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5 × 5 Matrix Patch Type Frequency Selective Surface Based Miniaturized Enhanced Gain Broadband Microstrip Antenna for WLAN/WiMAX/ISM Band Applications

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Abstract—In this work FSS (Frequency Selective Surface) based broadband, compact and improved gain microstrip patch antenna with defected ground structures for WLAN and WiMAX applications are proposed. A comparative study has been done by using the proposed antenna. It is designed on a Rogers RT/duroid substrate (dielectric constant 2.2, thickness 1.6 mm, and loss tangent 0.0009). The structure of the rectangular patch is $0.10\lambda_0 \times 0.18\lambda_0$ at 5.5 GHz, where λ_0 is the free space wavelength. The lateral ground plane dimensions are $0.29\lambda_0 \times 0.27\lambda_0 \times 0.03\lambda_0\,\text{mm}^3$. A patch type FSS is loaded under the ground plane with separation 10 mm from the antenna. Broad frequency band is obtained along with three resonant frequencies at 5.25 GHz, 6.7 GHz and 11.05 GHz. The achieved frequency band and peak gain are 6.79 GHz (4.93 GHz–11.72 GHz) and 8.82 dBi, respectively. Maximum size reduction of 86% is achieved. The designed antenna is simulated, fabricated and measured to verify the results. The measured results are in good agreement with simulated data. It may be applied in WLAN, WiMAX 5.5/5.8 GHz wireless communication and X band applications.

1. INTRODUCTION

Microstrip patch antennas have some inherent properties, some of which are advantageous and some disadvantageous. The most advantageous properties of a patch antenna are low cost and planar; linear and circular polarizations are possible. It is easily used in any electronic device and has versatile applications. The main drawbacks of the microstrip patch antenna are low gain, narrow bandwidth, low power handling capacity, and high power losses. Various methods have been reported in different journals to fix the drawbacks of microstrip antennas. Some of them are presented here. The gain and bandwidth of a planer microstrip antenna were enhanced by array techniques in [1]. The radiating patch and ground plane both were modified to enhance antenna gain and frequency band simultaneously in [2]. The bandwidth of an antenna was enhanced by monopole microstrip antenna concept in [3]. The main problem of the monopole microstrip antenna is low gain. The gain of the monopole antenna was decreased abruptly with the increase of bandwidth. A broadband microstrip patch antenna was reported in [4]. The designed antenna provided 54% impedance bandwidth. In [5], a broadband microstrip patch antenna was designed covering WLAN 2.4/5.2/5.8 GHz, WiMAX 3.5/5.5, LTE-2500 and UWB lower application bands. In [6], the reported antenna was designed by a circular patch, and it was shorted with conductive vias. The reported antenna covered 18% impedance bandwidth with 6 dBi gain. In [7–26], multiple compact, multiband, broadband microstrip and monopole patch antennas were designed. In [9, 10, 18], three different shapes of broadband microstrip and monopole antennas by modified ground

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plane were designed. In [20, 21], a semi-circular patch and curved slot inside the rectangular patch were used on a monopole antenna to enhance the bandwidth. In [21], a compact microstrip antenna was designed. The designed antenna covered 10% frequency band with 81.6% size reduction. In [22–25], half cutting method was used to design a miniaturized monopole antenna. In [27–32], an FSS based broadband, multibands and high gain antenna was designed. Multiband was obtained by U-shaped FSS in [33]. The microstrip antenna was covered with Left Handed metamaterial in [34]. In this work, a miniature size, broadband microstrip patch antenna is designed. The proposed antenna is very small compared to reported works. Maximum size reduction of 86% with broadband is achieved. It is simulated using MOM based Ansoft Designer software and measured by vector network analyzer (instrument). Some related works on the given topic (without FSS antenna) published in different reputed journals are given in Table 1.

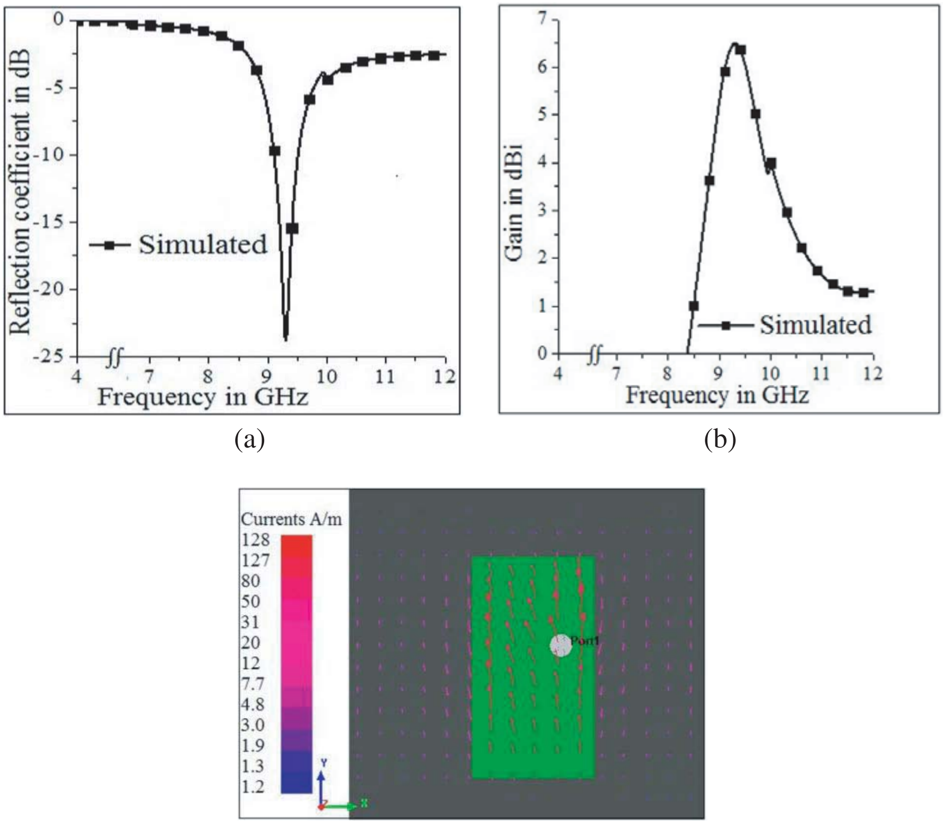
Table 1. Related published works on given topic.

