(3.1-20) GHz MIMO Antennas

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Abstract: In this paper, a super-wideband (SWB) printed monopole antenna has been designed and manufactured. The measured frequency band in terms of reflection coefficient is from 3.1 to 20 GHz under a -10 dB criteria, thanks to the inclusion of a taper impedance adapter. This single antenna has been used to implement and analyze several MIMO antenna configurations, where the isolation between the compounding elements has been checked and optimized to improve the Envelope Correlation Coefficient. Two elements MIMO configurations (parallel ports or orthogonal diversity), as well as four element MIMO antennas with parallel ports are presented. Non continuous ground planes of the MIMO antenna elements with the inclusion of L shaped thin strips are proposed as valid structures to significantly improve the side by side mutual coupling from an initial peak value of 15 dB to better than 24 dB within the entire frequency band. In all the presented MIMO antenna structures, the measured values demonstrate good performance up to 20 GHz, both in reflection and isolation. Nevertheless, the influence of the mutual coupling effects has been checked as more significant in the lower part of the frequency band, especially in the 4 element MIMO configuration. The inclusion of the L shaped strips in the ground plane significantly mitigates this effect. Although the antennas have only been measured up to 20 GHz (upper frequency limit of the laboratory Vector Network Analyzer), simulations show satisfactory antennas' performance up to 50 GHz.

Key words: SWB antenna; MIMO antenna; polarization diversity MIMO antenna

1- INTRODUCTION

A given communication system is considered as ultra-wideband (UWB) system when it has a large relative bandwidth (20% or higher) or a large absolute bandwidth (500 MHz or higher) or both of them. In 2002, the Federal Communications Commission (FCC) designated the (3.1–10.6) GHz band with Effective Isotropic Radiated Power (EIRP) below −41.3 dBm/MHz for UWB communications [1]. Thus, the total Effective Isotropic Radiated Power within the whole UWB band should be lower than – 2.55 dBm (typically lower than -5 dBm).

Multiple-Input Multiple-Output (MIMO) systems are used to increase channel capacity allowing several users to access the various services at the same time. The Ultra-wideband technology in combination with MIMO techniques has proven to be a solution for the limitation of short range communications, which requires devices to transmit extremely low power. In [2-4] it has been demonstrated that the channel throughput can be increased when MIMO systems are used. In [5-8], several UWB MIMO antennas with different working bandwidths were designed and fabricated.

In MIMO systems, antennas are designed to ensure that the mutual coupling among their elements is lower than -12 dB (preferred to be lesser than -15 dB). To get this objective, many techniques have been used to reduce the mutual coupling between the antenna radiating elements. Various stubs have been introduced on the ground plane to make the antennas work at (3.0-10.2) GHz as given in references [9] and [10]. In order to increase the isolation between the two elements UWB-MIMO antenna, work [11] proposed the utilization of parasitic elements to get this objective. Work [12], presents a 4 elements MIMO antenna where four multimode resonators (MMR) between the antenna elements have been used to decrease the mutual coupling between the elements. Recently, works [13-17] investigated the design and implementation of more UWB antennas showing the continuous interest in this theme.

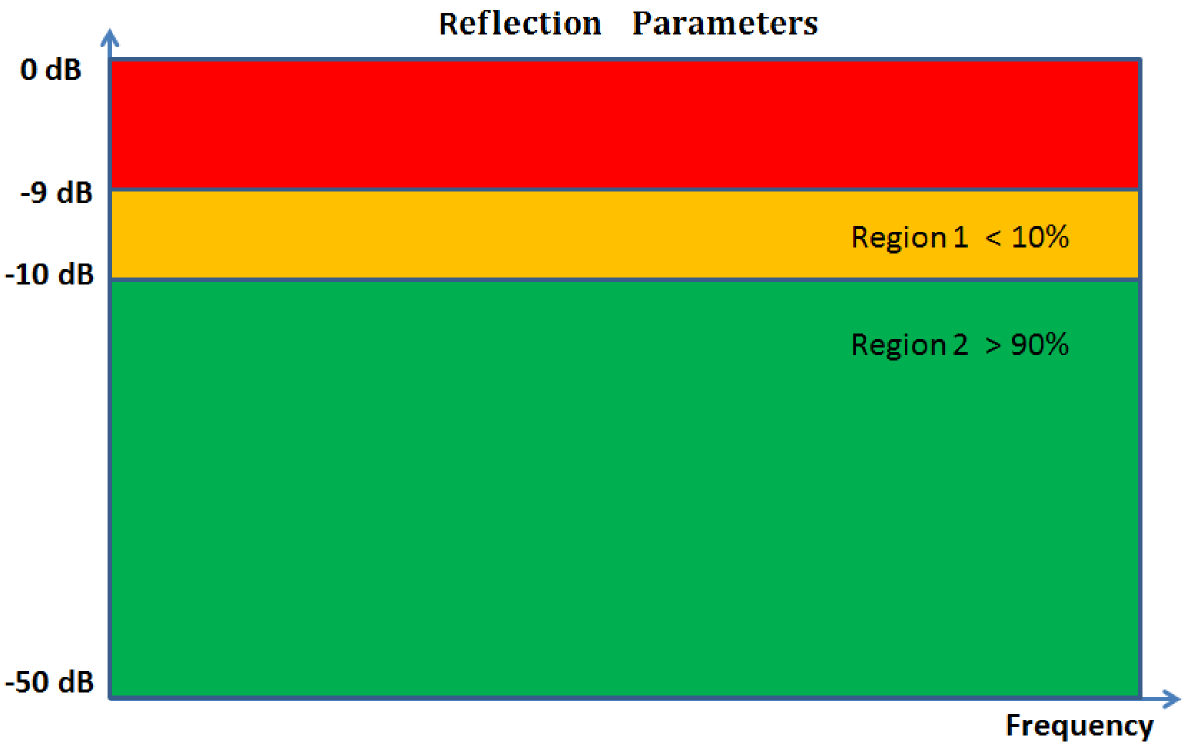
Super wide MIMO antennas are MIMO antennas that work well beyond 11 GHz reaching 20 GHz (for example). To the author’s best knowledge, high isolation parallel ports four elements super wideband MIMO antennas has not presented till now.

The main contribution of this article is to present many Super Wide Bandwidth MIMO antennas (especially high isolation parallel ports four elements super wideband MIMO antennas presented for first time) that work up to 20 GHz (maximum working frequency of the instruments that are available at our school). Theoretically, antennas work well up to 50 GHz.

The rest of the work is organized as follows. In Section II the criteria of the MIMO antennas design are presented. In Section III many MIMO antennas are presented. Finally in section IV, conclusions are addressed.

2- CRITERIA OF THE MIMO ANTENNAS DESIGN

To have a good UWB or SWB antenna, the following conditions must be satisfied. Firstly, the Reflection Coefficient of each port should be lower than -9 dB in the entire band and it should be better than -10 dB in at least 90% of the band. Secondly, the Isolation Coefficient should be lower than -13 dB in the entire band and it should be better than -15 dB in at least 90% of the band. Fig. 1 shows the design criteria of the MIMO antennas.



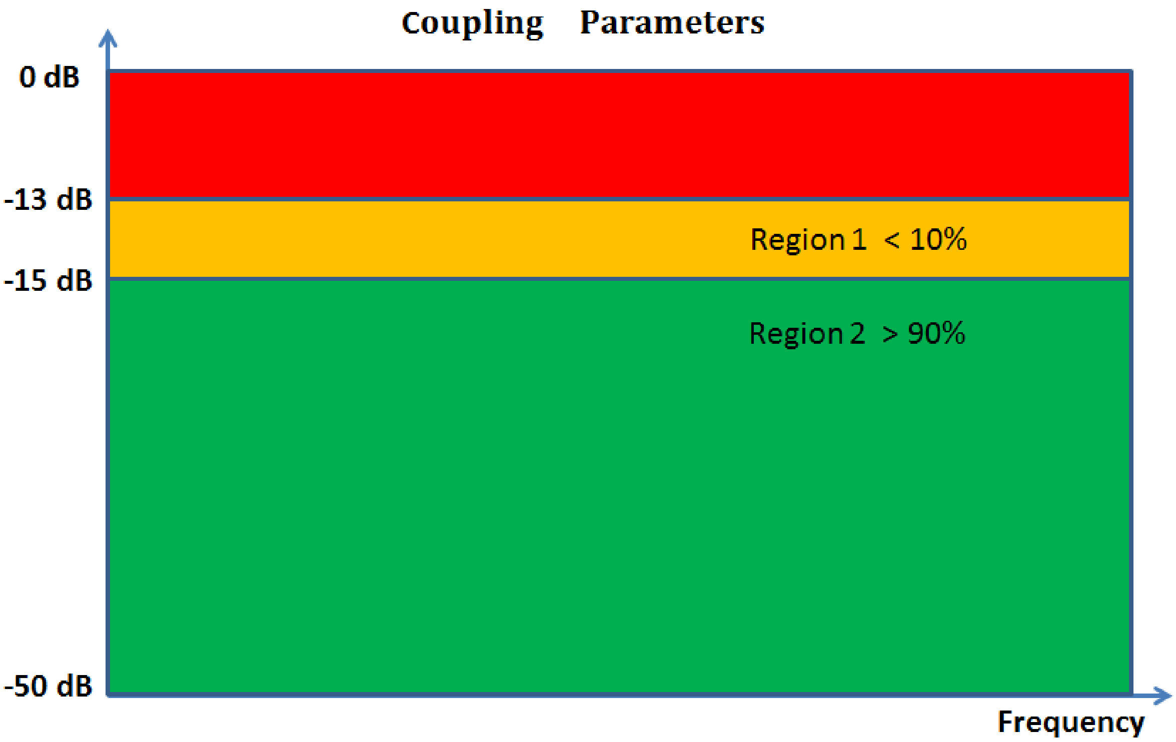


Fig. 1: Design criteria of MIMO antennas.

3- MIMO ANTENNAS

In the fabrication process, the dielectric material TLY-5 has been used. It has a thickness of 1.575 mm and a dielectric constant ε_r of 2.17 with tan $\delta = 0.0009$.

The S parameters measurement is carried out using the Vector Network Analyzer E5071C of Agilent, operating up to 20 GHz. The radiation pattern is measured using an echoic chamber with instruments that work up to 12.5 GHz.

The first resonance frequency of a monopole antenna occurs at a resonance length of 0.24 λ. Thus, to design an antenna that works well in the band (3.1-10.6) GHz, its effective length should be equal or higher than 24 mm.

Radiating element can be circular, rectangular, hexagonal or other different shapes. Input impedance of these elements is usually higher than 100 ohms. Fig. 2 shows the geometry of the single elements antenna. It can be seen that the radiating element is a circular one. The feeding system consists of a 50 ohm microstrip line followed by a taper that adapts the 50 ohms connector impedance to the higher value radiating element input impedance. The antenna is designed to have its first resonance frequency at almost 2 GHz. The physical dimensions of the single elements antenna are given by Table 1.

