Development of Microstrip Patch Antenna through Variant Shapes Technique for 5G Application and Future Wireless Communication Systems

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Abstract. The rapid development of wireless communication from the first to the fifth generation has created demand for antennas with a wide band that are capable of processing large amounts of information. Microstrip patch antennas (MPA) are one of the most efficient when it comes to handheld devices using wireless communication because they are low-profile, less expensive, and not difficult to manufacture. Theoretically, certain features like type of substrate, height of substrate, shape of radiating patch, among others can alter the quality of MPA. The goal of this re-search is to examine the role of shapes on the general performance of microstrip patch antennas while using flame retardant woven glass-reinforced epoxy resin (FR4) as a substrate. Selected shapes of square, rectangle, triangle, circle, E, H, and T were chosen and simulated using an adaptive high frequency structure simulator (HFSS) at a frequency of 28 GHz. The simulation result showed that the rectangular shape performed maximally, having the highest gain, directivity, and considerable bandwidth.

Keywords: Microstrip-antenna, Wireless, Bandwidth, FR4, HFSS, Millimeter wave.

1 INTRODUCTION

The microstrip patch antenna (MPA) came to the limelight in the 1970s' and gained more attention globally, although it was first invented in the 1950s' (Pantel *et al.*, 2013). MPA are made up of a thin metallic strip (usually far less than the operating wavelength) that is etched on a substrate. The physical structure of the antenna is such that a metallic strip is placed on a ground plane with a substrate in between. It also has a feed line through which current from an amplifier is channeled to the patch for radiation. There are many substrates available for the design of the MPA, with their corresponding dielectric constants ranging from 1 to 12 (Vettumperumal and Dhineshbabu 2022)]. The most suitable and desirable dielectrics for maximum antenna performance are those with low values and thick widths. Generally, MPAs are low-profile, possess planar and non-planar surfaces, are conformable, simple, and cost effective to produce because of their ability to be manufactured on modern printed-circuit technology. Furthermore, they are durable mechanically when placed on surfaces that are rigid, well suited for multiple inputs, multiple outputs (MIMO)

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designs, and very adaptable in terms of pattern, impedance, polarization and resonant frequency whenever any patch shape is selected (Suresh *et al.*, 2021).

On the other hand, communication systems have in recent times been geared towards the fifth generation, 5G and other future wireless generations are underway (Elo *et al*. 2017; Sufyan *et al* 2023). This is a result of the escalation in the number of users, the advent of internet of things (IOT), artificial intelligence, and a host of others. Earlier, there were the first to fourth generations of communication systems, which, in their own capacity, allowed for communications and the transfer of data and information. However, they were limited in capacity, ranging from the amount of information they could transfer per second to the number of users, the quality of the information being transferred, etc. These all led to the advent of the fifth generation of communication systems as a remedy to the inabilities of the previous generations of systems to provide access to a large number of users and also data transfer at a higher speed (Dangi *et al* 2022).

Conversely, it is appropriate to consider the antenna (mostly microstrip antenna) that will be employed to work within the frequency spectrum of the fifth-generation systems, as antenna working with the previous generation does not provide optimum capacity (Al-hetar *et al*. 2021). Hence, the need to introduce microstrip antennas that will help devices connected to the 5G network work efficiently. Also, in other to maximize the efficiency of the antenna to be employed, there is need to do a comparison between available shapes of MPA to identify the premier with reference to gain, directivity return loss and bandwidth. Previous study by Pathak and Kumar Singh (2021) was based on four different shapes: E, T, H and F, with antenna designed to function at 2.4 GHz for RFID radar applications. Also, recently there have been efforts to optimize the Microstrip patch antenna's performance for 5G purposes using innovative shapes such as hexagonal (Karthikeyan *et al.*), circular (Sigh *et al.*), and elliptical (Liu *et al.*) shapes, all leading to improved gain and bandwidth. Further research using shapes of pentagon (Kumar *et al.*) and triangle (Singh *et al.*) led to reduced size and isolation. However, there has been a research gap between alphabet-based shape and geometrical-based shape. Thus, this research is geared towards bridging this gap by combining basic geometric shapes and some selected alphabets based on previous research for simulation and consequently selecting the best shape based on antenna parameters. It is also intended that a miniature version of the best shape is fabricated by way of optimization.

