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Multi-Resonator Structure for Small Size Chipless Radio Frequency Identification Tag

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Abstract: The recent growth in identification, tracking, and sensing applications for the Internet of Things (IoT) has pushed the RFID technology to gain much attention due to its remarkable advantages compared to conventional identification techniques. New resonator structure for chipless RFID tags is proposed. The proposed tag consists of three resonators arranged in a compact form, vertically polarized receiving antenna and horizontally polarized transmitting antenna. Two resonators are based on spiral type and the third is a simple transmission line configured in compact shape. The two antennas are designed to be wide band and orthogonally polarized for realizing the cross polarization retransmission process. The tag provides eight different codes in the range from 2.2 to 2.5 GHz. The prototype resonator structure of the tag is designed and fabricated on RT Duroid 5880 substrate (with a dielectric constant 2.2, loss tangent 0.0009 and thickness 0.79 mm). Area saving in the order of 30% with respect to conventional spiral resonator can be achieved. Good agreement between simulated and measured results is observed.

Keywords: UWB, Chipless RFID, Multiresonating based , IOT

1. INTRODUCTION

Radio frequency identification techniques have been developed in recent years to overcome the barcode limitations such as low storage capacity, line of sight, small range, and they cannot be reprogrammed [1, 2]. Conventional chipped RFID tag is still suffering from its high cost compared to barcodes. Passive chipless RFID tags are considered to be promising candidate with respect to other RFID [2-4].

Chipless RFID tags can be classified into two classes: Radar Cross Section (RCS) tag based [5, 6] and retransmission tag based [7, 8]. Compared to RCS tag the chipless RFID based on retransmission has little effect of clutter in the reverse channel with weak mutual coupling between reader transmitter and receiver antennas.

In this paper, multi-resonator structure based on spiral resonators and simple transmission line arranged in compact shape for chipless tag is proposed. The proposed resonators are connected to two orthogonal UWB monopole antennas. Simulation are performed using Computer Simulation Technology (CST) microwave studio.

The paper is organized as follows: Section 2 explains the design methodology of the proposed tag and antennas structures. Section 3 presents the simulated and measured results. Conclusions are given in Section 4.

2. CHIPLESS RFID TAG DESIGN

The general block diagram of the proposed chipless RFID tag is shown in Fig. 1. It consists of new multi-resonator structure placed between two orthogonally polarized antennas, one is vertically polarized monopole and the other is horizontally polarized monopole antenna. The cross polarization arrangement is used to reduce the effect of the interference.

A. Ultra Wide Band Antenna

The proposed UWB antennas are designed on RT Duroid substrate of dielectric constant 2.2, loss tangent 0.0009 and thickness 0.79 mm. As shown in Fig. 2, the chosen antenna configuration is a simple slotted rectangular patch implemented on a single side substrate. The antenna size and parameters are optimized to be used in the frequency range 2 – 4 GHz. The antenna is fed by a 50-Ω microstrip line.

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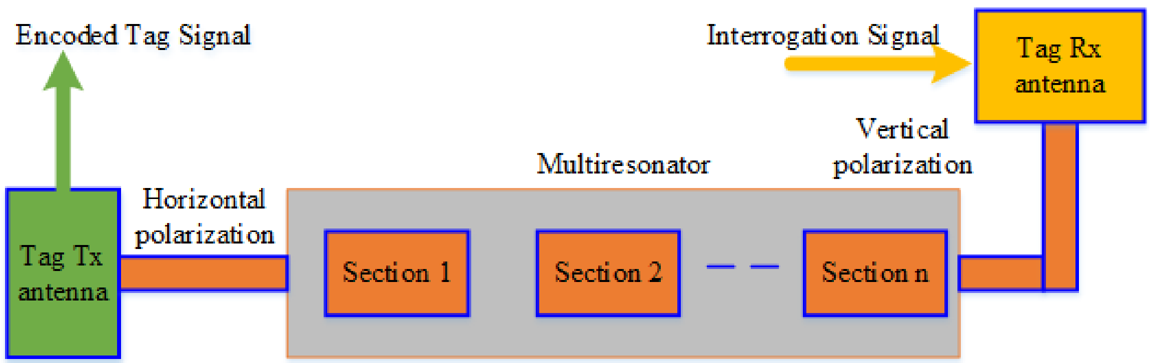

Figure 1. Gemoetry of chipless RFID tag [9].

