Design and Analysis of Different Patch Geometry and Complementary Split Ring Resonator for X-band Applications

K.Srinivasa Naik, S.Aruna, Kondalu Banavathu, P.Vamsy Prasad

ABSTRACT--- In this paper, a comparative study between the probe feed and strip line feed on a circular, rectangular, triangular and hexagonal Patch Antenna are presented in this paper to compare the performance of antenna parameters. Rectangular and Circular configurations are most popular because they exhibit better characteristics but here triangular and hexagonal shapes are also taken due to advantage of compact size. At later stage, two metamaterial inspired rectangular and circular complementary split ring resonators are proposed and designed using microstrip line feeding to achieve antenna miniaturization. The proposed antennas are structured with flame retardant FR4 Epoxy substrate has thickness h=1.6mm and relative permittivity ε_r=4.4. The proposed microstrip patch antennas are designed for X-band application. The proposed antennas are implemented and pretended utilizing High Frequency Structure Simulator (HFSS) software version v17.2.

Keywords— Complementary Split Ring Resonator(CSRR),Metamaterial, Probe feeding, strip line feeding, FR4 Epoxy, HFSS, Microstrip Patch Antenna(MPA), X-band

I. INTRODUCTION

Microstrip patch antennas(MPA) are utilized in numerous applications because they have certain advantages like less space occupancy, inexpensive to manufacture and is easy to design when compared to the other antennas. Different kinds of shapes available for patch antennas. In literature traditional shapes like circular and rectangular patch antennas are given more importance. Right now specialists are extremely pulled in by the triangular shape and hexagonal shape than the traditional shapes because of their less size contrasted with old structures. The merits and demerits of each shape is evaluated by comparing their performance parameters. Coaxial probe feeding and microstrip line feeding are used to excite the proposed antennas. These two feeding techniques are utilized to fed the RF power directly to radiating patch utilizing an associated element.

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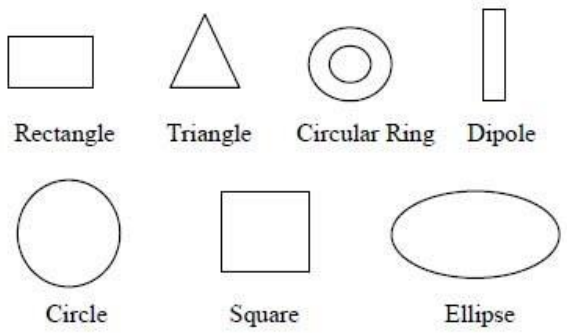

Fig.1.Different Shapes of Patch Antenna

In recent technology trends in integrated circuits results rapid decrease in size of antennas and cost effective as well. Rectangular CSRR and Circular CSRR are proposed in this paper to reduce the metalized area on the substrate. Designing this CSRR is a tough task because of its complex structure. SRR is a subset of Metamaterial structures, which has a pair of enclosed loops that are separated by a gap with splits are having 180 degrees phase difference between them.FR4 Epoxy with dielectric constant 4.4 is chosen as substrate because of low cost. The frequency range for X-band specified by IEEE is 8 to 12 GHz. These antennas are proposed for radar application.

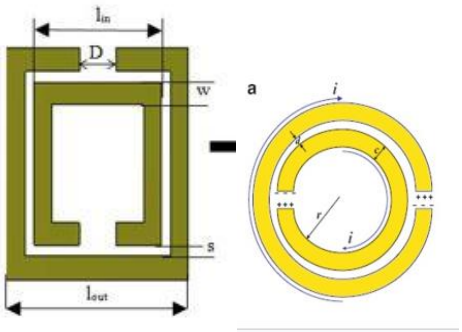

Fig.2 Rectangular and Circular CSRR

II. ANTENNA DESIGN FORMULAE

A. Selecting a Template (Heading 2)

The formulae utilized in calculating antenna design parameters of circular, rectangular and triangular patch shapes are as shown below.

A. Rectangular Patch Antenna

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

$$w = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{w}\right)^{-\frac{1}{2}}; \frac{w}{h} > 1$$

$$W_g = 6h + W$$

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L$$

B. Circular Patch Antenna

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[\ln\left[\frac{\pi f}{2h}\right]+1.7726\right]\right\}^{\frac{1}{2}}}$$

$$F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}}$$

$$\varepsilon_{eff} = \frac{1}{2}(\varepsilon_r+1) + \frac{1}{4}\frac{(\varepsilon_r-1)}{\sqrt{1+\frac{12h}{a}}}$$

$$a_e = \frac{1.8412c}{2\pi f_r\sqrt{\varepsilon_r}}$$

C. Triangular Patch Antenna

$$f_r = \frac{ck_{mn}}{2\pi\sqrt{\varepsilon_r}}$$

$$k_{mn} = \frac{4\pi}{3a}\sqrt{m^2+mn+n^2}$$

The resonant frequency for the m=0, n=1(fundamental resonant mode) is given by,

$$f_r = \frac{2c}{3a\sqrt{\varepsilon_r}}$$

$$a = \frac{2c}{3f_r\sqrt{\varepsilon_r}}$$

Where, C is velocity of light

TABLE.1 Parameters of Patch Antenna from the above formulas

S.No.	Name of the Parameter	Calculated Values
1	rectangular patch Length, L	9.12 mm
2	rectangular patch width, W	7.44 mm
3	ground Length, Lg	18.72 mm
4	ground width, Wg	16.02 mm
5	substrate thickness, h	1.6 mm
6	Substrate dielectric permittivity, εr	4.4
7	Effective dielectric constant, εreff	3.67
8	Resonant frequency, fr	9 GHZ
9	equilateral triangle patch Side length, a	9.5 mm
10	circular patch effective radius, ae	4 mm

III. ANTENNA DESIGN MODEL

The ground plane has a length (Lg) and width (Wg) is kept consistent for every one of the shapes considered here. The probe feed position in the patch is centered at (9.36mm,7.51mm) from the origin.

