RESEARCH ARTICLE OPEN ACCESS

A Circularly Polarized Substrate Integrated Waveguide Antenna of Dual-Band Dual-Sense type

Dr.Pravat Kumar Subudhi [1], Ipsita Samal [2]

[1]*Professor, Department of Electronics and Communication Engineering, Gandhi Institute For Technology (GIFT), Bhubaneswar*

[2] *Assistant Professor, Department of Electronics and Communication Engineering, Gandhi Engineering College, Bhubaneswar*

,Professor, Engineering, GIFT, Bhubaneswar ,GEC,Bhubaneswar

ABSTRACT—Adual-banddual-sense circularly polarized (CP)an- tenna is presented in substrate integrated waveguide technology. The proposed antenna consists of four V-shaped asymmetricalres- onators that are placed on acircularsubstratesy mmetricallywith respect to its center. The antenna is excited by a probe on thecen- tral axis.Adual-band C Pantenna is designed and fabricated. The antenna provides left-hand circular polarization (LHCP) in the lower band and right-hand circular polarization (RHCP) in the upperb and.Total size of theantennais1963.5mm^{2}ona0.787mm thick RT/Duroid 5880 substrate. Measured axial ratios are below 3dBover8.78–8.90and9.52–9.66GHz.Overthebands, the return loss is more than 10dB.Measured cross-polarizationlevelsare31.1 and24.65dB,andfront-to-backratiosare14.93and18.35dBover the LHCP and RHCP bands, respectively. Depending on applica- tion requirements, the band ratio can be tuned. Also, the sense of polarization can be interchanged. The antenna does not use any ground plane perturbation. Thus, it can be directly attached to a micro wave circuit.

Index Terms—Circularly polarized (CP) antenna, dual-band, dual-sense, substrate integrated waveguide (SIW).

I. INTRODUCTION

CIRCULARLYpolarized(CP)antennasarepopulardu etotheircapabilitytoavoidadverseeffectscausedbyFar adayrotation,multipathpropagation,andpolarization mismatchduetomisalignmentsbetweentransmittinga ndreceivingantennas.PrintedCPantennasarepreferre dastheyhavelowprofile,lowcost, and ease of fabrication [1], [2]. Dual-bandCPantennas[3],[4]minimizetherequirementofu singtwoantennasfortwobands. Moreover, extra feature of polarization diversitycanbeincorporated in dual-band antennas by keepingpolarizationoftwo bands opposite to each other. Recently,manydual-band,dual-sense CP antennas are reported [5]–[11].However,mostof them provide bidirectional radiation patterns. Also,the tun-abilityofthebandsisnotshownin[5]–[8] and [10].Good radiation characteristics in low- profile antennas can be obtained when antennas are designed in substrate integrated wave guide(SIW). SIW-based linearly polarized antennas are reported in

ManuscriptreceivedJanuary19,2018;acceptedJanuary29,2018.Dateofpublication January 31, 2018; date of current version March 1, 2018. (Corre- sponding author: Kundan Kumar.)

K.KumarandS.DwariarewiththeDepartmentofElectronicsEngineering, Indian Institute of Technology (Indian School of Mines), Dhanbad 826004, India (e-mail: kundansingh. singh5@gmail.com; sdwari@ gmail.com).

M. K. Mandal is with the Department of Electronics and Electrical Com- munication Engineering, Indian Institute of Technology, Kharagpur 721302, India (e-mail: mkmandal @ece.iitkgp.ernet.in). Digital Object Identifier 10.1109/LAWP.2018.2800295

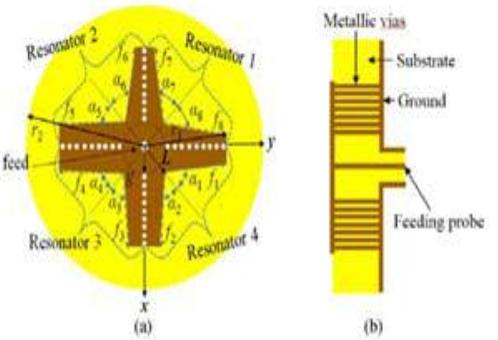

Fig. 1. Geometry of basic dual-band dual-sense antenna. (a) Top view and (b) side view. (α_1 = 47.7, α_2= 49.67, α_3= 51.2, α_4= 45, α_5= 50.2,α_6= 57.8,α_7=57.8,α_8=60.25;unit:degrees),($\mathbf{f}_1$=12.85,$\mathbf{f}_2$= 13.0,$\mathbf{f}_3$= 13.13,$\mathbf{f}_4$=12.65,$\mathbf{f}_5$=13.0,$\mathbf{f}_6$=$\mathbf{f}_7$=13.71,$\mathbf{f}_8$=13.95,$\mathbf{r}_1$= 19,$\mathbf{r}_2$= 25, g = 4.0, L = 8.48; unit: millimeters).