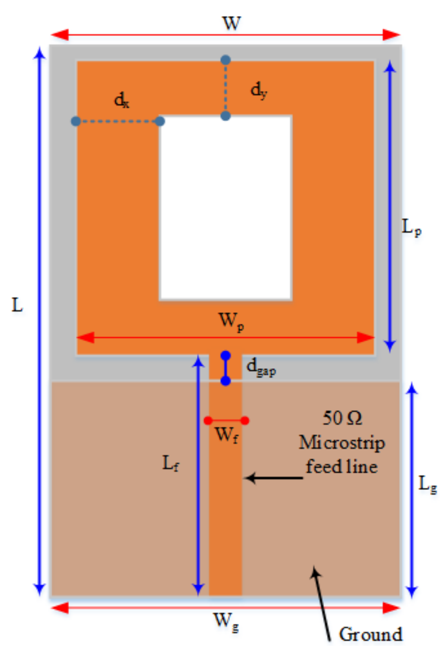

Figure 2. UWB monopole antenna [10].

The antenna dimensions including lengths and widths of all lines of the slotted rectangular patch, the ground plane size, and the feed lines are shown in Table I.

B. Multi-resonator Circuit

Spiral microstrip resonators are recently proposed in [2, 9]. Adding an extra transmission line resonator with each two spiral resonators is investigated in this work. The added resonator will increase the capacity of the tag structure almost without increasing the whole size of the tag. To this end, the transmission line resonator is shaped as shown in Fig. 3.

Therefore, approximate size reduction of about 30% is expected. The new proposed multi-resonator structure firstly investigated for only 3-bits arrangement (2^3 codes) as shown in Fig. 3.

The dimensions of each resonator is selected to adjust its resonant frequency. The parameters of the three resonators configuration shown in Table II are optimized for resonance frequencies of about f_1=2.25 GHz, f_2=2.35 GHz, and f_3=2.45.

TABLE I. UWB MONOPOLE ANTENNA PARAMETERS

Parameter	Parameter description	Physical value (mm)
L	Length of the proposed antenna	50
W	Width of the proposed antenna	30
L_p	Length of the rectangular patch	26
W_p	Width of the rectangular patch	26
L_g	Ground length	13.3
W_g	Ground width	30
d_{gap}	Gap between patch and ground	1.7
L_f	Feeder length	22
W_f	Feeder width	2.45
d_x	Length of the patch arm in x-direction	8
d_y	Length of the patch arm in y-direction	5

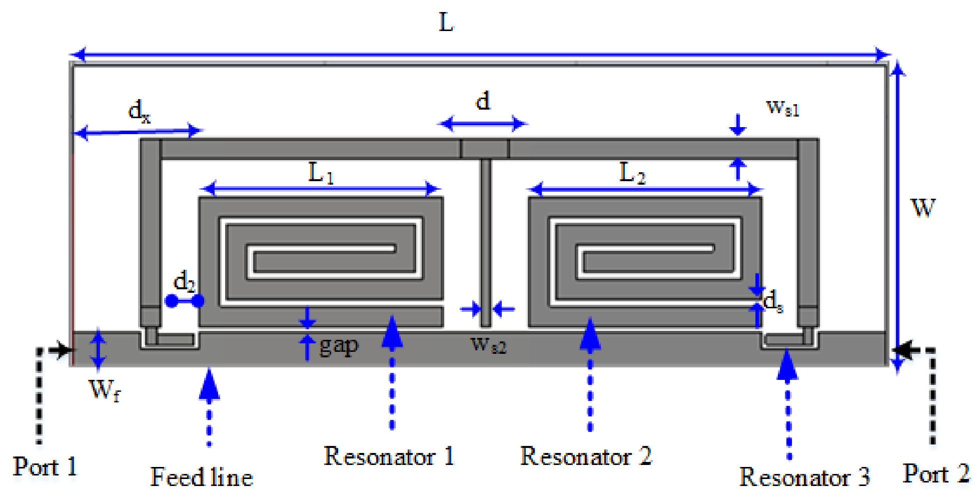

Figure 3. Geometry of the multi-resonator structure.