Therefore, in this work, seven different shapes such as rectangle, square, triangle, circle, E, T and H have been chosen to deduce the best antenna shape for a higher frequency of 28 GHz.

2. DESIGN AND ANALYSIS

In this work, seven selected shapes which include square, rectangle, triangle, circle, E, T and H have been chosen for the purpose of comparison and to choose the best. For the purpose of simulation, antenna parameters are deduced using the following set of equations based on the selected shapes.

2.1. Square and Rectangle

Antenna parameters for square and rectangular-shapes are designed using:

$$Wp = \frac{c}{2fr}\sqrt{\frac{2}{\mathcal{E}r+1}} \tag{1}$$

$$Lp = Leff - 2\Delta l \tag{2}$$

$$Leff = \frac{c}{2fr\sqrt{\mathcal{E}r}} \tag{3}$$

$$\Delta L = \frac{(\mathcal{E}reff+0.3)\left(\frac{Wp}{h}+0.264\right)}{(\mathcal{E}reff-0.258)\left(\frac{Wp}{h}+0.82\right)} \tag{4}$$

$$\mathcal{E}reff = \frac{\mathcal{E}r+1}{2} + \frac{\mathcal{E}r-1}{2}\left[1 + 12\frac{h}{w}\right]\frac{1}{2} \tag{5}$$

$$Ls = 6h + lp \tag{6}$$

$$Ws = 6h + wp \tag{7}$$

where Lp and Wp are length and width of patch respectively, Leff is the effective length, ΔL is the change in length, Ɛreff is effective dielectric constant, while Ls is length of substrate and Ws is width of the substrate.

By adopting appropriate expression for the simulations, Tables 1 and 2 shows the design dimensions needed for designing square and rectangular-shapes.

2.2. Triangle

In addition to the expressions in equations (1) to (7), the length of a triangular-shape can be expressed in terms of

$$L = \frac{2c}{3fr\sqrt{\mathcal{E}r}} \tag{8}$$

where L is the length of one side of the equilateral triangle. Table 3 shows the design dimensions needed for triangle.

2.3. Circle

In addition to the antenna mentioned in equations (1) to (7), area of a circle is necessary in designing a circular-shape and can be expressed as:

$$A = \frac{F}{\sqrt{\left[1+\frac{2}{\pi \varepsilon r F}\left[ln\left(\frac{\pi f}{2h}\right)+1.7726\right]\right]}} \quad (9)$$

where $F = \frac{8791 \times 10^9}{Fr\sqrt{\varepsilon r}}$ and A is the radius of the circle. Table 4 shows the design dimension needed for circled-shape.

2.4. E, T and H shapes

The shapes of E, T and H, are gotten from precision drawings, the dimensions which are taken from the optimization of the rectangular and square shape. Table 5 presents the design dimensions needed for them.

Table 1: Design parameters for square

Parameter symbol	Details of parameters	Value (mm)
Ls	Length of substrate	8.00
Ws	Width of substrate	8.00
Hs	Height of substrate	1.60
Lp	Length of patch	3.00
Wp	Width of patch	3.00

Table 2: Design parameters for rectangle

Parameter symbol	Details of parameters	Value (mm)
Ls	Length of substrate	11.27
Ws	Width of substrate	12.86
Hs	Height of substrate	1.60
Lp	Length of patch	3.00
Wp	Width of patch	4.00

Table 3: Design parameters for triangle

Parameter symbol	Details of parameters	Value (mm)
Ls	Length of substrate	8.00
Ws	Width of substrate	8.00
Hs	Height of substrate	1.60
Lp	Length of patch	3.40

Table 4: Design parameters for circle

Parameter symbol	Details of parameters	Value (mm)
Ls	Length of substrate	8.00
Ws	Width of substrate	8.00

Hs	Height of substrate	1.60
Rp	Radius of patch	1.60

Table 5: Design parameters for E, T and H shapes

Parameter symbol	Details of parameters	Value (mm)
Ls	Length of substrate	8.00 – 10.00
Ws	Width of substrate	8.00 – 10.00
Hs	Height of substrate	1.60
Lp	Length of patch	3.00 – 6.00
Wp	Width of patch	5.00 – 6.00

Based on the dimensions presented in Tables 1 to Tables 5, the antennas were simulated using HFSS (Awad and Abdelazeez, 2018). Figures. I to 7 show the structures for the simulation for square, circular, triangular, E, H, T, and rectangular shapes respectively.