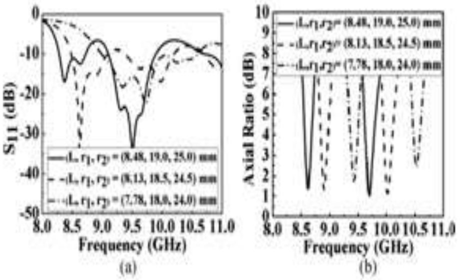

Fig. 2.Simulated (a) $S_{11}$and (b) axial ratio of the basic antenna. LHCP and RHCP are obtained in the lower and upper bands, respectively.

[12]and[13].Single-bandanddual-bandCPSIWantennasare proposed in [14]–[17]. However, the CP antennas in [16]and [17] have the same sense of polarization in both the bands.

In this letter, a novel dual-band dual-sense antenna is pre- sentedin SIW technology. The proposed antenna has high front- to-back ratio and low cross-polarization level. The antenna is realized on a single-layer substrate and supported by an unper-turbedgroundplane.Thus,itcanbedirectlyattachedtoanymi- crowavecircuit. Moreover, the band position can be controlled independently. The polarization of any band can be changed simply by changing dimensions of the resonators. To the best of the authors' knowledge, this is the first dual-band dual-sense C Pantenna that uses SIW technology to obtain improved performances.

TABLE I DIFFERENT DUAL-BAND CP ANTENNAS WITH DIFFERENT FLARE ANGLES

	Flareangle(degree)								Frequency band and polarizationstate	
	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	Lower band	Upper band
Ant 1	47.7	49.7	51.2	45	50.2	57.8	57.8	60.25	(8.56–8.66) GHz LHCP	(9.64–9.76) GHzRHCP
Ant 2	45	51.2	49.7	47.7	50.2	57.8	57.8	60.25	(8.54–8.62) GHzRHCP	(9.51–9.68) GHzRHCP
Ant 3	47.7	49.7	51.2	45	60.25	57.8	57.8	50.2	(8.55–8.63) GHz LHCP	(9.51–9.69) GHz LHCP
Ant 4	45	51.2	49.7	47.7	60.25	57.8	57.8	50.2	(8.53–8.64) GHzRHCP	(9.61–9.75) GHz LHCP

II. DESIGN ANDANALYSIS

The configuration of the basic dual-band dual-sense CP an- tenna is shown in Fig. 1. The antenna is designed on a single- layer circular substrate, Roger RT/Duroid5880 having rela-tivepermittivity of 2.2, loss tangent of 0.0009, and thickness of 0.787 mm. Four asymmetric V-shape resonators are placed symmetrically with respect to a central feeding probe. Four electrical walls realized by a set of metallic vias connect them side-by-side.Forthe electricwalls, periodicity p=1.5mmand viadiameterd=1.0mm.The optimized dimensions of the an- tenna to obtain CP radiation at 8.6 and 9.7 GHz with opposite sense of polarization are given in Fig. 1. The ground plane ra- diusr$_2$has an impact on axial ratio. A minimum substrate size must be maintained. For this example, aminimum r_2=22 mm behaves as an infinite ground plane, and good axial ratios are obtained. It starts to degrade below this value. The antenna char- acteristics and performances are investigated and analyzed by electromagnetic simulation software Ans of tHFSS.

DesignoftheantennastartswithL =λ_0/4andr$_1$–g/2=λ_0/2 at the center of lower CP band. Resonant frequencies of res- onators 1 and 2 are close to each other, and their dimensions L, r_1,r_2, α_5, α_6, α_7, and $\alpha_8$determine the frequency of up- per radiating band. Similarly, resonators 3 and 4 are tuned for the lower operating band. Fig. 2 shows the variation of input matching and the CP bands with resonator dimensions. Other dimensions are kept fixed as shown in Fig.1.

