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# GAIN AND BANDWIDTH ENHANCEMENT WITH DUAL-PORT UWB-MIMO MICROSTRIP ANTENNA FOR SATELLITE COMMUNICATIONS

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*Abstract*
***In this paper, a compact (22×22×1.6 mm3) dual-port UWB (Ultra-wide-band) MIMO (Multiple-input-multiple-output) microstrip antenna are perceived with gain, bandwidth and isolation enhancement for downlink of the X-band satellite communications. The proposed MIMO antenna system consists of two identical glue gun-shaped radiating element associated with ground plane as well as co-axial feeds. Four antenna designs (A1-A4) are systematically inspected of proposed antenna (A4) have been elevated for desired antenna parameters and operations. The proposed and measured dual-band behavior at (7.99-8.38) GHz and (9.10-12.97) GHz with impedance bandwidth of 5.13% and 35.07% respectively for port-1 and (7.96-8.39) GHz and (9.10-13.03) GHz with impedance bandwidth of 5.13% and 35.51% respectively at port-2 is observed and moreover achieved the pent-resonances has 8.10 GHz, 9.65 GHz, 10.92 GHz, 11.97 GHz and 12.61 GHz with peak gain of 2.67 dBi, 6.78 dBi, 5.90 dBi, 5.03 dBi and 3.79 dBi respectively at port-1 and 8.10 GHz, 9.65 GHz, 10.92 GHz, 11.97 GHz and 12.61 GHz with peak gain of 2.67 dBi, 6.78 dBi, 5.90 dBi, 5.03 dBi and 3.79 dBi respectively at port-2. The proposed antenna has minimum isolation less than -15 dB (a major portion < -20 dB), envelope correlation coefficient (ECC) less than 0.0451, diversity gain (DG) between 9.954-9.996, total active reflection coefficient (TARC) less than -10 dB, antenna gain varies in the range of (2.67-6.78) dBi and radiation efficiency up to 75% is obtained during the entire operating frequency bands. The simulated and measured results of the proposed antenna have been validated and minor deviation between simulated and measured results has been observed. The proposed design is simulated on FR-4 epoxy substrate ($\varepsilon_r$= 4.4, tan δ = 0.02 and h = 1.6 mm) with carried out by ANSOFT HFSS 13 electromagnetic solver.***

***Keywords:***
***MIMO Antenna, Radiation Efficiency, DG, ECC and TARC***

## 1. INTRODUCTION

The rapid explosion of wireless devices is to enhance the data along with superiority of transmission rate [1]; UWB (Ultra-wideband) technology has appeared as a prevalent power efficient of wireless communication scheme. UWB system has the gain of low cost, high data rate, low power consumption, low complexity, and good time domain resolution [2]. Though, the problem of multipath channel fading still remains in UWB, and it can be disputed by merging UWB and multiple-input-multiple-output (MIMO) technologies conniving a compact UWB-MIMO antenna which assemblages to portable wireless devices is a leading challenge, as thoroughly placed radiating patches suffer from reduced inter-element isolation [3]-[4].

Nowadays, UWB-MIMO antenna has drawn a lot of consideration due to its prospective to enhance the capacity and reliability of the wireless communication system. Mutual coupling is frequently undesirable since it affects the performance of the MIMO antenna and antenna array system [5]. The relationship between the array elements/MIMO elements decreases the system performance by increasing mutual coupling; envelop correlation coefficient, channel capacity loss and falling diversity gain and varying the radiation pattern [6]-[7]. This problem may ascend when antennas are sited neighboring, UWB-MIMO antenna comprises at least two spaced radiating elements with the intention of succeeding good isolation between them. Though, the existing space is inappropriate for practical portable devices. In this appreciation, lots of techniques have been espoused to lower the mutual coupling between UWB-MIMO elements [8]-[9]. With the impartial of higher consistency and functionality, quite a lot of techniques have been newly introduced to reduce the inter-element coupling and consequently, increase isolation [10].

