# Design And Simulation of a Hexagonal High-Gain MIMO Patch Antenna For 5G Applications

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**Abstract:** View of the technological evolution and the problems encountered by the world, researchers are obliged to find solutions, particularly researchers in the field of antennas. This article has been devoted to the design and study of a hexagonal dual-band MIMO patch antenna for Satellite and 5G applications. Several parameters have been studied, we can quote among other things the gain, the bandwidth, the radiation diagram, the directivity, and the distribution of the electric field E. To achieve these studies and find optimal solutions, several designs have been made like the design of a simple hexagonal patch antenna, and, in the end, the proposed antenna is a MIMO with a hexagonal shape and 2 feeding ports. The proposed antenna operates at 25 GHz as the central frequency. The obtained ECC (envelope correlation coefficient) value is less than 0.006 for the entire operating bandwidth, which satisfies the standard value criteria of less than 0.5 and indicates minimal isolation between the antenna arrays. The values of the gain and the maximum directivity of the antenna obtained are respectively 8.12 dB and 8.37 dB, which gives us an efficiency of the antenna at 97.01% with high isolation > 25 dB. The results are found to be sufficient for the device to be used for mm-wave 5G MIMO applications. Additional MIMO performance metrics, such as the channel capacity loss (CCL), diversity gain (DG), and total active reflection coefficient (TARC), are evaluated. All this work has been done using HFSS 15 as software.

**Keywords** -- MIMO, ECC, Patch Antenna, 5$^{th}$ generation, Gain

## 1. INTRODUCTION

With the high demand for better data transmission speed, MIMO antennas have been developed by 1970 [1,2] and conquered the market, and are the most widely used nowadays. It is important to note that the acronym MIMO stands for Multiple Input Multiple Output, which suggests that an antenna has at least 2 radiative elements within it which are placed at a very small distance from each other to allow mutual coupling. Different approaches have been advocated by the researchers to reduce mutual coupling between the radiators and they have come up with some remarkable techniques to reduce mutual coupling between radiators, such as employing a defective ground structure, electromagnetic bandgap structures, etc. MIMO technology improves the performance of wireless communication systems by improving transmission speed and channel capacity [3]. MIMO uses multipath propagation by using multiple antennas to transmit and receive data. The shape of the MIMO antennas is in the array form as said above, it takes at least 2 elements which make emit electromagnetic waves. Figure 1 illustrates the operating principle of MIMO antennas. There are different possible configurations for MIMO antennas such as 2 x 2, 4 x 4, 6 x 6, and 8 x 8 which are the most popular. 5G technology manipulates these different configurations to allow for extended network capacity.

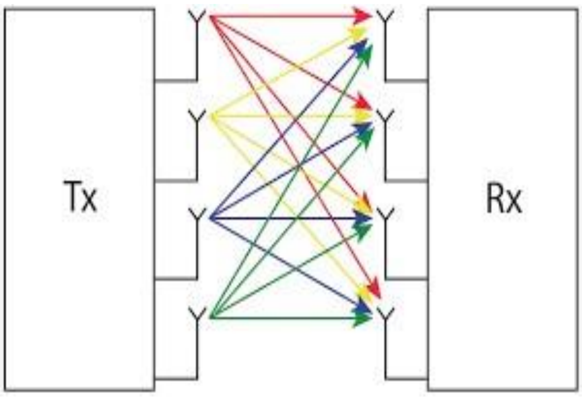



**Fig. 1.** 4 x 4 MIMO antennas [4]

MIMO continues to upgrade and expand through its use in massive new applications as the wireless industry strives to accommodate more antennas, networks, and devices. One of the most striking examples of this is

the deployment of 5G. 5G technology does not yet have a clear definition, rather it is treated as the integration of several techniques, cases, and scenarios. This technology will use unused Millimeter wave spectra from 30 to 300 GHz, in order to achieve higher data rates and bandwidths [4,5]. Despite many desirable features, 5G technology has a serious power penetration problem. This signal attenuates the range from the receiver side to the transmitter side using an antenna. Multiple Input Multiple Output (MIMO) antennas have been found to solve this problem. The antennas which will face the problems encountered by 5G technologies are nowadays a big challenge to design and which will have good performances such as a good value of gain and a
good bandwidth to allow fluid communication between the sender and receiver. 5G antennas can be designed with multiple frequency bands ranging from 600 MHz to 900 MHz, 1.6 GHz to 6 GHz, and 24 GHz to 54 GHz. Our study will be based on the Millimeter band which goes from 24 GHz to 54 GHz [6]. Regarding the antennas themselves, we can have several shapes to represent them, including rectangular, triangular, circular, hexagonal, etc. We used hexagonal shapes to design our MIMO antenna.

