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Novel Design of Rectangular Microstrip Slotted Patch Antenna with Modified Ground Plane for Wideband Wireless Applications

Authors
Romeesa[1], Narinder Sharma[1] and Vipul Sharma[2]
[1]ECE Department, Amritsar College of Engineering and Technology, Amritsar, Punjab, India
[2]ECE Department, Gurukula Kangri Vishwavidyalaya, Haridwar

Abstract:
The paper presents the novel design of rectangular microstrip slotted patch antenna loaded with modified ground plane for wideband wireless applications. In this design different types of ground plane has been employed to achieve wideband characteristics over the frequency range of 1GHz to 10GHz. Proposed antenna is investigated on low cost FR4 glass epoxy substrate with 1.6mm thickness, 4.4 dielectric constant and is designed by using the resonant frequency of 2.45GHz. By varying the dimensions of ground plane and after adding horizontal stub or vertical stub; the final geometry of proposed antenna exhibits wide bandwidth of 1959MHz, 700MHz and 2970MHz. The proposed antenna is also tested by using VNA (Vector Network Analyzer) to validate the simulated results with the measured results and it has been observed that both the results are in good agreement with each other. The wideband characteristic of proposed antenna makes it suitable for the different wireless applications such as GSM standards (DCS 1.71 – 1.88GHz and PCS 1.85 – 1.99GHz), UMTS (1.92 – 2.17GHz), Bluetooth (2.41 – 2.49GHz) of ISM band, 2.45GHz, WiMAX (3.3GHz – 3.7GHz, 5.25GHz – 5.85GHz), WLAN (5.15GHz – 5.85GHz), X-band satellite applications (7.1GHz – 7.76GHz) and point to point high speed wireless communication (5.925GHz – 8.5GHz).

1. Introduction

Microstrip patch antenna is the ideal choice for the researchers in today's world of wireless applications due to its various advantages such as low cost, light weight, low profile, ease of fabrication etc [1]. One of the main disadvantages of microstrip antenna is narrow bandwidth due to which it restricts to use for various wireless applications [2]. The structure of microstrip patch antenna consists of a thin metallic patch on the one side of a substrate and the other side of a substrate there is a plane metallic ground [3]. This development and usage of communication devices opened large interest in small antenna and its miniaturization techniques [4] [5]. From technical point of view, antenna is an important part of these handheld devices that are used for communication purpose [6]. There are many different shapes of microstrip antennas has been designed so far to analyze the different parameters of antennas. The bandwidth and the radiation efficiency of microstrip antennas depends upon many factors such as patch size, patch shape, substrate material, substrate thickness, dielectric constant of substrate, type of feed and its location etc [7]. The shape of the radiating patch is one of the most important characteristics of microstrip patch antenna; the patch can be of many different shapes such as rectangular, square, circular, elliptical, triangular, dipole, ring etc [8]. Patch antennas play a very important role in today's world of wireless communication systems. A microstrip antenna is very simple in construction and easily fabricated on printed circuit board of different materials [9]. The circular and rectangular patch antennas are most commonly used microstrip patch antenna. These antennas are widely used for different wireless applications. Different characteristics of antennas such as circular polarization, dual band frequency operation, broad band width, beam scattering can be easily obtained from these patch antennas [10]. The antenna can be designed for different wireless applications such as WLAN (Wireless Local Area Network) frequency ranges are 2.4GHz (2.4-2.484 GHz), 5.2GHz (5.15-5.35 GHz) and 5.8GHz (5.725-5.825 GHz). Wi-Max (World Interoperability for Microwave Access) frequency ranges are 2.5GHz (2.5-2.69 GHz), 3.5GHz (3.4-3.69 GHz) and 5.8GHz (5.25-5.825GHz). Bluetooth frequency range is 2.4GHz [11]. These frequency ranges are used while designing the antenna for a particular application. The proper selection of patch shape and feeding technique is very important for the antenna to work efficiently for specific wireless applications.

In this design a novel design of slotted microstrip rectangular patch antenna has been designed using transmission line feeding technique and different types of ground planes. These ground planes are used to achieve the wideband characteristics of the proposed antenna. The details of design and results of proposed antenna have been elaborated in section 2 and section 3 respectively.

