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Broadband Dual Circularly Polarized C-Band Antennas

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***Abstract*— Designing and fabricating an antenna with compact size, improved bandwidth, gain and directivity has been an important issue especially for the satellite based applications. In addition to this multipath interference has to be managed. To satisfy these criteria, microstrip fed broadband monopole antenna of different structures (U-Shaped slot monopole antenna, modified asymmetric hexagonal shaped monopole) having dual circularly polarization is designed in this paper for C-Band applications. Once CP is generated, then new challenge for generating wide impedance bandwidth, AR bandwidth, high gain and directivity should be handled. These antennas are designed and simulated using HFSS software of version 17. The designed antennas are compared based on its performance. The simulated results are verified with fabricated antennas and tested with Vector Network Analyzer (VNA) Agilent E5071C.**

Keyword - Monopole, Dual Circularly Polarized, HFSS (High Frequency Structure Simulator), C-Band, Axial Ratio (AR) Bandwidth.

I. INTRODUCTION

In this modern industrial world, human utilizes electromagnetic spectrum for their communication purpose and the antenna has been used for utilizing this natural resource. For broadcasting and mobile application, there is no idea about the location of transmitter and receiver. Hence antenna has to be designed, in order to transmit and receive the signal equally in all azimuthal directions**.** So, monopole antenna can be used. It will equally radiate power in all azimuthal directions. In addition to this, effect of multipath should be managed. For handling multi-reflection environment, dual circular polarization antenna can be used. The broadband CP antenna will manage the signal traffic, thereby allowing large data transmission. The feeding process plays a major role to improve input impedance matching. On considering all these information into an account, dual circularly polarized microstrip fed broadband monopole antennas are designed for C-Band applications.

II. RELATED WORK

By adjusting the position of the feed in U-shaped slot antenna [1] good Axial Ratio Bandwidth is achieved and broadband CP is obtained with asymmetric feed in U-shaped slot. A novel broadband monopole antenna with orthogonal tapered feed lines for dual circular polarization is designed in [2] .The diversity in polarization has been ensured by symmetry nature of the design and AR bandwidth is about 80.7%. The Proposed antenna can be used for the C-Band wireless systems. Broadband CP structure with an open-loop coupled to the vertical stub embedded in the ground plane for C-Shaped monopole antenna is designed in [3]. A dual circularly polarized microstrip antenna for Radio Frequency Identification (RFID) reader application with wideband isolation is designed in [4]. A CP antenna array with SIW-fed for 60GHz WPAN applications using Low Temperature Co-fired Ceramic (LTCC) technology having wide AR is designed [5].

A Circularly Polarized (CP) shorted loop with Sequential Phase (SP) is designed in [6]. The simultaneous optimization of multiple matching segments and four cross slots provide wide beam width in [7]. Improved AR with enhanced CP radiation in [8] can be achieved by placing short stub above the feed line. A low-profile antenna with single-feed, dual-band and dual-CP structure having two CECRs is designed in [9] which can be used for applications such as WIMAX, CDMA, and UMTS. Wide impedance bandwidth and wide AR bandwidth can be achieved simultaneously in [10] by using two inverted L-Shaped grounded strips of monopole patch. Great concern is given to AR bandwidth, impedance bandwidth.

The effect of modification of size and shape of ground plane with respect to impedance bandwidth is analysed in [11] for U-shaped patch antenna. The wideband behaviour of the antenna in accordance with dimension and position of the ground plane is analysed in [12]. Circularly polarized antenna with conical beam structure for the extended ground plane is analysed in [13] with respect to polarization and size of metal platform. The analysis on effect of change in impedance bandwidth for changing the shape of inverted L strip which extends from ground is done in [14]. The effect of wideband operating frequency and AR with respect to position of the feeding is analysed in [15].

On considering all these information into an account, dual circularly polarized microstrip fed broadband U-shaped slot monopole antenna and asymmetric hexagonal shaped antenna are designed for C-Band applications.

III. ANTENNA DESIGN

The specifications and procedures for designing modified asymmetric hexagonal shaped monopole antenna, and U-shaped slot monopole antenna are discussed.

A. Design Specifications

In order to design and simulate antenna using software like HFSS, various specifications like frequency of operation for the antenna, type of feed and its location etc should be considered. In addition to this, type, speed and memory capacity processor are also playing a major role. For asymmetric hexagonal shape monopole antenna, FR4 substrate of 1mm thickness with 32mm × 32 mm dimension [1] and for its modified work FR4 substrate of 1mm thickness with 32mm × 28 mm dimension is considered. In case of U-Shaped slot monopole antenna, 1mm thickness of FR4 substrate with 48mm × 41 mm dimension is considered. The centre frequency for these antenna structures is 6 GHz and loss tangent value is about 0.02.

B. Design Analysis and Procedures for Modified Asymmetric Hexagonal Shaped Monopole Antenna

Generally monopole antenna is linearly-polarized. By modifying the structure, it can generate circular polarization. Various complex methods have been used to produce CP from monopole. In [1], the antenna covers portion of L-Band (1.4-2) GHz, S-band (2-4) GHz, C-Band (4-8) GHz and smaller portion of X-Band (8-9) GHz.The frequency of operation is from 1.4 to 9.0533 GHz. So there may be interference for the C-Band applications. In addition to this gain, directivity has to be improved.

Two orthogonal tapered microstrip feed lines with modified ground plane, LSSs and ILSSs is shown in Fig.1. This modified antenna covers only the range of C-Band (4-8) GHz. It is achieved by modifying the design of L-Shaped strips and Inverted L-Shaped Strips along the edges of the radiating monopole. Ground plane structure is modified by changing its position and dimension. The circular polarization bands produced due to LSSs and ILSSs get overlapped to produce wideband operation and wide Axial Ratio bandwidth.

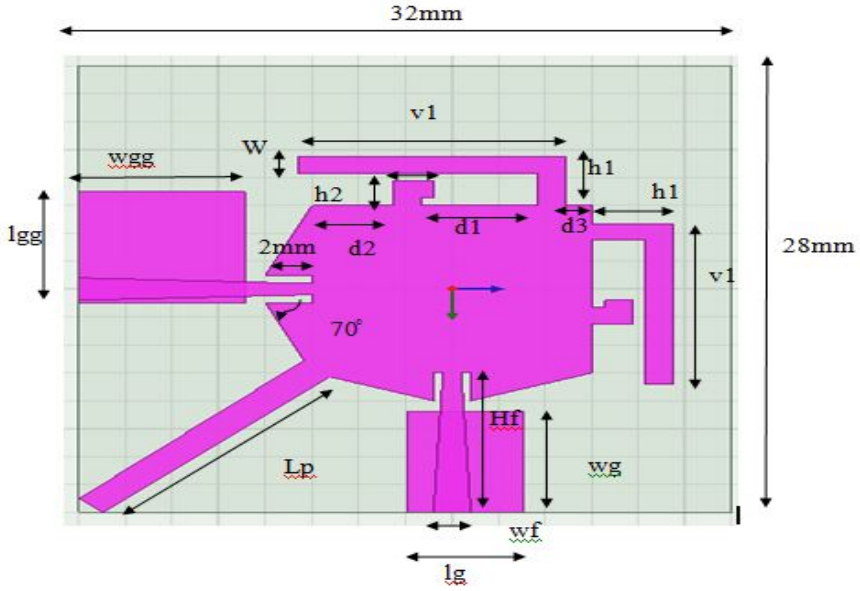


Fig. 1. Schematic of Modified Asymmetric Hexagonal Shaped Monopole Antenna

The design procedures are explained as follows. The calculation of the Width (W) of the monopole is expressed as

$$w = \frac{c}{2 f_0 \sqrt{\frac{(\varepsilon_r + 1)}{2}}} \tag{1}$$

Where,

C=speed of light, ε_r =dielectric Constant of substrate

Effective Dielectric Constant (ε_{eff}) calculation is given as

$$\varepsilon_{eff} = \frac{(\varepsilon_r + 1)}{2} + \frac{(\varepsilon_r - 1)}{2}[1 + 12\frac{h}{w}]½ \tag{2}$$

