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Design of Ultra-Wideband Circular Patch with L-Slits Antenna for Wireless Applications

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Abstract*- In this paper, a compact antenna is designed for wireless applications with ultra-wideband frequencies. The circular-shaped patch antenna is designed with four L-slits on the patch and two complementary split-ring resonators (C.S.R.R.) on the ground plane to obtain ultra-wideband. The L-slits on circular patch (L.S.C.P.) antenna are operated at ultra-wideband frequencies below -10dB return loss. The LSCP antenna resonates at 11.55GHz, 12.35GHz, 13.26GHz and 14.23GHz frequencies with returns loss of -25.5dB,-18.75dB,-33.8dB and 48.1dB respectively. Also the gain is observed as 5.9dB, 6.42dB, 4.97dB and 6.05dB respectively. The L.S.C.P. antenna impedance bandwidth is 3345MHz (11.153GHz-14.498GHz) is observed. The E-Plane and H-plane radiation patterns are also presented for the L.S.C.P. antenna. A small compact antenna has 3.345GHz impedance bandwidth, with good gain throughout the band. The L.S.C.P. antenna simulated results are matched with experimental results.

***Index Terms*- Ultra Wide Band, Circular patch, X-band, L-slits**

I. INTRODUCTION

Day to day changes in technology offers many advantages in high-speed wireless communication networks and smart antennas over traditional technologies [1]. Compact antennas have delivered better connectivity with the fixed and mobile devices ultimately lead to a superior user experience. These advantages include miniaturization and multiband frequency applications. These antennas have a huge demand in telecommunications, defense systems, aeronautical radio navigation, I.S.M. (Industrial Scientific Medical) applications, etc. [2]. Many single-feed single-layer dual-frequency microstrip antennas have been demonstrated in [3]–[5] to improvise the antenna parameters. Some researchers use defective ground structures to enhance the gain and bandwidth to resonate at multiband frequency applications [6-8]. The limitations of microstrip patch antenna are lower efficiency and larger area consumption. The gain and bandwidth enhancement can be increased by employing slits and slots on the L.S.C.P. antenna's radiating patch and the ground plane. This paper proposes a circular-shaped microstrip patch antenna with rectangular slits and circular slots to obtain multiple-frequency. The proposed L.S.C.P. antenna with single feed produce circular polarization.

To minimize the size and area of the proposed antenna, one needs to design a single antenna element with various features to perform the multiband operation. Antennas with wide impedance bandwidth have the potential to operate at multiple functions. Numerous techniques were introduced in the literature works to improve the impedance bandwidth. A polygonal shaped patch antenna is presented with minimum gain and bandwidth resonates at RFID applications in [9]. A CPW fed triangular patch antenna [10,11] resonates at Wi-MAX applications having a low gain. In [12], a rectangular patch antenna presented with two concentric rings on the patch obtained with dual bands operates at X band applications with minimum bandwidth. In [13], a 'Y' shaped patch antenna is working tri bands for satellite applications with minimum bandwidth. A cylindrical antenna with P.U.B.G. lattice is

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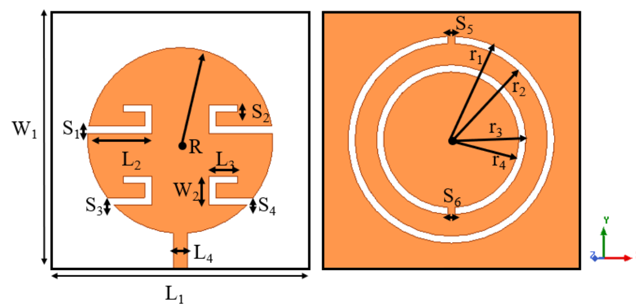
presented at the X band having lower bandwidth, and efficiency is reported in [14]. In [15], an E-shaped patch antenna with meander line slots is demonstrated for X band applications with lower bandwidth. In [16], double split-ring resonators are loaded on either side of the transmission line, respectively, and its characteristics are observed at WLAN and WiMAX applications. In [17], a hexadecogonal patch antenna is presented at dual bands perform lower bandwidth. In [18, 19], a hybrid antenna with F-shaped slits is etched on the flexible polyimide substrate resonates at satellite applications. A flexible antenna is presented with limited bandwidth, and it works at wireless communication applications with triple bands resonant frequency [20]. A circular monopole antenna with D.G.S. structure operates with lower bandwidth is reported in [21]. In the literature, various microstrip patch antennas are reported [22-27] to resonate for wide-band applications. In the literature [28-30], microstrip patch antennas are presented for different applications. However, the impedance bandwidth is limited, and the size of the antenna is also larger. Moreover, this compact antenna is achieved a very wide impedance band. Such wide-band is not reported with good gain throughout the literature as per the author's knowledge.