2. Antenna Design and Configuration

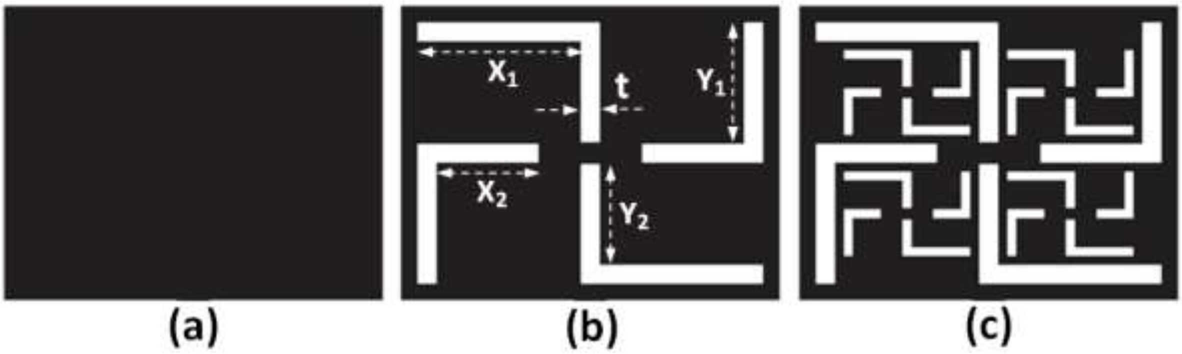

Figure 1: Design evolution for the patch of proposed antenna; (a) 0^{th} iteration, (b) 1^{st} iteration and (c) 2^{nd} iteration (final patch geometry of proposed antenna)

The geometry of patch of proposed antenna has been initiated with the rectangular microstrip patch whose length and width is calculated by using various design parameters and also by using different design equations as shown below. Basic design parameters which are used to calculate the length and width of patch are material of substrate, thickness of substrate, resonant frequency of designed antenna and dielectric constant of substrate. In this design a low cost FR4 glass epoxy substrate has been used with a thickness of 1.6mm, dielectric constant 4.4 and a resonant frequency of 2.45GHz. By using all these design parameters the length of patch P_L=29mm and width of patch P_W=37mm of rectangular patch has been obtained by using rectangular design equations.

$$P_W = \frac{c}{2 f_o \sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{P_W}\right]^{\frac{1}{2}} \tag{2}$$

$$L_{eff} = \frac{c}{2 f_o \sqrt{\varepsilon_{reff}}}$$

(3)

$$\Delta L = 0.412h \frac{(\varepsilon_{reff} + 0.3)\left(\frac{P_W}{h} + 0.246\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{P_W}{h} + 0.8\right)} \qquad (4)$$

$$P_L = L_{eff} + 2\Delta L \qquad (5)$$

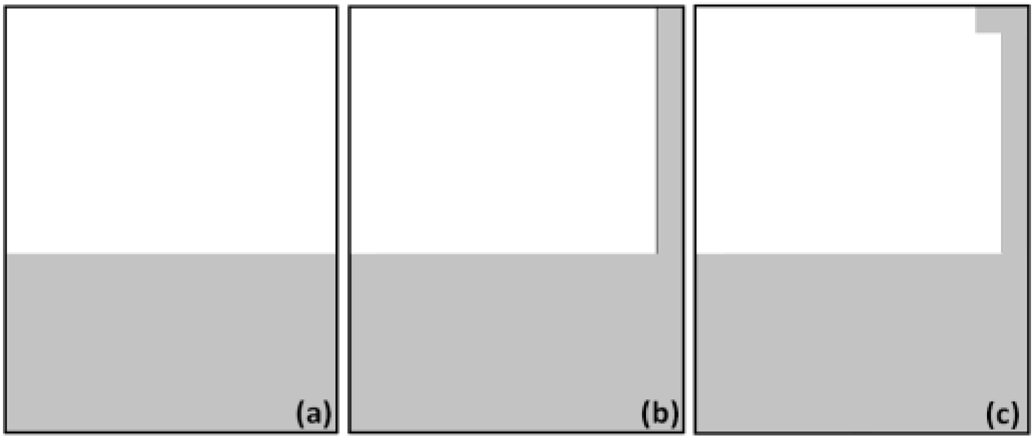

Figure 2: Ground structures of proposed antenna; (a) partial ground plane, (b) partial ground plane with vertical stub (c) partial ground plane with vertical and horizontal stub

The basic geometry of patch of proposed antenna is depicted in Figure 1(a), which is also called as the 0^{th} iteration of the proposed antenna. After designing the 0^{th} iteration of proposed antenna the 1^{st} iteration is designed by applying L-shaped slots as shown in Figure 1(b) and the design parameters of the slots are tabulated in Table 1. Further, the patch of proposed antenna is again modified by applying the more L-shaped slots with thickness 1mm, at varying dimensions to get 2^{nd} iteration or the final geometry of the proposed antenna as shown in Figure 1(c). The final geometry of the patch of proposed antenna is excited by using transmission line feeding technique and different types of ground planes are used to analyze the performance of designed antenna. The final geometry of patch with microstrip line feed has been analyzed using different shapes of ground planes such as partial ground plane, partial ground plane with vertical stub and partial ground plane with vertical as well as horizontal stub as shown in Figure 2 (a), (b) and (c) respectively. These ground planes are employed to enhance the bandwidth of the proposed antenna and are also used to achieve wideband characteristics. The Final geometry of proposed antenna with modified ground plane is shown in Figure 3 and design parametric values are tabulated in Table 1.

