International Journal of Electrical and Computer Engineering (IJECE)
Vol. 9, No. 1, February 2019, pp. 452∼ 459
ISSN: 2088-8708, DOI: 10.11591/ijece.v9i1.pp452-459

An ultra wideband antenna for Ku band applications

Aziz El Fatimi[1], Seddik Bri[2], and Adil Saadi[3]
[1,3]Modeling, Information Processing and Control Systems (MIPCS),
National Graduate School of Arts and Crafts, Moulay Ismail University, Meknes, Morocco
[2]Materials and Instrumentation (MIM),
High School of Technology, Moulay Ismail University, Meknes, Morocco

Article Info

Article history:
Received Mar 21, 2018
Revised Nov 12, 2018
Accepted Nov 26, 2018

Keywords:
Ku band
Wideband
Microstrip patch
Finite element method

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 ε_r = 4,4, loss tangent $tan\ \delta$ = 0,02 and thickness hs = 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.

Corresponding Author:
Aziz Elfatimi,
Modeling, Information Processing and Control Systems (MPICS),
National Graduate School of Arts and Crafts,
Moulay Ismail University, Meknes, Morocco,
B.P. 15290 EL Mansour Meknes 50500, Meknes, Morocco.
Email: aziz.elfatimi@edu.umi.ac.ma

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-unten), 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 $t << \lambda_0$ and the height hs is restricted by $0.003\ \lambda_0 \leq hs \leq 0.05\ \lambda_0$ [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 ε_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 $W > h$:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + [\frac{\varepsilon_r - 1}{2\sqrt{1 + 12\frac{h}{W}}}] \tag{1}$$

And

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}}[\frac{W}{h} + 1.393 + \frac{2}{3}ln(\frac{W}{h} + 1.444)]} \tag{2}$$

To have an input impedance equal to 50 Ω, 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.

$$Result \begin{cases} Width/Height &= 1.875 \\ Effective\ Dielectric\ Constant &= 3.325 \\ Impedanc\,e = & 50.83\ \Omega \end{cases}$$

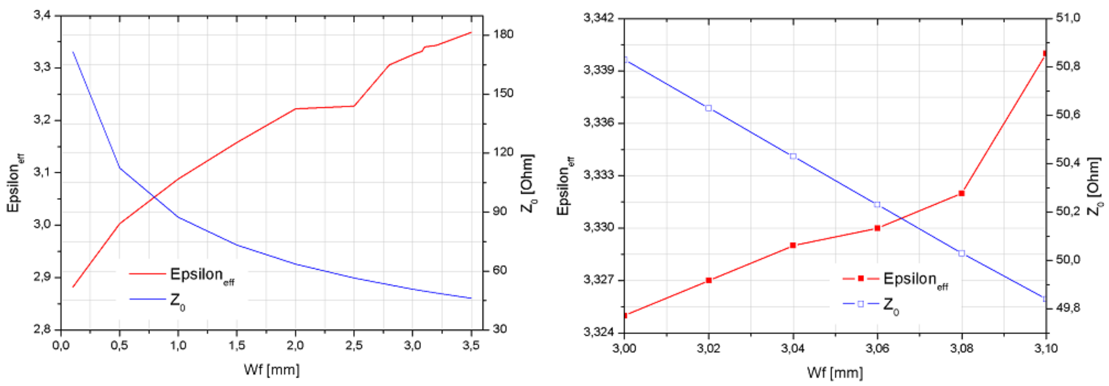

Figure 1. Effective dielectric constant and impedance vs microstrip line width

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).

$$L_f = L_g/2 \tag{3}$$

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].

$$L_{slot} = \frac{\lambda_g}{2} \tag{4}$$

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} \tag{5}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \tag{6}$$

$$\lambda_0 = \frac{c}{f_r} \tag{7}$$

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 Ω. 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 × 20 × 1.6 mm^3.

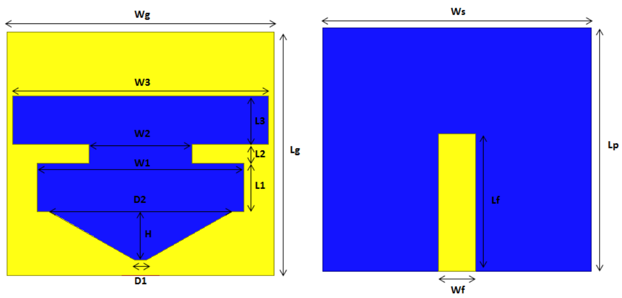

Figure 2. Top view and bottom view of the proposed antenna

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 ε_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.