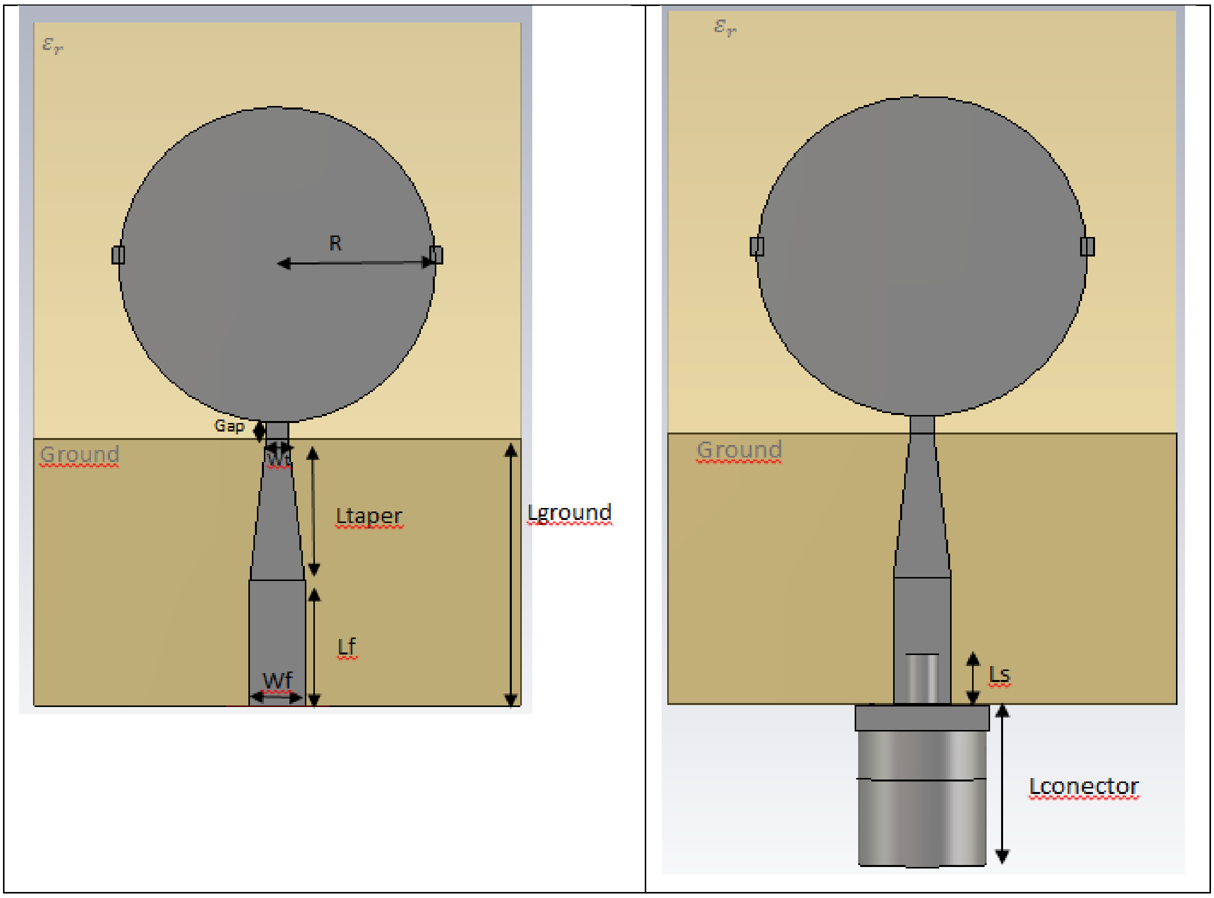


Fig. 2: Geometry of the single elements antenna.

Table 1: Physical dimensions of the SWB single element antenna.

Dimensions (mm)	
R	13
W_f	4.5
W_t	1.8
L_f	10.33
L_{taper}	11.7
L_{ground}	22
Gap	1.4
L_s	6.9
$L_{connector}$	16.6

The effective length (l_{eff}) of the UWB antenna is given by:

$$l_{eff} = \sqrt[2]{\frac{\varepsilon_r+1}{2}} \quad (D + g + Rc) \tag{1}$$

Where

- ε_r is dielectric constant = 2.17
- D is the diameter of the radiating element.
- g is the gap between the antenna patch and the ground plane = 1.4 mm.
- Rc is the effective radius of the patch considered as a cylinder = D/8.

Thus the effective length of this antenna is 38.59 mm.

The theoretical minimum operating frequency of the UWB antenna is given by:

$$f_{min}(GHz) = \frac{72}{l_{eff}\,(mm)} \tag{2}$$

Thus, the theoretical minimum operating frequency of the UWB antenna is 1.87 GHz.

The fabricated single element antenna is shown in Fig. 3. The measured S_{11} parameter of the fabricated antenna is shown in Fig. 4. It can be seen that S_{11} is higher than -10 dB near to 3.3 GHz and 6 GHz. In the rest of the band, the S_{11} value is lower than -10 dB.

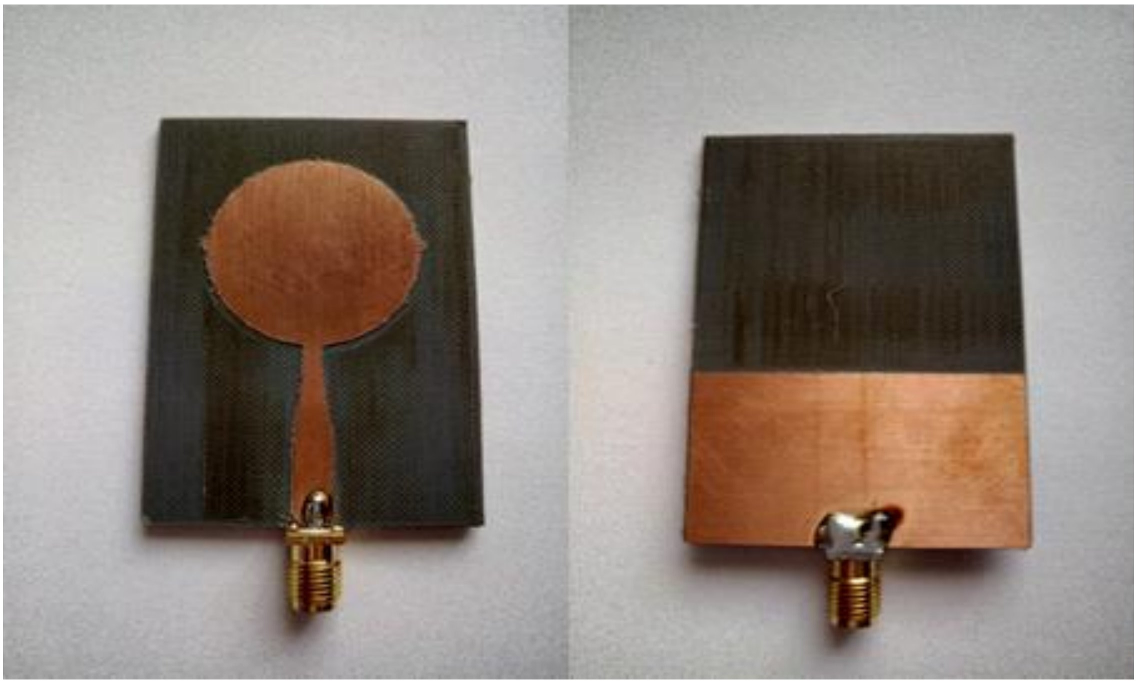


Fig. 3: Fabricated single element antenna.

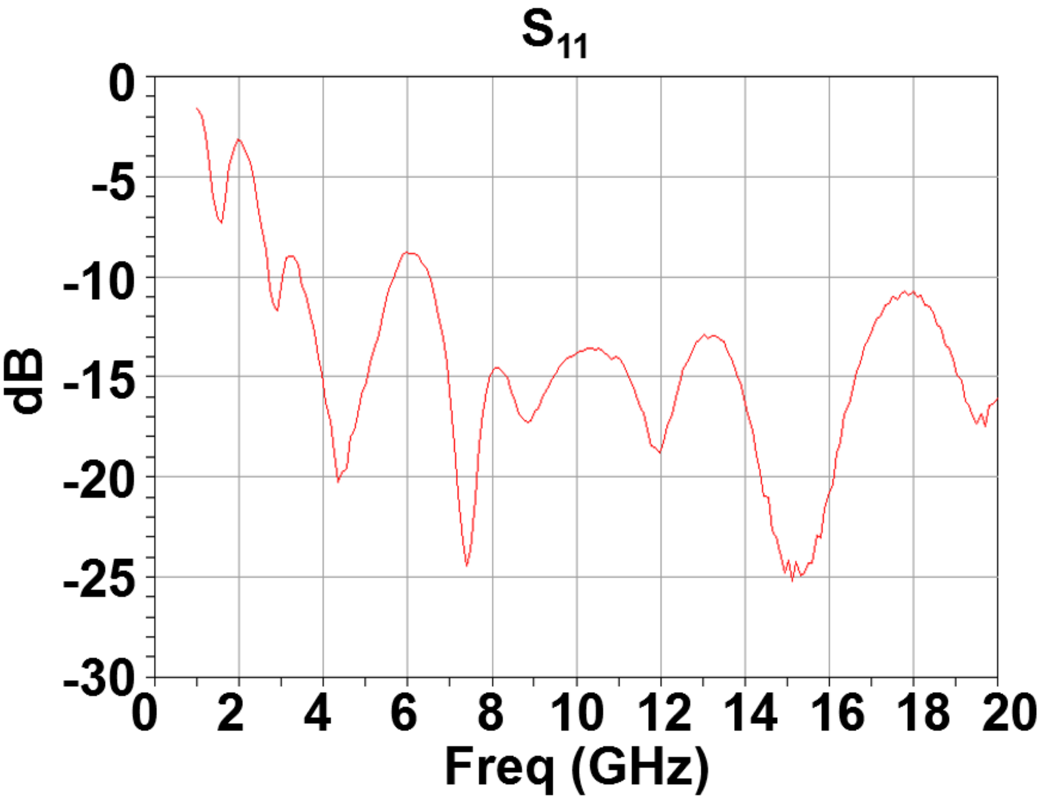


Fig. 4: Measured S_{11} of the fabricated single element antenna.

Fig. 5 shows the geometry of two elements parallel ports MIMO antenna. Their optimized dimensions are shown in Table 2.

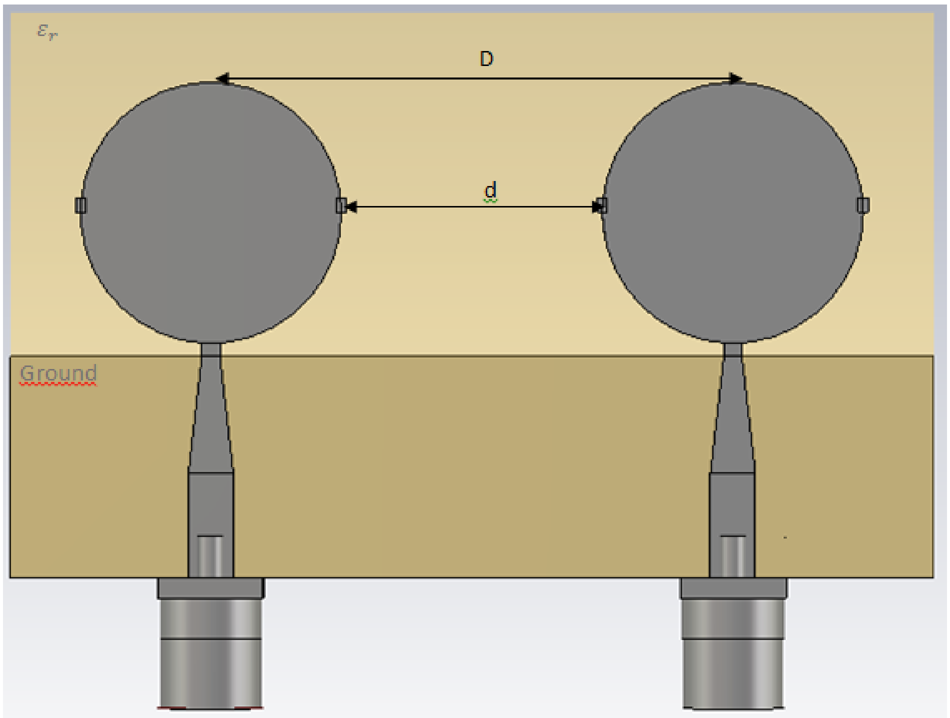


Fig. 5: Geometry of two elements MIMO antenna.

