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A Wireless Power Transfer System for Small-Sized Sensor Applications

Y. Akihara[1], T. Hirose[1], Y. Tanaka[1], N. Kuroki[1], M. Numa[1], M. Hashimoto[2]

[1]Dept. of Electrical and Electronic Engineering, Kobe University. 1-1, Rokkodai, Nada, Kobe 657-8501, Japan.
Phone: +81-78-803-6075, Email: hirose@eedept.kobe-u.ac.jp
[2]Dept. of Information Systems Engineering, Osaka University. 1-5, Yamada-oka, Suita 565-0871, Japan.

Abstract

This paper presents a design of wireless power transfer (WPT) system for small-sized sensor applications. The proposed WPT system uses the magnetic resonant coupling. To design a high Q resonator, we use an off-chip resonator together with an on-chip inductor. A rectifier circuit is also implemented on the chip to obtain a DC output voltage. The volume of the power receiver including the resonator and the LSI chip is 50 mm^3. Measurement results demonstrated that the maximum output power was 450 μW.

1. Introduction

Small-sized sensor devices are expected to be a key device for next generation IoT (Internet of Things) technology. Power management for such devices is one of the big challenges to be addressed. We present here a design of wireless power transfer (WPT) system for small-sized sensor nodes (< 1 cm^3).

The WPT systems have been attracted attention as an alternative energy source for next generation electronics systems. The WPT systems using magnetic resonant coupling have been adopted in applications such as electric vehicles, smartphones, and medical implantable applications [1]. Although they can transfer the power in long distance, these systems are relatively large and the developments for small-sized sensor nodes (< 1 cm^3) have not been studied enough.

In light of this background, we develop a WPT system for small-sized sensor nodes, focusing on the power receiver design, using an electromagnetic resonance field.

2. WPT System using magnetic resonant coupling

The power transfer efficiency of the WPT system using magnetic resonant coupling is mainly determined by "kQ" product [2], where k is coupling coefficient and Q is quality factor of a resonator. A high Q resonator is required to improve power transfer efficiency because k depends on the distance between resonators and decreases as the distance increases. However, it is difficult to design a high Q resonator with an on-chip inductor because both the parasitic resistance and capacitance of the metal wires (e.g., aluminum) in CMOS process are high. To solve the problem, we consider to use a high Q off-chip resonator together with an on-chip inductor.

Figure 1 shows our proposed WPT system using magnetic resonant coupling. The system consists of power transceiver and receiver. The power receiver consists of a resonator and an LSI chip including an on-chip inductor and a rectifier circuit. Because the resonator is composed of off-chip components, a high Q resonator can be realized. The power

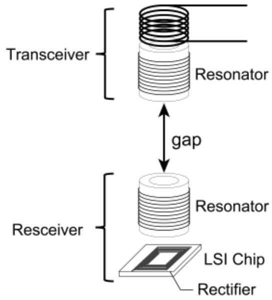

Fig. 1 WPT System.

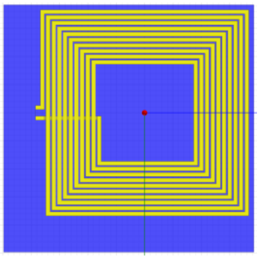
Fig. 2 On-Chip inductor.

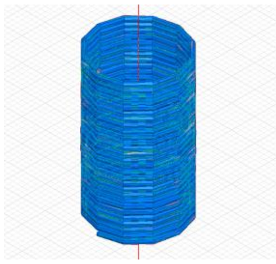
Fig. 3 Off-chip Resonator.

transceiver consists of a resonator, which has the same resonant frequency as the receiver's resonator ($f = 1/2\pi\sqrt{LC}$), and an excitation coil.

3. Receiver design

We design a power receiver for a small-sized sensor node. Figure 2 and 3 show an on-chip inductor and a resonator simulated by the electro-magnetic field simulator.

Figure 2 shows the on-chip inductor. In the 0.18 μm CMOS process we use, the inductor is designed with 6th metal, which is UTM (Ultra Thick Metal: 2.3 μm). The series resistance of the inductor can be minimized by using UTM. Table 1 summarizes simulated specification of the on-chip inductor. The Q-factor of the inductor was 9.9, which was quite low as expected. Thus, we consider to use a resonator together with the inductor.

Figure 3 shows the resonator. The resonator needs to have a high Q factor. The Q factor of the resonator is given by $Q = (1/R)\sqrt{L/C}$, where R, L, and C are the equivalent series resistance (ESR), the inductance, and the capacitance of the resonator. We use a helical coil made of copper wire, which has low resistance. When we use a discreet capacitor to obtain LC resonance, we need a large capacitor and it degrades the Q-factor as shown in the previous equation. Therefore, we use a parasitic capacitance of the helical coil without connecting an additional capacitor. Table 2 summarizes simulated specification of the resonators. The Q-factor of 257 was obtained by using the helical coil.

