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Multilayer antenna dedicated to MIMO Beamforming antenna for 5G telecommunication applications

Meriem DRISSI
dept.electronics MERLab &ESIGELEC
University of Tunis EL Manar &
Normandie University
Rouen, France
drissimeriem1@gmail.com

Nabil BENJELLOUN
IRSEEM lab, ESIGELEC, Rouen
Normandie University France
Rouen, France
Nabil.benjelloun@esigelec.fr

Philippe DESCAMPS
Ensi, Caen
Normandie University France
Rouen, France
philippe.descamps@ensicaen.fr

Ali GHARSALLAH
dept. electronics MERLab
University of Tunis EL Manar
Tunis, Tunisia
ali.gharsallah@fst.utm.tn

Abstract—

This paper presents a printed antenna used on 5G applications. The studied structure has a high directivity, narrow beamwidth and operated at 3.5 GHz. The antenna's prototypes were fabricated on FR4 substrate, a thickness of 1.6mm and a loss tangent of 0.002. A good agreement between the measured and simulated results is observed.

Keywords—component, Multilayer antenna, Directivity, beamwidth, 5G.

I. INTRODUCTION (HEADING 1)

With the rapid development of wireless mobile communication the number of mobile users and the scale of related industries have kept explosive growth.

Consequently, the wireless communication system needs to meet higher system capacity and higher data transmission rate. As the communication system requires to utilize the bandwidth resource efficiently, due to the shortage of spectrum resource, it is necessary to perform the system's spectrum utilization.

As one of the key technologies of future 5G, MIMO beamforming system satisfies the demands of future wireless communication, perform the spectrum efficiency and communication system's channel capacity, data transmission rate and effectively improve link reliability [1].

For this purpose, Special emphasis is put on smart antenna [2].

The Fundamental theory of Smart Antenna is to improve the performance of the wireless communication system by increasing the gain in a particular direction. This can be achieved by steering the adaptive directional and narrow beam patterns towards the desired users in order to avoid interferences [3].

Nowadays, due to its smaller size and high data rate required, intensive research on 5G MIMO Microstrip Patch Antenna is increasing.

On this issue, the objective of this paper is to design a directive patch antenna dedicated to the MIMO beamforming system.

In order to provide high gain in a specific direction, an antenna array will be integrated as a basic element for the deployment of MIMO-Beamforming system

Initially, a comparative performance analysis of rectangular and circular patch antennas is carried-out, then

combine the most performance configurations (circular) in a 2x2-patch- array, before modeling a multilayer antenna system operating at 3.5 GHz.

II. SINGLE ELEMENT SHAPE

Due to their light weight, low profile, flat structure, multiband properties, low cost, moderate to high gain, and ease of fabrication, microstrip antennas are the most widely used in telecommunication application [4]

Where the most popular shapes of microstrip patch antenna taken into consideration are rectangular and circular patch. [5]

The proposed antennas are designed to operate at 3.5GHz frequency. They are simulated on FR4 substrate with relative permittivity of 4.4 and thickness of 1.6mm. The simulation is carried out using HFSS software. The coaxial feeding technique is used to excite the patch. Both are fed by 50-Ω SMA. The parameters studied are return loss, gain, radiation pattern, polarization and beamwidth.

A. Rectangular antenna patch

The design geometry of the rectangular microstrip patch antenna is shown in Figure 1, the patch's dimensions with $27 \times 20 \text{ mm}^2$.

The structure incorporates an antenna was used as a substrate FR4 material which is a good dielectric constant $\epsilon_r=4.4$ and thickness $h=1.6\text{mm}$.

