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A Novel Metamaterial Loaded Circular Ring Microstrip Antenna for 5G Applications

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Abstract: In this manuscript, a new design of inset feed metamaterial (CSRR) loaded Circular ring Microstrip Antenna (CRMA) has been presented. The dimensions of the radiating element are 20 mm x 20 mm x 1.6 mm at first resonating frequency where the metamaterial is loaded in the ground plane and the microstrip feed line is connected through Subminiature version A connector. Improved characteristics of patch antenna can be achieved by modifying the structure of CSRR. The modified CSRR structure exhibits impedance bandwidth for S_{11}< -10 dB at 9.5, 11.83 and 15.67 GHz which is useful for X and ku band applications. The proposed metamaterial antenna had 2 GHz (10.24 – 12.28) and 3 GHz (13.57-16.63) overall bandwidth. The effect of different substrate materials in the designed antenna structure is also compared. Optimization is done by commercially available 3D electromagnetic simulation software Ansys HFSS 2019 version.It is understood from the experiment that the measured results enjoy good agreement with the simulated results.

Keywords: Circular ring microstrip antenna, Metamaterial, Complementary split ring resonator, Multiband, FR4 substrate, Electromagnetic bandgap.

1. Introduction

The demand to integrate more communication standards and to provide quality service is rapidly increasing in the sector of wireless communication and microwave system. Microstrip patch antenna also referred to as printed antenna which is fabricated using microstrip techniques is gaining more popularity due to its compactness, low profile, less weight and its underlying qualities are also widely reported in the literature [1].

In order to reduce the limitations of the patch antenna, several approaches have been suggested using artificial structures known as metamaterials which are not found in nature. To enhance the antenna gain, bandwidth and to achieve miniaturization, metamaterial structures are used in planar antennas due to the fact that the operating wavelength is higher than its size. The unique features of the split-ring resonator (SRR) and the complementary split ring resonator (CSRR) which are the elemental components of metamaterial have already been discussed in literature [2].Discussion and analysis have been on corresponding circuit of SRR and CSRR consisting of parallel LC circuit [3].CSRR proposed by Pendry which is the dual counterpart of split ring resonator (SRR) originally has already received considerable attention due to its negative permeability and negative permittivity in planar configurations [4-7].

There has been fast growth in administering Electromagnetic bandgap (EBG) structures in microwave circuits and antenna applications recently [8-9]. It is employed to minimize the losses occurring due to dielectric material, to suppress the surface waves and to design low profile antenna.

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The proposed antenna covers the X-band and Ku-band applications such as Fixed satellite services (FSS), Free-To-Air (FTA) systems, satellite TV and for VSAT systems.

The authors have reported microstrip antenna with CSRR employed on the ground plane for WLAN applications [10]. Metamaterial loaded compact patch antenna is designed in order to achieve new structure for various wireless standards [11]. A compact microstrip antenna with a complementary split ring resonator loaded with non-uniform metasurfaces on a ground plane is developed for indoor based wireless station and wireless communication structures [12].Miniaturized UWB antenna using EBG structure is presented in [13] for 5G applications.

The objective of this paper is to improve the bandwidth further and gain in a conventional circular ring microstrip antenna (CRMA) by modifying the structure of CSRR on the ground plane. This metamaterial loaded CRMA gives better impedance matching, enhancement in gain and wide bandwidth. EBG cylindrical structure is also inserted to reduce the surface wave losses. In this work, the effect of codirectional CSRR on the conventional inset feed CRMA has been studied and examined in terms of different antenna parameters and with different substrate materials.

This paper is set up as follows: Section II covers the geometrical shape of CRMA and modified codirectional CSRR unit cell along with its illustration of designs. In section III, the results of modified CSRR antenna designs are given and validated by comparing with conventional CRMA and different substrate materials. In section IV, concluding remarks of the work is presented.

