Chapter 5

A Combined Matching Approaches Based UHF RFID Planar Tag Antenna

5.1 Introduction

In past few years non-contacting identification has become excessive popular due to its various applications like vehicle security, electronic toll collection, retail item identification, animal tracking, marathon player tracking etc. RFID system in Ultra High Frequency has achieved much attention in researchers' interest due to its prolonged range identification potential with small size.

In RFID system tracking mechanism, impedance matching in tag plays crucial role. In an RFID system, the data are deposited in a transponder which is nothing but the tag. The interrogator which is also called as RFID reader, communicates with the tag using electromagnetic waves. Tags can either be active tag (battery assisted) or passive tag (with no battery). The primary elements of a passive tag are tag antenna and ASIC (Application Specific Integrated Circuit). The overall dimension of tag depends on the size of antenna for the most part which gives rise for tags to be low profile and small in size. The four particular frequency bands granted for RFID systems have already been discussed in Section 2.3. The UHF RFID systems are favoured as they empower spotting tags to a larger extents concurrently. These tags render extensive read ranges with faster reading speeds and require smaller antennas as well when compared to LF and HF band RFID tags.

The state of art used in UHF based tags is the principle of backscatter modulation in exchanging data between tag and reader. In this mechanism, an interrogator which is nothing but the reader, transmits a modulated wave to tag or the transponder. The electric field present in the wave , introduces a potential difference between the terminals of tag antenna. This produces a current in tag. As soon as this generated power gets equal to greater than ASIC sensitivity, the chip is turned on. The internal impedance of chip is transitioned between matched state and shorted state and leads to backscattering the signal back to reader.

Long read range tag antennas, metal mountable tag antennasand matching techniques based tag antennas have been popular in researchers' area of interest for few decades. In [70], read range enhancement was achieved by using a shorting pin in tag antenna. In [72], differential feed technique was used in designing long read range tag antenna. In order to obtain long read range, a low cost wristband RFID tag antenna, using Teflon substrate and metal-substrate-metal layered structure was introduced in [73]. In [74], AMC meta surface integrated tag antenna was designed with middleware implementation for metallic surface. Different matching techniques have also been used in designing tag antennas such as module matching technique was used in [75]. In [76], loop-fed method was introduced in designing tag antenna for metallic surfaces. In [40], RFID tag antenna matching was done using micro-strip coupling-feed technique. In [77], a slot tag antenna was designed having CP radiation by using T-matching network. In, [20], a U-shaped Inductively coupled feeding matching technique was used for designing metal attachable RFID tag antenna. Numerous planar antennas have been proposed in recent past year that are based on Nested slot technique, T-matching technique or Inductively coupled loop technique for impedance matching. All the aforementioned techniques have been elaborated in [41]. For making patch antenna compact in size and bringing the resonating frequency in UHF band, meandering technique is used in radiating plate[78]. Patch antenna exhibits different properties and they can be designed in various types. A brief review about some of the properties is explained in[79]. Some of prior reported literature show progressing results concerning read range and gain when hybridization among aforementioned matching techniques were employed. In [80], all the three methods with their effect on different parameters of RFID tag antenna is presented. [81] presents a comparison of two matching techniques. Further, hybridization of first two techniques i.e. Nested slot and T-matching was used in [71] to elaborate effect on impedance matching and enhanced read range. Additionally, for size contraction of antenna, meandering lines are used in RFID tag. A Meandered Inductively-coupled Loop (MIL) was used for impedance matching between chip and tag in [82], which resulted in higher read range while having reduced size.

In this chapter, hybridization of nested slot, T-match network and MIL is presented. This amalgamation turns out an innovative compact size and long read-range. Here, tag antenna reflection coefficient, input impedance, radiation pattern, radiation efficiency and read-range is presented.

5.2 Planar Tag Design

The schematics of proposed tag is represented in Figure 5.1(a). Proposed antenna patch is designed on a substrate of Rogers' RT/duroid-5880 having dielectric constant 2.2 with loss tangent 0.0009. The depth of substrate is 1.6mm. The microchip used for this tag antenna design is the RI_UHF_00001_01 UHF RFID chip of TI (Texas Instruments Corporation) as used in [6]. The input impedance of microchip is 9.4 - j64.2 Ω at 866.5 MHz.

Design Process and Parameter Optimization: The proposed antenna utilized a hybrid configuration of nested slot, T-match, meandered structure, and inductively coupled loop to achieve both miniaturization and impedance matching. The initial dimensions were estimated to provide a resonant condition suitable for the UHF band. The nested slot and T-matching network helped fine-tune inductive response, while the meandering and MIL elements further reduced size and enhanced match accuracy. Simulations guided the optimization of loop dimensions, trace height, and spacing to achieve a reflection coefficient below -10 dB across the target band. The resulting tag demonstrated close alignment with the input impedance of the RFID chip, and the established parameter set formed the basis for detailed parametric analysis.

