Robustness Improvements of Chipless Radiofreqeuency Identification Using a Combinatorial Encoding Scheme

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***Abstract*—In this paper, the limitation of the conventional encoding scheme is illustrated for frequency-coded chipless radiofrequency identification (RFID), and an encoding technique that improves robustness is presented. Chipless RFID faces the challenge of capacity and robustness enhancement. Conventional frequency-coded chipless tags consist of resonators that represent information. The number of resonators is the same as the number of bits. As a high-capacity system uses an increasing number of bits, numerous resonators that are closely spaced with each other appear on the tag. We analyze the radar cross section (RCS) for the conventional encoding scheme, observing that mutual coupling incurs frequency detuning, which reduces the reliability of detection. To overcome this limitation, we present a combinatorial encoding technique and demonstrate its advantage. This technique uses a reduced number of resonators, thereby improving the mutual coupling between adjacent resonators; meanwhile, the separation between resonance frequencies increases, and thus the frequency detuning effect is mitigated.**

Keywords—printed circuits, radiofrequency identification, resonators, RFID tags, wireless sensor networks

I. Introduction

Frequency-coded chipless radiofrequency identification (RFID) draws attention to the feature of cost reduction as compared to ultrahigh frequency (UHF) RFID. This technique reduces a system cost by eliminating the use of a chip from an UHF tag [1]. To encode binary data without using the chip, the chipless tag is comprised of printable resonators. Each resonator operates at a certain frequency by varying the associated radar cross section (RCS); thus, two levels can be defined by whether or not the resonator is present [2]. However, the frequency-coded chipless RFID has not yet been commercialized, for enhanced data capacity and improving robustness are demanded.

The conventional encoding scheme uses one resonator at an operating frequency [3]–[7]. The number of bits is the same as that of resonators used. As higher and higher data capacity is desired, the number of resonators inevitably increases. For a given design space, these resonators become closely spaced. In this case, mutual coupling between resonators causes a frequency detuning effect, which may incur the alias of two adjacent bits and the false detection of data. More studies should be conducted to examine the degradation of reliability.

In this paper, the frequency detuning effect that results from the conventional encoding is analyzed, and the advantage of a new approach called combinatorial encoding scheme [8] is illustrated. We select two tag topologies to demonstrate the mutual coupling between resonators. The first one consists of strip resonators with a back conductor [9], and the second one comprises half-wave slots. Both chipless tags have a data capacity of 21 bits. Their geometries are depicted in Fig. 1. The RCS results are performed through using CST full-wave simulation.

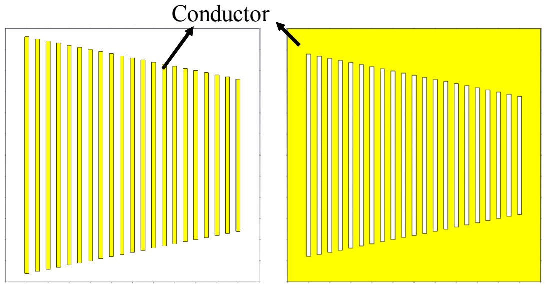

Fig. 1. Two resonators that are selected for the demonstration of the conventional encoding scheme.

II. Conventional Encoding Scheme

The first chipless tag that uses strips backed with a conductor is designed on a 0.1-mm-thick RO4350 substrate. The operating frequency range is 2.2 GHz to 3.5 GHz. This tag consists of 21 strips that represent 21 bits. We first evaluate two encoding topologies, including all the resonators exist, namely, 111111111111111111111, and removing the sixth and the sixteenth resonators, namely, 111110111111111011111. The simulated results are shown in Fig. 2. When the sixth resonator is removed, the RCS at 2.5 GHz mixes up with the RCS at 2.6 GHz. To distinguish the data at these frequencies is difficult.

Next, the mutual coupling between the first and the second resonators are examined. We simulate the RCS of the first resonator and that of the second resonator, respectively. Fig. 3 depicts their RCS responses. Each tag topology has RCS reduction at the resonance frequency, so a reader can detect the data. However, when the two resonators are present simultaneously, namely, 110000000000000000000, the information is confouding, as shown in Fig. 3. Although the first resonator depicts RCS reduction, the second resonator varies the RCS level insignificantly. This indicates that the second bit cannot be detected by a reader. Thus, two closely-spaced resonators incur severe mutual coupling, which reduces reliability and system robustness.

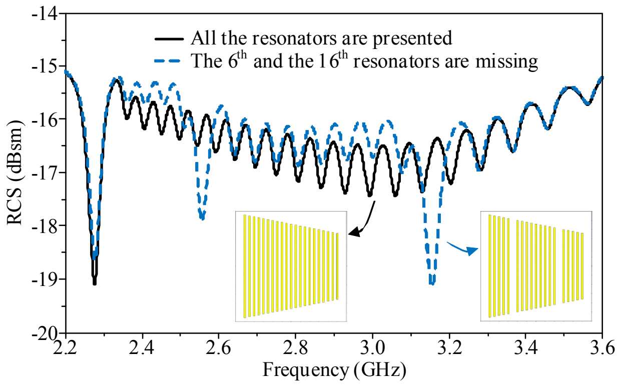

Fig. 2. Simulated RCS frequency responses for two chipless RFID tags that use strip resonators with a back conductor.

