# Design of dual and Wideband Rectangular Patch antenna for C and X Band Applications

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## Abstract

In this paper, we resolve two issues of microstrip antennas, which are miniaturization and efficiency behavior. For that, a rectangular patch antenna with 16×18×1.6 $mm^3$ dimensions with dual-band characteristics, was designed, fabricated and characterized.

In order to improve the problem of narrow bandwidth in microstrip antennas, we implement in this study the slot technique, allowing us to achieve our purpose. This technique, lead to a good reflection coefficient and VSWR. The characteristics of the fabricated antenna were measured and analyzed by Vector Network Analyzer. The results show two resonance frequencies that define two bandwidths defined by a return loss less than -10 dB and are respectively; 400 MHz at a frequency of 7.47 GHz, and 790 MHz at a frequency of 11.01 GHz. Also, the obtained gain has a good value and it's very remarkable according to the small size of the structure, with a peak value of 6.1 dBi at 12.5 GHz.

The small size and good characteristics enlarged the applications domains of our structure, from telecommunications and especially Radar, satellite communications to medical and wireless applications.

***Keywords***: Compact, Microstrip, SMA female connector, Ultra-wideband (UWB), Return loss, VSWR, HFSS

## 1. Introduction

Recently, microstrip antennas are part of different new technologies due to their miniaturization, efficiency, easy to fabricate and very flexible to integrate into any PCB circuit, which makes them too much requested and developed.

Radiating elements present the important part of these antennas. As the challenge in microstrip antenna design is increasing the bandwidth and the gain as described in [1], this radiating element characterized by small surface and few micrometers of thickness led to the development of different technology by using different techniques; for instance: Array process to enhance the gain, and insertion of slots to improve narrow bandwidth.

Hence, any equipment made of these antennas are reliable and efficient as described in [2]. Also, the cost of fabrication is very low, making these antennas very flexible and well integrated into any PCB circuit with the conformability to the complex mounting surfaces as presented in [3].

However, one of the limitations of these antennas, inciting researchers to overcome this limitation, is the narrow bandwidth. For that, several types of research have been developed: In [4]-[7], the authors have used the slots insertion in the radiating element, while researches in [8]-[11] adopt the partial ground plane technique. In [12], a Frequency reconfigurable wide to narrow band monopole antenna is demonstrated, the usage of a switch for frequency reconfigurability for Biomedical Applications is also discussed in [13].

Therefore, patch antenna arrays have been widely reported in researches [14]-[16] and authors in [17, 18] have focused on the technical design of microstrip patch antennas for X-band Applications.

In this paper, we present an efficient and small rectangular patch antenna operating in C and X bands. This structure is very reliable by combining small size and high gain which are very interesting and promising results. The 50Ω microstrip line was used as a feeding technique. The designed antenna in this work was performed by ANSYS Electronics HFSS Simulator. The comparison of our structure with some related works [7, 18, 19] show the advantages of our fabricated antenna in size, operating bandwidth, and gain. The present work is a more detailed study of our previous papers [10, 16]. The used design technique is a combination between slots technique and partial ground plane technique.

In fact, the structure of the antenna is the same as that of the previous paper, but the analysis of this paper contains more explanations of the different design steps.

## 2. Rectangular microstrip antenna Theory

In order to understand the design and analysis processes of our microstrip antenna, there are some important principles and theoretical tools [20] that are suitable to be presented.

Choosing the rectangular shape for our antenna as shown in figure 1, conducts us to think about how to relate the dimensions, W and L, to the radiation characteristics of this radiating element. The width W influences the radiated power and the bandwidth. Thus, W is chosen so that the bandwidth and the radiation efficiency are satisfactory. The literature suggests that 1< W/L < 2 [21]. As for the length L, it influences the resonant frequency to which it is linked by (1):

### 2.1. Patch Length & Width

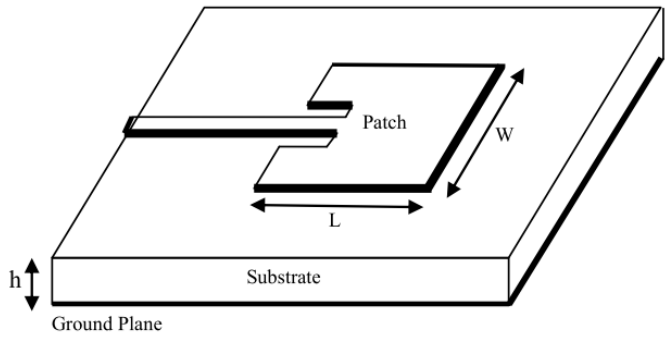



Fig. 1. Microstrip patch antenna [22].

$$L = \frac{C}{2f_r\sqrt{\varepsilon_r}} \tag{1}$$

Where $f_r$ is the resonant frequency.