2. Antenna Geometry

The layout of the radiating layer (i.e. top view) and the ground plane (i.e. bottom view) of the proposed antenna with dimensions are presented in Fig.1.

The upper layer or radiating layer consists of microstrip line fed annular ring patch with inner radius R_1=4 mm and outer radius R_2=8 mm. The substrate selected was commercially available FR4 with thickness (h) of 1.6 mm, dielectric constant (ε_r) of 4.4 and loss tangent (δ) of 0.02. Impedance matching between the transmission line and the circular ring patch is attained by using inset feed microstrip line with a width of 3 mm and length of 7 mm.

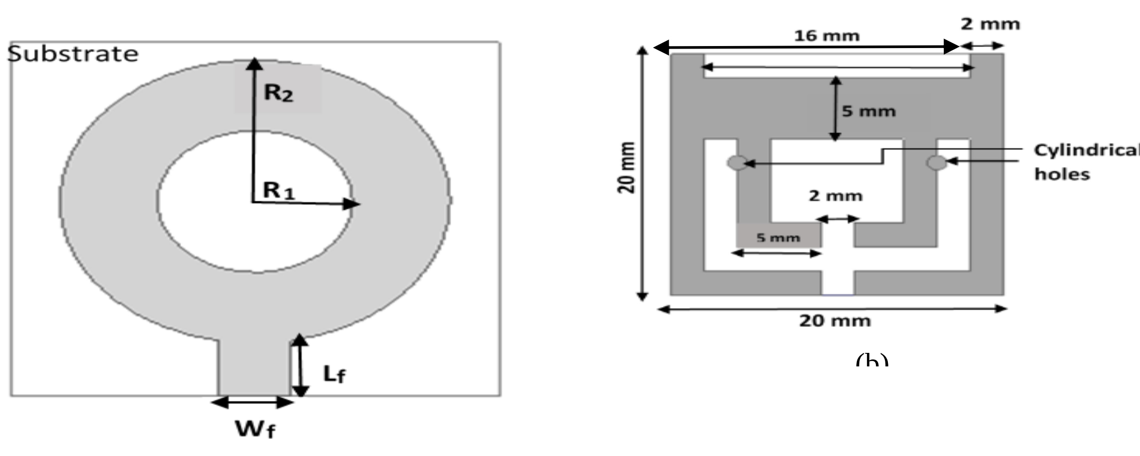

Fig.1. Sketch of proposed antenna structure (a) Radiating layer-Top view (b)Codirectional CSRR-Bottom view

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The radius dimension of the circular ring patch element can be computed by equation as below [14]

$$f_r = \frac{c}{\pi R_2}\sqrt{\frac{1+\varepsilon_r}{2\varepsilon_r}} \qquad (1)$$

where, c = velocity of light in free space (m/s), ε_r is the relative dielectric constant (F/m), R_2 is the outer radius (m) and f_r is the resonance frequency (GHz).

The required minimum width of the ground plane of microstrip antenna can be obtained by expression as below [15]

$$W_g = 6h + \frac{\pi}{2}R_2 \qquad (2)$$

W_g =minimum width of ground plane (mm).
R_2 =outer radius of circular ring patch (mm).

In the presented antenna structure, the solid copper ground plane is replaced with a codirectional etched CSRR structure which means that the splits of the two rings are oriented in the same direction. The codirectional CSRR metamaterial has been designed using copper conductor material with a conductivity of 5.8 X 10^7 S/m. Here EBG structure is also inserted in the proposed antenna to suppress the surface wave losses by making cylindrical holes in the dielectric as well as in the ground plane of same diameter. The radius of the cylindrical holes is 0.6 mm. Here one Dimensional EBG surface is used in which two cylindrical holes in dielectric surface above ground plane are cut and the power to the microstrip antenna is given through micro strip feed line.