In this work, a circular shaped microstrip patch antenna is presented. Four L-slits and two C.S.R.R.s are etched on the patch and ground, respectively, to enhance gain and bandwidth. The proposed L.S.C.P. antenna is used for wireless applications. The evolution process is performed to validate the performance, and the antenna is resonating at four resonant frequency bands. The L.S.C.P. antenna attains higher impedance bandwidth (11.153GHz-14.498GHz) of 3345 MHz improvements. The pattern characteristics of the L.S.C.P. antenna with E-plane and H-plane are presented at four operating frequency bands. The gain is obtained for the L.S.C.P. model antenna is greater than 5dBi. The proposed L.S.C.P. antenna is used to operate at X-band and Ku-band. The L.S.C.P. antenna works at RADAR, V.S.A.T., mobile, and satellite in wireless communications.

II. ANTENNA DESIGN

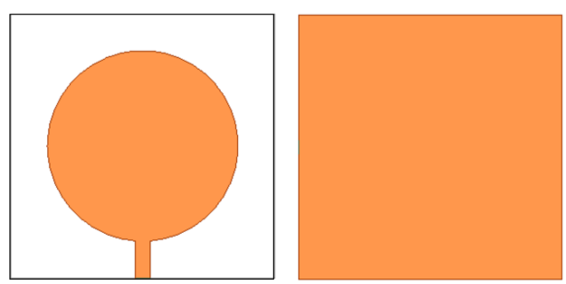
Fig. 1 shows the design of the L.S.C.P. antenna with rectangular slits having a radius R of 12mm. This antenna is designed on (FR-4) substrate with a dielectric constant (ε_r) of 4.4, the height of the substrate is 1.6mm, dimensions of the substrate are 35×35 mm^2 with loss tangent (δ) of 0.002.



(a) (b)

Fig.1. The geometry of the circular shaped patch antenna (a) Top view (b) Bottom View

The upper layer of the patch is loaded with rectangular slits L_2 and L_3. The microstrip patch feed width is 2mm connected to an S.M.A. connector. Fig.1.(b) shows the full ground plane with defected concentric rings with radius r_1, r_2, r_3, and r_4 are considered to enhance the gain and bandwidth. The circular patch with 'L' shaped slits are mounted on the substrate and results in wider bandwidth with multiple frequency bands.



(a)

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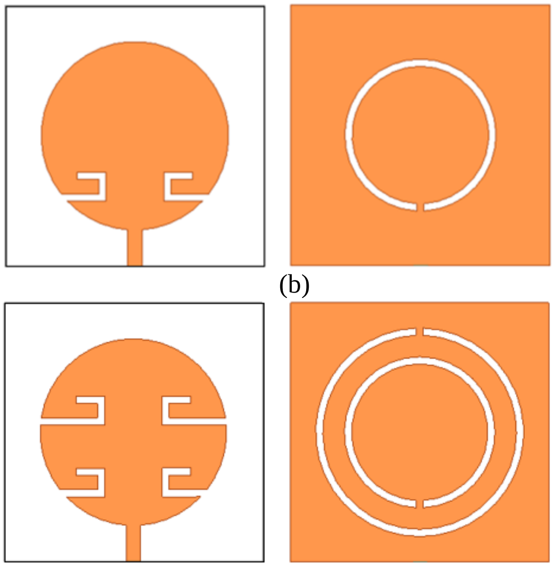

(b)

(c)

Fig.2. The geometry evolution process of the circular shaped patch antenna (a) Ant.1 (b) Ant.2 (c) Ant.3

The equivalent model of L.S.C.P. microstrip patch antenna loaded with C.S.R.R.s is shown in Fig.3.