3.1.Rectangular Patch Antenna utilizing probe feeding

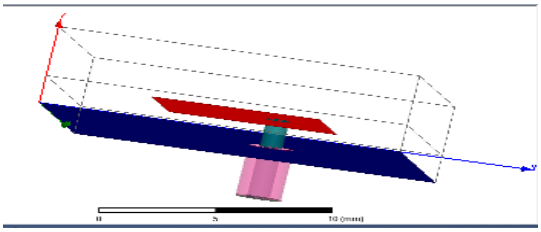

Fig.3 Rectangular MPA using probefeeding

3.2 Circular Patch Antenna utilizing probe feeding

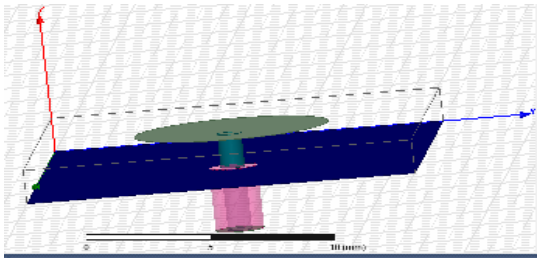

Fig.4 Circular MPA using probe feeding

3.3 Triangular Patch Antenna utilizing probe feeding

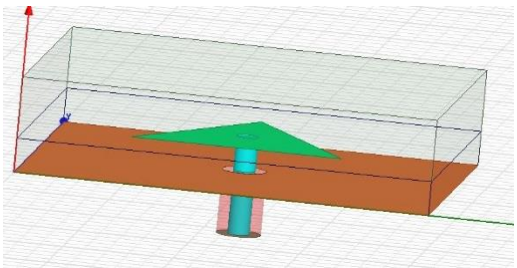

Fig.5Triangular MPA using probe feeding

3.4 Hexagonal Patch Antenna utilizing probe feeding

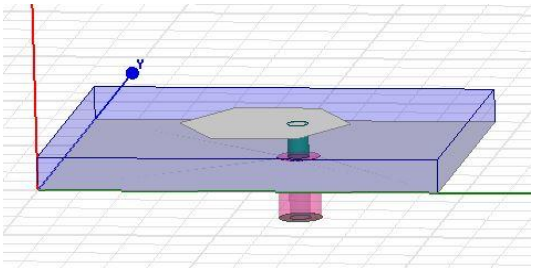

Fig.6Hexagonal MPA using probe feeding

3.5 Rectangular Patch Antenna utilizing strip line feeding

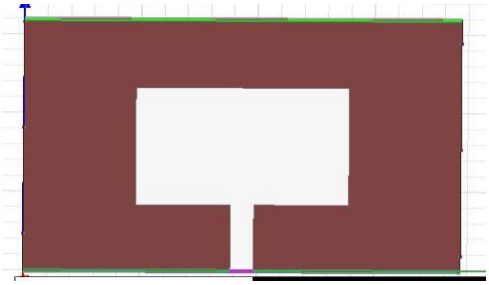

Fig.7Rectangular MPA using microstrip line feeding

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3.6 Circular Patch Antenna utilizing strip line feeding

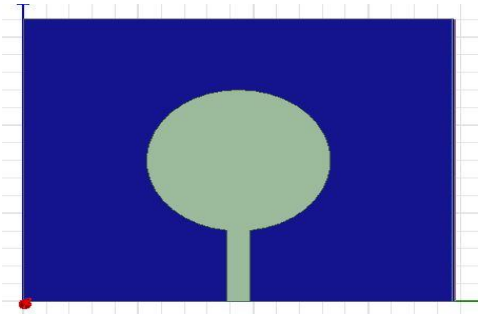

Fig.8Circular MPA using Microstrip line feeding

3.7 Triangular Patch Antenna utilizing strip line feeding

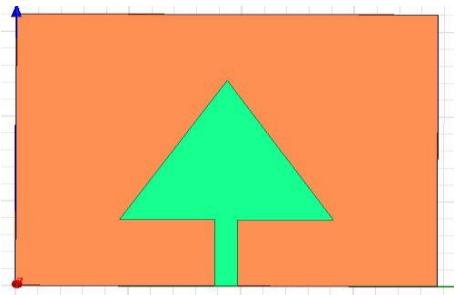

Fig.9Triangular MPA using Microstrip line feeding

3.8 Hexagonal Patch Antenna utilizing strip line feeding

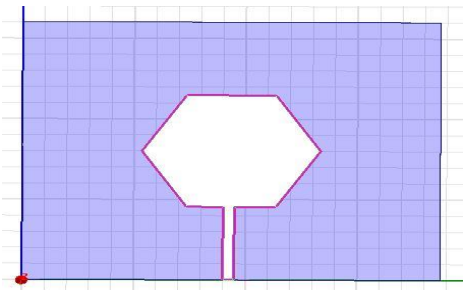

Fig.10 Hexagonal MPA using Microstrip line feeding

3.9 Rectangular Complementary Split Ring Resonator

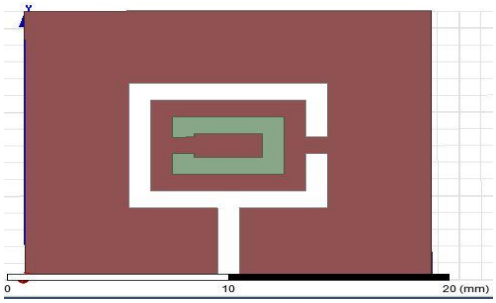

Fig.11 Rectangular Complementary Split Ring Resonator

3.10 Circular Complementary Split Ring Resonator

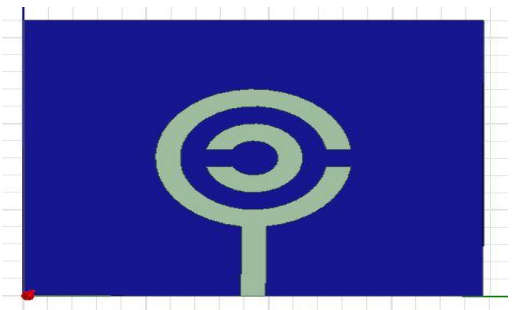

Fig.12 Circular Complementary Split Ring Resonator

IV. SIMULATED RESULTS AND DISCUSSION

4.1 Rectangular Patch Antenna utilizing coaxial feeding

RETURN LOSS

The return loss value for rectangular patch antenna utilizing probe feeding obtained is -31.0034 dB at a frequency of 9.4 GHz. Bandwidth obtained from below graph is 940 MHZ.

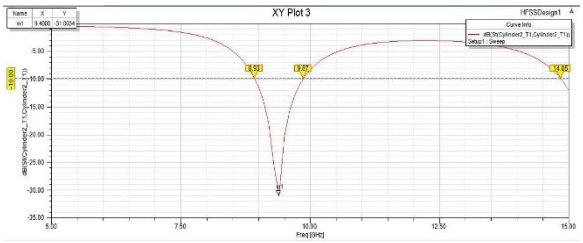

Fig.13 Return loss obtained for Rectangular MPA using probe feeding

VSWR

The VSWR for rectangular patch antenna utilizing probe feeding obtained value is 1.0580 at a frequency of 9.4 GHz.

Fig.14 VSWR obtained for Rectangular MPA using probe feeding

GAIN

The gain for rectangular patch antenna utilizing probe feeding obtained is 3.4577 dB .

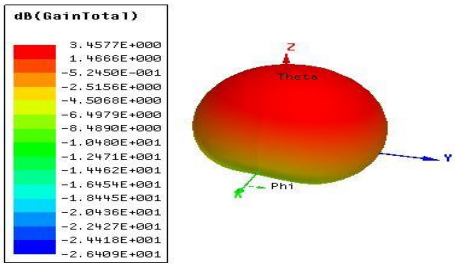

Fig.15 Gain obtained for Rectangular MPA using probe feeding

RADIATION PATTERN

The radiation pattern value for rectangular patch antenna utilizing probe feeding is 1.1935 V.

