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New Ultra wideband Butterfly Patch Antenna for Application of Upgrading Mobile Networks

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ABSTRACT

This paper presents a compact Butterfly patch Antenna which covers 4G, 5G, 6G and millimetre wave bands. The patch radiator is shaped from butterfly which consists of three ellipses and fine circles. The study of a single element and two MIMO elements are presented to obtain the radiation characteristics of the proposed antennas. In this paper it will be used Roger RT/5880 substrate to achieve the ultra-wide band applications. Such that the Roger RT/5880 substrate material with dielectric constant ε_r= 2.2. The proposed antenna cover bands (5-57.2GHz), (57.2- 63.9 GHZ) and (63.9- 270GHz) .The antenna has achieved maximum gain is about 10dB. The single and MIMO antenna is modelled and simulated by CST®2020 and the result compared by HFSS simulation program.

1. Introduction

The predicted mobile population will be raised over the years, requiring higher data rates, bandwidth and channel capacity.to satisfy this requirements, The Federal Communication Commission (FCC) specifies the frequency bands of millimeter wave that from 30GHz to 300GHz.[1]. Federal Communications Commission had specified the millimeter wave groups 24GHz, 37GHz, 39GHz, and 47GHz bands. At world radio communication in 2015 the bands have been discussed that are 24.25-27.5GHz, 31.8-33.4GHz, 37-40.5GHz, 40.5-42.5GHz, 45.5-47 GHz, 47-47.2GHz, 47.2-50.2GHz, 50.4-52.6GHz, 66-76GHz, and 81-86GHz [2]. Also recently it recommends that from 95 GHz to 3THz is dedicated to next 6G that recommended for use in the year 2030. The demand for high transmission has increased enormously channel capacity in the last few years has been observed. The research focus was geared towards the development of MIMO antennas. MIMO's desirable properties involve high-performance individual elements that better suit impedance and improve the separation of components [3]. In the literature, several MIMO antennas have been reported. Ultra-wideband (UWB) communication systems like UWB banded antennas [4]. In [5], multi-band mm-wave antenna to combine 5 G with Wi Gig apps in mobile or tablet applications at 38GHz and 60GHz. In [6], 2×2 MIMO antenna array for 5G applications tri-band is presented. It consists of two orthogonally-placed compact tri-band 28/38/60 GHz antennas with the realized gain varying between 3.5 and 8.5 dB over the operating frequencies. In [7], design of a (5G) antenna arrays for future which operate at 28 GHz, 38 GHz and 60 GHz as well as the millimeter wave (mm Wave) bands of 70 GHz and 80 GHz. Many techniques in designs were tried to reduce the mutual coupling of elements. Many techniques in designs were tried to reduce the interconnection of elements as using electromagnetic band gap (EBG) structure [8]. In [9], a structure based on complementary split-ring resonators (SRRs) is produced to reduce the mutual coupling between two microstrip antennas that radiate in the same frequency band. In [10],

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Table1: Comparison with related work

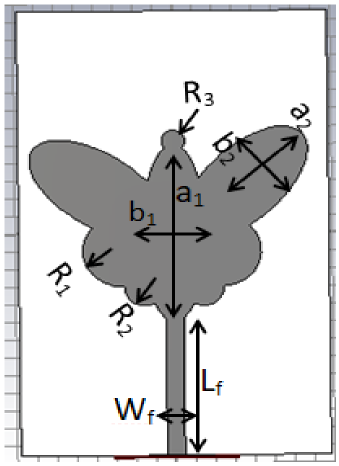
Ref. no	Freq. (GHz	BW (GHz)	Gain of two elements (dB)	Eff. (%)
[7]	28, 38, 60, 70, and 80	68.67	6.37, 8.248,	-
[11]	38 -60 GHz	2 at 38 GHz -3.2 at 60GHz	6.5 - 5.5	-
[12]	28, 33 and 38	-	10.58, 8.87 ,and11.45	70 %
[13]	30 and70	-	4.8	-
This work	28, 38, 60, 70, 80, 95, beyond 100	77GHz(23:100GHz) -130GHz(100:230 GHz) -45.7GHz (5.3:51GHz)	7.564, 5.056, and 7.178 4.6, 6.95, 7.7	96.8% in four case over UWB design

The mutual coupling in reduced by adding I- shaped resonator in the same plane of microstrip radiator. Table 1 below refers to the comparison between this work and other work which shows that this work has very wide band width, efficiency and also with high gain.

In this paper, a new compact butterfly single element is introduced that support 5G requirements of wide bandwidth at 28GHz, 38GHz, 60GHz and millimetre wave bands at 70GHz and 80GHz. Also the design supports the next evolution of communications of 6G band from 95 GHz to 3THz according to the recommendation of FCC. The antenna has been studied by using Roger 5880 substrate to show its effect on impedance matching, gain, radiation pattern and efficiency. A two elements MIMO is simulated by CST® studio software 2020. This research is proposed four cases of two element configuration designs to improve the mutual coupling between two elements.

