Triangular Patch Antenna with Asymmetric V-Slots for Tri-band Wireless Applications

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Abstract — Single probe feed triangular patch antenna with asymmetric dual V-shaped slots is designed, fabricated and tested for tri-band applications. The unequal length arms of inner and outer V-slots gives provision to achieve two degenerate orthogonal modes, which lead to circular polarization (CP) at lower and middle bands respectively. The antenna resonates at frequencies of 2.4GHz, 3.5GHz with CP and 5.28GHz with linear polarization (LP). Good agreement obtained between simulated and measured results.

Index Terms — Circular Polarization, Slots, Tri band, Impedance bandwidth, Axial Ratio bandwidth, Triangular patch.

I. Introduction

Mobile handsets and wireless communication devices have been demanding the constraints of small, light weight and multi-band operation. These demands are achieved by the development of tri band low profile antennas with superior performance [1-3]. Triangular shaped patch antennas are found suitable in applications such as dual band, multiband antennas [4-6] and broad band antennas [7-9]. Elsadek [10] investigated slit based triangular patch which is linear polarized at tri bands with high average gain. Related work of circularly polarized antennas with dual band is discussed in [11-13]. Among the regular shaped microstrip patch antennas, the triangular geometry drew attention in investigating the structure as planar circuit component and as radiating elements in conventional and multilayered configurations [14-15]. The basic formulas to design triangular patch antenna are also presented in [16]. However, in order to improve -10dB bandwidth and 3-dB axial ratio bandwidth along with stable gain, slot loaded modification is required for the triangular patch antenna.

In this paper, a technique is proposed for designing the triangular patch antenna with enhanced impedance bandwidth and significant gain at resonant frequencies. This is achieved by introducing dual V- shaped slots which excite three resonant frequencies simultaneously. Moreover, CP radiation is expected due to the excitation of two orthogonal near-degenerate modes for proposed antenna and is controlled by unequal arm lengths of V-slots or tuning the required asymmetry. The slot related geometrical parameters, placing location and dielectric constant also have significant effects on the impedance matching, especially at lower frequencies. However, the width the V-slots hardly affects the impedance. The objective of the paper is to present planar triangular patch antenna with V-slots which benefits in producing tri bands with improved bandwidth and circular polarization occurs due to the asymmetry. The V-slot widths are selected to be narrow (1mm) and are inclined with an angle of 25^0 and with the nonlinear coupling, the fundamental resonant mode generates degenerate modes with equal amplitudes and 90^0 phase difference, which results in CP operation.

II. Antenna Design and Simulations

The conventional triangular patch antenna is chosen with side length ‘a’ as shown in Fig. 1(a) achieves dual band operation with narrow bandwidth.

A. Design equations of the patch

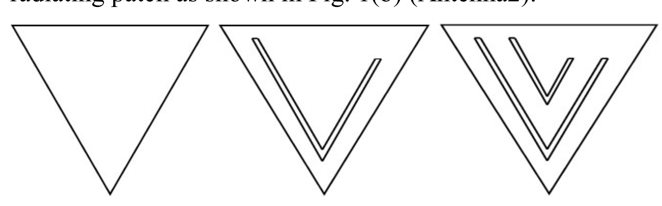
A nearly equivalent triangular patch can be found to sustain circular polarization. The theoretical resonant frequency (f_{mn}) of the patch antenna is determined by proper selection of design parameters and is given by [17],

$$f_{mn} = \frac{ck_{mn}}{2\pi\sqrt{\varepsilon_r}} = \frac{2c}{3a_e\sqrt{\varepsilon_r}}\sqrt{m^2+mn+n^2}\,. \quad (1)$$

Where

$$a_e = a\left[1 + 2.199\frac{h}{a} - 12.853\frac{h}{a\sqrt{\varepsilon_r}} + 16.436\frac{h}{a\varepsilon_r} + 6.182\left(\frac{h}{a}\right)^2 - 9.802\frac{1}{\varepsilon_r}\left(\frac{h}{a}\right)^2\right] \quad (2)$$

where a is the length of a side of the triangle, a_e is the effective side length of patch, c is the speed of the light in free space, ε_r is the relative permittivity, m and n are integers that are never zero simultaneously, k_{mn} are the various modes generated with reference to the TM_{mn} modes of the equilateral triangular patch. A narrow V-shaped slot is cut on the radiating patch as shown in Fig. 1(b) (Antenna2).



