adaptors or cables. The technology has two types, radiative or non-radiative. The magnetic induction method is a radiative type. This method is used for wireless recharge in smart phones and electric toothbrushes.

Being sensitive to magnetic field direction, however, this method shows high transfer efficiency only when transmitter and receiver coils have same direction. The magnetic resonance method is a non-radiative type. In this method, transmitter and receiver coils resonate in the same frequency based on the resonant coupling to transfer energy. Hence, it is less sensitive to the directions of transmitter and receiver coils than the magnetic induction method. The magnetic resonance method requires high Quality-factor (Q-factor) of transmitter and receiver coils to secure resonance characteristics and transfer distance. The Q-factor, however, can be affected by the impedance change or nearby conductors[1-3]. For this reason, a superconducting coil was applied in this study to enhance the Q-factor of the magnetic resonance method. As a result, the superconducting coil showed higher Q-factor than the copper one. Also, it was confirmed that the transfer efficiency of the superconducting coil was higher than that of the copper one[4, 5]. As the superconducting coil needs to be cooled below the critical temperature, it requires additional equipment, which is a cooling container. The coil is closely located to the cooling container. In this case, electromagnetic interference can occur according to the materials of composition of the cooling container, and it can affect the transfer efficiency of the superconducting coil. For this reason, studies on shielding materials are required to block the impacts of the electromagnetic interference and outside noises. In this study, shielding materials were applied at both ends of the transmitter and receiver coils. The materials were plastic, aluminum, and iron. The Electric field(E-field) and S-parameter of the superconducting coil were analyzed.

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2. Experimental Principles and Design

2.1 Electromagnetic Shielding Effectiveness Theory

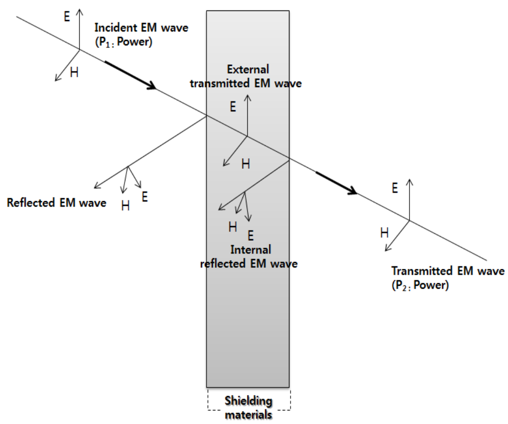


그림 1 전자기 차폐 원리

Fig. 1 Electromagnetic Shielding Principle

The electromagnetic shielding effect refers to the limitation in or entry into a specific area where there are conductors or ferromagnetic materials. The principle is as shown in Fig. 1. The electromagnetic wave incident on a shielding material undergoes absorption, reflection, diffraction or penetration. The sum of the shielding effects is called the shielding efficiency. Equation (1) shows the shielding efficiency.

$$SE = SR+SA+SB \qquad (1)$$

S_R is the attenuation by reflection, S_A is the attenuation by absorption, and S_B is the attenuation by internal reflection of the shielding material. In Equation (1), S_A is ignored because there is hardly any shielding effect at 10 dB or higher. Equation (2) and (3) show S_R and S_A, wherein ρ is the volume resistivity, F is the frequency, and t is the thickness.

$$SR = 50 + 10\log(\rho F)-1 \qquad (2)$$

$$SA = 1.7t(F/\rho)0.5 \qquad (3)$$

$$IL = 10\log(P1/P2) \qquad (4)$$

To measure the shielding effect, power is applied to the wireless power transmission system, and the received power is measured with and without the shielding materials on the transmission side (P_1 and P_2, respectively). The ratio of the received power values is the insertion loss, which is expressed as in Eq. 4[6-9].

2.2 Experimental Design

Fig. 2 is a WPT system using the magnetic resonance method with superconducting coils. Table 1 is the specifications of the superconducting resonance coil. The WPT characteristics and shielding performance were examined with the shielding materials applied to the coil. The materials were plastic, aluminum, and iron. Table 2 is the specifications of the materials. The shielding materials were 100mm away from the transmitter coil. The same distance was applied to the receiver coil.

