FLOW SENSORS AND RF ENERGY HARVESTING DEVELOPMENT FOR INTERNET OF THINGS

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Abstract— With the advent of IOT (Internet of Things), energy harvesting and new sensor technologies has been attracting more attention from the research community. Here we present a new flow sensor that can robustly sense the flow in gas and liquid, and a new energy harvesting module that uses RF (radio frequency) waves as the media. The flow sensor uses commercial piezoresistive pressure sensors as sensing part and three dimensional printing for the receiving structure. The flow sensor was able to measure 4 m/s in air, and the energy harvesting module was able to 1mW from +20 dBm transmission power.

Keywords— IOT, biomimetic, flow sensor, energy harvesting, RF power

I. INTRODUCTION

The IOT technology is one of the key component that will realize the fourth industrial revolution that will change the manufacturing from mass production to customized production. IOT (Internet of Things) sensor device that uses RF (radio frequency) as wireless power media has been gaining attention. This is because RF power can be acquired almost anywhere in urban environments. With the help of power management, the system can store enough power to use in sensor applications. For sensors, inertial sensors are well developed for vibration sensing or motion sensing, but flow sensing in the environment is still done by macro sensors. In this work, we focus on the development of RF energy harvesting and low cost robust flow sensors. A system block diagram of the RF energy powered sensor module is shown in Fig 1.

II. METHOD

For the RF energy harvesting experiment, a Keysight N9310A RF signal generator is used to create RF waves at 915 MHz frequency at +20 dBm of power. Then, the RF waves are emitted wirelessly by a panel antenna (Fig. 2). The receiver is a small device that includes a receiving antenna, impedance matching network (IMN), voltage multiplier, and a resistive load.

In order to obtain maximum energy transfer from the antenna to the load, the IMN is required to be optimized. Here, the IMN is designed individually for each circuits using the Impedance Matching Tool in ADS software (Agilent). The matching frequency is set up from 902 MHz to 928 MHz. Efficiency of the IMN is evaluated by S11 parameter measurements.
S11 parameter presents how much power is reflected back to the antenna.

The voltage multiplier is a special rectifier circuit providing the output that is theoretically an integer multiplied by the input AC peak value. Although assuming that the output voltage equals to N times the input, in which N is order of the voltage multiplier, a small voltage drop between the diode terminals is present. The drop is higher as the order of voltage multiplier is increased.

The first prototype WPH circuit is built on a breadboard. After some modifications and evaluations, a printed circuit board (PCB) and a custom PCB is used to assemble the circuit. For custom PCB versions, surface mount electrical components are preferred to minimize the size of the overall circuit.

For the flow sensor, we mimic the design of the hair cell that can be found in fish lateral line or inside human cochlea.[1,2] We use a 3D printer to fabricate hair cell structure, PCB (printed circuit board) technology to make circuit board, and commercial piezoresistive pressure sensor die as the sensing part. The design and fabrication method is shown in Fig. 3.

**Figure 1.** System block diagram of RF energy harvested sensor module. The red blocks are the focus of this paper

**Figure 2.** A WPH experiment setup

**Figure 3.** Design and fabrication method of the flow sensor. (1) Four piezoresistive pressure sensors are mounted on the PCB and then wirebonded. The four sensors are located on 4 directions. (2) 3D printed hair cell is mounted on top. (3) 3D printed packaging cover is attached on top for protection and guidance for the hair cell. (4) 3D printed bottom part is joined and attached to hold the ball joint and finish the packaging. External connectors are also attached.

**III. RESULTS**

One version of WPH circuit built on custom PCB is shown in Fig. 4.

In this work, S11 parameters of all 3 circuits are lower than -10 dB at the frequency band from 902 MHz to 928 MHz, which satisfies the requirements of IMN design in this application. According to Fig. 5, the S11 measurement of the 6 stage multiplier at 915 MHz is -
10.435 dB and the bandwidth is 180 MHz (890-1070 MHz). Also, S11 measurement of the 10 stage multiplier is -23.387 dB with the bandwidth of 180 MHz (795-975 MHz). Finally, in the case of 20 stage multiplier, S11 parameter is -12.9 dB and the bandwidth is 25 MHz (895-920 MHz). Although the experimental results are not as good as the simulation results on ADS, the impedance matching network meets the requirement (S11 < -10 dB).

The measured maximum harvested output DC voltage is 3.1 V with a corresponding power of 1 mW. The experimental results are in good agreement with the theory that the higher stage voltage multipliers yields higher output voltages (Figure 6). As a consequence, the output power and efficiency is also increased as the number of multiplier stages increase.

In this experiment, the RF transmitting power is +20 dBm, while the frequency and load resistance are 915 MHz and 10 kΩ, respectively.

The experimental data shows that 10 and 20 stage circuits work efficiently at a distance from 10 to 60 cm from the transmitting antenna. In comparison to relevant previous research, this distance is suitable for many applications [3-6]. Moreover, for output power around 1 mW, our WPH circuit is able to power small sensors and low power consumption devices.

Besides, since our wireless power harvesting circuits operate in the zone of near-field, the power density in the space is unstable and unpredictable. In consequence, the data acquired at this zone possesses high tolerance.

**Figure 4.** A prototype of 6 stage voltage multiplier WPH circuit. The size of this circuit is 25.6 x 37.9 mm.

**Figure 5.** S11 parameter measurements

**Figure 6.** Output voltage and power versus distance.
For the flow sensor, the sensors were tested in wind tunnel. To increase the area of the hair cell, a larger area flap was added initially. The measured air flow resolution was 4.07 m/s. The change of voltage was 12.6mV with a 5V supply. Results are shown in Figure 7.

**Figure 7.** Voltage output from flow sensor and the sensor used for the experiment

IV. **CONCLUSIONS**

A Wireless power harvester is a key to making health care systems and biomedical devices free of batteries. Our proposed system is able to retrieve 1 mW power from +20 dBm electromagnetic power input (915 MHz) source. The miniaturization of the circuit is the next step to enhance portability of the system. For future investigation, integrating the antenna on-chip to reduce the size and enhance transmission efficiency is a promising direction.

A flow sensor fabricated using commercial pressure sensors and 3D printed parts was easy to customize and robust enough to be used in gas or liquid environment.

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