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Circularly Polarized Square Patch Microstrip Antenna with Y- Shaped Slot for Wi-Max Application

Sumita Shekhawat[1] and Vijay Sharma[2]

[1]Department of Physics, JK Lakshmipat University, Jaipur- 302026
[2]Department of Physics, Govt. Mahila Engineering College, Ajmer -305002
phyvijay@gmail.com

ABSTRACT

A compact design of a circularly-polarized (CP) antenna to achieve wide-band behavior for Wi- Max applications is presented. Single feed is used to excite a single-layered square patch integrated with a novel Y-shaped slot and two different truncated corners to achieve CP polarization. Besides its structural simplicity, ease of fabrication and low cost, the proposed antenna features a satisfactory impedance bandwidth of value 5.76 % in the lower frequency band of Wi-Max application (2.3GHz - 2.4GHz) and also exhibits axial ratio bandwidth 1.71%.The measured radiation pattern of the proposed antenna demonstrates directional patterns in both E- and H-planes. The simulated results are well in agreement with measured results.

Key words: Microstrip patch antenna, circular polarization, axial ratio, wi-max, gain

INTRODUCTION

In modern wireless communication systems patch antenna is playing a very important role for wireless service requirements due to its characteristics such as small size, light weight, low profile and low cost. Wireless local area network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX) have been widely applied in mobile devices such as handheld computers and intelligent phones. These two techniques have been widely recognized as a viable, cost-effective, and high-speed data connectivity solution, enabling user mobility. In practice, IEEE 802.11 standard covers the WiMAX frequency for the lower band of 2.3-2.4 GHz, for median band and upper band 3.5-GHz (3.3–3.6 GHz) and 5.5-GHz (5.25–5.85 GHz) frequency bands [1]. 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 obtained two degenerated orthogonal modes with different resonant frequencies and there is a phase difference of 90° between two orthogonal modes. 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. Circular polarization (CP) operation may be obtained by certain modifications to the basic antenna either in geometry and/or feed [2].

Various single- and dual-band CP patch antennas have been investigated and reported in literature. Such as in [3], a single-feed square patch was truncated at its corners to obtain CP, which typically results in narrow axial-ratio bandwidths. This design involves four slits incorporated into a square patch for circular polarization at 2.2 GHz with an axial ratio bandwidth of about 1.62 %. In [4], another truncated-corner antenna with the aid of several slits produced CP and an axial ratio bandwidth of around 1.45 % at 2.45 GHz has achieved by researchers. This structure offers a size reduction of about 36 % compared to conventional truncated corner CP antenna designs.
In recent time our group has designed and discussed many CP antennas with various shapes for practical use in Wi- Max and other applications in open literature [5 -11]. In [5], a dual band circularly polarized single-feed modified rectangular microstrip antenna having one protruded curved edge for wireless communication systems is

proposed. 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. In [6], a wideband gap coupled assembly of rectangular microstrip patches applicable in lower and upper band of Wi-Max applications utilizing six directly and parasitically coupled patches is discussed. The proposed antenna is designed to function in the lower band (2.4-2.69 GHz) and upper band (5.25-5.85 GHz) of Wi-Max systems. In [7] the design and performance of a modified semi elliptical microstrip patch antenna is proposed to achieve circularly polarized broadband performance. The proposed structure consists of a semi-elliptical patch having a D-shaped slot designed on three layered substrate material. In [8], the design and performance of a novel single-layer assembly of gap coupled elements in elliptical shape is proposed to achieve broadband performance with circular polarization. In [9] the radiation performance of broadband circularly polarized gap-coupled arrangement of rectangular patches is reported which consists of three rectangular patches having separation between them. The central designed patch is excited through a single inset feed point while the other two patches are gap coupled to the central patch. The antenna provides nearly 12% impedance bandwidth with circularly polarized radiation. In [10], the design of a compact multi-band elliptical patch antenna with a narrow sector slot multi-band operation is discussed. The measured results shows that antenna is capable in resonating at frequencies 2.66 GHz, 3.86 GHz and 5.46 GHz at atime enabling its possible application in Wi-MAX communication systems in all three bands. In [11], the design and analysis of a single feed stacked square patch using tuning stubs is proposed which is capable in providing circular polarization along with broadband performance. The axial ratio obtained at two frequencies 2.3GHz and 2.66GHz are 1.61dBi and 0.45dBi. In [12], a novel dual-frequency broadband design of a single-layer single-feed circular microstrip antenna with an off-centered Y-slot is demonstrated by selecting an appropriate location of the Y-slot in the circle.

