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DEVELOPMENT OF MULTIRESONATOR BASED CHIPLESS RFID TAG USING ANSYS HFSS SOFTWARE

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Abstract

In this research article, compact multiresonator based chipless RFID tag employing open stubs in a microstrip transmission line has been presented. The multiresonator tag consists of microstrip open stub resonators and cross polarised transmitting and receiving disc monopole antennas. Nine bit data encoding capacity of multiresonator circuit and wideband disc monopole tag antenna is simulated in ANSYS HFSS software. This Chipless RFID tag is simulated on a FR4 substrate of dielectric constant 4.3 and loss tangent 0.0018 and the backscatter signal performance of multiresonator tag and operating bandwidth of disc monopole antenna is analysed.

Keywords: Chipless RFID, Multiresonator circuit, Antenna, Cross polarisation, Ultra Wideband

1. Introduction

Chipless Radio Frequency Identification (RFID) has become very interesting research area in recent years. As its name itself mentioned, chipless RFID is a contactless data-capturing technique, which uses RF waves for wide range of application such as Supply Chain Management (SCM), health care, traffic monitoring, retail, access control automatic identification (ID) of objects, tracking, security surveillance etc. RFID technology was introduced during the 2nd World War for the identification friend aircrafts. In this method friend aircraft is identified from enemy aircraft by assigning a unique identifier code to aircraft transponders. In 1945, the first RFID tag was developed by Leon Theremin known as "The thing" or "spy device" because it captures human voice sound waves. The function of the thing, it's membrane of the cavity vibrates in accordance with the sound conversation in the room. This will alter the impedance of the cavity and hence changes the antenna impedance. Therefore an incident current on the antenna is modulated with sound waves. The backscattered signal is demodulated at the receiver.

RFID was first proposed by H. Stockman. He has introduced RFID systems in his landmark paper Communication by Means of Reflected Power. Stockman advocates that considerable research and development works need to be done to solve the basic problems of wireless identification by means of reflected power. Nowadays RFID tags haven't replaced the barcode is due to the price of the tag which is still much higher when compared to the price of the barcode. Hence, a huge amount of investments and investigations focusing on lowering the price of the transponder have been put in motion, Even though the conventional RFID has numerous advantages like specificity in information, long read range and mass storage of data, its growth has been slow down mainly because of the economical reasons and RFID is now becoming a major player in the commercial market. Due to this rapid research the price of the RFID tag is getting lower and lower every year. RFID system contains three main modules these are RFID reader, RFID tag, and middle software and it has shown in the Figure 1. RFID tags are to store a unique identification number in the chip, same as that of a barcode or a magnetic strip on the back of a credit card or ATM card. To retrieve information stored in the bar code or magnetic strip, the device must be scanned in a close proximity with its scanning device. Each tag carries information such as serial number, model number, location of assembly in the case of Electronic Product Code (EPC). According to the application read range requirement, RFID divide into three categories. These are LF (1 meter), HF (2 meter), and VHF (10 – 12 meter). Commonly used frequencies at microwave band for RFID technologies are2.45GHz and 5.8GHzandwhy are we going RFID into chipless RFID Tag? The reason is following to below.

- Chipped RFID tags are fabricated on a Silicon wafer and there is a fixed cost per wafer (around US $1,000).
- Design on Silicon wafer and testing along with the tag antenna result in a costly manufacturing process.
- We need some space to fix the chip in RFID tag.

