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A Circular Slotted Patch Antenna with Defected Ground Structure for 5G Applications

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***Abstract*--- Much research is carried out to improve the performance of equipment using antennas in the field of telecommunications, in particular the development of patch antennas. Our research in this paper is to design a circular slotted patch antenna with the defected ground structure (DGS) for 5G applications. Initially, the antenna was made without DGS, and the results not convincing enough, we opted for an antenna with DGS to increase the performance of its parameters such as gain, bandwidth, reflection coefficient (S11), and voltage standing wave ratio (VSWR). The dimensions of the antenna we proposed are 12mm x 8mm x 0.5mm and that antenna has two operating frequencies which are 26 GHz and 28 GHz with an ultrawide frequency band equal to 4.5 GHz. Based on this frequency band, the proposed antenna can be used for several applications such as 5G. All this has been possible in terms of simulation by the software HFSS 15 (high-frequency structure simulator).**

Keywords--- 5th generation, Deflected Ground Structure, Patch Antenna, Bandwidth

I. INTRODUCTION

The field of networks and telecommunications is undergoing an exponential evolution and a great demand for antennas can ensure this evolution is seen day by day. The 1G communication network came out in the 1980s, then followed by the 2G, 3G, and 4G networks over the years. 40 years later we are now talking about 5G which is a network with particular specificities. We observe all these developments in the world because the demand and the needs of humans are growing. To meet all these needs, engineers work day and night. In this paper, we are going to work on the patch antennas in the 5G network.

The different frequency bands that are allocated to 5G are 3.5 GHz, 6 GHz, and 26 GHz. The antenna we propose will be linked to 26 GHz and 28 GHz frequencies.

It is important to define what a patch antenna is a patch antenna is an antenna known to have very low bandwidth and low gain.

It is a very small antenna, thus requiring a small financial means to carry it out, and is easily printable on electronic cards.

Microstrip patch antennas have three basic parts: patch, ground, and substrate. The patch is the part that emits electromagnetic waves and can have any shape.

The standard shapes given to them by antenna engineers are the rectangle, the circle, and the triangle. Note that the performance of the patch antenna does not necessarily depend on its shape. We have several ways to supply microstrip patch antennas such as microstrip line feeding, coaxial probe feeding, coupled aperture feeding, etc. As part of our research, the power supply we have chosen is the microstrip line one because it is easy and simple to implement.

Defected ground structure (DGS) is widely used in the design of antennas to improve their performance such as gain, bandwidth, etc. it can also have any shape. No form of DGS can predict the result in a simulation, which is why the antenna engineer must have a fairly advanced imagination to properly design his antenna. Regarding our research on the subject, we have opted for a rectangular shape of DGS.

DGS was easily integrated into the ground part. By adding slot resistance, each imperfection etched in the ground plane beneath the microstrip line alters the effective capacitance and inductance of the microstrip line. Comparably simple to design and manufacture, DGS is also simple to actualize as a circuit. Greater precisions are attained compared to other constructions with incorporated defects.

DGS unit and periodic DGS are two ways to make use of DGS performance. Different shapes of geometries in various configurations are embedded in the ground plane beneath the microstrip line.

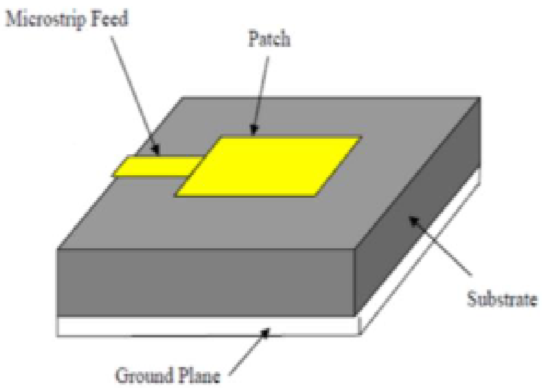

Fig 1: Microstrip patch antenna with microstrip line feeding

All the components of a microstrip antenna with a microstrip line feed are depicted in Figure 1. The microstrip antenna has a rectangular shape, however many other geometric shapes may also be employed.