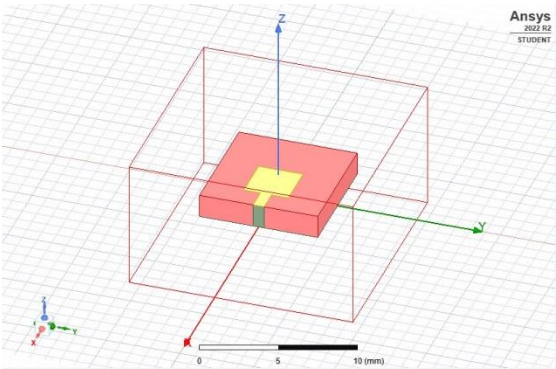

Figure 1: Design of a Squared-shape antenna

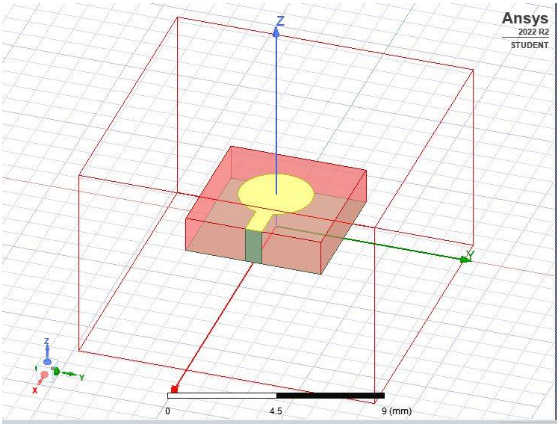

Figure 2: Design of a Circular-shape antenna

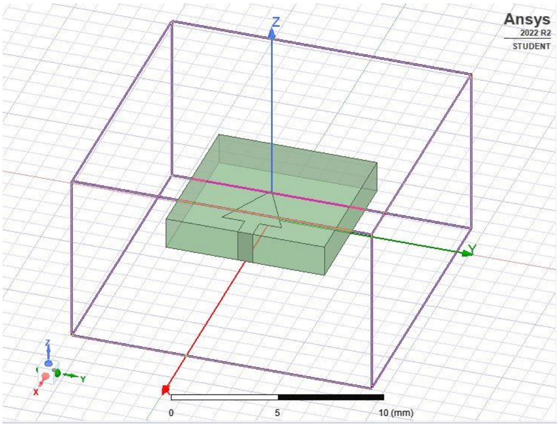

Fig 3: Design of a Triangular-shape antenna

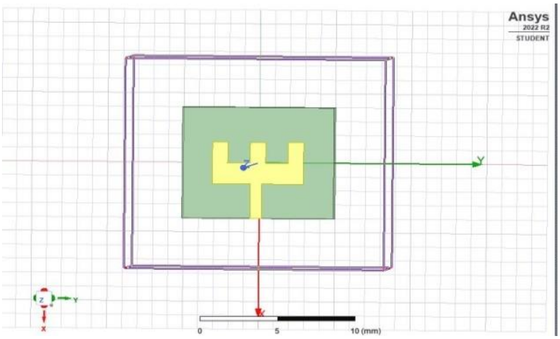

Fig. 4: Design of an E-shape antenna

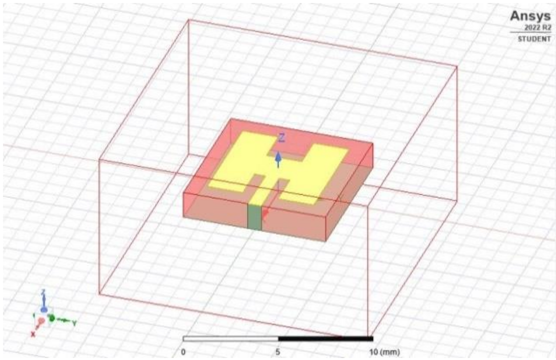

Fig. 5: Design of a H-shape antenna

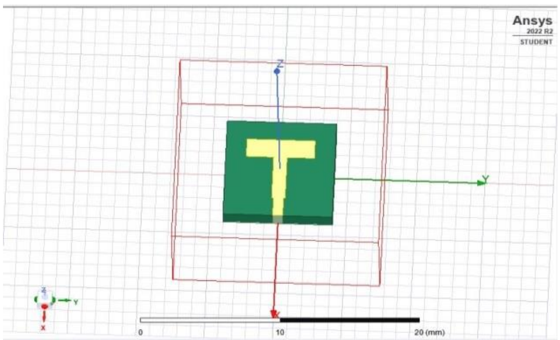

Fig. 6: Design of a T-shape antenna

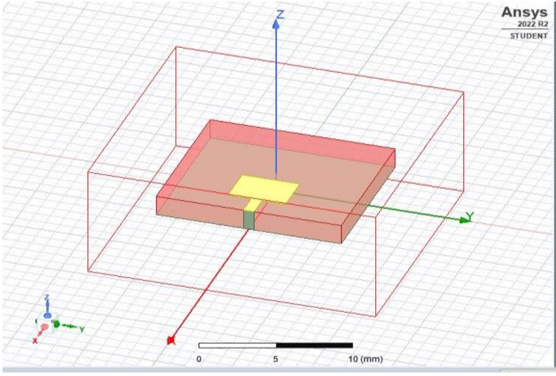

Fig. 7: Design of a rectangular-shape antenna

3. RESULTS AND DISCUSSION

Simulation outcome for the selected shapes is presented in in Tables 6 and 7 for the gain, directivity, and bandwidth as well as resonated frequency, return loss and VSWR, respectively. From the simulated result as presented in Tables 6 and 7, it is seen that the E shape has the largest bandwidth, the least VSWR and return loss, which implies that only an infinitesimal amount of power is reflected back and also allowing for information in the excess of 5 GHz to be passed (Mohamed, 2021). However, the antenna has a low gain and directivity denoting that the distance coverable by radiation will be poor. Therefore E-Shape antenna is not good for 5G communication, albeit it is useful in devices where proximity is needed such as MiFI. The inverse of this result is the H-shape, having a low bandwidth but high gain and directivity. Also, this is useful where bandwidth is needed to be traded off for directivity and gain, or where the amount of information to be transferred is not large (Ramya *et al*. 2023). Next is the rectangular shape having the highest gain, directivity, a low VSWR and the second largest bandwidth.