TABLE II. DIMENSIONS OF THE PROPOSEZD TAG

Parameter	Parameter description	Physical value (mm)
L	Length of the proposed tag	44.65
W	Width of the proposed tag	15.152
L_1	Length of the spiral resonator #1	9.35
L_2	Length of the spiral resonator #2	8.9
W_{s1}	Width of thick arm of the coupled line	0.8
W_{s2}	Width of thin arm of the coupled line	0.4
W_f	Feeder width	2.452
Gap	Gap between spiral resonators and microstrip feed line	0.2
d	Separation between two resonators	3.4
d_x	Separation between spiral resonator and port	10
d_s	Separation between two arms of spiral resonator	0.3
d_2	Separation between coupled line and spiral resonator	1.5

Each resonator can be placed either in passive or in active mode. Spiral resonator can be either programmed in the active mode if it is kept as is as shown in Fig. 3 or in the passive mode if it is short circuited at its end as shown in Fig. 4.

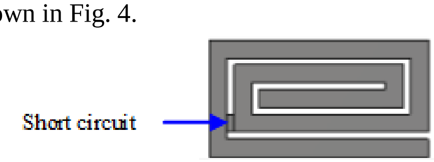

Figure 4. Disconnect the spiral resonator.

The third transmission line resonator is operated in active mode as shown in Fig. 3, or in passive mode by introducing cut at its top center as shown in Fig. 5.

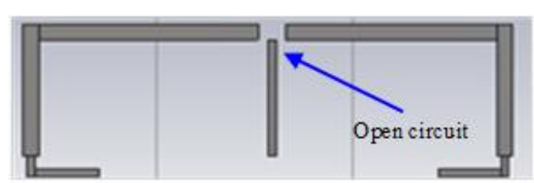

Figure 5. Disconnect the coupled line.by an open circuit.

The active resonator expresses a logic “1” and the inactive (passive) represents logic “0”. All possible eight states of the proposed tag (000, 001, 010, 011, 100, 101, 110, and 111) are shown in Fig. 6.

