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DESIGN AND MODELLING OF CIRCULARLY POLARIZED SLOT ANTENNA FOR 5G COMMUNICATION SYSTEMS

Ayyada KhalIfa Mahmoud Faraj and Goh Chin Hock
Department of Electrical and Electronics Engineering, College of Engineering, Universiti Tenaga Nasional, Malaysia

Abstract

In recent years, the size of receivers and transmitters has decreased in size (mobile phones, laptops, and satellites) and others, making researchers work to reduce the antenna size to fit the size of these devices. In this paper, two antennas were designed to operate on one of the fifth generation's frequencies, a frequency of (28 GHz). The antenna dimensions were modelled using the CST simulation software, and the results were obtained, compared with the antenna, which will be mentioned here. Several methods related to shrinking antennas have been reviewed, Among the methods chosen to participate in reducing the size of the antenna are changing the size and shape of the aperture, changing the thickness and type of the substrate. the methods examined help to improve antenna properties such as gain, directivity, and efficiency. In antenna number one, a substrate with a higher permittivity than that of the chosen antenna was used for comparison., and a U-shaped slot was created in the copper layer. as the Gain, Directivity and Efficiency of 5.227, 6.020 and 85.82 were achieved, respectively. As for antenna number two, a square-shaped opening was made, and a substrate was chosen with the same permittivity and thickness less than the antenna to be compared with. In addition, the antenna number two gave good results at thickness of 0.127, and satisfactory results with a thickness of 0.873. With a thickness of 0.127 the gain, Directivity and Efficiency of 5.975, 5.997 and 99.63% were achieved, respectively, while the results of a thickness of 0.837 Gain, Directivity and Efficiency were 1.77, 3.55 and 48.08%, respectively. A slot antenna was selected for comparison, which operated at the frequency (of 28 GHz), has a length of 7 mm, a width of 12 mm, and a height of 0.203 mm. A material Rogers RT/Duroid 4003 was used as the antenna substrate, with εr = 3.55. The antenna number one, compared to the antenna above, has a length of 8 mm, a width of 8 mm, and a thickness of 0.127. In addition, the antenna was fed by microstrip technology, A material FR-4 was used as the antenna substrate, with permittivity εr = 4.3. The antenna number two bore the exact same dimensions as the first one, however, the substrate has been changed to be Roger's RT6035HTC material with permittivity εr = 3.60. From the above, it is clear that the antenna size has been reduced by more than 45% at the first and second antennae.

Keywords:

Circularly Polarized, Slot Antenna, 5G, Antenna Size Reduction, Bandwidth

1. INTRODUCTION

The increasing demand for data transmission and the diversity of applications made researchers work on developing communications systems to become seven times more data traffic and with a transmission capacity of up to one gigabyte per second [1]. The communications systems have evolved in recent years from 2G, 3G, 4G to 5G. The fifth-generation wireless communication system is a quantum leap in the world of communications because will provide several services that will improve people's lives and their way of living, e.g., smart cities, smart homes, connected cars, etc. [2] wireless communication systems depend primarily on antennas to send the signal through the space between the sender and receiver, for this reason, 5G wireless communication systems need antennas of small size and high efficiency [3]. The slot antenna is one of the most recommended antennas in the fifth-generation communication system. Its advantages include ease of manufacturing, large bandwidths and the ability to produce direction at low cross-polarization levels. in addition, it is attractive in the mobile phone industry due to its small size [4]. The slot antenna consists of a metal plate in which a hole is made, the size of the hole is close to half the wavelength, with this antenna, circular polarisation can be generated by controlling the radiation distribution on the patch or aperture. One of the advantages of circular polarization is to reduce the losses caused by multipath between the transmitter and receiver antenna, [5] [6]. In addition to decreasing path mismatch, for this reason, circular polarization is much better compared to line polarisation [7].

1.1 FREQUENCY BAND

It is known that the 5G network operates at high frequencies compared to previous generations to obtain a large bandwidth. The fifth-generation frequencies range between 20 GHz and 1.00 tera Hz. The frequency bands have been classified both according to the bandwidth and the applications in which this band is included. The following table presents the names of some of these bands and their frequency rate.

