Dual Band Circularly Polarized Modified Rectangular Patch Antenna for Wireless Communication

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Abstract. *A dual band circularly polarized single-feed microstrip antenna for wireless communication systems is proposed here and its performance is tested in free space. This modified rectangular microstrip antenna having one protruded curved edge is simulated by using the IE3D simulation software. In between conducting patch and ground plane, designed antenna has two layers of glass epoxy FR-4 substrates separated by a thin layer of foam substrate. This designed antenna operates at two frequencies 3.10 GHz and 3.55 GHz and presents circularly polarized performance in far-field region. The measured impedance bandwidth of designed antenna is 26% (0.846 GHz) with respect to the central frequency 3.31 GHz. The axial ratio bandwidth at two frequencies 3.10 GHz and 3.55 GHz is close to 1.36% & 2.21% respectively. The measured E plane co and cross radiation patterns in entire impedance bandwidth are identical in shape and direction of maximum radiations is normal to patch geometry as the losses in cavity reduce as the quality factor of the cavity is decreased.*

Keywords

Microstrip antenna, dual frequency, multilayer, broadband, circularly polarized.

1. Introduction

The increasing demand of wireless and mobile communication systems has increased the demand for smaller devices with wider bandwidth. The limitation of the transmitter-to-receiver orientation can be effectively solved when antennas with circular polarization (CP) are utilized. Circular polarized (CP) antenna can reduce the loss caused by misalignment between the signal and the receiving antenna. The CP wave obtains two degenerated orthogonal modes with different resonant frequencies and there is a phase difference of 90° between two orthogonal modes [1]. Antennas following these trends must be compact in size and they must have the capability to integrate with host object with desired impedance behavior and radiation characteristics. Microstrip antennas are now finding wide applications in mobile and wireless devices due to their lightweight, low profile, planar configuration and compactness [2]. However, their narrow impedance bandwidth, low gain and capability to operate at a single frequency are the major constraints, which make these antennas less popular in consumer world. Several methods are available in open literature to improve their performance. These includes application of an impedance matching network [3], application of thick substrates with low dielectric constant and multiple resonator [4-8], design of parasitic patches stacked on the top of the main patch or close to the main patch in same plane [9], design of a capacitive probe feed structure [10] and L- probe feeding [11] etc. Antennas with various shapes of microstrip feed line and rectangular wide slot have been introduced for large impedance bandwidth [12-14]. The bandwidth and gain of antenna can also be improved by applying an air gap between the patch radiator and the ground plane [15].

Various single and dual-band CP patch antennas have been investigated and reported in literature. The CP antennas are classified as a single feed type or dual feed type depending on the number of feed points necessary to generate the CP waves. Various new designs of circular polarized antenna can be found in the present literature, such as in [16], the CP characteristics are achieved by an unequal cross-slot embedded in the circular patch and two orthogonal linear stubs spurred from the annular-ring with small frequency ratio (about 1:1.1). In [17] to achieve simultaneous dual-band CP and a wide impedance bandwidth, researchers proposed the asymmetrical U-slot and achieved axial ratio bandwidths of 1 % and 3.1 % in lower and higher bands respectively. In [18] a single feed low-profile and easy to fabricate circularly polarized microstrip patch antenna has been developed for GPS applications. For dual frequency operation, four slots are etched near edges of the patch and a crossed slot etched in the center for generating circular polarization. In [19] a novel CP antenna has been introduced, which is the combination of stacked technique with a truncated edge method for both high and low frequency patches. The researcher improved the return loss and bandwidth by adding semi-groove on the patch. In [20] a single-layered feed is used to excite a single square patch integrated with a novel asymmetrical slot and two different truncated corners to achieve CP polarization in both bands. An impedance bandwidth of 7.2 % in the lower band (2.53 GHz) and 3.6 % in the upper band (5.73 GHz) with a 3 dB axial ratio of 2 % and 3.2 % in the lower and upper band respectively is achieved.

In this communication, in the first step a single patch rectangular microstrip antenna is modified by introducing a protruding semi ellipse on one of the edge of the patch. An interesting phenomenon is observed that by a simple change in the regular coplanar rectangular microstrip antenna, the modified antenna geometry provides a dual frequency behavior. Out of these two resonant frequencies, one is similar to the resonant frequency of conventional patch that can be calculated by equation [1], while the other originates due the alteration in geometry. This protruding semi ellipse significantly changes both the resonance frequency and radiation performance of the patch when compared with conventional rectangular patch antenna. The second frequency can be altered by changing the dimension of the protruding part. The resonant frequency of a rectangular microstrip patch can be calculated by equation [1]

$$(f_r) = \frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0\varepsilon_0}}. \tag{1}$$

Since it does not account for fringing, it must be modified to include edge effects using reference [21].

In the second part, we have adopted a method which is different from the other researchers, that applies foam substrate in between the two dielectric substrate layers with the help of spacers instead of applying foam substrate between the conducting patch and substrate with ground plane. As we know that impedance bandwidth of a patch antenna is strongly influenced by the spacing between the patch and the ground plane, it is realized that this modification increases the impedance bandwidth of the antenna. When the patch is moved closer to the ground plane, less energy is radiated and more energy is stored in the patch capacitance and inductance, that is, the quality factor Q of the antenna increases. As the spacing increases, Q factor decreases, in turn the impedance bandwidth increases. It also provides the mechanical strength to the patch, since the patch is used with substrate layer.

