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High Security Identity Tags Using Spiral Resonators

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Abstract A highly compact chipless tag based on Frequency coding technique using Spiral Resonators is proposed in this paper. Spirals are well known metamaterial structures and thus capable of sharp resonance, and hence Spiral Resonators can serve as a good candidate for RF Identity Tags. The bit capacity of the proposed tag is 10 bits per sqcm. The prototype of the tag is fabricated on a low-cost substrate of dielectric constant 4.4 and loss tangent 0.02. The overall dimension of tag is 15.4 x 3 x 1.6mm^3. Two methods for reading the tags are also discussed in this paper. Scope for bit enhancement is also provided.

Keywords: High security tag, metamaterial, spiral resonator, reader antenna.

1 Introduction

Radio Frequency Identification (RFID) is a data capturing technique that uses radio frequency signals (3 KHz to 300 GHz) for automatic identification in asset tracking, security surveillance etc. RFID was first proposed by H. Stockman in his landmark paper ―Communication by Means of Reflected Power [Stockman, Harry.(1948)]. An RFID system consists of three major components: the source, which sends the interrogation signals to the RFID tag; the RFID tag, which contains the identification code; and the middleware software, which maintains the interface between the reader and a mainframe or a personal computer [Daneshmandt, Mahmoud; Wang, Chonggang; Sohraby, Kazem.(2007)].

Presently tags are classified as active, which require a battery or passive, which rely entirely on the reader for energy.

DC power consumption is the major factor determining the size of data storage, speed of information transfer, Tx/Rx range, cost and size of the tag [Robertson, I D and Jalaly, I.(2003)]. RFID tags that do not contain a silicon chip are called chipless tags. The potential benefit of chipless tags is that eventually they can be printed directly on products and packaging. There are mainly two types of chipless RFID tags- temporal and spectral types. In temporal approach, an antenna connected to a delay line with discontinuity can be used to encode data using either pulse position modulation method or group delay to encode data as a function of relative time delay between scattered and input modes [Hartmann, C. S.(2002); Zheng, L; Rodriguez,S; Zhang, L; Shao, B; and Zheng, L.R.(2008); Mandel,C; Schüßler,M; Maasch, M; and Jakoby, R.(2009); Nair, R; Perret, E; and Tedjini, S.(2013)]. Spectral signature-based chipless tags encode its spectral signature into the interrogation signal spectrum using a multi-resonating circuit, which is detected as abrupt amplitude attenuations and phase

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jumps by the RFID reader [Nijas, C M; R, Dinesh; U, Deepak; Rasheed,Abdul; S, Mridula; Vasudevan, K.; and Mohanan,P. (2012)]. Reported tags of this category have better coding efficiency compared to temporal approach [Preradovic, S; and Karmakar, N. (2009); Jang,H.S; Lim,W.G; Oh, K.S; Moon,S.M and Yu, J.W. (2010); Jalaly, I; and Robertson, D.(2005); Vena, A; Perret, E and Tedjini, S. (2011); McVay, J; Hoorfar, A; and Engheta, N.(2006)].

2 Frequency Coding Technique

The concept of frequency coding [Vena, A; Perret, E and Tedjini, S.(2012)] has been used in this work to achieve compactness and better coding efficiency; with spiral resonators as the basic elements. The advantage of this frequency coding approach is that the encoded data can be deciphered only by authorised readers. The details of each registered tag are stored in an authorised data base. The tag reader goes through the look up table in the data base to get the details of the tag holder. Hence identity of tag holder remains safe.