Table 1. On-Chip inductor specification.

Area	1.8 × 1.8 mm^2
Self-resonant frequency	790 MHz
ESR*	36.8 Ω @ 300 MHz
Inductance	193 nH @ 300 MHz
Q factor	9.89 @ 300 MHz

Table 2. Resonator specification.

Diameter	ϕ3 mm
Wire	0.2 mm UEW
Turns	27
Length	5.5 mm
Self-resonant frequency	286 MHz
ESR*	7.18 Ω @ 286 MHz
Inductance	1.03 μH @ 286 MHz
Q factor	257 @ 286 MHz

*ESR : Equivalent Series Resistance

4. Experimental Results

We evaluated our proposed WPT system. The volume of the power receiver including the resonator and the LSI chip was 50 mm^3. Figure 4 shows the measurement setup and chip micrograph. The area of the on-chip inductor was 1.8×1.8 mm^2.

Figure 5 shows measured output voltage and power as a function of input frequency. The sharp peaks of the output voltage and the power were obtained at the resonant frequency of 283 MHz. The peak output voltage were 1.74 V. This can drive electronic circuits properly. However, the output voltage and power became almost zero when the frequency shifts about 10 MHz from the resonant frequency. Therefore, it is important to control the frequency according to the resonance frequency.

Figure 6 shows measured output voltage and power as a function of load resistance R_L. The output voltage increased as the load resistance increased. The output voltage was 2.6 V when the load was 10 MΩ. The maximum output power was 450 μW when the load was 2.2 kΩ.

Figure 7 shows measured output voltage and power as a function of gap between two resonators. The output voltage became maximum at 10 mm. The voltage decreased when the gap was changed from the distance. The reason for this could be the change of the resonant frequency. As the gap changed, the mutual inductance and capacitance were also changed. This changed the resonant frequency.

4. Conclusion

We presented a design of wireless power transfer (WPT) system for small sized sensor applications. The proposed WPT system uses the magnetic resonant coupling. To obtain a high *Q* resonator, we used the off-chip resonator together with the on-chip inductor. The rectifier was also implemented on the chip to obtain the DC output voltage. The volume of the power receiver including the resonator and the LSI chip was 50 mm^3. Measurement results demonstrated that the maximum output power was 450 μW.

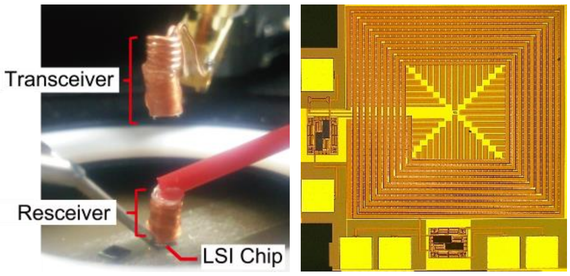

Fig. 4 Measurement setup and chip micrograph.

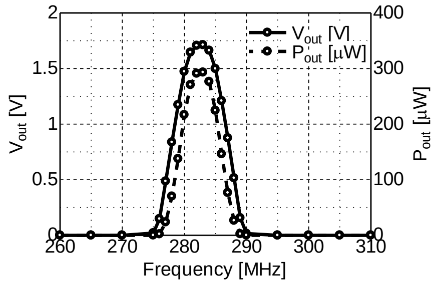

Fig. 5 Measured frequency characteristics.

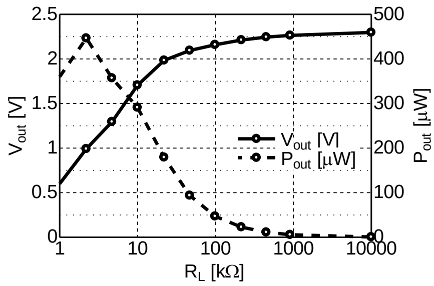

Fig. 6 Measured load characteristics.

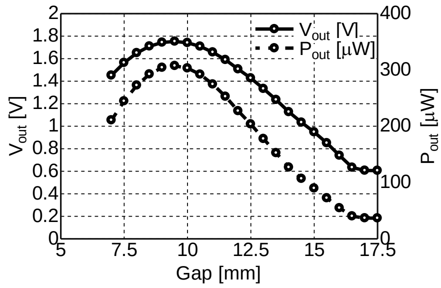

Fig. 7 Measured gap characteristics.

Acknowledgements

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