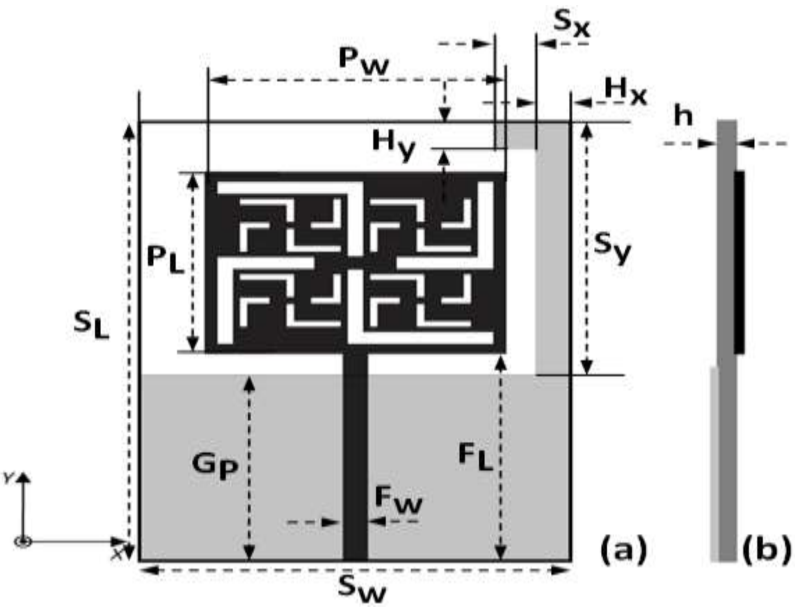

Figure 3: Final geometry of proposed antenna with modified ground plane; (a) front view and (b) side view

Table 1: Parametric values of proposed antenna

Antenna design parameters	Description	Values (mm)
P_L	Length of patch	29.0
P_W	Width of patch	37.0
F_L	Length of feed line	33.0
F_W	Width of feed line	3.0
S_L	Length of substrate	70.0
S_W	Width of substrate	53.0
S_X	Width of horizontal stub	5.0
H_X	Width of vertical stub	3.5
S_Y	Length of vertical stub	38.5
H_Y	Length of horizontal stub	3.5
G_P	Length of partial ground plane	31.5
X_1	Length of L-shaped slot	16.0
X_2	Length of L-shaped slot	10.0
Y_1	Length of L-shaped slot	12.0
Y_2	Length of L-shaped slot	10.0
t	Thickness of L-shaped slot	2.0
h	Thickness of substrate	1.6

3. Result and Discussions

3.1 Return loss and Bandwidth

This section describes the different results which are obtained and analyzed from the proposed antenna by using different ground structures to get wideband characteristics. Proposed antenna has been designed up to 2^{nd} iteration which is called as final geometry of the patch and is analyzed for different ground planes using HFSS V13 simulator based on finite element method. Transmission line has been used to provide the excitation to the proposed antenna. In this manuscript the final geometry of proposed antenna is designed and analyzed using three types of ground planes such as partial ground plane, partial ground plane with vertical stub and ground plane with vertical stub as well as horizontal stub. Initially, the length of ground plane 'Gp' has been taken as 29mm, further the length is increased by 0.5mm and same procedure has been repeated till the length 31.5mm. Return loss versus frequency curve of proposed antenna with ground length variation is shown in Figure 4. It has been observed from Figure 4, that the proposed antenna with 'Gp=29mm' works on two frequencies 1.7GHz and 3.7GHz with corresponding bandwidth of 1840MHz and 188MHz respectively. Similarly, when the 'Gp' is taken as 29.5mm, antenna resonates at three frequencies 1.8GHz, 3.7GHz and 6.8GHz with corresponding bandwidth of 1785MHz, 260MHz and 860MHz respectively. This process of optimization of ground length has been repeated up to the length 31.5mm. At this length, it has been observed that the proposed antenna exhibits more appropriate results as compared to the other lengths. Proposed antenna with 'Gp=31.5mm' resonates at four frequencies 2.1GHz, 3.7GHz, 6.9GHz and 8.2GHz with bandwidth of 1680MHz, 340MHz and 2680MHz. For more clarity, the results of proposed antenna for different variations in the ground length have been tabulated in Table 2. It is clearly observed that the result obtained by taking 'Gp=31.5mm' is more appropriate in terms of bandwidth as compared to the other values.

