A New Design of UHF RFID Tag Antenna Based on Negative Index Metamaterial

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ABSTRACT

In this paper, A new design of dipole tag antenna based left-handed metamaterial is proposed for ultra-high-frequency (UHF) RF identification (RFID) applications. The proposed tag antenna is composed of two modified split ring resonators. To ensure the conjugate matching between the tag antenna and the electronic chip, a double T-matching structure combined with meander line technique are employed. The antenna is designed by using ADS based on momentum technique on a paper substrate. The tag antenna has an overall dimension of 76.6 mm x 25 mm. The simulated results show that the antenna provides a reflection coefficient about -39dB, gain about 1.34 dB and bandwidth about 32 MHz which cover the American UHF RFID band.

KEYWORDS

Left-handed metamaterial, RFID, SRR, tag antenna, UHF.

1 INTRODUCTION

In recent years, the interest in Radio Frequency Identification (RFID) systems and its applications has widely increased. RFID is a non-contact automatic identification and data acquisition technology that uses radio waves to identify objects, animal or person and it is practiced in a variety of fields. An RFID system is composed of a reader, a transponder and, a backend system. The basic components of an RFID system are illustrated in Fig.1 [1].

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The transponder or the tag is a small device that can be attached to or incorporated into a product, animal, or person. Based on power source, RFID tag can be divided into three main categories: active tags, semi-passive tags, and passive tags. the active tags are equipped with a battery that can be used as a partial or complete source of power for the communication between the tag and the reader. However, the passive tags are an RFID tag that does not contain a battery; the power is supplied by the reader [2].

Several frequency bands have been standardized for this technology. There are the Low-Frequency band (LF, 125–134 KHz), the High frequency band (HF, 13.56 MHz), the Ultra-High Frequency band (UHF, 860–960 MHz) and the microwave frequency band (2.4 GHz and 5.8 GHz). The UHF RFID technology uses three main frequency ranges in different regions: 952–955 MHz band in Japan, 902–928-MHz band in North and South of America, 866–869 MHz in Europe, India, Middle East, and Africa [3].

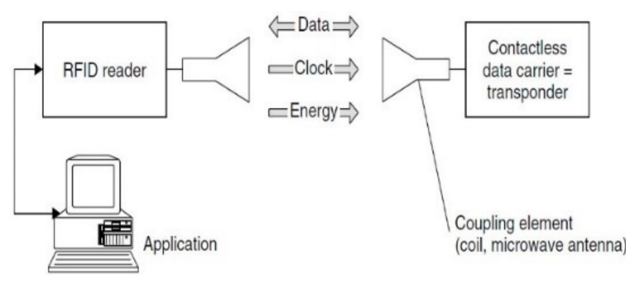

Figure 1: Basic component of RFID system.

Nowadays, metamaterials have been received much attention in wireless communications and antenna applications, due to their unique characteristic and its attractive electromagnetic properties. Metamaterials are artificially engineered materials, they have some unusual properties, which natural materials do not have like negative permittivity or negative permeability. If both the electric permittivity and the magnetic permeability are simultaneously negative, then such materials can exhibit an effective negative refractive index and it is known as a left-handed metamaterial [4]. The Russian theorist Victor Veselago was the first physicist who introduced this extraordinary invention of metamaterials in 1967 [5]. Based on of Veselago's work, Pendry et al. rediscovered the same characteristic and proposed a new technique for its practical implementation. They suggested an artificial thin wire medium to give negative permittivity in 1996 and split ring resonators (SRR) to give negative permittivity in 1999 [6][7]. However, the first practical demonstration was made in 2000 by Smith [8].

In this work, we propose a new design of miniaturized passive UHF RFID tag antenna based on left-handed metamaterial using a modified split ring resonator. The rest of this paper is as follows: in the second section, we present the metamaterial unit cell, in section III we present antenna design, in section IV we present the results and discussion and section V conclude this work.

2 DESIGN PROCEDURE

In this section, we will introduce and describe the proposed left-handed metamaterial unit cell, then we describe the final geometry of the proposed antenna.