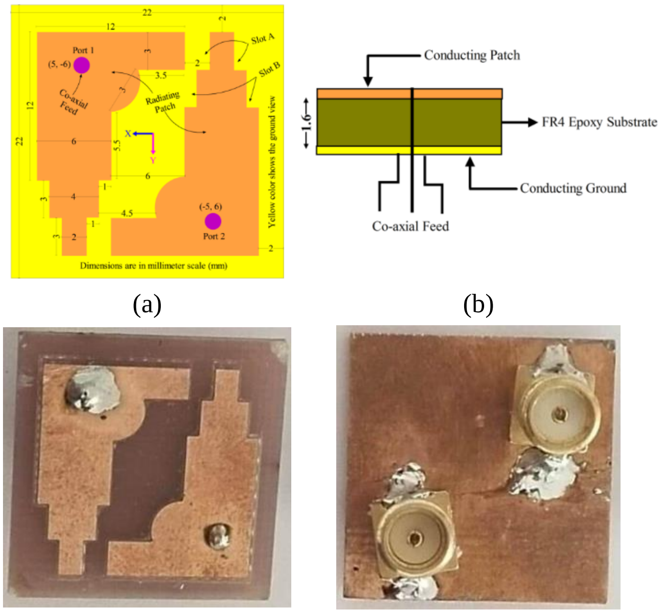
Alternatively in expectable transmission systems, the transmitter and receiver face degradation problem in the transmission medium that cause multipath propagation. Therefore, the most possible selection for solving this multipath problem is the multiple input multiple output (MIMO) technology [11]-[12]. It has the proficiency to use many diversity methods to increase the consistency of the transmission links by shrinking the multipath fading issue [13]. Some MIMO configurations described in the literature, consume different categories of decoupling structures to achieve low mutual coupling between radiating elements such as slots [14], parasitic elements [15] and meandered lines strips [16], etc.

Quite a few methods for reducing mutual coupling between radiating components in MIMO antenna systems have been described, including the use of defected ground structures and orthogonal orientation-based designs [17]. MIMO technology has convinced benefits, together with data transfer at high speeds, inexpensive cost, and simplicity of production. Though, such a foremost area of technology grieves from multipath fading in factual executions [18]. This standard is constructed on MIMO communication technology which has received considerable attention as a practical method to significantly growth of wireless channel capacity without added power and spectrum. Consequently, it will be an actual challenging assignment to design a MIMO antenna with lesser size while finding a very high isolation coefficient [19]. In strip and slot-clipping with the basis of radiating elements to enhance isolation is accessible, most of in that way produce within 10-20 dB isolation between antennas, so it has been validated to be sufficient for as protracted as dressed enhance in MIMO capability [20]. The problem becomes starker when nearby is a shared ground plane. Sinking mutual coupling in compact UWB devices is stimulating and techniques such as neutralization line [21], electromagnetic band-gap (EBG) structures [22], meta-materials [23], decoupling and identical networks become less reasonable as these are additional auspicious for narrowband and wideband MIMO antennas [24]. Some designs addressing broadband applications such as satellite, mobile, radiolocation, etc. as well as their parametric study have been distributed [25]-[26].

In this communication, two identical glue gun-shaped radiating element associated with ground plane as well as co-axial feeds. The two identical shaped are arranged orthogonally to maximize the inter-connection element. Proposed MIMO antenna is designed and simulated by means of electromagnetic tool "High Frequency Structure Simulator" (HFSS) v13 by AnSoft.

## 2. DESIGN APPROACHES AND PROGRESSION OF PROPOSED ANTENNA STRUCTURE

The proposed antenna has an orange color (upper-outlook) of radiating elements; yellow color (lower-outlook) of ground plane and green color (middle-outlook) of FR-4 epoxy substrate along with entire geometrical specifications are exhibited in Fig.1(a) and Fig.1(b). The dimensions of these antennas ($A_1$-$A_4$) in millimeter scale are clearly displayed in Fig.1. The proposed design has two radiating elements by using co-axial feed with 50 Ω characteristic impedance.




(a) (b)

(c) (d)

Fig.1(a-b). Upper-view (orange), lower-view (yellow), middle-view (green) and (c) fabricated upper-view, (d) fabricated lower-view of the proposed antenna ($A_4$)

Step-wise progression path to achieve the proposed design are cited in Fig.3(a) and likewise in Table.1. Antenna-1 ($A_1$) is acquired by designing with deform of simple rectangular shaped radiating structure (Fig.3(a) and Table.1). Antenna-2 ($A_2$) is achieved by presenting two parallel symmetrical rectangular slots A (2×3mm$^2$) cut in radiating elements on Antenna-1 (cf. inset Fig.3 (a) and Table.1). Antenna-3 ($A_3$) is obtained by Antenna-2 with two parallel symmetrical rectangular slots B (1×3mm$^2$) cut in the radiating elements on Antenna-2 (Fig.3(a) and Table.1). Antenna-4 ($A_4$) (proposed) is originating from Antenna-3 with adding a circle diameter of 3 mm in radiating elements on Antenna-3 (Fig.1 and Fig.3(a) and Table.1). Two symmetrical designs are separated by a spacing (2 mm) of the radiating patches to create a MIMO structure and these antennas ($A_1$-$A_4$) are designed with FR-4 epoxy substrate ($\varepsilon_r$=4.4, tan$\delta$=0.02 and $h$=1.6mm) with simulated by Ansoft HFSS version 13.

