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A novel compact dual band RFID handheld reader antenna for microwave ISM band application

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ABSTRACT

This paper presents a new design of dual band RFID reader antenna for ISM-band industrial science and medical applications at 2.4 GHz and 5.8 GHz. The antenna is designed and physically built using FR4 substrate and taking a 1.5 thickness, 4.3 relative permittivity and 0.025 loss tangents. Different slots have been introduced to reduce the antenna dimensions and to achieve the dual band for microwave ISM band application. The dimension of the proposed antenna is 34 × 34 × 1.5 mm3, which it could be easily integrated into RFID readers. Numerical simulations have been performed using computer simulation technology (CST) Microwave Studio software. A parametric study was investigated in order to show the effect of slots variation and to obtain the desired functional characteristics. Experimental results show a good agreement with results obtained by simulations. A satisfactorily omnidirectional for the radiation patterns across the antenna operation bands was obtained.

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1. INTRODUCTION

Radio frequency identification (RFID) is a technology automatically encodes or stores digital data into an RFID tags (also known as RFID transponders). RFID transponder is affixed to an object, and which permits to a radio wave device reading or tracking data regarding the object remotely. In contrast to bar-code technology, which requires that codes printed on a label pass in direct view in front of an optical reader to allow the corresponding data to be read, RFID tags can be read without a direct line of sight [1]-[25]. This ease and speed of reading make RFID technology, particularly suitable for a large number of applications where the individual reading of each bar code would slow down the information acquisition process. The RFID system consists of an RFID tag that contains an integrated circuit connected to an antenna and encapsulated in a protective bracket, which depends on the needs of the intended application and an RFID reader is a receiver, transmitter controlled by a microprocessor or a digital signal processor. Using an antenna to which it is connected, the reader "captures" the data stored in the tags and then transmits it to a computer for processing [1].

Many operating frequencies have been assigned to the RFID systems, there are the low-frequency (LF) around 125 KHz, the high-frequency (HF) around 13.56 MHz, the ultra-high-frequency (UHF) from 860 MHz to 960 MHz and the microwave band (MW) around 2.45 GHz or 5.8 GHz. The important components in the RFID system are the reader and tag antenna, and their capability determines the performance of the whole system. RFID technologies require antennas with small sizes and high performances such as a large bandwidth, a multi-band operation [3]-[10] and, a high gain [11], [12]. There exists various techniques to realize multi-band antenna, for example, metamaterial technology [6], [14], [15], multilayer substrates [14], fractal technology [6], [16], slot reactive loading [4], and [17]-[20]. A slot loading can not only realize antenna multi band, but also realize broadband and miniaturization. A number of antennas have been proposed previously [4], [13], [16]-[33]. However, many of them they are not compact and sometimes a physical realisation of the antenna is difficult in reality.

In this paper, we propose a new design of a compact and low profile dual band RFID reader antenna for ISM band application. Our antenna is with one connection port dualband reader antenna. Two connection ports dual-band reader antenna puts additional requirement on sufficient port isolation [25]. The design initially begins with a conventional rectangular microstrip patch antenna. Then an intermediate design is given with introducing five C-shape slots to achieve the dual band and to improve radiation characteristics such as return loss and gain. Finally, a new last design is proposed by introducing another rectangular slot in the center to the radiating element to achieve each resonant frequency (2.4 GHz and 5.8 GHz) and to obtain a good adaptation and gain in both frequencies. A good characteristic were achieved by using slots technique. All antenna structures are designed and analysed using computer simulation technology (CST) Microwave Studio software. A detailed design process and a parametric study was performed and discussed. A simulation and experimental studies are given for our final new antenna. The antenna was physically built using FR4 substrate in telecommunications laboratory, Tlemcen. We provide a comparison between experiments and simulations results of the antenna return loss. The antenna has a good agreement between measurements and simulations. Finally, we validate our results and we notice that our new antenna design has a comparable dimension and offers a better adaptation and gain values compared with some other recent published antennas in literatures.