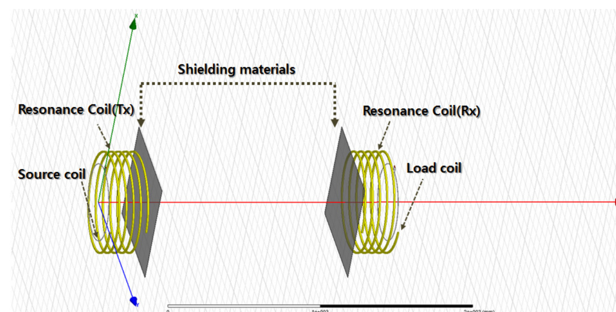


그림 2 초전도 공진 코일에 차폐재를 적용한 WPT 시스템

Fig. 2 WPT system with shielding materials applied to superconducting resonance coils

Table 1 Specification of superconductor coil

	Source coil	Resonance coil(Tx)	Resonance coil(Rx)	Load coil
Turn	1	5	5	1
Diameter (mm)	253	325.7	325.7	253
Thickness (mm)	3	10	10	3

Table 2 Specification of shielding materials

	Iron Shielding materials	Aluminum Shielding materials	Plastic Shielding materials
Width (mm)	700	700	700
length (mm)	700	700	700
Thickness (mm)	2	2	2

2.3 Experimental Results and Analysis

Fig. 3 is the S-parameters of the superconducting coils. They are the graph representing the reflection coefficient(S_{11}) and penetration coefficient(S_{21}) when no shielding materials were applied. The resonance frequency is 9.86MHz. The reflection(S_{11}) was -26.6658dB, and the penetration coefficient(S_{21}) was −7.3960dB. Fig. 4 is the S-parameters under iron shielding

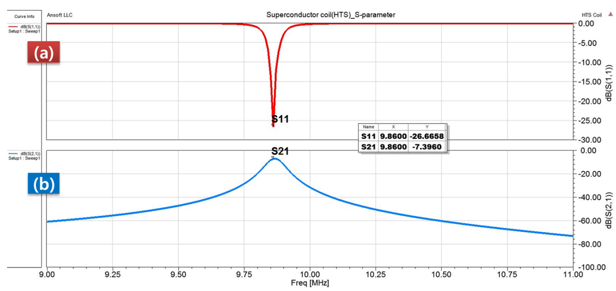


그림 3 초전도 공진 코일의 S-parameter (a) S_{11}(b) S_{21}

Fig. 3 S-parameters (a) S_{11}(b) S_{21} of superconducting resonance coils

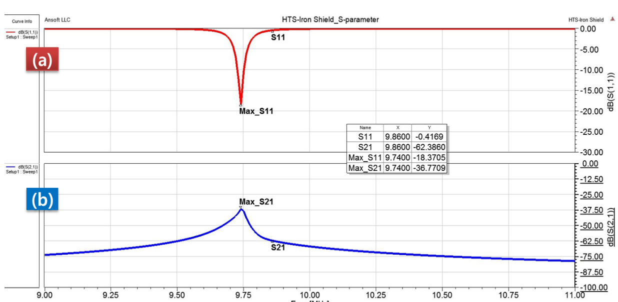


그림 4 초전도 공진 코일의 철 차폐재 적용에 따른 S-parameter (a) S_{11} (b) S_{21}

Fig. 4 S-parameters (a) S_{11} (b) S_{21} of superconducting resonance coils with iron shielding

S_{11} and S_{21} were -0.1169dB and -62.3860dB respectively at 9.86MHz. The resonance frequency that had maximum S-parameters under iron shielding was 9.74MHz, when S_{11} and S_{21} were -18.3705 and −36.7709dB respectively. Fig. 5 is the S-parameters under aluminum shielding. The reflection coefficient and penetration coefficient were measured at the same frequency as there was no shielding. S_{11} was -0.3575dB, and S_{21} was -56.2253dB. The S-parameters were measured at the resonance frequency that had maximum characteristics under aluminum shielding. The resonance frequency was 9.75MHz. Max_S_{11} was

