# Design and optimization of a rectangular microstrip patch antenna for dual-band 2.45 GHz/ 5.8 GHz RFID application

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**ABSTRACT**

This paper introduces a new rectangular slot antenna structure based on a simple rectangular shape with two symmetrical rectangular slots on the radiated element. The aim of this work is to design an antenna and enhance it to function in the band (2.45 GHz and 5.8 GHz). We formulated the dimensions of the antenna using the transmission line model of the analytical methods and then we optimized these parameters using the CST Microwave Studio simulator. We made changes to two important parameters in our design: the position and width of the slots when the other parameters are kept constant. The resulting antenna provides good adaptation, high gain that achieves 5.96 dBi at 2.45 GHz and 6.491 dBi at 5.8 GHz, good return loss values of -49.859 dB and -34.303 dB for the lower and upper operating frequencies respectively. For radio frequency identification (RFID) implementations, the proposed antenna is ideal, and its main advantage is that it has high gain and is simple to design and fabricate.



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## 1. INTRODUCTION

For various uses, including tracking and monitoring systems, medical and health surveillance sensors and wireless energy transfer, radio frequency identification (RFID) or radio frequency identification technologies have been developed and investigated [1]–[8]. E.g. tracking by RFID transponder incorporated with a global positioning system (GPS) module [1], using a dual-band RFID transmitter to implement a tracking system [2]. Also, using a wireless power transfer technique to power a chi-integrated RFID antenna as in [5] where an RFID antenna was developed for this purpose, or wirelessly powering a neuroprosthetic unit using a dual-band antenna [4]. RFID works in many frequency ranges to satisfy the limitations of desired applications. For RFID implementations, four distinct bands of frequencies are allocated [9]: low-frequency, high-frequency, ultra-high frequency, super high frequency. A large number of the developed antenna designs are dedicated to these bands [10].

To date, antennas have proven to be the most important part of any wireless communication system of all types, including satellite, cellular, global positioning system (GPS), Wi-Fi, and also the current distributed artificial intelligence where multi-agent systems are often employed and, of course, require a system to communicate [11], [12]. In addition, the antennas have a crucial role, especially in the domain of RFID communications. In the field of antennas, microstrip patch antennas (MPA) have stood out as an important innovative activity during the last twenty years. Having long been used only for military applications, after the 1990s there was a sudden interest in microstrip technologies for commercial applications. This openness to commercial applications has resulted in the appearance of a large number of products intended for wireless technologies on the market.

To encounter the current needs of the telecommunications field, microwave designers have to develop devices based on patch antennas. These antennas have very advantageous characteristics, especially in the case where they have to operate at high frequencies [13]. Because of their inherent properties, including small size, light in weight, easy production with low production costs, and the ability of integration with certain microwave printed circuits. Considering the increasing demand for connectivity and the need for higher data speeds and greater mobility in the wireless world of recent years, it is essential to improve dual-band antennas operating at industrial, scientific, and medical (ISM) bands 2.45/5.8 GHz. Since microwave RFIDs are primarily known for their ability to detect at a high speed [14]. The multi-band antennas are designed using a variety of antenna techniques, including etching slots in ground plane or radiating element, using monopole strips, and adding dielectric resonator(s) [15].

In previous work for dual-band ISM operations, numerous patch antenna designs have been published in [16]. A new patch antenna that works at both ISM frequencies has been developed from a reference model [17] and proposed changes, not only by making an antenna which performs at higher frequencies but also by providing a more minimalistic size. For RFID uses, a microstrip antenna design is presented in [18], the shape of the proposed patch is octagonal obtained by four cuts in rectangular patch corners. For vehicular communication systems, Sasikala *et al.* [19] suggested a rectangular dual-band patch antenna for the ISM operating frequencies, and used the slots technique at the ground layer to reach the dual band. A microstrip antenna that is circularly polarized is built and implemented in [20] by placing two square patches, part of which is cut off on the dielectric substrate. Microstrip antenna research in general is focused primarily on small designs, wide bandwidth, dual or multi band operating frequencies, and relatively high-gain [21], [22]. The patch can be made up using various design structures, but the easiest and best configurations are rectangular and circular [23]. A significant improvement in patch antenna performance, reported in several studies published in the literature [24]–[28], by adding different slot geometries to the patch.

