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International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-5, March 2020

Ultra-Wideband Compact Microstrip Patch Antenna for C, X and K-band Applications

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Abstract: A novel stacked double U, angular ring shaped MIMO antenna is designed using DGS, and a pair of balanced shorting pin is proposed for C, X, and K-band applications. The aim of this design is to enhance the bandwidth by using different techniques in a compact MSA. The proposed antenna is designed on an FR4 substrate with permittivity of 4.4 is used in this design with dimension of 10×10 mm^2 with two-microstrip line and one coaxial feed as a feeding mechanism. Two asymmetrical antennas of FR4 substrate are stacked with an air gap of thickness 1.6mm that exhibits a low correlation coefficient; low mutual coupling and refection coefficient is below-25 dB. The antenna is simulated through HFSS software 13.0 version shows Operates at UWB of frequency range 6.17-9.3, 18.1-18.7 GHz with maximum radiation efficiency of 83%.

Keywords : C-Band, DGS, MIMO, Stacking, UWB, U-shape, X-Band.

I. INTRODUCTION

In today's scenario light weight and miniaturized microstrip patch antenna with, UWB, wide band are preferred as it can be easily integrated in handheld devices. The Microstrip patch antenna is known for lightweight, low cost, compactness, easy fabrication process. Researchers are more oriented to design antenna with high impedance bandwidth, high gain and good radiation efficiency. One of the disadvantages of microstrip antennas is narrow bandwidth so researchers try to enhance the bandwidth by using the different types of technique applied in microstrip antenna [1],[2]. WB has many advantage low power consumption, low complexity, low cost, less interference, secure, large channel capacity, excellent multipath interference, high data rate, Narrow pulses of nano second and sub nano second duration [3],[4]. Various techniques like multiple port, stacking, defected ground structure, shorting, loading slots and notchesare used to design an antenna. MIMO technology has gained researchers' attention by reducing mutual coupling, multipath fading and increasing transmission capacity with lower bit error rate by enhancing port isolation. This technique helps in increasing the channel capacity, and allow several users to access various services at the same time [5], which can be commonly visualized using two schemes (i) spatial diversity (ii) spatial multiplexing. Several types of isolation method like decoupling networks, Negative group delay lines, parasitic, monopole element artificial magnetic conductor reflector, ground plane modification method or combine all method can be used in an antenna [6]. In stacking different shaped radiating patch along with air, gaps in between individual dielectric substrate. These factors are responsible for the enhancement of impedance bandwidth and gain of an antenna using the electromagnetically coupled stacked patch (ECSP) [7] or stacking technique [8]-[10].

Shorting is a conventional technique used for size reduction at fixed operating frequency and bandwidth enhancement [11]. It is working as capacitive loaded patch and decreased the resonant frequency [12]-[13]. When a defect of Periodic or non-periodic shape is etched on the ground plane it is considered as defected ground structure. The defect ground plane is responsible for current distributions of the ground plane and helps frequency to shift towards the lower range [16]. Thus achieve the band-stop characteristics and suppressed the mutual coupling with higher mode harmonics [17]-[18].

A comparative overview of the proposed antenna and multiple layered reported antennas is presented in Table I with respect to the antenna parameters such as size, resonance frequency, impedance bandwidth, gain. It can be clearly observed from Table I that the proposed antenna is miniaturized in size with highest impedance bandwidth.

In this paper, UWB stacked patch antenna with rectangular defected ground structure and two U-shape patch on upper substrate and circular ring lower substrate patch for C and X band is proposed[19], [20], [21]. A copper shorting pin is inserted between the ground plane and radiating patch to enhance the bandwidth and gain of the proposed antenna. This proposed antenna has reported minimum volume and area as compare to the work reported. UWB characteristic of the antenna is applicable for C,X and K-Band applications. The

Revised Manuscript Received on March 30, 2020.

