Design Analysis and Testing of Broadband Circularly Polarized Compact Microstrip Antenna for Wireless Applications

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Abstract- **GPS, Satellite phones, requires broadband, miniature size and circularly polarized antennas. Microstrip antennas have inherently narrow bandwidth, hence demanded enhanced bandwidth and size reduction. The present paper discusses the design analysis and testing of wideband compact and circular polarized MSA. The bandwidth of designed antenna is enhanced by using EC stacked patch antenna. The designed antenna has 3 dB AR BW of 16.71 % and VSWR BW (VSWR< 2) of 20.17 %. It achieves a significant amount of size reduction by loading cross slots on radiating patch. The paper also analyzes different simulated designs in terms of VSWR, AR, Impedance, Gain, Return loss. The antenna after fabrication is tested using Vector Network Analyzer (R & S 300KHz- 8GHz). It was found that measured results are in good agreement with simulated results.**

Keywords- **Axial ratio (AR), Voltage standing wave ratio (VSWR), Impedance, Compactness, Electromagnetically coupled (EC), Circular Polarization (CP), Stacked microstrip antenna**

I. INTRODUCTION

Nowadays, demand of antennas is arising due to the rapidly growth of wireless systems, especially satellite communication. In satellite communications, it is desirable to transmit and receive signals at a constant level despite the variations in the elevation angle and the attitude of the mobile station; consequently, wide band circular polarization characteristics with small size are required for the antenna element. Microstrip antennas are well-suited for such applications because of Light weight, small size, and low production cost. Though a conventional patch antenna can provide a circularly polarized radiation pattern with a single feed, the gain of the antenna decreases as we move from the zenith towards tile horizon, and the gain reduction is accompanied by deterioration in the axial ratio as well. Over past several years patch antennas with slots are being investigated to make the antenna more compact and broadband. Therefore appropriate selection of feeding technique, substrate material, polarization type, broadband technique, size reduction method has the crucial role for successful design of an antenna. Single-fed circularly polarized (CP) microstrip antenna has been of considerable interest because of its simple structure. They can be realized more compactly by using less board space than the dual feed circularly polarized microstrip antennas [8].

Yan Shan Boo et al used a probe-fed rectangular patch with a parasitic element to achieve 12% AR bandwidth [10]. Their main patch is (86.0 mm × 77.5 mm) is fabricated on thick FR4 substrate ($\varepsilon r = 4.3$, $\tan \delta = 0.02$) and upper patch (114.0 mm × 104.0 mm) on thin FR4 substrate with foam. However, the fabrication of the parasitic patch on foam is difficult and so is its alignment with the driven patch. Hence in the present paper, instead air dielectric is used that relaxes manufacturing difficulty.

For designing a single-feed microstrip patch antenna with circular polarization (CP), the perturbation methods often used include truncating patch corners, using a nearly square patch, and embedding a cross slot on the radiating patch [6][7], in which, the advantage of using the cross slot is that the required patch size is smaller for a given CP frequency compared to the other methods [1]. To excite two orthogonal modes with equal amplitudes and 90^0 phase difference, the cross slot has to be designed with a proper slot-length ratio, and by adjusting the feed position, 50 Ω input impedance can be found on the patch. The required slot-length ratio of the cross slot is mainly decided by its slot lengths. For larger slot lengths, the microstrip antenna has a relatively lower CP operating frequency. The present paper analyses the effect of various slot lengths on CP bandwidth and resonant frequency.

In order to achieve good circular polarization, location of coaxial feed position was optimized, on the arc by changing the feed position (X0, Y0) according to $X0=X \cos\theta$ and $Y0=X \sin\theta$ as stated in [3]. This feed optimization technique is useful for rapid design of circular polarized stacked microstrip antennas.

