Dual-band Chipless RFID Sensor for A Material Quality Monitoring Application

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***Abstract* – The dual-band chipless RFID sensor is proposed to employ as a wireless material quality monitoring application. A printed perpendicular rectangular loop tag and a printed concentric rectangular loop tag are designed and optimized using the CST Microwave Studio program. The chipless RFID sensors are located on a material surface to determine qualities of a material under test. From numerical results, it is found that the proposed dual-band chipless RFID-sensor has a significant different radar cross section (RCS) compared with the single-band one. Therefore, both RFID sensors can be used together in the material quality monitoring system to improve the accuracy.**

***Index Terms* — Chipless RFID sensor, dielectric material, dual-band frequency, light weight concrete, radar cross section.**

1. Introduction

The traditional radio frequency identification (RFID) is widely used in many applications. However, it is employed as an RFID sensor, which can be categorized into two types, i.e., the chipped and chipless RFID sensors. In order to minimize cost, the chipless RFID sensor is employed instead of the chipped one. In [1]-[2], a chipless tag based on multiresonators was presented. It is possible to decode the information by measuring the magnitude and phase of the backscattered tag signal and also the radar cross section (RCS). In addition, the polarization diversity technique to encode information was presented [3]. This technique is based on the versatility of the rotation angle of split ring resonators. Furthermore, a hybrid RFID strain sensor utilizing both chipped and chipless approaches was presented in [4] to detect an embroidered RFID-enabled sensor. However, these techniques of the chipless RFID sensors require a two-port vector network analyzer (VNA).

To improve the accuracy of the material quality monitoring, the dual-band chipless RFID tag without a VNA is proposed in this paper to minimize the system cost.

2. Analysis and Design of Chipless RFID sensors

A passive RFID tag without any IC chip, called a chipless RFID sensor, is employed as a wireless sensor to determine the dielectric constant of the material under test (MUT) and finally its quality as shown in Fig. 1. The chipless tag can sense MUTs through their RCS characteristic. Therefore, the chipless RFID sensors are designed and optimized to maximize associated RCS by using an EM simulation program. Note that the received power (P_r) and the read range (R_{mat}) of chipless RFID sensors in the presence of an MUT are calculated by using the radar equation instead of the modified Friis transmission formula employed in [5] due to using the low-sensitivity receiver of the RFID reader to reduce the system cost.

Using the radar equation, the received power can be expressed as

$$P_r = \sigma \cdot P_{reader-tx} \cdot \frac{\left(G_{reader-tx}\right)^2}{4\pi}\left[\frac{\lambda}{4\pi R_{mat}^2}\right]^2, \quad (1)$$

where σ is the RCS of an MUT with an attached chipless RFID tag, $P_{reader-tx}$ is the input power of the reader antenna, $G_{reader-tx}$ is the gain of the reader antenna, λ is the free space wavelength, and the R_{mat} is the distance between the RFID reader antenna and the tag antenna in the presence of the MUT. Rearranging (1), we can express the read range $R_{max,mat}$ as

$$R_{\max,mat} = \sqrt[4]{\sigma \cdot \left(\frac{P_{reader-tx}}{P_{r,\min}}\right) \cdot \frac{\left(G_{reader-tx}\right)^2}{4\pi} \cdot \left(\frac{\lambda}{4\pi}\right)^2}, \quad (2)$$

where $P_{r,min}$ is the minimum received power of the RFID reader.

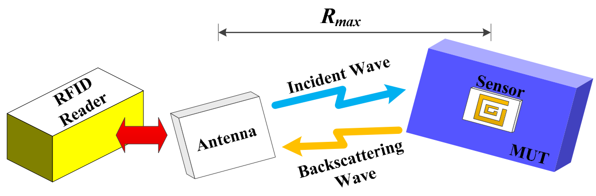

Fig. 1. A chipless RFID-sensor system.

3. Results

This paper presents two structures of tag antennas based on the printed loop configuration, where they are designed and optimized using the CST Microwave Studio program [6] to maximize associated RCS. The optimum tag antenna parameters are tabulated in Table I and Table II below. The light weight concrete (LWC) with the dielectric constant $\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$ is employed as an MUT in this study.