Calculation of the Effective length is given as

$$L_{eff} = \frac{c}{2 f_0 \sqrt{\varepsilon_{eff}}} \tag{3}$$

Where, L_{eff} =Effective length, f_0 = Centre frequency

Extension length (ΔL) and actual length can be expressed as

$$\Delta L = 0.412h \frac{(\varepsilon_{eff} + 0.3)(\frac{w}{h} + 0.264)}{(\varepsilon_{eff} - 0.258)(\frac{w}{h} + 0.8)} \tag{4}$$

$$L = L_{eff} - 2\Delta L \tag{5}$$

The width and length of the ground plane calculation is given as,

$$L_g = 6h + L \tag{6}$$

$$W_g = 6h + L \tag{7}$$

Wavelength (λ_g) calculation is expressed as

$$\lambda_g = \frac{c/f}{\sqrt{\varepsilon_{eff}}} \tag{8}$$

These are all some of the formulas involved in calculating the parameters of the modified asymmetric hexagonal shaped monopole antenna.

C. Design Analysis and Procedures for U- shaped slot monopole antenna

The antenna is designed using two microstrip-fed ports, a U-shaped slot, and a frame structure ground is shown in Fig.2. In this antenna design, U-shaped slot and asymmetric feeding structure together produces broadband circular polarized wave.

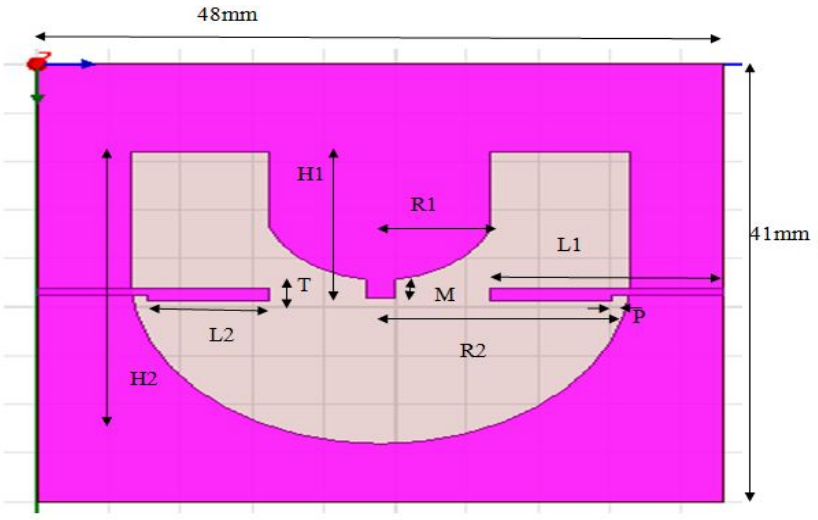


Fig.2. Schematic of U-Shaped slot monopole antenna

In order to excite U-shaped slot this CP antenna make use of microstrip fed rectangular radiator. After the generation of CP, new challenges for generating wide AR bandwidth, high gain and impedance bandwidth will appear. In order to expand the impedance bandwidth, the metal patch of size ($P \times L_2$) is added at the end of the feed line. AR bandwidth can be improved, by making rectangular strip (2*15.3) to be connected along x-direction. The length of the radiator is expressed as

$$L_1 = \frac{300}{4 f_m \sqrt{\frac{\varepsilon_r}{2}}} \tag{9}$$

Where f_m = mid frequency

D. Design Parameters of modified asymmetric hexagonal shaped monopole antenna and U- shaped monopole antenna

Various parameters values for designing modified asymmetric hexagonal shaped monopole antenna and U-shaped slot monopole antenna are shown in Table I and II.

TABLE I. Designed Parameter Value of Modified Asymmetric Hexagonal Shape Monopole Antenna

Symbols	Unit (mm)	Descriptions
G	32*28	Length of Substrate
L	12	Length of Monopole
L_g	5	Length of ground plane
W_g	7.25	Width of Ground plane
l_p	13.74	Length of Protruded Strip
W	1.2	Width of LSS and ILSS
w_f	1.6	Width of Feed Line
H_f	12.7	Height of Feed Line
d_1	5.1	Distance between LSS and ILSS
d_2	3.5	Distance from Edge of Monopole to the Strip(for both LSS and ILSS)
h_1	3.5	Height of ILSS from Monopole
h_2	3.5	Height of LSS from Monopole
v_1	2.1	Length of ILSS
v_2	1.4	Length of LSS

TABLE III. Symbols, Descriptions and Designed Parameter Value U-Shaped Slot Monopole Antenna

Symbols	Unit (mm)	Description
G	48*41	Length of Substrate
L_1	16.3	Length of Ground plane
$P * L_2$	1.26*8.5	Metal Patch Added at End of Feed Line
$K * H_1$	2*15.3	Rectangular Strip
R_1	8	Radius of Inner Circular Chamfers
R_2	17	Radius of Outer Circular Chamfers
d_2	1.5	Distance fom Edge of Monopole to the Strip (for both LSS and ILSS)
H_2	6.75	Height of U-Haped Slot

IV. RESULTS AND DISCUSSIONS

The S-Parameter graph for the modified asymmetric hexagonal shaped monopole antenna is shown in Fig.3. It represents amount of reflected power with respect to ports.