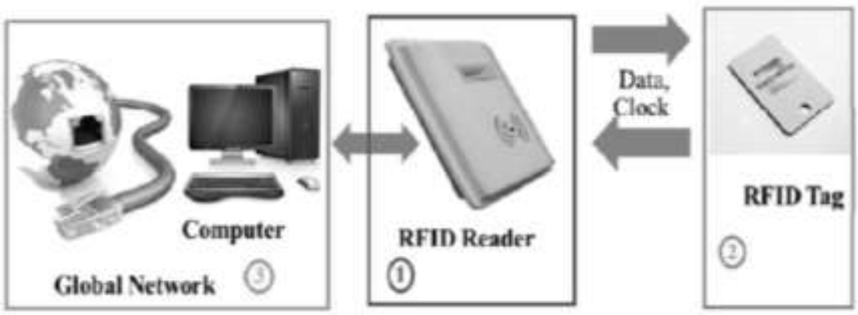

Figure 1 Block Diagram of the RFID Systems

2. Chipless RFID System

Chipless RFID tag is store the unique identification number without the silicon chip. In this type of tag, unique number is store in time or frequency domain of the interrogation signal. It's based on using the electromagnetic properties of materials or designing various conductor properties of tag. Chipless RFID tag implementation divided into two categories. These are time domain reflectometry and Spectral signature based tags. Time domain based has two types. These are following below

- Surface Acoustic Wave(SAW) tags
- Delay line based tags Spectral signature based tag has two types. These are following below
- Multiresonator Based tag
- Multiscaterrer based tag

Spectral signature based tag is fully printable but time based tag is not fully printable. Time based tag train of pulses is thereby created by tag, which can be used to encode data. Spectral signature-based chipless tags use a specific frequency band to encode data using resonant structures and Spectral based tag gives better encoding capacity compare to time domain reflectometry. Each data bit is usually associated with the presence or absence of a resonant peak or dip at a predetermined frequency in the spectrum. The advantages of these tags are, they are fully printable, robust, greater data storage capability and low cost.

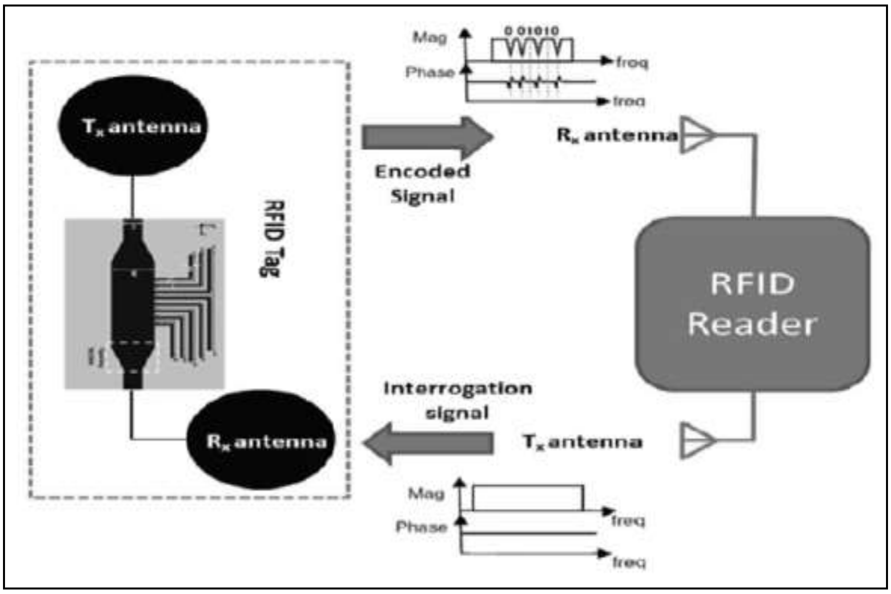

Figure 2 Block diagram of Multiresonator based Chipless RFID Tag

A block diagram of a multiresonator based tag with basic components is shown in Figure 2. The chipless RFID tag consists of a vertically polarized UWB disc-loaded monopole receiving tag antenna, a multiresonating circuit, and a horizontally polarized UWB disc-loaded monopole retransmitting tag antenna. The tag is interrogated by the reader by sending a frequency swept continuous wave signal with constant amplitude and phase. When the interrogation signal reaches the tag, it is received using the receive monopole antenna and propagates towards the multiresonating circuit. The multiresonating circuit encodes data bits using open stub resonator resonators, which introduce amplitude attenuations and phase jumps at particular frequencies of the spectrum. After passing through the multiresonating circuit, the signal contains the unique spectral signature of the tag, and is transmitted back to the reader using the transmit monopole tag antenna. The receiving and retransmitting tag antennas are cross polarized in order to minimize interference between the interrogation signal and the retransmitted encoded signal containing the spectral signature. In multiresonator circuit, due to open stub resonator create more insertion loss with number of resonators.

