Frequency Coded Chipless RFID Tag using Spurline Resonators

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Abstract. *A novel compact chipless RFID tag using spurline resonators is discussed in this paper. The detection of the tag's ID is using the spectral signature of a spurline resonator circuit. The tag has a data capacity of 8-bits in the range 2.38 to 4.04 GHz. The tag consists of a spurline multiresonating circuit and two cross polarized antennas. The prototype of the tag is fabricated on a substrate C-MET/LK4.3 of dielectric constant 4.3 and loss tangent 0.0018. The measured results show that group delay response can also be used to decode the tag's identity.*

Keywords

Band-stop filters (BSF), chipless RFID tag, folded monopole antenna, group delay, spurline resonator.

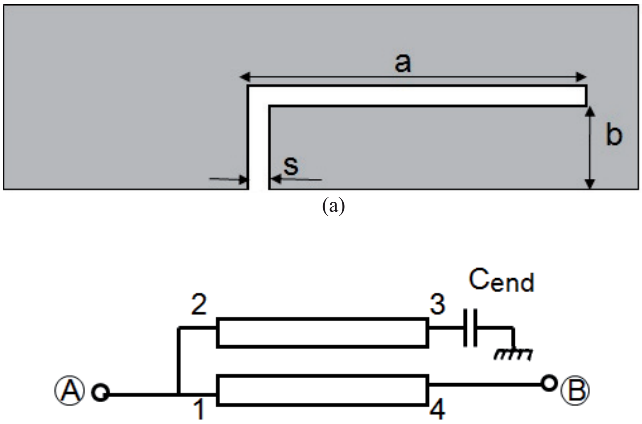
1. Introduction

Electronic tagging technologies using Radio Frequency Identification (RFID) are widely employed for automatic identification and tracking of objects in many applications. Communication by means of reflected power was first proposed by H. Stockman [1]. The need for greater reading range and automation has put RFID technology as the premier data capturing technique implemented widely in supply chain management, asset tracking, logistics, tracking books in library, equipment/personnel tracking in hospitals and many other similar applications.

Chipless RFID tags are now gaining importance over barcodes due to benefits of low cost, absence of power source, no line of sight requirements etc. [2]. The chipless RFID can be classified into three main categories such as Spectral signature based chipless tags, Amplitude/Phase backscatter modulation based chipless tags, and Time Domain Reflectometry (TDR) based chipless tags [3]. Spectral signature based chipless tag which uses multiple resonators is a multi-stop band filter that encodes data in the frequency spectrum. In Amplitude/Phase backscatter modulation based chipless RFID tags, data encoding is performed by varying the amplitude or the phase of backscattered signal based on the loading of the chipless tag. TDR based chipless RFID tags are interrogated by sending a signal from the reader in the form of a pulse and listening to the echoes of the pulse sent by the tag. Spectral signature encoding based chipless RFID tags using microstrip quarter wavelength open stub resonators are proposed in [4]. A narrowband chipless multiresonator tag for UHF RFID using two cross-polarized transmitting and receiving microstrip broadband circular monopole antennas loaded with multiple cascaded 'U' resonators is reported in [5]. Polarization independent chipless tags are reported in [6]. Various other types of multiresonator based chipless RFID tags are proposed in [7-9]. This paper discusses a spectral signature based fully printable chipless RFID tag. The tag is implemented using spurline resonators and cross-polarized wide band monopole antennas.

2. Spurline

A spurline is a simple L-shaped slot etched in a microstrip line which is described by three parameters: slot width s, slot length a, and slot height b. The schematic view of a conventional spurline is shown in Fig. 1a. The spurline exhibits excellent band gap characteristics by virtue of the capacitive effect of the slot width and inductive effect of the narrow microstrip line [10]. The total length ($a + b = \lambda/4$) at the desired stop band frequency [11].



(b)

Fig. 1. (a) Microwave spurline section (Single bit chipless RFID tag). (b) Spurline configuration.

