Design of a 2×2 dual band 28/38 GHz MIMO antenna in millimeter band for 5G

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ABSTRACT

In this paper, we design and simulate a 28/38 GHz dual-band multiple-input multiple-output (MIMO) patch antenna array that operates in the FR2 frequency band (28 GHz and 38 GHz). This antenna array comprises four similar patch antennas with a rectangular “L minus two slots” shape. In addition, it applies to 5G electronic components such as a smartphone. We used high-frequency structure simulator (HFSS) software to perform the design and simulation for this antenna. In addition, this proposed antenna array provides better performance, such as; bandwidth around 28 GHz is equal to 0.69 GHz and 38 GHz is equal to 0.86 GHz, equal gains 5. 9 dB at 28 GHz and 9 dB at 38 GHz, directivities are 6.3 dB at 28 GHz and 9.4 dB at 38 GHz, the efficiency of 95.38% at 28 GHz, and efficiency of 96.53% at 38 GHz.

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1. INTRODUCTION

In June 2015, the International Telecommunication Union (ITU) published the 5G cell phone standard and established new frequency bands. Although these new frequency bands offer new perspectives in terms of bandwidth. They nevertheless remain a real challenge for antenna and smartphone designers, as equipment would have to be designed that can operate in the new frequency bands on the one hand and ensure compatibility with existing communications systems on the other [1], [2].

Indeed, through the multiple-input multiple-output (MIMO) system, various diversity systems now allow the creation of new universal diversity categories. This technique is often intended to take the best possible advantage of the phenomena related to the dispersion of electromagnetic waves and the effects of the multipath phenomenon, which were initially qualified as obstacles to developing digital technologies. Multiple antennas are used simultaneously to receive and associate different records of identical signals, independently related to the parasitic effects of fading. Thus, the receiver makes the proper decision to reconstruct the original messages without errors. In a nutshell, multiple antennas in MIMO systems contribute to increasing the security of the service offered by reducing the risk of failure (diversity gain) while at the same time improving the transfer rate (multiplexing gain) [3], [4].

The fundamental principle governing the operation of MIMO systems is relatively basic: the transmission of information is ensured, within each frequency band, successively using several “transmission antennas” or “reception antennas”. The data rate carried to this frequency band will, approximately, also be affected according to the number of transmission antennas. Consequently, using antenna arrays in transmission and reception ensures reliability and/or improves the spectrum performance for digital transmissions in environments with high broadcast density [5], [6].

Indeed, 5G technology is expected to be integrated into the frequency spectrums surrounding what is located in the vicinity of the 28 GHz band, the 38 GHz band, the 60 GHz, and the 73 GHz ranges. These millimeter wave frequency ranges also pose challenges for realizing MIMO antennas for portable devices [7], [8]. Due to the accelerated growth of the global wireless communication industry, there is an ever-increasing need to provide portable network users with highly separated MIMO multi-band antennas. Various references to dual-band MIMO antennas can be found throughout the literature. Tu *et al.* [9] proposes a new concept for dual-band antennas of the 4×4 MIMO type with operating frequencies of 28/38 GHz; this antenna incorporates a rounded electromagnetic bandgap (EBG) cell patch offering a reduced level of mutual coupling for both bands, even for a distance close to 0.7 mm. Zhang *et al.* [10] contains the results obtained by the design of a planar inverted F antenna (PIFA) antenna that operates in 2 frequency bands for 5G. Specifically, this device provides both 3.34 GHz and 1.395 GHz bandwidths in the case of the 28 GHz and 38 GHz frequency bands and corresponding gain levels of 3.75 dB and 5.06 dB in these same frequency regions. Ahmad and Khan [11], proposes the creation of a substrate integrated waveguide (SIW) antenna. It also provides performance compatible with 5G standards for gain and bandwidth in the 28 GHz and 38 GHz operational frequency bands. Indeed, these offer bandwidths of 0.45 GHz and 2.2 GHz and gains of 5.2 dBi and 5.9 dBi in these same frequency bands. Ashraf *et al.* [12] deals with creating AiP-type antennas that operate within the 28 GHz and 38 GHz frequency bands; this antenna has gains of 4 dBi and 6 dBi, respectively, and two bandwidths of 1.02 GHz and 3.49 GHz, respectively. Thus, Chu *et al.* [13] aims to compactly create an antenna fed by means of or near the coplanar waveguide (CPW). In this case, it was installed on a roger RT5880 mount, whose dimensions were 5×5 mm^2 with a thickness of 0.254 mm, and its maximum gain reached 6.6 dB at 28 GHz. Ali and Sebak [14] suggests the design of an microstrip patch antenna (MPA)-type antenna operating in three bands and offering at the same time a gain of 7.02 dBi for 28 GHz and another of 5.05 dBi at 38 GHz. as well as its bandwidth which is also narrow (0.9 GHz and 0.48 GHz).