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Table-I:
Comparative analysis of proposed antenna with other reported antenna

	Size(mm²)	CF/RF(GHz)	IBW (%)	Gain(dBi)
[1]	54×45	4.8	31.5	4
[6]	60×95	1.75, 2.5	25.25	NA
[8]	30×24.8	2.28/2.65/4.80/5.89/8.73	4.16/5.71/10.25/6.25/2.39	2.16/1.91/2.65/2.81/3.01
[9]	25×22	5.8	5.09	3.15
[10]	29×27	1.65/2.44/3.56/5.1	13.33/16.66/8.45/5.82	2.4/2.1/2.7/1.8
[19]	17×42	25.45	7.2, 8.57	5, 1.7
[20]	32×32	3.1/4.7/6.4/7.6/8.9/10.4/11.8	6.5/8.5/7.6/3.9/5/.7/1.2/2.2	4.54/5.97/3.46/2.41/6.51/4.14/6.51
[21]	28×30	1.6/2.5/5.8/9.8	11.1/10.5/5.2/9.3	2.9/2.4/3.1/1.8
Proposed	10×10	6.67 ,7.84,18.46	40,0.51	1.75

II. ANTENNA DESIGN

The proposed multilayer compact UWB antenna of dimension (10×10) mm^2 is shown in Fig. 1. In this present work, two different patches with FR4 as dielectric substrate are stacked together, which increases the thickness of an antenna. The upper radiating patch comprises of dual U shaped patch with the height of 1.6 mm whereas on the lower patch shape multiple circular rings have been designed. The dimension of rectangular notches (8×2.5) mm^2 is etched from the both side of ground plane. The geometrical layout of the upper radiating patch, lower radiating patch ,defected ground and side view are shown in Fig.1.The lower patch antenna comprises of dual microstrip line feed and a coaxial feeding.

