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Spectral Signature Based Chipless RFID Tag Loaded by Meandered Line Multi-Resonator

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Abstract—A meandered line multi-resonator design is proposed for a chipless Radio Frequency Identification (RFID) tag. The tag is equipped with a set of identical resonant elements and two orthogonally polarized monopole ultrawide band (M-UWB) antennas. The proposed multi-resonator design is realized on an FR-4 substrate ($\varepsilon_r = 4.4$; $\tan\delta = 0.01$) in a surface area of $13 \times 17\,\mathrm{mm}^2$, occupying a coding density of $4.52\,\mathrm{bits/cm}^2$ by encoding 10 bits of data. The bit is encoded using absence/presence coding and frequency shift coding technique. The data can be read and transmitted from the multi-resonator structure through the orthogonally polarized M-UWB antennas operating in the frequency range of 2 GHz to 4.5 GHz. The span of the meandered line multi-resonator design is $13\,\mathrm{mm} \times 17\,\mathrm{mm}$. The tag is designed using ADS software and tested using vector network analyzer (VNA).

1. INTRODUCTION

RFID is the next generation of bar code technology and non-contact automatic identification technology. RFID tag can be used to track and identify products automatically in large scale manufacturing industries. The bar code technology requires line of sight scanning with closer proximity, and each scanner sees one code at a time. Further, it is not a secure means of identification, and scratched and crumbled codes can also cause problems. The limitations of barcode can be overcome by RFID technology which uses radio waves to transmit information and also requires less need of human intervention with non-line of sight operations. A complete RFID system consists of an RFID tag (transponder), middleware software, and a reader.

RFID can scan more than 100 tags simultaneously with secure and robust higher data storage capability. The only drawback of RFID is that it uses electronic circuits to encode data bits, which makes them expensive. Hence, the need of chipless RFID tag has been demanded amongst the small-scale manufacturers and low-priced products.

The encoding of bits in chipless tag becomes a challenge without the circuits. However, the data can be coded using RF waves either in time domain or in frequency domain. In time domain-based tags, piezoelectric substrate with reflectors or delay lines can be used for encoding data bits. Even though a piezo-electric substrate offers greater storage, it is expensive equivalent to chipped tags. In frequency domain-based tags, the bits are encoded with the linear correspondence between radiating structures and resonant peaks.

Chipless tags can be designed either with multi-resonators or multi-scatterer based approach. In multi-resonator-based tags [17], multiple resonating elements with transmission line are connected with the two orthogonally polarized antennas for transmission and reception of data. In multi-scatterer based

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approach [6, 18], the elementary coding particles can transmit and receive the data from the RFID tag using backscattering method which is similar to radar principle.

In this paper, the spectral signature tag in retransmission-based approach is proposed by designing a microstrip transmission line loaded with multiple meandered line resonators (to reduce the size). The multi-resonator structure used in the chipless tag can be designed with different shapes to obtain varying resonant frequency ranges.

In [1], multi-resonators are designed with L-shaped resonators with a tapering section in the transmission line. In [2], the authors proposed a meander line resonator using a Taconic substrate ($\varepsilon_r = 2.75$; $\tan\delta = 0.0003$) by encoding 6 bits of information with UW-M-antenna with dimension of 30 mm × 35 mm occupying frequency range of 3 GHz to 4.5 GHz. In [3], a short stub resonator with bit capacity of 8 bits in absence/presence coding realized in C-MET/LK4.3 of substrate ($\varepsilon_r = 4.3$; $\tan\delta = 0.00018$) is discussed.

Multi-resonators can also be defined as band-stop filter structures that stop many bands of frequencies at a time. Such band-stop filters designed using embedded and spur line open stubs are discussed in [4, 5, 14]. In [7], the rectangular and circular ring resonators are realized on a Taconic substrate ($\varepsilon_r = 2.45$) with single bit resonating at 2.45 GHz loaded on a 50Ω transmission line. The wideband microstrip band-stop filter with combination of a spur line and an open stub filter is proposed to achieve high rejection of 60 dB in wideband occupying frequency range of 2.3–5.7 GHz [8].

An ORR structure resonator is proposed for 3-bits on an RO3010 Rogers substrate ($\varepsilon_r = 10.2$; $\tan\delta = 0.0022$). The bits are encoded by varying ring gap width in different angular positions with single ORR occupying $20 \times 20\,\text{mm}^2$ [9]. Dual-band resonators for a chipless RFID tag is designed in [10]. In [11], an asymmetric hairpin shaped resonator is proposed to encode 8 bits of data using absence/presence coding technique. The spur line multi-resonator structure capable of encoding 8 bits of data is realized on MET/LK4.3 with two folded monopole antennae for transmitting and receiving [12].