2. PREPOSED ANTENNA

The structure of the proposed RFID reader antenna is given in Figure 1. This antenna is simulated on computer simulation technology (CST) software. Designed on a low cost FR4 substrate that has a permittivity of 4.3, loss tangent of 0.025 and a compact size of (34 × 34 × 1.5) mm^3. The radiating patch is connected to a rectangular feed-line with a width of W_3 = 3.89 mm and a length of h_3 = 10 mm. On the other side of the substrate, a conducting partial ground plane, with a width of W = 34 mm and a length of h_1 = 9 mm, is placed. The patch and the ground plane are both made of copper material with thickness t = 0.035 mm. The antenna is connected to a 50 Ω SMA connector for signal transmission. The width of the microstrip feed-line is adjusted to improve matched impedance. Table 1 shows optimized dimensions of the patch, slots, ground plane and substrate. Slots were embedded in the printed patch to achieve the proposed antenna design and the desired resonant frequency, and to also improve the return loss. Several optimization processes were applied by using computer simulation technology (CST) software. We properly select the dimensions, positions and number of slots.

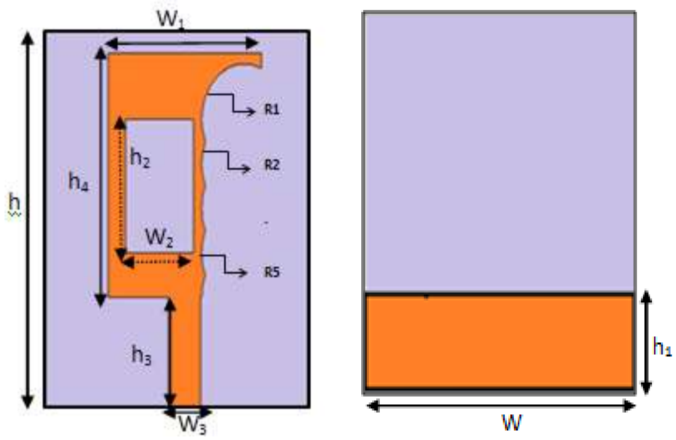


Figure 1. The geometry of the proposed RFID dual band reader antenna

Table 1.Optimized dimensions of the proposed RFID dual band reader antenna

Parameters	Proposed Antenna (ANT3) Dimensions [mm]
H	34
h_1	9
h_2	12
h_3	10
h_4	18
W	34
W_1	22
W_2	8
W_3	3.89
R_1=R_2=...=R_5	5

3. DESIGN PROCEDURE

In Figure 2, we propose first a design antenna (ANT1). A conventional rectangular microstrip patch antenna, which is designed by applying equations of the transmission line model to resonate around 2.4 GHz ISM band, see [11]. A rectangular radiating patch is placed on the top side of the FR4 substrate and it is fed with a microstrip line. On backside of the substrate, a partial ground plane is embedded. The size of this antenna (ANT1), its performance and its characteristics should meet the RFID system requirements. Then, in order to achieve the dual band, another antenna structure (ANT2) is proposed in Figure 2 by adding five C-shape slots. However this antenna was not adapted to the desired resonant frequencies. Therefore, to also achieve this, a new desired antenna (ANT3) is finally obtained, see Figure 2. Several optimization processes were applied to fillfull or satisfay each resonant frequency. Another rectangular slot was introduced in the center to the radiating element. Then, a geometrical modification of the slot dimensions was applied to boost the antenna characteristics. In particular to obtain a good adaptation and gain in both frequencies. These antennas are printed on the front side of FR4 substrate with the same partial ground plane. The proposed antenna ANT3 gives dual-band characteristic covering 2.4 GHz and 5.8 GHz.