2.1 Metamaterial Unit Cell Structure

In this part, we are going to discuss the modeling of the proposed left-handed metamaterial unit cell. Firstly, we have designed the conventional square split ring resonator to exhibit a negative permeability at the UHF band, the configuration of the conventional square SRR in a TEM waveguide is illustrated in Fig.2. The substrate used is an Advanced HP photopaper having a total dimension of 25mm x 25 mm, a permittivity of 3.3 and a loss tangent of 0.04 and a thickness of 0.25mm.

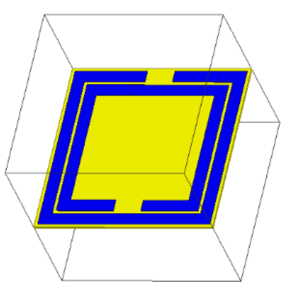

Figure 2: The Square split ring resonators embedded in a TEM waveguide.

Secondly, a thin wire is loaded to the square SRR on the same face of the substrate, which exhibit a negative permittivity. To analyze this structure, it is embedded at the middle of a TEM waveguide. Fig.3 illustrates the proposed left-handed metamaterial unit cell. The simulated S-parameters is presented in Fig.4.

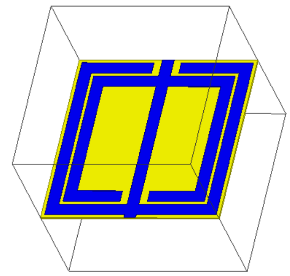

Figure 3: The left-handed metamaterial structure embedded in a TEM. waveguide.

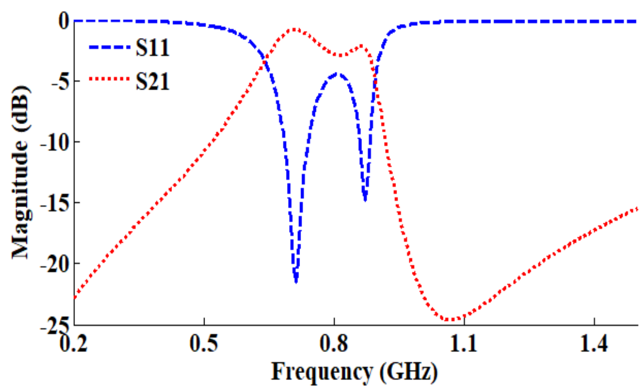

Figure 4: The simulated S-parameters of the left-handed metamaterial unit cell.

The extraction of the effective parameters of the metamaterial unit cell (permittivity and permeability) is carried out using the S parameters as described in [9]:

$$S_{11} = \frac{i}{2}\left(\frac{1}{z} - z\right)\sin(nkd) \tag{1}$$

$$S_{21} = \frac{1}{\cos(nkd) - \frac{i}{2}\left(z + \frac{1}{z}\right)\sin(nkd)} \tag{2}$$

where n is the refractive index, z is the wave impedance, k is the wave number and d is the thickness of the unit cell. Then, the refractive index and the wave impedance can be computed by:

$$z = \sqrt{\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}} \tag{3}$$

$$n = \frac{1}{kd}\cos^{-1}\left[\frac{1}{2S_{21}}(1 - S_{11}^2 + S_{21}^2)\right] \tag{4}$$

the expression for the electric permeability and the magnetic permittivity can be calculated by $\varepsilon = n/z$ and $\mu = nz$ respectively.

Figure 5 presents the results of the retrieved constitutive parameters against frequency. According to this figure, both permittivity and permeability parameters are negative in the studied frequency region. The refractive index is negative around the UHF band.

