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Design of Chipless Rfid Tag Based on Stepped Impedance Resonator In Frequency Domain

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***Abstract**: A novel compact 12 bit encoded chipless RFID tag using Stepped Impedance Resonator (SIR) is proposed. The main advantage of SIR compared to other resonators is the independent control over the fundamental as well as harmonic frequency by varying either Impedance ratio (K) or length ratio (α). This type of tag utilizes both fundamental and the harmonic frequency of the SIR to represent two bit information with single resonator. The structural information is encoded based on backscattered resonance signature in the frequency response of the tag. In this paper 6 SIR structures is designed to store 12bit information in the tag. The tag are designeded on FR4 Epoxy (ε_r =4.4) substrate. The simulation of this resonator is done in HFSS platform.*

***Keywords**: Chipless RFID, Stepped Impedance Resonator, Backscattering*

I. Introduction

Radio Frequency Identification (RFID) is a wireless data capturing technology that uses radio frequency (RF) waves for extracting the encoded data from remotely placed tags. This system consists of two main elements, the RFID tag, where data is encoded, and the RFID reader, which is used for extracting the encoded data from the tags [1]. RFID systems are composed of three components – an interrogator (reader), a passive tag, and a host computer. The tag is composed of an antenna coil and a silicon chip that includes basic modulation circuitry and non-volatile memory. The tag is energized by a time-varying electromagnetic Radio Frequency (RF) wave that is transmitted by the reader. This RF signal is called a carrier signal. When the RF field passes through an antenna coil, there is an AC voltage generated across the coil. This voltage is rectified to supply power to the tag. The information stored in the tag is transmitted back to the reader. This is often called backscattering [1], by detecting the backscattering signal; the information stored in the tag can be fully identified. It is one of the fastest growing sectors in today's market of radio communication technology and IT areas.

The ever evolving application area of RFID has attracted lots of research interest and industry investments in developing a low-cost, fully printable RFID tag. As the conventional RFID tags require an application specific integrated circuit (ASIC) or microchip to store information and the ASIC has a significant cost associated with its fabrication and assembly, conventional tags are relatively costly. Another version of RFID also known as chipless RFID[2], which does not require any ASIC to store information, offers tags that are inexpensive and holds the promise to deliver an ultra-low cost item tagging and tracking solution. Based on the method of data bit encoding, the tag can be classified as time domain reflectormetry based tags and spectral signature or frequency domain based tags. In time domain based tag, information bits are encoded through the placement of inductive or capacitive discontinuities along a transmission line. In the reader or interrogating device, information encoded in the tag is extracted by analyzing the absence and presence of the reflected echoes originating from those transmission line discontinuities. Time domain based tags [3] have simple calibration procedure and reasonable readable ranges up to 80cm; but the bit encoding capacity of such tags are low. The data encoding capacity limitation in time domain tags can be overcome by using frequency domain tags but it requires complex calibration procedure [4]. In frequency signature RFID the interrogator sends waves of several frequencies and monitors the echoes frequency content. The presence or absence of certain frequency components in the received waves encodes the data. Backscattering or frequency domain based tags do not require separate dedicated antenna, the resonators used in the tag [5] themselves serve the purpose of antenna. Absence of antenna makes these tags relatively compact in size compared to other tags. Data bit encoding capacity of the tag depends on the number of resonators and dielectric constant of the substrate [6].

Most of the reported tags use only the fundamental frequency mode of the resonator to encode the data. Their available frequency band is limited between the lower resonating frequency and its next possible harmonic. In this paper, Stepped Impedance Resonator (SIR) is used as the basic data encoding structure .The main advantage of using this type of resonator is the bit encoding capacity of tag, is enhanced by utilizing both fundamental (f_0) and first harmonic (fs_1) frequency of the SIR [6]. Thus a single SIR can represent four different combinations (00, 01, 10 & 11) by suitably applying different boundary conditions. A tag comprising N number of resonators can therefore represent 2^{2N} combinations. Another main advantage of SIR is the independent control over the fundamental (f_0) as well as first harmonic (fs_1) frequency compared to other resonators.

