Journal of Engineering Science and Technology
Vol. 11, No. 2 (2016) 267 - 277

CIRCULARLY POLARIZED SLOTTED APERTURE ANTENNA WITH COPLANAR WAVEGUIDE FED FOR BROADBAND APPLICATIONS

B. T. P. MADHAV*, HABIBULLA KHAN, SARAT K. KOTAMRAJU

Department of ECE, K L University, Guntur DT, AP, India
*Corresponding Author: btpmadhav@kluniversity.in

Abstract

Coplanar waveguide fed circularly polarized microstrip patch antenna performance evaluation is presented in this paper. The broadband characteristics are attained by placing open end slot at the lower side of the antenna. The proposed design has the return loss of less than -10dB and VSWR<2 in the desired band of operation. A gain of 3dB to 4dB is attained in the desired band with good radiation characteristics and a suitable axial ratio of less than 3 dB is attained in the prescribed band of operation. Proposed antenna is fabricated on the FR4 substrate with dielectric constant of 4.4. Parametric analysis with change in substrate permittivity also performed and the optimized dimensions are presented in this work.

Keywords: Circular polarization, Slotted aperture, Broadband, Coplanar waveguide, Axial ratio, Half power beam width, Impedance bandwidth.

1. Introduction

Due to high bandwidth, low profile, uni-planar geometry and ease of integration with monolithic microwave integrated circuits, coplanar waveguide fed antennas got much attention in these days. Wideband and broadband characteristics can be obtained by taking different configurations, slotted apertures and defected ground structures in these models. Circular polarization is becoming popular in wireless Communications to enhance the system performance [1-5]. The operation principle of circular polarization is to excite two orthogonal modes with equal amplitude but in phase quadrature. It can be achieved by introducing some symmetric and asymmetric perturbations into a wide slot antenna. These perturbations can be obtained and implemented by slot configurations or feed lines.

Nomenclatures

G	Gap between feed line and ground plane
h	Height of the substrate, mm
L1	Length of the patch element, mm
L2	Length of left side ground plane to feed line, mm
L3	Length of right side ground plane to feed line, mm
L4	Length of the feed line, mm
L5	Length of patch plus feed line, mm
L6	Length of the slot on the ground plane, mm
Ls	Substrate length, mm
W	Width of the feed line, mm
Ws	Width of the substrate, mm
W1	Width of the patch element, mm
W2	Width of the left plane ground, mm
W3	Width of the right plane ground, mm
W4	Width of the ground plane slot, mm

Greek Symbols

ε_{eff}	Effective dielectric constant
ε_r	Dielectric constant

Abbreviations

AR	Axial Ratio
CP	Circular Polarization
CPW	Coplanar Waveguide Feeding
HPBW	Half Power Beam Width
VSWR	Voltage Standing Wave ratio

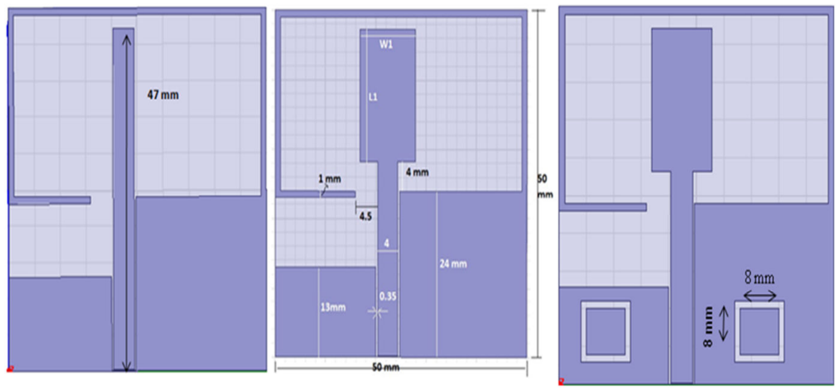
Axial ratio bandwidth can be improved by using different techniques. By implanting a pair of grounded strips or three inverted L-Shaped grounded strips, the axial ratio bandwidth can be improved [6-9].