References	**Electrical Dimensions of the patch antenna (in mm^3)**	**Max bandwidth (in %)**	**Gain (in dBi)**	**Size reduction**
[3]	$0.4\lambda_0 \times 0.44\lambda_0 \times 0.012\lambda_0$	109% (2–6.8 GHz)	4.8	——
[5]	$0.28\lambda_0 \times 0.22\lambda_0 \times 0.013\lambda_0$	94% (2.27–6.23 GHz)	3.5	——
[7]	$0.12\lambda_0 \times 0.403\lambda_0 \times 0.012\lambda_0$	27.79% (3–4.05) GHz	4.85	——
[8]	$0.162\lambda_0 \times 0.364\lambda_0 \times 0.013\lambda_0$	18.8% (5.12–6.18) GHz	4.97	——
[9]	$0.6\lambda_0 \times 0.6\lambda_0 \times 0.02\lambda_0$	100.35% (4.23–12.75 GHz)	3.2	——
[10]	$0.32\lambda_0 \times 0.21\lambda_0 \times 0.01\lambda_0$	86.71% (2.4–6) GHz	2.85	——
[11]	$0.206\lambda_0 \times 0.174\lambda_0 \times 0.0128\lambda_0$	13.7% (2.26–2.57) GHz	2.58	——
[18]	$0.3\lambda_0 \times 0.3\lambda_0 \times 0.013\lambda_0$	80% (2.23–5.35 GHz)	5	——
[20]	$0.71\lambda_0 \times 0.71\lambda_0 \times 0.02\lambda_0$	105.8% (2.65–8.6 GHz)	6.18	—-
[21]	$0.4\lambda_0 \times 0.44\lambda_0 \times 0.012\lambda_0$	109% (2–6.8 GHz)	4.8	—-
[22]	$42\lambda_0 \times 0.28\lambda_0 \times 0.02\lambda_0$	10% (3.36–3.715 GHz)	2.15	81.6%
[23]	$0.36\lambda_0 \times 0.18\lambda_0 \times 0.02\lambda_0$	84.35 (2.92–7.18 GHz)	5.85	75.5%
[24]	$0.33\lambda_0 \times 0.12\lambda_0 \times 0.012\lambda_0$	114% (3–11.1 GHz)	—-	50%
Proposed	$0.87\lambda_0 \times 0.82\lambda_0 \times 0.23\lambda_0$	81.56% (4.93–11.72 GHz)	8.82	86%

2. ANTENNA DESIGN METHODOLOGY

2.1. Fabricated Antenna Design

A rectangular patch of dimensions $0.10\lambda_0 \times 0.18\lambda_0$ and a rectangular ground plane of dimensions $0.29\lambda_0 \times 0.27\lambda_0$ are separated by a $0.029\lambda_0$ thick substrate at 5.5 GHz, where λ_0 is the free space wavelength. The parameters of Rogers RT/duroid substrate are relative permittivity $\varepsilon_r = 2.2$, thickness $h = 1.6$ mm, and loss tangent $\tan\delta = 0.0009$. The centre coordinates of the reference antenna are considered at (−1.75, −8) (radiating patch 1) and (−2, −7.5) (ground plane). Feeding point located on the reference antenna is 4 mm from top edge and 4 mm from the left edge of patch 1. The results of the reference antenna are given in Figure 1. Resonant frequency at 9.3 GHz with 6.57 dBi peak gain is obtained by the reference antenna. The patch is modified according to Figure 2(a) to improve the results. Two slits are loaded one by one into two opposite sides of the patch, and a U-shaped slot is embedded at an optimum position on the ground plane of the proposed antenna (Figure 2(a)) to enhance the frequency band. The modified patch and ground planes are separated by a Rogers RT/duroid dielectric substrate. The microstrip patch antenna and a photograph of the fabricated antenna are given in Figures 2(b) and 2(c), respectively. The feed point of the proposed antenna is located 0.5 mm from the bottom edge and left edge of the proposed patch. The dimensions of the microstrip antenna are shown



(a) (b)

(c)

Figure 1. Results of the reference antenna. (a) Reflection coefficients versus frequency, (b) gain versus frequency and (c) surface current distribution of the reference antenna at 9.3 GHz.

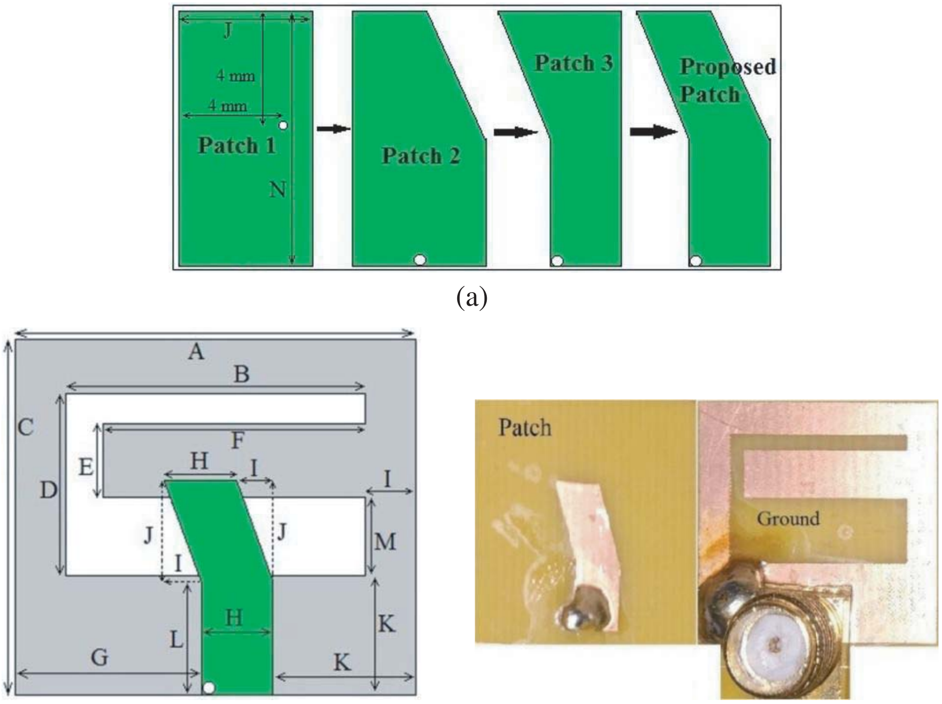
Table 2. Results of the antenna for the variation of parametric dimensions (all dimensions are in mm).

