CHIPLESS RADIO FREQUENCY IDENTIFICATION TAG WITH HIGH ENCODING CAPACITY BASED ON THREE CODING LEVELS

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ABSTRACT
One of the key factors that provides the potential for chipless radiofrequency identification (RFID) tags as an excellent alternative to conventional barcode tags is the capacity of identities produced. This study proposes a design of chipless RFID tag with high bit capacity. Base-3 levels encoding, which consists of three encoding levels (0, 1, and 2), is employed. This new technique ensures the efficient use of each resonance frequency in the ultra-wide band (UWB) region, which entails a high encoding capacity compared with conventional base-2 levels encoding. The proposed tag comprises two coplanar wave guide (CPW) UWB monopole antennas with a CPW multiresonator that connects the antennas. The insertions loss of the multiresonator is investigated here in terms of magnitude and phase. The uniplanar propriety of the proposed tag makes this tag fully printable and low cost. Thus, the proposed technique is suitable for tagging low-cost items, such as paper documents.

Keywords: radio frequency identification, chipless tag, multiresonator, base-3 levels encoding.

INTRODUCTION
Radiofrequency identification (RFID) is a wireless identification and data capturing technique that uses electromagnetic energy to communicate. RFID system consists of three main parts: a reader (interrogator) that transmits interrogation signal, a tag (transceiver) that encodes and retransmits incident signal, and a data processing system that processes information received by the reader. The advantages of RFID systems over barcode systems makes RFID a preferable choice for many applications, such as supply chain management, retail industry, items tracking, and access control [1, 2].

Despite the advantages of RFID over conventional barcode identification systems, barcodes are not replaced by RFID in the market because of the relatively high price of RFID tags, which is mainly due to high chip production cost. Therefore, much research has been performed to design a chipless RFID tag [3-6]. However, most of the reported tags are still prototypes, and the only tag type available in the market is surface acoustic wave (SAW) tag [7]. This tag type can be categorized as time domain reflectometry-based tags (TDR-based), which work by sending a signal from the reader in the form of a pulse and detecting the echoes of the pulse retransmitted by the tag. SAW tags have high production cost and are not fully printable [8]. Another type of chipless RFID tag is spectral signature-based chipless tags, in which a resonant structure is used to encode data into the spectrum. These tags work in the ultra-wide band region (UWB) (3.1–10.6 GHz). One example of this tag type is multiresonator-based tag [9-12], in which a reader sends a wide band interrogation signal; this signal is received by the tag through an UWB antenna Rx, and then the signal is propagated toward the multiresonator structure that encodes data bits into the spectrum. The signal is then retransmitted through a co-polarized transmitter antenna Tx. The presence or absence of a resonance frequency can be interpreted as 0 or 1 [base-2 levels (B2L) coding]. The number of resonance frequency in the UWB spectrum is limited because of practical detection considerations, thereby limiting the number of tag IDs produced by B2L tags. Moreover, each resonance frequency has a spurious resonance that appears at approximately twice the first frequency [11]. These spurious resonances may cause detection error at the higher region of the UWB spectrum; the erroneous part may be avoided, but the efficiency of the detection system may be compromised.

In this study, a base-3 level (B3L) chipless RFID tag is developed, This tag is a spectral signature-based chipless tag in which a resonant structure is used to encode data into three coding levels (0, 1, and 2) instead of the conventional two coding levels (0 and 1). This technique ensures the efficient use of the resonance frequencies in the UWB region, which in turn increases the number of tag IDs dramatically. Coplanar wave guide structure is employed in the tag design because this structure is uniplanar and fully printable. The main application of the proposed technique is tagging of low-cost items, such as paper documents and envelopes.

PRINCIPLE OF OPERATION
A chipless RFID tag is developed, which consists of two copolarized UWB monopole antennas (Tx and Rx) and a multiresonator placed between the two antennas, as shown in Figure-1.

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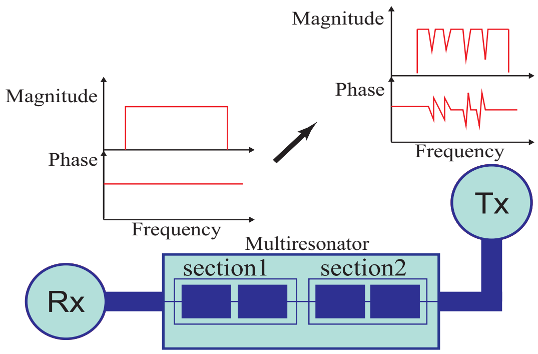
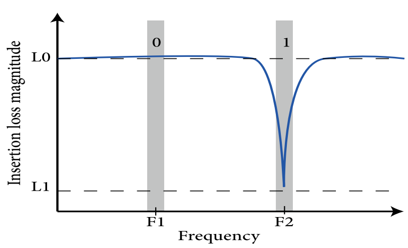


Figure-1. Multiresonator based chipless RFID tag diagram.