The printed perpendicular rectangular loop tag is proposed to use as a chipless RFID sensor, called Sensor#1, is shown in Fig. 2. It is a single-band chipless RFID tag operating at the frequency of 922.5 MHz.

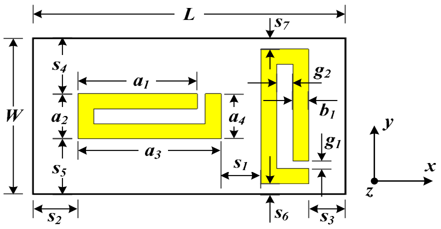

Fig. 2. A perpendicular rectangular loop tag structure.

TABLE I
Optimum Parameters of Chipless RFID Sensor#1

Parameter (mm)	Dimension	Parameter (mm)	Dimension
L	39.5	g_2	2
W	25	s_1	5
a_1	15	s_2	5.75
a_2, a_4	6	s_3	4.75
a_3	18	s_4, s_5	7.5
b_1	2	s_6, s_7	1.5
g_1	1		

Figure 3 illustrates the printed dual-band chipless RFID tag structure, called Sensor#2, designed based on a concentric rectangular loop operating at 922.5 MHz and 2.45 GHz.

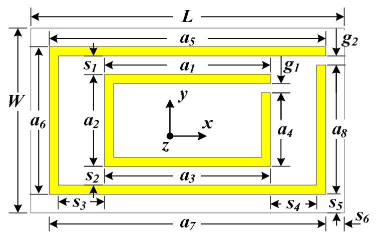

Fig. 3. A concentric rectangular loop tag structure.

TABLE II
Optimum Parameters of Chipless RFID Sensor#2

Parameter (mm)	Dimension	Parameter (mm)	Dimension
L	100	a_8	39
W	50	s_1, s_2	4.5
a_1, a_3	60	s_3, s_4	14
a_2	30	s_5, s_6	3
a_4	26	g_1	2
a_5, a_7	94	g_2	2.5
a_6	44		

The RCSs of Sensor#1 and Sensor#2 are shown in Fig. 4. It is obvious that the averaged RCS of Sensor#2 at 2.45 GHz is more than that of chipless RFID sensors at 922.5 MHz. The maximum read ranges R_{max} are calculated by using (2) and displayed in Fig. 5, which have similar trend as the corresponding RCS in Fig. 4.

4. Conclusions

This paper presents the dual-band chipless RFID tag designed based on the multiresonators operating at 922.5 MHz and 2.45 GHz. It is found that its RCS and R_{max} in the presence of the lossy LWC depends on ε_r'. In addition, the RCS of Sensor#2 at frequency of 2.45 GHz is noticeably greater than that of Sensor#1. Therefore, the proposed dual-band chipless RFID tag can be a good candidate as a material quality monitoring sensor. Future works include relevant measurements and performance analysis.

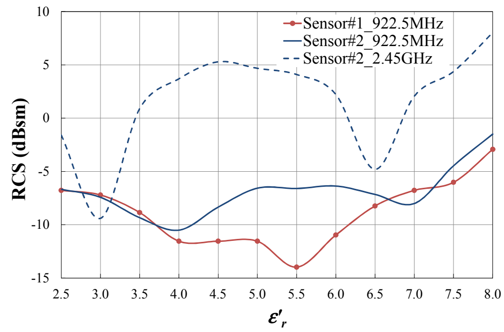

Fig. 4. The RCS of Sensor#1 and Sensor#2 on the lossy LWC as a function of ε_r' with $\varepsilon_r'' = 0.2$.

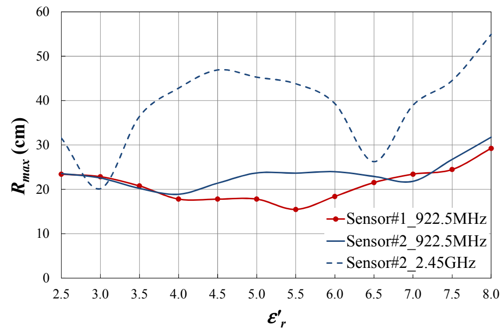

Fig. 5. R_{max} of Sensor#1 and Sensor#2 on the lossy LWC as a function of ε_r' with $\varepsilon_r'' = 0.2$.

Acknowledgment

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