Highly-Efficient Power Transmitter Coil Design for Small Wireless Sensor Nodes

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Abstract - **We present a power transmitter coil design for millimeter-size small wireless sensor nodes to improve coupling coefficient. We also develop a wireless power transfer (WPT) system using resonant coupling to achieve higher power transfer efficiency. Simulation results demonstrated that the power transfer efficiency was 60% at z-gap = 10 mm. Compared with conventional system, coupling coefficient was improved about 2.5 times higher and the power transfer efficiency was improved by 3% when z-gap = 10 mm.**

***Index Terms* — Position gap, Wireless power transfer, Coupling coefficient, Resonance.**

1. Introduction

Small sensor devices are expected to be a key component for next generation IoT (Internet of Things) technology. Power management for such devices is one of the big challenges to be addressed [1]. We present here a power transmitter coil design that has little dependence on the receiver's gap and position.

The wireless power transfer (WPT) systems have been attracted attention as an alternative energy source for next generation electronics systems. Because the power transfer efficiency (PTE) of the WPT system using resonant coupling is mainly determined by "kQ" product, where k is the coupling coefficient and Q is the quality factor of the resonator [2], we have to pay careful attention to the design of coils to achieve higher PTE.

Figure 1 (a) shows our conventional WPT system using resonant coupling [3]. The system consists of a power transmitter and receiver. The receiver is composed of a resonator and an LSI chip including an on-chip inductor, while the transmitter is composed of a resonator and TX coil, which has the same size and resonant frequency as the receiver's resonator. The resonant frequency is set to 350 MHz. When the distance between two resonators becomes long (z-gap and x-gap), k decreases and then PTE also decreases. On the other hand, when the distance between them becomes short, PTE decreases because k increases significantly and the resonant frequency splits into two frequency.

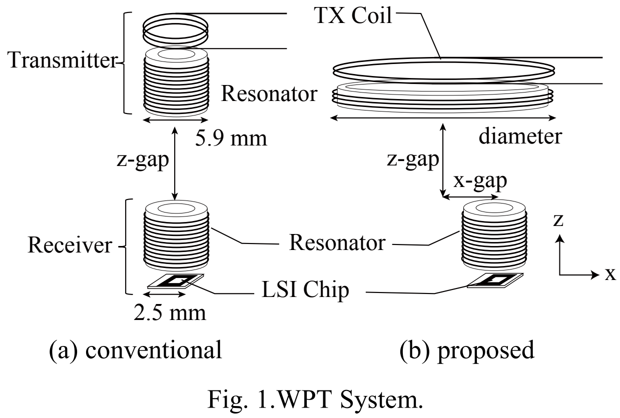

Fig. 1.WPT System.

In light of this background, we consider to change the size of the transmitter. Because k depends on both the size of transmitter and the distance between resonators, we explore the appropriate transmitter coil size by changing the transmitter's diameter. Details of this work are as follows.

2. Transmitter Design

We consider the size of the transmitter that maximizes coupling coefficient k between the resonators, using electromagnetic field simulator (HFSS). Figure 1 (b) shows our proposed WPT system. The resonators are made of the copper wire, and the thickness and pitch of the wire are 0.2 and 0.05 mm, respectively.

Figure 2 shows simulated k between the resonators as a function of transmitter's diameter d (solid line, z-gap = 10 mm). As shown in the figure, k increased and then decreased as the diameter increased. When the diameter was 24.6 mm, k became maximum of 0.026.

Coupling coefficient k between the transmitter and receiver is mainly determined by the magnetic flux density B. The magnetic flux density B induced by a single-turn circular coil with radius r at z-gap z is given by

$$B = \frac{\mu_0 I r^2}{2(z^2 + r^2)^{\frac{3}{2}}},$$

where μ_0 and I are the magnetic permeability and current, respectively. Calculated B was also plotted in Fig. 2 (dashed line). As shown in the figure, calculated B increased and then decreased as the diameter increased. From the equation, when the diameter d of the transmitter satisfies the following equations, B becomes maximum,

$$d = 2r = 2\sqrt{2} \cdot \mathrm{z}.$$

Therefore, the distance that gives maximum B can be calculated as 28 mm.