Microstrip E-shaped multi-resonators are placed on either side of the transmission line and are coupled in [13]. The multi-spur line filter with a meandered slot line which acts as a high-performance band-stop filter is designed in [15]. The split open loop resonator is placed inside the transmission line to occupy the capacity of 8-bit data within the surface area of $28 \times 13.2\,\text{mm}^2$ [16].

In [1], a chipless RFID tag is designed using shorted stub resonators. A half wavelength stub is shorted to ground through a hole connected at its far end to the microstrip transmission line. To overcome the limitations of the shorted stub multi-resonators, an open stub multi-resonator structure is designed.

2. MULTIRESONATOR DESIGN

2.1. Simple Line Multiresonator Design

The simple open stub multi-resonator design (Figure 1) with quarter wavelength λ_g (where λ_g is the guided wavelength) is designed and proposed. The design is realized on a low-cost FR4 substrate ($\varepsilon_r = 4.4$; $\tan\delta = 0.01$) with transmission line of area 17 mm × 3 mm × 1.6 mm. The radiating patch is with 30 μm thickness. To reduce the mutual coupling between the resonators, the stubs are adjusted parametrically and kept 1 mm apart. Hence, on designing open stubs, the size of the multi-resonator structure can be reduced by up to 50% for that of the shorted stub multi-resonator design. However, the 10-bit multi-resonator structure as shown in Figure 2 has an overall dimension of $23.8 \times 17 \times 1.6\,\text{mm}^3$ occupying a frequency range of 2 GHz to 4 GHz.

2.2. Meandered Line Multiresonator Design

The area of the multi-resonator-based tags (Figure 4) can be greatly reduced by choosing meandered line shape. A meandered line can be squared, mitered, or curved. A meandered line has specifications such as line length, feed length, width of the line, and spacing between the bends. The orientation of the line can be either horizontal or vertical. It can also be laid out in a clockwise or anti-clockwise direction. All these specifications have to be carefully selected during the design of the multi-resonator structure.

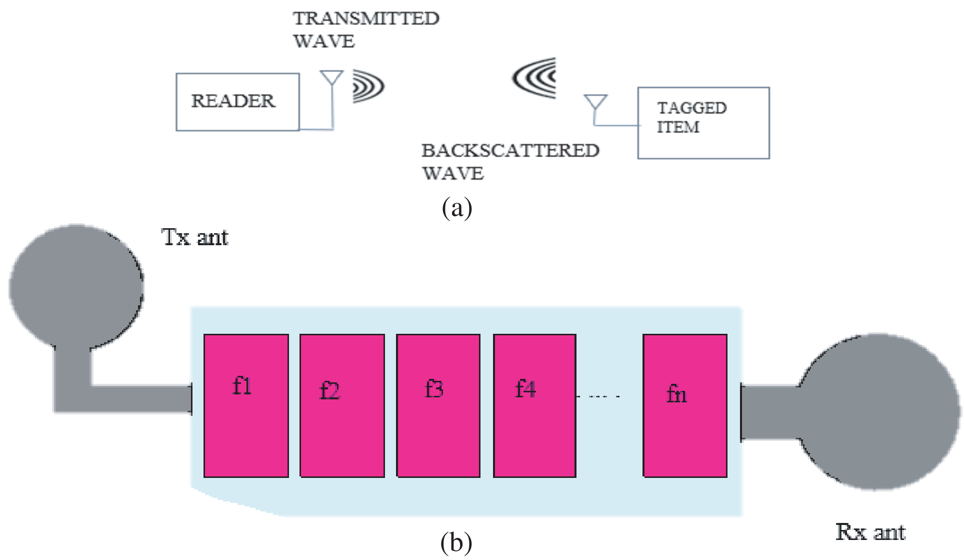

Figure 1. (a) Principle of Multi-scatterer tags. (b) Multi-resonator or retransmission-based tags.