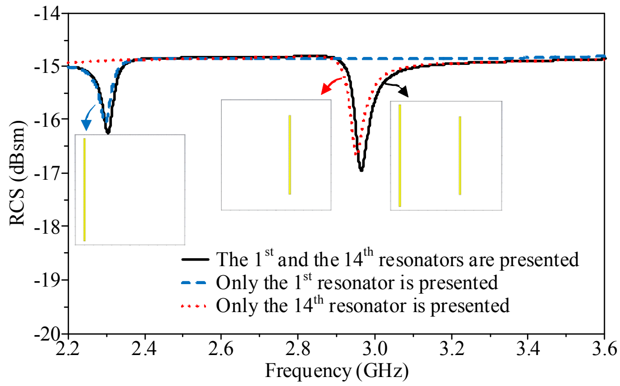

Fig. 4. Comparison of simulated RCS frequency responses for two widely-spaced strip resonators with a back conductor.

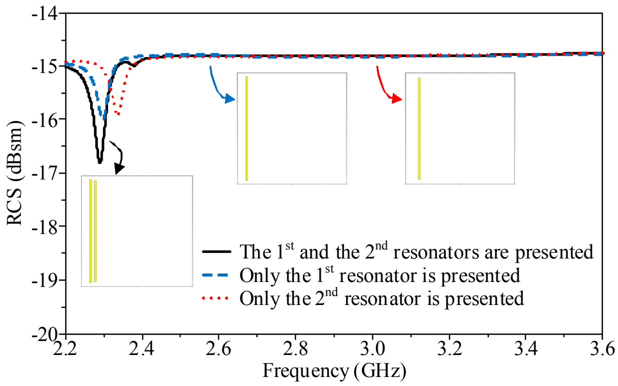

Fig. 3. Comparison of simulated RCS frequency responses for two closely-spaced strip resonators with a back conductor.

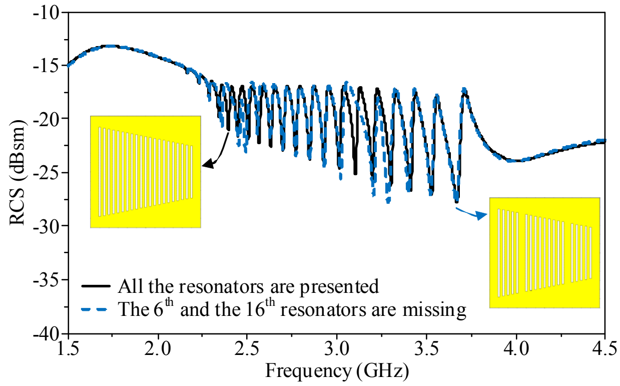

Fig. 5. Simulated RCS frequency responses for two chipless RFID tags that use half-wave slot resonators.

A method to mitigate the detuning effect is to increase the frequency and physical separations. That is, the distance between two resonators is enlarged, and the range between resonance frequencies is extended. We test the RCS of the first resonator and that of the fourteenth resonator, respectively, and we evaluate the RCS response when these resonators coexist. Fig. 4 depicts the results for the three scenarios. Clearly, the detuning effect is recovered. When the two resonators are activated simultaneously, the frequency of RCS reduction occurs at 2.3 GHz and 3.0 GHz, which is the resonance frequency of the first resonator and that of the fourteenth resonator, respectively. An insignificant detuning effect is observed; thus, the information of 100000000000010000000 can be successfully detected.

To demonstrate that our study is not only suitable to the use of strip-wise resonators, we analyze the mutual coupling effect for slot-wise resonators. A similar operating frequency range is defined, and a data capacity of 21 bits is assigned. At first, we analyze the detection of two chipless tags. The first tag has a coding word of 111111111111111111111, and the second one has a word of 111110111111111011111. Note that the information is the same as those used in the strip-wise case. The associated RCS results are depicted in Fig. 5. Although we expect that the second tag should have no RCS reduction at the sixth resonance frequency, namely, 2.4 GHz, the frequency that is decoded as 0 shifts to 2.3 GHz. Thus, a reader assigns 0 to the fifth bit, instead of the sixth bit. A similar observation can be found for the sixteenth resonator, which, once again, results in false detection.

If we activate only the first and the second half-wave slots, the RCS response depicts the frequency detuning effect. Fig. 6 shows the RCS for 100000000000000000000, 010000000000000000000, and 110000000000000000000. When the first and the second slots coexist, severe mutual coupling leads to a frequency shift, and the resonance that represents the first bit (1.9 GHz) vanishes.