2. Antenna Design

In the paper a new compact design antenna is modelled to cover 5th generation bands 28GHz, 38GHz, 60GHz and mm Wave bands 70GHz, 80GHz and also expanded beyond 100GHz.The shape of the patch taking shape butterfly that combined from union of three ellipses and five circles as shown in Fig.1. The type of the substrate is one of important steps in antenna design whereas the height (h), dielectric constant (ε_r) and loss tangent ($tan\delta$) of substrate have big effect on antenna bandwidth and impedance matching. This paper present design with Roger RT-5880 substrate with height$h = 0.8\ mm$, $tan\delta\ = 0.0009$ and ε_r= 2.2 The design presented by Roger RT-5880 substrate with dimension $15.3 \times 25 \times 0.8mm^3$ with ground length= $7.5\ mm$. Table 2 shows the optimized dimensions of proposed antenna.



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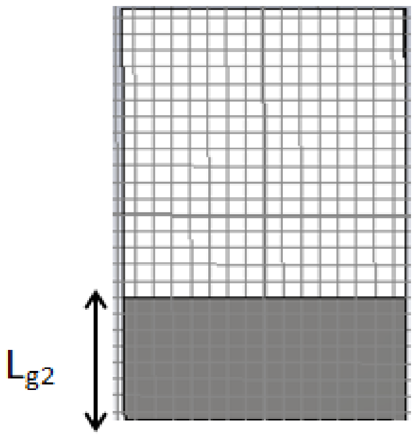


(b)

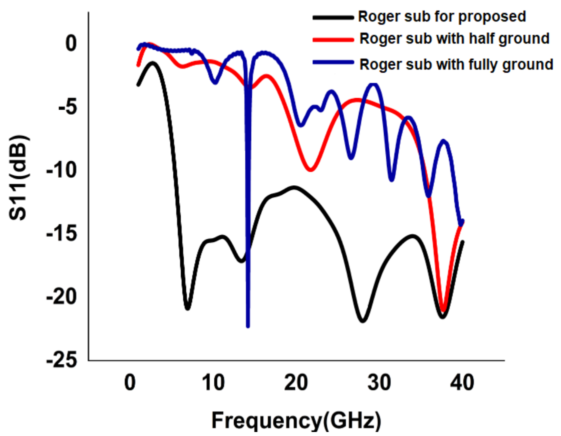
Fig. 1: the Proposed Antenna (a) Top View (b) Bottom View For Roger Substrate.

Table 2: Dimension of Butterfly proposed antenna

parameter	Dimension (mm)	**parameter**	Dimension (mm)
a_1	1.6	**R_2**	0.85
b_1	5	**R_3**	0.6
a_2	2	**L_f**	8
b_2	4	**W_f**	0.9
R_1	2		

2.1 Parametric Study of proposed antenna

In this section a parametric study about the ground plane of the proposed antenna with Roger material. Fig 2(a) shows the different between fully, half and partially ground. From this result, the partially ground achieves the good matching at 28 and 38 GHz. Also parametric studies are applied to the major and minor dimensions of the presented butterfly patch. The optimized dimension of a_1, b_1, a_2, and b_2 are shown in Table2. Fig 2 (b& c) Show the change of the dimension of ellipses (wings of butterfly patch) where confirms that a_2= 2mm and b_2= 4mm are better choices. Also, for the better dimension of middle ellipse that confirm the results are a_1= 1.6mm and b_1=5 mm. that also showed any decrease and increase in dimension by 1mm leads to shift far from the proposed frequencies.



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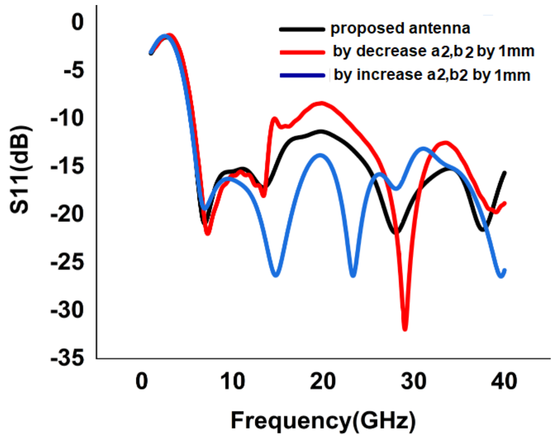

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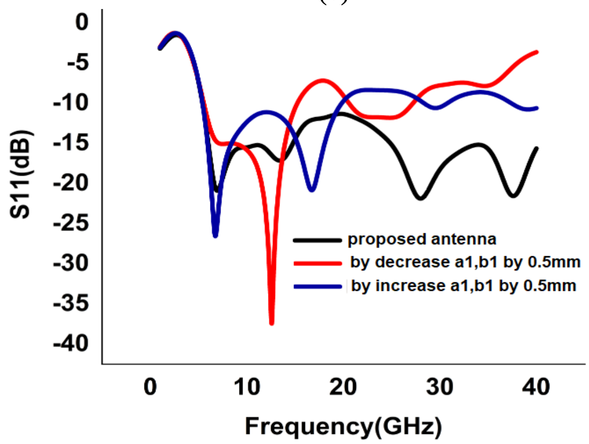


