## Abstract

Compact multiresonator based chipless RFID tag employing open stubs in a microstrip transmission line is proposed. The prototype of the tag is fabricated on a substrate of dielectric constant 4.4 and loss tangent 0.0018. The multiresonator tag consists of microstrip open stub resonators and cross polarised transmitting and receiving disc monopole antennas. Equivalent circuit of the single bit tag is studied and validated with simulation results. A prototype of 8 bit data encoded tag is demonstrated in this chapter. Method for enhancing the performance of the RFID tag is also proposed. Magnitude or group delay response of the backscattered signal is used to decode the tag information. The readable range of the tag is found to be 40cm inside the anechoic chamber, using a PNA E8362B network analyser with source power of 0dBm.
2.1. Introduction

As explained in the earlier chapter, the frequency spectra based chipless RFID tags can be divided into two categories, multiresonator and multiscatterer based tags. This chapter highlights the design and development of multiresonator based tag. It consists of a receiving antenna for the reception of the interrogation signal from the RFID reader, a multi resonating structure consisting of a number of resonators and a retransmitting antenna. Multiresonator circuit is basically a narrow band rejection filter comprised of different resonators and it will alter the amplitude and phase of the interrogating signal. The output of the filter is connected to a transmitting antenna which will retransmit the encoded signal back to the reader. Block diagram of the multiresonator based chipless RFID system is depicted in Fig.2.1. The system is not based on radar cross section (RCS) backscattering, but on retransmission of the interrogation signal with the encoded unique spectral ID. RFID reader for the multiresonator based system consists of two linearly polarised wide band antennas orthogonally polarised to each other. This arrangement helps the reader to minimise direct coupling between the reader antennas and also reduces the mutual coupling between the interrogation and backscattered signals. RFID reader comprises of a wide band microwave source and other RF devices like Low Noise Amplifier (LNA), directional coupler, power splitters, frequency mixer, etc. Reader has to generate an interrogation signal with constant phase and amplitude as shown in Fig.2.1. Backscattered or retransmitted signal from the chipless tag will have different amplitude and phase, which depends on the characteristics of the multiresonating circuit. A control section is also needed in the reader system to manage all the activities and communication with middleware software.
Components of a multiresonator based tag are

2.1.1. Multiresonating circuits

2.1.2. Receiving and retransmitting UWB antenna

2.1.1. Multiresonating Circuits

Numerous chipless RFID tags are reported based on the method proposed by Stevan Preradovic et.al. [1]-[9]. Multiresonating circuit is designed to attenuate particular frequency in the desired band. Basic resonators used in the design of multiresonating circuits are spiral, hair pin, ‘C’ like structures, split ring resonator (SRR), Complementary SRR (CSRR), Stepped Impedance Resonator (SIR), etc. Most of the tags are designed on microstrip based resonators [1]-[7] and some of them are based on CPW [8]-[9]. In CPW based multiresonating circuits, resonators are etched in the feed lines. In the case of microstrip based circuits, resonators are either connected
or coupled to the transmission line. Because of the resonators in the feed line, CPW based multiresonating circuits create more insertion loss with number of resonators and also requires large space in the feed line to accommodate lower frequency resonators. Fig.2.2 shows some of the resonators reported in the literature for the design of multiresonating circuits. Fig.2.2 (a) to (d) shows the multiresonating circuits based on microstrip line and Fig.2.2 (e) & (f) are based on CPW. In all cases, the size of the multiresonating circuit depends on the number of parameters like operating frequency band, dielectric properties of the substrate, the separation between the resonators, common coupling area between the transmission line and resonator, etc.

![Figure 2.2 Reported resonators used for the design of multiresonator based tag. (a) to (d): microstrip based resonators and (e) to (f): CPW based resonators.](image)

### 2.1.2. Receiving and Retransmitting UWB Antenna

The complete design of RFID tag based on multiresonator requires two UWB antennas, one for receiving the interrogation signal from reader and another for retransmitting the encoded signal from the multiresonating circuits to the reader. This antenna should provide a good impedance match.
and radiation characteristics at the desired frequency band. Fig. 2.3 shows the reported antennas used in the design of the chipless tag. All the antennas are UWB with CPW or microstrip feed. The overall size of the antenna depends on substrate permittivity, geometry and lowest operating frequency of the tag. Compact tag antennas are preferred to accommodate more number of bits in a limited tag size (size of the credit card or bank note).

