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Compact Modified Ground Plane (MGP) Microstrip Antenna with Narrowband and Wideband Resonance Characteristics

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Abstract

A single layer, coaxial probe feed slotted microstrip patch antenna with modified ground plane has been designed and analyzed. The ground plane of the antenna is modified by incorporating an open-ended asymmetric T-shaped slot. The proposed antenna depicts narrowband and wideband resonance characteristics due to the modified structure. The miniaturized antenna dimension is only about 30 ($0.645\lambda_r$) × 20 ($0.430\lambda_r$) mm^2, where λ_r is the wavelength of the resonant frequency of the conventional antenna (i.e., 6.45GHz). The measured result shows that the proposed antenna exhibits −10-dB wide impedance bandwidth of 62.3% from 2.53 to 4.82 GHz and two distinct narrow resonant frequencies at 6.165 and 8.18 GHz due to modifications in the ground plane. The size of the proposed antenna has been reduced by 70% in comparison to the conventional rectangular microstrip antenna with same patch area. An extensive analysis of the antenna parameters (reflection coefficient, VSWR, radiation pattern, gain, directivity, radiation efficiency etc.) including surface current distribution is presented in this paper. The proposed antenna could be promising for a number of modern wireless communication applications due to its small size, low cost and wide operating bandwidth.

Keywords: *Compact, modified ground plane, narrowband, wideband, wireless communication*

1. Introduction

Microstrip patch antennas (MPAs) are popular for wireless communication applications due to their well-known attractive features, such as low profile, light weight, conformable to planar and non-planar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology, mechanically robust when mounted on rigid surfaces and compatible with MMIC designs. Apart from its various attractive features, microstrip patch antenna suffers from an inherent limitation of narrow impedance bandwidth typically of about $2-4\%$. However, in some applications, such as in astronomy, cognitive radio and government security systems, narrow bandwidths are desirable. Several narrowband microstrip antennas are reported by researchers [1-4]. But the increasing demands for wireless connectivity in modern wireless communication systems necessitate a single antenna to cover several allocated wireless frequency bands. The usage of many antennas is usually limited by the volume and cost constraints of the applications. Researchers have offered numerous techniques for bandwidth enhancement of microstrip patch antennas to support multiple wireless communication systems using single antenna. These techniques include use of shorting pin [5], aperture coupling [6],

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stacked patch [7], staggering effect [8], modified feed [9], thick foam substrate [10], fractal slots [11], PBG structure [12], and slots on the radiating patch [13] to enhance the bandwidth of microstrip antennas. The combinations of radiating patch and the ground plane slots [14] were also analyzed to achieve compact broadband operation. W. Cao et.al [5] proposed a broadband microstrip antenna loaded with shorting pin but only 9.5% bandwidth at 2 GHz has been achieved. Maximum bandwidth of 16% has been achieved ranging from 2.25–2.65 GHz using aperture coupled feeding, which is not suitable for 3.5 GHz WiMAX system [6]. The Stacked dual wide slit loaded rectangular microstrip antenna gives a broad bandwidth of 27% and 24% reduction in antenna size but due to stacking height of the antenna increases [7]. K.Mandal et al. has increased the bandwidth of microstrip antenna up to 27% using staggered effect, but the large size of the antenna is a major problem [8]. Ahmed et al [9] has proposed a wide-band small size microstrip antenna proximately coupled to a hook shape probe. The patch size is reduced to 25% with over 30% matching band-width. The microstrip antenna with 47% bandwidth is proposed but it uses thick substrate, which increases the height of the antenna [10]. Khanna and Srivastava [11] designed a square patch antenna with modified edges and square fractal slots with a bandwidth of 30%. Tyagi and Vyas [12] designed a slotted U-shaped microstrip antenna with PBG structure which has an impedance bandwidth of 35%. Diego et al [13] designed a wide band E shaped patch antenna that provides an impedance bandwidth of about 29.8% by cutting a zigzag slot on the patch. Kaur et al [14] has designed a U-shaped slot loaded inverted circular patch antenna with maximum bandwidth of 24.2%.

In this paper, a single layer coaxially fed slot loaded microstrip patch antenna with modified ground plane has been presented. The proposed antenna covers some important design aspects of microstrip patch antennas, such as (i) size reduction, (ii) narrowband multi-resonance characteristics, and (iii) enhancement of bandwidth. The novelty of our work is narrowband and wideband resonance characteristics in compact size by a single antenna without using thick foam substrate, shorting pin, stacked patch, multiple radiating patch element, complex fractal slots or modifications in the feed. The proposed antenna is successfully designed with thin, inexpensive, low dielectric constant FR-4 substrate. The structure of the proposed antenna is very simple and easy to fabricate. The wideband operation is achieved by defecting only 8% of the total ground plane area. The proposed antenna provides much better operating bandwidth (62.3%) and size reduction (70%) with simple and new structure in comparison to the previously reported antennas [1-14].