The optimized arithmatic values of tag parameters is shown in Table 5.1. In the pre-

Table 5.1: Arithmetic Values Of optimized Variables Of Planar Antenna

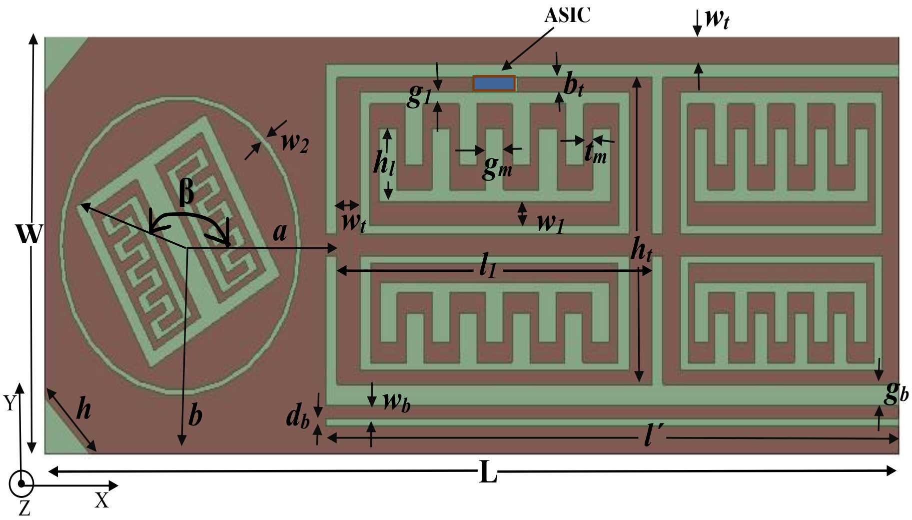
Variable	Value(mm)	Variable	Value(mm)
L	76	W	30
l'	51	d_b	0.5
w_b	1	g_b	1.5
l_1	28	h_t	22
w_t	2	w_1	1.74
h_l	5.227	g_m	1.6
b_t	1	h	5.66
b	15	w_2	0.4
a	13	t_m	0.8
g_1	0.9	β	120^o

sented tag, four techniques have been used in designing namely Nested slot, T-matching, Inductively-coupled loop and meandering. The Nested slot begins from $(L - l')$ distance with length of l' and width of $(W - 2w_t - d_b - w_b)$. The T-matching network is introduced inside the Nested slot having width of l_1 and height of h_t. Then two Meandered Inductively-coupled Loops (MILs) have been introduced in both sides of T-matching network. This combination forms one segment of tag antenna. There are three segments in patch as shown in Fig. 5.1(a). One is in center, which is amalgamation of all aforementioned techniques. Second is scaled down to 75% in X-direction of the one residing in center. In third segment, T-matching tracery was scaled down to 47% and 60% in X and Y-direction respectively, while MIL tracery was scaled down to 45% in X-direction and 41% in Y-direction followed by rotation of 120^0. The impedance fluctuation of proposed tag is displayed in Figure 5.1(b). Figure 5.1(c) displays the simulated return loss of proposed hybrid tag. The return loss depends on the scattering parameter given by[83].

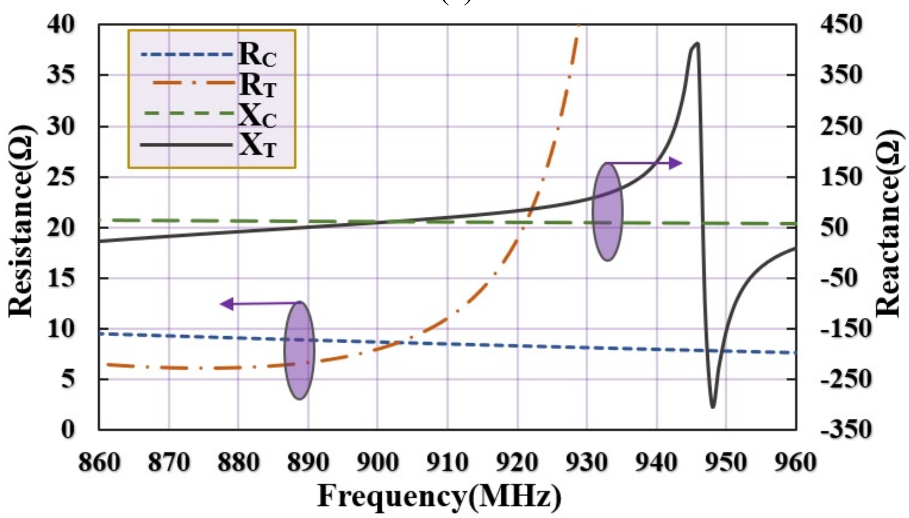
$$RL = 20log|S_{11}| \tag{5.1}$$

The reflection coefficient of tag is calculated by

$$S_{11} = \frac{Z_c - Z_t^*}{Z_c + Z_t} \tag{5.2}$$



(a)



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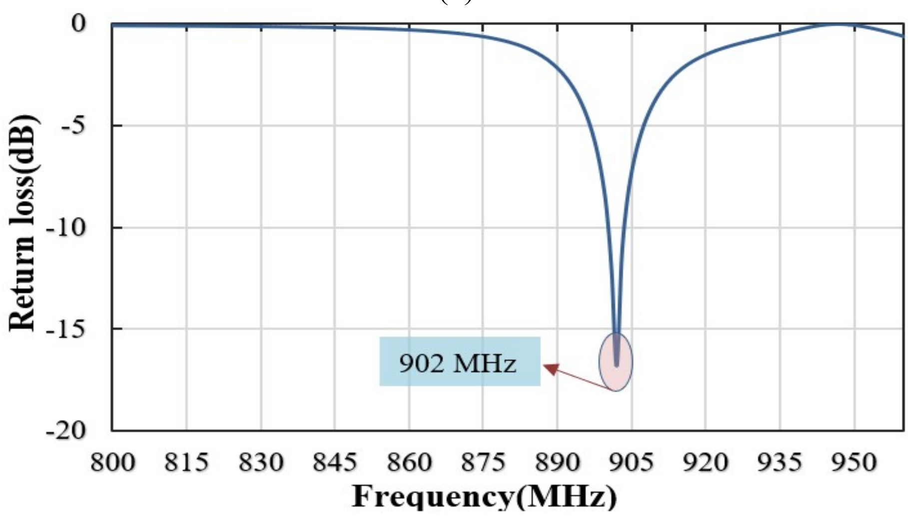


(c)

Figure 5.1: Tag design and simulated results. (a) Schematics of proposed tag antenna, (b) Impedance variation of proposed tag, (c) Simulated return loss of tag antenna.

where Z_c and Z_t are the impedance of semiconductor microchip used for impedance matching and the tag respectively.

