ZANCO Journal of Pure and Applied Sciences
The official scientific journal of Salahaddin University-Erbil
https://zancojournals.su.edu.krd/index.php/JPAS

ISSN (print):2218-0230, **ISSN (online):** 2412-3986, **DOI: http://dx.doi.org/10.21271/zjpas**

RESEARCH PAPER

Radiation Performance of Different Triangular Microstrip Patch Antenna Configuration Shapes Operating at 28 GHz

Bushra Adnan Rahman 1 , Sattar Othman Hasan1
[1]Department of Physics, College of Education, Salahaddin University, Kurdistan Region, Iraq.

ABSTRACT:

The radiation performance of different triangular microstrip patch antenna (TMPA) shapes such as right triangle (RTMPA), isosceles triangle (ITMPA), obtuse triangle (OTMPA), and equilateral triangle (ETMPA) operating at (28 GHz) are computed and compared using inset-fed techniques and Rogers-RT5880 substrate material of permittivity ($\varepsilon_r = 2.2$) and (h=0.15 mm) height. The directivity, gain, efficiency, bandwidth, VSWR, S11 and 2D-radiation pattern for each mentioned triangular patch shapes are computed utilizing CST and HFSS method. The computed results reveal generally that the ETMPA provide better radiation performance whereas the OTMPA displays lower antenna radiation parameter values compared to the other considered ones. In addition, the antenna parameters of ETMPA with the use of coaxial probe fed are also simulated and the results are compared to those previously achieved experimentally and theoretically by other researchers. Generally, a good agreement between mentioned antenna parameter results is displayed and reliability of those achieved by CST with inset fed techniques is clearly observed. Moreover, the overall antenna parameter obtained, respectively, with CST and HFSS techniques for inset fed ETMPA are S11 (-28.68, -20.64), VSWR (1.076,1.20), gain (5.82, 6.29) dB, directivity (6.85, 7.09) dB, bandwidth (0.452, 0.369) GHz, efficiency (78.9%, 83.2%) and with a small antenna size of about (3.88 mm^3) which is most reliable for 5G technology application systems.

KEY WORDS: triangular Microstrip Antenna,5G, Gain**,** wireless communication system, directivity
DOI: http://dx.doi.org/10.21271/ZJPAS.34.6.6
ZJPAS (2022) , 34(6);45-55 .

1. INTRODUCTION

An antenna is a fundamental feature in a wireless communication system that is described as a device which used for propagating electromagnetic waves. Mobile wireless communication networks have introduced since 1970's and during the next fifty years experienced remarkable changes and development (Johari et al., 2018, Stutzman and Thiele, 2012).

The mobile wireless generation systems generally refer to a change in the nature of the system speed, technology, frequency, data capacity, latency etc. Each generation has some standards, different capacities, new techniques, and new features which differentiate it from the previous one. The revolution and evolution of wireless mobile technology systems from 1G to 5G are shown in Figure (1) (Vora, 2015).

The 5G is basically the next generation mobile and wireless connectivity system intended to offer greater capacity and be highly needed with much more cost effective and energy efficient than anything available so far (Surendran et al., 2019). The 5G network systems are expected to greatly enhance communication capacity by exploiting the vast spectrum of millimeter wave. It is also expected to be ready to provide and support very high data rates, which in turn to a replacement challenge on network requirements as well as in the antenna designs to satisfy the expected data rate and capacity (Darboe et al., 2019, Gemeda et al., 2021).

---

* **Corresponding Author:**
Sattar Othman Hasan
E-mail: sattar.hasan@su.edu.krd or star_2004OS@yahoo.som

Article History:
Received: 05 /08 /2022
Accepted: 05/09/2022
Published: 20/12 /2022

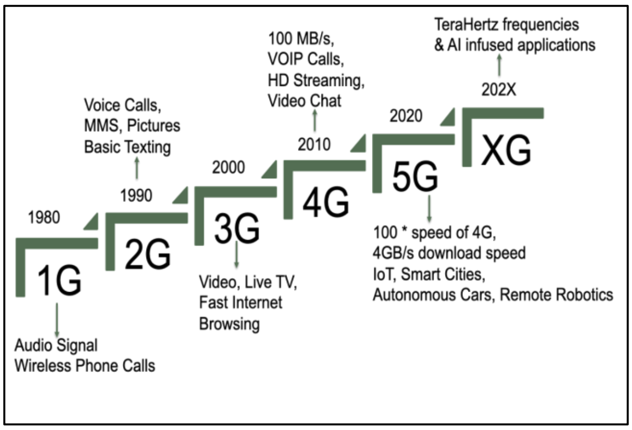


Figure 1: Evolution of mobile generation systems (DARBOE O. and et. al. 2019)

The 5G technology employs high-frequency bands and wide signal bandwidth, which increase the transmission of data bit rates, thereby providing better coverage with low battery consumption at low cost. Moreover, the frequency bands of 5G application are in the range (20-90) GHz, and the antenna designed usually operate at frequencies 28, 38, and 72 GHz as they have high data rate, comparatively low latency and are highly directional in nature (Mohammed et al., 2019, Kompella and Abdul Rajak, 2022). Therefore, a good understanding among different groups of researchers how to try to work on a large amount of softness of 5G technologies to reach the speed of transmitting excellent information from 1Gb/s to users in motion, as well as 10 Gb/s for users in stable conditions and not less than 100 MB per second in residential areas (Ezzulddin et al., 2022b).