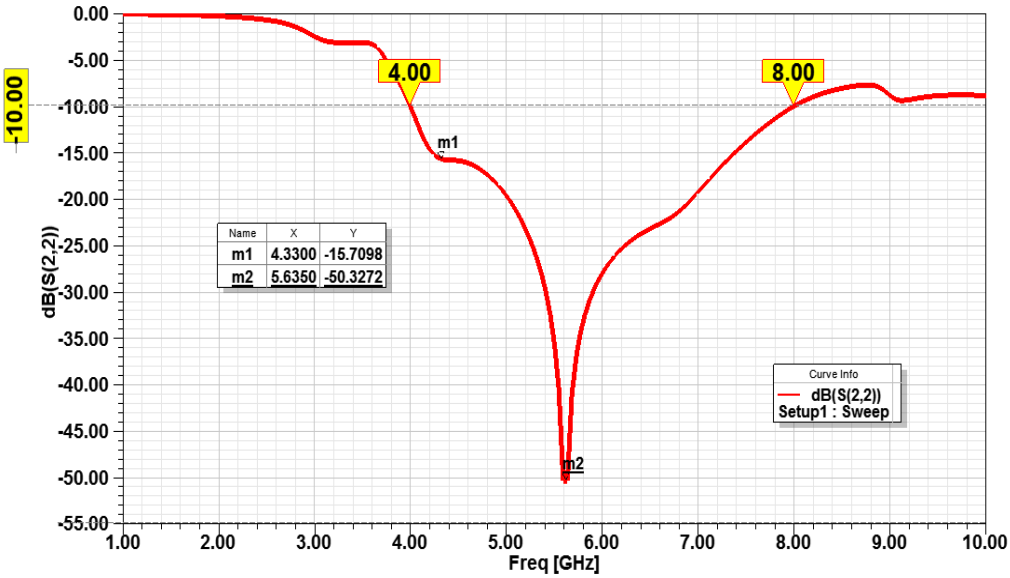
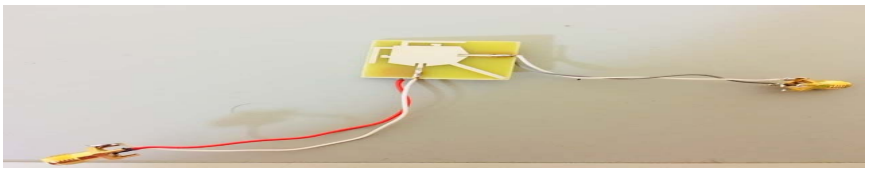
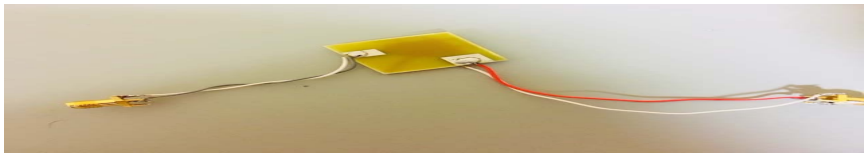


Fig. 3. S-Parameter of Modified Asymmetric Hexagonal Shaped Monopole Antenna

It covers the range from 4 to 8 GHz (C-Band only). The picture of the fabricated antenna is shown in Fig. 4.



(a) Top view



(b) Bottom view

Fig. 4. Fabricated Modified Asymmetric Hexagonal Shaped Monopole Antenna

The Simulated results are verified with measured results using fabricated antenna and tested with Agilent E5071C. The Fig.5 shows the testing setup.

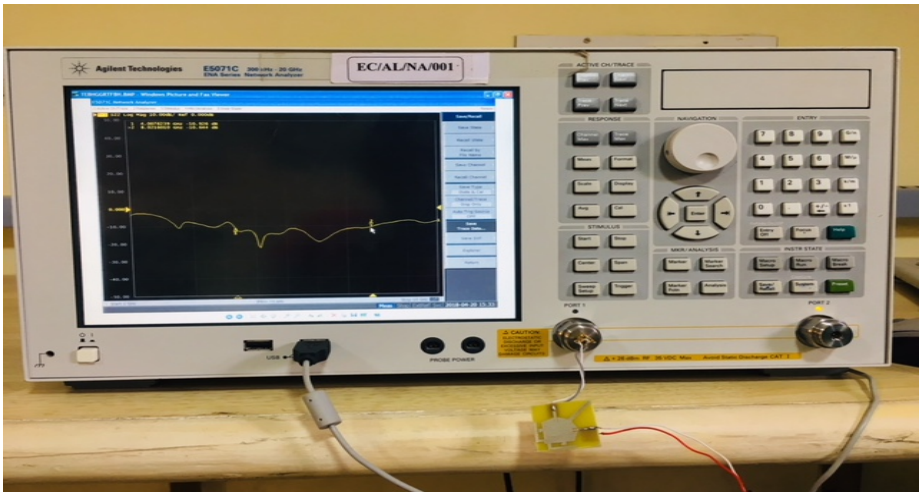


Fig. 5. Fabricated Modified Asymmetric Hexagonal Shaped Monopole Antenna Tested with Agilent E5071C

The Fig.6 shows that the simulated results agree well measured results.

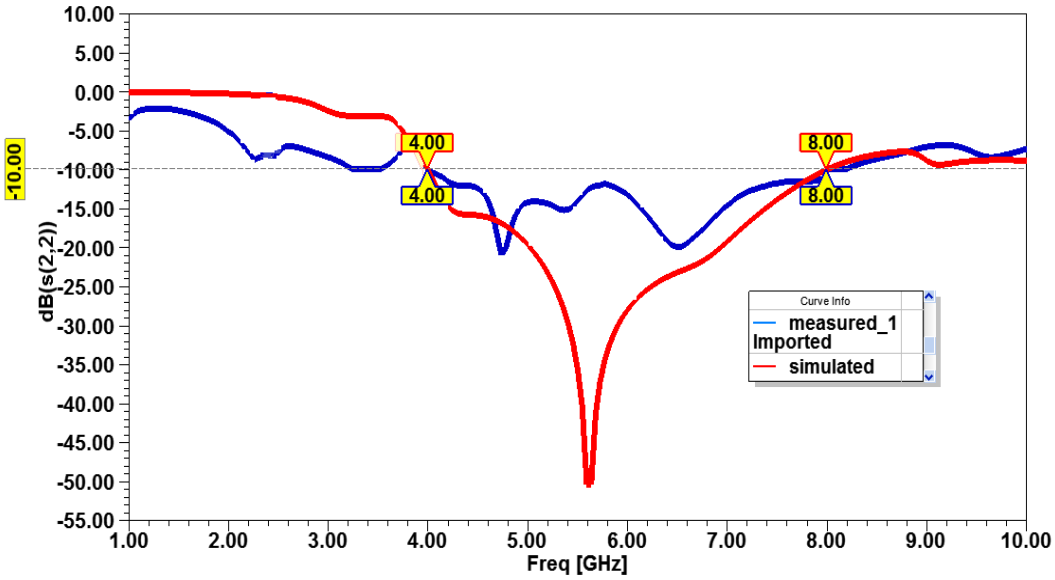


Fig. 6. Measued and simulated S-Parameter plot of Modified Asymmetric Hexagonal Shaped Monopole Antenna

The quality of circular polarization of an antenna can be explained through AR bandwidth graph. Based on the AR < 3dB, circular polarization is typically defined. The Fig.7 represents that the 3-dB Axial Ratio bandwidth graph covers the range from 4.84 GHz to 7.46 GHz. Hence it can be used for limited applications like WIFI, WIMAX, WLAN, some weather radars, cordless phone etc under dual CP concept.