As shown in Table I, sense of polarization can be controlled by the flare angles $\alpha_{n(n=1–8)}$. Among the antennas listed in the table, Ant 1 is the basic antenna shown in Fig. 1. Ant 2 is obtained by inter changing the values of $\alpha_1$and α_4, and those of α_2 and α_3 of Ant 1. As a result, right-hand circular polarization (RHCP) is obtained at the lower band. Similarlyfor Ant3,inter changing α_5 and α_8, and $\alpha_6$and α_7, of Ant 1 provides left-hand circular polarization (LHCP) at the upper band. Ant 4 is obtained by interchanging flare angles between resonators 1 and 2, and resonators 3 and 4, of Ant 1. Thus, its sense of polarizations of the CP bands is opposite to Ant1.

However, the antenna Ant 1 in Fig. 1 provides lower gain at the upper band, typically 0 dB. It is observed that a set of horizontal metallic vias, as shown in Fig. 3, improves the gain at least by 2.2 dB. In the figure, the offset L_v= 2 mm. This modification affects the overall surface current distributionson the structure. Fig. 4 compares the antenna characteristics with and without the horizontal vias. Fig. 4(d) shows high current densities on the patch at the lower side of resonators 3 and 4, which is responsible for lowering the gain at the upper band.

Fig. 3.Modified antenna with horizontal vias at bottom.

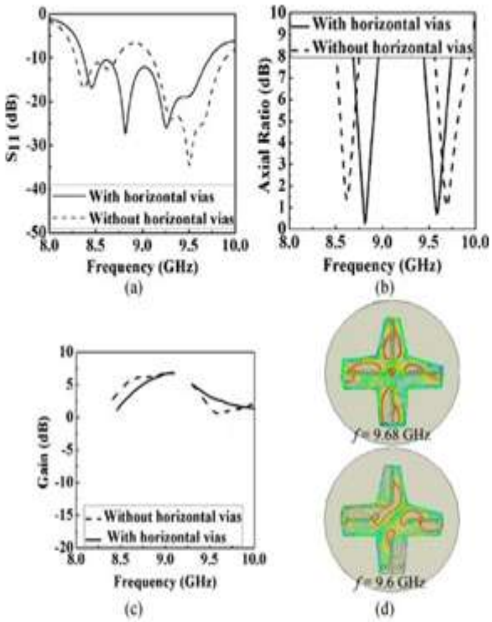

Fig. 4. Simulated (a) S_{11}(dB), (b) axial ratio, (c) broadside gains, and (d) surface current density distributions with and without the horizontal vias.

Because radiation in the upperband is obtained from resonators 1 and 2, the undesired current densities could not be decreased just by tuning resonator dimensions. A set of horizontal vias reduces the current densities and improves the gain.

Simulated fringing electric fields of the antenna at 8.82GHz at two time instances with 90° phase difference are shown in Fig. 5(a). The same at 9.6 GHz is illustrated in Fig. 5(b). It is observed that at 8.82 GHz, rotation of dominant component of electricfieldswithtimeisinclockwisedirection.TheV-shaped apertures of resonators 3 and 4 are excited in such a fashion that the fringing electric fields duet other esonators have equal magnitude with+90° phase difference.Thus, LHC Pisobtained. Conversely, it is in anti clock wise direction for resonators 1and 2 providing RHC Pat 9.6 GHz.Variation of $\alpha_1$changes the ratio of

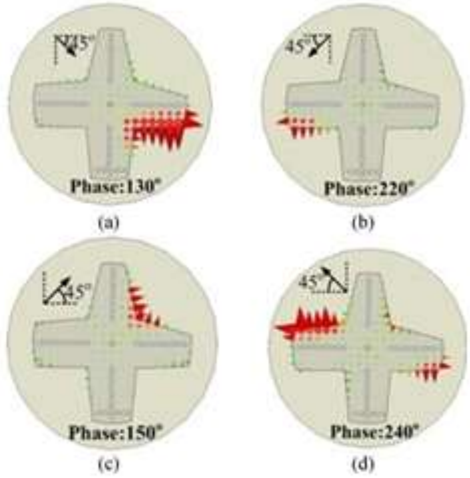

Fig. 5. Electric field distribution at: (a) 8.82 and (b) 9.6 GHz.