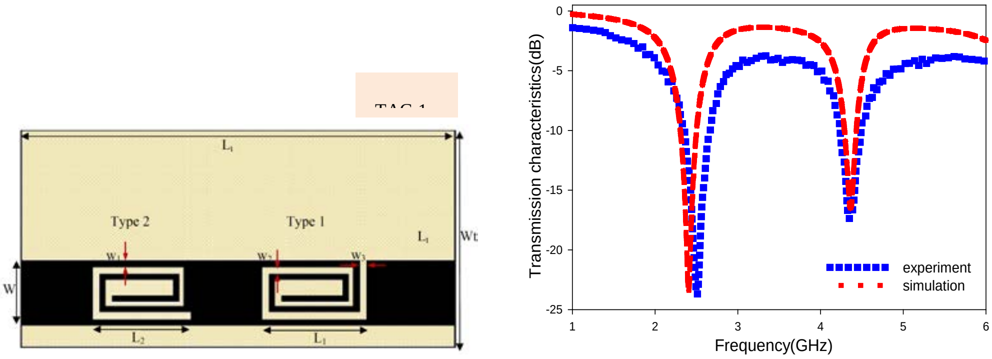
The concept of frequency coding can be explained as follows. The transmission characteristics will contain as many resonances as the number of resonators the tag holds. A reference dimension is chosen for each resonator and the resonant frequency of these resonators are marked as reference frequencies f1, f2 …etc. If each resonator is capable of resonating at eight different frequencies within a band without interfering with other resonator's resonance, then f1 is assigned bit combination '0 0 0'. Similarly, f2 is assigned '0 0 0' in its band. Now, any change in dimension of second resonator changes its frequency to f2 which is equal to f2 + Δf. Resonant frequency of first resonator remains as f1 and so its bit coding is '0 0 0', while the bit coding of second resonator will be '0 0 1'. Therefore the resulting bit combination is '0 0 0 0 0 1'. Hence, f1 and f2 +2 Δf will be '0 0 0 0 1 0' and so on. Thus the tag is capable of coding 6 bits using two resonators. This approach is extremely useful in making the tag compact.

3 Identity Tag Using Spiral Resonators

Frequency coding in identity tags depends on the frequencies of the resonant structures used. Spiral resonators (SR) are highly compact and possess a sharp resonance by virtue of their metamaterial property. This nature of SR can be utilised to yield a variety of tags employing different SR combinations embedded into a transmission line. A few of them are presented in this paper.

The proposed tag consists of two spiral resonators embedded into a transmission line of length L_t. Each spiral is characterised by its length (L_1 or L_2), number of turns or arms, width of spiral arm (w_1) and the gap between spiral arms (w_2). Tag is made using SRs designated as Type 1 and Type 2 SRs. The structure of the identity tag is shown in Fig. 1. The spiral with a gap (w_3) at its edge is referred to as Type 1 and the one without gap (w_3 =0) is referred to as Type 2. The width of transmission line (W) is 3 mm corresponding to 50 Ω impedance on a substrate of relative permittivity 4.4 and thickness 1.6 mm. SRs can be placed near to each other or embedded at different positions on the transmission line. Results are not affected if positions of Type 1 and Type 2 spirals are interchanged. The spirals resonate independent of each other, hence can be tuned independently as observed through field plots at the resonant frequencies of Type 1 and Type 2 respectively in Fig. 2. Spirals are excited only at their respective resonant frequencies. The tag is read either by inserting it into a slot similar to ATM cards to get the transmission characteristics or by loading of a reader antenna.

The metamaterial nature of Type 1 and Type 2 spirals are validated through dispersion diagram plotted using Eigen solver in Ansys HFSS. Dispersion is plotted for first two modes of Type 1 and Type 2 as shown in Fig. 3 (a-b). Dispersion diagram reveals a zeroth order resonance (zero phase advancement) for both spirals at their resonant frequencies.