On the other hand, Chu *et al*. [15] a 2×2 MIMO antenna array is designed for the fifth generation, which operates in three bands. Indeed, this antenna array consists of two compact tri-band 28/38/60 GHz antennas positioned orthogonally to each other. This work allows production gains between 3.5 dB and 8.5 dB, depending on the operating frequency. In addition, Ullah *et al*. [16] illustrates the design of future antenna arrays (5G) using three operational frequency bands: 28 GHz, 38 GHz, and 60 GHz, as well as mm-wave bands corresponding to 70 GHz and 80 GHz. Researchers specifically dedicated to antenna designs have endeavored to develop techniques to minimize the problem of coupling with other network components through open-band electromagnetic (EBG) structures [17]–[19].

This paper deals in detail with the design and simulations of an inverted L-shaped patch antenna array. This array consists of four components identically located next to each other. A stub and additional holes are added for these components, which contribute significantly to this array's remarkable success in bandwidth and size reduction in the millimeter bands of 5G operating in the bands (28 GHz and 38 GHz). This study proceeds as follows: in section 2, we describe the process for the design of this antenna. Then, in the third part, we simulate the simulation results performed using the corresponding tool, called the high-frequency structure simulator (HFSS) software, followed by an analysis of the results and comparisons with existing antennas. Finally, we conclude in section 4.

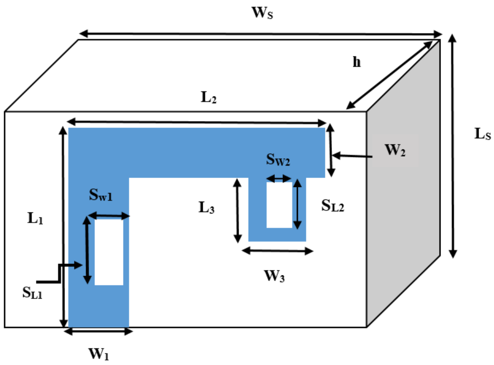
2. MODELING METHOD AND ANTENNA DESIGN

2.1. The choice of the 28/38GHz band

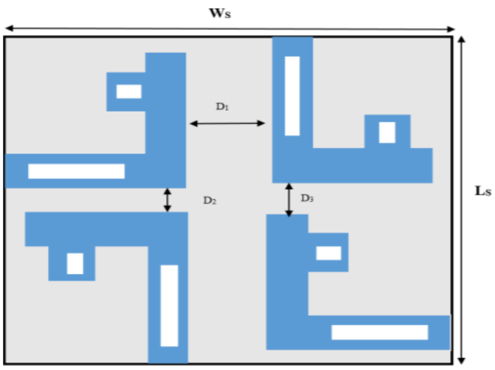
The two frequency bands of 28 GHz and 38 GHz that we studied are included in the frequency zone established by the ITU, called the Ka-band (27 GHz to 40 GHz), which satellite communications have long exploited. Indeed, it offers several opportunities in terms of bandwidth: it is twice as large as that of Ku (12 GHz to 18 GHz) but also more than four times greater than that of C (4 GHZ to 8 GHz). The decentralized multi-site broadcast service (LMDS) also has an extended frequency spectrum in the Ka frequency band (27-40 GHz) of 28 GHz. Due to its low atmospheric absorption, this 28 GHz spectrum allows open space path losses comparable primarily to currently available cellular frequency bands (1-2 GHz). In addition, the reduction of rain-related effects as well as oxygen loss is low in the 28 GHz frequency band and provides more favorable conditions in this area than current cellular networks due to the presence or availability of scalable high-gain antennas as well as their cell size, which is at most 200 meters [20], [21].