In other research articles such as in [13], 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 [14] 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. In [15] 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 two 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 paper, the investigation is done on a single-layer single feed corner truncated square patch antenna, having a narrow Y-slot. In first step the square radiating patch is truncated at two corners (diagonally) and thereafter in second step two rectangular slots which are perpendicular to each other are cut at the center of the patch. These two rectangular slots appears like Y, therefore we call it Y-Slot. The proposed antenna is fed by using coaxial probe feed. The simulated reflection coefficient, gain, and axial ratio bandwidth are compared with measured results. Results show that the proposed antenna has very small size, wide bandwidth, moderate gain and very good axial ratio bandwidth in comparison to conventional patch antenna of same size.

ANTENNA DESIGN AND PARAMATRIC ANALYSIS

In first step a conventional square patch antenna (without any slot / modification) is analyzed with a ground plane size of 50× 60 mm^2. The glass epoxy FR4 substrate having relative permittivity, $\varepsilon_r = 4.4$, loss tangent, $\tan\delta = 0.025$ and height h =1.59 mm is used, with a fully-metalized reverse side as its ground. The size of square patch is 30 ×30 mm^2. The antenna is fed through simple coaxial probe feed enable to match with 50Ω input impedance. The resonant frequency of a square microstrip patch can be calculated by equation [1] –

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

Since it does not account for fringing, it must be modified to include edge effects. The simulated resonance frequency corresponding to dominant mode (TE10 mode) of conventional square patch antenna is 2.33GHz, which matches with the calculated frequency. The impedance bandwidth of this antenna is ~2.53% with a peak gain 1.22dBi. This antenna is linearly polarized having 40 dB minimum value of axial ratio. These antenna parameter values are much lower than the desired values for practical use of antenna in modern communication systems.

This square patch antenna is therefore modified by the conventional technique of edge-truncation at the two corners of resonator patch with a Y-shaped slot consist of two perpendicular slots at the centre gives a good CP bandwidth as shown in fig.1. Once integrated onto the square patch, two orthogonal modes with a quadrature phase for CP generation are enabled. Extensive parametric analysis is carried out with modified conventional square patch antenna by varying dimension of truncation at the two corners, length (L) and width (W) of two perpendicular slots at the centre of patch using IE3D simulation software [11], the results obtained are presented below. An antenna with axial ratio smaller than 3dB may be considered as antenna. Therefore in order to check whether our antenna is circularly polarized or not; we have studied the simulated axial ratio variation with frequency for each variation.