3. Design of Multiresonator Circuit and Disc Monopole Antenna

3.1 Multiresonator Circuit Design

Multiresonating circuit is designed to attenuate particular frequency in the desired band. Multiresonator will alter the amplitude and phase of the interrogating signal. Size of the multiresonating circuit depends on the number of the parameters of operating frequency bands, separation between the resonators, dielectric properties of the substrate. In various types of the multiresonating techniques, the sizes of the proposed resonators are small compared with other tags working on the same frequency. Structure of the multiresonator circuit has shown in Figure 3. Advantage of open stub resonator is directly connected to the transmission line.

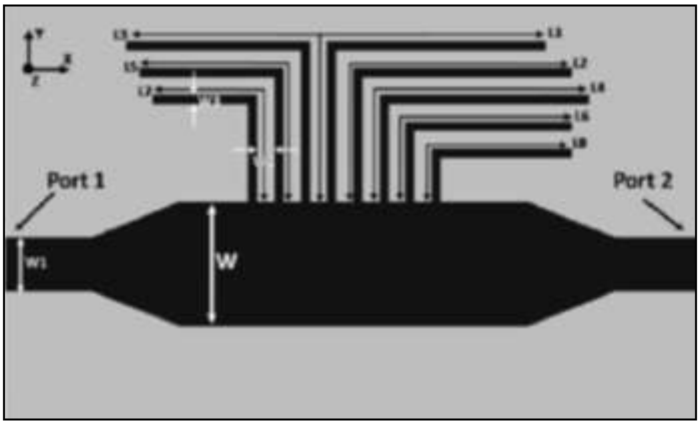

Figure 3 Structure of Eight Bit Multiresonator Circuit using Open Stub Resonator

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 λg/4 open stub is demonstrated in Figure 4, where λg is the guided wavelength at the operating frequency. Ansys HFSS software is used for the simulation analysis.

Table 1 Multiresonator Circuit Transmission Line Width and Length Values

Transmission line width and length	Value (mm)
W	7
W1	3
W2	1
W3	0.5
L_f	17.59
L_{tx}	16.84
L_P	12
L1	21
L2	19.5
L3	19
L4	17.5
L5	12.25
L6	13.5
L7	11.5
L8	10.5

To make compact tag, ‘L’ shape open stub resonator is placed on the transmission line as shown in Figure 4. 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 (λg/4). To minimize the mutual coupling between the two resonators they are kept 1mm apart. Specification of the design is given below:

- Substrate = FR4
- Dielectric permittivity = 4.3
- Substrate height = 1.6 mm
- Tangent loss = 0.0018
- Conductor thickness = 30 µm
- Character impedance = 50 Ω

