Design of circularly polarized edge truncated elliptical patch antenna with improved performance

Pratibha Sekra, Sumita Shekhawat, Manoj Dubey, D Bhatnagar, V K Saxena & J S Saini
Microwave Laboratory, Department of Physics, University of Rajasthan, Jaipur 30 2004
E-mail: dbhatnagar_2000@rediffmail.com

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The performance of a circularly polarized edge truncated elliptical patch microstrip antenna has been investigated experimentally in free space and has been compared with the performance of a conventional elliptical patch antenna. Extensive optimizations in feed locations and in edge lengths along major and minor axes of conventional elliptical patch antenna have been carried out to achieve best performance from modified elliptical patch geometry. In addition to circular polarization, proposed antenna presents impedance bandwidth close to 180 MHz or 6.54%. With proposed feed arrangement, right circular polarization with axial ratio 0.9 dB at frequency 2.751 GHz is realized and axial ratio bandwidth close to 2.17% has been achieved. The gain of proposed antenna is lower than desired value for modern communication systems. In entire bandwidth, the radiation patterns are identical in shape.

Keywords: Elliptical patch antenna, Circularly polarized antenna, Microstrip antenna
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1 Introduction

In modern communication systems, like cellular phones, personal computer cards for wireless local area networks (WLAN), microstrip antennas are more preferred than any other radiator. The reason for application of these antennas is their low cost, light weight, low profile and easy integration with circuit components of portable personal equipments. However, the limitations, like narrow bandwidth, poor gain, low power handling capacity and low radiation efficiency associated with conventional patch antennas cannot be ignored. Among the conventional patch geometries, microstrip antennas with rectangular, circular or triangular shapes are extensively analyzed. Other regular shapes of patch geometries are rarely touched upon perhaps due to involvement of difficult mathematical modeling and boundary conditions in their analysis. For example, elliptical patch geometry cannot become popular perhaps due to involvement of elliptical coordinate systems and application of Mathieu function in theoretical analysis. However, owing to the advantage of having smaller patch size at a given frequency, as compared to rectangular and circular patch antennas, several papers on elliptical patch antennas have been published. Microstrip antennas, in their conventional form, have narrow bandwidth and operate efficiently at a single resonance corresponding to their dominant mode. Considering demand of compact size antennas for modern communication systems, antenna designers in recent times have focused their efforts more towards fulfilling the higher bandwidth requirements without affecting their compactness. Wong et al. obtained a compact circular microstrip antenna with a patch size of less than 10% of the conventional circular patch antenna by using a shorting pin along with meandering of circular patch. Hsu & Wong designed a circular patch antenna on a thick air substrate with a pair of wide slits with an impedance bandwidth greater than 25% and a peak antenna gain about 8.3 dBi. Krishna et al. reported the improved bandwidth design of a compact dual band slot loaded circular microstrip antenna with a superstrate applicable for major wireless communication bands. Bao & Ammann proposed the design of a compact circularly polarized wideband circular patch antenna embedded in a narrow annular ring which uses an unequal cross-slotted ground plane. A novel design to achieve dual circularly polarization, wide impedance bandwidth and high isolation level is proposed by Wu et al., where patch
contains cross slots and is fed by two L-strips. Ray & Thomas\textsuperscript{13} presented the design and performance of a proximity coupled microstrip patch antenna where the radiating patch is loaded by a V-slot. This circularly polarized broadband microstrip patch antenna is suitable for WLAN application. In this paper, an edge truncated elliptical patch microstrip antenna has been analyzed in free space and its performance has been compared with that of a conventional elliptical patch antenna. Through variation in edge lengths and feed location on patch, antenna performance has been optimized to obtain improved bandwidth and circularly polarized radiations.