II. DESIGN OF ANTENNA

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Recently there have been numerous methods of enhancing the bandwidth of an antenna for example modifying the probe feed, using multiple resonances, using folded patch feed, or using the slotted radiating element. The shape of the planar radiating element was designed and modified by Chair.R et al [4] by reactively loading it with slots. It was proved that a U shape slot in the radiating element tends to have wideband characteristics. It also suggests that a U shape slot introduces the capacitive component in the input impedance to counteract the inductive component of the probe. Also to compensate the increasing inductive effect due to the slots, thickness of the substrate is increased, therefore as thickness increases the bandwidth increases accordingly. In this paper, two orthogonal cross slots are introduced to achieve the desired characteristics.

A. Simulation Setup

The antenna's resonant properties were predicted and optimized using High electromagnetic field simulation software IE3D which uses method of moments optimization technique. The design procedure begins with determining the length, width and the type of dielectric substance for the given operating frequency as per the standard equations using MATLAB software. Then the multilayered dielectric method (stacked) is used to introduce the thick air dielectric to further enhance the bandwidth [5]. Furthermore two cross slots are incorporated and optimized; this decreases the size of the antenna. At last the probe feeding is introduced for attaining a required bandwidth, resonating frequency and gain value.

B. Geometry of the antenna

The two nearly square patches are etched on separate substrates, they are the bottom substrate with thickness h1 and relative permittivity ε1, and the top substrate with thickness h3 and relative permittivity ε3. For convenience in practical design, both substrates is h1=h3=1.6 mm, and ε1=ε3= 4.4.To achieve a wide bandwidth, the upper patch (17.0 mm × 13.90 mm) and the lower patch (15.89 mm × 13.9 mm) fabricated on FR4 substrate ($\varepsilon r = 4.4$, tan $\delta = 0.02$) with air dielectric ($\varepsilon r = 1.0$, tan $\delta = 0.001$) sandwiched between the two. The patch is fed at an optimum feed location to radiate wide and good CP waves. The slot parameters are optimized to achieve good AR performance. The antenna designed dimensions are given in Table I, and all are in mm.

An electromagnetically coupled (proximity coupling) microstrip antenna using coaxial probe is used in the present work. This feeding mechanism benefits from flexibility in manufacturing and matching. The exact location of the probe is determined by varying the probe along an arc to locate the optimum point between *x-y* axes. The coaxial-probe location is first determined as approximately one third of the upper patch length. The coaxial-probe location is then simulated along the *x*-axis to obtain the best impedance matching with the load. Thereafter, the probe location is simulated along the xy-axis with varying angles to find the optimum circularly polarized performance at which the good impedance matching of the antenna within the operating frequency.

III. RESULTS AND DISCUSSION

A. Simulation Results

The simulation is done assuming ground plane as infinite. The simulated results of slotted patch antenna with two cross slots at the center are shown in fig.1 and fig.2. The return loss characteristics of the patch shown in fig.1 gives the understanding that by adding slots symmetrically the resonant frequency of the nearly square patch is decreased leading to reduction in overall size of antenna.

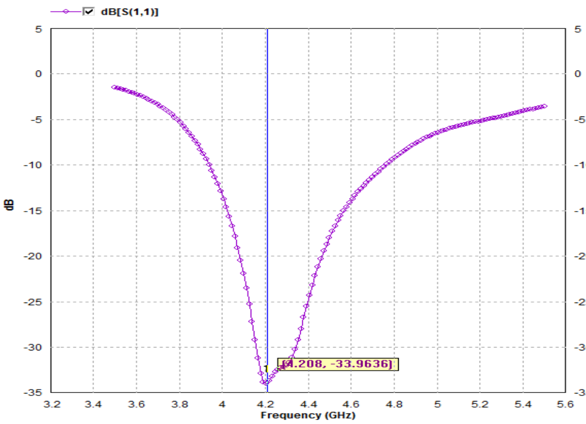


Fig.1 Return loss versus frequency characteristics

It should be noted that the designed antenna resonates at 4.208 GHz. The antenna's simulated VSWR bandwidth is of about 849 MHz (20.17 %) covering the frequency range from 3.9344 GHz to 4.784 GHz and the antenna's axial ratio bandwidth is of about 703.28 MHz (16.71 %) as shown in fig. 2. It achieves the gain over 6.0 dBi at the resonant frequency and antenna efficiency about 61 %.