II. DESIGN OF THE PATCH ANTENNAS

Our aim in this paper is to design a slotted rectangular patch antenna with the defected ground structure (DGS) for

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5G applications. The first antenna without DGS was designed with an operating frequency of 28 GHz and dimensions of 12 mm x 8 mm x 0.5 mm. Two circular slots with a corresponding radius of 1 mm and 0.5 mm were present on the patch section. The results were extremely considerable because of those slots. The material used for the substrate is FR4 with a dielectric constant equal to 4.4 and for the patch we used copper. The second antenna which is the proposed one is with DGS and the DGS part has half dimension of the ground with a rectangular shape (15 mm x 10 mm). Table 1 displays all of the measurements for the top-view of patch antennas with and without DGS [10].

The equations that allowed us to calculate the dimensions of the patch antenna based on the frequency and dielectric constant are just below:

$$Wp = \frac{c}{2f} * \sqrt{\frac{2}{\varepsilon_r+1}} \qquad (1)$$

$$\Delta L = 0.412h \frac{(\varepsilon_r+0.3)(\frac{W}{h}+0.264)}{\varepsilon_r-0.258)(\frac{W}{h}+0.8} \qquad (2)$$

$$Lp = \frac{c}{2f}\left(\frac{\varepsilon_r+1}{2} - \frac{\varepsilon_r-1}{2}\sqrt{\left[1+12\frac{h}{w}\right]}\right)^{-\frac{1}{2}} - 2\Delta L \ (3) \qquad (3)$$

Wp: width of the patch antenna
Lp: length of the patch antenna
ε_r: dielectric constant
H: height of the substrate

TABLE 1: ANTENNA DIMENSIONS FROM TOP

Symbols	Details	Values (mm)
h	Thickness	0.5
Wp	Width of patch	8
Lp	Length of patch	12
Wg	Width of ground	15
Lg	Length of ground	20
Wf	Width of feeding	1
Lf	Length of feeding	5
R1	The radius of the small circle	1
R2	The radius of the big circle	0.5
a		3
b		2

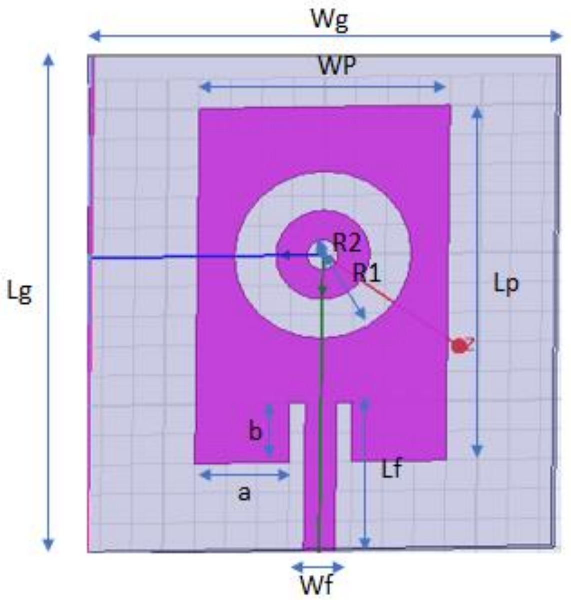

Fig2. Top view of the circular slotted patch antenna

TABLE 2: ANTENNA DIMENSIONS FROM THE BOTTOM

Symbols	Details	Values (mm)
C	Length of DGS	10
Wg	Width of ground or DGS	15
Lg	Length of ground	20