(a) (b)

Figure 1: (a) Tag 1- L_1 = 4.9 mm, L_2 = 4.5 mm, L_t = 15.4 mm, W = 3 mm,w_1= 0.2mm, w_2 = 0.4mm,w_3 = 0.3 mm.(b) Transmission characteristics f1=2.43GHz,f2=4.36GHz

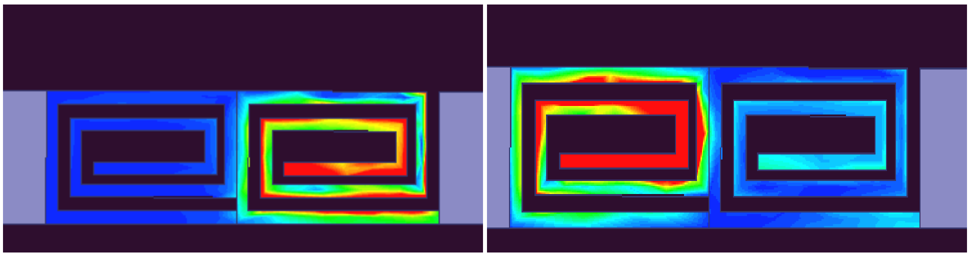
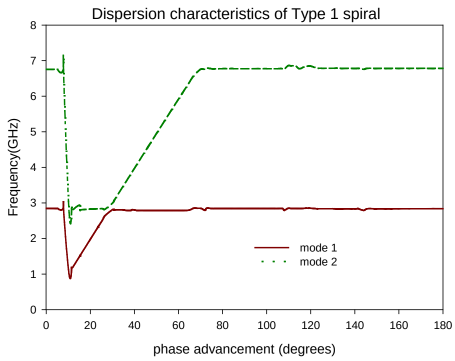


Figure 2: Field distribution in Type 1 and Type 2 Spiral Resonators at resonance

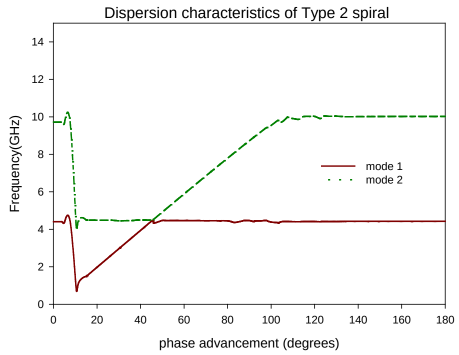
4 Tuning of Tag

Each spiral has four variables for tuning- length of spiral (L_1or L_2), number of turns, width of individual spiral arm (w_1) and gap between turns of spiral (w_2). Type 1 SR has one more variable namely, the gap between spiral and transmission line (w_3). Overall width of spiral is maintained as 'W' for matching. As length of spiral (L_1 or L_2) increases, the inductance also increases resulting in lower resonant frequency. The same effect occurs when number of arms is increased. When the width of arms (w_1) is

increased, the inductance of spiral decreases and results in increase of resonant frequency. Similarly, increased gap between turns (w_2) reduce coupling between arms and lower the capacitance. This results in increase of resonant frequency. Type 1 spiral resonates at lower frequency due to the additional capacitance introduced through the gap (w_3).



(a)



(b)

Figure 3: Dispersion characteristics of Spiral Resonator showing zero phase at 2.84 GHz for Type 1 and at 4.4 GHz for Type 2 SRs

While designing tag using Type 1 and Type 2 Spiral resonators, second harmonic of Type 1 should be far away from the frequency band of Type 2. For the spiral under study, this restriction limits the number of bit patterns possible through Type 1.

From exhaustive simulation studies it is concluded that bit combinations of Type 1 is limited to eight within the range of 2.35 GHz to 3 GHz resulting in a 3 bit code. The bit capacity of the tag can be enhanced through careful tuning of spiral dimensions. As this constraint of second resonance is not applicable to Type 2 spiral, 32 bit patterns are possible within the range of 3.5 GHz to 6 GHz resulting in a 5 bit code. A guard band of 0.5GHz is intentionally introduced to differentiate the resonances of the 2 SRs. Four sample tags are explained in the coming sections.