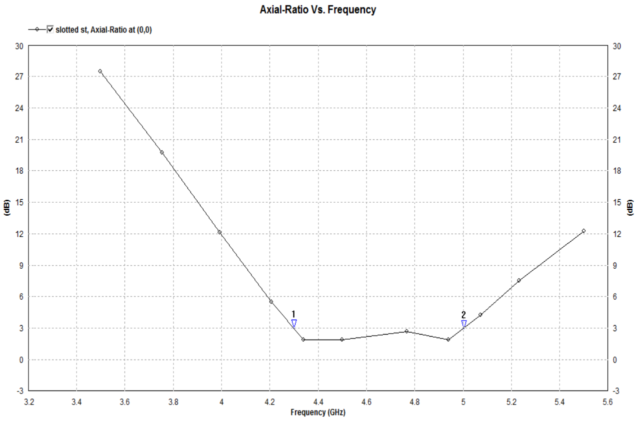


Fig.2 Axial Ratio versus frequency characteristics

B. Parametric study

a. Effect of varying slot length

Then the different prototypes of antenna were simulated for different slot lengths with L1=15.89 mm, L2=17.5 mm and W1=W2=13.90 mm. It is first noted that, when l1 is increased and l2 keeps constant to retain good CP performance, the feed point is moved towards the patch centre to obtain a 50 Ω input impedance. Also, the centre frequency of the CP bandwidth is decreased as l1 increases (Table II). For the case of l1=6 mm and l2=4 mm, the centre frequency is decreased to 4.1792 GHz, which is about a 5.3 % reduction compared with that of the antenna I, and the slot-length ratio of the cross slot on the radiating patch is increased to 1.5.(Refer fig.3 and fig.4)

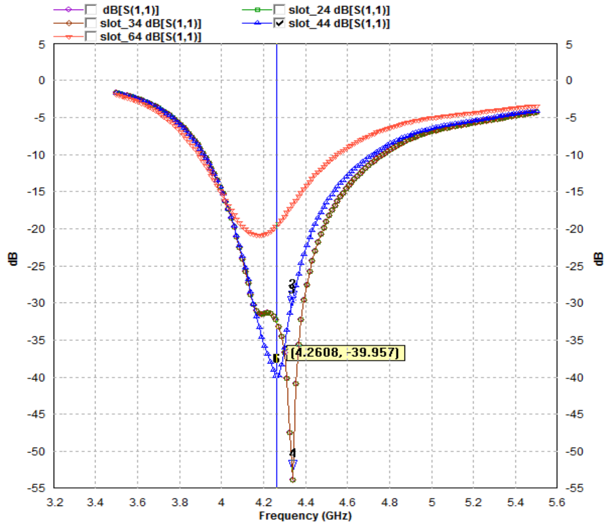


Fig.3 Variation of Return loss with frequency for different slot lengths

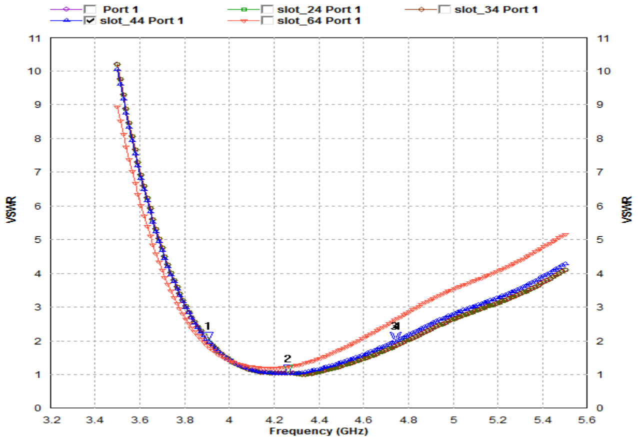


Fig.4 Variation of VSWR with frequency for different slot lengths

b. Effect of varying length of parasitic patch

The lower square patch length *L*1 is taken as 15.89 mm and the top square patch length *L*2 is varied from 16.0 mm to 17.5 mm (Table III). For air gap (h2 = 5),VSWR and impedance plots obtained using IE3D, for four values of *L*2 are shown in Fig.5 and fig.6. The impedance BW achieved for L2=17.5 mm is 772.8 MHz which is much larger than the BW of 360 MHz obtained for zero air gap.