It is important to specify here that the MIMO antenna proposed in this study is above all a microstrip patch antenna so it comprises 3
important elements which are the patch, the substrate, and the ground. Figure 2 below illustrates a patch antenna and highlights its different parts. The patch is the part that radiates the electromagnetic waves, the substrate is the material used for the manufacture of the antenna
and has particular properties, which have a significant impact on the capacities of the antenna, and finally, the ground part which is considered as the part with a negative polarity if we consider the antenna as a battery.

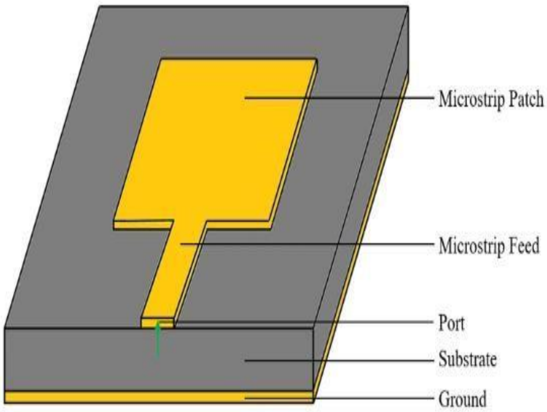


**Fig. 2.** Microstrip patch antenna [6]

Due to recent developments in the requirements of communication systems in portable devices, it is, therefore, necessary to design a lightweight, compact, portable, and efficient antenna. Several researchers have developed and are still developing optimal designs to reduce the size and weight of multiband antennas while providing better performance. In wireless communications, small integrated or patch antennas are preferred over other radiating systems, due to their fiery weight, advantageous size, and low cost.

In this study, a dual-band MIMO antenna was designed, fully applicable to 5G and satellite applications. Multiband antennas are very effective in wireless communication systems for broadcasting signals. A dual-band antenna is designed with high gain, high bandwidth, and a microstrip line defective ground plane feed. Satellite applications are very often classified into different frequency bands, we can locate among others, the C, X, Ku, and Ka bands. As our antenna operates between 25 GHz and 40 GHz, it can be used for satellites in the Ka-band applications.

We cannot speak of MIMO antennas without speaking of the envelope correlation coefficient (ECC) which makes it possible to understand the level of independence that the radiations of the two antennas have and the diversity gain (DG) which corresponds to the power reduction when a diversity scheme is introduced, with no loss of performance [5,6]. The formulas below will show how to calculate ECC and DG

$$\rho_{ij} = \frac{|S_{ii}*S_{ij}+S_{ji}*S_{jj}|}{(1-|S_{ii}|^2-S_{ij}{}^2)(1-|S_{ji}|^2-S_{jj}{}^2)} \quad (1)$$

$$DG = 10\sqrt{1-|ECC|^2} \quad (2)$$

With $\rho_{ij}$ representing the envelope correlation coefficient that antenna port i has on the antenna port and S representing the value of the reflection coefficient.

It is important to talk about channel capacity loss (CCL) and total active reflection coefficient (TARC). The capacity channel loss is the most important factor to consider while examining a MIMO system. It is crucial to go into detail about the two-port antenna's channel capacity losses. The following formula was used to determine the CCL. CCL refers to the highest achievable limit at which the signal can be transferred without suffering significant loss [12, 17].

$$CCL = -log_2 \det(\alpha) \qquad (3)$$

With $\alpha = [\alpha\alpha 1121 \alpha\alpha 1222]$

$$\alpha ii = 1 - \sum_{j=1}^{2} |Sij|2$$

$$\alpha ij = S*ii.\ Sij + S*ij.\ Sii$$

The minimum necessary for a MIMO antenna design is 0.4 bits/s/Hz.