Table.1. Names of the bands and frequency range with wavelengths

Name of band	Frequency range	Wavelength
Ka-band	26.5 to 40GHz	5mmto11.3mm
V- band	50 to 75GHz	4mm to 6mm
W-band	75 to 110GHz	2.7mm to 4mm

It is noted that the wavelength of these frequencies is calculated in millimetres, from which the name millimetre waves came. The Ka-band is used in satellite and satellite communications applications. Three frequencies of 28.1, 38, and 36.7 GHz were chosen to enter the fifth-generation mobile networks. Among the advantages of the 28.1 and 36.7 frequencies are that they have a bandwidth of 0.522 and 1.00 GHz, respectively. In addition, the 28 GHz frequency does not need an NLOS line of sight for communication, and therefore multiple communication paths can be generated. As for the v-band, it has greater bandwidth than the ka-band, as the bandwidth reaches 5 GHz. The v-band is used to research millimetre-wave radars and short-range Wi-Fi networks. The w-band provides high data rate output, so it is used in military radars whose function is to track and trace targets. In addition to using the w range in-car systems. It is noticeable from the above that the higher the frequency, the greater the advantages such as obtaining a larger bandwidth and a smaller antenna size [8] [9].

1.2 ANTENNA SIZE REDUCTION METHODS

In this chapter, some antennas that have been designed by researchers will be reviewed, showing the possible ways through which, the antenna size is reduced, together with improving the properties related to this antenna such as gain, directivity, loss, and other characteristics that researchers are interested in improving the antenna. Several factors can help reduce the size of the antenna and improve its characteristics. Slot width and length, Type and thickness of substrate additive and Defected ground structure (DGS)[10].

2. DESIGN STEPS AND NEEDS

This research will design and simulate the three antennas, which will be compared to the design mentioned in the second chapter. Using the Computer Simulation Technology CST, the process of modelling the dimensions of the three antennas and obtaining a three-dimensional simulation

First, the type of substrate on which the antenna will be based is determined, so that this is a pillar of high tolerance to help reduce the size of the antenna. In this research, two types of substrates will be used. In the first antenna, FR-4 substrate with dielectric constant ε_r =4.3, loss δ =0.001 material will be used. In the second and third antennae, Rogers RT/Duroid 4003 will be used as the antenna substrate, with dielectric constant ε_r = 3.55. Copper will be used in the three antennas as a layer.

2.1 DIMENSIONS CALCULATION

The slot antenna is considered one of the most promising antennas to enter the industries of smartphones and wireless networks. In addition, t this type of antenna is inexpensive due to the simplicity of its structure and ease of manufacture. In addition, the researchers found the possibility of printing this hobby on an insulating substrate [11]. To be able to it into various electronic devices and help reduce its size by using the following relationships.

$$\text{Width} = \frac{c}{2f_0\sqrt{\frac{\varepsilon_R+2}{2}}} \tag{1}$$

$$L_{\text{eff}} = \frac{c}{2f_r\sqrt{\varepsilon_{\text{eff}}}} \tag{2}$$

where ε_R is the dielectric of a substrate. $f\ z$ is frequency [10] C is spread of light.

2.2 FEEDING CALCULATION

The antenna can be fed several diver feeding methods, and each type has characteristics that differ from the other in terms of the effect on the beam and antenna performance.

The Microstrip feed line is considered one of the simplest types of feed, as it is a rectangular line made of the same metal as the patch. The function of this line is to deliver the current from the window to the patch. One of the advantages of this type of feed is the ease of manufacture, in addition to being connected to the insulation. However, this has some disadvantages; it hurts the antenna properties, so the side parts are cut to improve the antenna performance. This method obtains a matching impedance between the rectification and feed antenna [12]. When designing the dimensions of the feed line, it should result in a resistance of 50 Ω, using the following equations. The microstrip feeding technique adopted in this paper is determined by.

$$Z_{\text{in}} = \sqrt{Z_0 \cdot Z_1} \tag{3}$$

$$w_f = \frac{2H}{\pi}\left\{B-1-\ln(2B-1)+\frac{\varepsilon_0-1}{2\varepsilon_r}\left[\ln(B-1)+0.39-\frac{0.61}{\varepsilon_r}\right]\right\} \tag{4}$$

$$L_f = 3.96\times w_f \tag{5}$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \tag{6}$$

Z_0=50 Ω, Z_1 is the characteristic impedance [13] [14].

