New Miniature Microstrip Antenna Based On Metamaterial For RFID Applications

A. Ennajih*1, J. Zbitou1, M. Latrach2, A. Errkik1, L. El Abdellaoui1, A. Tajmouati1
1LMEET FST of Settat, Hassan 1st University, Settat, Morocco
2Microwave Group (ESEO), Angers, France
*Corresponding author, e-mail: abdelhadi.ennajih@gmail.com

Abstract

This paper presents a new dual-band metamaterial monopole antenna for radio frequency identification applications (RFID) in UHF and microwave band. This antenna is designed on an FR4 epoxy substrate with dielectric constant 4.4, loss tangent 0.025 and thickness 1.6mm and fed by 50 Ohms microstrip line. The proposed antenna consists of a rectangular patch incorporated with U slot and a partial ground plane, a split ring resonator (SRR) is inserted on the opposite side of the patch for dual-band operation. The antenna operates at 900MHz and 2.45GHz with a return loss of -33.73 dBi and -38.43 dB respectively. The numerical results show that the input impedance bandwidth of the antenna at the lower frequency band is 87 MHz (0.861GHz-0.948GHz) and in the upper-frequency band is 516MHz (2.255GHz-2.771GHz). The design parameters and performance are analyzed by using CST microwave studio. A prototype of the proposed antenna was fabricated to validate numerical results.

Keywords: RFID, Metamaterial, SRR, UHF band, Miniature antenna

1. Introduction

RFID stands for radio frequency identification, it is an automated data collection technology, which uses radio waves to locate, track and identify animals, objects or people [1]. RFID technology has been rapidly developing in recent years; it can be applied in many service industries, distribution, discard goods management, animal control, security, logistic, manufacturing companies [2]. Several frequency bands have been assigned to the RFID applications, such as low-frequency band LF (125 KHz-134 KHz), high-frequency band HF (13.56MHz), ultra-high frequency band UHF (860MHz-960MHz) and microwave band MW (2.45GHz or 5.8GHz) [3]. However, the UHF band is preferred in many applications due to the merits of high data transfer rate broad readable range. In the UHF RFID band, each country has its own allocation. For example, 866-869 MHz in Europe, 902-928 MHz in North and South America, 950-956 MHz in Japan and some Asian countries [4].

An RFID system requires at least three components, a reader, a transponder, and database. The RFID tag or transponder is a simple device that can store unique identification information of tagged object [5]. The RFID reader contains an RF transceiver module communicates with the tag via radio signals and the back-end database associate arbitrary records with the tag identifying data [6]. Figure 1 illustrates the basic components of an RFID system.
In this work, a monopole antenna by using U-shaped slots in the radiation patch for UHF RFID applications based on metamaterial is investigated. Without inserting the split rings resonators (SRR), the monopole antenna operates at 920MHz. The second band is achieved by adding the metamaterial unit cells in the ground plane. This paper is organized as follows, section II describes the design of metamaterial unit cell, section III presents the antenna design, section IV gives the simulated results and section V concludes this paper.

2. Design of a Metamaterial Unit

Metamaterial is artificial metallic structures having simultaneously negative permittivity and permeability, and consequently, have a negative index of refraction. It gains its properties from structure rather than composition [7], the subject of metamaterials started with the Russian theorist Victor Veselago in 1967 [8]. Veselago proposed a new type of material, which has simultaneously negative permittivity and permeability, and he showed the general electromagnetic properties of such material. Then, Pendry and his colleagues presented their studies about the negative permittivity and the negative permeability as in [9] and [10]. They declared that a negative permittivity medium can be obtained by arranging thin metallic wires periodically [9] and negative permeability can be obtained by metallization of split rings resonators [10]. Inspired by the theoretical works of Pendry, Smith and his group had been firstly fabricated the first artificial metamaterial [11]. After these works, metamaterial has attracted a great attention of researchers in various devices such as antennas, filters, amplifiers and others [12-18]. In this work, we have designed a metamaterial unit cell formed by two rectangular split-ring resonators to operate at 2.45 GHz. The geometrical parameters are chosen by using the optimization technique integrated into CST Microwave Studio. After many series of optimization, the final dimensions of the metamaterial unit cell are as follows; the length, the width and the height of the outer ring are Lr = 13mm, Wr = 19mm, and Wr1 = 1.5mm respectively. The separation between the inner and the outer ring g1 = 2mm, the gap at the split of both rings g = 2mm, and the distance between two SRR is 1mm. the geometry of the proposed metamaterial unit cell in a TEM waveguide is illustrated in Figure 2.

