A Small Dual Band (28/38 GHz) Elliptical Antenna For 5G Applications With DGS

Pierre Moukala Mpele, Franck Moukanda Mbango, Dominic Bernard Onyango Konditi

Abstract: In this paper, a compact elliptical dual-band microstrip antenna fed with a coplanar waveguide is presented. The proposed antenna is designed and analyzed using a 3-D full-wave electromagnetic software named, High Frequency Structure Simulator (HFSS) software based on finite element method (FEM). The design adopts a bi-layer substrate configuration where the elliptical radiating patch is printed on a Rogers RO3010 substrate of dimensions 2.265x2x0.75mm^3, with a dielectric constant of 10.2 and loss tangent of 3.5.10^{-3} at 9.4 GHz on which the radiating patch occupies a surface area of 0.754mm^2. Moreover, Rogers RO3010 is placed on the top of another dielectric, which is a Rogers RO4350B, having a relative permittivity constant of 3.66 and loss tangent of 4.10^{-3} at 9.4 GHz. The antenna operates at 28GHz and 38GHz, two of the selected bands allocated to 5G by International Telecommunications Union. The simulation results show that the antenna achieves a minimum wide bandwidth of 4.14GHz and a constant gain of 6dB over the operating frequency range. As a miniaturized antenna, its electric characteristics (impedance, bandwidth, radiation efficiency and gain) along with the antenna's size have been chosen as comparison parameters with those found in recent research works. In addition, previous electric parameters, together with the return loss and VSWR have been selected for the proposed Elliptical antenna that have been improved by inserting two F-shaped slots in the ground plane. These slots in the ground plane are well-known as Defected Ground Structure (DGS) technique.

Index Terms: Elliptical microstrip antenna, 5G, CPW-fed, multilayered substrate, 28 GHz, 38 GHz, wideband antenna, DGS, HFSS, miniature antenna, small antenna.

1 Introduction

Antennas for the next-generation wireless communication systems are expected to achieve high data rate while being low cost, lightweight, and small in size with multi-frequency features. For 5G network, they are, in addition, supposed to have high gain to overcome the high path loss at mm-wave frequencies. Microstrip antennas can fulfil these requirements as compared to the other types of antennas. However, in their basic form, microstrip antennas suffer from some drawbacks such as low radiation efficiency, narrow bandwidth, and excitation of surface waves [1]. The literature survey shows that various approaches have been explored to improve printed circuits and antennas performances. Defected Ground Structure (DGS) is one of the techniques used by researchers to overcome some of the drawbacks[2], mainly when designing electrically small antennas. On the other hand, antennas with different shapes and design techniques[3] for 28 GHz and 38GHz communication have been proposed by researchers worldwide. Some of them are focused on antenna array[4],[5],[6],[7], while others researchers keep on working on single element antennas [8],[9],[10],[11] for the same applications. As specified in [12] antennas design for high-speed networks for multimedia applications is a challenging task. Wideband systems are encouraging for 5G since they provide high data rates, less power consumption and wide bandwidth. Such systems and antennas design have gained researchers attention worldwide. For instance, a tri-band antenna has been presented for higher 5G bands [13]. It was observed that antenna achieves quite good performances but the overall size of the optimized design (30x40mm^2) is not suitable for mobile devices. The same year, another antenna was proposed by Seker [14], who proposed a single band antenna with a bandwidth of about 1.021GHz, but having a low gain of about 1.2dB at the operating frequency. Recently a 28/38-GHz Dual-Band Millimeter antenna was presented in [9]with good performances for the two bands of operation in terms of impedance, bandwidth and overall size, but the antenna bandwidth in the upper band is low. With the help of DGS, a compact size "Y" slotted antenna with a microstrip feed line proposed by Awan et al. in [15]has a compact size and also good performance but was designed to operate only at 28GHz with a bandwidth of 1.38GHz. From recent works, progresses have been made in millimeter-wave antennas design. However, for high data rates transmission systems and multifunctional devices, wideband directional antennas with a constant gain over the operating frequency range are essential [16]. In this paper, we propose a small dual band directional antenna which operates in two frequency bands that have been allocated for 5G mobile communications by International Telecommunications Union (ITU). Those bands are 28, 38, 60 and 73 GHz [14]. The design technique of small antennas is adopted in which the impedance-match, radiation efficiency, and the bandwidth or antenna multiband behavior are primary concerns[17]. An elliptical shape has been selected because it provides a larger bandwidth in comparison to other shapes [18].