![Reported antennas used for the design of multiresonator based chipless RFID tag](image)

**Figure 2.3** Reported antennas used for the design of multiresonator based chipless RFID tag [9], [7] and [1].

### 2.2. Expression for Free Space Losses in the Multiresonator Based Chipless RFID System

The expected power levels of the received signals from the chipless tags in an anechoic chamber (lossless environment) can be calculated using the Friis free-space transmission formula [10]. The power density of the signal that reaches the chipless RFID tag in free space is given by

\[
S = \frac{P_t G_r}{4\pi r^2} \tag{2.1}
\]

where \( P_t \) is the transmitted power, \( G_r \) is the gain of the reader transmitting antenna and \( r \) is the distance between the tag and reader antenna. The power collected by the transponder antenna is defined as
where $A_{e}$ is the effective area of the tag antenna, $G_t$ is the gain of the tag antenna and $\lambda$ is the wavelength. In this calculation, both antennas used by the RFID reader for transmission and reception of interrogation signal are identical. Similarly, antenna in the RFID tag for receiving and retransmitting is also considered as identical. Hence, the signal received by the reader after interrogating the tag is

$$P_{rx} = \frac{P_t G_t^2 G_r^2 \lambda^4 L(f)}{(4\pi r)^2}$$

where $L(f)$ is the insertion loss of the tag’s multiresonating circuit as a function of frequency $f$. Received signal strength $P_{rx}$ should be above the noise floor, for the successful identification of backscattered signal. In the RFID system, the noise floor of the backscattered signal depends on the polarisation isolation between the reader antennas and environmental conditions (interference from different wireless systems, scattering from stationary objects, etc.)

### 2.3. Multiresonator Circuit Design Using Open Stub Resonator

This chapter proposes a multiresonator based chipless RFID tag using open stub resonators. The proposed tags are resonating at quarter wavelength ($\lambda/4$) whereas most of reported tag resonators are half wavelength ($\lambda/2$). Therefore, the sizes of the proposed resonators are small compared with other tags working on the same frequency. Another advantage is that open stub resonator is directly connected to the transmission line, but in normal tags a coupling is required. As shown in Fig.2.2, all the resonators have to be placed close to a transmission line with common coupling area between the two.
The evolution of an RFID tag from a simple microstrip transmission line using $\lambda g/4$ open stub is demonstrated in Fig.2.4, where $\lambda g$ is the guided wavelength at the operating frequency. Ansys HFSS software is used for the simulation analysis. The width of the microstrip transmission line is found to be 3mm for 50$\Omega$ impedance and it is simulated on a substrate of dielectric constant 4.4, loss tangent 0.0018 and substrate height 1.6mm. To make compact tag, ‘L’ shape open stub resonator is placed on the transmission line as shown in Fig.2.4. Width ($W_2$) and length ($L$) of the open stub resonator is selected as 0.5mm and 21mm, respectively. The two 50$\Omega$ excitation ports are connected at the end of the microstrip transmission line with characteristic impedance of 50$\Omega$ ($W_1 = 3$mm). The simulated frequency response of the open stub resonator is depicted in Fig.2.5. Narrow band notch filter response at 2.12GHz is clearly shown in the figure. The resonant frequency ($f_0$) of a $\lambda g/4$ resonator can be accurately found analytically by taking care of appropriate corrections due to open end [11] and microstrip bend [12] effects of the microstrip line. The length $\Delta L$ (seen in Fig.2.4) is the extended length due to open end fringing field on the microstrip line. Field distribution (surface current and E field) on the resonator at the resonant frequency (2.12GHz) is shown in Fig.2.6 and confirms the quarter wavelength operation at the resonant frequency.

Figure 2.4 Microstrip Transmission line with open stub resonator, $W_1 = 3$mm, $W_2 = 0.5$mm, $L = 21$mm and $\Delta L = 0.629$mm.
2.3.1. Equivalent Circuit Design of Open Stub Microstrip Resonator

Equivalent circuit of an open stub resonator can be derived by finding the capacitance and inductance of each section in the microstrip line. Open end fringing field and microstrip bend effects are also to be incorporated into the analysis for the accurate calculation of resonant frequency. Transmission line and open stub resonator are assumed to be lossless i.e., distributed resistance is zero. Equivalent circuit of the open end microstrip line is shown in Fig.2.7. $L_S$ and $C_P$ are the equivalent series inductance and shunt capacitance per unit length of microstrip line, $L_B$ and $C_B$ are the equivalent series inductance and shunt capacitance due to microstrip bend. $\Delta C_P$ is the
shunt capacitance due to open end fringing field. Closed form expressions for finding the unknown quantities are given in the following steps [11]-[15].