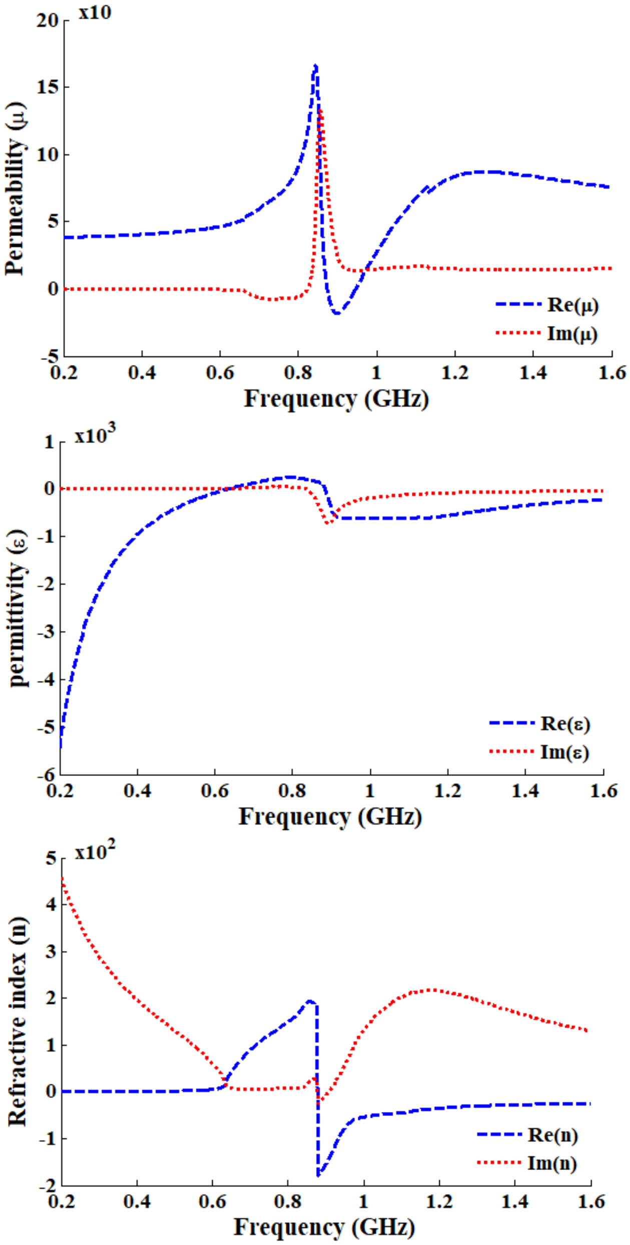

Figure 5: Real and imaginary parts of the permeability, permittivity and, the refractive index against frequency.

2.2 Antenna Design

The configuration of the proposed tag antenna is presented in Fig. 6. This antenna is designed on a paper substrate having dielectric permittivity of 3.3, loss tangent of 0.04 and thickness of 0.25mm. the proposed tag antenna consists of metamaterial unit cell formed by a modified square split ring resonator and a double T-matching structure combined with a meander line technique. The total dimension of the tag antenna is 76.6mm x 25mm. The optimal dimensions of the proposed RFID antenna are presented in Table 1. A "Monza 1a" microchip having input impedance of at the North American UHF RFID frequency band was attached at the center of the proposed RFID antenna.

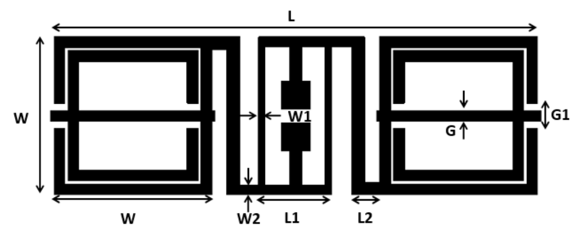

Figure 6: The configuration of the proposed Tag antenna.

Table 1: Optimal dimension of the proposed antenna.