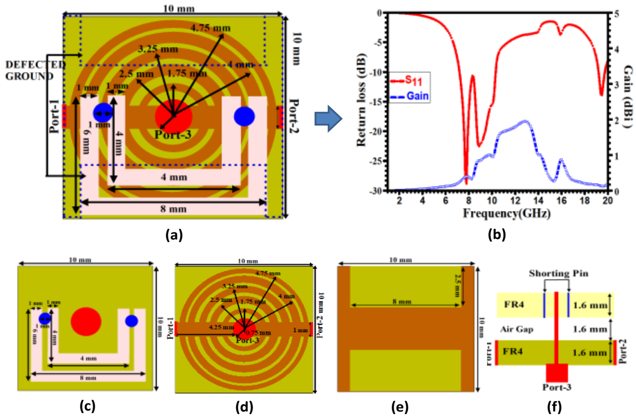
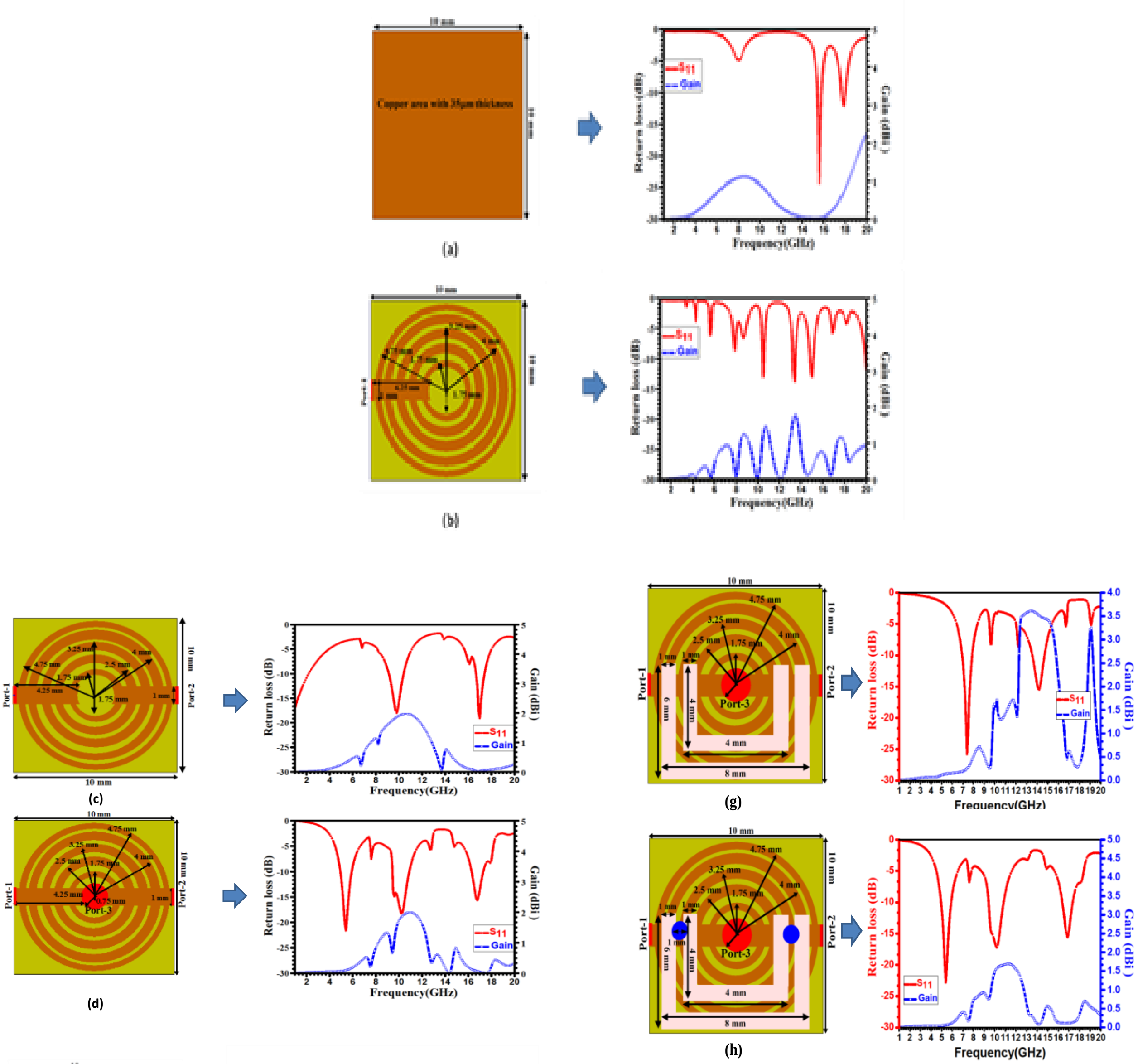


Fig. 1. Principle diagram of proposed antenna (i) compilation of proposed antenna with its S_{11} parameter and gain as a function of frequency (1) top view of upper substrate of proposed antenna (2) top view of lower substrate of proposed antenna (3) bottom view (4) side view of the proposed antenna .

The evolution of the proposed antenna design is achieved by applying different techniques like multiport, stacking, shorting and DGS on the radiating patch, which is clearly shown in Fig.1. Initially modeling a square shape-radiating patch (10×10 mm^2) on the FR4 substrate with microstrip feed excitation. This shape had not produced any resonance than according to the multiple annular ring structure mutually dependent on each other with current distribution of circular ring. We made Circular ring radiating patch with same microstrip line feed, observed the no resonance, after than increasing the microstrip feed line was produced resonance shown in Fig.1., Due to the need of better performance further when an antenna was fed by coaxial feed, the antenna circular ring shape radiated the multiple number of bands. For good results we applied some more theoretical concept technique like as stacking, shorting later on introducing DGS structure, it was observed that the multiple band got overlapped and generated ultra wide band. The enhancement of gain is achieved by introducing two shorting pins on the radiating patch at locating the position S1 (-0.5) andS2 (3,-0.8). Applied all the techniques in circular ring shape we justify what we learn in theoretical is similar.