Table 2: Physical dimensions of the two elements MIMO antenna.

Dimensions (mm)	
Width	93
Length	56
d	25
D	52

Fig. 6 shows the photograph of the fabricated two elements MIMO antenna.

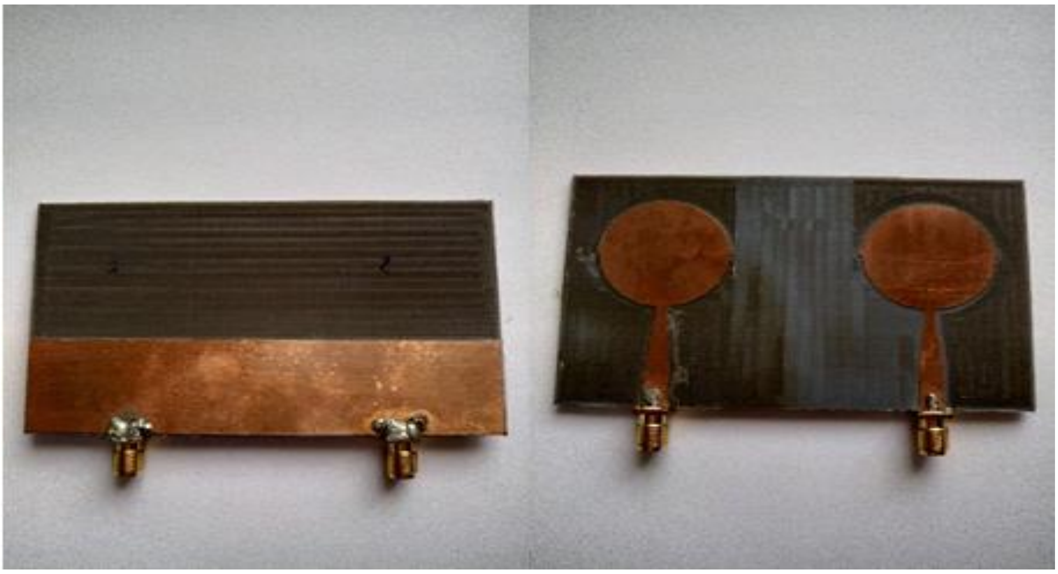


Fig. 6: Fabricated parallel ports two elements MIMO antenna.

Fig. 7 shows the measured S_{11} parameter of the fabricated antenna. It can be noticed that S_{11} is higher than -10 dB near to 2.6 GHz. In the (3.1-20) GHz band, the S_{11} and S_{22} values are lower than -10 dB.

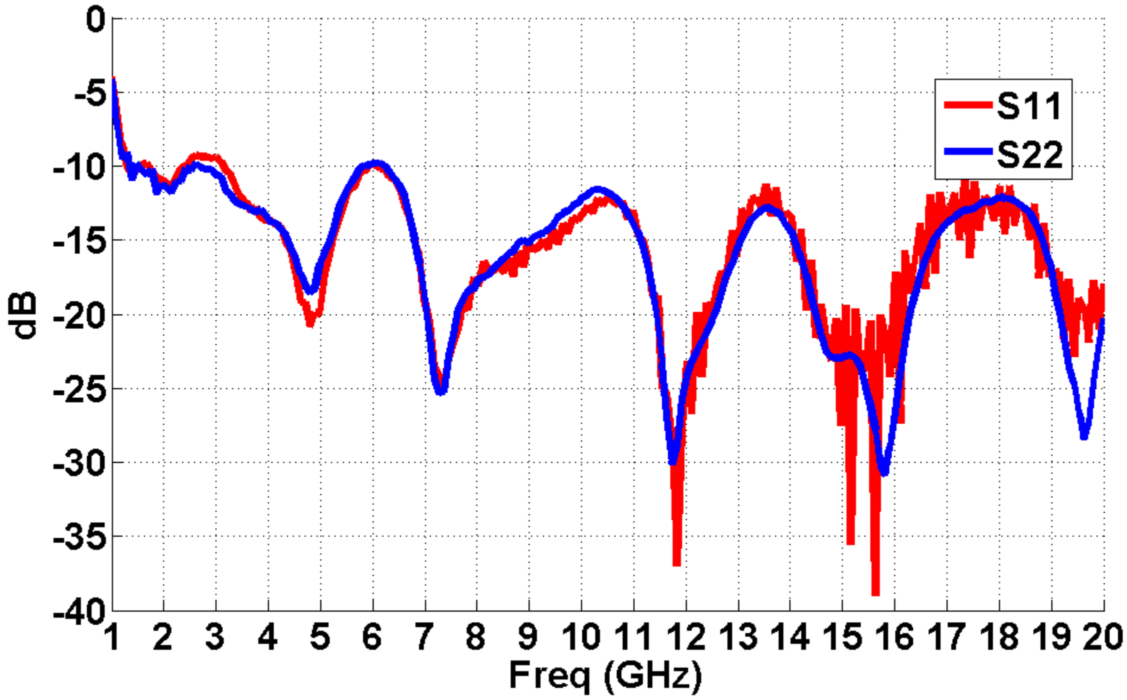


Fig. 7: Measured S_{11} and S_{22} of the fabricated two elements MIMO antenna.

Fig. 8 shows the measured S_{21} and S_{12} parameter of the fabricated antenna. It can be seen that S_{21} and S_{12} are lower than -15 dB in the (3.6-20) GHz band. In the (3.1 to 3.6) GHz band, the S_{21} and S_{12} values are lower than -14 dB.

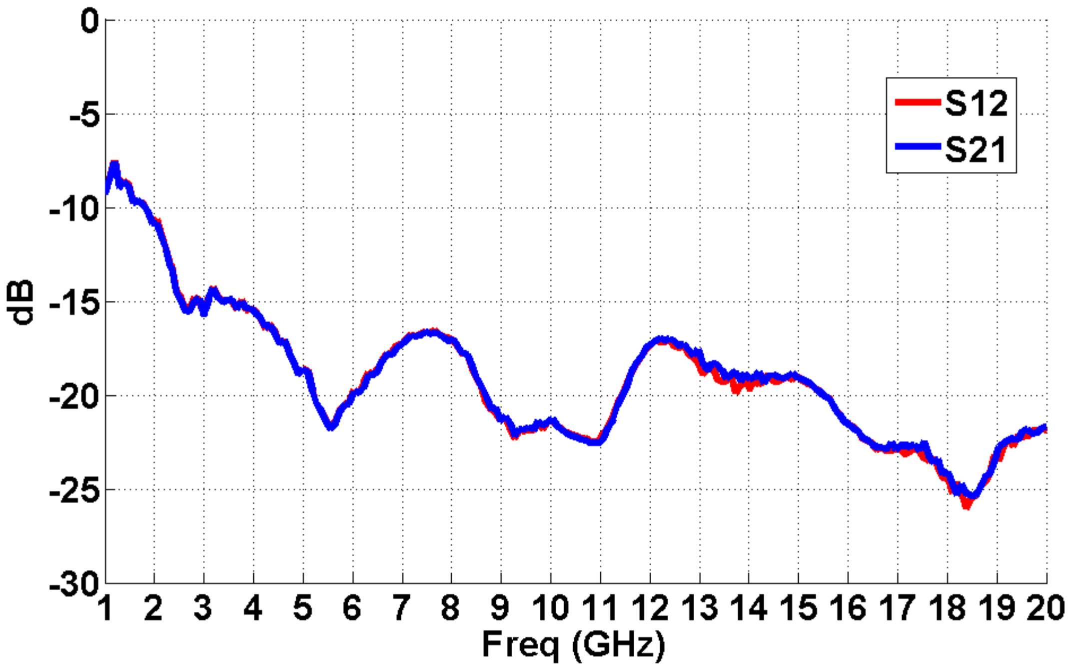


Fig. 8: Measured S_{21} and S_{12} parameter of the fabricated two elements MIMO antenna.

It has been noticed that reducing the width of the antenna to 84 mm and its length to 52 mm by cutting its edges, has an insignificant effect on its performance.

The Envelope Correlation Coefficient ρ of the MIMO antenna is given by:

$$\rho_{\mathrm{ECC}} = \frac{\iint_{4\pi} \boldsymbol{E}_1(\theta,\phi) \cdot \boldsymbol{E}_2^*(\theta,\phi) d\Omega}{\sqrt{\iint_{4\pi} \boldsymbol{E}_1(\theta,\phi) \cdot \boldsymbol{E}_1^*(\theta,\phi) d\Omega \iint_{4\pi} \boldsymbol{E}_2(\theta,\phi) \cdot \boldsymbol{E}_2^*(\theta,\phi) d\Omega}} \quad (1)$$

Where E1 and E2 are far-field radiation patterns, generated from ports 1 and 2 respectively.

Fig. 9 shows the Envelope Correlation Coefficient (ECC) of the MIMO antenna. In the 3 to 12 GHz band, it has a value lower than 0.15. The diversity gain is higher than 9.64 dB.