### 2.2. Fringing Effect

The fringing effect is accounted for by defining an effective dielectric constant $\varepsilon_{reff}$ as follows:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{\frac{1}{2}} \frac{W}{h} \gg 1 \tag{2}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{\frac{1}{2}} + 0.041\left[1 - \sqrt{\frac{W}{h}}\right], \frac{W}{h} \ll 1 \tag{3}$$

### 2.3. Length and width and fringing effect

The fringing effect influences the calculation of L and W as follows:

$$W = \frac{C}{2f_r\sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{4}$$

As for the length L, we define an effective length by using $\varepsilon_{reff}$ in (1) and subtracting 2ΔL:

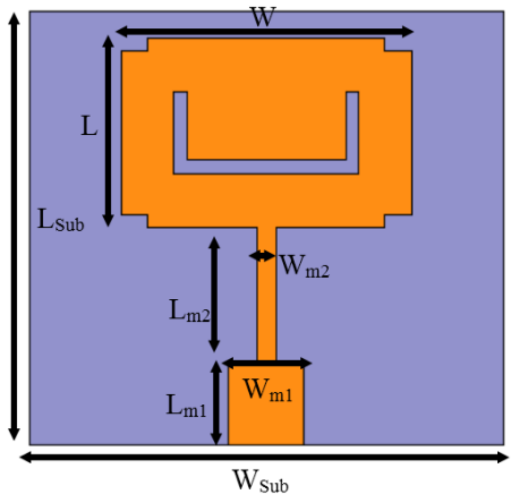
$$L = \frac{C}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{5}$$

ΔL is called the normalized length extension and is given by:

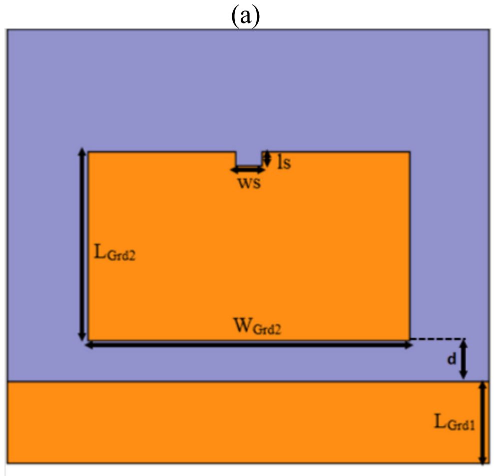
$$\Delta L = 0.412h\frac{(\varepsilon_r + 0.3)\left(\frac{W}{h} + 0.364\right)}{(\varepsilon_r + 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{6}$$

## 3. Proposed Antenna Geometry and Design

In this paper, we present the microstrip patch antenna shown in figure 2. It has a rectangular form to which we have added some shapes: steps, slots and a U-shaped slot. On the other side, we have made a partial ground plane beside which we added a parasitic element in which there is a slot to broaden the bandwidth. The substrate is FR4-epoxy whose dimensions are 16x18x1.6mm$^3$. It is characterized by a thickness of 1.6mm, a dielectric permittivity of 4.4 and a loss tangent of 0.02. The feeding is ensured by a microstrip line matched to 50Ω by a quarter wavelength line. The design and optimization were done by HFSS and have led to parameters summarized in Table1.




(a)




(b)

Fig. 2. The geometry of the proposed antenna, (a) Top view (b) Bottom view.