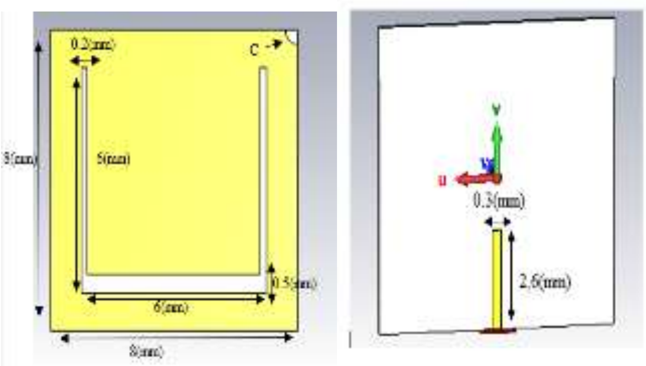
2.3 START MODELLING AND INSERTING DIMENSIONS FOR THE ANTENNA NUMBER ONE IN CST

First, the dimensions of the antenna number one will be determined and modelled on CST. In Table 2 the dimensions of the first antenna can be seen.

Table.2. Dimensions of the antenna number one

Name	Values (mm)
Length (L)	8
Width (w)	8
Thickness of substrate (h)	0.127
Feeding length (f_l)	2.6
Feed width (f_w)	0.3
A quarter of a circle of radius (C)	0.4
copper layer thickness (h_1, h_2)	0.035

From Fig.1, the shape of antenna number one can be seen. (a) shows the front of the antenna, and (b) shows the back of the antenna.

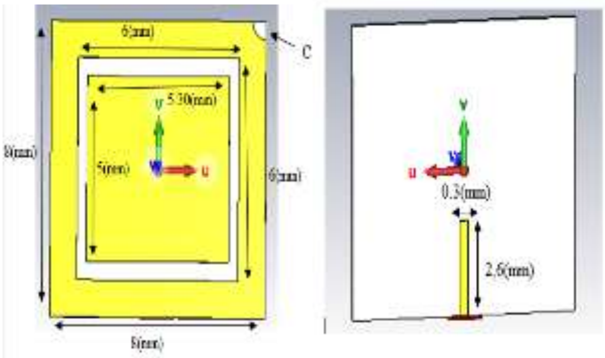


(a) (b)

Fig.1. Antenna number one (a) Front face (b) Back face.

2.4 ANTENNA NUMBER TWO

The antenna number two will be the same length, width, and thickness as the antenna number one, however. The difference will be in the shape and size of the hole created on the copper layer, so that the hole is in the shape of a square. In addition, the substrate will change and will have a lower permittivity than the substrate used in the antenna number one. In the following figure, the dimensions of the aperture will be shown.



(a) (b)

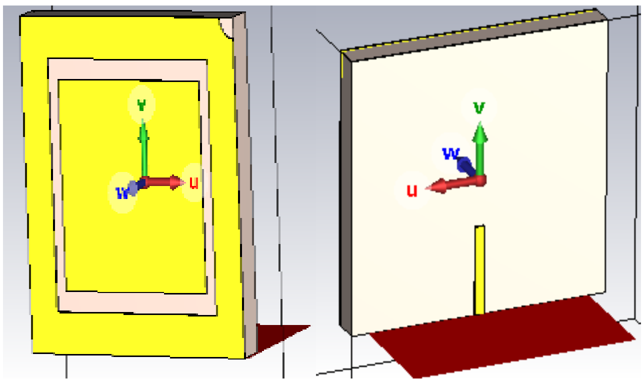
Fig.2. (a) front face (b) back front of the antenna number two.

Table.3. Diminution of antenna number two

Name	Values (mm)
Length (L)	8
Width (W)	8
Thickness (H)	0.127
Length of feeding (L_F)	2.6
With of feeding (W_F)	0.3
Length of slot (L_S)	6
Width of slot (W_S)	6
A quarter of a circle of radius(C)	0.4
Long of square (L_s)	5
Width of square (W_s)	5.30

2.5 ANTENNA NUMBER TWO (A)

In the antenna number two (A), the dimensions of the length and width will be the same as the length and width of the antennas number one and two, However, this time the thickness of the antenna will be change to 0.837 mm. And a square gesture with the same dimensions as the antenna number two.