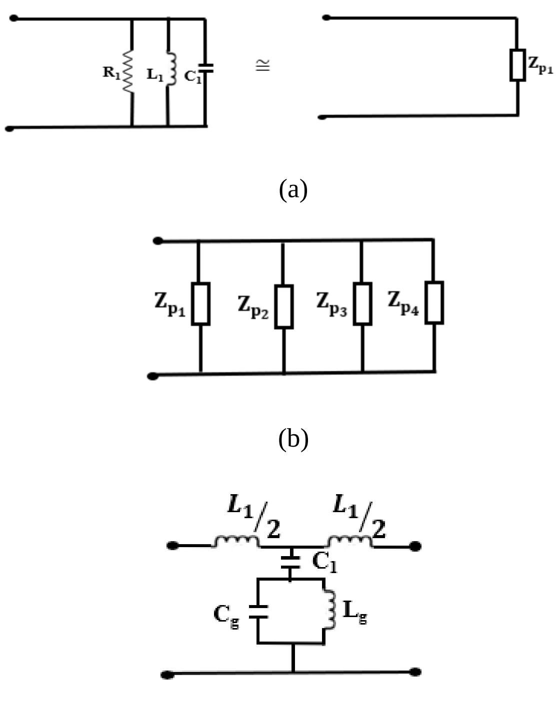

Fig.3. The equivalent circuit of the L.S.C.P. antenna (a) single 'L' slit on the patch (b) four 'L' slits on the patch (c) ground.

For one 'L' slit on the patch, the equivalent circuit is presented above. Fig. 3(a) of the proposed L.S.C.P. antenna [31].

$$Z_{p_1} = \frac{1}{\frac{1}{R_1} + \frac{1}{j\omega L_1} + j\omega C_1} \quad (1)$$

Similarly, four 'L' slits on the patch, the equivalent circuit is presented above. Fig. 3(b) of the proposed L.S.C.P. antenna is,

$$Z_p = Z_{p_1} + Z_{p_2} + Z_{p_3} + Z_{p_4} \quad (2)$$

The metal strip line loaded with C.S.R.R. in the ground plane is considered from [32], the equivalent circuit is presented above shown in Fig. 3(c) as,

$$Z_R = \frac{1}{2\pi\sqrt{L_g(C_1 + C_g)}} \quad (3)$$

$$Z_0 = \frac{1}{2\pi\sqrt{L_g C_g}} \quad (4)$$

$$Z_s(j\omega_{\pi/2}) = -Z_p(j\omega_{\pi/2}) \quad (5)$$

The resonant frequency of the proposed antenna is evaluated from [31, 32],

$$f_r = \frac{8.794}{r_e\sqrt{\varepsilon_r}} \quad (6)$$

$$r_e = r_1\left[1 + \frac{2h}{\pi r_1 \varepsilon_r}\left\{\ln\left(\frac{r_1}{2h}\right) + (1.41\varepsilon_r + 1.77) + \frac{h}{r_1}(0.268\varepsilon_r + 1.65)\right\}\right]^{1/2} \quad (7)$$

Table 1: The dimensions of the L.S.C.P. antenna

Parameter	Dimension (mm)	Parameter	Dimension (mm)
L_1	35	S_3	1
W_1	35	S_4	1
L_2	8	S_5	1
L_3	4	S_6	1
W_2	3	r_1	13.5
R	12	r_2	12.5
S_1	1	r_3	9.5
S_2	1	r_4	8.5

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The evolution steps of the L.S.C.P. antenna are shown in Fig. 2. In the 1st evolutionary process, the plain circular patch antenna (Ant.1) is considered with perfect ground and resonates at one frequency. In the 2nd evolution, a circular patch antenna with two 'L' shaped slits are loaded at the bottom of the metallic patch (Ant.2) with one complimentary split-ring resonator (C.S.R.R.) is considered on the perfect ground resonates at three operating frequencies. Subsequently, in the 3rd stage, the four 'L' shaped slits are loaded on the patch and two C.S.R.R.s on the ground plane (Ant.3) to resonate at four operating frequency bands with a wider bandwidth.

III. RESULTS AND DISCUSSION

The proposed antenna is simulated in the C.S.T. tool. The optimized L.S.C.P. antenna dimensions are shown in Table.1, and the optimization is carried out for ultra-wideband with finite differential time domain and computer simulation technology.

