



# Compact Wideband Meandered Slotted Multi Frequency Microstrip Antenna

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## Abstract

A compact wideband multi frequency microstrip antenna for wireless communication is proposed in this paper. The antenna is designed by introducing meandered slot on the patch and a pair of spur lines along the triangular notch on the finite ground plane. The overall size of the fabricated antenna is very small and low profile as the total dimension is  $20 \times 16 \text{ mm}^2$ . The proposed antenna operates at 3.7 GHz, 4.27 GHz and 5.1 GHz which may be suitable for WiMAX and WLAN applications. In addition with multi frequency operation a wide bandwidth ( $VSWR \leq 2$ ) has been achieved from 6 to 13.7 GHz i.e. 78.2% bandwidth of center frequency, which is suitable for X-band communication and ITU band applications. The meandered slot on the patch causes multi frequency operation of the antenna with 60% compactness and the spur line along with triangular notch on finite ground plane cause bandwidth enhancement.

**Keywords** Compact microstrip antenna · Wideband · Compactness · Meandered slot · Spur lines

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## 1 Introduction

Modern wireless communication system demands compact and portable devices for multipurpose applications which require a compact antenna with multi frequency operation. Microstrip antenna plays a very significant role as a part of the communication devices because of its attractive features like low profile, small size, low cost, easy fabrication capabilities etc.[1]. Along with multi frequency operation such as WiMAX, WLAN applications etc., some wideband applications like X-band satellite communication, ITU band applications are desired to be present in a single device to improve the functionality of wireless communication systems [2].

Various researchers have investigated on compactness, multi frequency and wideband operation of microstrip patch antenna separately. In this regard several techniques for compactness and multi frequency operation have been explored in some literature utilizing slots on the patch [3], slots on ground [4], parasitic element [5] etc. Simultaneously several techniques have been discussed to achieve wideband operation of microstrip antenna such as utilizing shorting pin [6], introducing rectangular slots on patch to look like E shaped patch [7]. Some other useful techniques like stacked patch antenna [8], shorting post loaded patch antenna [9] have been discussed in some articles for wideband operation. With respect to above discussion the problem of achieving compact antenna with wideband operation has been considered in this article. Many efforts have been reported in this purpose, such as half U shaped slot has been introduced in [10], to get the compact and broadband microstrip antenna, in [11], a L-strip fed microstrip antenna with 74% bandwidth has been presented where hexagonal slot has been etched on a square microstrip antenna and a rectangular strip has been incorporated symmetrically on the top portion of the slot to achieve proper impedance matching. Also an E shaped patch antenna fed by a folded patch feed has been presented in [12] to get the impedance bandwidth of 70% but the antenna proposed in [12] has complicated geometrical configuration. A design of a miniaturized multi band slotted microstrip antenna has been proposed in [13]. In this design the antenna consists of C shaped slotted patch with partial ground plane. A bandwidth enhancement technique using L shaped patch and parasitic element has been discussed in [14] where 6.5% bandwidth has been obtained at 5.89 GHz. In [15], a design of a miniaturized microstrip antenna embedded with open ended ground slot has been reported and 85.83% size reduction with only 6.97% fractional bandwidth has been achieved. A bandwidth enhancement approach using monopole structure with Y-shaped half annular ring microstrip antenna has been presented in [16]. In [17], a multiband antenna design with slotted patch has been reported and only 36% miniaturization has been achieved with this design. The performance comparison of the proposed antenna with some of the above discussed design with respect to achieved bandwidth and antenna size is presented in Table 1.

In this article a small size meandered slotted microstrip patch antenna with slotted finite ground has been proposed. The fabricated antenna has resonating frequencies 3.7 GHz, 4.27 GHz, 5.1 GHz and a wide operating band 6–13.7 GHz. The wide impedance bandwidth has been achieved by means of the rectangular slot, spur lines and triangular notch on the ground plane. The antenna resonates at lower frequencies due to the effects of meandered slots on the patch. According to measured results the proposed antenna exhibits 7700 MHz of wide bandwidth i.e. 78.2% bandwidth of center frequency and 60% compactness. The antenna may be suitable for WiMAX, WLAN, X-band satellite communication and ITU band applications.