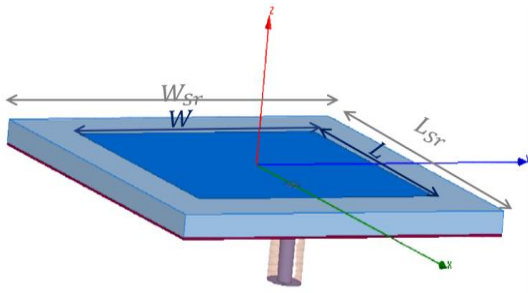


Figure 1: Rectangular antenna patch

The probe feed(coaxial feed) is a technique that used in this project for feeding microstrip patch antennas and fed by a SMA connector. The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance.

The dimension of ground plane is 40mm x 50mm and thickness 0.035mm.

Since the dimension of the rectangular patch is given by

$$W = \frac{c}{2f_r \sqrt{\frac{\epsilon_r+1}{2}}} \quad \text{et} \quad L = \frac{c}{2 \times f_r \times \epsilon_{\text{reff}}} - 2 \Delta L$$

$$\text{Avec } \epsilon_{\text{eff}} = \frac{(\epsilon_r+1)}{2} + \frac{(\epsilon_r-1)}{2} \left[1 + 12 \frac{h}{W}\right]^{-\frac{1}{2}} \quad \text{et} \quad \Delta L = 0.412 \cdot h \frac{(\epsilon_{\text{eff}}+0.3) \left(\frac{W}{h} + 0.264\right)}{(\epsilon_{\text{eff}}-0.258) \left(\frac{W}{h} + 0.8\right)} \quad [6]$$

B. Circular antenna patch

In addition, for circular patch, the expression of the radius “a” is given by

$$a = \frac{F}{\sqrt{1 + \frac{2h}{\pi \epsilon_r F} \left[\ln\left(\frac{\pi F}{2h}\right) + 1,7726 \right]}} \quad \text{Avec } F = \frac{8,791 \times 10^9}{f_r \sqrt{\epsilon_r}}$$

$$a_e = a \left\{ 1 + \frac{2h}{\pi \epsilon_r a} \ln\left[\left(\frac{\pi a}{2h}\right) + 1,7726\right] \right\}^{1/2} \quad [2].$$

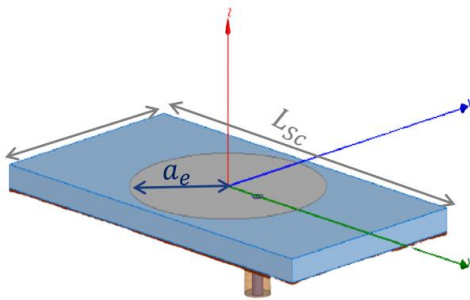


Figure 3: Circular patch antenna

While the design geometry of the circular microstrip patch antenna is shown in Figure 2, the patch’s radius is 12mm.

C. Simulations results

Both circular and rectangular shaped microstrip fed patch antennas were designed using High Frequency Structure Simulator(HFSS).

The proposed antennas have been designed on the substrate FR4.

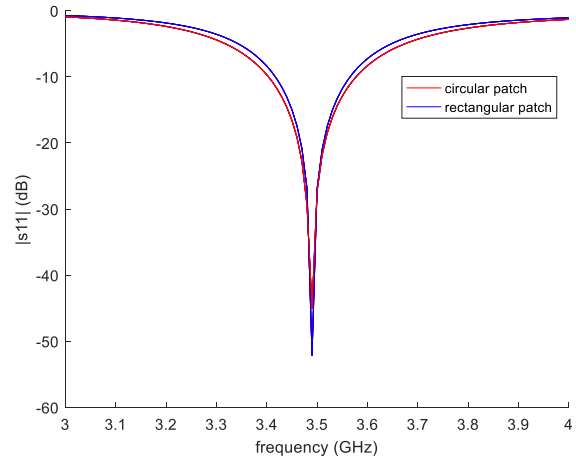


Figure 2: Comparison of return loss

As shown in Figure 3, Both of rectangular and circular patch present a good adaptation.

The |S11| plots of both antennas points at the same resonant frequency (3.5GHz). In fact the rectangular antenna has a better return loss value of 50dB than that of circular patch with S11 = 47dB.

