Chipless RFID Sensor Tag for Angular Velocity and Displacement Measurement

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***Abstract*—A novel chipless RFID sensor tag is investigated for angular velocity and displacement measurement. The designed sensor tag consists of horizontal and vertical I-shaped bar resonators which are both symmetrically arranged. The whole of the longest resonators acts as a sensing element while the others are used as encoders. The angular variation can be detected by measuring the Radar Cross-Section (RCS) magnitude of the sensing element as the object, to which the tag is attached, rotates. Meanwhile, a depolarizing technique is applied, which makes the detection process more robust. In addition, due to the fact that the dual polarization (DP) can increase the encoding capacity doubly in the same frequency band, the proposed tag with a compact dimension of 22 × 30 × 0.8 mm^3 can encode 18-bit data. As compared with angular displacement and velocity sensors based on inductive coupling modulation, the proposed sensor tag can make a significant increase of the sensing distance.**

***Index Terms*—Angular sensor; chipless RFID; depolarization; dual polarization.**

I. Introduction

As a mature wireless technology, RFID has been widely applied to many fields, including access control, logistics, and attendance system. However, its applications are still limited because of its inner integrated circuits. On the contrary, chipless RFID possesses several advantages over the traditional RFID in terms of cost, simplicity, and working in harsh environments [1]. Hence, chipless RFID has aroused the interest of researchers in the field of sensors. Various sensors such as temperature sensing [2], crack detection [3], and angular measurement [4] have been accomplished by using chipless RFID tags.

Concerning angular sensors, as most of the implemented sensors are based on inductive coupling, the reader and the sensing element need to be closely approached. An angular sensor was accomplished by the inductive coupling between the CPW and the S-SRRs of the chain [4]. In [5], another angular velocity sensor was constructed through a CPW coupled to an ELC resonator. Apparently, their sensing distances are strictly limited, which is inconvenient in some application environments.

In this article, a chipless RFID sensor tag is designed for angular velocity and displacement measurement. The proposed tag is dual-polarized, which can double the bit encoding capacity to 18 bits [6]. Furthermore, the sensing distance can be significantly improved because the proposed sensor obtains angular information by measuring the Radar Cross-Section (RCS) magnitude variation of the specified frequency point. The application of the depolarizing technique can also enhance the robustness of the measuring process.

II. Tag Design and Analysis

The geometry and dimensions of the proposed sensor tag are illustrated in Fig. 1. The proposed tag is etched on a Taconic TLX-8 laminate which has a relative dielectric constant of $\varepsilon_r = 2.55$, a loss tangent of $tan\delta = 0.0019$ and a dimension of 22 mm × 30 mm × 0.8 mm. The designed sensor tag mainly consists of horizontal and vertical I-shaped bar resonators which are both symmetrically arranged. Among these resonators, the whole of the longest resonators in the horizontal and vertical directions acts as a sensing element while the others are used to encode data.

To greatly increase the encoding capacity, a dual polarization technique is implemented here. As shown in Fig. 2, an independent horizontal part of the designed tag is simulated, which is excited by horizontal (X) and vertical (Y) polarized

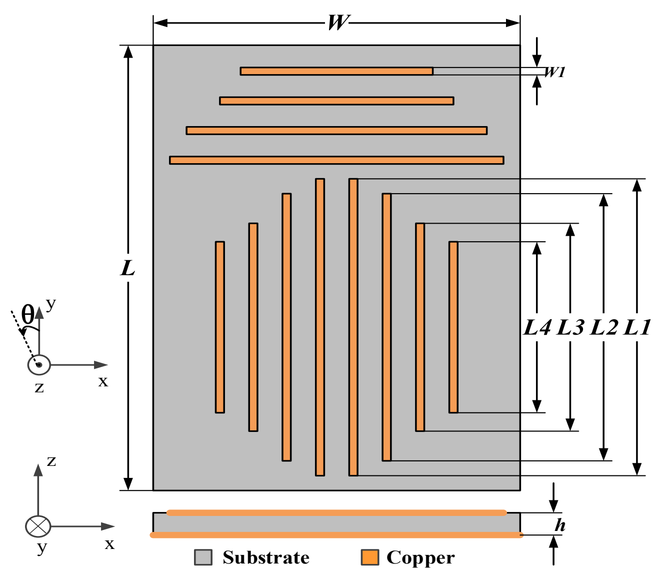

Fig. 1. Geometry of the proposed sensor tag. Dimensions are L = 30 mm, W = 22 mm, $L1$ = 20 mm, $L2$ = 18 mm, $L3$ = 14 mm, $L4$ = 11.5 mm, $W1$ = 0.5 mm, and h = 0.8 mm.