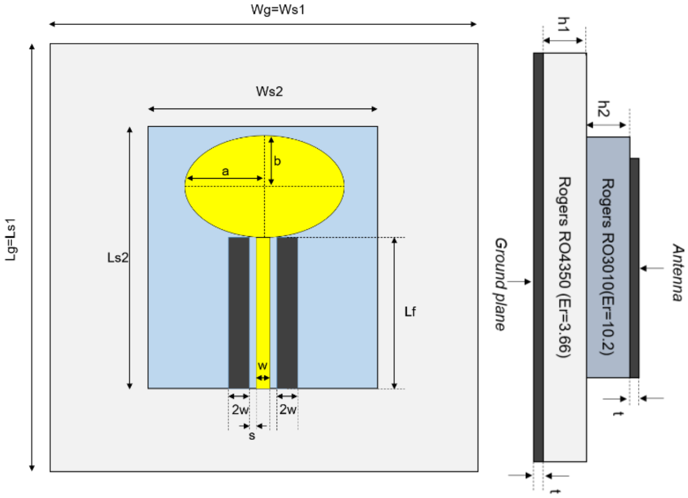
Because of its advantages over microstrip type feed lines, such as wideband characteristics[19], low dispersion and low radiation leakage, the ability to effectively control the characteristic impedance [20], the coplanar waveguide (CPW) feed has been selected for our design. From the foregoing, we present all important antenna parameters which we developed through design and simulations through 3D full-wave Electromagnetic simulator before analyzing and discussing the simulated results.

- *Pierre Moukala Mpele, Department of Electrical Engineering, Pan African University Institute for Basic Sciences Technology and Innovation (PAUISTI), Kenya, E-mail: moukala.mpele@students.jkuat.ac.ke*
- *Franck Moukanda Mbango, School of Sciences and Techniques, Marien Ngouabi University, Republic of Congo E-mail: franck.moukandambango@umng.cg*
- *Dominic Bernard Onyango Konditi, School of Electrical and Electronics Engineering, The Technical University of Kenya, Kenya. E-mail: konditidbo@gmail.com*

2 ANTENNA DESIGN

2.1 Antenna configuration

The antenna is designed using two substrates with different dimensions. The first substrate is a Rogers RO4350B with the dielectric constant of 3.66, loss tangent of 0.004, and dimensions 5x5x0.75mm^3. The second one is a Rogers RO3010 with the dielectric permittivity of 10.2, loss tangent of 0.0035 and dimensions 2.265x2x0.75mm^3 on which the elliptical patch with the total surface area of 0.754mm^2 is printed. The antenna geometry is provided in Fig.1 and its all design parameters are presented in Table 1



(a) (b)

Fig. 1: Geometry of a proposed antenna: (a) Top view, (a) Side view

Table 1: Design parameters of the proposed antenna

Parameter	Description	Value (mm)
L_g	Ground plane length	5
W_g	Ground plane width	5
L_{s1}	First substrate (Rogers RO4350) length	5
W_{s1}	First substrate width	5
h_1	First substrate height	0.75
L_{s2}	Second substrate(Rogers RO3010) length	2.265
W_{s2}	Second substrate width	2
h_2	Second substrate height	0.75
a	Major axis radius (y-direction)	0.6
b	Minor axis radius (x-direction)	0.4
s	Separation between the central strip and each of the coplanar ground planes	0.0192
t	Ground plane and patch thickness	0.002
w	Width of the central coplanar strip	0.034
L_f	Length of the central coplanar strip	1.166

2.2 Mathematical modeling

Resonant frequency

Given all the above parameters presented in Table 1, we can predict the resonant frequency of the elliptical microstrip antenna as [21]

$$f_{rL} = \frac{7.2}{(L + r + P)}\ GHz \qquad (1)$$

in which $L = 2b$, and $r = \frac{a}{4}$; L, r and P are in centimeters.