Thus, having considered all parameters expresses the performance of an antenna, it is concluded that at 28 GHz the rectangular-shape antenna can provided optimum performance for 5G wireless communication systems. Consequently, square and triangle comes next after rectangle, all having a good VSWR, gain and directivity with considerable large bandwidth.

Table 6: Simulation result showing the Resonated Gain, directivity and bandwidth for the selected shapes

Shape of Antenna	Gain (dB)	Directivity (dB)	Bandwidth (GHz)
E-Shape	2.72	3.28	5.2
Square	6.26	7.08	4.1
Circle	6.31	6.97	2.7
Rectangle	7.04	8.25	4.9
Triangle	6.73	7.45	3.5
H-Shape	5.34	7.04	0.8
T-Shape	3.88	5.27	0.7

Table 7: Simulation result showing the resonated frequency, return loss and VSWR for the selected shapes

Shape of Antenna	Resonated Frequency (GHz)	Return Loss (dB)	VSWR
E-Shape	29.1	-16.54	1.35
Square	33.4	-18.84	1.25
Circle	32.4	-13.08	1.57
Rectangle	31.5	-28.39	1.08
Triangle	40.7	-18.55	1.26
H-Shape	30.9	-14.03	1.49
T-Shape	31.9	-13.30	1.54

In furtherance of the research's aim, which is to fabricate a miniatured prototype of the best shape, the shape was fabricated in the laboratory using a direct-contact method as opposed to the normal photolithographic method of fabricating patch antennas as a way of improvisation when such an instrument is unavailable. In this method, the best shape was redesigned on Proteus software using the same parameter on the simulation software. Subsequently, we printed the shape onto a glossing paper and used toluene to dissolve it on the substrate board. The shape based on the substrate was finally transferred into an etching tank for the final formation of the patch antenna.

