Wearable Inkjet Printed Energy Harvester

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***Abstract*—This paper proposes two types of inkjet printed wearable energy harvesters scavenging energy from an off-the-shelf two-way radio which operates at 464 MHz. One of them uses loop antenna and the other applies segmented loop antenna to reduce the interference from human tissue. The effects of the human tissue on the RF link are taken into consideration both in simulation and measurement. The maximum output powers of the loop-type and the segmented-loop-type harvesters are 96 and 55 mW, respectively while the distance between the radio and the harvesters is 5 cm. Moreover, the effects of misalignment between the radio and the harvesters are also addressed.**

Keywords—Wearable antenna; Energy Harvester; Inkjet Printing

I. Introduction

Harvesting ambient energy has become more and more popular during the last decade. Among all different ambient energy sources, the RF energy is particularly popular because it is available almost everywhere and every time [1]. One of the key challenges of harnessing ambient RF energy is the relatively low energy density, but this can be solved by locating RF energy harvester near the energy source. Thus, harvesting RF energy from hand-hold devices utilizing wearable harvester on a wrist would be a suitable solution. An energy harvester harvesting energy from a two-way radio is proposed in [2]. However, water is used to mimic the human tissue in [2] which might lead to discrepancies between the experiments and real applications. The human tissue can be viewed as a material with high permittivity and poor conductivity which leads to high dielectric losses. Therefore, it is necessary to include the effects of human tissue on the RF link between the wearable energy harvesters and the hand-hold devices. The loop and segmented loop antennas are usually applied to wearable designs since the effects of the human tissue is alleviated [3].

In this paper, both loop and segmented loop antenna are used to fabricated two types of wearable inkjet printed energy harvesters harnessing energy from an off-the-shelf two-way radio. The complete simulation model including the two-way radio, human hand, and the receiving antenna are built to estimate the coupling between them. By including the human hand model, the effects of the human tissue on the RF link are taken into consideration. Besides, all measurements are performed using real human hand so that the results of the experiments are the same as real applications. The impacts of different angles between the two-way radio and the proposed energy harvesters due to active movement of the human hand are also addressed.

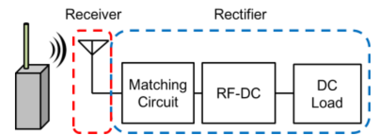
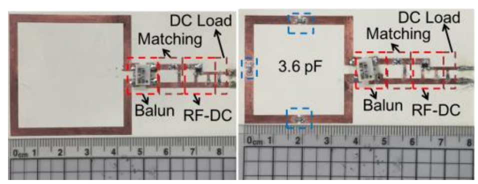


Fig. 1. The block diagram of the proposed system.



(a) (b)

Fig. 2. The prototype of the proposed (a) loop-type and (b) segmented-loop-type harvester.

II. Energy Harvester Designs

The block diagram of the proposed system is shown in Fig. 1. As shown in Fig. 1, the energy harvester is composed of a receiver and a rectifier which is made up of a matching circuit, a RF-DC circuit, and a DC load. The energy source is the Motorola RDU4100 two-way radio operates at 464 MHz. A removable stubby antenna is used as the transmitted antenna and the transmitted power is about 3.6 W while in the high power mode.

A. Antenna Design

The prototypes of the proposed energy harvesters are shown in Fig. 2. As demonstrated in Fig. 2, there are two types of receivers. Different circumferences of the loop antenna are tested and the maximum power transfer is achieved while the circumference is about quarter wavelength. However, the current along the loop is not uniform anymore. Thus, the loop-type receiver is E-field coupling receiver. The segmented loop antenna breaks the loop antenna into four segments and connecting them with 3.6 pF capacitors. Thus, the current along the loop is forced to be uniform. Therefore, the segmented loop receiver is H-field coupling receiver.