**Table 1** Performance comparison of proposed antenna with other antenna with respect to bandwidth and size

References	Type of patch	Method of design	Total size of antenna in mm <sup>2</sup>	Bandwidth in %
[6]	Square	Air filled substrate and using shorting post	38 × 38	67.5
[7]	Rectangular	Air substrate and E shaped patch	70 × 50	30.3
[8]	Rectangular	Slotted and stacked patch	39.4 × 29.4	59.7
[9]	Circular	Circular ring patch with shorting post	1130 <sup>2</sup>	68.5
[10]	Rectangular	Half U and rectangular slotted patch and air substrate	45 × 45	14.6
[11]	Rectangular	Strip loaded slotted antenna fed by an L strip feed line	55 × 42	74
Proposed antenna	Rectangular	Meandered slotted patch and slotted finite ground plane	20 × 16	78.2

## 2 Antenna Design and Structure

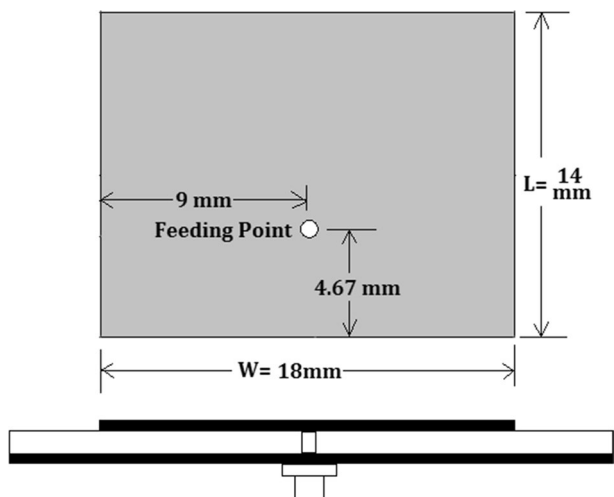
The proposed antenna consists of a slotted rectangular microstrip patch with slotted rectangular finite ground plane with coaxial SMA probe feed having  $50\Omega$  characteristics impedance. The antenna has been fabricated on Arlon AD300A substrate of dielectric constant  $\epsilon_r=3$ , thickness  $h=1.524$  mm and loss tangent is 0.002. The dimension of reference patch antenna has been taken as  $18\times 14$  mm<sup>2</sup> with infinite ground plane for resonant frequency of 5.8 GHz which is used as WLAN application. To achieve the multi frequency operation, the meandered slots have been cut on the patch and the ground plane has been reduced to  $20\times 16$  mm<sup>2</sup> incorporating rectangular slots, spur lines and a triangular notch to achieve wideband operation. In addition with the slots on ground multiple resonances can be obtained very closely and these is the reason of achieving wide bandwidth for the single layered microstrip patch antenna. The overall dimension of the proposed antenna becomes very small i.e.  $20\times 16$  mm<sup>2</sup>. The patches of both Antenna 1 and Antenna 2 are fed by coaxial cable at optimum location to achieve characteristic impedance of  $50\Omega$ . The structure of reference antenna and proposed antenna are shown in Figs. 1 and 2. The fabricated proposed antenna is shown in Fig. 3. The values of parameters referring Antenna 2 are given in Table 2.

## 3 Parametric Study

The antenna characteristics have been simulated in commercially available MOM based software IE3D. Several parametric studies have been carried out by simulation to investigate the effects of different slots on the patch and ground plane. The simulated results of reference Antenna 1 and proposed Antenna 2 are given in Table 3. Table 4 shows the effects of slots on patch without slots on the ground plane initially and the ground plane has been taken as  $20\times 16$  mm<sup>2</sup>. Effect of slots on the ground plane with slotted patch is shown in Table 5.