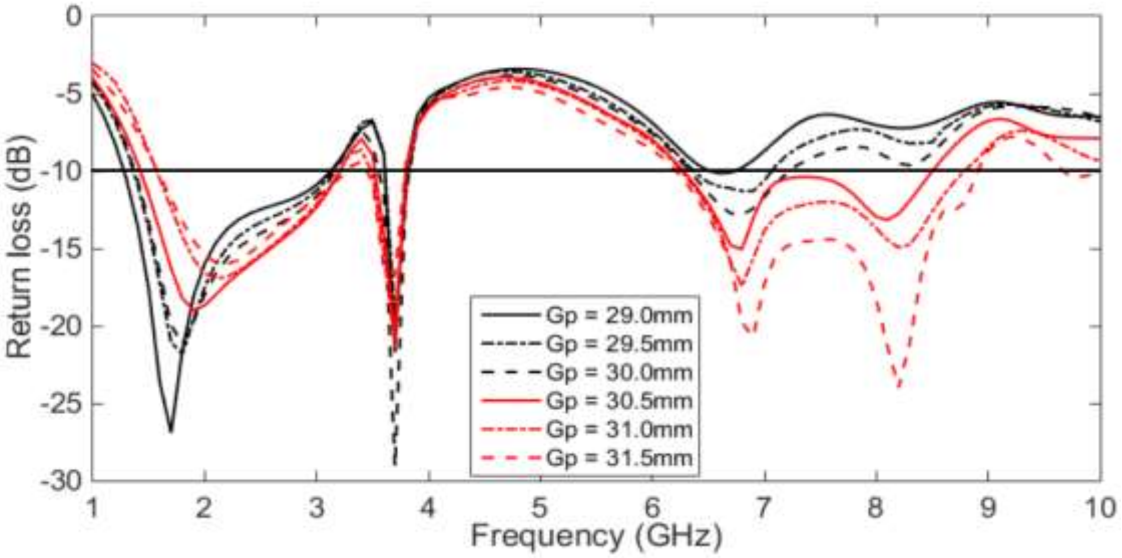

Figure 4: Return loss versus frequency plot of proposed antenna with ground length variation 'Gp'

Table 2: Comparison of the results of proposed antenna with variation in ground length 'Gp'

Partial ground plane length 'Gp'	Resonant Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)
29.0mm	1.70/3.70	-26.89/-21.71	1840/188
29.5mm	1.8/3.7/6.9	-21.82/-19.64/-11.29	1775/218/680
30.0mm	1.8/3.7/6.8	-21.14/-29.13/-12.83	1785/260/860
30.5mm	1.9/3.7/6.8/8.1	-18.99/-20.49/-15.05/-13.16	1770/275/2220
31.0mm	2.1/3.7/6.8/8.2	-16.94/-21.40/-17.44/-14.92	1630/310/2540
31.5mm	2.1/3.7/6.9/8.2	-15.92/-16.71/-20.72/-23.98	1680/340/2680

Further the proposed antenna is again modified to increase the bandwidth by adding vertical stub along with the partial ground plane. Vertical stub has been applied at all the lengths of the ground plane which has been taken in the previous step. The width ‘Hx’ of vertical stub is fixed as 3.5mm and the length ‘Sy’ has been varied according to the length of ground plane ‘Gp’; from 41mm to 38.5mm which has been decreased at the factor of 0.5mm till the length of 38.5mm. Return loss versus frequency plot of proposed antenna with variation in vertical stub length and ground plane length is shown in Figure 5. It is observed that proposed antenna with stub length ‘Sy=38.5mm’ and ‘Gp=31.5mm’ shows more bandwidth as compared to the other values. The values of the results obtained from different variations in stub length ‘Sy’ and ground length ‘Gp’ are tabulated in Table 3.