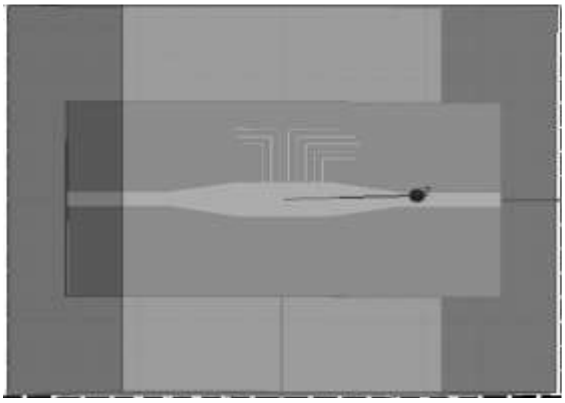

Figure 4 Design of the Eight Bit Multiresonator Circuit using Open Stub

To reduce the impedance mismatch between antenna terminal (50Ω) and microstrip transmission line (28Ω), an impedance transformer section (tapering section) is also included. The length of this tapering section (LT) is equal to 0.25λd, where, λd 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 Figure 4. 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.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. The eight bit multiresonator circuit design using microstrip open circuit resonator is given unique identification code is 11111111.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 minimize the frequency shift in the multiresonating circuit. Connection removed multiresonator circuit design is shown in the Figure 5, which is unique identification number is 1011111.

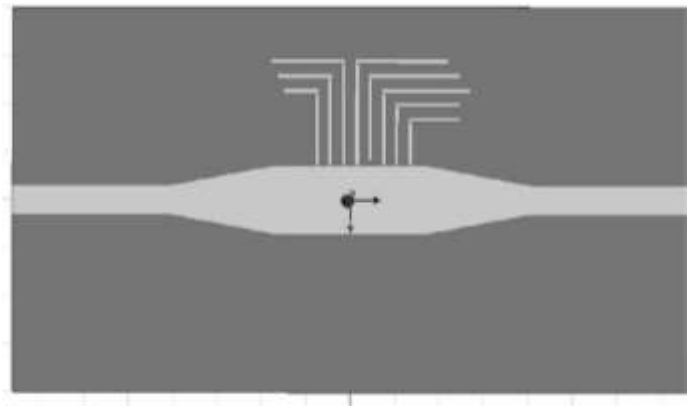

Figure 5 Design of the Multiresonating Circuit with Disconnected Open Stub Resonators

This 8-bit multiresonator circuit design can create 256 unique identification code using presence or absence of resonance coding techniques Nine bit encoding capacity of multiresonator circuit has designed and it has shown in the Figure 6. It unique identification number is 111111111. If you want create more unique identification code, you will increase the number of the microstrip open stub resonator.

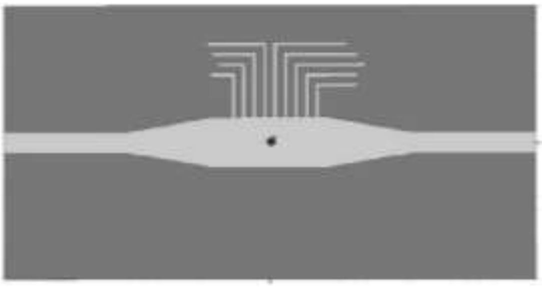

Figure 6 Design of Nine Bit Data Capacity of Multiresonator Circuit using Open Stub Resonator

3.2 Wideband Disc Monopole Antenna Design

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

$$S = \frac{P_t G_r}{4\pi r^2}$$

Where Pt 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

$$P_a = sA_e = \frac{s\lambda^2 G_t}{4\pi}$$

A_e is the effective area of the tag antenna, G_t is the gain of the tag antenna and λ 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

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

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 polarization isolation between the reader antennas and environmental conditions (interference from different wireless systems, scattering from stationary objects, etc.) Selection of UWB antenna in the multiresonator based tag depends on impedance match, polarisation, radiation pattern and overall size. Specification of the design is given below

- Substrate = FR4
- Dielectric permittivity = 4.3
- Substrate height = 1.6 mm
- Tangent loss = 0.0018
- Conductor thickness = 30 µm
- Character impedance = 50 Ω

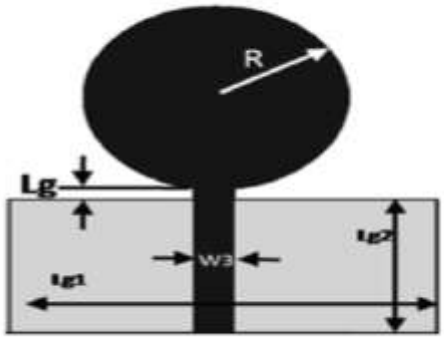

Figure 7 Structure of Ultra Wide Band Disc Monopole Antenna

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. Figure 7 shows the geometry of the monopole antenna, along with the design parameters.