The spurline can be modeled as a four-port coupled-line network with port 3 terminated by a capacitance which represents the discontinuity capacitance at the end of the spurline as shown in Fig. 1b. The effect of the end capacitance is to increase the effective length of the spurline [12].

By applying proper termination conditions, mentioned in [13], this four-port coupled-line network becomes a two-port spurline network and the chain matrix can be derived as

$$\begin{bmatrix} V_A \\ I_A \end{bmatrix} = \begin{bmatrix} \cos\theta_e & \frac{1}{2} jZ_{oe} \sin\theta_e \\ j2Y_{oe}\sin\theta_e & \cos\theta_e \end{bmatrix} \begin{bmatrix} 1 & \frac{1}{2} jZ_{oo} \tan\theta_o \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_B \\ I_B \end{bmatrix}$$

From the cascade of [A] matrix, the equivalent circuit of spurline can be drawn as in Fig. 2a.

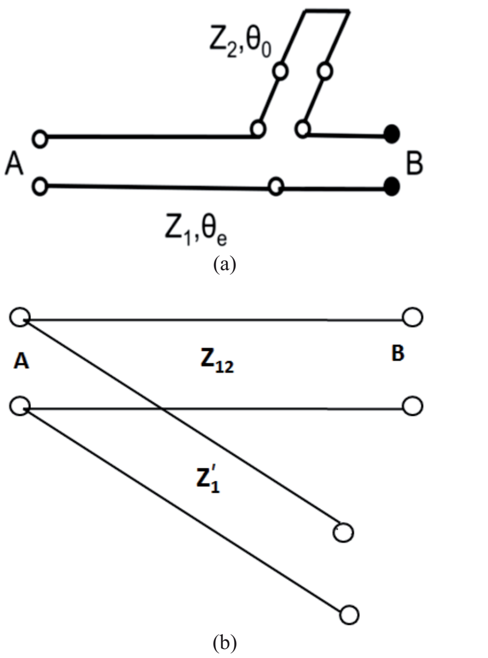


Fig. 2. Equivalent circuit of spurline.

$$\theta_e = \frac{2\pi}{V_{pe}} lf \ , \ \theta_o = \frac{2\pi}{V_{po}} lf, \ Z_1 = \frac{Z_{oe}}{2} \ , \ Z_2 = \frac{Z_{oo}}{2},$$

$$Z_1{}' = \frac{Z_{oe}+Z_{oo}}{2},$$

$$Z_{12} = \frac{Z_{oe}}{Z_{oo}} \frac{Z_{oe}+Z_{oo}}{2}$$

where l is the physical length of the spurline, f is the frequency of interest, θ_e, $V_{pe,}$ Z_{oe}, θ_o, V_{po}, Z_{oo} are the electrical length, phase velocity and impedances of even and odd modes respectively. The impedance of the short-circuited series stub is infinity when $\theta_o = \pi/2$ or $l=V_{po}/4f$. Assuming that the odd and even mode phase velocities are equal, the circuit can be changed to the form of Fig. 2b with the use of Kuroda's transformation [14], exhibiting band stop characteristics.

3. Chipless RFID Tag Design

The design of chipless RFID tag evolves from the concept of spurline band stop filters. The basic structure of the tag is the same as the conventional spurline shown in Fig. 1a. Simulation studies in Ansoft HFSS are performed on an indigenously developed substrate C-MET/LK4.3 by C-MET Thrissur, India with dielectric constant 4.3 and loss tangent 0.0018. It is seen that a band notch centered at 3.1662GHz is obtained when a = 15 mm, b = 2.5 mm and s = 1mm. The simulated transmission characteristics of a single bit chipless RFID tag is shown in Fig. 3.