2. Antenna Configuration

The design of the antenna begins with a conventional rectangular microstrip antenna with patch length (L_P) = 10 mm and width (W_P) = 14 mm. The FR-4 substrate chosen for realizing the antenna has dielectric constant, ε_r = 4.4 and thickness (h) of 1.5875 mm. The geometry of the proposed antenna is shown in Figure 1. The structure of the modified rectangular patch is shown in Figure 1(a). The optimal dimensions of the proposed slot loaded patch are W_P = 14 mm, L_P = 10 mm, W_{P1} = W_{P2} =0.5 mm, L_{P1} = L_{P4}= 5 mm, L_{P2} = 4.25 mm, L_{P3} = 0.5 mm. The structure of the proposed modified ground plane of the proposed antenna is shown in Figure 1(b). Narrowband resonance characteristics and also wide operating bandwidth are achieved when the ground plane of the slotted patch is modified with etched open ended asymmetric T-shaped slot. The desired result is achieved for ground plane of width W_g = 30 mm and Length L_g = 20 mm. The width of the ground plane can be calculated using the empirical formula W_g = W_P+10h and length of the ground plane can be calculated by the empirical relation L_g= L_P+6.25h, where h is the thickness of the FR-4 substrate. The optimal dimensions of the modified ground plane of proposed antenna are W_g = 30 mm, L_g = 20 mm, W_{g1} = 3 mm, W_{g2} = 13.5 mm, $W_{g3} = 3\ mm$, L_{g1} = 11 mm, L_{g2} = 5 mm, L_{g3} = 4 mm. The feeding point is located at a position (X, Y) = (4 mm, 6 mm) from centre (X = 0 mm, Y = 0 mm) of the patch. All the parameters such as position of the slots on the patch and ground plane, dimension of the slots and position of the feed point were finalized by parametric study through a number of simulations using a method of moment based full wave commercial EM software IE3D [15]. The top view of the proposed antenna is shown in Figure 2. The prototype of the fabricated antenna is shown in Figure 3. The fabricated structure of the patch is shown in Figure 3(a), and the modified ground plane is shown in Figure 3(b).

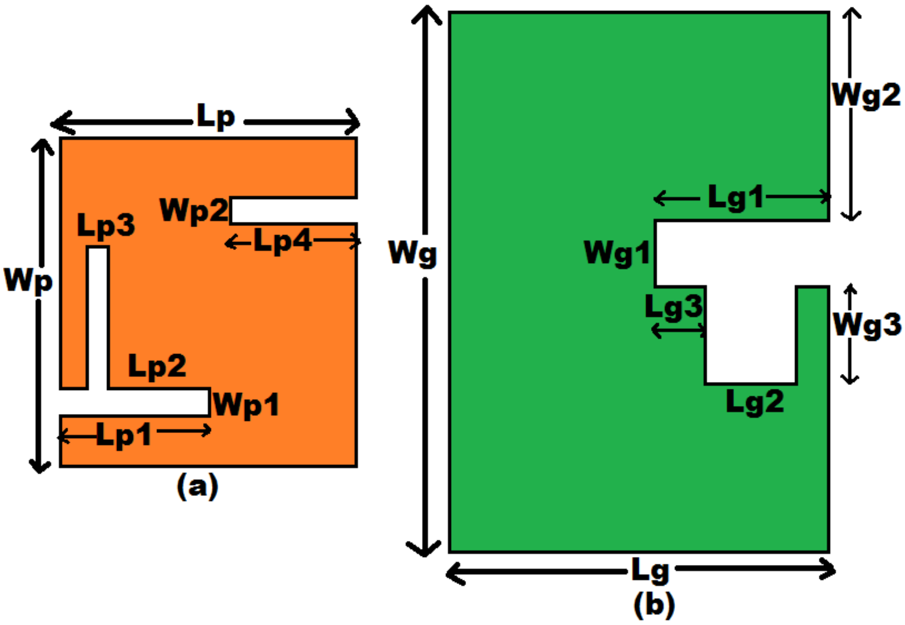

Figure 1. Structure of (a) Modified Rectangular Patch (b) Modified Ground Plane of the Proposed Antenna

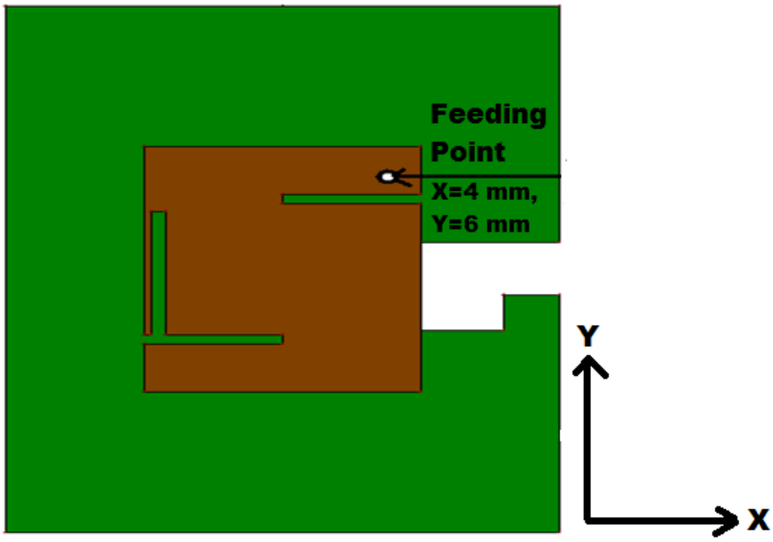

Figure 2. Top View of Proposed Antenna

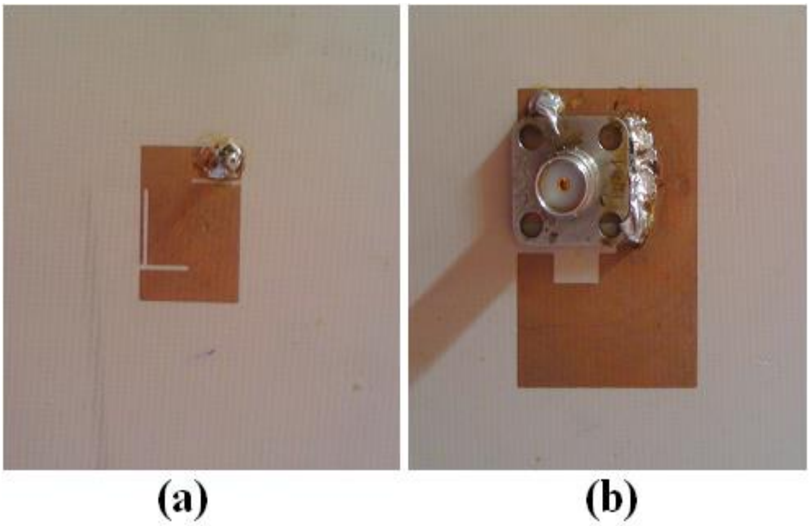

Figure 3. Fabricated Structure of the Proposed Antenna (a) Patch (b) Modified ground plane