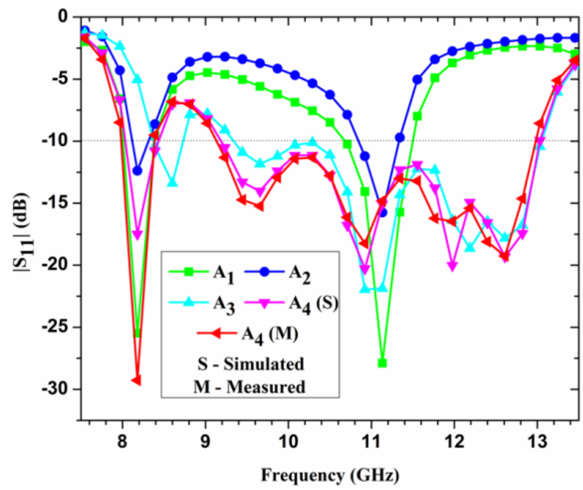
## 3. RESULTS AND DISCUSSION

The proposed model of antenna has been fabricated on FR4-epoxy substrate (Fig.1(c) and Fig.1(d)) and tested using the Rohde and Schwarz Vector Network Analyzer ZNB40 for measurement of scattering parameter and anechoic chamber is used to measure the gain. The proposed model of antenna is validated and simulated by using ANSOFT High-Frequency Structure Simulator (HFSS) version 13 software. The proposed model is considered in expressions of return loss (in terms of $S_{11}$ and $S_{22}$), radiation efficiency, gain, current distribution, mutual coupling between ports (in terms of $S_{12}$ and $S_{21}$), envelope correlation coefficient (ECC), radiation pattern, diversity gain (DG) and total active reflection coefficient (TARC).

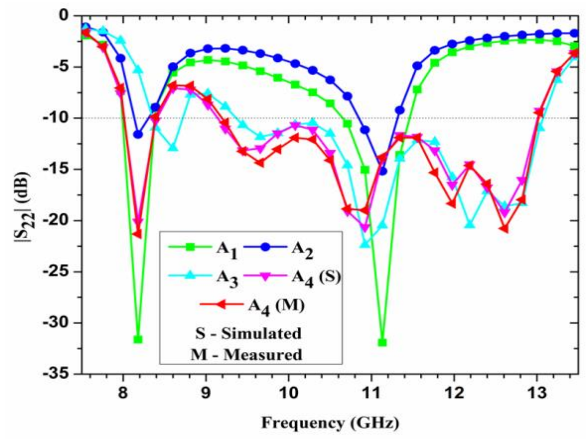
Whole antennas ($A_1$-$A_4$), dual-band operation is observed. Table.1 signifies the data in expressions of operating band (in GHz) with impedance bandwidth (in%), isolation (or mutual coupling between the ports in terms of $S_{12}$ and $S_{21}$ and both scheming in dB), resonant frequency (in GHz), reflection coefficient (in dB) and peak gain (in GHz) of antennas ($A_1$-$A_4$) at both ports, i.e., port 1 and 2 for ready reference.

### 3.1 RETURN LOSS AND MUTUAL COUPLING (BETWEEN THE PORTS) OF THE ANTENNAS

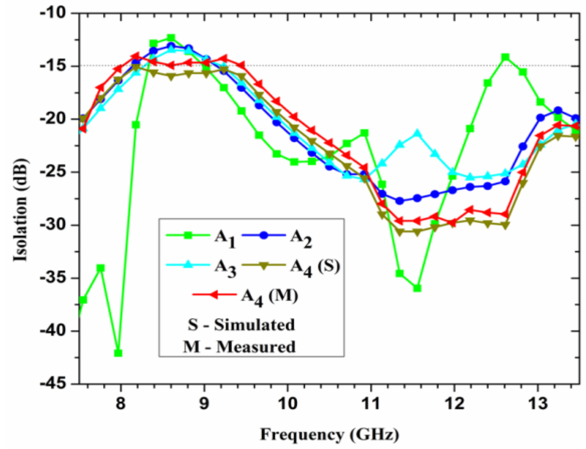
The Fig.2(a)-Fig.2(c) represents the simulated return loss ($|S_{11}|$ and $|S_{22}|$) and mutual coupling ($|S_{12}|$ and $|S_{21}|$) between the antenna mechanisms at mutually port 1 and 2. In proposed MIMO arrangement with a dual-band behavior (7.99-8.38) GHz and (9.10-12.97) GHz with impedance bandwidth of 5.13% and 35.07% respectively for port-1 and (7.96-8.39) GHz and (9.10-13.03) GHz with impedance bandwidth of 5.13% and 35.51% respectively at port-2 is observed, the proposed second operating band (9.10-12.97) GHz and (9.10-13.03) GHz at port 1 and 2 respectively, both are shows the ultra-wideband (UWB) characteristics, and entire proposed band of $|S_{11}|$ and $|S_{22}|$ is <-10 dB and $|S_{12}|$ and $|S_{21}|$ is < - 15 dB (a major portion < -20 dB) is observed (cf. Fig.2(a)- Fig.2(c) and Table.1).