Table 3 shows that the reference antenna which is a conventional rectangular microstrip antenna, resonates at single frequency, 5.7 GHz with 23 dB return loss and bandwidth has

**Fig. 1** Structure of reference antenna (Antenna 1)



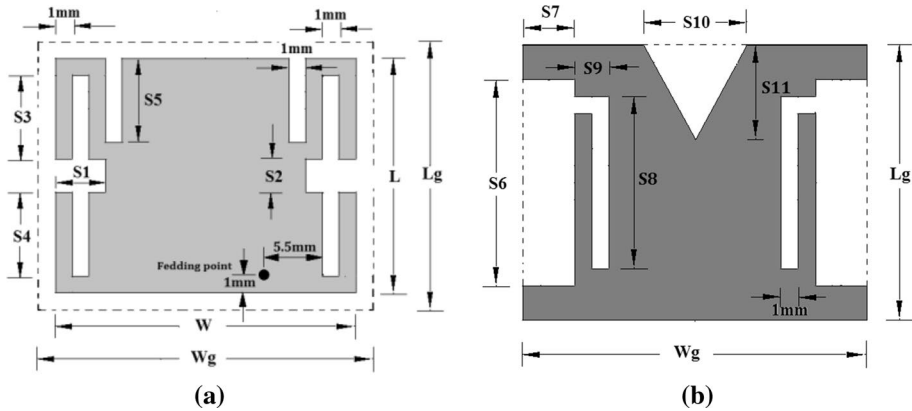


Fig. 2 Structure of proposed antenna (Antenna 2), a slotted patch and b slotted ground

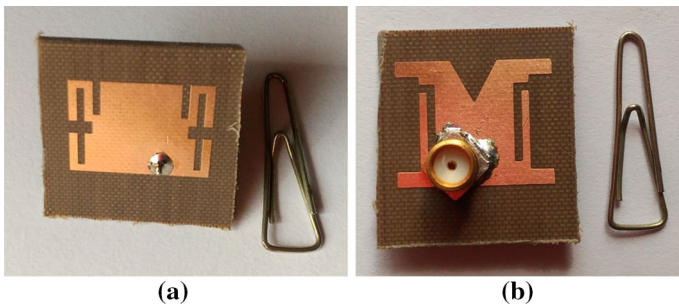


Fig. 3 Fabricated proposed antenna, a patch and b ground

Table 2 Dimension of Antenna 2 (units are in mm)

Parameters	Values	Parameters	Values
$S_1$	3	$S_9$	2
$S_2$	2	$S_{10}$	6
$S_3$	5	$S_{11}$	5.5
$S_4$	5	$W$	18
$S_5$	5	$L$	14
$S_6$	12	$W_g$	20
$S_7$	3	$L_g$	16
$S_8$	10		

been found very narrow, only 3.2% of center frequency. In the proposed antenna 2 multi frequencies have been achieved due to the incorporation of slots on the patch and a wide bandwidth of 73.5% has been obtained for introducing slots on the ground.

According to simulation results the proposed Antenna 2 resonates at 3.8 GHz, 4.3 GHz and 5.3 GHz frequencies with 19 dB, 23 dB and 27 dB return losses respectively. With these multi frequencies a 10 dB wide bandwidth of 7.2 GHz (6.2 GHz to

**Table 3** Simulated results of Antenna 1 and Antenna 2

Antenna	Resonant frequency (GHz)	Return loss (dB)	Bandwidth (GHz), %	Gain (dBi)
Antenna 1	5.7	23	0.182, 3.2%	4.6
Antenna 2	3.8	19	0.12, 3.15%	2
	4.3	23	0.13, 3%	1.2
	5.3	27	0.12, 2.26%	4.5
	9.8	25	7.2 (6.2–13.4), 73.5%	1.2