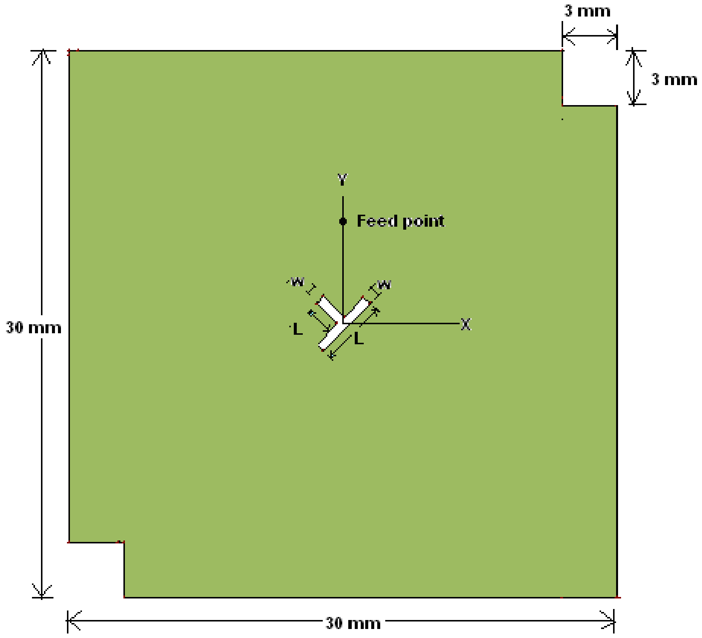

Fig 1 Geometry of proposed antenna

Effect of Truncation

On applying truncation of appropriate dimension at the two opposite sides of a conventional square antenna it gives circular polarized radiation along with improved impedance bandwidth. First of all truncation area is optimized. The variation of axial ratio value with frequency for different truncation area is plotted in fig.2. From fig. 2 it can also be concluded that on making truncation area 3mm x 3mm maximum axial ratio bandwidth (1.251%) with minimum axial ratio value (0.47dB) is obtained. On decreasing or increasing truncation size further; axial ratio increases again. It is observed from simulations that creating truncation of corners facilitates the lowering of the axial ratio. Moreover, the corners are also utilized to reverse the negative effect of the parasitic slots on the axial ratio.

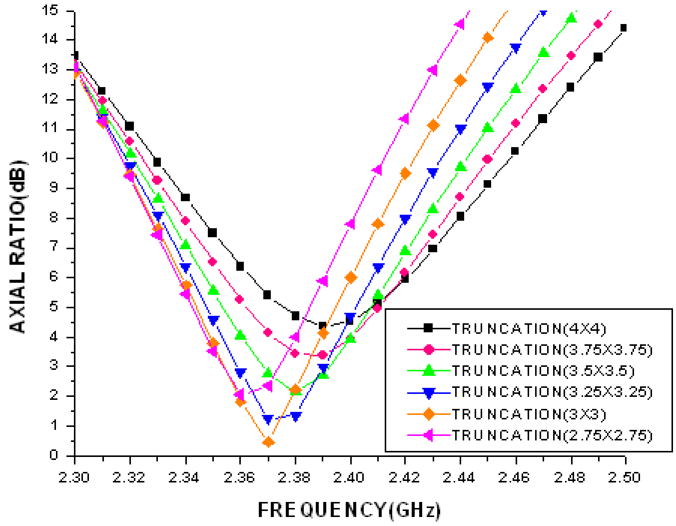

Fig 2 Variation of axial ratio with frequency for different truncation area

Effect of Slot Dimensions (Length & Width)

For pure circular polarization the value of axial ratio should be 0 dB therefore we have further modified this truncated square patch by inserting a rectangular slot along the diagonal, maintaining the symmetry of geometry so that same geometry may be used to achieve right hand circular polarization and left hand circular polarization. The variation of axial ratio bandwidth and minimum value of axial ratio with length and width of slot is shown in fig. 3

and fig.4 respectively. It is observed from figures that applying a narrow slot of dimensions length L = 3.2mm and W=0.5mm inclined at 450 to horizontal axis, a maximum axial ratio bandwidth with minimum value of axial ratio may be achieved. The minimum axial ratio in this condition is close to 0.453 while the axial ratio bandwidth with respect to central frequency 2.36GHz is close to 1.322%.