Using Eq. (1) and (2), the computed values of the outer radius (R_2) of the patch element and the minimum width of the ground plane are 8.3 mm and 22.16 mm respectively. The optimized values of the proposed antenna structure to obtain good results are mentioned in Table 1

Table 1. Antenna Specification

Description	Size(mm)
Inner radius of patch (R_1)	4
Outer radius of the patch (R_2)	8
Length of the substrate	20
Width of the substrate	20
Height of the substrate (h)	1.6
Length of feed line (L_f)	7
Width of feed line (W_f)	3
Length of ground plane	20
Width of the ground plane	20
Radius of cylindrical holes	0.6

3. Results and Discussion

The suggested metamaterial antenna has been fabricated by photolithographic process using commercially available FR4 printed circuit board material as shown in Fig.2.The return

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loss and VSWR are measured using Anritsu vector network analyzer (frequency range 5 kHz-20 GHz).

(a) (b)

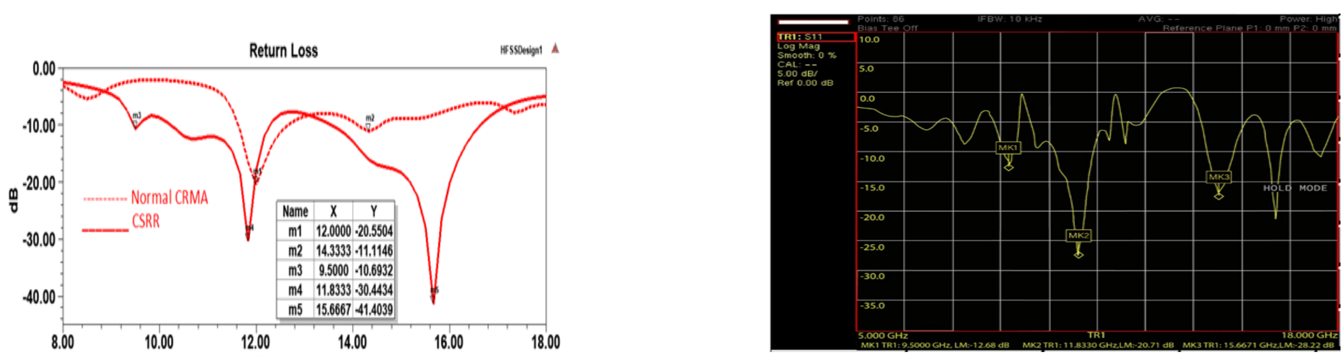
Fig.2.Prototype of the proposed antenna
(a) top view and (b) bottom view

The CRMA with full ground plane resonates at 12 and 14.33 GHz with return loss of −20.55 dB and −11.11 dB and −10 dB impedance bandwidth of 1 GHz (11.63−12.63) and 410 MHz (14.13−14.54) respectively.

CRMA loaded with modified CSRR configuration exhibited resonance frequencies at 9.5, 11.83 and 15.66 GHz with return loss of −10.69 dB, −30.44 dB and −41.40 dB respectively. The simulated −10 dB impedance bandwidth was from 9.44 to 9.63 GHz,10.15 to 12.32 GHz which covers the X-band applications and 13.43 to 16.70 GHz that covers Ku band applicationswith the bandwidth of 190 MHz, 2.17and 3.17GHz respectively.

The measured triple band frequencies are 9.5, 11.83 and 15.66 GHz with return loss of −12.68 dB, −20.71 dB and −28.22 dB respectively.

The simulated and experimental VSWR of the proposed antenna are shown in fig.4.The value of VSWR are found to be 1.82,1.06 and 1.02 at the resonant frequencyof 9.5,11.83 and 15.66 GHz respectively. The obtained simulated values of VSWR indicates that the proposed structure works efficiently for the given range of frequencies with better impedance matching.