In this article, we present a novel patch antenna geometry with two resonance frequencies using the slots technique for microwave RFID applications based on a simple rectangular shape that operates at ISM-centered 2.45/5.8 GHz frequencies. The chosen patch antenna is rectangular with two rectangular slots on the radiated element, fed by a 50 Ω microstrip line. The inserted slots have a significant effect on the antenna's radiating performance, allowing the two resonance frequencies to be reached. The radiation characteristics, such as the coefficient of reflection, bandwidth, and gain, have been improved by adjusting the dimensions and the position of these slots. Our antenna has the best performance compared to previous work which offers antennas for similar frequency bands.

This article focuses on the analysis and design of a rectangular and with slots patch antenna. First, we present our design method and the rectangular patch antenna's schematic model. After that, we examine the impacts of various antenna parameters on its performance, and the different results obtained will be presented and discussed, and we finish with a conclusion.

## 2. THE PROPOSED ANTENNA DESIGN

The design method we use for our antenna is provided in detail below to fully understand this work and Figure 1 illustrates this method. Once the application of RFID technology is selected and therefore the operating frequencies are defined, the definition of dielectric and conductive materials is possible. Using the transmission line model of the analytical methods, we can roughly calculate the patch length and width and this is the most practical method for rectangular patch [29]. The width (W) of the patch and its length (L) are shown by (1) and (2) [29], [30]:

$$W = \frac{c}{2f}\left(\frac{\varepsilon_r+1}{2}\right)^{-0.5} \quad (1)$$

$$L = \frac{c}{2f\sqrt{\varepsilon_r}} \quad (2)$$

where *f* is the frequency of resonance, εr is the substrate's relative permittivity and c is the speed of light.

The modification of the geometry of the radiating element by the insertion of the slots. By exploiting this technique, we were able to control the resonant frequency thus to widen the bandwidth in order to cover the whole of the desired bandwidth. In order to identify the geometric parameters of the antenna and the slots that can improve the desired properties, it is possible to launch a parametric study that will allow to see the influence of a parameter on the properties of the antenna. The electromagnetic software

CST Microwave Studio was used in the design and optimization of the proposed antenna. We started by designing an antenna based on formulas (1) and (2), and then two rectangular slots were engraved on the patch. The role of the slots is to create a resonance frequency response at 5.8 GHz and attenuate other resonances at undesired frequencies. The slots dimensions and positions have been well optimized to have a dual frequency band response. The goal of this research was to create a new antenna structure with good adaptation for ISM RFID implementations using the slot technique. To validate the final design, it was simulated using two electromagnetic simulators, CST and high-frequency structure simulator (HFSS) software.

Figure 2 depicts the design structure of the proposed MPA without slots and its S11 parameter, which operate at several frequencies as shown in Figure 2(a). The upper surface of our structure as shown in Figure 2(b) is a rectangular patch with two identical slots that have a length and width of Lp=39.9 mm and Wp=55.91 mm respectively, and are fed by a 50 Ohm microstrip line with a length and width of Lf = 15.30 mm and Wf = 4.85 mm. For the designed antenna, with a low dissipation factor (0.0004) the Rogers RT/Duroid 5880 substrate was used, with a relative permittivity of 2.2, and with 1.575 mm of thickness.