5.3 Evolution steps

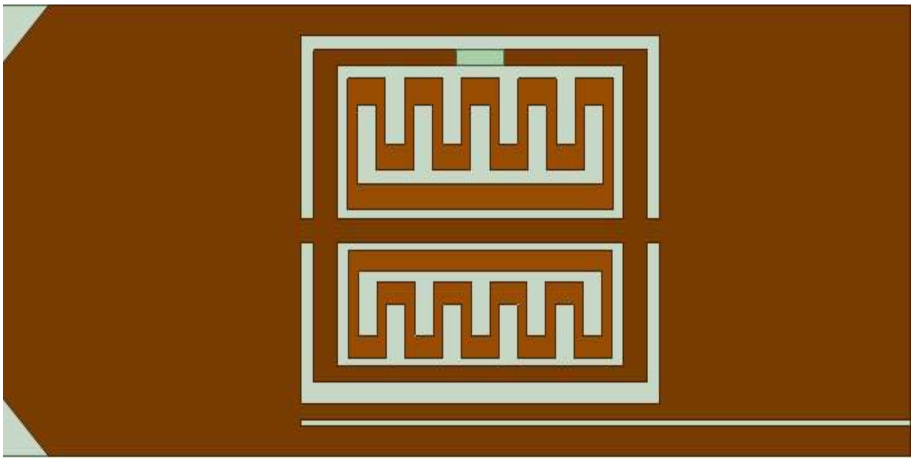
The presented tag antenna is designed in predominantly three steps, which are the three segments of tag that is earlier elaborated in section 5.2. The evolution steps are shown in Figure 5.2.

Input impedance of planar tag antenna obtained at every evolution step is shown in Figure 5.3(a). It can be seen, in Antenna I, resistance matching happens at 955 MHz and 991 MHz while reactance matching occur at beyond 1 GHz frequency. For Antenna II, resistance matching occur at 971 MHz and 990 MHz while reactance matching occur at 922 MHz and 1002 MHz. While for Antenna III, both matching occur at 902 MHz.

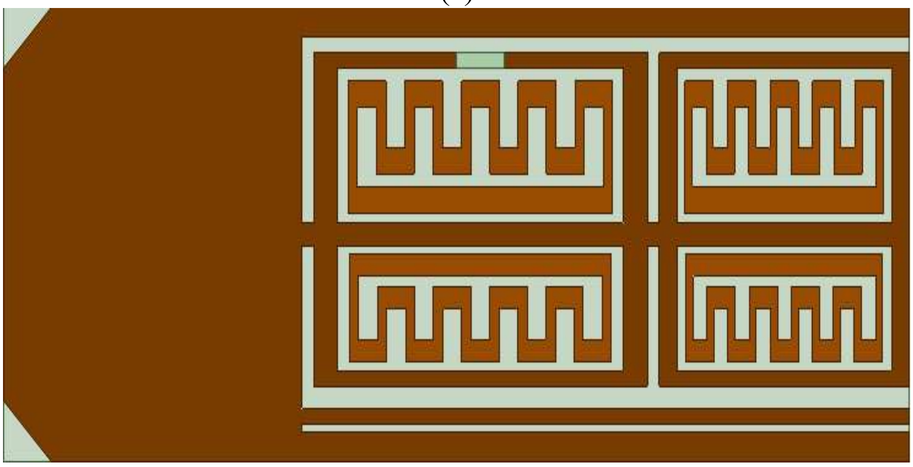
The return loss obtained at each step of antenna design is shown in Figure 5.3(b). In the first design, when amalgamation was done in tag, resonance occured at 992 MHz with poor return loss of -4 dB. However, this resonance lies out side the band of UHF RFID systems. Further, evolving the structure of patch antenna, second segment was introduced and this Antenna II resonates at 985 MHz with some improvement in reflection coefficient of tag. Antenna II return loss reaches to -9.35 dB, which is still not adequate for antenna performance and frequency of resonance still lies outside of the alloted UHF band for RFID. Finally, from the graph of return loss of every step of antenna, it can be seen that after introducing the third segment, required frequency is achieved with outstanding value of reflection coefficient.