In this paper structurally simple circularly polarized antenna model is proposed. Asymmetric perturbation is introduced by placing a slot on the lower side of the design. The current antenna is fed by a wide tuning stub can provide circular polarization and impedance bandwidth.

2. Antenna Configuration

The proposed antenna is printed on an FR4 substrate with dielectric constant of 4.4 and a thickness of 0.8 mm. A 50 ohm CPW feeding line is connected as shown in the figure. In order for the CP operation, an open slot having an open width is used at lower side of the model. This is an open slot with a configuration which is open along the ground plane in X and the CPW feeding line in Y directions. The new technique of this slotted configuration can provide the perturbation with magnetic current distributions in X and Y directions. This can generate the Circular polarization operation by exciting two orthogonal modes in X and Y directions with equal amplitude but in phase quadrature.

It is obvious that the change in ground plane would sensitively influence the performance of Circular Polarization operation [10-11]. A wide tuning stub with length L1 and width W1 is used to improve the circular polarization. If open slot is taken at lower right side of the feeding line then circular polarized waves of opposite sense will be produced. In order for the AR bandwidth enhancement, a wide tuning stub is used in the model as shown in the Fig 1.



(a) **(b)** **(c)**

Fig. 1. Broadband monopole antenna iterations.
(a) Slotted broadband monopole, (b) Slotted broadband rectangular monopole, (c) Slotted ground broadband rectangular monopole.

3. Results and Discussion

Figure 1 shows the proposed coplanar waveguide fed circularly polarized slot antennas of 50 ohm CPW feeding with signal strip and gaps have the width of 4 and 0.35 mm. The first model is a slotted broadband monopole with strip length of 47 mm and the second model is the slotted rectangular broadband monopole with wider tuning stub. For wider impedance bandwidth and axial ratio bandwidth, an asymmetric ground plane is used in this design. The third model is the modified model of 2 with slots on the ground plane on either side to the feed line. The length of the feed line is tuned for good circular polarization bandwidth. Figure 2 shows the fabricated prototype of proposed model. Figure 3 shows the simulated return loss Vs frequency characteristics of the three models. It is been observed from the results that an impedance bandwidth of 70% (2.4-5 GHz) from the first model, impedance bandwidth of 100% (2.4-7.2 GHz) from second model and 102% from the third model is attained. Figure 4 shows the measured and simulation return loss of proposed model 3. Simulation and measurement results are in good agreement with each other.

To achieve efficient excitation and good impedance matching, parametric analysis on open slot parameters and tuning stub are carried out with Ansys HFSS EM-Simulator and are presented in this work. To accurately realize the influence of these parameters, only one parameter at a time is varied by keeping others constant. Figure 5 shows the reflection coefficient of the antenna with change in slot length L1. Bandwidth is almost same for change in slot length L1 from 16 mm to 20 mm, but with L1=18 mm the reflection coefficient is stable in the lower frequency band. Figure 6 shows the axial ratio curve with change in L1. Impedance bandwidth of 21.3% from L1=16 mm, 34.2% from L1=18 mm, 31.6% from L1=19 mm and 40% from L1=20 mm attained from this result.

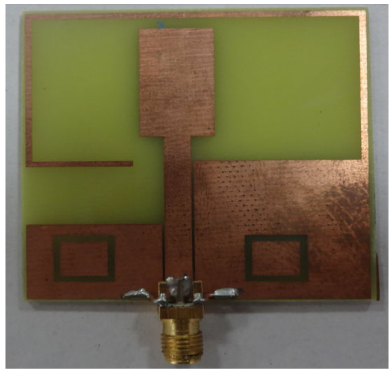


Fig. 2. Fabricated prototype antenna.