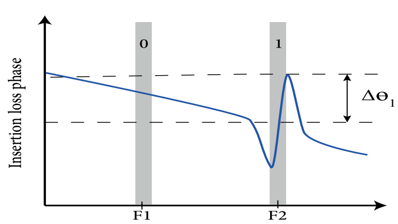
The multiresonator encodes data into the frequency spectrum in terms of both magnitude and phase. In conventional B2L tags, interrogation signal is encoded into two levels: (0 or 1), that is, at a specific frequency, either a resonance occurs or not, as shown in Figure-2. In terms of magnitude (S21), level 0 = 0 dB when a resonance does not exist, whereas level 1 = L_1 dB when resonance occurs. In terms of phase, level 0 corresponds to phase change $\Delta\theta = 0°$ when resonance does not occur, whereas level 1 corresponds to phase change $\Delta\theta = \Delta\theta_1°$ when resonance occurs. The number of tag IDs is given by

$$N_{B2L} = 2^R \quad (1)$$

where R is the number of resonance frequencies.



(a)



(b)

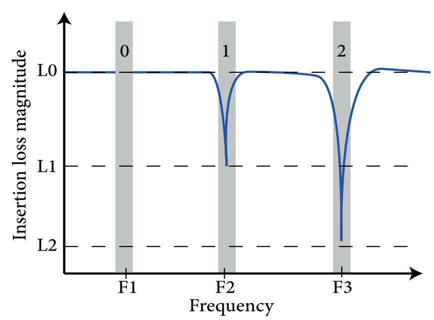
Figure-2. Insertion loss magnitude **(a)** and phase **(b)** for B2L chipless tags.

In our B3L chipless tag, the interrogation signal is encoded into three levels: 0, 1, or 2. At a specific frequency, no resonance occurs, resonance occurs with low insertion loss, or resonance occurs with high insertion loss, as shown in Figure-3. Hence, a new level (level 2) appears in addition to the previously mentioned two levels. In terms of magnitude of insertion loss (S21), level 2 = L_2 dB (in terms of phase, this corresponds to phase change $\Delta\theta = \Delta\theta_2°$). The number of tag IDs is expressed by

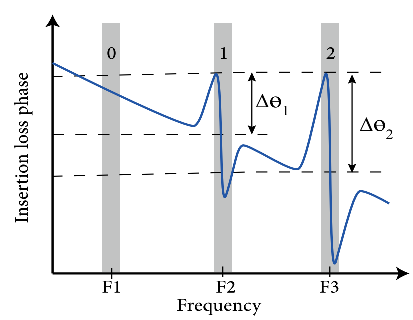
$$N_{B3L} = 3^R, \quad (2)$$

where R is the number of resonance frequencies. The tag ID combinations for B2L and B3L tags are shown in Table-1 for R = 2.

Figure-4 shows the number of tag IDs produced by both B2L and B3L chipless tags. The gain in the number of IDs for the proposed method over the B2L method exponentially increases as the number of resonance frequencies (R) grows, as shown in Figure-5.



(a)



(b)

Figure-3. Insertion loss magnitude **(a)** and phase **(b)** for B3L chipless tags.

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Table-1. Tags ID combinations for B2L and B3L tags.

Tag no.	B2L ID	B3L ID
1	00	00
2	01	01
3	10	02
4	11	10
5	-	11
6	-	12
7	-	20
8	-	21
9	-	22

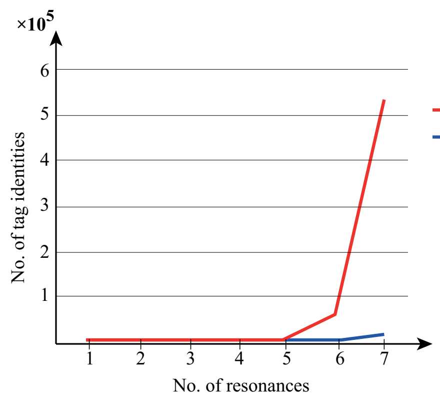

Figure-4. Number of tag IDs for B2L and B3L tags.