The S-parameters are used to estimate the coupling between the two-way radio and the receiver. Models of the two-way radio, human hand, and the deformed receivers are built in the HFSS. The material properties of the homogeneous human hand model are set to two-third of the muscle [4]. The simulated results and the HFSS models are shown in Fig. 3 and Fig. 4. The prototypes are wrapped on the wrist with a distance 5 cm away from the radio to obtain the measured results and

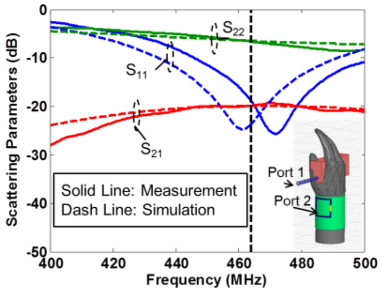


Fig. 3. Simulated and measured scatter parameters of the loop-type receiver.

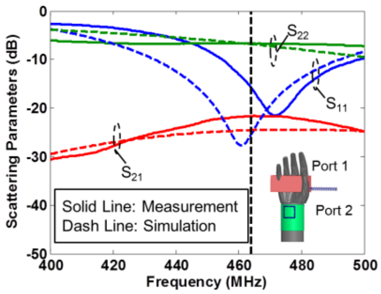


Fig. 4. Simulated and measured scatter parameters of the segmented-loop-type receiver.

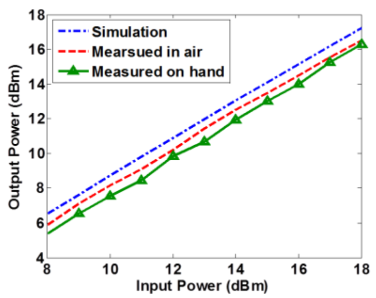


Fig. 5. Simulated and measured output power of the rectifier.

they are also included in Fig. 3 and Fig. 4 for comparisons. As shown in these figures, good agreement is observed. Moreover, to achieve the maximum power transfer, two types of harvesters need to be put on different relative positions. This is because one is E-field coupling and the other is H-field coupling. The measured S-parameters are import into the Advanced Design System (ADS) to simulate the output power. While complex conjugated matching condition is achieved, the output powers for the loop and segmented loop receiver are 53.2 and 35.1 mW, respectively.

B. Rectifier Design

The prototypes of the rectifiers are shown in Fig. 2. The voltage doubler is used as the RF-DC circuit. The voltage doubler is composed of a 100 pF capacitor, two HSMS2828 Schottky diodes, and a 330 pF capacitor. A 1.5 kΩ resistor acted as the DC load. The simulated and measured results of the output powers with different input powers are shown in Fig. 5 and the maximum DC conversion efficiency is about 68 % while the input power is 18 dBm. Moreover, the effect of the human hand on the rectifier are also taken into consideration.

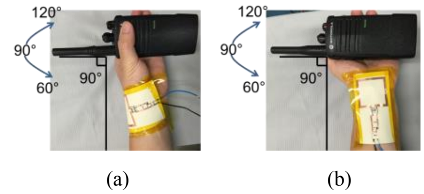


Fig. 6. Measurement setup for the (a) loop- and (b) segmented-loop-type energy harvester.

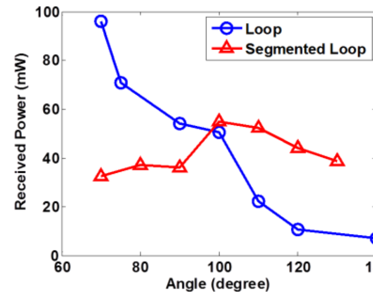


Fig. 7. The measured output powers with different angles.

III. System Performance

The measurement setup is shown in Fig. 6 and the measured output powers with different angles are shown in Fig. 7. The angles are defined as the angle between the transmitted antenna and the arm. For example, in Fig. 6, the angle is 90 degree. The distance between the radio and the energy harvesters is 5 cm. As demonstrated in Fig. 7, the maximum output power for the loop- and segmented-loop-type energy harvester are 96 and 55 mW, respectively. Although the maximum output power can be achieved using loop-type, the segmented-loop-type is more stable with the change of angles.

IV. Conclusion

Inkjet printed wearable loop- and segmented-loop-type energy harvesters harvesting energy from a two-way radio are proposed. The effects of the human tissue are taken into consideration in both simulation and measurement. Effects of different angles caused by active motion are addressed. The maximum output powers harvested from the loop- and segmented-loop-type energy harvesters are 96 and 55 mW while the distance between the radio and the harvester is 5 cm.

References

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