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Circular patch antenna for WLAN and X-Band applications

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***Abstract*—A novel coplanar wave guide(CPW) fed circular patch antenna with capacitive loading is proposed. The structure is characterised by WLAN,X-Band and ITU band applications. The radiating patch is not in contact with feed. The desired antenna has dimensions 28x25 mm^2 .The proposed antenna has wide frequency bandwidth of 7.7GHz starting from 4.63GHz to 12.33GHz for a return loss(S_{11})of less than -10dB.**

Keyword - CPW,Circular patch,Capacitive loading,Return loss

I. INTRODUCTION

In modern wireless communiation there is need and demand for systems which are tiny in size,lower cost,lighter weight which may exhibit high data rate and giving up high performance especially in Ultra wide band region[1].Microstrip patch (MSP)antenna which may satisfies most of the requirements.MSP antenna are easily integrated with microwave integrated circuits.CPW feeding ground and radiating patch is on same planar plane.In CPW feeding no via holes are required so that it is considered less complex and fabrication is easy.The designing of compact antenna for portable wireless communication systems is the major task,which could meet the high bandwidth requirements.

A 32x16 mm^2 ring monopole antenna with double meander lines for dual band operation was presented in [2].Another compact 20x15.5mm^2 CPW-monopole antenna using two strips for dual-band wireless local area(WLAN) operation was proposed in [3] giving bandwidth from 2.4 to 2.484GHz and 5.15 to 5.825GHz.In[4],a 30x20mm^2 CPW-fed patch antenna for dual band is proposed.A very wide bandwidth is achieved with circular slot fed with CPW line through a circular patch[5].In [6],41.6x28.38mm^2 CPW-fed planar monopole antenna composed of circular radiating patch with smiling slot for dual band operation was presented, and the antenna achieved dual impedance bandwidths from 2.3 to 3 GHz and 4.7 to 5.9 GHz.The antenna presented in [7] has large ground plane.A 30x30mm^2 was proposed in[8] for an impedance bandwidth of 3.1-8.3GHz.Which consists of tapered radiating patch over rectangular patch.Feed patch is close to radiating patch but not in contact with that is developed in [9] shows the capacitive loading of the antenna.

II. ANTENNA DESIGN

A. CPW design

CPW feeding is applied in this proposed antenna where feed is a centre strip that carries the signal and side-plane conductor is ground. Ground is on either side of the feed on the same plane so no via holes are required.CPW feeding applied in this design is finite dielectric thickness and finite width ground plane as shown in Fig 1.CPW structures usually provide wider bandwidth, easy integration with RF circuitry, better impedance matching and less dispersion.

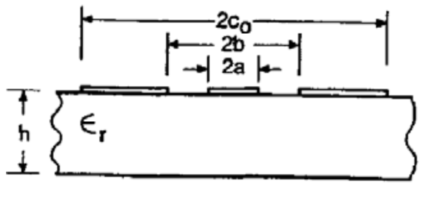

Fig 1:CPW Structure

The transmission line structure is divided into two halves:upper half which is above metalization,and lower half which is below metalization.Capacitance per unit length for each half is determined by transforming into a parallel plate geometry using conformal transformation. The below equations are based on the quasi-static analysis, q is known as filling factor.

$$q = \frac{1}{2}\frac{K(k_4)}{K'(k_4)}\frac{K(k_3)}{K'(k_3)} \quad (1)$$

$$k_3 = \frac{a}{b}\sqrt{\frac{1-b^2/c_0^2}{1-a^2/c_0^2}} \quad (2)$$

$$k_4 = \frac{\sinh\left(\frac{\pi a}{2h}\right)}{\sinh\left(\frac{\pi b}{2h}\right)}\sqrt{\frac{1-\sinh^2\left(\frac{\pi b}{2h}\right)/\sinh^2\left(\frac{\pi c_0}{2h}\right)}{1-\sinh^2\left(\frac{\pi a}{2h}\right)/\sinh^2\left(\frac{\pi c_0}{2h}\right)}} \quad (3)$$

$$Z_{0cp} = \frac{30}{\sqrt{\epsilon_{re}}}\frac{\pi K'(k_3)}{K(k_3)} \quad (4)$$

$$\mathcal{E}_{re}=1+q(\mathcal{E}_r - 1) \quad (5)$$

$$K'(k_3) = K(k_3') \quad (6)$$

$$k_3'=\sqrt{1-k_3^2} \quad (7)$$

K(k)=Complete elliptical integral of first kind and K' (k) is it's compliment.