In addition, the (5G) network will provide several new functions, containing those related to, an enhanced mobile broadband (EMBB), which qualify high-speed internet advances in mechanics access (up to 1 Gbps), the Internet of Things (IoT), and ultra-reliable low latency communications (URLLC), which enabling a technology of minimum (1 ms) latency for data transfer over a mobile system network applications (Todosioska, 2020) and (Ezzulddin et al., 2021). Due to miniaturizations requirement in 5G wireless system device, the antenna weight, small size, low-cost, simple design, easy installation for planar and non-planar surface and mechanically steered when mounted on a rigid surface as well as compatibility with monolithic microwave integrated circuit are of quite interest. Despite of the bandwidth is narrow; it is reasonable to consider microstrip patch antenna (MPA) as an ideal candidate to fulfil these requirements (Altufaili et al., 2022). On the other hand, the rapid growth in demand for smartphone users/subscribers for different wireless communication applications has brought the MPA to the forefront due to its smaller size and low-profile characteristics. The significant advantages of MPAs are its small size, easy fabrication, low weight, and low-profile which replaced the conventional large-size antennas in mobiles and wearable devices (H Patel and D Makwana, 2021). However, due to the creation of surface wave inside the dielectric substrate material, make the MPA to operate with a lower gain and narrow bandwidths (Ezzulddin et al., 2022b). The patch may be made in any shape, although rectangular and circular patches are the most common shapes that have been extensively investigated theoretically and empirically by various researchers. For such patch shapes, different investigation has been taken into consideration to improving their performance by adding split ring resonators and slots of various sizes to the patch material or applying alternative dielectric substrates of various material with different height and loss tangents. Besides, due to the tiny size requirements in current communication systems, triangular microstrip patches of different angle configuration have lately acquired popularity. Many scholars have explored the triangular microstrip patch antennas of various angle formation functioning at low-frequency operations. However, little study has been done on triangular patch antennas operating at high frequency bands acceptable for the new 5G mobile communication system technologies (Udofia 2019 and Bushra 2022).

Thus, this work is established for designing a single TMPA operating at 28 GHz by implementing two different numerical simulation methods. For this various triangular patch configuration shapes such as right triangle microstrip antenna (RTMPA) (30° 60° 90°), isosceles triangle (ITMPA) (45° 45° 90°), obtuse triangle (OTMPA) (30° 30° 120°), and equilateral triangle (ETMPA) (60° 60° 60°) are designed and their radiation performance is compared. Moreover, the inset-fed and coaxial probe-fed techniques are also investigated to verify which of them provides reliable antenna performance suitable for application in 5G mobile systems. Finally, the overall computed results are compared to those studied previously by other research workers for various patch shapes at (28 GHz) frequency operation.

2. THEORETICAL MODELING

The microstrip patch antenna's basic construction consists of (radiating element), dielectric substrate and conductor ground plane. The typical range of the relative permittivity for the substrate dielectric constant varies from $(2.2 \leq \varepsilon_r \leq 12)$. The microstrip patch antennas are designed simply, easily modified according to the requirement applications, not coasting, lightweight and can be made of various shape configurations such as circular, rectangular, triangular, square, semi-circular etc. (Mehta, 2015). The triangular patch antennas have recently acquired popularity due to miniaturization in its size which is considered as a main requirement in modern communication system devices (Joshi and Gond, 2017). Figure (2) shows a general cartesian coordinate system representations for a structure configuration of the single TMPA.

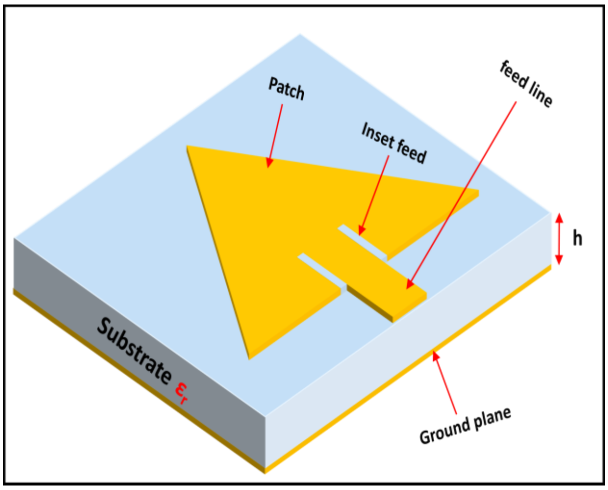
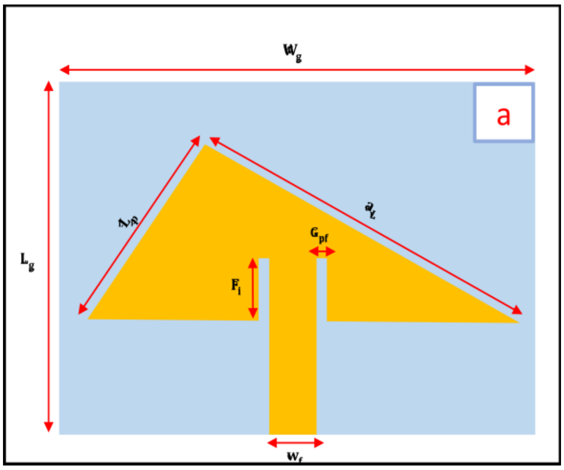
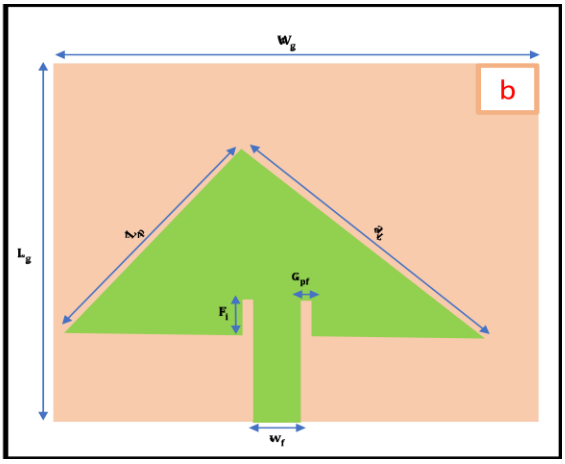


Figure 2: Representation of a single TMPA design construction

In this study, a triangular microstrip patch antenna of different angle constructions, such as (right triangle microstrip patch antenna (RTMPA) (30°-60°-90°), isosceles triangle microstrip patch antenna (ITMPA) (45°-45°-90°), obtuse triangle microstrip patch antenna (OTMPA) (30°-30°-120°), equilateral triangle microstrip patch antenna (ETMPA) (60°-60°-60°) are designed by implementing mentioned simulation methods.

The dielectric substrate material (Rogers-RT5880) of relative permittivity $(\varepsilon_r = 2.2)$ with (h=0.15) height and copper conductor material for the patch and ground plane is considered. The geometrical dimension of the proposed mentioned TMPA of different angle configurations with inset feed techniques is shown in Figures (3).