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

Fig. 1. Design iteration of (a) Antenna1 (b) Antenna2 (c) Antenna3

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The dimension of the narrow outer slot ($l_1 \neq l_2$) is adjusted by iterations to get a perfect dual band operation with slight increase in the bandwidth. Asymmetric dual V-slots with variation in lengths are cut ($l_1 \neq l_2$ and $l_3 \neq l_4$) as shown in Fig. 1(c). By controlling the lengths of V-slots at the sides of the radiating patch (Antenna3) in Fig. 1c, the antenna resonates at triple bands.

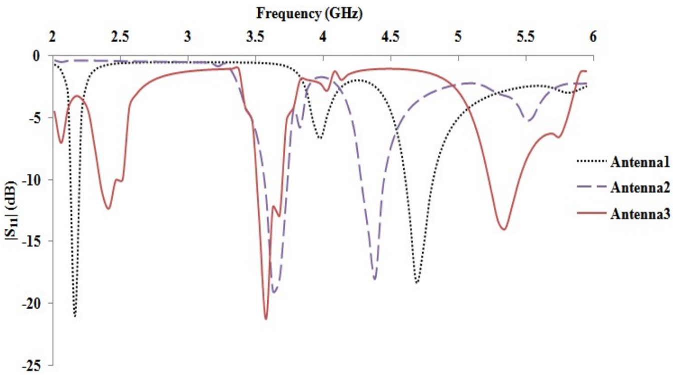


Fig. 2. Simulated Return Loss for Antenna 1-3 evolved structures

TABLE I
SIMULATED RESULTS OF SINGLE PROBE FEED TRIANGULAR PATCH

Structure	Freq. (GHz)	-10 dB IBW (MHz), %	-3dB ARBW (MHz)	Gain (dBi)
Antenna1	2.18	50, 2.29	LP	3.2
	4.62	230, 4.88	LP	4.1
Antenna2	3.6	220, 6.04	42MHz	4.6
	4.32	190, 4.36	LP	2.2
Antenna3	2.41	180, 7.41	37MHz	**4.8**
	3.57	240, 6.9	15MHz	**2.5**
	5.32	270, 4.06	LP	**4.6**

IBW-Impedance Bandwidth, ARBW-Axial Ratio Bandwidth, and LP Linear polarized

The optimum dimensions of the slot and substrate are selected for perfect impedance match and stable radiation pattern at the resonant frequencies. For comparison, the reference antennas (Antenna1) as shown in Fig. 1a is used and the return loss is plotted for design iterative Antennas1-3. A representative plot of the return loss characteristic of this antenna is shown in Fig. 2.

The result shows impedance bandwidth of 180MHz, 240MHz and 270MHz for 2.41GHz, 3.57GHz and 5.32GHz resonant frequencies respectively with antenna height less than $0.46\lambda_0$. Antenna gain of 5.8dBi, 2.5dBi and 4.6dBi for three bands is reported using this structure. The first and second band produces CP bandwidth of 37MHz and 15MHz as tabulated in Table I.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The configuration of the tri band patch antenna under consideration is as shown in Fig. 3 and is patterned on FR-4 epoxy laminate with relative permittivity (ϵ_r) of 4.4 with thickness of h=3.175 and loss tangent of 0.0012. The optimized parameters of the proposed antenna with metallic ground plane are given as: a= 50, L=55, l_1 =14, l_2 =18, l_3 =10, l_4 =7, w_1 =w_2 =1, w_3 =w_4 =9, w_5 =w_6 =5, s_1 =6, s_2 =4, l_5 =14, p =2, l_6 =11, $\theta=25^0$ and the coaxial probe feed position is located at (x, y) = (0, 10) from top base length for better impedance matching. The prototype layout photograph of the proposed antenna with optimal dimensions shown in Fig. 4(a) and Fig. 4(b) was constructed and experimentally investigated. The return loss and axial ratio against the frequency for this tri-band antenna was measured by using Agilent N5230 vector network analyzer.