At the same resonant frequency specifying a 3dB of better value occurs for the rectangular patch antenna.

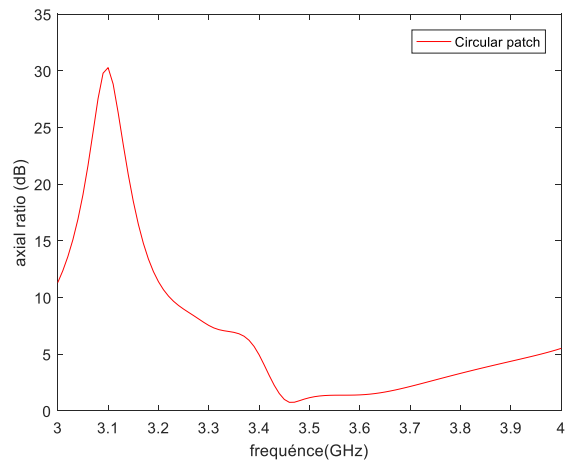


Figure 4: Axial ratio Vs Frequency

A circularly polarized antenna should have an axial ratio of less than 3dB at the design frequency.[7]

Based on the simulation result, the axial ratio for the circular patch antenna design at 3.5 GHz is less than 3 dB which is 0.7dB with bandwidth (ARBW) starting from 3.4-3.8 GHz.

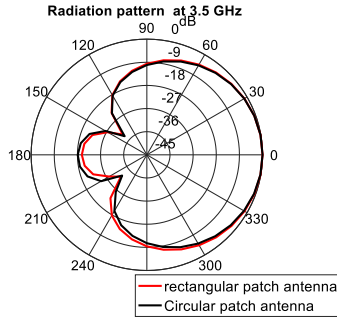


Figure 5: comparison of radiation pattern

For a 5G applications purposes antenna, high directivity and narrow beam width are required. On this issue, the circular antenna patch's radiation pattern presents the narrower beam width value of 90° against 100° that of rectangular patch. It can be seen that the radiation patterns in both designs are in broadside direction. And at the same resonant frequency, the maximum gain value of the rectangular patch antenna is 2dB, whereas for circular patch antenna a maximum value of 3dB.

For 5G applications, both antenna configurations performed quite well on the perspectives of return coefficient, beamwidth, gain and radiation efficiency.

Based on the simulation results with HFSS, from the perspective of return loss, the rectangular configuration shows better performance, while the circular configuration shows better results on bandwidth, radiation pattern, narrower beamwidth, gain and miniaturization.

At the same resonant frequency specifying a 10% of better miniaturization occurs for the circular patch antenna.

In specific applications, the desired antenna characteristics can be accomplished with a single microstrip element.

However, as in our case, characteristics such as high gain, beam scanning and steering capability are only possible when discrete radiators are combined. Therefore, at the beginning of the paper, a comparison between both rectangular and circular antenna is presented in order to combine the most efficient shape to form 2x2 antenna array (Configuration1).[2]

As scheduled, the single element design of the microstrip antenna cannot meet the requirement of our objective. Therefore, an antenna array with the best performing configuration (circular) is designed to improve the directivity and gain of the antenna.

III. ANTENNA ARRAY

A. Parametrix study

To improve the antenna's gain and directivity, an antenna array uses the circular microstrip with a corporate feed network through the quarter-wave impedance transformers is used to equally distribute the power to 2x2 antenna array. [2]

The geometry of the design of 2x2 microstrip patch array for 5G C-band access point applications is shown in Figure 6.

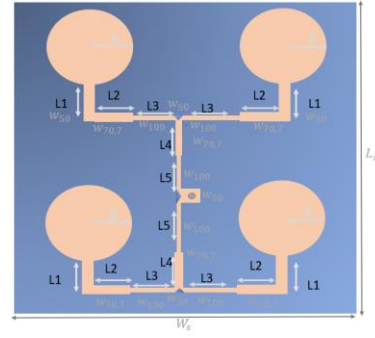


Figure 6: The Schematic diagram of microstrip patch antenna planar array(configuration 1).