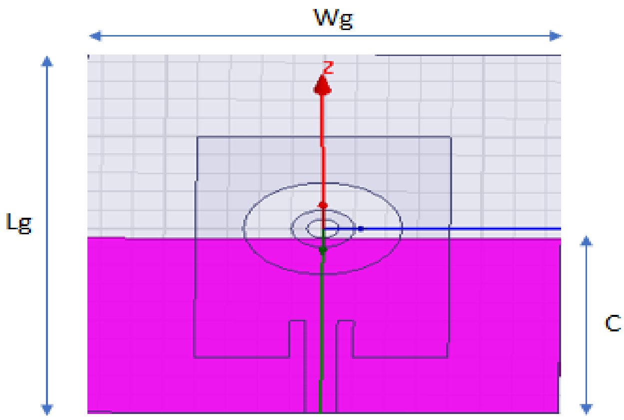

Fig3. Bottom view of the circular slotted patch antenna with DGS

Table 2 represents the dimensions of the ground (DGS) of the proposed antenna and we can notice that the Value of the length of the ground without DGS has been divided into 2 and this allowed us to improve the values of the parameters of our antenna

Figures 2 and 3 show us the different faces of the antennas on which we have worked. It is important to remember that the top parts of microstrip antennas with and without DGS are similar. The difference between the designs of these antennas is in the ground. The purple part of Figure 3

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represents the DGS of the microstrip antenna. All those antennas have been designed on HFSS 15.

III. RESULTS AND DISCUSSIONS

We will be more focused on some microstrip antenna parameters such as gain, bandwidth, VSWR, reflection coefficient (S11), and directivity. Note that all 2 antennas were simulated at a frequency of 28 GHz. Concerning the microstrip antenna without DGS we obtained

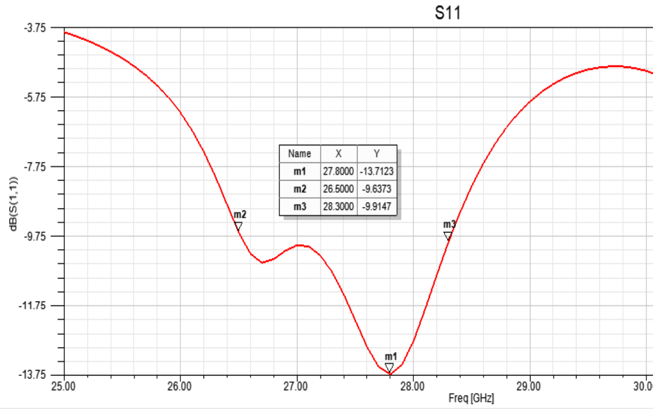

Fig 4: S11 of the rectangular slotted patch antenna without DGS

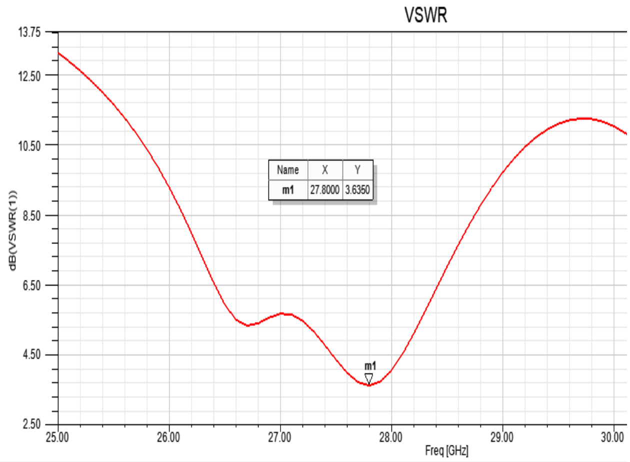

Fig 5: VSWR of the rectangular slotted patch antenna without DGS

Fig. 4 represents the reflection coefficient (S11) of the microstrip antenna without DGS.

We can see in figure 4 the points m1, m2, and m3 which are the central frequency, the low frequency, and the high frequency.