2 Antenna structure and Discussion

2.1 Conventional elliptical patch antenna

In this study, first a conventional elliptical patch microstrip antenna, of semi-major and semi-minor axes of length \(a\) and \(b\), respectively, has been considered. The patch is considered lying in XY plane over a large ground plane with substrate thickness \((h \ll \lambda_0)\), substrate dielectric constant \((\varepsilon_r)\) and relative permeability \((\mu_r = 1)\) as shown in Fig. (1a). The fabricated structure for experimentation is shown in Fig. 1(b). The magnetic field in such structure has essentially x and y components. Because \(h \ll \lambda_0\), the fields do not vary along the z-direction and the component of the current normal to the edge of the microstrip antenna approaches to zero at the edges. With these assumptions, this elliptical structure can be considered as a cylindrical resonator with magnetic sidewalls, bounded at its top and bottom by electric walls. In the designed structure, length of semi-major and semi-minor axes are \(a = 15\) mm, \(b = 14.43\) mm, respectively with eccentricity \(e = 0.962\). The structure has been designed on glass epoxy FR4 substrate having substrate thickness \(h = 1.59\) mm, substrate relative permittivity \(\varepsilon_r = 4.4\) and loss tangent \(\tan \delta = 0.025\). The simulation analysis has been carried out by applying IE3D simulation software\textsuperscript{14} while experimental work has been carried out at ISAC, Bangalore by using the available facilities.

The simulation analysis reveals that in the range of 2-4 GHz, antenna resonates at a single resonance frequency 2.760 GHz corresponding to its dominant mode as shown in Fig. 2. The measured resonance frequency of this antenna as shown in same figure is 2.776 GHz, which is in close agreement with the simulated frequency. The impedance bandwidth corresponding to 10 dB return loss is 55 MHz or close to 2\% with respect to resonance frequency. This bandwidth is narrow and not much suitable for modern communication systems. The simulated input impedance of antenna at frequency 2.760 GHz is \((48.72 + j 4.21)\) ohm while the measured input impedance of antenna as shown in Fig. 3 is

![Fig. 1(a) — Geometry and feed arrangement of conventional elliptical patch antenna](image)

![Fig. 1(b) — Top view of designed elliptical patch antenna](image)

![Fig. 2 — Simulated and measured reflection coefficients of elliptical patch antenna](image)
The purity of circular polarization can be seen from the Smith chart, where the variation of input impedance must have a small loop. If the two degenerated modes, necessary for obtaining circular polarization, are very close to each other, then the loop area becomes zero as may be seen in Fig. 4. The central frequency of the antenna for circular polarization is 2.788 GHz and gives a 3 dB axial ratio bandwidth close to 1.12% with minimum axial ratio of 0.51 dB. The simulated input impedance presented by antenna at this frequency is (43.96 – j6.98) ohm, which is in better agreement with measured value of input impedance. The radiation patterns under two polarization conditions at frequency 2.788 GHz are shown in Fig. 4(a), which suggests that the radiations are right circularly polarized (RHCP) in nature. The simulated E and H plane radiation patterns of antenna at resonance frequency 2.77 GHz are shown in Fig. 4(b) while co-polar and cross-polar patterns at resonance frequency are shown in Fig. 4(c). These patterns suggest that the direction
of maximum radiations is normal to patch geometry and patterns are systematical in nature. The co-polar patterns are 2 dB higher than cross-polar patterns. The variation in simulated gain of antenna as a function of frequency is shown in Fig. 5, which suggests that gain of antenna is low (1.98 dB). Though radiations from antenna are circularly polarized in nature but due to narrow bandwidth and low gain, application of this antenna in its present form is not possible in modern communication systems. Therefore, this antenna is modified by truncating edges of patch geometry.

2.2 Edge truncated elliptical patch antenna

The elliptical patch considered above has been modified by applying edge truncation in the patch geometry parallel to major axis of elliptical patch as shown in Fig. 6(a). The lengths of semi-major axis $a$ and semi-minor axis $b$ of elliptical patch without any truncation are 15 mm and 14.43 mm, respectively. The antenna has been again designed on glass epoxy FR-4 substrate ($\varepsilon_r = 4.37$, $\tan\delta = 0.025$, substrate thickness $h = 0.158$ cm) and has been tested in free space by applying single inset feed arrangement by using SMA connector as shown in Fig. 6(b). Using IE3D simulation software, extensive optimizations in edge lengths $L_1$ and $L_2$ have been done and finally on making edge lengths $L_1 = L_2 = 7.75$ mm, best performance with this antenna has been achieved. The two equal truncated edges lie parallel to major axis of elliptical patch antenna as shown in Fig. 6(a) by dotted lines.