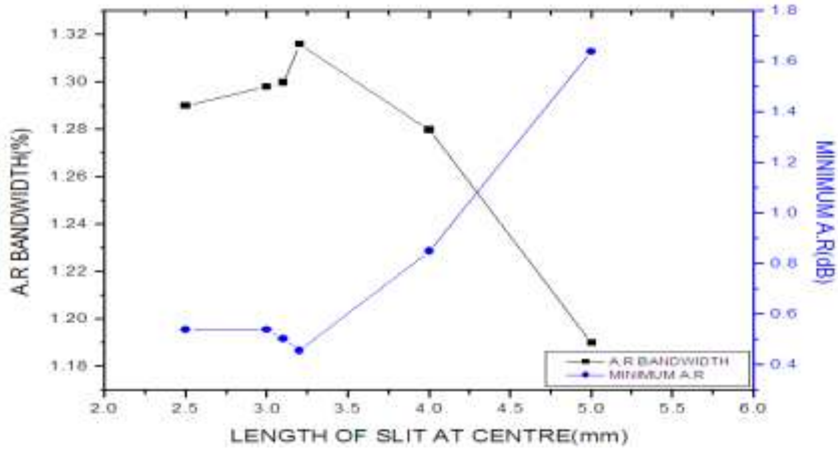

Fig 3 Variation of A.R bandwidth and minimum A.R with length of slit

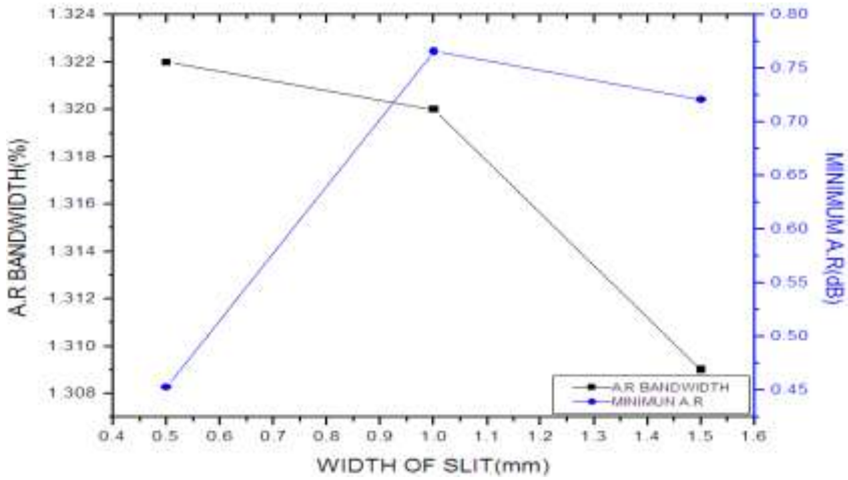

Fig 4 Variation of A.R bandwidth and minimum A.R with width of slit

The purity of polarization is further tried to improve by inserting another narrow rectangular slit of width (W=0.5mm) and length (L/2=1.6mm) perpendicular to first slit of width (W) and length (L), which looks like Y-shaped slit. This second slit is inclined at an angle 1350 with respect to horizontal x-axis. From fig.5 it is observed that on inserting two slits at the centre, axial ratio is minimum having a value 0.08 dB which is comparable to 0dB, without any compromise with axial ratio band width. After doing all these optimization a prototype has fabricated with following dimensions as shown in fig. 6.