Series inductance ($L_S$) and shunt capacitance ($C_P$) of a microstrip line can be calculated by solving closed form equation [11].

$$Z_0 = \frac{87}{\sqrt{\varepsilon_r+1.41}} l_n \left[ \frac{5.98h}{0.8W+T} \right] \Omega$$  \hspace{1cm} (2.4)

$$C_P = \frac{2.64.10^{-11}(\varepsilon_r+1.41)}{l_n[5.98h/(0.8W+T)]} F/m$$  \hspace{1cm} (2.5)

$$L_S = c_0Z_0^2 \text{ H/m}$$  \hspace{1cm} (2.6)

where $\varepsilon_r$, $h$, $W$, and $T$ are the permittivity, height of substrate, width of microstrip line and thickness of the metal, respectively. $c_0$ is the speed of light in the free space. Parallel capacitance $C_B$ and series inductance $L_B$ per unit length due to microstrip bend can be computed by [12].

$$\frac{C_B}{W} \text{ (pF/m)} = \begin{cases} (14\varepsilon_r + 12.5)W/h - (1.83\varepsilon_r - 2.25) & \text{for } W/h < 1 \\ \frac{0.02\varepsilon_r}{W/h} & \text{for } W/h \geq 1 \end{cases}$$  \hspace{1cm} (2.7)

$$\frac{L_B}{h} \text{ (nH/m)} = 100 \left\{ 4 \sqrt{\frac{W}{h}} - 4.21 \right\}$$  \hspace{1cm} (2.8)

Capacitance due to open end effect ($\Delta C_P$) can be found by [13].
\[ \Delta C_p = \frac{\Delta L \sqrt{\varepsilon_r}}{C_0 Z_c} \]  
(2.9)

where \( \Delta L \) is the extended length due to fringing field are given by

\[
\frac{\Delta L}{h} = \frac{\xi_1 \xi_3 \xi_5}{\xi_4} 
(2.10)
\]

\[
\xi_1 = 0.434907 \left( \frac{\varepsilon_r^{0.81}}{\varepsilon_r^{0.81} + 0.26(W/h)^{0.8544} + 0.236} \right)
\]

\[
\xi_2 = 1 + \frac{(W/h)^{0.371}}{2.35 \varepsilon_r + 1}
\]

\[
\xi_3 = 1 + \frac{0.5274 \tan^{-1}\left(0.084(W/h)^{1.9413/\xi_2}\right)}{\varepsilon_r^{0.9236}}
\]

\[
\xi_4 = 1 + 0.037\tan^{-1}\left(0.067(W/h)1.456\right) \cdot \{6 - 5\exp[0.036(1 - \varepsilon_r)]\}
\]

\[
\xi_5 = 1 - 0.218 \exp\left(\frac{-7.5W}{h}\right)
\]

where \( \varepsilon_r \) is the effective dielectric constant of the microstrip line. As per the above equations, extracted values of inductance and capacitance of the open stub resonator and microstrip line are detailed in Table 1. The parameter \( L_{_TL_S} \) and \( C_{_TL_P} \) are the series inductance and shunt capacitance of the 50\(\Omega\) microstrip transmission line shown in Fig. 2.4.

<table>
<thead>
<tr>
<th>Table 1: Extracted parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>L_S</td>
</tr>
<tr>
<td>C_P</td>
</tr>
<tr>
<td>L_B</td>
</tr>
<tr>
<td>C_B</td>
</tr>
<tr>
<td>( \Delta C_p )</td>
</tr>
<tr>
<td>L_{_TL_S}</td>
</tr>
<tr>
<td>C_{_TL_P}</td>
</tr>
</tbody>
</table>
The equivalent circuit of the open stub resonator with 50Ω transmission line is modelled in Agilent ADS software with values given in Table 1 and its frequency response with HFSS simulation is validated. Fig.2.8 shows the equivalent circuit designed in Agilent ADS software with two ports connected across the 50Ω transmission line. Fig.2.9 shows the frequency response comparison between equivalent circuit and the 3D numerical result. Equivalent circuit results show good agreement with numerical results.

Figure 2.8 Equivalent circuit of an open stub resonator (Fig.2.4) connected with 50Ω transmission line using Agilent ADS.