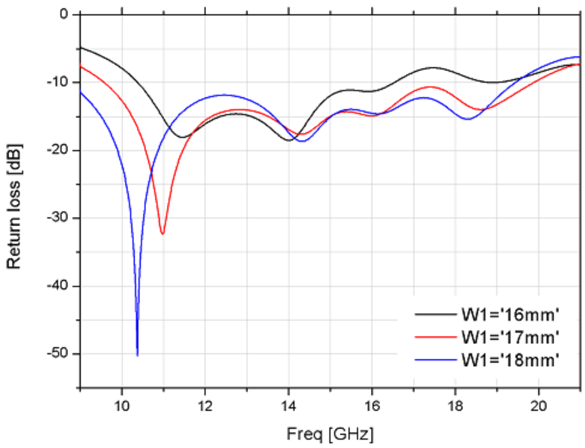

Figure 3. Return loss by varying W_1

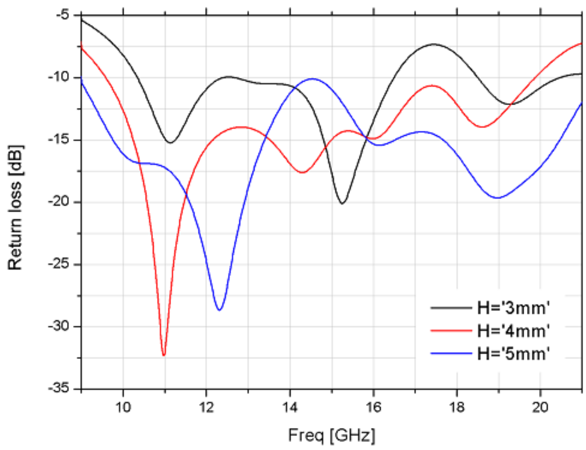

Figure 4. Return loss by varying H

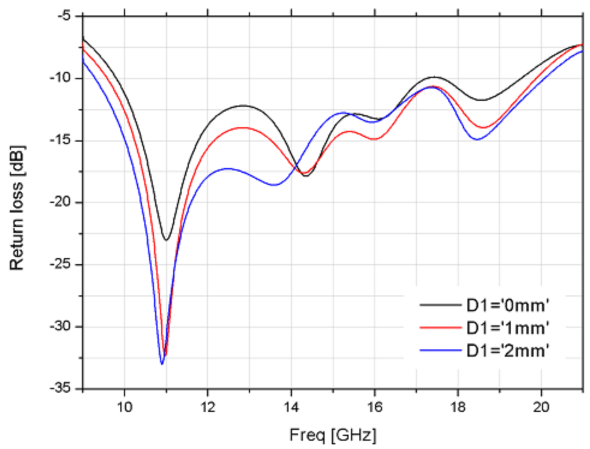

Figure 5. Return loss by varying D_1

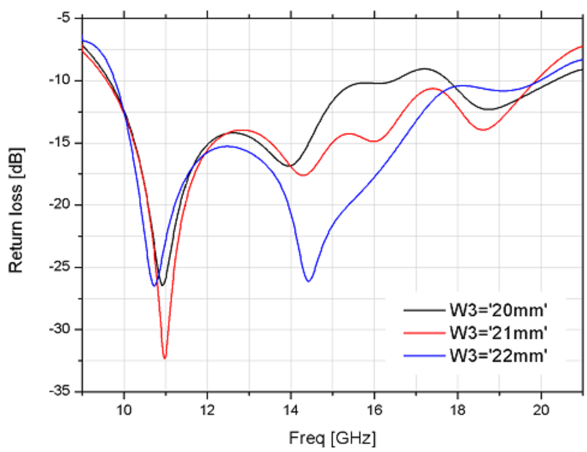

Figure 6. Return loss by varying W_3

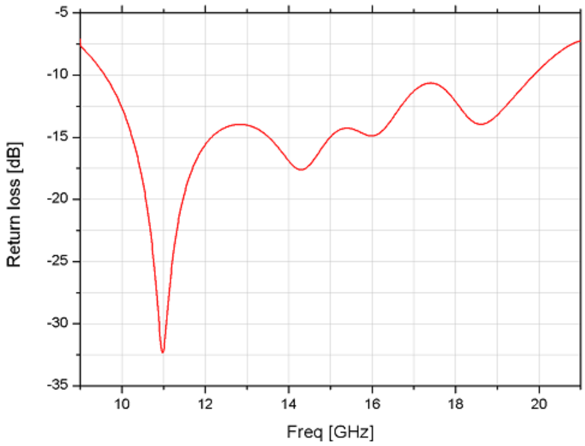

Figure 7. Return loss vs frequency

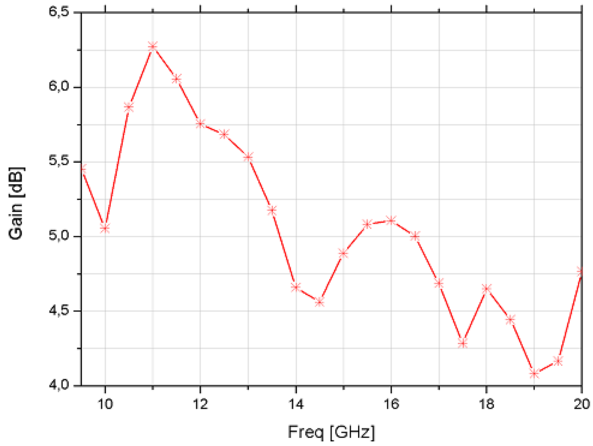

Figure 8. Gain vs frequency

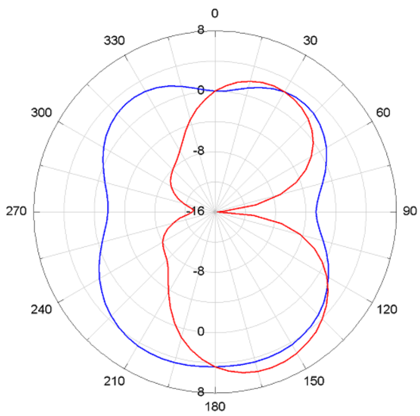

Figure 9. Directivity at f = 10.98 GHz

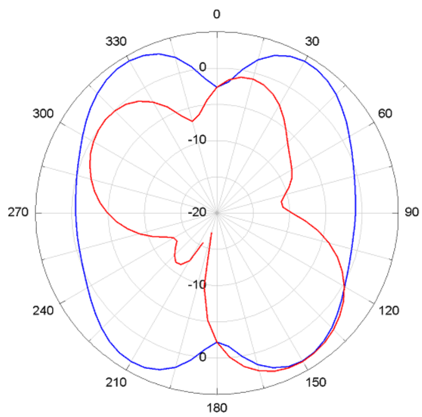

Figure 10. Directivity at f = 14.3 GHz

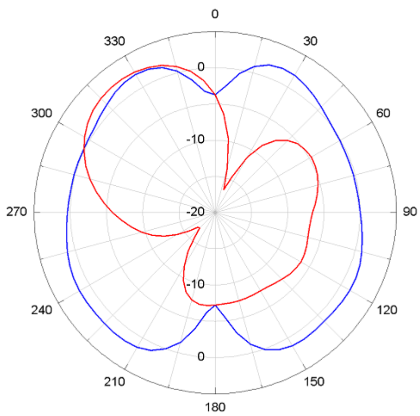

Figure 11. Directivity at f = 16 GHz

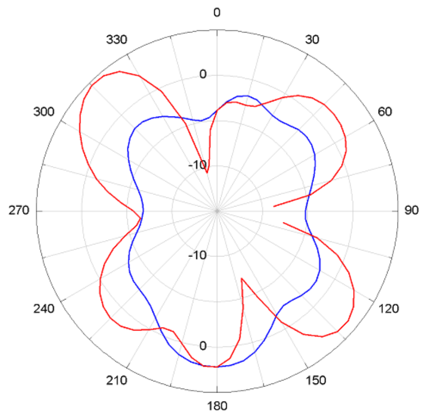

Figure 12. Directivity at f = 18.6 GHz

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

REFERENCES

[1] I. Singh and V. Tripathi, "Micro strip patch antenna and its applications: a survey," *Int. J. Comp. Tech. Appl*, vol. 2, no. 5, pp. 1595–1599, 2011.

[2] A. Dalli, L. Zenkouar, and S. Bri, "Comparison of circular sector and rectangular patch antenna arrays in c-band," *Journal of Electromagnetic Analysis and Applications*, vol. 4, no. 11, p. 457, 2012.

[3] M. Matin, B. Sharif, and C. Tsimenidis, "Probe fed stacked patch antenna for wideband applications," *IEEE Transactions on Antennas and Propagation*, vol. 55, no. 8, pp. 2385–2388, 2007.

[4] R. Arora, A. Kumar, S. Khan, and S. Arya, "Finite element modeling and design of rectangular patch antenna with different feeding techniques," *Open Journal of Antennas and Propagation*, vol. 1, no. 02, p. 11, 2013.