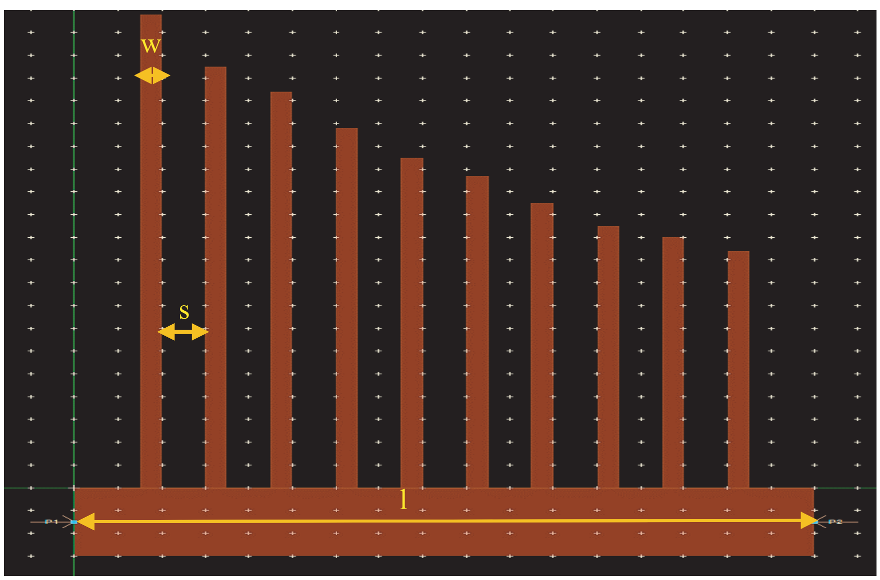

Figure 2. Layout of a 10-bit simple line multi-resonator structure ($l = 17\,\text{mm}$, $w = 0.5\,\text{mm}$, $s = 1\,\text{mm}$).

Specifications of the meander trace can be explained by Figure 3. In Figure 3, 'fl' denotes the length of the feed, 'w' the width of the stub, and 's' the spacing between the bends of the stub. It can be seen that the length of the resonators is maintained the same throughout its length. The colored line running throughout the stub represents the line length of the meandered line. Due to the ease of fabrication and compactness of the stub placement, the feed length, width of the line, and the spacing between the bends are all kept as 0.3 mm. The line length for the meandered line is varied accordingly such that the stub resonates at different frequencies.

The geometry of the proposed multi-resonator design is given in Figure 3, and the length of each resonator is given in Table 1. Unlike the open stub line multi-resonator structure, the operating frequency range is extended here due to the complications that arise from mutual resonance. The operating range of the meandered line multi-resonator design is from 2 GHz to 4.5 GHz. 10 stubs are loaded along with the 50 Ω transmission line of length 17 mm and width 3 mm.

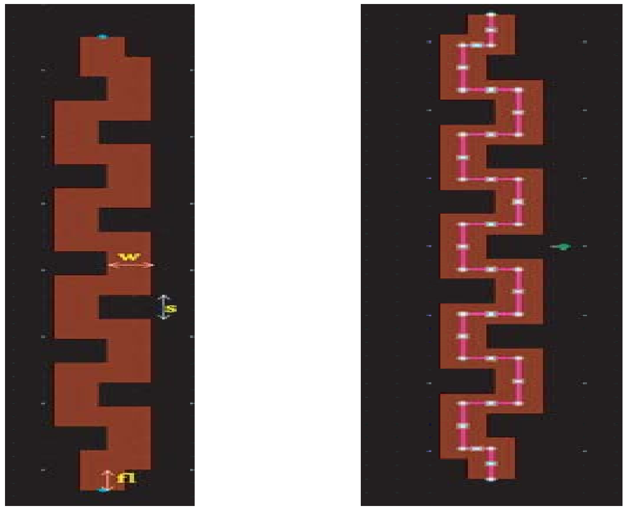

Figure 3. Specifications of a meandered line ($fl = 0.2\,\mathrm{mm}$, $w = 0.5\,\mathrm{mm}$, $s = 0.3\,\mathrm{mm}$).