(a) (b)

Fig.3. Return loss (a) Simulated and (b) Measured using network analyzer

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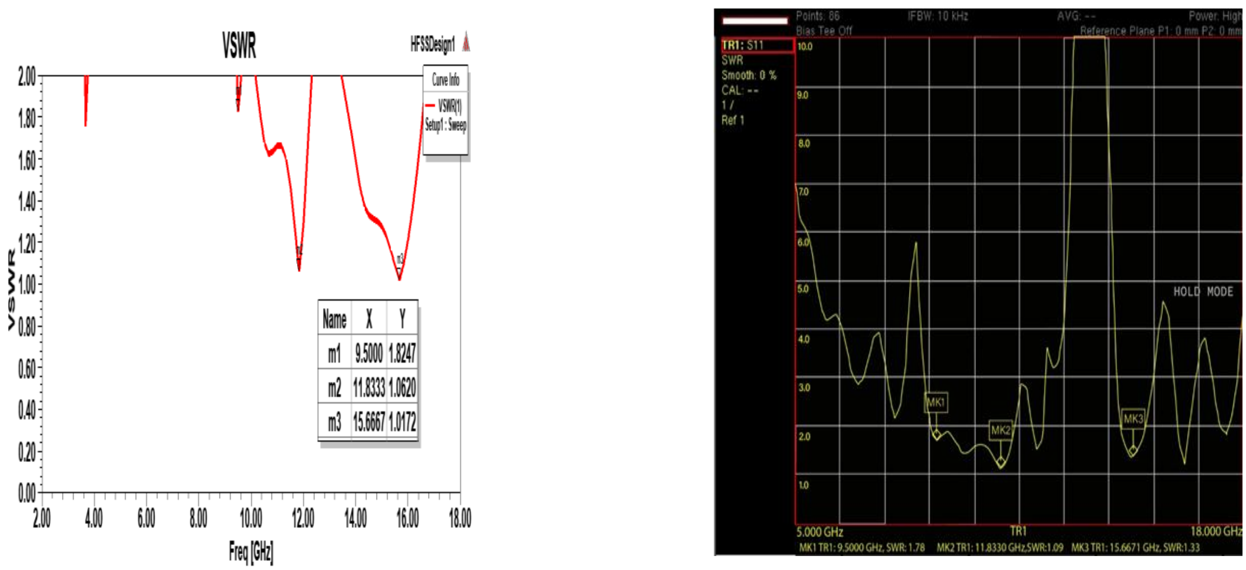
The measured VSWR values are 1.78, 1.09 and 1.3 for the resonant frequencies 9.5, 11.83 and 15.66 GHz respectively.

The smith chart implies that at the triple band resonant frequency, the normalized impedances are closer to unity which implies that insignificant amount of incident energy is reflected at its operating frequency.



(a) (b)

Fig.4. VSWR (a) Simulated and (b) Measured using network analyzer

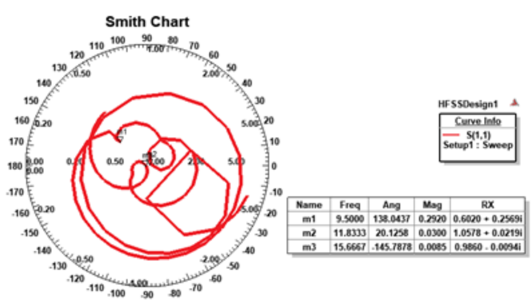


Fig.5. Simulated smith chart

The simulated and experimental results of S_{11} and VSWR of the conventional CRMA and CRMA loaded with modified codirectional CSRR on the ground plane are given in Table 2 below

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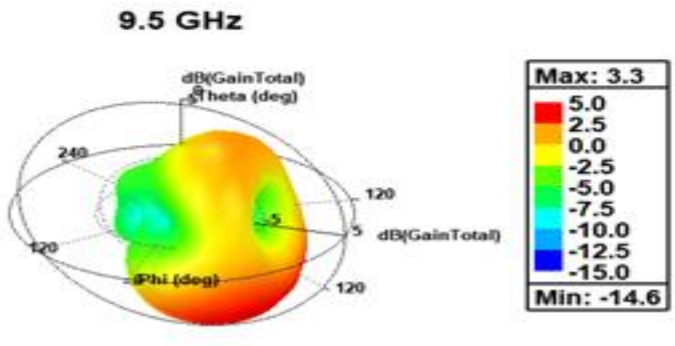
Table.2 Comparison of simulated and measured results