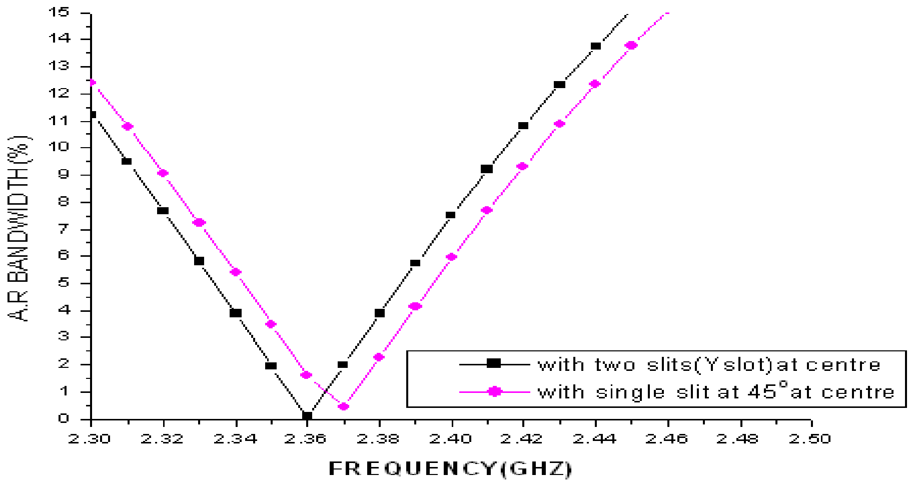

Fig 5 Variation of A.R bandwidth with frequency for two cases

Fig. 6 Geometry of modified corner truncated square patch antenna

RESULTS AND DISCUSSION

For the measurement propose, this corner truncated square patch with Y-slot is fed through coaxial probe feed using SMA connector. The reflection coefficient and input impedance are measured by using Vector Network Analyzer and radiation patterns are measured in anechoic chamber. Fig. 7 & 8 depicts the variation of simulated and measured reflection coefficient of corner truncated square patch with Y-slot in the frequency range 2.2-2.6 GHz. These results suggest that simulated resonance frequencies for proposed antenna are 2.339GHz and 2.379GHz whereas the measured resonance frequencies are 2.316GHz and 2.387. The simulated impedance bandwidth of this modified antenna is 130 MHz while measured impedance bandwidth of antenna is 136MHz. The measured results suggest that the presence of Y-shaped slot has improved the impedance bandwidth of antenna marginally.

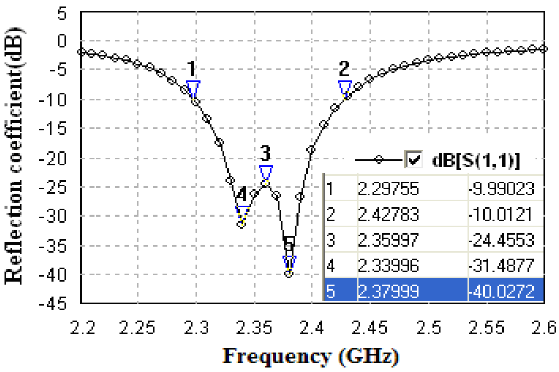

Fig. 7 Variation of reflection coefficient of modified square patch antenna with frequency

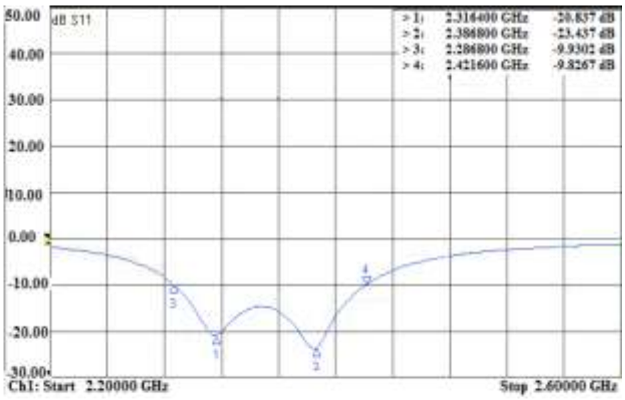

Fig. 8 Variation of measured reflection coefficient of modified square patch antenna with frequency

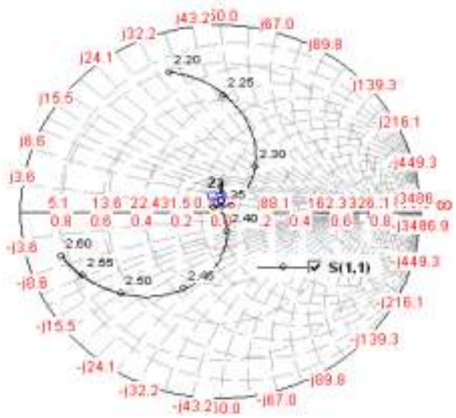

Fig. 9: Variation of simulated input impedance of modified square patch antenna with frequency

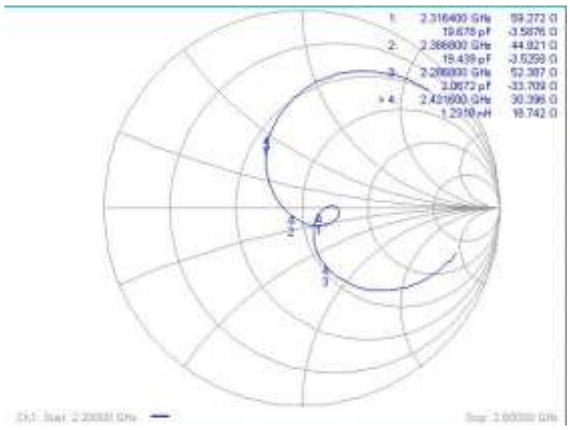

Fig. 10: Variation of measured input impedance of modified square patch antenna with frequency