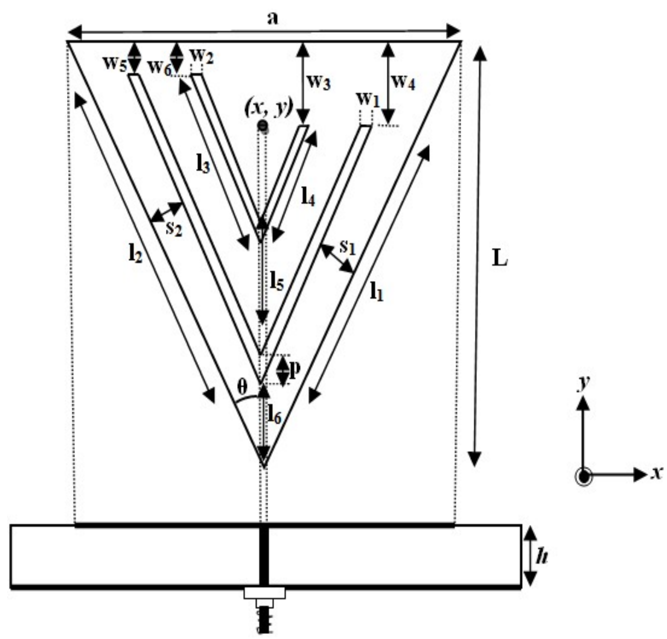
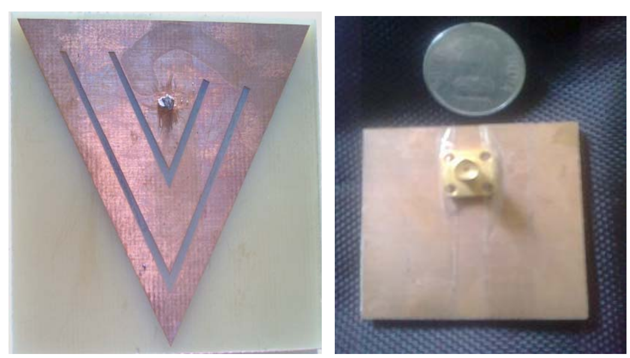


Fig. 3. Geometry of the proposed antenna (dimensions in mm)



(a) **(b)**

Fig. 4. Fabricated antenna (a) Top view (b) Bottom view

Fig. 5 shows the comparison of measured and simulated return loss (dB) of the antenna. The experimental results show wider bandwidths and good CP than the simulated ones for this structure. This could be attributed due to the reason of simulating the radiating patch on infinite ground plane. Table

II gives the performance of the proposed antenna in terms of impedance bandwidth and increase in the axial ratio bandwidth due to good CP radiation when compared with the earlier designs on slot loaded triangular patches. This novel design also gives better gain values at all bands except at center band 3.5GHz. This is due to the non uniform surface current distribution with the choice of higher substrate thickness.

TABLE II
CALCULATED BANDWIDTH AND GAIN PARAMETERS OF PROPOSED SLOT LOADED TRIANGULAR PATCH

Antenna	Description	Freq. (GHz)	10-dB RLBW (%)	3-dB ARBW (MHz)	Gain (dBi)
[8]	Dual-band triangular patch	2.45 5.8	8.3 11	LP LP	2 3.5
[10]	Tri-band triangular patch	1.42 2.95 3.65	4.8 4.7 4.1	LP LP LP	8 - -
[11]	Broadband CP for triangular patch	2.89	5.6	16.2	3.2
[12]	Slit-based triangular patch	1.9	4	20	-
[13]	CP based triangular patch	2.5	4.2	20	5 (dBc)
[This Work]	Triangular patch with asymmetric V-slots	2.41 3.5 5.28	**6.6** **4.54** **3.28**	**34** **16** **LP**	**5.4** **2.5** **4.2**