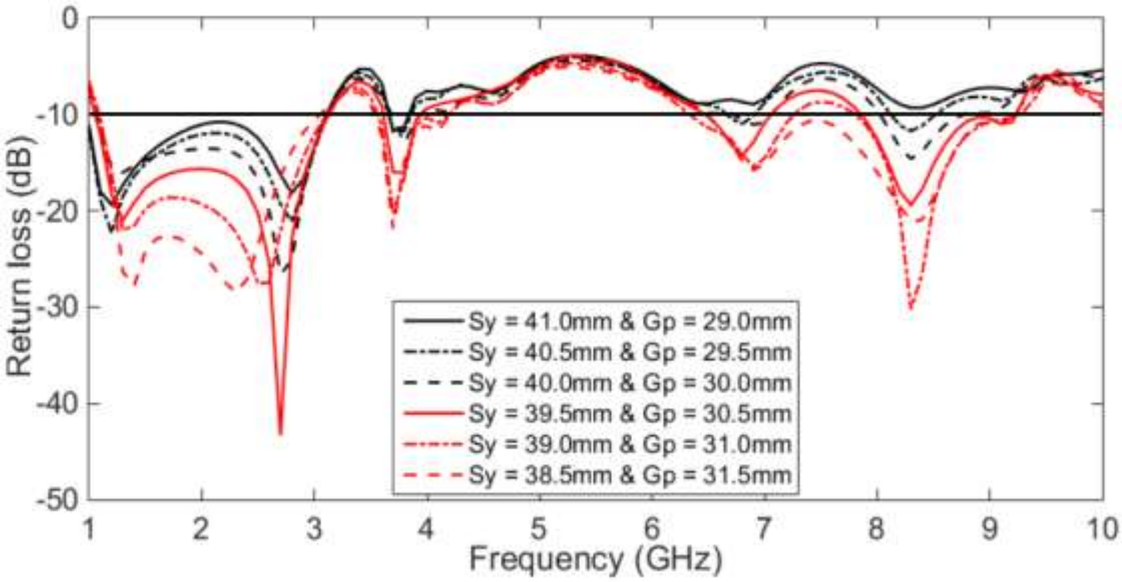

Figure 5: Return loss versus frequency plot of proposed antenna with variation ‘Gp’ and ‘Sy’ parameters

Table 3: Comparison of the results of proposed antenna with variation in ‘Gp’ and ‘Sy’ parameters

Vertical stub length ‘Sy’	Partial ground plane length ‘Gp’	Resonant Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)
41.0mm	29.0mm	1.2/2.8/3.7	-19.38/-18.17/-11.75	2105/175
40.5mm	29.5mm	1.2/2.8/3.7/6.8/8.3	-22.33/-21.10/-11.59/-10.97/-11.70	2120/199/240/395
40.0mm	30.0mm	1.3/2.7/3.8/6.9/8.3	-16.03/-26.59/-12.98/-11.06/-14.60	2050/250/360/770
39.5mm	30.5mm	1.3/2.7/3.7/6.8/8.3	-21.00/-43.34/-15.98/-14.27/-19.45	2075/335/590/1375
39.0mm	31.0mm	1.3/2.5/3.7/6.9/8.3	-22.03/-27.57/-20.26/-15.42/-30.23	2020/630/920/1500
38.5mm	31.5mm	1.4/2.3/3.7/6.9/8.3	-27.80/-28.43/-21.83/-15.77/-21.12	1967/665/2720

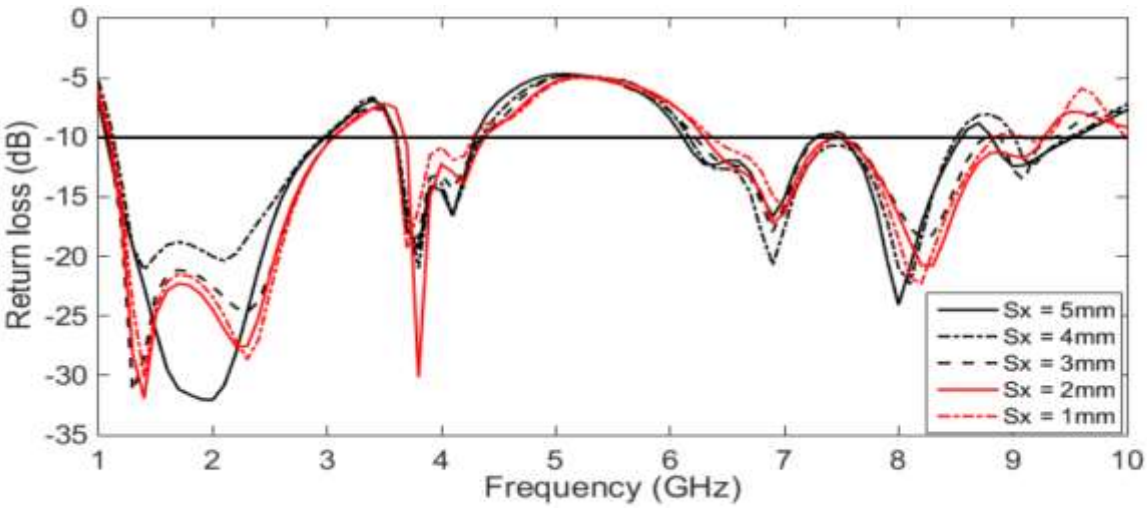

Figure 6: Return loss versus frequency plot of proposed antenna with variation 'Sx' parameters