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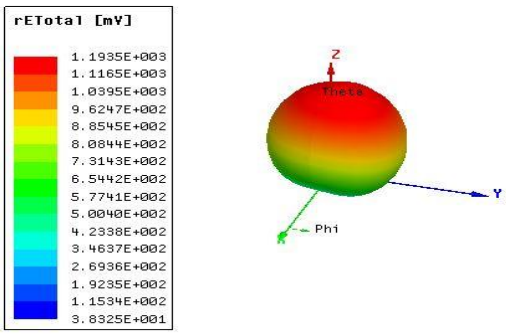

Fig.16 Radiation Pattern obtained for Rectangular MPA using probe feeding

DIRECTIVITY

The directivity value for rectangular patch antenna utilizing probe feeding obtained is 4.2902 dB.

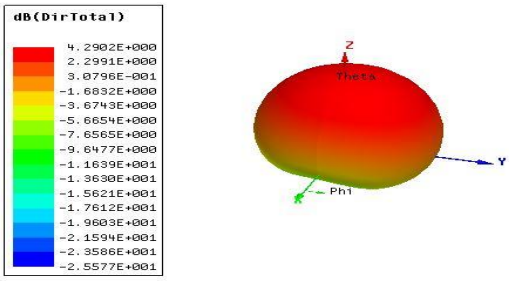

Fig.17 Directivity obtained for Rectangular MPA using probe feeding

4.2 Circular Patch Antenna utilizing probe Feeding

RETURN LOSS

The return loss value for Circular Patch Antenna utilizing probe feeding obtained is -14.5125 dB at a frequency of 9.4 GHz. Bandwidth obtained from below graph is 910 MHz

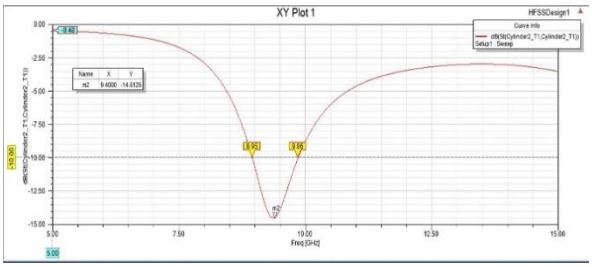

Fig.18 Return loss obtained for Circular MPA using probe feeding

VSWR

The VSWR for Circular Patch Antenna utilizing probe feeding obtained value is 1.4633 at a frequency of 9.4 GHz.

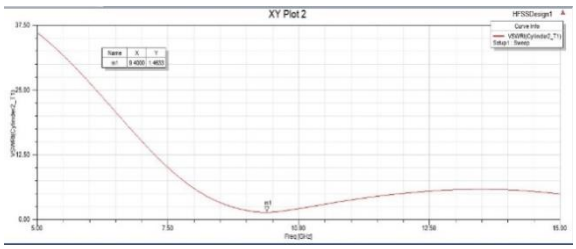

Fig.19 VSWR obtained for Circular MPA using probe feeding

GAIN

The gain for Circular Patch Antenna utilizing probe feeding obtained is 3.2479 dB.

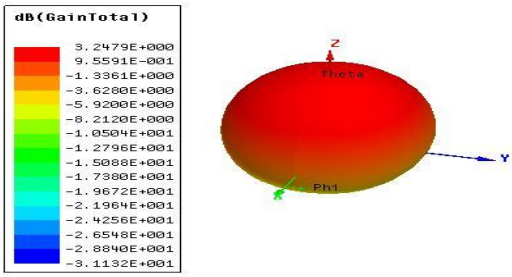

Fig.20 Gain obtained for Circular MPA using probe feeding

RADIATION PATTERN

The radiation pattern for Circular Patch Antenna utilizing probe feeding is 1.1598 Volts.

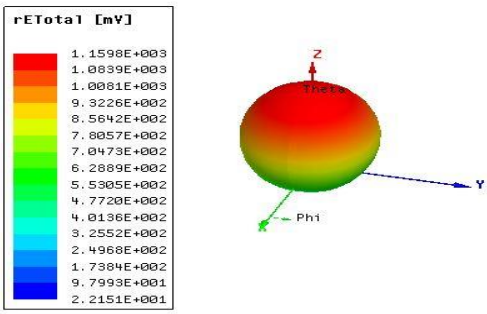

Fig.21 Radiation Pattern obtained for Circular MPA using probe feeding

DIRECTIVITY

The directivity value for Circular Patch Antenna utilizing probe feeding obtained is 4.0914 dB.

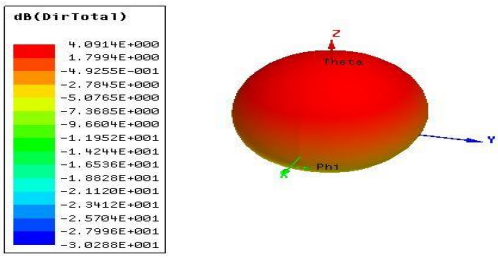

Fig.22 Directivity obtained for Circular MPA using probe feeding

4.3 Triangular Patch Antenna utilizing Probe Feeding

RETURN LOSS

The return loss value for Triangular Patch Antenna utilizing probe feeding obtained is -14.010 dB at a frequency of 8.9 GHz. Bandwidth obtained from below graph is 400 MHz

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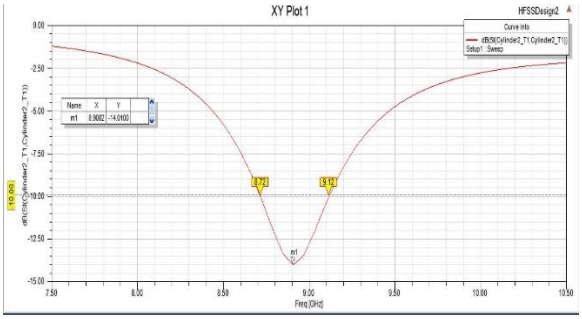

Fig.23 Return loss obtained for Triangular MPA using probe feeding

VSWR

The VSWR for Triangular Patch Antenna utilizing probe feeding obtained value is 1.5046 at a frequency of 8.9 GHz.

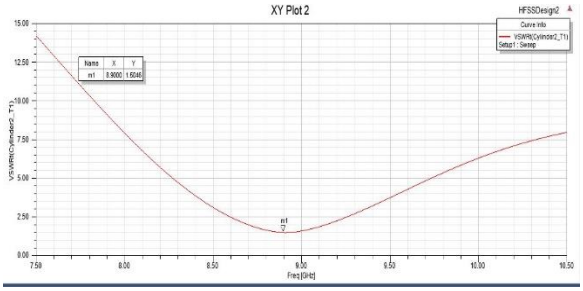

Fig.24 VSWR obtained for Triangular MPA using probe feeding

GAIN

The gain for Triangular Patch Antenna utilizing probe feeding obtained is 2.7473 dB.

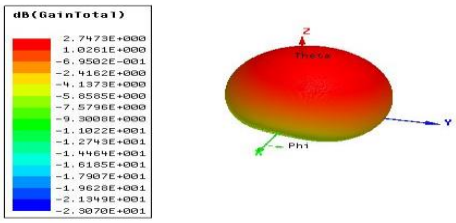

Fig.25 Gain obtained for Triangular MPA using probe feeding

RADIATION PATTERN

The radiation pattern for Triangular Patch Antenna utilizing probe feeding is 1.1271 Volts.

