

# An ultra wideband antenna for Ku band applications

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## ABSTRACT

This paper presents a candidate ultra wideband antenna for Ku-band wireless communications applications, analyzed and optimized by the finite element method (FEM). This three-dimensional modeling was realized and compared with published antennas for validate the performances of the proposed antenna. Its design is based on the insertion of several symmetrical slots of different sizes on the ground plane of a mono-layer patch antenna to overcome the main limitation of the narrow bandwidth of patch antennas. The proposed antenna, made on an FR-4 epoxy mono-layer substrate with a defected ground plane (dielectric constant  $\epsilon_r = 4,4$ , loss tangent  $\tan \delta = 0,02$  and thickness  $h_s = 1.6$  mm). The simulated numerical results obtained are very satisfying; Bandwidth = 10.48 GHz from  $f_1 = 9.34$  GHz to  $f_2 = 19.82$  GHz,  $S_{11} = -34.17$  dB, Voltage Stationary Wave Ratio VSWR = 1.04, Gain = 6.27 dB.

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## 1. INTRODUCTION

The advent of the microstrip patch antenna has brought a technological revolution in the field of wireless communication because the advantages they offer in terms of manufacturing cost, flexibility and mobility [1], [2]. Today, it is omnipresent in our daily lives including the GSM phone, satellite TV and other commercial applications [3], [4], [5].

The typical patch antenna consists of a metal plane (called patch) placed on a dielectric substrate in contact with a ground plane [6]. The patch antenna offers better gain performance compared to conventional dipole or monopole antennas used in the past [7], [8]. However, it suffers from several limitations in relation to the low efficiency and low ability to radiate electromagnetic energy in the free space [9], [10]. Different forms of microstrip patch antennas are possible depending on the performance and the resonances frequencies required [11], [12].

Today, the increasing demand for frequencies has led to the appearance of several frequency bands. Among them, there is the Ku band (Kurz-untent), it is the most used of all other frequency bands for satellite television. It is conventionally defined in the electromagnetic spectrum defined by the microwave frequency band from 12.4 GHz to 18 GHz. This band is the most widespread in the world, because of the small size of the parables needed for its reception. However, it require many demodulators as well as several universal low noise block-converter (LNBS) to receive Ku-band satellites [13], [14], [15].

The shape chosen for the proposed antenna is the rectangular and trapeze shapes since they are very easy to analyze using both the transmission line and the cavity model, which are the most accurate for thin substrates [16].

In a general way in physics, before proceeding to the realization of such a physical model one passes by the reduced model. In the field of electromagnetism, several numerical simulation methods have been used to design three-dimensional structures of patches. These methods are the finite difference time domain (FDTD), the transmission line matrix (TLM), the finite element method (FEM), the finite integration technique (FIT) and other numerical methods [17], [18], [19], [20], [21].

In the following of this paper, the first section will be devoted to the mathematical formulation of the Maxwell's equations, then the following section will describe in detail the proposed antenna and how to determine its parameters, at the end of this document a comparison between this antenna and other antennas presented in [22], [23], [24] will be done.

## 2. ULTRA WIDEBAND ANTENNA DESIGN

The microstrip patch antennas (MSA) principle consists of very thin metallic strip (called patch) placed above a ground plane where the thickness of the metallic strip is restricted by  $t \ll \lambda_0$  and the height  $h$  is restricted by  $0.003 \lambda_0 \leq h \leq 0.05 \lambda_0$  [9][25]. In this section, a Defected Ground Structure antenna is presented, studied and optimized using the finite element method. The antenna is designed on a low cost FR-4 epoxy substrate with dielectric constant  $\epsilon_r = 4.4$  and loss tangent  $\tan \delta = 0.02$  with thickness of 1.6 mm.

### 2.1. Design of initial patch antenna

The calculation of the initial parameters of the proposed microstrip antenna is based on the classical equations presented in [9].

a) Microstrip line width:

For  $W > h$  :

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \left[ \frac{\epsilon_r - 1}{2\sqrt{1 + 12\frac{h}{W}}} \right] \quad (1)$$

And

$$Z_0 = \frac{120\pi}{\sqrt{\epsilon_{eff}} \left[ \frac{W}{h} + 1.393 + \frac{2}{3} \ln \left( \frac{W}{h} + 1.444 \right) \right]} \quad (2)$$

To have an input impedance equal to  $50 \Omega$ , the width of the microstrip must be equal to  $W_f = 3.08$  mm as shown in Figure 1). In this case we will take a rounded value of  $W_f = 3$  mm.