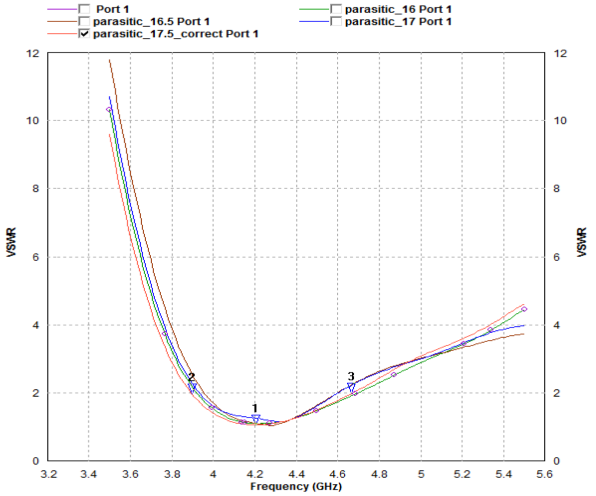


Fig.5 Variation of VSWR for different parasitic patch lengths

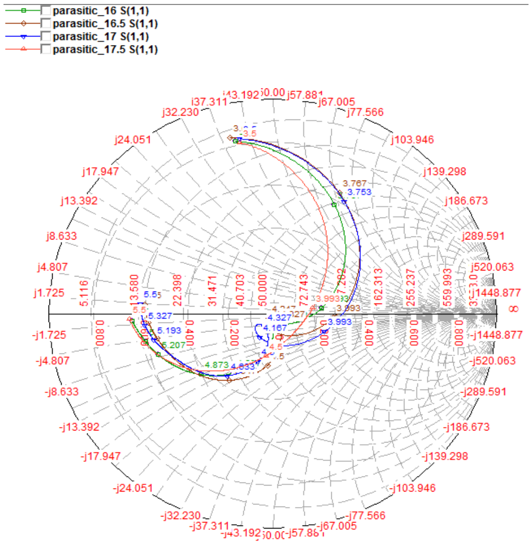


Fig.6 Impedance characteristics for different parasitic patch lengths

c. Effect of Finite ground plane

When the radiation from a circularly polarized microstrip antenna is considered, it is normally assumed that the ground plane is extended to infinite. However, in practice, the ground plane is always finite, though it can be approximated by a very large size. The effect of the ground plane edges may considerably modify the radiation patterns as well as the axial ratio [2]. The ground plane's size is 35 mm x 32 mm with antenna parameters calculated as stated in Table I. It can be observed that the axial ratio is noticeably modified (Fig. 7) by the effect of a finite

TABLE I DESIGNED ANTENNA DIMENSIONS (IN MM) (FINITE GROUND)

L1	**L2**	**Lg**	**h1**	**h3**	**l1**	**l2**	**X0**
15.89	17.0	35.0	1.6	1.6	5.0	4.0	4.557
W1	**W2**	**Wg**	**h2**	**θ**	**w1**	**w2**	**Y0**
13.90	13.90	32.0	5.0	40^0	0.5	0.5	3.824

TABLE II EFFECT OF VARIATION OF SLOT LENGTH ON ANTENNA PERFORMANCE (INFINITE GROUND)