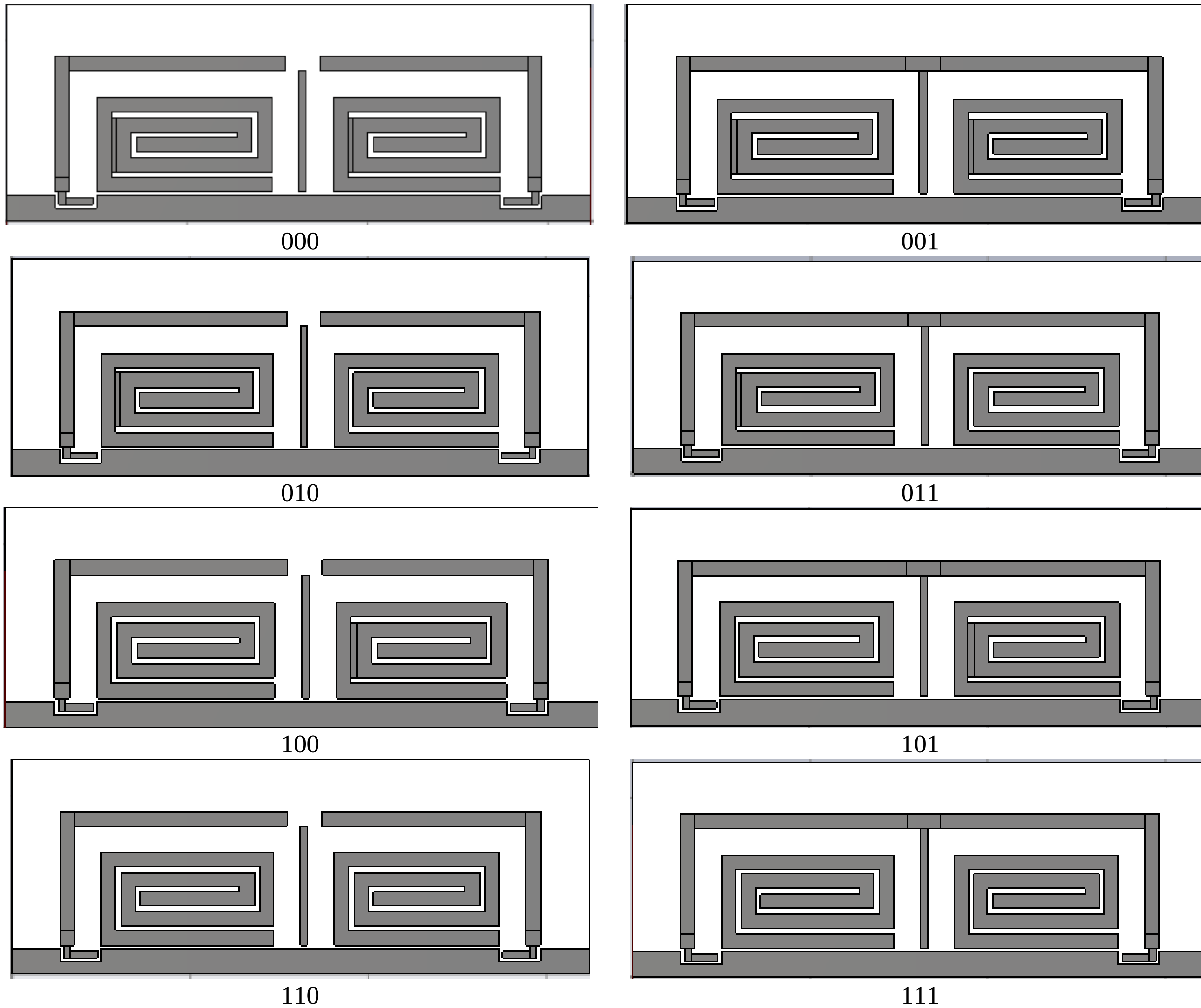

Figure 6. All possible states for the proposed tag.

3. RESULTS AND DISCUSSIONS

The chipless RFID tag is designed on RT Duroid 5880 substrate with dielectric constant 2.2 and loss tangent of 0.0009 (thickness = 0.79 mm). The simulations are performed using CST EM simulator.

Fig. 7 illustrates the simulated return loss (S_{11}) of the proposed microstrip feed UWB monopole antenna. This antenna displays 10 dB return loss bandwidth starting from 1.9 GHz to 4.8 GHz. The 3D radiation pattern of this antenna at two different frequencies (2.36 and 2.5 GHz) are shown in Fig. 8 and Fig. 9 respectively.

Fig. 10 displays the simulated insertion loss of the three bits multi-resonating tag for the two cases: (1) all resonators are active (code “111”) and (2) all resonators are inactive (code “000”). From these results, there are three distinct resonant nulls in the magnitude. The existence of a null in the insertion loss represents logic “1” while the absence of the null represents logic “0”. In state “111”, three null frequencies are retransmitted from the tag. However, all the frequency signatures are removed in second case when all are zeros.

The simulation results for chipless tags with identification codes “100”, “010” and “100” are shown in Fig. 11.

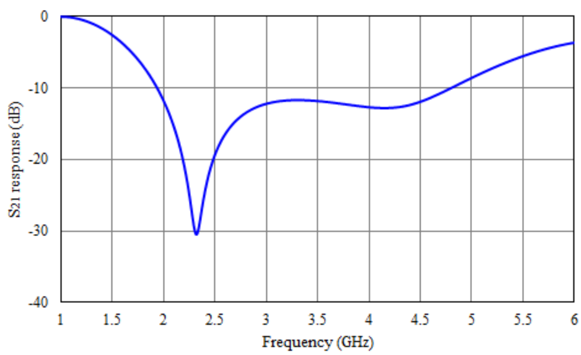

Figure 7. S_{11} response for the proposed antenna.

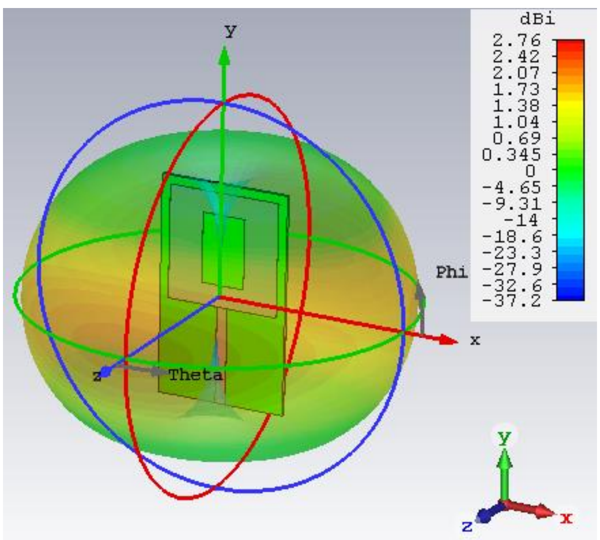

Figure 8. Radiation pattern of the monopole antenna at 2.36 GHz.