Table- II: Basic Evolution Parameters of Proposed Antenna

TECHNIQUES	CUT-OFF FREQUENCY(GHz)	BANDWIDTH(GHz)	PEAK GAIN (dBi)	IMPEDANCE BANDWIDTH (%)
SIMPLE SQUARE PATCH	15.59, 17.86	15.39-15.79, 17.64-18.04	0.70	2.56 2.24
MICROSTRIP FEED	10.46, 13.40, 15.00	10.42-10.54, 13.25-13.48 14.80-15.11	1.73	1.14 1.72 2.07
DOUBLE MICROSTRIP FEED	9.78,16.96	0.00- 2.19, 9.08-10.38, 16.60-17.40	1.88	200.00 5.906 4.70
DOUBLE MICROSTRIP WITH CO-AX FEED	5.4, 10.19, 16.75	4.9-5.9, 9.4-10.86, 16.2-17.26	1.80	20.20 14.41 6.33
STACKING	5.28, 10.6, 16.8	4.9-5.79, 9.5-11.08, 16.34-17.26	1.29	16.65 15.35 5.47
SINGLE U	7.48, 14.09	6.91-7.89 13.46-14.64	3.7	13.24 8.39
DOUBLE U	5.39, 9.97, 16.9	4.93-5.88, 9.42-10.78, 16.42-17.6	1.5	17.57 13.46 6.93
SHORTING NEAR TO CO-AX WITH DOUBLE- U	6.67 ,7.84	6.17-9.32, 18.1-18.7	1.75	40.67 0.51



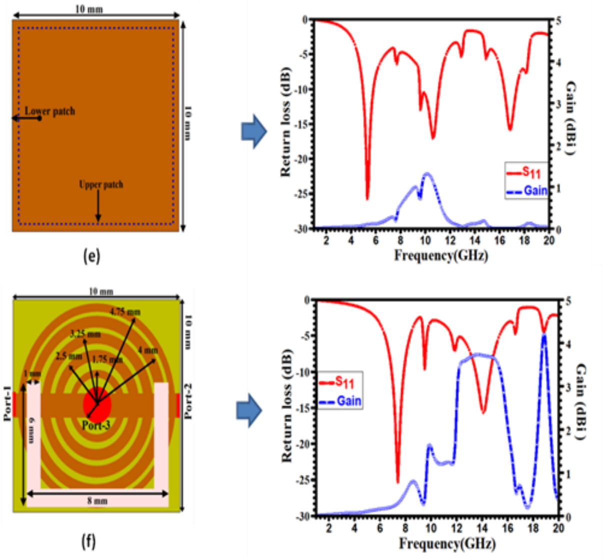


Fig. 2. Parametric analysis of Proposed antenna with step by step variation (a) complete copper patch (b) Multiple angular ring with single feed of microstrip line (c) antenna with dual port which is excited by microstrip line (d) antenna with 3 ports 2 microstrip line and a coaxial feed (e) antenna with stacking technique with air gap between two substrate (f) U shaped radiating patch on upper substrate of antenna (g) dual U shaped radiating patch on the upper substrate of proposed antenna (h) antenna "g" with pair of balaned shorting pins on equidistance from the coaxial feed.

II. RESULT AND DISCUSSIONS

The proposed antenna is designed, simulated and optimized using commercial finite element method solver Ansyst HFSS v13.0 simulator tool. The antenna behavior is analyzed according to the design proceed stepwise. Firstly, we have analyze square shaped patch which resonates at 15.59GHz and 17.6GHz with Impedance bandwidth of 2.56% and 2.24% and gain of 0.7d

Retrieval Number: E2239039520/2020©BEIESP
DOI: 10.35940/ijitee.E2239.039520
Journal Website: www.ijitee.org

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Bi then on the same patch multiple circular ring patch structure is designed and fed by a microstrip feed line and it is observed that it resonate with multiple band of 10.42-10.54GHz, 13.25-13.48GHz, 14.80-15.11GHz frequency range with a peak gain of 1.75dBi.