TARC is primarily used for multiple-input, multiple-output (MIMO) antenna systems and array antennas, where the outgoing power is the unwanted reflected power. The name shows similarities with the active reflection coefficient, which is used for simple elements. The TARC of an N-port antenna is equal to the square root of the total power at the ports divided by the total power at the ports of the incident signal. It is calculated using the following equation with 2 ports [14, 15]:

$$TARC = \sqrt{\frac{|S_{11}+S_{12}|^2 + |S_{21}+S_{22}|^2}{2}} \qquad (4)$$

Mean effective gain (MEG) is also one of the most important parameters characterizing an antenna for wireless channels. It is defined as the average power received by the diversity antenna over the power received by the isotropic antenna. It is calculated using the following equation with 2 ports.

$$MEG = 0.5\ (1 - \sum\nolimits^{2}_{j=1} |S_{ij}|^2) \qquad (5)$$

And this value should be -12 < MEG < -3

**2. ANTENNA CONFIGURATIONS**

Several designs were made to carry out this research which consisted in designing a hexagonal high-gain MIMO patch antenna for 5G applications. As the theme indicates, we worked on 2 x 2 MIMO antennas with hexagonal shapes of equal sides. First, we worked on the design of a simple hexagonal antenna with dimensions of 24 mm x 17 mm for the substrate. From the results obtained from this antenna, we were able to do it for the 2 x 2 MIMO antenna. The antennas each have a side dimension (A) of 5 mm. The patches are printed on Roger RT/ Duroid 5880 substrate with a 1.6 mm thickness and relative permittivity of 2.2, while the ground plan is printed on the back side of the substrate. The dimensions of the substrate part are 30 mm x 24 mm x 1.6 mm and the ground which has dimensions of 30 mm x 24 mm. The simulation of this project has been done with HFSS 15 (HighFrequency Simulator Structure).

Table 1 below will show the dimensions of the MIMO antenna

**Table 1.** Dimensions of the 2 x 2 MIMO hexagonal patch antenna

| Configurations | Parameters | Values (mm) |
|---|---|---|
| **Substrate** | Ls | 30 |
| | Ws | 30 |
| | h | 1.6 |
| **Patch** | A | 5 |
| | R | 4.75 |
| | B | 10.67 |
| | C | 2 |
| | D | 4 |
| **Ground** | Lg | 8.5 |
| | Wg | 30 |

To find the dimensions of the final antenna, we had to use the known equations [10, 11, 13] below using an operating frequency of 25 GHz.

To calculate the side of the hexagonal patch antenna (A):

$$A = \frac{C}{23.1033 * f\sqrt{\varepsilon_r}} \quad (6)$$

To calculate the radius of the hexagonal patch antenna (R):

$$R = A * \sqrt{\frac{2.598}{\pi}} \quad (7)$$

$$Ws = 6h + \lambda \quad (8)$$

To calculate the dimensions of the substrate:

$$Ls = 6h + \lambda \quad (9)$$

$$\lambda = \frac{C}{f * \sqrt{\varepsilon_r}} \quad (10)$$

Where C is the speed of light with C = $3*10^8$ $m.s^{-1}$ and f is the operating frequency of the antenna.