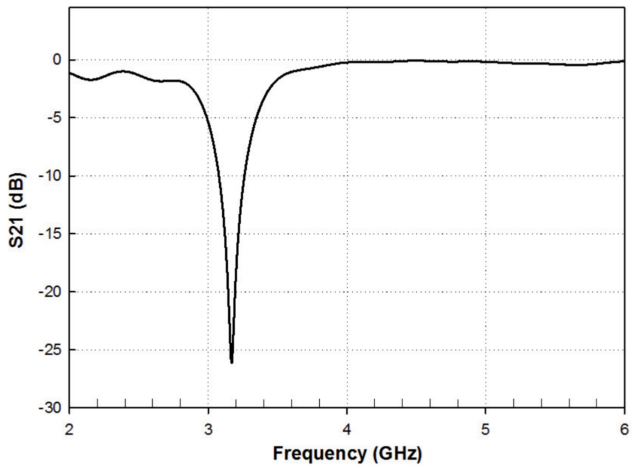


Fig. 3. Simulated transmission characteristics of single bit chipless RFID tag.

The chipless RFID tag encodes its signature into a spectrum using a multiresonating circuit. Multiresonance is achieved by using several spurline resonators in the microstrip line. Each spurline introduces a different stop-band resonance. By varying the dimensions of the spurline, the resonance can be varied and therefore different data bits can be represented. Fig. 4 shows the structure of an 8-bit spurline resonator.

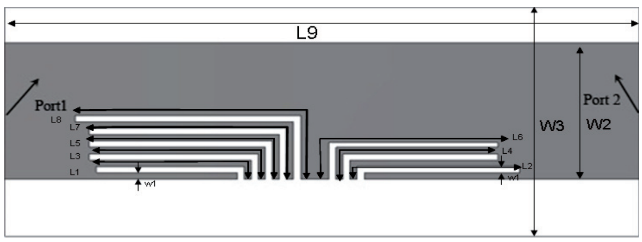
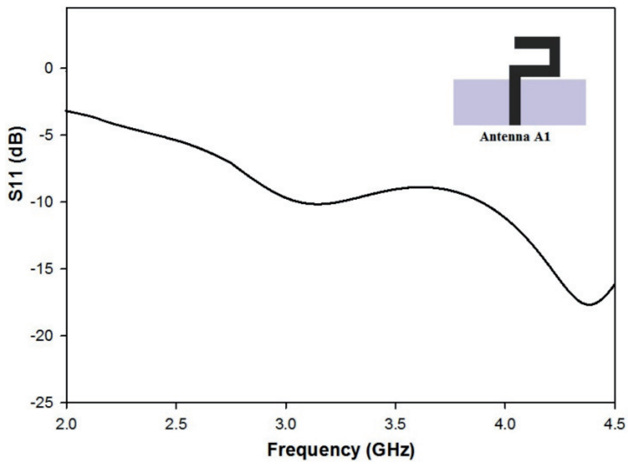
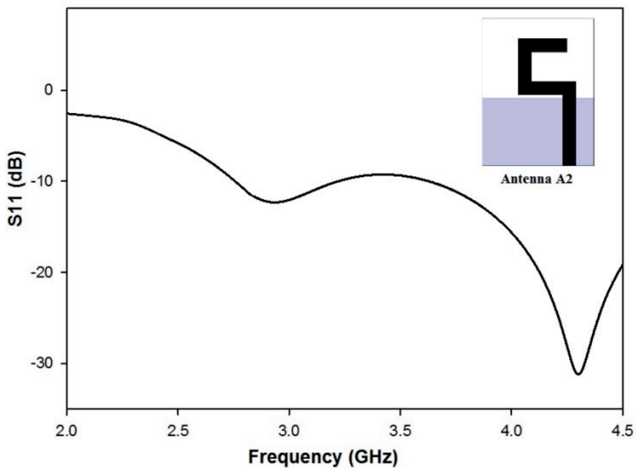


Fig. 4. Proposed 8-bit spurline resonator
W1 = 0.5 mm, W2 = 11 mm, W3 = 27 mm,
L1 = 10.5 mm, L2 = 19.5 mm, L3 = 14 mm,
L4 = 13 mm, L5 = 15 mm, L6 = 14.5 mm,
L7 = 18 mm, L8 = 21 mm and L9 = 40 mm.

The proposed chipless RFID system operates from 2.38 GHz to 4.04 GHz and hence requires antennas operating in this frequency range for increased sensitivity.