The conformal mapping of coplanar lines gives rise to analytical expressions for the dielectric constant and characteristic impedance in terms of ratio of complete elliptical integral of first kind [11]and it's compliment.

B. Antenna Design

The basic geometry and parameters of the coplanar waveguide monopole circular antenna shown in Fig 2 having radius r=7.3mm.The antenna is fabricated on FR4 substrate having $\mathcal{E}_r$=4.4,width of h=1.6mm.The CPW feeding which has single strip with a width W=3mm and length L=9.5mm.From that feed line rectangle having length b=4mm is added with circle shape in the other end and gap S=0.3mm,has loss tangent 0.02 and characteristic impedance of 50Ω. A gap(g) of 0.3mm is maintained between arc shaped feed and radiating patch. Arc shaped feed has radius(ro) at the edge from the same center as circular patch antenna radius(r) is calculated. Two equal finite ground planes each with a width of 10.7mm and height of 7mm.A small triangle shape is added on the top with height of 1 mm of either side of the ground plane. A plus shape slot having width of 0.3mm is created on the circular radiating patch which can make the patch into four parts. Antenna effective radius a_e can be calculated by the formula given in[10].Radiating patch antenna effective radius is calculated as 7.72mm from the given formula(8) and resonant frequency is calculated as 5.43GHz from equation (9) for χ_{nm} value is 1.8418 for the dominant mode for the normal circular patch. When we make plus slot on that patch, resonant frequency has been changed to 5.47GHz.In this design,0.3mm gap is maintained between feed strip and radiating patch.

$$\text{Antenna effective radius } r_e = r\sqrt{1+\frac{2h}{\pi r \mathcal{E}_r}\left(ln\frac{\pi r}{2h}+1.7726\right)} \quad (8)$$

$$f_{nm} = \frac{\chi_{nm}}{\sqrt{\mathcal{E}_r}}\frac{c}{2\pi r_e} \quad (9)$$

Antenna effective radius is calculated from equation(8) as 7.72mm and from the equation (9) resonant frequency is calculated as 5.43GHz,these values are calculated for the general circular patch antenna without plus slot and there is no capacitive loading with radiating patch as shown in Fig 2,we get multiple resonant frequencies exists at 3.48GHz , 7.84 GHz and 11.47GHz .When plus slot is on the patch and CPW arc shape feeding with capacitive loading as shown in Fig 3 then resonant frequency(where the minimum dB value calculated) changed to 5.47GHz(4.63GHz to 12.33GHz) and bandwidth is achieved as 90.08% for the simulation model.