In the third stage we have analyzed the same radiating patch with dual port microstrip line placed opposite to each other. When the designed structure is simulated it is observed that antenna resonates at frequency range of 0.00 - 2.19GHz, 9.08-10.38GHz, 16.60-17.40 GHz with a 1.8dBi peak gain and impedance bandwidth of 200.00%, 5.90%, 4.70% respectively. Later, other direct contact coaxial feed was introduced in the center of the radiating patch that resonates at 4.9-5.9 GHz, 9.4-10.86GHz,16.2-17.26GHz frequencies and impedance bandwidth observed are 20.20%,14.41%, 6.33% with peak gain of 1.80 dBi. The antenna was further advanced by introducing stacking with the air gap of 1.6 mm thickness in between the two FR4 substrate the multiple wide band of operating frequency range (4.9-5.79, 9.5-11.08,16.34-17.26)GHz are observed with a slight decrement in the peak gain to 1.29dBi. Further parametric analysis is done by placing single U shape patch (frequency range 6.91-7.89, 13.46-14.64 GHz) and then dual U shaped patch (frequency range 9.42-10.78, 16.42-17.6 GHz) with peak gain of 3.7 dBi and 1.5 dBi respectively. Finally, the pair of shorting pin of size 1mm is placed at equidistance from the coaxial feed of an antenna (g) resonates at (6.17-9.32, 18.1-18.7) GHz frequencies and with the peak gain of 1.75dBi is shown in Fig. (2).

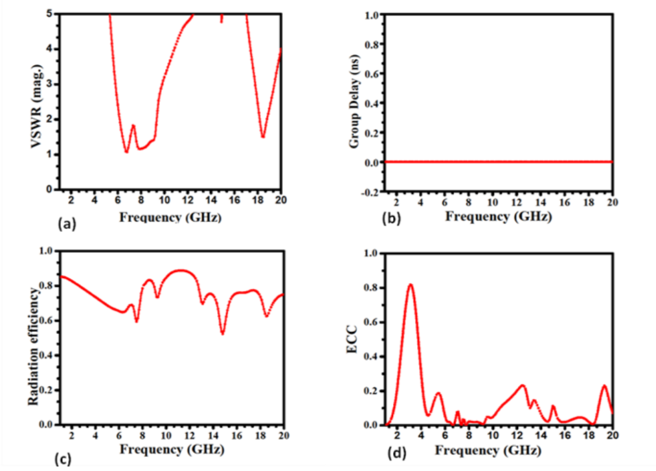

Fig.3. proposed antenna parameters (a) VSWR as a function of frequency (b) group delay as a function of frequency (c) envelop correlation coefficient as a function of frequency (d) radiation efficiency as a function of frequency.

The VSWR of the proposed antenna with respect to frequency is shown in Fig. 3(a) It can be clearly perceived that the VSWR is between 1 and 2 at the resonating frequencies. The group delay explains the distortion in the transmission pulse form Fig. 3(b) it is observed that the group delay of the proposed antenna is near 0 ns whereas antenna with group delay from -1 to 1 ns is acceptable which shows that the antenna radiates with minimum distortion. The ratio of power radiated to the power received by an antenna indicates the radiation efficiency of an antenna Fig. 3(c) illustrates the radiation efficiency of proposed antenna which is between 60% to 90 %. Correlation between multiple antenna elements is measured in terms of ECC to evaluate the diverse capabilities for MIMO system application. Diversity gain and ECC are related to each other, ECC is also known as correlation coefficient (ρ) and it is determined from scattering parameters or radiation patterns. For decreasing the coupling between the antenna element we need to increase the isolation between antenna's elements. The value of Correlation coefficient is less than 0.02 on Ultra Wide band range. It is a value of 2-port is calculated by giving formulas.

$$ECC = \frac{|S_{11}S_{12} + S_{21}S_{22} + S_{13}S_{31}|^2}{[1-(|S_{11}|^2 + |S_{21}|^2 + |S_{31}|^2)][1-(|S_{12}|^2 + |S_{22}|^2 + |S_{32}|^2)]}$$