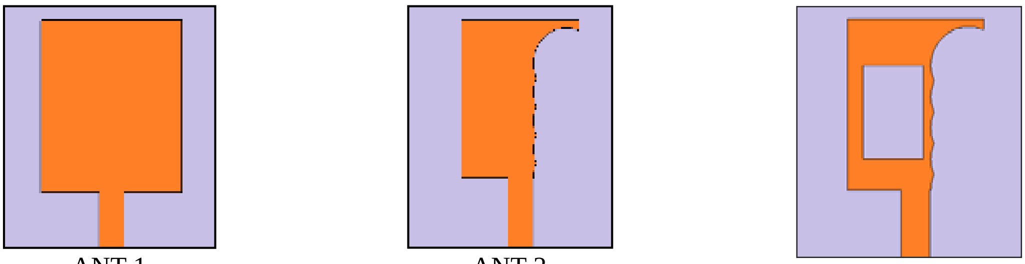


Figure 2. Antenna design and simulation evolution process

A comparison of the evolution the return losses of the three proposed structures designs as a function of frequency is given in Figure 3. We notice that the first antenna (ANT1) was adapted near the desired frequencies. The second design (ANT2) with five slots has a poor return loss factor and there exists a frequency deviation from the desired frequencies, i.e 2.4 GHz and 5.8 GHz. Finally, for the last antenna design (ANT3), we notice that the return loss and the impedance matching was improved by adding the rectangular slot and with adjusting its dimension and position along the radiating element. The antenna was adapted at the exact frequencies.

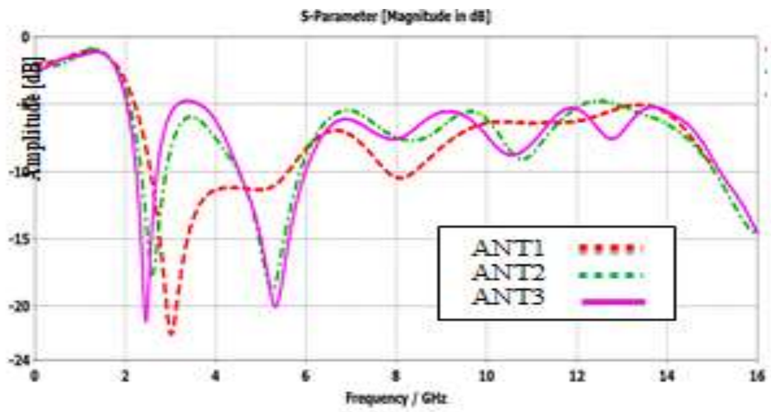


Figure 3. Simulated return losses versus frequency for the three designed antennas

3.1. Parametric study

A parametric study of the proposed antenna was performed using CST Microwave Studio. In fact, we variate the slot (rectangular) width, length, and the position to see their effects on the impedance matching and to optimize the final design. However, the only one that has a significant effect on the results obtained is the slot width. The Figure 4, shows a comparison graph of the evolution of the return losses when the slot width is increased from 2.5 mm to 8 mm. Where, the return loss peaks were increased by increasing the slot width. Table 2 presents a comparaison of the obtained results in terms of impedance matching, gain and the voltage standing wave ratio (VSWR).