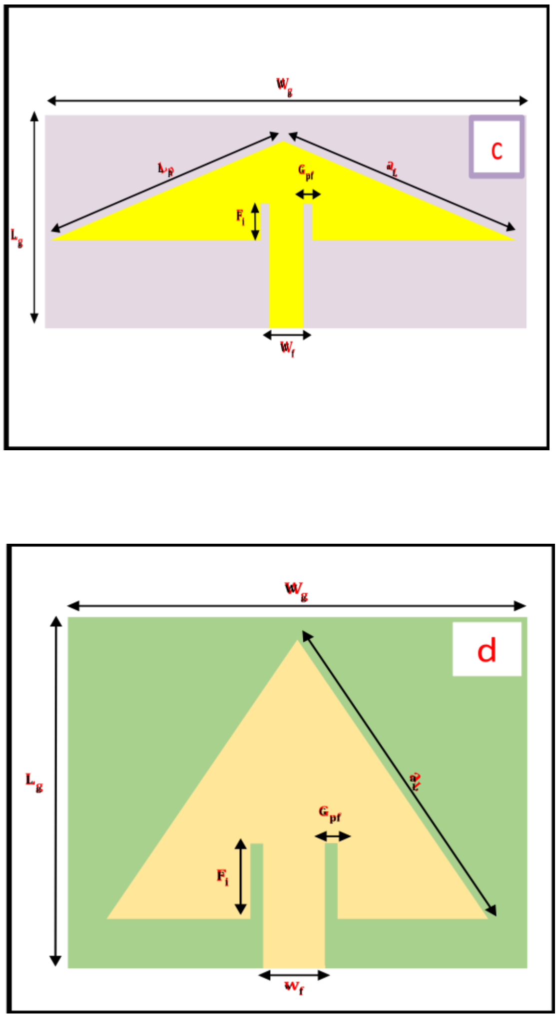


Figure 3: the geometry structure proposed TMPA for top view different triangular shapes patch dimensions **(a)** RTMPA , **(b)** ITMPA , **(c)** OTMPA and **(d)** ETMPA

where, (G_{pf}), (F_i) and (W_f) are represent, respectively, the inset fed gap separation, the length and width of the microstrip fed line.

Also, for each shape, the side length and height of the triangular patch are represented by (a_L) and (L_p), respectively. The resonant frequency of the TMPA operating at 28 GHz for triangle different angles is evaluated using the following equations (Olaimat, 2010, Maity and Gupta, 2014, Maity and Gupta, 2015, Afandi and Hadi, 2018, Maity and Gupta, 2018):

For RTMPA (30°-60°-90°):

$$f_r = \frac{c}{a_L\sqrt{3\varepsilon_r}}\left(m^2 + mn + n^2\right)^{1/2} \qquad (1)$$

For ITMPA (45°-45°-90°):

$$f_r = \frac{c}{2a_L\sqrt{\varepsilon_r}}\left(m^2 + n^2\right)^{1/2} \qquad (2)$$

For OTMPA (30°-30°-120°):

$$f_r = \frac{2c}{a_L\sqrt{3\varepsilon_r}}\left(m^2 + mn + n^2\right)^{1/2} \qquad (3)$$

For ETMPA (60°-60°-60°):

$$f_r = \frac{2c}{3a_L\sqrt{\varepsilon_r}}\left(m^2 + mn + n^2\right)^{1/2} \qquad (4)$$

where, (c) is the speed of light. The side length of each mentioned triangular patch shape for the lowest dominant mode is extracted from the above equations by setting $(m = 1 \; and \; n = 0)$ and the results are reduced to the following equations (Olaimat and Dib, 2011):

For RTMPA (30° 60° 90°):

$$a_L = \frac{c}{f_r\sqrt{3\varepsilon_r}} \qquad (5)$$

For ITMPA (45° 45° 90°):

$$a_L = \frac{c}{2f_r\sqrt{\varepsilon_r}} \qquad (6)$$

For OTMPA (30° 30° 120°):

$$a_L = \frac{2c}{f_r\sqrt{3\varepsilon_r}} \qquad (7)$$

For ETMPA (60° 60° 60°):

$$a_L = \frac{2c}{3f_r\sqrt{\varepsilon_r}} \qquad (8)$$

However, the height (L_p) of the RTMPA and ITMPA is calculated using the following mathematical expression given by (Afandi and Hadi, 2018):

$$\mathrm{L_p} = a_L \tan\theta \qquad (9)$$

While the height (L_p) of the OTMPA and ETMPA is calculated using the formula expression given by (Afandi and Hadi, 2018):

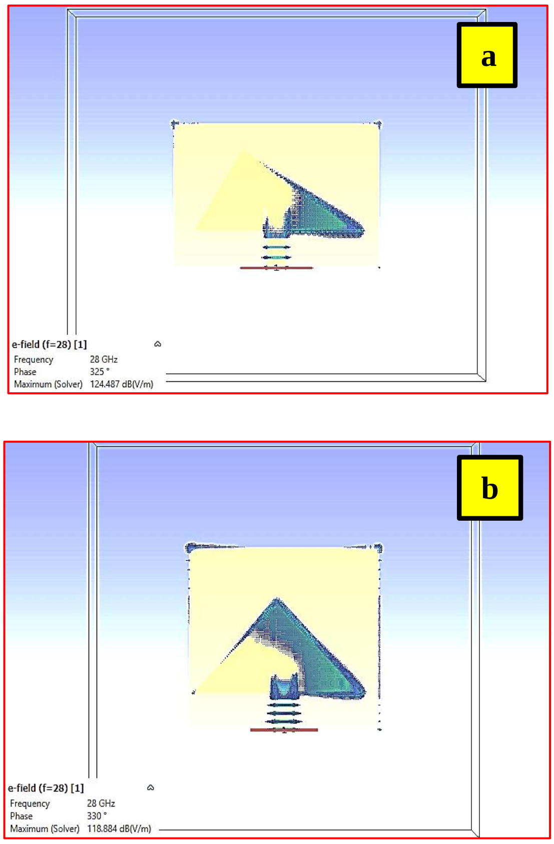
$$L_p = \frac{a_L}{2}\tan\theta \qquad (10)$$

The dimensions of the rectangular ground plane for each triangular patch construction angles are computed using the following expression formula (Ezzulddin et al., 2022b):

$$L_g = 6h + L_p \qquad (11)$$

$$W_g = 6h + W_p \qquad (12)$$

With the implementation of the above equations and substrate parameter specification, the dimensions of the ground plane, microstrip line dimensions and geometrical dimensions of each triangular patch configuration are computed using a MATLAB code prepared for this purpose and the evaluated parameter results are presented in Table (1). In addition, the top view design construction of the proposed mentioned TMPA with their electric field distribution is simulated in the mentioned simulation windows and the results are displayed in Figures (4).