(a)




(b)




(c)

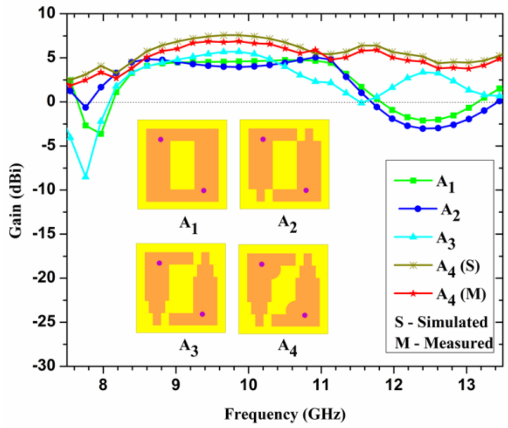
Fig.2. Simulated and Measured analysis of (a) $|S_{11}|$, (b) $|S_{22}|$ and (c) Mutual coupling (between the ports in term of $|S_{12}|$ or $|S_{21}|$) versus frequency curve of the antennas ($A_1$-$A_4$)

## 3.2 SCATTERING PARAMETER AND GAIN

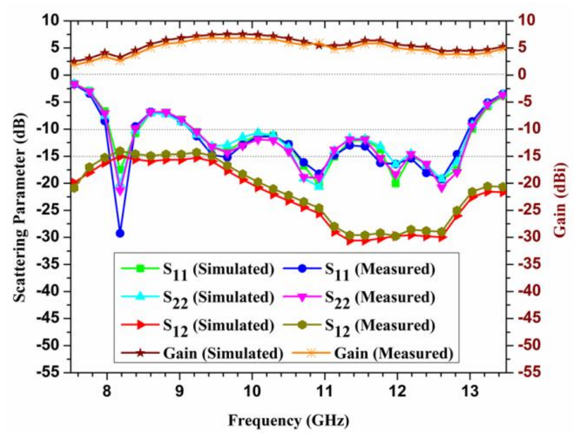
Compared these antennas ($A_1$, $A_2$, $A_3$ and $A_4$), the performance of antenna $A_4$ is superior in terms of impedance bandwidth, peak gain, reflection coefficient and isolation, proposed band and gain characteristics of A4 are identical at both the ports with marginal difference, whereas the variation of proposed antenna ($A_4$) in term of bandwidth, gain and isolation are larger as compared to antenna $A_1$, $A_2$ and $A_3$ (cf. Fig.2(a)- Fig.2(c) and Fig.3(a)- Fig.3(b) as well as Table.1]. The proposed and simulated dual-band behavior at (7.99-8.39) GHz and (9.10-13.04) GHz with impedance bandwidth of 4.88% and 35.59% respectively for port-1 and (7.97-8.39) GHz and (9.10-13.04) GHz with impedance bandwidth of 5.13% and 35.59% respectively at port-2 is observed and moreover achieved the pent-resonances of simulated has 8.10 GHz, 9.61 GHz, 10.89 GHz, 11.94 GHz and 12.57 GHz with peak gain of 3.27 dBi, 7.55 dBi, 5.48 dBi, 5.68 dBi and 5.94 dBi respectively at port-1 and 8.10 GHz, 9.40 GHz, 10.89 GHz, 11.94 GHz and 12.55 GHz with peak gain of 3.27 dBi, 7.43 dBi, 5.48 dBi, 5.68 dBi and 5.94 dBi respectively at port-2 [cf. Fig.3(a)- Fig.3(b) or as well as Table.1]. The proposed and measured dual-band behavior at (7.99-8.38) GHz and (9.10-12.97) GHz with impedance bandwidth of 5.13% and 35.07% respectively for port-1 and (7.96-8.39) GHz and (9.10-13.03) GHz with impedance bandwidth of 5.13% and 35.51% respectively at port-2 is observed and moreover achieved the pent-resonances has 8.10 GHz, 9.65 GHz, 10.92 GHz, 11.97 GHz and 12.61 GHz with peak gain of 2.67 dBi, 6.78 dBi, 5.90 dBi, 5.03 dBi and 3.79 dBi respectively at port-1 and 8.10 GHz, 9.65 GHz, 10.92 GHz, 11.97 GHz and 12.61 GHz with peak gain of 2.67 dBi, 6.78 dBi, 5.90 dBi, 5.03 dBi and 3.79 dBi respectively at port-2.

The Table.1 portrays the number of operating bands and their operating band along with percentage impedance bandwidth, isolation or mutual coupling, reflection coefficient, resonant frequency of the concerned band and maximum peak gain. The Fig.2(a)- Fig.2(c) and Fig.3(a)-Fig.2(b) represents the variation of the $|S_{11}|$, $|S_{22}|$, mutual coupling between the ports ($|S_{12}|$ and $|S_{21}|$) and overall gain of antennas ($A_1$-$A_4$) versus frequency as tabulated in Table.1.