3. Parametric Study of the Proposed Antenna

The structural effect of the ground plane on the antenna performance is investigated by mounting the proposed patch antenna on either of two different types of ground plane. The first is a conventional perfect electrical conductor (PEC) ground plane i.e., without modification in the ground plane and the other is a modified ground plane (MGP). Figure 4 compares the simulated reflection coefficient versus frequency of the conventional rectangular microstrip patch antenna (CRMPA) and proposed patch antenna with simple and modified ground plane. It can be observed from Figure 4 that in Case I, the conventional rectangular microstrip patch antenna resonates at 6.45 GHz. The antenna shows multifrequency operation with narrowband resonance characteristics, when designed with modified patch but simple (without slot) ground plane (Case II). The proposed antenna shows narrow band resonant frequencies and also wide operating bandwidth due to modified ground plane (MGP) structure (Case III). The effect of variations in the dimensions of the ground plane slots on the resonant characteristics of the proposed antenna were investigated by parametric study. The effective parameters are investigated by varying one parameter at a time when fixing the other parameters. The simulated results of variations in resonant frequency and reflection coefficient of the proposed antenna as a function of ground plane slots are shown in Figures 5-8. The proposed antenna with its optimum dimension provides bandwidth of 57.3 % from 2.49 to 4.49 GHz and two distinct narrow resonant frequencies at 5.905 and 7.76 GHz. Figure 5 indicates that if the length of the slot (L_{g1}) on the ground plane is decreased from 11 mm to 9 mm keeping other optimum dimension parameters fixed then the higher order resonant frequency is not excited below −10 dB and fractional bandwidth of the antenna is decreased to 13% (3.88−4.42 GHz). Further increase in L_{g1} from 11 mm to 13 mm provides fractional bandwidth of only 33.7 % (3.03−4.26 GHz) and higher resonant frequency is excited at 7.55 GHz with reflection coefficient −15 dB. It is noticed from Figure 6 that the fractional bandwidth of proposed antenna remains almost unchanged (55%) with further increase or decrease in ground plane slot parameter (L_{g2}) compared to proposed slot dimension. But the higher order resonant frequency is not excited when the value of L_{g2} decreases to 4 mm. It is observed from Figure 7 that if the dimension of W_{g1} is decreased from proposed value (3 mm) to 1 mm, the higher order resonant frequency is not excited below −10dB and the fractional bandwidth of the antenna decreases to 52.9% (2.68−4.61 GHz). The higher order resonant frequency can be easily exited below −10dB level by increasing the dimension of ground plane slot parameter (W_{g1}). It is clearly observed from Figure 8 that the fractional bandwidth (57.3%) of the proposed antenna remains unaltered with further increase in W_{g3} parameter. But when the dimension of W_{g3} is decreased to 1 mm compared to proposed slot dimension ($W_{g3} = 3\ mm$), the fractional bandwidth of the antenna is reduced to 48.6 % (2.57−4.22 GHz) and also the higher order resonant frequency is not excited. So, it can be concluded that the resonance behavior of the proposed antenna is greatly influenced by ground plane slot parameters and any further increase or decrease in these parameters than the proposed dimensions will drastically change the desired characteristics of the proposed antenna. The results of Figures 5-8 are summarized in Table 1.