5.4 Parametric Study

The impedance matching conditions between microchip and tag's antenna can be achieved by adjusting height of T-matching network as shown in Figure 5.4(b). It can be seen for T-matching network height of 21.2 mm, the resistance and reactance matching occur at 910 MHz and 900 MHz respectively. for $h_t = 21.6$ mm, the same happens at 912 MHz and



(a)



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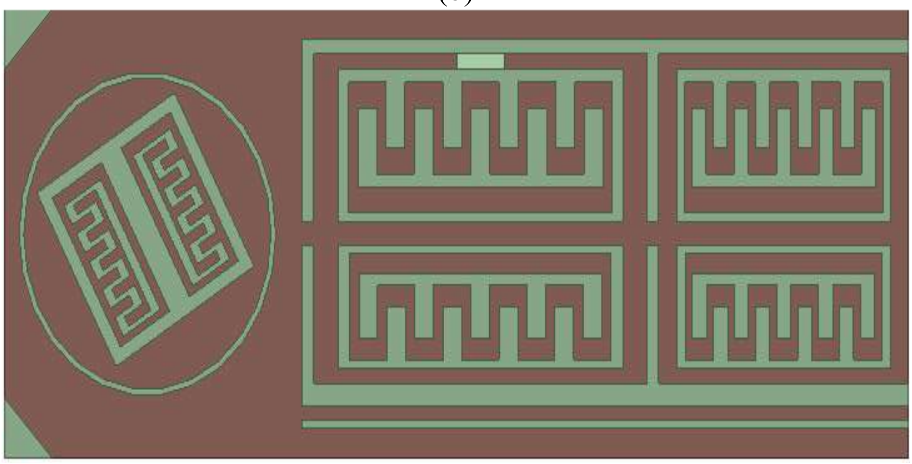
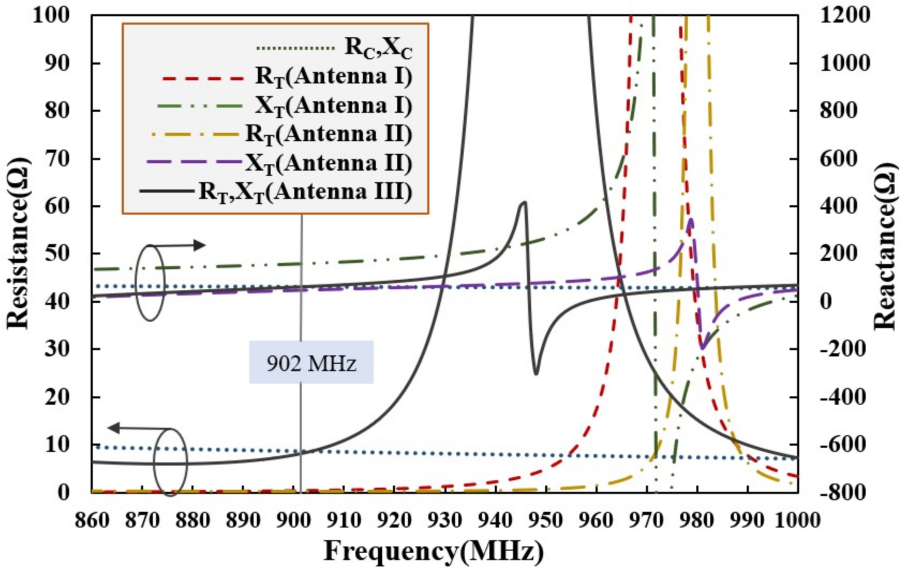
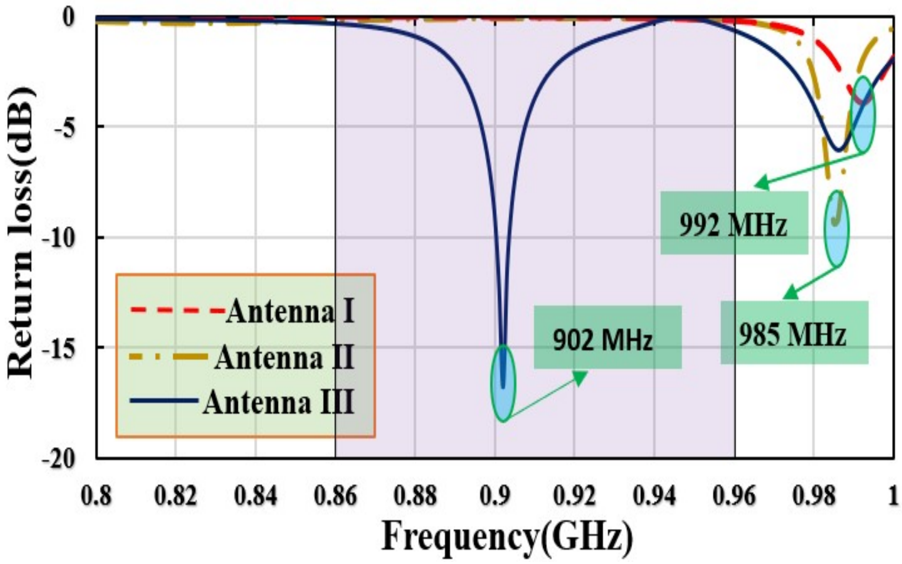


(c)