Antenna	**l1 (mm)**	**l2 (mm)**	**X0 (mm)**	**Y0 (mm)**	**Fr (GHz)**	**VSWR BW (MHz)**	**AR BW (MHz)**
I	-	-	4.351	4.057	4.4096	945.6, 21.44 %	619.68, 14.05 %
II	2	4	4.490	3.903	4.3808	912, 20.81 %	595.08, 13.58 %
III	3	4	4.554	3.824	4.3328	878.4, 20.27 %	565.58, 13.05 %
IV	4	4	4.421	3.981	4.2608	840, 19.71 %	580.33, 13.62 %
V	5	4	4.207	4.207	4.2032	772.8, 18.38 %	553.28, 13.16 %
VI	6	4	4.280	4.133	4.1792	686.4, 16.31 %	467.21, 11.17 %

ground plane while the gain, efficiency of the antenna is decreased. Also, for the finite ground plane, the back lobes are present, whereas for the infinite ground plane, there are no back lobes in the radiation pattern as shown in Fig. 8. The simulated values of impedance BW and axial ratio BW are listed in the Table IV. The geometry of the designed antenna is as shown in Fig.9(a).

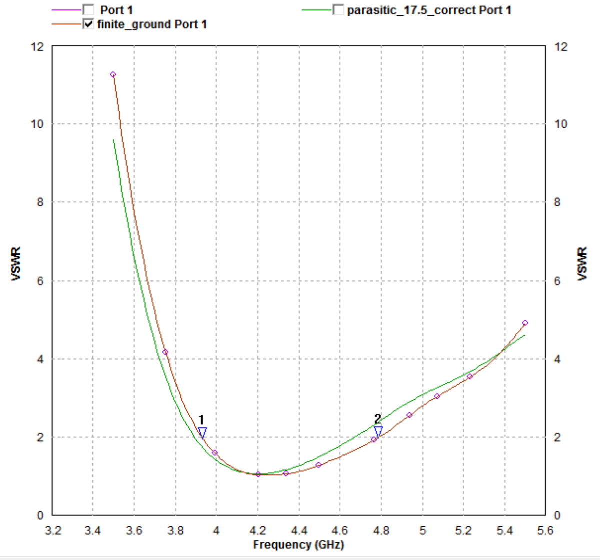


Fig. 7 VSWR characteristics for Finite ground

C. Measured Results

The antenna after fabrication (figure 9(b)) is tested using Vector Network Analyzer (VNA) (R&S 300 KHz- 8 GHz). The VSWR bandwidth measured is 806 MHz with return loss of -25.769 dB resonating at 3.89 GHz (Refer fig. 10,11). The comparison of measured and simulated results is given in Table V