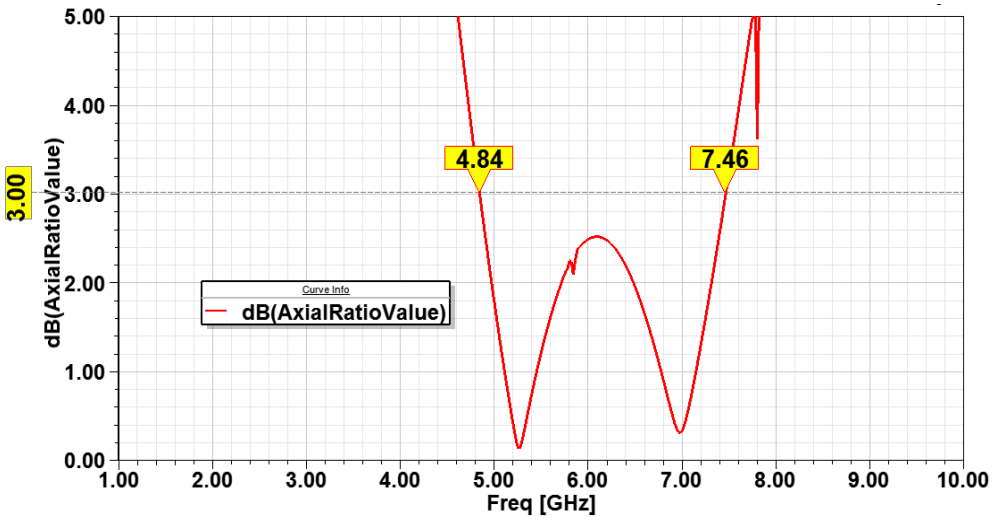


Fig. 7. 3dB-Axial ratio graph for modified asymmetric hexagonal shaped monopole antenna

From the VSWR graph shown in Fig.8, more power transmission with less reflection gets proved within the range.

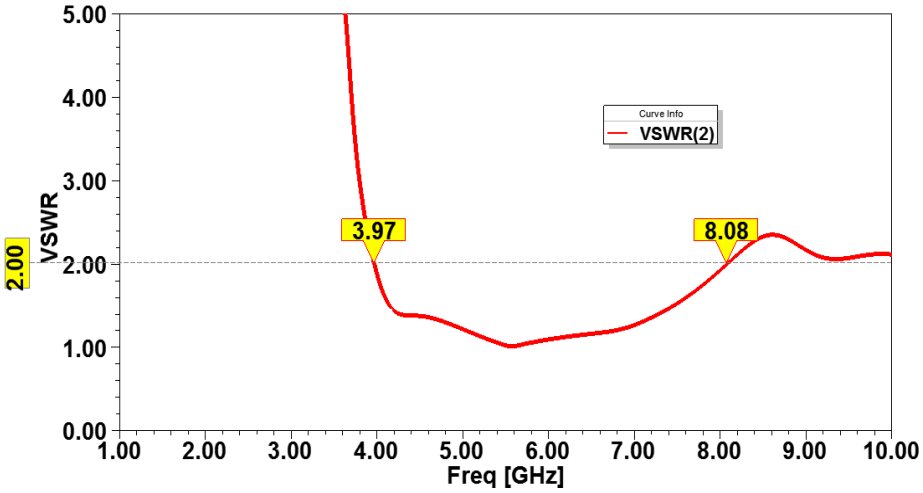
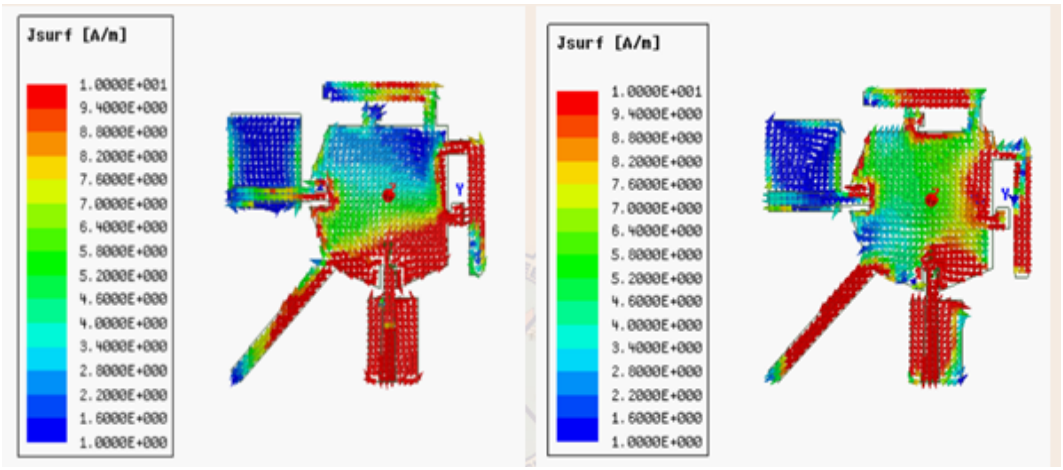


Fig. 8. VSWR Plot for Modified Asymmetric Hexagonal Shaped Monopole Antenna

The surface current distribution of modified asymmetric hexagonal shaped monopole antenna at φ=0˚ and φ=90˚ is shown in the Fig. 9.



(a) (b)

Fig.9 (a) Current flow at φ=0˚, (b) Current flow at φ=90˚of Modified Asymmetric Hexagonal Shaped Monopole Antenna

The gain plot for modified asymmetric hexagonal shaped monopole antenna is shown in Fig.10. In this peak gain of 5.7570 dB is achieved at 6 GHz.