The equation (1)does not account for the effect of the multilayer structure which is inhomogeneous. Accordingly, this equation is modified to [22],[23] and [24],

$$f_{rL} = \frac{7.2}{\sqrt[4]{\varepsilon_{eff}}\left(2b + \frac{a}{4} + P\right)}\ GHz \qquad (2)$$

where P is the length of the 50Ω feed line, a the major axis radius and b the minor axis radius.

Effective permittivity

From the equivalent relative permittivity of two layers [25],[26]

$$\varepsilon_{req} = \frac{\varepsilon_{eff\,1}\varepsilon_{eff\,2}(h_1 + h_2)}{\varepsilon_{eff\,1}h_2 + \varepsilon_{eff\,2}h_1} \qquad (3)$$

each layer's effective permittivity is approximated as below,

$$\varepsilon_{eff\,1} = \frac{\varepsilon_{r1} + 1}{2} \qquad (4)$$

$$\varepsilon_{eff\,2} = \frac{\varepsilon_{r2} + 1}{2} \qquad (5)$$

So, we express the global effective permittivity of bi-layer dielectric substrates with coplanar waveguide feed line[27]

$$\varepsilon_{eff} = 0.5(\varepsilon_{req} + 1)(A + B) \qquad (6)$$

where A and B are given by equation (7) and (8) respectively

$$A = \tanh\left[1.785\log\left(\frac{h_1 + h_2}{s}\right) + 1.75\right] \qquad (7)$$

$$B = \left(\frac{ks}{h_1 + h_2}\right)\left[0.04 - 0.7k + 0.01(1 - 0.1\varepsilon_{req})(0.25 + k)\right] \qquad (8)$$

in which

$$k = \frac{w}{w + 2s} \qquad (9)$$

where w is the width of the center strip, s is the separation between the signal conductor and its neighbor ground planes placed on the top of the Rogers RO3010 dielectric, h_1 and h_2 denote the first and second substrate thickness respectively. Taking P=Lf=1.166mm, a=0.6mm and b=0.4mm, and the ellipticity ratio[21] of 1.5, we get the lower frequency of the antenna by using (2) to (9):

$$f_{rL} = 28.129\ GHz$$

3 RESULTS AND DISCUSSION

The proposed Elliptical microstrip patch antenna results were performed using High Frequency Structure Simulator (HFSS). The reflection coefficients of the dual-band are presented in Fig.2 from which it can be observed a -10dB impedance bandwidths of 4.78GHz (27.02-31.80GHz) in the lower band and 4.16GHz (36.15-40.31GHz) in the upper band. The resonances were approximately found at 28.84 GHz and 38.78GHz with a return loss of -26.90dB and -20.89dB respectively.

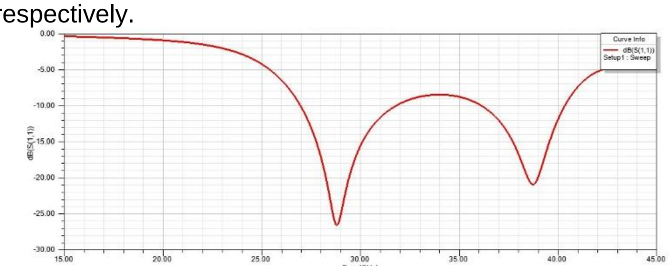
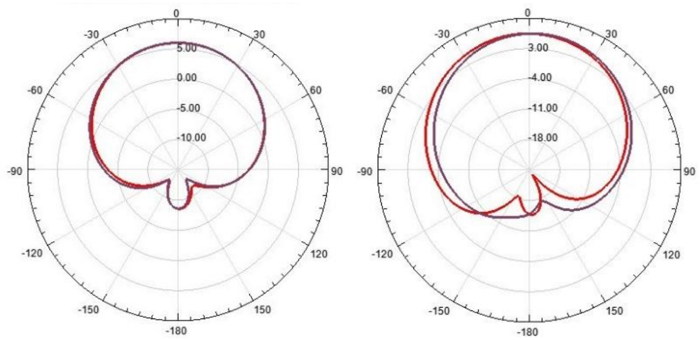