The simulation and measurement results of the L.S.C.P. antenna are discussed in this section. The reflection coefficients are presented for the L.S.C.P. antenna are given in Fig. 4. As it can be observed that the antenna operates at four bands, 11.55 GHz, 12.35GHz, 13.26GHz, and 14.23GHz frequencies with return loss of -25.5dB -18.75dB, -33.8dB, and -48.1dB respectively.

The response of the reflection coefficient (S_{11}) for each evolution step is illustrated in Fig.4. In the 1st evolutionary step, the circular patch design antenna (Ant.1) is considered with the perfect ground, and it resonates at 13.58GHz frequency with S_{11} of -37.1dB. Impedance bandwidths are observed below -10 dB, with a resonant frequency of 1.23 GHz (12.98GHz-14.21GHz). The Ant.1 does not cover a wider impedance band, and it works only in one band. Therefore, two 'L' shaped slots on the metallic patch with one C.S.R.R. on the perfect ground (Ant.2) were considered, resonates triple frequency bands at 10.55GHz,12.5GHz, and 14.77GHz with a coefficient of reflection of -21.5dB,-13.3dB, and -15.5dB. Ant.2 also does not cover a wider bandwidth. The final step of the evolution process (Ant III) is considered with four 'L' slits on the patch with two C.S.R.R.s on the ground resonates at multiple frequencies cover wider bandwidth. Subsequently, in the last step of the process to get extensive bandwidth, two C.S.R.R.s are etched on the ground. The impedance bandwidth is 3.345 GHz (11.153-14.498 GHz), with 90% improvement. However, Ant.3 resonates at 11.55GHz, 12.35GHz, 13.26GHz, and 14.23 GHz frequencies with the coefficients of -25.5 dB, -18.75 dB, -33.85 dB, and -48.1 dB. The antenna's performance in the evolution process for each iterative step is presented in Table 2.

As shown in Fig.5, the proposed L.S.C.P. antenna prototype and measurements were taken in the laboratory with a vector network analyzer (N9918A). Fig. 6 shows the simulation and measurement results of the L.S.C.P. antenna. The prototype antenna resonates at four frequency bands below -10 dB return loss.

Measurement of the L.S.C.P. antenna is summarized in Table.3. From Fig.6. It is observed that the reflection coefficient and the bandwidth are observed for all resonant bands. These deviations are due to antenna fabrication errors and parasitic effects.

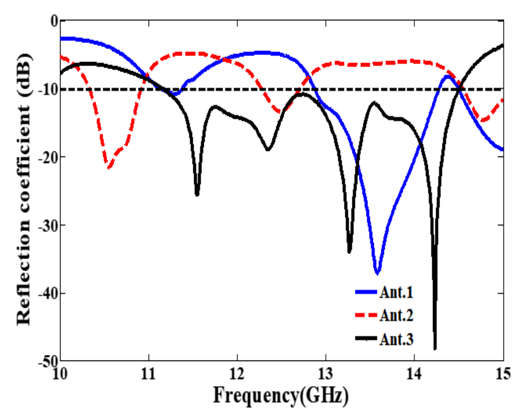

Fig.4. Reflection coefficient response of L.S.C.P. antenna for each evolution process.

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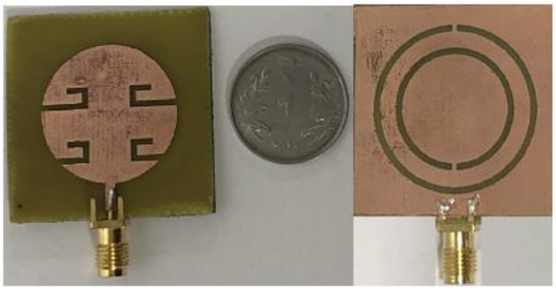


(a) (b)

Fig.5. Fabricated prototype of the L.S.C.P. antenna (a) Top view (b) Bottom view

Table 2: Evolution process of the L.S.C.P. antenna

Configuration	Frequency (GHz)	Reflection Coefficient (dB)	Gain (dBi)
Ant.1	13.58	-37.1	4.22
Ant.2	10.55, 12.5, 14.77	-21.5, 13.3, -15.5	3.17, 3.97, 3.77
Ant.3	11.55, 12.35, 13.26, 14.23	-25.5, -18.75, -33.8, -48.1	5.97, 6.42, 4.97, 6.05

The L.S.C.P. antenna radiation pattern characteristics are presented in Fig.7-9. The pattern characteristics are observed for the (Ant.3) presented with E-Plane and H-Plane. The experimental results of the model antenna with simulated results are given in Fig.6. It is observed that the semi omnidirectional and butterfly-shaped patterns are observed for the E plane and H Plane at 0° and 90°. The radiation patterns are observed at 11.55GHz, 12.35GHz, 13.26GHz, and 14.23GHz operating frequencies. The simulated and measured radiations patterns are presented in Fig.7, Fig.8, Fig.9 of the L.S.C.P. antenna.