The variation of simulated and measured input impedance of modified antenna with frequency is shown in fig. 9 and 10 respectively. The input impedance curve in both the cases depicts the presence of a sharp notch in desired range of frequency, which indicates the presence of circularly polarized radiations. The purity of circular polarization demands presence of input impedance variation with frequency. If the two degenerate modes which are necessary for obtaining circular polarization are very close to each other then the loop area becomes zero and presents a sharp notch. In simulated result sharp dip is observed at frequency 2.36GHz whereas in measured result it is at 2.35GHz which is well in agreement.

The main target behind designing of this structure was to achieve circular polarization in addition to improvement in impedance bandwidth of antenna. By optimizing the dimension of corner truncation and inserted Y-slot, both these targets were achieved. The comparison of measured and simulated axial ratio of prototype antenna is shown in fig. 11 which shows a slight variation in measured axial ratio band width (1.71%) and the simulated axial ratio bandwidth (1.32%), which is perhaps due to measurement errors. Both impedance bandwidth (5.76%) and axial bandwidth (1.71%) are improved in comparison to that at of a conventional square patch antenna fed under similar conditions. The variation of simulated and measured gain value of antenna as a function of frequency is shown in fig. 12, which indicates that gain of antenna is less than 2dBi which is nearly the same achieved with a conventional square patch antenna. No variation in gain of antenna in the entire bandwidth range is realized.

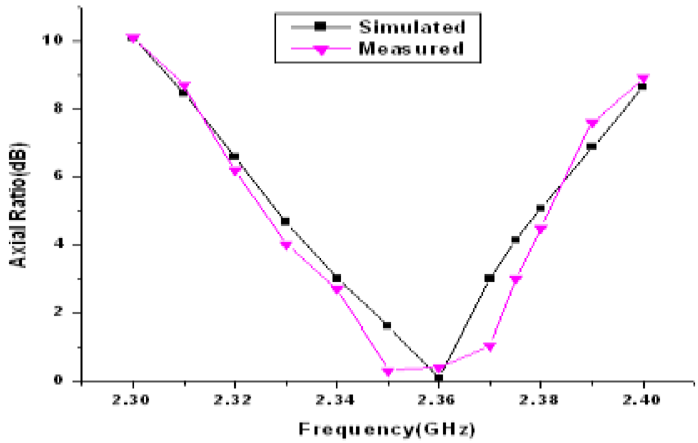

Fig. 11 Variation of simulated and measured axial ratio of modified square patch antenna with frequency

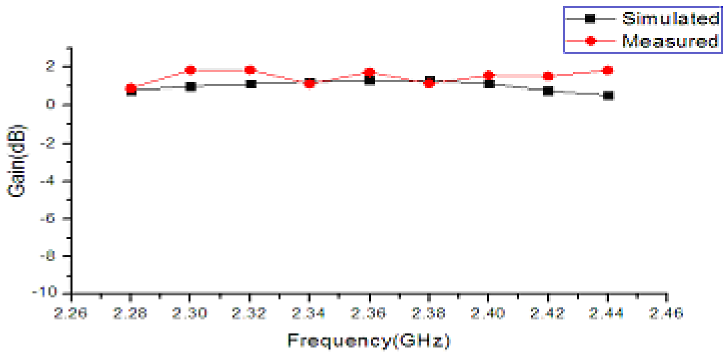

Fig. 12 Variation of measured and simulated gain of modified square patch versus frequency

The two dimensional measured E-plane co and cross polarization radiation patterns of proposed antenna at two frequencies 2.31GHz and 2.38GHz (corresponding to -10dB scale) are shown in fig. 13 and 14 respectively. At frequency 2.31GHz, the co polar patterns in E plane are nearly 14 dB higher than cross polar patterns while at frequency 2.38GHz, the co polar patterns in E plane are nearly 12 dB higher than cross polar patterns. The direction of maximum radiation intensity is normal to the patch geometry. The radiation patterns of modified antennas are identical in shape and nature in the entire bandwidth range. The simulated 3dB beam width at frequency 2.38 is nearly 100^0 while at frequency 2.31GHz it is only 60^0. An overall comparison in the performance of proposed modified square patch antenna with conventional square patch antenna is reported in Table 1.