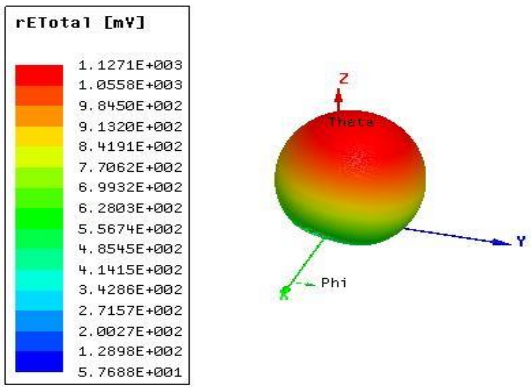

Fig.26 Radiation Pattern obtained for Triangular MPA using probe feeding

DIRECTIVITY

The directivity value for Triangular Patch Antenna utilizing probe feeding obtained is 3.7102 dB.

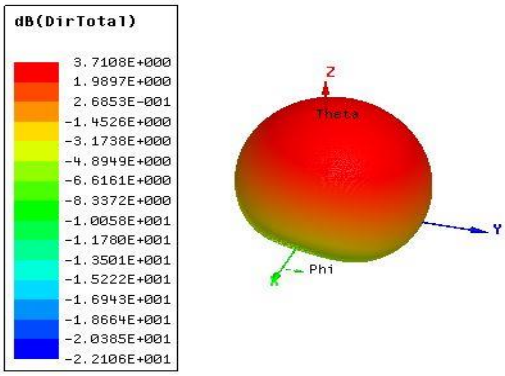

Fig.27 Directivity obtained for Triangular MPA using probe feeding

4.4 Hexagonal Patch Antenna utilizing probe Feeding

RETURN LOSS

The return loss value for Hexagonal Patch Antenna utilizing probe feeding obtained is -11.6644 dB at a frequency of 10 GHz. Bandwidth obtained from below graph is 840 MHz

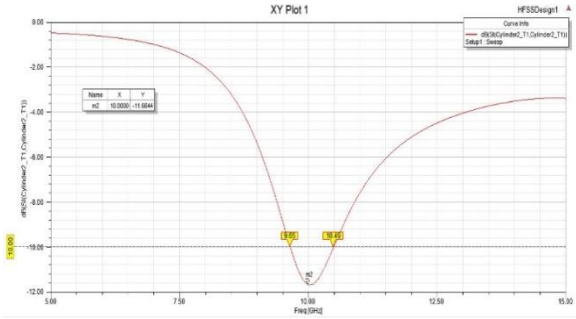

Fig.28 Return loss obtained for Hexagonal MPA using probe feeding

VSWR

The VSWR for Hexagonal Patch Antenna utilizing probe feeding obtained value is 1.7067 at a frequency of 10 GHz.

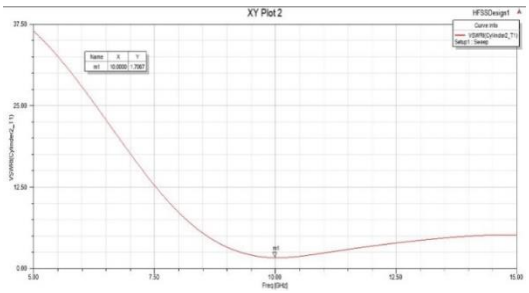

Fig.29 VSWR obtained for Hexagonal MPA using probe feeding

GAIN

The gain for Hexagonal Patch Antenna utilizing probe feeding obtained is2.8605 dB.

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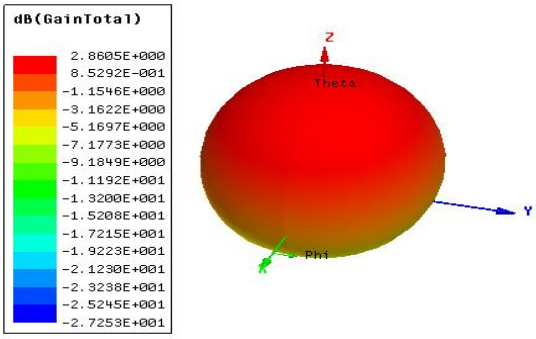

Fig.30 Gain obtained for Hexagonal MPA using probe feeding

RADIATION PATTERN

The radiation pattern for Hexagonal Patch Antenna utilizing probe feeding is 0.94388 Volts.

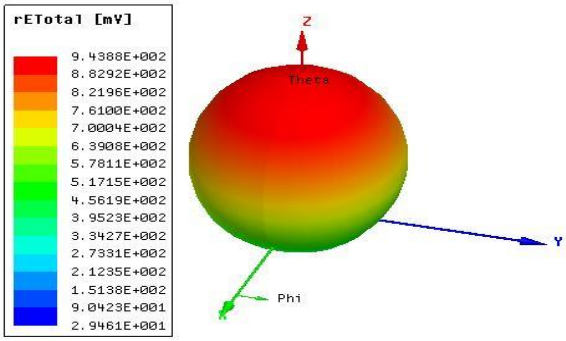

Fig.31 Radiation Pattern obtained for Hexagonal MPA using probe feeding

DIRECTIVITY

The directivity value for Hexagonal Patch Antenna utilizing probe feeding obtained is 3.7547 dB.

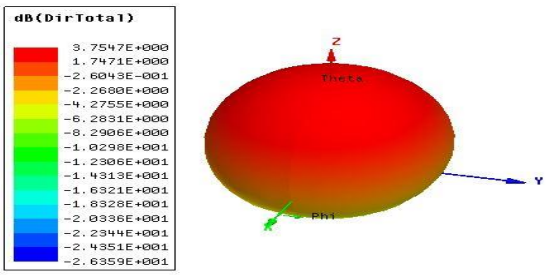

Fig.32 Directivity obtained for Hexagonal MPA using probe feeding

4.5 Rectangular Patch Antenna utilizing strip Line Feeding

RETURN LOSS

The return loss value for Rectangular Patch Antenna utilizing strip line feeding obtained is -22.5996 dB at a frequency of 8.5 GHz. Bandwidth obtained from below graph is 490 MHZ.

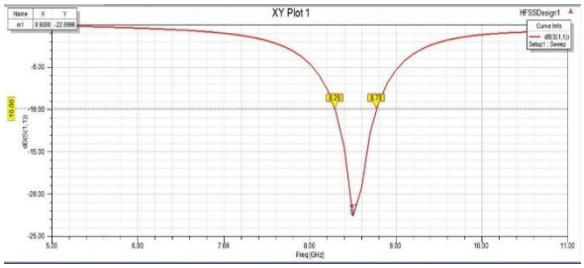

Fig.33 Return loss obtained for Rectangular MPA using strip line feeding

VSWR

The VSWR for Rectangular Patch Antenna utilizing strip line feeding obtained value is 1.1601 at a frequency of 8.5 GHz.