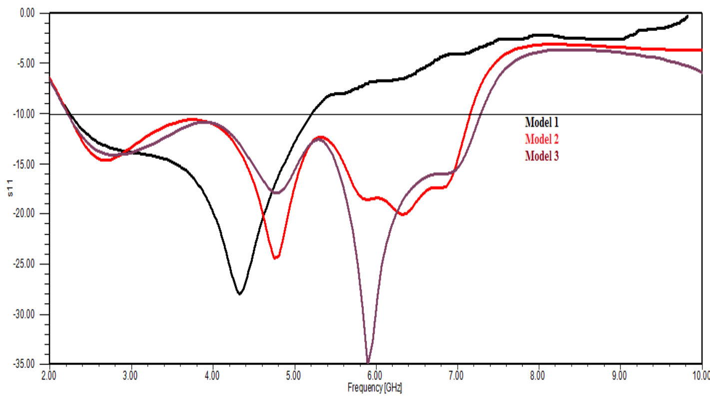


Fig. 3. Simulated return loss curve for three models.

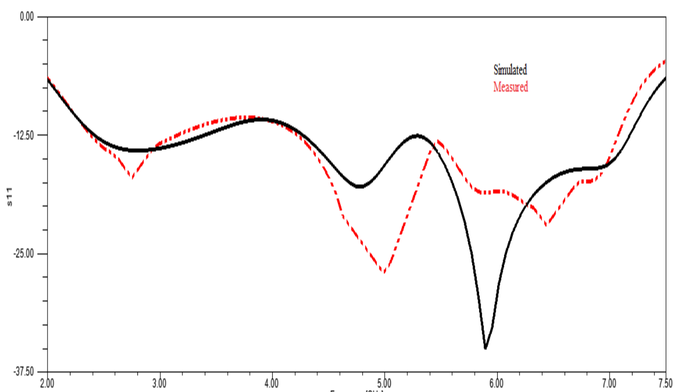


Fig. 4. Simulation and measured results of return loss.

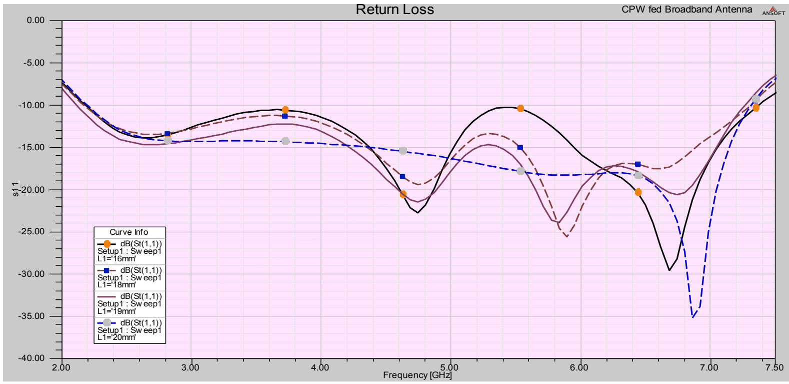


Fig. 5. Return loss variations in length of slot L1=16 mm, 18 mm, 19 mm, 20 mm.

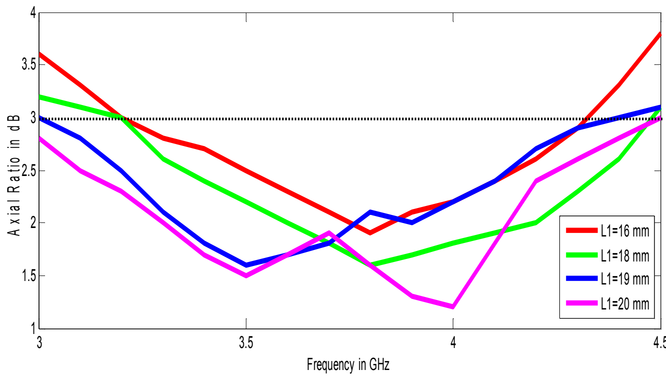


Fig. 6. Axial ratio variations in length of slot L1=16 mm, 18 mm, 19 mm, 20 mm.