(a) (b)

Fig.3. (a) front face (b) back front of antenna number two (A)

Table.4. Dimensions of the antenna number two (A)

name	Values(mm)
Length	8
Width	8
Thickness	0.837
Length of feeding	2.6
With of feeding	0.3
Length of slot	6
Width of slot	6
Long of square	5
Width of square	5.30

3. ANTENNAS RESULTS

3.1 RETURN LOSS FOR ANTENNA NUMBER ONE

The In Fig.4, the return loss in the antenna number one can be seen at a frequency of 28 GHz, which is -17.912. At the same time, it achieves an impedance bandwidth at -10 between (27.081-28.826 = 1.745).

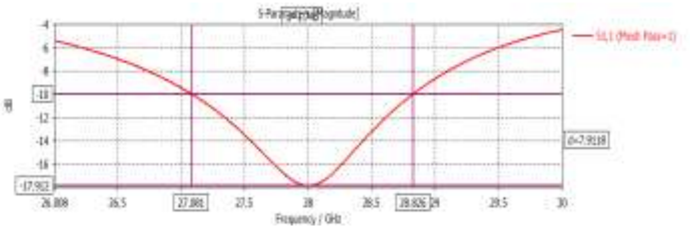


Fig.4 return loss in the antenna number one

3.2 RETURN LOSS FOR ANTENNA NUMBER TWO

The Fig.5 displays the return loss in antenna number two at 28 GHz of 15.716 dB, while the bandwidth was 1.863 GHz.

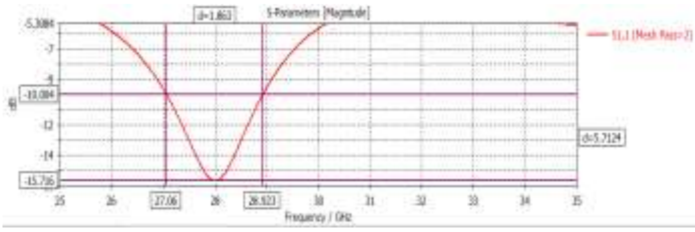


Fig.5. Return loss in the antenna number two.

3.3 RETURN LOSS FOR ANTENNA TWO (A)

The Fig.6 displays the return loss in the antenna number two (A) at 28GHz of -20.875dB, while the bandwidth was 1.267 GHz.

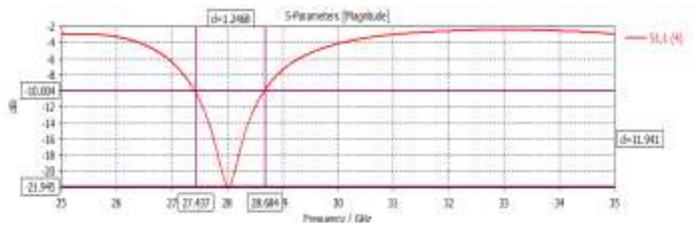


Fig.6. Return loss in the antenna number two (A)

3.4 GAIN FOR ANTENNA NUMBER ONE

The Fig.7 presents a 3D simulation of the gain, where the red portion defines the value of gain 5.23 dB at 28 GHz.

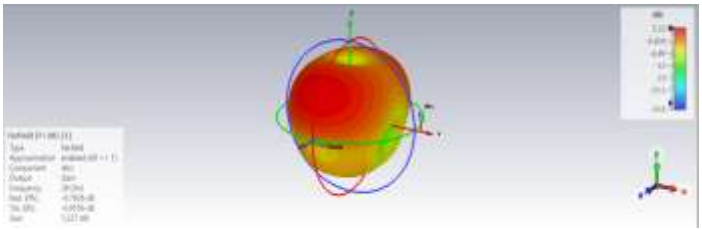


Fig.7. 3D simulation of the gain, where the red portion defines the value of gain 5.23 dB at 28 GHz.

3.5 GAIN FOR ANTENNA NUMBER TWO

From Fig.8, the gain value at the frequency of 28 GHz can be seen in red, as the gain value at antenna number two was 5.975 dB.