Table 2 Antenna Transmission Line Width and Length Values

Transmission line width and length	Value (mm)
W_3	3
L_g	0.6
L_{g1}	40
L_{g2}	20
R	15
W_3	3

The antenna shows very good impedance match over operating range of multiresonator circuits. In order to minimize the interference between the interrogation signal and the encoded signal, we have cross polarized the transmitting and receiving antennas of the transponder. Another advantage of having cross-polarized antennas is that it minimizes noise interference at the reader's receiver end due to the fact that the receiver is "looking" for a particularly polarized signal as shown in Figure 8. The concept of frequency signature is based on encoding a N-bit digital word with N frequencies where each bit is represented by a single frequency and the variation of the amplitude. Return loss S (1,1) of the UWB disc monopole antenna must above in -10 dB . Then only maximum of the power pass through the conductor. Over the frequency range of RFID tag, UWB antenna confirms omni directional radiation pattern. For reducing the external noise, simulation doing in the closed area and it has shown in the Figure 9. The frequency range of RFID tag, UWB antenna confirms omni directional radiation pattern.

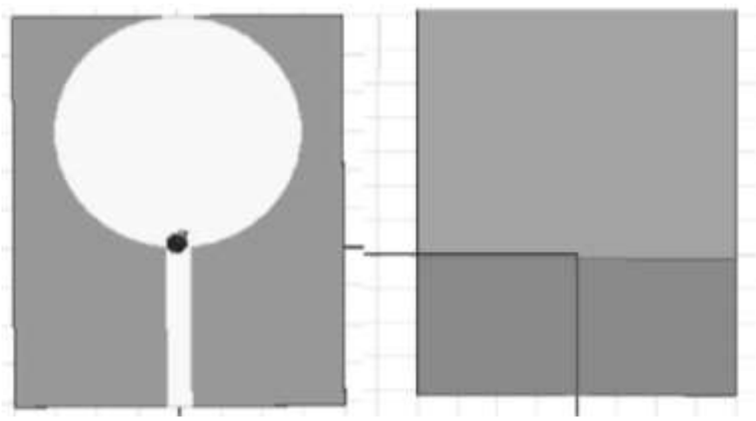

Figure 8 Different View Design of Ultra-Wideband Disc Monopole Antenna

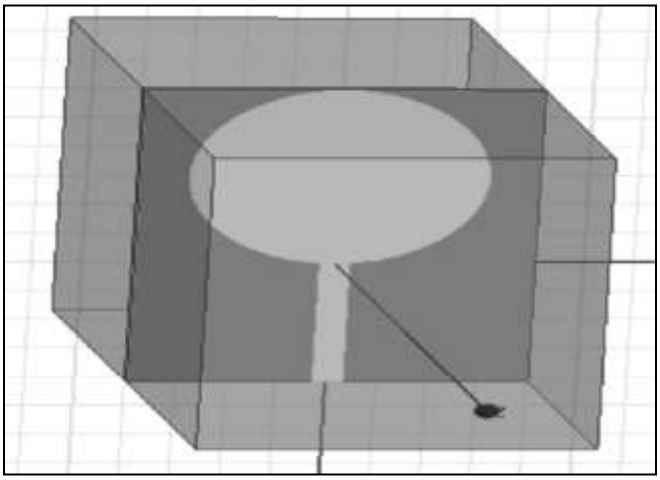

Figure 9 Design of UWB Disc Monopole Antenna is placed in the Closed Surface Area