Parameters	Dimensions	Parameters	Dimensions
A	16	H	3.5
B	12	I	2
C	15	J	5.5
D	8	K	5
E	3	L	4.5
F	11	M	4
G	8	N	10

in Table 2. To improve antenna results, an FSS layer (Rogers RT/duroid substrate) is placed to the back side and 10 mm away from the antenna.

2.2. FSS Layer Design

The dimensions of each rectangular unit cell patch of the FSS are 9.5 mm × 9 mm. Five slots are introduced on each unit cell patch of the FSS. In a row, five unit cell patches are placed. Five such rows are repeated to make the two-dimensional array. The separation between two successive unit cells along the row and column is 0.5 mm which is less than one wavelength for the broadside incident cone



(a)

(b) (c)

Figure 2. Designed of the antenna. (a) Modified radiating patch, (b) proposed micristrip patch antenna and (c) photograph of the fabricated antenna.

according to [35, 36]. The dimensions of FSS and centre coordinate are 49.5 mm × 47 mm and (−3.5, −7.75). The structure of the FSS is given in Figure 3.

3. ANTENNA RESULTS AND DISCUSSIONS (WITHOUT FSS)

Impedance bandwidth, antenna gain and radiation patterns of the designed antenna are analyzed. The parametric studies have been done on the reference antenna to improve the result. The gain is reduced to 3.5 dBi with the increase of frequency band for the loaded slot on the ground plane.

3.1. Results for Different Patch with Modified Ground Plane

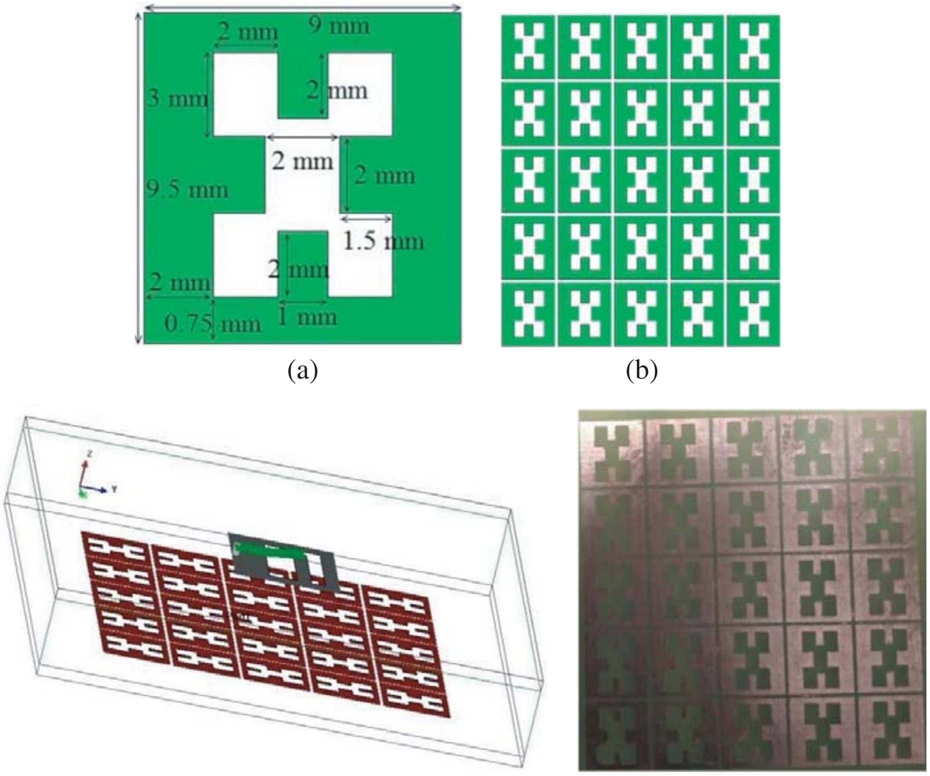
In Figure 4, reflection coefficient and antenna gain versus frequency for different patch shapes with U-shaped slot embedded ground plane are portrayed. It is found that the reflection coefficient and antenna gain (at the high frequency) both are enhanced for the modification of the patch. Two resonant frequencies at 5.5 GHz, 11.05 GHz and 5.6 GHz, 11.1 GHz of patch 1 and patch 2 antennas are obtained. Two broad frequency bands around the resonant frequencies for patch 1 are 1.1 GHz (5.2 GHz–6.3 GHz) and 2.60 GHz (9.05 GHz–11.65 GHz) are obtained. Similarly, broad bandwidth of 1.0 GHz (5.3 GHz–6.3 GHz) and 2.62 GHz (9.05 GHz–11.67 GHz) for patch 2 is found. For patch 3 and the proposed patch antennas, reflection coefficient, number of resonant frequencies and impedance bandwidth are improved. For patch 3, two frequency bands of 1.2 GHz (5.1 GHz–6.3 GHz) and 3.85 GHz (8 GHz–11.85 GHz) at 5.35 GHz, 9.8 GHz and 11.3 GHz are obtained. The peak antenna gains for patch 1 to patch 3 with modified ground plane are 3.5 dBi, 3.5 dBi, and 3.4 dBi. Gain and reflection coefficient of the proposed patch (with bend) are 0.4 dBi and −19.6 dB. They are more than a simple rectangular patch. Bandwidth and reflection coefficient both are improved gradually for introducing slits on the patch one by one. The fringing field at the edge of the proposed patch is increased for loaded slits on the patch.