Fig. 2: Antenna Return Loss of the proposed antenna

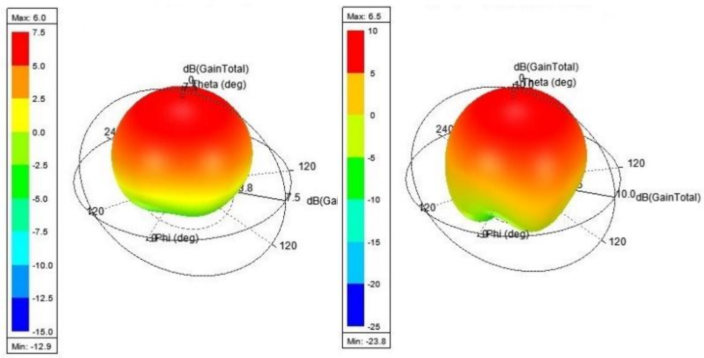
The directivity of the elliptical CPW-fed antenna at the resonant frequencies in E and H is presented in Fig.3. After having optimized the antenna dimensions, the obtained results, demonstrate that the antenna is characterized by a directional pattern with a directivity peak of 6.29dB and 6.81dB at 28GHz and 38GHz, respectively, from φ= 0 and φ= 90 degrees.



(a) (b)

Fig. 3: 2-D Radiation pattern for 28GHz (a) and 38GHz (b) bands

Fig.4: shows a stable gain with a value of 6.0 dB in the 28 GHz band and 6.5dB in the second band (38 GHz) which is good for 5G high data rate communications.



(a) (b)

Fig. 4: 3-D Radiation pattern for 28 GHz (a) and 38 GHz (b) bands

In Fig.5, the Voltage Standing Wave Ratio (VSWR) of the proposed Elliptical antenna is presented. The value was found approximately below 2 and in the range of 1-2 which is a wanted value.

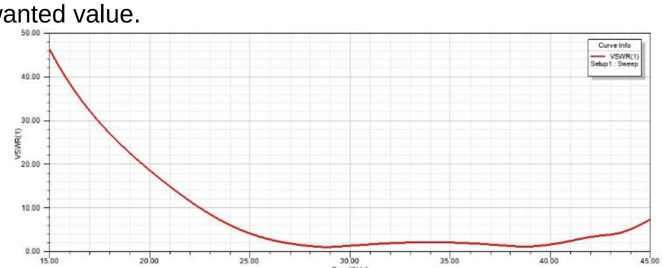


Fig. 5: Voltage Standing Wave Ratio (VSWR)

The input impedance presented in Fig.6 at the resonance frequencies is (46.77-j2.9487) Ω for 28.8376 GHz and (53.26+j8.7639) Ω for 38.775 GHz which indicate unfair matching between the antenna and the input source.

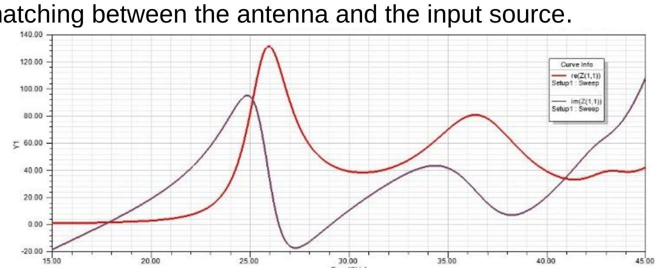


Fig. 6: Impedance of the Elliptical antenna

From the above simulation results, it can be observed that the antenna has quite good performance. However, since the antenna is electrically small (maximum dimension less than radian length $\lambda / 2\pi$), the antenna input impedance-match is the first goal followed by the antenna bandwidth and the radiation efficiency that have also to be taken as primary concerns[17]. Among its applications in microwave technologies [2], defected ground structure (DGS) disturbs the shield current distribution in the ground plane[28] and, results in a controlled excitation together with electromagnetic propagation waves through the substrate layer[29] can be used for antenna performance enhancement [30],[31]. Similarly in [15], the antenna performances have been improved by using DGS. The same technique was used to increase the bandwidth, the antenna efficiency and the antenna return loss as indicated in [32]. After a detailed parametric study, two F-shaped slots have been introduced in the ground plane as reported in Fig.7.