Figure 2.9 Frequency response of the above open stub resonator extracted using HFSS and Agilent ADS
2.4. Substrates for Chipless RFID Tag

Multiresonating circuit using open stub resonator is analysed with different substrate are discussed in this section. Different substrates used for the analysis are FR4 ($\varepsilon_r = 4.3$, $\tan\delta = 0.02$, $h = 1.6\text{mm}$), C-MET LK 4.3 ($\varepsilon_r = 4.3$, $\tan\delta = 0.0018$, $h = 1.6\text{mm}$), RT Duroid ($\varepsilon_r = 2.2$, $\tan\delta = 0.0009$, $h = 1\text{mm}$) and glossy paper ($\varepsilon_r = 3$, $\tan\delta = 0.09$, $h = 0.22\text{mm}$). The dimension of the open stub resonator given in the Fig.2.4 is analysed on different transmission lines designed on the above substrates with characteristic impedance ($Z_0$) of $50\Omega$. From the figure it is clear that, the resonator printed on a lossy glossy paper can also encode the data in the frequency spectrum, but it requires large bandwidth to represent resonance due to low Q. The better Quality factor can be achieved with low loss substrate ($<<\tan\delta$). The resonant frequency variation with respect to the dielectric constant of the structure is also shown in the figure. C-MET LK 4.3 substrate is used for the design and analysis of multiresonator based chipless tag, which is indigenously developed by C-MET (Centre for Materials for Electronics Technology, India). Substrate properties given by the manufacturer are given in Table 2.

Figure 2.10. Simulated frequency response of the open stub resonator on different substrate.
Table 2. Material Properties of C-MET LK-4.3 Substrate

<table>
<thead>
<tr>
<th>Material Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric constant</td>
<td>4.3 ±0.03 at 10 GHz</td>
</tr>
<tr>
<td>Loss tangent</td>
<td>0.0018 at 10 GHz</td>
</tr>
<tr>
<td>Temperature coefficient of dielectric constant</td>
<td>-27 ppm/°C</td>
</tr>
<tr>
<td>Linear coefficient of thermal expansion</td>
<td>19 ppm/°C</td>
</tr>
<tr>
<td>Copper peel strength</td>
<td>1.2 N/mm</td>
</tr>
<tr>
<td>Water absorption</td>
<td>0.05%</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>&gt;1 W/mK</td>
</tr>
</tbody>
</table>

2.5. Optimisation of Open Stub Resonator

Frequency spectrum available for the design of chipless tag is limited due to allocation of bands to different applications. Hence, to encode more bits in the limited spectrum, the bandwidth of the resonators to represent the bit/resonator should be small as possible. It is noted that there is a band notch centred at 2.35GHz when an open circuited stub of length 18mm and width 0.5mm is connected to the 50Ω microstrip transmission line. Simulation analysis on different parameters of the single open stub resonator with microstrip line is carried out in this section. Fig.2.11 shows the variation of resonant frequency with respect to the width of the transmission line (W1). As the width of transmission line increases, Fractional Band Width (FBW) decreases, ie. FBW changes from 39.42% to 12.57% when W1 varies from 2mm to 7mm. The FBW is estimated using, FBW=Δf/f₀*100%, where Δf is the 3dB S21 band width and f₀ is the notch frequency. Similar parametric study on open stub resonator width (W2) is also carried out and its frequency response is shown in Fig.2.12. FBW is decreased with the width of the resonator as demonstrated in Fig.2.12.
Figure 2.11 Frequency response of the structure with different transmission line width (W1), εr = 4.3, tanδ = 0.0018, h = 1.6mm and W2 = 0.5mm

Figure 2.12 Frequency response of the structure with different open stub resonator width (W2), εr = 4.3, tanδ = 0.0018, h = 1.6mm and W1 = 3mm

The results of the parametric analysis shown in Fig.2.11 and 2.12 are detailed in Table 3. It is found that when the transmission line impedance is 50Ω (W=3mm), the system offers a Fractional Band Width (FBW) of 30.05%. As seen in the Table 3.a increasing the width of the transmission line will reduce the FBW. However, when the transmission line impedance is about 28Ω (W= 7mm), optimum FBW (12.57%) is achieved. It is noted that
further decrease in the impedance of the transmission line distorts the $S_{21}$ characteristics. So this impedance is selected for further analysis. From Table 3.b it is again found that when the width of the $\lambda g/4$ stub ($W_2$) is decreasing, FBW of the resonator is also decreasing. Due to the fabrication limitation, the width $W_2$ is taken as 0.5mm in the present study. It is also observed that there is a small frequency shift with the width of the stub. This may be due to the increased inductance of the stub for small width [17]. Similarly, the small shift in the resonance with the width of the transmission line may be due to the change in effective capacitance of the line with width.