$$\text{Result} \begin{cases} \text{Width/Height} = 1.875 \\ \text{Effective Dielectric Constant} = 3.325 \\ \text{Impedance} = 50.83 \Omega \end{cases}$$

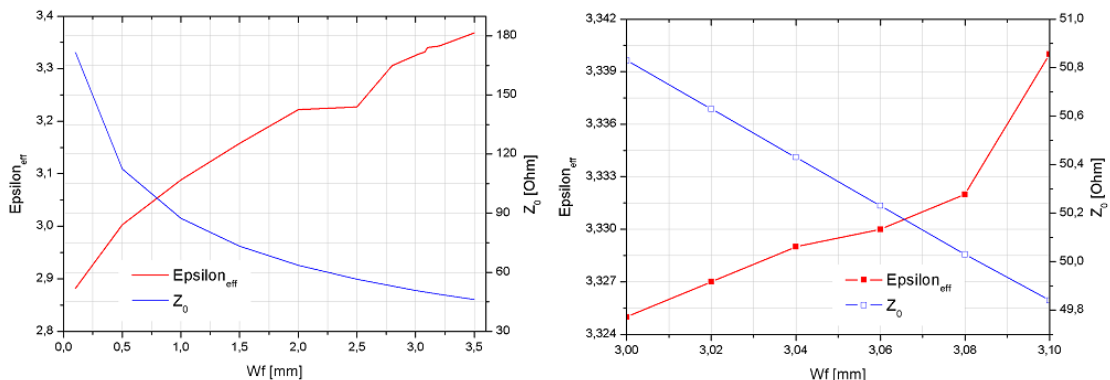


Figure 1. Effective dielectric constant and impedance vs microstrip line width

b) Microstrip line length:

The choice of the start length of the microstrip line was calculated using equation (3). It is based on a condition for the maximum signal coupling [26]. Then, the design process was based on the optimization of these parameters on a numerical platform based on the finite element method (FEM).

$$L_f = L_g/2 \quad (3)$$

Table 1 presents a parametric study of the effect of the variation of  $L_f$  on the resonance frequency and the return loss. The microstrip line length has been varied from 8 mm to 12 mm by a step of 1 mm. The chosen values of the starting parameters are  $W_f = 3$  mm and  $L_f = 10$  mm.

Table 1. Effect of the variation of  $L_f$  on the resonance frequency and the return loss

$L_f$ [mm]	Resonance frequency [GHz]	Return loss [dB]
8	25.18	-29.68
9	22.8	-21.83
10	21.05	-15.17
11	19.52	-11.45
12	23.6	-11.62

c) Slot antenna:

The multiple slot allow to control the resonance frequency, the reflection coefficient and the bandwidth by adjusting the width and length of the slot ( $W_{slot}$  and  $L_{slot}$ ). The parameter  $L_f$  allows to control the characteristic input impedance of the antenna. The slot is modeled as a waveguide inserted into the substrate. Its parameters are calculated from the following classical equations given in [27].

$$L_{slot} = \frac{\lambda_g}{2} \quad (4)$$

$$\lambda_g = \frac{\lambda_0}{\sqrt{\epsilon_{eff}}} \quad (5)$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} \quad (6)$$

$$\lambda_0 = \frac{c}{f_r} \quad (7)$$

## 2.2. Design of the proposed antenna

Figure 2 shows the final design of the antenna for a wider bandwidth covering the Ku band is achieved by developing several symmetrical slots. This new structure uses four slots with nine parameters namely  $W_1, W_2, W_3, L_1, L_2, L_3, H, D_1$  and  $D_2$  to get better performance;  $L_f$  is always used to match the impedance of the antenna to  $50 \Omega$ . In this article, the value of these parameters mentioned above was determined using a numerical platform with a discretization of 0.01 GHz for the calculation of the frequency. The total dimension of the proposed antenna is  $22 \times 20 \times 1.6 \text{ mm}^3$ .

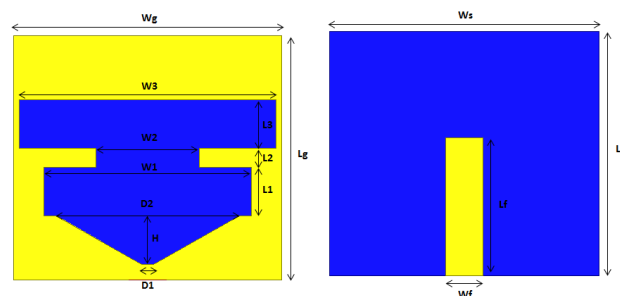


Figure 2. Top view and bottom view of the proposed antenna

Table 2 illustrates the different dimensions of the proposed antenna after a series of numerical optimization.