4.1 Tag 1 and Tag 2

Tag 1 consists of Type 1 and Type 2 SRs embedded in transmission line as shown in Fig.1(a). The transmission characteristics of

transmission line (L_t) and width of substrate (Wt) are not critical in designing the tag. Wt can be chosen as per convenience. Type 1 SR in Tag 1 resonates at 2.43 GHz and Type 2 SR resonates at 4.36 GHz.

By tuning dimensions of resonators, new tags can be made. Tag 2 is similar in structure to Tag 1 shown in Fig.1 (a) but with different dimensions as listed in Table.1. Type 1 SR in Tag 2 resonates at 2.41 GHz and Type 2 SR resonates at 3.97 GHz.

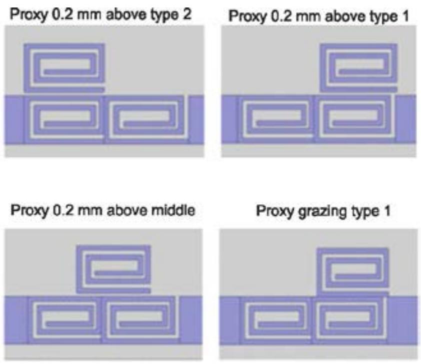
4.2 Tag 3 and Tag 4

As explained earlier, Type 1 and Type 2 together contribute an 8 bit tag. To extend the capacity of tag, a novel bit enhancement technique is employed in Tag 3 and Tag 4. This is elucidated in the next subsection.

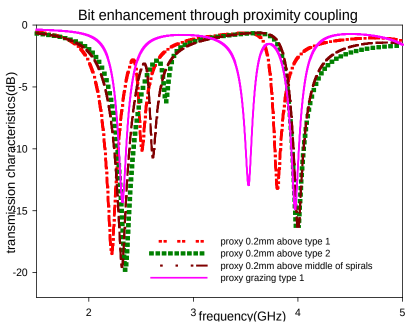
4.2.1 Bit Enhancement

Proximity coupling method is used to enhance the bit capacity by placing another spiral resonator here after named proxy spiral near the embedded spiral resonators whereby a third resonance is obtained. Only Type 1 SR is used as proxy spiral in this work. The third resonance occurs in between the resonances of Type 1 SR and Type 2 SR. Type 2 is not used as proxy spiral to avoid the misinterpretation of additional resonance as second resonance of Type 1 SR. Dimension of proxy spiral is maintained constant as the dimension of Type 1 SR used in Tag 1. Proxy spiral is placed either grazing Type

Type 2 or at the middle of two spirals shown in Fig.4 (a). Proxy spiral above Type 1 shifts the resonance of Type 1 and Type 2 (red curve in Fig.4 (b)). Hence this is not utilised for bit enhancement. Three new resonances and the absence of third resonance are treated as the enhanced 2 bit combination. As Type 1 and Type 2 are independent of each other, total bit capacity is 10 (2 of proxy, 3 of Type 1 and 5 of Type 2). Tag 3 and Tag 4 contain proxy spiral also. Details of tags and results obtained are summarised in Table.1.



(a)



(b)

Figure 4: (a) Possible positions of proxy spiral to obtain third resonance (b) transmission characteristics showing third resonance

Table 1: Results of validation of tags

parameters	Tag 1	Tag 2	Tag3	Tag 4
L_1 (mm)	4.9	5.1	5.1	5
L_2 (mm)	4.5	4.8	4.8	4.5
L_t (mm)	15.4	15.4	15.4	15.4
W (mm)	3	3	3	3
w_1(mm)	0.2	0.2	0.2	0.2
w_2(mm)	0.4	0.4	0.4	0.4
w_3(mm)	0.3	0.3	0.3	0.3
Presence of proxy	no	no	Yes (0.2 mm above Type 2)	Yes (0.2 mm above Type 2)
f1(GHz)	2.4(sim) 2.43(exp)	2.37(sim) 2.41(exp)	2.37(sim) 2.4(exp)	2.39(sim) 2.33(exp)
f2(GHz)	4.36(sim) 4.36(exp)	4(sim) 3.97(exp)	4(sim) 4(exp)	4.38(sim) 4.43(exp)
f3(GHz)	Not present	Not present	2.72(sim) 2.68(exp)	2.69(sim) 2.63(exp)

5 Validation of Tag

Experimental validation of sample tags is done by two methods. Direct contact method and reader antenna method. Both methods are user friendly and dependable, but calibration has to be done for each approach separately.