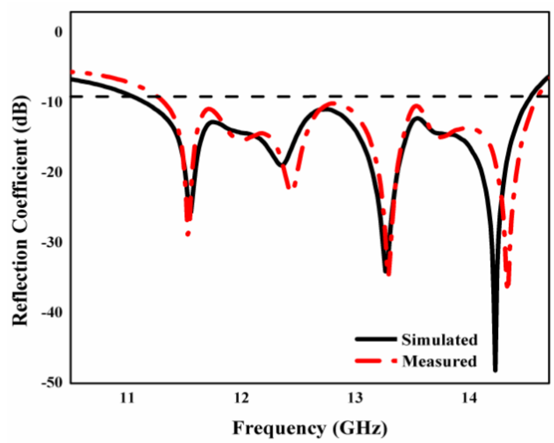
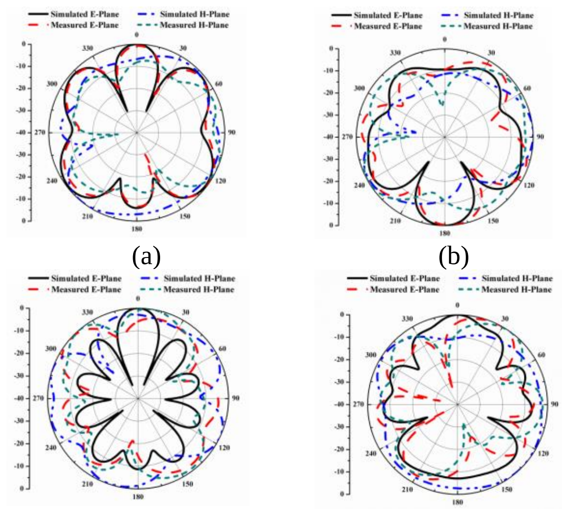


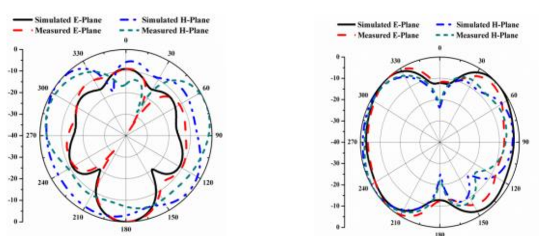
Fig.6. The reflection coefficient of L.S.C.P. antenna with simulated and measured data.



(a) (b)

(c) (d)

Fig.7. The simulated and measured pattern characteristics of the L.S.C.P. antenna at X.Y. Plane for four (a) 11.55 GHz (b) 12.35GHz (c) 13.26GHz, (d) 14.23GHz frequencies, respectively.



(a) (b)

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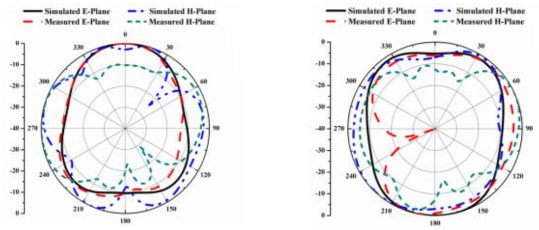
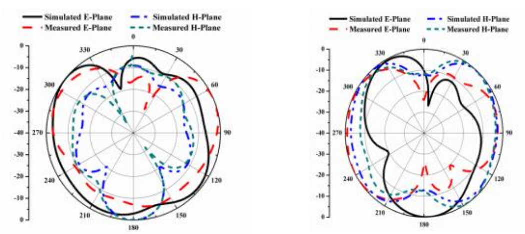
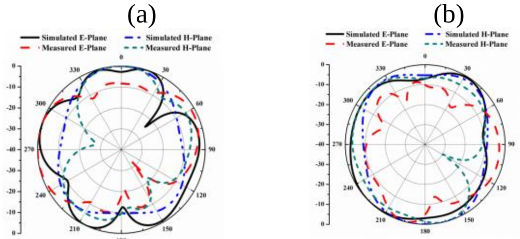


(c) (d)

Fig.8. The simulated and measured pattern characteristics of the L.S.C.P. antenna at X.Z. Plane for four (a) 11.55 GHz (b) 12.35GHz (c) 13.26GHz, (d) 14.23GHz frequencies, respectively.