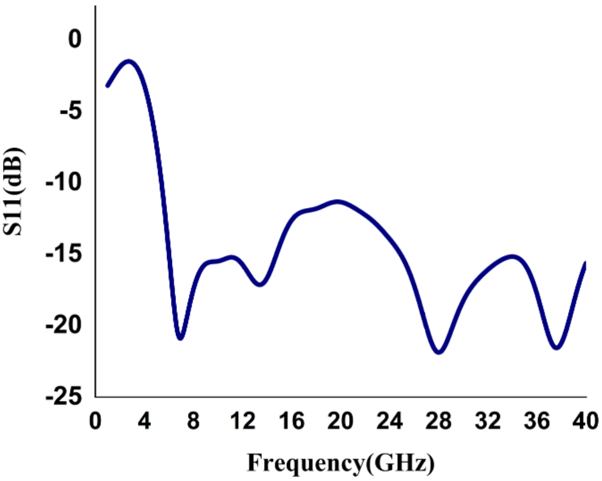
(c)

Fig 2:A parametric study (a) ground plane, (b) besides ellipses, (c) middle ellipse

2.2 *S-Parameter*

This section illustrates choosing the suitable length of ground planes which $7.5 \times 25\ mm^2$ for Roger RT5880 substrate. Figure3 illustrates the return loss of proposed antenna at 4^{th} generation, 5^{th} Generation (28 GHz, 38GHz and 60GHz) and mm Wave bands (70GHz and 80 GHz). Also it extended to include 6^{th} Generation bands which was identified by the U.S. FCC recommends that frequencies higher than 5G, such as 95 GHz to 3 THz. These figures showed ultra-wideband for over all the frequencies.

Fig.3 (a-d) shows the study of matching impedance and the bandwidth on the proposed butterfly antenna where: at Fig 3a shows band (5-40 GHz), at Fig 3b shows band (40-100 GHz), at Fig 3c shows bands (100- 200GHz) and at Fig 3d shows bands (200-270GHz). All of these figures show broad band response with an overall -10dB band width. It’s clear that after 300 GHz the curve of return loss becomes approach to distortion wave as shown in Fig 3(d).



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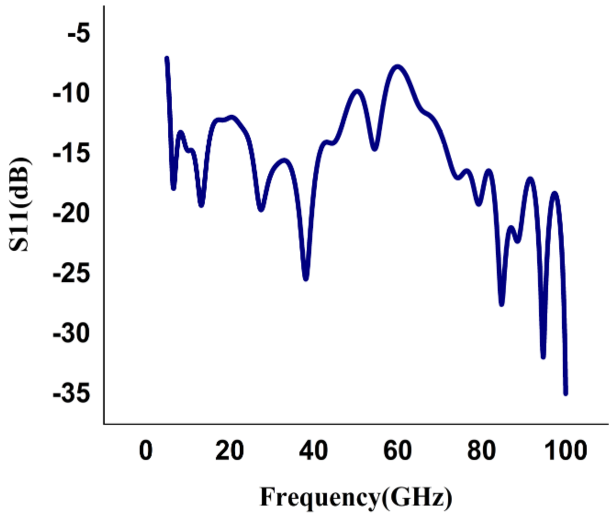

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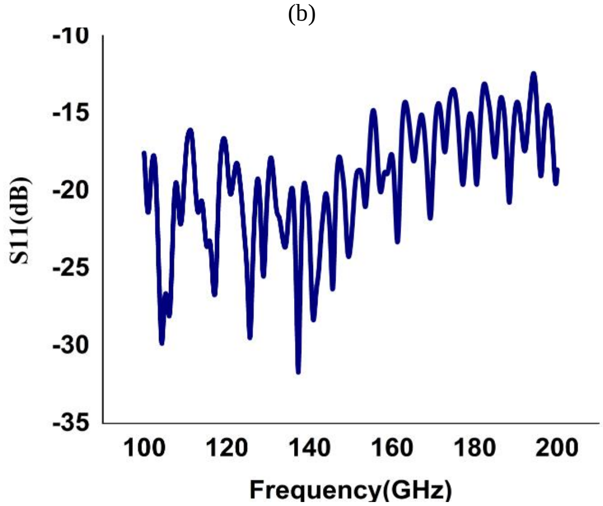

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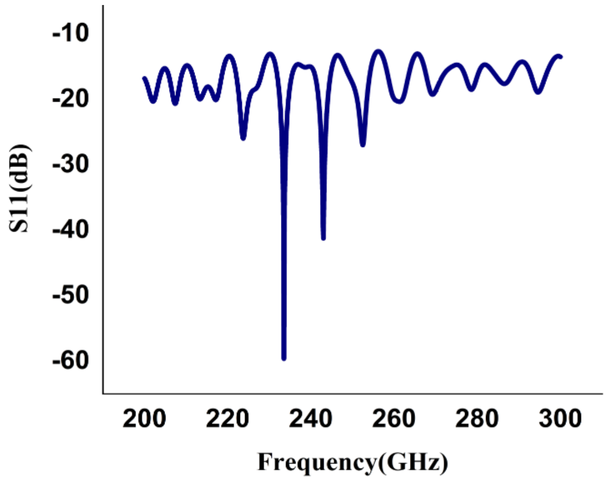


(d)

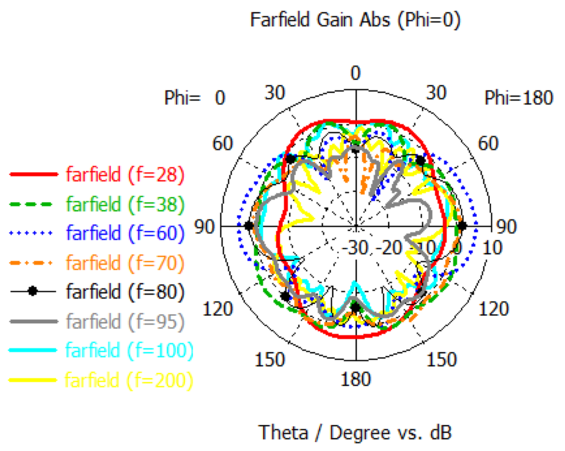
Fig 3: The return loss over all frequencies of the proposed antenna