**Table 4** Effects of slots on patch without slots on ground

Slot dimensions (mm)	Resonant frequency (GHz)	Return loss (dB)	Bandwidth (GHz), %
$S_1=3, S_2=2$	4.75	30	0.11, 2.3%
	9.12	10	–
	10.6	29	0.14, 1.3%
	11.76	22	0.4, 3.4%
$S_1=3, S_2=2, S_3=5, S_4=5$	4.4	10	–
	5.2	11	–
	6.7	11	–
	8	18	0.3, 3.75%
	10.6	19	0.8, 7.5%
$S_1=3, S_2=2, S_3=5, S_4=5, S_5=5$	3.76	11	–
	5.52	12	0.15, 2.7%
	8.33	14	0.3, 3.6%
	10.9	37	0.9, 8.3%

**Table 5** Effects of slots on ground with slots on patch

Slot dimensions (mm)	Resonant frequency (GHz)	Return loss (dB)	Bandwidth (GHz), %
$S_6=12, S_7=3$	4.2	10	–
	5.7	18	0.2, 3.5%
	8.13	20	1.14 (7.5–8.7), 14%
	12	22	3.16 (10.4–13.6), 26.3%
$S_1=12, S_7=3, S_8=10, S_9=2$	4.45	14	0.25, 5.6%
	5.55	20	0.2, 3.6%
	7.55	15	2.85 (6.1–8.9), 37.8%
	11.67	16	3.26 (10–13.3), 28%
$S_1=12, S_7=3, S_8=10, S_9=2, S_{10}=6, S_{11}=5.5$	<b>3.8</b>	<b>19</b>	<b>0.12, 3.15%</b>
	<b>4.3</b>	<b>23</b>	<b>0.13, 3%</b>
	<b>5.3</b>	<b>27</b>	<b>0.12, 2.26%</b>
	<b>9.8</b>	<b>25</b>	<b>7.2 (6.2–13.4), 73.5%</b>

The accepted result among all the different results in the table, has been depicted as bold

13.4 GHz) has been found also having 9.8 GHz center frequency. It has been shown in Table 4 clearly that slot  $S_1$  results multi frequency operation,  $S_3$  and  $S_4$  are responsible for a new frequency addition i.e. 5.2 GHz and  $S_5$  lowers the first resonant frequency. From Table 5 it has been seen that slot  $S_6$  causes the bandwidth enhancement,  $S_8$  increases more bandwidth and addition of  $S_{10}$  lowers the first resonant frequency more and increase the bandwidth up to 7.2 GHz. The optimum values of all parameters have been taken from parametric studies.

The different antenna characteristics of Antenna 2 with the variation of  $S_1$ ,  $S_2$ ,  $S_3$ ,  $S_4$  and  $S_5$  are shown in Tables 6, 7, 8 and 9 which clearly depicts the individual effects of each slots on the patch. During the parametric study of a particular parameter variation, optimum values have been taken for other parameters.

From Table 6 it has been seen that maximum bandwidth has been found for  $S_1=3$  mm, so this value has been taken as optimum value for slot  $S_1$ . Maximum bandwidth has been also found for  $S_2=1$  mm in Table 7, but to get the much lower first resonant frequency along with a good bandwidth  $S_2=2$  mm has been taken as optimum value. From Tables 8 and 9, the optimum value of  $S_3$ ,  $S_4$  and  $S_5$  has been taken as 5 mm to achieve the good bandwidth along with minimum first resonant frequency.

The parametric study in Table 8 shows that with the decreasing of the value of both  $S_3$  and  $S_4$  slots the resonating frequencies are increasing and bandwidth in higher resonating frequency are also decreasing considerably. To achieve the higher bandwidth and lower resonating frequencies the optimum values for these two parameters have been taken as 5 mm.

It has been depicted in Table 9 that with the decreasing of the value of  $S_5$  slot, the bandwidth in higher frequency is also decreasing which is not desirable. So, the optimum value for this parameter has been taken as 5 mm.