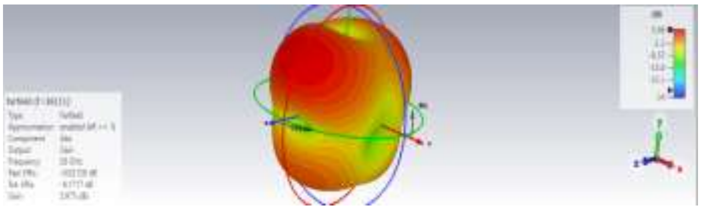


Fig.8. Gain value at antenna number two.

3.6 GAIN FOR ANTENNA NUMBER TWO (A)

The Fig.9 presents a 3D simulation of the gain, where the red portion defines the value of gain 1.77 dB at 28 GHz.

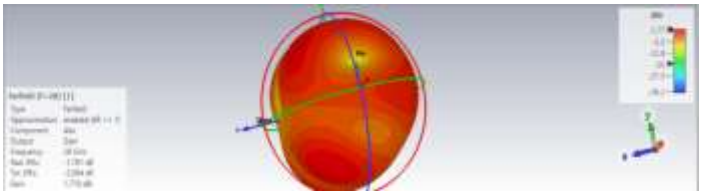


Fig.9. 3D simulation of the gain in antenna number two (A)

3.7 DIRECTIVITY FOR ANTENNA NUMBER ONE

The directivity or radiation pattern plot represents the intensity of 6.02 dB at a frequency of 28 GHz. The simulated antenna radiates more power in the direction of the main lobe. The red portion in the Fig.defines the maximum radiation. The Fig.10 shows the directivity plot of the for-antenna number one.

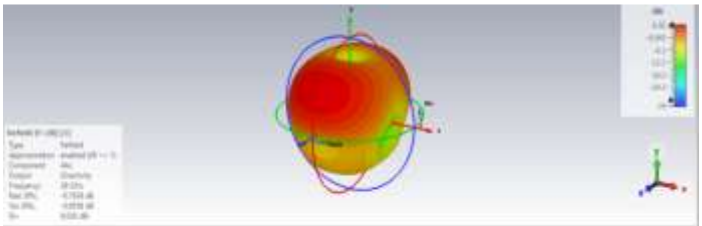


Fig.10. Directivity in antenna number one.

3.8 DIRECTIVITY FOR ANTENNA NUMBER TWO

The Fig.11 shows a three-dimensional shape of directivity radiation, which had a value of 5.997dB.

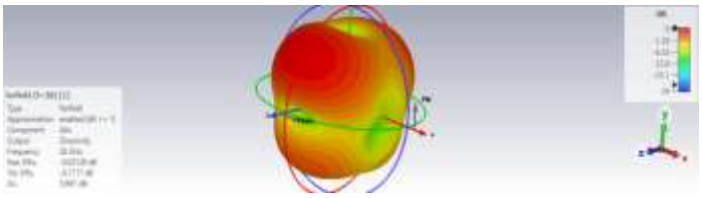


Fig.11 Directivity in antenna number two.

3.9 DIRECTIVITY FOR ANTENNA TWO (A)

The Fig.12 shows a three-dimensional shape of the directivity radiation in the third, which had a value of 3.55 dB.

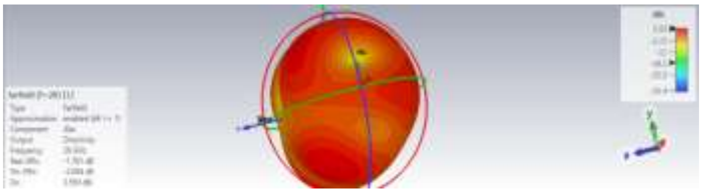
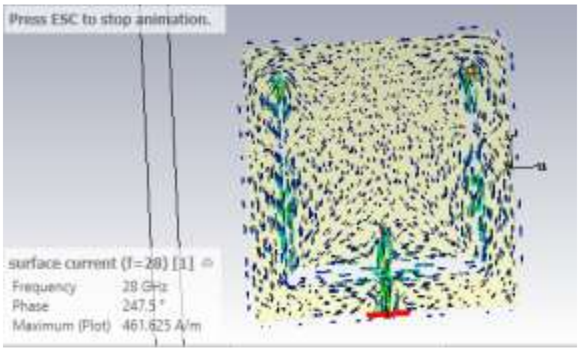