2.3Radiation patterns and Gains

Fig 4 illustrate the gain pattern of the single butterfly antenna in both E-Plane ($xy, \varphi = 0$)and in the plane that normal to antenna plane H-Plane ($xz, \theta = 90°$) that discussed in this section. Table 3 shows the gain of the presented butterfly antenna. It’s noticed that from this table, the gain of this antenna is suitable for 5G mobile bands and mm Wave communications. The proposed antenna achieves better gain by increasing the frequency where at 28GHz achieve 5.196dB and increase to 11.21 at 200GHz.

Table3: The gain Roger RT/5880 substrate.

Frequency bands(GHz)	*Gain of Roger RT/5880 substrate with ground length* $= 7.5mm$ *(dBi)*
28	5.196
38	5.665
60	6.861
70	8.115
80	8.881
95	8.585
100	10.06
200	11.21



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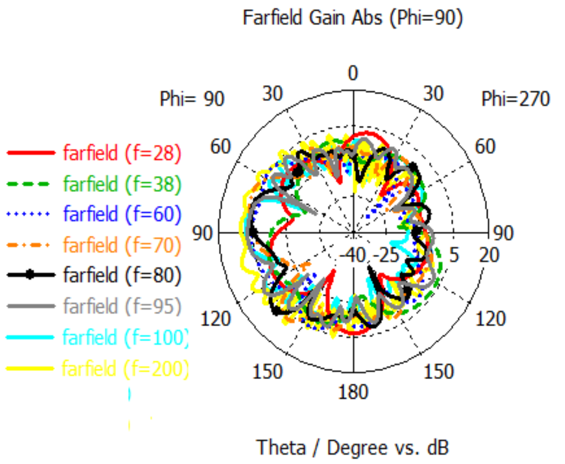


(b)

Fig. 4:Gain pattern of proposed single element butter fly antenna (a) E-plane Roger5880, and (b) H-plane Roger5880

2.4 *Efficiency*

Fig 5 shows the radiation and the total efficiencies of the proposed butterfly antenna. The values of radiation efficiency and total efficiency are mentioned in Table 4. From these results note that the efficiency of the proposed butterfly antenna is about 98% over all frequencies

Table4: Radiation Efficiency and Total Efficiency for proposed antenna

Frequency (GHz)	Roger	
	Rad eff. %	Total eff. %
28	98	97.40
38	98.66	98.52
60	98.77	90.04
70	99.15	96.6
80	98.85	98.14
95	98.10	98
100	97.70	97.69

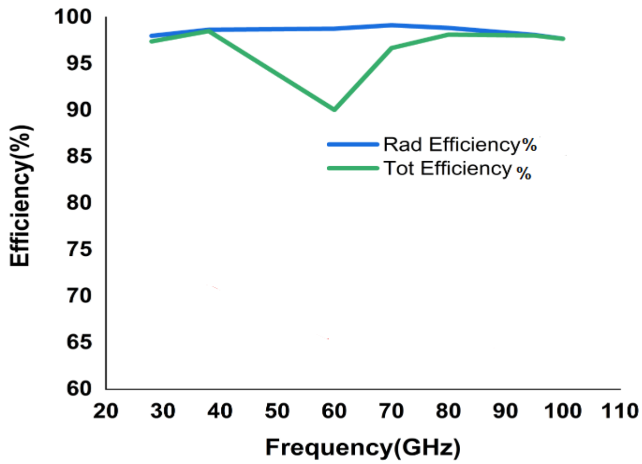


Fig. 5: Rad and Tot efficiency in two different substrates in percentage

The results are obtained by two different simulation programs as shown in Fig 6. The two simulation programs are CST®2020 and HFSS which are basically different where one of them depend on FIT “finite integrated technique” and the other depend on FDTD “finite difference time domain”. From this result notes that there are a slight difference between results due to the different analysis method of each simulation program.

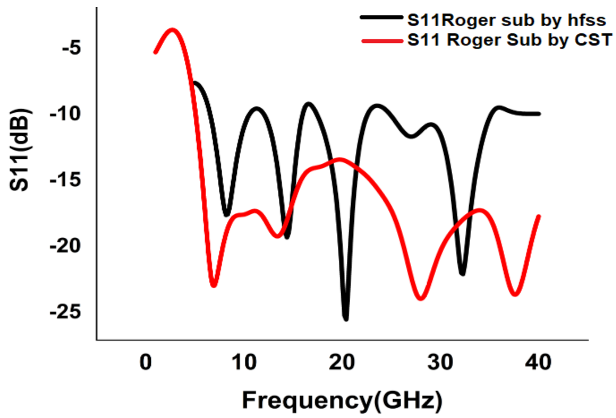
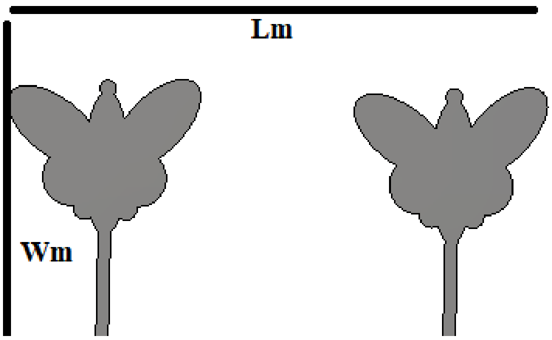