II. Stepped Impedance Resonatr (Sir)

In SIR, the fundamental and higher harmonic frequencies are determined by K (Impedance Ratio) and α (Length Ratio). K and α can be expressed as

$$\mathbf{K = Z_2/ Z_1} \quad (1)$$

$$\alpha = \theta_2/ \theta_1 + \theta_2 = 2\,\theta_2/ \theta_t \quad (2)$$

Where Z and θ are the impedance and electrical length of the respective resonator section [6]. Fig.1 (a) and (b) show the typical structure of half wave length SIR for K<1 and K>1, respectively. Fig.1(c) is the micro strip version of the SIR, here, corresponding Z and θ are converted into its equivalent physical length. It is noted that the fundamental frequency (f_0) and other higher order modes (f_{S1}, f_{S2}..) can be accurately determined by choosing a suitable combination of K and α. The physical length L'_2 can be expressed

$$\mathbf{L'_2 = L_2 - \Delta L_2} \quad (3)$$

Where L_2 is micro strip line length corresponding to the electrical length θ_2, and L'_2 is the extension of micro strip line due to fringing field [7]. It is obvious that $fs_1/f_0 < 2$ for the cases K >1. The larger the impedance ratio K, the closer the distance between the fundamental and the first spurious frequencies can be obtained. The most interesting observation is that for a given impedance ratio K, it is better to choose α~ 0.7 in order to obtain the smaller values of fs_1/f_0. On the contrary if $fs_1/f_0>2$ is required, then the cases of K<1 must be chosen [8].

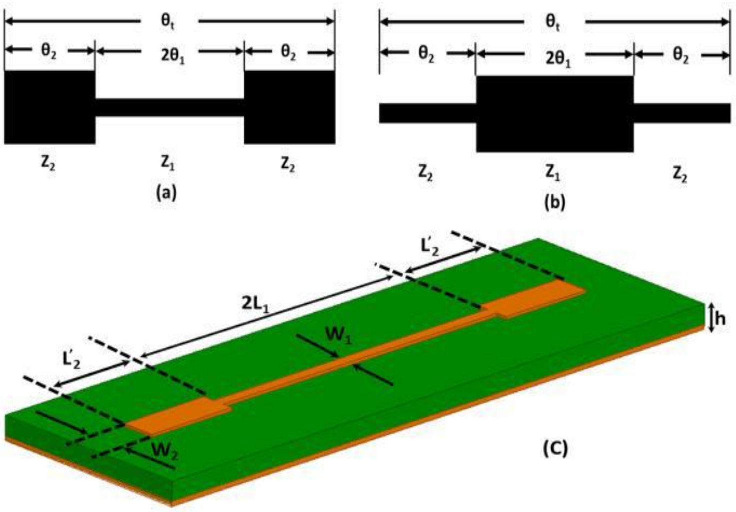

Fig.1. Structure of SIR (a) K <1, (b) K > 1 and (c) Microstrip version of SIR, K<1

III. Tag Design And Results

The SIR is designed on an FR4 Epoxy with permittivity 4.4 with different K and α value for the independent control of v f_0 and fs_1. Resonators in the tag are placed in an asymmetric order to minimize the mutual coupling between them and they are separated by a gap (G) of 5mm. Ansys HFSS software with plane wave or linear antenna wave (used for the simulation of far field of a linear antenna) excitation is used for simulation. Presence of a bit can be identified from a resonant peak or dip in the backscattered signal. This depends on many factors like polarization of incident and scattered wave, shape of the resonator etc. While keeping K constant, as per the dimension values of SIRs the value of α is varied from 0.47 to 0.73 to designing the tag. The resonant frequency f_0 and fs_1 are found to between at 3.8GHz and 9.62GHz respectively. In [2] the designed tag can only store 6 bit information with using 6 split wheel resonators. By increasing the information carrying capacity of the tag the available spectrum efficiency of can also be increased. The structural dimensions of 6 SIR structures used here for desgning the tag are given in Table 1. The figure 2 shows the tag structure based on values shown on the table 1. The figure 3 and figure 4 shows the results of FR4 Epoxy substrate with single and six SIR structures respectively.