Figure 7 shows the reflection coefficient of the antenna with change in slot width W1. Maximum bandwidth of 5400 MHz from W1=9 mm and minimum of 5000 MHz from W1=11 mm is attained from the current study result. Figure 8 shows the axial ratio curve with change in width of the slot W1 and an impedance bandwidth of 35% is attained for the case of W1=13 mm.

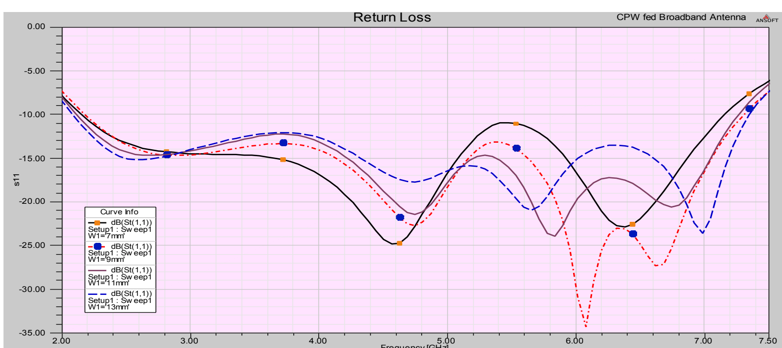


Fig. 7. Variations in width of slots W1=7 mm, 9 mm, 11 mm, 13 mm.

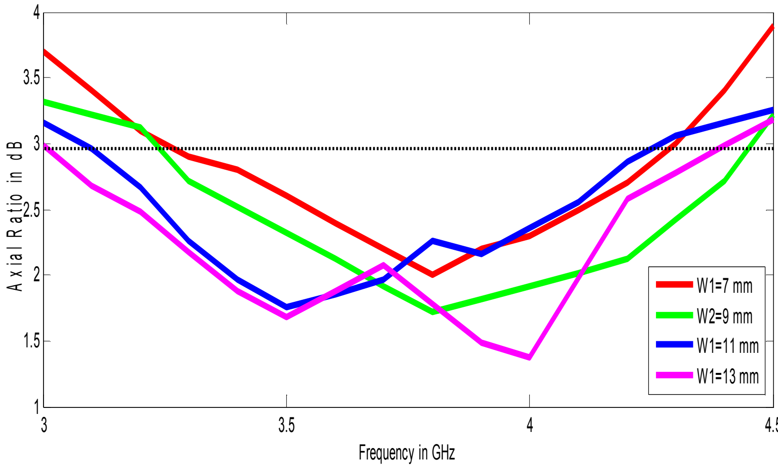


Fig. 8. Axial ratio variations in length of slot W1=7 mm, 9 mm, 11 mm, 13 mm.

Figure 9 shows the reflection coefficient with change in thickness of the substrate material. Generally 1.6 mm thickness FR4 material is widely available, but the result shows the superior performance for 0.8 mm thickness, so we fabricated the model on 0.8 mm thickness FR4 material, which gives impedance bandwidth of 88% in the frequency range 2-7.25 GHz with centre frequency of 4.625 GHz. Figure 10 shows the parametric analysis for reflection coefficient with change in width of the ground plane slot. The simulation result shows that with the optimized dimension of 8 mm, the antenna is resonating in the wide band. Figure 11 shows the axial ratio of the proposed model with change in width of the ground plane slot.