These points show us that this antenna has an operational frequency of 27.8 GHz with a wide bandwidth of 1.8 GHz and a Value of S11 equal to -13.71 dB (4.25% of the transmitted power has been reflected back)

Fig. 5 gives us the curve of VSWR as a function of frequency. For good communication from the antenna to its reception area the Value of VSWR must be between 1 and 2.2 [3,14], for our antenna we found a Value of 3.63 which is not as bad but a duty of improvement is imposed. We also can get that value by following the equation below.

$$VSWR = \frac{|1+r|}{|1-r|} \qquad (4)$$

Equation 4 shows us the voltage standing wave ratio (VSWR) and the reflection coefficient (S11 or r) are related.

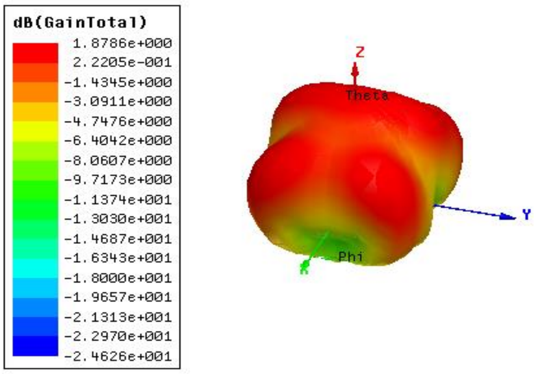

Fig 6: Gain of the rectangular slotted patch antenna without DGS

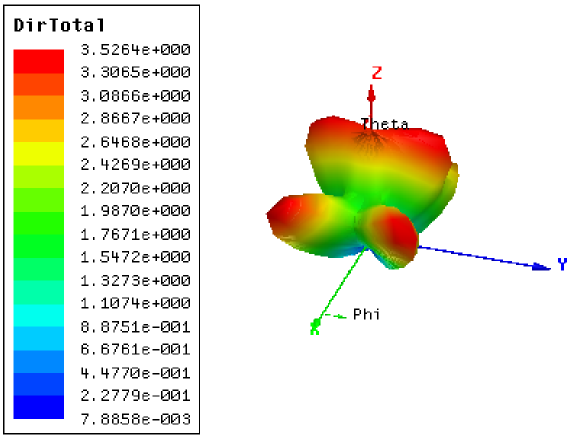

Fig 7: Directivity of the rectangular slotted patch antenna without DGS

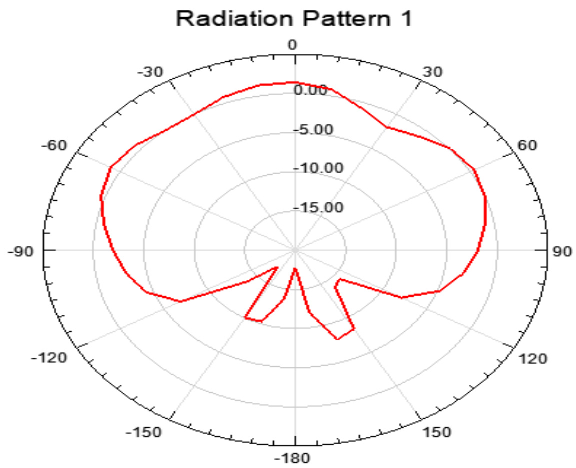

Fig 8: Radiation pattern of the rectangular slotted patch antenna without DGS

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Remember that the gain of an antenna is the amount of power transmitted in a specific direction [3,14]; Figure 6 shows the gain of the patch antenna without DGS, and we can see the maximum value of the gain, which is 1.876 dB. Low gain and bandwidth are known characteristics of patch antennas. The same antenna has a directivity of 3.526 dB as we can see in figure 7 and this lets us know the efficiency of the antenna is 53.20%. The equation below allows us to calculate the efficiency of the patch antenna [15]

$$\epsilon = \frac{G}{D} \quad (5)$$

ϵ: antenna efficiency
G: antenna gain
D: directivity of the antenna

Fig. 8 represents the radiation diagram of the patch antenna without DGS, we can see the field of action of the antenna and we notice that it mainly emits in the main lobe, a very small amount of energy is reflected in the back lobe