The simulation analysis of this patch geometry reveals that in the frequency range 2 - 4 GHz, this modified antenna resonates at two closely spaced frequencies 2.71 and 2.80 GHz, which are in very close agreement with measured resonance frequencies 2.692 and 2.802 GHz shown in Fig. 7(a). The impedance bandwidth presented by antenna is 180 MHz or 6.54 %. The measured input impedances at two resonance frequencies are $(62.30 + j 11.71)$ ohm and $(48.49 + j 5.34)$ ohm, respectively as shown in Fig. 7(b). Smith chart presents a small loop in the input impedance variation with frequency which suggests that circular polarization may still be realised with the modified geometry. However, purity of polarization is reduced marginally as the size of loop is more than that has been realised with conventional elliptical patch antenna. The simulated variation of axial ratio with frequency is shown in Fig. 8(a), which indicates that axial ratio has minimum value of 0.86 dB at 2.751 GHz, which is considered as central frequency. A comparison of simulated and measured axial ratios with frequency is shown in Fig. 8(b) presents good agreement between the two results. The measured axial ratio bandwidth close to 60 MHz or 2.17% with respect to central frequency 2.751 GHz has been achieved, which is higher than the one achieved for conventional elliptical patch antenna. The radiation...
Fig. 7(a) — Measured reflection coefficients of modified elliptical patch antenna

Fig. 7(b) — Measured input impedance of modified elliptical patch antenna

Fig. 8(a) — Simulated variation of axial ratio with frequency

Fig. 8(b) — Measured and simulated axial ratio of modified elliptical patch antenna

Fig. 9 — Simulated elevation pattern of elliptical patch antenna under two polarization conditions

Fig. 10 — Measured and simulated gain of modified elliptical patch antenna
patterns at central frequency for the two circular polarization conditions are shown in Fig. 9, which indicates the presence of good right circularly polarised radiations. With proposed modifications, the central frequency of modified elliptical patch antenna is marginally reduced (1.3%) in comparison to the conventional elliptical patch antenna which suggests marginal size reduction in patch geometry.

The simulated variation of gain of antenna with frequency is shown in Fig. 10, which indicates that at central frequency 2.751 GHz, the gain is close to 1.71 dB which is marginally lower than that of a conventional elliptical patch antenna. Marginal lowering of central frequency applies minor reduction in effective antenna size at a fixed circular polarization (CP) operation, which in turn reduces the CP bandwidth and antenna gain. The variations in simulated and measured gain values of proposed antenna as a function of frequency are in good agreement. The measured E-plane radiation patterns of antenna at two resonance frequencies 2.69 and 2.80 GHz are shown in Figs 11(a) and 11(b), respectively. These patterns suggest that the direction of maximum radiations is normal to patch geometry and patterns are symmetric in nature.

3 Results and Conclusions

This paper presents the radiation performance of a circularly polarized edge truncated elliptical patch antenna in free space. The performance of proposed antenna has been compared with a conventional elliptical patch antenna through simulated and measured results. The simulated and measured results indicate that proposed antenna resonates at two closely spaced frequencies and provides improved impedance bandwidth (6.54%) than a conventional elliptical patch antenna (2%). Antenna provides right circularly polarized radiations in far-field and presents much improved axial ratio bandwidth that can be achieved with conventional elliptical patch antenna. The gain of antenna is marginally reduced due to effective reduction in antenna size. The gain enhancement for the proposed geometry may be achieved through superstrate loading suggested by Huang et al. Similarly, for further enhancement of bandwidth, electrically thick dielectric substrate with lower permittivity and loss tangent may be applied. The direction of maximum radiations in each case is normal to patch geometry and radiation patterns are symmetric in nature.

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