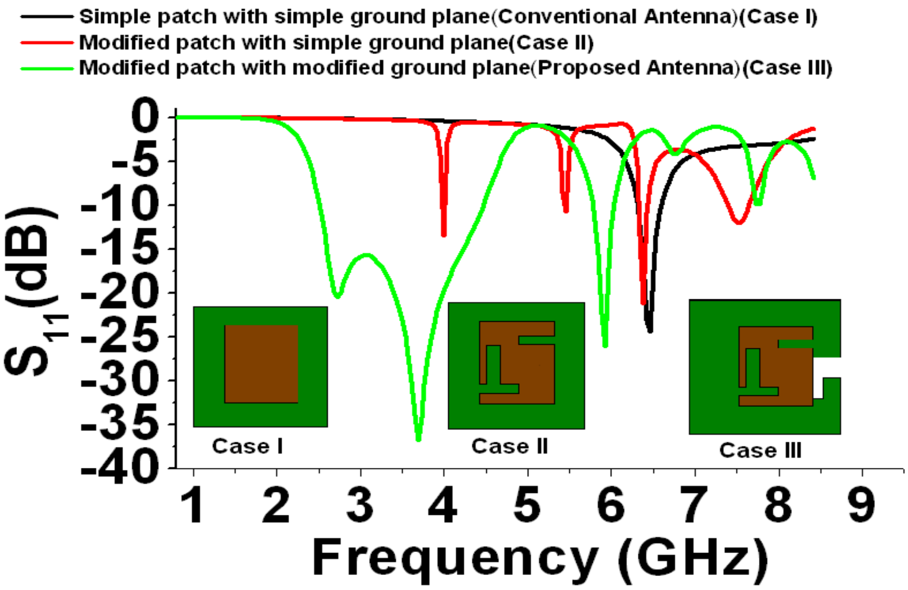

Figure 4. S_{11} Versus Frequency Comparisons in Different Cases

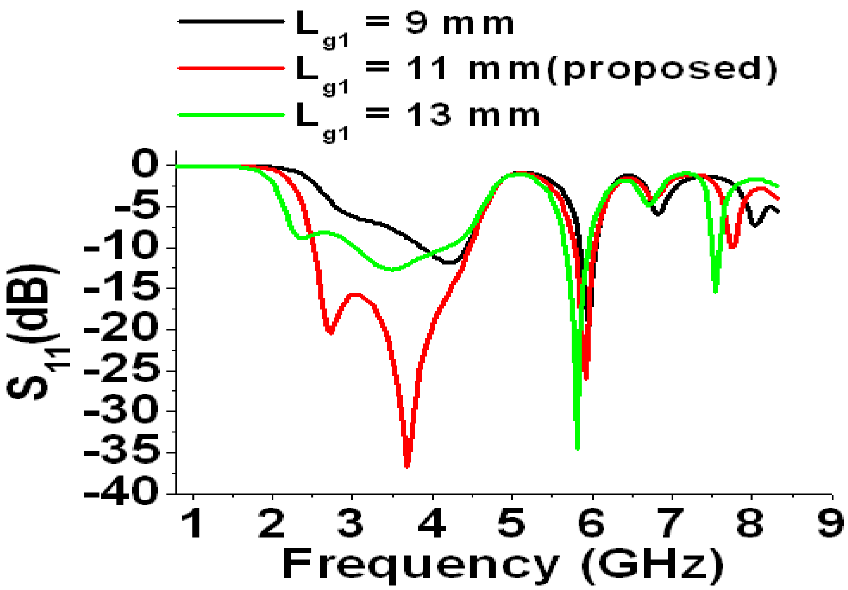

Figure 5. S_{11} Vs. Frequency as a Function of L_{g1}

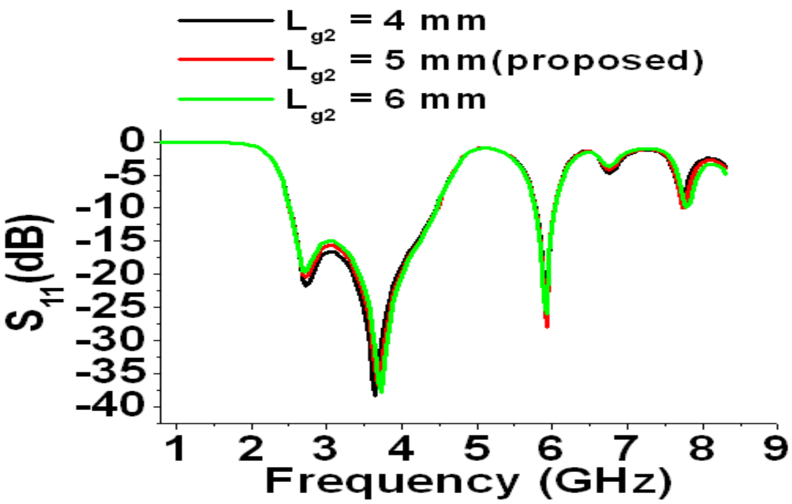

Figure 6. S11 Vs. Frequency as a Function of L_{g2}

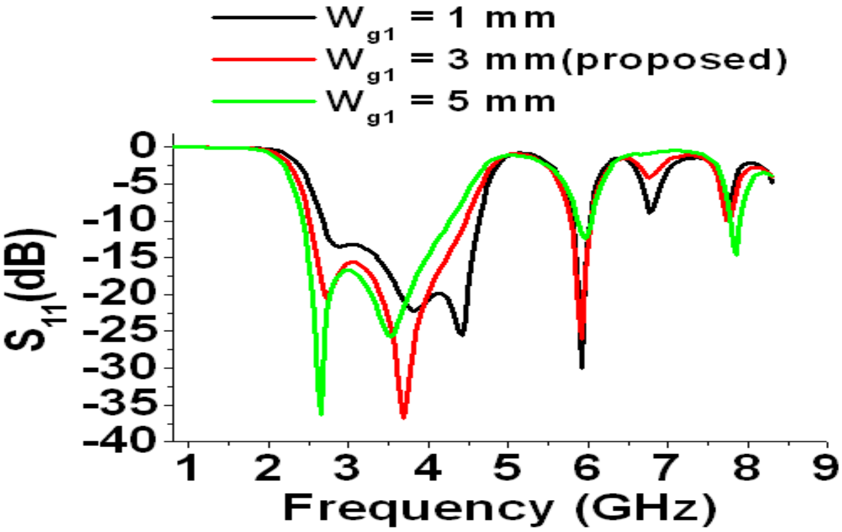

Figure 7. S11 Vs. Frequency as a Function of W_{g1}

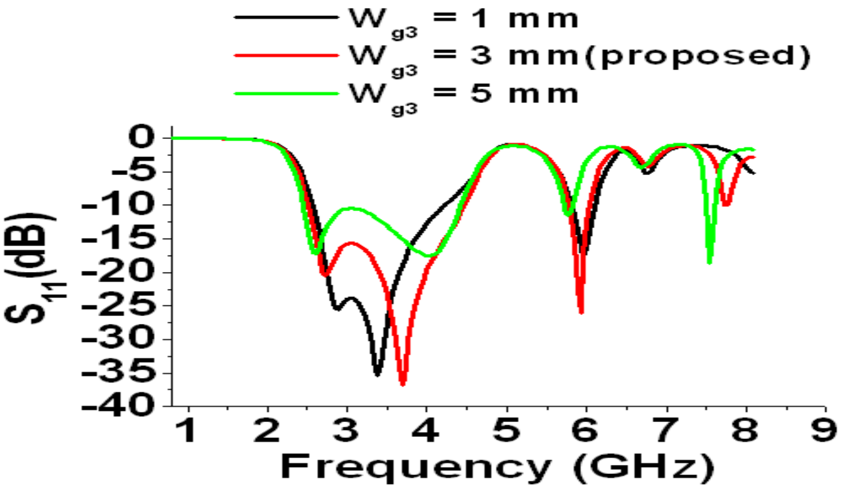

Figure 8. S11 Vs. Frequency as a Function of W_{g3}

Table 1. Simulated Results of Proposed Antenna for Variations of Ground Plane Parameters