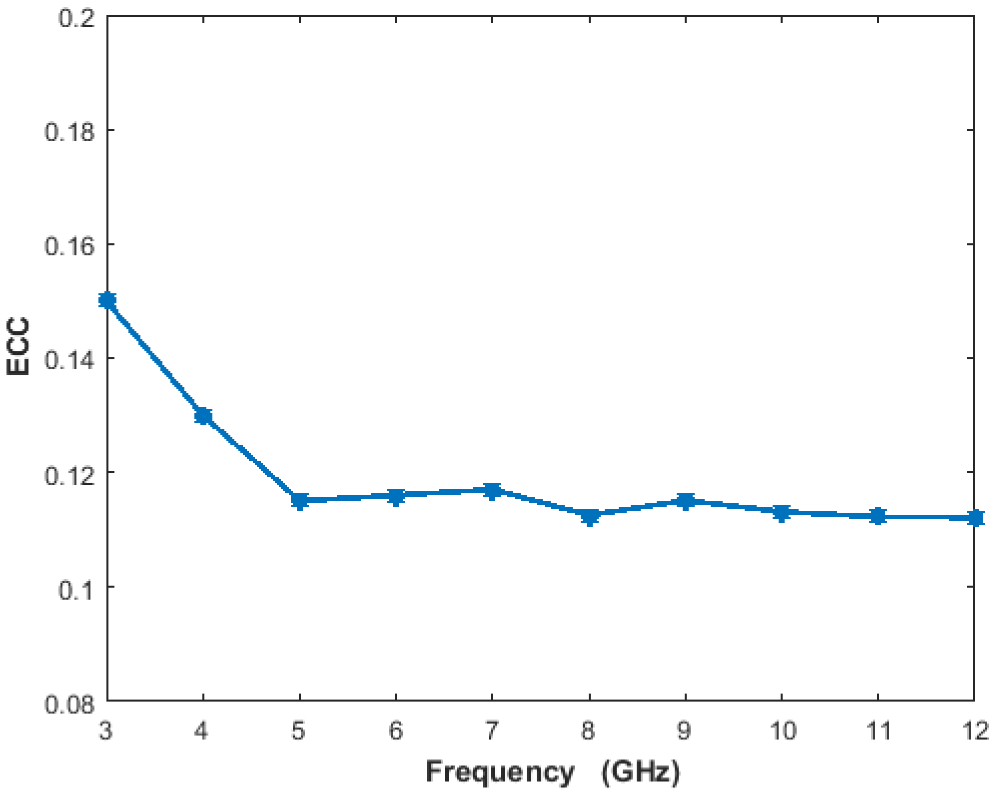
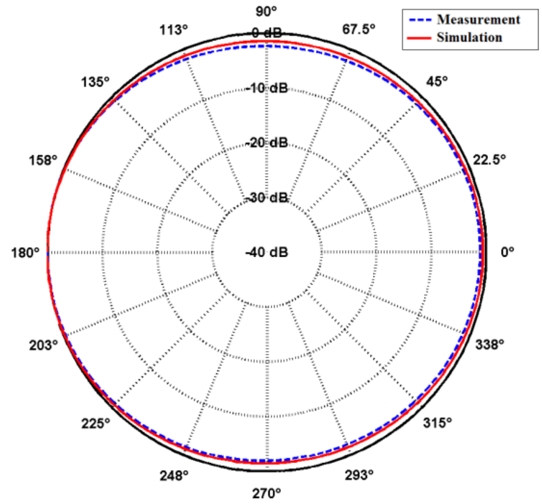
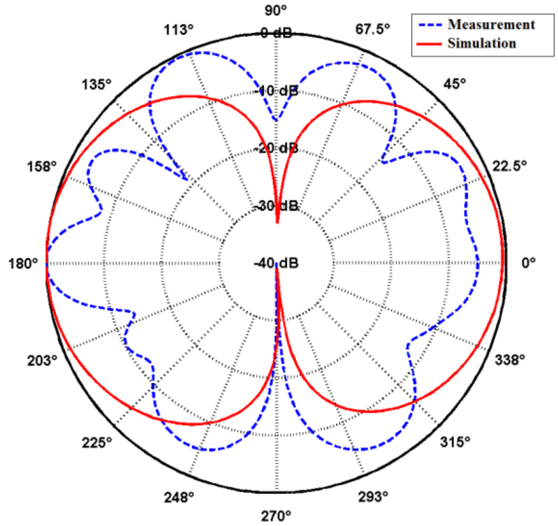


Fig. 9: Envelope Correlation Coefficient (ECC) of the two elements MIMO antenna.

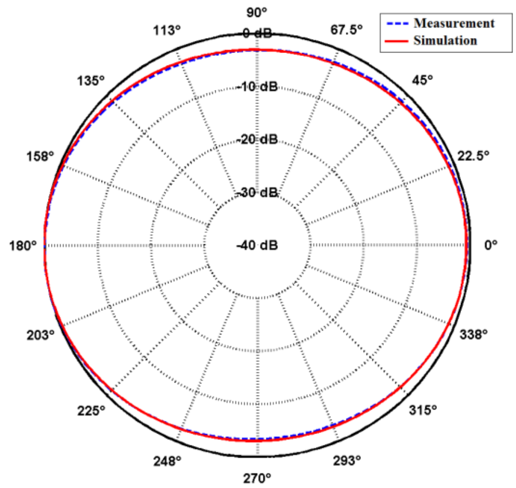
The radiation pattern of the fabricated 2 elements MIMO antenna at three frequencies is given by Figure 10. It can be seen that at 4 GHz, the horizontal (H-plane) radiation pattern of the antenna is almost omnidirectional mean while it is not for the two higher frequencies. The vertical radiation pattern (E plane), has an 8-like shape with maximum gain at almost at 0 and 180 degrees.



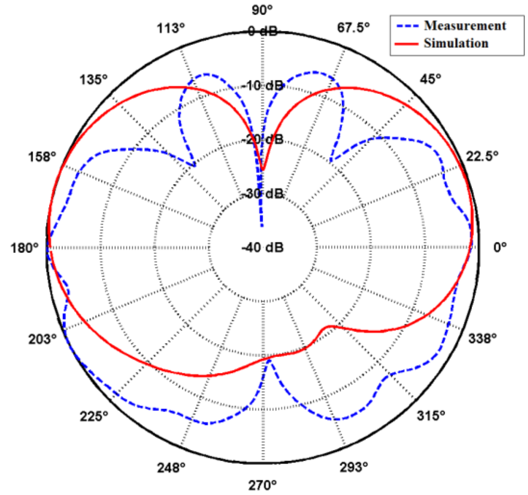
Azimuth radiation pattern at 4.0 GHz



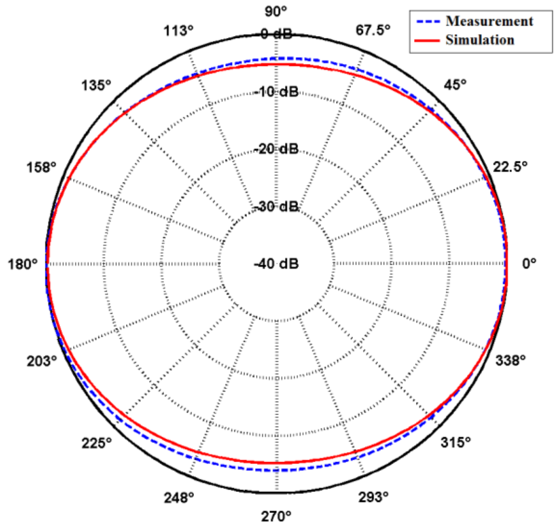
Elevation radiation pattern at 4.0 GHz



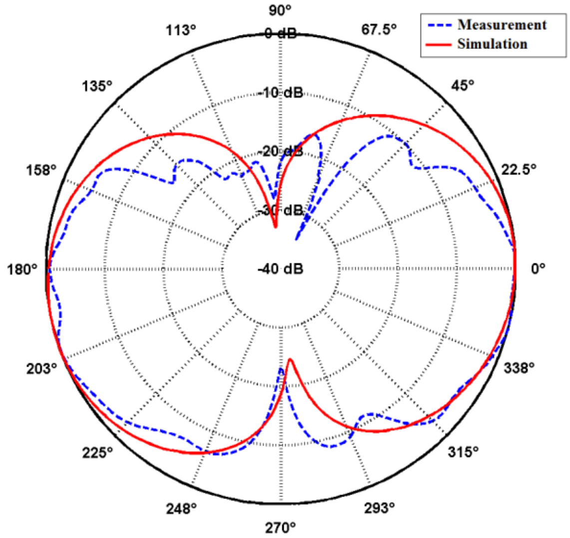
Azimuth radiation pattern at 8.0 GHz



Elevation radiation pattern at 8.0 GHz



Azimuth radiation pattern at 12.0 GHz



Elevation radiation pattern at 12.0 GHz

Fig. 10: Azimuth and elevation radiation pattern at three different frequencies.

To improve the isolation between the two radiating elements of the MIMO antenna, another version of the antenna is designed. This new antenna shown in Fig. 11, uses separated ground plane (14 mm separation) and two isolation inverted L-like lines to improve the isolation between the two radiating elements. The length of the vertical part and horizontal part of the L-like line is 28 mm and 33 mm respectively.

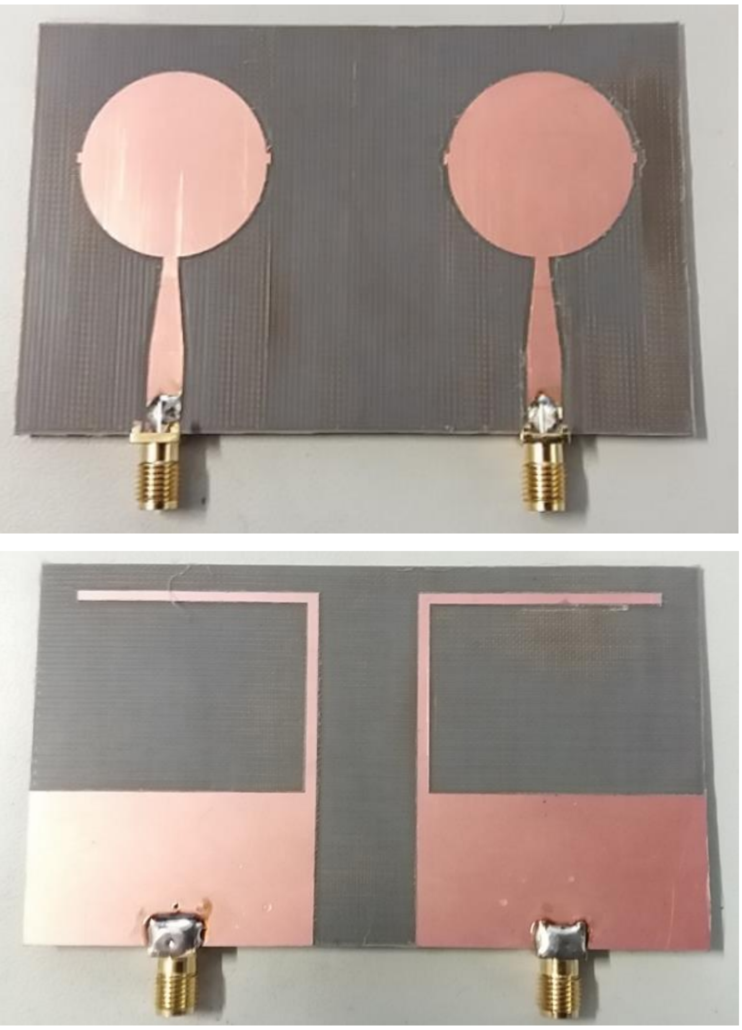


Fig. 11: Second version of the parallel ports two elements MIMO antenna.

Fig. 12 shows the measured S_{11} and S_{22} parameters of the fabricated antenna. It can be seen that S_{11} is higher than -10 dB for a frequency lower than 3.5 GHz. In the rest of the band, the S_{11} value is lower than -10 dB.