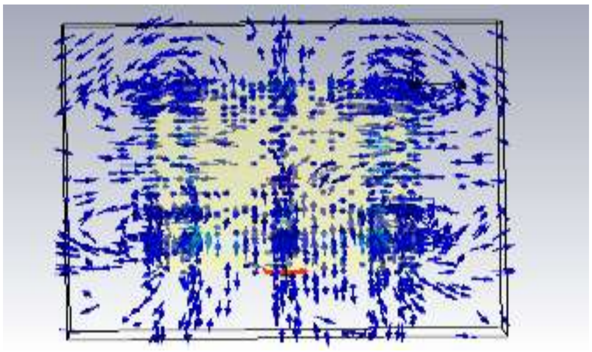
Fig.12. Directivity radiation in antenna number two (A).

3.10 SURFACE CURRENT DISTRIBUTION FOR ANTENNA NUMBER ONE

The Fig.13 shows the condensation of the current distribution and circular polarization at the aperture edges of the antenna number one.



(a)

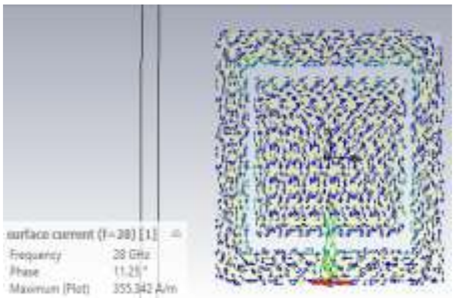


(b)

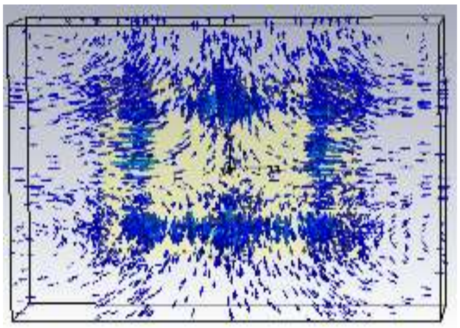
Fig.13. (a) Surface current distribution (b) Circular polarization in antenna number one

3.11 SURFACE CURRENT DISTRIBUTION FOR ANTENNA NUMBER TWO

The Fig.14 shows the electric current distribution on the surface and circular polarization of antenna number two, the cantering around the edges of the antenna, and the square shape of the aperture.



(a)

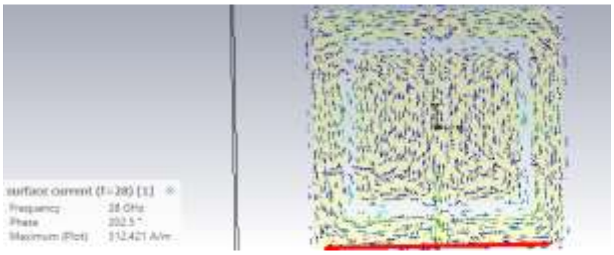


(b)

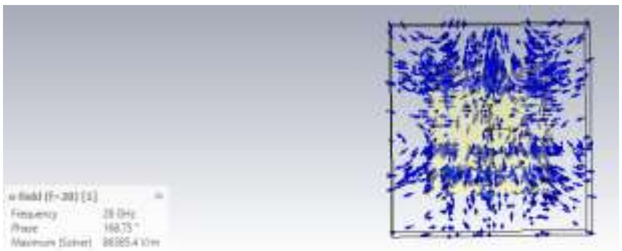
Fig.14. (a) Surface current distribution (b) Circular polarization in antenna number two.

3.12 SURFACE CURRENT DISTRIBUTION FOR ANTENNA NUMBER TWO (A)

The Fig.15 shows the electric current distribution and circular polarization on the surface of antenna number two (A) at 28 GHz.



(a)



(b)

Fig.15. (a) Surface current distribution (b) Circular polarization in antenna number two (A).