Figure 5.2: (a) Antenna I, (b) Antenna II, (c) Antenna III

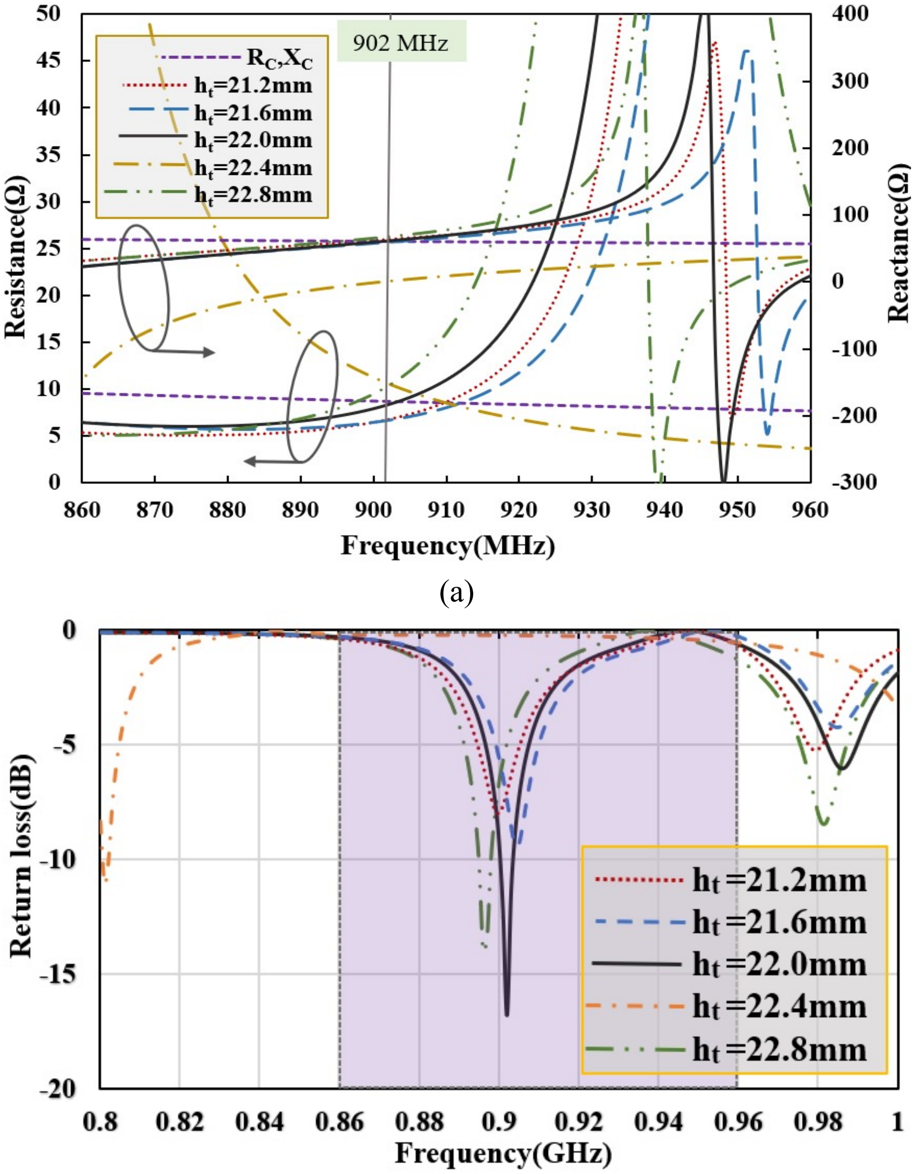


(a)



(b)

Figure 5.3: (a) Impedance and (b) Return loss obtained at each step



(a)

(b)

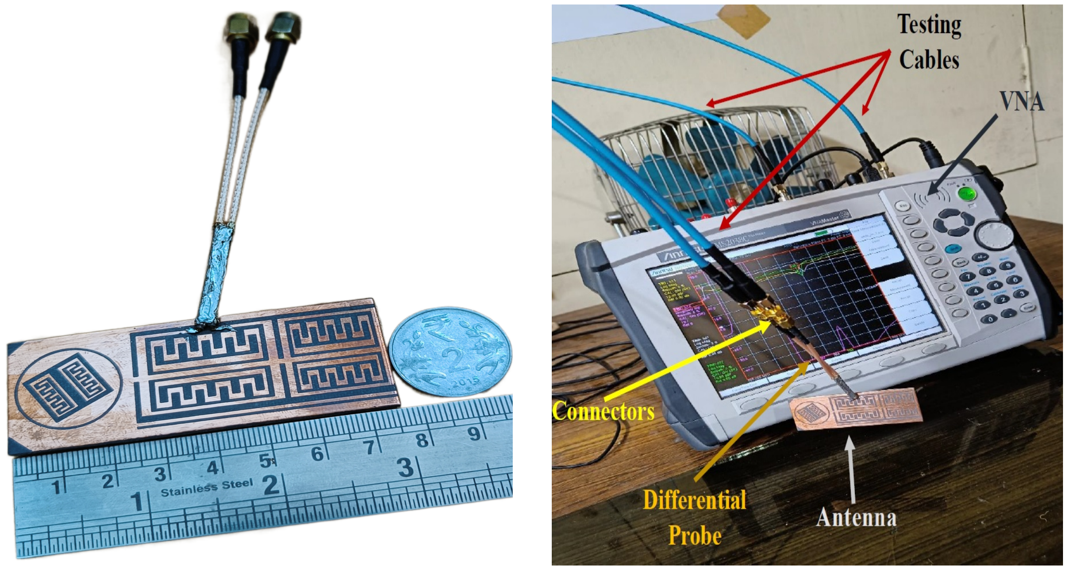
Figure 5.4: Parametric analysis (a) Input impedance of planar tag antenna after variation in h_t (b) Return loss attained after variation in h_t

904 MHz respectively. For $h_t = 22.4$ mm, resistance match at 910 MHz, while reactance doesn't match in UHF band of RFID. For $h_t = 22.8$ mm, resistance match at 898 MHz while reactance match at 896 MHz. It can be seen that both values match with microchip respective values at 902 MHz for $h_t = 22.0$ mm. The effect on return loss by varying height of T-matching tracery is shown in Figure 5.4(b). The tag antenna obtains return loss value of -7.9 dB at 900 MHz, -9.35 dB at 905 MHz, -16.8 dB at 902 MHz, -14 dB at 896 MHz for T-match height of 21.2 mm, 21.6 mm, 22.0 mm, 22.8 mm respectively.