2.2. Structure of this proposed antenna

Figure 1(a) shows a printed L-shaped antenna array element with a stub and two slots. We will use this element to create a MIMO array, like the one shown in Figure 1(b). This array formed by four of the elements of the patch antennas similar and perpendicular to each other, and which are printed on the support (substrate) of the type Isola Gigaver 210 (tm), has been chosen in such a way as to obtain a relative permittivity of $\varepsilon r = 3.75$ as well as a loss tangent of 0.003 having a format of 7.5×6×0.3 mm^3. The patch is a copper component having an "L" shape with a thickness of $Cu = 0.035$ mm and a reasoning frequency of 38 GHz. We add an insert to the top of the patch to achieve the second reasoning band at 28 GHz and two slots at this patch to increase its performance, including its bandwidth, gain' and directivity. The Table 1 summarizes all the physical parameters necessary for the design of this antenna. These physical parameters also result in the mathematical formulas [22], [23].



(a)



(b)

Figure 1. The diagram shows: (a) the structure of the patch antenna and (b) that of the proposed array antenna

Table 1. Metric values of the proposed antenna array

Parameters	Values (mm)	Parameters	Values (mm)
(L1-W1)	(5.5-1.04)	(SW2- SL2)	(0.3-0.8)
(L2- W2)	(4.25-1.04)	(WS-LS)	(15.46-14.77)
(L3- W3)	(1.5-0.946)	D1	4.46
h	0.3	D2	3
(SW1- SL1)	(0.4-1)	D3	4.54

3. RESULTS AND DISCUSSION

3.1. Return loss S11 and voltage standing wave ratio

The parameters determining the performance of an antenna, namely its matching quality, can be determined either by its characteristic impedance (often 50 ohms) or by the degree of return loss. At the level of the source of the electromagnetic radiation, there exists in the plane between the transmitted signal and the antenna the guaranteed discontinuity that the return loss coefficient is S11. Indeed, this coefficient (usually in dB) is characterized as the ratio between the reflection wave at an antenna and the incident wave at the same level.

Standing wave ratio (SWR) objectives check the degree of compatibility and flexibility the chain can achieve (or, better, the lack of consistency). Indeed, this rate approaches 1 when there is a perfectly matched chain or infinity if the chain completely misses the match. To guarantee the quality of data transmissions, there are various methods to adapt the signal, such as single stub, double stub, and quarter wave adaptation. The proposed antenna array produces remarkable results concerning the S11 reflection coefficients (-15.41 dB and -16.7 dB), VSWR (1.41 and 1.34), and bandwidth (0.69 GHz and 0.86 GHz) at frequencies 28 GHz and 38 GHz, respectively, as shown in Figure 2 and Figure 3.

