Design of phase coded spiral resonator based Chipless RFID tag for tracking applications

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Abstract. RFID (Radio identification) is a technology which deals with the wireless identification of people and products. This chipless RFID tag design is on research to replace chipped RFID tags, which employs high cost silicon wafer to store unique identification code. The main challenge in the design of chipless RFID tag is how to encode the data without a chip. This challenge is overcome by the use of electromagnetic properties of the resonators, filters etc to encode the data bits. In this work RFID tag is designed based on multiresonators with each resonator representing a data bit. The proposed tag consists of the multiresonating circuit to store information bits and transmitting and receiving UWB antenna for wireless communication with the RFID reader for identification. The multiresonating circuit designed consists of 4-spiral resonators electromagnetically coupled to the microstrip coupled line. Each spiral resonates at unique resonating frequency representing the unique data bit. The data encoding is carried out with the help of phase ripples at the resonating frequency of the spirals. Three variations are observed and corresponding 3-logic states (0, 1, 2) are encoded. The designed tag is simulated in Advanced Design System (ADS) using RO-4003 substrate with the dielectric constant 3.38 and thickness of 20 mil. From the proposed methodology, a total of $3^4 = 81$ unique tags can be designed that can be employed in cheap item tracking. The Monopole disc antenna is designed which operates for wide band covering all resonating frequency of the spiral resonator.

Keywords— chipless RFID tag, Multiresonators, microstrip coupled line, Monopole disc antenna.

1. Introduction

RFID (Radio Frequency Identification) can be defined as the Automatic identification technology which used to identify objects carrying tags when they come close to a reader. It is recently being used in a wide range of applications such as Supply Chain Management (SCM), health care, traffic monitoring, retail, access control, etc. The idea behind the RFID tag is to store a unique identification number, same as that of a bar code or a magnetic strip. To retrieve information stored in the bar code or magnetic strip, the device must be scanned in a close proximity with its scanning device. But in RFID, the data transfer between RFID tag and RFID Reader is done wirelessly and hence enables remote identification. The paper [1] deals with the design of spiral resonator based RFID tag. Each spiral resonator resonates at unique frequency and three states in any resonant frequency (encoding in base-3) can be realized and more data bits can be encoded using the same bandwidth as base-2 encoding method[3].

Microstrip Spiral Resonator for the UWB chipless RFID Tag [2] deals with the simulation of the single spiral resonator coupled to the transmission line. Employment of circular and rectangular resonators in the multiresonating circuit of the chipless RFID is compared with its simulations results and the area occupied.

In [3], the tag encodes data based on spectral signature using a multiresonator. Both amplitude and phase components of the spectral signature are used for data encoding with base-2 coding methods. A novel chipless RFID tag using spiral resonator to achieve the pentamorous data encoding form [4] and deals with the new method of data encoding to increase the number of coded
bits in multiresonator circuit. The phase of scattering parameters (S-parameters) at a certain frequency is considered for coding bits. The different phases of S parameters created by different coupling positions of the spiral resonator are considered for bit encoding.

This book [5] gives a complete review of the chipless RFID tag and the advantages of chipless tag over chipped tags and its future growth of replacing barcode. It also gives an complete overview of the employment of spiral resonators in chipless RFID design. In [6], a fully passive flexible chipless RFID system is presented in this paper. The designed chipless tag uses the magnitude and phase of the frequency signature of a multiresonator circuit for encoding of data bits. The tag comprises of a microstrip spiral multiresonator and cross-polarized transmitting and receiving microstrip UWB monopole antennas.

The chipless RFID transponder consists of three microstrip patch antennas, which are loaded with open circuited stubs. The antennas are resonant at nearby frequencies, and when excited with their respective resonant frequency signals, they re-radiate backscattered signals with distinct phase characteristics. This phase information is encoded as hexadecimal bits [7].