2. Antenna Design and Results

2.1 Single Layer Rectangular Microstrip Antenna with Protruding Curved Edge

In first step, a conventional rectangular patch having length $L = 28$ mm and width $W = 20$ mm is considered on glass epoxy FR4 substrate having substrate dielectric constant $\varepsilon_r = 4.4$, loss tangent $\tan\delta = 0.025$ and thickness $h = 1.59$ mm. On one of the straight edge, a protruded curved part having elliptical shape is added as shown in Fig. 1. The dimension of protrude is taken $b = 3.0$ mm after several optimizations. The antenna is fed through an inset feed arrangement using SMA connector and associated with 50 ohm feed line. The IE3D full wave electromagnetic simulation software [22] based on method-of-moments is used for optimization and analysis of considered geometry. This antenna is later designed and tested in free space.

A conventional rectangular patch antenna (all four straight edges) with $L = 2.8$ cm and $W = 2.0$ cm resonates at frequency 2.489 GHz corresponding to dominant TM_{10} mode of excitation [23], this frequency matches with the first resonance of modified geometry having an addition of a protruding curved edge and also gives an additional resonance frequency 3.046 GHz as shown in Fig. 2 through measured S_{11} results. With the proposed modification in conventional rectangular patch geometry, an additional mode along with the existing dominant TM_{10} mode gets excited.

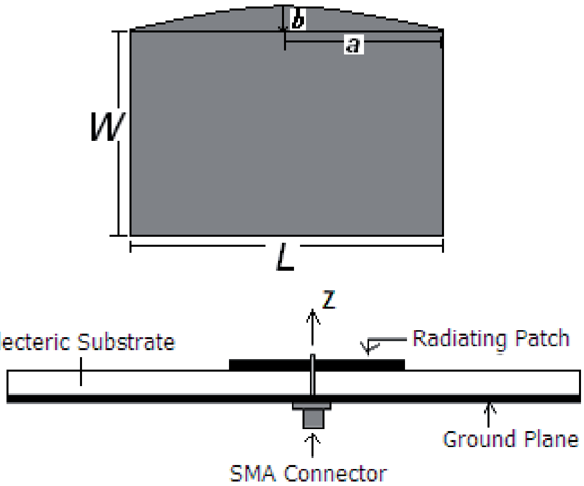

Fig. 1. Top and side view of the designed single layer modified rectangular patch antenna with feed arrangement.

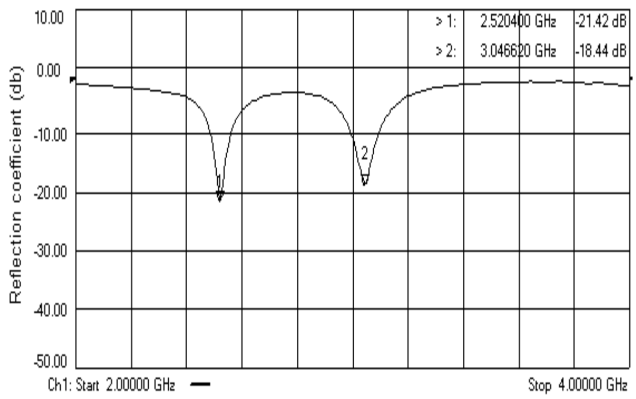

Fig. 2. Measured variation of reflection coefficient with frequency for the single layer modified rectangular patch antenna.

The measured input impedance variation of antenna is shown in Fig. 3 which provides input impedance values (44.3 – j 5.2) ohm and (41.89 + j 6.8) ohm at two resonance frequencies, which suggests fair matching between the antenna and 50 ohm impedance feed line. The impedance bandwidths of this antenna at both the frequencies are narrow (2.33 % and 3.25 % respectively) hence this antenna needs improvement for making it suitable for modern communication systems.

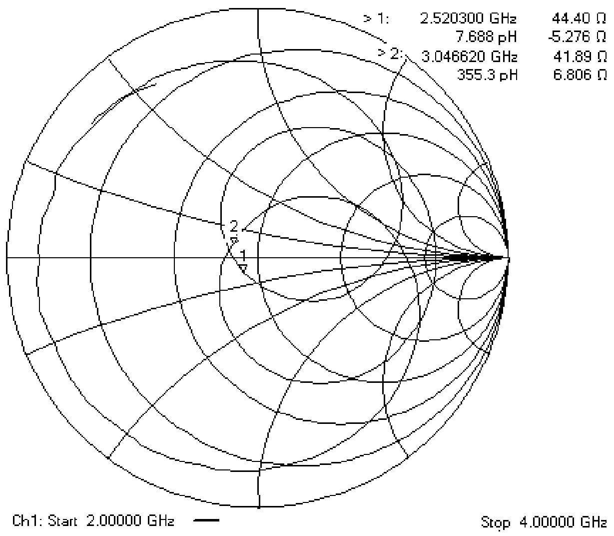

Fig. 3. Measured variation of input impedance for the single layer modified rectangular patch antenna.

