pISSN 1229-3008 eISSN 2287-6251
Progress in Superconductivity and Cryogenics
Vol.19, No.2, (2017), pp.29~32
https://doi.org/10.9714/psac.2017.19.2.029

Analysis of reflection-coefficient by wireless power transmission using superconducting coils

In-Sung Jeong[a], Hyo-Sang Choi[*,a], and Dong-Chul Chung[b]

[a] *Chosun University, Gwangju, Korea*
[b] *Korea Institute of Carbon Convergence Technology, Jeonju, Korea*

(Received 13 February 2017; revised or reviewed 17 April 2017; accepted 18 April 2017)

Abstract

The use of electronic devices such as mobile phones and tablet PCs has increased of late. However, the power which is supplied through wires has a limitation of the free use of devices and portability. Magnetic-resonance wireless power transfer (WPT) can achieve increased transfer distance and efficiency compared to the existing electromagnetic inductive coupling. A superconducting coil can be applied to increase the efficiency and distance of magnetic-resonance WPT. As superconducting coils have lower resistance than copper coils, they can increase the quality factor (Q-factor) and can overcome the limitations of magnetic-resonance WPT. In this study, copper coils were made from ordinary copper under the same condition as the superconducting coils for a comparison experiment. Superconducting coils use liquid nitrogen to keep the critical temperature. As there is a difference of medium between liquid nitrogen and air, liquid nitrogen was also used in the normal conductor coil to compare the experiment with under the same condition. It was confirmed that superconducting coils have a lower reflection-coefficient(S_{11}) than the normal conductor coils.

Keywords: Quality-factor, Reflection-Coefficient, Superconducting coil, WPT

1. INTRODUCTION

The power consumption is on the rise due to the expansion of mobile devices, electric vehicles, and others. The inconvenience of the wired power supply and the problem with the battery lifetime is increasing [1]. Wireless recharging using wireless power transmission (WPT) is attracting a lot of attention as a solution to above problems [2]. The WPT technology can enhance the convenience of using electronic devices. As such, research activities on the application of WPT not only to small devices like mobile phones but also to large devices like electric vehicles and trains are underway [4-6]. The magnetic resonance method which is based on electromagnetic coupling is a WPT technology using in middle-distance. It combines the advantages of the inductive and electromagnetic wave methods. Thus, it can reach a farther distance than inductive coupling, and it can maintain high efficiency. However, further studies on it are needed to increase its distance and efficiency as it is still in the early stage of development [4-9]. In this paper, superconducting coils were considered to increase the efficiency of magnetic-resonance WPT. As superconducting coils have low resistance under the critical temperature, they can increase the Q-factor.

For the comparison, the copper that is used in the normal conductor coils was prepared under the same condition as the superconducting coils. Superconducting coils may be immersed in liquid nitrogen as they work at the critical temperature. To maintain the condition, the normal conductor coils were also immersed in liquid nitrogen.

* Corresponding author: hyosang@chosun.ac.kr

2. MAIN PARAMETERS

2.1. Magnetic Resonance WPT

Fig. 1 is the circuit diagram of a magnetic-resonance WPT system. The system consists of transmitter (Tx) · receiver (Rx) resonance coils, a source coil and a load coil. The tx·rx resonance coils were manufactured with a helical structure. For the two transmitter and receiver coils to resonate, they have to have the same resonance frequency f, evaluated with Eq. (1) where L and C are the induction and capacitance of the coil respectively.

$$\text{Frequency}(f) = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

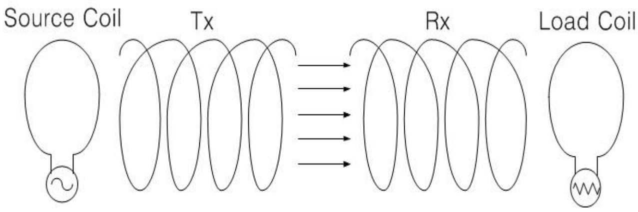


Fig. 1. Magnetic resonance WPT system.