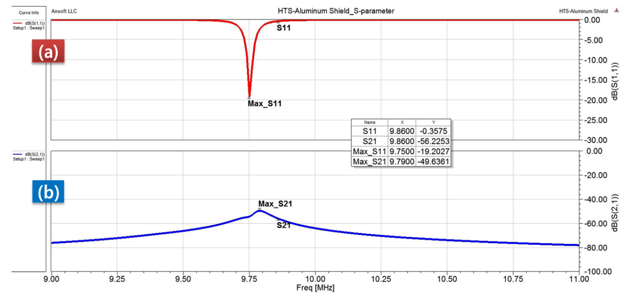


그림 5 초전도 공진 코일의 알루미늄 차폐재 적용에 따른 S-parameter(a) S_{11} (b) S_{21}

Fig. 5 S-parameters (a) S_{11} (b) S_{21} of superconducting resonance coils with aluminum shielding

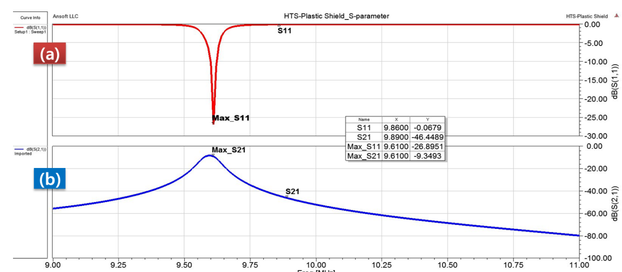
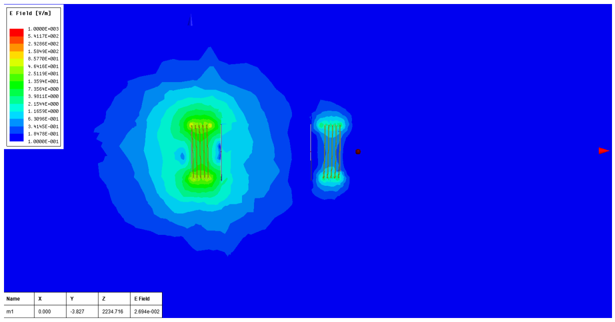


그림 6 초전도 공진 코일의 플라스틱 차폐재 적용에 따른 S-parameter (a) S_{11} (b) S_{21}

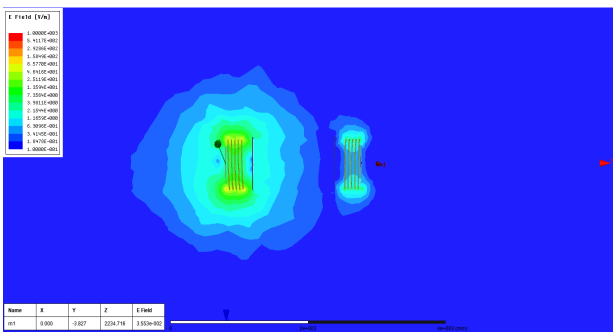
Fig. 6 S-parameters (a) S_{11} (b) S_{21} of superconducting resonance coils with plastic shielding

-19.2027dB and Max_S_{21} was -49.6361dB under aluminum shielding. It was confirmed that the resonance frequency and S-parameter varied when shielding materials were applied. This is because when the electromagnetic waves meet the aluminum or iron shielding, the eddy current is generated by electromagnetic induction and it reflects the waves. ig. 6 is the S-parameters under plastic shielding. S_{11} and S_{21} were measured at 9.86MHz in the same previous manner, and they were respectively -0.0679dB and -46.4489dB. The resonance frequency that had maximum characteristics under plastic shielding was 9.61MHz, when Max_S_{11} was -28.8951dB and Max_S_{21} was -9.4393dB. These values were found to be similar to the S-parameters of the coil without any shielding. The insulation materials such as plastic do not reflect the electromagnetic waves, but pass them. Thus, S-parameters were not affected.

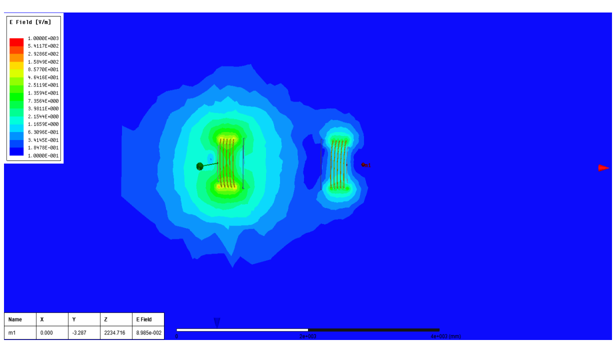
Fig. 7 is the E-field distribution of superconducting resonance coils with shielding. The resonance characteristics of superconducting coils according to shielding materials were identified. Fig. 7(a) is the E-field under iron shielding. The maximum electric strengths of the transmitter and