5.5 Discussion of The Results

5.5.1 Impedance and Return loss

Figure 5.5 shows the fabricated prototype and measurement setup of proposed RFID tag antenna with Anritsu MS2038C VNA. The measurement of impedance of introduced pla-



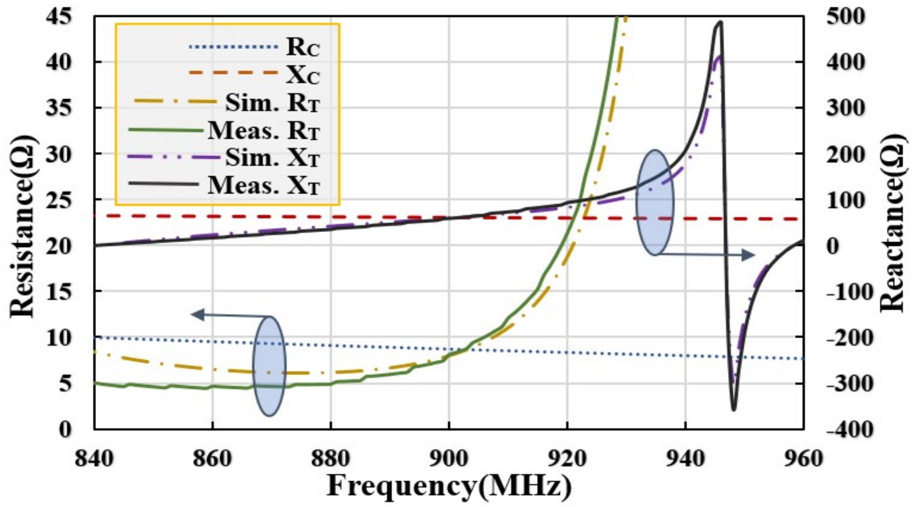
(a) (b)

Figure 5.5: Fabricated antenna and Measurement setup with Anritsu VNA

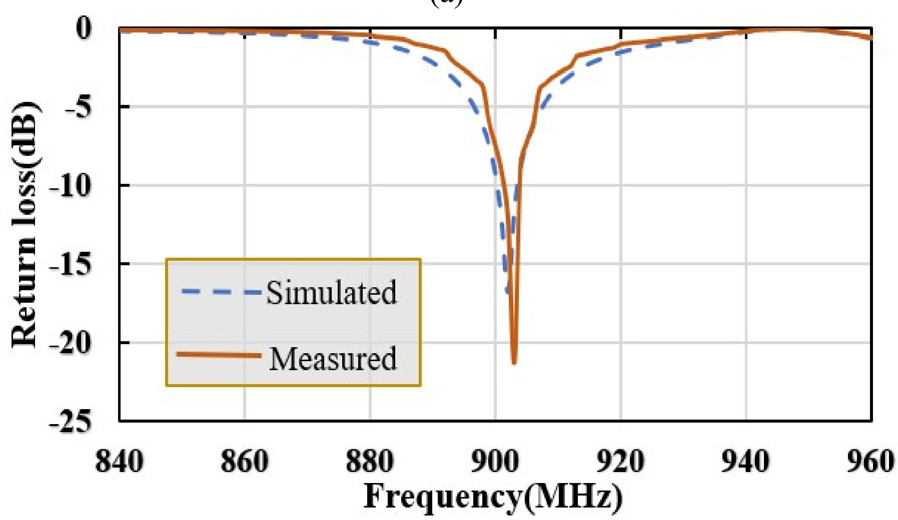
nar antenna was transacted by a Vector Network Analyzer. The aforesaid measurement evaluation was done by employing differential probes. In this tactic, after the calibration of VNA, the differential probe was affixed to tag antenna. The differential probe is assembled by making use of two coaxial cables. Their outer cables were soldered with together and remaining two inner conductors were soldered with input port of tag antenna. Now, each complex S-parameters are evaluated by VNA which is affixed with planar tag by the differential probe. Further, the tag antenna input impedance is derived by the following equation[68]:

$$Z_{Diff.} = 2Z_o \frac{(1 + S_{12}S_{21} - S_{22}S_{11} - S_{21} - S_{12})}{(1 - S_{11})(1 - S_{22}) - S_{21}S_{12}} \tag{5.3}$$

The simulated and measured impedance values with respect to frequency is displayed in Figure 5.6(a). It is observed that simulated and measured input impedance of tag antenna



(a)



(b)

Figure 5.6: Fabricated tag antenna results. (a) Input impedance of tag antenna (measured and simulated), (b) Return loss of tag antenna (measured and simulated).

at 902 MHz, are 8.37 + j61.47 Ω and 8.54 + j60.24 Ω respectively. The simulated and measured return loss is shown in Figure 5.6(b). The simulated and measured values of return loss are found to be -16.8 dB and -21.3 dB respectively at desired frequency.

5.5.2 Radiation Efficiency and Realized Gain

The simulated efficiency and realized gain of the proposed planar tag antenna is shown in Figure 5.7. It is found to be radiation efficiency of 37% at 902 MHz. Also, this tag exhibits realized gain of 1.03 dBi at the resonating frequency.