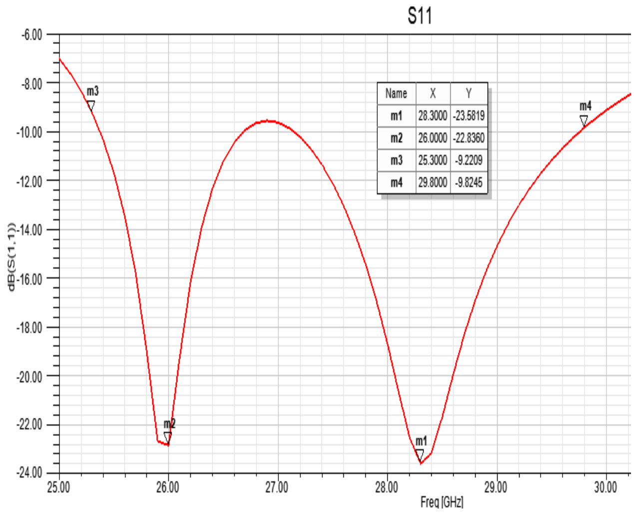

Fig 9: S11 of the rectangular slotted patch antenna with DGS

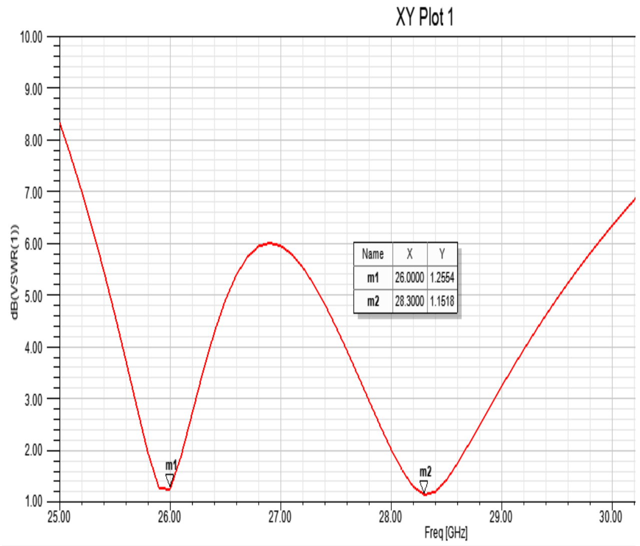

Fig. 10: VSWR of the rectangular slotted patch antenna with DGS

Fig. 9 represents the reflection coefficient (S11) of the microstrip antenna with DGS. We can see in figure 9 the points m1 and m2 which are the central frequencies, and m3, and m4 which are the low frequency, and the high frequency. These points show us that this antenna has 2 operating frequencies of 26 GHz and 28.3 GHz with an ultra-wide bandwidth of 4.5 GHz and a Value of S11 equal to -23.58 dB and -22.83 dB

Fig. 10 gives us the curve of VSWR as a function of frequency. For our antenna with DGS, we found 2 Values of VSWR which are 1.2 at 26 GHz and 1.15 at 28.3 GHz.