Parameter	Value (mm)	Parameter	Value (mm)
L	76.6	W	25
L1	11.6	W1	1
L2	4.4	W2	1.6
G	1.7	G2	4

In order to deliver maximum power from the tag antenna to the RFID chip, the input impedance of the proposed antenna needs to be highly inductive and equal to the conjugate impedance of the tag chip . The power reflection coefficient is adapted to deal with the complex impedance of the tag antenna and the chip. The power reflection coefficient denotes as follows [10]:

$$\Gamma^* = \frac{Z_a - Z_{chip}^*}{Z_a + Z_{chip}} \tag{5}$$

3 RESULTS AND DISCUSSION

The simulated real and imaginary part of the input impedance of the proposed dipole tag antenna versus frequency is illustrated in Fig.7. As can be seen in the figure the input impedance of the antenna is $Z_a = 32.7 + j11.3\Omega$, which is match to the conjugate of the tag chip.

Figure 8 presents the computed reflection coefficient against frequency. The return loss is about -38dB and the bandwidth is about 30MHz which, cover the North American UHF RFID frequency band.

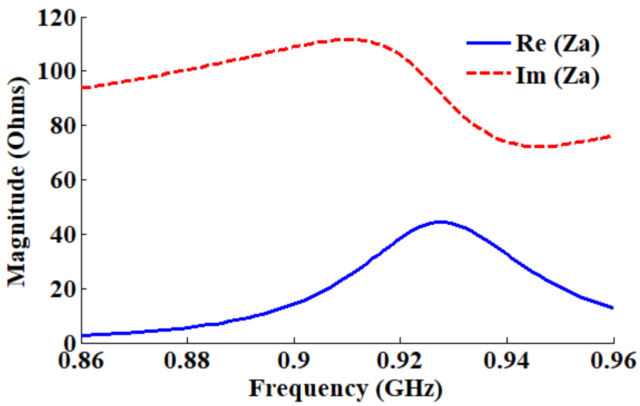

Figure 7: Simulated input impedance of the proposed antenna.

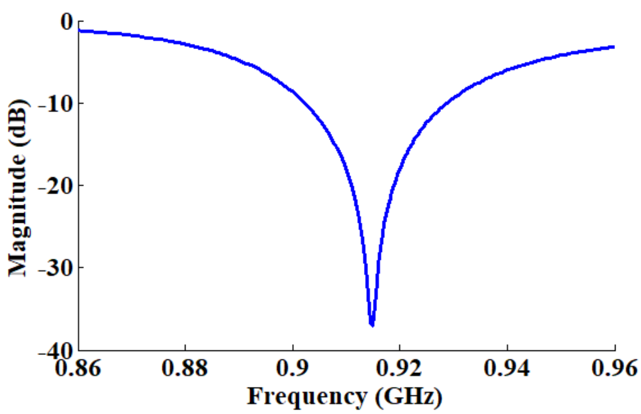

Figure 8: Simulated return loss vs frequency.

The simulated gain of the proposed tag antenna against frequency is presented in Fig. 9. We can notice that the gain is between 1.2dB and 1.4dB at the desired frequency band.

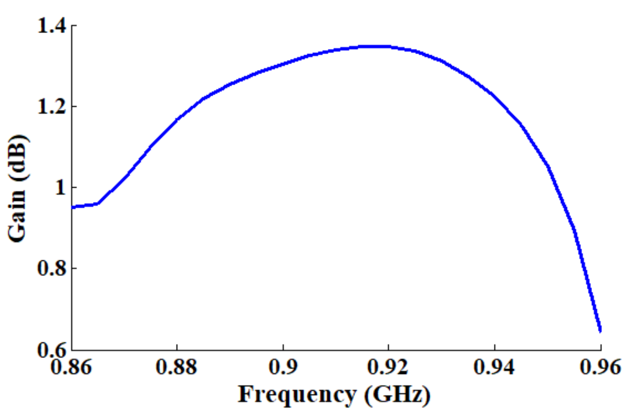

Figure 9: Gain Vs. Frequency of the proposed antenna.

The simulated 2D radiation pattern at H-plane and E-plane is shown in Fig.10. It can be observed that both E-plane and H-plane radiation pattern are omni-directional pattern.