(a)



(b)

Fig. 5. (a) Simulated reflection characteristics of antenna A1. (b) Simulated reflection characteristics of antenna A2.

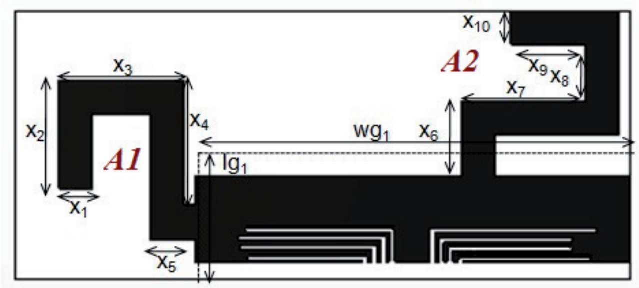


Fig. 6. Proposed chipless RFID tag x1 = 3 mm, x2 = 9.6 mm, x3 = 11 mm, x4 = 11 mm, x5 = 4 mm, x6 = 6.6 mm, x7 = 11 mm, x8 = 5 mm, x9 = 6.6 mm, x10 = 3 mm, lg1 = 11.7 mm and wg1 = 23.4 mm.

Microstrip fed folded monopole antennas are integrated to the tag act as transmit and receive antennas. Folded monopole antenna [15] is chosen due to its simple structure and compactness. The reflection characteristics of these antennas are as shown in Fig. 5a and Fig. 5b. Similar antennas with optimized dimensions are placed on the tag and used as reader antennas. Fig. 6 shows the proposed chipless RFID tag.

Two microstrip fed folded monopole antennas are designed for transmission and reception purpose by RFID reader. Fig. 7 shows the proposed antenna structure. The measured operating band is from 2.2 to 4.1 GHz.

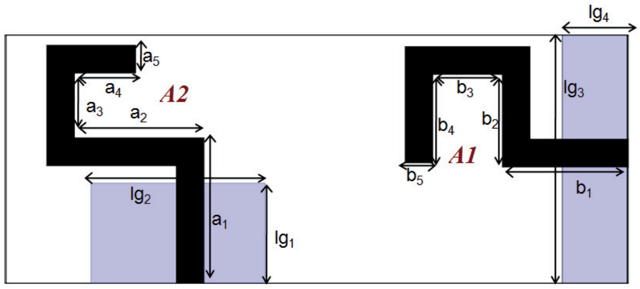
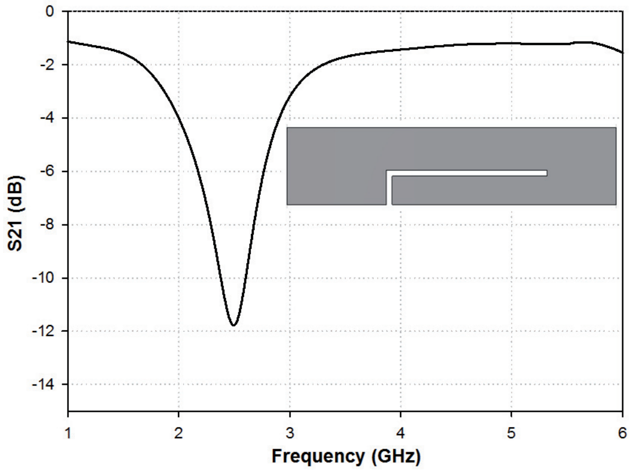


Fig. 7. Proposed microstrip fed folded monopole reader antennas: a1 = 15.7 mm, a2 = 14 mm, a3 = 7 mm, a4 = 6.6 mm, a5 = 3 mm, b1 = 13.6 mm, b2 = 10 mm, b3 = 7.5 mm, b4 = 9.5 mm, b5 = 3 mm, lg1 = 10.8 mm, lg2 = 18.8 mm, lg3 = 26.8 mm and lg4 = 7 mm.