**Table 6** Antenna characteristics with the variation of  $S_1$

$S_1$	Resonant frequency (GHz)	Return loss (dB)	Bandwidth (GHz), %
3	<b>3.8</b>	<b>19</b>	<b>0.12, 3.15%</b>
	<b>4.3</b>	<b>23</b>	<b>0.13, 3%</b>
	<b>5.3</b>	<b>27</b>	<b>0.12, 2.26%</b>
	<b>9.8</b>	<b>25</b>	<b>7.2 (6.2–13.4), 73.5%</b>
4	3.6	11	–
	4.24	12.3	0.1, 2.4%
	5	18	0.2, 4%
	7.368	22	2.7 (6.016–8.72), 36.7%
5	3.54	15	0.15, 4.2%
	4.24	22	0.2, 4.7%
	4.928	13	0.1, 2%
	7.592	23	3.38 (5.9–9.28), 44.46%
6	3.5	15	0.15, 4.3%
	4.22	16	0.2, 4.7%
	4.9	14	0.12, 2.4%
	7.415	22	3.3 (5.76–9.07), 44.6%

The accepted result among all the different results in the table, has been depicted as bold

**Table 7** Antenna characteristics with the variation of  $S_2$ 

$S_2$	Resonant frequency (GHz)	Return loss (dB)	Bandwidth (GHz), %
1	3.92	21	0.15, 3.8
	5.12	36	0.3, 5.9
	9.704	27	7.2 (6.1–13.3), 74.2
2	<b>3.8</b>	<b>19</b>	<b>0.12, 3.15</b>
	<b>4.3</b>	<b>23</b>	<b>0.13, 3</b>
	<b>5.3</b>	<b>27</b>	<b>0.12, 2.26</b>
	<b>9.8</b>	<b>25</b>	<b>7.2 (6.2–13.4), 73.5</b>
3	3.74	20	0.1, 2.7
	4.26	21	0.12, 2.8
	5.4	30	0.14, 2.6
	9.93	22	7.15 (6.35–13.5), 72

The accepted result among all the different results in the table, has been depicted as bold

**Table 8** Antenna characteristics with the variation of  $S_3$  and  $S_4$ 

$S_3$ and $S_4$	Resonant frequency (GHz)	Return loss (dB)	Bandwidth (GHz), %
5	<b>3.8</b>	<b>19</b>	<b>0.12, 3.15%</b>
	<b>4.3</b>	<b>23</b>	<b>0.13, 3%</b>
	<b>5.3</b>	<b>27</b>	<b>0.12, 2.26%</b>
	<b>9.8</b>	<b>25</b>	<b>7.2 (6.2–13.4), 73.5%</b>
4	3.89	12	0.1, 2.6%
	4.39	14	0.12, 2.7%
	5.76	28	0.25, 4.3%
	6.86	15	0.5, 7.3%
	11.94	20	2.83 (10.5–13.4), 23.7%
3	3.92	14	0.15, 3.8%
	4.42	15	0.15, 3.4%
	5.84	26	0.3, 5.1%
	6.9	16	0.4, 5.8%
	10.89	24	0.35, 3.2%
	12.488	23	0.4, 3.2%

The accepted result among all the different results in the table, has been depicted as bold

## 4 Results and Discussion

Return losses of all fabricated antennas have been measured in Anritsu MS2038C vector network analyzer and the results are given in Table 10. The frequency vs return loss graphs of Antenna 1 and Antenna 2 are shown in Figs. 4 and 5. The proposed antenna resonates at 3.7 GHz, 4.27 GHz and 5.1 GHz with 22 dB, 27 dB, 26 dB return losses and bandwidths are 6.5%, 6% and 4.3% respectively. The measured result of the antenna also exhibits a