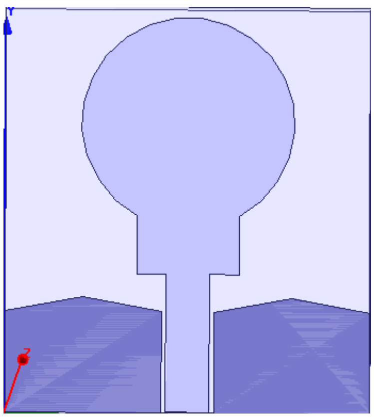

Fig. 2. Antenna without capacitive load

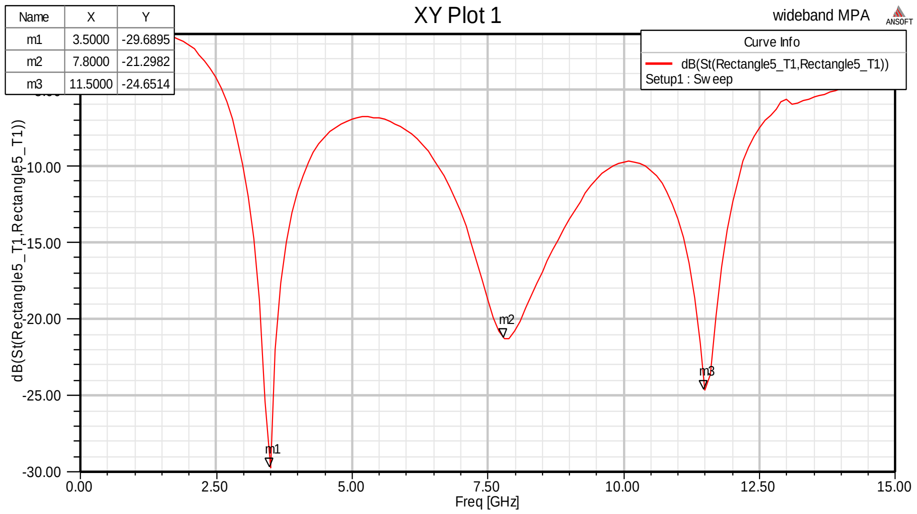

Fig. 2 a. Return loss characteristics without capacitive load

Without capacitive loading shown in Fig 2.a.the antenna gives multiple resonant frequencies at 3.5GHz,7.8GHz and 11.5GHz but with capacitive loading, arc shaped feed and plus slot included on the circular slot gives impedance bandwidth of 90% as shown if Fig 3.