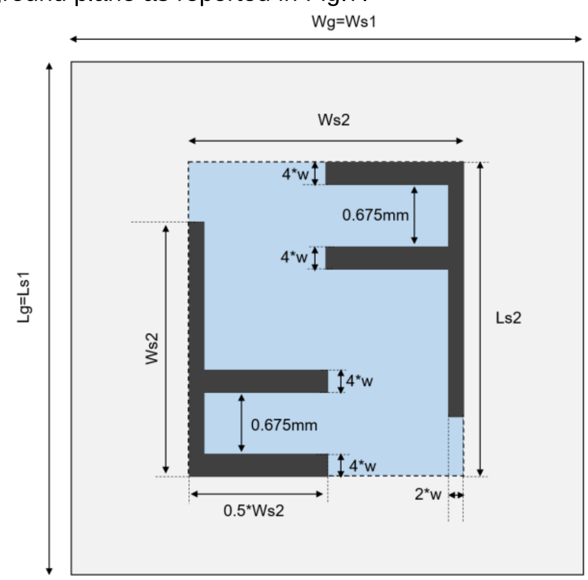


Fig. 7: Defected Ground Structure configuration

The return loss is improved as shown in Fig.8 with -48.17 dB and -40.25 dB for the lower (28 GHz) and upper (38 GHz) bands respectively, which are the 5G operating frequencies. In Fig.10, the antenna directivity gain pattern is presented. The antenna impedance as reported in Fig.11 has a real part of about 50Ω within the two frequency bands, and lastly, the antenna Voltage Standing Wave Ratio (VSWR) reposted in Fig.12 is about 1.0078 for the 5G microwave's band and 1.0196 for the 38 GHz band.

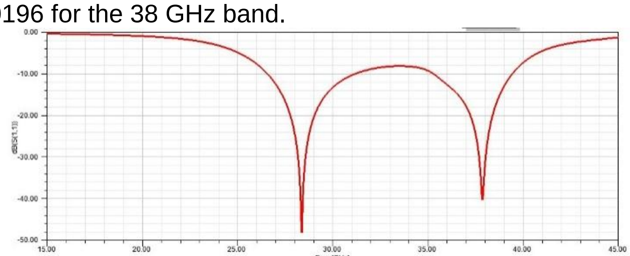
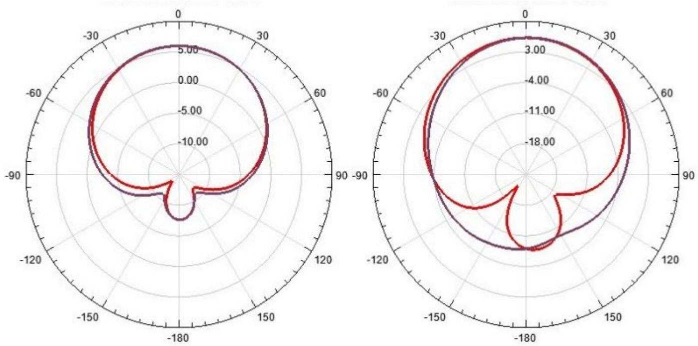
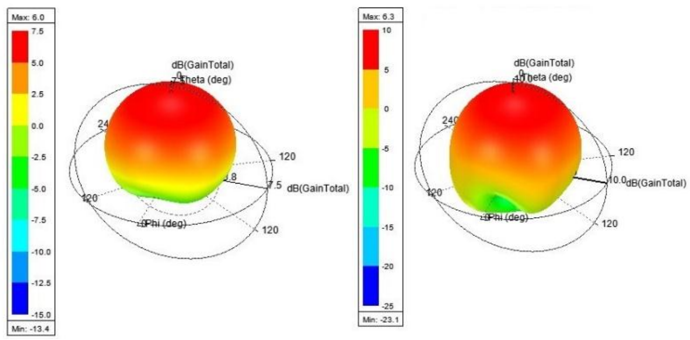


Fig. 8: Return Loss of the proposed antenna with DGS



(a) (b)

Fig. 9: 2-D Radiation pattern 28 GHz (a) and 38 GHz (b) bands with DGS



(a) (b)

Fig. 10: 3-D Radiation pattern for 28 GHz (a) and 38 GHz (a) bands with DGS

It can be seen from Fig.10 that the antenna has a stable gain of about 6 dB within the two frequency bands of operation.