3.2. Results for Different Ground Plane Dimensions

The reflection coefficient and antenna gain for the variation of length (A) and width (C) of the ground plane are investigated. Different investigated areas of the ground planes are 14 mm × 14 mm, 15 mm × 15 mm, 16 mm × 16 mm and 17 mm × 17 mm. Two frequency bands for the dimensions 14 mm × 14 mm are 0.82 GHz (5.23 GHz–6.05 GHz) and 5.34 GHz (6.5 GHz–11.84 GHz). For dimensions 15 mm×15 mm, bandwidth of the antenna is increased from 5.34 GHz to 6.83 GHz (5.02 GHz–11.85 GHz). After that for ground plane dimensions of 17 mm × 17 mm, frequency band is reduced to 2.30 GHz (5.15 GHz–7.45 GHz). All the demonstrated results are shown in Figure 5. It is found from the analysis that the frequency band directly depends on the ground plane dimensions. Antenna gain is varied with the frequency band. All the simulated results of the designed antenna are presented in Table 3.

Table 3. Results for different modified patches with modified ground plane.

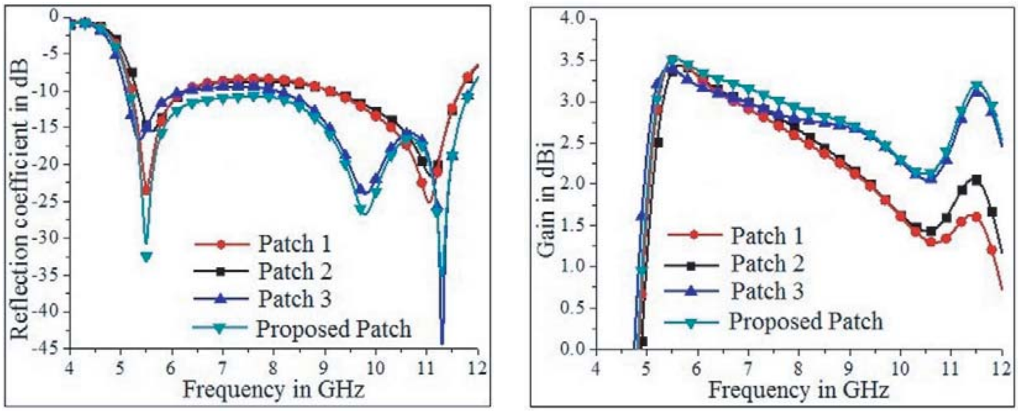
Shaped of patch	Resonant (in GHz)	Reflection coefficient at resonant (in dB)	Bandwidth (in GHz)	Peak gain (in dBi)
Patch 1	5.5 and 11.05	−23.5 and −25.35	5.2–6.3 and 9.05–11.65	3.5 (at 5.55 GHz)
Patch 2	5.6 and 11.1	−15.6 and −21.60	5.3–6.3 and 9.05–11.67	3.5 (at 5.65 GHz)
Patch 3	5.35, 9.8 and 11.3	−16.8, −24 and −50	5.1–6.3 and 8–11.85	3.4 (at 5.45 GHz)



(a) (b)

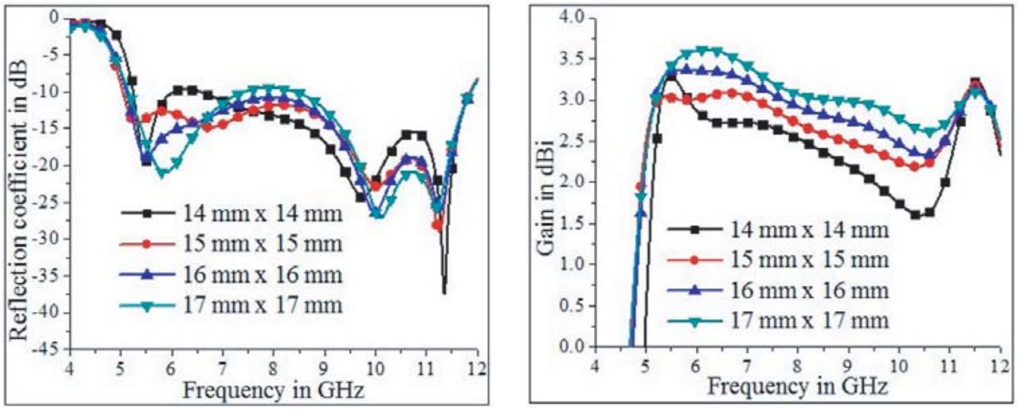
(c) (d)

Figure 3. Design of the FSS. (a) Unit cell patch of the FSS, (b) proposed FSS, (c) 3D view of the proposed antenna and (d) fabricated FSS.



(a) (b)

Figure 4. Reflection coefficients versus frequency and gain versus frequency for different shapes of the patch.