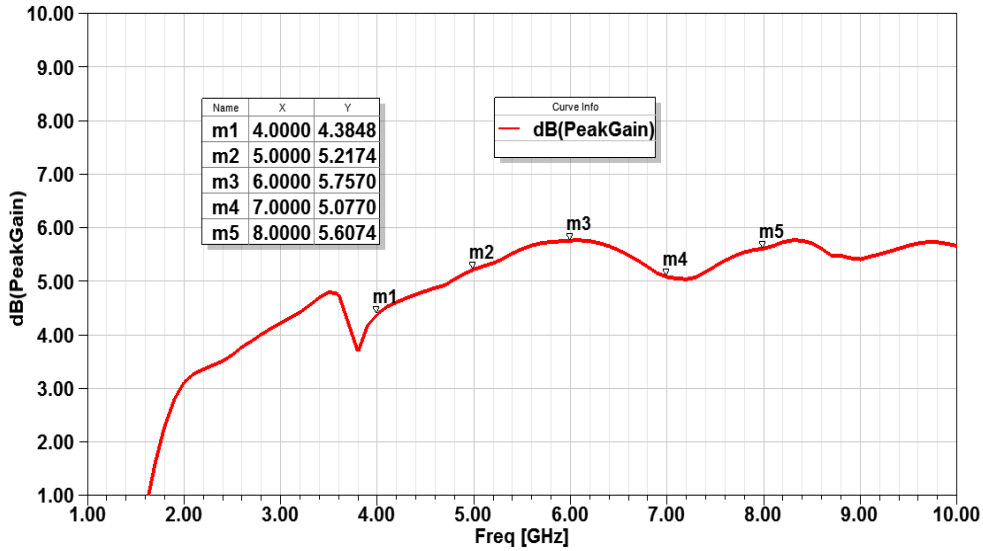


Fig. 10. Gain Plot for Modified Asymmetric Hexagonal Shaped Monopole Antenna

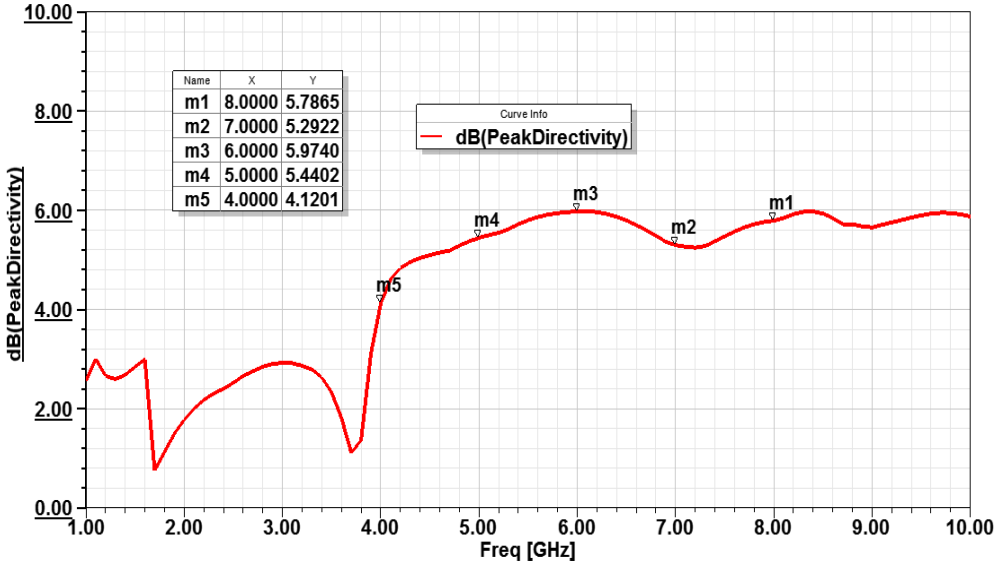
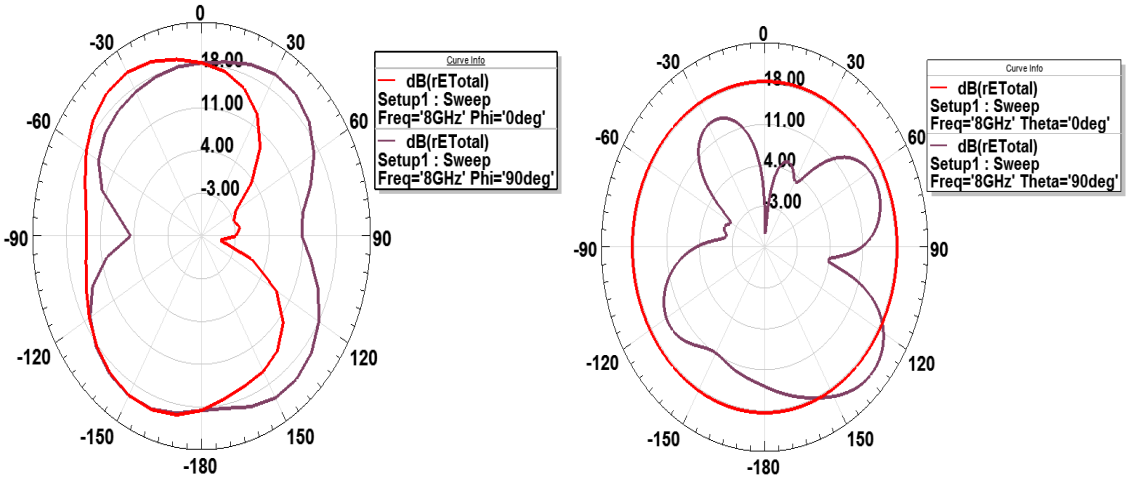


Fig. 11. Directivity Plot for Modified Asymmetric Hexagonal Shaped Monopole Antenna

From the Fig. 11, it is shown that the peak directivity of 5.9740 dB is achieved at 6 GHz. The radiation pattern for modified asymmetric hexagonal shaped monopole antenna with respect to elevation plane and azimuthal plane are shown in Fig 12(a), 12(b)



(a) (b)

Fig. 12. Radiation Pattern for Modified Asymmetric Hexagonal Shaped Monopole antenna - (a) Elevation Plane , (b) Azimuthal Plane

The co polarization and cross polarization graph for modified asymmetric hexagonal shaped monopole antenna is shown in Fig. 13. On plotting the component phi of the electric field (rEphi) for phi=0, it represents the co polar component, however, on plotting the rEtheta on the same plane it represents cross polar component. A purely polarized antenna will have low cross polarized radiation.

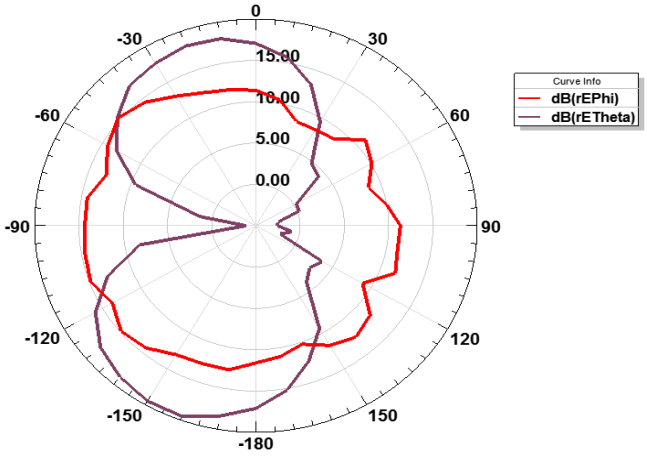
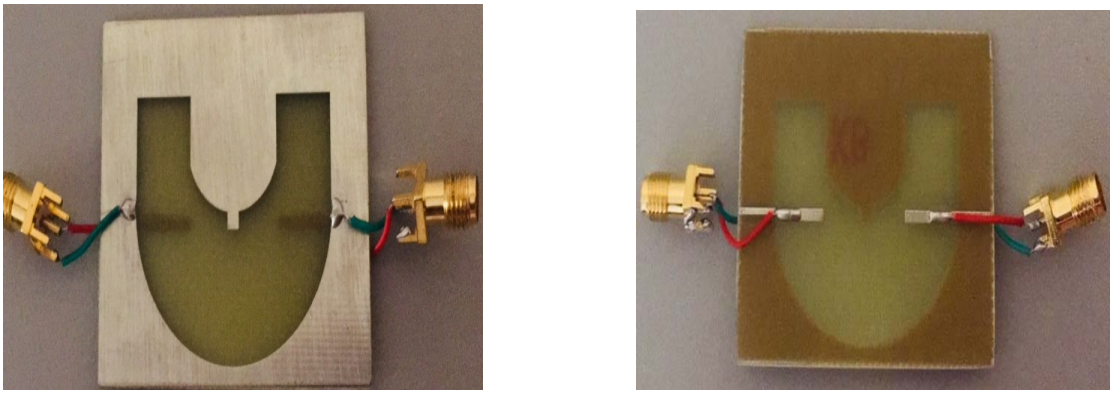


Fig. 13. Co polarization and Cross Polarization of Modified Asymmetric Hexagonal Shaped Monopole Antenna

By using this modified antenna structure, interference get completely eliminated for C-Band applications with improved gain,directivity when compared with previous antenna design [1]. But 3-dB Axial Ratio Bandwidth has to be improved in order to support more applications of C-Band under dual circular polarization with improved gain, directivity and less design complexity.