4. Result and Discussion

4.1 Result of Multiresonator Circuit

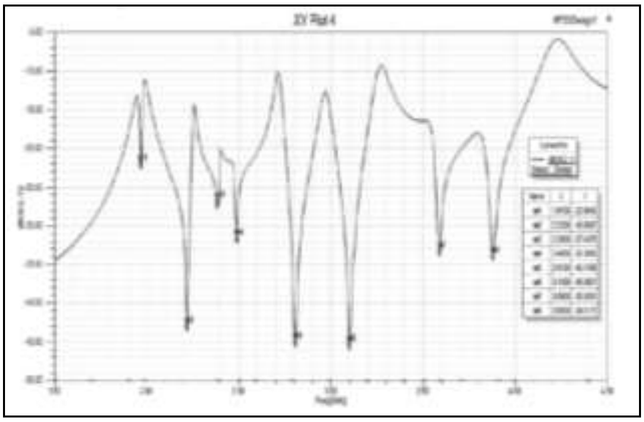

Figure 10 Resonance of Eight Multiresonator Circuit Design

The resonant frequencies of the circuit are found to be at 1.97GHz, 2.22GHz, 2.39GHz, 2.49GHz, 2.81GHz, 3.1GHz, 3.59GHz and 3.88GHz.Absence or Presence Coding technique is used in the design of present tag, hence one resonator represents 1 bit of information. The presence of the resonance at a predefined frequency indicate bit 1 and absence will indicate bit 0.The eight bit multiresonator circuit design using microstrip open circuit resonator as shown in Figure 10 is given unique identification code is 11111111. 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 minimize the frequency shift in the multi resonator circuit. In eight bit and nine bit data stub resonators multiresonator circuit designs resonance is above -10 dB.

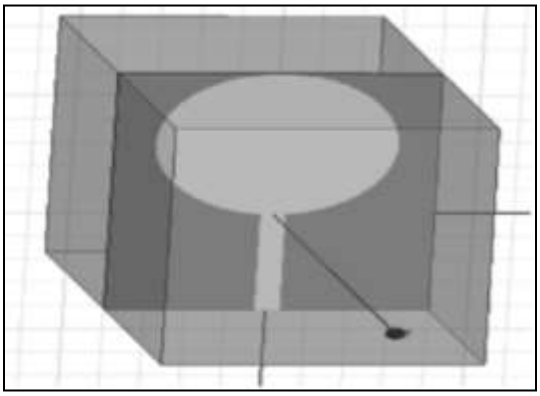

Figure 11 Resonance of Multiresonating Circuit with Disconnected Open

Every resonance is indicates one bit of the unique identification code. Connection removed multiresonator circuit design is shown in the Figure 11 which is given unique identification code 10111111. This 8-bit multiresonator circuit design can create 256 unique identification codes using presence or absence of resonance coding techniques. Current flow in port of multiresonator circuit is shown in the Figure 12.

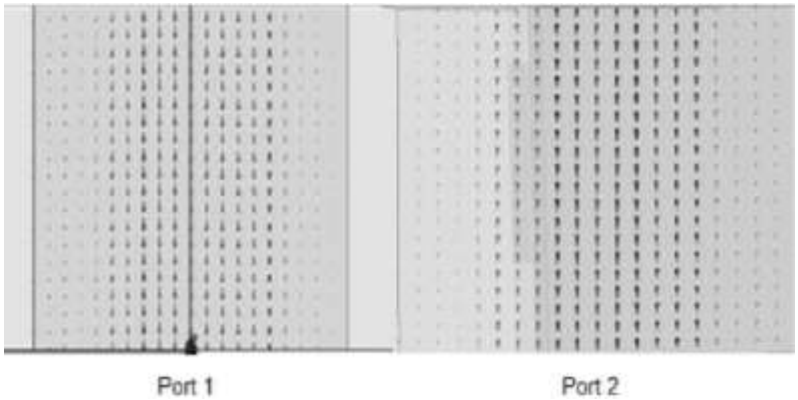

Figure 12 Current flow in the Multiresonator Circuit Port 1 & 2 Transmission Lines

Nine bit data capacity of multiresonator based tag resonance is shown in the Figure 13. The nine bit data capacity structure of multiresonator circuit design can generate 512 unique identification codes using presence or absence of resonance coding techniques. If you want create more unique identification code, you will increase the number of the microstrip open stub resonator. Current distribution of the multiresonator circuit is shown in the Figure 14. Current distributions of multiresonator circuit have less emission because of the uniform surface. Blue color indicate less emission value and red color indicate high emission value in the below Figure 14.