<table>
<thead>
<tr>
<th>$W_1$ (mm)</th>
<th>$F_0$ (GHz)</th>
<th>FBW (%)</th>
<th>$W_2$ (mm)</th>
<th>$F_0$ (GHz)</th>
<th>FBW (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2.37</td>
<td>39.42</td>
<td>0.3</td>
<td>2.33</td>
<td>27.27</td>
</tr>
<tr>
<td>3</td>
<td>2.35</td>
<td>30.05</td>
<td>0.5</td>
<td>2.35</td>
<td>30.05</td>
</tr>
<tr>
<td>4</td>
<td>2.32</td>
<td>23.50</td>
<td>0.7</td>
<td>2.36</td>
<td>33.69</td>
</tr>
<tr>
<td>5</td>
<td>2.31</td>
<td>17.90</td>
<td>0.9</td>
<td>2.38</td>
<td>37.21</td>
</tr>
<tr>
<td>6</td>
<td>2.30</td>
<td>15.11</td>
<td>1.1</td>
<td>2.41</td>
<td>39.48</td>
</tr>
<tr>
<td>7</td>
<td>2.29</td>
<td>12.57</td>
<td>1.3</td>
<td>2.44</td>
<td>40.08</td>
</tr>
<tr>
<td>8</td>
<td>2.27</td>
<td>9.21</td>
<td>1.5</td>
<td>2.47</td>
<td>44.45</td>
</tr>
</tbody>
</table>

To reduce the impedance mismatch between antenna terminal (50Ω) and microstrip transmission line (28Ω), an impedance transformer section (tapering section) is also included [18]. The length of this tapering section ($L_T$) is equal to $0.25\lambda_d$, where $\lambda_d$ is the wavelength in the substrate corresponding to the lowest frequency of operation. Final model of the single bit open stub resonator based multiresonator circuit is depicted in Fig.2.13. A parametric study on the multiresonating circuit with different resonator length ($L$) is depicted in Fig.2.14 and all other parameters of the structures are same as that shown in Fig.2.13. It is clear from the figure that, the resonant
frequency of the multiresonating structure can be easily controlled by the resonator length.

![Figure 2.13](image1.png)

**Figure 2.13** Final model of a single bit open stub resonator based multiresonator circuit, where $W_1 = 3\text{mm}$, $W_2 = 0.5\text{mm}$, $W = 7\text{mm}$, $L_1 = 12\text{mm}$, $L = 18\text{mm}$, $\varepsilon_r = 4.3$, $\tan\delta = 0.0018$ and substrate height $= 1.6\text{mm}$.

![Figure 2.14](image2.png)

**Figure 2.14** Simulated resonant frequency variation of open stub resonator with respect to its length ($L$).
2.6. Tag Design

From the above knowledge, a multiresonator circuit with 8 open stub resonator is designed and fabricated on a C-MET LK 4.3 substrate. Fig.2.15 shows the structure of the proposed 8 bit multiresonator circuit with an overall dimension of 30x25x1.6mm$^3$. Each resonator is independently resonating at its quarter wavelength frequency ($\lambda/4$). To minimise the mutual coupling between the two resonators they are kept 1mm apart. Experiments of the multiresonating circuit are conducted using the PNA E8362B network analyser. Fig.2.16 shows the measured and simulated frequency response of the 8 bit RFID tag. The simulated results are in good agreement with the measured one. The resonant frequencies of the circuit are found to be at 2.08GHz, 2.23GHz, 2.36GHz, 2.56GHz, 2.81GHz, 3.21GHz, 3.61GHz and 4.03GHz.