There is a small difference between the simulated and calculated diameter. One possible reason for this could be the

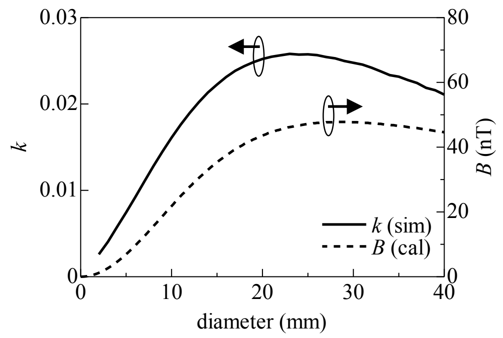

Fig. 2. Simulated transmitter's diameter characteristics.

Table I.

Transmitter and Receiver specification.

Antenna		Diameter (mm)	Turns	Q factor	resonance frequency
Transmitter	TX coil	24.6 mm	1	252	350 MHz
	Resonator	24.6 mm	2	134	
Receiver	Resonator	5.92 mm	17	218	350 MHz
	Chip Coil	2.5 mm	1	144	

size of the receiver. Table I summarizes parameters of the transmitter and receiver we designed.

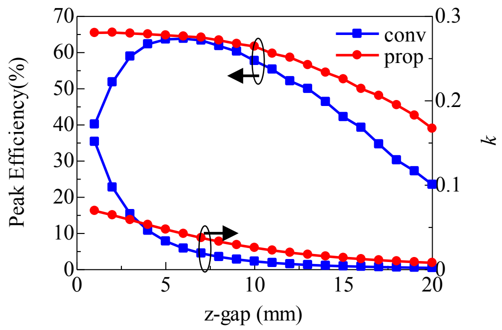

Fig. 3. Simulated z-gap characteristics.

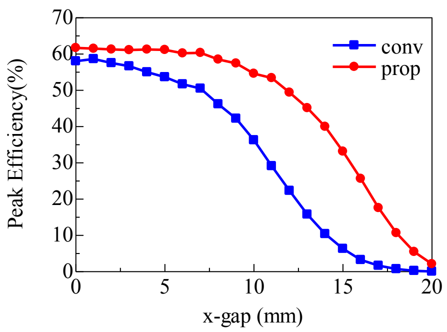

Fig. 4. Simulated x-gap characteristics.

3. Power Transfer Efficiency

Using the transmitter and receiver discussed in Sect. 2, we analyzed PTE that is defined as the following equation [4],

$$\mathrm{PTE} = \frac{|S_{21}|^2}{1 - |S_{11}|^2}.$$

We evaluated PTE when the load resistance is optimal value that realizes maximum PTE at resonance frequency of 350 MHz [5].

Figure 3 shows simulated PTE and k as a function of z-gap (x-gap = 0 mm). When z-gap was less than 5 mm, PTE of conventional system decreased greatly. This was because the resonance frequency splits into two frequency due to the increase of k. On the other hand, the proposed system achieved higher PTE than the conventional system at all z-gap, achieving 60% PTE at z-gap = 10 mm. Compared with conventional system, k was improved about 2.5 times higher and PTE was improved by 3% at z-gap = 10 mm. This was because the proposed system does not increase k too much at short z-gap and shows higher k than conventional system at long z-gap as shown in Fig. 3. In the case of z-gap = 1 and 20 mm, PTE was improved 25% and 15%, respectively.

Figure 4 shows simulated PTE as a function of x-gap (z-gap = 10 mm). The proposed system exhibited higher PTE than the conventional system at all x-gap. In the case at x-gap = 14 mm, PTE was improved 30%.

From these results, we confirmed that the proposed system using designed transmitter shows higher PTE even though z-gap and x-gap change.

4. Conclusion

We present WPT system for small-sized sensor nodes using designed transmitter. The proposed system exhibited higher PTE than the conventional system in all receiver's gap, achieving PTE of 60% at z-gap = 10 mm. Compared with conventional system, PTE was improved 3%. We confirmed that the proposed system using designed transmitter shows higher PTE even though z-gap and x-gap change.

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