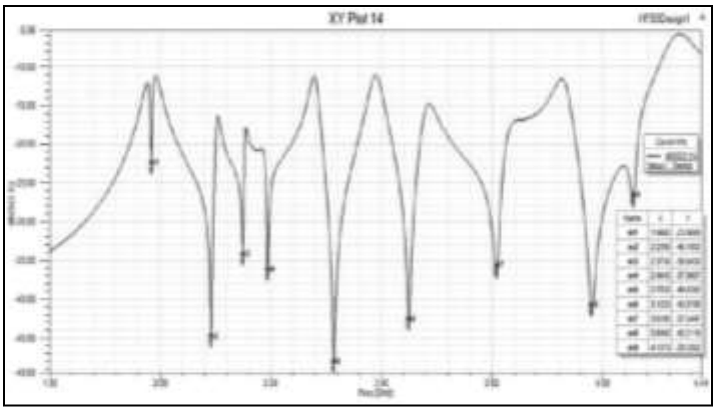

Figure 13 Resonance of Nine Bit Open Stub Multiresonator Circuit

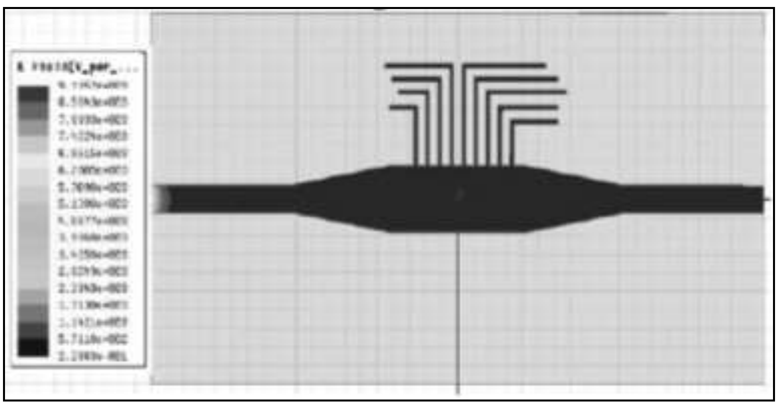

Figure 14 Current Distribution of the Modified Multiresonator Circuit Design

4.2 **Result of Disc Monopole Antenna**

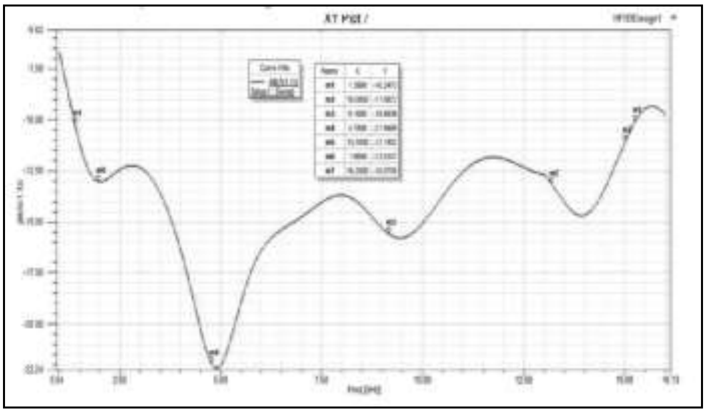

Figure 15 Reflection Characteristics of UWB Monopole Antenna

Return loss of UWB disc monopole antenna is above -10 dB from 1.39 GHz frequency to 15.25 GHz. It means 0.1 percentage of input signal reflected back. Reflected characteristic has shown in the Figure 15. We can generate resonance in between frequency from 1.39 GHz to 15.25 GHz. Especially in 5 GHz ISM frequency return loss value 0.01 percentage. UWB disc monopole antenna bandwidth is 13.86 GHz.