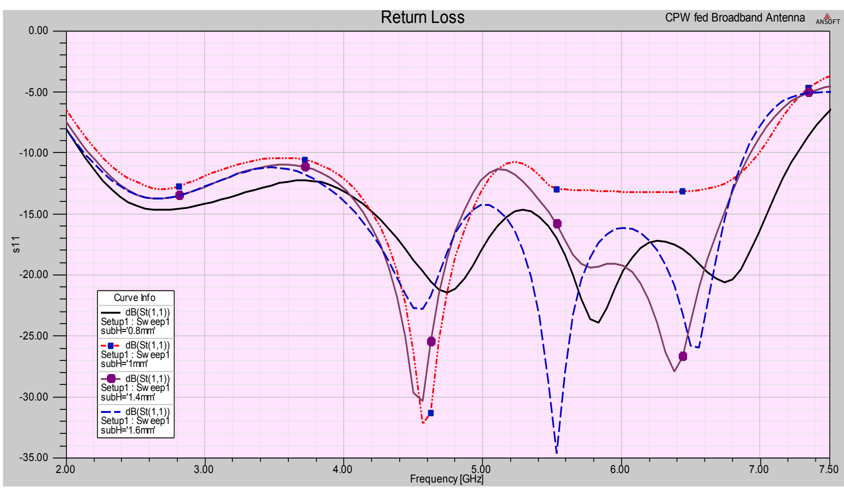


Fig. 9. Variations in substrate height sub H=0.8 mm, 1 mm, 1.4 mm, 1.6 mm.

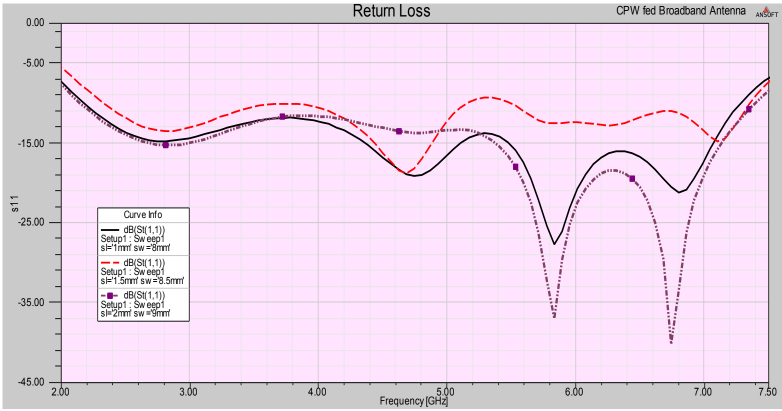


Fig. 10. Variations in ground plane slot width for modified model of 8 mm, 8.5 mm and 9 mm.

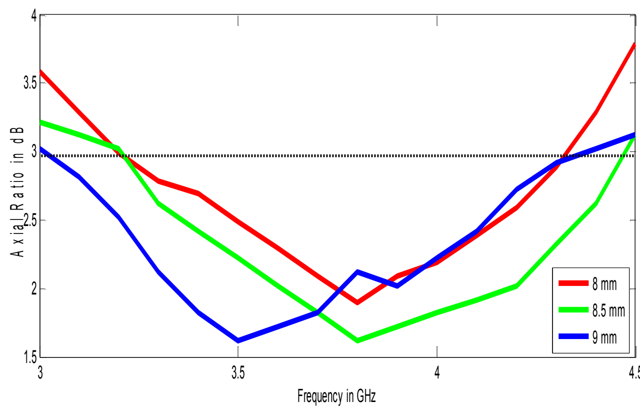


Fig. 11. Axial ratio variations in ground plane slot width 8, 8.5 and 9 mm.