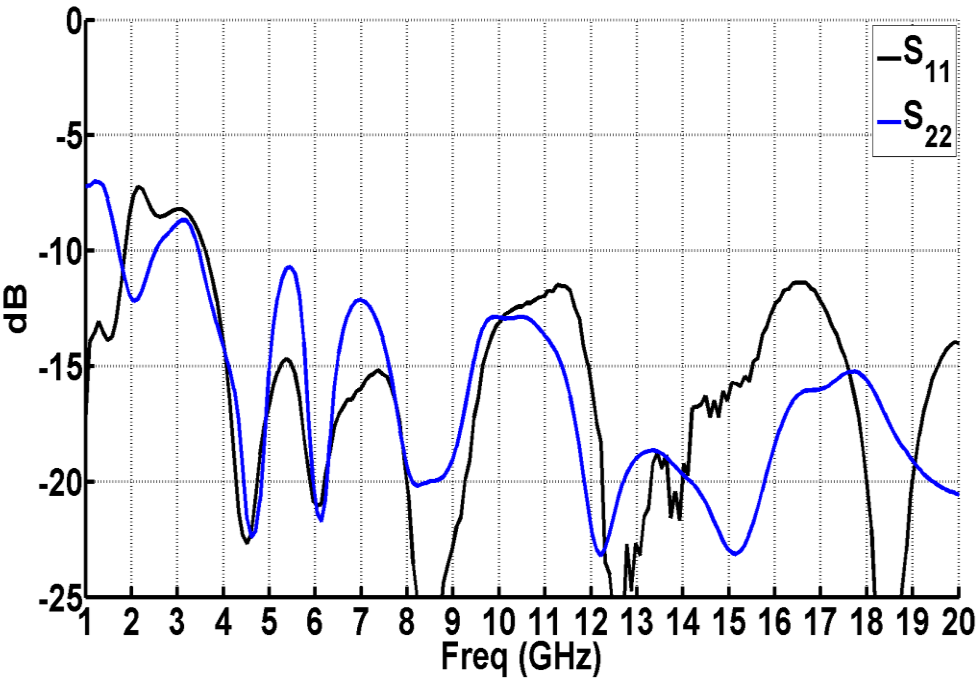


Fig. 12: Measured S_{11} and S_{22} parameters of the fabricated antenna.

Fig. 13 depicts the measured S_{21} and S_{12} parameters of the fabricated antenna. It can be noticed that both of them are lower than –24 dB within the whole band of (3.1-20) GHz. This shows that the separation of the ground plane and the utilization of the L-like lines is a good solution to increase the isolation between the two elements.

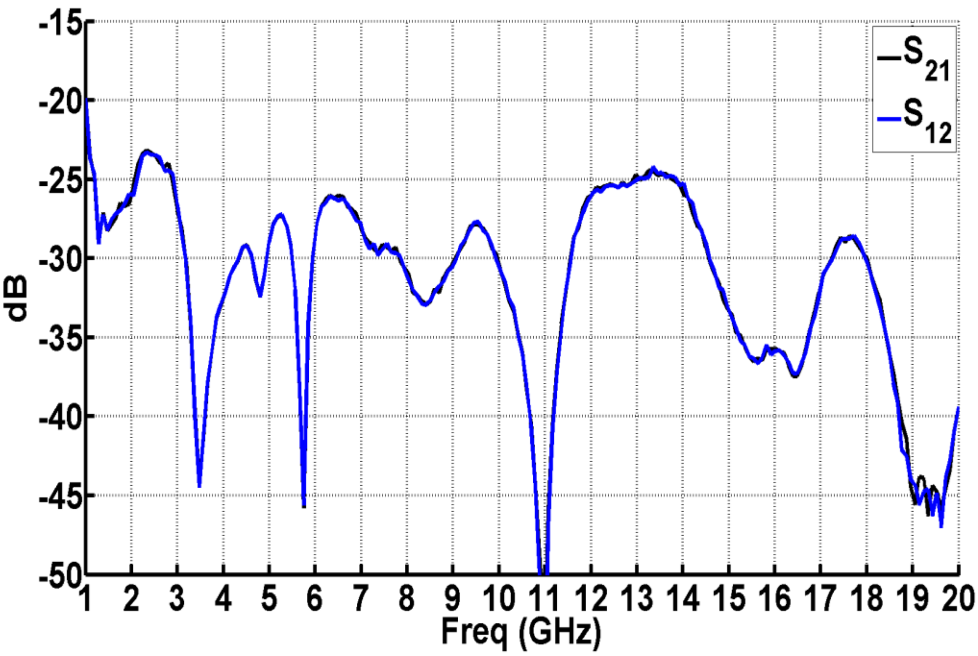


Fig. 13: Measured S_{21} and S_{12} parameters of the fabricated antenna.

Here also, it has been noticed that reducing the width of the antenna to 84 mm and its length to 52 mm by cutting its edges, has an insignificant effect on its performance.

Fig. 14 shows the geometry of two elements polarization diversity MIMO antenna. This antenna can receive simultaneously vertical and horizontal polarized signals. The optimized separations of the antenna elements are given by Table 3.

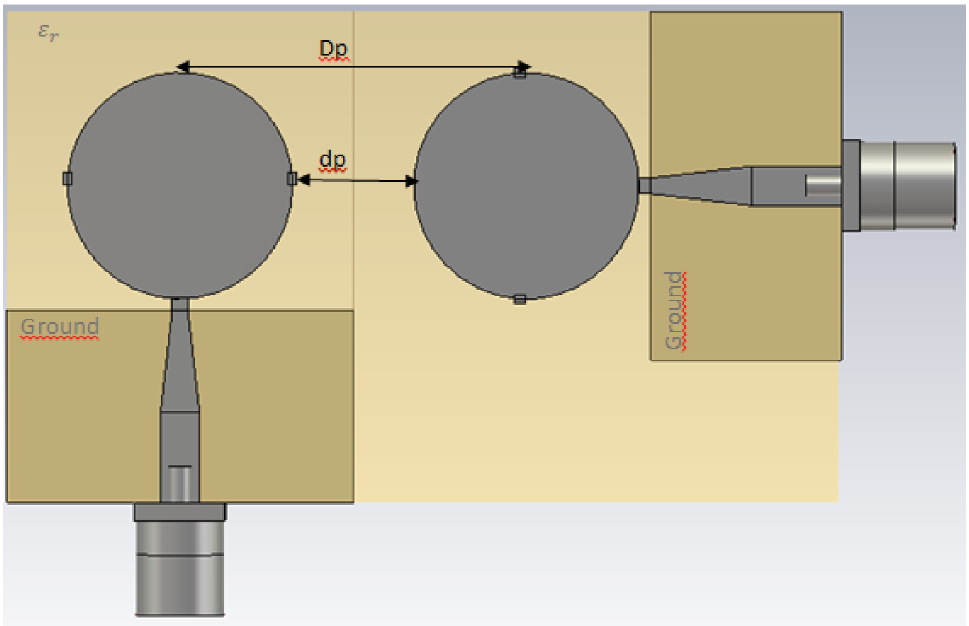


Fig. 14: Geometry of the two elements polarization diversity MIMO antenna.

Table 3: Separations between the two elements of the polarization diversity MIMO antenna.

Parameter	Value (mm)
dp	26.5
Dp	40

Fig. 15 shows the photograph of the fabricated two elements polarization diversity MIMO antenna.

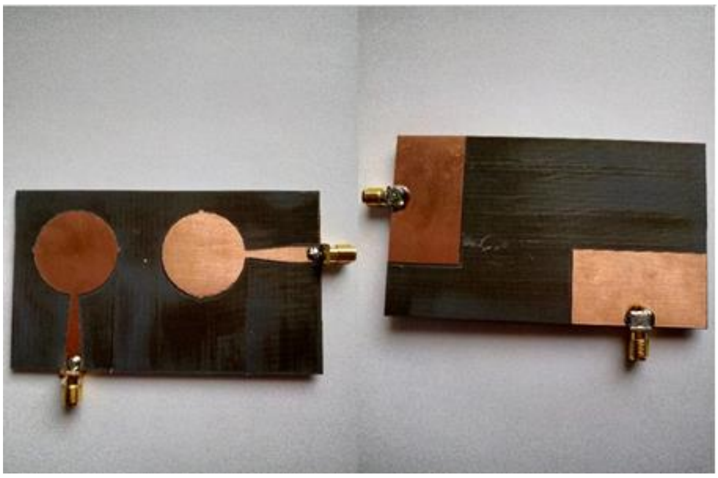


Fig. 15: Photograph of the fabricated two elements polarization diversity MIMO antenna.

Fig. 16 shows the measured S_{11} and S_{22} parameters of the fabricated antenna. It can be seen that S_{11} and S_{22} are lower than -10 dB in the whole band of (3.1-20) GHz.

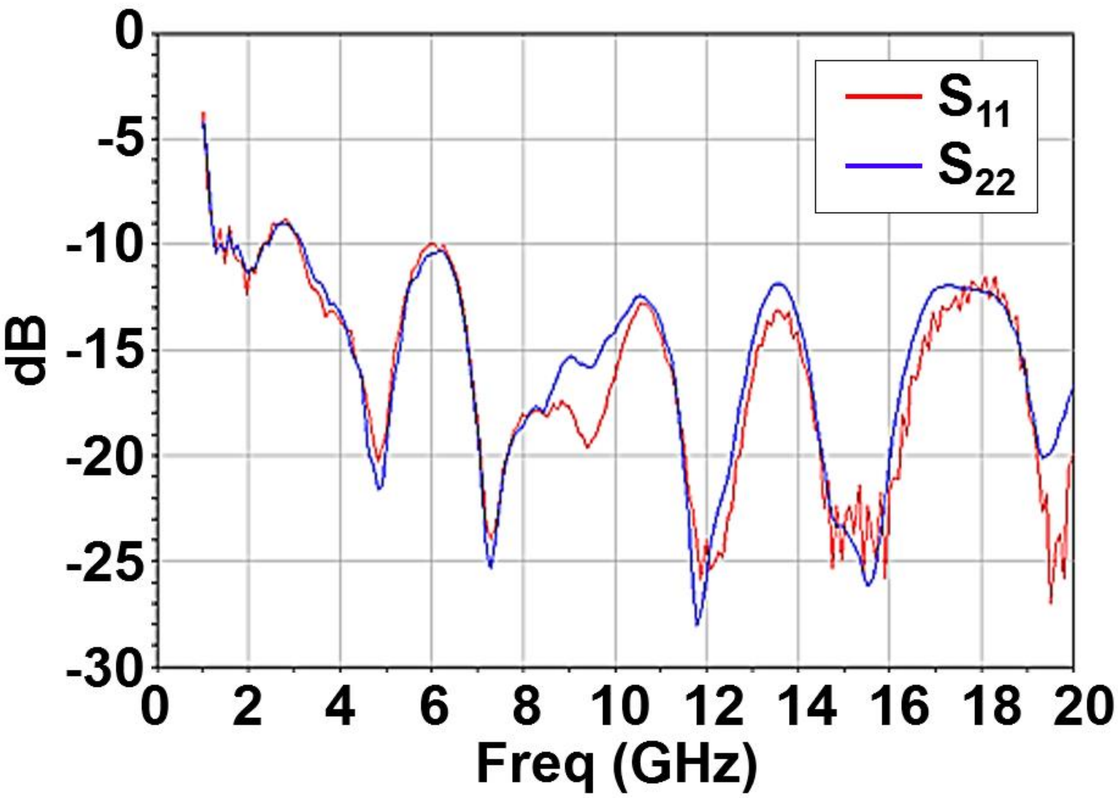


Fig. 16: Measured S_{11} and S_{22} parameter of the fabricated two elements polarization diversity MIMO antenna.

Fig. 17 shows the measured S_{21} and S_{12} parameters of the fabricated antenna. It can be seen that in the whole band they have a value lower than -20 dB. The polarization diversity antenna given in [18] has an operating band of (3-12) GHz.