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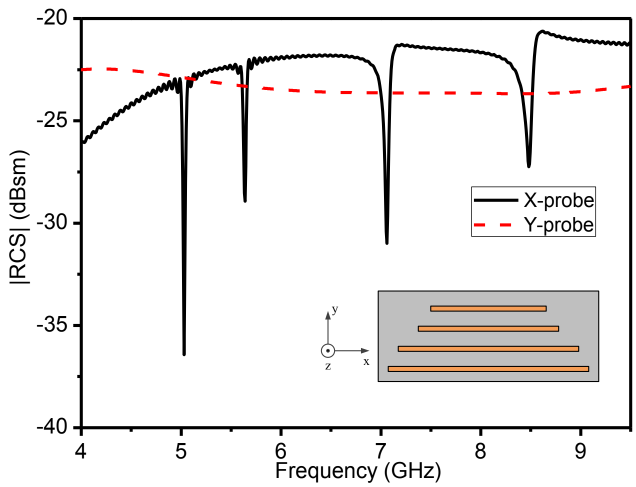

Fig. 2. Simulated RCS magnitude of the independent horizontal part of the proposed tag corresponding to X- and Y- polarized incident waves.

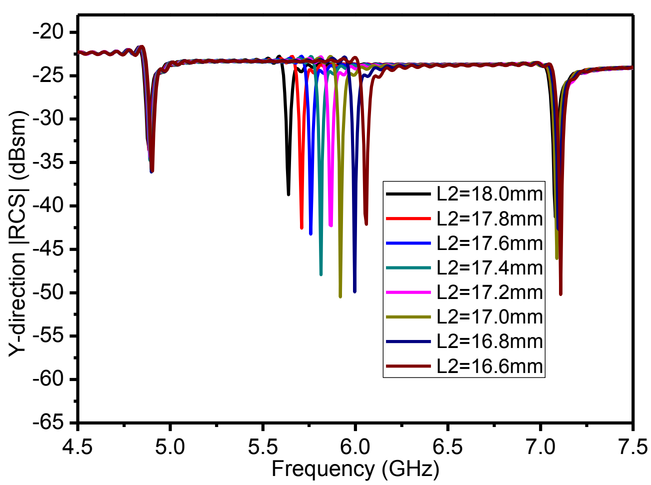

Fig. 3. Simulated RCS magnitude of the proposed tag in the Y direction with a Y-polarized incident wave corresponding to different length of $L2$.

incident plane waves sequentially. Apparently, when excited by Y-polarized incident waves, the simulated tag doesn't response. Therefore, the encoding capacity can be doubled by using such resonators with two orthogonal polarities simultaneously [6].

In addition, for the purpose of improving the encoding capacity, another encoding technique, *i.e.*, the frequency shift technique, is introduced. As shown in Fig. 3, the resonant frequency of $L2$ is obviously shifted by changing the length of $L2$ while not affecting the adjacent resonant frequency points. Consequently, eight distinguished frequency points can be obtained by only utilizing one resonator, which can encode 3-bit data. Similarly, the same method can be applied to resonator $L3$, $L4$.

Finally, by combining the frequency shift technique and the dual polarization technique, the designed sensor tag can achieve an encoding capacity of 18 bits.

