3D Printed Inverted-F Antenna and Temperature Sensor using Microfluidics Technologies

Shicong Wang and Meisong Tong
Department of Electronic Science and Technology
Tongji University
Shanghai 201804, China
wangshicong@tongji.edu.cn,mstong@tongji.edu.cn,

Yangyang Guan and Manos M. Tentzeris
Department of Department of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, USA
yanggy@bupt.edu.cn, etentze@ece.gatech.edu

***Abstract*—A novel wireless and passive temperature sensor that utilizes 3D printed inverted-F antenna (IFA) microfluidic and liquid metal technologies for the temperature sensor is introduced in this paper. The thermal volume expansion of liquid metal to progressively increase the length of the arm of IFA which will effectively increase or decrease with respect to temperature. In this way, the sensed temperature value can be accurately quantified by the change in its resonant frequency. Simulation result shows the sensitivity of temperature is 2.54 MHz/$^{\circ}C$.**

I. Introduction

Temperature monitoring is an essential problem in electronic device maintenance, refrigerated food transport, agriculture, and nuclear waste storage and buildings wall temperature [1]. For a long time, the temperature measurement always depends on the human. So the temperature data are inaccurate, and people may make mistakes in reading the temperature, which still leads to a miss of fault. Therefore, a wireless way to monitor temperature is needed to track the temperature.

Low-cost wireless automation solutions are critical to monitoring objects in real-time through unpredictable environments. Passive tags that can be read by radar or illumination will allow real-time temperature monitoring in the measurement of building wall temperatures and other scenarios. Passive antenna sensors can also be used for real-time monitoring of temperature in agricultural products and product transportation processes where maintaining a stable temperature is critical for the health, safety, and maintenance of the product. [2], [3].

Meanwhile, 3D printing, especially low-cost dielectric 3D printing, has been involved in the fabrication of antennas and microwave components recently, due to its simplicity in printing lightweight complex-shape 3D objects.

In this paper, we used the FormLabs Form2 3D printer to fabricate the IFA temperature sensor. We extend this technique by using the thermal volume expansion of mercury to progressively increase the arm of IFA which will effectively increase or decrease with respect to temperature. The novel sensor design and its electromagnetic simulation will be discussed. RFID chip and remote interrogation will be used in future work. And the measurable temperature range depends on the operating frequency band of RFID chip.The fabrication flow and benchmarking measurement is the next work for the realistic 3D microfluidics liquid metal case.

II. ANTENNA DESIGN

In this paper, we use a simple inverted-F antenna (IFA) in Ultra High Frequency (UHF) band as a temperature sensor. The design, the fabrication, and the obtained simulated results are discussed. Three elements compose the antenna design: the ground plane, which used here is a rectangular box, the dielectric structure, and the radiating element.

This IFA is designed to resonate in the UHF band at 915 MHz. The geometry and dimensions of the antenna are presented in Fig. 1. The dielectric material used is FormLabs clear resin. This antenna is printed with a Form LabsForm2 3D printer, which has 50 μm special resolution scale. The main operation principle lies in the SLA printing technology which utilizes a light source-ultraviolet (UV) laser or projector-to selectively cure liquid resin into a hardened plastic layer by layer to create 3D models. Thus, SLA is adopted in this paper for its low-cost and fast to satisfy various structure demand of 3D objects. The 3D printed antenna is shown in Fig.2.

We have characterized this material with a permittivity ϵ_r equals to 2.8, and loss tangent is 0.03. The liquid metal used is mercury because the volume of mercury is very sensitive to the changes in temperature.

The ground box of the antenna is filled with mercury, whose volume will expand along the arm of IFA. The arm of IFA is a microfluidic channel whose radius is 0.5 mm. So this sensor will be more sensitive if the channel is narrower. And we designed the support to keep the balance between the arm and ground box. When the temperature changes, the length of arm L will be correlated to the temperature value. Besides, an SMA probe feeds the antenna, and a short conducting wire are used to link the vertical short circuit of the IFA to the ground box, which is shown in Fig. 1 (b).

III. SIMULATED RESULT

The simulated results are presented in this part. As shown in Fig.1 the radius of the microfluidic channel is 0.5mm, so the relationship between the length of the arm L and the increment of temperature ΔT can be presented by Eq. (1), which means that L will increase 0.2166mm as the temperature raising 1 $^{\circ}C$.

$$\Delta L = \Delta T \times 0.2166mm. \tag{1}$$

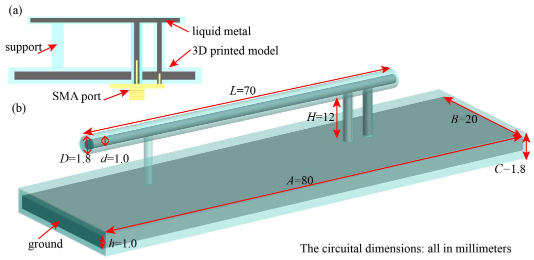

Fig. 1. The topology of the proposed inverted F antenna. (a) Front view. (b) Complete structure.