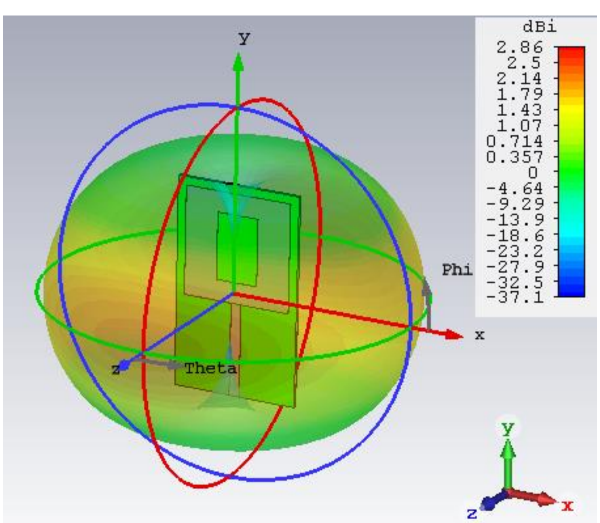

Figure 9. Radiation pattern of the monopole antenna at 2.5 GHz.

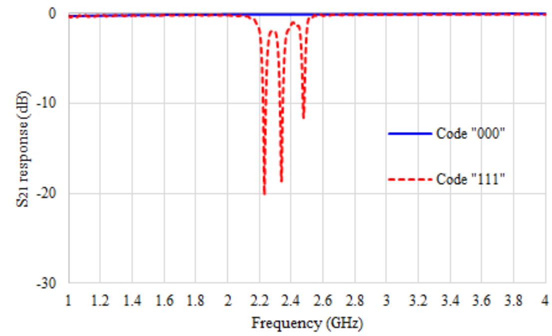

Figure 10. Simulated S_{21} of the designed multi-resonator tag with different codes “000” and “111”.

The three resonance frequencies achieved by the multi-resonators structure are 2.25, 2.35, and 2.45 GHz. Fig. 12 illustrates the simulation results for chipless tags with identification codes “110”, “011” and “101”.

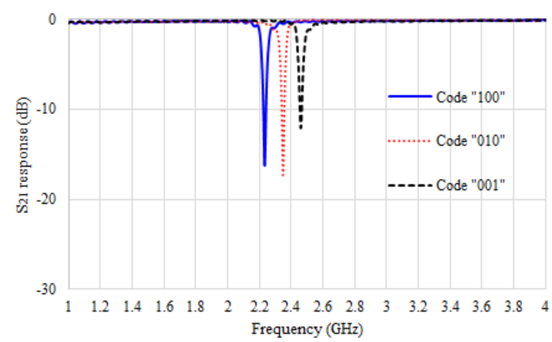

Figure 11. Simulated S_{21} of the designed multi-resonator tag with different codes “100”, “010” and “001”.

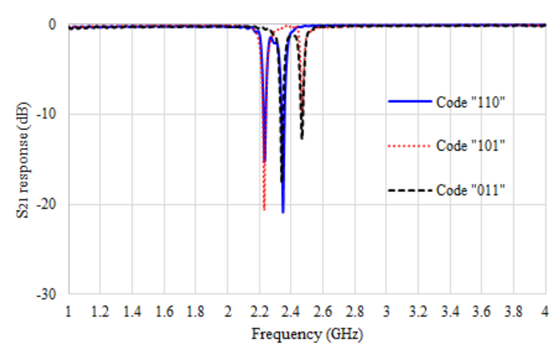

Figure 12. Simulated S_{21} of the designed multi-resonator tag with different codes “110”, “101” and “011”.

The proposed resonator structure is implemented and measured. The photograph of the fabricated resonator structure is shown in Fig. 13. The size of the circuit is 4.46×1.52×0.08 cm^3 (width × length × height). The two-port S-parameters measurements are done using the Agilent’s microwave Vector Network Analyzer (VNA) N9925A.