So U-shaped slot monopole antenna with dual CP mode is designed.The picture of the fabricated U-Shaped Slot Monopole Antenna is shown in Fig. 14 and it is tested with Agilent E5071C.The Fig.15 shows S-Parameter graph of U-Shaped slot monopole antenna which covers only C-Band (4-8) GHz. Hence interference due to other bands gets eliminated.



Bottom view Top view

Fig. 14. Fabricated U-shaped slot monopole antenna

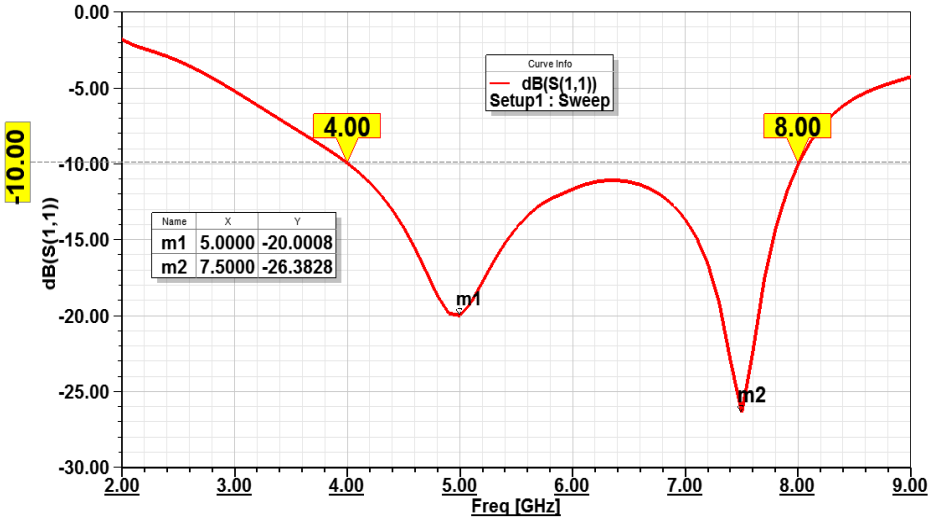


Fig. 15. S-parameter plot of U-shaped slot monopole antenna

The Simulated results are verified with measured results using fabricated antenna and tested with Agilent E5071C. The Fig.16 shows the testing setup. The Fig.17 shows combined graph of measured and simulated S-Parameter. The simulated results agree well measured results

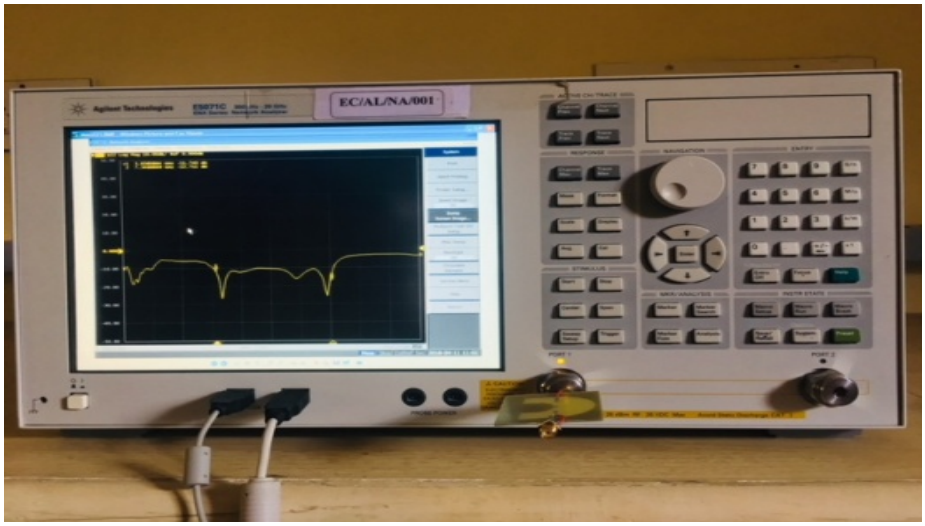


Fig. 16. Fabricated U-Shaped Slot Monopole Antenna Tested with Agilent E5071C

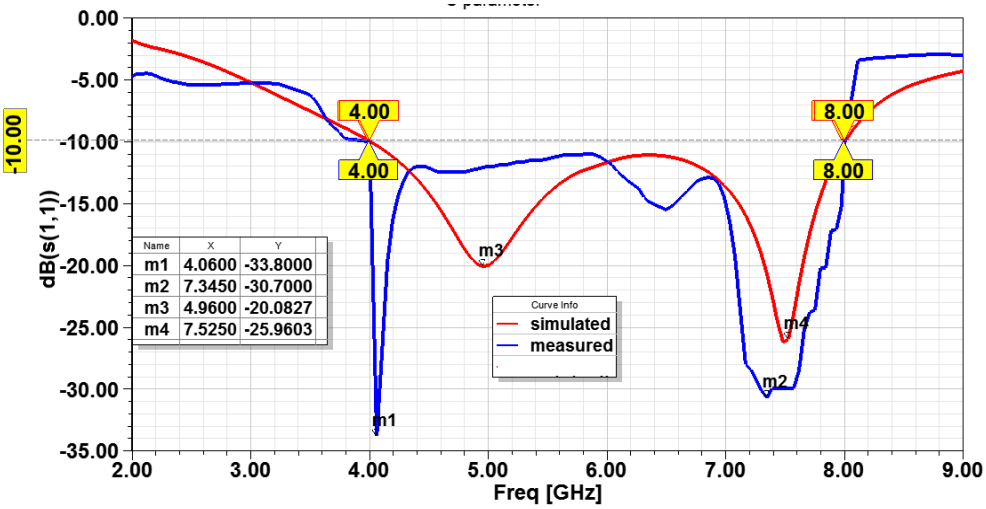


Fig. 17. Measured and Simulated S-Parameter Plot of U-Shaped Slot Monopole antenna

From Fig. 18, it is shown that VSWR value < 2 from 3.92 to 8.03. Hence retransmission is less.