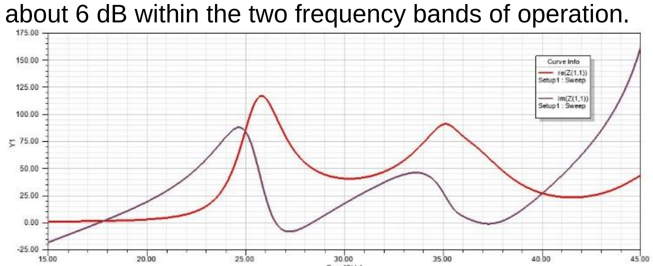


Fig. 11: Impedance of the Elliptical antenna with DGS

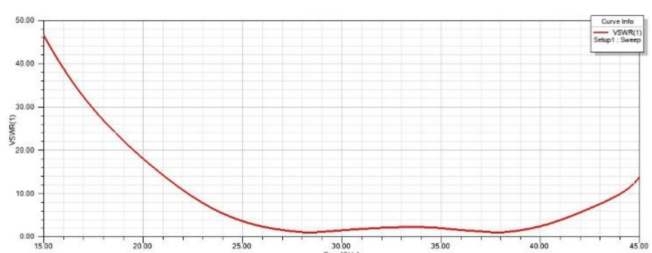


Fig. 12: Voltage Standing Wave Ratio (VSWR) with DGS

Due to the above results, it can be observed that the insertion of two F-shaped slots in the ground plane has improved the antenna's performances. The antenna return loss, the VSWR and the impedance matching have enhanced while the antenna shifted from the mixed lumped capacitance-inductance behavior to the simple lumped inductance behavior for both frequency ranges as shown in Fig.11. A summary of all simulation results is provided in table 2.

Table 2: Summary of the proposed antenna performance parameters

Antenna performance parameter		Before DGS		After DGS	
		28 GHz band	38 GHz band	28 GHz band	38 GHz band
Resonant frequency		28.84 GHz	38.78 GHz	28.19 GHz	37.96 GHz
Return Loss		-26.90 dB	-20.89 dB	-48.17dB	-40.256 dB
Bandwidth		4.78 GHz	4.16 GHz	4.59 GHz	4.14 GHz
Radiation efficiency		93.75%	92.4%	93.63%	91.08%
Input impedance	(Real part,	46.77 Ω	53.26 Ω	50.13 Ω	50.45 Ω
	Imaginary part	-3.75 Ω	8.76 Ω	0.37 Ω	0.86 Ω
Gain		6.0 dB	6.5 dB	6.0 dB	6.3 dB
VSWR		1.1233	1.2267	1.0078	1.0196

Although the defected of the ground plane slightly deteriorates the antenna's bandwidth and radiation efficiency as it is summed up in table 2, it greatly improves the network's matching through the antenna input characteristic impedance, the VSWR, the return loss level and the central or resonance frequency. Meanwhile, the antenna's gain is the same for the lowest frequency range and quasi-identical for the highest one. However, the designed antenna is mono-directional in terms of radiation as seen in Fig. 9. Additionally, we have compared the primary concern parameters with some of the references used in this paper as illustrated in table 3

Table 3: Comparison of the designed antenna with other reference antennas

Reference papers	Antenna total size(mm^2)	Antenna patch size(mm^2)	Operating frequency(GHz)	Bandwidth (GHz)	Gain (dB)	Efficiency (%)
[9]	64	11.56	28 38	1.43 3.54	2.7 6.0	Not specified
[10]	100	5.42	28	3.9	5.54	Not specified
[14]	48.8	9.76	38	1.021	1.26	Not specified
[15]	25	9.4076	28	1.38	7.6	98%
This work	25	0.754	28 38	4.5188 4.2750	6.0 6.3	93.63% 91.08%

Table 3 shows that the designed elliptical antenna is better in terms of bandwidth and antenna patch size, compared to those found in the literature, for the same resonant frequencies.