![Figure 2](image)

Figure 2. (a) The proposed metamaterial unit cell. (b) S-parameters of the proposed metamaterial unit cell

The effective permittivity and permeability are extracted by using the following Equations [19]:

\[
\mu_{\text{eff}} = \frac{2}{JK_0} \frac{1-V_2}{1+V_2} \tag{1}
\]

\[
\varepsilon_{\text{eff}} = \frac{2}{JK_0} \frac{1-V_1}{1+V_1} \tag{2}
\]

Where V1 and V2 are calculated by the following equations:
\[ V_1 = S_{21} + S_{11} \quad \text{and} \quad V_2 = S_{21} - S_{11} \]  \hspace{1cm} (3)

The extracted parameters are illustrated in Figure 3. We can conclude from this figure that by using two metamaterial unit cells, a simultaneously negative region of permittivity permeability around 2.45 GHz is obtained.

![Image of Figure 3](image-url)

**Figure 3.** Permeability and permittivity of the proposed metamaterial unit cell
(a) 1 SRR (b) 2 SRRs

### 3. Antenna Design

The proposed antenna consists of a rectangular patch with U slot on the front side and two metamaterial unit cells formed by split ring resonators (SRR) are placed on the opposite side of the patch. The SRR is used to achieve the dual-band operation. A microstrip feed line has a characteristic impedance of 50 ohms is used to excite the antenna. Figure 4 represents the geometry of the proposed antenna. The antenna is designed on an FR4 epoxy substrate with dielectric constant of 4.4, loss tangent of 0.025 and substrate thickness of 1.6 mm. The proposed antenna with optimum dimensions has been simulated and optimized by using CST microwave studio. The total size of the proposed antenna is 85 mm x 50 mm. The optimum values of the structural parameters of the antenna are shown in Table 1.

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**Table 1.** Optimum values of structural parameters of the antenna
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3. Results and Analysis

Figure 5 illustrates the simulated return loss of the final geometry of the proposed monopole antenna with and without metamaterial. It can be observed that the antenna without SRRs operates at 925 MHz with a return loss of -24 dB. However, by using metamaterial the antenna resonates at 900 MHz with a return loss of -33.37 dB and 2.45 GHz with a return loss of -38.43 dB. The impedance bandwidth is 87 MHz at the first frequency band and 516 MHz at the second frequency band.

The simulated gain versus frequency of the proposed antenna is illustrated in Figure 6. According to the figure, the peak gain is 2.2 dB at the first frequency band and 3.6 dB at the second frequency band.
Figures 7 and 8 illustrate the 2D radiation patterns at 2.45 GHz and 900 MHz at E-plane and H-plane respectively. The proposed monopole antenna has an omnidirectional radiation pattern at both, the UHF band and ISM band for both H-plane and E-plane. The angular width is 86.5 degree at 900MHz and 56.3 degrees at 2.45GHz.

The surface current distribution of the proposed antenna for both frequencies is represented in Figure 9. It clearly observed that a maximum current is shown around the U slot at 900MHz and around the SRRs at 2.45GHz and around the feed line for both frequencies.
After optimization of the antenna by CST Microwave Studio, we have launched the same antenna by HFSS. Figure 10 illustrates the comparison results of the reflection coefficient obtained by CST Microwave Studio and HFSS. According to this figure, the results of the return loss obtained by CST are similar to the results computed by HFSS. The minor difference observed is due to the different calculation method used by both simulators. CST Microwave is based on the finite integration technique and HFSS is based on the finite element method.

4. Fabrication and Measurement
After optimization by CST microwave studio and validation of the simulated results by HFSS, we have conducted the realization to check the performance of the simulation results of the radiation pattern and the reflection coefficient of the proposed antenna. The designed antenna was fabricated on FR4 substrate with the dielectric constant $\varepsilon_r = 4.4$, loss tangent $\tan = 0.025$ and thickness $h = 1.6$ mm by using LPKF machine and tested using an R&S VNA. The fabricated antenna is shown in Figure 11, it's having a total area of 75 mm x 50 mm.
The comparison between the measured and simulated reflection coefficient of the proposed antenna is illustrated in Figure 12. We can notice that the measured result is close to the simulated one. The difference between the measurement and simulation results is due to the error of fabrication, lower quality of SMA port used, uncertainty in substrate thickness and dielectric constant. The measured radiation pattern at 2.45 GHz and 900 MHz is presented in Figure 13.
4. Conclusion

In this paper, a design of a new miniature dual-band metamaterial monopole antenna embedded U slot for RFID reader applications is presented. The antenna is designed, simulated, and optimized by using CST microwave studio. The simulated results were compared and agreed between both computed results is observed. The use of the split rings resonators makes the antenna suitable for dual-band operation and improve the antenna performance. The radiation patterns of the proposed monopole antenna are quasi-omnidirectional in both H-plane and E-plane.

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