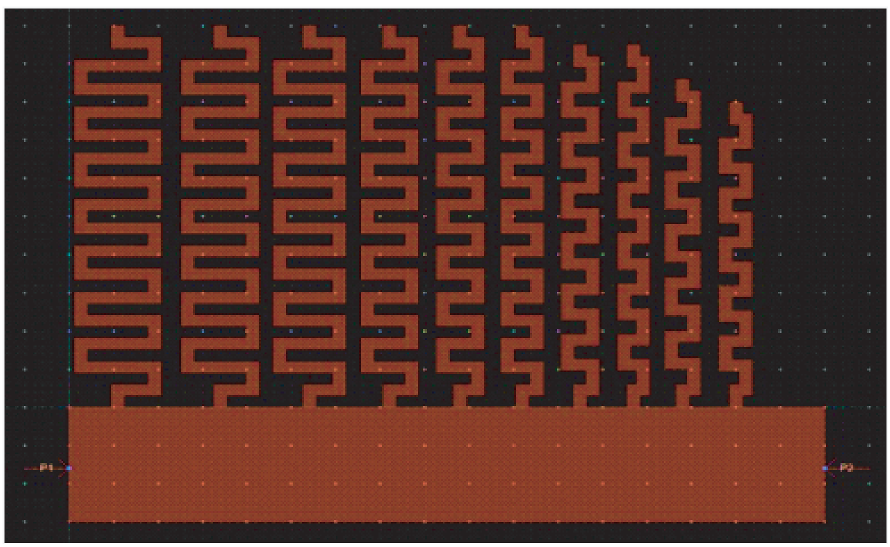

Figure 4. Layout of a 10-bit meandered line multi-resonator design.

3. CODING TECHNIQUES

There are various coding techniques involved in the encryption of RFID tag. Two techniques are used here.

3.1. Absence or Presence Coding Technique

The absence or presence coding technique is the simplest method used in the coding of the multi-resonator design. Each stub in the multi-resonator structure is made to resonate at a particular frequency. The presence or absence of resonant peak at designed frequencies is used to encode the bit as '0' or '1', respectively. To be precise, when there is a resonant peak at one of the 10 frequencies designed, that bit can be encoded as '1' else as '0', i.e., there 1 : 1 correspondence between the resonators and encoded bits. Thus, each multi-resonator structure is used to represent 10 bits which can provide a maximum of 1024 unique identification codes.

Table 1. Summary of the proposed meandered line multi-resonator length.

Resonating Frequency (GHz)	Line length of meandered stub (mm)
2.11	35
2.32	32
2.57	30
2.81	25
3.04	22
3.24	20
3.52	17
3.75	15
4.0	14
4.21	12.5

3.2. Frequency Shift Coding Technique

The frequency shift coding is one of the coding techniques for increasing encoding capacity in chipless RFID tags. It is based on the principle that stubs of different lengths resonate at different frequencies by decreasing the feed length of the stub by a minimal amount, and the stub is made to resonate at a slightly higher frequency. Each resonant frequency corresponds to a unique bit. The frequency at which the stub resonates represents the bit to be encoded. This is far more effective than the absence or presence coding technique. The increase in feed length has to be smaller such that the resonant frequencies are packed in a particular bandwidth. The frequency shift has to be as small as possible. The resonant frequency and the bandwidth to be allotted have to be defined clearly.

In this meandered line multi-resonator design (Figure 5), four stubs are used for the frequency shift coding. Each stub is used for representation of one data bit out of nine bits. In this technique, 6561 different identification codes can be created with different data bit combinations.

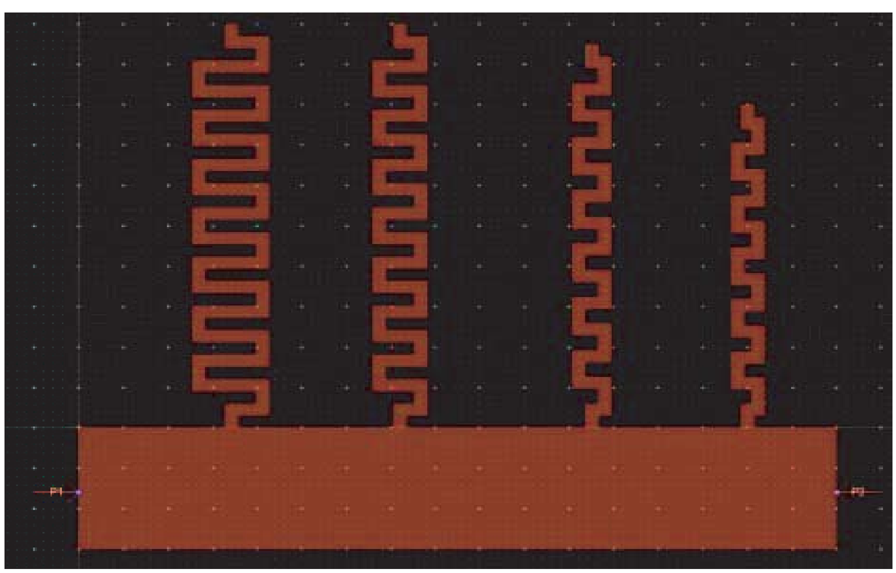

Figure 5. Layout of meandered line multi-resonator structure for frequency shift coding.