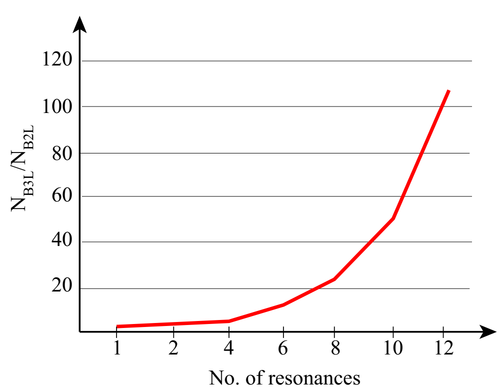

Figure-5. The ratio of N_{B3L} to N_{B3L}.

CHIPLESS TAG DESIGN

The two antennas are planar half disk for size reduction [13] with a CPW structure, as shown in Figure-6. The substrate used is Rogers RO4350B with a thickness of (h = 0.762 mm), and the copper thickness is (t = 0.035mm). To increase the isolation between the antennas, the antennas are cross polarized, thus, the received and transmitted signals are isolated from each other. The CPW center conductor is placed (0.25 mm) apart from the ground conductor, this space (s) value together with the width of the center conductor (G = 3.5) are chosen to achieve characteristic impedance (z_c = 50 Ω).

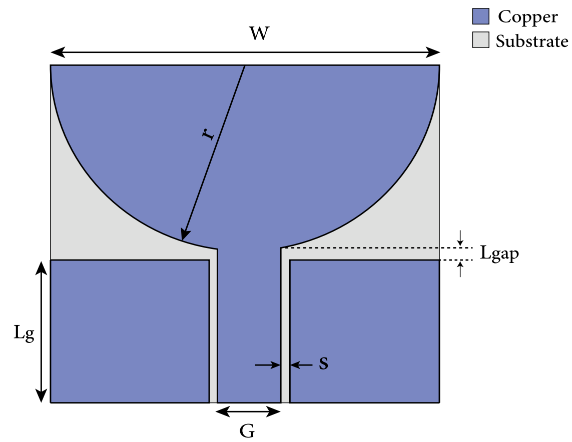

Figure-6. UWB half disck antenna with r=15mm, W=30mm, Lgap=0.25mm, S=0.25, G=3.5mm Lg=12mm.

The transmitting antenna is connected to the receiving antenna through a two-section multiresonator CPW structure. The first section contains nested resonators with low insertion loss (S21) that corresponds to level 1, whereas the other section consists of cascading resonators with high insertion loss that corresponds to level 2. The need for the two types of resonators for each resonance frequency to achieve the proposed B3L chipless tagging method. A meandered CPW slot resonator, as shown in Figure-7, was designed and optimized to achieve maximum insertion loss. This resonator is referred as the high insertion loss or level 2 resonator because this resonator is related to code state = 2.

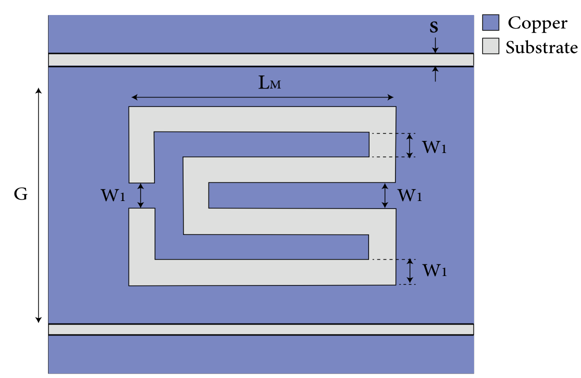

Figure-7. Meandered CPW slot resonator, G=3.5mm, S=0.25mm, W_1=0.3mm.

The low insertion loss resonator is a simple CPW C-slot resonator Figure-8. The slot width (w_2) and the C-shape width (w_3) were optimized to attain approximately (50%) of the insertion loss of level 2 resonator for the same resonance frequency. The idea behind choosing 50% is to ensure maximum isolation among the three levels (0,

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1, and 2), and consequently to reduce the probability of error during detection.

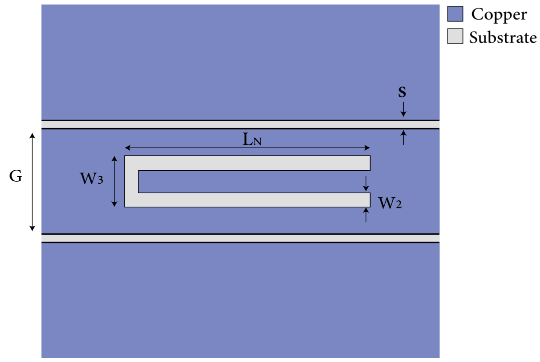

Figure-8. CPW C-slot resonator, W_2=0.25, W_3=1mm.

