Inductively Coupled Split Ring Resonator as Small RFID Pressure Sensor for Biomedical Applications

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***Abstract*—We present an inductively coupled split-ring resonator based small passive RFID pressure sensor for wireless intracranial pressure measurement. The proposed sensor has a volume as small as π × (4 mm)^2 × 1 mm. In the simulation, the proposed sensor can provide nearly 1 m operation distance when implanted in the intracranial environment. In our preliminary measurement in the air, the sensor has a resolution of 3 cmH2O.**

Keywords—implantable pressure sensor; split ring resonator; radio frequency identification; implantable antenna.

I. INTRODUCTION

The measurement of the pressures in various locations of the human body provides valuable medical indicators. For instance, the systolic and diastolic pressures are commonly measured to evaluate the condition of the cardiovascular system; the abnormal high intraocular pressure (IOP) usually indicates the risk of the glaucoma; the measurement of intra-abdominal pressure (IAP) is used to identify the patients with intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS) and the intracranial pressure (ICP) is usually measured to diagnose the brain trauma or neurological disorders.

In the literature, different approaches to develop the pressure sensors for biomedical applications have been investigated, including the microelectromechanical (MEMS) based pressure sensors to measure the IOP [1], ICP [2], IAP [3] and blood pressure [4], the capacitive polymeric foams based pressure sensor for atrial pulse detection [5], passive resonator based pressure sensors for ICP monitoring [6-7] and the bioinspired pressure sensor for body movement monitoring [8]. Most of the proposed sensors are wireless with a small sensor footprint, however the operation distance between the off-body reader and the sensor is limited to several centimeters [1, 6, 7]. Moreover, to sense the pressure, the work in [2, 6, 7] need the spectrum analyzer to detect the peak value of the pressure-related resonant frequency of the sensor. This configuration will increase the system complexity and cost.

In this paper, we introduce a small passive RFID pressure sensor based on a pair of inductively coupled split rings. The proposed sensor shifts its center frequency of the backscatter signal according to the ambient pressure with a resolution of 3 cmH2O. The sensed pressure can be readily read out with commercial RFID readers. In the simulation, the operation distance can be 0.97 m when implanted in the intracranial environment.

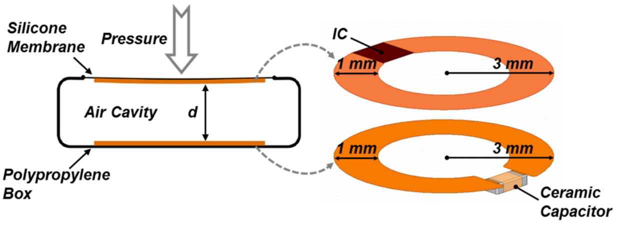

Fig. 1. Structure of the proposed sensor with its geometrical parameters.

II. SENSOR STRUCTURE AND DEVELOPMENT

Fig. 1 shows the cross-sectional structure of the proposed pressure sensor with its dimensions. This sensor is developed based on our recently proposed RFID tag antenna in [9]. The major parts of the sensor are the double split rings adhered to the silicone membrane and the bottom of the polypropylene box, respectively. The RFID IC, NXP UCODE G2iL with a wake-up power of 15.8 μW and RF input impedance of 12 - j191 Ω at 915 MHz, is soldered to the terminals of the upper ring's split. Correspondingly, a ceramic capacitor with the capacitance of 4.3 pF is soldered to that of the lower ring. The two rings are inductively coupled, and the resonance of the lower ring helps to archive a complex conjugate matching between the sensor and the IC. Fig. 2. compares the simulated impedance of the IC and that of the sensor with a fixed separation distance of 0.04 mm between the two rings in a tissue phantom (20 cm ×20 cm ×20 cm) assigned with the frequency dependent dielectric properties (ε_r=45.74, σ=0.77 S/m at 915 MHz) to simulate the intracranial environment (U.S. FCC). A good complex conjugate matching can be observed near 915 MHz and the estimated maximum attainable read range [10] of the sensor reaches 0.97 m.