4. RESULTS AND DISCUSSIONS

The simulated results for various meandered line multi-resonators are discussed in this section. The multi-resonator structure is simulated using the ADS software and then tested in a vector network analyzer after fabrication.

4.1. Absence or Presence Coding Technique

The fabricated multi-resonator structure on an FR4 substrate ($\varepsilon_r = 4.4$; $\tan\delta = 0.01$) is shown in Figure 6.

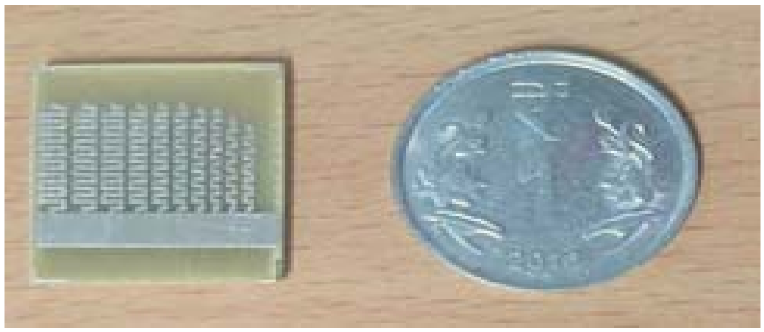

Figure 6. Fabricated meandered line multi-resonator structure.

With the proposed open stub meandered line multi-resonator design, dimensions are $13 \times 17 \times 1.6\,\text{mm}^3$. It can be seen that there is a reduction of nearly 45.3% in the length of the multi-resonator structure. The size of the multi-resonator structure is reduced to almost half of the size of the open stub line multi-resonator structure. Thus, the objective of designing a compact size multi-resonator structure is achieved by the meandered line. However, the operating range has to be increased for this type of multi-resonator design.

The insertion loss characteristics taken in the vector network analyzer (Figure 12) are compared with the simulated results in ADS (Figure 7). The resonant frequencies of these stubs are found at 2.11 GHz, 2.32 GHz, 2.57 GHz, 2.81 GHz, 3.04 GHz, 3.24 GHz, 3.52 GHz, 3.75 GHz, 4 GHz, and 4.21 GHz.

4.2. Frequency Shift Coding Technique

Four stubs are used in this multi-resonator design. Each stub can be used for the encoding of 1 bit. The feed length of each stub is increased by 0.2 mm to get resonance at a lower frequency than the previous resonance. Thus, each stub is made to resonate at 9 different frequencies. Hence, a stub can represent 1 bit out of total 9 bits. The bandwidth must be suitably allocated for each bit that the stub can represent. For example, each stub can represent any number from 0 to 8. The stub with feed length 1.7 mm and line length 32 mm which resonates at 2.03 GHz represents '0'. Then when the feed length of the stub is decreased by 0.2 mm (1.5 mm) and the line length kept unchanged, it resonates at 2.05 GHz representing '1'. When the feed length is further reduced to 1.3 mm, it resonates at 2.07 GHz representing '2' and so on.

To explain precisely, the length of each stub is varied, and results are analyzed separately. Initially, the feed lengths of all the stubs are kept as 1.7 mm. The line lengths of the stubs are kept as 32 mm, 24 mm, 17 mm, and 13 mm, respectively.

For tuning of the first stub, the feed length of the stub is decreased by 0.2 mm every time, and the feed lengths of the other stubs are kept constant. The feed length of the first stub is varied by decreasing 0.2 mm for nine times so that the stub resonates at 9 different frequencies. The tuning of the first stub is shown in Figure 8, the tuning of the second stub in Figure 9, the tuning of the third stub in Figure 10, and the tuning of the fourth stub in Figure 11.