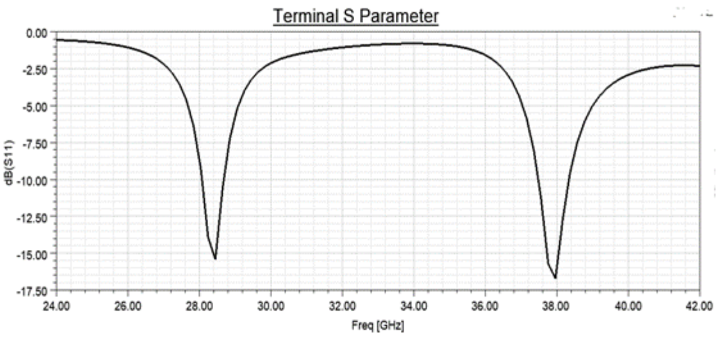


Figure 2. The representative curve of S11

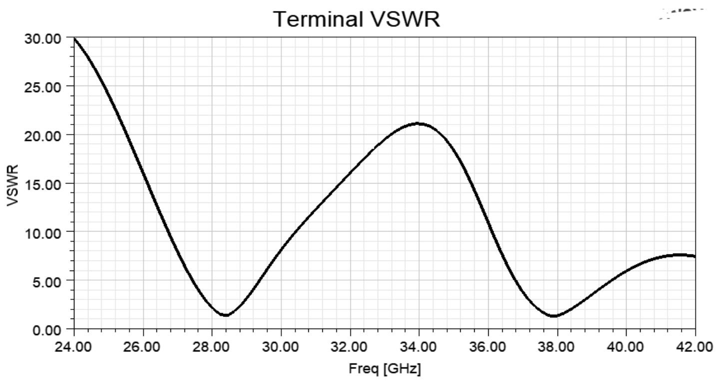


Figure 3. The representative curve of VSWR

3.2. The bandwidth of an antenna

The bandwidth of an antenna is the frequency range in which it can typically be used. Apart from the dummy antenna (which is, in fact, a purely resistive load), any antenna has an impedance that varies with frequency, as does any circuit composed of capacitive or inductive elements [24], [25]. Some antennas can be explicitly used, while others can be used over a wide frequency band.

3.3. Gain and directivity

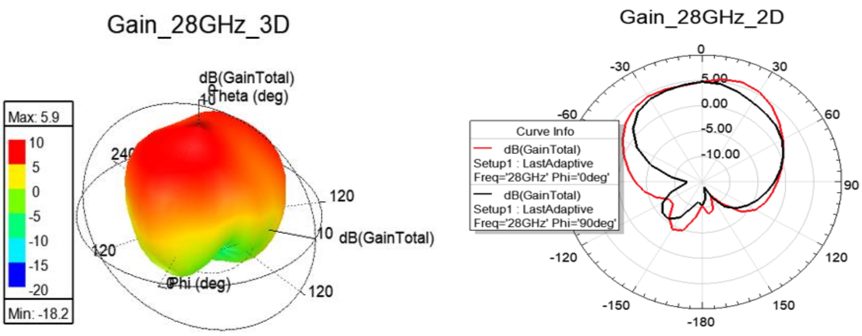
The directivity of an antenna in the direction $(\theta,\ \varphi)$ direction is the ratio of the power density U (r,θ,φ) radiated by the antenna in this direction at distance r and the power density that would be radiated by an isotropic antenna radiating the same total power P_{ANT} [26]. Moreover, the directivity has no unit. In general, it is expressed in decibels: $D(\theta,\varphi)dB = 20\ log\ D(\theta,\varphi)$. If the directivity is greater than 1 (or 0 dB) in some directions, i.e., it radiates more than the isotropic antenna, it is necessarily less than 1 in other directions since the total radiated power is the same for these two antennas.

$$D(\theta,\phi) = \frac{U(r,\theta,\phi)}{U_{iso}(r)} = \frac{U(r,\theta,\phi)}{P_{ANT}/4\pi r^2}$$

The directivity has no unit. In general, it is expressed in decibels: $D\ (\theta,\varphi)\ dB = 20\ log\ D\ (\theta,\varphi)$. If the directivity is greater than 1 (or 0 dB) in some directions, i.e., it radiates more than the isotropic antenna, it is necessarily less than 1 in other directions since the total radiated power is the same for these two antennas.