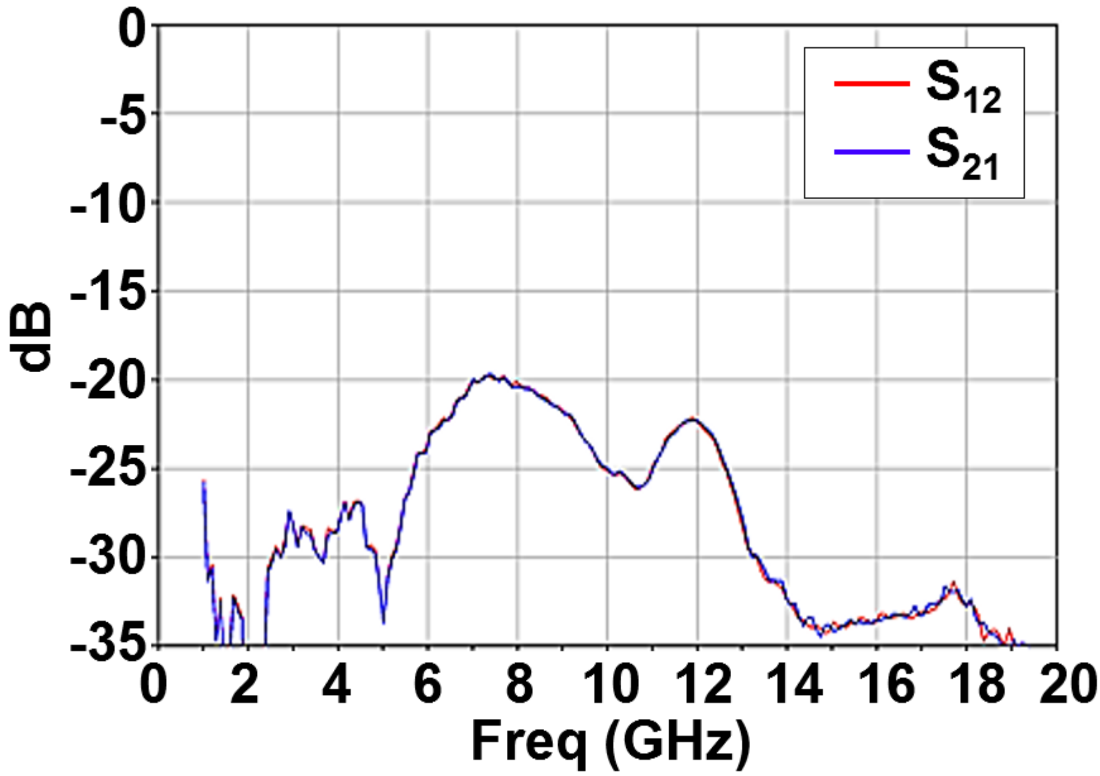


Fig. 17: Measured S_{21} and S_{12} parameter of the fabricated antenna.

Table 4 shows a performance comparison between our antennas and old fabricated antennas.

Table 4: Performance comparison between our antennas and old fabricated antennas.

Ref	Operating band (GHz)	Isolation (dB)	Dimensions (mm)
19	2.5-2.6	>20	56*60
20	3.1-10.6	>25	32*32
21	2.5-2.6	>30	31*31
22	Multiband	>15	60*36
23	2.85-11.8	>20	50*50
24	3-12	>15	29*23
25	2.4	38	
26	3-11	>15	27*25
27	3-10.6	>15	24.3*22
This work (Parallel ports)	3.1-20	>25	Version 1 90*56 Version 2 84*52
This work (Polariz. Diversity)	3.1-20	>20	93*56

Our antennas are not the most compacts ones but they have higher operating bandwidth. We have to mention that the object of this article is to get MIMO antennas the higher possible operating band and that miniaturization will be studied in future article.

Fig. 18 shows the geometry of the 4 elements parallel port MIMO antenna. Separations between its elements are given in Table 5.

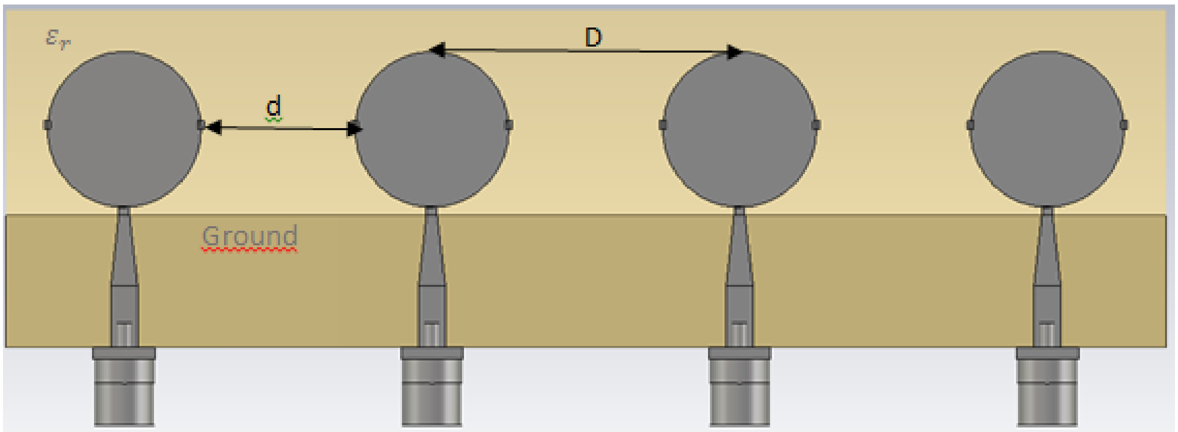


Fig. 18: Geometry of the parallel ports 4 elements MIMO antenna.

Table 5: Separations between the radiating elements.

Parameter	Value (mm)
d	25
D	52

Fig. 19 shows the photograph of the fabricated four elements parallel ports MIMO antenna.

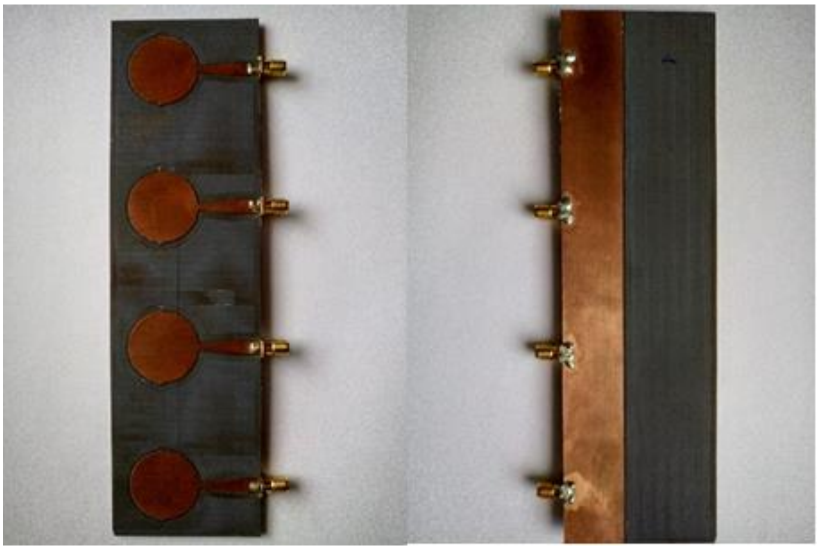


Fig. 19: Photograph of the fabricated four elements parallel ports MIMO antenna.

Fig. 20 shows the measured S_{11}, S_{22}, S_{33} and S_{44} parameters of the fabricated antenna. It can be seen that in almost the whole band of (3.1 - 20 GHz), their values are lower than -10 dB.

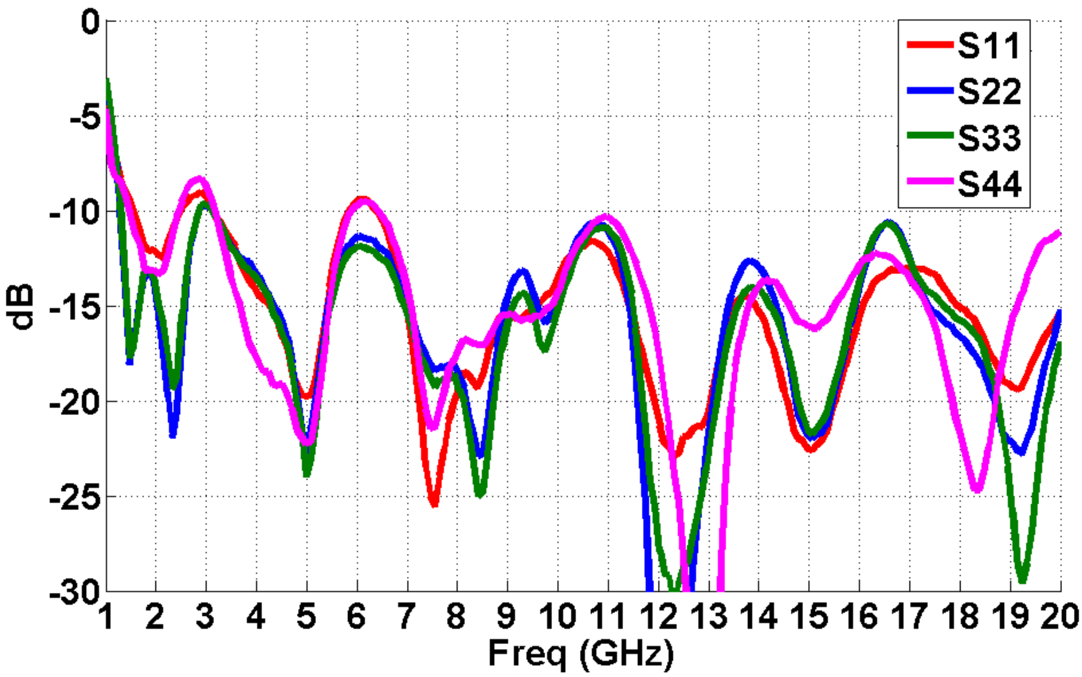
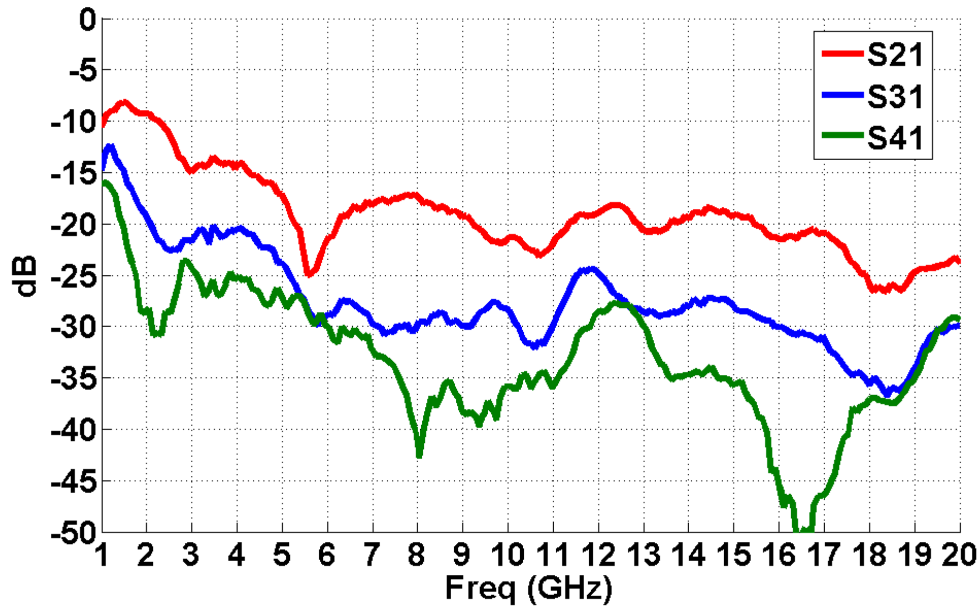


Fig. 20: Measured S_{11}, S_{22}, S_{33} and S_{44} parameters of the fabricated antenna.