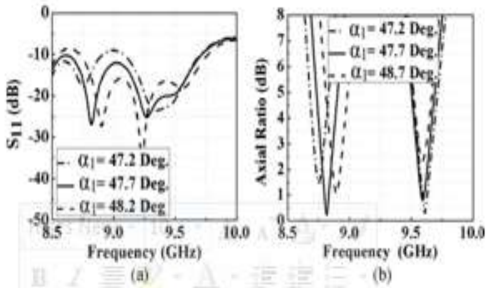

Fig. 6.Effects of different values of $\alpha_1$on (a) $|S_{11}|$ and (b) axial ratio.

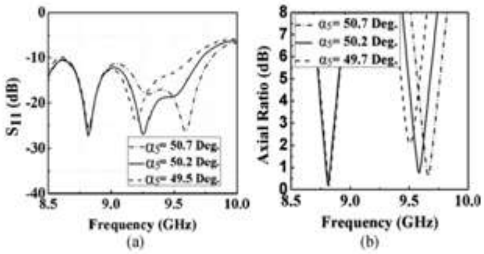

Fig. 7.Effects of different values of $\alpha_5$on (a) $|S_{11}|$ (dB) and (b) axial ratio.

horizontal to vertical components of the fringing electric fields of resonator 4. Thus, the lower CP band position changes. As an example, effects of $\alpha_1$on antenna performances are shown in Fig. 6. Similarly, as shown in Fig. 7, the upper band can be tuned by varying $\alpha_5$of resonator 2. In both cases, one band is tuned, keeping the other band almost intact.

Fig. 8 shows vector electric field distribution on the cross- sectional plane AA^1in Fig. 3 is like the TE_{10}mode in a half mode SIW.

III. EXPERIMENTALRESULTS

Antenna Ant 1 is fabricated. Fig.9 shows a photograph. The simulated and measured $|S_{11}|$ of the antenna is shownin Fig.10.

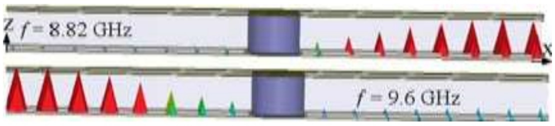

Fig. 8. Cross-sectional view of vector E-field distribution at AA[1] of Fig. 3.

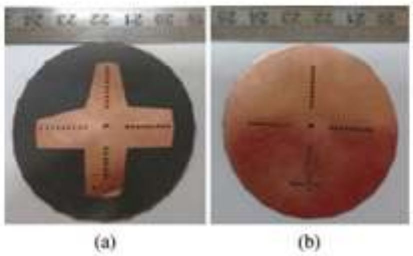

Fig. 9. Photograph of the fabricated antenna. (a) Top view. (b) Bottom view.

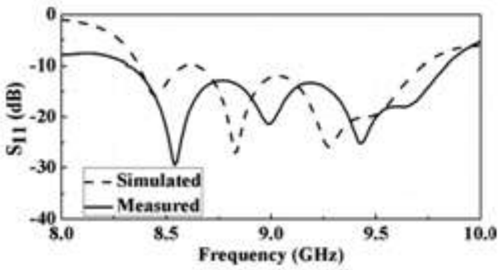

Fig. 10.Simulated and measured $|S_{11}|$ of the proposed antenna.

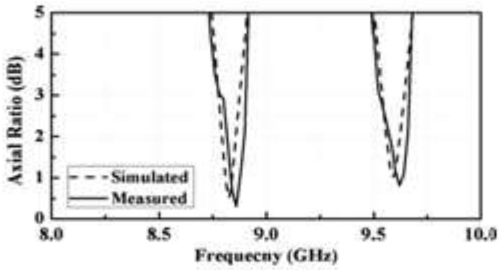

Fig. 11. Simulated and measured axial ratio of the proposed antenna.