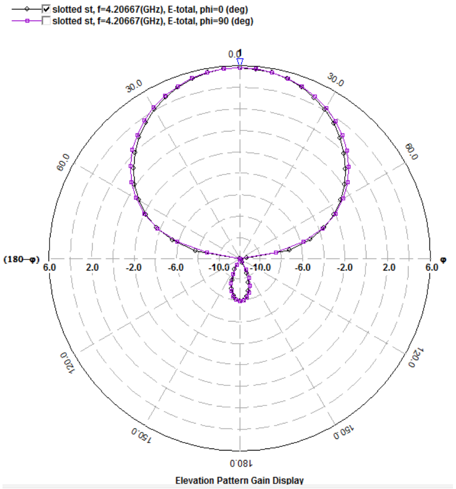


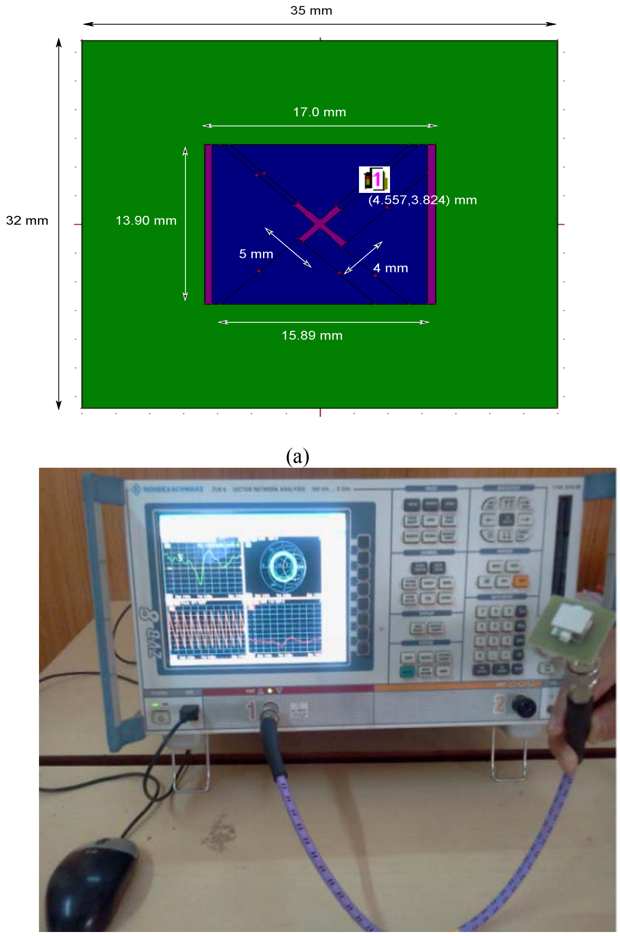
Fig. 8 Radiation pattern for Finite ground

TABLE III EFFECT OF VARIATION OF PARASITIC PATCH LENGTH ON ANTENNA PERFORMANCE (INFINITE GROUND)

Antenna	**L1 (mm)**	**L2 (mm)**	**X0 (mm)**	**Y0(mm)**	**Fr (GHz)**	**VSWR BW(MHz)**	**AR BW(MHz)**
A	15.89	16.0	4.490	3.903	4.241	753.6, 17.76 %	194.26, 4.58 %
B	15.89	16.5	4.554	3.824	4.232	763.2, 18.03 %	76.23, 1.80 %
C	15.89	17.0	4.421	3.981	4.224	763.2, 18.06 %	393.44, 9.31 %
D	15.89	17.5	4.207	4.207	4.2032	772.8, 18.38 %	553.28, 13.15 %

TABLE IV EFFECT OF FINITE GROUND ON ANTENNA PERFORMANCE

Antenna	**Resonant frequency (Fr) (GHz)**	VSWR BW (MHz)	3 dB AR BW (MHz)	**Gain (dBi)**	**% Efficiency**
Finite ground with slotted patch	4.208	849, 20.17 %	703.28, 16.71 %	5.81259 dBi	60.5837 %
Infinite ground with slotted patch (antenna C)	4.2224	763.2, 18.07 %	393.44, 9.31 %	6.129 dBi	68.99 %



(a)

(b)

Fig. 9 (a) Designed antenna (b) Measurement setup using VNA (R&S 300 KHz- 8 GHz)

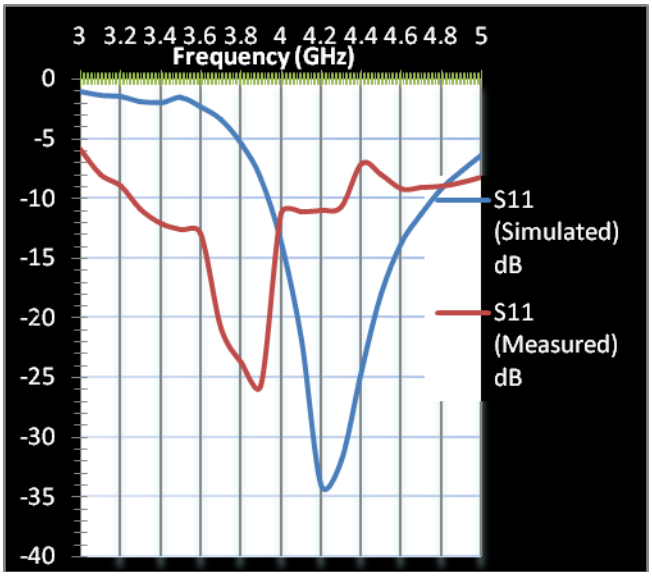


Fig. 10 Comparison of S_{11} (Return loss) for Simulated and measured results

IV. CONCLUSION

A technique for enhancing bandwidth of a patch antenna has been designed. The stacked patch antenna with air dielectric between the upper and lower patch and cross slots are incorporated in the lower patch; also it can be fabricated conveniently due to its simple structure. The antenna is successfully designed, matches the desired characteristics and attains a VSWR bandwidth of about 20.17 %, AR BW of 16.71 % and peak gain value of about 6.0 dBi covering the range of frequency from 3.9344 GHz to 4.784 GHz which can be used by numerous wireless devices, especially in satellite communication.