Ground plane slot dimensions (mm)	Ratio of removed area/ Total ground Plane area (%)	Operating centre frequency (GHz)	−10 dB bandwidth (GHz)	Fractional Bandwidth (%)
L_{g1} = 9	7	f_{c1} = 4.15 f_{c2} =5.955	(3.88–4.42) (5.88–6.03)	13 2.51
L_{g1} = 11 (Proposed)	8	f_{c1} =3.49 f_{c2} =5.905 f_{c3} =7.76	(2.49–4.49) (5.78–6.03) (7.74–7.78)	57.3 4.23 0.5
L_{g1} = 13	9	f_{c1} =3.645 f_{c2} =5.80 f_{c3} =7.55	(3.03–4.26) (5.68–5.92) (7.53–7.57)	33.7 4.13 0.5
L_{g2} = 4	7.5	f_{c1} =3.49 f_{c2} =5.895	(2.53–4.45) (5.80–5.99)	55 3.22
L_{g2} = 5 (Proposed)	8	f_{c1} =3.49 f_{c2} =5.905 f_{c3} =7.76	(2.49–4.49) (5.78–6.03) (7.74–7.78)	57.3 4.23 0.5
L_{g2} = 6	8.5	f_{c1} =3.49 f_{c2} =5.895 f_{c3} =7.76	(2.53–4.45) (5.80–5.99) (7.74–7.78)	55 3.22 0.5
W_{g1} = 1	4.33	f_{c1} =3.645 f_{c2} =5.895	(2.68–4.61) (5.80–5.99)	52.9 3.22
W_{g1} = 3 (Proposed)	8	f_{c1} =3.49 f_{c2} =5.905 f_{c3} =7.76	(2.49–4.49) (5.78–6.03) (7.74–7.78)	57.3 4.23 0.5
W_{g1} = 5	11.66	f_{c1} =3.335 f_{c2} =5.955 f_{c3} =7.84	(2.41–4.26) (5.88–6.03) (7.80–7.88)	55.4 2.51 1.02
W_{g3}=1	6.33	f_{c1} =3.395 f_{c2} =5.955	(2.57–4.22) (5.84–6.07)	48.6 3.86
W_{g3} = 3 (Proposed)	8	f_{c1} =3.49 f_{c2} =5.905 f_{c3} =7.76	(2.49–4.49) (5.78–6.03) (7.74–7.78)	57.3 4.23 0.5
W_{g3}= 5	9.66	f_{c1} =3.43 f_{c2} =5.76 f_{c3} =7.55	(2.45–4.41) (5.72–5.80) (7.53–7.57)	57.3 1.38 0.5

4. Analysis and Working of the Proposed Antenna

The working principle of the proposed antenna can be explained with the help of surface current distributions. The effect of each optimized ground plane slot on the resonance behavior of the proposed antenna is depicted in Figure 9. The current distribution at the modified ground plane of the proposed antenna at different frequencies is shown in Fig. 10. The maximum surface current density varies from about 22.6 A/m (at 3.22 GHz) to 163.5 A/m (at 5.905 GHz). As depicted in Figure 9, the resonance behavior of the antenna changes drastically with the addition of each optimized slot on the ground plane of the proposed antenna. In Case I, Due to the introduction of optimized horizontal slot of dimensions, $W_{g1} = 3\,mm\,, L_{g1} = 11\,mm$ on the ground plane, the antenna resonates at 6.0, 8.30 GHz with reflection coefficients −16.4, −19.2 dB, respectively. In this case the antenna also provides a broad impedance bandwidth of 1570 MHz (2.57−4.14 GHz) for $S_{11} < -10$ dB. For the (2.57−4.14 GHz) operation, [see Figure 10(a)], it is observed that surface current density is much stronger around the horizontal slot (W_{g1}, L_{g1}) at the centre frequency 3.355 GHz of this band. Finally in case II, the incorporation of an optimized vertical slot $L_{g2} = 5\,mm, W_{g3} = 3\,mm$ has further reduced the resonant frequencies to 5.905 and 7.76 GHz, respectively. It has also increased the operating bandwidth of the antenna. The frequency bands get wider by 430 MHz, and the new operating bandwidth (2000 MHz) of the antenna ranges from 2.49 to 4.49 GHz. It is verified from Figure 10(b) that at 4.35 GHz, surface current density is much stronger around the vertical slot (L_{g2}, W_{g3}), which creates extra resonance path and varies the resonant frequency of the antenna. It is observed from Figure 10(c) that for 5.905 GHz, the surface current is mainly concentrated around the horizontal slot (W_{g1}, L_{g1}) for which this resonance mode is excited. But due to lengthening of the surface current around the vertical slot (L_{g2}, W_{g3}), the resonant frequency decreases to 5.905 GHz. So, the surface current also partly circulates around vertical slot at 5.905 GHz. For the 7.76 GHz operation [see Figure 10(d)], it is observed that the surface current circulates around both horizontal and vertical slot but it is mainly concentrated around the vertical slot (L_{g2}, W_{g3}) for which it generated and controlled. Thus, both from the S_{11} characteristic curves and surface current distributions, we can clearly comprehend the function of the related geometrical mechanism of the proposed antenna at three resonant modes. The modified ground plane disturbs the shield current distribution in the ground plane. As a result they change the inductance and capacitance. Basically modified ground plane increases the value of inductance and capacitance. Due to modifications in the ground plane, a parasitic field or fringing is created and this creation of fringing field increases the coupling between the conducting patch and ground plane. This increased coupling enhances the bandwidth of operation of the antenna. The bandwidth enhancement process may also be realized by obtaining multiple resonant frequencies that radiate very close to each other under −10dB levels, and their resonance envelopes provide the desired bandwidth.