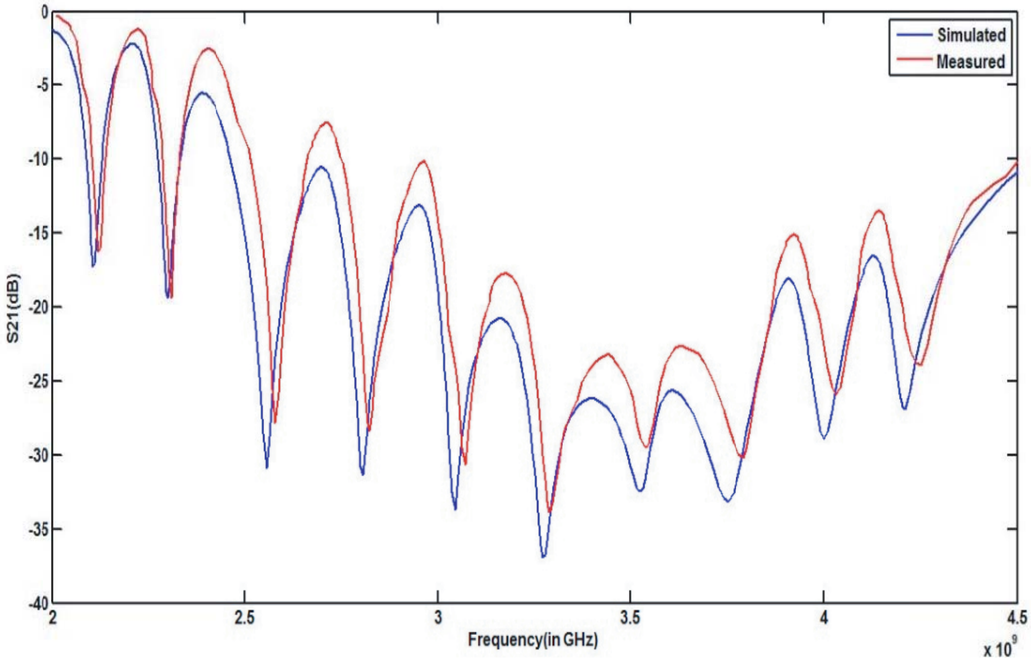

Figure 7. Measured and Computed S_{21} magnitudes of a 10-bit meandered line multi-resonator structure.

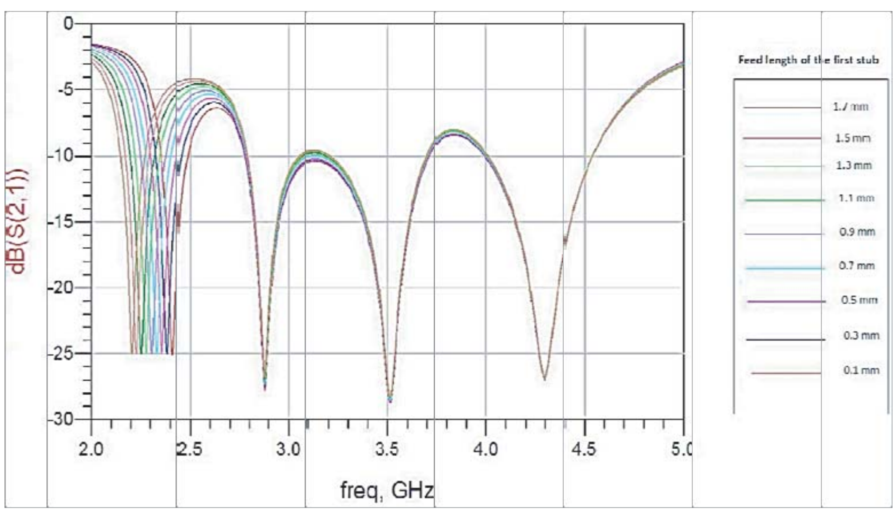

Figure 8. Tuning of the first stub of meandered line multi-resonator design.

4.2.1. Comparison of Coding Techniques

The absence or presence coding technique and frequency shift coding technique have their own advantages and limitations. In the absence or presence coding technique, a minimum of zero stubs and maximum of 10 stubs of the multi-resonator structure have to be used for representation of the bits. Thus, the conductor requirement may vary greatly for each identification code that can be generated using the multi-resonator structure. So, the fabrication cost increases with the design required. The range of frequencies used for bandwidth allocation stays the same for all the stubs. A maximum of 10 bits can be represented using this technique. Each of the 10 stubs represents either '0' or '1' which gives a total of 1024 unique identification codes.