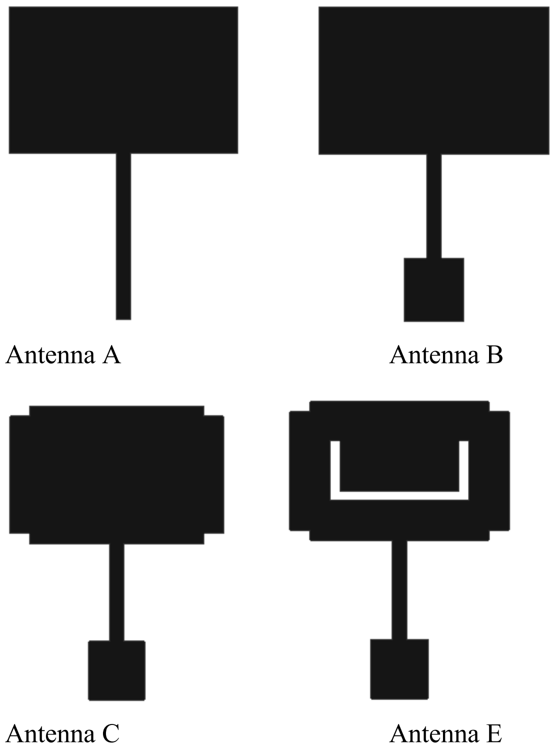



Fig. 3. The different geometric shapes of the radiation element

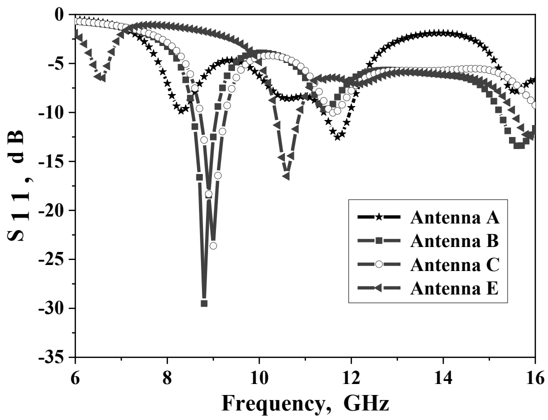



Fig. 4. The simulated $S_{11}$ curves for the antennas shown in Fig. 3

Fig. 3 presents the different steps followed to get the antenna structure. First, we made a simple rectangular patch fed by a microstrip line. Then, we added a quarter wavelength line in the feed line for impedance matching. Following this, U and edge slots were added to enhance the degree of the resonance. These results are presented in figure 4.

Five values of the length of the partial ground plane were tested. In Figure 5 we show the effect of changing the length of the ground plane on adaptation. We find that when we diminished the value of LGrd1, we get improved bandwidth; the best value obtained is for 3mm with increased bandwidth as is illustrated in Figure 5.

To assess the effect of the size of the ground plane, we will proceed as follows: All previously optimized parameters are kept constant with their best values, and we proceed to optimize the distance between the added metal surface and the ground plane, by varying the distance d of 0.5mm to 3mm.

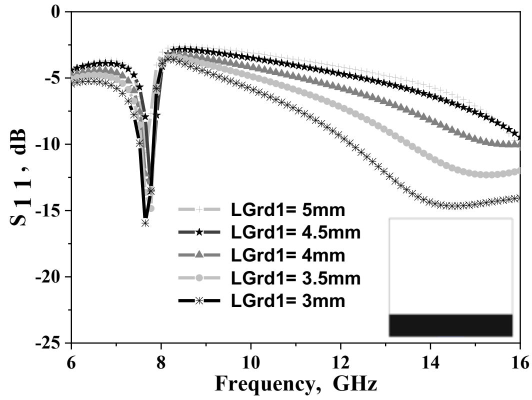



Fig. 5. $S_{11}$ optimization for different values of LGrd1

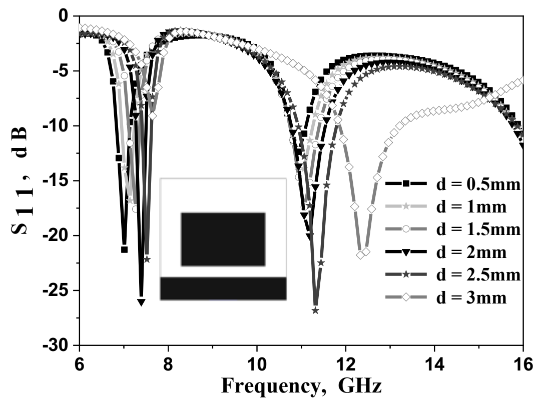



Fig. 6. $S_{11}$ optimization for different values of d

Table 1: Parameters values of proposed antenna.

| Basic configuration | Parameter | Value (mm) |
|---|---|---|
| Substrate | WSub | 18 |
| FR4-epoxy | LSub | 16 |
| Patch antenna | W | 11 |
| | L | 7 |
| | Wm2 | 0.7 |
| | Lm2 | 5 |
| | Wm1 | 2.8 |
| | Lm1 | 3 |
| Ground Plane | WGrd2 | 15 |
| | LGrd2 | 11 |
| | LGrd1 | 3 |
| | ls | 0.5 |
| | Ws | 1 |

According to the results of the $S_{11}$, we see an improvement in bandwidth with the introduction of the metal part. Thus, when increasing the value of a good adaptation of the reflection coefficient is noticed when we exceed certain values, we notice a decrease in the features of $S_{11}$. This is what allows us to conclude that the best results are obtained for d=1.5mm, as was illustrated in Figure 6.