Fig 6 comparison between using two different ways of simulations Roger RT5580 material

3 Two Element MIMO Design

In this section, the design of two element antenna is presented. The results of proposed antenna are studied by using substrate (Roger RT/5880). The two patches are simulated on substrate (Roger RT/5880). with ground plane dimension $W1m \times Lm = 7.5 \times 40\ mm^2$. This design studied by several ways to improve the mutual coupling. Fig 7 shows the configuration of proposed antenna. The two antennas are feeding by two microstrip feed lined that achieved 50Ω to keep good matching impedance.

A- Case1



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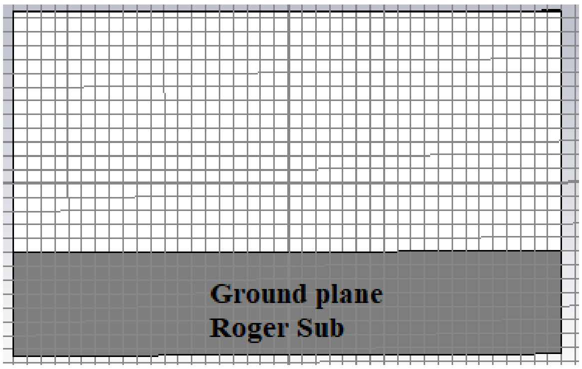
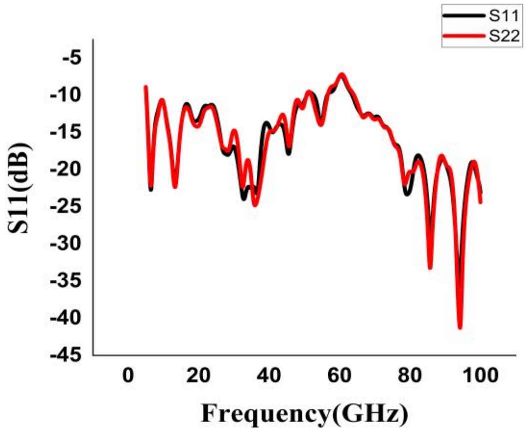


(b)

Fig. 7: the configuration of simulated proposed MIMOantenna (a) front plane , (b) ground plane

in case 1, the two ports of butterfly patches are on the same direction which the inter element spacing is λ with respect to 28GHz. Figure 8(a) presents the S-parameter of two element where it was calculated up to 100 GHz, which shows the broadband response over all -10dB, it's cleared that the bandwidth of antenna remains unchanged like single element design because of the correct inter-element spacing selection. The mutual coupling between two elements array is< -12.48dB that presented at Fig 8(b). The gain is about 5.230dB to10.34dB, and the efficiency is about 87.7% to 96.5% for the MIMO.



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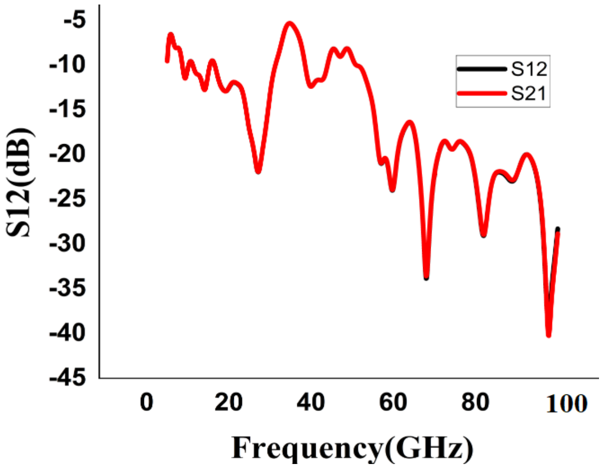
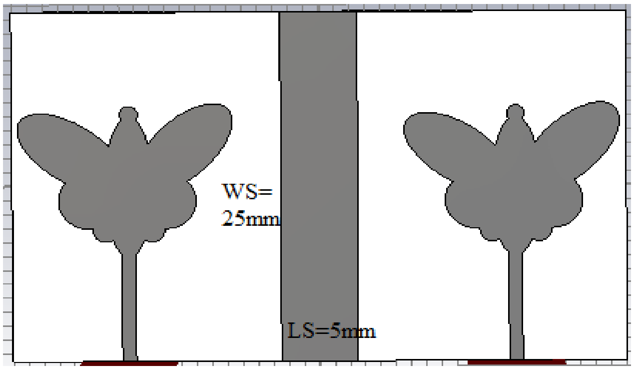


(b)

Fig. 8: Comparison between two elements S-parameter (a) return loss and (b) mutual coupling

B- Case 2

To improve the mutual coupling between two elements, a rectangle plate is added in the middle distance between two patches on the top of the substrate as shown in Fig 9. The dimensions $WS \times LS = 25 \times 5mm^2$ where LS=0.5λ with respect frequency of 28GHz. Figure11 introduces broad band of 100GHz. The mutual coupling between two elements is < -20 dB. The gain is about 4.856dB to 10.24dB and efficiency is about 87.62% to96.8% for the MIMO antenna.