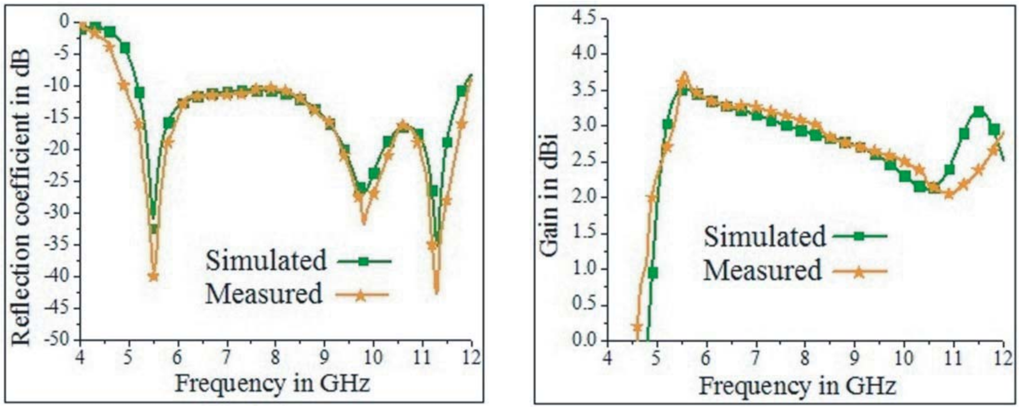
(a) (b)

Figure 5. Reflection coefficients versus frequency and gain versus frequency for different ground plane dimensions.

4. RESULTS OF THE FABRICATED ANTENNA (WITHOUT FSS)

The measured results of the proposed antenna are presented in Figure 6. The dimensions of the proposed antenna are given in Table 1. Figure 6(a) shows the reflection coefficient response of the proposed antenna. The achieved simulated and measured frequency bands of the proposed antenna are 6.72 GHz (5.16 GHz–11.88 GHz) and 7.05 GHz (4.9 GHz–11.95 GHz). Three resonant frequencies at 5.5 GHz, 9.8 GHz and 11.3 GHz are generated due to the multiple current paths throughout the modified surface. By cutting slits on optimum positions of the radiating surface and ground plane, normal flow of the surface current is interrupted. All these nearby resonant frequencies are combined, and a broad frequency band of 7.05 GHz is obtained. The reflection coefficient at the resonant frequency 5.5 GHz is -40 dB. The measured peak gain of 3.8 dBi at 5.5 GHz is obtained. All the simulated and measured results of the proposed antenna are given in Table 4.

Simulated co and cross polarizations (E and H plane) of the proposed antenna at 5.5 GHz, 9.8 GHz and 11.3 GHz are presented in Figure 7. Simulated and measured results of E plane radiation patterns are demonstrated in Figure 8, and they are in good parity. Far field distributions of the conventional antenna and fabricated antenna at 9.3 GHz and 5.5 GHz respectively are presented in Figure 9. Surface current distributions of the reference patch with modified ground plane and proposed antenna are demonstrated in Figures 10 and 11. The maximum surface current density of the conventional patch

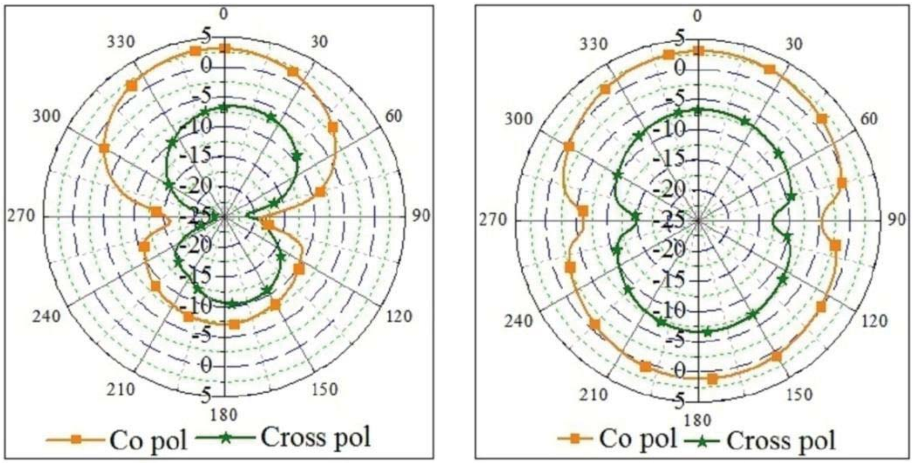


(a) (b)

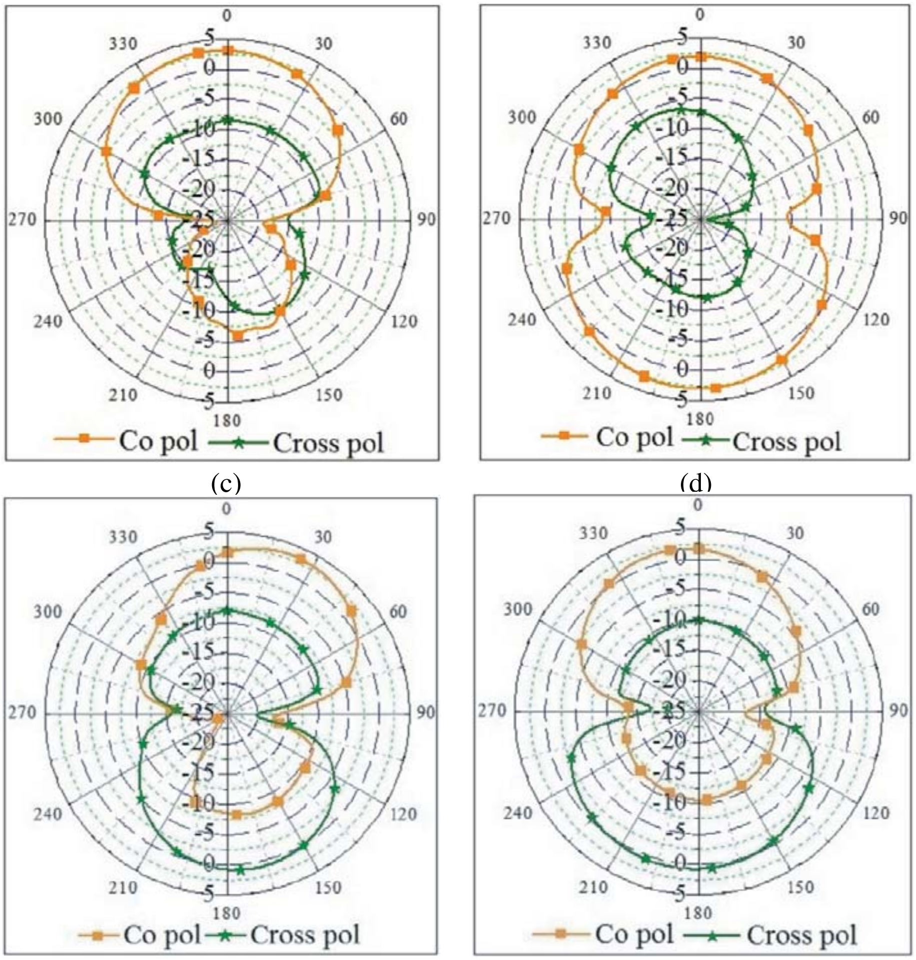
Figure 6. Reflection coefficients versus frequency and gain versus frequency response of the proposed antenna.