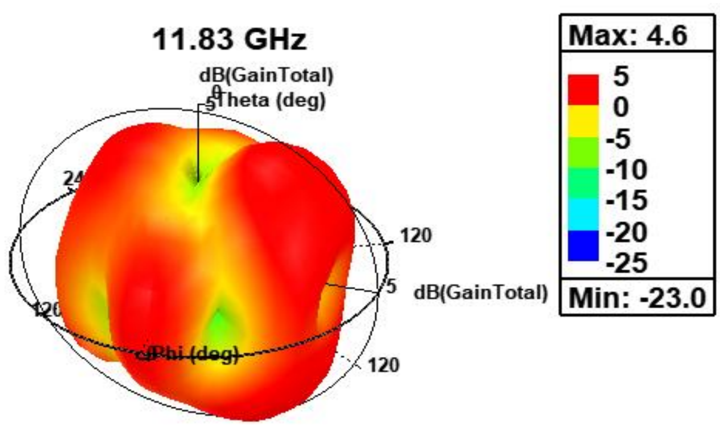
	Operating frequency (GHz)	Simulated	Measured
S_{11} (dB)	9.5	−10.69	−12.68
	11.83	−30.44	−20.71
	15.66	−41.40	−28.22
VSWR	9.5	1.82	1.78
	11.83	1.06	1.09
	15.66	1	1.3

Due to SMA connector, tolerances in fabrication and imperfection in hand soldering , there occurs disparity in the simulated and experimental results.

The gain and the directivity plots in 3D view at 9.5, 11.83 and 15.66 GHz are illustrated in figs. 6 and 7. The simulated maximum total gain and directivity are 3.3 dB and 4.9 dB at 9.5 GHz, 4.6 dB and 5.6 dB at 11.83 GHz,4 dB and 4.7 dB at 15.66 GHz respectively.



(a)



(b)

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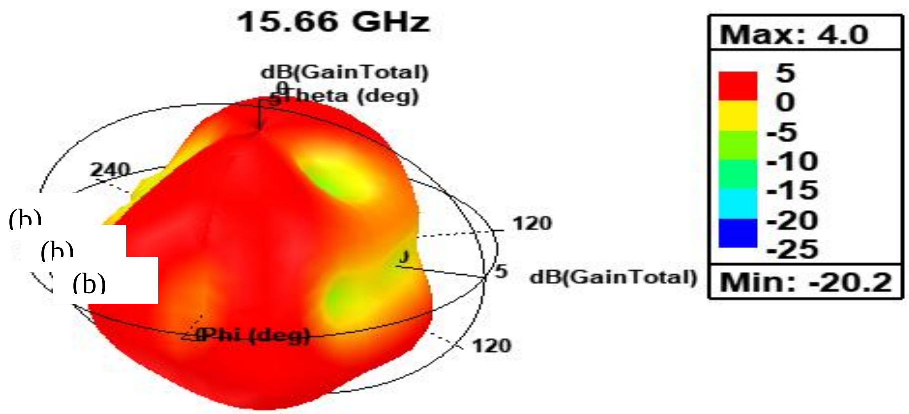
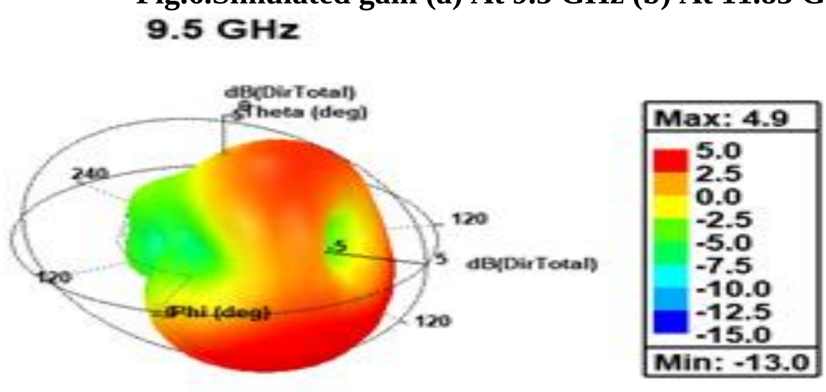
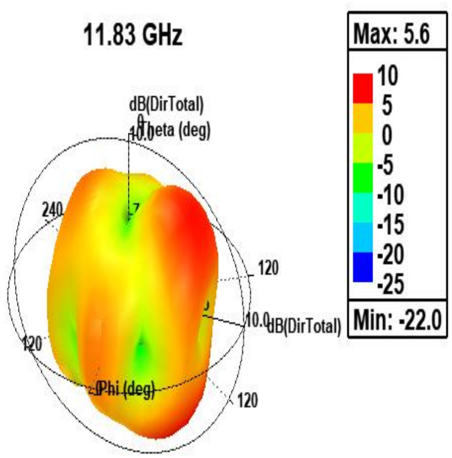