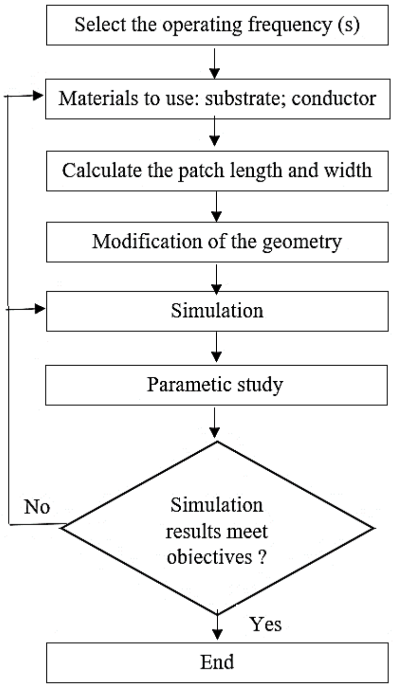



Figure 1. Antenna design method

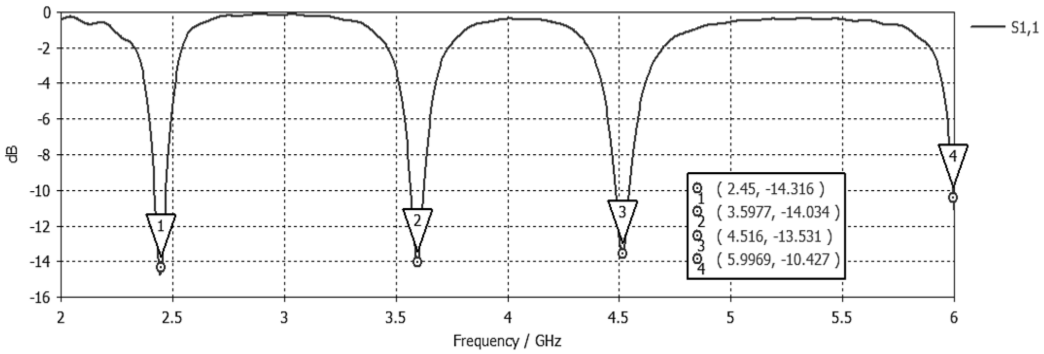
### 2.1. Optimization and key design parameters

The impacts of various antenna parameters on its performance can vary. We will consider making changes to two important parameters in our design; the position or the distance that separates the slots from the boundary of the rectangle (i2) and the width (m2) of the slots, which are made on the radiating patch element of the antenna. When other parameters are kept constant to survey the consequences of these changes, to be able to reach the resonant frequencies that we want and improve the reflection coefficient of the resulted antenna at these frequencies. Figure 3 shows the i2 and m2 parameters on the patch.

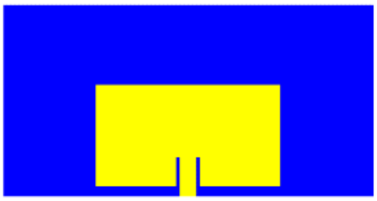
Parametric improvement is performed using CST, the target desired by this optimization is an optimal reflection coefficient, a magnitude s11 value of less than -20 dB for both resonant frequencies, and additionally attenuates resonances at unwanted frequencies created by the first antenna design as it is shown in Figure 4. The Figure 4 shows the effect of the position i2 of the rectangular slots on s11 for the two desired frequencies knowing that we have fixed the value of m2 on 1 mm and we changed the position of the two slots i2 along the x-axis from 5.75 to 6.95 mm.

We deduce that the proper value of i2 is 6.65 mm compared to the other values because it makes it possible to reach the maximum return loss S11 on the two frequencies. In this second optimization, we have changed the widths of the slots. Figure 5 show the graphs $S11$ for different values of m2 from 1.83 to

4.31 mm. We can conclude that the coefficient of reflection is more optimal for the value of m2 =3.69 mm knowing that the value of i2 is constant at 6.65 mm. We can deduct from the provided results that the optimizations carried out have allowed our antenna to resonate better at the two desired frequencies, and we can also see that the variation of the width and the position of the rectangular slots significantly influence the operating frequencies and the parameter S11.




(a)



(b)

Figure 2. The MPA without slots (a) Top view of the antenna and (b) S11 parameters of the antenna