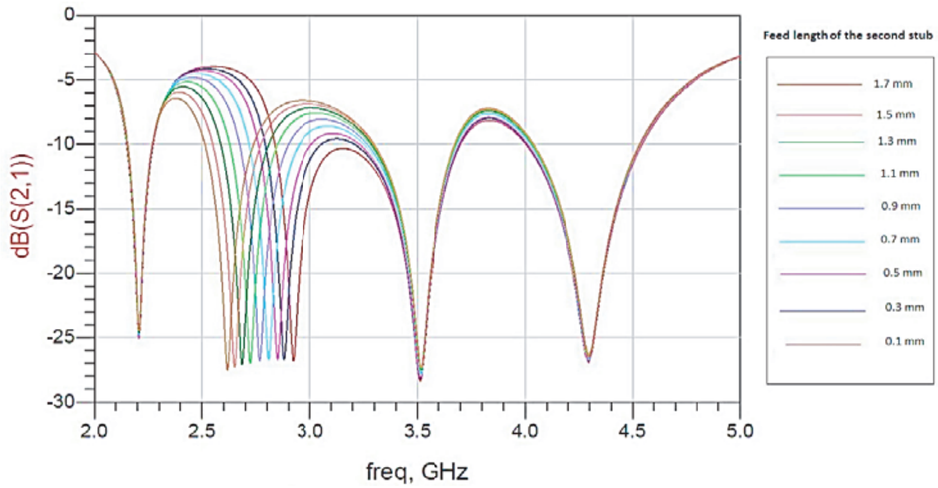

Figure 9. Tuning of the second stub of meandered line multi-resonator design.

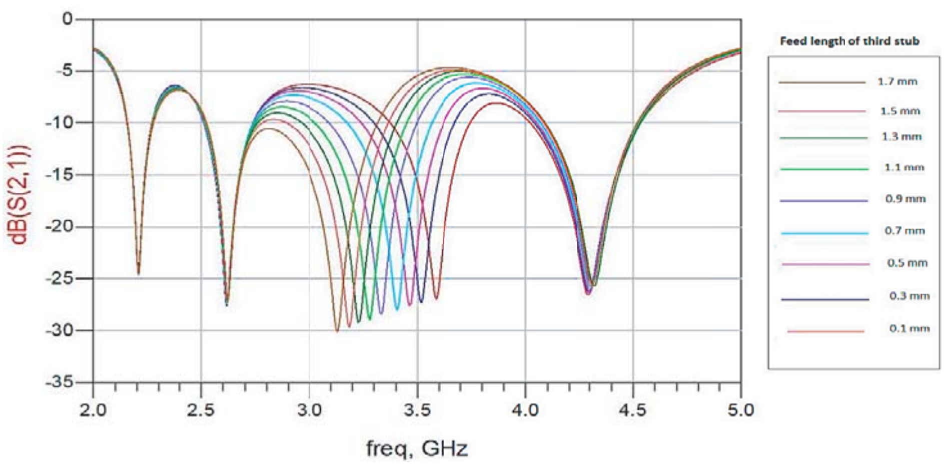

Figure 10. Tuning of the third stub of meandered line multi-resonator structure.

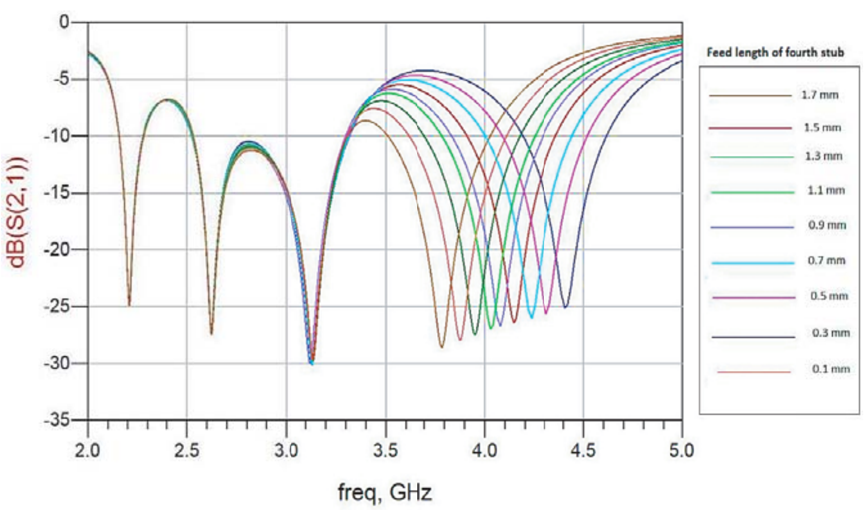

Figure 11. Tuning of the fourth stub of meandered line multi-resonator structure.

In the frequency shift coding technique, four stubs are mandatory for representing any identification code. The codes are represented by varying the feed lengths of stubs by a few millimeters. Hence the conductor requirement stays almost within a range for any identification code. The fabrication cost remains almost constant here, but bandwidth allocation is complicated. At lower frequencies, the bandwidth for every digit representation should be small. As frequencies increase, the bandwidth requirement also gets higher. However, the effect of mutual resonance is lower by this technique. A maximum of 4 digits can be represented using this technique. Each of the stubs can represent any digit from '0' to '8' which provides a total of 6561 identification codes.