4 CONCLUSION

In this paper, we focused on the conception of a dual-band Elliptical microstrip antenna with improved performances, using the detected ground structure technique. The two bandwidths are 4.59 GHz in the range [26.59-31.18] GHz and 4.14 GHz in [35.29-39.43] GHz where the operating frequencies are 28GHz and 38 GHz. The bandwidth has been selected at -10 dB of the return loss parameter. It has been pointed out a 93.63% and 91.08% of the antenna radiation efficiency at 28 GHz and 38 GHz respectively, while the in-band gains are 6.0 dB and 6.3dB. The lowest return loss level is approximately -48.17dB and -40.25dB. The designed antenna is miniaturized with a global surface size of 0.754 mm^2 while using a Rogers RO3010 combined with RO4350B. The study has shown that this antenna is a very good candidate for future 5G wireless devices that require high-speed data rate.

ACKNOWLEDGEMENT

The authors would like to thank the support and contribution of the African Union in sponsoring the research through the Pan African University Institute of Basic Sciences Technology and Innovation.

REFERENCES

[1] Z. N. Chen and M. Y. W. Chia, Broadband planar antennas : design and applications. John Wiley & Sons, 2006.

[2] M. K. Khandelwal, B. K. Kanaujia, and S. Kumar, “Defected Ground Structure : Fundamentals, Analysis, and Applications in Modern Wireless Trends,” Int. J. Antennas Propag., vol. 2017, 2017.

[3] M. Abirami, “A review of patch antenna design for 5G,” Proc. - 2017 IEEE Int. Conf. Electr. Instrum. Commun. Eng. ICEICE 2017, vol. 2017-Decem, pp. 1–3, 2017.

[4] H. Xia, T. Zhang, L. Li, and F. C. Zheng, “A low-cost dual-polarized 28 GHz phased array antenna for 5G communications,” 2018 IEEE Int. Work. Antenna Technol. iWAT2018 - Proc., pp. 1–4, 2018.

[5] P. Jeyakumar, P. P. Chitra, and M. G. Christina, “Design and Simulation of Directive High Gain Microstrip Array Antenna for 5G Cellular Communication,” Asian J. Appl. Sci. Technol., vol. 2, no. 2, pp. 301–313, 2018.

[6] D. Mungur and S. Duraikannan, “Design and Analysis of 28 GHz Millimeter Wave Antenna Array for 5G Communication Systems,” J. Sci. Technol. Eng. Manag. Res. Innov., vol. 1, no. 3, pp. 1–10, 2018.

[7] M. N. Hasan, S. Bashir, and S. Chu, “Dual band omnidirectional millimeter wave antenna for 5G communications,” J. Electromagn. Waves Appl., vol. 33, no. 12, pp. 1581–1590, 2019.

[8] S. Verma, L. Mahajan, R. Kumar, H. S. Saini, and N. Kumar, “A small microstrip patch antenna for future 5G applications,” 2016 5th Int. Conf. Reliab. Infocom Technol. Optim. ICRITO 2016 Trends Futur. Dir., pp. 460–463, 2016.

[9] S. Muhammad, A. S. Yaro, I. Ya’u, and A. S. Abubakar, “Design of Single Feed Dual-Band Millimeter Wave Antenna for Future 5G Wireless Applications,” Sci. World J., vol. 14, no. 1, pp. 84–87, 2019.

[10] J. Saini and S. K. Agarwal, “T and L slotted patch antenna for future mobile and wireless communication,” 8th Int. Conf. Comput. Commun. Netw. Technol. ICCCNT 2017, pp. 3–7, 2017.

[11] N. Kothari and S. Sharma, “A 28-GHz U-slot Microstrip Patch Antenna for 5G Applications,” Int. J. Eng. Dev. Res., vol. 6, no. 1, pp. 363–368, 2018.

[12] A. Desai, T. Upadhyaya, and R. Patel, “Compact wideband transparent antenna for 5G communication systems,” Microw. Opt. Technol. Lett., vol. 61, no. 3, pp. 781–786, 2019.

[13] S. Subramanian, S. K. Selvaperumal, V. Thangasamy, and C. Nataraj, “Modified triple band microstrip patch antenna for higher 5G bands,” Proc. 4th IEEE Int. Conf. Adv. Electr. Electron. Information, Commun. Bio-Informatics, AEEICB 2018, no. December, pp. 1–5, 2018.