Table 4. Results for various dimensions of ground plane with proposed patch.

Dimensions	**Resonant frequency (in GHz)**	**Reflection coefficient at resonance (in dB)**	**Bandwidth (in GHz)**	**Peak gain (in dB)**
$14 \times 14\,\mathrm{mm}^2$	5.45, 9.75 and 11.35	−20.26, −24.3 and −41	5.23–6.05 and 6.5–11.84	3.28 (at 5.5 GHz)
$15 \times 15\,\mathrm{mm}^2$	5.3, 10.1 and 11.25	−14.35, −22.7 and −29.45	5.02–11.85	3.2 (at 11.5 GHz)
$16 \times 16\,\mathrm{mm}^2$	5.5, 10 and 11.25	−18.9, −26.4 and −26.3	5.1–11.88	3.4 (at 5.6 GHz)
$17 \times 17\,\mathrm{mm}^2$	5.5, 10.1 and 11.2	−21, −27.2 and −25.7	5.15–7.45 and 8.44–11.86	3.6 (at 6 GHz)
Proposed patch	5.5, 9.8 and 11.3	−32.4, −26.8 and −37.2	5.16–11.88	3.52 (at 5.5 GHz)
Measured	5.5, 9.81 and 11.4	−40, −32 and −45	4.9–11.95	3.8 (at 5.5 GHz)



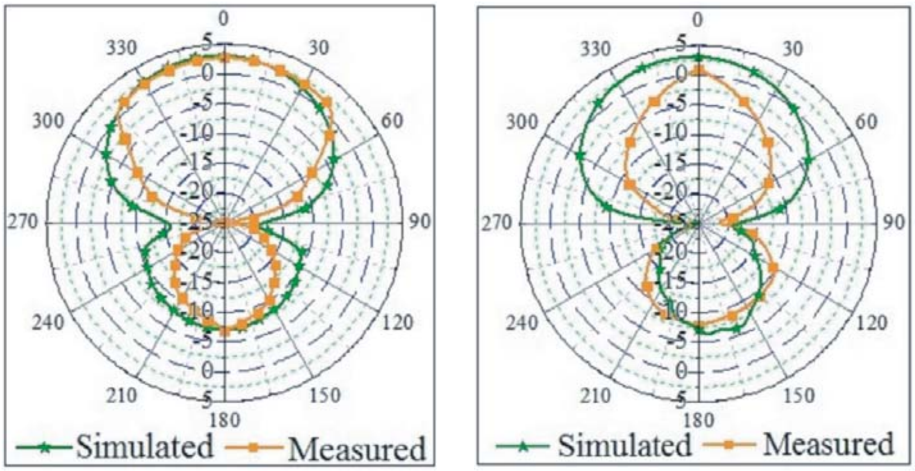
(a) (b)



(c) (d)

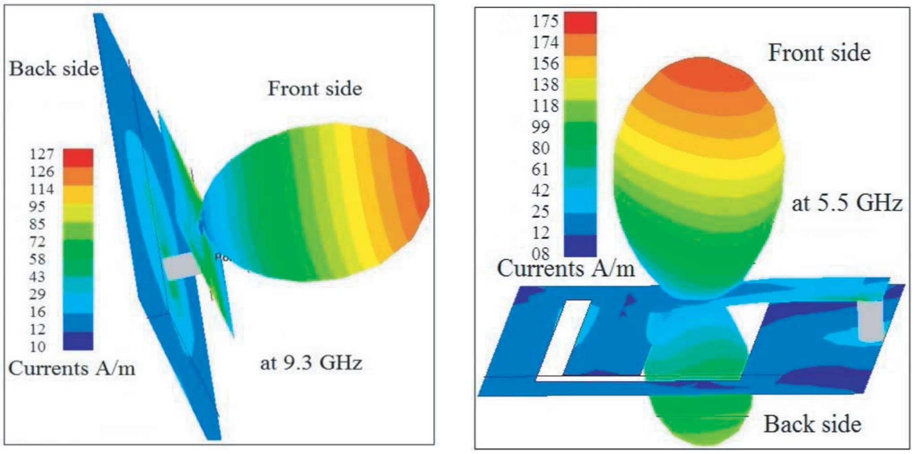
(e) (f)

Figure 7. *E*-plane radiation patterns of the proposed antenna at (a) 5.5 GHz, (c) 9.8 GHz and (e) 11.3 GHz and *H*-plane radiation at (b) 5.5 GHz, (d) 9.8 GHz and (f) 11.3 GHz.



(a) (b)

Figure 8. *E* plane simulated and measured radiation patterns of the proposed antenna at (a) 5.5 GHz, (b) 9.8 GHz.



(a) (b)

Figure 9. Far field distribution. (a) Conventional antenna at 9.3 GHz and (b) proposed antenna at 5.5 GHz.