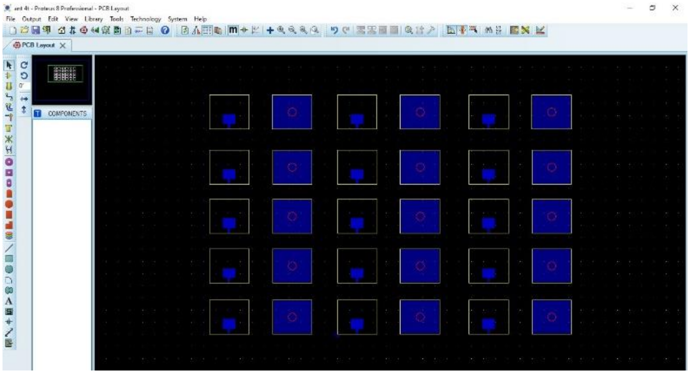

Figure 8: Design of the rectangular shape on Proteus

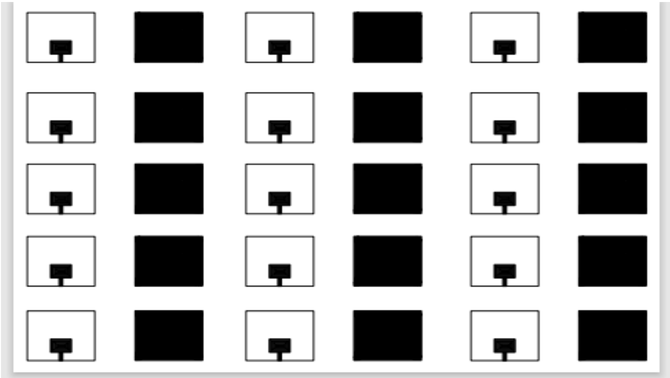

Figure 9: Printed copy of the designed shape

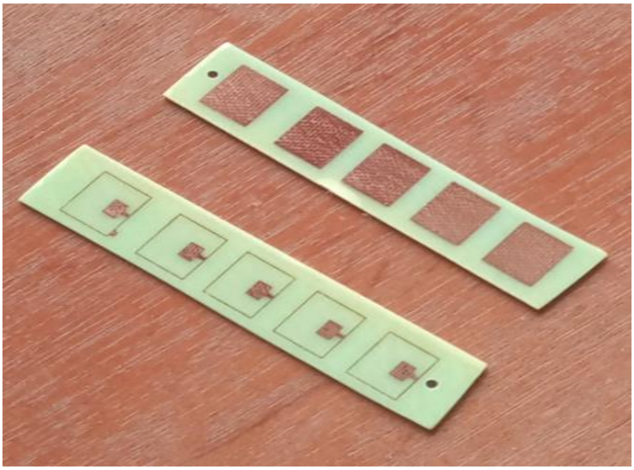

Figure 10: A prototype of the fabricated rectangular patch

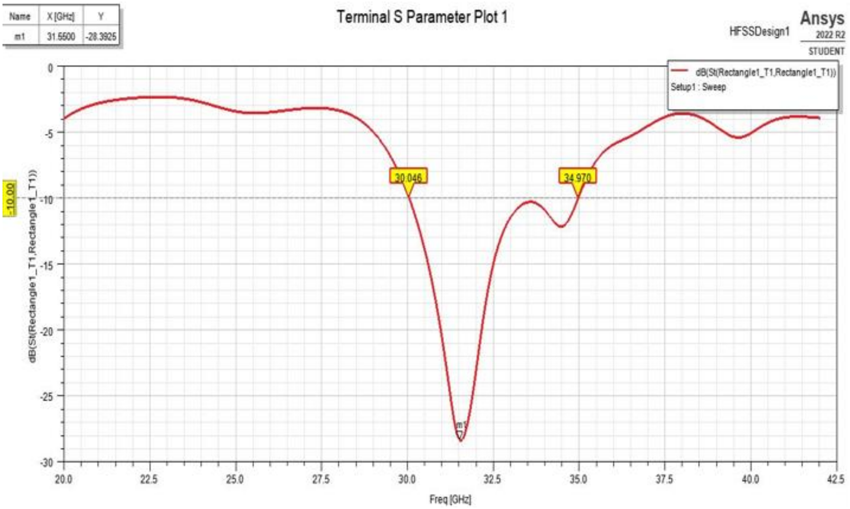

Figure 11: S11 parameter for rectangular shaped antenna

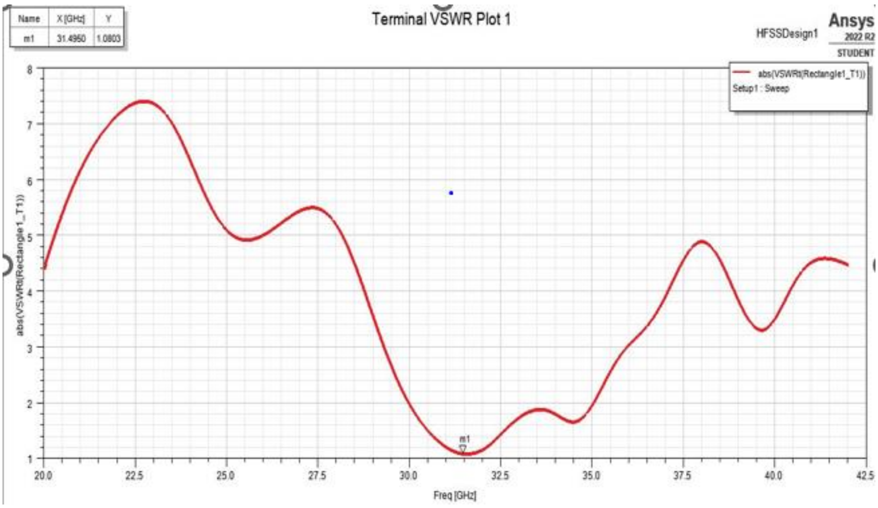

Figure 12: VSWR for rectangular-shaped antenna

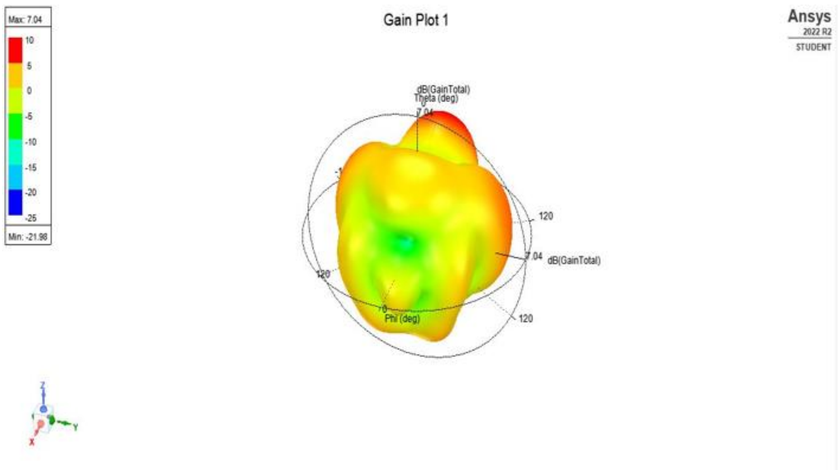

Figure 4.18: Gain and 3D polar plot for rectangular-shaped antenna

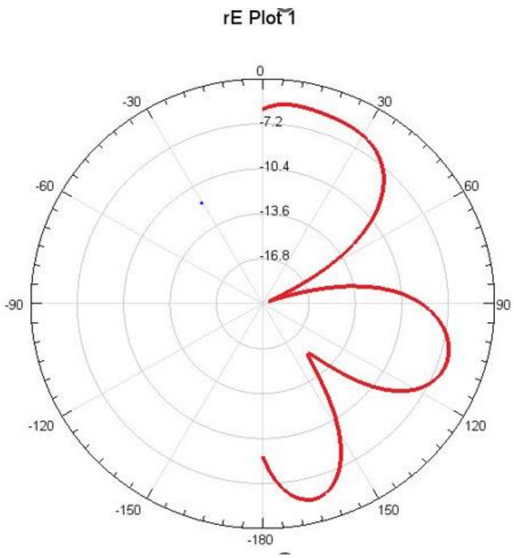

Figure 4.20: 2D radiation pattern for rectangular-shaped antenna

3.1 Findings and comparison with previous work

Having subjected the selected shapes to antenna parameters of gain, directivity, voltage standing wave ratio (VSWR) etc. for analysis, the rectangular shape came out best, followed by shapes of triangle and square. The rectangular shape has a design parameter of 3mm by 4mm for the radiating patch, while the substrate has a dimension of 11.27 mm by 12.86 mm. The substrate material of fire resistance (FR4) used has a height of 1.6mm. Simulation results show that the shape has the maximum gain and directivity of 7.04 dB and 8.25 dB respectively. It also has a considerably high bandwidth of 4.9 GHz making it the best amongst the seven selected shapes. For further analysis, the rectangular shape was then compared with previous similar works which were simulated at 28 GHz and subjected to antenna parameters of S11 parameter, gain, radiation