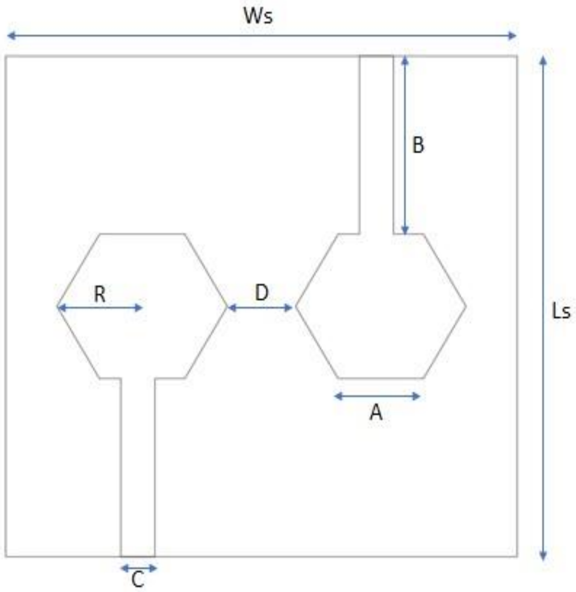



**Fig. 3.** Design of MIMO hexagonal patch antenna

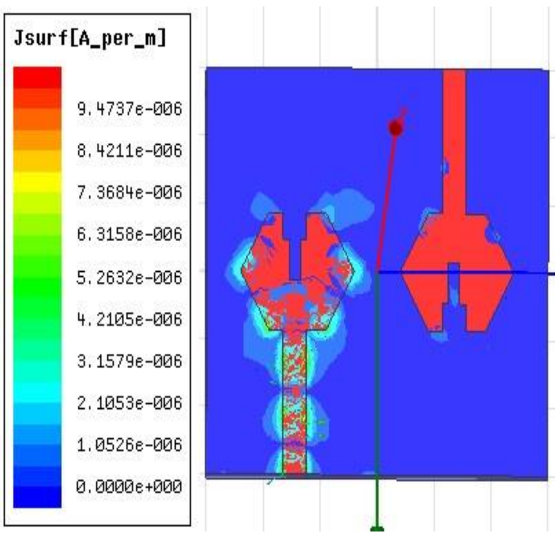



**Fig. 4**. Distribution of current of MIMO hexagonal patch antenna

Figure 3 shows us the evolution in the design of the 2 x 2 MIMO antenna. This was done with the aim of optimizing the antenna parameters such as gain, directivity, and bandwidth and reducing the interference rate between the signals that will be emitted from the two antennas, in other words, reducing the value of the envelope correlation coefficient (ECC) [15,23].

## 3. RESULTS AND DISCUSSIONS

The results after the simulation of the proposed antenna will be discussed in this section. We will highlight the values of Gain, Bandwidth, Directivity, Reflection Coefficient, Envelope Correlation Coefficient, Diversity Gain, Radiation Pattern, channel capacity loss (CCL), and total active reflection coefficient (TARC).

### 3.1. Return Loss and Bandwidth

We have designed and simulated a hexagonal high gain MIMO patch antenna for 5G applications at 25 GHz as the operating frequency. We got the reflection coefficients equals to -21.3 dB and the bandwidth obtained is quite large such as 2,4 GHz. Figure 5 shows the results of S11 (reflection coefficient). For a good antenna, we must have S11 at least greater than -10 dB and we measure the value of bandwidth from S11equals to -10 (that means, 10% of transmitted power has been reflected back).

As we were working on the 2 x 2 MIMO antennas, it was also a question for us to show the values of S12, S22 and S21.

S12: Represents the power transmitted from port 2 to port 1 S21: Represents the power transmitted from port 1 to port 2

S22: represents the reflected power that radio 2
tries to supply to antenna 2.

The VSWR (Voltage Standing Wave Ratio) must be between 1 and 2 [18,22]. Based on our result, we found that at the operating frequency which is 25 GHz, the value of VSWR is 1.5 dB. Equation 11 will help us calculate the percentage of reflected power in watts.