The overall size of the design is 100 × 100mm × 1.6mm and printed on Flame Retardant 4(FR4), with arelative permittivity of 4.4, and a loss tangent of 0.024. The antenna is fed by 50-Ω SMA.

To obtain the width of the feed lines of the different impedances the equations below are used [8].

$$Z_1 = \sqrt{Z_2 \times Z_0}$$

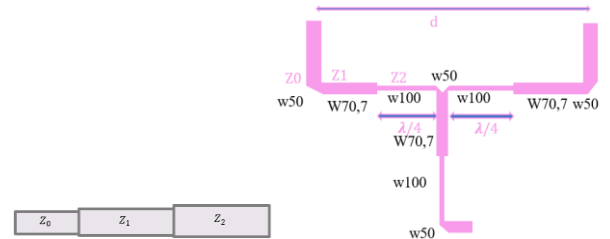


Figure 7: Corporate feed network

Corporate feed network is used to supply a uniformly distributed power to all four patch elements. To ensure a smoother transition of impedance the transmission line should be tapered and no right angles for the feed bends. A quarter-wave transformer is also used wherever an impedance matching is needed. The Corporate feed network constructed is as displayed in Figure 7 the feed network is constructed from 50Ω impedance of the patches Then, the 50Ω and 100 Ω feed lines have connected with 70,7 Ω feed lines to match the quarter wave impedance which is exactly after the 50 Ohm excitation line. Just before the main feed, the 50Ω feed line is tapered into the main feed that connects it with the SMA input power connector.

Indeed, three different widths of the 50Ω,70.7Ω and 100Ω microstrip lines are used to feed the array [8].

The dimensions of prototype antennas are illustrated below in millimeters (mm).

L1	L2	L3	L4	L5	Ls	Ws	W1	W7	W5	R
13.9	10.9	2.4	12	8.75	10.0	10.0	0.65	1.55	3	12.5

Table 1: Detailed dimensions of the proposed antenna array

B. Results and discussions

A 2X2 patch antenna has been simulated, fabricated and tested.

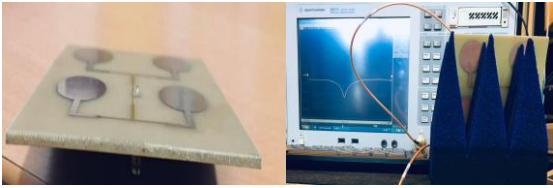


Figure 8: Patch antenna

In order to measure the return loss, a vector Network Analyzer is used.

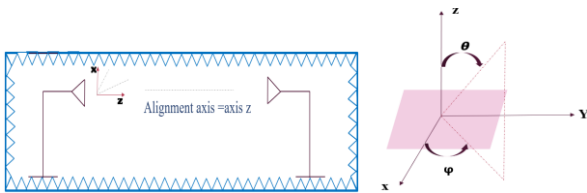


Figure 9: antenna's positioning

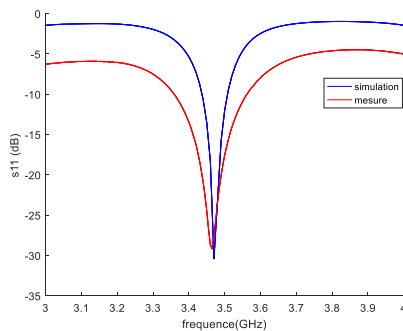


Figure 10: comparative performance analysis measurement and simulation.

As shown in Figure 10, the simulated and measured results match perfectly, a slight variation seems to exist between the experimental and measured results.

The measurement results show that S11 reaches -30 dB at the resonant frequency of 3.5 GHz. We can notice also that the simulated S11 is smaller than the realized one. Consequently, the bandwidth is extended to 200 MHz against 100 MHz in simulation.