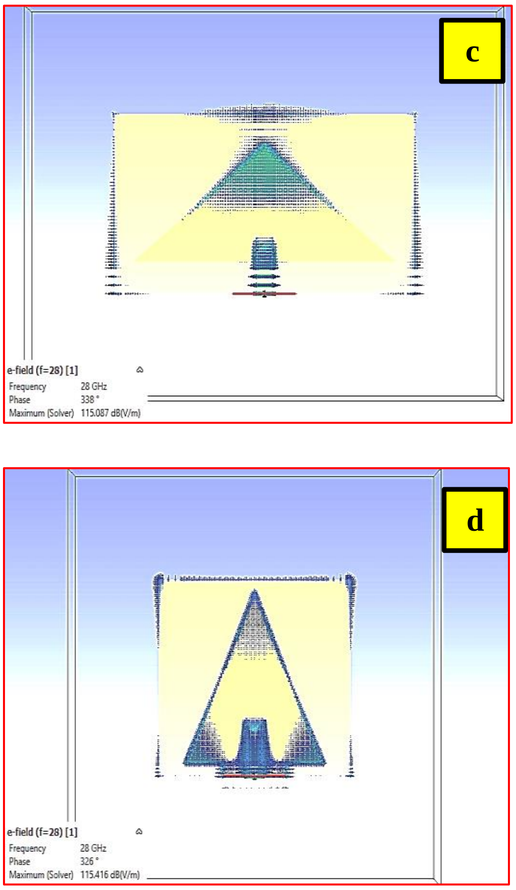


Figure 4: Electric field formation of the simulated single element (TMPA) designation for different triangular angle configurations **(a)** RTMPA, **(b)** ITMPA, **(c)** OTMPA and **(d)** ETMPA

Table (1): Dimension parameter specification for each triangular angle configurations.

Dimension parameter in **(mm)**	**RTMPA**	**ITMPA**	**OTMPA**	**ETMPA**
Ground and Substrate width ($\mathbf{W_g}$)	5.07	5	8.88	5.6
Ground and Substrate length ($\mathbf{L_g}$)	3.3	4.4	4.3	4.62
Triangular side length ($\mathbf{a_L}$)	3.444	3.124	7.75	4.0099
height of triangular patch ($\mathbf{L_p}$)	2.2	3.124	2.79	3.5
Gap between patch and feed line ($\mathbf{G_{pf}}$)	0.087	0.087	0.087	0.087
Distance inset feed ($\mathbf{F_i}$)	1.4	1.4	1.4	1.4
Microstrip line feed width ($\mathbf{w_f}$)	0.46	0.46	0.46	0.46

3. Result and Discussion

This work is composed of two parts, in the first step, the radiation parameters of different triangular MPA configuration shapes resonating at 28 GHz are investigated using inset fed techniques and their performance are compared. This step specifies the best triangular patch shapes that provide reliable radiation performance suitable for 5G application systems. The second part of this work, is concern with the evaluation of radiation performance of the identified triangular patch shapes with coaxial probe fed techniques and the results are compared to those achieved with inset fed techniques. Finally, the simulated results acquired by both mentioned simulation methods are compared to those predicted theoretically or experimentally by other researchers.

In the first scenario, the designation of single element TMPA of various angle construction operating at 28 GHz is performed using both mentioned numerical methods. For this, the RTMPA, ITMPA, OTMPA and ETMPA are selected for the design purpose with the use of (Rogers-RT5880) substrate material of height (h=0.15 mm) and the copper material is assumed for the microstrip patch and ground plane. The fundamental antenna parameters such as VSWR, S11, directivity, gain, bandwidth and efficiency are computed using the geometrical parameters specified for each mentioned triangular patch shape presented in Table (1). The computation procedure for each mentioned antenna parameter is performed using both simulation techniques.

The result of the antenna returns loss parameters (S11) and VSWR which are represent the amount of power that is reflected back to the antennas are evaluated and graphically presented in Figures (5) and (6). The calculated values of return loss displayed in Figures (5) reveals that all of the mentioned triangular patch shapes are provide suitable S11 parameters which are less than (-10 dB) especially with the use of CST simulation techniques. Moreover, from the same figures one clearly observes that the smaller S11 parameter values are achieved with ETMPA configuration shapes and with the implementation of both simulation techniques. On the other hand, the computation of the VSWR values for each mentioned triangular shapes as shown in Figures (6) are also indicates that they are located within standard acceptable ranges especially for ETMPA which provide smaller values compare to the other triangular shapes. Therefore, according to the S11 and VSWR parameters value of ETMPA obtained with CST and HFFS methods which are, respectively, (-28.68dB, -20.64 dB) and (1.076,1.20), one may consider it as a best triangular patch shape for 5G application systems.