2. Proposed work

2.1. Multiresonating circuit design

The proposed circuit consists of transmission line with coupled spiral resonators along its sides. The line is matched to 50Ω at both ends and the spiral resonators have different resonance frequencies. Every spiral resonators produces attenuation in magnitude and ripple in phase at its resonating frequency. The resonating frequency can be modified by changing the dimensions of the spiral resonators. Every resonating frequency carry a bit binary data bit, and by increasing the number of data bits more bits can be encoded. The following Table 1. shows the design specification of the proposed design.

| Design tool | ADS (Advanced design system) |
|-------------|------------------------------|
| No of spiral resonator | 4 |
| Bit capacity(Base-3 code) | $3^4 = 81$ unique ID's |
| Size of the tag | 13mm X 13mm |
| Substrate | Ro-4003 substrate with the dielectric constant 3.38 and thickness of 20 mil |
| Resonating frequencies | 2.95GHz, 3.19GHz, 3.37GHz, 3.60GHz |

The 50Ω impedance matching is achieved by the following equations, for $Z_0=50\Omega$, thickness of the substrate $H=20$ mil, Dielectric constant $\varepsilon_r=3.38$,

$$\frac{W}{H} = \frac{R_0 A}{\varepsilon_r A - 2}$$

(1)

Where, $w=\text{width of the 50Ω line},$

$$A = 2\pi \frac{Z_0}{Z_f} \sqrt{\frac{1}{2} \left( \frac{\varepsilon_{r+1}}{\varepsilon_{r-1}} + \frac{\varepsilon_{r-1}}{\varepsilon_{r+1}} \right) \left( 0.23 + \frac{0.11}{\varepsilon_r} \right)}$$

(2)
The length of the 50Ω transmission line,

\[ l = \frac{\kappa_0 \sqrt{\frac{\pi}{180}}}{\sqrt{\varepsilon_{\text{eff}} K_0}} \]  

(3)

Where,

\[ \varepsilon_{\text{eff}} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} \left( 1 + \frac{12H}{W} \right)^{-\frac{1}{2}} \]  

(4)

From the above equations the length of the line=3mm and width of the line=1.15mm.

The 4 spiral resonators are designed which resonates for a unique frequencies, this could be achieved by using varying number of turns and length of the spiral resonators. The spiral resonators are designed to resonate at different frequencies. This unique frequency resonation is being achieved by the variation of the length of the spiral resonator. The designed spiral resonators specification is shown in the Table 2.

| Spiral Resonators | No of turns | Length of the resonator (mm) | Width of the resonator (mm) | Space (mm) | Resonating Frequency (GHz) |
|-------------------|-------------|-----------------------------|-----------------------------|------------|---------------------------|
| Resonator 1       | 4           | 3.8                         | 1.5                         | 0.1        | 2.95                      |
| Resonator 2       | 4           | 3.6                         | 1.5                         | 0.1        | 3.19                      |
| Resonator 3       | 4           | 3.4                         | 1.5                         | 0.1        | 3.37                      |
| Resonator 4       | 4           | 3.2                         | 1.5                         | 0.1        | 3.60                      |

2.3. Antenna design

The Monopole disc antenna designed covers all the resonating frequency of the spiral resonators. This Monopole UWB antenna is used for the reception of interrogating signals from the reader and transmission of the encoded information to the reader. The designed ultra wideband monopole antenna has the following specifications as shown in the Table 3.

| Table 3. Designed antenna parameters |
|--------------------------------------|
| Design tool                          | ADS (Advanced design system)   |
| Substrate                            | Ro-4003 substrate with the dielectric constant 3.38 and thickness of 20 mil |
| Radius of the disc                   | 25mm                             |
| Length of the feed line              | 32mm                             |
| Width of the feed line               | 2mm                              |
| Length of the ground plane           | 34mm                             |
| Width of the ground plane            | 60mm                             |

2.4. Bit encoding technique

The bit encoding method employed in this design is the presence and absence of resonating frequency band. In every literature discussed, absence or presence of the stop band in each frequency can be translated to logic states

- Presence of stop band -logic 1
- Absence of stop band -logic 0
In this design, for each resonating frequency 3-logic states are employed as the base-3 code (0, 1, 2). This is achieved by encoding the corresponding phase ripples of each spiral resonator with respect to frequency. Hence coding capacity is improved with higher bandwidth efficiency.

