Design Analysis of Broadband Circularly Polarised 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 of wideband compact and circular polarised MSA. The bandwidth of proposed antenna is enhanced by using EC stacked patch antenna. The proposed antenna has 3 dB AR BW of 13.62 % and impedance BW (VSWR< 2) of 19.71%. 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.

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

I. Introduction

In order to satisfy the miniaturization requirements of portable communication equipment, researchers have given much attention to compact microstrip antenna. The size reduction and bandwidth enhancement are becoming major design consideration for practical applications of microstrip antennas[1,9]. 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 (ε_r = 4.3, tan δ= 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 900 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 Cosθ, Y0=X Sinθ as stated in [3]. This feed optimization technique is useful for rapid design of circular polarized stacked microstrip antennas.

II. Design of Antenna

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 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 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 ε_1, and the top substrate with thickness h3 and relative permittivity ε_3. For convenience in practical design, both substrates is h1=h3=1.6 mm, and $\varepsilon_1=\varepsilon_3$= 4.4.To achieve a wide bandwidth, the upper patch (17.5 mm × 13.90 mm) and the lower patch (15.89 mm × 13.9 mm) fabricated on FR4 substrate (ε_r = 4.4, tan δ= 0.02) with air dielectric (ε_r = 1.0, tan δ= 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 proposed dimensions are given in Table 1, and all are in mm.

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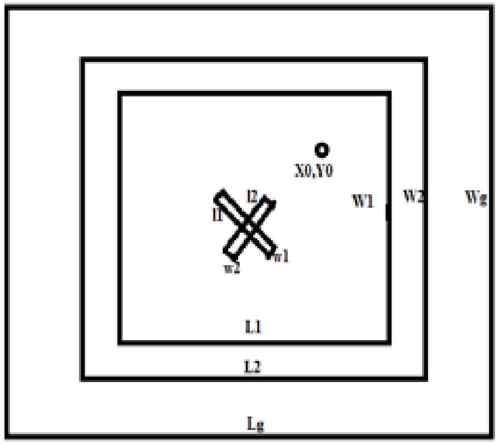
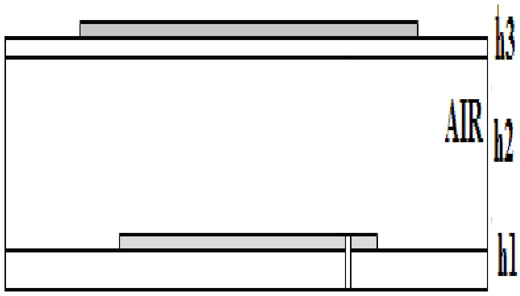
An electromagnetically coupled (proximity coupling) microstrip antenna using coaxial probe is used in the present work. This feeding mechanism benefits from flexibility in manufacturing and matching. The exact location of the probe is determined by varying the probe along an arc to locate the optimum point between x-y axes.



(a)



(b)

Fig. 1: Geometry of the proposed antenna (Finite Ground)

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. 2 and Fig. 3. The return loss characteristics of the patch

Table 1: Antenna designed dimensions (in mm)

L1	L2	h1	h3	l1	l2	X0
15.89	17.5	1.6	1.6	4.0	4.0	4.421
W1	W2	h2	θ	w1	w2	Y0
13.9	13.9	5.0	420	0.5	0.5	3.981

shown in fig. 2 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. It should be noted that the designed antenna resonates at 4.2608 GHz. The antenna's simulated impedance bandwidth is of about 840 MHz (19.71 %) covering the frequency range from 3.9056 GHz to 4.7456 GHz and the antenna's axial ratio bandwidth is of about 580.33 MHz (13.62 %) as shown in Fig. 3. It achieves the gain over 6.5 dBi at the resonant frequency and antenna efficiency about 71 %.

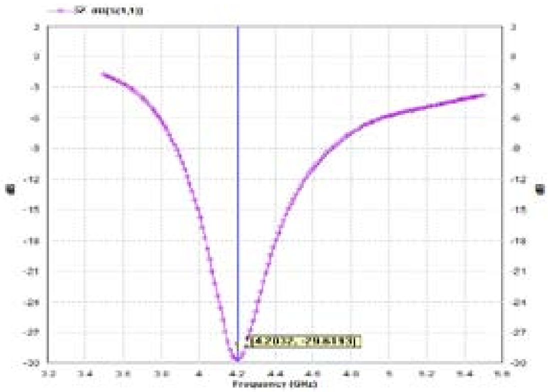


Fig. 2: Return loss versus frequency characteristics

B. Parametric study

1. Effect of varying slot length

Then the different prototypes of antenna were simulated for different slot lengths. 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.