![Proposed 8 bit open stub RFID tag, where $\varepsilon_r = 4.3$, $\tan\delta = 0.0018$, $h = 1.6mm$, $W = 7mm$, $W1 = 3mm$, $W2 = 1mm$, $W3 = 0.5mm$, $L1 = 21mm$, $L2 = 19.5mm$, $L3 = 19mm$, $L4 = 17.5mm$, $L5 = 15.25mm$, $L6 = 13.5mm$, $L7 = 11.5mm$ and $L8 = 10.5mm
Absence or Presence Coding technique is used in the design of present tag, hence one resonator can represent 1 bit of information. The presence of the resonance at a predefined frequency indicate bit 1 and absence will indicate bit 0. Fig.2.17 shows the method of generating different bit combination from the multiresonator circuit. Instead of removing entire resonator from the tag, the connection between transmission line and resonator is removed to minimise the frequency shift in the multiresonating circuit. Measured transfer function ($S_{21}$) of the tag with different bit combinations are depicted in Fig.2.18.
Figure 2.18 Measured frequency response of the multiresonator circuit with different bit combination

Bit information of the multiresonating tag also can be encoded in the group delay of the transfer function as shown in Fig.2.19. Group delay is defined as the negative derivative of the signal phase with respect to frequency. When a signal passes through a device or medium, it experiences both amplitude and phase distortion. The amount of distortion depends on the characteristics of the device/medium. A wave incident at the input of a device may have several frequency components. The group delay gives a measure of average time delay of input signal at each frequency or it gives a measure of the dispersive nature of the device. Mathematically, the group delay can be expressed as,

$$\tau_g = \frac{-d\theta(\omega)}{d\omega}$$  \hspace{1cm} (2.11)$$

where $\theta$ and $\omega$ are the phase and the angular frequency of the signal.

If the phase of the backscattered signal varies, the group delay will vary with frequency ie., backscattered signal will have different delays at
different frequencies. From [19] it is clear that the group delay signal may have positive or negative symmetry depending on the phase change direction (+ve to –ve or –ve to +ve). The group delay plot is very efficient to analyse any nonlinearity that is present in the phase. From Fig.2.19, all the resonances can be easily identified from the backscattered group delay signal. Small shifts in the resonant frequency due to the removal of connection between the open stub and transmission lines are also shown in the figure.

![Group Delay of the multiresonator circuit with different bit combinations](image)

**Figure 2.19** Group Delay of the multiresonator circuit with different bit combinations

2.7. **Receiving and Retransmitting UWB Antennas: Disc Monopole Antenna**

A complete chipless RFID tag requires two UWB antennas at the two ends of multiresonating circuit. Selection of UWB antenna in the multiresonator based tag depends on impedance match, polarisation, radiation pattern and overall size. The antenna should possess very good impedance match over the operating frequency band of the RFID tag and also need better
linear polarisation characteristics. For successful reception and retransmission of interrogation signal, the radiation pattern of the antenna also needs to be uniform. In this tag, microstrip disc monopole antenna is opted due to its simple structure and wide band operation [4]. Fig.2.20 shows the geometry of the monopole antenna, along with the design parameters. Measured return loss characteristic of the antenna from 1.5GHz to 11GHz is shown in Fig.2.21. The antenna shows very good impedance match over operating range of multiresonator circuits (1.9GHz to 4.5GHz).

**Figure 2.20** Disc monopole antenna $\varepsilon_r = 4.3$, $\tan\delta = 0.0018$, $h = 1.6$mm, $R = 15$mm, $W3 = 3$mm, $Lg = 0.6$mm, $Lg1 = 40$mm and $Lg2 = 20$mm

**Figure 2.21** Measured reflection characteristics of Disc Monopole Antenna
The measured radiation patterns of the antenna both in H and E plane at 3GHz, 7GHz and 10GHz are shown in Fig.2.22. Over the frequency range of RFID tag, UWB antenna confirms omnidirectional radiation pattern. This antenna is not suitable for a wide range of application due to the degradation in the polarisation and radiation pattern. Above 7GHz radiation pattern of the antenna is changing drastically due to the excitation of higher order modes. For most of the angular directions (in E and H plane), the antenna is showing polarisation better than 20dB (below 7GHz), hence it will improve the isolation between received and retransmitted interrogation signal.

![Radiation pattern of the Disc monopole antenna at three different frequencies (3GHz, 7GHz and 10GHz). (a) H Plane and (b) E Plane.](image)

Figure 2.22 Radiation pattern of the Disc monopole antenna at three different frequencies (3GHz, 7GHz and 10GHz). (a) H Plane and (b) E Plane.
2.8. 8 bits Open Stub Resonator Based Multiresonating Chipless RFID Tag

Complete microstrip open stub resonator based multiresonating chipless RFID tag is shown in Fig. 2.23. The receiving and retransmitting disc monopole antennas are connected in such a way that they are orthogonally polarised. The backscattered signal from the retransmitting antenna has been used for the encoding purposes. If all resonators operating at different frequencies (2.08GHz, 2.23GHz, 2.36GHz, 2.56GHz, 2.81GHz, 3.21GHz, 3.61GHz and 4.03GHz) are present, then the bit pattern is 1111 1111. The overall dimension of the RFID tag is 80x60x1.6 mm³.