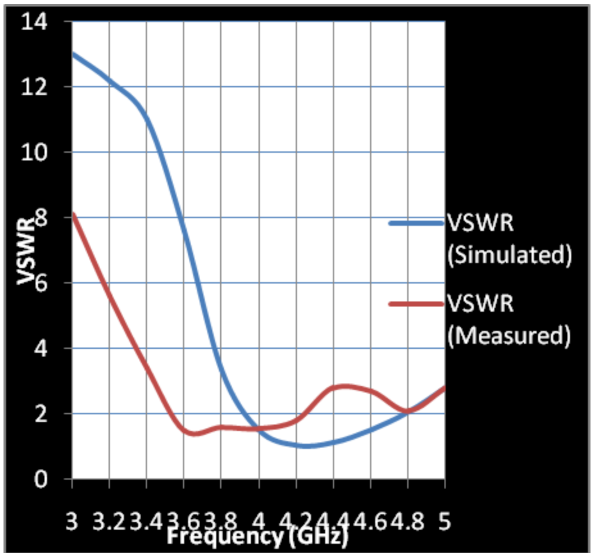


Fig. 11 Comparison of VSWR for Simulated and measured results

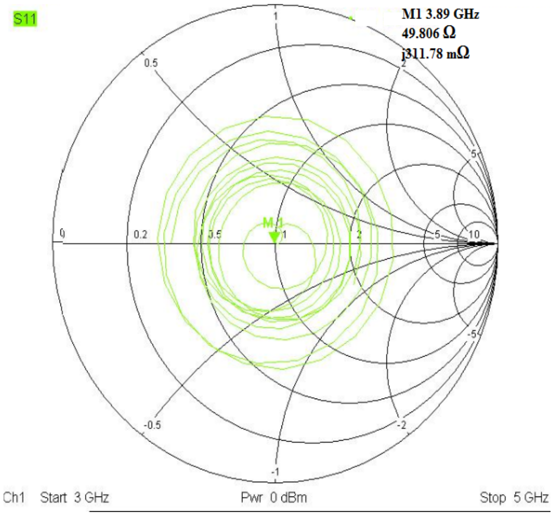


Fig. 12 Measured Input impedance (smith chart)

The effect of variation of slot length and parasitic patch length on antenna performance has been studied. It is observed that resonant frequency reduces and hence the antenna size reduces when the slot length ratio approaches to unity. The design of the antenna was formulated and optimized using Zeland's IE3D software using Method of Moments. The effect of a finite ground plane on circularly polarized microstrip antennas also has been studied. It has been shown that the axial ratio can be greatly modified about to 16.71 % by introducing a finite ground plane while the gain, efficiency of the antenna is decreased. The measured results obtained are satisfactory with an error shift of 7.5 % in resonant frequency, mostly due to fabrication tolerances. The gain and efficiency does not satisfy the specifications, hence can be further increased by using superstrate layer, also acting as protective cover for the antenna.

TABLE V COMPARISON OF SIMULATED AND MEASURED RESULTS

	Simulated Results	**Measured Results**
Resonant frequency (Fr)	4.208 GHz	3.89 GHz
Input Impedance (Zi)	49.507 Ω - j1.635 Ω	49.806 Ω + j311.78 mΩ
VSWR BW **VSWR at Fr**	849 MHz 1.04	806 MHz 1.2
Return loss (S11)	-33.9636 dB	-25.769 dB

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