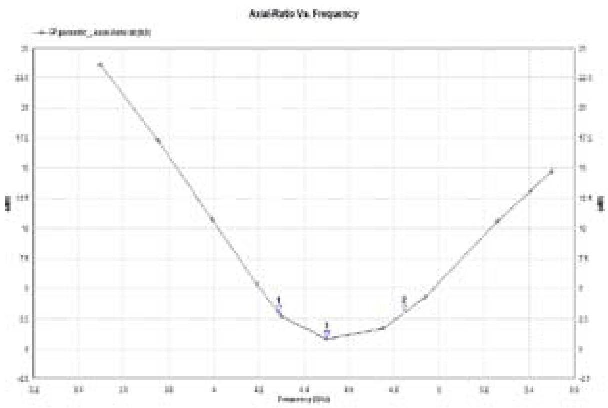


Fig. 3: Axial Ratio versus frequency characteristics

Also, the centre frequency of the CP bandwidth is decreased as l1 increases (table 2). 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. 4 and fig. 5)

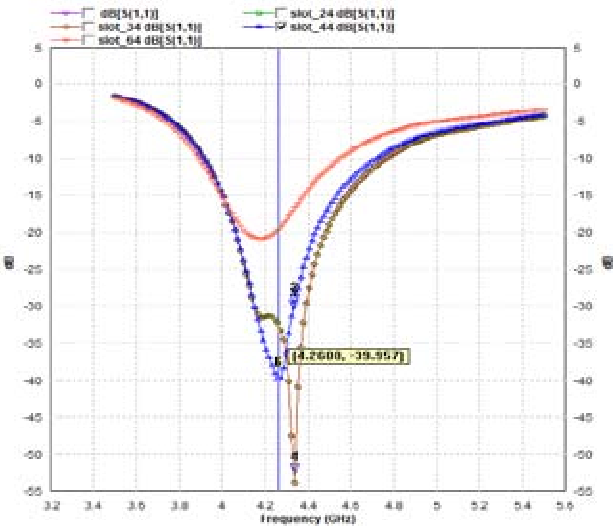


Fig. 4: Variation of Return loss with Frequency for different slot lengths

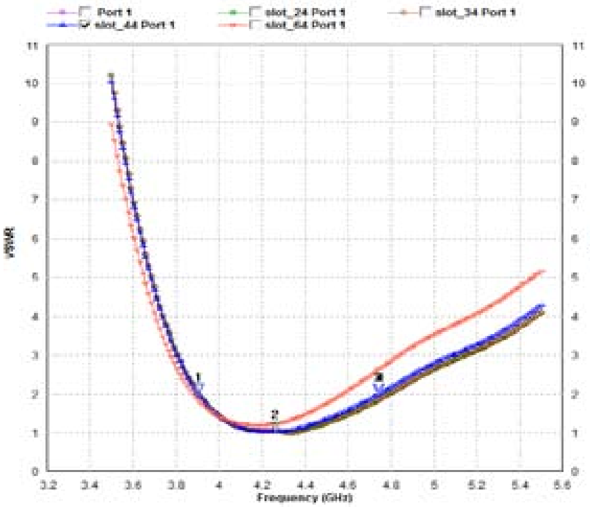


Fig. 5: Variation of VSWR with frequency for different slot lengths

Table 2: Effect of variation of slot length on antenna performance

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 %

Table 3: Effect of variation of parasitic patch length on antenna performance

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 %
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 %

2. Effect of varying length of parasitic patch

The lower square patch length L1 is taken as 15.89 mm and the top square patch length L2 is varied from 16.0 mm to 17.5 mm (table 3). For air gap (h2 = 5),Return loss and AR plots obtained using IE3D, for four values of L2 are shown in Fig. 6 and Fig. 7. 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.