4. Results and Discussions



(a)

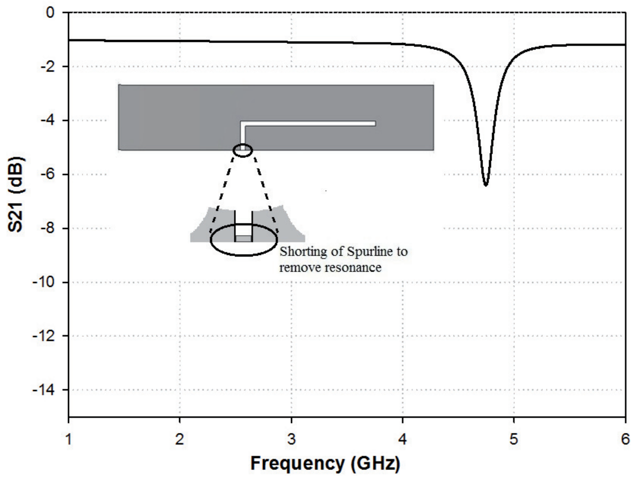


Fig. 8. a) Spurline resonating at frequency 2.5 GHz when *a* = 15.5 mm, *b* = 4 mm and *s* = 1 mm. b) The resonant frequency shifted to 4.73 GHz when spurline is shorted (*a* = 15.5 mm, *b* = 4 mm and *s* = 1 mm).

The multi-resonator RFID tag and the reader antennas are fabricated on a substrate C-MET/LK4.3 of dielectric constant 4.3 and loss tangent 0.0018. The eight bits are represented by eight resonant nulls. The individual resonators operate at different frequencies 2.38 GHz, 2.5 GHz, 2.75 GHz, 2.98 GHz, 3.44 GHz, 3.79 GHz, 3.85 GHz and 4.04 GHz. The dimensions of the RFID tag are 60 mm x 30 mm x 1.6 mm. A spurline of dimensions $a = 15.5$ mm, $b = 4$ mm and $s = 1$ mm resonating at 2.5 GHz is shown in Fig. 8a. The idea of shorting the spurline is used to shift the resonant frequency outside the required range [16]. Fig. 8b shows how the frequency gets shifted to 4.73 GHz with shorting of spurline. Shorted spur will act as a slot on a metal patch and it will resonate at a higher frequency outside the required range.

The measurement set up is shown in Fig. 9a. The tag is kept 5 cm away from the reader antenna. The back scattered signal from the retransmitting antenna is very weak to identify the response of the tag. So the calibration method proposed in [17] is followed for the measurement. Frequency and time domain measurements are carried out using PNA E8362B for various bit combinations. S21 and group delay response of the RFID tag for 1111 1111, 0111 1111 bit combinations are shown in Fig. 9b, 9c. From the figures, it is clear that the S21 or group delay can be used for identifying the tag. Other combinations of bits are also tried and found to be working properly.

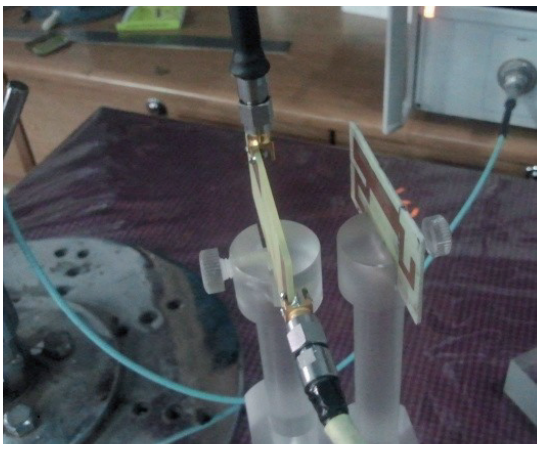


Fig. 9a. Measurement setup.