efficiency and bandwidth as shown in Table 4.3. The antenna achieved a remarkable improvement based on the fact that its S11 parameter is amongst the first six best which is in the range of -10 to -30 dB. Its gain of 7.08 dB came out the second best behind the gain of 7.5 and 7.58 dB. Also, its VSWR is amongst the lowest. While radiation efficiency was not put into consideration in the course of this research, it has the highest bandwidth of 4.9 GHz in which only one of the previous works came close. It is therefore concluded that the rectangular shape antenna from this research achieved a remarkable improvement when compared to other previous works, mostly especially when considering the demands of 5G and future wireless communications system. The fabricated antenna can be used in mobile and telecommunication devices such as pebbles, mobile phones, smart home etc. it can also be employed in instances where there is space constrain due to its miniature dimension.

Table 8: Simulation results of the previous works and proposed antenna at 28 GHz

References	S11 (dB)	Gain (dB)	VSWR	ηrad (%)	BW (GHz)
Ershadi *et al.*, 2017	-54.49	7.55	1.011	98.00	1.062
Awan *et al.*, 2019	-56.95	7.60	1.002	79.80	1.380
Kaeib *et al.*, 2019	-39.37	6.37	1.022	86.73	2.480
Darboe *et al.*, 2019	-13.48	6.63	1.537	70.18	0.849
Parachi *et al.*, 2020	-20.03	5.23	1.220	95.90	2.110
Subramaninam *et al.*, 2020	-17.83	-	1.299	92.65	-
Ghazaoui *et al.*,2020	-39.7	5.23	-	-	4.100
Darsono and Wijaya, 2020	-27.7	6.72	1.220	75.87	0.463
Sivabalan *et al.*, 2020	-22.2	6.85	1.340	-	-
Gemeda *et al.*,2021	-38.86	7.585	1.023	98.215	1.046
This work	-28.39	7.04	1.080	-	4.900

4. CONCLUSION

In other to identify the shape which gives a MPA maximum performance at 28 GHz, for the combination of alphabet and geometric-based shapes, shapes of rectangle, square, triangle, circle E, T and H were selected, designed and simulated. The rectangular shape came out best with the highest gain, directivity, a considerable large bandwidth and a minimal VSWR, making it the best shape amongst the selected shapes.

Although the E-Shape has the highest bandwidth, it has low gain and directivity, therefore making it not suitable for 5G application. Albeit, configuring it in arrays will significantly improves the gain and directivity, thus making it a major competitor in the world of shape-based patch antenna. Shapes of square and triangle also have good performance, but not compared to the result gotten from the rectangular shape. Overall, the analysis shows that each of the shapes can be adopted, depending on the application and where they fit to. However, futuristically, for maximum performance, application of optimization techniques such as choice of substrate material with a higher or lower dielectric constant than the one used in this research depending on tradeoffs, configuration of shapes in array, parasitic patch element etc. will tremendously increase their performance. Also, a combination of two, three or more optimization techniques depending on intended applications will also improve the overall performance of the antenna.

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