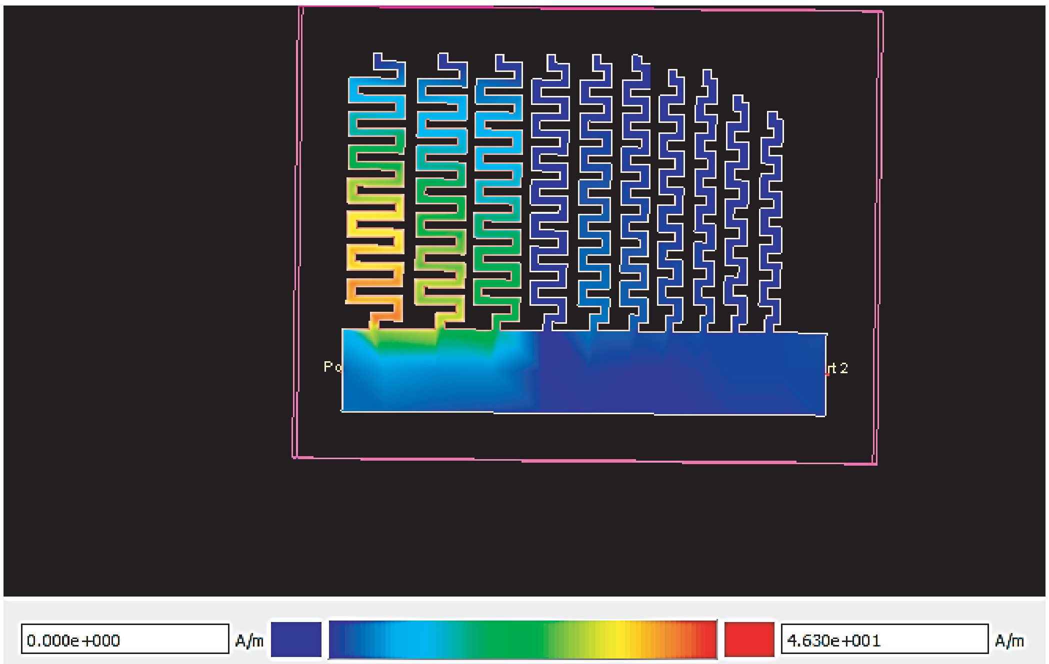

Figure 12. Surface current distribution at 2.1 GHz.

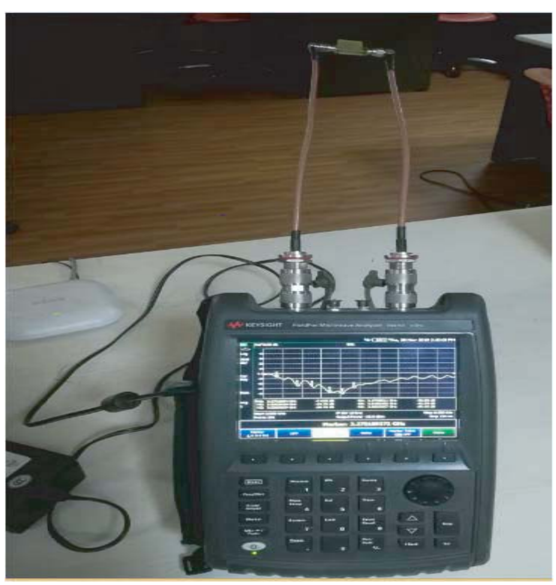

Figure 13. Measurement setup.

4.2.2. Surface Current Distribution

The effect of a multi-resonator structure is analyzed in terms of surface current distribution at 2.1 GHz as shown in Figure 12. The highest surface current distribution exists at relevant resonant frequency. Figure 13 shows the measurement setup for multi-resonator based chipless RFID tags. The multi-resonator circuit alone is tested in VNA without transmitting and receiving antennas.

5. CONCLUSION

In this paper, a meandered line multi-resonator design with various coding techniques is proposed. It occupies less area than that of the simple open stub multi-resonator structure designed with quarter wavelength. The multi-resonator structure achieves greater encoding capacity through the frequency shift coding method than absence/presence coding. So, this can store information equivalent to a chipped tag. The meandered line multi-resonator structure is simulated and tested using vector network analyzer, and the deviation in the measured results is observed due to the variation in the dielectric properties of the low cost FR4 substrate used for the fabrication process, and also it encounters edge effects during measurements. The miniaturized dimension of the meander line multi-resonator structure used for chipless RFID tag can be employed in IOT applications.

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