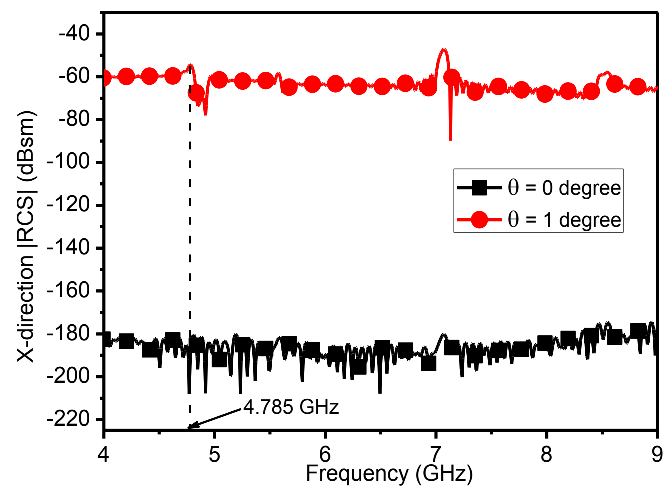

Fig. 4. Simulated RCS magnitude in the X direction when the rotation angle θ is 0 degree and 1 degree, respectively.

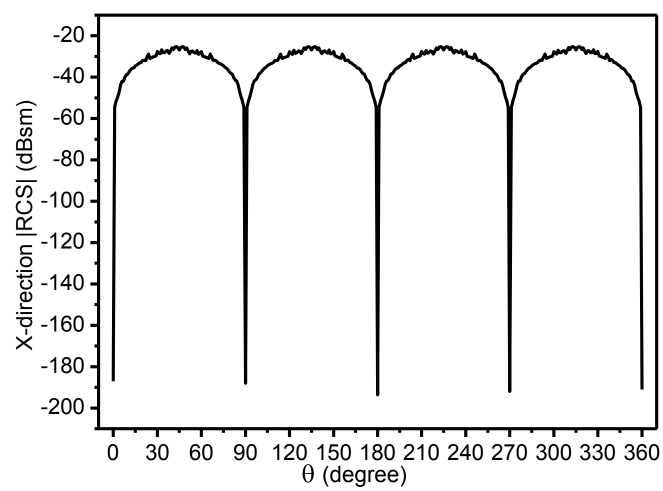

Fig. 5. Simulated RCS magnitude in the X direction at 4.785GHz when θ varies from 0 degree to 360 degrees.

III. Angular Sensing Principle

As mentioned above, the whole of the longest bar resonators $L1$ of the proposed tag acts as a sensing element. The angular information can be acquired by measuring the responsive RCS magnitude of $L1$. As shown in Fig. 1, making the proposed tag rotate θ degree around the Z axis can change the responsive RCS magnitude. Here, the measured responsive RCS magnitude is acquired in the X direction when the proposed tag is illuminated by Y-polarized incident plane waves. That means a depolarizing technique is applied here, decreasing the influences of the background environment and enhancing the robustness of the measuring process.

In Fig. 4, it can be seen that there is a sharply rise of the responsive RCS magnitude when the rotation angle θ varies from 0 degree to 1 degree. Furthermore, as shown in Fig. 5, with the rotation angle θ varying from 0 degree to 360 degrees at 4.785 GHz, it is obvious that there is a deep notch appearing when the rotation angle θ is 0°, 90°, 180°, 270° and 360°, respectively. Therefore, it can be concluded that the angular displacement of two adjacent notches is 90°, and by using a reader to obtain the responsive RCS magnitude of the designed tag at the 4.785 GHz and record the time T_0 and T_1 of two adjacent notches simultaneously, the corresponding angular velocity ω can be calculated as

$$\omega = \frac{\pi}{2\left(T_1 - T_0\right)} . \tag{1}$$

In addition, due to simply measuring the responsive RCS magnitude of the sensor tag at 4.785 GHz, the amount of data that the reader needs to read and process is greatly decreased. Meanwhile, in contrast to angular velocity sensors based on inductive coupling, the proposed sensor can significantly increase the sensing distance as a result of only needing to measure the responsive RCS Magnitude.

IV. Conclusions and Future Work

A novel chipless RFID sensor tag has been presented with simulations in CST MWS. The proposed sensor can obtain the angular information of the attached objects by measuring the responsive RCS magnitude, which can achieve a significant increase of the sensing distance. With the aid of depolarizing method, the robustness of the proposed sensor tag is greatly enhanced. In addition, the proposed tag can also encode 18-bit data by using a dual polarization technique and a frequency shift technique.

In the following research, the designed tag will be fabricated. A measurement system needs to be constructed to take the practical measurement of the tag, so that the sensing principle can be validated.

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