Measured 10d Bimped an ceband wid this from 8.32 to9.83GHz, which covers both the bands. The simulated and measured ax- ial ratios are shown in Fig. 11. The 3 dB LHCP axial-ratio bandwidth at the lower band is 1.35% (8.78–8.90 GHz), and RHCP axial-ratio band wid that the upperband is1.45% (9.52–9.66GHz).AsshowninFig.12,the measured LHCP and RHCP gains vary from 5 to 5.8 dB and 2.7 to 4 dB, respectively. The measuredefficiencyismorethan92%overboththeband s.The radiation patterns are shown in Fig. 13. It is observed from the patterns that the antenna radiates LHCP wave at the lowerband and RHC Pwaveat the upperband. The cross-polarization levels are31.1and24.65Db in the broad side direction at the lower and upper bands, respectively. Also, the antenna has directivera dia- tion pattern with high front-to-back ratio of 14.93and18.35dB at the bands, respectively. Its measured CP beam widths in

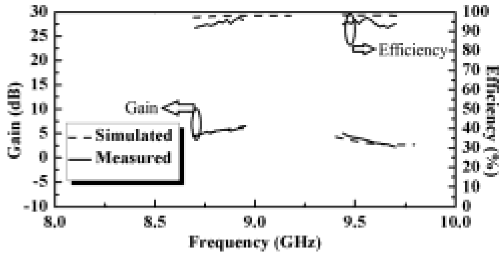

Fig. 12. Simulated and measured gains and efficiencies of the antenna.

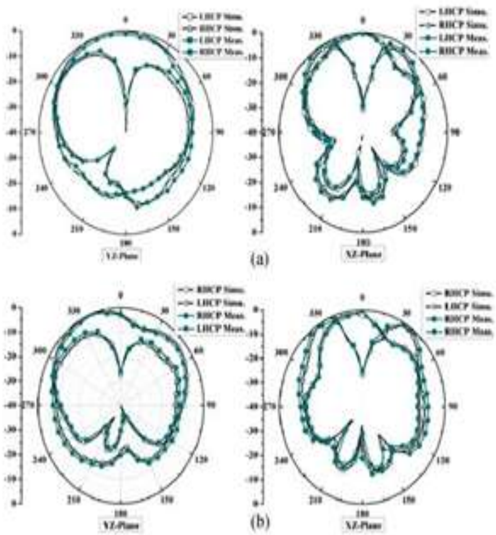

Fig. 13. Simulated and measured radiation patterns at (a) 8.82 and

(b) 9.6 GHz.

TABLE II PERFORMANCE COMPARISON WITH DUAL-BAND CP SIW ANTENNAS

Parameters	[15]	[16]		[17]		This work	
	f	f_1	f_2	f_1	f_2	f_1	f_2
Freq.(GHz)	12.5	9.5	11.8	37.5	47.8	8.82	9.6
ARBW (%)	11.2	8	5	1.1	1.5	1.35	1.45
CP state	LH/RH	LH	LH	LH	LH	LH	RH
Size(λ_0^2)	0.982	2.679		1.875		1.605	
Independenttunability	NR	NR		NR		Yes	
Designflexibility	NR	NR		NR		Yes	

NR = Not reported, LH = Left-hand, RH = Right-hand

*yz*plane are 19° (lower band) and 15° (upper band). The re- spective values in *xz*plane are 20° and 14°.

IV. CONCLUSION

A dual-band dual-sense probe-fed CP antenna with metallic vias is presented in printed circuit board technology. The an- tenna is realized on a single-layer substrate and supported by anunperturbed ground plane.The antenna is composed of four asymmetrical resonators with V-shaped apertures. Asymmetry creates two orthogonal modes having 90° phase difference at thebands of interest. Anyone of the CP bands can be tuned in de- pendently keeping the other one almost fixed. The antenna has good radiation characteristics. In TableII, performance of the

present antenna is compared with the dual-sense CP and dual- bandCPSIWantennasof[15]–[17].It should be noted that the dual-band SIW antennas have the same sense of polarization at the bands, whereas the proposed antenna can provide the same sense of polarization as well as different sense of polarization. Moreover, it shows that the sense of polarization can be easily selected by a proper choice of the flare angle. The size of the proposed antenna is smaller than in [16] and [17]. The bands can be tuned independently, which is not shown in [16] and[17]. Since the antenna provides narrow CP beam width, it can be ef- fectively used in point-to-point communication systems and in satellites and radar systems where highly directional beams are used.

REFERENCES

[1]. J.Y.Sze,C.I.G.Hsu,Z.W.Chen,andC.C.Chang, “BroadbandCPW-fed circularly polarized square slot antenna with lightening-shaped feedline and inverted-L grounded strips, ”IEEE Trans. Antennas Propag., vol.58, no. 3, pp. 973–977, Mar.2010.