(a) (b)



(c) (d)

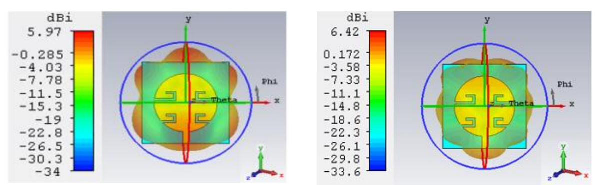
Fig.9. The simulated and measured pattern characteristics of the L.S.C.P. antenna at Y.Z. Plane for four (a) 11.55 GHz (b) 12.35GHz (c) 13.26GHz, (d) 14.23GHz frequencies, respectively.

The proposed L.S.C.P. antenna (ant.III) radiation patterns are obtained for XY, XZ, and YZ Planes. Fig. 7, Fig. 8, Fig. 9 shows the simulated and measured radiation characteristics at resonant frequency bands 11.55GHz, 12.35GHz, 13.26GHz, 14.23GHz corresponding to E and H planes. The radiation patterns for the L.S.C.P. antenna are carried out at different planes.

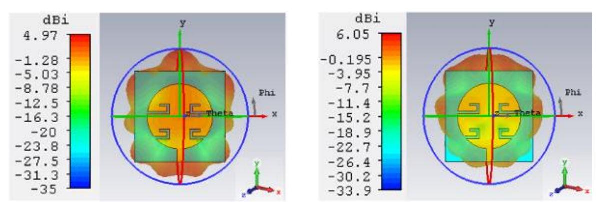
The 3D polar plots of the L.S.C.P. antenna are observed in Fig.10. It is observed that the final antenna model operates at four operating frequency bands attains a maximum gain of 6.42dBi. The gain is observed high at 12.35GHz, and it is low at 13.26GHz. The preferred gain should be considered for the antennas are in between 1-3dBi. The L.S.C.P. model antenna gain is 5.97dBi, 6.42dBi, 4.97dBi, and 6.05dBi at 11.55GHz, 12.35GHz, 13.26GHz, and 14.23GHz frequencies respectively, and also proposed model attains higher impedance bandwidth of 3345MHz.

Table.3. Performance analysis of the L.S.C.P. antenna

Mode	Frequency (GHz)	Reflection Coefficient (dB)	Bandwidth (MHz)	Gain (dBi)
Simulated	11.55, 12.35, 13.26, 14.23	-25.5, -18.75, -33.8, -48.1	3345 (11.153 - 14.498)	5.97, 6.42, 4.97, 6.05
Measured	11.53, 12.43, 13.29, 14.34	-28.5, -22.8, -34.8 -36.9	3272 (11.305 - 14.577)	5.83, 6.4, 4.29, 5.95



(a) (b)



(c) (d)

Fig.10. 3-D polar plots of L.S.C.P. antenna at 11.55 GHz, 12.35GHz, 13.26GHz, 14.23GHz frequency.

The proposed circular patch antenna with L-shaped slits and two C.S.R.R.s are etched to resonate with higher impedance bandwidth and attain maximum gain. The surface current distributions (S.C.D.) of the L.S.C.P. antenna is presented in Fig.11. at 11.55GHz, 12.35GHz, 13.26GHz, and 14.23GHz operating frequencies, respectively. The performance analysis L.S.C.P. antenna with simulated and measured results are shown in Table.3. The S.C.D. for the four

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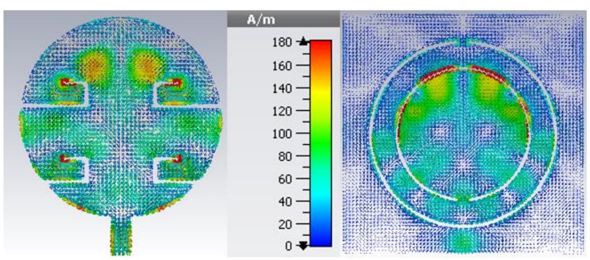
operating frequency bands is 180A/m, 126A/m, 116A/m and 135A/m.