3. Results and discussion

The designed coupled line with impedance matching is shown in the Figure 1. Based on the operating frequency of the coupled transmission line, spiral resonators are designed. The Figure 2. which shows the $S_{21}$ magnitude and phase variation for coupled transmission line of 7mm, the start frequency is from 1GHz up to the range of 12GHz.

Figure 1. Layout of the proposed coupled line

Figure 2. $S_{21}$ magnitude and phase simulation for the designed coupled line

Each spiral resonator coupled to the transmission line with a distance of 0.1mm acts as the band stop filter, producing attenuation and phase ripples at resonating frequencies. This phase ripples corresponding to each spiral is taken for the corresponding bit encoding, when the spirals are coupled above the line, the current distribution in the coupled line and the spiral are in phase (current flow in same direction), hence maximum phase ripple occurs which corresponds to a single unique bit ‘1’, similarly when the spirals are coupled below the line, the current distribution in the coupled line and the spiral are out of phase (current flow in opposite direction), hence minimum phase occurs which corresponds to a single unique bit ‘2’, also absence of spiral produces no phase ripples which corresponds to bit ‘0’ which are shown in below Figure 3, Figure 4, Figure 5 respectively.

Figure 3., Figure 4., Figure 5. shows the $S_{12}$ magnitude and phase simulations for different specific codes of 1111, 2222 and 1102 for the corresponding layout designed in ADS. The magnitude simulation shows that the loss corresponding to the layout designed is optimum and corresponding phase simulation with the desired output of phase ripples which can be taken for encoding the base-3 code.

The steps involved in base-3 encoding is as follows,
If minimum happened in $S_{21}$ phase, this phase state is set to '2' in base-3 code
If maximum happened in $S_{21}$ phase, this phase state is set to '1' in base-3 code
If no changes happened in $S_{21}$ phase, this phase state is set to '0' in base-3 code

**Figure 3.** (a) Layout of the proposed tag with encoded bit (1111) (b) $S_{21}$ Magnitude simulation for the corresponding layout (c) $S_{21}$ phase simulation for the corresponding layout

The number of spiral resonators ($M$) according to the ID number ($n$) is calculated by the below equation 5,

$$M = \log_3^n$$  \hspace{1cm} (5)

In this design $M=4$, hence number of unique ID's generated are 81 Unique identification can be designed.

In the proposed design there is a reduction in the size of the tag, which is the major challenge in wireless identification. Also, there is increase in operating frequency of the spiral resonators and
hence greater range of communication can be achieved. There is an efficient use of total frequency bandwidth.

Figure 4. (a) Layout of the proposed tag with encoded bit (2222) (b) $S_{21}$ Magnitude simulation for the corresponding layout (c) $S_{21}$ phase simulation for the corresponding layout

The tag design also uses coupled transmission line which contributes to the expected current distribution which produces phase ripples required for encoding of the data in the chipless tag.
Figure 5. (a) Layout of the proposed tag with encoded bit (1102) (b) $S_{21}$ Magnitude simulation for the corresponding layout (c) $S_{21}$ phase simulation for the corresponding layout.

The layout of the designed monopole antenna is shown in the Figure 6. and the return loss ($S_{11}$) is shown in the Figure 7., which covers all the operating frequency of the spiral resonators from 2.4 GHz to 3.8 GHz. The proposed tag can be used for variety of applications such as tracking applications like cheap and mass item tracking, Electronic surveillance to keep track of people, Toll bill collection and other wide variety of RFID applications.
4. Conclusion

In the proposed work, reduction of tag size has been successfully implemented with same encoding methods and substrate elements [1]. This method of chipless RFID tag design has many advantages in terms of printability/fabrication, wide range of applications, computation and cost compared to that of the chipped tag design. In future, the number of bits encoded can be increased by increasing the number of spiral resonators. The operating frequency of the spiral resonators can be made higher, which increases the range of communication. The resonating circuit part and the antenna part can be designed as a single prototype and wireless measurements can be made using signal analyzers. The alternative shape of the spiral which has the better performance can also be employed instead of the conventional rectangular spiral resonator design.

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