Table 2. The Optimum Dimensions of the Proposed Antenna

Parameter	Symbol	Dimension (mm)
Ground width	$W_g$	22
Ground length	$L_g$	20
Substrate thickness	$h_s$	1.6
Width of the slot 1	$W_1$	17
Length of the slot 1	$L_1$	4
Width of the slot 2	$W_2$	8.5
Length of the slot 2	$L_2$	1.5
Width of the slot 3	$W_3$	21
Length of the slot 3	$L_3$	4
Top width of the slot 4	$H$	4
Base width of the slot 4	$D_1$	1
Height of the slot 4	$D_2$	15

### 3. NUMERICAL RESULTS

#### 3.1. Analysis of the proposed antenna

The fundamental criterion for designing an antenna is the value of the return loss ( $S_{11}$ ). For this purpose, the various parameters of the antenna are varied, analyzed and optimized on a numerical platform based on the finite element method (FEM). The effect on the return loss by varying  $W_1$ ,  $H$ ,  $D_1$  and  $W_3$  are depicted in the Figures 3, 4, 5 and 6 respectively.

Figure 3 shows that with increasing the width  $W_1$ , the resonant frequency shifts to the left side. While increasing the height  $H$ , the resonance frequency shifts to the right side as shown in Figure 4). In both cases, the bandwidth improves considerably by increasing  $W_1$  and  $H$ .

Similar investigations are observed by varying the two parameters  $D_1$  and  $W_3$ . From the analysis of figures 5 and 6, we can conclude that the base width  $D_1$  and the width  $W_3$  of the slots primarily control the value of the reflection coefficient of the antenna. Simulated return loss shifts to the upper with the increase of the value of  $D_1$  and it shifts to the lower with the increase of  $W_3$ . The variation of  $D_1$  and  $W_3$  has no effect on the bandwidth size.

The result obtained from the final geometry of the proposed antenna is shown in Figure 7. The graph shows a maximum value of  $S_{11} = -34.17$  dB at a resonance frequency of 10.82 GHz. The graph also shows that below a threshold of -10 dB, the antenna has reached a bandwidth of 10.48 GHz from 9.34 GHz to 19.82 GHz. This which represents more than the bandwidth reached in [22], [23], [24].

Figure 8 shows the variation of antenna gain relative to the frequency. The antenna has maximum gain of 6.27 dB at 11 GHz and a gain greater than 4.08 dB over the entire frequency band from 9.34 GHz to 19.82 GHz.

The antenna radiation patterns in the E and H planes at 10.98 GHz, 14.3 GHz, 16 GHz and 18.6 GHz are illustrated in Figure 9, 10, 11 and 12. A directional diagram is observed in the plane E and the pseudo omnidirectional diagram in the plane H.

#### 3.2. Comparison between the proposed antenna and antennas cited in [22], [23], [24]

The antenna proposed in [22] achieves a reflection coefficient of -26 dB, a bandwidth of 2.8 GHz from 11.20 GHz to 14.0 GHz and a gain of 4,65 dB. Another antenna structure was presented in [23] achieves a maximum reflection coefficient of -33 dB at a resonance frequency of 14.13 GHz. It also achieves below -10 dB, a bandwidth of 2.5 GHz from 12 GHz to 14.5 GHz with an average gain of 8 dB over the entire band range of 12 GHz to 14.5 GHz. According to [24], an improved bandwidth microstrip antenna has been proposed for satellite communications. Bandwidth has been improved by using parasitic patches. This antenna has a bandwidth of 4.08 GHz, a return loss of -49.07 dB at the center frequency, a maximum gain of 8.25 dB.

In summary, Table 3 presents a comparison between the performances of these antennas. We find that our proposed antenna realized on a low cost FR-4 epoxy substrate realizes a competitive performance compared to

the other antennas presented in [22], [23], [24]. It also offers a very wide bandwidth can be candidate for satellite communication applications or other cognitive applications in the frequency range from 9.34 GHz to 19.83 GHz.

#### 4. CONCLUSION

In this work, a structure of a miniaturized ultra wideband patch, having a simplicity of construction at low cost and a better performance, has been proposed for wireless communication applications in the Ku band. It can also be performed in antenna array to increase gain and directivity. This patch has a low cost FR-4 epoxy substrate with constant dielectric  $\epsilon_r = 4.4$  and  $\tan \delta = 0.02$ . Several symmetrical slots have been inserted on the ground to increase the size of the bandwidth. This antenna offers a gain of 6.27 dB, a very wide band of 10.48 GHz from 9.34 GHz to 19.82 GHz, a low cost of implementation and a simplicity of manufacture.