ECC for 3-port can be calculated by following equation.

$$ECC = \frac{|S_{11}S_{12} + S_{21}S_{22} + S_{13}S_{31}|^2}{[1-(|S_{11}|^2 + |S_{21}|^2 + |S_{31}|^2)][1-(|S_{12}|^2 + |S_{22}|^2 + |S_{32}|^2)][1-(|S_{13}|^2 + |S_{23}|^2 + |S_{33}|^2)]}$$

The isolation characteristics and impedance matching of the proposed MIMO antenna have been considered in terms of transmission coefficient [(S_{21} and S_{12}), (S_{12} and S_{32}), (S_{13} and S_{23})] and reflection co-efficient parameters (S_{11}, S_{22} , S_{33}) .In this MIMO antenna the reflection coefficient is less than -10dB and mutual coupling lower than -15 dB in most of the frequency band of Ultra-Wide Band range. For obtaining better impedance matching, the mutual coupling should be stronger on the side of the lower frequency range. In the formula S_{11} is the reflection coefficient from port-1 when the port-2 is connected to a matched load.

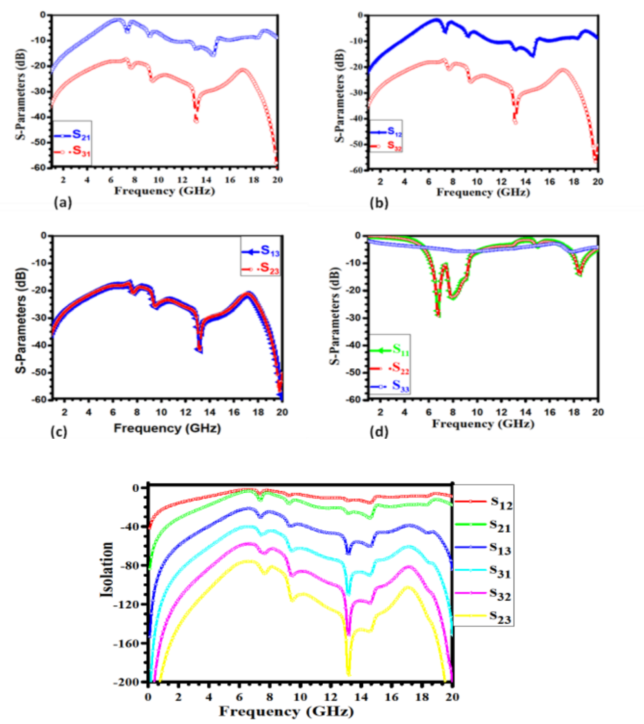

Fig.4. (a) Simulated mutual coupling of the proposed MIMO antenna (b) Simulated mutual coupling of the proposed MIMO antenna (c) Simulated mutual coupling of the proposed antenna (d) S-Parameters of MIMO antenna (e) Simulated mutual coupling of whole MIMO antennas.

The isolation characteristics and impedance matching have discussed in terms of the transmission coefficient (S_{21} and S_{12}, S_{31} and S_{13}, S_{32} and S_{23}) and reflection coefficient (S_{11}, S_{22} and S_{33}). The simulated mutual coupling and reflection coefficients of proposed MIMO antenna are shown in Fig.4 (a, b, c) and 4(d), respectively. The proposed structure of the MIMO microstrip patch antenna exhibits reflection coefficient of less than -10 dB and mutual coupling of less than -15 dB in most of the band of UWB range. The Proposed structure of MIMO antenna also maintains higher oscillation between three antenna ports in UWB range. Fig. 4(e) shows that isolation based on all reference port combinations.