[14] C. Şeker, T. Ozturk, and M. T. Güneşer, “A Single Band Antenna Design for Future Millimeter Wave Wireless Communication at 38 GHz,” Eur. J. Eng. Form. Sci., vol. 3, no. 1, p. 35, 2018.

[15] W. A. Awan, A. Zaidi, and A. Baghdad, “Patch antenna with improved performance using DGS for 28GHz applications,” 2019 Int. Conf. Wirel. Technol. Embed. Intell. Syst. WITS 2019, pp. 1–4, 2019.

[16] Y. El Gholb, M. El Bakkali, and N. El Amrani El Idrissi, “Wide-band circular antenna for 5G applications,” Proc. 2018 Int. Conf. Optim. Appl. ICOA 2018, pp. 1–4, 2018.

[17] K. (Kyōhei) Fujimoto and K. Ito, Antennas for small mobile terminals, 2nd ed. Artech House, 2018.

[18] A. Pingale, A. Shende, A. Jadhav, C. Ghanote, and U. Sonare, “Design of Elliptical Microstrip Antenna for Ultra Wide Band Applications,” no. 3, pp. 276–279, 2015.

[19] S. Sinha, B. Rana, C. K. Ghosh, and S. K. Parui, “A CPW-Fed Microstrip Antenna for WLAN Application,” Procedia Technol., vol. 4, pp. 417–420, 2012.

[20] K. Vyas and P. K. Singhal, “Bandwidth Enhancement in CPW Fed Rectangular Patch Antenna by Modified Ground Structure,” vol. 8, no. 2, pp. 25–28, 2014.

[21] G. Kumar and K. P. Ray, Broadband microstrip antennas. Artech House, 2003.

[22] M. Gupta and V. Mathur, “Multiband Multiple Elliptical Microstrip Patch Antenna with Circular Polarization,” Wirel. Pers. Commun., vol. 102, no. 1, pp. 355–368, 2018.

[23] K. H. Sayidmarie and Y. A. Fadhel, “Design aspects of UWB printed elliptical monopole antenna with impedance matching,” LAPC 2012 - 2012 Loughbrgh. Antennas Propag. Conf., no. May 2014, 2012.

[24] K. P. Ray and Y. Ranga, “Ultrawideband printed elliptical monopole antennas,” IEEE Trans. Antennas Propag., vol. 55, no. 4, pp. 1189–1192, 2007.

[25] K. F. Lee, K. M. Luk, and H. W. Lai, Microstrip Patch Antennas, 2nd ed. WORLD SCIENTIFIC, 2017.

[26] F. Hu and J. Song, “Modeling of Multilayered Media Using Effective Medium Theory,” vol. 1, no. 2, pp. 225–228, 2010.

[27] T. C. Edwards and M. B. Steer, Foundations for Microstrip Circuit Design, 4th ed. Chichester, UK: John Wiley & Sons, Ltd, 2016.

[28] L. H. Weng, Y. C. Guo, X. W. Shi, and X. Q. Chen, “An overview on defected ground structure,” Prog. Electromagn. Res. B, vol. 7, pp. 173–189, 2008.

[29] S. Dhanashri S. and M. Shamala R., “A Review of Defected Ground Structure for Microstrip Antennas,” Int. Res. J. Eng. Technol., vol. 02, no. 06, pp. 150–154, 2015.

[30] F. Chetouah, S. Aidel, N. Bouzit, and I. Messaoudene, “A miniaturized printed monopole antenna for 5.2-5.8 GHz WLAN applications,” Int. J. RF Microw. Comput. Eng., vol. 28, no. 5, p. e21250, Jun. 2018.

[31] Charmolavy G. L. Nkouka Moukengue, Franck Moukanda Mbango, Nzonzolo and Désiré Lilonga-Boyenga, “An 80 GHz Microstrip Leaky-Wave Antenna with Degraded Ground Plane Design,” vol. 6, no. 8, pp. 97–101, 2019.

[32] I. Tabakh, N. El, A. El, and M. Jorio, “Impact of a simple DGS size on the radiation characteristics of an elementary MPA,” Int. J. Sci. Eng. Res., vol. 7, pp. 985–994, 2016.