Table - 1 Comparison between the Radiation Performances of Simple Square Patch, Truncated Square Patch and Truncated Square Patch Antenna with Y-slot

Antenna Geometries	Resonance Frequency (GHz)	Impedance Bandwidth (%)	Min A.R Value (dB)	A.R Bandwidth (%)
Simple Square patch	2.33	2.1	40	0
Truncated Square Patch	2.349	5.24	0.478	1.251
Truncated Square With Y- slot	2.316, 2.386	5.76	0.092	1.71

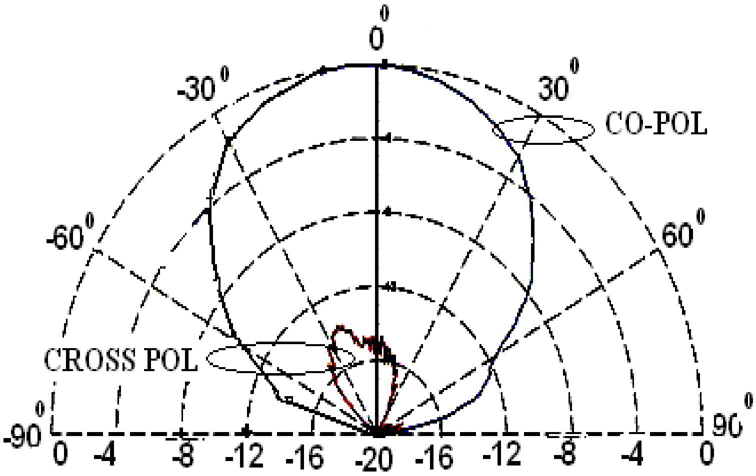

Fig. 13 Measured E-plane radiation pattern for proposed antenna at frequency 2.31GHz

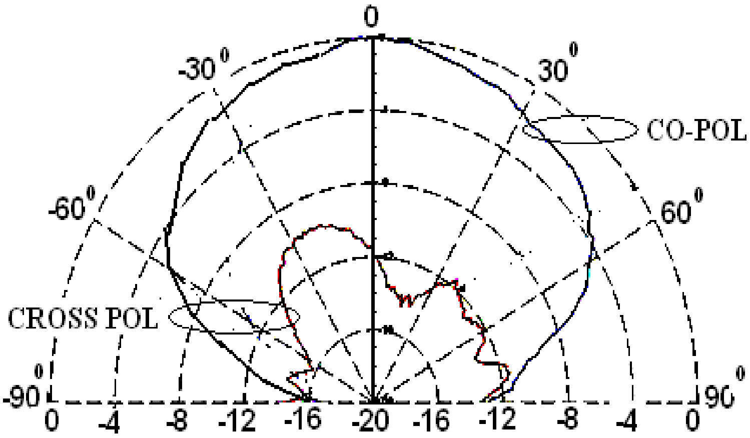

Fig. 14 Measured E-plane radiation pattern for proposed antenna at frequency 2.38 GHz

CONCLUSION

The proposed analysis suggests that by applying appropriate truncations and narrow Y-shaped slot in square patch antenna, both impedance and axial bandwidths of antenna are improved without losing compactness of the patch geometry. After truncation, patch area is marginally reduced but the performance of antenna is significantly improved. On applying Y-shaped slot at the centre of truncated square the quality of circular polarization is highly improved. The radiation patterns in entire bandwidth are identical in nature and the direction of maximum radiations in entire bandwidth is directed normal to the patch geometry. The present antenna proved applicable for Wi-Max application (2.3GHz-2.4 GHz).The performance of antenna in terms of gain and efficiency can be improved further by applying better substrate material.

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