Due to the elasticity of the silicone membrane, with applied pressure, the deformation of the membrane will shorten the distance between the rings and influence the mutual coupling between the two rings and ultimately change the input impedance of the sensor. We use the power transfer efficiency τ, given in eq. (1), to evaluate the impedance matching between the IC and the sensor,

$$\tau = \frac{4\mathrm{Re}(Z_s)\mathrm{Re}(Z_{ic})}{|Z_s+Z_{ic}|^2} \qquad (1)$$

where Z_s is the impedance of the sensor and Z_{ic} is IC impedance. Fig. 3. compares the simulated τ with different distance between the rings in the tissue phantom. The proposed sensor has a very high sensitivity to the change of the distance between the two

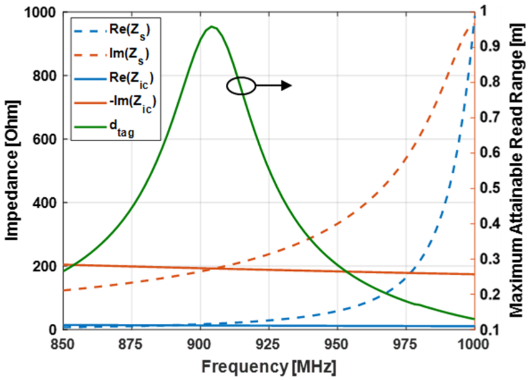

Fig. 2. Impedance of the sensor and the IC with the estimated maximum read range of the sensor with a fixed d of 0.04 mm in the tissue phantom.

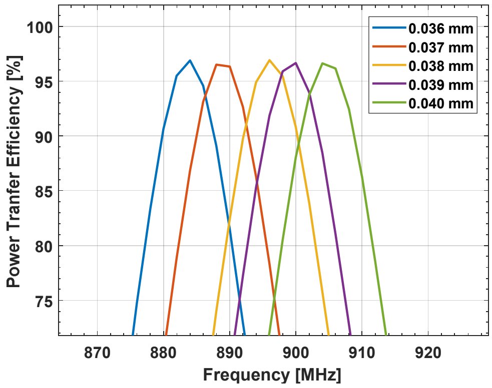

Fig. 3. Comparison of the τ with d sweeping from 0.036 mm to 0.04 mm with a step of 0.001 mm.

rings. A difference of 0.001 mm in d results in a frequency shift of 4 MHz. This high sensitivity can be potentially utilized for pressure sensing.

III. SENSOR PROTOTYPE AND MEASUREMENT RESULTS

To evaluate the feasibility of the proposed sensor, we fabricated the sensor prototype and conducted the preliminary measurement in the air. Fig. 4. shows the prototyped sensor placed on the tip of a syringe and the setup of the wireless measurement. Since the normal ICP is in a range of 10 to 20 cmH2O. In the measurement, the syringe is gradually filled with water with the markers from 17 cm to 23 cm with a step of 1 cm. In each step, we measured the read range of the sensor. According to the results in Fig. 5., with the increased water pressure, the center frequency of the maximum read range shifts to the lower end. The resolution of the pressure sensor is 3 cmH2O with a 2 MHz frequency shift.

IV. CONCLUSION

A small passive RFID pressure sensor has been proposed in this paper. A novel structure has been used to develop the sensor with high resolution of 3 cmH2O in the air test. In the simulation, the proposed sensor is capable to operate in a lossy tissue environment with a read range of more than 0.9 m. Our future work focuses on the optimization of the sensor structure and the wireless measurement in the tissue mimicking liquid.

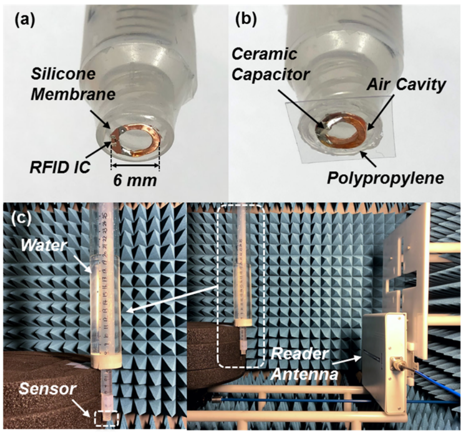

Fig. 4. Prototyped sensor and measurement setup in EMC chamber.

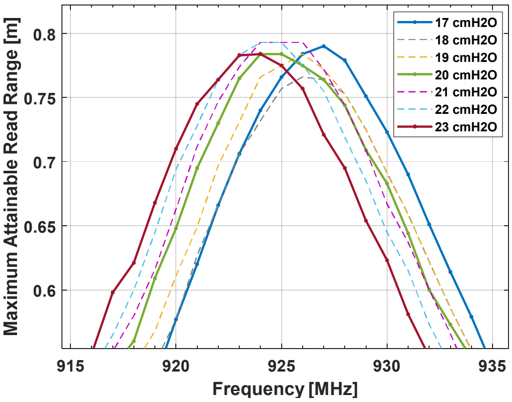

Fig. 5. Measured sensor read range versus different water pressures.

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