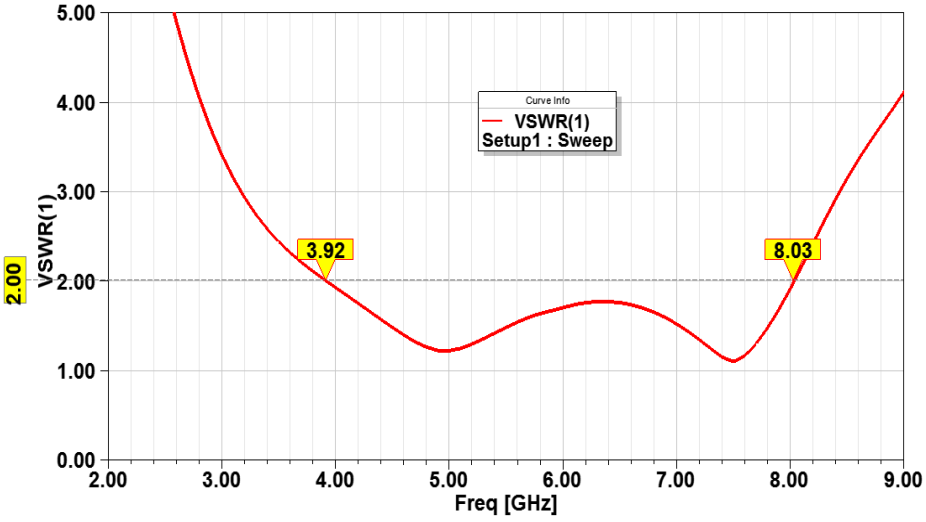


Fig. 18 VSWR Plot for U-shaped Slot Monopole Antenna

The Fig. 19 shows that 3dB axial ratio is good from 4.04 to 8 GHz, Hence it supports almost all C-Band applications under Dual CP concept. So it can be used for the applications likeWi-Fi (5.15-5.85) GHz, WIMAX (5.15-5.85) GHz, WLAN (5, 5.2, 5.8), INSAT (4.5-4.8) GHz, cordless telephone applications, Terrestrial microwave system (4 to 6 GHz), weather radars, Military applications (7.25-7.3,7.3-7.75)GHz, RSA(7.75-7.85) GHz etc.

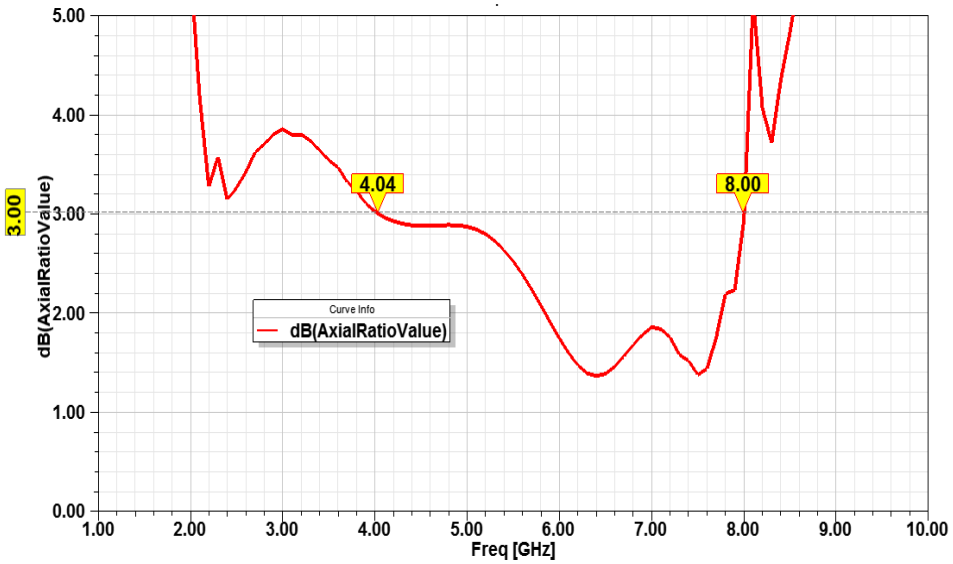
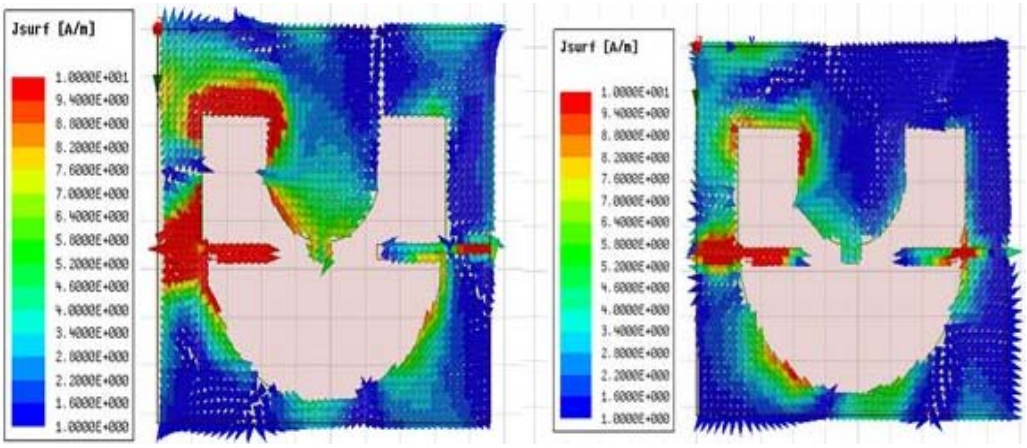


Fig. 19. 3dB-Axial Ratio Graph for U-shaped Slot Monopole Antenna

The surface current distribution of U-shaped slot antenna at phi value of 0 and 90 degree is shown in the Fig. 20. The U-shaped slot in antenna will shorten the path of the current flow.



(a) (b)

Fig .20 (a) Current flow at φ=0˚in antenna , (b) Current flow at φ=90˚in Antenna

The Fig.21 shows that the U-shaped slot antenna is having peak gain of 7.2831 dB at 4 GHz.

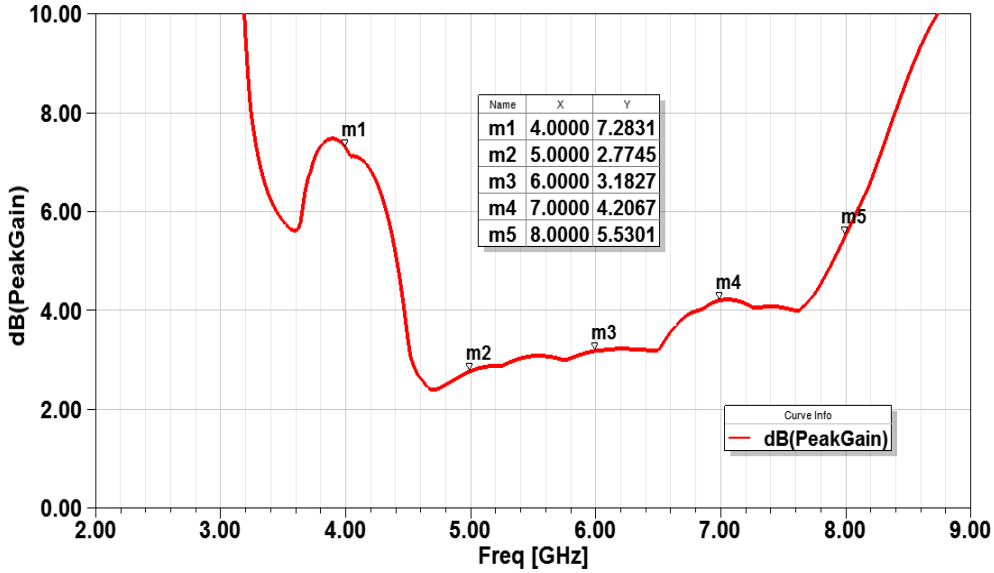


Fig. 21. Gain Plot of U-shaped Slot Monopole Antenna

The designed antenna is having peak directivity of 6.6365 dB at 4 GHz is shown in the Fig. 22. It explains how directional Antenna's pattern of radiation.