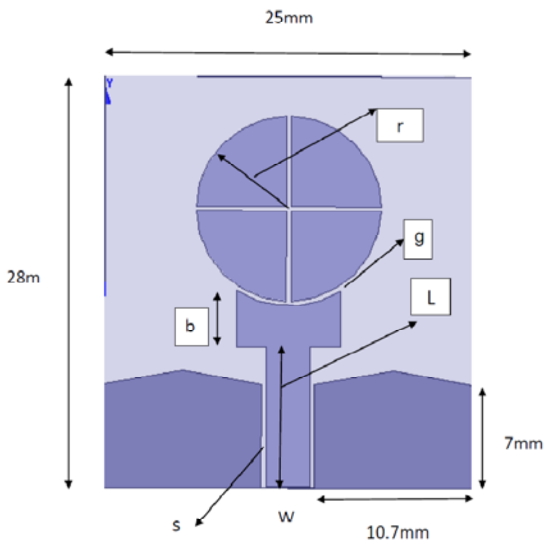

Fig. 3. Proposed antenna

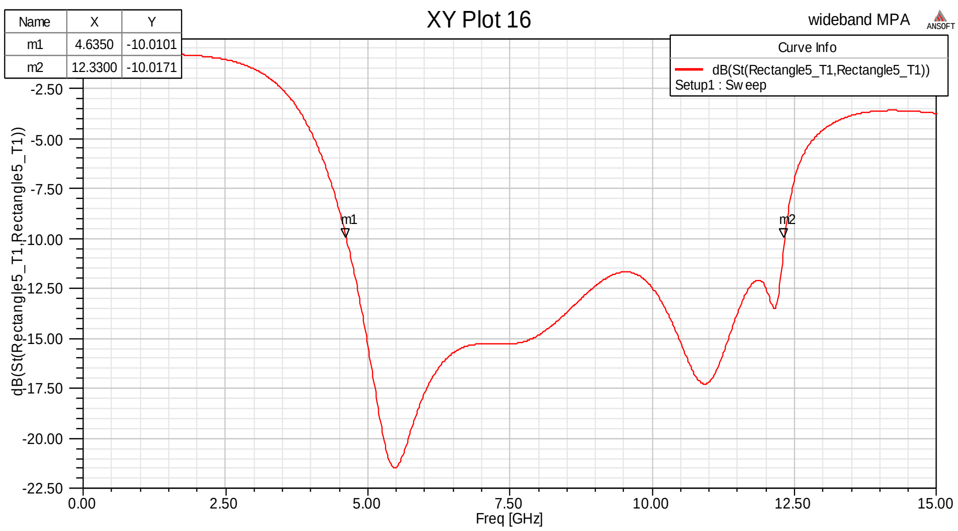

Fig. 3.a. Return loss characteristics of Proposed antenna

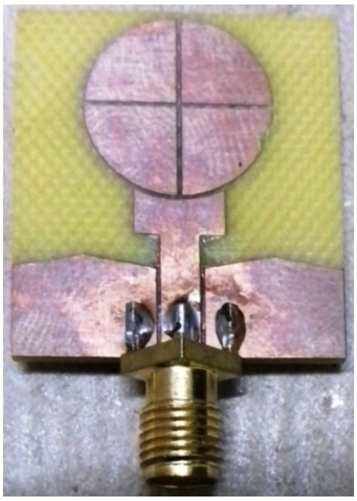

Fig. 4. Fabricated antenna

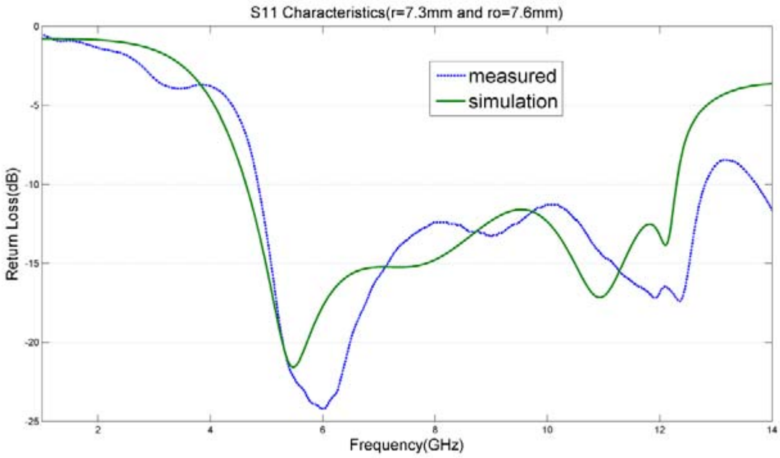

Fig. 5. S11 Characteristics of proposed antenna

III. PARAMETRIC STUDY

By changing the circular patch antenna radius, gap between the feed strip and radiating patch we can get different return loss characteristics, which will gives the results as shown in the Fig 6.It is shown that by keeping the feed strip curve radius(ro) constant as 6.6mm and varying the radius r of the radiating patch, so that gap (g) between the patch and feed strip is varied. It is shown in Fig.8,that keeping the radius of the circular patch constant as 7.3mm and varying the feed strip curve radius (ro) and varying the gap between the feed strip and circular radiating patch is varied. The length b is also changing in proportion to feed strip curve. Maximum impedance bandwidth is achieved when the distance between the arc shaped feed and circular patch is less, that is 0.3mm as 92.1%.

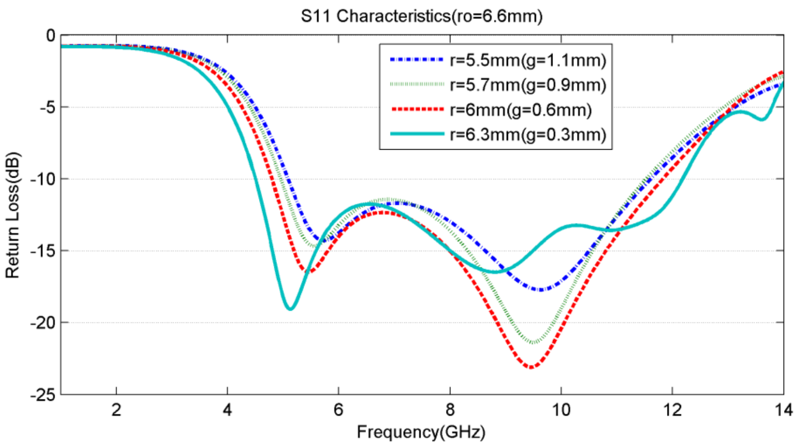

Fig 6.Return loss characteristics by varying radius(r)-BW shown in TABLE-I

TABLE I

ro=6.6mm (constant)	r=6.3mm	r=6mm	r=5.7mm	r=5.5mm
g	0.3mm	0.6mm	0.9mm	1.1mm
BW(%)	92.1	84.45	80.46	77.77

The separation between radiator patch and feed strip was varied from 0.3mm to 1.1mm.It can be noted from the TABLE I, impedance bandwidth is increasing with gap(g) and decreases with gap. It reaches to maximum of 92.1% when the gap is 0.3mm and radius of the patch is 6.3mm as shown in Fig.6.

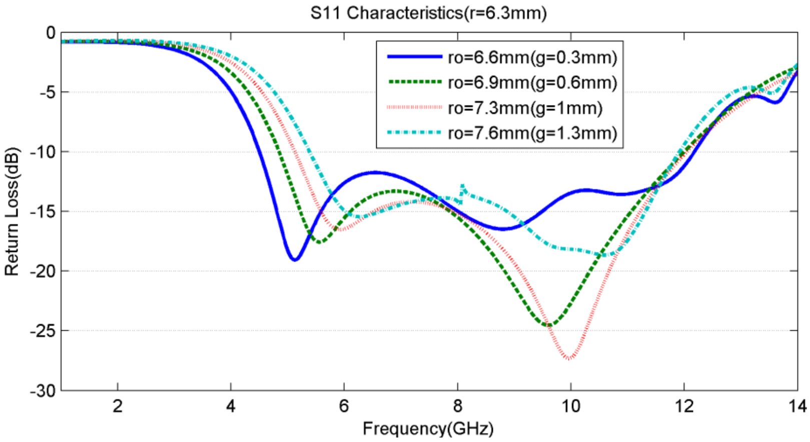

Fig. 7.Return loss characteristics by varying ro-BW shown in TABLE-II

As shown in TABLE II by keeping the radius(r) of the circular patch is constant and arc shaped feed radius is increased insteps of 0.3mm, and it is observed that impedance bandwidth is increased if the gap between the patch and feed is reduced.