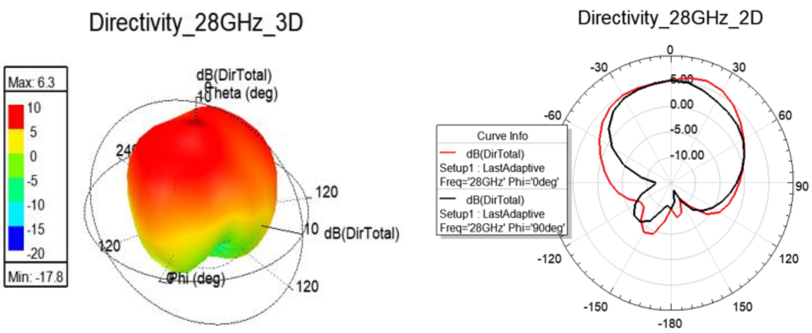
The gain $G\ (\theta, \varphi)$ in the (θ, φ) direction is a quantity close to the directivity. It is defined as $G\ (\theta, \varphi) = \eta\ D\ (\theta, \varphi)$ with η as the efficiency of the antenna: it is a number between 0 and 1 which reflects the losses present on the antenna (it is the difference between pant and pray: pray = η pant). The closer η is to 1, the more power injected into the antenna is radiated, so the more efficient [27], [28].

The simulation results performed in our study regarding the gains as well as the directivities obtained by the proposed antenna array are very interesting. In the 28 GHz frequency band, the designed array produces a gain $G = 5.9$ dB, as shown in Figure 4, which includes Figure 4(a) representing the 3D gain and Figure 4(b) representing the 2D gain. Furthermore, in the same 28 GHz frequency band, the designed array produces a directivity $D = 6.3$ dB, as shown in Figure 5, which includes Figure 5(a) representing the 3D directivity and Figure 5(b) representing the 2D directivity. In addition, the 38 GHz frequency band, the designed array produces a gain $G = 9$ dB, as shown in Figure 6, which includes Figure 6(a) representing the 3D gain and Figure 6(b) representing the 2D gain. Furthermore, in the same 38 GHz frequency band, the designed network produces a directivity $D = 9.4$ dB, as shown in Figure 7, which includes Figure 7(a) representing the 3D directivity and Figure 7(b) representing the 2D directivity.



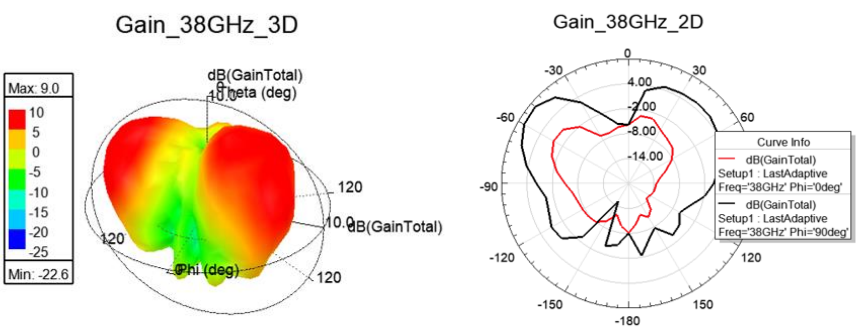
(a) (b)

Figure 4. Illustration of: (a) the 3D gain representation, as well as (b) the 2D gain representation



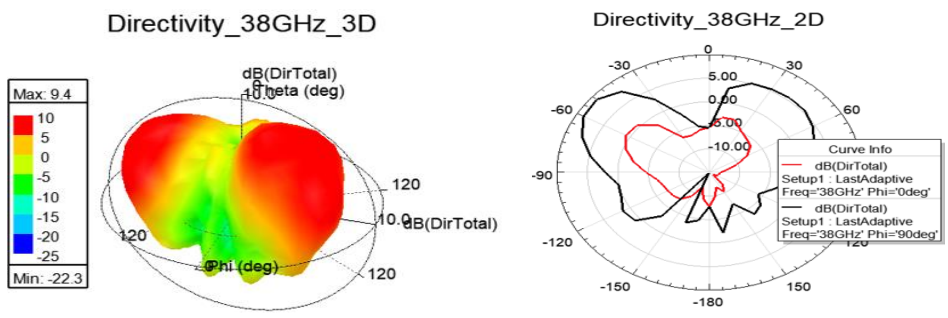
(a) (b)