The only variable dimension of this resonator is the length of the C-slot (L_N), which is directly proportional to λ/4. For 8 resonators (L_N = 15, 13.7, 12.6, 11.65, 10.8, 10.13, 9.47, and 8.93 mm), these resonators are related to level 1 (code state = 1). A multiresonator was designed with only eight resonance frequencies to prove the proposed concept. These resonances lie in the region (3.2–5.5 GHz) with an almost equal frequency span among the resonators. For the eight resonators, the lengths of the level 1 resonators are (L_N = 15, 13.7, 12.6, 11.65, 10.8, 10.13, 9.47, and 8.93 mm), whereas those for the level 2 resonators are (L_M=9.5, 8.6, 7.92, 7.32, 6.8, 6.35, 5.94, and 5.62 mm). The level 2 resonators are cascaded in the center conductor with a spacing of (2 mm) to reduce the mutual coupling among the resonators. To reduce size, the level 1 resonators are not only cascaded but also nested in two rows in the way shown in Figure-9; the spacing among these rows is optimized to achieve minimum mutual coupling. To simplify the future massive production procedure, a basic (all zeros) tag has been designed, which contains all the resonators but are shorted, as shown in Figure-10. This idea of shorting was used in Refs. [11, 14] to shift the resonance frequency out of the UWB region.

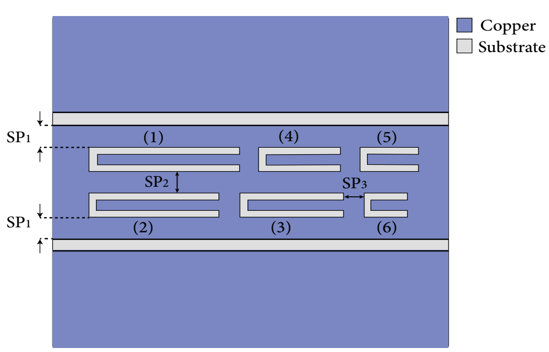

Figure-9. Nested level1 resonators, SP_1=SP_2=SP_3=0.5mm.

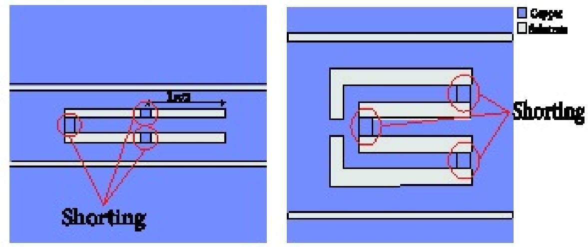

Figure-10. Shorted resonators.

RESULTS AND DISCUSSION

A simulation is performed using the software CST microwave studio. The return loss (S11) for the UWB antenna is shown in Figure-11, which shows an excellent coverage for the UWB region (3.1–10.6 GHz) at (S11 < −10 dB). Figure-12 shows the insertion loss (S21) for two multiresonators, one with an all-low insertion loss of ID = 11111111, and another with an all-high insertion loss of ID = 22222222. The eight resonances achieved by the resonators are (3.3, 3.64, 3.94, 4.26, 4.58, 4.9, 5.23, and 5.52 GHz). From the same figure, level 1 evidently has (S21 ≈ −8 dB) and level 2 has (S21 ≈ −16 dB), which is almost twice the insertion loss of level 1 resonators to ensure maximum isolation among the three levels (1, 2 and 3).

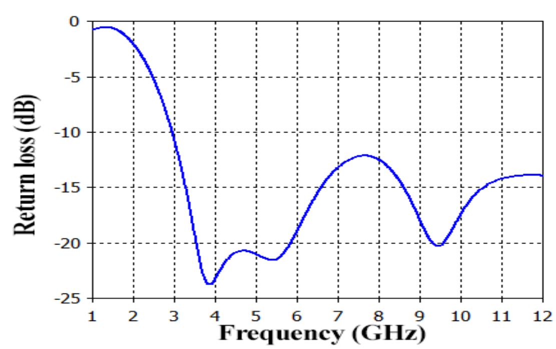

Figure-11. Return loss for the UWB antenna.