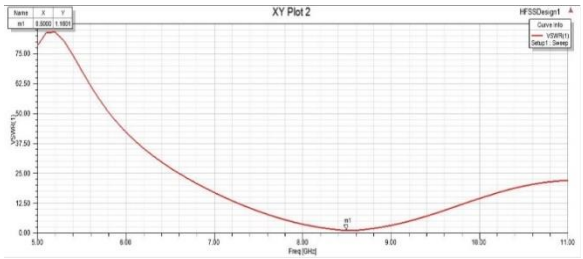

Fig.34 VSWR obtained for Rectangular MPA usingstrip line feeding

GAIN

The gain for Rectangular Patch Antenna utilizing strip line feeding obtained is 5.9370 dB.

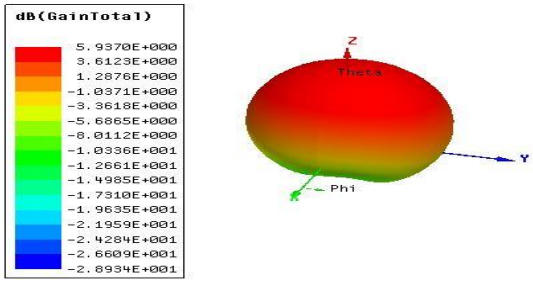

Fig.35 Gain obtained for Rectangular MPA using strip line feeding

RADIATION PATTERN

The radiation pattern for Rectangular Patch Antenna utilizing strip line feeding is 13.018 Volts.

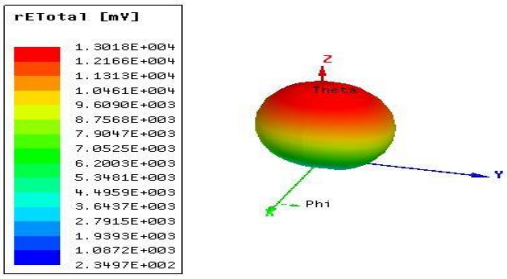

Fig.36 Radiation Pattern obtained for Rectangular MPA using strip line feeding

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DIRECTIVITY

The directivity value for Rectangular Patch Antenna utilizing strip line feeding obtained is 7.1400 dB.

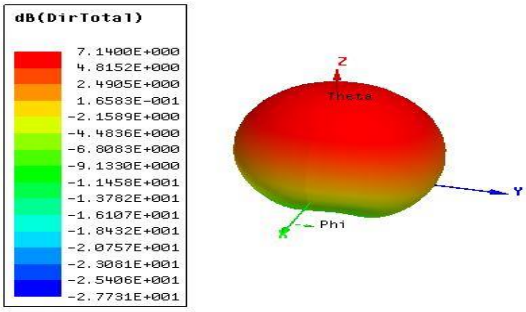

Fig.37 Directivity obtained for Rectangular MPA using strip line feeding

4.6 Circular Patch Antenna utilizing Strip line Feeding

RETURN LOSS

The return loss value for Circular Patch Antenna utilizing Strip line feeding obtained is -12.3646 dB at a frequency of 9.4 GHz. Bandwidth obtained from below graph is 410 MHZ.

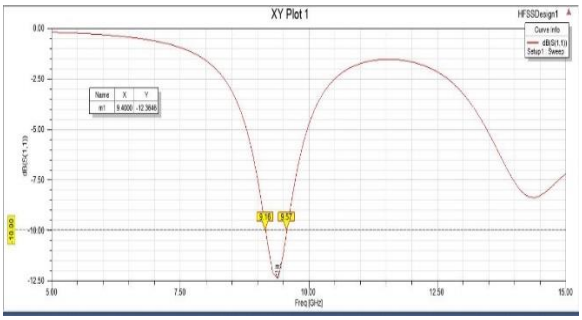

Fig.38 Return Loss obtained for Circular MPA using strip line feeding

VSWR

The VSWR value for Circular Patch Antenna utilizing Strip line feedingobtained is 1.6346 at a frequency of 9.4 GHz.

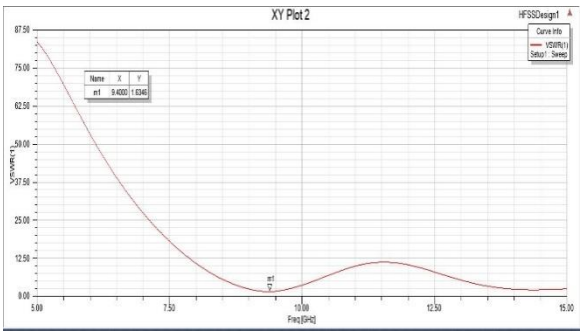

Fig.39 VSWR obtained for Circular MPA using strip line feeding

GAIN

The gain for Circular Patch Antenna utilizing Strip line feeding is3.4577 dB.

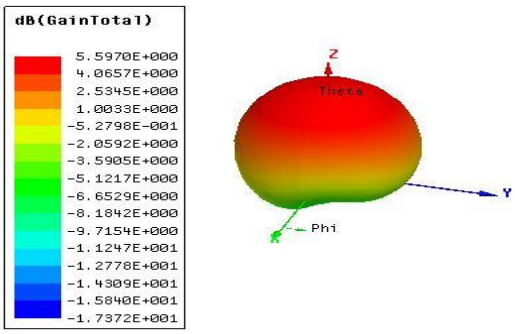

Fig.40 Gain obtained for Circular MPA using strip line feeding

RADIATION PATTERN

The radiation pattern for Circular Patch Antenna utilizing Strip line feeding is 5.597 V.

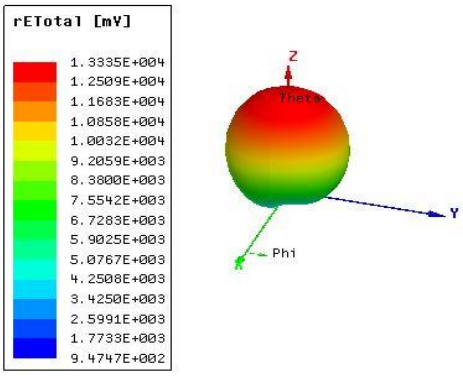

Fig.41 Radiation Pattern obtained for Circular MPA using strip line feeding

DIRECTIVITY

The directivity value for Circular Patch Antenna utilizing Strip line feedingobtained is 6.8944 dB.

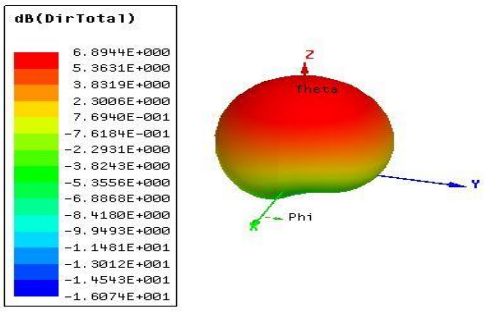

Fig.42 Directivity obtained for Circular MPA using strip line feeding

4.7 Triangular Patch Antenna utilizing strip Line Feeding

RETURN LOSS

The return loss value for Triangular Patch Antenna utilizing strip line feeding obtained is -30.1583 dB at a frequency of 8.9694 GHz. Bandwidth obtained from below graph is 400 MHZ.