2.2 Multilayered Rectangular Microstrip Antenna with Protruding Curved Edge

The modified rectangular patch antenna geometry proposed in Section 2.1 resonates at two frequencies but represents narrow bandwidth. In this section, this single layer modified rectangular patch antenna is altered by applying a thin layer of foam substrate between two dielectric layers of glass epoxy FR4 substrate. With such alteration not only the impedance bandwidth but also other parameters like gain, directivity and efficiency of the antenna are also improved. This happens because the effective dielectric constant of cavity reduces in this case, which in turn decreases the quality factor of cavity and hence the bandwidth increases.

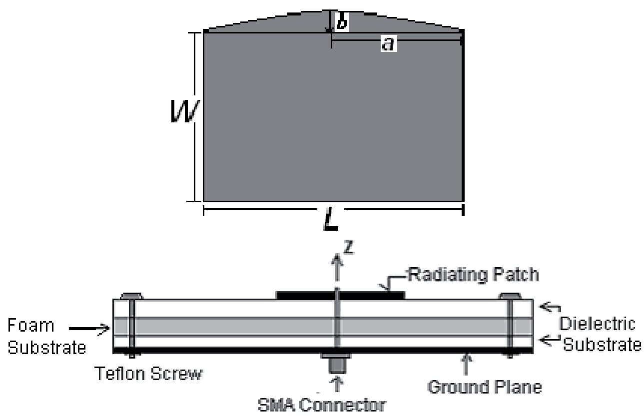

Fig. 4. Geometry of the modified rectangular patch antenna with protruded curved edge designed on multilayered structure.

This multilayer antenna has two identical layers of glass epoxy FR-4 substrates, separated by a thin foam layer having dielectric constant $\varepsilon_r = 1.057$ and loss tangent $\tan\delta = 0.0002$. The foam substrate is fixed between the two FR-4 substrates by using a high quality thin (thickness 0.05 mm) adhesive transfer tape. The top view and side view of the proposed arrangement is shown in Fig. 4 with associated feed arrangement.

2.2.1 Antenna Analysis and Parametric Study

The performance of the aforesaid antenna and the effects of various key parameters on antenna design are studied using IE3D simulation tool. Many simulations have been done by changing the parameters like height of foam substrate h_f between the substrate layers and the dimension of semi minor axis b of protruding semi ellipse, to obtain the optimum bandwidth keeping the other parameters same as considered in the previous section.

(i) Effect of Height of Foam Substrate

The first parameter to be explored using the simulation is the height of the foam substrate (layer). This parameter has a strong influence on the bandwidth. The foam substrate is sandwiched between the two dielectric substrate layers. The patch dimensions are kept constant and the height of foam substrate h_f is varied between 0.5 mm to 1.5 mm. The variations of reflection coefficient of the antenna as a function of frequency for different values of h_f are illustrated in Fig. 5. It may be noted that on increasing the height of foam substrate, it results in reduction of effective permittivity of the substrate and change in the feed reactance (increases the inductance of the feed pin).

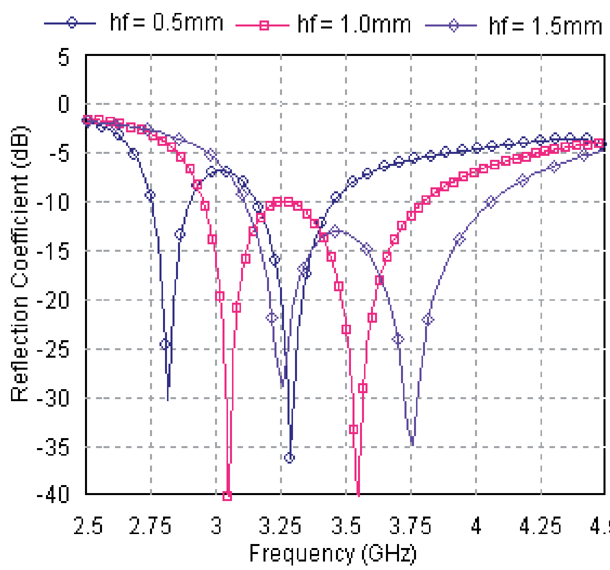

Fig. 5. Simulated reflection coefficient of the proposed antenna with different h_f values (with constant b = 3.0 mm).

From Fig. 5, it is seen that maximum bandwidth is obtained for a height of foam substrate h_f= 1.0 mm. In this case, the reflection coefficient of the antenna shows two well defined resonances at frequencies 3.09 GHz and 3.62 GHz with an impedance bandwidth of order of 0.846 GHz or (27.37 % or 23.37 %). The overall thickness of proposed structure is now 4.18 mm.

(ii) Effect of Variation in Value of Semi Minor Axis ‘b’ of Protruding Semi Ellipse

In this portion, the effect of the length of semi minor axis *b* of protruding semi ellipse parameter on the performance of the antenna is studied. The other parameters are kept constant in this investigation. The height of foam substrate in each case is taken equal to 1.0 mm. Variations in simulated reflection coefficient with frequency for different values of semi minor axis *b* of protruding semi ellipse are shown in Fig. 6. It is realized that for the optimum value $b = 3.0$ mm, the widest impedance bandwidth with stable radiation pattern is achieved. The two simulated frequencies in this case are 3.05 GHz and 3.55 GHz with impedance bandwidth close to 0.85 GHz or 26 % with respect to the central frequency 3.35 GHz.