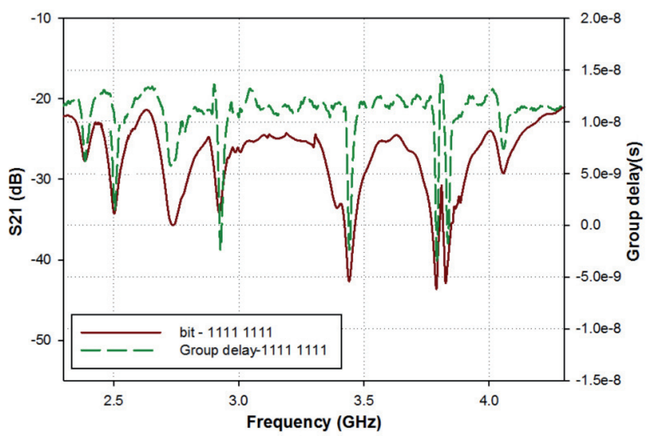


Fig. 9b. Measured response of the tag with identity 1111 1111.

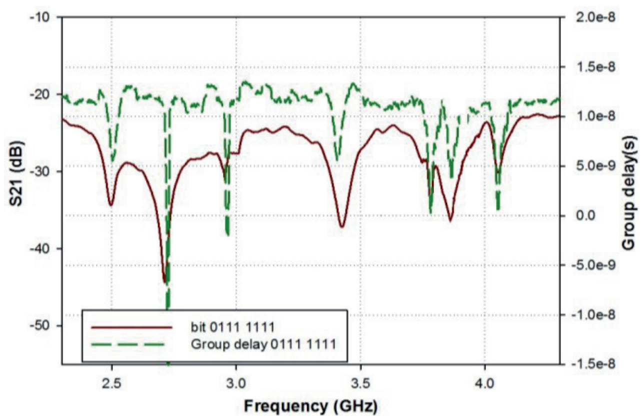


Fig. 9c. Measured response of the tag with identity 0111 1111.

5. Equivalent Circuit Design of Spurline Resonator

5.1 Single Spurline Section

Spurline can be modeled as a simple RLC-network [18]. In this model, the LC circuit is used to get the resonant characteristics and the resistance R accounts for the radiation effect and loss. Based on the transmission line theory and the spectral domain approach, the circuit parameters can be extracted using the following equations.

$$R = 2Z_0\left(\frac{1}{|S_{21}|} - 1\right)$$

$$C = \frac{\sqrt{0.5(R + 2Z_0)^2 - 4Z_0^{\,2}}}{2.83\pi Z_0 R\Delta f}$$

$$L = \frac{1}{4(\pi f_0)^2 C}$$

5.2 Eight Spurline Sections

An eight section RLC network for the eight spurline sections in the chipless RFID tag is as shown in Fig. 10.

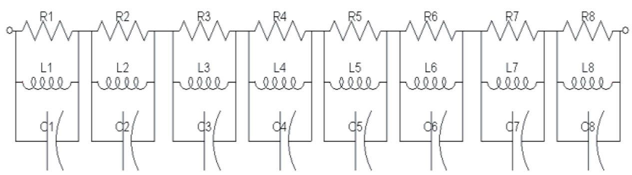


Fig. 10. Equivalent circuit of eight section spurline.

i	F_i (GHz)	R_i (KΩ)	C_i (pF)	L_i (nH)
1	2.38	1.765	15.46	0.28397
2	2.50	1.911	11.01	0.345
3	2.75	1.912	9.39	0.3454
4	2.98	0.909	10.87	0.242
5	3.44	1.602	17.02	0.1287
6	3.79	0.391	26.8	0.0653
7	3.85	6.529	8.703	0.1829
8	4.04	0.774	21.86	0.0659

Tab. 1. Values of R, L and C of Fig.10.

The spurlines are arranged in such a way that the individual resonances do not merge with each other. Hence the effect of mutual coupling can be neglected. The R, L, and C values are shown in Tab. 1.

6. Conclusion

In this paper a compact chipless RFID tag using spurline resonators is presented. The tag enables data encoding in the spectral signature with a data capacity of 8-bits.The bit capacity can be enhanced to 14 bits without increasing the overall size, since the additional spur lines can be engraved within the microstrip line**.** The proposed chipless RFID tag is an economical way of replacing the conventional barcode. The range of the tag can be improved by using high gain antennas for transmission and reception purposes.

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