Figure 2.23. 8 bit RFID Tag with Disc Monopole antenna, G1 = 50mm, G2 = 30mm, dotted line showing the ground at the backside of the substrate (ε_r = 4.4, tanδ = 0.0018 and height = 1.6mm)

2.9. Measurement System

Reader system proposed by S. Preradovic et. al [1]-[3] is opted for the measurement. Agilent PNA E8362B network analyser with transmitted power of 0dBm is used as the RFID reader and two medium gain horn antennas are
used at the reader end for transmitting and receiving signals from the RFID tag. Schematic diagram of the reader system with two cross polarised antennas and proposed chipless tag is shown in Fig.2.24. Proposed system requires proper arrangement with the reader and tag antenna for successful detection of the encoded signal. Fig.2.25 shows the gain of a linearly polarised reader antenna (horn) and tag antenna (disc monopole). In the desired frequency band the reader antenna has a gain of about 8-10dB and for the tag antenna it is about 1.5-4.5dB. Calibrations are not required to get the backscattered signal from the retransmitting antenna for a distance of 40cm due to the orthogonal polarisation arrangement of the RFID system. From the Friis transmission equation, the readable range of the tag can be further improved by setting high gain antennas at the reader and tag ends. Increasing the power from the microwave source can also be used to increase the range.

![Schematic diagram of the measurement system using Agilent PNA E8362B.](image)

**Figure 2.24** Schematic diagram of the measurement system using Agilent PNA E8362B.
The RFID tag decoded up to a distance of 1-2 meters are reported in the literature, but it requires complex calibration procedure [20] - [21] including reference measurements with metal sheets and time domain gating, etc. These calibration techniques will create complex measurements which is not suitable for practical applications.

2.10. Result and Discussion

All the measurements are carried out inside the anechoic chamber and the measurement setup is shown in Fig.2.26. As shown in the figure, the RFID tag is placed at a distance of 40cm away from horn antennas. Identification of each bit is very clear from magnitude and group delay measurements. The typical response of the RFID tag for 1111 1111, 1001 1110, 1001 1010 and 1001 0010 bits are shown in Fig.2.27 to 2.30, respectively. All the bits can be identified from the backscattered magnitude and group delay signal. RFID without antenna in Fig.2.27 to 2.30, means the direct measurement of multiresonator circuit as shown in Fig.2.18. The band
notches are well defined and in the worst case the magnitude of the dip is better than 5dB. From the figure, it is well understood that the magnitude and group delay can be conveniently used for reading the tag.

![Figure 2.26 Measurement setup inside the anechoic chamber](image1)

![Figure 2.27 Measured backscattered response (Magnitude and Group delay) of RFID tag (11111111)](image2)
Figure 2.28 Measured backscattered response (Magnitude and Group delay) of RFID tag (10011110)

Figure 2.29 Measured backscattered response (Magnitude and Group delay) of RFID tag (10011010)
Proposed system successfully measured backscattered amplitude and phase (group delay) variation of different multiresonator based tag up to a distance of 40cm. Hence the system can be adopted for applications like automatic identification of items in the conveyor belt. The barcode technology can be replaced with the proposed system, providing proper arrangement with the reader.

2.11. Conclusion

A novel RFID tag with multiple open stub resonators is proposed in this chapter. The quarter wavelength resonance of the open stub resonator makes proposed tag more compact than other existing tags. Equivalent circuit model with different parametric studies are conducted on the open stub resonator. The tag enables to encode data in magnitude as well as in group delay. Without having any additional calibration technique, the proposed system is able to decode the tag information up to a distance of 40cm. The method introduced in this chapter can be effectively implemented using low cost substrate materials which in turn reduce the overall cost.
2.12. Reference


Arnaud Vena, Etienne Perret and Smail Tedjini “RFID Chipless Tag Based on Multiple Phase shifters” Microwave Symposium Digest (MTT), 2011 IEEE MTT-S International, pp.1-4, 5-10 June 2011.


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