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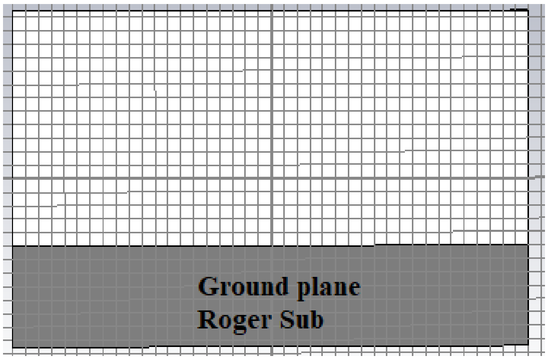
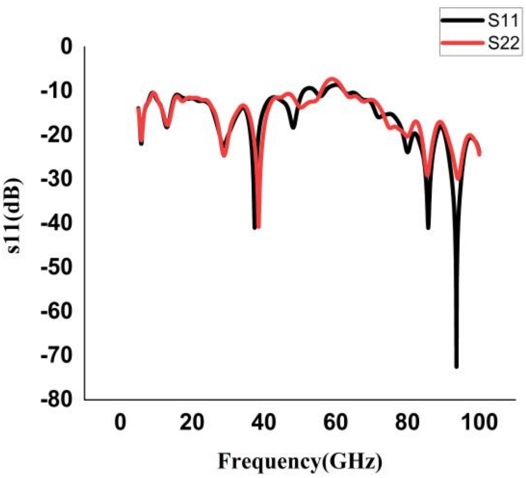


Fig.9: Simulated two elements MIMO with rectangular slot.(a) patch antenna, (b) Ground Plane.



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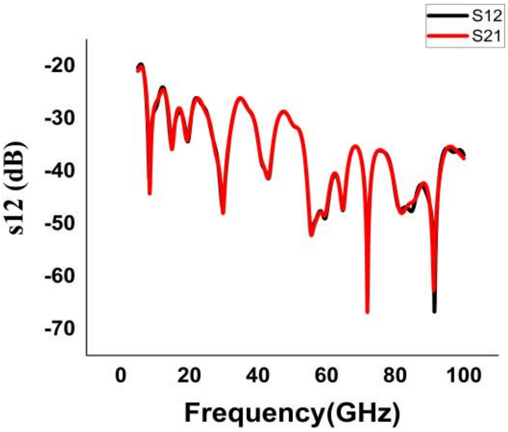
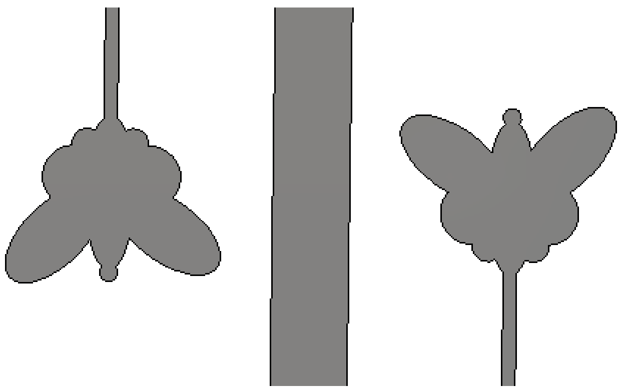


(b)

Fig 10: Two elements S-parameters for second case(a) Return loss and (b) Isolation between elements

A- Case 3

In case 3, MIMO antenna also keeping on the properties of antenna to operate on the same frequencies and achieving wideband beyond to100 GHz to support next generation (6G).The orientation of the two MIMO elements is adjusted to achieve better isolation as shown in Fig 11. the mutual coupling between two elements is < -24.6 dB as shown in Fig (12a-b). The gain varying between 5.1dB and 10.67dB over all frequencies range up to 100GHz and efficiency is from 88% to 97% which suitable to support high data applications.



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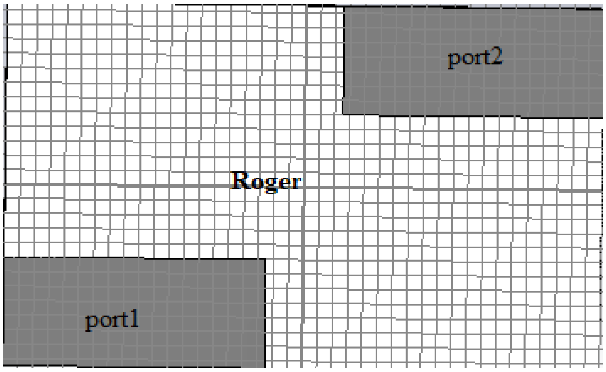
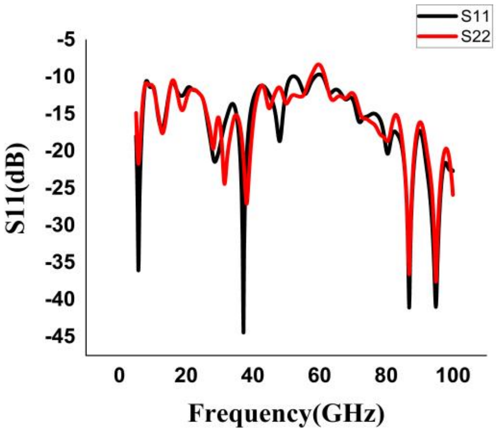


(b)

Fig. 11: The configuration of proposed Antenna by oriented one of the patches.