In the field or realization of FR-4 Epoxy, in which there is a dielectric substrate with dielectric constant $\epsilon_r = 4.4$, height of 1.6 mm, but $\tan \delta$ is unknown. This factor makes performance curves in simulations and measurements have a differences.

While the radiation pattern and gain are measured in full anechoic chamber with dimensions $7\text{m} \times 4\text{m} \times 3\text{m}$ and maximum field strength of 10V/m.

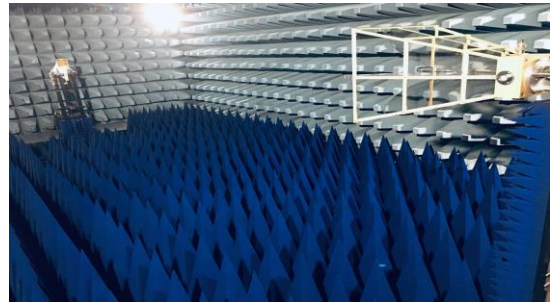


Figure 11: Measurement of Radiation pattern in a full anechoic chamber IRSEEM

As illustrated in the figure 11, two positioners are placed in the chamber. While the first one is used to modify the polarization of the reference antenna, the second positioner is used to scan the antenna under test in both planes in order to measure the power transmitted between the two antennas.

The reference antenna used is a QRH18 (QUAD RIDGED HORN).

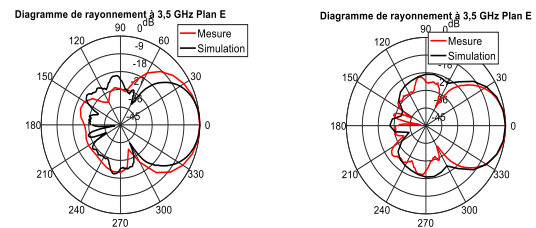


Figure 12: Radiation pattern simulated and measured plan 3.5GHz; (a) $\varphi=90$ (b) $\varphi=0$

As shown in Figure 12, the simulated and measured results match perfectly. It can be clearly deduced that the array antenna has a narrow beamwidth compared to the single element antennas.

The aperture angle is reduced to 40° compared to 45° in simulation.

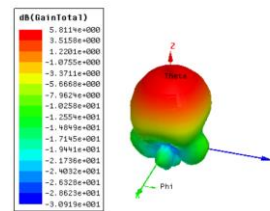


Figure 13: Simulated radiation pattern at 3.5GHz of the proposed antenna.

Both gain and directivity are increasing as the number of elements is increased, which is expected. The gain reaches 5.8 dB.

As already mentioned a 5G applications antenna requires high directivity and narrow beam width, So a multilayer antenna is modeling in order to improve gain, minimise interference and increase bandwidth.[9]

IV. MULTILAYER ANTENNA

A. Possible configurations

This paper has presented for increasing the bandwidth and directivity and so multilayer proximity coupled antenna is used. [10]

Employing this technique, it is also improved the directivity of antenna which is highly desirable for 5G MIMO Microstrip Patch application.

Indeed, a performance investigation of two configurations of multilayer patch antennas consisting of two substrates of the same type and dimensions FR4 (100x100x0.8mm³) is carried out.

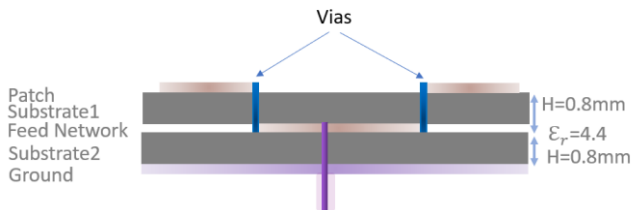


Figure 14: Multilayer antenna with feed network in the middle (Configuration 2).