Fig. 21 shows the measured S_{21}, S_{31}, S_{41}, S_{12}, S_{32} and S_{42} parameters of the 4 elements fabricated antenna. It can be noticed that S_{21}, S_{12} and S_{32} are lower than -14 dB in the (3-5) GHz meanwhile for the band (5 - 20) GHz; their values are better than -15 dB. Parameters S_{31}, S_{41} and S_{42} have values lower than -20 dB in the whole band of (3.1-20 GHz).



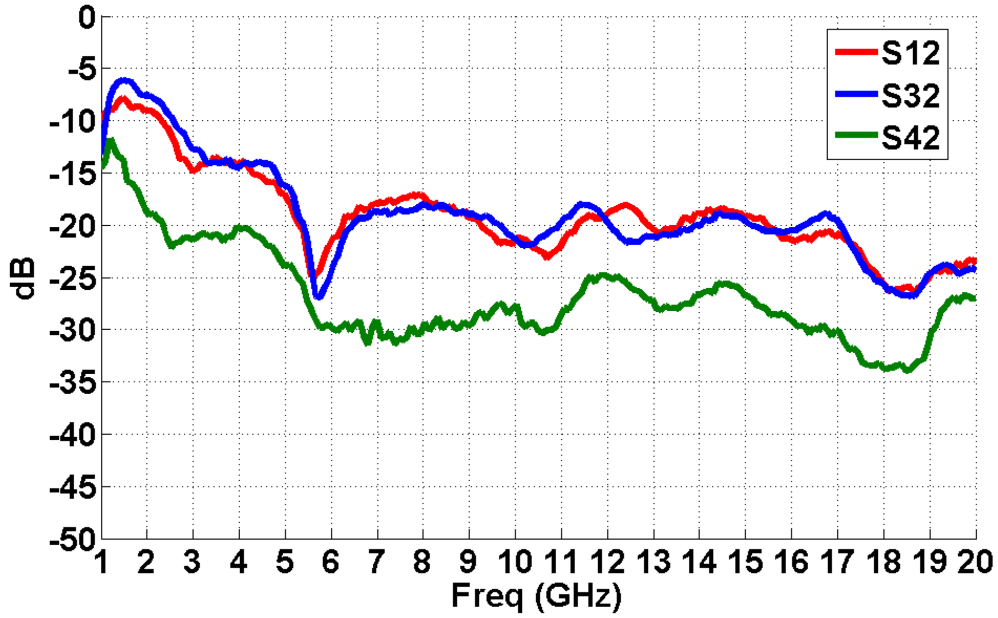


Fig. 21: Measured S_{21}, S_{31}, S_{41}, S_{12}, S_{32}, S_{43} parameters of the 4 elements fabricated antenna.

To improve the isolation between ports, another version of the 4 elements parallel ports MIMO antenna has been designed and fabricated. This new version of the antenna uses separated ground plane (14 mm separation) and six isolation inverted L-like lines to improve the isolation between the four radiating elements. The length of the vertical part and horizontal part of the L-like line is 28 mm and 15 mm respectively.

Fig. 22 shows the bottom view of the fabricated antenna. The top view is similar to that given by Fig. 19.

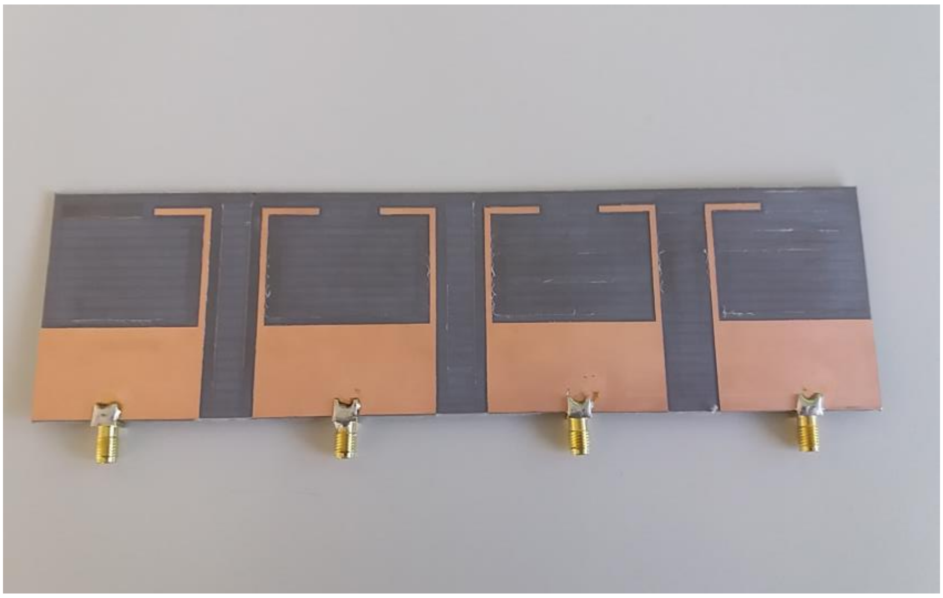


Fig. 22: Bottom view of the second version of the fabricated parallel ports 4 elements MIMO antenna.

Fig. 23 shows the measured reflection parameters S_{11}, S_{22}, S_{33} and S_{44} of the fabricated antenna. It can be seen that they are lower than -10 dB in the majority of the band (3.1-20 GHz).

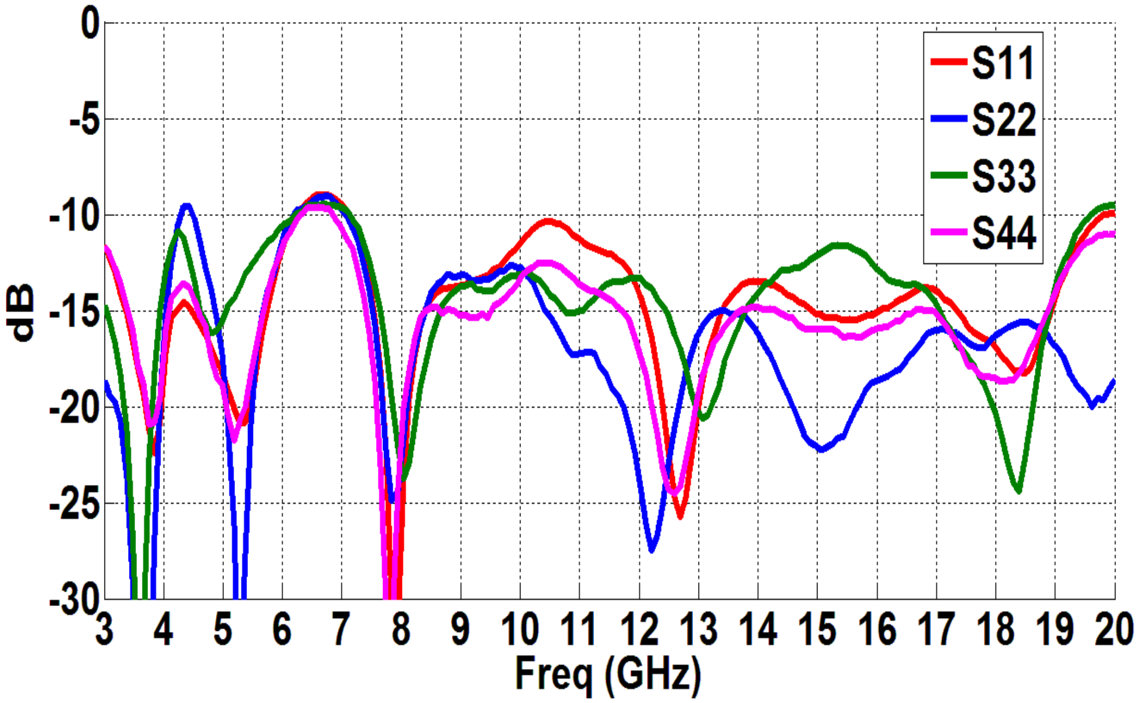
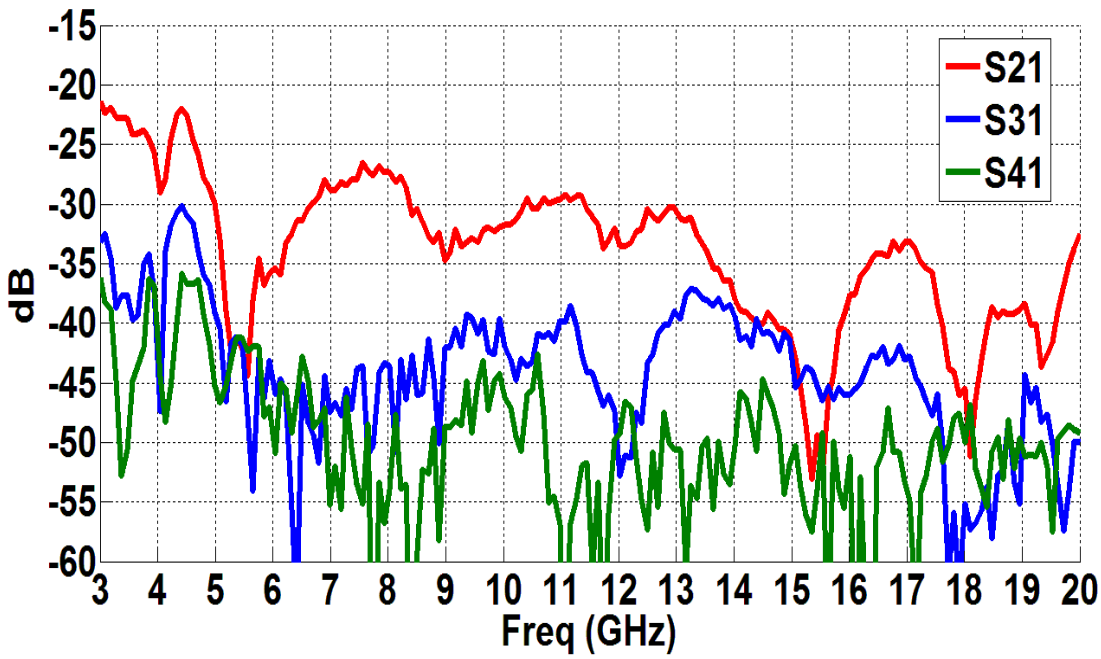


Fig. 23: Measured reflection parameters of the fabricated antenna.

Fig. 24 shows the measured isolation parameters of the fabricated antenna. It can be noticed that they are lower than -20 dB in the whole band of (3.1-20 GHz). In the (5-20) GHz band, isolation is better than 26.5 dB.