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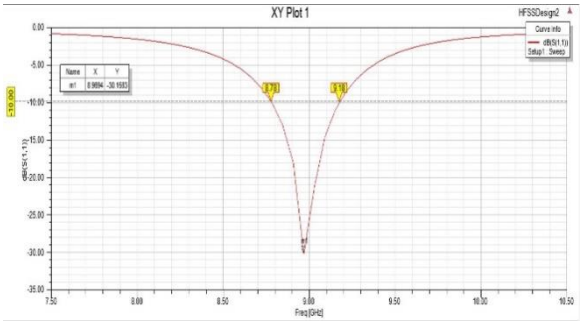

Fig.43 Return Loss obtained for Triangular MPA using strip line feeding

VSWR

The VSWR for Triangular Patch Antenna utilizing strip line feeding obtained value is 1.0641 at a frequency of 8.9694 GHz.

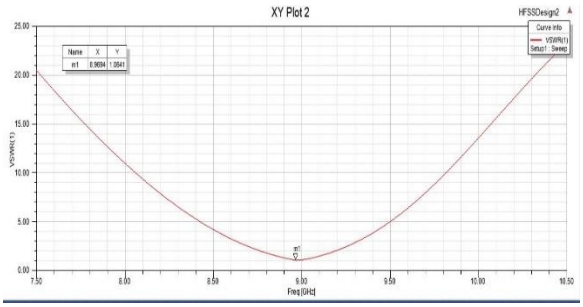

Fig.44 VSWR obtained for Triangular MPA using strip line feeding

GAIN

The gain for Triangular Patch Antenna utilizing strip line feeding obtained is 5.3247 dB.

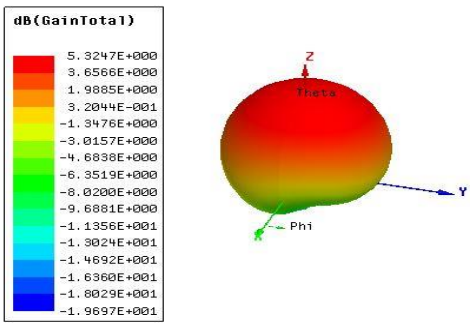

Fig.45 Gain obtained for Triangular MPA using strip line feeding

RADIATION PATTERN

The radiation pattern for Triangular Patch Antenna utilizing strip line feeding is 14.289 V.

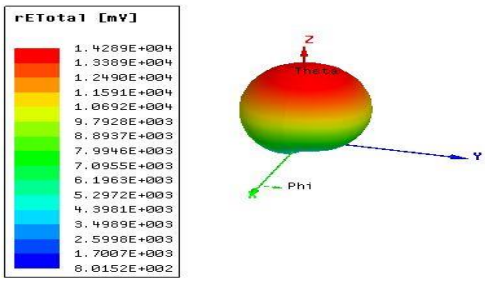

Fig.46 Radiation Pattern obtained for Triangular MPA using strip line feeding

DIRECTIVITY

The directivity value for Triangular Patch Antenna utilizing strip line feeding is 6.7556 dB.

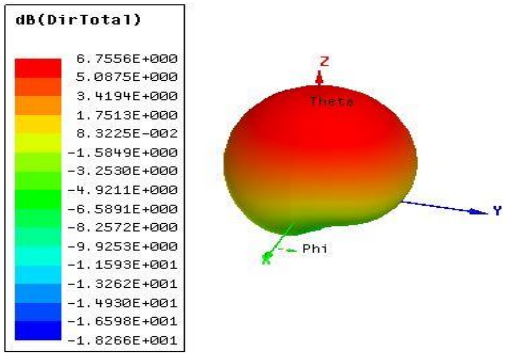

Fig.47 Directivity obtained for Triangular MPA using strip line feeding

4.8 Hexagonal Patch Antenna utilizing strip Line Feeding

RETURN LOSS

The return loss value for Hexagonal Patch Antenna utilizing strip line feeding obtained is -24.4239 dB at a frequency of 9.7085 GHz. Bandwidth obtained from below graph is 530 MHz

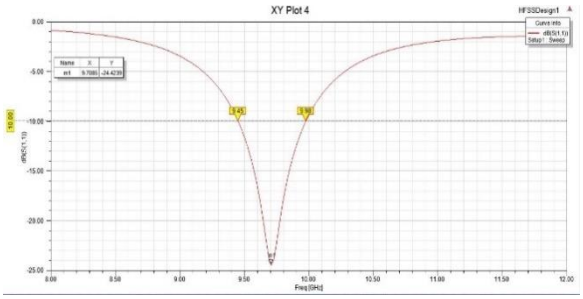

Fig.48 Return loss obtained for Hexagonal MPA using strip line feeding

VSWR

The VSWR value for Hexagonal Patch Antenna utilizing strip line feeding obtained is 1.1279 at a frequency of 9.7085 GHz

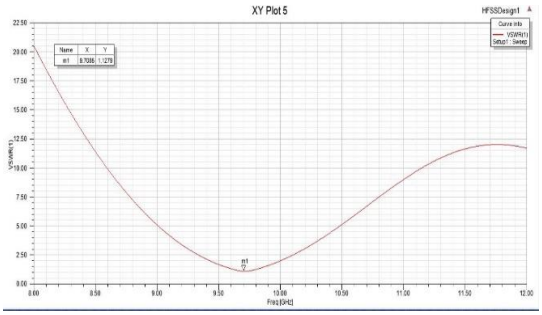

Fig.49 VSWR obtained for Hexagonal MPA using strip line feeding

GAIN

The gain for Hexagonal Patch Antenna utilizing strip line feeding obtained is 5.5316 dB.

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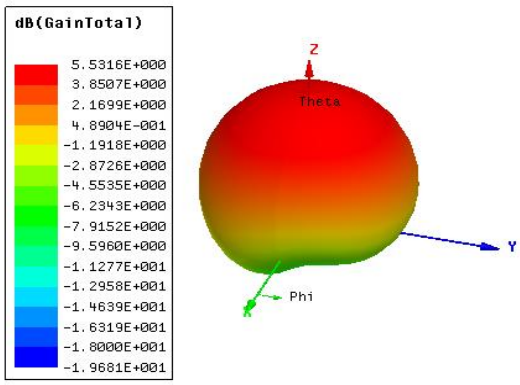

Fig.50 Gain obtained for Hexagonal MPA using strip line feeding

RADIATION PATTERN

The radiation pattern for Hexagonal Patch Antenna utilizing strip line feeding is 10.823 V.