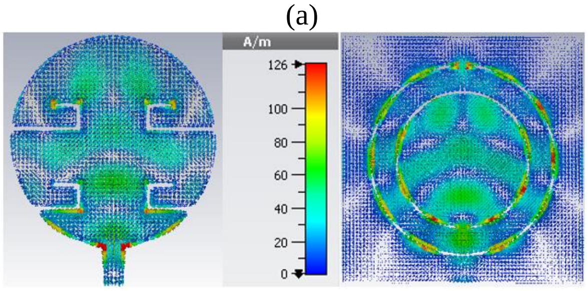
The maximum distributions of current are observed at 11.55GHz and 12.35GHz, respectively. The L.S.C.P. antenna is compared with the literature in Table.4.

Table 4: Comparison of the L.S.C.P. antenna with literature works

Ref	Antenna Dimension (mm³)	Operating frequency (GHz)	Reflection coefficient (dB)	Bandwidth (MHz)	Gain (dBi)	Application
[9]	50×50×1.6	2.45	-20	30	3.85	WLAN
[11]	53×38.5×1.6	2.44,5.25		2.1	4.85	UWB
[14]	51×51×2.5	10.2	-19.2	1000	6	X-band
[17]	40×48×1.59	13.67, 15.28	42.1,38.3	800, 1100	8.01, 6.01	Satellite communication
[20]	25×28×0.1	2.65 ,2.94, 3.24	-15.7, -20.6, -36.2	30,30,70	1.57,2.24, 4	Wireless communication
This work	35×35×1.6	11.55,12.35,13.26,14.23	-25.5, -18.75, -33.8, -48.1	3345	5.97, 6.42, 4.97 and 6.05	Wireless communication



(a)



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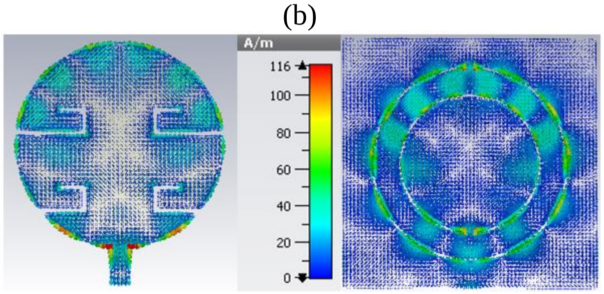
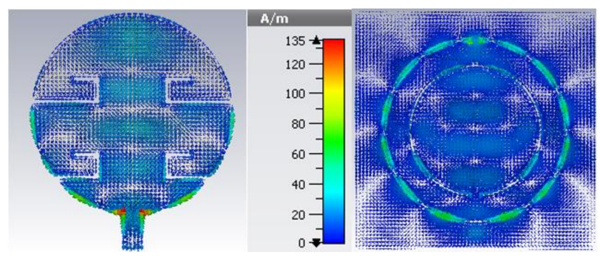


(c)



(d)

Fig.11. The L.S.C.P. antenna model (Ant.3) at 11.55 GHz, 12.35GHz, 13.26GHz, and 14.23GHz frequency presents current distributions.

VI. CONCLUSION

The L.S.C.P. antenna is designed for wireless communication with U.W.B. frequency. The proposed antenna resonates at four frequency bands of 11.55GHz, 12.35GHz, 13.26GHz and 14.23GHz with returns loss of -25.5dB, -18.75dB, -33.8dB and -48.1dB respectively. The L.S.C.P. antenna directional pattern is observed at these four frequency bands. The surface current distributions are also presented for the L.S.C.P. antenna. The gain is observed for all the four bands nearly greater than 5dBi. The simulated results are matched with the measured results. The L.S.C.P. antenna impedance bandwidth is 3345MHz, and this high impedance bandwidth is used in wireless applications for high data rate transmission. The proposed L.S.C.P. antenna works in wireless communications at X-band and Ku-band. The L.S.C.P. antenna four operating bands are used for RADAR, V.S.A.T., mobile, and satellite applications.

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