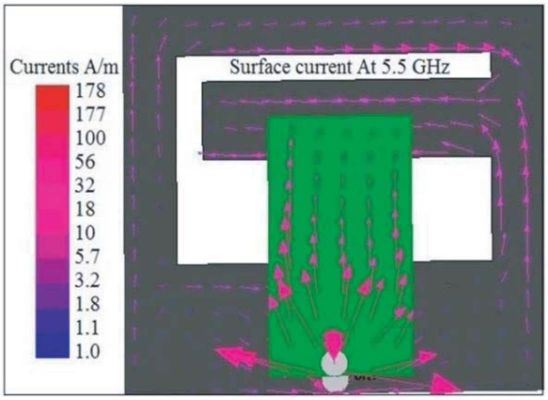
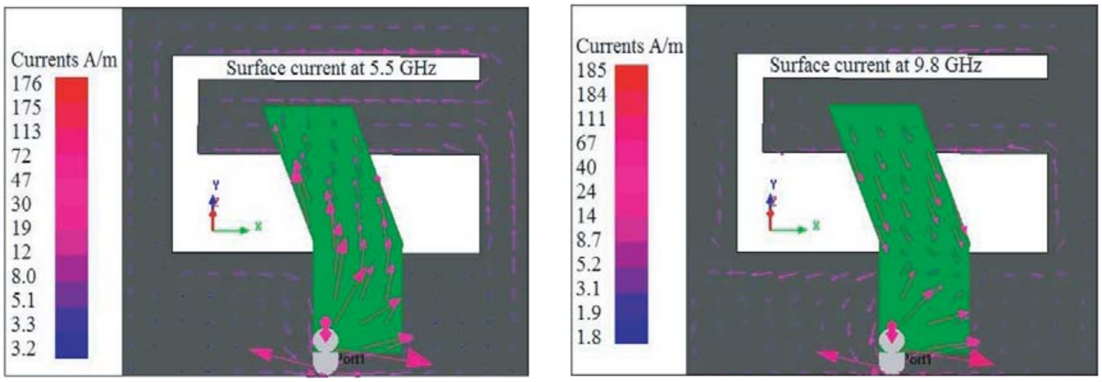
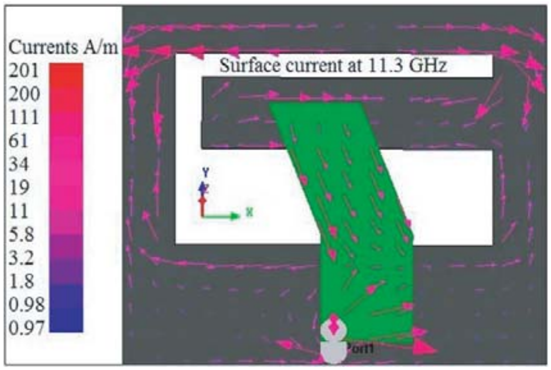


Figure 10. Surface current distribution of reference patch 1 with modified ground plane at 5.5 GHz.

with modified ground plane is 178 A/m. Current density is further increased by the modified radiating patch (proposed patch). The current distributions of the proposed patch antenna at 5.5 GHz, 9.8 GHz and 11.3 GHz are demonstrated. Maximum current density of 201 A/m at 11.3 GHz is found.

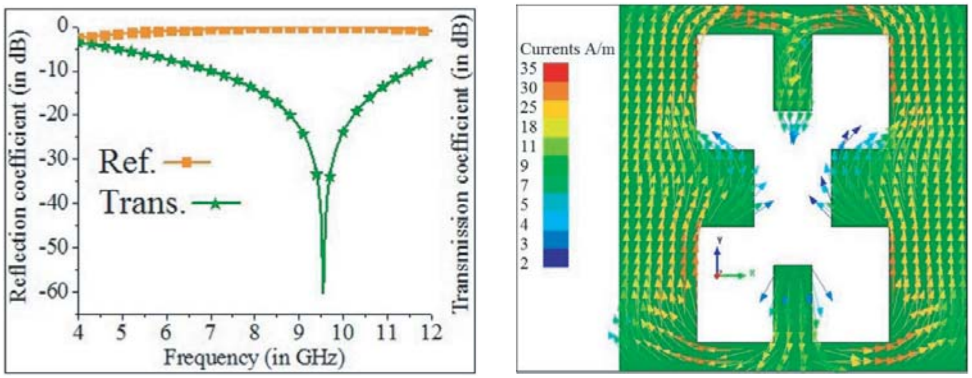


(a) (b)



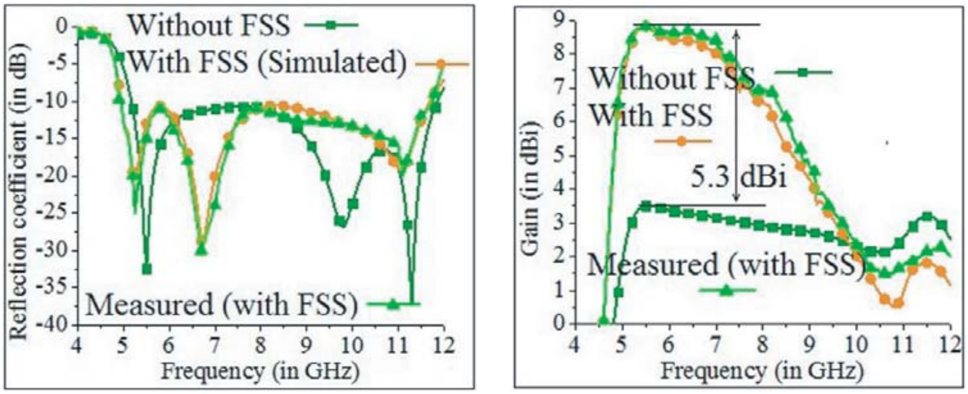
(c)

Figure 11. Surface current distribution of the proposed antenna at (a) 5.5 GHz and (b) 9.8 GHz and (c) 11.3 GHz.