5.1 Direct Contact Method

First approach is to measure the transmission characteristics of tag by inserting the tag between two feeds, so that the tags are in direct contact with feeds. This resembles an ATM card being inserted into the specialised slot. The setup is shown in Fig.5. Experiment is done using substrate of ε_r 4.4 and tan δ 0.02. The results match perfectly with simulation. Frequency coding technique depends on distinct and closely occurring resonances, which calls for very sharp resonance for high bit capacity. In this perspective, substrate loss is critical. Lossy substrate widens the resonance limiting the number of adjacent and distinct resonances. Hence, improvement in performance is expected by using low loss substrate.

Another approach of validation by loading a dedicated reader antenna is also tried and explained in the next section.

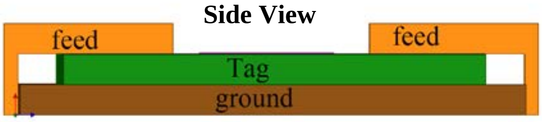


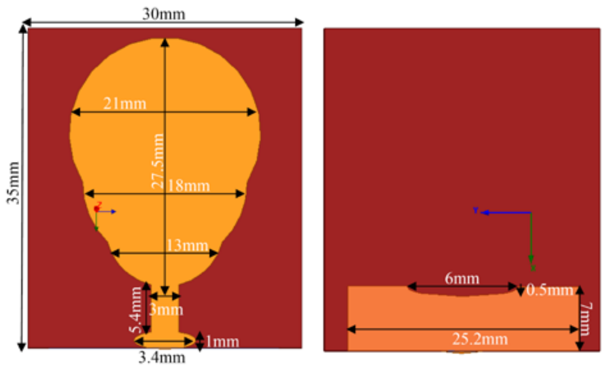
Figure 5: Setup to measure transmission characteristics of tag using-direct contact

5.2 Reader Antenna Method

A dedicated reader antenna has to operate in the entire range of tag frequencies (2 GHz - 6 GHz). A reader antenna catering to the frequency requirement is designed and is shown in Fig.6(a). The reflection characteristics of antenna shown in Fig.6(b) confirms the suitability of the proposed antenna for this application.

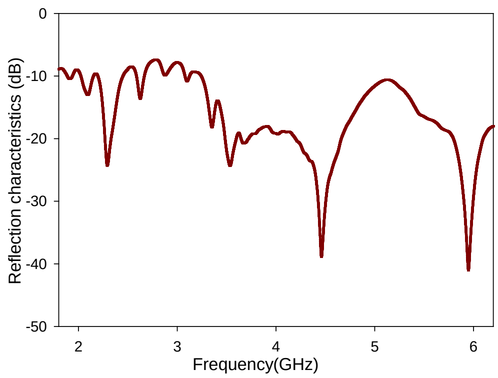
A wide band antenna normally has different radiation patterns within the operating band. This can be crucial when the antenna is loaded as the sensitivity will be different for different frequencies. To avoid any misinterpretation of bit pattern due to variation in radiation pattern, radiation pattern is studied at different frequencies as shown in Fig.7. Hence, the tag is loaded towards the top left edge of the head shaped reader antenna, where the field strength is maximum. In this position, the sensitivity is appreciable at all frequencies.