Figure 5. Illustration of: (a) the 3D directivity representation, as well as (b) the 2D directivity representation



(a) (b)

Figure 6. Illustration of: (a) the 3D gain representation, as well as (b) the 2D gain representation



(a) (b)

Figure 7. Illustration of: (a) the 3D directivity representation, as well as (b) the 2D directivity representation

3.4. The comparison of the results obtained by the proposed antenna to previous research

Table 2 presents a close view of the performance and results of recently published articles in the literature and the results obtained by the proposed antenna, in other words, the results of simulations and designs of MIMO antennas with two frequency bands of 28 GHz and 38 GHz in the millimeter 5G group. The proposed antenna has achieved exciting results from these research works, as shown in Table 2. The work presented [29] achieves a better gain compared to the other works, as illustrated in Table 2. On the other hand, the results obtained [30] provide better qualities in terms of S_{11} and bandwidth and another advantage associated with its smaller dimensions than those of the other works. The proposed antenna obtains better gain and efficiency than the others, as shown in Table 2.

Table 2. Comparative results

Ref	Size (mm^2)	Freq (GHz)	S_{11}(dB)	BW(GHz)	Gain (dB)	Eff (%)
[29]	30×7.5	28	-16	0.99	7.2	93.28
		38	-29	0.4	11.2	85.68
[30]	5×5	28	-48.17	4.59	6	93.63
		38	-40.25	4.14	6.3	91.08
[31]	55×110	28	-13.79	1	5.126	91.02
		38	-30.36	1.3	4.607	92,81
[32]	13×11.25	28	-23.6	1.49	5.41	90.3%
		38	-27.1	1.01	4.89	84.3%
[33]	13×23	28	-34.5	1.23	6.6	-
		38	-27.3	1.06	5.86	-
[34]	9×9	28	<-10	14.2	-	-
		39			-	-
[35]	60×60	28	-30	3.05	8.14	99.5
		38	-40	2.41	8.04	70
This work	15.46×14.77	28	-15.41	0.69	5.9	95.38
		38	-16.7	0.86	9	96.53

4. CONCLUSION

The main objectives of our work in this paper were first to introduce MIMO antennas, the new 5G standard, its basic principles, and expectations, and we propose the design of a 5G millimeter band MIMO patch antenna array, which reasons on the 28 GHz and 38 GHz bands that fully meets the requirements of 5G applications. The latter provides the best bandwidth, gain, directionality, and efficiency performance. Indeed, these better radiation characteristics granted by this antenna array prove they are indeed compatible with 5G electronics. My next objective will be to develop this antenna proposal to design another 5G millimeter band MIMO antenna array with better performance.

Initially, the idea was to design a MIMO antenna array with a relatively high number of elements as required by massive MIMO. However, the simulation of an antenna structure with a relatively large number of radiating elements requires large CPU resources. Which forced us to limit the number of elements to four.

The realization of this article was for us a time of research and deepening, during which we deepened our knowledge of mobile networks and antennas. The realization of the 2×2 MIMO antenna system also allowed us to master the HFSS software and to learn techniques used in the design of patch antennas (coupling reduction techniques, gain, and bandwidth optimization). It is with real enthusiasm that we wrote the article on antenna design. Convinced by our choice of frequency, we think that the 28/38 GHz frequency bands will be the most used for the next 5G applications.

Although the proposed structure is fully operational in the desired frequency bands and has acceptable characteristics for 5G applications. We believe that the bandwidth can be further increased through further parametric study. Which will extend its use to other areas, such as radar systems and satellite communications.

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