(a)



(b)



(c)

그림 7 차폐제 적용에 따른 초전도 공진 코일의 E-field 분포도 (a) 철 (b) 알루미늄 (c) 플라스틱

Fig. 7 E-field distribution of superconducting resonance coils with shielding (a) iron (b) aluminum (c) plastic

receiver were found to be $4.6416 \cdot E^{+001}$[V/m] and 2.1544·E[V/m] respectively. Fig. 7(b) is the E-field under aluminum shielding. The maximum electric strengths of the transmitter and receiver coils were $8.5700 \cdot E^{+001}$[V/m] and 2.1544·E[V/m] respectively. Fig. 7(c) is the E-field under plastic shielding. The maximum electrical strength of the transmitter was $1.5849 \cdot E^{+002}$[V/m], and that of the receiver was $2.5119 \cdot E^{+001}$[V/m]. It was confirmed that plastic had the highest electrical strength and the best resonance characteristics in the S-parameter analysis.

3. Conclusion

It is essential that superconducting WPT systems have cooling containers. The containers, however, interfere with electromagnetic waves of transmitter and receiver coils according to their materials and characteristics, and affect transfer efficiency. Thus, studies on the WPT characteristics according to container materials are necessary. Shielding materials were applied at both ends of the transmitter and receiver coils in this study. The S-parameters and E-fields with and without shielding were compared. Iron, aluminum, and plastic were used as shielding materials.

As a result, the S-parameter characteristics with aluminum or iron shielding, which are conductors, were not good as they reflected electromagnetic waves. Plastic shielding, however, was found to pass energy without specific influence. Also, the proportion of the electric field distribution was examined to see how much electromagnetic wave from a source diminishes. Plastic shielding showed the highest received proportion as it passed energy without significantly affecting the transfer efficiency. Iron and aluminum showed lower proportion as they caused energy loss while the electromagnetic waves were penetrated or absorbed.

It is suggested that the transfer efficiency of superconducting WPT systems can be improved if cooling containers are manufactured using plastic shielding materials based on the results of this study.

감사의 글

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References

[1] Andre Kurs, Aristeidis Karalis, J. D. Joannopoulos, and Marin Soljacic, "Wireless power transfer via strongly coupled magnetic resonances", Science, vol. 317, no.5834, pp. 83-86, 2007.

[2] J. D Jannopoulos, A Karalis, and M. Soljacic, " Wireless non-radiative energy tasnfer", US patent No. US 7, 741734 B2, Jun, 22, 2010.

[3] In-Sung Jeong, Hyo-Sang Choi, “Characteristics of Wireless Power Transmission applying the superconducting coil”, KIEE, vol.62, no.6, pp. 762-766, 2013.

[4] Aristeidis Karalis, J. D Joannopoulos, Marin Soljacic, “Efficient wirelss non-radiative mid-range energy transfer”, Annals of Physics, vol.323, pp. 34-48, 2008.

[5] Mi-Kyung Song, Seung-min Hong, Jong-myeong Park, “Coatings material for shielding of electromagnetic wave”, Polymer science and technology, vol.12, no.5, pp. 689-697, 2001.

[6] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, “Electron spectroscopy studies on magneto-optical media and plastic substrate interface”, IEEE Transl. J. Magn. Japan, Vol. 2, pp. 740-741, 1987.

[7] Seok Bae, Don-Chul Choi, Soon-Young Hyun, Sang Won Lee, “Electromagnetic wave shielding Materials for the wireless power transfer module in mobile handset”, KMS, vol.23, no.2, pp. 68-76, 2013.

[8] S. A. Schelkunoff, Electromagnetic Wave, pp. 303-315, Van Nostrand, New York, 1943.

[9] SAE ARP 1173, “Test procedure to measure the RF shielding characteristics of EMI gaskets”, Society of Automotive Engineers, Aerospace Recommended Practice," July 1975.

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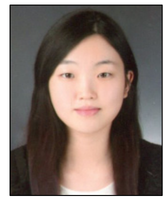

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