(c)

Fig.6.Simulated gain (a) At 9.5 GHz (b) At 11.83 GHz (c) At 15.66 GHz



(a)



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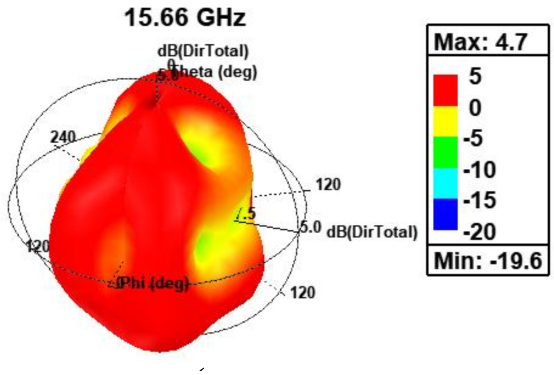
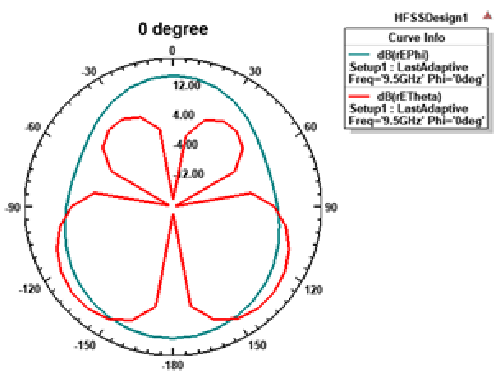
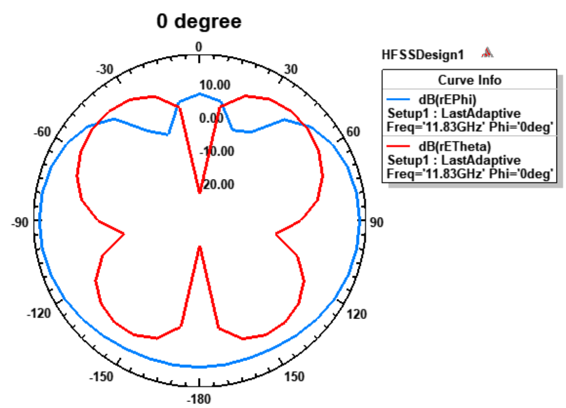


(c)