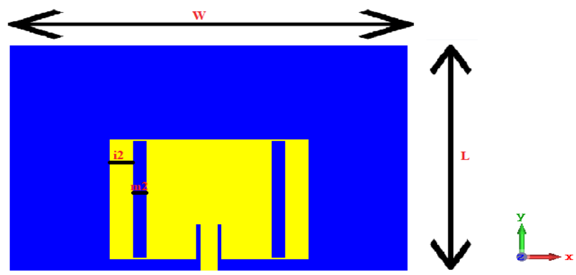



Figure 3. The location of the parameters i2 and m2 on the patch

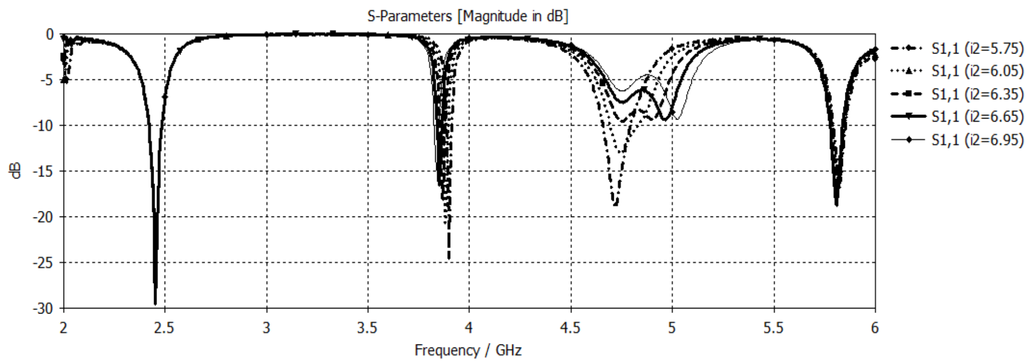



Figure 4. The effect of the position (i2) on s11

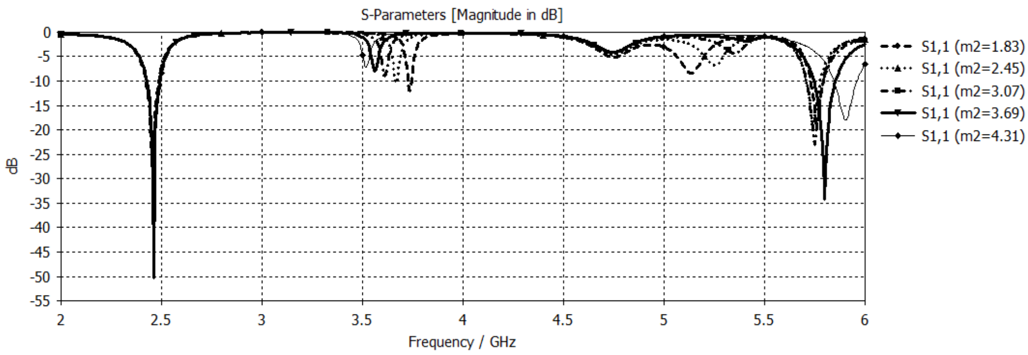



Figure 5. The effect of the position (m2) on s11

## 3. RESULTS AND DISCUSSION

### 3.1. Coefficient of reflection

We will present the different simulated results obtained after the design of the suggested patch antenna. In order to design an antenna with better performance, the value of the return attenuation should be under the value of -10 dB. Figure 6 displays the simulated reflection coefficient of our antenna on CST and HFSS. It reaches in CST a value of -49.859 dB with a bandwidth of 70 MHz (2.42-2.49 GHz) and -34.303 dB with a bandwidth ranging from 5.74 to 5.85 GHz approximately 110 MHz at the two resonant frequencies respectively. While it reaches a –16.844 dB (2.43-2.49 GHz) and -32.816 dB (5.75-5.86 GHz) at the two frequency ranges respectively using HFSS.

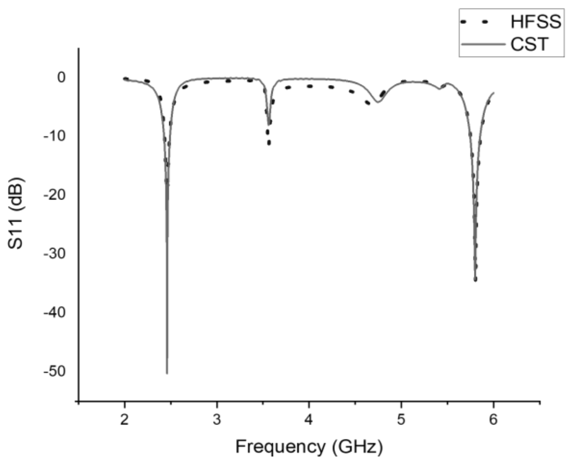


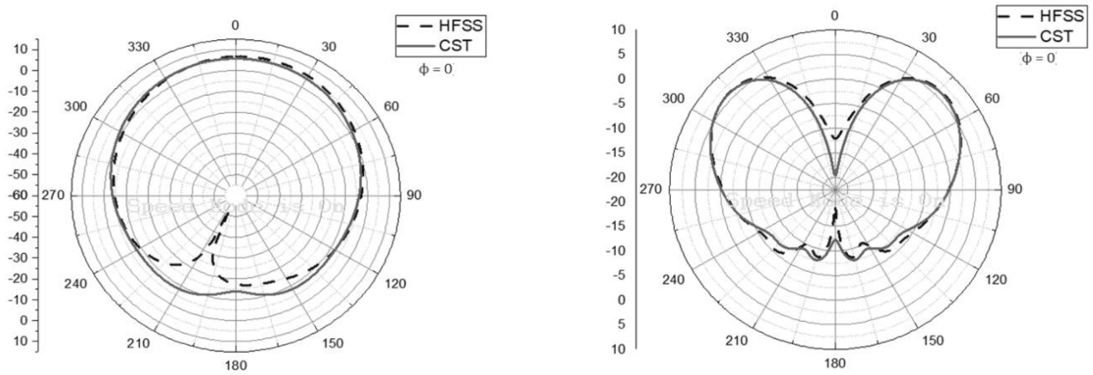

Figure 6. Coefficient of reflection calculated by CST and HFSS

From these results, it is evident that the choice of the correct location and width of the slots in the patch allowed us to obtain a good reflection coefficient centered on the desired frequencies. Because of the different calculation techniques used with each simulator, we can see a difference in the return loss obtained with CST and HFSS. Therefore, the variance between them can be considered acceptable.