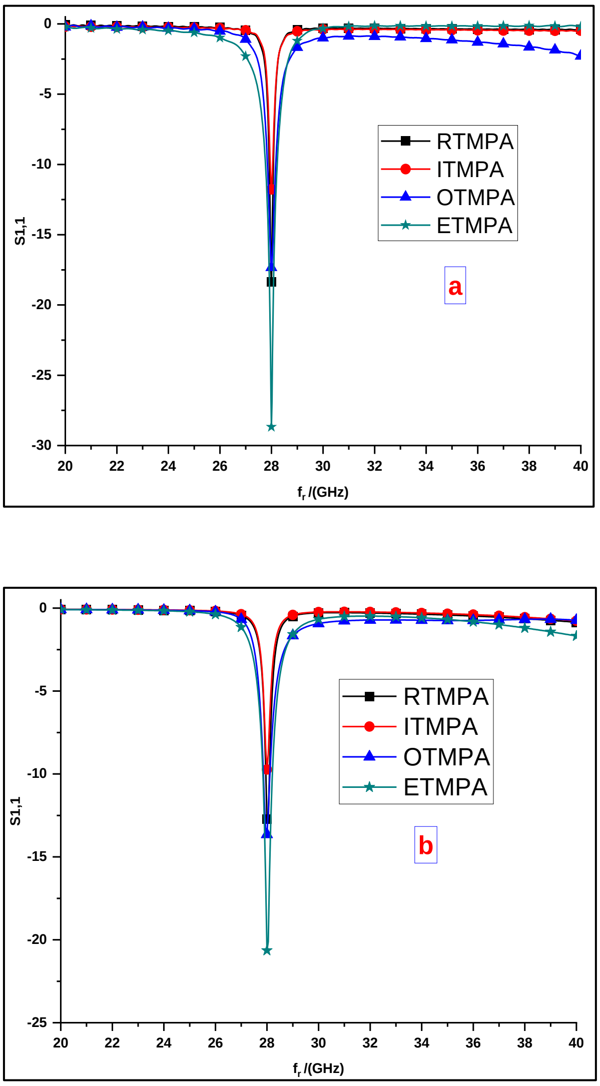


Figure 5: Result of S11-parameter as a function of frequency for various triangular shapes patch:**(a)** CST and **(b)** HFSS

In addition, the radiation efficiency, antenna size, gain, directivity, and bandwidth for each mentioned triangular patch shape configuration are also calculated by both CST and HFFS numerical methods and the results are shown in the form of a histogram in Figures (7-a) and (7-b), respectively. The result of these two figures reveals obviously that the gain and directivity of ETMPA and ITMPA are generally greater than the other triangular shape configurations. This behavior can be attributed to the fact that the charge and hence electric field distribution of these two triangular shapes are concentrated mostly within the patch as displayed in Figures (4). Moreover, these histogram figures indicate that the size of the OTMPA and RTMPA are smaller than those of ETMPA and ITMPA and this can be considered as another factor which lead to the production of less radiation powers and hence produce smaller gain and directivity.

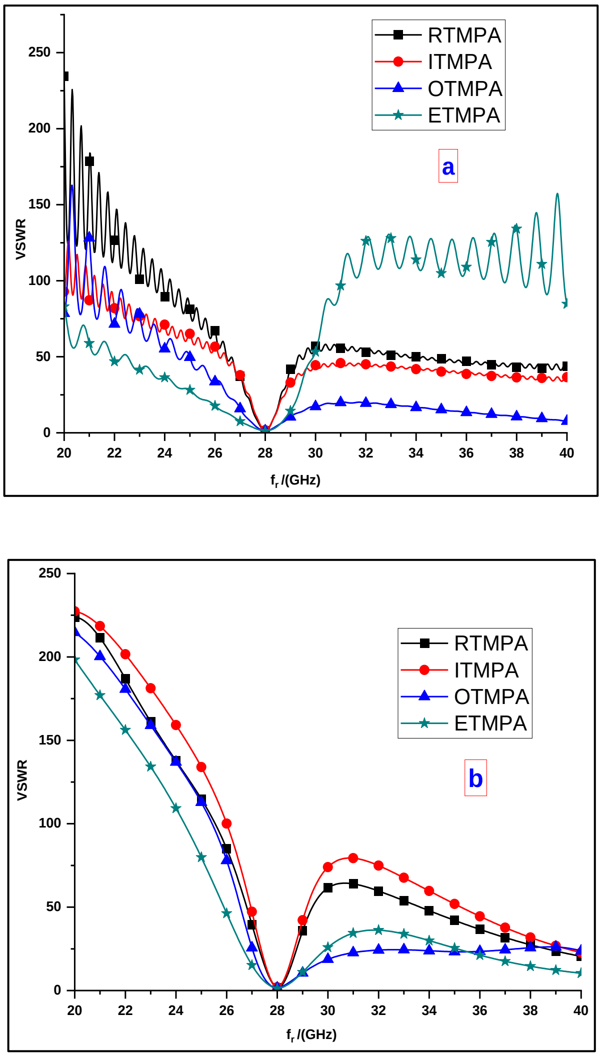


Figure 6: Values of VSWR as a function of frequency for various triangular shapes patch: **(a)** CST and **(b)** HFSS

In addition, these figures implies that the computed results of efficiency and bandwidth of ETMPA and OTMPA are generally greater than the other triangular patch shapes and with the use of both mentioned simulation techniques. Besides, the 2D view polar radiation pattern for the gain and directivity for all consider triangular patch shapes are computed and the results are presented in **Figures (8)** and **(9)**, respectively. One confidently observes from these two figures that the RTMPA and ETMPA provide lower back lobe level radiation with both implemented simulation method. Therefore, on the bases of the above result discussion, one confidently can decide that the ETMPA with a size of the order of (3.88 mm^3) displays generally higher radiation performance compare to the other triangular patch under consideration. Since, it provides reliable antenna parameters suitable for 5G application systems such as gain (5.82 dB, 6.29 dB), directivity (6.85 dB, 7.09 dB), efficiency (78.9%, 83.2%) and bandwidth (0.452 GHz, 0.369 GHz), respectively, for CST and HFSS techniques.