TABLE II

r=6.3mm (constant)	ro=6.6mm	ro=6.9mm	ro=7.3mm	ro=7.6mm
g	0.3mm	0.6mm	1mm	1.3mm
BW(%)	92.1	84.70	80.53	75.14

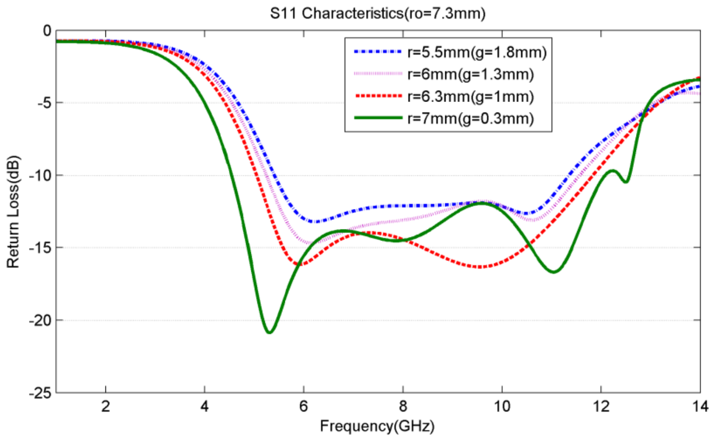

Fig. 8.Return loss characteristics by varying r-BW shown in TABLE-III

TABLE III

ro=7.3mm (constant)	r=7mm	r=6.3mm	r=6mm	r=5.5mm
g	0.3mm	1mm	1.3mm	1.8mm
BW(%)	90.60	81.69	74.58	70.08

From the TABLE III when the radius of the radiator patch is increased to 7mm and the gap(g) is varied from 0.3mm to 1.8mm between radiator patch and feed strip,bandwidth obtained as 90.6% with minimum gap(g) of 0.3mm.Bandwidth is decreasing when gap increases between feed strip and radiator patch. It is observed that return loss of -22 dB is obtained for the circular patch dimension of 7mm ,When the circular patch dimension is changed 7.3mm for the proposed antenna bandwidth is obtained as 90.08% and the return loss is obtained as -25dB as shown in Fig.9 at the resonant frequency. Simulated results almost matches with the measured results as shown in Fig.5

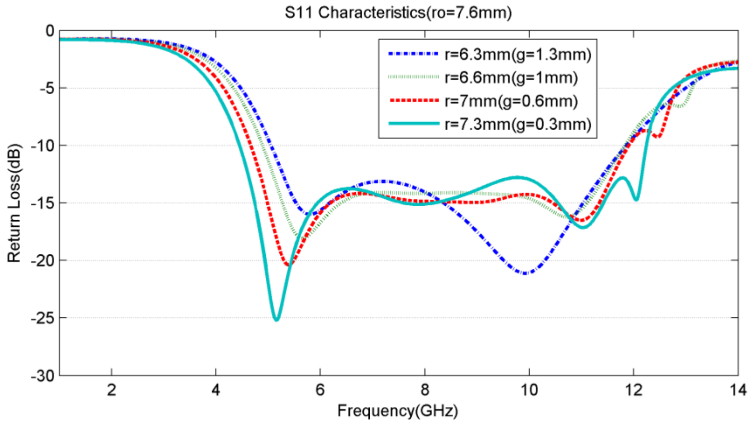

Fig. 9.Return loss characteristics by varying r-BW shown in TABLE-IV

TABLE IV

ro=7.6mm (constant)	r=7.3mm	r=7mm	r=6.6mm	r=6.3mm
g	0.3mm	0.6mm	1mm	1.3mm
BW(%)	90.08	87.37	83.33	80.47

For the values shown in Table III and Table IV radiating patch circle center is shifted up wards from 19mm to 20mm in y direction over the substrate