2.2. Quality-factor

Q-factor is a parameter that represents the status of the resonance coil or determines the bandwidth of the resonator depending on the center frequency. A high Q-factor means low loss of the energy stored in the resonator, and narrow bandwidth. Low Q-factor, on the other hand, means high energy loss and wide bandwidth. The Q-factor can be represented as shown in equation (2), where f is the resonance frequency and L and R are the coil inductance and coil resistance, respectively [4].

$$\text{Quality} - \text{factor} = \frac{2\pi f L}{R} \qquad (2)$$

2.3 Superconductivity

When the temperature decreases, the resistance of the normal conductors will be lower but there is limitation of it. However, superconductors have zero resistance characteristics under the critical temperature. A high-temperature superconductor was used in this study. This superconductor contains scs12050 made by sunpower. The critical temperature of the used superconductor was 93 K.

2.4. Experimental Design

Fig. 2 is a picture of the manufactured superconducting coil. The normal conductor coil was made using copper under the same condition for a comparison experiment. Table 1 shows the parameters that were used in the manufacture of the resonance coils. The inductance of the resonance coils was measured with a power meter. The capacitance Q-factor were obtained using the inductance Eq. (1) and (2). Table 2 shows the obtained values.

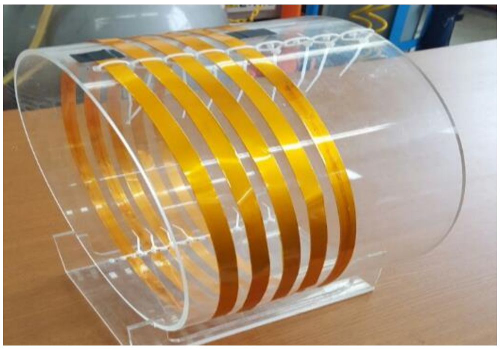


Fig. 2. Coil design.

TABLE 1
PARAMETERS OF A COIL.

Parameter	Value
Coil distance (L)	200 (mm)
Coil height (H)	300 (mm)
Coil width (D)	100 (mm)
Coil pitch (s)	50(mm)
Turn number (n)	5
Impedence matching	50 (Ω)

TABLE 2
R,L,C AND Q-FACTOR.

	Resistanc e (Ω)	Inductance (μH)	Q-factor
Normal Conductor coil	0.4	12	2.2E3
Normal conductor coil at liquid nitrogen	0.2	12	4.4E3
Superconducting coil	0.1	22.3	1.6E4

3. EXPERIMENTAL

3.1. Simulation

Fig. 3 shows the magnetic-resonance WPT simulation design using the High-Frequency Structure Simulation (HFSS, Ansys) program. The resonance coils were identically modeled as the actual coils. The parameters of a coil are shown in Table 1. The distance between the two coils was 1 m. The resonance frequency was 11.10 MHz, and the electric power that is introduced for the transmitter was 1 W. The S_{11} of S-Parameter was analyzed in this case. The S_{11} of S-Parameter represents the self-reflection value of the input port. A high S_{11} value means that the input power was not transmitted but returned whereas a low S_{11} value means that the input power was transmitted to the maximum without being reflected. The comparative experiment has conducted among the coils which are the normal conductor coils in the room temperature, the normal conductor coils in liquid nitrogen, and the superconducting coils.

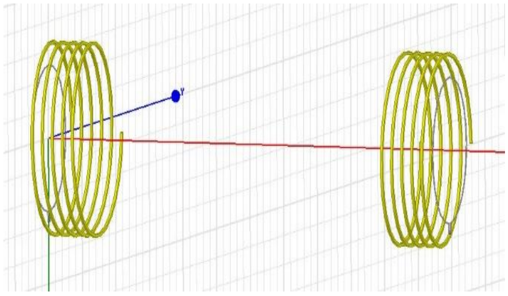


Fig. 3. Simulation design of WPT.