Next, we extend the frequency and physical separations between two slots to observe whether the mutual coupling is mitigated. Fig. 7 shows the RCS of the first resonator and that of the fourteenth resonator. When only the first and the fourteenth slots is activated, respectively, the resonance frequency is at about 2.0 GHz and 3.2 GHz. When the two slots resonate simultaneously, the resonance depicted at 3.2 GHz remains the same, but the one at 2.0 GHz shifts to 2.3 GHz. Nevertheless, although the interaction between the resonators still exists, extending the frequency and physical separations is helpful for reducing the mutual coupling between resonators.

III. Combinatorial Encoding Scheme

The analysis of the conventional encoding scheme illustrates that extending the separation between adjacent resonance frequencies is important. Meanwhile, to enlarge the physical spacing between resonators within given dimensions, it is desired to minimize the number of resonators used. The combinatorial encoding scheme can meet the two requirements simultaneously.

Consider that a chipless RFID system is implemented through the following parameters: the lower and upper operating frequency f_L and f_U, respectively, the number of resonators on a tag N, the bandwidth of a resonator Δf, and

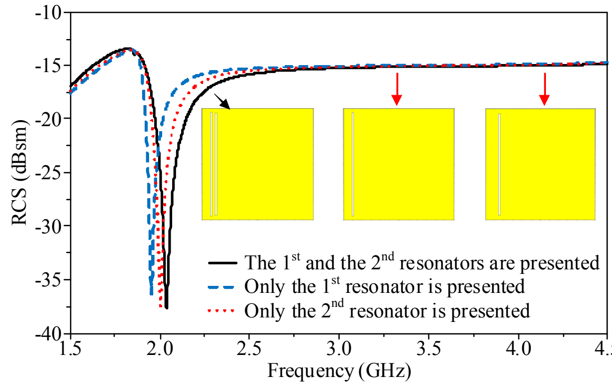

Fig. 6. Comparison of simulated RCS frequency responses for two closely-spaced half-wave slot resonators.

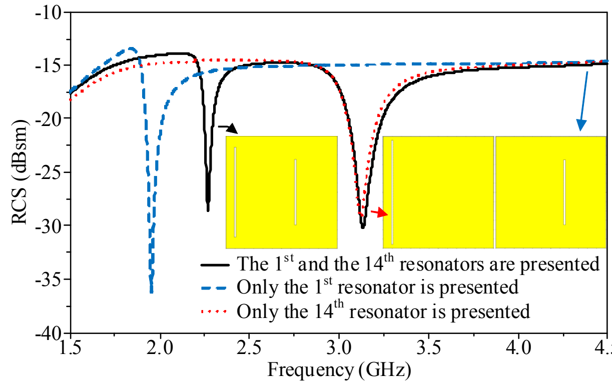

Fig. 7. Comparison of simulated RCS frequency responses for two widely-spaced half-wave slot resonators.

the required data capacity M. The combinatorial encoding scheme divides the frequency range into N sub-frequency bands, which are assigned to the operation of the N resonators, respectively. Each sub-frequency band is further divided into $(f_U - f_L)/(N \times \Delta f)$ frequency slots. By designing each resonator to depict an RCS variation at the corresponding frequency slot, the resultant capacity can be computed using $[(f_U - f_L)/(N \times \Delta f)]^N$.

For example, our group at National Taipei University of Technology (Taipei Tech) aims at a full implementation of chipless RFID for library management. We put a chipless tag on each library collection, including books, periodicals, and multimedia resources. As this application transforms the 7-digit barcode number of a collection to the data encoded on a tag, a capacity of 21 bits is required (M = 21). In this situation, we assign f_U = 5 GHz, f_L = 2 GHz, and N = 7. By using 7 resonators that have a bandwidth smaller than 50 MHz, the system requirement can be achieved using only 7 resonators. In contrast, the conventional encoding requires 21 resonators to meet the specification, and thus it may lead to severe interaction between the 21 resonators. As a reduced number of resonators are applied, the physical separation is enhanced, and so does the isolation between resonators. Moreover, the combinatorial encoding scheme can insert a guard band between two sub-frequency bands. Thus, the separation between two resonance frequencies is extended, and the limitation of the conventional encoding scheme is overcome.

IV. Conclusion

In this paper, the frequency detuning effect that results from the conventional encoding scheme has been analyzed for the frequency-coded chipless RFID. As high data capacity is desired, the conventional approach uses a large number of resonators that are closely spaced with each other. The separation between two adjacent resonance frequencies also decreases. In this situation, we have demonstrated that the mutual coupling between resonators lead to false detection. We also clarify that increasing the frequency and physical separations between two resonators is important.

The combinatorial encoding scheme can overcome the limitation of the conventional encoding. This approach enhances the frequency and physical separations between resonators simultaneously. For a chipless RFID system with a data capacity of 21 bits, the combinatorial encoding scheme needs only 7 resonators, and the frequency separation can be extended by inserting a guard band between adjacent sub-frequency bands. This technique is expected to provide robustness improvements for future chipless RFID development.

Acknowledgment

This work was supported by the Ministry of Science and Technology, Taiwan, under Contract MOST 107-2636-E-027-001.

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