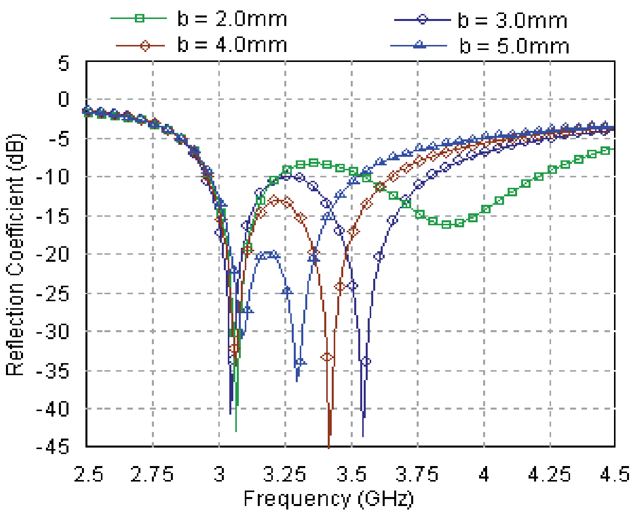

Fig. 6. Simulated reflection coefficient of the proposed antenna with different *b* values (with constant $h_f = 3.0$ mm).

The measured S_{11} variation of the designed antenna with frequency is shown in Fig. 7. The two measured frequencies of this antenna are 3.07 GHz and 3.56 GHz and impedance bandwidth is nearly 0.846 GHz or 26 % with respect to central frequency 3.31 GHz. It is realized that on applying the multi layer structure between the conducting patch and the ground plane both the resonance frequencies shifts towards higher frequency side in comparison to the single layer structure. It is because that in the presence of a foam substrate, the effective permittivity of the substrate material under the patch is reduced, which in turn has increased the resonance frequency of the antenna as the frequency is inversely proportional to the effective dielectric constant of the substrate. The obtained bandwidth is nearly ten times higher than that obtained in the previous case with single layer geometry. The measured variation of input impedance with frequency of the antenna is shown in Fig. 8. The measured input impedance value of the antenna are (49.75 – j 0.5) ohm and (54.06 + j 2.57) ohm respectively. These values of input impedance are very close to 50 ohm impedance of the feed line. A careful inspection of input impedance variation on Smith chart indicates the presence of two small loops at frequencies 3.07 GHz and 3.55 GHz which suggest the possibility of circularly polarized radiations at these frequencies. This result is checked by analyzing axial ratio variation with frequency shown in Fig. 9.

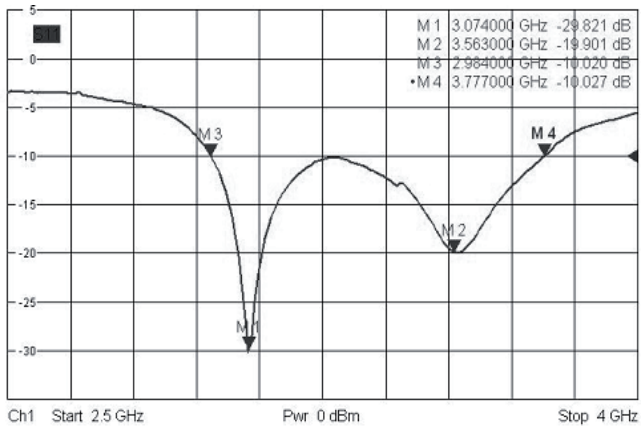

Fig. 7. Measured S_{11} variation of the multi-layered modified rectangular patch antenna with frequency.

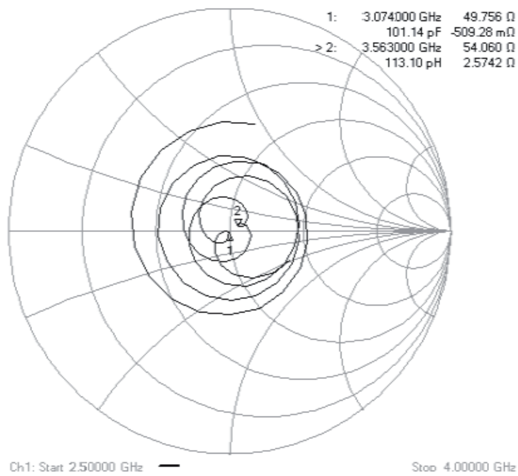

Fig. 8. Measured input impedance variation of the multi-layered modified rectangular patch antenna with frequency.

Fig. 9 depicts that axial ratio value at these frequencies 3.07 GHz and 3.55 GHz are 2.2 dB and 1.1 dB respectively. The axial ratio bandwidth at these frequencies are 1.36% & 2.21% that suggest that radiations at these frequencies are circularly polarized in nature. The simulated two dimensional radiation patterns drawn at frequencies 3.07 GHz and 3.55 GHz are shown in Fig. 10 and Fig. 11, which indicates that the antenna is providing right circularly polarized radiation at both the frequencies.