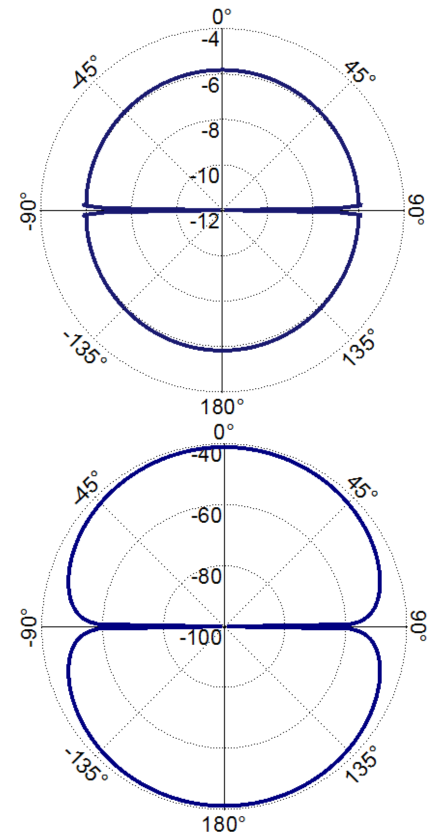

Figure 10: Radiation pattern of the proposed antenna at E-plane and H-plane.

If we analysis current distribution of the designed tag antenna it could be observed that a maximum current is around the metamaterial unit cell and the double T-matching structure, Fig.11 show the computed surface current distribution.

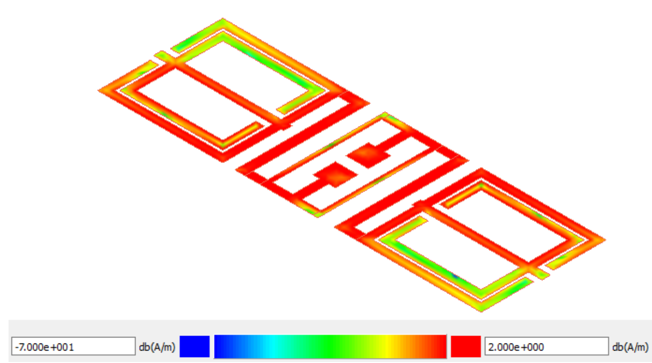

Figure 1: Simulated surface current distributions of the antenna at 915MHz.

The performance of the tag is evaluated using the read range which is the maximum distance that a tag can communicate with the reader. It can be computed by Friis equation [11]:

$$d_{\max} = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_r \tau}{P_{th}}} \tag{6}$$

where G_t and G_r are respectively the gain transmitted and received, P_t is the power transmitted to the tag antenna, P_{th} is the minimum threshold power necessary to activate the chip and τ is the power transmission coefficient. It is given by [11]:

$$\tau = \frac{4R_a R_c}{\left|Z_a + Z_c\right|^2} \tag{7}$$

The gain of the proposed antenna is about 1.34 dB and is equal to -9 dBm, then the read range is estimated by 5.42 m. the computed power transmission coefficient and the read range are presented in Fig. 12 and 13 respectively.

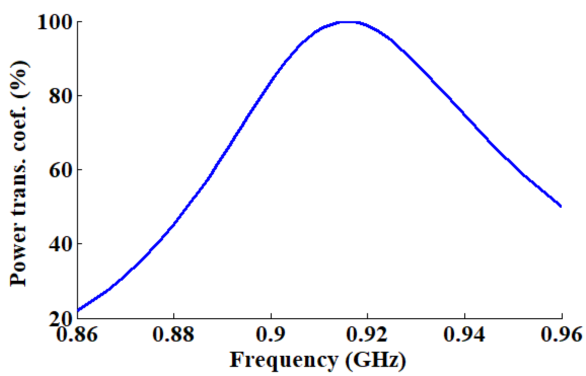

Figure 12: Computed power transmission coefficient.