## 4. Results and Discussion

Figure 7 shows the variation of the antenna $S_{11}$ as a function of frequency simulated by HFSS which uses finite elements method (FEM). The resonance frequencies are 7.24GHz and 11.08GHz. Their respective level of the return losses is -23.60dB and -17.16dB. The two frequency bands around these frequencies are: 7.13GHz to 7.38GHz and 10.68GHz to 11.42GHz. In fact, this can be used for radar and satellite applications.

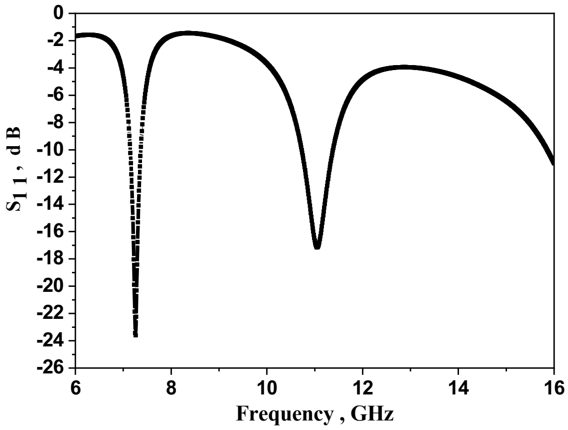
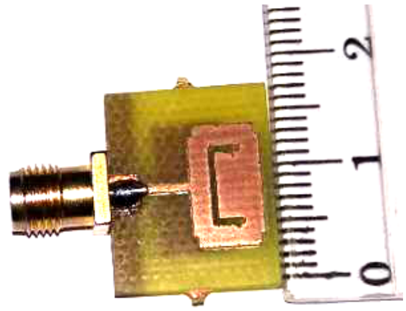


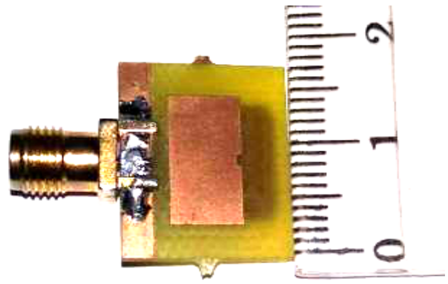

Fig.7. The simulated $S_{11}$ of the proposed antenna.

The fabricated prototype of the proposed antenna is shown in Fig. 8 according to the aforementioned parameters. Commercial FR4 was used because it resists heating and has excellent chemical and mechanical properties. The $S_{11}$ of the fabricated antenna was measured using a vector network analyzer Master MS2028C. The measured and simulated values for the reflection coefficient are shown in Figure 9. The simulated and measured results are very comparable, the fabricated antenna satisfies the -10dB $S_{11}$ for the two bands.

The simulated and measured characteristics such as reflection coefficient, bandwidth and resonant frequencies of the antenna are compared in fig. 9 and illustrated in table 2. Although measured and simulated results are not exactly the same, the important characteristics such as pass-band are the same.




(a)




(b)

Fig.8. The fabricated antenna (a) Top view and (b) Bottom view.

For the proposed antenna, two principle planes are selected to present the radiation pattern. These are referred to as the E and H planes. Figure 10 illustrates the radiation patterns in the H-plane (x–z plane) and the E-plane (y–z plane). It can be seen that the radiation patterns in x–z plane present two to three lobes for the two frequencies.

The gain of the antenna at various frequencies is shown in Figure 11. The gain has some stability in the simulation frequency band and has a peak value of 6.1dB at 12.5GHz. The gain is relatively good and can be improved by inserting our antenna in an array.