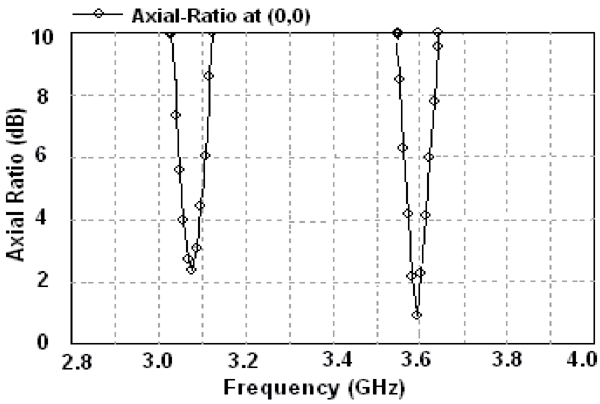

Fig. 9. Measured axial ratio variation with frequency for the multi-layered modified rectangular patch antenna.

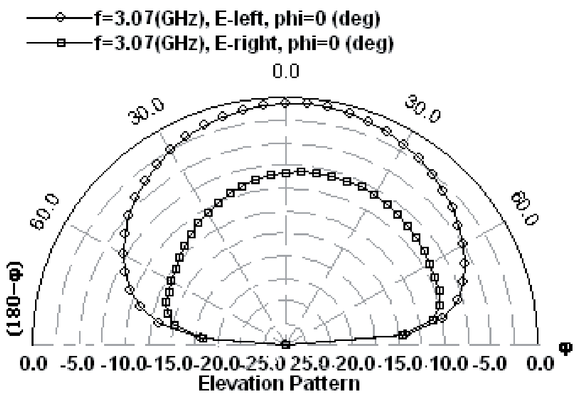

Fig. 10. E plane left and right circularly polarized patterns at 3.07 GHz for the proposed antenna.

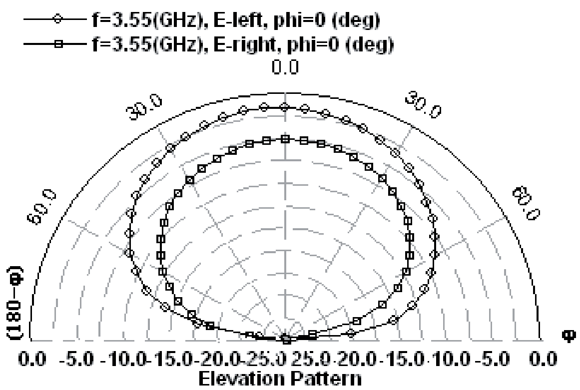

Fig. 11. E plane left and right circularly polarized patterns at 3.55 GHz for the proposed antenna.

The simulated variations of the total field directivity and gain of the proposed antenna geometry with frequency are shown in Fig. 12 and Fig. 13 respectively. It is observed that directivity and gain of the antenna increase significantly in comparison to that achieved for a single layer patch reported in the previous sections. It is perhaps due to the presence of the foam substrate, which has lowered the quality factor of the cavity. It is also observed that directivity and gain of the antenna are more or less unaffected in the entire range of frequency bandwidth. The peak value of directivity and gain are 7.81 dBi and 5.96 dBi respectively.

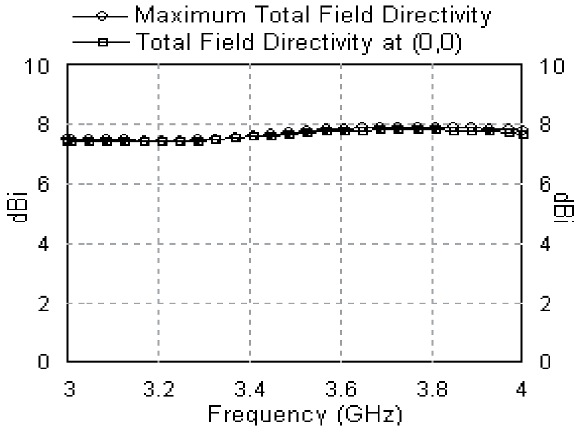

Fig. 12. Variation of the total field directivity with frequency for the proposed antenna.

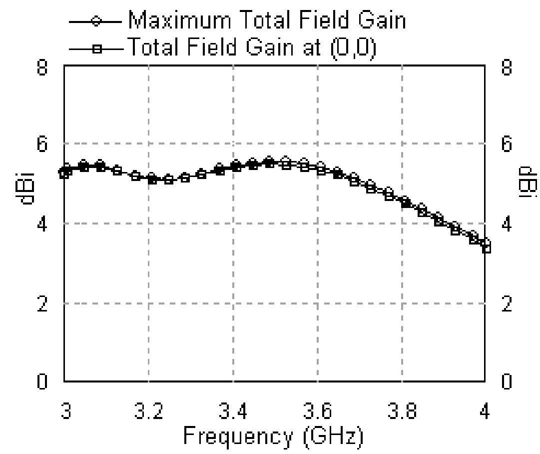

Fig. 13. Variation of the directive gain with frequency for the proposed antenna.

The simulated two dimensional radiation patterns of the antenna at two frequencies 3.07 GHz and 3.55 GHz and for two additional frequencies within the bandwidth range i.e. 2.93 GHz and 3.81 GHz are shown in Fig. 13(a)–13(d). These simulated patterns at all four frequencies have one well-defined lobe in broadside direction, i.e. normal to the plane of the radiating element and patterns are more or less identical in shape.