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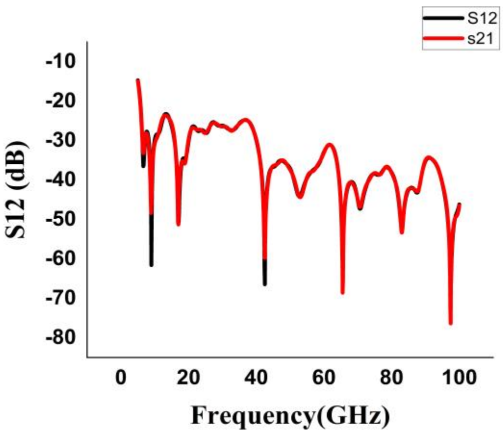


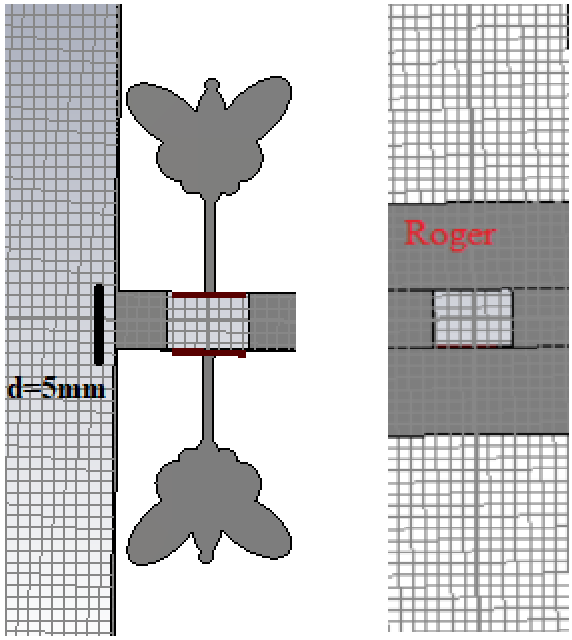
(b)

Fig. 12: Comparison between proposed oriented antenna (a) Snn and(b) Smn

A- Case4

In case 4, a new geometric configuration of two elements MIMO antenna have been proposed on Fig. 13. This Figure illustrates the two elements are opposite each other while the substrate of each patch is separated. Also, the spacing between the two patches is a gap which is etched in ground plane. The length of the gap is 5 mm which equal approximately λ/2 with respect to 28GHz. Further, the dimension of ground is $7.5 \times 25 mm^2$. Fig 14(a) presents a study of impedance matching of proposed MIMO.

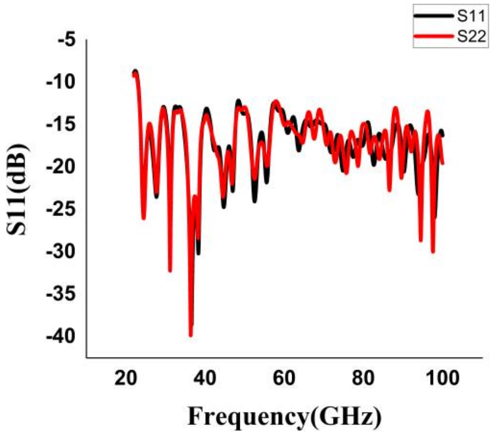
It's shown from these figures that the matching is lost from 14.7GHz to 20.9GHz. For the other band the matching is as shown above. The gain is about from 5.063dB to 10.35dB for proposed MIMO. And efficiency is about 91.8% to96.89% .



(a) (b)

Fig. 13:(a)front view of Antenna and,(b) back view for FR4 and Roger ground

Figure 14 (b) shows a good isolation between two elements where S21=S12 is about less than -33dB by CST simulation and less than -25dB by using HFSS simulator. Figure 15showed comparison between the gains of proposed MIMO two element antennas at four cases, it's clear that the gain of the proposed design is better for 5G and millimeter wave applications. As shown in Fig 16 comparison between S-parameters by using two simulation programs CST 2020 studio and HFSS. The difference in results is due to the different analysis method of each program in calculating the data. Such that the method of solution of the CST is FIT "finite integrated technique" counters to HFSS that use FDTD "finite difference time



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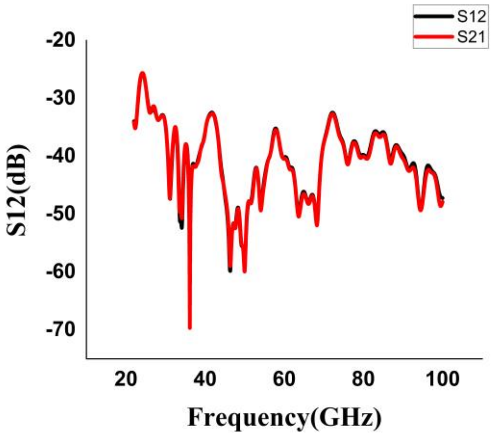


(b)