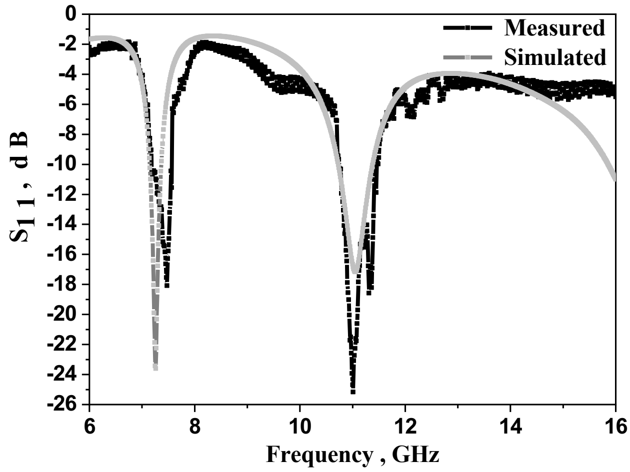
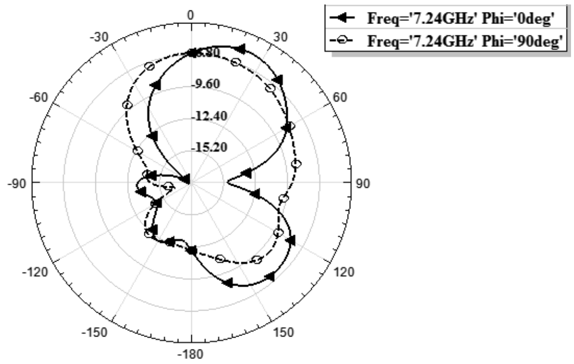


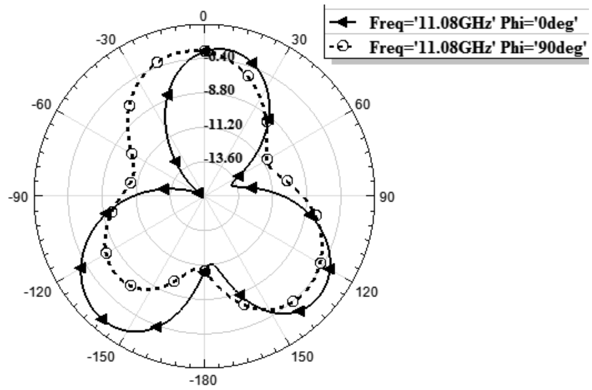

Fig.9. Comparison between the simulated and measured $S_{11}$ of the proposed antenna.

Table 2
Comparison between measured and simulated values of $S_{11}$.

| | Bandwidth at -10dB (GHz) | Resonant frequency | Level $S_{11}$(dB) |
|---|---|---|---|
| Simulated | 7.13-7.38<br>10.68-11.42 | 7.24 GHz<br>11.08 GHz | -23.60<br>-17,16 |
| Measured | 7.16-7.56<br>10.71-11.50 | 7.47 GHz<br>11.01GHz | -18.08<br>-25.16 |




(a)




(b)

Fig. 10. Simulated E-Plane and H-Plane Radiation patterns of the proposed antenna at different frequencies (a) 7.24GHz and (b) 11.08GHz


Fig.11. The gain of the antenna at a different frequency.

Table 3 presents a comparison between the performance of some recently developed antennas for C and X-band applications and the proposed antenna. Our antenna shows two wide impedance bandwidth, compact size, and good gain features.

Table 3: Comparison of previous designs with the proposed antenna

| Antenna | Bandwidth (GHz) at VSWR < 2 | Resonance frequency GHz | Antenna size (mm3) | Average Gain (dBi) |
|---|---|---|---|---|
| This work | 400<br>790 | 7.47<br>11.01 | 16×18 | 5.36<br>4.65 |
| [18] | 450, 1010, 450 | 8.95<br>11.06<br>11.85 | 20×17.2 | 4.45<br>3.99<br>4.17 |
| [23] | 3700 | 10.16 | 43.25×30 | N/A |
| [24] | 1100 | 10 | 30.08×45 .9 | 6 |
| [25] | 1801 | 9.75 | 17.56×18 .04 | 3.56 |

## 5. Conclusions

In this paper, we presented a new miniature rectangular patch antenna with two resonant frequencies and wide bandwidth. The proposed antenna has two resonance frequencies that determine two bandwidths defined by a $S_{11}$ (reflection coefficient) less than -10dB and are respectively: (7.24$GHz$, 400MHz) and (11.08GHz, 790MHz). The gain peak value is 6.1dB at 12.5GHz. The design and analysis processes were articulated around the reflection coefficient and gain over a frequency range of 6 $GHz$ to 16 $GHz$. The technology used for the patch has the advantage of the printed circuits easiness of manufacturing and low cost. Thus, our antenna is a good candidate for many modern wireless applications such as Radar, satellite and wireless communications.

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