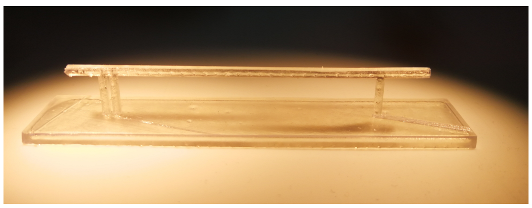

Fig. 2. The printed model of the proposed antenna

The thermal volume expansion of liquid metal will progressively increase the arm of IFA L. Meanwhile, the resonant frequency will decrease with respect to temperature. Fig.3 shows the resonant frequency shift with the different length of arm L. Fig.4 shows there is a nearly linear relationship between temperature and resonant frequency. When the temperature raises 1 °C, the resonate frequency will reduce 2.54 MHz. As shown in Eq.(2). f is measured temperature and f_0 is reference temperature. In Fig. 5, the radiation pattern in the azimuth plane is presented.

$$f = f_0 - \Delta T \times 2.54MHz. \tag{2}$$

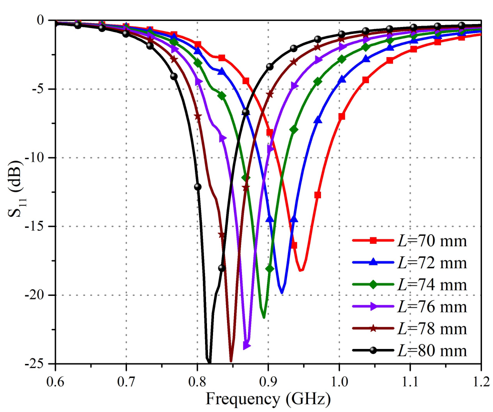

Fig. 3. The resonant frequency shift with the different length of arm L

IV. CONCLUSION

In this paper, the new concept of a wireless passive temperature sensor based on IFA and microfluidics and liquid metal technologies is presented. There is a linear relationship between temperature and resonant frequency. And this IFA antenna can be used as a temperature sensor. Simulated results show that when the temperature raises 1 $^\circ C$ the resonant frequency will reduce 2.54MHz. In the next step, we will do the experiments using liquid metal to validate the sensor performance with microfluidics technology. This work will set the foundation for a new type of conformal wireless sensors.

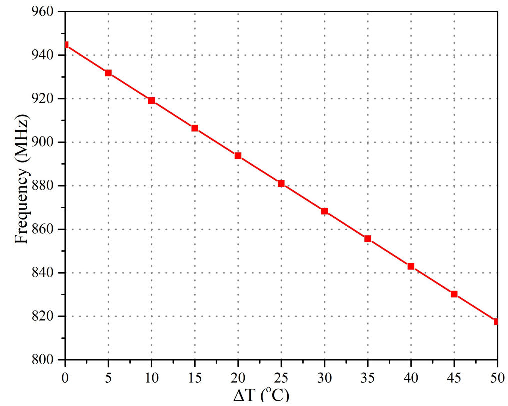

Fig. 4. Relationship between temperature and resonant frequency

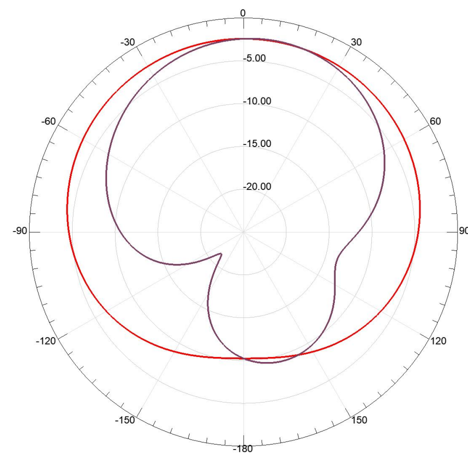

Fig. 5. The radiation pattern in the azimuth plane

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REFERENCES

[1] L. Ruiz-Garcia, L. Lunadei, P. Barreiro, and I. Robla, *A Review of Wireless Sensor Technologies and Applications in Agriculture and Food Industry: State of the Art and Current Trends, Sensors*, vol. 9, Jun. 2009, pp. 4728-4750

[2] J. Wisniak,*"The Thermometer-From The Feeling To The Instrument, The Chemical Educator*, vol. 5, No. 2, Apr 2, 2000.

[3] A. Traille, S. Bouaziz, S. Pinon, P. Pons, H. Aubert, A. Boukabache, et. M. Tentzeris, *A wireless passive RCS-based temperature sensor using liquid metal and microfluidics technologies*, in Microwave Conference (EuMC), 2011 41st European, 2011, pp. 4548.