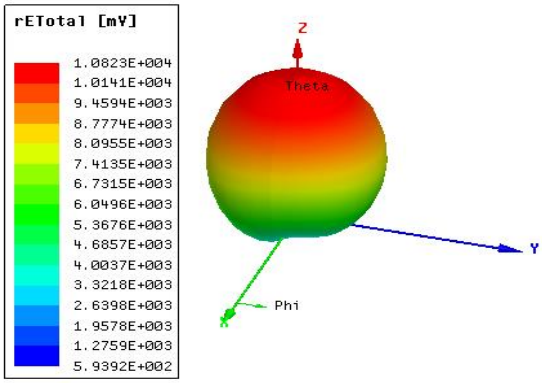

Fig.51 Radiation Pattern obtained for Hexagonal MPA using strip line feeding

DIRECTIVITY

The directivity value for Hexagonal Patch Antenna utilizing strip line feeding obtained is 6.8622 dB.

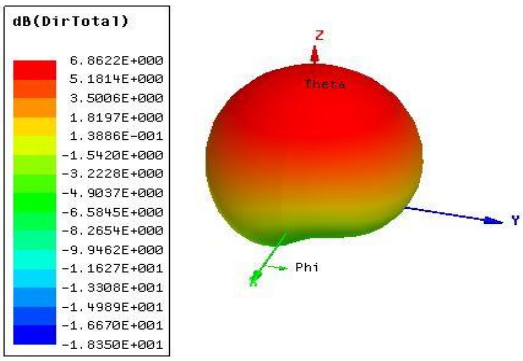

Fig.52 Directivity obtained for Hexagonal MPA using strip line feeding

4.9 Rectangular Complementary Split Ring Resonator

RETURN LOSS

The return loss value for Rectangular Complementary Split Ring Resonator obtained is -21.6873 dB at a frequency of 9.1 GHz. Bandwidth obtained from below graph is 310 MHz

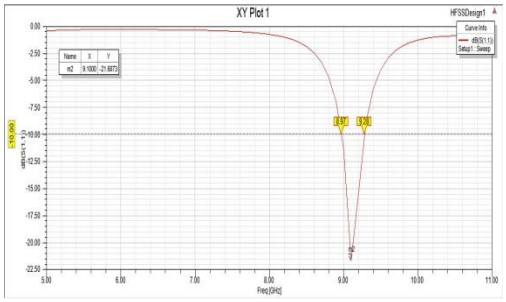

Fig.53 Return loss obtained for Rectangular CSRR

VSWR

The VSWR value for Rectangular Complementary Split Ring Resonator obtained is 1.1795 at a frequency of 9.1 GHz.

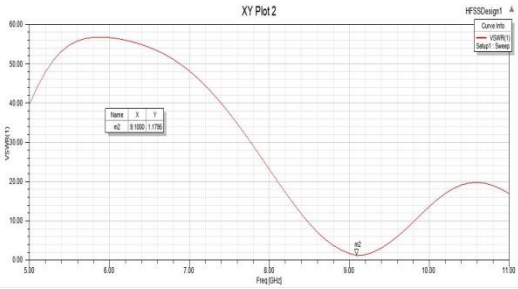

Fig.54 VSWR obtained for Rectangular CSRR

GAIN

The gain for Rectangular Complementary Split Ring Resonator obtained is 4.7741 dB.

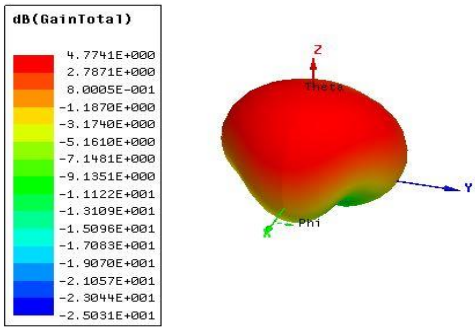

Fig.55 Gain obtained for Rectangular CSRR

RADIATION PATTERN

The radiation pattern for Rectangular Complementary Split Ring Resonator is 12.876 V.

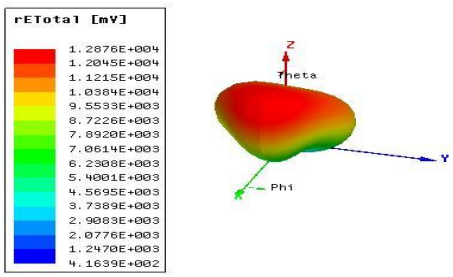

Fig.56 Radiation Pattern obtained for Rectangular CSRR

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DIRECTIVITY

The directivity value for Rectangular Complementary Split Ring Resonator obtained is 6.7281 dB.

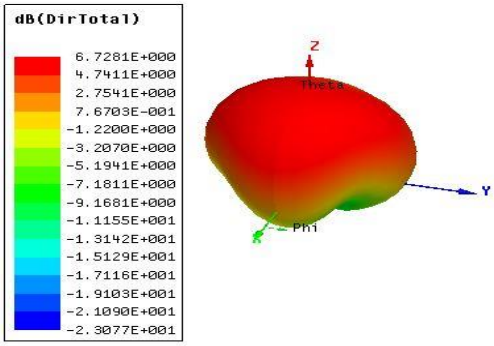

Fig.57 Directivity obtained for Rectangular CSRR

4.10 Circular Complementary Split Ring Resonator:

RETURN LOSS

Multiband operation obtained for Circular complementary Split Ring Resonator Antenna. The return loss value for first band of Circular complementary Split Ring Resonator Antenna obtained at 10 GHz is -10.9554 dB at a frequency of 10 GHz. Bandwidth obtained for first band from below graph is 130 MHz .The return loss value for second band of Circular complementary Split Ring Resonator Antenna obtained at 11.4 GHz is -22.3030 dB at a frequency of 11.4 GHz. Bandwidth obtained for second band from below graph is 360 MHz

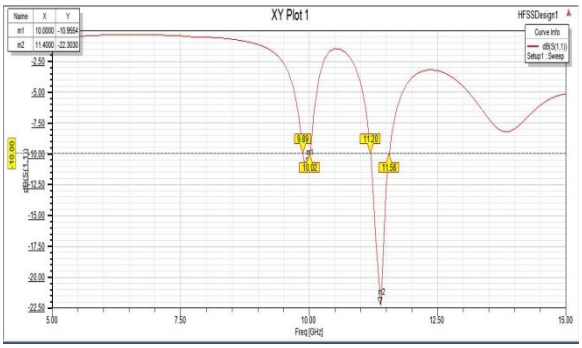

Fig.58 Return loss obtained for Circular CSRR

VSWR

The VSWR value for first band of Circular complementary Split Ring Resonator Antenna obtained is 1.7905 at a frequency of 10 GHz. The VSWR value for second band of Circular complementary Split Ring Resonator Antenna obtained is 1.1662 at a frequency of 11.4 GHz.