table 1. structural dimensions of 6 sir for different α values

SIR	□	$2L_1$	L'_2	W_1	W_2
1	0.69	45	10	10	.6
2	0.71	35	15	10	.6
3	0.473	25	20	10	.8
4	0.73	35	15	15	.8
5	0.572	25	20	15	.8
6	0.76	15	25	20	.9

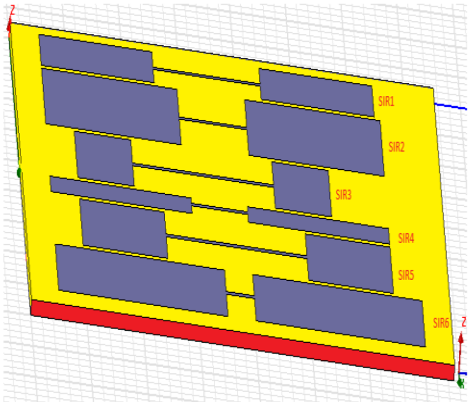

Fig 2. 12 bit SIR based RFID tag, where G = 5mm, ε_r= 4.4 and h= 1.6mm

The Fig.3 shows the result of single SIR structure used inside this tag, here the first frequency dip shows the fundamental frequency value at 6.7Ghz and the second dip shows the harmonic frequency value at 7.6 Ghz. These two dip represents two bits i.e. represented by 11.

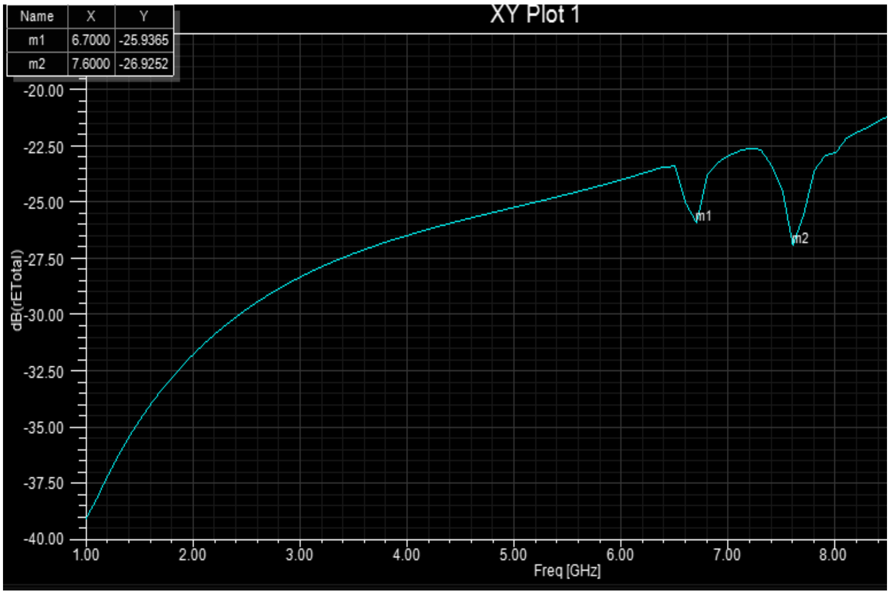

Fig.3. Resultant HFSS output of single SIR

Figure.4 shows the final output of the designed tag, here the first six frequency dip shows the fundamental frequency values carrying information bit 1111 and last 2 dips shows the harmonics frequency values with information bits 11000.