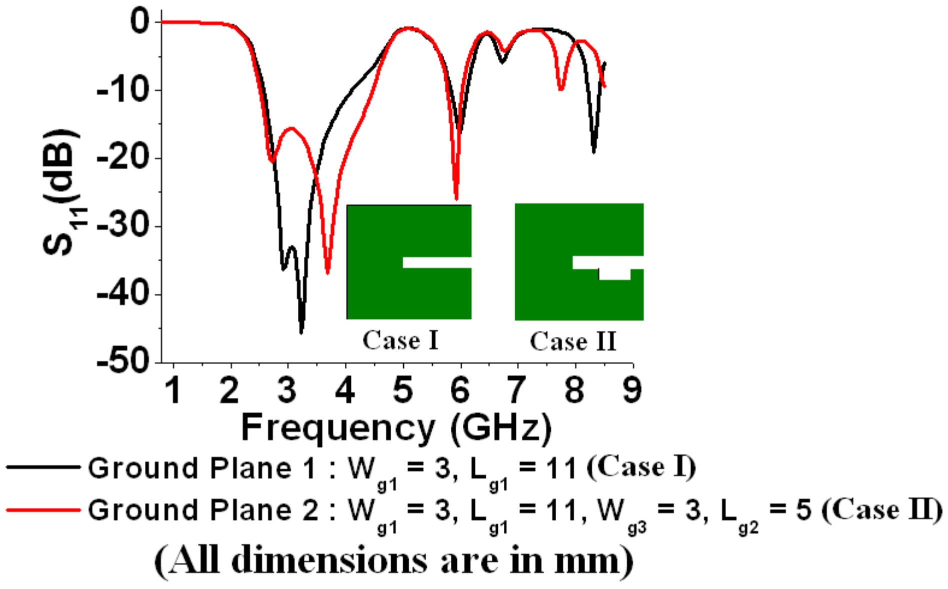

Figure 9. Effect of Each Optimized Ground Plane Slot

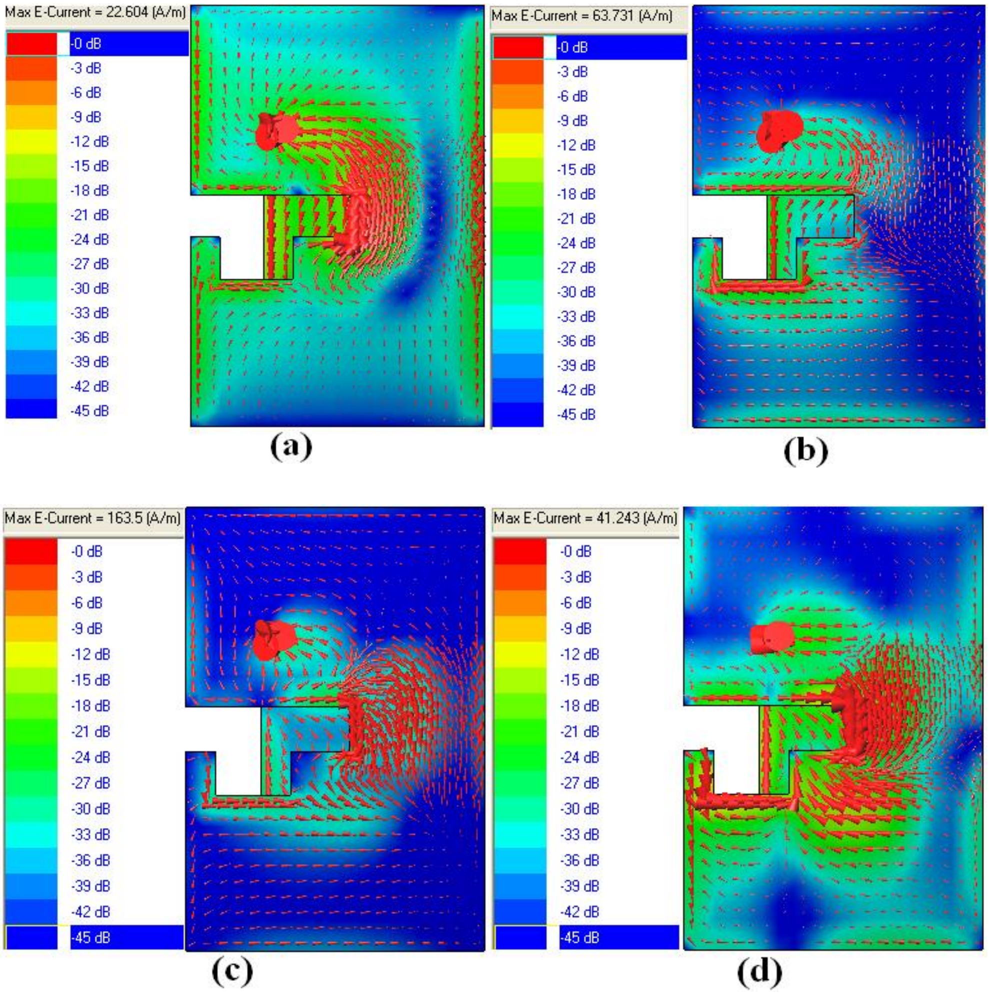

Figure 10. Current Distribution on the Ground Plane of Proposed Antenna at (a) 3.355 GHz, (b) 4.35 GHz, (c) 5.905 GHz, and (d) 7.76 GHz

5. Results and Discussion

The reflection coefficient of the fabricated antenna was measured using Agilent E5071B vector network analyzer. The agreement between the simulated and measured results is reasonably good. The discrepancy between the measured and simulated results may be due to the effect of improper soldering of SMA connector or fabrication tolerance. The simulated and measured reflection coefficient of proposed antenna is shown in Figure 11. The results of Figure 11 are summarized in Table 2. The measured result shows that the size of the proposed antenna has been reduced by 70% in comparison to the conventional rectangular microstrip antenna operating at 3.675 GHz with patch area (19×25 mm^2). The E and H plane radiation pattern of the proposed antenna is shown in Figure 12(a)-(c). The nearly bidirectional characteristics are achieved due to partial removal of conducting material below the radiating patch. The removed area is only 8% of the total ground plane dimension. Depending on the shape and dimensions of the defect on the ground plane, the shielded current distribution in the ground plane is disturbed which results in a controlled excitation and propagation of the electromagnetic waves through the substrate layer. This disturbance will cause change in radiation characteristics of the proposed antenna [16]. It is notable that cross polarization levels of the antenna are improved due to modified ground structure. Figure 12(a) indicates 20 dB higher co polar patterns than cross polar pattern for both E and H plane at 2.75 GHz. It is seen from