**Table 9** Antenna characteristics with the variation of  $S_5$

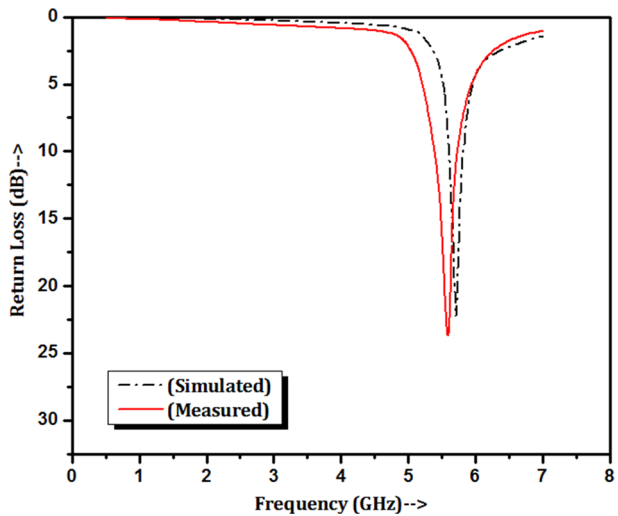
$S_5$	Resonant frequency (GHz)	Return loss (dB)	Bandwidth (GHz), %
5	<b>3.8</b>	<b>19</b>	<b>0.12, 3.15%</b>
	<b>4.3</b>	<b>23</b>	<b>0.13, 3%</b>
	<b>5.3</b>	<b>27</b>	<b>0.12, 2.26%</b>
	<b>9.8</b>	<b>25</b>	<b>7.2 (6.2–13.4), 73.5%</b>
4	3.95	10	–
	4.65	13	0.15, 3.2%
	5.35	18	0.2, 3.7%
	9.9	30	6.8 (6.5–13.3), 68.7%
3	4.2	11	–
	4.8	13	0.12, 2.5%
	5.4	15	0.15, 2.8%
	10.5	25	6.1 (7–13.1), 58%

The accepted result among all the different results in the table, has been depicted as bold

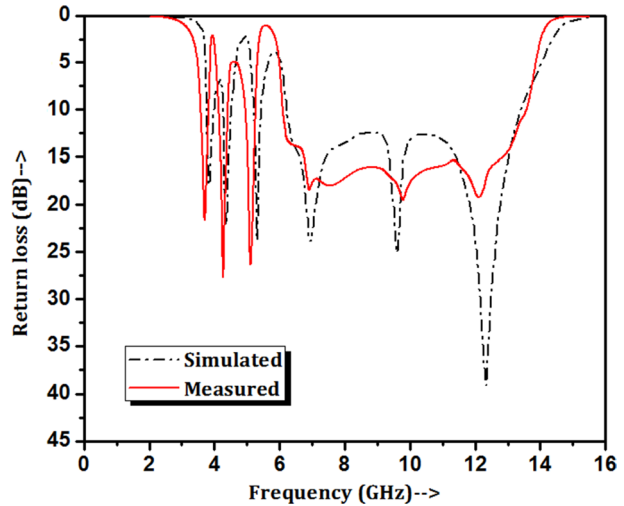
**Table 10** Measured results of Antenna 1 and Antenna 2

Antenna	Resonant frequency (GHz)	Return loss (dB)	Bandwidth (GHz), %	Gain (dBi)
Antenna 1	5.6	24	0.2, 3.57%	5
Antenna 2	3.7	22	0.12, 3.24%	2.5
	4.27	27	0.125, 2.9%	2
	5.1	26	0.13, 2.5%	5
	9.85	19	7.7 (6–13.7), 78.2%	1.8