$S11(dB)$

$$S11(watts) = 10^{\frac{S11(dB)}{10}} \quad (11)$$

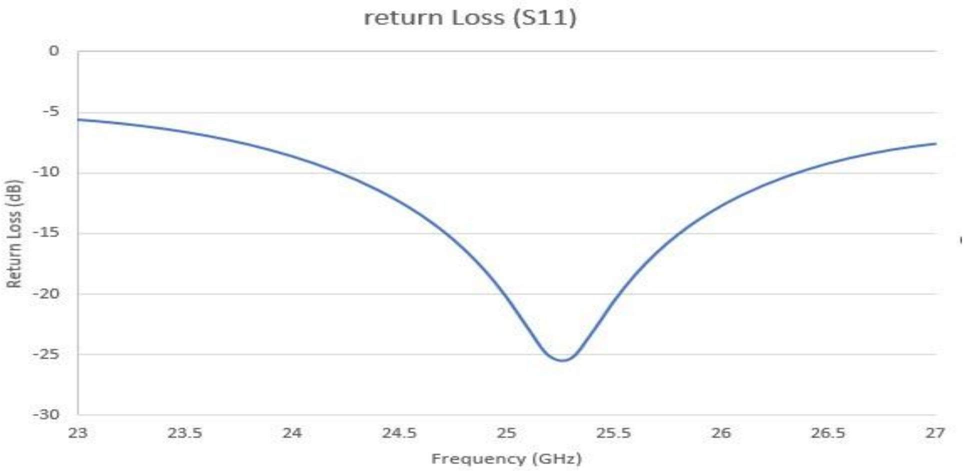



**Fig. 5.** Return Loss of MIMO patch antenna

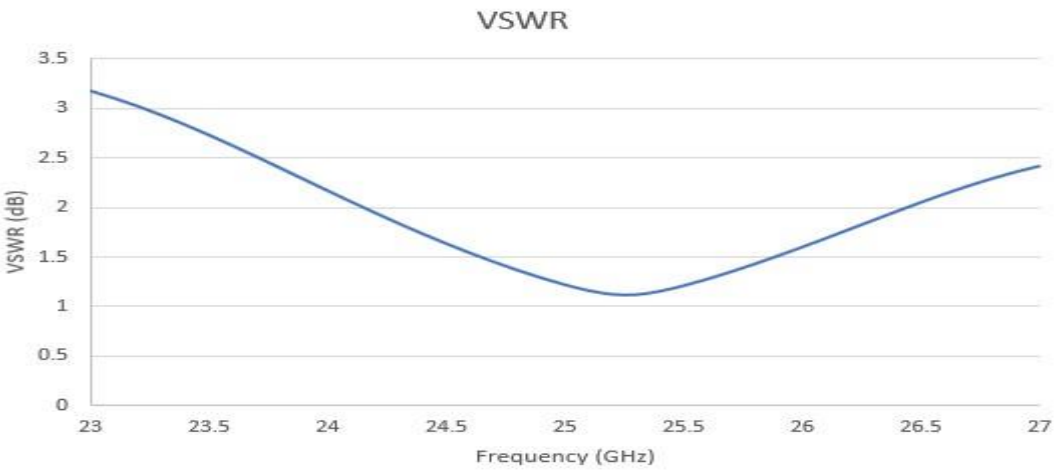



**Fig. 6.** VSWR of MIMO patch antenna

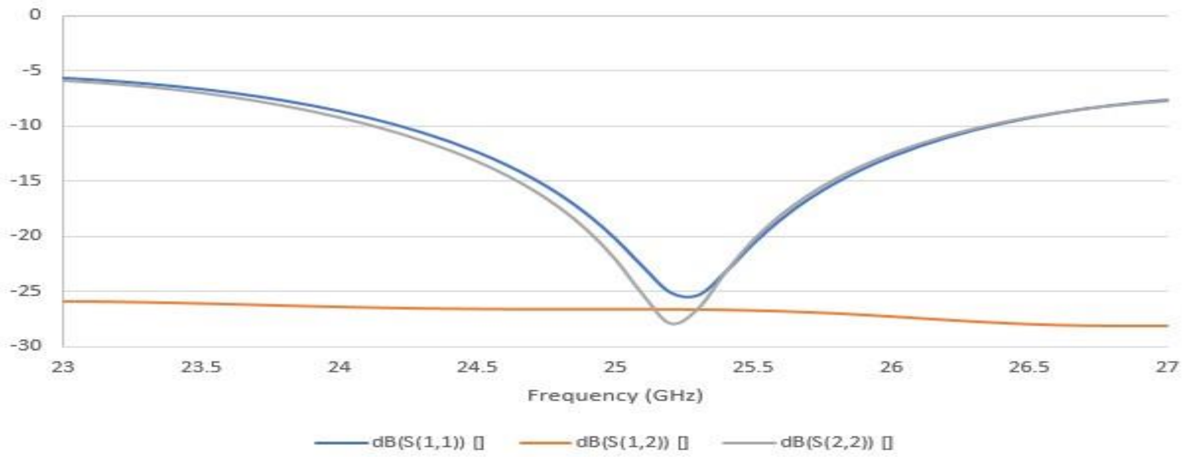



**Fig. 7.** S11, S12, S22 of MIMO patch antenna

As can be seen in Figure 5 which highlights the bandwidths and the different operating frequencies of the proposed antenna. Figures 6 and 7 show respectively the values of VSWR, S11, S12, and S22.