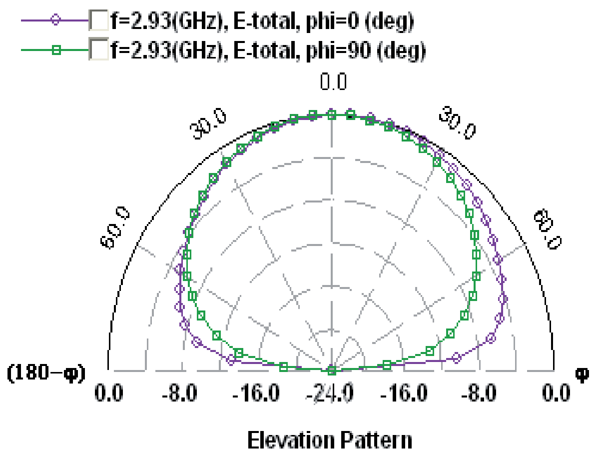

Fig. 13. (a) Two dimensional E and H plane elevation patterns at frequency 2.93 GHz.

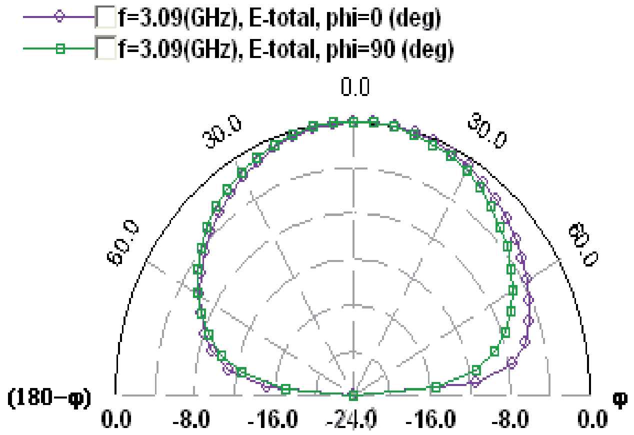

Fig. 13. (b) Two dimensional E and H plane elevation patterns at frequency 3.09 GHz.

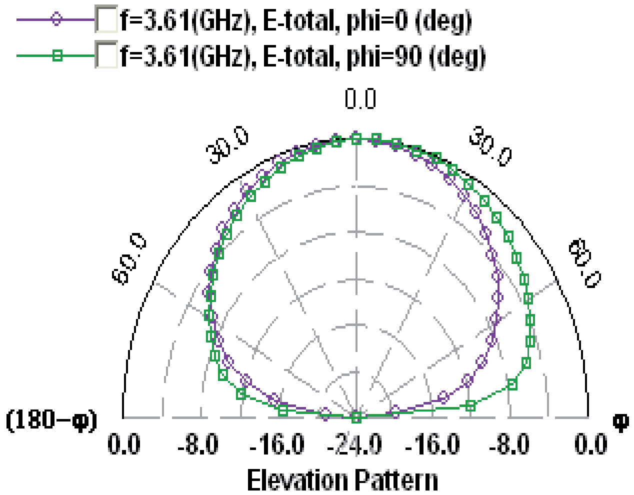

Fig. 13. (c) Two dimensional E and H plane elevation patterns at frequency 3.61 GHz.

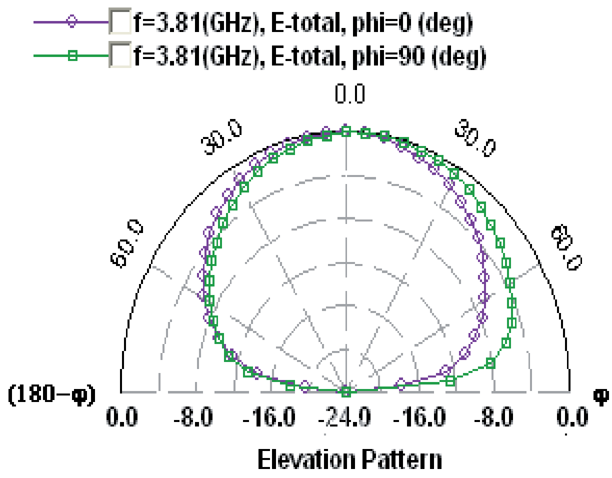

Fig. 13. (d) Two dimensional E and H plane elevation patterns at frequency 3.81 GHz.

The two-dimensional measured E plane co and cross-polar radiation patterns of the proposed antenna at two resonant frequencies 3.07 GHz and 3.55 GHz are shown in Fig. 14(a) and 14(b) respectively. It is observed that for both the frequencies, cross-polar patterns are nearly 10 dB down than the co-polar patterns. At both frequencies, the direction of maximum radiations is directed normal to the patch geometry. Such results are obtained because we have reduced the losses within the cavity. These results are necessarily required as per the definition of bandwidth which defines the frequency range over which the antenna will perform satisfactorily, i.e. its one or more characteristics (e.g., gain, pattern, terminal impedance) have acceptable values between the bandwidth limits. A comparison between the performances of the single layered and multilayered modified rectangular patch antenna is shown in Tab. 1. The table indicates clearly that the performance of the multilayered modified rectangular patch antenna has improved significantly.