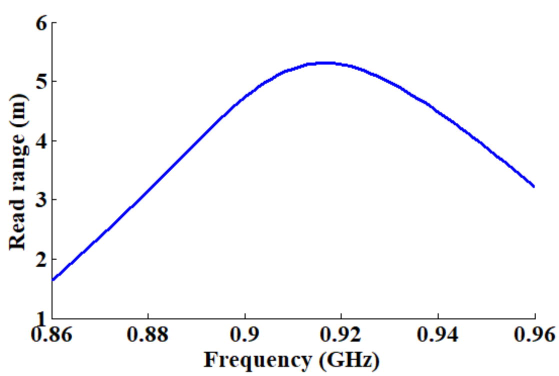

Figure 13: Computed read range of the proposed antenna.

After this validation, we have conducted another study by using a 3D electromagnetic solver to consider the dimensions of substrate, by consequent; we have launched the simulation of the same tag antenna by using CST Microwave Studio. The substrate used have a size of 79 mm x 27 mm x 0.25 mm as shown in the 3D layout presented in the Fig. 14.

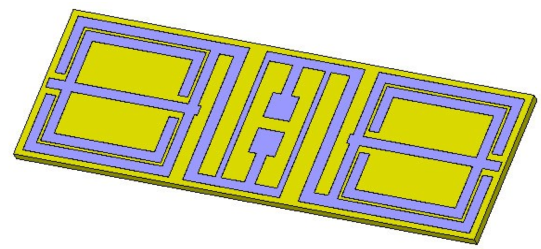

Figure 14: The 3D layout by CST of the proposed antenna.

According to the Fig. 15 and Fig. 16, the simulated results obtained by both solver is close. The input impedance obtained by CST is equal to $38 + j111\Omega$ with reflection coefficient of -19 dB, however, the impedance obtained by ADS is equal to $32 + j112\Omega$ with return loss of -38 dB. This difference is due to the software which are based on two different methods.

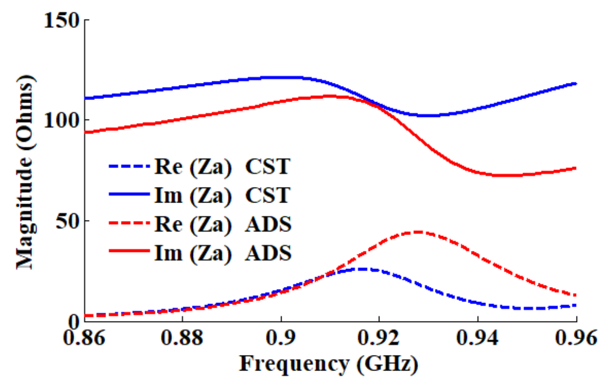

Figure 15: Comparison of the input impedance obtained by CST and ADS.

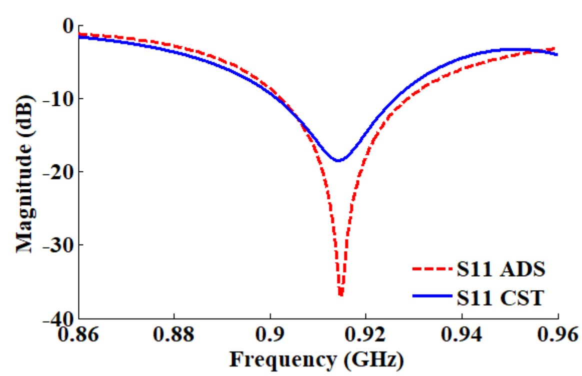

Figure 16: Comparison of the reflection coefficient obtained by CST and ADS.

4 CONCLUSION

The paper has presented the design of a miniaturized RFID tag dipole antenna consisting of a left-handed metamaterial unit cell and a double T-matching structure combined with meander line technique to conjugate match the impedance of the tag chip with the impedance of the tag antenna. Before the validation of the final antenna, we have described the complete design technique for the negative index unit cells and the methodology followed to match the input impedance of the antenna with the chip. The proposed tag antenna has a small size of 76.6mm x 25 mm. the computed results show that the antenna has a good return loss about -38dB, gain about 1.34db and a bandwidth about 30MHz which cover the desired frequency band. the maximum reading range of the proposed tag antenna is estimated by 5.42m.

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