IV. Results and Discussion

The effectiveness of the proposed design, antenna prototype was shown in Fig 2 and fabricated antenna shown in Fig 3.The proposed antenna is simulated using HFSS and measured using ANRITSU combinational analyser MS2037C.The measured data is agreed with simulation results. Impedance Bandwidth is calculated as 90.08%(for S_{11}< -10dB) corresponding to lower end of the frequency(LEF) 4.63 GHz and upper end of the frequency (UEF)12.33 GHz. Difference between LEF and UEF is known as bandwidth and it is 7.7GHz.Return loss characteristics shown in Fig 4,simulated and measured results are almost agreed. The bandwidth covers the X-band frequencies between 8GHz-12GHz.As per the IEEE 802.11a,WLAN operation between 5.150GHz to 5.825GHz and antenna also can be used for ITU 8GHz band operating at 7.725GHz -8.275GHz. Comparison of the measured S11 with simulation results presented in Fig.5, which helps to verify the accuracy of the HFSS simulation. It is clearly shown that proposed antenna perform wide bandwidth antenna which could be used to radiate WLAN and X-Band frequencies whose impedance bandwidth is 7.7GHz ranging from 4.63GHz to 12.33 GHz. The measured results shown in Fig 4 agree well with the simulated ones, although there are minor differences. These discrepancies between the measured and simulated results may be attributed to tolerance errors in fabrication and manual welding inaccuracies.

Radiation pattern of antenna of E-plane and H-plane for frequencies at 5.2GHz and 8.7GHz shown in Fig.9 and Fig.10 respectively. Radiation pattern is Omni directional in E-plane and monotype radiation characteristics in H-plane.

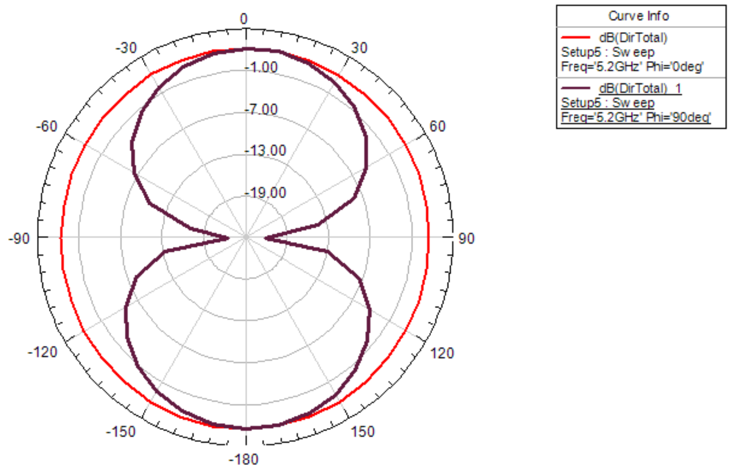

Fig.9.Radiation pattern at 5.2GHz

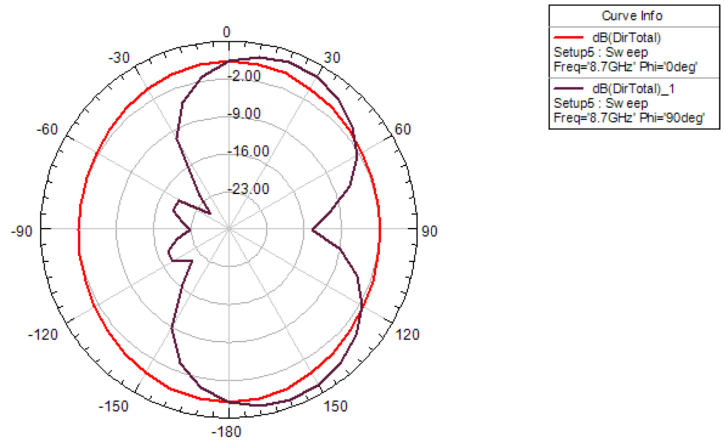

Fig.9.Radiation pattern at 8.7GHz

V CONCLUSION

A new design for WLAN and X-band applications has been proposed and implemented. The antenna structure is very simple and light weight. The proposed antenna has circular patch with arc shaped capacitive loading which gives impedance bandwidth of 90%.The plus slot incorporated on the circular slot improves the impedance bandwidth from multiband to wide band. Parametric variation is observed for different configurations by varying the circular patch radius(r) and arc feed radius(ro),and different impedance bandwidths are obtained as shown in Fig.6 to Fig.9

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