[2]. R. K. Saini and S. Dwari, “A broadband dual circularly polarized square slotantenna, ”IEEE Trans. Antennas Propag., vol.64,no.1,pp.290–294, Jan.2016.

[3]. C.H.ChenandE. K.N.Yung, “Dual-bandcircularly-polarizedCPW-fed slot antenna with a small frequency ratio and wide band widths,” IEEE Trans. Antennas Propag., vol. 59, no. 4, pp. 1379–1384,Apr. 2011.

[4]. W. Liang, Y. C. Jiao, Y. Luan, and C. Tian, “A dual band circularly polarized complementary antenna, ”IEEE Antennas Wireless Propag. Lett., vol. 14, pp. 1153–1156,2015.

[5]. X. L. Bao and M. J. Amman, “Monofilar spiral slot antenna for dual fre- quency dual sense circularly polarization, ”IEEE Trans.Antennas Propag., vol. 59, no. 8, pp. 3061–3065, Aug.2011.

[6]. X. Bao and M. J. Amman, “Dual frequency dual sense circularly polar- izedslot antenna fed by micro stripline, ”IEEE Trans. Antennas Propag., vol. 56, no. 3, pp. 645–649, Mar.2008.

[7]. Y. Shao and Z. Chen, “A design of dual frequency dual sense circularly polarized slot antenna,” IEEE Trans. Antennas Propag., vol. 60, no. 11, pp. 4992–4997, Nov. 2012.

[8]. Y. Y. Chen, Y. C. Jiao, G. Zhao, F. Zhang, Z. L. Liao, and Y. Tian, “Dual band dual sense circularly polarized slot antenna with a C- shaped groundedstrip, ”IEEE Antennas Wireless Propag. Lett., vol.10, pp.915–918,2011.

[9]. Z.X. Liang, D.CYang, X.C.Wei,and E.P.Li,“Dual band dual circularly polarized micro stripantenna with twoe ccentricrings and an arcshaped conducting strip,”IEEE Antennas Wireless Propag. Lett., vol.15, pp.834–837, 2016.

[10]. C.F.Jou,J.W.Wu,andC.J.Wang,“Novelbroad band monopole antennas with dual-band circular polarization,” IEEE Trans. Antennas Propag., vol. 57, no. 4, pp. 1027–1034, Apr.2009.

[11]. R.K.Saini,S.Dwari,andM.K.Mandal,“CPW-feddual-banddual-sense circularly polarized monopole antenna,”IEEE Antennas Wireless Propag. Lett., vol. 16, pp. 2497–2500,2017.

[12]. G. Q. Luo, Z. F. Hu, L. X. Dong, and L. L Sun, “Planar slot antenna backed by substrate integrated wave guidecavity, ”IEEE AntennasWireless Propag. Lett., vol. 7, pp. 236–239,2008.

[13]. S. Mukherjee, A. Biswas, and K. V. Srivastava, “Broadband substrate integratedwaveguidecavity-backedbow-tieslotantenna,”IEEEAntennas Wireless Propag. Lett., vol. 13, pp. 1152–1155,2014.

[14]. G. Q. Luo, Z. F. Hu, Y. Liang, L. Y. Yu, and L. L. Sun, "Development of low profile cavity backed crosss lotantennas for planar integration,"IEEE Trans.AntennasPropag.,vol.57,no.10,pp.2972–2979,Oct.2009.

[15]. K. Kumar, S. Dwari, and M. K. Mandal, "Broadband dual circularly po- larized substrate integrated wave guide antenna, "IEEEAntennasWireless Propag. Lett., vol. 16, pp. 2971–2974,2017.

[16]. T. Zhang, W. Hong, Y. Zhang, and K. Wu, "Design and analysis of SIW cavity backed dual band antennas with a dual mode triangular ring slot," IEEE Trans. Antennas Propag., vol. 57, no. 10, pp. 5007–5016, Oct.2014.

[17]. Q. Wu, J. Yin, C. Yu, H. Wang, and W. Hong, "Low-profile millimeter- wave SIW cavity-backed dual-band circularly polarized antenna," IEEE Trans.AntennasPropag.,vol.65,no.12,pp.7310–7315,Dec.2017.

Dr.Pravat Kumar Subudhi as, " A Circularly Polarized Substrate Integrated Waveguide Antenna " *International Journal of Engineering Research and Applications (IJERA*), vol.5(8), 2015, pp 282-287.