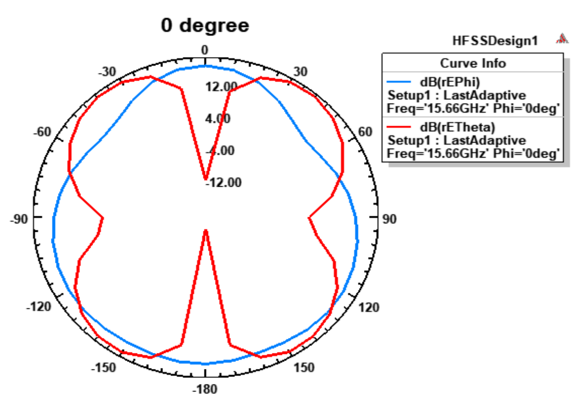
Fig.7. Simulated directivity (a) At 9.5 GHz (b) At 11.83 GHz (c) At 15.66 GHz



(a)



(b)



(c)

Fig.8. Radiation pattern at 0^o(a) 9.5 GHz (b) 11.83 GHz (c) 15.66 GHz

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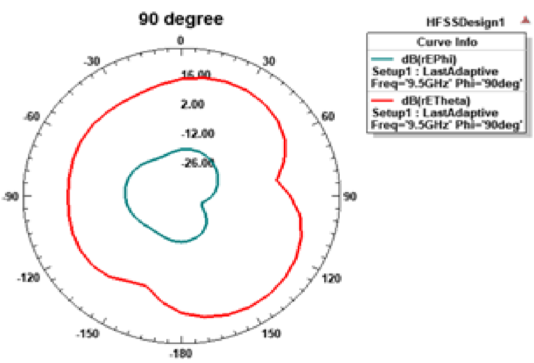
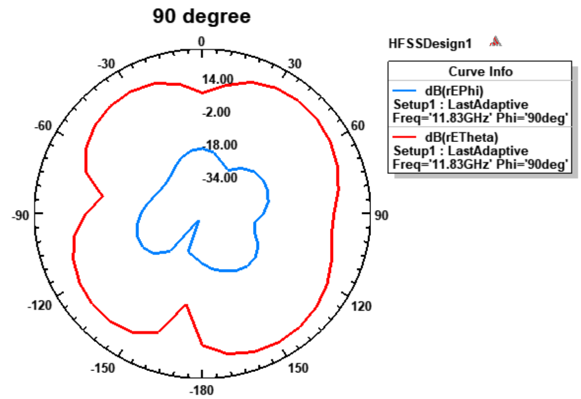
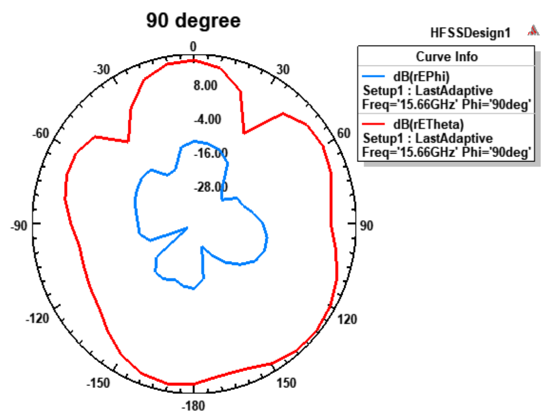


(a)

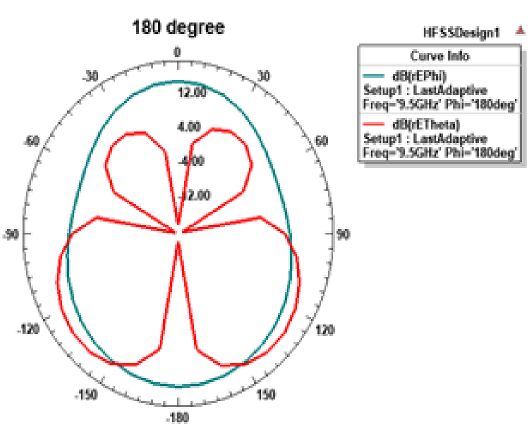


(b)