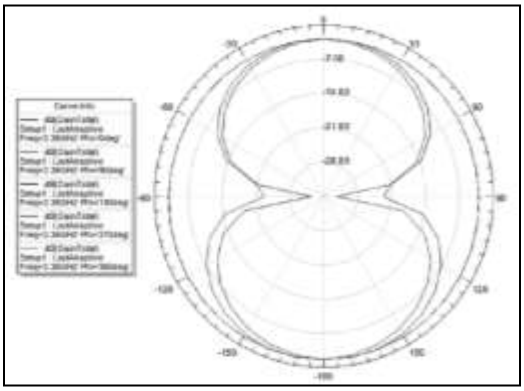

Figure 16 Radiation Pattern of Ultra Wide Band Disc Monopole Antenna

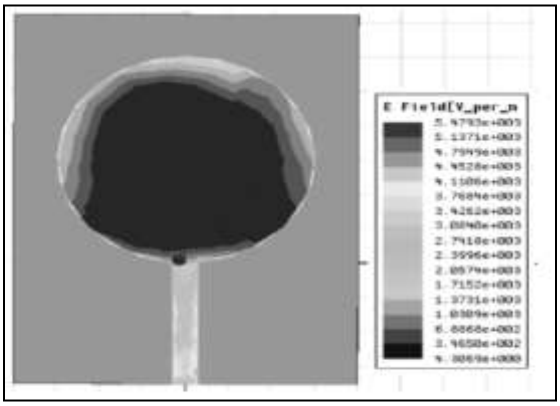

Figure 17 Current Distribution of Ultra-Wide Band Disc Monopole Antenna

Radiation signal power of antenna is maximum at 0 and 180 degrees. Current distribution of the ultra-wide band disc monopole antenna has shown in the Figure 16. It is emitting maximum power of 5.48 e^3 V/m. Current distribution of UWB disc monopole antenna has less emission because of the uniform surface. Uniform surface is needed for successful reception and retransmission signal as shown in Figure 17. Current flow in the port of monopole antenna has shown in the Figure 18. Current flow indicates upper side that mean current pass to conductor of the antenna.

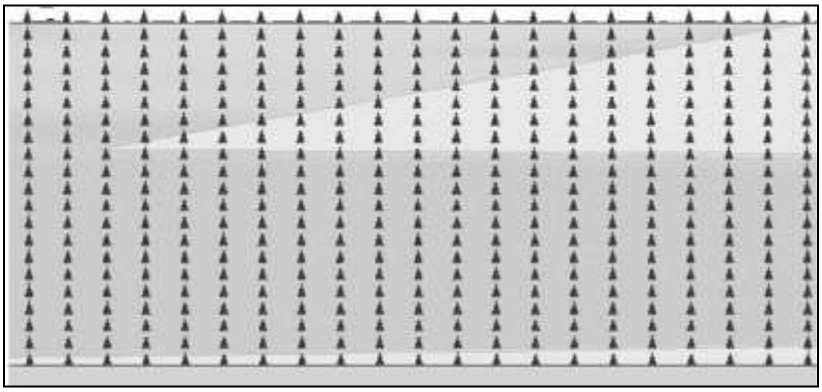

Figure 18 Current Flow of Port Transmission Line in Monopole Antenna

5. Conclusion

The proposal of nine bit microstrip open stub multiresonator circuit and UWB disc monopole antenna was done in this project. This chipless tag enables to encode data in magnitude and phase. Advantages of this tags are, they are fully printable, robust, greater data storage capability and low cost. The quarter wavelength resonance of the open stub resonator and advantage of tag makes proposed tag more compact than other existing tags.

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