Therefore, simulated and measured results of the proposed MIMO antenna are signifying the minor deviations of the results as displayed in Fig.2(a)- Fig.2(c) and Fig.3(a)- Fig.3(b) as well as Table.1, the inspection of Fig.3(b) and Table.1, a marginal difference between port 1 and 2 is observed due to two symmetrical designs are separated by a spacing (2mm) of the radiating patches to create a MIMO structure are placed in low-profile (22×22×1.6 mm$^3$) of the proposed antenna.



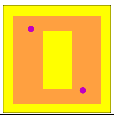
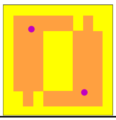
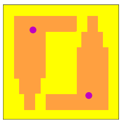
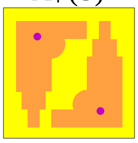
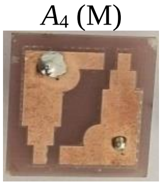

(a)




(b)

Fig.3. Simulated and Measured analysis of (a) Gain of antennas ($A_1$-$A_4$) and (b) Scattering parameter and Gain versus frequency curve of the proposed antenna ($A_4$)

Table.1. Port characteristics of the Antennas ($A_1$-$A_4$)

| Antenna | Port No. | Number of bands | Operating band (GHz) / Impedance BW (in %) | Isolation (dB) | Resonant frequency (GHz) | Reflection Coefficients (dB) | Peak Gain (dBi) |
|---|---|---|---|---|---|---|---|
| $A_1$  | Port-1 | 1 | 7.95-08.35/4.90 | < -12 | 8.10 | -25.24 | 1.09 |
| | | 2 | 10.66-11.48/7.40 | < -14 | 11.09 | -27.70 | 4.41 |
| | Port-2 | 1 | 7.93-8.33/4.92 | < -12 | 8.10 | -31.35 | 1.09 |
| | | 2 | 10.62-11.44/7.43 | < -14 | 11.09 | -31.72 | 4.41 |
| $A_2$  | Port-1 | 1 | 8.07-8.27/2.44 | < -13 | 8.10 | -12.10 | 3.27 |
| | | 2 | 10.83-11.29/4.15 | < -18 | 11.09 | -15.24 | 4.78 |
| | Port-2 | 1 | 8.07-8.27/2.44 | < -13 | 8.10 | -11.15 | 3.27 |
| | | 2 | 10.83-11.29/4.15 | < -18 | 11.09 | -15 | 4.78 |
| $A_3$  | Port-1 | 1 | 8.3-8.68/4.47 | < -13 | 8.50 | -13.08 | 2.05 |
| | | 2 | 9.3-13.04/33.48 | < -19 | 9.61 | -11.75 | 5.10 |
| | | | | | 10.99 | -21.83 | 2.15 |
| | | | | | 12.17 | -18.47 | 1.72 |
| | | | | | 12.59 | -17.59 | 2.95 |
| | Port-2 | 1 | 8.3-8.68/4.47 | < -13 | 8.50 | -12.81 | 2.05 |
| | | 2 | 9.3-13.04/33.48 | < -19 | 9.63 | -11.75 | 5.10 |
| | | | | | 10.87 | -22.19 | 2.12 |
| | | | | | 12.15 | -20.15 | 1.72 |
| | | | | | 12.57 | -18.65 | 2.95 |
| $A_4$ (S)  | Port-1 | 1 | 7.99-8.39/4.88 | < -15 | 8.10 | -16.97 | 3.27 |
| | | 2 | 9.1-13.04/35.59 | < -20 | 9.61 | -13.88 | 7.55 |
| | | | | | 10.89 | -19.98 | 5.48 |
| | | | | | 11.94 | -19.62 | 5.68 |
| | | | | | 12.57 | -19 | 5.94 |
| | Port-2 | 1 | 7.97-8.39/5.13 | < -15 | 8.10 | -19.98 | 3.27 |
| | | 2 | 9.1-13.04/35.59 | < -20 | 9.40 | -12.99 | 7.43 |
| | | | | | 10.89 | -20.42 | 5.48 |
| | | | | | 11.94 | -16 | 5.68 |
| | | | | | 12.55 | -18.91 | 5.94 |
| $A_4$ (M)  | Port-1 | 1 | 7.99-8.38/5.13 | < -15 | 8.10 | -29.21 | 2.67 |
| | | 2 | 9.10-12.97/35.07 | < -20 | 9.65 | -14.73 | 6.78 |
| | | | | | 10.92 | -18.23 | 5.90 |
| | | | | | 11.97 | -16.45 | 5.03 |
| | | | | | 12.61 | -19.25 | 3.79 |
| | Port-2 | 1 | 7.96-8.38/5.13 | < -15 | 8.10 | -21.31 | 2.67 |
| | | 2 | 9.10-13.03/35.51 | < -20 | 9.65 | -14.35 | 6.78 |
| | | | | | 10.92 | -18.98 | 5.90 |
| | | | | | 11.97 | -18.34 | 5.03 |
| | | | | | 12.61 | -20.77 | 3.79 |