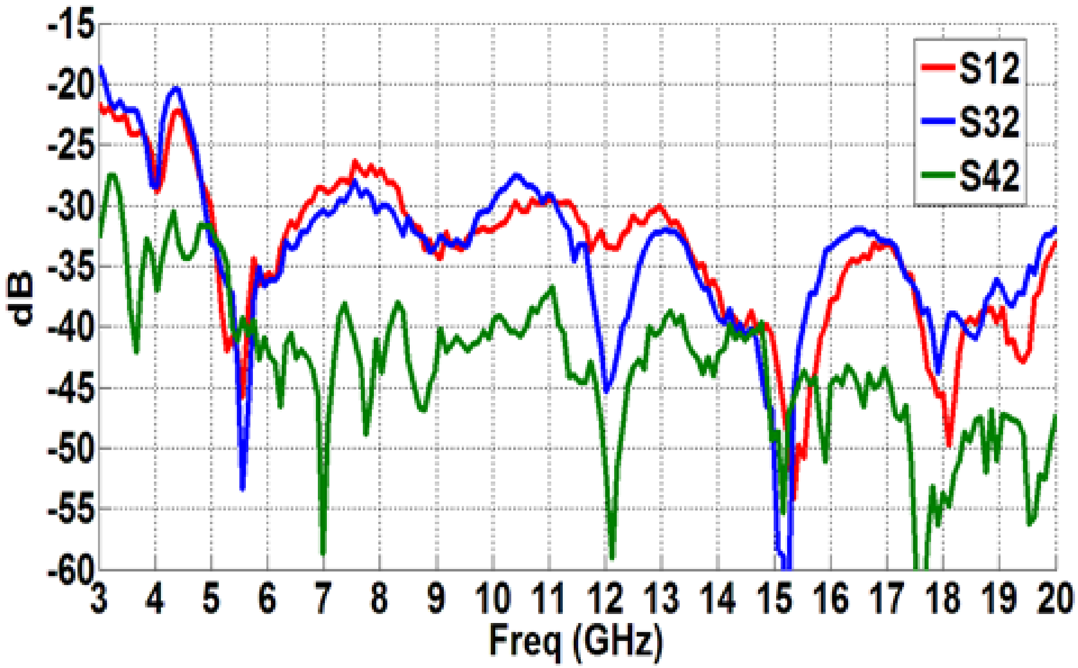


Fig. 24: Measured isolation parameters of the fabricated antenna.

This also shows that the separation of the ground plane and the utilization of the inverted L-like lines is a good solution to increase the isolation between the four elements.

Fig. 25 depicts the simulated reflection parameters of the second version of the 4 elements MIMO antenna. It can be noticed that they work well up to 50 GHz.

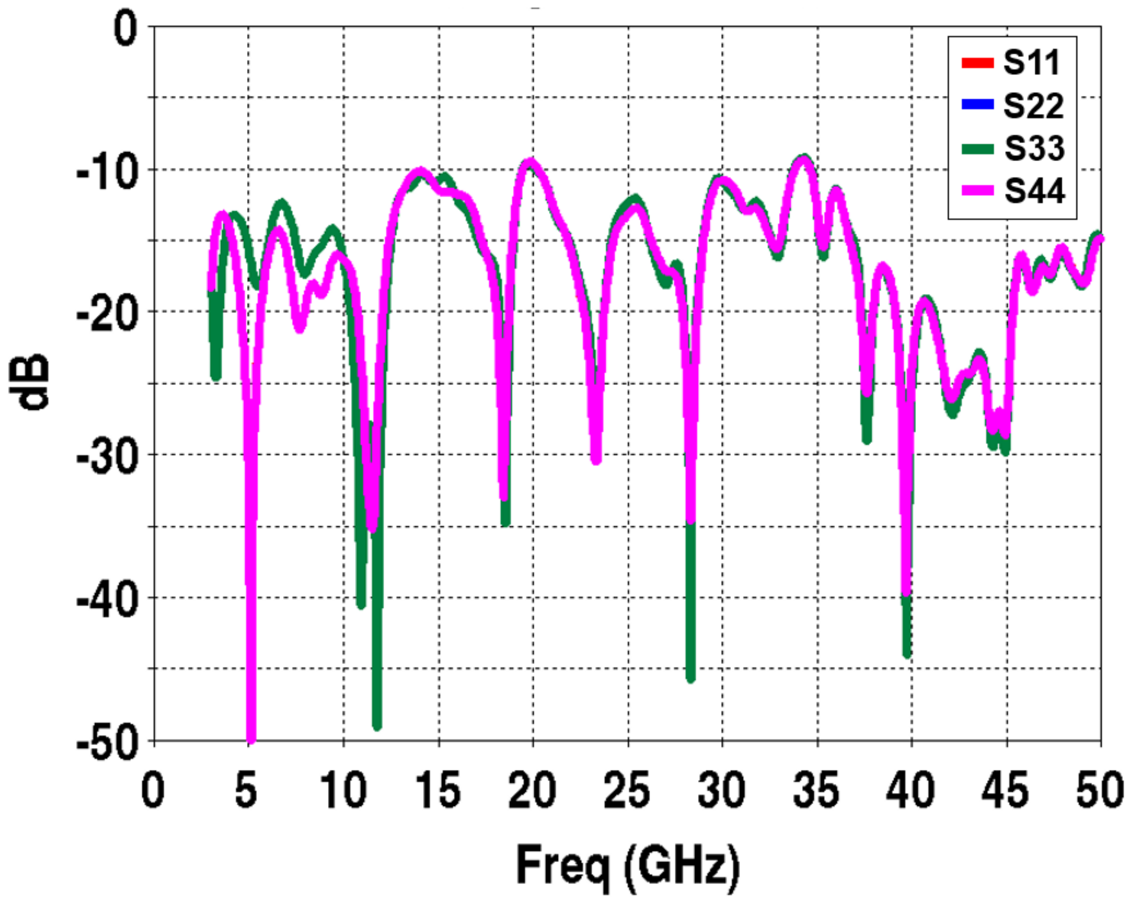


Fig. 25: Simulated reflection parameters of the second 4 elements MIMO antenna.

Figure 26 shows the simulated isolation parameters of the second version of the 4 elements MIMO antenna. It can be seen that they work well (with isolation better than 27 dB) from 5 GHz up to 50 GHz. Minimum solation is 18 dB at 4 GHz.

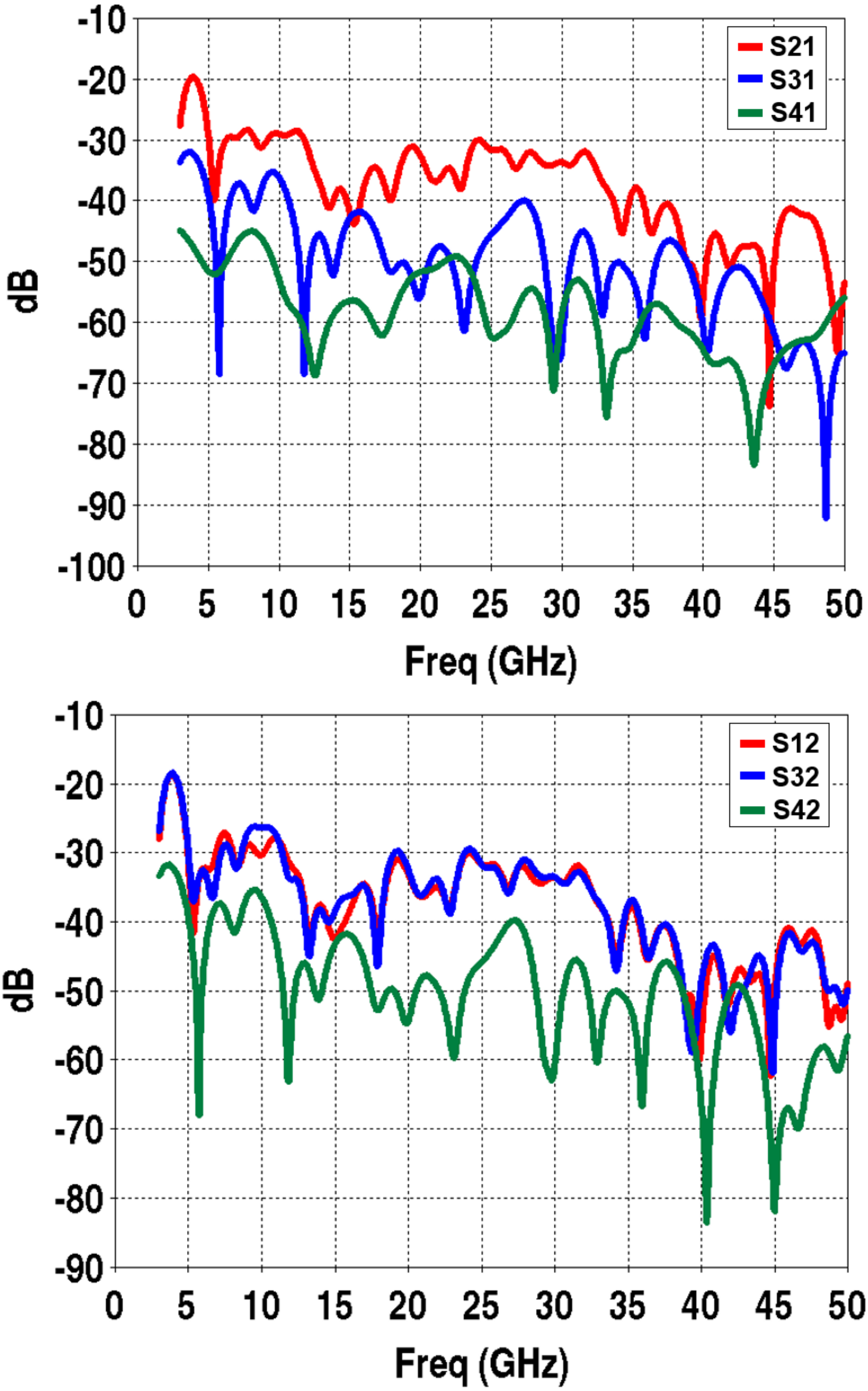


Fig. 26: Simulated isolation parameters of the second version of the 4 elements MIMO antenna.

4- CONCLUSIONS

In this article, a couple of 2 elements parallel ports MIMO antennas, 2 elements polarization diversity MIMO antenna, and a couple of parallel ports 4 elements MIMO antennas have been presented. The first 2 elements parallel ports MIMO antenna without isolation increment techniques has isolation better than 15 dB in almost the whole band of (3.1-20 GHz). The second 2 elements parallel ports MIMO antenna with isolation increment techniques (with separated ground plane and two isolation L lines), has isolation better than 24 dB within the whole band of (3.1-20) GHz. The two elements polarization diversity MIMO antenna has isolation better than 20 dB in the entire band of (3.1-20) GHz. The first 4 elements parallel ports MIMO antenna without isolation increment techniques, works very well within the (5-20) GHz band with isolation better than 15 dB. The second version of the 4 elements parallel ports MIMO antenna with isolation increment techniques has isolation of 20 dB within the working band. Simulations using CST Software show that these antennas work well up to 50 GHz. We have not attempt to increase the simulation range to a higher frequency.

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