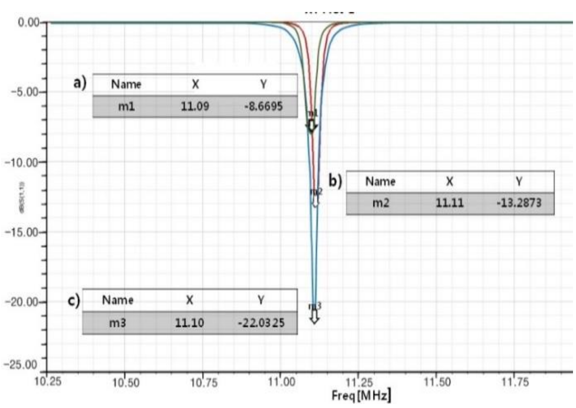


Fig. 4. S-Parameters of simulation (a) normal conductor coil, (b) normal conductor coil at liquid nitrogen, (c) superconducting coil.

Fig. 4 is the S-Parameter of the magnetic-resonance WPT system using simulation. Fig. 4(a) is the S-Parameter for the WPT of the normal conductor coils at room temperature. The resonance frequency was approximately 11.1 MHz, and the reflection coefficient (S_{11}) was about -8.67 dB. Fig. 4(b) is the S-Parameter of the normal conductor coils in liquid nitrogen. The resonance frequency was approximately 11.1 MHz, and the reflection coefficient was about -13.29 dB.

As shown in Table 2, the resistance of the normal conductor coils which is cooled by liquid nitrogen is approximately 0.2Ω . Because of the results, the reflection coefficient can be increased. Fig. 4(c) is the S-Parameter of the superconducting coils. The coils were immersed in liquid nitrogen to maintain their superconducting status. The resonance frequency was about 11.1 MHz, and the reflection coefficient was -22.03 dB. The superconducting coils had higher inductance and lower resistance than the normal conductor coils. Thus, the superconducting coils had higher Q-factors and lower reflection coefficients than the normal conductor coils.

3.2. Experimental results

Fig. 5 shows the experimental setup of the WPT characteristics using the network analyzer. The resonance frequency was 11.10 MHz. The reflection-coefficient (S_{11}) was measured with the equipment.

Fig. 6 shows the graph of the S-Parameters. Fig. 6(a) is the reflection coefficient for the WPT of the normal conductor coils at room temperature. The reflection coefficient was -7.49 dB. Fig. 6 (b) shows the reflection coefficient of the normal conductor coils in liquid nitrogen. The reflection coefficient was -16.14 dB. It was found that the reflection coefficient was diminished by about -3 dB compared to the simulation value. Fig. 6 (c) is the reflection coefficient for the WPT of the superconducting coils. The reflection coefficient was -22.21 dB. These results show almost the same reflection coefficient as in the simulation. When the experimental results were compared with the simulation, S_{11} and resonance frequency were slightly different. The reason is variation of air capacitor which is affected from the environmental condition such as temperature, humidity, etc. So, S_{11} and resonance frequency were also slightly changed. Table 3 shows S_{11} of simulation and experimental results.