Figure 12 (b) that the radiation characteristics of the proposed antenna shows good cross-polarization level of −28 dB in comparison to the co polarization level of the main lobe at E plane and H plane for the centre frequency 3.675 GHz of the broadband frequency range. So, the proposed antenna shows considerably good cross polar pattern over the entire impedance bandwidth (2.49–4.49 GHz). The antenna radiation patterns are almost identical in shape with in broadband frequency range. However, Figure 12(c) suggests that at narrowband frequency 5.905 GHz, co polar pattern is nearly 30 dB higher than cross polar pattern for E plane while it is 16 dB higher than cross polar pattern for H plane. So, the result of Figure 12 shows that isolation between co and cross polarization is quite high. Due to nearly bidirectional radiation characteristics, the proposed antenna may be used in bidirectional radar. The simulated and measured gain of the proposed antenna is shown in Figure 13. The measured peak gain of the antenna is about 2.70dBi at 3.7 GHz, which is better than the peak gains of some previously reported band width enhanced microstrip antennas [17-20]. The peak gain is measured by applying gain comparison method, in which a pre calibrated standard gain horn antenna is used as a reference antenna for measurement. The simulated result of directivity and radiation efficiency of the proposed antenna is shown in Figure 14. Peak radiation efficiency of about 73% is achieved in the broad band operating range. Peak directivity of about 7.0dBi is obtained at 7.76 GHz. The VSWR of the proposed antenna is shown in Figure 15. The maximum VSWR lies within 1.7:1 at the desired frequencies.

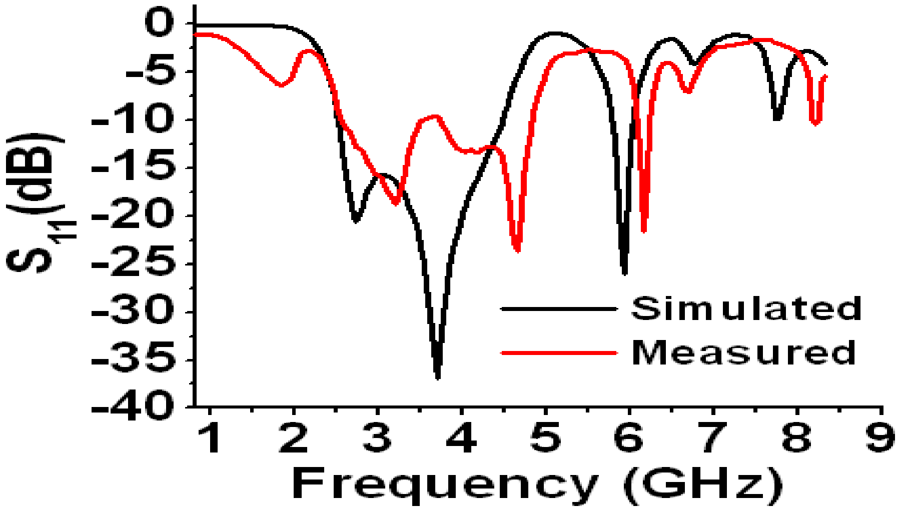

Figure 11. Reflection Coefficient of Proposed Antenna

Table 2. Simulated and Measured Results of Proposed antenna

Proposed Antenna	Operating centre frequency (GHz)	−10 dB Band Width (GHz)	Band-width (%)
Simulated	3.49	(2.49−4.49)	57.3
	5.905	(5.78−6.03)	4.23
	7.76	(7.74−7.78)	0.5
Measured	3.675	(2.53−4.82)	62.3
	6.165	(6.10−6.23)	2.1
	8.18	(8.15−8.21)	0.6

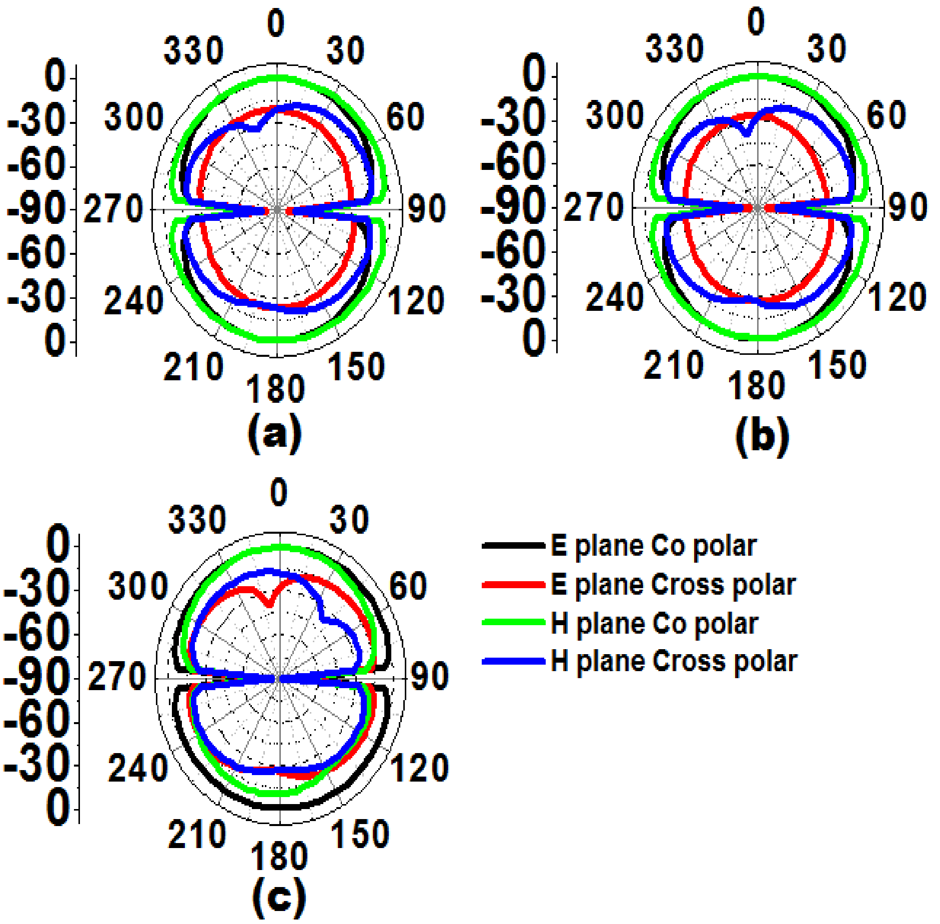

Figure 12. E and H Plane Radiation Pattern at (a) 2.75 GHz, (b) 3.675 GHz, (c) 5.905 GHz