The comparative study conducted in the last section showed a better performance achieved especially the bandwidth. So this antenna can be a very good candidate for telecommunication applications in Ku-band or other cognitive applications.

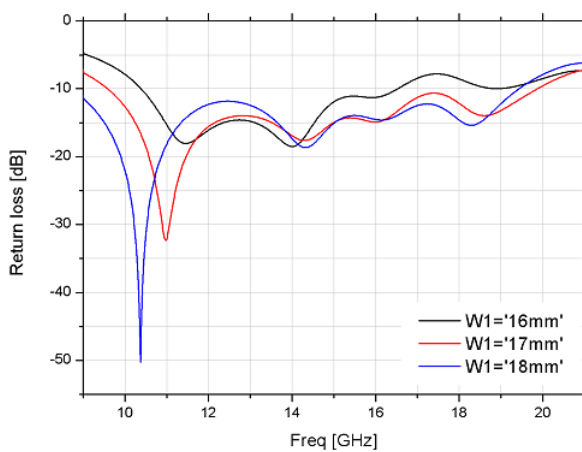


Figure 3. Return loss by varying  $W_1$

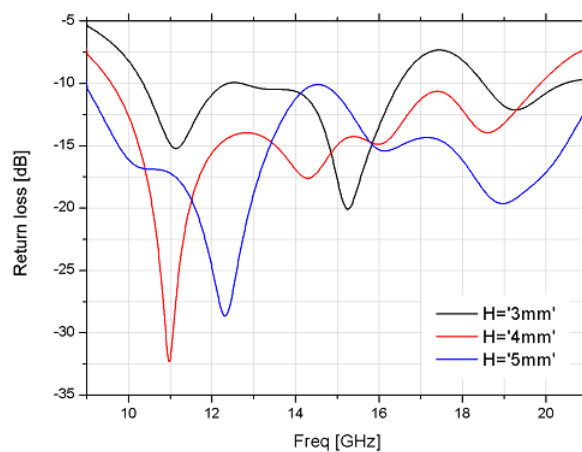


Figure 4. Return loss by varying  $H$

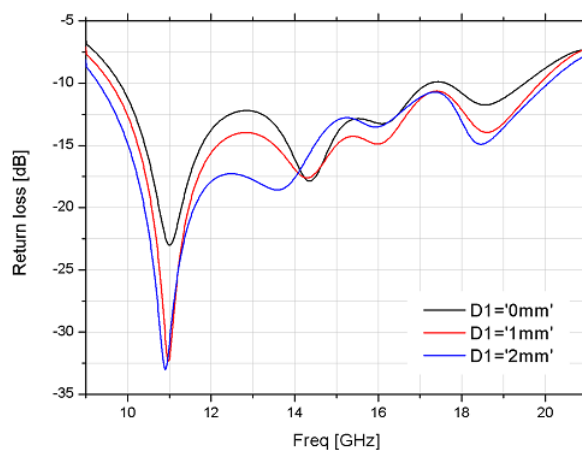


Figure 5. Return loss by varying  $D_1$

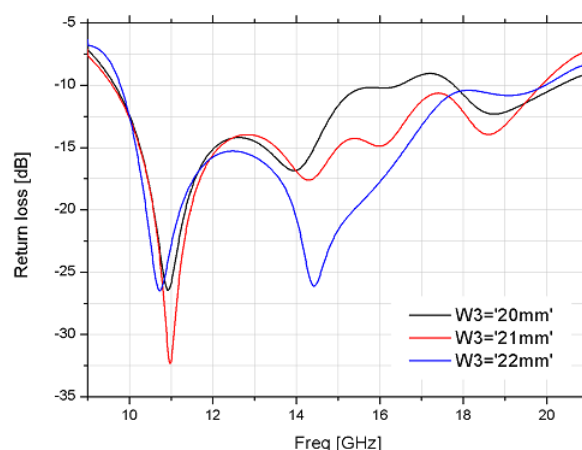


Figure 6. Return loss by varying  $W_3$

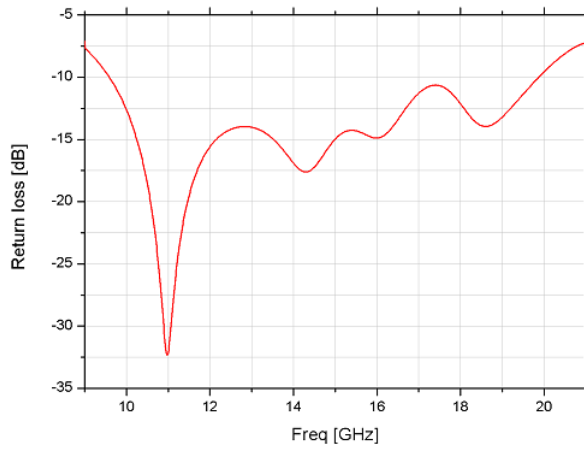


Figure 7. Return loss vs frequency

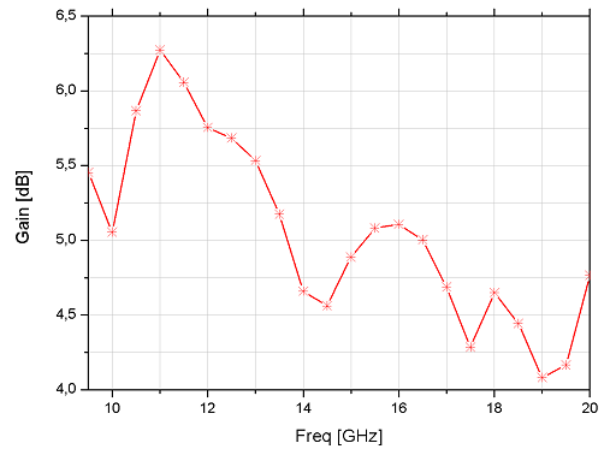


Figure 8. Gain vs frequency

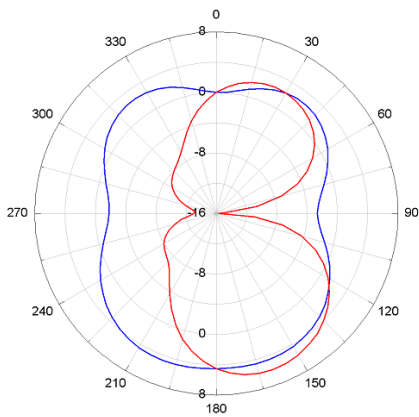