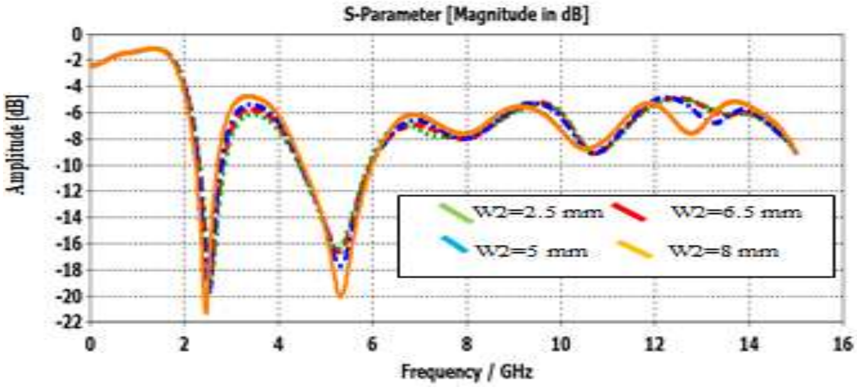


Figure 4. Return losses for different width values W2 of slot

Table 2. The simulation results antenna for different values of slot width

	Return loss [dB]		Gain[dBi]		VSWR	
Width [mm]	f= 2.4 GHz.	f= 5.8 GHz.	f= 2.4 GHz.	f= 5.8 GHz.	f= 2.4 GHz.	f= 5.8 GHz.
W_2= 2.5	-12.77	-11.04	1.63	4.61	1.61	1.79
W_2= 5	-13.26	-11.23	1.64	4.76	1.59	1.77
W_2= 6.5	-14.74	-11.66	1.669	4.962	1.44	1.7
W_2= 8	-18.53	-12.07	1.724	5.02	1.26	1.66

4. SIMULATIONS AND RESULTS

In the following, we present some other simulations of the proposed antenna to investigate the bi-band operation properties, for example, to show results of radiation patterns, the gain, the efficiency, and the current distribution.

4.1. Return loss versus frequency

The Figure 5 shows the simulation result of the return loss versus frequency of the proposed antenna. The graph shows clearly that the design provides a good return loss of −18.95 dB and −12.09 dB at the operating frequencies 2.4 GHz and 5.8 GHz respectivily. The Figure 6 shows the simulation result of the voltage standing wave ratio (VSWR) as a function of frequency. The simulation demonstrates that the antenna is well adapted and provides a better VSWR of 1.26 at 2.4 GHz and 1.66 at 5.8 GHz.

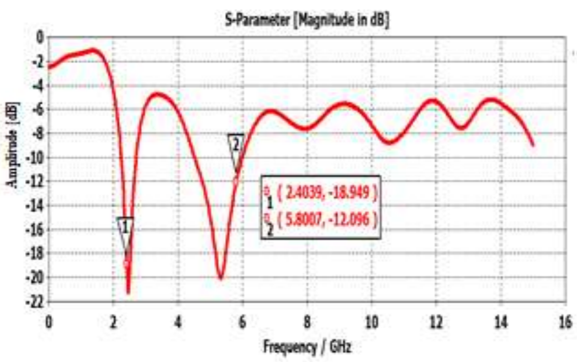


Figure 5. Simulated return loss versus frequency of the proposed antenna

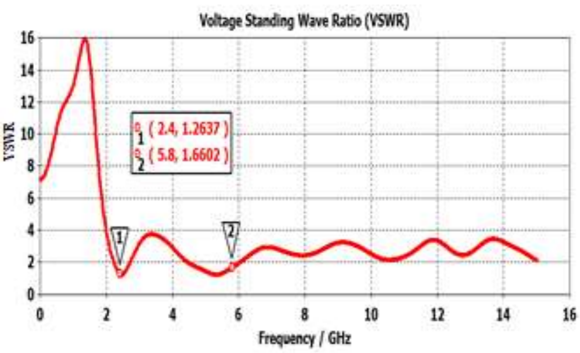
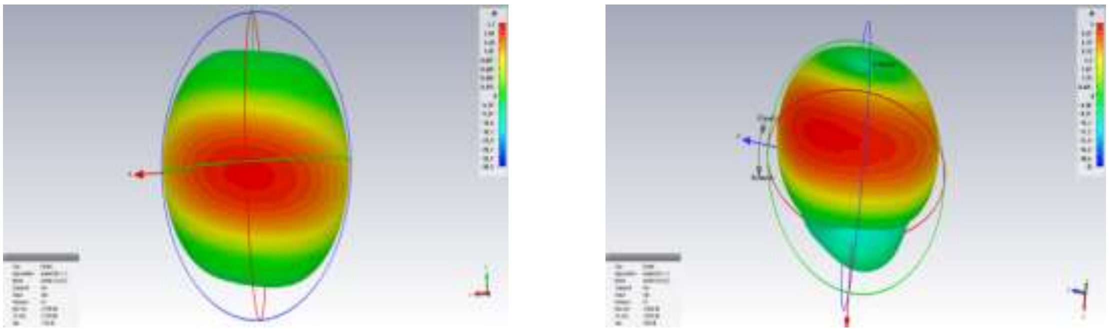