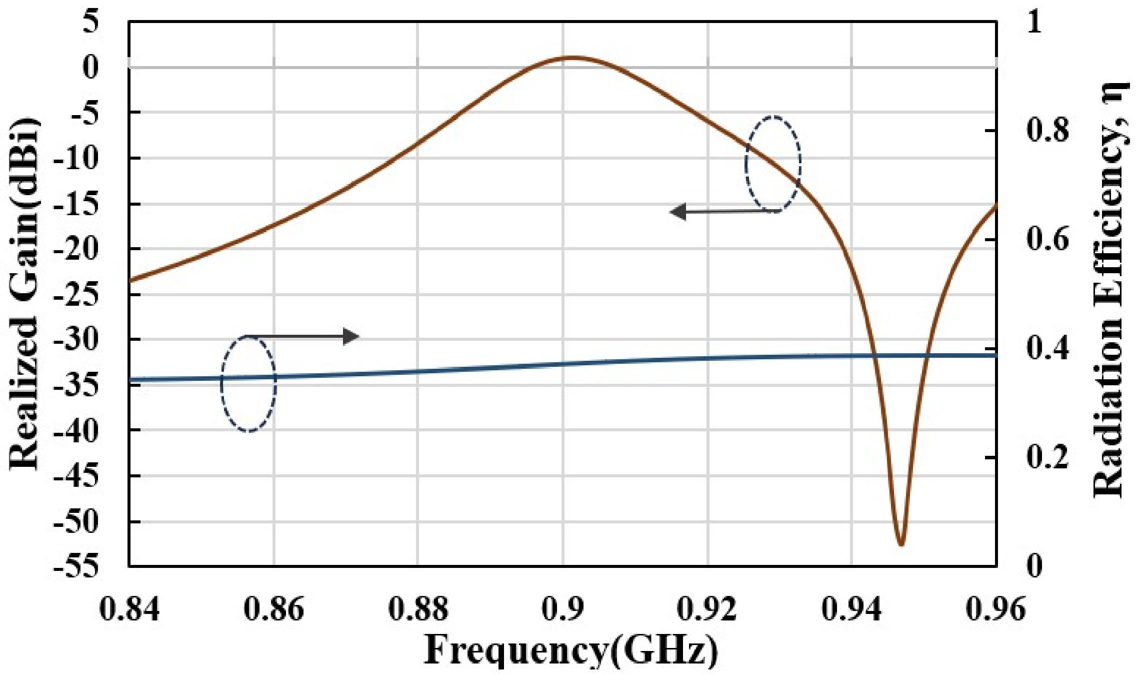


Figure 5.7: Simulated realized gain and radiation efficiency of planar tag antenna

5.5.3 Read range

The ultimate achievable segregation between tag and reader, which is known as read range of tag, is derived by following equation:

$$S_{max} = \left(\frac{\lambda_0}{4\pi}\right)\sqrt{\frac{EIRP_{reader}}{P_{th}}(1-|S_{11}|^2)G_t} \tag{5.4}$$

where G_t represents gain, $(1-|S_{11}|^2)$ is power transmission coefficient. This tag is evaluated for 4W EIRP reader, which is standard value for American UHF RFID passband (902 to 928 MHz). The gain was found to be 1.03 dB at the resonating frequency. The measured and simulated read range obtained from equation 5.4 is shown in Figure 5.8.

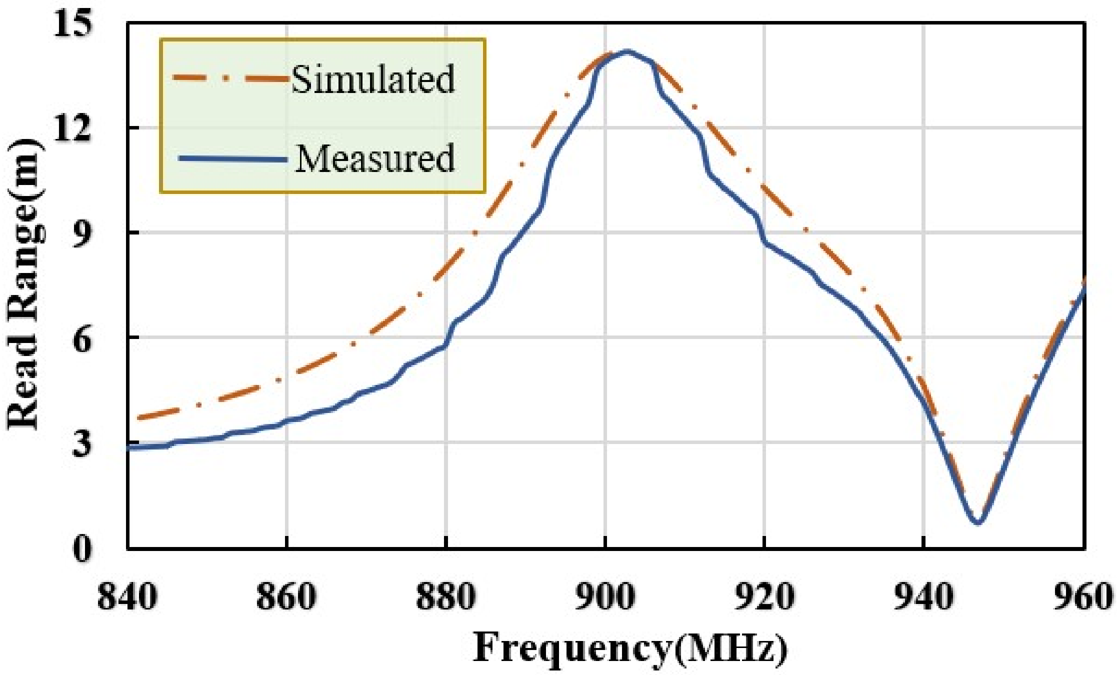


Figure 5.8: Read range of tag antenna (measured and simulated)

5.5.4 Radiation Pattern

The simulated radiation pattern of presented compact long read range tag antenna at 902 MHz is shown in Figure 5.9 for E and H plane. Since the tag has complex inductive impedance, and because of having non-50Ω impedance, the radiation pattern could not be measured in anechoic chamber.