Finally, the proposed antenna is further modified by adding the horizontal stub along with the partial ground plane and vertical stub. The width of horizontal stub 'Sx' has been varied by fixing the length of horizontal stub 'Hy' as 3.5mm. This variation in the width of horizontal stub has been employed in the geometry of ground plane to achieve the wideband characteristics and also to improve the other characteristics of the proposed antenna. Horizontal stub has been introduced in the geometry of proposed antenna by restricting the 'Gp' and 'Sy' parameters as 31.5mm and 38.5mm respectively. The return loss versus frequency plot of proposed antenna with horizontal stub width variation is shown in Figure 6. It is observed that when stub width 'Sx' is taken as 5mm, proposed antenna resonates at five frequencies 1.9GHz, 3.8GHz, 6.9GHz, 8.0GHz and 9.1GHz with corresponding bandwidth of 1910MHz, 687MHz, 1160MHz, 1050MHz and 705MHz respectively. Further, this length is varied by decreasing at the factor of 1mm up till the width 'Sx' as 1mm. It is clearly seen from the obtained results that the proposed antenna with horizontal stub width 'Sx=2.0mm' exhibits wider bandwidth as compared to the other values. Lastly, the proposed antenna with parametric values as 'Gp=31.5mm', 'Sy=38.5mm' and 'Sx=2.0mm' are taken for the final geometry; which resonates at seven frequency bands as 1.4GHz, 2.2GHz, 3.8GHz, 4.2GHz, 6.9GHz, 8.3GHz and 9.1GHz with the bandwidth of 1959MHz, 700MHz and 2970MHz. The values of all the variations in the width of horizontal stub 'Sx' has been tabulated in Table 4, for more lucidity.

Table 4: Comparison of the results of proposed antenna with variation in ground length 'Sx'

Horizontal stub width 'Sx'	**Resonant Frequency (GHz)**	**Return loss (dB)**	**Bandwidth (MHz)**
5.0mm	1.9/3.8/6.9/8.0/9.1	-32.01/-19.24/-16.65/-24.06/-12.33	1910/687/1160/1050/705
4.0mm	1.4/2.1/3.8/4.1/6.9/8.1/9.2	-21.12/-20.36/-21.00/-16.49/-20.69/-22.30/-12.19	1835/743/2330/470
3.0mm	1.3/2.3/3.7/4.1/6.9/8.2/9.1	-31.35/-24.69/-18.42/-14.39/-17.92/-18.51/-13.62	1945/748/1050/1180/460
2.0mm	1.4/2.2/3.8/4.2/6.9/8.3/9.1	-31.93/-27.54/-30.15/-13.87/-17.17/-20.78/-11.74	1959/700/2970
1.0mm	1.4/2.3/3.7/4.1/7.0/8.2	-30.11/-28.64/-19.36/-11.87/-15.99/-22.24	1940/680/2460