Fig. 14:comparison between two substrate (a) Snn, and (b)Smn

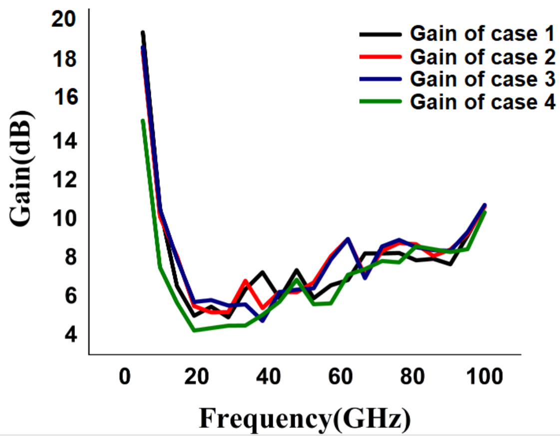


Fig. 15: comparison of realize gain at four cases of design of
two elements MIMO antenna

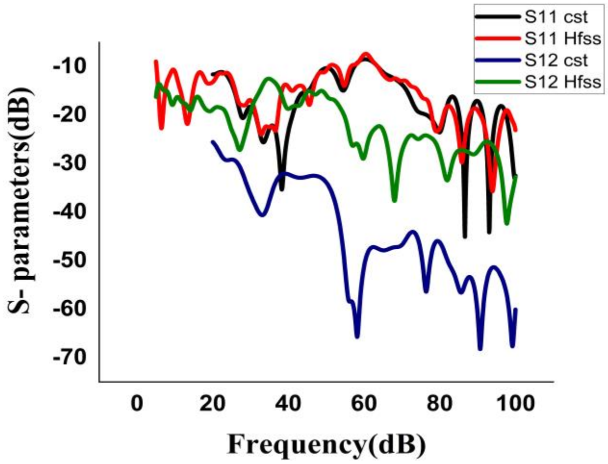


Fig 16: comparison of s- parameters by CST and HFSS simulation programs about case 4 in MIMO antenna design.

domain"

4 Envelop correlation coefficient and diversity gain

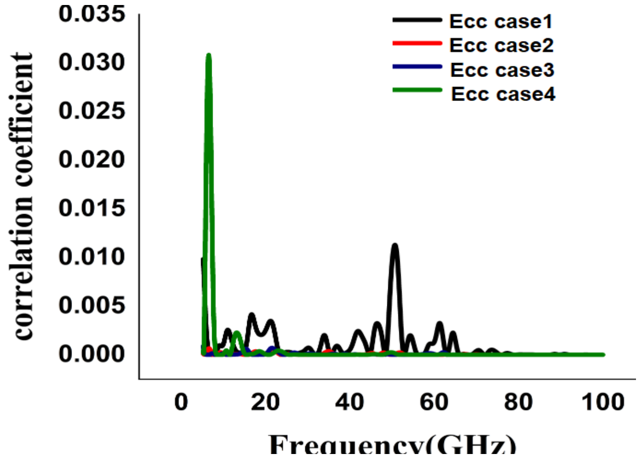
The envelope correlation coefficient (ECC), is conceded on of the most essential parameter of the MIMO antenna system, which quantifies multiple port efficiency. A lower ECC means more diversified patterns. For standard MIMO system the $ECC < 0.5$ to be acceptable. For two port MIMO antenna the ECC can calculate by

$$ECC(\rho) = \frac{|S_{11} * S_{12} + S_{21} * S_{22}|^2}{(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)} \quad (1)$$

Another important parameter in these systems has to be considered is diversity gain (DG) that is how much the transmission power can be reduced when a diversity scheme is introduced. Diversity Gain can be calculated from its relationship with correlation coefficient as:

Diversity Gain= $10\sqrt{1 - |\rho^2|}$ (2)

Fig 17 showed that the value of envelop correlation coefficient that approximately near to zero over all frequencies 28GHz, 38GHz, 60GHz, 70GHz, 80GHz , 95GHz,and 100GHz also the diversity gain is represented to be 10 over all this frequencies



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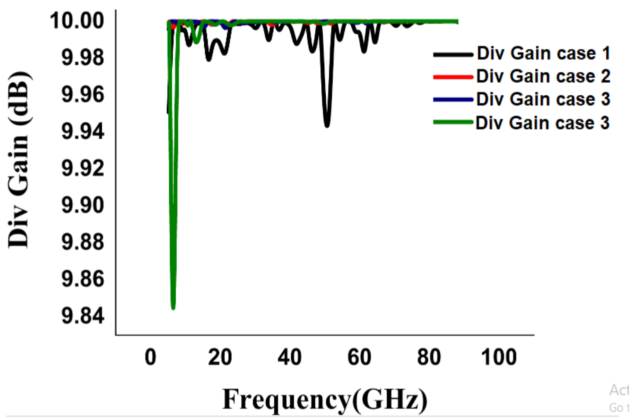

(b)

Fig.17: the two elements (a) ECC and (b) DG for the two substrates in four cases.

5 Conclusion

In this paper, a novel ultra-wide band butterfly antenna for future 4G, 5G, millimeter wave application and 6 G communication system. This paper showed the design of single and two element antennas by using Roger RT/5880 substrate with dielectric constant $\varepsilon_r = 2.2$. From the results, it's clear that the proposed design has achieved better performance with the 5 G Applications whereas the gain over all bands is about from 5dB to 11dB for single element and it has achieved maximum efficiency is about 98.52%. In addition to the 2-elements MIMO design the gain over all bands is about from 6dB to 12dB which achieved a better performance.

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