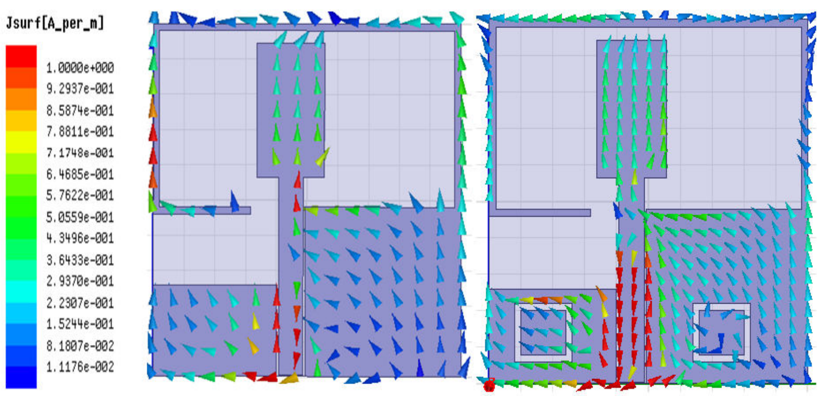


Fig. 12. Current distribution over the slotted broadband rectangular monopole and slotted ground broadband rectangular monopole at 3 GHz.

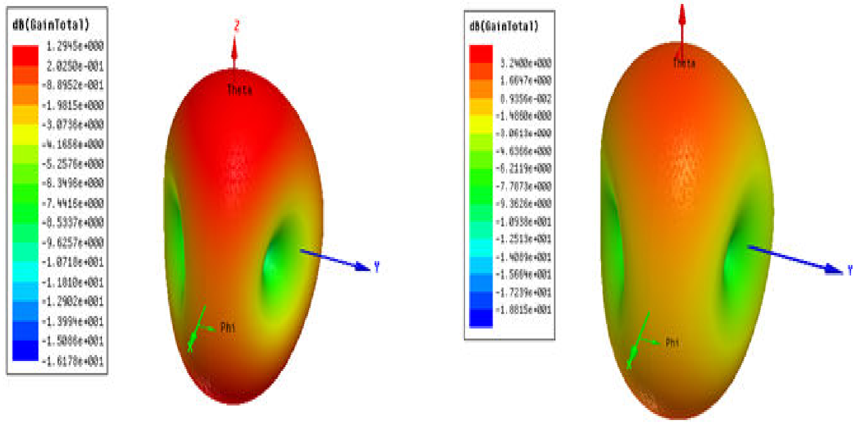


Fig. 13. 3D Radiation plot for slotted broadband rectangular monopole and slotted ground broadband rectangular monopole at 3 GHz.

When the slotted ground broadband rectangular monopole antenna is resonating at 3 GHz, large current density can be observed along the feed line compared to slotted broadband rectangular monopole antenna. So from the result, it is been observed that strong surface currents are distributed around the feed line to produce the resonance mode. The radiation patterns at 3 GHz in the xz-plane (H-plane) and yz-plane (E-plane) are plotted in Figure 14. The radiation patterns are omnidirectional in the E-plane and monopole-like in the H-plane. The radiation characteristic of the antenna is stable within the operating bands, and the cross-polarization radiation patterns are relatively small in E-Plane. A Half power beam width (HPBW) of 81 degrees in E-plane and 54 degrees in H-plane is attained from the radiation pattern results.

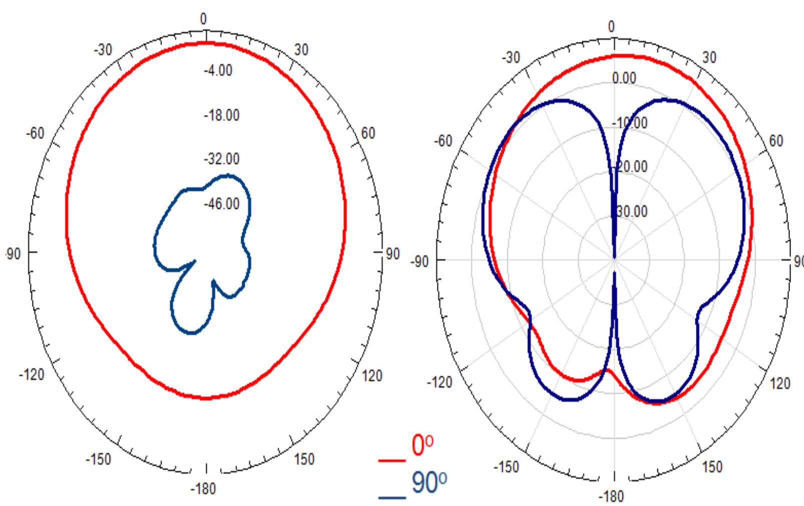


Fig. 14. Antenna radiation pattern in E and H-Plane at 3 GHz.