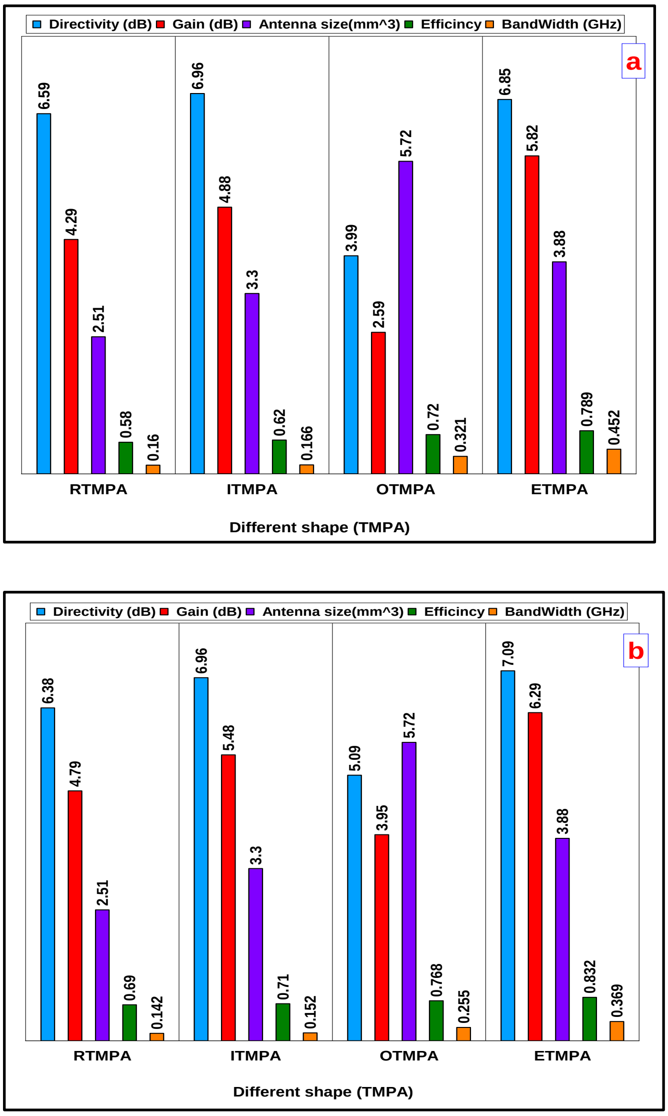


Figure 7: Histogram representation of the variation of TMPA parameters as a function for the different triangular shapes patch by using **(a)** CST and **(b)** HFSS simulation techniques.

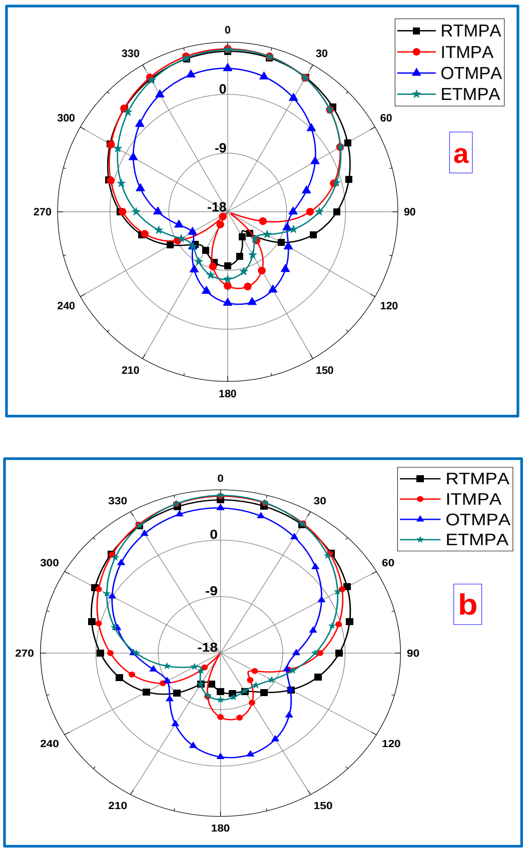


Figure 8: The compare 2D-polar radiation pattern of the Directivity by the for different triangular shapes patch by using **(a)** CST and **(b)** HFSS simulation techniques

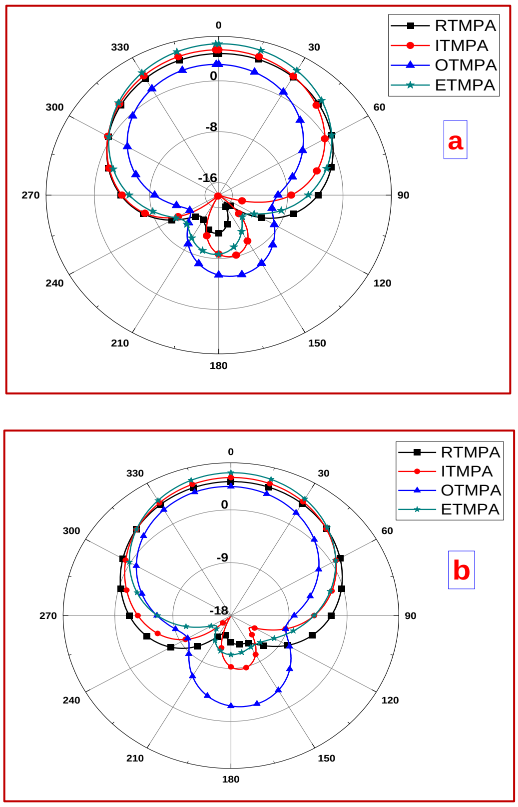


Figure 9: The compare 2D-polar radiation pattern of the Gain by the for different triangular shapes patch: **(a)** CST and **(b)** HFSS simulation method

Accordingly, the ETMPA is selected for the second procedure of this work and its overall antenna radiation parameters with the same geometrical and conductor material parameters specified previously are calculated using coaxial probe fed techniques. The computed results with both simulation methods and with both fed techniques are summarized and presented in **Table (2).** The inner and outer radius of the coaxial probe fed transmission line with its position point on the patch which produce nearly (50 Ω) input impedance are evaluated using formula expression given by (Stutzman and Thiele, 2012, Mokal et al., 2017) as:

$$\mathbf{Z_0} = \frac{60}{\sqrt{\boldsymbol{\varepsilon}_\mathbf{r}}} \ln \frac{\mathrm{R_{out}}}{\mathrm{R_{in}}} \qquad (13)$$

$$\mathbf{y} = \frac{\mathrm{L_p}}{2\sqrt{\boldsymbol{\varepsilon}_\mathbf{r}}} \qquad (14)$$

The results of this table indicates that the antenna directivity and hence gain values obtained by probe fed techniques seems to be somewhat higher than those predicted by inset fed method. In contrast, the bandwidth and efficiency values obtained with coaxial probe fed is generally smaller than those achieved with inset fed techniques.

Therefore, the accuracy of the antenna parameter values achieved by both fed techniques can be specified only by comparing these results with the corresponding practical or theoretical results of other researchers. Hence, these computed antenna parameters are compared to their corresponding values achieved previously for various MPA shapes operating at 28 GHZ and the results are presented in **Table (3)**. Generally, the results of this table displays that the present computed results are in good agreement with those previously calculated and measured by other researchers. Moreover, it is clearly observed from this table that the overall antenna parameter values obtained with the inset fed techniques and by using CST simulation techniques are more accurate ones as compared to those measured experimentally by (Ezzulddin et al., 2022a).