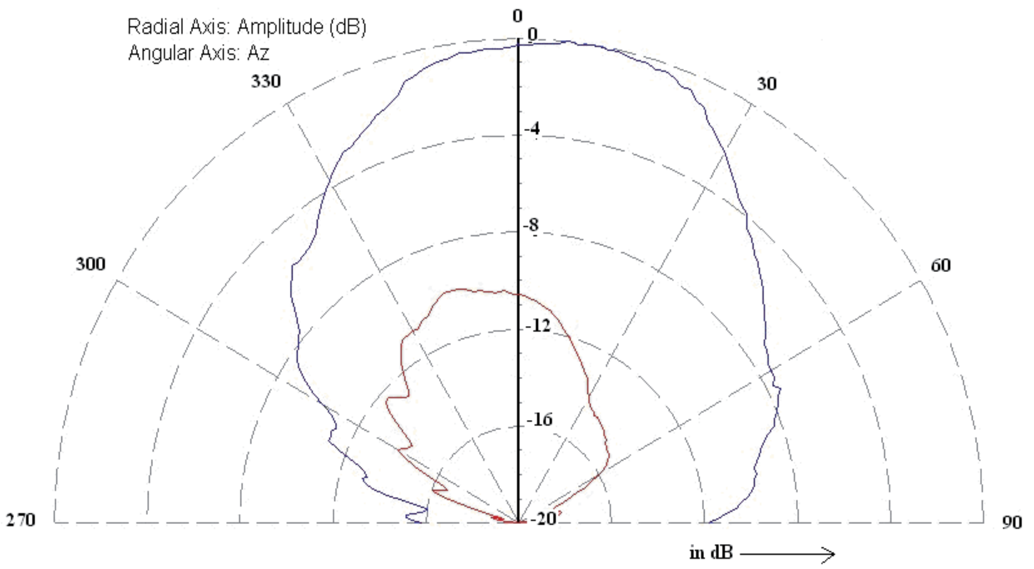

Fig. 14. (a) Measured E plane co and cross-polar radiation patterns at frequency 3.07 GHz.

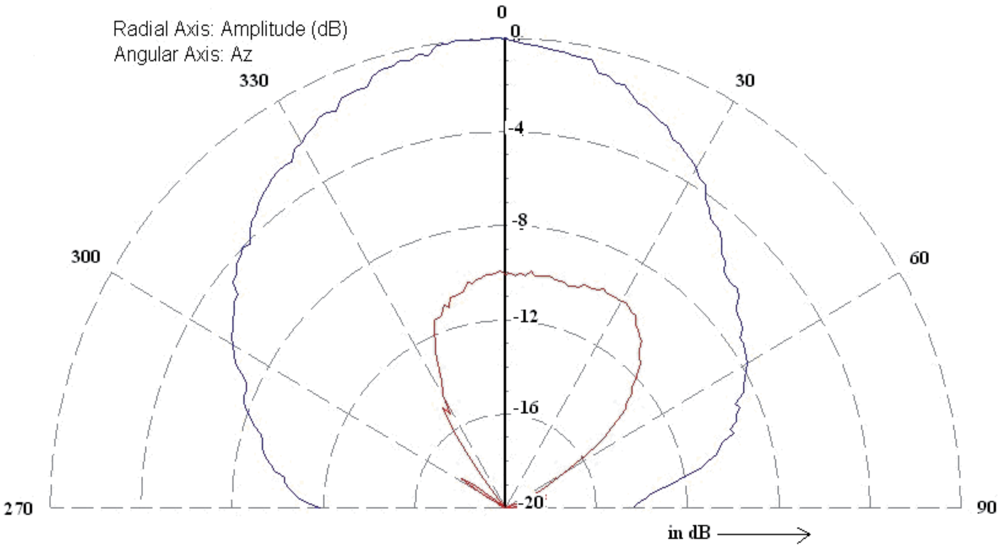

Fig. 14. (b) Measured E plane co and cross-polar radiation patterns at frequency 3.55 GHz.

Nature of geometry	Frequency (GHz)	Directivity (dBi)	Radiation Efficiency (%)	Antenna Efficiency (%)	Gain (dBi)
Single Layer Modified	2.565	6.32	30.24	30.22	1.12
Rectangular Patch Antenna	3.055	6.48	39.27	39.26	2.42
Multi Layer Modified	3.05	7.46	64.00	63.17	5.47
Rectangular Patch Antenna	3.55	7.73	63.21	60.27	5.53

Tab.1. Simulated performance for the single layered and multilayered modified rectangular microstrip patch.

3. Conclusion

A new design for a single feed, dual-band, circularly polarized patch antenna is presented. The use of a protruding curved edge on a conventional rectangular patch generated 1.36% & 2.21% CP axial ratio bandwidth in two bands respectively. Besides this, the multilayered arrangement has also facilitated impedance bandwidth broadening starting from a conventional, single patch topology. Two orthogonal modes are produced to allow circular polarization through the optimization of the dimension of protruding curve and height of foam substrate. The measured results are in well agreement with the simulated results. The proposed multilayered antenna exhibits stable far field radiation characteristics in the entire operating bandwidth with improved gain and low cross polarization. Besides featuring a simple and compact topology, the antenna is low-cost and is well suited for wireless communication applications.

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References

[1] WONG, K. L. *Compact and Broadband Microstrip Antennas*. John Wiley & Sons, 2003.

[2] ZURCHER, J. F., GARDIOL, F. E. *Broadband Patch Antennas*. Norwood: Artech House, 1995.