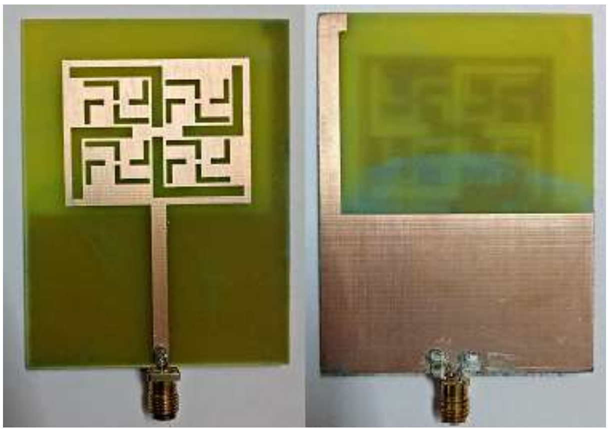

Figure 7: Fabricated structure of designed antenna

By adjusting all the parameters of proposed antenna and after analyzing the performance of simulated results of designed antenna; the final geometry has been fabricated on FR4 glass epoxy substrate. Fabricated antenna is tested to validate the simulated results with the experimental results and Anritsu MS46322A; VNA (Vector Network Analyzer) ranging from 1MHz to 20 GHz is used for testing the prototype of proposed antenna. Fabricated structure of designed antenna is shown in Figure 7 and the comparison of simulated and measured return loss versus frequency curve is shown in Figure 8. It has been observed that both results are in good agreement with each other. Measured antenna works on seven frequency bands such as 1.4GHz, 2.3GHz, 3.7GHz, 4.1GHz, 6.9GHz, 8.1GHz and 9.2GHz with bandwidth of 1956MHz, 753MHz, 1090MHz, 1114MHz and 340MHz. So, we claim that the proposed antenna with modified ground plane (with horizontal and vertical stub) exhibits wideband characteristics and can be used for different wireless frequency bands and applications such as GSM standards (DCS 1.71 – 1.88GHz and PCS 1.85 – 1.99GHz), UMTS (1.92 – 2.17GHz), Bluetooth (2.41 – 2.49GHz) of ISM band, 2.45GHz, WiMAX (3.3GHz – 3.7GHz, 5.25GHz – 5.85GHz), WLAN (5.15GHz – 5.85GHz), X-band satellite applications (7.1GHz – 7.76GHz) and point to point high speed wireless communication (5.925GHz – 8.5GHz).

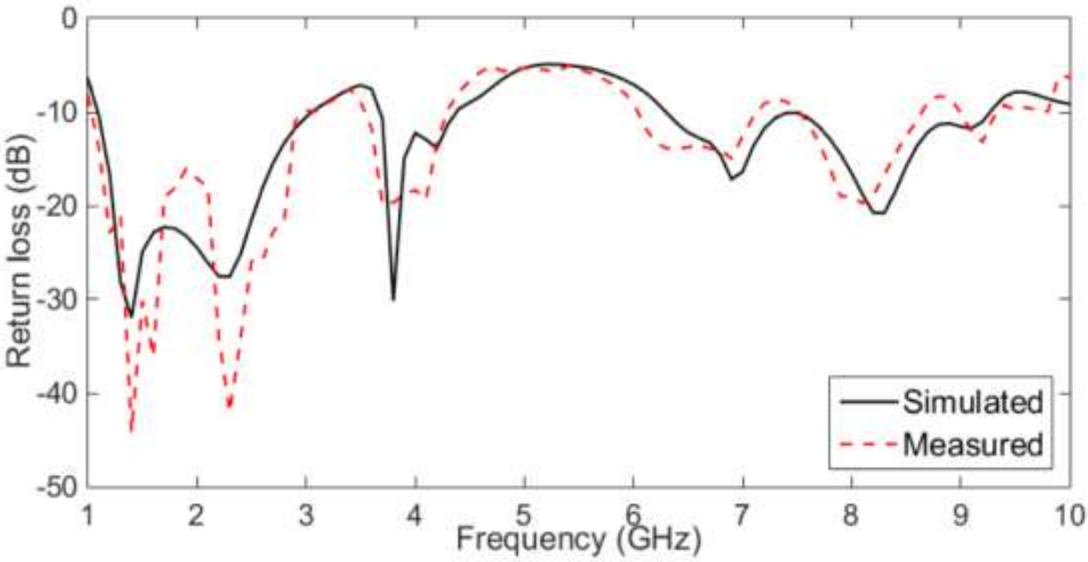

Figure 8: Comparison of simulated and measured return loss versus frequency plot for the final structure of proposed antenna

Table 5: Comparison of simulated and measured values of proposed antenna

Proposed Antenna	Resonant Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)
Simulated	1.4/2.2/3.8/4.2/6.9/8.3/9.1	-31.93/-27.54/-30.15/-13.87/-17.17/-20.78/-11.74	1959/700/2970
Measured	1.4/2.3/3.7/4.1/6.9/8.1/9.2	-44.14/-42.05/-19.80/-19.31/-14.94/-19.72/-13.19	1956/753/1090/1114/340