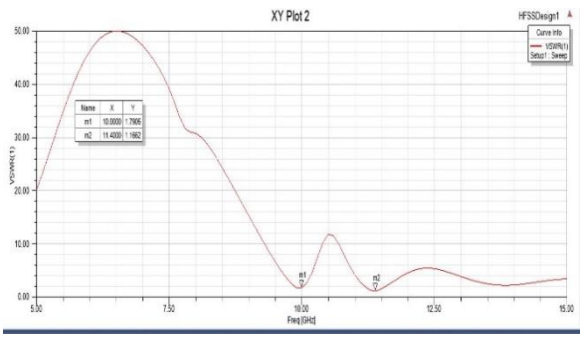

Fig.59 VSWR obtained for Circular CSRR

GAIN

The gain for Circular complementary Split Ring Resonator Antenna obtained is 4.9004 dB.

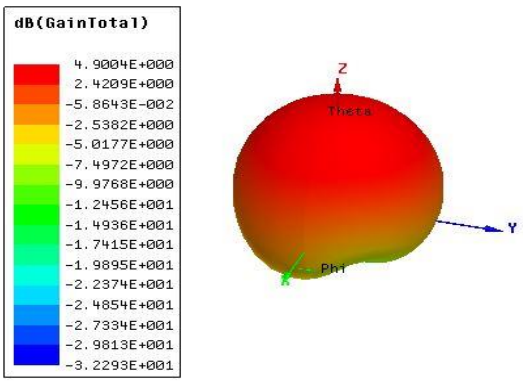

Fig.60 Gain obtained for Circular CSRR

RADIATION PATTERN

The radiation pattern for Circular complementary Split Ring Resonator Antenna is 6.5245 V.

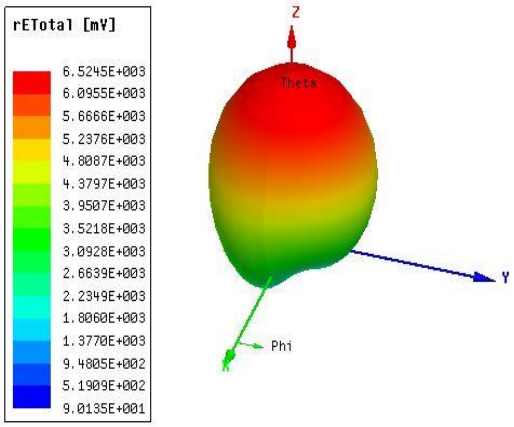

Fig.61 Radiation Pattern obtained for Circular CSRR

DIRECTIVITY

The directivity value for Circular complementary Split Ring Resonator Antenna obtained is 6.7603 dB.

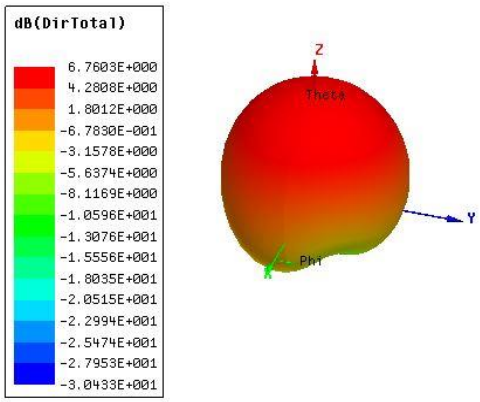

Fig.62 Directivity obtained for Circular CSRR

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V. RESULT ANALYSIS

Simulations results of antenna performance parameters are given table 2 and table 3.

TABLE 2: SIMULATIONS RESULTS OF ANTENNA PERFORMANCE PARAMETERS

	Resonant frequency (GHz)	Return loss (dB)	VSWR	Gain (dB)
Rectangular Patch using coaxial feed	9.4	-31.0034	1.0580	3.4577
Circular Patch using coaxial feed	9.4	-14.5125	1.4633	3.2479
Triangular Patch using coaxial feed	8.9	-14.010	1.5046	2.7473
Hexagonal Patch using coaxial feed	10	-11.6644	1.7067	2.8605
Rectangular Patch using Microstrip line feed	8.5	-22.5996	1.1601	5.9370
Circular Patch using Microstrip line feed	9.4	-12.3646	1.6346	5.597
Triangular Patch using Microstrip line feed	8.9694	-30.1583	1.0641	5.3247
Hexagonal Patch using Microstrip line feed	9.7085	-24.4239	1.1279	5.5316
Rectangular complementary split ring resonator	9.1	-21.6873	1.1795	4.7741
circular complementary split ring resonator	10	-10.9554	1.7905	4.9004
	11.4	-22.3030	1.1662	

TABLE 3: SIMULATIONS RESULTS OF ANTENNA PERFORMANCE PARAMETERS

	Directivity (dB)	Radiation Pattern (volts)	Bandwidth(MHz)
Rectangular Patch using coaxial feed	4.2902	1.1935	940
Circular Patch using coaxial feed	4.0914	1.1598	910
Triangular Patch using coaxial feed	3.7102	1.1271	400
Hexagonal Patch using coaxial feed	3.7547	0.94388	840
Rectangular Patch using Microstrip line feed	7.1400	13.018	490
Circular Patch using Microstrip line feed	6.8944	13.335	410
Triangular Patch using Microstrip line feed	6.7556	14.289	400
Hexagonal Patch using Microstrip line feed	6.8622	10.823	530
Rectangular complementary split ring resonator	6.7281	12.876	310
Circular complementary split ring resonator	6.7603	6.5245	130

From the above results it is obtained that with all patch designs rectangular patch with coaxial feeding and triangular patch with microstrip line feeding has better return loss compared to other designs.

Rectangular, circular and triangular patch using microstrip line feeding has more gain when compared to rectangular, circular and triangular patch using coaxial feeding.

Rectangular patch using microstrip line feeding has better directivity compared to other patch designs.

Rectangular Patch using probe feed, circular patch using probe feed has better bandwidth compared to other patch designs.

Rectangular complementary split ring resonator and circular complementary split ring resonator has more gain when compared to rectangular, circular and triangular patch using probe feeding.

Better directivity and gain obtained for rectangular complementary split ring resonator and circular complementary split ring resonator even though it has less metalized area on the substrate. So rectangular and circular complementary split ring resonator requires less cost compared to remaining antennas.

VI. CONCLUSION

In this paper, Rectangular, circular, triangular and hexagonal patch antenna with probe feed and strip line feed are designed and analyzed. At later stage, two meta-material inspired SRR-loaded antennas, rectangular complementary split ring resonator and circular complementary split ring resonator are designed and analyzed. Each shape has its own advantages in any of the antenna performance parameters for X-band application. From the above results the rectangular patch antenna provides better performance parameters as compared to other designs.

The fundamental objective for the X-band application is high directivity and high gain and is accomplished by rectangular patch antenna utilizing strip line feeding. Wider bandwidth is achieved by the rectangular patch antenna

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using probe feeding. Triangular patch antenna using strip line feeding provides finest return loss, gain and directivity even though it has compact size compared to rectangular and triangular.

Meta-material inspired rectangular complementary split ring resonators (CSRR) has obtained finest return loss, directivity, gain and radiation pattern compared to remaining antennas. Circular complementary split ring resonator (CSRR) has obtained dual band in X-band frequency range. Hence the rectangular complementary split ring resonator (CSRR) and circular complementary split ring resonator (CSRR) has obtained finest results even though it occupies less metalized area on substrate.

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