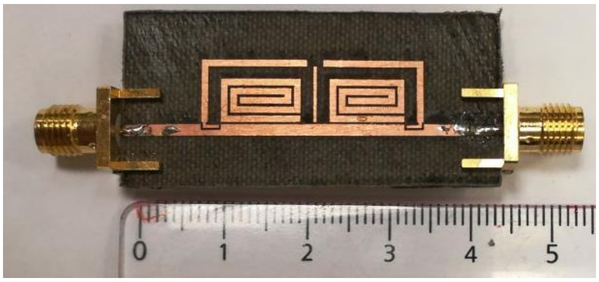

Figure 13. Photograph of the RFID chipless tag.

The measured insertion loss along with the simulated results of some selected states are shown in Fig. 14, Fig. 15, Fig. 16 and Fig. 17. The measured results are in good agreement with the simulated results.

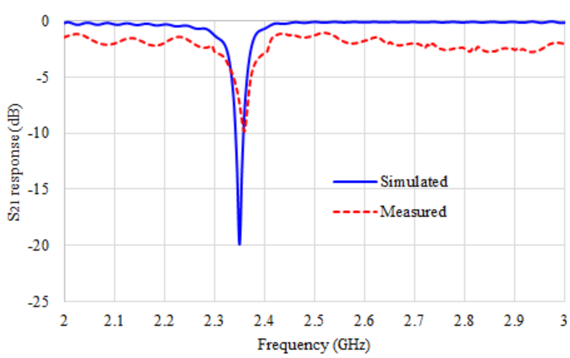

Figure 14. Simulated and measured S_{21} of the manufactured multi-resonator tag with code “010”.

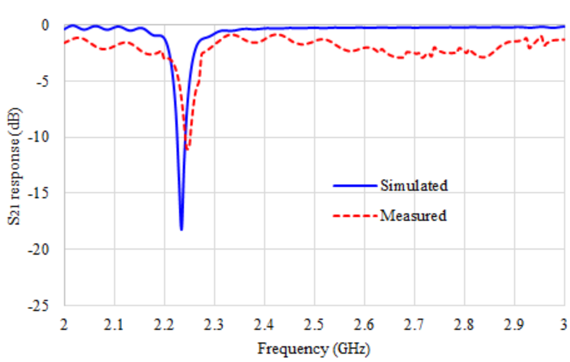

Figure 15. Simulated and measured S_{21} of the manufactured multi-resonator tag with code “100”.

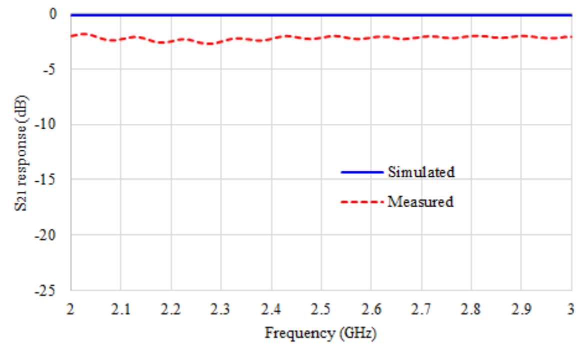

Figure 16. Simulated and measured S_{21} of the manufactured multi-resonator tag with code “000”.

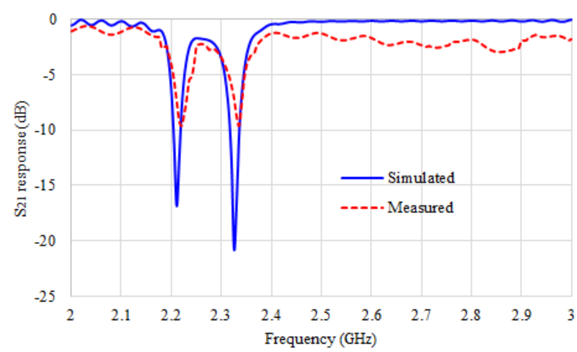

Figure 17. Simulated and measured S_{21} of the manufactured multi-resonator tag with code “110”.

CONCLUSION

This article presents the design of a compact chipless RFID tag. Two cross-polarized antennas are used to receive the RF activation waveform and retransmit the response of the tag. The proposed tag is based on spiral resonators in a compact way by adding single coupled-line resonator with each two spiral resonators. Thus, resulting in a very compact shape that saves around 30% of the overall area. Goode agreement between simulations and measurements is observed.

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