Figure 6. VSWR of the proposed antenna

4.2. Radiation patterns and gain

Figures 7 presents a 3D radiation pattern at the resonant frequencies 2.4 and 5.8 GHz of the antenna. For the two frequencies, we notice that the radiated power is concentrated along the x-z plane. The Figure 8 shows the gain at the operating frequency bands for the proposed antenna. The gain obtained of this antenna is equal to 1.7 dBi at 2.4 GHz and 5 dBi at 5.8 GHz. Where, these gains satisfy the requirement of RFID applications in far field. Figures 9 present the 2D radiation pattern in the E-plane and H-plane at the resonant frequencies 2.4 and 5.8 GHz of the antenna. We notice that in the E-plane and H-plane the antenna radiates bidirectionally at 2.4 GHz and provides an omnidirectional radiation pattern at 5.8 GHz.



(a) (b)

Figure 7. Simulated 3D radiation patterns at (a) 2.4 GHz and (b) 5.8 GHz

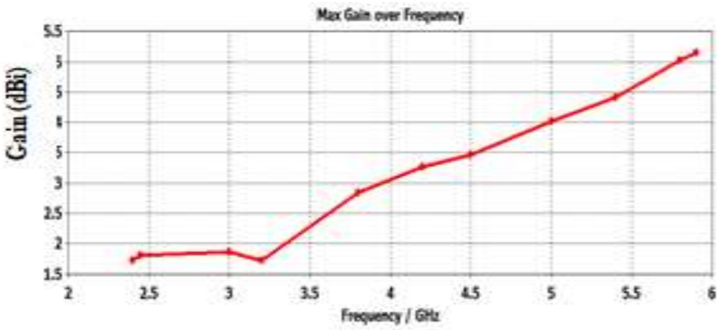
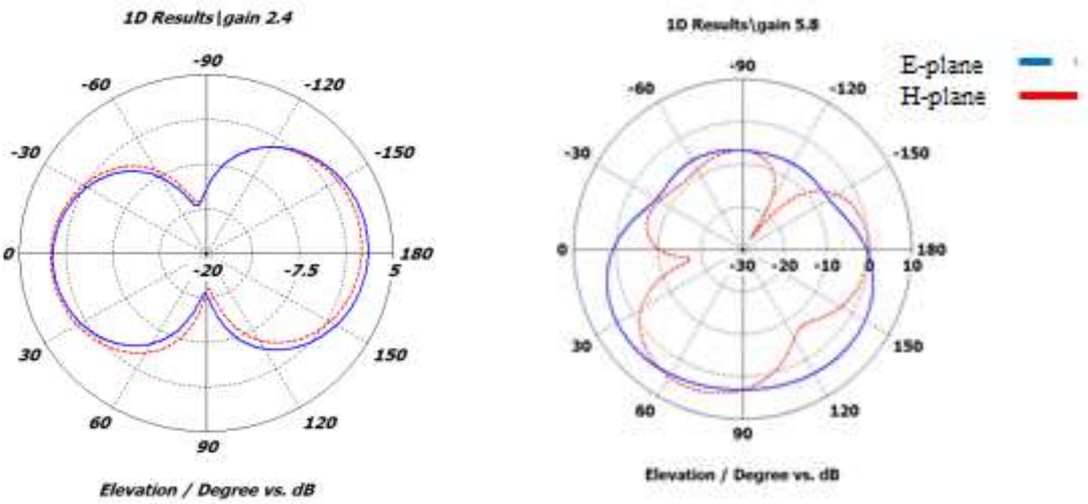