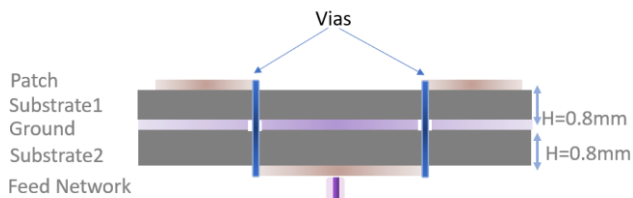


Figure 15: Multilayer antenna with ground in the middle (Configuration 3).

In order to isolate the feed network from the radiating patch, increasing gain and keep out the losses, radiating patches and the feed networks are connecting by shorting vias as shown in the Figure 13 and Figure 14. [10]

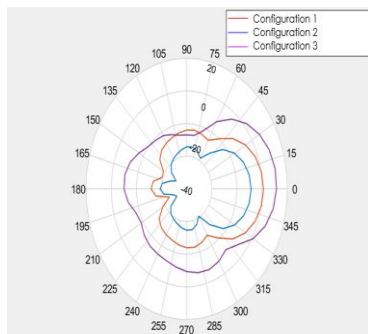


Figure 16: comparative performance analysis of 3 configurations of antenna array.

The figure above shows how the different radiation patterns are directed.

The configuration 3 with the ground in the middle has the narrowest beam width, its beam width at - 3 dB is 25° compared to the first configuration (30°) against 40° in planar array.

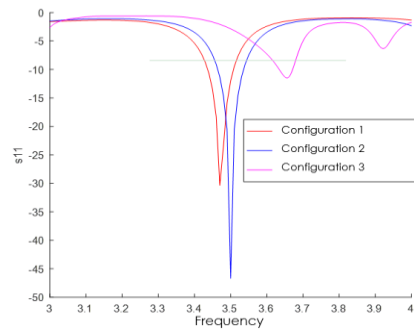


Figure 17: Comparative performance analysis of 3 structures of antenna array..

Based on the simulation results presented above, the configuration 2 offers a wider bandwidth and a smaller reflection coefficient at 3.5 GHz.

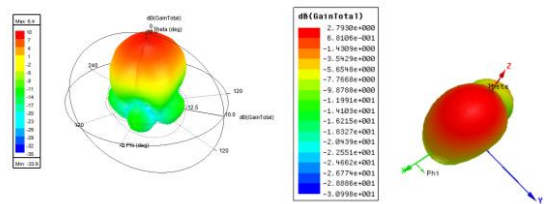


Figure 18: Radiation pattern of a patch antenna in 3D.

The radiation pattern of the second configuration is more directional than the other configurations. In addition, it offers a lower level of side lobes, the narrowest beam and highest gain (6.4 dB). As shown in figure 16, 17 and 18, configuration 2 shows better results on beamwidth, radiation pattern, narrower aperture angle, gain and lower side-lobe.

The design of multilayer (configuration 2) has been completed results are good enough to satisfy our requirements for MIMO Beamforming system.

V. CONCLUSION

In this paper, we have presented the design, simulation and fabrication of antennas used for MIMO beamforming system single patch, 2x2 and multilayers configuration patch antenna arrays are proposed offering high directivity and narrow beamwidth. Hence, a novel circularly polarized antenna is designed and simulated at 3.5GHz using the multilayer structure which offers specifying a 24% of better gain occurs for the multilayer antenna structure.

Starting with employing circular shape which offers circular polarization, and higher gain and not forgetting the size optimized. Then a 2X2 circular shapes are combined in order to require certain characteristics such as high gain, beam scanning and steering capability are only possible when discrete radiators are combined, The multilayer antenna with the corporate feed network in the middle provides the most optimum results with beamwidth of 35° and reaches the return loss of -48dB at 3.5Ghz. The gain reaches 6.4dB. The antenna meets the required 5G antenna .

In the further work, a design and realization of an intelligent antenna system of four sub-arrays patch antenna (configuration 2) in perspective of its integration as a base element for the deployment of MIMO beamforming system through our SDR platform consisting of control boards based on the ettus USRP development kit, 4 sub-arrays and PC with our subsystem will be investigated.

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