Table 5.2 shows a brief comparison between some of previously reported tag antenna

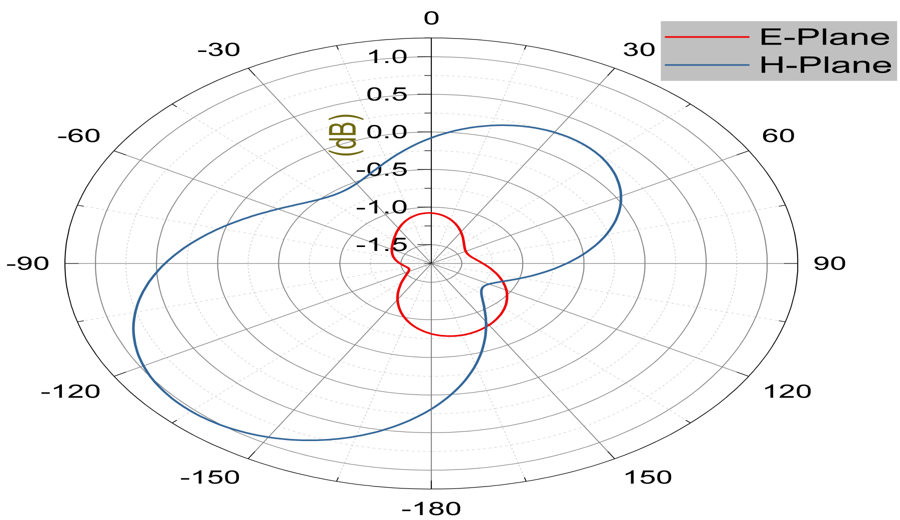


Figure 5.9: Radiation Patterns of tag antenna for E and H plane.

and proposed work. The comparison is made in respect to those articles whose operating

Table 5.2: Comparison of proposed antenna with few formerly described tag antennas

Antenna	**Freq.**	**Substrate's ϵ_r & $tan\delta$**	**Chip Sensitivity**	**Dimension (mm^3)**	**Gain (dB)**	**% size reduced**	**Read range**
[70]	915 MHz	ϵ_r=4.4, $tan\delta$=0.02	-21 dBm	$128 \times 50 \times 1.6$	-1.83	62	6.8m
[72]	865 MHz	ϵ_r=3.66, $tan\delta$=0.004	-19 dBm	$50 \times 50 \times 1.52$	2.23	4	13.3
[73]	926 MHz	ϵ_r=2.09, $tan\delta$=0.0002	-20.5 dBm	$220 \times 30 \times 1$	5	44.72	5m
[74]	915 MHz	ϵ_r=4.4, $tan\delta$=0.02	-20 dBm	$69 \times 45 \times 3.6$	1.58	67.36	11.9m
[75]	910 MHz	ϵ_r=4.4, $tan\delta$=0.02	-16.7 dBm	$\pi \times 33 \times 33 \times 1.6$	-6.9	33.3	4.5m
[76]	915 MHz	ϵ_r=3.2, $tan\delta$=0.08	-15.8 dBm	$80 \times 25 \times 3.5$	-3.6	47.8	1m
[40]	956 MHz	ϵ_r=4.4, $tan\delta$=0.02	-17.4 dBm	$91 \times 91 \times 1.6$	-10	72.46	2.6m
[77]	915 MHz	ϵ_r=4.4, $tan\delta$=0.02	-17.6 dBm	$120 \times 120 \times 1.6$	–	84.16	10.8
[20]	919 MHz	ϵ_r=2.55, $tan\delta$=0.0015	-20.5 dBm	$57.72 \times 60.9 \times 1.5$	-3.7	30.8	8.44m
Proposed work	902 MHz	ϵ_r=2.2, $tan\delta$=0.0009	-13 dBm	$76 \times 30 \times 1.6$	1.03	–	14.1m

frequency were closer to the reported antenna except [72]. However operating frequency used in [40] is little more in compared to our proposed tag antenna operating frequency, presented tag has 72.46% lesser volume. This tag antenna has least value of dielectric constant and loss tangent in the table except [73]. The size reduction percentage is with respect to proposed work. It can be seen, despite having lesser dimensions, this tag antenna is having higher read range and gain.

5.6 Outcome

Here, in this research article, a miniaturized UHF RFID tag antenna is designed and fabricated, which is operatable at 902 MHz. The tag antenna blueprint is made by amalgamation of T-match and Meandered Inductively-coupled loop network inside Nested slot. The combination of these above techniques introduces a novel antenna with good impedance matching and remarkable return loss with long read range of 14.1m despite compact size. The simulated and measurement result plots match with each other very well. The simulated E and H-plane radiation patterns are obtained at 902 MHz. The proposed UHF RFID tag antenna is convenient for different RFID application on metallic objects in America UHF band.

The integration of multiple matching techniques in Chapter 5 showcases substantial improvements in read range and compactness for frequencies up to 928 MHz. In Chapter 6, we shift focus to a circularly polarized tag antenna operating at 915 MHz, an optimal frequency for enhancing tag readability on metallic surfaces. This design incorporates L-shaped load bars and sectorial patches to maintain impedance matching while mitigating interference from metal, demonstrating the utility of circular polarization in overcoming the challenges of RFID applications in industrial environments.