LP-Linear Polarization, RLBW-Return Loss Bandwidth,
ARBW-Axial Ratio Bandwidth

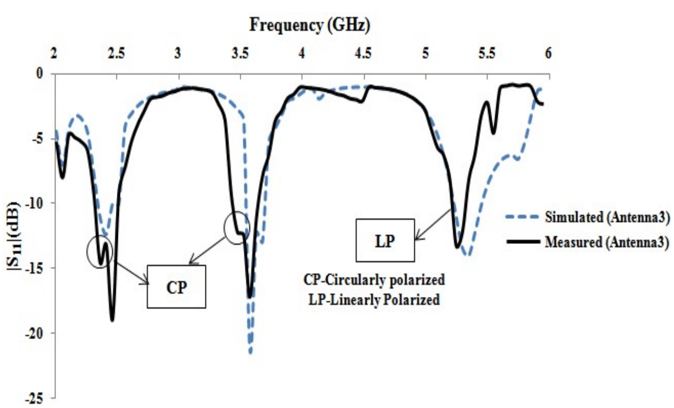


Fig. 5. Measured and Simulated Return loss of Antenna3

The simulated antenna peak gains are shown in Fig. 6. As can be seen, stable gain variation across the three desired bands has been obtained. The perturbation of length dimension variations of both V-slots of the patch and feed at appropriate location, two modes with orthogonal LP are generated with resonant frequencies which are slightly different. The patch is feed on the axis parallel to y-axis and by slightly adjusting the resonant frequency of one mode with respect to the other, overall phase difference between the self impedances of the modes and therefore the fields will be 90^0, satisfying the CP generation for first two bands.

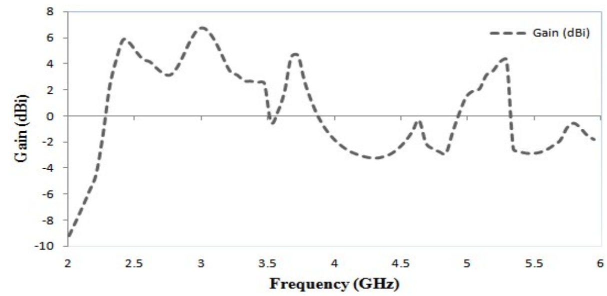


Fig. 6. Measured gain versus frequency response of Antenna3

The effect of changing the position of the feed point is to change the relative amplitudes of the x-directed and y-directed electric fields. The phase however, is not sensitive function of feed position. The measured and simulated axial ratio curve of the Antenna 3 is shown in Fig. 7. The measured impedance bandwidths ($|S_{11}| \leq$-10dB) of the three resonant bands are 6.6% (2.32-2.48GHz), 4.54% (3.44-3.6GHz) and 3.28% (5.20-5.34GHz) respectively. It is also found that probe feed with asymmetric V-slots achieved a significant reduction in size.