### 3.2. The radiation pattern and gain

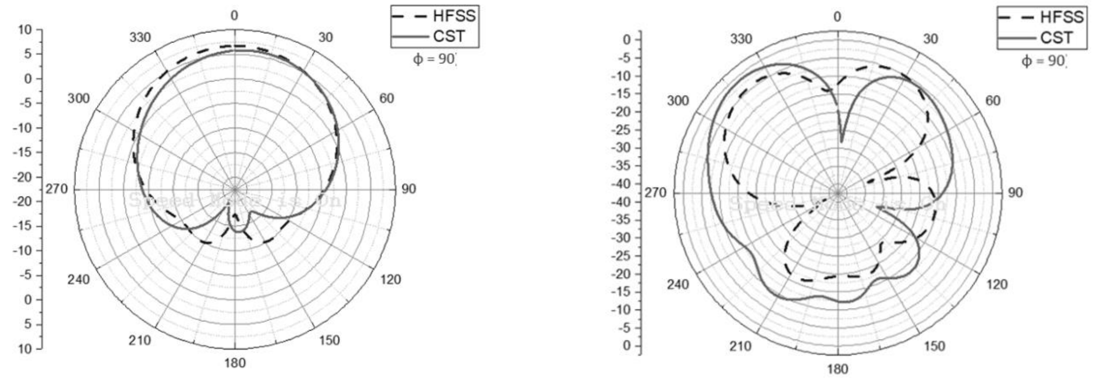
The 2D and 3D radiation pattern diagrams of the resulted antenna, at the interested frequencies, obtained with CST and HFSS are exhibited in Figure 7. Figure 7(a) represent radiation pattern diagrams in plane E (φ=0) for 2.45 GHz and Figure 7(b) for 5.8 GHz. Figure 8 represent radiation pattern diagrams in plane H (φ=90) Figure 8(a) for 2.45 GHz and Figure 8(b) for 5.8 GHz.

The gain variance on the frequency band from 2 to 6 GHz is also calculated using the two simulators, as shown in Figure 9. The results in Figure 9 show that the proposed antenna provides a gain of 5.96 dBi with CST and 6.62 dBi with HFSS at 2.45 GHz. The values of 6.49 dBi and 7.73 dBi were obtained at 5.8 GHz in CST and HFSS respectively.




(a) (b)

Figure 7. Gain diagrams in the plane E: at (a) 2.45 GHz and (b) 5.8 GHz




(a) (b)

Figure 8. Gain diagrams in the plane H: at (a) 2.45 GHz and (b) 5.8 GHz

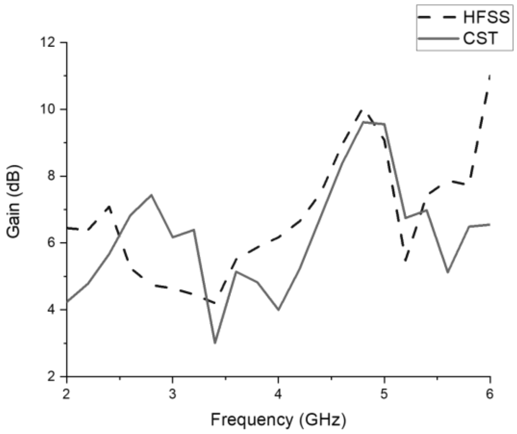
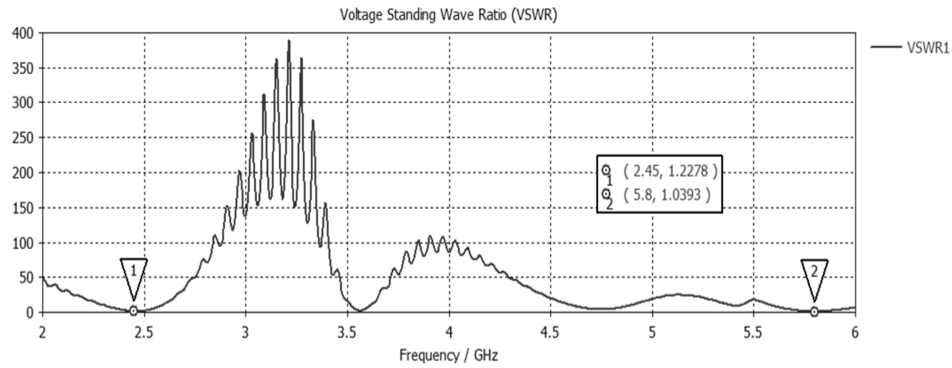