The tag is tested by initially storing the reflection characteristics of reader antenna in memory. Then the antenna is loaded with tag under test. The new reflection characteristics under loaded condition is averaged and then subtracted from the stored unloaded reflection characteristics. Averaging of reflection characteristics is done to avoid any possible error. The result of testing of two tags (Tag 1 and Tag 4) are shown in Fig.8 (a-b).



Top view   Bottom view

(a)



(b)

Figure 6: (a) Reader antenna top and bottom views (b) reflection characteristics

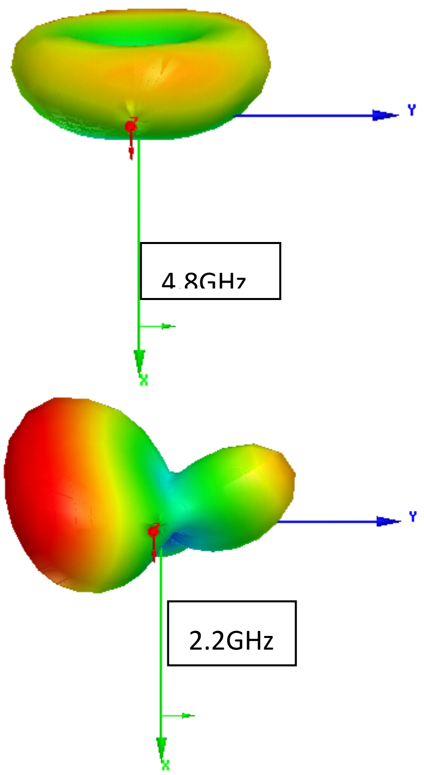
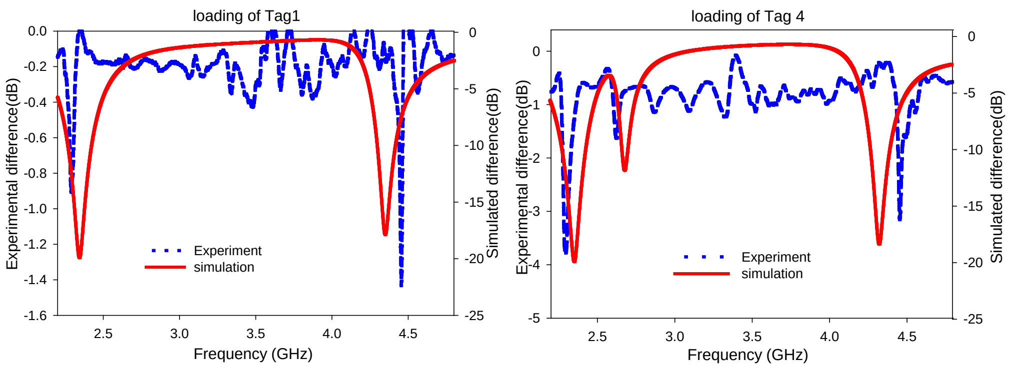


Figure 7: Varying Radiation pattern at different frequencies

Fig.8 reveals that the loading of reader antenna is also an effective method for tag identification. However, it can be seen that the tag frequencies of Tag 1 are slightly different from the transmission method approach. Hence, it is desired that correct calibration is done for the adopted technique.



(a) (b)

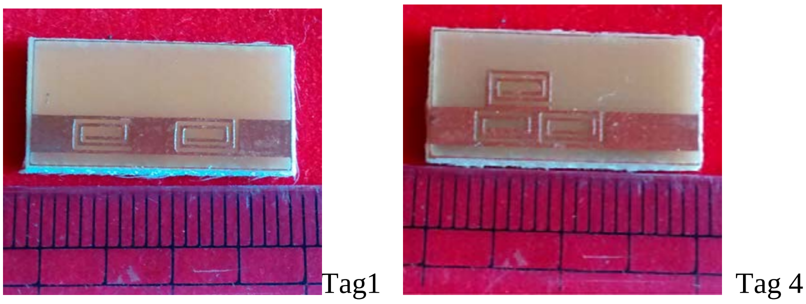
Figure 8: Difference between averaged reflection characteristics of reader antenna with loading of (a) Tag 1 (b) Tag 4