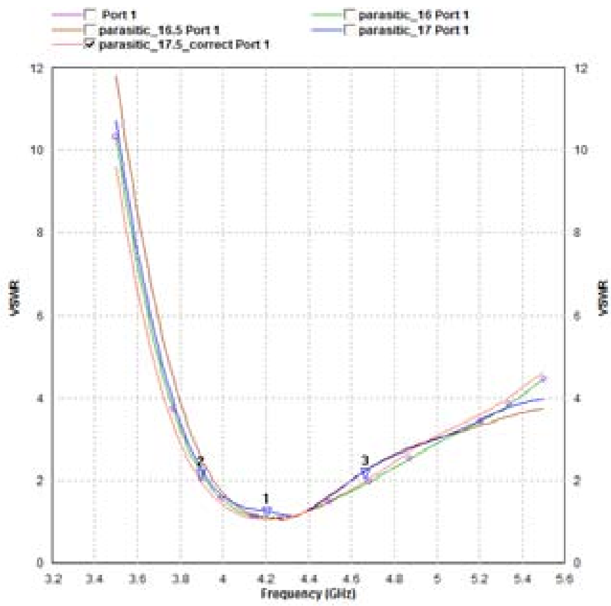


Fig. 6: Variation of VSWR with frequency or different parasitic patch lengths

3. Effect of Finite ground plane

When the radiation from a circularly polarized microstrip antenna is considered,

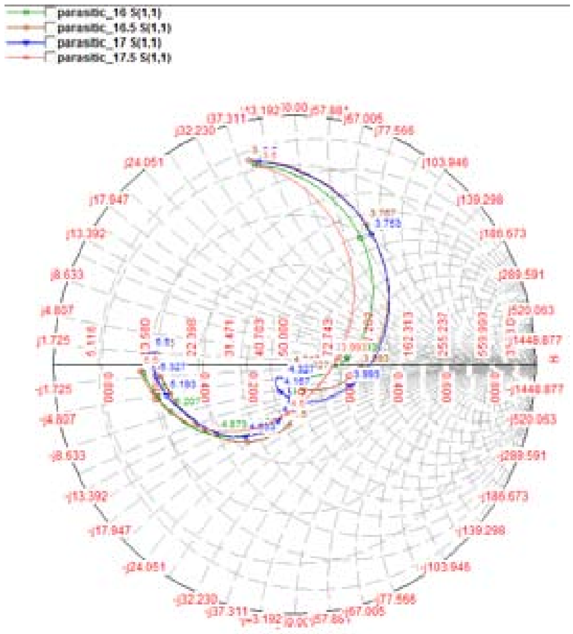


Fig. 7: Impedance characteristics

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 1. The geometry of the proposed antenna is

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as shown in Fig. 1.

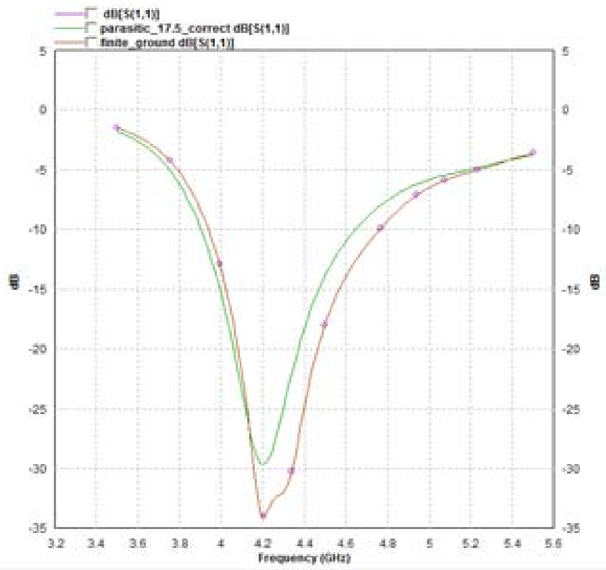

Fig. 8: Return loss characteristics for Finite ground

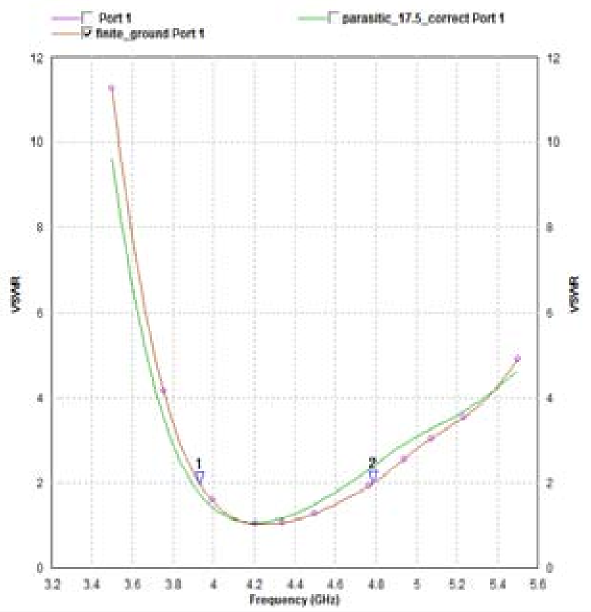

Fig. 9: AR characteristics for Finite ground

It can be observed that the axial ratio is noticeably modified by the effect of a finite ground plane while the gain, efficiency of the antenna is decreased (Fig. 8 and Fig. 9). The simulated values of impedance BW and axial ratio BW are listed in the table 4.

IV. Conclusion

A technique for enhancing bandwidth of a patch antenna has been proposed. 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 19.71 %, AR BW of 13.62 % and peak gain value of about 6.5 dBi covering the range of frequency from 3.9056 GHz to 4.7456 GHz which can be used by numerous wireless devices, especially in satellite communication.

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 Zealand'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 17.18 % by introducing a finite ground plane while the gain, efficiency of the antenna is decreased.

Table 4: Effect of Finite ground on antenna performance

Antenna	Resonant frequency (GHz)	VSWR BW (MHz)	AR BW (MHz)	Gain (dBi)	% Efficiency
Finite ground with plain patch	4.5572	1032.8, 22.66 %	309.84, 6.79 %	6.1508	63.0367 %
Finite ground with slotted patch	4.2224	854.4, 20.23 %	725.41, 17.18 %	5.683	59.8288 %
Infinite ground with slotted patch (antenna C)	4.2224	763.2, 18.07 %	393.44, 9.31 %	6.129	68.99 %

The gain and efficiency can be further increased by using superstrate layer, also acting as protective cover for the antenna.

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