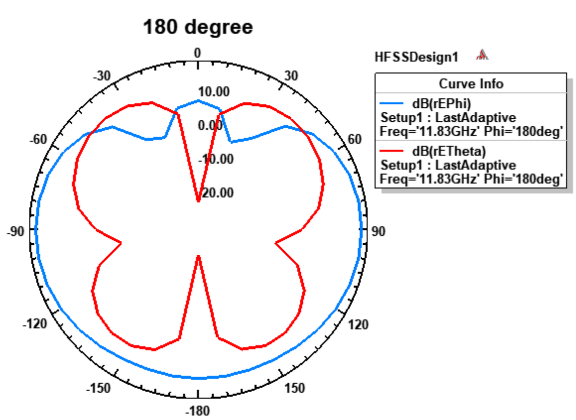


(c)

Fig.9: Radiation pattern at 90^{o} (a) 9.5 GHz (b) 11.83 GHz (c) 15.66 GHz



(a)



(b)

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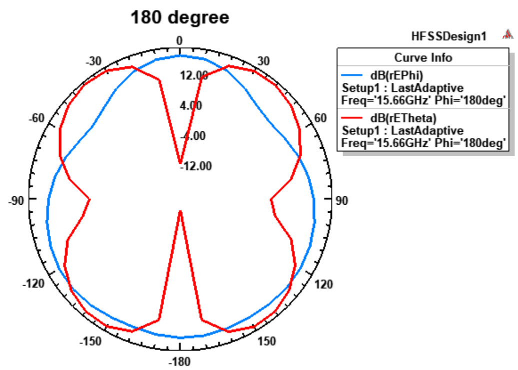

(c)

Fig.10: Radiation pattern at 180^o (a) 9.5 GHz (b) 11.83 GHz (c) 15.66 GHz

The simulated 2D radiation patterns of the CRMA loaded with modified codirectional CSRR in the E plane and H plane corresponding to 0^0, 90^0, and 180^0 respectively at 9.5, 11.83 and 15.66 GHz are shown in Figs.8, 9, and 10.

The efficiency (η) of the antenna is calculated using the expression given below

$$\eta = \frac{Gain}{Directivity} \quad (3)$$

The computed efficiency is 67.34 % at 9.5 GHz, 82.14 % at 11.83 GHz and 85.12 % at 15.66 GHz.

The comparison of the proposed antenna structure with different substrate materials is shown in Table 3.

It is observed from the simulated results that the triple band, better return loss, broad bandwidth, considerable gain and efficiency are the few advantages of the presented codirectional CSRR loaded circular ring microstrip antenna using FR4 as substrate material.

Table.3 Comparative analysis of antenna parameters with different substrate materials

Substrate materials	Relative Permittivity	Loss tangent	Return Loss		Bandwidth (MHz)	Gain (dB)	Directivity(dB)
FR4	4.4	0.02	9.5 GHz	-10.69 dB	190	3.3	4.9
			11.83 GHz	-30.44 dB	2000	4.6	5.6
			15.66 GHz	-41.4 dB	3000	4	4.7
RT Duroid	2.2	0.0009	16.66	-17.70 dB	920	4.4	4.4
Arlang AD 250	2.5	0.0015	15.33	-17.24 dB	910	4.1	4.2

4. Conclusion

A codirectional CSRR loaded circular ring microstrip antenna using FR4 as substrate material is sketched, fabricated and tested. The antenna functional parameters such as magnitude of return loss, VSWR, gain and directivity are compared with conventional circular ring microstrip antenna and also using different substrate materials. The computed efficiency of the designed antenna was 67.43% at 9.5 GHz, 82.14% at 11.83 GHz and 85.12% at 15.66 GHz which is suitable for X-band and Ku-band applications. The performance of the fabricated antenna was evaluated and the experimental and simulated results show that they are in good agreement with each other.

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