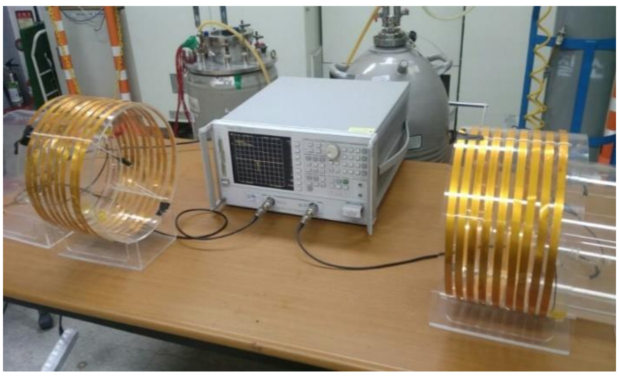
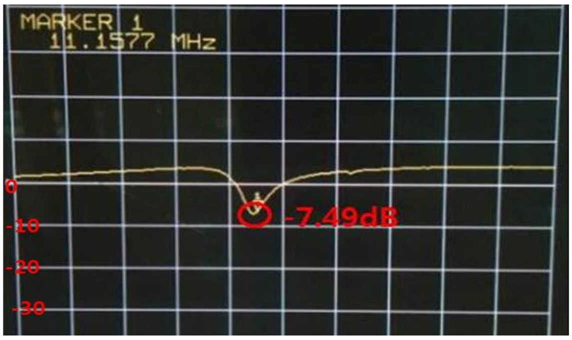
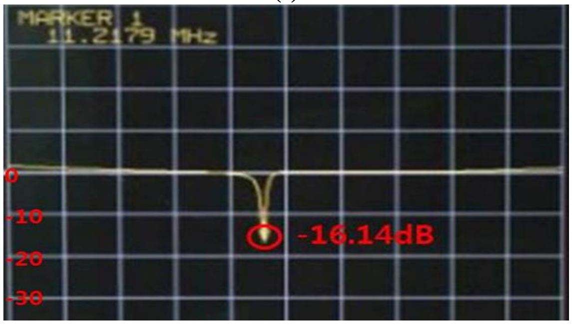


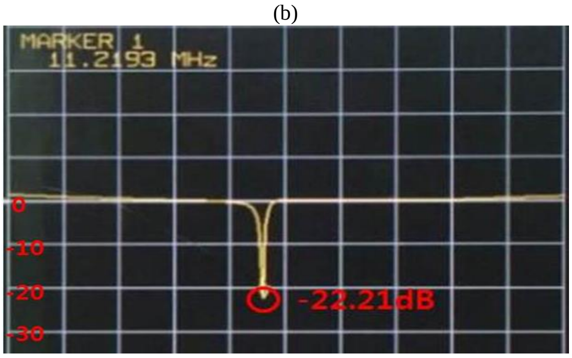
Fig. 5. Experimental setup of WPT using network analyzer.



(a)



(b)



(c)

Fig. 6. S-Parameters of experimental coils (a) normal conductor coil and (b) normal conductor coil at liquid nitrogen and (c) superconducting coil.

TABLE 3
COMPARISON OF S_{11} IN SIMULATION AND EXPERIMENTAL RESULTS.

	S_{11} of Simulation (dB)	S_{11} of Experiment (dB)	Difference (%)
Normal Conductor coil	-8.67	-7.49	13.6
Normal conductor coil at liquid nitrogen	-13.29	-16.14	17.6
Superconducting coil	-22.03	-22.21	0.8

Fig. 7 shows the efficiency of the WPT system from simulation. This figure has converted the S_{11} by the Eq. (3). The antenna efficiency was obtained through Eq. (3).

$$\text{Efficiency } (\%) = |S_{11}|^2 \times 100 \tag{3}$$

The maximum efficiencies of the coils are 65 %, 78 %,

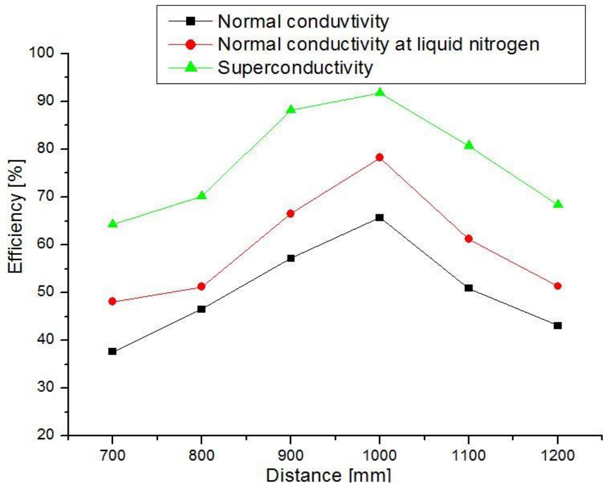


Fig. 7. Efficiency of antenna according to the distance of transmitter coil and receiver coil.

and 90 %. The figures represent the normal conductor coils in the room temperature, the normal conductor coils in liquid nitrogen, and the superconducting coils, respectively.