[3] PUES, H. F., VAN DE CAPELLE, A. R. An impedance matching technique for increasing the bandwidth of microstrip antennas. *IEEE Trans. Antennas Propagation,* 1989, vol. 37, p. 1345-1354.

[4] YANG, F., ZHANG, X. X., YE, X., RAHMAT-SAMII, Y. Wide-band E-patched patch antenna for wireless communications. *IEEE Trans. Antennas Propagation*, 2001, vol. 49, p. 1094 -1100.

[5] CHANG, E., LONG, S. A., RICHARDS, W. F. Experimental investigation of electrically thick rectangular microstrip antennas. *IEEE Trans. Antennas Propagation*, 1986, vol. 34, p. 767-772.

[6] SHARMA, V., SAXENA, V. K., SHARMA, K. B., BHATNAGAR, D. Radiation performance of circularly polarized broadband gap coupled elliptical patch antenna. *Frequenz - Journal of RF-Engineering and Telecommunications*, 2012, vol. 66, no. 3, p. 69-74.

[7] SHARMA, V., SAXENA, V. K., SHARMA, K. B., BHATNAGAR, D. Radiation performance of an elliptical patch antenna with three orthogonal sector slots. *Romanian Journal of Information Science and Tech.*, 2011, vol. 14, no. 2, p. 123 -130.

[8] SHARMA, V., SAXENA, V. K., SAINI, J. S., BHATNAGAR, D., SHARMA, K. B., JOSHI, L. M. Broadband gap coupled assembly of patches forming elliptical patch antenna. *Microwave and Optical Technology Letters,* 2011, vol. 5 no. 2, p. 340 -344.

[9] WU, C. K., WONG, K. L. Broadband microstrip antenna with directly coupled and gap-coupled parasitic patches. *Microwave Opt. Technology Letter*, 1999, vol. 22, p. 348 - 349.

[10] GONZALEZ DE AZA, M. A., ZAPATA, J., ENCINAR, J. A. Broadband cavity-backed and capacitively probe-fed microstrip patch arrays. *IEEE Transaction Antennas Propagation,* 2001, vol. 48, p. 784 -789.

[11] GUO, Y. X., MAK, C. L., LUK, K. M., LEE, K. F. Analysis and design of L-probe proximity fed patch antenna. *IEEE Trans. Antennas Propagation*, 2001, vol. 49, p. 145 -149.

[12] LIU, Y., LAU, K. L., XUE, Q., CHAN, C. H. Experimental studies of printed wide-slot antenna for wide-band applications. *IEEE Transaction on Antenna Wireless Propagation Letter,* 2004, vol. 3, p. 273 - 275.

[13] LI, P., LIANG, J., CHEN, X. Ultra-wide band elliptical slot antenna fed by tapered microstrip line with U-shaped tuning stub. *Microwave and Optical Tech. Letters,* 2005, vol. 47, p. 140 -143.

[14] SHARMA, V, SAXENA, V. K., SAINI, J. S., BHATNAGAR, D., SHARMA, K. B., PAL, D., JOSHI, L. M. Wide band dual frequency right triangular microstrip antenna with parallel narrow slits. *Microwave and Optical Technology Letter*, 2010, vol. 52, p. 1082 -1087.

[15] LEE, K. F., DAHELE, J. S. Mode characteristics of annular-ring and circular disc microstrip antenna with and without air gaps. *IEEE Antenna Propagation. SOC. Int. Sum. Digest*, 1983, p. 55 to 58.

[16] LIAO, W., CHU, Q.X. Dual-band circularly polarized microstrip antenna with small frequency ratio. *Progress In Electromagnetics Research Letters*, 2010, vol. 15, p. 145-152.

[17] NAYERI, P., LEE, K. F., ELSHERBENI, A. Z., YANG, F., Dual-band circularly polarized antennas using stacked patches with asymmetric U-slots. *IEEE Transaction on Antennas and Wireless Propagation Letters*, 2011, vol. 10, p. 285-288.

[18] HEIDARI, A. A., HEYRANI, M., NAKHKASH, M. A dual-band circularly polarized stub loaded microstrip patch antenna for GPS applications. *Progress In Electromagnetics Research*, 2009, vol. 92, p. 195–208.

[19] ZAKARIA, N., RAHIM, S. K. A., OOI, T. S., TAN, K. G., REZA, A. W., RANI, M. S. A. Design of stacked microstrip dual-band circular polarized antenna. *Radioengineering*, 2012, vol. 21, p. 875-880.

[20] NOGHABAEI, S. M., RAHIM, S. K. A., SOH, P. J., ABEDIAN, M., VANDENBOSCH, G. A. E. A dual-band circularly-polarized patch antenna with a novel asymmetric slot for WiMAX application. *Radioengineering*, 2013, vol. 22, no. 1, p. 291–295.

[21] BALANIS, C. A. *Antenna Theory*. 2nd edition. John Wiley&Sons, 1997.

[22] IE3D Software, Release 8, *Zeland Software*, Inc., Freemont, USA.

[23] CARVER, K. R. Practical analytical techniques for the microstrip antenna. In *Proc. Workshop Printed Circuit Antenna Tech*.. New Mexico State University, Las Cruces, 1979, p.7.

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