**Fig. 4** Frequency versus return loss graph of Antenna 1



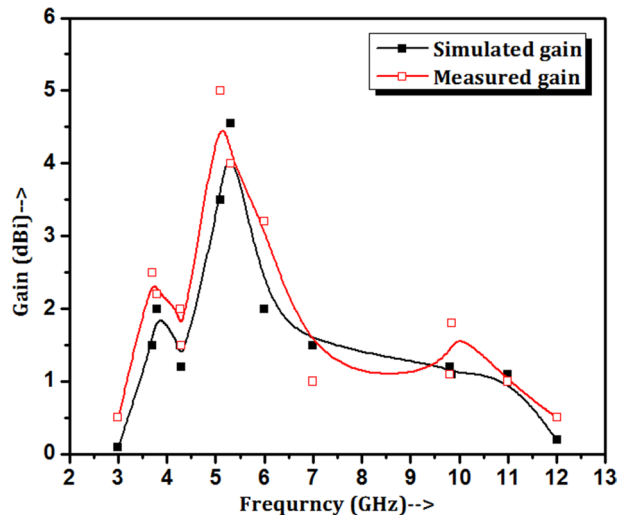
**Fig. 5** Frequency versus return loss graph of Antenna 2



10 dB wide bandwidth of 7.7 GHz i.e. 6 GHz to 13.7 GHz which is 78.2% of center frequency. The measured gains at 3.7 GHz, 4.27 GHz, 5.1 GHz and 9.85 GHz have been found as 2.5 dBi, 2 dBi, 5 dBi and 1.8 dBi respectively. The frequency versus gain graph is shown in Fig. 6.

Table 10 shows that the fabricated reference antenna resonates at single frequency, 5.6 GHz and fabricated proposed antenna resonates at multi frequencies along with wide bandwidth of 78.2% of center frequency. The gains of the designed antenna at every frequency point have been found very satisfactory. The graphical representation of the simulated and measured results for both Antenna 1 and Antenna 2 show very good similarities between simulated and measured results of the antennas. Thus the simulation results have been verified by measurement very well.

**Fig. 6** Frequency versus gain graph of Antenna 2

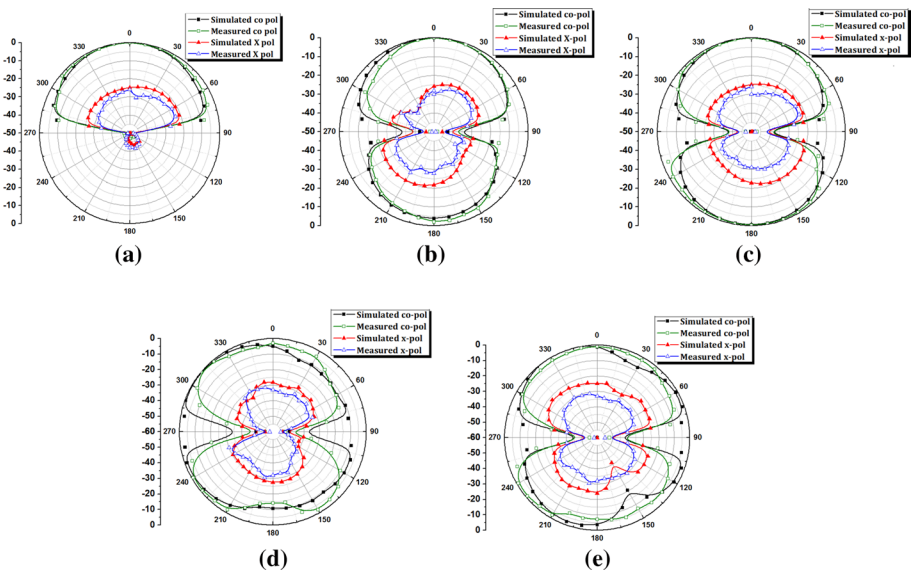


The E plane radiation patterns of Antenna 1 and Antenna 2 have been measured using standard microwave test bench. The measured co-polarization and cross-polarization of E plane radiation patterns for Antenna 1 at 5.6 GHz and Antenna 2 at 3.7 GHz, 4.27 GHz, 5.1 GHz and 9.85 GHz are shown in Fig. 7a–e. The beam widths for all the patterns have been found within  $40^{\circ}$ – $60^{\circ}$ . The radiation patterns of the proposed antenna look like dipole in nature due to presence of slots on the ground plane. The simulated current distribution of Antenna 2 at 3.8 GHz, 4.3 GHz, 5.3 GHz and 9.8 GHz are shown in Fig. 8a–d.