### 3.2. Gain and Directivity

Let us already note that the gain of an antenna is the ratio between the power transmitted at a precise point and that of a reference point and the directivity of an antenna can be defined as the concentration of a power emitted in one direction particular [15, 16]. Our proposed antenna, we had for the operative frequency of 25 GHz, a gain of 8.12 dB was found and on the other hand the directivity of the proposed antenna gave 8.37 dB. This being done, we can calculate the value of the efficiency of the antenna and obtain about 97.01%. figures 8 and 9 will illustrate the different values of gain and directivity depending on the position of the transmitted signal at certain given points.

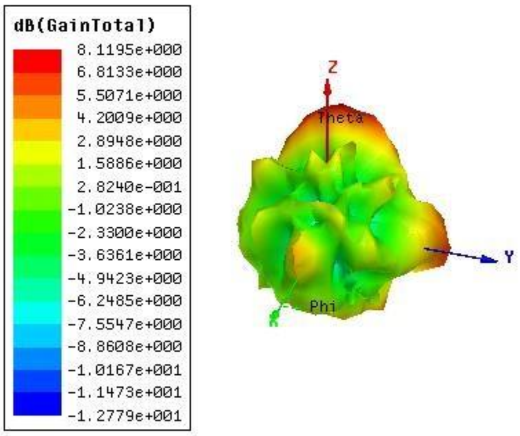
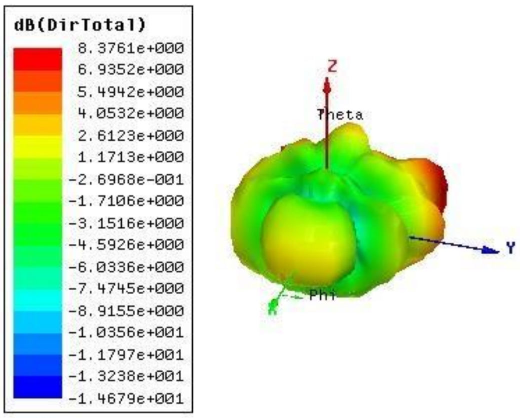



**Fig. 8** Gain of MIMO patch antenna.




**Fig, 9.** Directivity of MIMO patch antenna

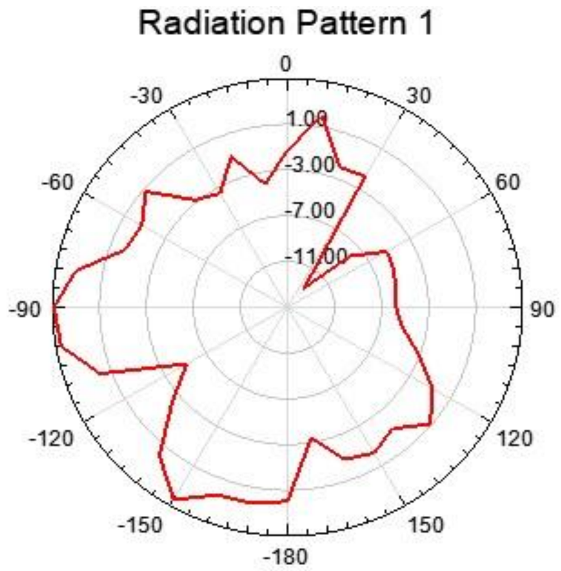



**Fig. 10.** Radiation pattern of 2 x 2 MIMO patch antenna

The radiation pattern of an antenna is the set where the antenna has emitted a signal and Figure 18 and Figure 19 illustrate the radiation pattern of a simple hexagonal patch antenna and our proposed antenna

### 3.3. Envelope correlation coefficient (ECG) and diversity gain (DG)

As said earlier, we cannot work on 2 x 2 MIMO hexagonal antennas without finding the envelope correlation coefficient (ECC) which makes it possible to understand the level of independence that the radiations of the two antennas have and the diversity gain (DG) which corresponds to the power reduction when a diversity scheme is introduced, with no loss of performance. Figures 12 and 13 will illustrate this well.