4. RATIO OF THE SIZE OF THE DESIGNED ANTENNAS TO THE SIZE OF THE ANTENNA CHOSEN FOR COMPARISON

The total size of the antennas is calculated by multiplying the length by the width by the height. so that the size of antenna number one and antenna number two, as shown below.

$$8\times8\times0.127 = 8.128\text{mm}^3$$

As for the antenna chosen for comparison, it was as shown in the following calculation.

$$7\times12\times0.203 = 17.052\ \text{mm}^3$$

From these values, the downsizing percentage can be calculated using the following equation.

$$\text{Size percentage} = \left(\frac{\text{Old value} - \text{New value}}{\text{Old value}}\right)\times100 \quad (7)$$

$$17.052 - 8.128 / 17.052 \times100 = 52.33\%$$

5. DISCUSSION

The results of the three designs will be compared with the antennas chosen for comparison. In Table 5, the results obtained from the three antennas designed in this research are presented, in addition to the antennas' values to be compared. In the table are the bandwidth, gain, directivity, and efficiency values for each antenna.

Table.5. Results values of the antennas

	Antenna Number One	**Antenna Number two**	**Antenna Number Two (A)**	**[15]**
Size *L*, *W*, *H* (mm)	8*8*0.127	8*8*0,127	8*8*0,873	7*12*0.203
Bandwidth (GHz)	27.081-28.826	27.06-28.923	27.3-28.646	26.62–29.5
Gain (dB)	5.227	5.975	1.657	4.43
Directivity (dB)	6.020	5.997	3.446	4.69
Efficiency	86.82%	99.63%	48.08%	94.16%

5.1 BANDWIDTH

The Fig.16 compares the bandwidth values for all the antennas mentioned in the table.

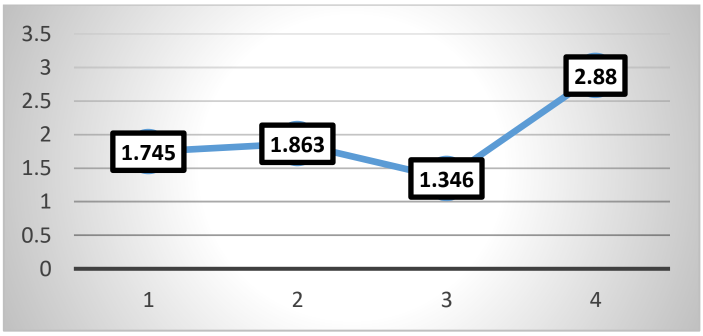


Fig.16. Compares the Bandwidth Values

The antenna number one can be seen with a bandwidth of 1.745G. In contrast, the antenna number two achieves a slightly higher bandwidth of about 1.863 G. In the antenna number two (A), a bandwidth was performed, the lowest among the antennas, reaching 1.348 GB Regarding the antenna chosen for comparison it had the highest number in bandwidth, where the bandwidth of the antenna chosen for comparison was 2.88G.

5.2 GAIN

In Fig.17, a comparison of the gain values of the four antennas can be seen. The antenna number one and antenna number two recorded the highest importance in gain compared to other antennas, as the antenna number one achieved 5.227 dB and the antenna number two 5.975 dB. The antenna number two (A) achieved the lowest beam gain, reaching 1.657 dB. While the antenna chosen for comparison was close in gain values, going 4.43 dB.

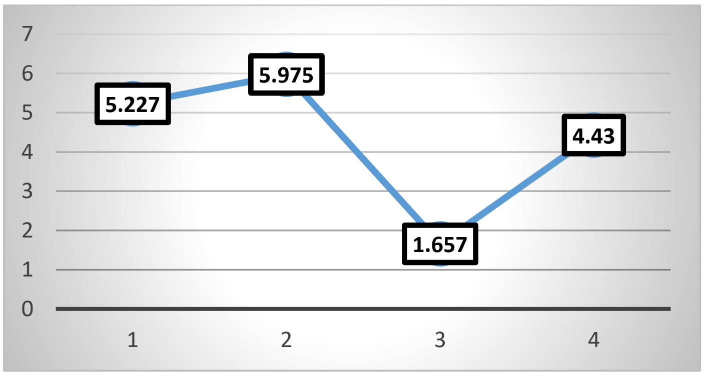


Fig.17. Comparison of the gain values

5.3 DIRECTIVITY

In Fig.18, a comparison of the directivity values of the four antennas can be seen. The antenna number one and antennas number two recorded the highest importance in gain compared to other antennas, as the antenna number one achieved 5.227 dB and the antenna number two 5.975 dB. The antenna number two (A) achieved the lowest beam gain, reaching 1.657 dB. While the antenna chosen for comparison was 4.43dB.