4. CONCLUSION

A superconducting coil was used in this study to improve the magnetic-resonance WPT efficiency. The S_{11} coefficient was measured using a network analyzer. Copper coils that are frequently used in the normal conductor coils were manufactured under the same condition for comparison. The superconducting coils showed low resistance under the critical temperature. Thus, the critical temperature was maintained using liquid nitrogen. The normal conductor coils were also tested in liquid nitrogen to compare characteristics. As a result, As a result, superconductive coil is -15 dB lower than normal conducting coil. Besides the superconductive coil is -6dB lower than the normal conducting coil in the extremely low temperature. It represents that superconductive coil has higher Q-factor than normal conducting coil. In the case of the normal conductor coils, the increase of the Q-factor was limited by the limitation value of resistance that can be obtained, 77 K.

There is a difficulty in using magnetic-resonance WPT to apply into real life because of the lack of efficiency than electromagnetic WPT. However, superconducting magnetic-resonance WPT has more than 90 % efficiency. This figure represents that it is enough to use in the real life applications. And also, transfer distance will be increased than using magnetic-resonance method. Therefore, it is considered that various applications can be derived.

ACKNOWLEDGMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education, Science and Technology (NRF-2015R1D1A1A01059489)

REFERENCES

[1] Y. J. Park, “Studies on Magnetic Resonance Wireless Power Transmission Technology,” *Kipe Magazine*, vol. 15, no. 6, pp. 47-53, 2010.

[2] Ryan Tseng, Bill von Novak, Sumukh Shevde and Kamil A. Grajski, “Introduction to the Alliance for Wireless Power Loosely-Coupled Wireless Power Transfer System Specification Version 1.0,” *IEEE Wireless Power Transfer Conference 2013*, *Technologies, Systems and Applications*, pp. 79-84, 2013.

[3] A. P. Sample, D. A. Meyer and J. R. Smith, “Analysis, Experimental Results, and Range Adaptation of Magnetically Coupled Resonators for Wireless Power Transfer,” *IEEE Transactions on Industrial Electronics*, vol. 58, no. 2, pp. 544-554, 2011.

[4] I. S. Jeong and H. S Choi, “Characteristics of Wireless Power Transmission applying the superconducting coil,” *KIEE*, vol. 62, no. 6, pp. 762-766, 2013.

[5] 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.

[6] S. H. Lee, H. M. Kim, H. J. Kim and S. W. Kim, “Wireless Power Transmission using Electromagnetic Inductive Coupling and LC Resonant,” *KIEE*, vol. 62, no. 3, pp. 349-354, 2013.

[7] Aristlidis Karalis, J. D. Joannopoulos and Marin Soljacic, “Efficient wirless non-radiative mid-range energy transfer,” *annals of Physics*, vol. 323, pp. 34-38, 2008.

[8] S. H. Cheon, Y. H. Kim, M. L. L and S. Y. Kang, “Circuit Model Based Analysis of a Wireless Energy Transfer System via Coupled Magnetic Resonances,” *IEEK*, vol. 16, no. 4, 2011.

[9] M. R. Lee, S. U. Kang, Y. H. Kim, S. H. Cheon and T. H. Jung, “wireless transfer,” *KIEE*, vol. 59, no. 1, 2010.

[10] I. S. Jeong, B. I. Jung, H. S. Choi, “Characteristic of wireless power transmission S-parameter for a superconductor coil,” *PSAC*, vol. 17, no. 1, 2015