[5] M. Alibakhshi-Kenari, "Modeling and constructing the microstrip notch-loaded rectangular s-shaped patch antennas using l-strip feeding for multi-band frequency performances in the recent wireless telecommunication systems," *International Journal of Microwave and Wireless Technologies*, vol. 8, no. 8, 2016.

[6] L. Kai-Fong, "Microstrip patch antennas—basic properties and some recent advances," *Journal of Atmospheric and Terrestrial Physics*, vol. 51, no. 9-10, pp. 811–818, 1989.

[7] H. Mosallaei and K. Sarabandi, "Antenna miniaturization and bandwidth enhancement using a reactive impedance substrate," *IEEE Transactions on Antennas and Propagation*, vol. 52, no. 9, pp. 2403–2414, 2004.

[8] N. Boukhennoufa, L. Djouane, H. Oudira, M. Amir, and T. Fortaki, "Effect of the thickness of high tc superconducting rectangular microstrip patch over ground plane with rectangular aperture," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8, no. 3, 2018.

[9] C. A. Balanis, "Antenna theroy analysis and design," 2005.

[10] D.-G. Fang, *Antenna theory and microstrip antennas*. CRC Press, 2017.

[11] R. Dakir, J. Zbitou, A. Mouhsen, A. Tribak, M. Latrach, and A. Sanchez, "A new compact and miniaturized gcpw-fed slotted rectangular antenna for wideband uhf fird applications," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 7, no. 2, pp. 767–774, 2017.

[12] Z. Chen *et al.*, "Wideband microstrip antennas with sandwich substrate," *IET Microwaves, Antennas & Propagation*, vol. 2, no. 6, pp. 538–546, 2008.

[13] R. Azim, M. T. Islam, and N. Misran, "Dual polarized microstrip patch antenna for ku-band application," *Informacije MIDEM*, vol. 41, no. 2, pp. 114–117, 2011.

[14] A. A. M. Ali, N. J. Fonseca, F. Coccetti, and H. Aubert, "Design and implementation of two-layer compact wideband butler matrices in siw technology for ku-band applications," *IEEE Transactions on Antennas and Propagation*, vol. 59, no. 2, pp. 503–512, 2011.

[15] M. M. Harane and H. Ammor, "A compact dual band elliptical microstrip antenna for ku/k band satellite applications," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8, no. 3, pp. 1596–1601, 2018.

[16] A. B. Constantine *et al.*, "Antenna theory: analysis and design," *MICROSTRIP ANTENNAS, third edition, John wiley & sons*, 2005.

[17] A. Taflove and S. C. Hagness, *Computational electrodynamics: the finite-difference time-domain method*. Artech house, 2005.

[18] D. Al-Mukhtar and J. Sitch, "Transmission-line matrix method with irregularly graded space," in *IEE Proceedings H (Microwaves, Optics and Antennas)*, vol. 128, no. 6. IET, 1981, pp. 299–305.

[19] J. L. Volakis, A. Chatterjee, and L. C. Kempel, *Finite element method electromagnetics: antennas, microwave circuits, and scattering applications*. John Wiley & Sons, 1998, vol. 6.

[20] R. Marklein, "The finite integration technique as a general tool to compute acoustic, electromagnetic, elasto-

dynamic, and coupled wave fields," *Review of radio science*, vol. 2002, pp. 201–244, 1999.
[21] S. Salon and M. Chari, *Numerical methods in electromagnetism*. Elsevier, 1999.
[22] M. A. H. Oweis and H. H. M. Ghouz, "A novel ku-band microstrip antenna," in *Engineering and Technology (ICET), 2014 International Conference on*. IEEE, 2014, pp. 1–4.
[23] H. Parikh, S. Pandey, and K. Modh, "Wideband and high gain stacked microstrip antenna for ku band application," in *Engineering (NUiCONE), 2012 Nirma University International Conference on*. IEEE, 2012, pp. 1–5.
[24] G. Ahmad, M. I. Babar, and M. Irfan, "A novel wideband microstrip patch antenna for satellite applications," *Journal of Engineering and Applied Sciences (JEAS), Peshawar*, vol. 36, no. 2, 2017.
[25] R. Garg, *Microstrip antenna design handbook*. Artech house, 2001.
[26] D. M. Pozar and B. Kaufman, "Increasing the bandwidth of a microstrip antenna by proximity coupling," *Electronics letters*, vol. 23, no. 8, pp. 368–369, 1987.
[27] K. Ray and Y. Ranga, "Ultrawideband printed elliptical monopole antennas," *IEEE transactions on antennas and propagation*, vol. 55, no. 4, pp. 1189–1192, 2007.