Figure 15 shows the parametric analysis with change in substrate permittivity on the proposed model. Except for Arlon and Alumina, the other materials based model is showing wide bandwidth. Ultralam 3850 (Liquid Crystal Polymer) substrate is showing superior performance over the other materials based antenna.

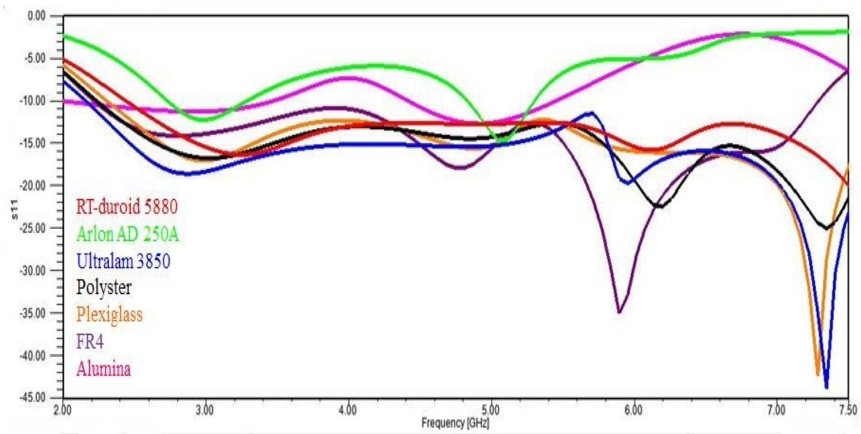


Fig. 15. Parametric analysis of return loss for slotted ground rectangular monopole antenna with change in substrate permittivity.

By considering different materials for the study on the proposed model, depending on the dielectric constant first we calculated the effective dielectric constant value and later calculated the width of the feed line and gap between ground planes to feed line [12] and placed in Table 1. Initially by taking centre frequency in the resonance band, we calculated wavelength (λc) corresponding to it. Later the overall dimensions of the antenna with change in substrate permittivity is calculated and tabulated in Table 2.

Table 1. Antenna 'W' and 'G' variation with respect to different laminates.

Laminate	Antenna 1 RT-duroid 5880	Antenna 2 Arlon AD-250	Antenna 3 Ultralam 3850	Antenna 4 Polyester	Antenna 5 Plexiglass	Antenna 6 FR4	Antenna 7 Alumina
h	1.56	1.6	1.56	1.56	1.5	1.6	1.2
ε_r	2.2	2.5	2.9	3.2	3.4	4.4	10.2
ε_{eff}	1.6	1.75	1.95	2.1	2.2	2.7	5.6
W	4	3.675	3.35	3.025	2.7	2.375	2.05
G	0.35	0.375	0.4	0.475	0.45	0.475	0.5

Table 2. Antenna dimensions for different substrate materials.

	Antenna 1	Antenna 2	Antenna 3	Antenna 4	Antenna 5	Antenna 6	Antenna 7
W1 (mm)	13.25	12.63	12.25	11.90	11.23	11	10.36
W2 (mm)	1,227	1.17	1.135	1.102	1.04	1	0.96
W3 (mm)	5.401	5.148	4.994	4.851	4.576	4.5	4.224
W4 (mm)	5.892	5.616	5.448	5.292	4.992	5	4.608
W (mm)	4.91	4.68	4.54	4.41	4.16	4	3.84
L1 (mm)	23.07	21.99	21.33	20.72	19.55	19	18.04
L2 (mm)	34.37	32.76	31.78	30.87	29.12	28	26.88
L3 (mm)	15.71	14.97	14.52	14.11	13.31	13	12.28
L4 (mm)	29.46	28.08	27.24	26.46	24.96	24	23.04
L5 (mm)	57.44	54.75	53.11	51.59	48.67	47	44.98
L6 (mm)	5.892	5.616	5.448	5.292	4.992	5	4.608
Ws(mm)	61.37	58.5	56.75	55.12	52	50	48
Ls(mm)	61.37	58.5	56.75	55.12	52	50	48