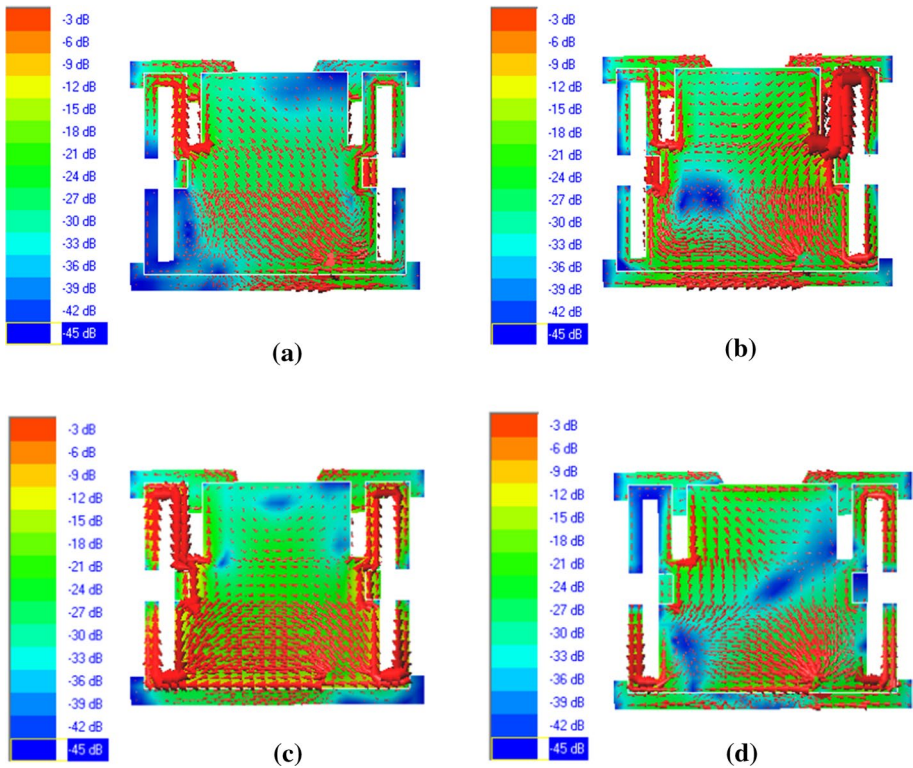
The current distributions depicted in Fig. 8a–d, show the current path for resonating each frequencies. Presence of slots on the patch disturb the current path on the patch and thus effective electrical length has been lengthened. So lower resonating frequencies has been generated. Different slots on the patch are responsible for different electrical length on the patch and incorporation of all slots on the patch simultaneously result multi frequency operation.

## 5 Conclusion

A compact wideband meandered slotted microstrip patch antenna has been designed and presented in this paper. The proposed antenna resonates at 3.7 GHz, 4.27 GHz and 5.1 GHz along with a wide bandwidth of 7.7 GHz i.e. 78.2% of its center frequency 9.85 GHz and almost 60% compactness has been found with respect to conventional rectangular microstrip antenna. The reference antenna and proposed antenna have been designed using MOM based software IE3D and the fabricated antennas have been measured by vector network analyzer. With several parametric studies it has been discussed in the paper that multi frequency operation has been achieved by cutting meandered slots on the patch and slots on finite ground plane lead to wideband operation. The antenna may be suitable for



**Fig. 7** Radiation pattern of **a** Antenna 1 at 5.6 GHz, Antenna 2 at **b** 3.7 GHz, **c** 4.27 GHz, **d** 5.1 GHz, **e** 9.85 GHz



**Fig. 8** Current distribution of Antenna 2 at **a** 3.8 GHz, **b** 4.3 GHz, **c** 5.3 GHz and **d** 9.8 GHz

WiMAX applications and 6–13.7 GHz wide band may be used for X band satellite communication and ITU band application.

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