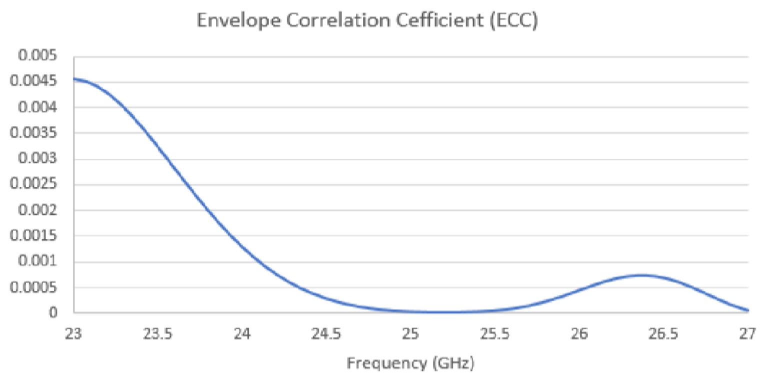



**Fig. 11.** ECC of MIMO patch antenna

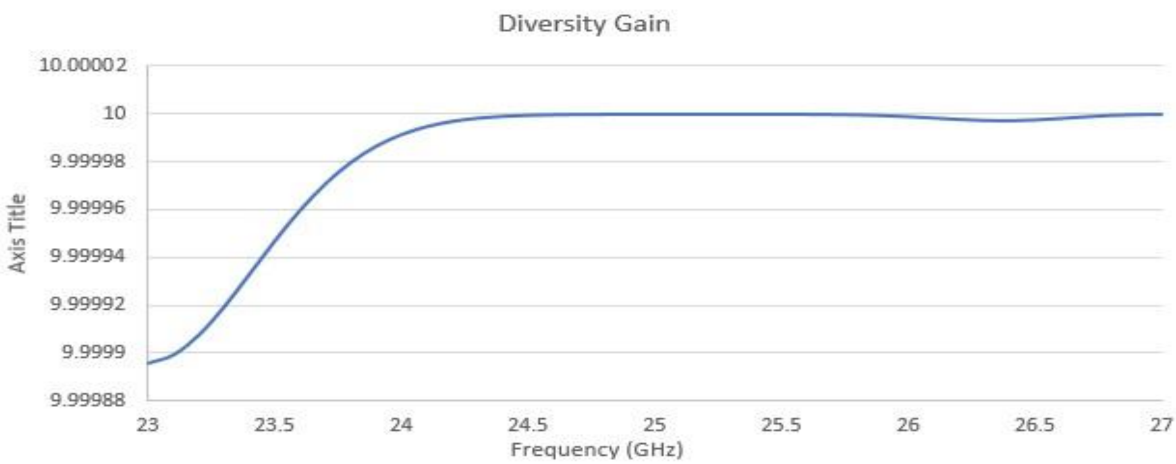



**Fig.12.** TARC of MIMO patch antenna

We found values comprise between 0 and 0.5, that is to say that our value is less than 0.006 so there is less interference between the two antennas. Since the ideal values of the diversity gain (DG) are between 9 and 10, this corresponds to the standards and with regard to our graph, our proposed antenna fulfils the condition.

### 3.4. Co and Cross Polarization

Cross-polarization occurs when an antenna's dipoles form a plus (+) or cross (x) shape and are oriented at right angles (90º) to each other whileCo-polarization is when the two dipoles of the antenna are oriented in the same direction. For our proposed MIMO antenna, Figures 13 and 14 will highlight Co and Cross polarization. Cross polarization is specified for an antenna as a power level. The value is usually represented in negative dB. In practice, it indicates how many decibels (dB) the cross-bias power level is below the desired bias. If a vertically polarized antenna has a -30 dB cross polarization, it means that the amplitude value of the horizontally polarized signal we will receive will be 30dB less than the desired/vertically polarized signal.