4. Conclusions

A novel broadband antenna is designed and its performance characteristics are demonstrated. The open slot can provide the perturbation into the wide slot antenna for circular polarization operation. In this model, with the use of wide tuning stub and slot on the ground plane the impedance and axial ratio bandwidths are improved. Three models are implemented and their parameters are discussed in detailed manner. The experimental results show that the antenna has excellent impedance bandwidth for the applications between 2-7 GHz. From the prototyped proposed model, an average gain of 3.2 dB and efficiency of more than 85% is attained in the desired band. Parametric analysis with change in substrate permittivity is also performed and the optimized dimensions for the studied materials are presented in this work.

Acknowledgements

Authors like to express their gratitude towards the department of ECE and management of K L University for their continuous support and encouragement during this work. Authors also like to express their gratitude towards the FIST grant from Department of Science and technology (SR/FST/ETI-316/2012) and Dr Sarat also likes to thank SERB-DST grant (SR/S4/AS-82/2011) from Government of India.

References

1. Fu, S. (2009). Broadband circularly polarized slot antenna array fed by asymmetric CPW for L-band application. *IEEE Antennas and Wireless Propag. Lett*, 8, 1014-1016.
2. Wong, K. L. (2002). *Compact and Broadband Microstrip Antennas*. New York, John Wiley & Sons Inc.
3. Sze, J. Y. (2008). Axial-ratio bandwidth enhancement of asymmetric-CPW-fed circularly-polarized square slot antenna. *Electron. Lett.* 44(18), 1048-1049.
4. Chang, T. N. (2009). Circular polarized antenna for 2.3-2.7 GHz Wi-MAX band. *Microw. Opt. Technol. Lett*. 51(12), 2921-2923.
5. Madhav, B. T. P. (2013). Substrate Permittivity Effects on the Performance of Slotted Aperture Stacked Patch Antenna. *International Journal of Applied Engineering Research*. 8(8), 909-916
6. Yeung, S. H. (2011). A Bandwidth improved circular polarized slot antenna using a slot composed of multiple circular sectors. *IEEE Trans. Antennas Propag*. 59(8), 3065-3070.
7. Sze, J. Y. (2003). Coplanar waveguide-fed square slot antenna for broadband circularly polarized radiation. *IEEE Trans Antennas Propag.* 51(8), 2141-2144.
8. Sarat, K.; and Madhav, B. T. P. (2013). Coaxial Fed Rotated Stacked Patch Antenna. *International Journal of Applied Engineering Research*, 8(15), 1873-1879.
9. Sze, J. Y. (2008). Circularly polarized square slot antenna with a pair of inverted-L grounded strips. *IEEE Antennas and Wireless Propag. Lett.* 7, 149-151.
10. Chu, Q. X.; and Du, S. (2010). A CPW-fed broadband circularly polarized square slot antenna. *Microw. Opt. Technol. Lett.* 52(2). 409-412.
11. Chang, T. N. (2011). Wideband circularly polarized antenna using two linked annular slots. *Electron. Lett.* 47(13). 737-739.
12. Sadasivarao, B.; and Madhav, B. T. P. (2014). Analysis of Hybrid Slot Antenna based on Substrate Permittivity. *ARPN Journal of Engineering and Applied Sciences*. 9(6), 885-890.