3.2 Radiation Pattern

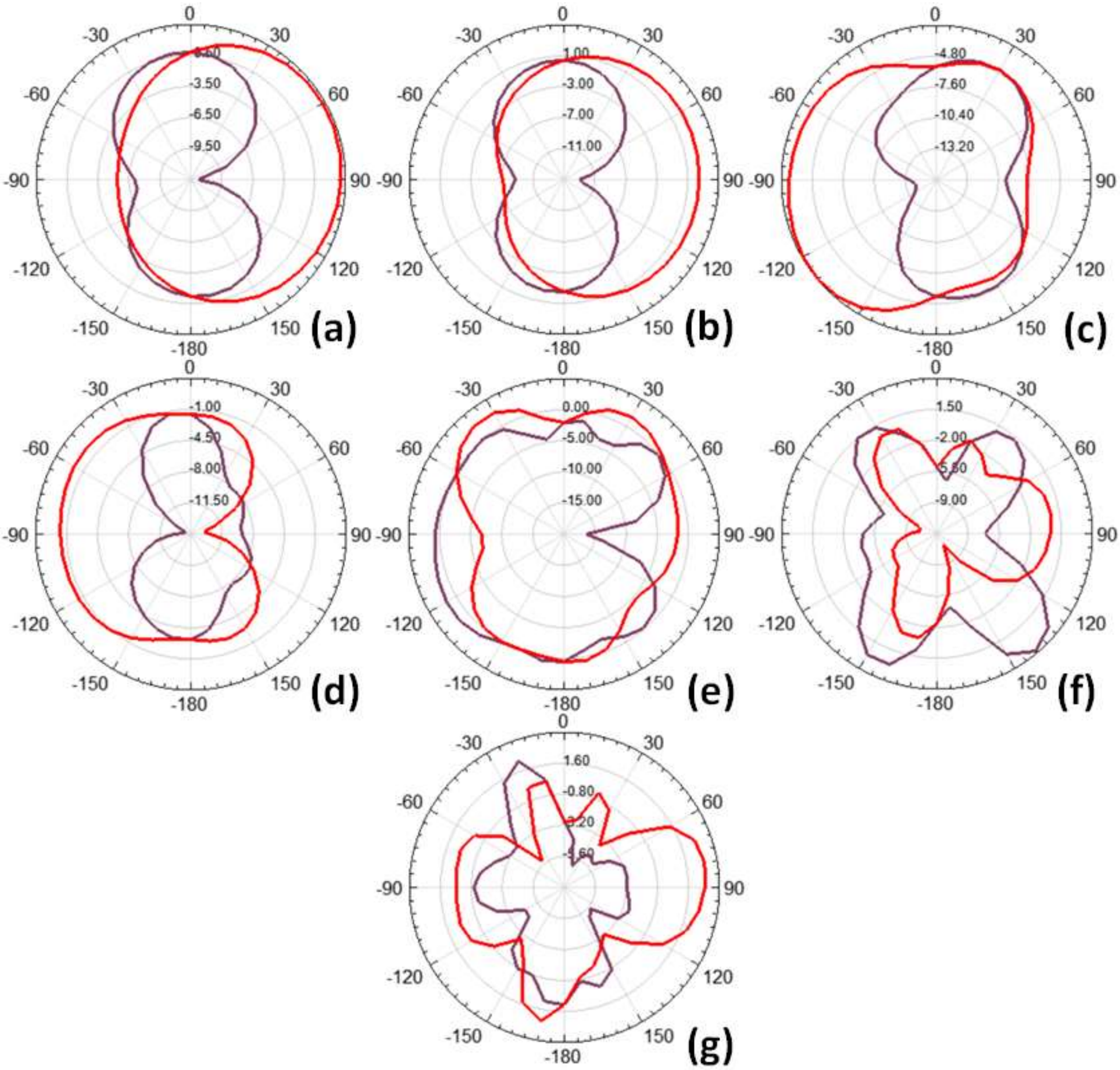

Figure 9: 2D radiation pattern of proposed antenna at (a) 1.4GHz, (b) 2.2GHz, (c) 3.8GHz, (d) 4.2GHz, (e) 6.9GHz, (f) 8.3GHz and (g) 9.1GHz frequency

The E-plane and H-plane, 2D radiation pattern of different frequencies such as 1.4GHz, 2.2GHz, 3.8GHz, 4.2GHz, 6.9GHz, 8.3GHz and 9.1GHz which are obtained from final geometry of proposed antenna is shown in Figure 9. Designed antenna exhibits nearly omnidirectional pattern at some frequency ranges of lower bands; but as we move towards the higher bands the pattern gets distorted due to the interference from adjacent frequency bands. It is also observed that the proposed antenna also exhibits bi-directional pattern at lower frequency bands of operation. From the 2D radiation pattern we have also calculated the gain of antenna at different frequency bands. Proposed antenna shows the gain of 2.41dB, 2.81dB, 2.02dB, 8.84dB, 3.85dB, 5.37dB and 3.57dB at the aforementioned frequency bands. Due to the omnidirectional, bidirectional and the acceptable value of gain at respective frequency bands the proposed antenna can be used for different wireless standards.

Conclusion

Proposed antenna is designed by using L-shaped slotted rectangular microstrip patch and a modified ground plane is employed for wideband wireless applications. Different performance parameters of proposed antenna such as return loss, gain and radiation pattern has been observed and investigated in this paper. It is analyzed from the obtained results that the proposed antenna is suitable for different wireless standards due to its wideband characteristics. Proposed antenna is fabricated and tested using VNA and both the results are in good agreement with each other. It also exhibits omnidirectional and bi-directional radiation pattern and have the acceptable value of gain at respective frequency bands of operation such as 1.4GHz, 2.2GHz, 3.8GHz, 4.2GHz, 6.9GHz, 8.3GHz and 9.1GHz.

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