BW = Bandwidth; S = Simulated; M = Measured

### 3.3 MIMO DIVERSITY PERFORMANCES AND RADIATION EFFICIENCY

MIMO diversity performance and consequence of proposed MIMO antenna are the crucial parameter, also there examined in terms of diversity gain (DG), envelope correlation coefficient (ECC) and total active reflection coefficient (TARC) have been deliberate in this section. The satisfactory values to exist of ECC < 0.5, TARC < 0 dB, and DG is near to 10 dB. ECC, DG and TARC as a utility of frequency are displayed in Fig.4(a) and Fig.4(b) and Table.2 respectively.

ECC and DG as a function of frequency is there are demonstrated in Fig.3(a). ECC and DG of the antenna are indicated [18] in Eq.(1) and Eq.(2).

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

$$10\sqrt{1-ECC^2} \qquad (2)$$

TARC is demarcated as the ratio of the square root of total reflected power and total incident power for the overall MIMO system of the antenna [14]. The existence value of TARC is less than 0 dB [16]. TARC of antenna is signifies with the help of return loss parameter of the MIMO antenna system as indicated in Eq.(3).

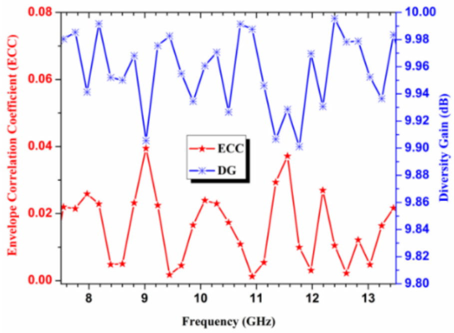
$$TARC = \frac{\sqrt{(S_{11}+S_{12})^2+(S_{22}+S_{21})^2}}{\sqrt{2}} \qquad (3)$$

Table.2. MIMO parameters of the proposed antenna ($A_4$)

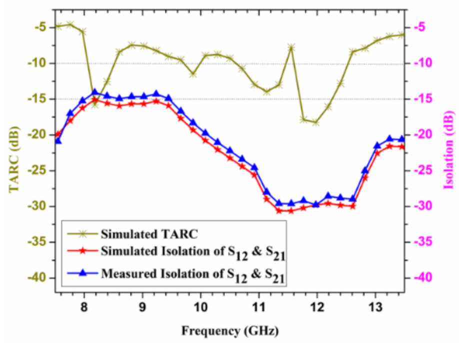
| $f_r$ (GHz) | ECC | DG (dB) | TARC (dB) | RE (%) (S) | RE (%) (M) |
|---|---|---|---|---|---|
| 8.10 | 0.00228 | 9.996 | -15.78 | 54.93 | 53.65 |
| 9.65 | 0.00451 | 9.954 | -10.41 | 74.40 | 74.18 |
| 10.92 | 0.00124 | 9.987 | -12.94 | 71.82 | 69.83 |
| 11.97 | 0.00304 | 9.969 | -18.23 | 55.51 | 54.27 |
| 12.61 | 0.00217 | 9.978 | -10.17 | 54.10 | 54.10 |

$f_r$ = Resonant frequency, RE = Radiation efficiency, S = Simulated, M = Measured.

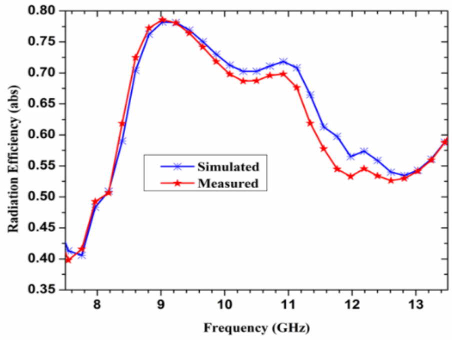
ECC disparity of the proposed antenna is obtained in the acceptable limit (0.00124-0.00451) (cf. Fig.4(a) and Table.2) which obeys to the smallest mutual coupling effect between antenna elements. The smallest mutual coupling of the proposed antenna indications to a high data rate transmission, and proposed MIMO antenna has obtained the diversity gain in acceptable range between (9.954-9.996) dB (cf. Fig.4(a) and Table.2).