Figure 9. Gain as a function of frequency

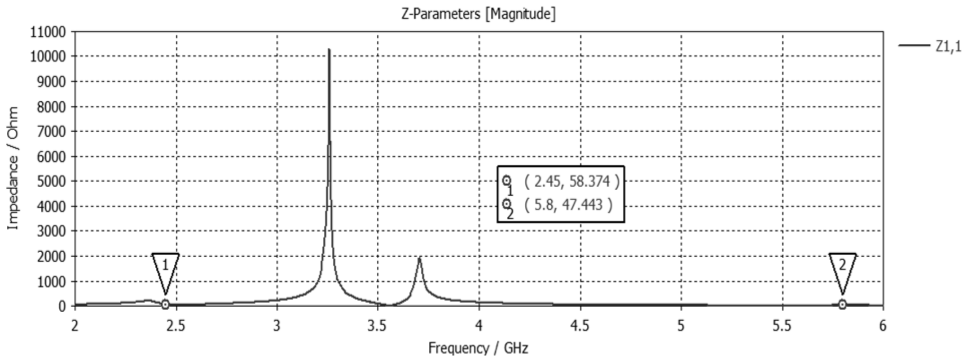
### 3.3. VSWR and input impedance

The voltage standing wave ratio (VSWR) and suggested antenna input impedance values are shown in Figure 10, and these values are summarized in Table 1. From the VSWR results, on the desired frequency ranges, we can see in Figure 10(a) that the values are less than 2 (<2). This means that our antenna as well as the transmission line are properly adapted, and the antenna receives more power as a result. Furthermore, it can be shown in Figure 10(b) that the proposed antenna is well-adapted based on input impedance values that are close to 50 Ω.

According to the results described in Table 2, we can deduce that our antenna resonates with a better return loss and high gain values in the center frequencies of the ISM band. For microwave RFID applications, the proposed antenna is ideal, and its main advantage is that it has high gain and is simple to design and fabricate.




(a)




(b)

Figure 10. Our antenna (a) VSWR and (b) input impedance

Table 1. The VSWR and input impedance values of the suggested antenna

| Frequency (GHz) | Input impedance (Ω) | VSWR |
|---|---|---|
| 2.45 | 58.374 | 1.2278 |
| 5.8 | 47.443 | 1.0393 |

Table 2. A comparison of our antenna and previously designed 2.45/5.8 GHz antennas

| Ref | Operating Frequency (GHz) | Return loss (dB) | Gain (dB) |
|---|---|---|---|
| [18] | 2.45 | -16.34 | 2.1 |
| | 5.8 | - 38.32 | 3.5 |
| [31] | 2.45 | -26.68 | 2.09 |
| | 5.8 | -38.33 | 3.51 |
| [32] | 2.47 | -25.7 | NM |
| | 5.8 | -33 | NM |
| [33] | 2.45 | -25 | 1.3 |
| | 5.8 | -46 | 3.8 |
| [34] | 2.45 | ≈-16 | 4.81 |
| | 5.25 | ≈-14 | 5.37 |
| | 5.8 | ≈-11 | 5.3 |
| Proposed antenna | 2.45 | -49.859 | 5.96 |
| | 5.8 | -34.303 | 6.49 |

## 4. CONCLUSION

A novel rectangular slot antenna structure for dual band RFID ISM bands applications was suggested and simulated in this paper. Using CST, many optimizations are made in the location and width of the slots in the patch. The choice of the correct values of these parameters allowed the antenna to be well matched with a VSWR ≈1 and input impedance near of 50 Ω, 58.374 Ω at 2.45 GHz and 47.443 Ω for 5.8 GHz. Based on the comparison made between our antenna and previous work, which offers antennas for the same frequency ranges, we can see that our design has the best performances. Characterized by a high gain of about 5.96 dBi at 2.45 GHz and 6.49 dBi at 5.8 GHz, and good return loss values of -49.859 dB and -34.303 dB for the lower and upper operating frequencies respectively. The proposed antenna performs well on the gain and return loss, and it is easy to manufacture because of its low profile and its simple structure with a basic topology.

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