(a) (b)

Figure 12. Results of the FSS. (a) Reflection and transmission coefficient of unit cell and (b) current distribution at 9.55 GHz.

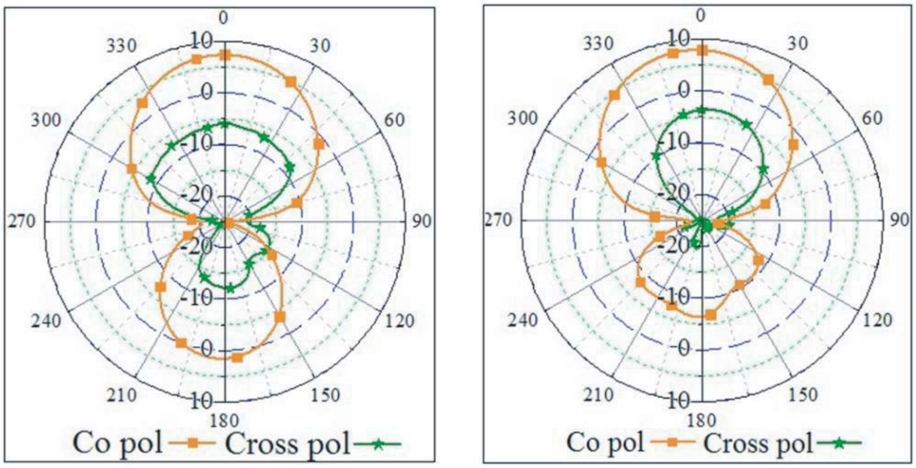


(a) (b)

Figure 13. Results of the proposed antenna. (a) Reflection coefficient and (a) gain.

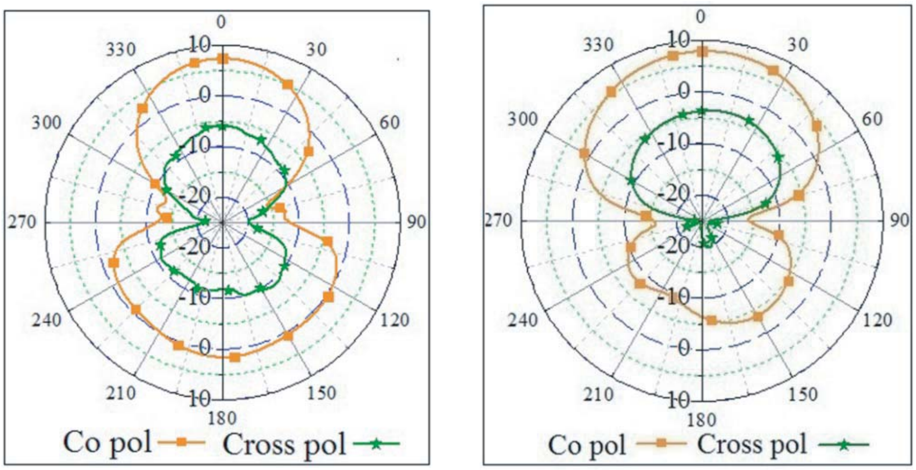
5. RESULTS OF THE PROPOSED ANTENNA (WITH FSS)

Basically two techniques are used in this work to enhance the antenna performance. First of all, frequency band is increased by loading slots on the radiating patch and ground plane. But the peak gain is reduced with the broad frequency band due to the loaded slots on the proposed antenna. An FSS layer is used to enhance the peak gain with maintained broad frequency band. The reflection coefficient, transmission coefficient and surface current distribution of unit cell patch of the FSS layer at 9.55 GHz are portrayed in Figure 12. Maximum surface current density obtained at 9.55 GHz is 35 A/m. The proposed FSS behaves as a band reject filter with frequency band 4.55 GHz (6.95 GHz–11.5 GHz) considering −10 dB frequency bands. In Figure 13, reflection coefficient and gain of the proposed antenna are presented. Three resonant frequencies are obtained at 5.25 GHz, 6.7 GHz and 11.05 GHz by the proposed antenna. The obtained simulated frequency band is 6.79 GHz (4.9 GHz–11.72 GHz). So, the impedance bandwidth is not changed significantly. The 2nd resonant frequency is shifted left by approximately 3 GHz. The gain of the proposed antenna (with FSS) is increased abruptly. The measured peak gain of 8.82 dBi is achieved, which is 5.3 dBi more than the microstrip antenna without FSS. Finally, the antenna gain is enhanced by FSS without degradation of frequency band and other characteristic parameters. The *E* and *H* plane radiation patterns are portrayed in Figures 14 and 15. The co polarization is much better than the cross polarization at 5.25 GHz and 6.7 GHz. Finally, back radiation of the proposed antenna is reduced by the FSS layer and enhanced peak gain. The simulated and measured results are in good parity.



(a) (b)

Figure 14. *E* plane radiation patterns at (a) 5.25 GHz and (b) 6.7 GHz.



(a) (b)

Figure 15. *H* plane radiation patterns at (a) 5.25 GHz and (b) 6.7 GHz.

6. CONCLUSION

A compact, broadband enhanced gain FSS based microstrip patch antenna is designed. A broadband is achieved by a small size 5.5 mm × 10 mm microstrip patch. Three resonant frequencies at 5.25 GHz, 6.7 GHz and 11.05 GHz are achieved. A broad impedance bandwidth of 6.79 GHz (4.93 GHz–11.72 GHz) with 8.82 dBi peak gain is achieved. Broad bandwidth, high gain, higher size reduction and stable radiation patterns are achieved by a single antenna. With the broadband, size reduction of 86% is achieved. Multiple parameter improvements by a single antenna is very rare. The small size, high gain broadband microstrip patch antenna is in very good demand in modern wireless communication system. The proposed antenna may be used in WLAN, WiMAX, 5.8 GHz ISM band and IEEE 802.11a HIPERLAN2 (5.45–5.725 GHz) and X band applications.

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