Figure 8. Simulated gain of the proposed antenna versus frequency

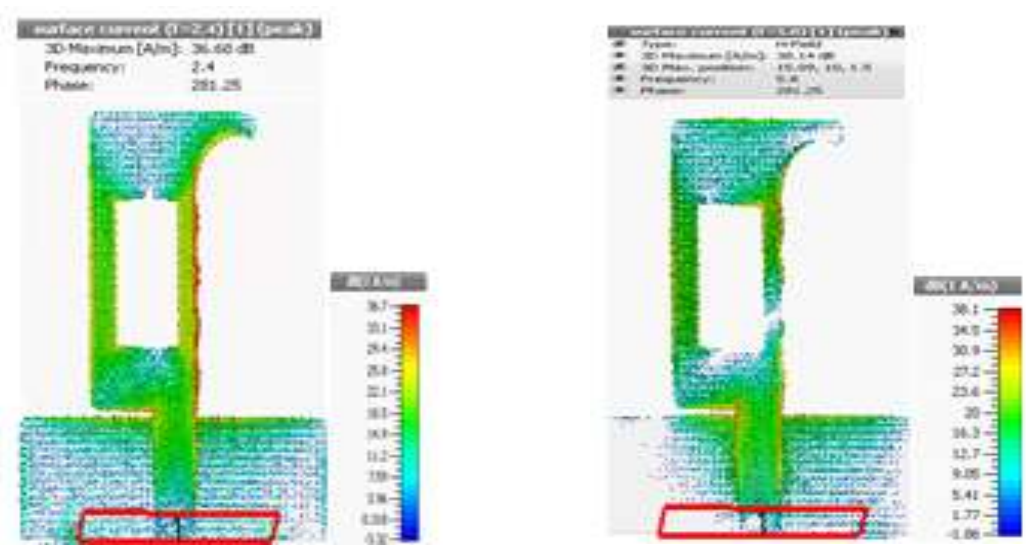


(a) (b)

Figure 9. Simulated 2D radiation pattern at 2.4 GHz (a) and 5.8 GHz (b)

4.3. Surface current distributions

Figures 10 shows the simulation results of surface current distributions of the antenna at frequencies 2.4 and 5.8 GHz. We notice that the current is concentrated on the microstrip line and around the slot. Also, strong distributions at 2.4 GHz, those are concentrated near the right-edge of the patch. Where, the radiation characteristics are stable. We notice that performances are strongly affected by the number and radius of slots and by the micro-strip feed-line dimensions.

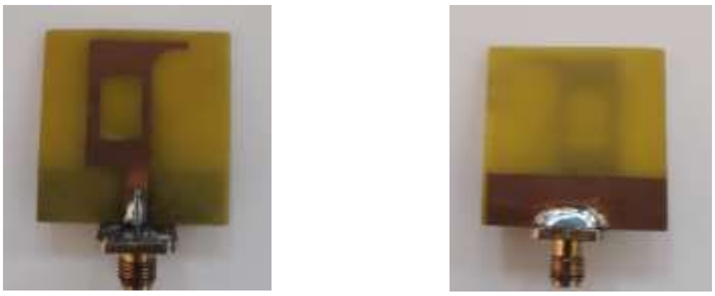


(a) (b)

Figure 10. Surface current distribution of the proposed antenna at 2.4 GHz and 5.8 GHz

5. A PHYSICAL REALISATION OF THE CIRCUIT ANTENNA

In Figure 11, some photographs were taken of the physical prototype of the dual band RFID Reader antenna using FR4 substrate (thickness of 1.5 mm, a relative permittivity of 4.3 and loss tangent of 0.025). The Figure 11(a) presents the front view and Figure 11(b) shows the back view. The achievement of the prototype of the antenna permits to check its performances and to validate our results obtained by simulations.



