

RCS Analysis for Frequency-Coded Chipless RFID Tags Using Single-Sided Printed Resonators

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Abstract – In this paper, the radar cross section (RCS) of resonators is characterized for frequency-coded chipless radio-frequency identification (RFID) tags. As capacity enhancement is important for chipless RFID, a tag for the frequency-coded system is desired to have a narrowband feature. Additionally, the second-order resonance should be eliminated from the operational frequency band. Although earlier studies have proposed several resonators for the frequency-coded chipless RFID tag, the topology that leads to the narrowest bandwidth and the harmonic-rejection feature simultaneously has not yet been identified. In this study, we analyze 37 types of resonators that are single-sided printed. Their RCS characteristics are evaluated, and the features of bandwidth and harmonic rejection are compared. We observe that the half-wave slot depicts the advantages of narrow bandwidth and harmonic rejection. Moreover, this resonator provides good frequency scalability, and thus it is suitable for the chipless RFID system with enhanced capacity.

Index Terms — Backscattering, internet of things, radar cross section, radio-frequency identification.

1. Introduction

In recent years, considerable concern has arisen in chipless radio-frequency identification (RFID). This technology eliminates the use of chip from conventional ultra high frequency (UHF) RFID tags, thereby reducing the system cost. Based on the encoding principle, chipless RFID can be classified into time-coded [1], frequency-coded [2], phase-coded [3], image-coded [4], and hybrid techniques [5], [6]. Among them, the frequency-coded chipless RFID has the potential of high capacity. This technique constructs a chipless tag by using electromagnetic (EM) resonators, which alter the backscattering field transmitting to a reader at an operational frequency. By encoding the high/low magnitude of the backscattering field into binary variables, data can be retrieved without the use of chip.

Using this frequency-coded mechanism, a high-capacity chipless RFID system demands that the resonator of the tag depicts a narrow bandwidth so that a given frequency band can assign more number of bits. Earlier studies have presented different topologies for the resonator. These topologies include a loop [7], a U-shape strip [8], and a slot [9], among others. In addition to the narrowband requirement, the resonator should depict harmonic rejection over the operational frequency band. Although several resonators have been proposed, the design that meets these requirements simultaneously is still inconclusive.

The purpose of this study is to characterize the radar cross section (RCS) for the EM resonators applied to the chipless tag. 37 types of resonators are examined. Their RCS characteristics are evaluated using CST simulation. We will demonstrate resonator design that achieves the requirement of a narrowband feature, harmonic rejection, and good frequency scalability. It is expected that this paper provides design guidelines for the frequency-coded chipless RFID tag.

2. System Requirement

The scenario considered in this study is library collection management, which requires that the coding capacity of a tag reaches 25 bits. We select the operational frequency band as 3.1 to 10.6 GHz. To achieve the requirement of capacity, the operational frequency band is divided into five uniform sections. Each section consists of 33 slots. Each slot has a bandwidth of 45 MHz. By using 5 resonators corresponding to each section, the capacity requirement can be achieved if a resonator depicts a RCS bandwidth smaller than 45 MHz.

To determine the resonator topology that is suitable to this scenario, 37 resonators are evaluated in terms of their RCS response. These resonators include 22 strip-wise topologies (thin strip, first- and second-order Z-curve strips, S-curve strip, dual circular loop, circular loop with a disk, meander-line strip, C-curve strip, C-curve extended strip, first- and higher-order Hilbert-curve strips, dual rhombic loop, dual square loop, square loop with a disk, spiral resonator, and split ring resonator with the shape of circle, square, pentagon, hexagon, heptangular, and octagon, respectively) and 15 slot-wise resonators (circular slot, half-wave slot, quarter-wave slot, square slot, Z-curve slot, S-curve slot, meander-line slot, C-curve slot, C-curve extended slot, Hilbert-curve slot, dual rhombic slot, pentagon slot, hexagon slot, heptangular slot, and octagon slot).

These structures are all single-sided printed. The width of these strips/slots is set to 0.5 mm. The design goal is to generate a fundamental resonance at 3 GHz. Their RCS characteristics are evaluated using CST, and the RCS bandwidth and the second-order harmonic are observed. Moreover, we fabricate these resonators to verify the simulated result. Some samples of the chipless tag are depicted in Fig. 1.

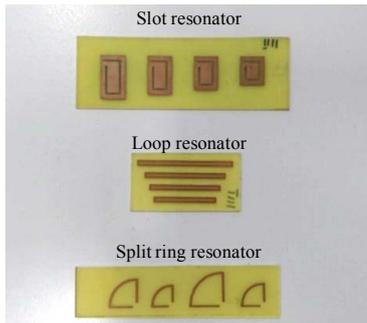


Fig. 1. Different topologies of the resonator for frequency-coded chipless RFID.

3. Results

The simulated results of the 37 resonators are recorded. In general, the strip-wise resonators exhibit a larger 3-dB RCS bandwidth as compared to the slot-wise resonators. The strip-wise resonators that have an RCS bandwidth smaller than 45 MHz are listed in Table I. Although 22 types of strip-wise resonators are considered, only 3 resonators achieve the bandwidth requirement. Among them, the C-curve strip and the C-curve extended strip depict a second-order harmonic over 3.1–10.6 GHz, and thus they lead to aliases with the data encoded at the second harmonic frequency. Only the spiral resonator meets all the design goals simultaneously.

TABLE I
 RCS Characteristics of the Strip-Wise Resonators

Type	Bandwidth (MHz)	Second harmonic (GHz)
C-curve strip	37	8.91
C-curve extended strip	37	7.24
Spiral resonator	34	Out of band

TABLE II
 RCS Characteristics of the Slot-Wise Resonators

Type	Bandwidth (MHz)	Second harmonic (GHz)
Circular slot	40	8.49
Half-wave slot	34	Out of band
Square slot	37	8.50
Z-curve slot	36	8.44
Meander-line slot	23	7.98
C-curve slot	36	Out of band
C-curve extended slot	38	6.02
Dual rhombic slot	39	Out of band
Pentagon slot	31	8.88
Hexagon slot	29	8.77
Heptangular slot	32	8.57
Octagon slot	31	8.61

In addition, the slot-wise resonators that have an RCS bandwidth smaller than 45 MHz are summarized in Table II. 12 out of 15 resonators achieve the bandwidth requirement, outnumbering the strip-wise resonators significantly. However, several resonators face the challenge of second

harmonic. Only 3 resonators depict the harmonic-rejection feature. To enhance the robustness of the chipless RFID, the candidates of the resonator are limited to those having the harmonic-rejection characteristic.

In addition to the design goals of narrow bandwidth and harmonic rejection, another important issue for the chipless tag is frequency scalability. Among those resonators that meet all the design goals, the half-wave slot depicts the advantage of simple topology. The number of design parameters is less than those for other resonators. Thus, this resonator is recommended for the chipless tag.

4. Conclusion

We have analyzed the RCS characteristics for the 37 conventional resonators. Considering that the RCS performance indices are in terms of a narrow bandwidth and harmonic rejection over 3.1–10.6 GHz, only the spiral resonator, the half-wave slot, the C-curve slot, and the dual rhombic slot meet the specification. In light of frequency scalability, in future work we will employ the half-wave slot as the chipless tag for library collection management.

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