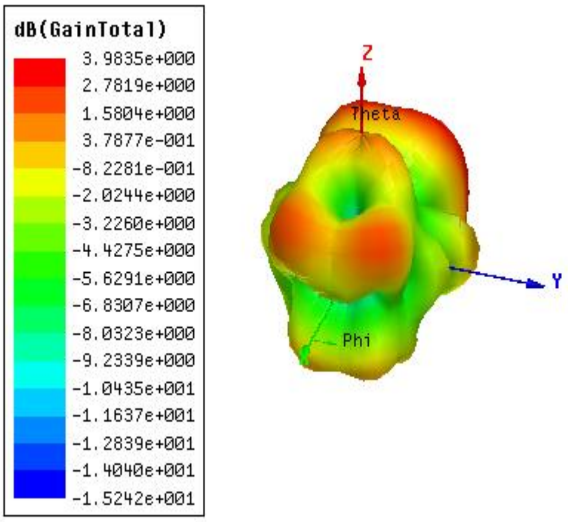

Fig 11: Gain of the rectangular slotted patch antenna with DGS

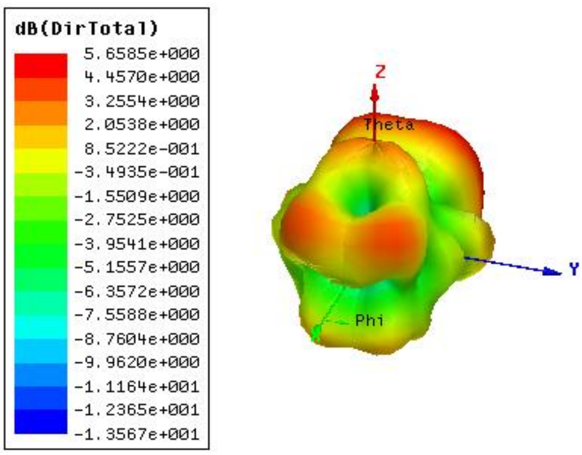

Fig 12: Directivity of the rectangular slotted patch antenna with DGS

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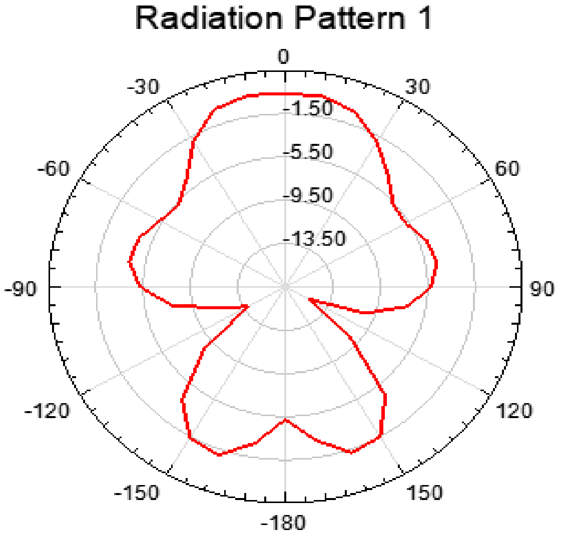

Fig 13: Radiation pattern of the circular slotted patch antenna with DGS

Fig. 11 shows the gain of the patch antenna with DGS, and we can see the maximum value of the gain, which is 3.98 dB. There is an improvement in the gain from 1.876 to 3.98 dB because of DGS. The same antenna has a directivity of 5.65 dB as we can see in figure 12 and this lets us know the efficiency of the antenna is 70.44%.

Fig. 13 represents the radiation diagram of the patch antenna with DGS and the radiation pattern can represent a lot of parameters such as gain, electric fields, directivity, etc. and it is a representation of the far fields.

TABLE 3: SUMMARY OF THE RESULTS

Antennas	Without DGS	With DGS	
Frequency	27.8 GHz	26 GHz	28.3 GHz
Bandwidth	1.8 GHz	4.5 GHz	
S11	-13.71 dB	-23.58 dB	-22.83 dB
VSWR	3.63	1.2	1.15
Gain	1.876 dB	3.98 dB	
Directivity	3.526 dB	5.65 dB	
Efficiency	53,20%	70.44%	

CONCLUSION

In order to support 5G applications, the authors of this research developed a rectangular slotted patch antenna with a defected ground structure (DGS). The first antenna was designed without DGS, and to enhance its performance of this one, the proposed antenna has been designed with DGS. As a result, the parameters shown in table 3 improved. Given the many properties of the proposed antenna, it is ideal for use in applications of the 5th communication technology.

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