(a)




(b)



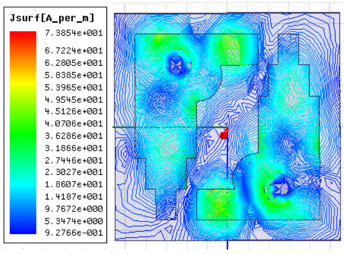

(c)

Fig.4. Analysis of (a) ECC and Diversity gain (DG), (b) TARC and Isolation and (c) Radiation efficiency versus frequency curve of the proposed antenna (A4)

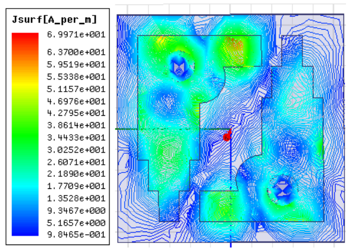
For MIMO configuration, the acceptable value of proposed TARC is less than -10 dB [cf. Fig.4(b) and Table.2]. The Fig.4 (b) illustrates a better TARC value, suitable for satellite communications. TARC is intended to provide good description of the MIMO antenna. Radiation efficiency up to 75% is obtained during the entire operating frequency bands (cf. Fig.4(c) and Table.2).

## 3.4 SURFACE CURRENT DISTRIBUTION AND FAR-FIELD RADIATION PATTERN

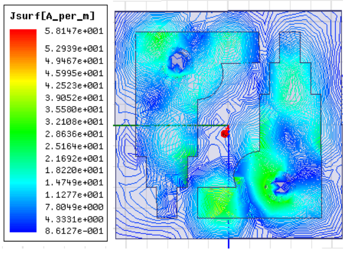
Surface current distribution of the proposed MIMO antenna are characterized at 8.10 GHz, 9.61 GHz, 10.89 GHz, 11.94 GHz and 12.57 GHz with 73.85 A/m, 69.97 A/m, 58.14 A/m, 50.62 A/m and 52.11 A/m respectively at port-1, and all has demonstrated in Fig.5(a)- Fig.5(e) respectively. Port-1 has a large current length as related to port-2. The obtained maximum surface current density is 73.85 A/m at 8.10 GHz and minimum surface current density of 50.62 A/m at 11.94 GHz.



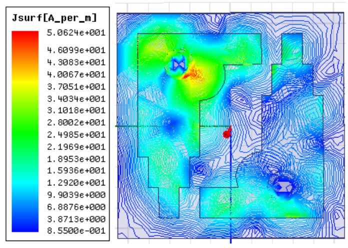

(a)



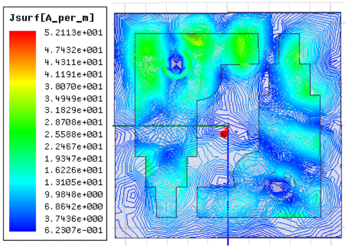

(b)




(c)



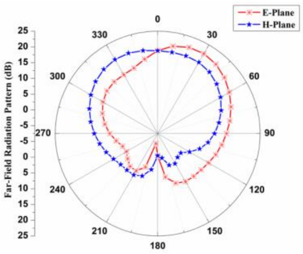

(d)



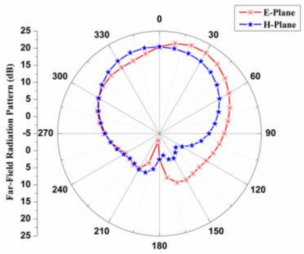

(e)

Fig.5. Surface current distribution at (a) 8.10 GHz, (b) 9.61 GHz, (c) 10.89 GHz, (d) 11.94 GHz and (e) 12.57 GHz of the proposed design (A4) at port-1

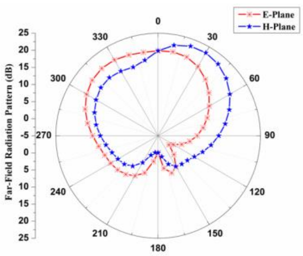
The proposed MIMO antenna ($A_4$) is simulated for E and H-plane far-field radiation patterns at both prime planes: azimuthal (Phi = 0) and elevation (Phi = 90), the far-field radiation pattern has presented at 8.10 GHz, 9.61 GHz, 10.89 GHz, 11.94 GHz and 12.57 GHz as exhibition in Fig.6(a)-Fig.6(e) respectively at port-1.



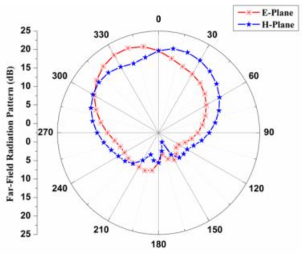

(a)



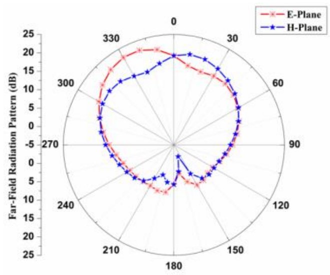

(b)




(c)




(d)




(e)

Fig.6 Far-Field Radiation Pattern in E and H-plane for (a) 8.10 GHz, (b) 9.61 GHz, (c) 10.89 GHz, (d) 11.94 GHz and (e) 12.57 GHz of the proposed design ($A_4$) at port-1

In proposed MIMO antenna has the similar radiation pattern at both the port 1 and 2, therefore at this point only discussed port 1 radiation pattern.