Figure 9. Directivity at  $f = 10.98$  GHz

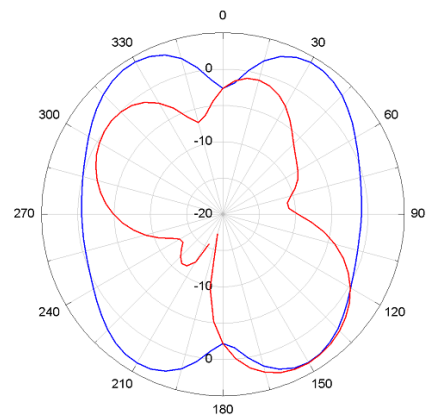


Figure 10. Directivity at  $f = 14.3$  GHz

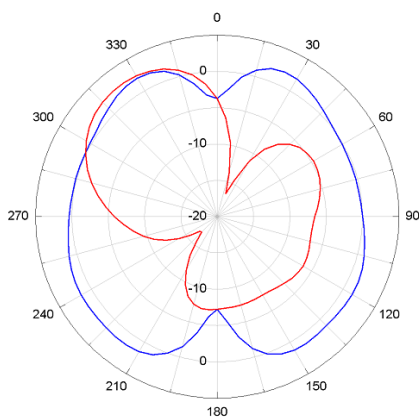


Figure 11. Directivity at  $f = 16$  GHz

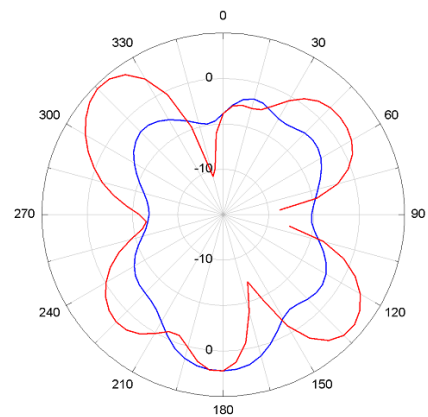


Figure 12. Directivity at  $f = 18.6$  GHz

Table 3. Comparison between antennas

Parameter	Proposed antenna	Ref.[22]	Ref. [23]	Ref. [24]
Substrate material	FR-4 epoxy	FR-4 epoxy	Teflon PTFE	-
Dielectric constant	4.4	4.4	2.55	-
Frequency range [GHz]	[9.34 - 19.82]	[11.2-14]	[12 - 14.5]	-
Return loss [dB]	-34.17 dB	-26	-33 dB	-49.07 dB
Bandwidth [GHz]	10.48 GHz	2.8	2.5 GHz	4.08 GHz
Gain [dB]	6.27 dB	5.65	8.44 dB	8.25 dB

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