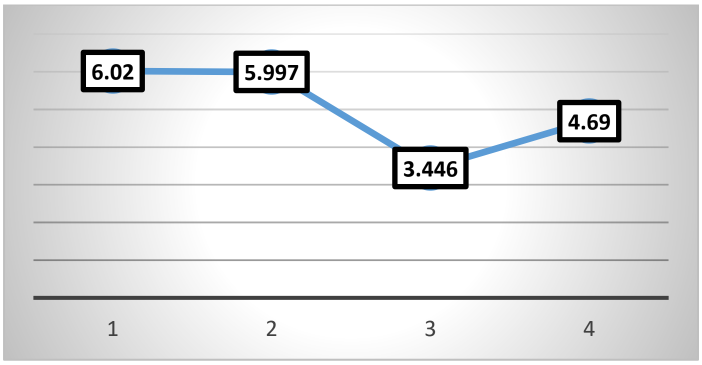


Fig.18. Comparison of the directivity

5.4 EFFICIENCY

The Fig.19 displays the efficiency values in percentage for each antenna. Antenna number two achieved the highest rate, reaching 99.62%, while the antenna number two (A) achieved the lowest rate, 48.08%. The antenna number one and the antenna chosen for comparison gained 68.82%, and 77%, respectively.

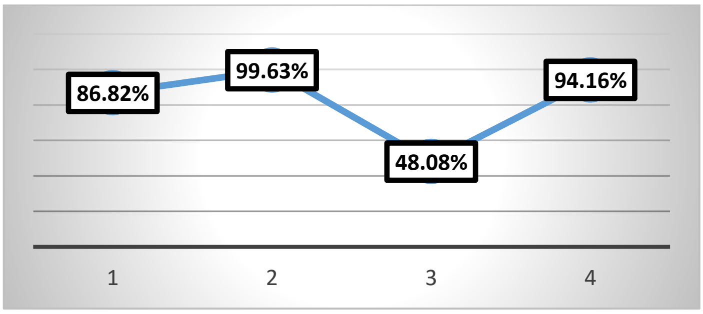


Fig.19. Comparison of the efficiency values

From the above, after reducing the thickness of antenna number one and antenna number two, gain, directivity, and efficiency were ob3tained better than the antenna chosen for comparison. However, in antenna number two (A), the thickness was larger, causing a decrease in the value of gain, directivity, and efficiency. Moreover, comparing the antenna number one with the antenna number two, can be seen that the antenna number one gives a slightly better performance than the antenna number one. That happens when the shape of the slot from the letter u-shape to a square shape changing. The effects of the materials used were not strong due to the dielectric convergence, which was in FR-4 ε_r=4.3 and in Rogers RT/Duroid 4003 substrate ε_r = 3.55.

6. CONCLUSION

In conclusion, the need for small antennas with high characteristics was the reason behind this research, to be used in manufacturing small devices such as laptops, mobile phones, and other small phones. The research presented two antennas operating on one of the fifth-generation telecommunications bands, the 28 gigahertz band. The antennas have been compared to other antennas that operates at the same frequency but with dimensions different from the ones designed in this research. The purpose was to reduce the antenna size as much as possible, With the preservation of the characteristics of the antenna possible as the methods used to reduce the antenna size were studied. Two antennas of varied sizes and substrates were modelled, in addition to feeding the antennas with adhesive tape. The CST software was used to model the antenna dimensions. After selecting an antenna for comparison, the percentage of shrinkage was determined, and it was more than 45% in antenna number one and antennas number two. As for antenna number two (A), its size increased due to the increase in the thickness of the substrate. It was observed that the gain, directivity, and efficiency increased in the first and second antennas, in contrast to what they decreased in bandwidth. Regarding antenna number two, the results were worse than the antenna number one and antenna number two in terms of gain, directionality, density, and bandwidth. This was due to an increase in the thickness of the antenna substrate.

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