The proposed antenna ($A_4$) is intended for all the resonating frequencies as demonstrated and suitable for omnidirectional broad radiation pattern characteristics. The omnidirectional radiation patterns are operational for vehicular applications along with satellite communications.

## 4. COMPARATIVE ANALYSIS WITH RECENT ANTENNAS

A reasonable overview of the dual-port glue gun-shaped MIMO antenna are described in terms of antenna size, number of elements used, peak gain, ECC, DG, isolation and TARC as accessible in Table.3. The proposed antenna occupies a smaller size as related to antennas reported in references [3] [6] [8] [9] [13] [15] [17] [20] [21]. Though, the proposed antenna exhibits the higher peak gain, enhanced envelope correlation coefficient (ECC); acceptable diversity gain (DG), well isolation and total active reflection coefficient (TARC) is exhibited as compared to reported antennas in references [3] [6] [8] [9] [13] [15] [17] [20] [21].

Table.3. A comparative overview of the proposed MIMO antenna (A4)

| Methods | Size of Antenna ($mm^3$) | Number of Elements used | Peak gain (dBi) | ECC | DG (dB) | Isolation (dB) | TARC (dB) |
|---|---|---|---|---|---|---|---|
| [3] | 50×42×1.6 | 2 | 1.8-3.5 (M) | < 0.14 (S) | NR | < -15 (M) | NR |
| [6] | 42×40×1.6 | 2 | NR | < 0.10 (S) | NR | < -18 (M) | < 0 (S) |
| [8] | 50×82×1.6 | 2 | 4.10-4.65 (M) | < 0.16 (S) | ≤ 9.99 (S) | < -15 (M) | NR |
| [9] | 44×44×1.6 | 2 | 2.10-5.95 (M) | < 0.08 (S) | ≤ 9.99 (S) | <-18 (M) | < 0 (S) |
| [13] | 38.5×38.5×0.8 | 2 | 2.8-3.10 (M) | < 0.06 (S) | NR | < -15 (M) | < 0 (S) |
| [15] | 27×36×1.6 | 2 | 2.64-3.24 (M) | < 0.13 (S) | NR | < -17 (M) | NR |
| [17] | 30×30×1.6 | 2 | 2.58-3.15 (M) | < 0.24 (S) | ≤ 9.99 (S) | < -15 (M) | NR |
| [20] | 50×30×1.6 | 2 | 2.7-3.10 (M) | < 0.12 (S) | NR | < -16 (M) | < -8 (S) |
| [21] | 26×28×1.6 | 2 | 1.84.2.74 (M) | < 0.14 (S) | NR | < -15 (M) | < -4 (S) |
| Proposed work | 22×22×1.6 | 2 | 3.27-7.55 (M) | < 0.04 (S) | ≤ 9.99 (S) | < -20 (M) | < -10 (S) |

ECC = Envelope correlation coefficient, DG = Diversity gain, NR = Not reported, TARC = Total active reflection coefficient, S = Simulated, M = Measured.

Comparative overview of the proposed MIMO antenna along with antenna parameters is as reported and tabulated in Table.3.

## 5. CONCLUSION

The purpose of this communication is to evaluate a compact ($22\times22\times1.6$ mm$^3$) and planar dual-port ultra-wideband (UWB) multiple-input–multiple-output (MIMO) antenna for downlink of the X-band satellite communications. The proposed design is simulated and measured on FR-4 epoxy substrate ($\varepsilon_r$=4.4, tan$\delta$= 0.02 and $h$=1.6 mm) and carried out by ANSOFT HFSS 13 electromagnetic solver, and its results, antenna gain varies in the range of (2.67-6.78) dBi measured, which include maximum peak gain of 6.78 dBi at port-1 and 2.67 dBi at port-2; diversity gain (DG) is in the acceptable range (near to 10 dB) between 9.954-9.996 dB, TARC (should be less than the 0 dB) less than -10 dB and radiation efficiency up to 75% is obtained during the entire operating frequency bands is observed. The operating band and gain characteristics of the proposed antenna are matching at port 1 and 2 with marginal deviation which conforms to good mutual coupling and excellent isolation is less than -15 dB (a major portion < -20 dB) between antenna elements (port 1 and 2) and ECC is < 0.0451. Omni-directional radiation pattern of the proposed antenna is beneficial even for vehicular applications. The simulated and measured results of the proposed antenna have been validated and minor deviation between simulated and measured results has been observed.

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