Table 2: Comparison between the inset and probe fed technique optimization of ETMPA parameters implementing CST and HFSS methods.

Parameter	**Feeding techniques**			
Type feeding	Inset feed		Prob-feed	
Patch dimension (mm)				
Line fed length ($\mathbf{F_i}$)	1.4		3.9	
Inner radius ($\mathbf{R_{in}}$)	-		0.15	
Outer radius ($\mathbf{R_{out}}$)	-		0.52	
Position feeding ($\mathbf{x, y, z}$)	-		(0, -1.1 ,0)	
Microstrip line feed width ($\mathbf{W_f}$)	0.46		-	
Antenna performance				
Simulation techniques	CST	HFSS	CST	HFSS
Antenna size(**mm**^{3})	3.88		3.88	
S11(**dB**)	-28.68	-20.64	-21.26	-21.95
VSWR (**dB**)	1.076	1.20	1.18	1.17
Efficiency	0.789	0.832	0.775	0.80
Directivity (**dB**)	6.85	7.09	7.16	8.07
Gain(**dB**)	5.82	6.29	6.05	7.11
f_r (**GHz**)	28		28	
Bandwidth (**GHz**)	0.452	0.369	0.356	0.259

Table 3: Comparison between the simulated ETMPA parameters with corresponding values obtained by other researchers.

Antenna parameters	Present work				Haneef et al., 2019	Darsono and Wijaya, 2020	Kumar and Kumar, 2019	Gharbi et al., 2017	Ezzulddin et al., 2022
Patch shape	**ETMPA**				**RMPA**	**RMPA**	**CMPA**	**RMPA**	**ETMPA**
Dielectric material	Rogers RT5880				Rogers RT5880	Taconic TLY-5	Rogers RT5880	Rogers RT5880	Rogers RT5880
Antenna size(mm^2)	**3.88**		**3.88**		221.07	7.29	18.28	23.40	5.208
Gain(dB)	**5.82**	**6.05**	**6.29**	**7.11**	3.29	6.71	7.78	7.8	5.26
Bandwidth (GHz)	**0.452**	**0.356**	**0.369**	**0.359**	-	0.465	-	1.7	0.744
Efficiency	**0.789**	**0.775**	**0.832**	**0.80**	-	-	-	-	0.84
Directivity (dB)	**6.85**	**7.16**	**7.09**	**8.07**	3.31	-	-	-	6.19
S11(dB)	**-28.68**	**-21.26**	**-20.64**	**-21.95**	-9.74	-27.78	-18	-27	-18.80
Feeding techniques	Inset feed	Prob feed	Inset feed	Prob feed	Inset feed	Inset feed	Inset feed	Prob feed	Inset feed
Simulation Techniques	**CST**		**HFSS**		**HFSS**	**CST**	**HFSS**	**CST**	**Measurement**

4. Conclusion

According to the simulation results evaluated by both numerical methods for various TMPA parameter values, it was found that better radiation performance is achieved generally with ETMPA compare to the other considered TMPA configuration shapes. Since its size is of the order of ($3.88mm^3$) and provides antenna gain, directivity, bandwidth, and radiation efficiency values of (5.82, 6.29), (6.85, 7.09) dB and (0.452, 0.369) GHz, (78.9%, 83.2%) with, respective, CST and HFSS method. Moreover, the results also indicate that the obtuse triangular patch shapes are unsuitable for 5G application systems due to their larger size and radiate with lower antenna gain and directivity compared to the other considered TMPA shapes.

Besides, it was obviously seen from the 2D view polar pattern that the RTMPA and ETMPA provide lower back lobe level radiation with both techniques CST and HFSS techniques. Consequently, the accuracy and reliability of the antenna parameter values obtained by CST method with the inset fed to those estimated by probe fed techniques for ETMPA was clearly observed compared to the previously achieved by other researchers experimentally and theoretically. Finally, further improvement in the performance of ETMPA could be made by constructing them in an array configuration and testing different substrate materials of various loss tangent and implementing different conductor patch materials.

Acknowledgement:

Conflict of Interest: There is no conflict of interest and any funding sources for this research

5 Reference

AFANDI, R. & HADI, D. R. Design and Bandwidth Optimization on Triangle Patch Microstrip Antenna for WLAN 2.4 GHz. MATEC Web of Conferences, **2018**, EDP Sciences, 01042: http://dx.doi.org /10.1051/matecconf/201816401042

ALTUFAILI, M. M. S., NAJAF, A. N. & IDAN, Z. S. **2022**, Design of circular-shaped microstrip patch antenna for 5G applications. TELKOMNIKA (Telecommunication Computing Electronics and Control), 20**,** 19-26: http://dx.doi.org/10.12928 /TELKOMNIKA.v20i1.21019.

BUSHRA A. R. & SATTAR O. H., Simulation Design of Low-Profile Equilateral Triangle Microstrip Patch Antenna Operating at 28 GH, International Journal on Communications Antenna and Propagation (IRECAP), Vol. 12, N. 2, April **2022**, https://doi.org/10.15866/ irecap.v12i2.21964.

DARBOE, O., KONDITI, D. B. O. & MANENE, F. **2019**, A 28 GHz rectangular microstrip patch antenna for 5G applications. International Journal of Engineering Research and Technology, 12**,** 854-857: https:// www.researchgate.net/publication/334170529.

DARSONO, M. & WIJAYA, A. Design and simulation of a rectangular patch microstrip antenna for the frequency of 28 GHz in 5G technology. Journal of Physics: Conference Series, **2020**. IOP Publishing, 012107: http://dx.doi.org/10.1088/17426596/1469/ 1 /012107.

EZZULDDIN, S. K., HASAN, S. O. & AMEEN, M. M. **2021**, Optimization of Rectangular Microstrip Antenna Substrate Parameters to Operate with High radiation Performances for 5G applications. Advances in Mechanics, 9**,** 273-286: https://www .researchgate.net/publication/357859141

EZZULDDIN, S. K., HASAN, S. O. & AMEEN, M. M. **2022**, Microstrip patch antenna design, simulation and fabrication for 5G applications. Simulation Modelling Practice and Theory, 116**,** 102497: http://dx.doi.org/10.1016/j.simpat.2022.102497.