The performance of tag is comparable with tags with similar bit capacities. In [8], the overall dimension of 8 bit tag is 30 x 25 x 1.6 mm^3. The authors have proposed the tag with built in disc monopole antenna making the overall size as 80 x 60 x 1.6 mm^3. The problem of coupling between adjacent resonators is also critical in [8], which is not present in this proposed paper. The Spiral Resonators are independent of each other, making design easier. In [9], the bit capacity of 35 bits is achieved by using one spiral resonator for each bit, whereas in the proposed tag frequency coding is used making it compact. In [10], 4 bit chipless tag is fabricated using Split Ring Resonators. Various combinations of SRR is used to get distinct resonances. Spiral Resonators have nearly half size compared to SRRs, which makes the proposed tag more compact. The 6 bit tag in [Das, Laila; Thomas, Riny; C. M, Nijas; and P, Mohanan.(2015)] has the advantage of polarisation independency at the cost of overall size of 62 x 32 x 1.6 mm^3. Dedicated reader requirement and fabrication accuracy are the limitations of proposed tag which is justifiable considering the compact size and user friendly reading approaches.

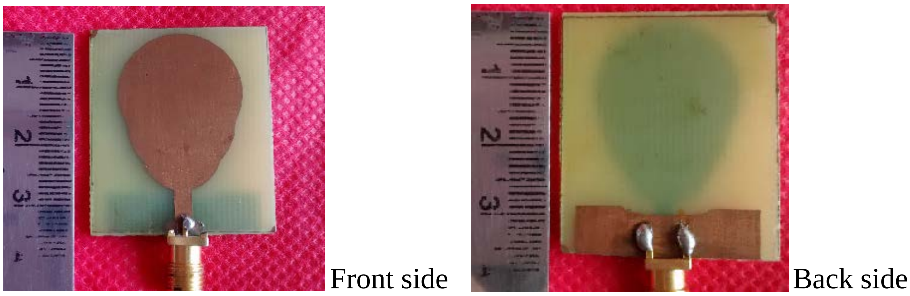
6 Conclusions

A new approach of identity tag design is proposed which offers high data security and bit enhancement capability. The bit capacity of the proposed tag is 10 bits per sqcm. The reader set up has to be dedicated for the proposed tag but it is user friendly. Two methods are suggested for tag reading; in the first approach, tag is to be inserted into a slot where the tag makes direct contact with feeds and transmission characteristics can be read out. The length of transmission line is not significant, the only requirement being able to make contact with feed points. In the second method, a dedicated reader antenna with sufficient bandwidth is designed and difference of reflection characteristics of the antenna with and without loading of tag is taken to identify the tag. In this method, transmission line length can be as minimum as possible as it does not affect the resonances of Spiral resonators. The bit capacity is specified without considering the length of transmission line.

The photographs of reader antenna as well as sample tags are shown in Fig.9. Fig.10 shows the tag attached to a slip of paper for ease of handling and its placement over the reader antenna at the position of maximum near field for the entire frequency range. Fabrication of the tags requires precision. The small disparity in results can be attributed to fabrication imperfections.

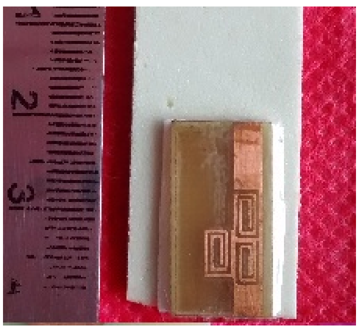


(a)



(b)

Figure 9: Sample tags (a) Tag 1 and Tag 4 (b) Reader antenna



(a)

(b)

Figure 10: (a) Sample tag attached to paper (b) placement of tag over reader antenna

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