(a) (b)

Figure 11. Photographs of the fabricated antenna, (a) Front view, (b) Back view

6. MEASUREMENT RESULTS

We used a network analyser for the experiment or the measurement procedure to observe the reflection characteristics, as shown in Figure 12. The measured and simulated return loss curves of the proposed antenna are given in Figure 13. We notice that the measured return loss is in agreement with the simulated one across the whole operating band with an acceptable discrepancy for the resonance frequency 2.4 GHz due to the manufacturing tolerance and the effect of the feeding cable.

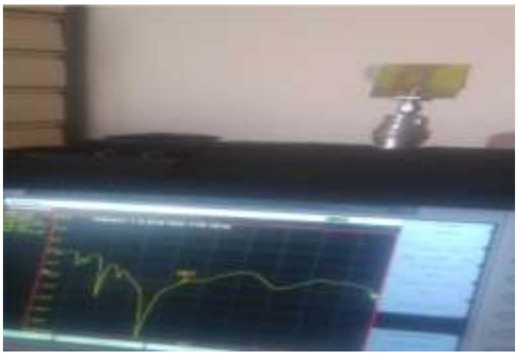


Figure 12. Measured return loss using a network analyzer

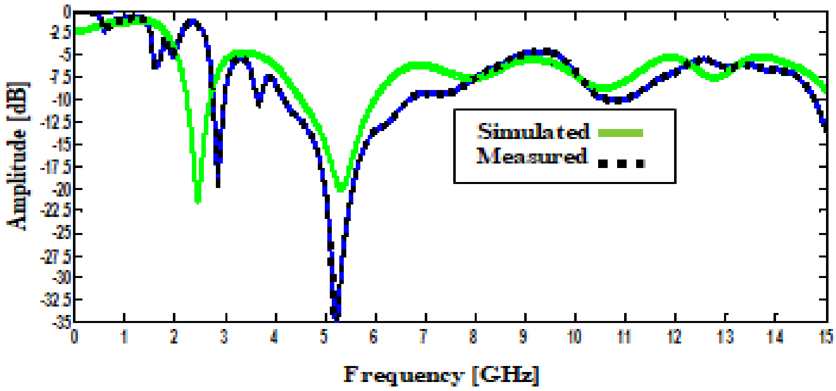


Figure 13. Measured and simulated return loss of the proposed antenna

7. PERFORMANCE COMPARISON WITH PREVIOUS PUBLISHED LITERATURE

Table 3 summarized a comparison of our antenna above and some other recent published antennas in terms of size, adaptation and gain. It is clearly shown that our antenna has a comparable dimension and offers a better adaptation and gain values compared with other antennas given in [2], [4], [5].

Table 3. Performance comparison of our antenna with some other recent antennas that we found in literature

Ref.	Band-wide (S11<-10 dB)	Size (mm)	Gain (dBi)
[2] Monopole Antenna	2.35–2.74 GHz, 5.2–6.5 GHz	38 mm x 35 mm 1.5 mm	1.36(dBi), 2.3 (dBi)
[4] patch antenna	2,39–2,496 GHz, 5.585–6,164 GHz	26 mm x 28 mm x 1,6 mm	2,09(dBi), 3,51 (dBi)
[5] metamaterial microstrip antenna	2.372–2.521 GHz, 5.7136–5.921GHz	34 mm x 34 mm x 1,6 mm	1,925(dBi), 3,385(dBi)
Proposed antenna	2,26–2,68 GHz, 4.536 – 5.985 GHz	34 mm x 34 mm x 1,5 mm	1.7 (dBi), 5 (dBi)

8. CONCLUSION

A new design of a compact and low profile dual band RFID reader antenna for ISM band applications has been proposed, implemented and measured. Good characteristics were achieved by using the slots technique. Numerous slots have been introduced along the length of the radiating element to reduce the antenna dimensions, to achieve the dual band and to improve radiation characteristics such as return loss and gain. A good agreement between measurement and the result of simulations, which validate this antenna. Our antenna is covering a dual band with good characteristics.

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