EZZULDDIN, S. K., HASAN, S. O. & AMEEN, M. M. Optimization of rectangular microstrip antenna patch parameters to operate with high radiation performances for 5G applications. AIP Conference Proceedings, **2022**, AIP Publishing LLC, 070002 https://doi.org/10.1063/5.0066800.

GEMEDA, M. T., FANTE, K. A., GOSHU, H. L. & GOSHU, A. L. **2021**, Design and Analysis of a 28 GHz Microstrip Patch Antenna for 5G Communication Systems. International Research Journal of Engineering and Technology (IRJET), 8**,** 881-88: https://www.researchgate.net/publication/349461706.

GHARBI, I., BARRAK, R., MENIF, M. & RAGAD, H. Design of patch array antennas for future 5G applications. 18th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA), **2017**, IEEE, 674-678: http://dx.doi.org/10.1109/ STA.2017.8314954.

H PATEL, D. & D MAKWANA, G. **2021**, A Comprehensive Review on Multi-band Microstrip Patch Antenna Comprising 5G Wireless Communication. International Journal of Computing and Digital System: https://dx.doi.org/10.12785/ijcds/110177.

HANEEF, S. R., SELVAPERUMAL, S. K. & JAYAPAL, V. **2019**, High Gain Rectangular Single Patch Antenna at Mmwave Band: http://dx.doi.org/10.13140 /RG.2.2.28455.70564.

JOHARI, S., JALIL, M. A., IBRAHIM, S. I., MOHAMMAD, M. N. & HASSAN, N. **2018**, 28 GHz microstrip patch antennas for future 5G. Journal of Engineering and Science Research, 2: https://doi.org/10.26666/ rmp.jesr.2018.4.1.

JOSHI, M. P. & GOND, V. J. Microstrip patch antennas for wireless communication: A review. 2017 International Conference on Trends in Electronics and Informatics (ICEI), **2017**. IEEE, 96-99: http://doi.org/10.5281/zenodo.2648966.

KOMPELLA, S. K. & ABDUL RAJAK, A. **2022**, Design and Study the Performance of Micro-Strip Patch Antennae for 5G Mobile Communication. ICT Systems and Sustainability. Springer: http://dx.doi.org/10.1007/978-981-16-5987-4_2.

KUMAR, S. & KUMAR, A. Design of circular patch antennas for 5G applications. 2019 2nd International Conference on Innovations in Electronics, Signal Processing and Communication (IESC), **2019**, IEEE, 287-289:

MAITY, S. & GUPTA, B. 2014. Simplified analysis for 30°–60°–90° triangular microstrip antenna. Journal of Electromagnetic Waves and Applications, 28**,** 91-101: http://dx.doi.org/10.1080/09205071.2013.857279.

MAITY, S. & GUPTA, B. **2015**, Cavity model analysis of 30°–60°–90° triangular microstrip antenna. AEU-International Journal of Electronics and Communications, 69**,** 923-932: http://dx.doi.org/10.1016/j.aeue.2015.02.012.

MAITY, S. & GUPTA, B. **2018**, Radiation Characteristics of an Isosceles 45–45–90 Triangular Microstrip Antenna. IETE Journal of Research, 64**,** 139-148: http://dx.doi.org/10.1080/03772063.2017.1341820.

MEHTA, A. **2015**, Microstrip antenna. International Journal of Scientific & Technology Research, 4**,** 54-57: www.ijstr.org

MOHAMMED, A. S., KAMAL, S., AIN, M. F., AHMAD, Z. A., ULLAH, U., OTHMAN, M., HUSSIN, R. & AB RAHMAN, M. F. **2019**, A review of microstrip patch antenna design at 28 GHz for 5G applications system. International Journal of Scientific & Technology Research, 8: https://www.researchgate.net/publication/336922387.

MOKAL, M. V., GAGARE, P. S. & LABADE, D. R. **2017**, Analysis of Micro strip patch Antenna Using Coaxial feed and Micro strip line feed for Wireless Application. IOSR Journal of Electronics and Communication Engineering (IOSR-JECE) e-ISSN**,** 2278-2834: http://dx.doi.org/10.9790/2834-1203033641.

NASEEB, C. **2020**, 5G — Fifth Generation of Mobile Networks. ILLUMINATION: https://medium.com/illumination/5g-fifth-generation-of-mobile-networks-part-1-f32d7f003686.

OLAIMAT, M. **2010**, Design and analysis of triangular microstrip patch antennas for wireless communication systems. Master Thesis, Jordan University of Science and Technology: http://dx.doi.org/10.13140/RG.2.2.34602.34248.

OLAIMAT, M. M. & DIB, N. I. 2011. A study of 15°-75°-90° angles triangular patch antenna. Progress In Electromagnetics Research Letters, 21**,** 1-9: https://www.researchgate.net/publication/328102556.

STUTZMAN, W. L. & THIELE, G. A. **2012**, Antenna theory and design, John Wiley & Sons.

SURENDRAN, A., SUBRAMANIAM, L., SELVAPERUMAL, S. K. & JAYAPAL, V. **2019**, High gain compact multi-band microstrip patch antenna for 5G network. International Journal of Advanced Science and Technology, 29**,** 1390-1410: https://www.researchgate.net/publication/339487905.

TODOSIOSKA, A. **2020**, The role of telecommunication companies in Internet of things: https://run.unl.pt/bitstream/10362/94883/1 /TGI0283.pdf.

UDOFIA, K. M. & SATURDAY, J. C. **2019**, Parametric comparison of circular, triangular and rectangular dual-band microstrip antennas for wireless communication. European Journal of Engineering and Technology Vol. 7: http://www.idpublications.org/wp-content/uploads/2019/03/Full-Paper-PARAMETRIC-COMPARISON-OF-CIRCULAR-TRIANGULAR-AND-RECTANGULAR-DUAL-BAND-MICROSTRIP-ANTENNAS.pdf.

VORA, L. J. **2015**, Evolution of mobile generation technology: 1G to 5G and review of upcoming wireless technology 5G. International journal of modern trends in engineering and research, 2**,** 281-290:https://ijmter.com/papers/volume-2/issue-10/evolution-of-mobile-generation technology-1g-to-5g-and-review-of-5g.pdf.