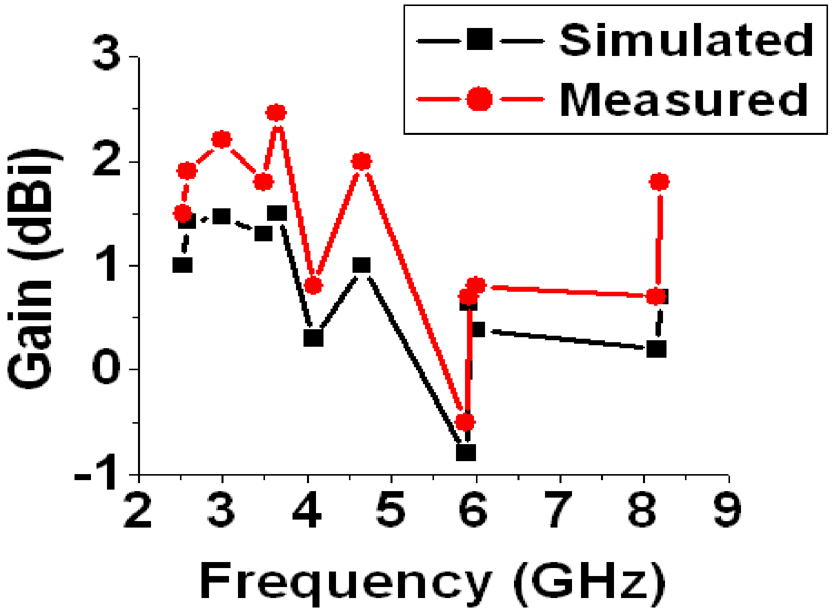

Figure 13. Gain Vs. Frequency Plot of the Proposed Antenna

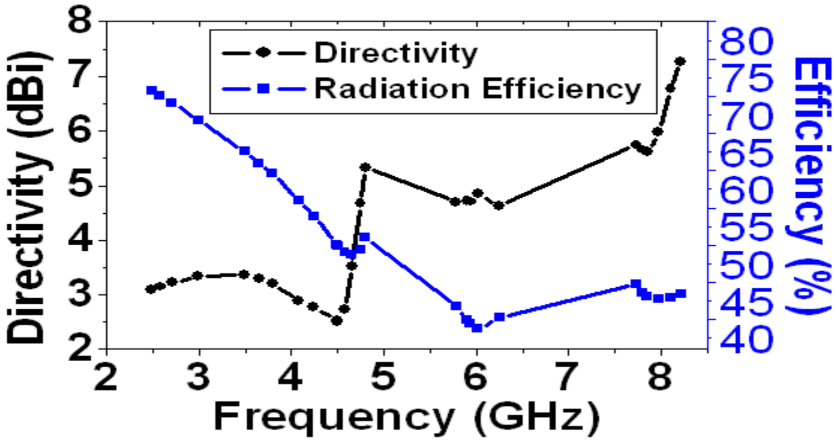

Figure 14. Directivity and Radiation Efficiency of the Proposed Antenna

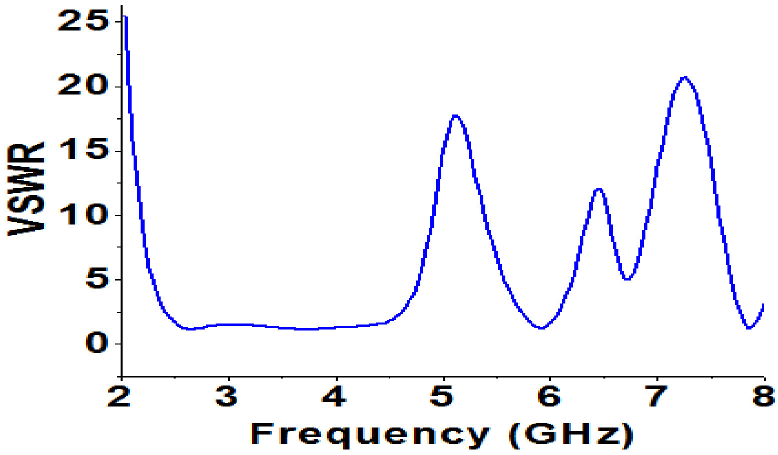

Figure 15. VSWR of the Proposed Antenna

5. Conclusion

This paper presents the design of a miniaturized slot loaded microstrip patch antenna with modified ground plane. Wideband and narrowband resonance characteristics are achieved by deforming the ground plane of the proposed antenna. Size reduction, multi-resonance and broad-banding have been achieved by the single antenna. The size of the antenna has been reduced by 70% in comparison to conventional antenna. Furthermore, good radiation pattern characteristics with almost stable gain and acceptable amount of 3-dB beam-widths are also obtained for the proposed compact antenna. The narrow band resonant frequencies of the proposed antenna may be utilized in government security systems. The wideband characteristics of the proposed antenna covers the bandwidth requirements of a number of modern wireless communication application bands such as WiMAX (2.5−2.69 GHz and 3.3−3.6 GHz), INSAT (4.5−4.8 GHz), IEEE 802.11y Wi-Fi/WLAN (3.65−3.7 GHz), UMTS 3G expansion band (2.5−2.7 GHz) and microwave S band (2−4 GHz).

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