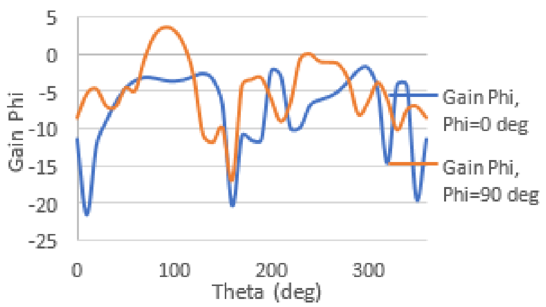



**Fig. 13.** Co and Cross polarization (Gain Phi) with Phi=0 and 90 deg of 2 x 2 MIMO patch antenna.

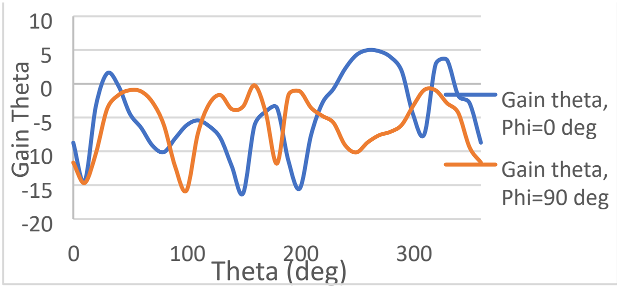



**Fig. 14.** Co and Cross polarization (Gain Theta)

### 3.5. Channel Capacity Loss (CCL) and Total Active Reflection Coefficient (TARC)

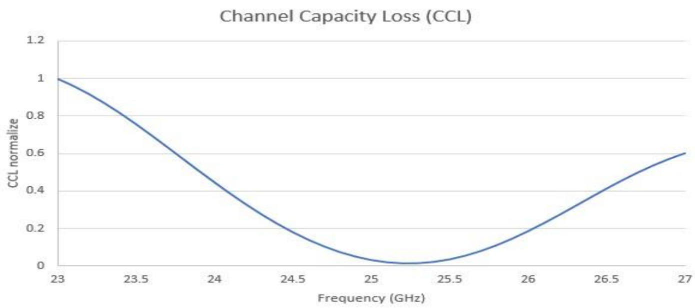



**Fig. 15.** CCL of 2 x 2 MIMO patch antenna

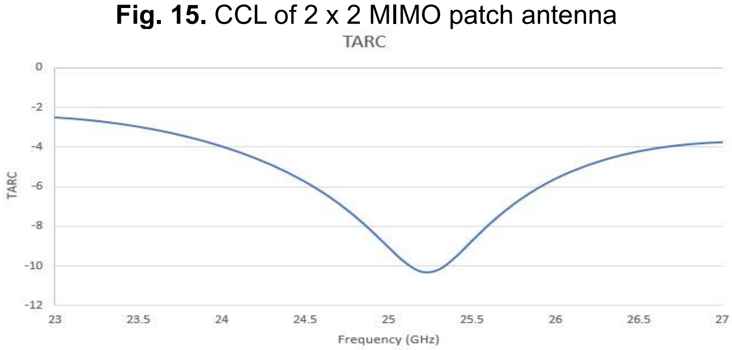



**Fig. 16.** TARC of 2 x 2 MIMO patch antenna

The figures 15 and 16 above are the results frequency bands the CCL values are less than 0.4 of CCL and TARC show us that they are in bits/s/Hz and the TARC values are all less than 0 agreement with the literature. In the different dB.

**Table 3**. Comparison of performances with recent papers in the literature

| References | Dimensions (mm x mm x mm) | | N* of ports | Operating frequency | Return loss (dB) | ECC | Bandwidth (GHz) | Gain (dBi) |
|---|---|---|---|---|---|---|---|---|
| **4** | 48 x 21 x 3.1 | | 2 | 30 | -23 | 0.0014 | 1 | 7 |
| **5** | 60 x 19.9 x 1.6 | | 4 | 28 | -37.5 | 0.000175 | 6 | 7.1 |
| **6** | 11.4 x 5.3x 0.8 | | 2 | 29.3 | -37 | 0.00112 | 1.3 | 6 |
| **9** | 14 x 14 x 0.508 | | 8 | 37 | -17.3 | 0.01 | 1.1 | 7.71 |
| **11** | 12.5 x 12.5 x 0. | 8 | 4 | 35 | -25 | 0.007 | 2.7 | 6 |
| **13** | 30 x 30 x 1.575 | | 4 | 28 | -27 | 0.003 | 3 | 7.1 |
| **18** | 35 x25 0.76 | | 2 | 29 | --- | 0.12 | 5.14 | 9.2 |
| **Proposed antenna** | 30 x 24 x 1.6 | | 2 | 25 | -21.3 | 0.006 | 2.4 | 8.12 |

## 4. CONCLUSION

The authors of this paper have proposed a hexagonal high-gain MIMO patch antenna for 5G applications. All this project has been done with the software HFSS 15 and the summary of the results in Table 2 shows that the antenna is very suitable for any application with an operating frequency from 24 GHz to 26.5 GHz with a high isolation > 25 dB. In the future, we have to fabricate the proposed antenna and compare its results with the simulated ones.

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