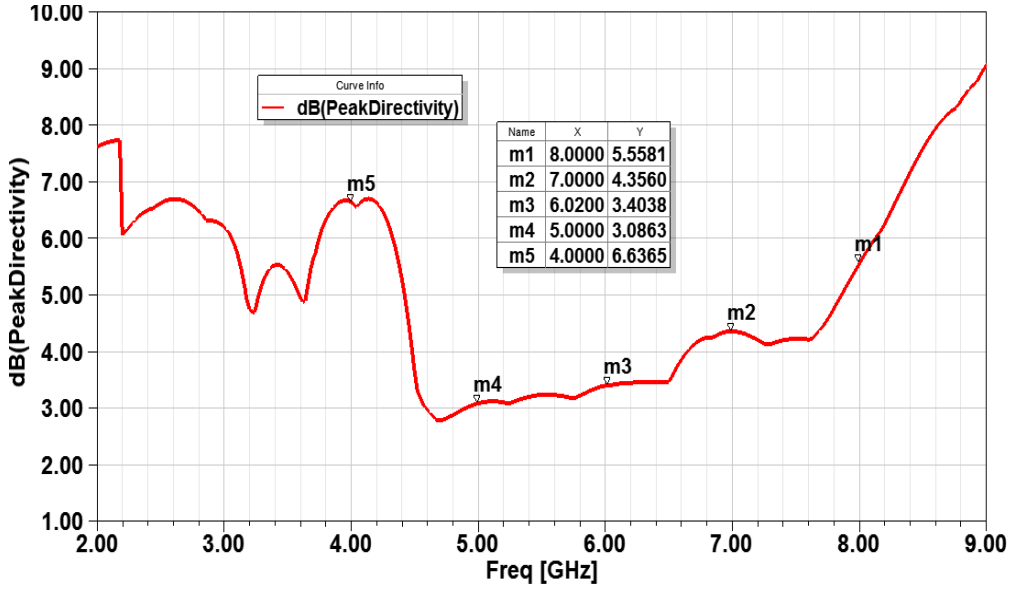
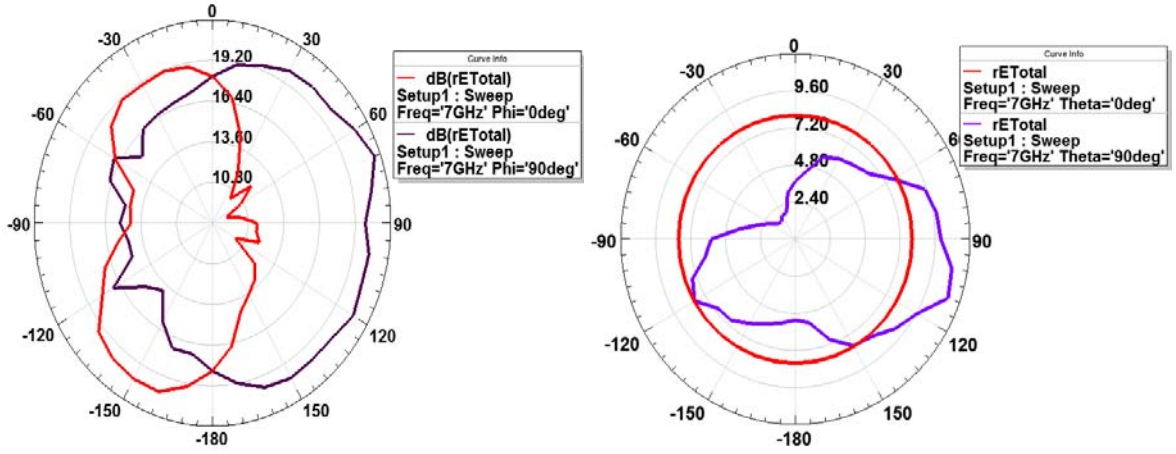


Fig. 22. Directivity Plot of U-shaped Slot Monopole antenna

The simulated far field radiation pattern of U-Shaped slot antenna with respect to elevation plane and azimuthal plane is shown in the Fig.23. It represents the direction of the strength of the radio waves.



(a) (b)

Fig. 23. Radiation Pattern for U-Shaped Slot Monopole Antenna- (a) Elevation Plane, (b) Azimuthal Plane

The co polarization and cross polarization graph for U-shaped slot monopole antenna is shown in Fig. 24. On plotting field (rEphi) for phi=0, it represents the co polar component, however, on plotting the rEtheta on the same plane it represents cross polar component.

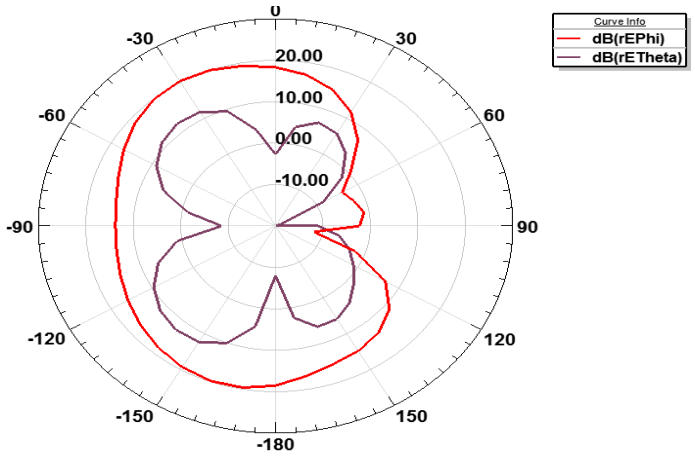


Fig. 24. Co polarization and Cross polarization of U-Shaped Slot Monopole Antenna

TABLE III. Performance Comparison

Parameters	Modified asymmetric Hexagonal Shaped Monopole Antenna	U-Shaped Slot Monopole Antenna
Peak Gain	5.77 dB	7.3307 dB
Peak Directivity	5.9 dB	6.66 dB
AR Bandwidth	(4.84-7.46) GHz	(4.04-8) dB
Complexity	High	Less
Antenna size	32 mm* 28 mm	48 mm* 41 mm

This U-shaped slot monopole antenna is having the advantage that broadband CP characteristics can be easily achieved due to its simplicity in its structure with good gain, directivity and support almost all applications of C-Band under dual circular polarization due to its 3 dB AR bandwidth improvement.Table III shows the comparision between modified asymmetric hexagonal shaped monopole antenna and U-Shaped slot monopole antenna.

V. CONCLUSION

The Dual CP based broadband monopole antennas have been designed and analyzed with the results obtained for C-Band applications. The results show that the frequency of operation from 4GHz to 8GHz is achieved for both the antennas. The U-Shaped slot monopole antenna is having good gain, directivity, AR bandwidth and less complexity when compared with modified asymmetric hexagonal shaped monopole antenna. This antenna design can be useful for applications like Wi-Fi (5.15-5.85)GHz, WIMAX (5.15-5.85)GHz, WLAN (5GHz, 5.2GHz, 5.8GHz), cordless phone, weather radars, INSAT (4.5-4.8)GHz, Terrestrial microwave applications (4-6) GHz ,Military applications (7.25-7.3,7.3-7.75)GHz, RSA(7.75-7.85) GHz and other C-Band wireless system.

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