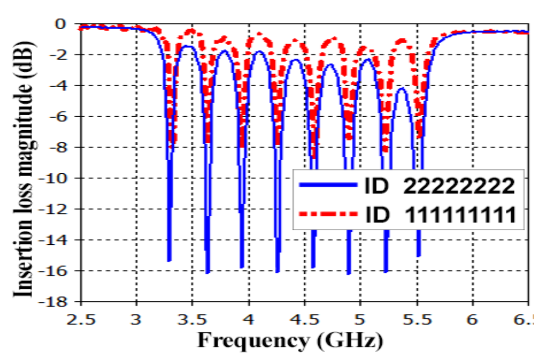

Figure-12. Insertion loss magnitude for eight resonance frequencies with tag ID=22222222 and ID=11111111.

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The insertion loss of a multiresonator with all-shorts resonators (ID = 00000000) in addition to the S21 of (ID = 22222222) is shown in Figure-13. Shorting removes all the resonances away from the entire UWB spectrum so that it will not interfere with the higher frequencies resonances which may cause detection error.

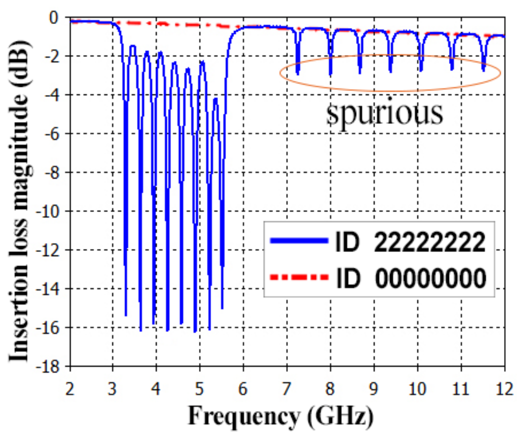
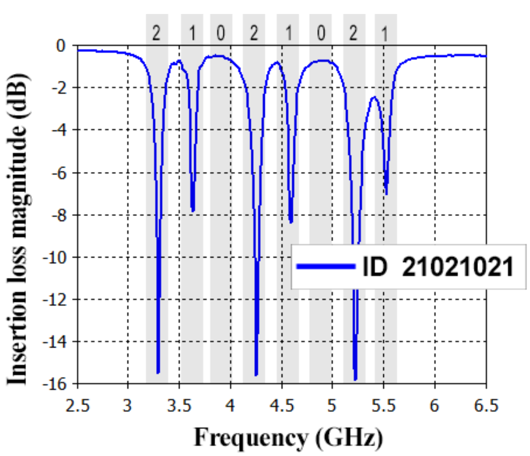
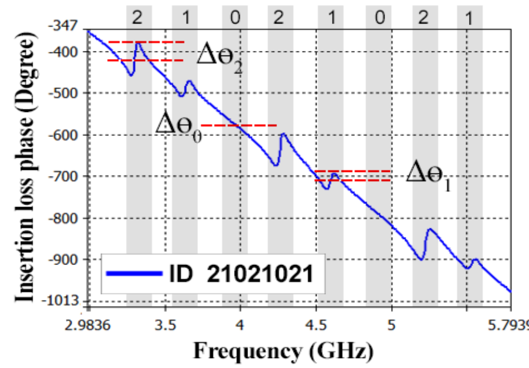


Figure-13. Insertion loss magnitude for eight resonance frequencies with tag ID=22222222 and ID=00000000.

Figure-14 shows the insertion loss magnitude and phase for the multiresonator with tag (ID = 21021021) for a better comparison between the levels (0, 1, and 2) in terms of magnitude and phase of (S21). From Figure-14 (b), $\Delta\theta_0 \approx 0°$, $\Delta\theta_1 \approx 20°$, and $\Delta\theta_2 \approx 40°$, which correspond to levels 0, 1, and 2, respectively. Practically, thresholds must exist to decide whether the detected level is 0, 1, or 2, and these thresholds should be set for every distance span between the reader and the tag.



(a)



(b)

Figure-14. Insertion loss magnitude **(a)** and phase **(b)** for eight resonance frequencies with tag ID=21021021.

CONCLUSIONS

This study proposes a new chipless multiresonator-based RFID tag. The low-cost tag is uniplanar and fully printable. The multiresonator employed B3L encoding technique, thereby producing a high encoding capacity. A multiresonator embedded with two types of resonators (low and high insertion loss resonators) can produce a unique code of three levels (0, 1, and 2) in terms of magnitude and phase of insertion loss. The high number of IDs produced by this B3L encoding technique leads to a more efficient way to use resonant frequencies on the UWB spectrum.

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