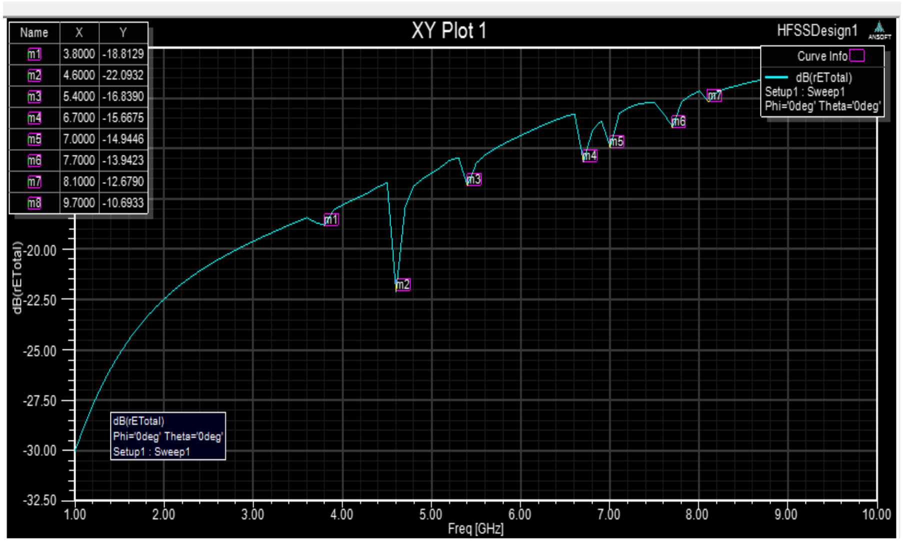

Fig4. Response of Six SIR Structure in HFSS

The table 2 and output plot figure 5 shows results of another designed tag with bit combination of 111110 111000.

Table 2 Dimensions for 6 SIRs with different α

SIR	□	2L$_1$	L'$_2$	W$_1$	W$_2$
1	0.3	24	9	18	.7
2	0.4	28	12	19	.7
3	0.473	25	14	20	.8
4	0.53	30	15	20	.8
5	0.48	55	14	17	.8
6	0.436	15	12.5	20	.8

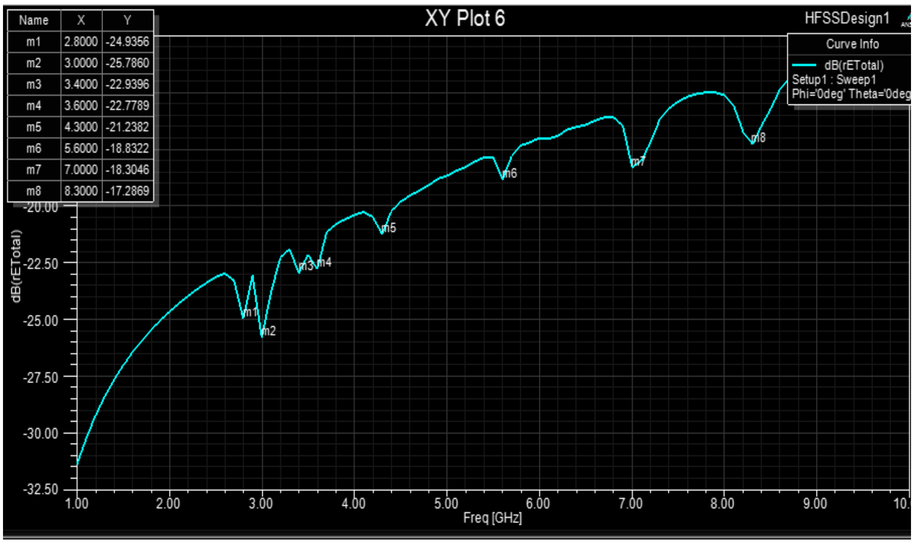

Fig 5 Response of Six SIR Structure in HFSS with various α values

IV. Conclusion

Design of different chipless RFID tag utilizing both fundamental and first harmonic frequency of SIR is presented in this paper. The resonator is capable of independent control of bits which gives more degree of freedom with lesser controls (K & α). All possible combination of 12 bit representations is successfully implemented by six SIR resonator and the proposed tag is capable of representing 2^{2N} number of bit combination using N(6) resonators. Measured resonant frequency of the tag is found to between at 3.6 to 9.6GHz and 2.8 to 8.3 GHz respectively. All the designing operations are done in HFSS antenna simulation software. Results obtained for the tag also shows great promise. The tag with four SIRs is designed on RT

Duroid substrate with dielectric constant of 2.2 and loss tangent of 0.0009and it works in the UWB frequency spectrum. Future research will focus on further miniaturization of the proposed tags. The proposed tag has a great potential for Ultra Wide Band low cost RFID applications.

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