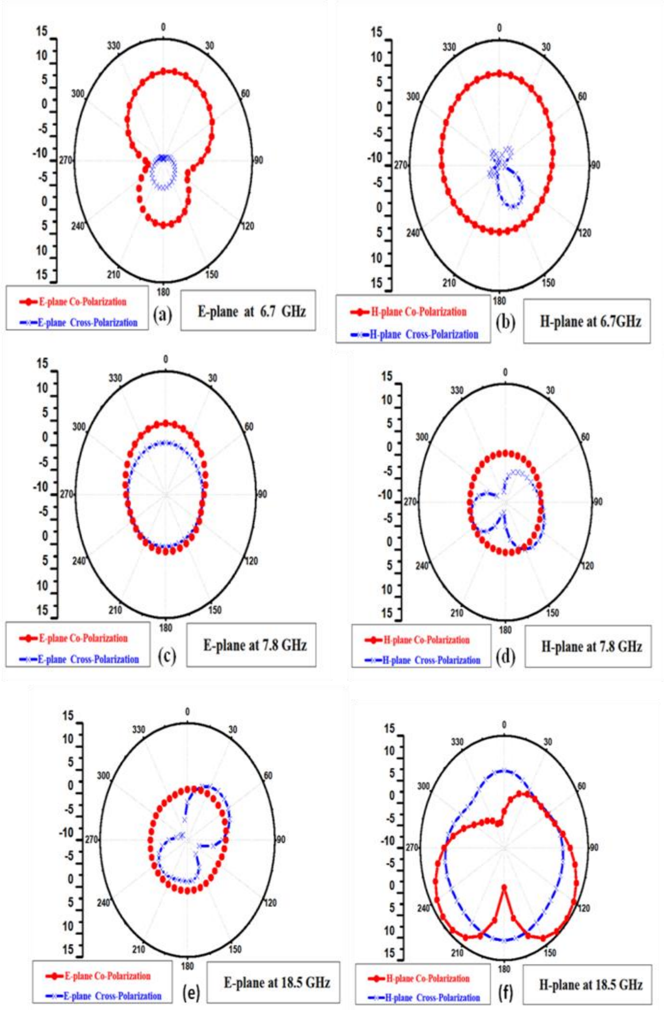

Fig.5. Radiation pattern of the proposed MIMO antenna (a) E-plane for 6.7GHz (b) H-plane for 6.7 GHz (c) E –plane for 7.8 GHz (d)H-plane for 7.8 GHz (e) E-plane For 18.5 GHz (f) H-plane for 18.5 GHz.

Radiation pattern shows that the graphical representation of the electric field strength "E" and magnetic field strength "H" from an antenna as a function of space/direction coordinates. It is usually very narrow or pencil beam, very wide or fan beam, Omni shapes, type of shaped beam or tilted beam. It may be single or multiple beam and beam may be steered mechanically or electronically. The radiation pattern of the proposed antenna with respect to the E-plane and H-plane for 6.7 GHz, 7.8GHz and 18.5 GHz is illustrated in Fig. 5. It is clearly observed that co-polarization has almost omni directional pattern with smaller cross polarization with respect to co polarization, which is desirable for proper signal transmission and reception.

III. CONCLUSION

A miniaturized MIMO stacked antenna with balance shorting pin along with defected ground is analyzed for UWB targeting applications of C, X, and K- band. The proposed antenna operates at 6.17-9.30GHz and 18.1-18.7GHz with the peak gain of 1.75 and bandwidths of 40 % and 0.51 %. The maximum radiation efficiency of the proposed antenna is 83% with less distortion. The performance of MIMO has a low reflection coefficient less than -10dB, low correlation coefficient less the 0.02 and mutual coupling less than 25dB. Maximum isolation between the elements of the proposed antenna195dB. The proposed antenna of dimensions $(10\times10)mm^2$ and overall volume of $480mm^3$ is applicable for RF devices, satellite communication, TV broadcast, Fixed space research, SART (Search and Rescue Radar Transponders), aeronautical and marine navigation.

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Retrieval Number: E2239039520/2020©BEIESP
DOI: 10.35940/ijitee.E2239.039520
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