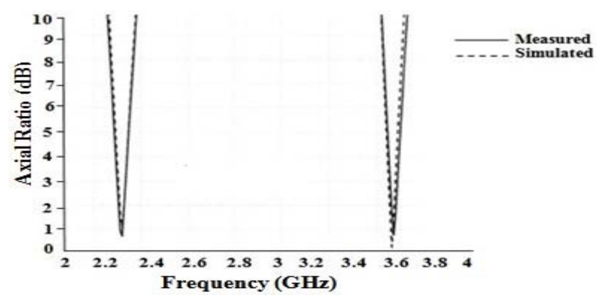


Fig. 7. Measured and Simulated Axial Ratio curve of Antenna3

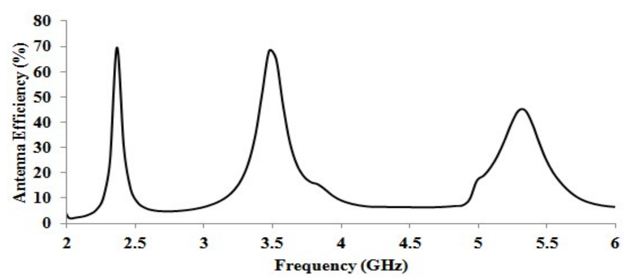
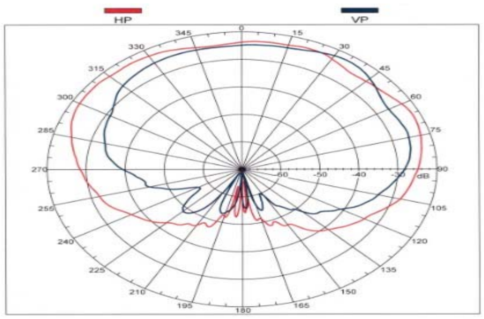
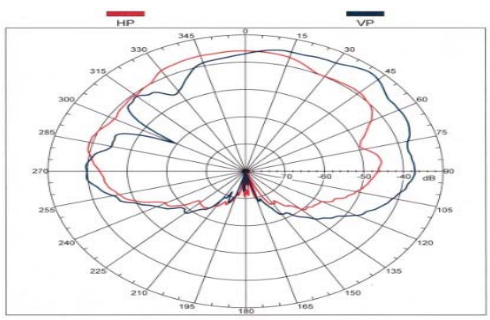


Fig. 8. Antenna efficiency of Antenna3

The obtained 3-dB axial ratio (AR) bandwidths are 1.42% (2.38-2.416GHz) for the lower band and 0.46% (3.57-3.586GHz) for the middle band respectively. The efficiency of the proposed antenna is 69.7, 68.4 and 44.75% for 2.41, 3.5, 5.28GHz resonant bands respectively. Although relatively simple to implement, the CP bandwidth (axial ratio less than 3dB) is extremely narrow, typically a fraction of the impedance (10dB return loss) bandwidth. The measured far-field radiation patterns at 2.41, 3.5 and 5.28GHz in the y-z plane (E-plane) are plotted in Fig. 9(a), Fig. 9(b) and Fig. 9(c) respectively. Because of the asymmetric slots, rather asymmetrical patterns are seen in y-z plane as depicted in the plots. The patterns are relatively smooth and there is a slight scalping evident in E-plane at higher resonance band. The direction of patterns is acceptable for mobile and wireless communication devices.



(a)



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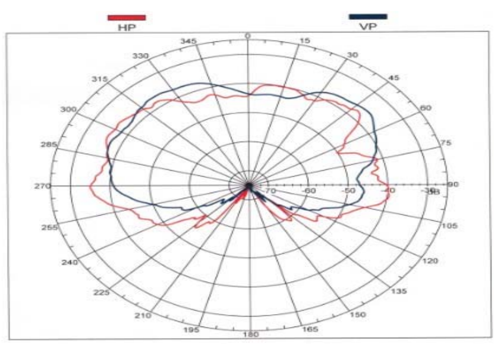

(c)

Fig. 9. E-field Radiation patterns at phi=0^0 and phi=90^0 for (a) 2.41GHz (b) 3.5GHz (c) 5.28GHz

IV. CONCLUSION

A novel asymmetric slot based triangular patch antenna is designed and measured for tri-band operation. The paper focuses on achieving high impedance bandwidth and good CP radiation at first two bands. Measured gain of 5.8dB, 2.5dB and 4.2 dB is achieved for 2.35, 3.5 and 5.28GHz frequencies respectively. Approximately 40% of size miniaturization is possible with designed antenna. Technique can also be extended tri band CP, but the process degrades the radiation patterns. Single layer coaxial feed slot loading technique for triangular shape concludes that the compactness of the antenna and its properties could benefit the Wi-MAX and WLAN wireless applications.

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