# Multi-Band Stacked Microstrip Patch Antenna with Wide Ground Slot for Wireless Communications

Ankita*, R.P.S. Gangwar, and Paras

*Department of Electronics & Communication Engineering,*
*College of Technology, G. B. Pant University of Ag. & Technology, Pantnagar-263145 (India)*
**email: ankitakec52224@gmail.com*

**Abstract.** Recently the requirement of low-profile antennas for wireless communications has greatly increased the demand of microstrip antennas because of their low-profile and light weight characteristics. In this paper a miniaturized, multiband dual-stacked probe fed microstrip antenna is presented. There exists S-shaped coupling structure between the patches and a wide ground slot to improve antenna characteristics. The proposed antenna operates at six resonant frequencies ($S_{11}$ below -10 dB), and is thus suitable for wireless communication applications including DCS, WiMax, WLAN, WiBro, Bluetooth and C-band applications such as satellite communications, weather radar systems etc. The proposed antenna is simulated using IE3D software and has bi-directional radiation patterns with a peak gain of 5.11dB.

*Key words:* Coupling structure, ground slot, multiband, probe feed, stacked microstrip antenna

## 1. Introduction

Recently there is an urgent need of size reduction in the field of antenna technology which has focused on the low-profile characteristics of microstrip antennas. The microstrip antennas are low-profile, light-weight and are easy to fabricate, thus are less expensive. With the advancement in technology, the design should be portable, cheap and multi-functions for wireless communications applications. Thus, multiband operation is highly desirable, as this helps in achieving multiple applications through a single device. This led to a rapid progress in the last few decades in the design of multiband microstrip antenna with reduced size. For reduction in antenna size, several techniques have come into picture like introduction of vias, shorting plates, coupling structures etc. Feeding using coupling structures has been very effective in size reduction as well as in bandwidth enhancement [1, 2, 3].

In this paper, introduction of S-shaped coupling structure between two stacked patches in the antenna design is studied. The use of two stacked patches instead of single patch helps in improving impedance bandwidth and gain of microstrip antenna as described in [4, 5]. Furthermore, the effect of slot on ground plane is analyzed which improves the antenna bandwidth and performance as discussed in [6, 7, 8]. U-shaped slot is cut on the lower patch as it provides improved resonance and also better performance as mentioned in [9], [10]. Also a T-shaped slot is cut on the upper patch.The proposed stacked microstrip antenna provides multiband operation in the frequency range 1-5 GHz, covering applications such as DCS transmission band (1.71-1.77 GHz), Bluetooth (2.4-2.48 GHz), WiBro (2.35 GHz), WLAN (2.4-2.484 GHz), WiMAX (2.5-2.69 GHz/3.4-3.69 GHz) and some C-band applications at resonant frequencies 4.38 GHz and 4.75 GHz, such as satellite communications, Wi-Fi devices, cordless telephones, and weather radar systems. The simulation of the proposed antenna is performed using Zeland IE3D software [11]. The transmission line model (TLM) is applied for analysis of the antenna. The initial dimensions of the proposed antenna are calculated using the basic formulae of TLM [12, 13] and the final dimensions are obtained after several optimization steps.

## 2. Proposed antenna structure and analysis

### 2.1. Method of analysis

Transmission line model is used for the analysis and design of the antenna. In this model, the microstrip patch antenna is considered as a transmission line of length $L$, separated by two slots of width $W$ and the substrate thickness $h$. An effective dielectric constant $\varepsilon_{reff}$ is obtained in order to account for the fringing of waves.

*Calculation of antenna parameters using TLM* [12], [13]

(a) *Width (W)*

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}$$

where, c is velocity of light.

(b) *Effective dielectric constant ($\varepsilon_{reff}$)*

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

(c) *Effective length ($L_{eff}$)*

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \tag{3}$$

(d) *Length extension (ΔL)*

$$\Delta L = {}^{0.412h}\frac{\left(\varepsilon_{reff}+0.3\right)\left(\frac{w}{h}+0.264\right)}{\left(\varepsilon_{reff}-0.258\right)\left(\frac{w}{h}+0.8\right)} \tag{4}$$

*(e) Actual length of patch (L):*

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

The antenna dimensions are calculated using the equations (1-5) at resonant frequency of $f$ = 2.4 GHz, are: $W$=37.35 mm, $\varepsilon_{reff}$=4.366, $L_{eff}$=29.9 mm, $\Delta L$=0.46 mm, and $L_{actual}$ =28.988 mm. Thus the initial dimensions taken are 37mm and 29mm as width and length of the antenna, respectively. The final dimensions obtained after optimization are less than these values and are 15mm and 30mm as width and length of main (upper) patch.

## 2.2. *Proposed antenna geometry*

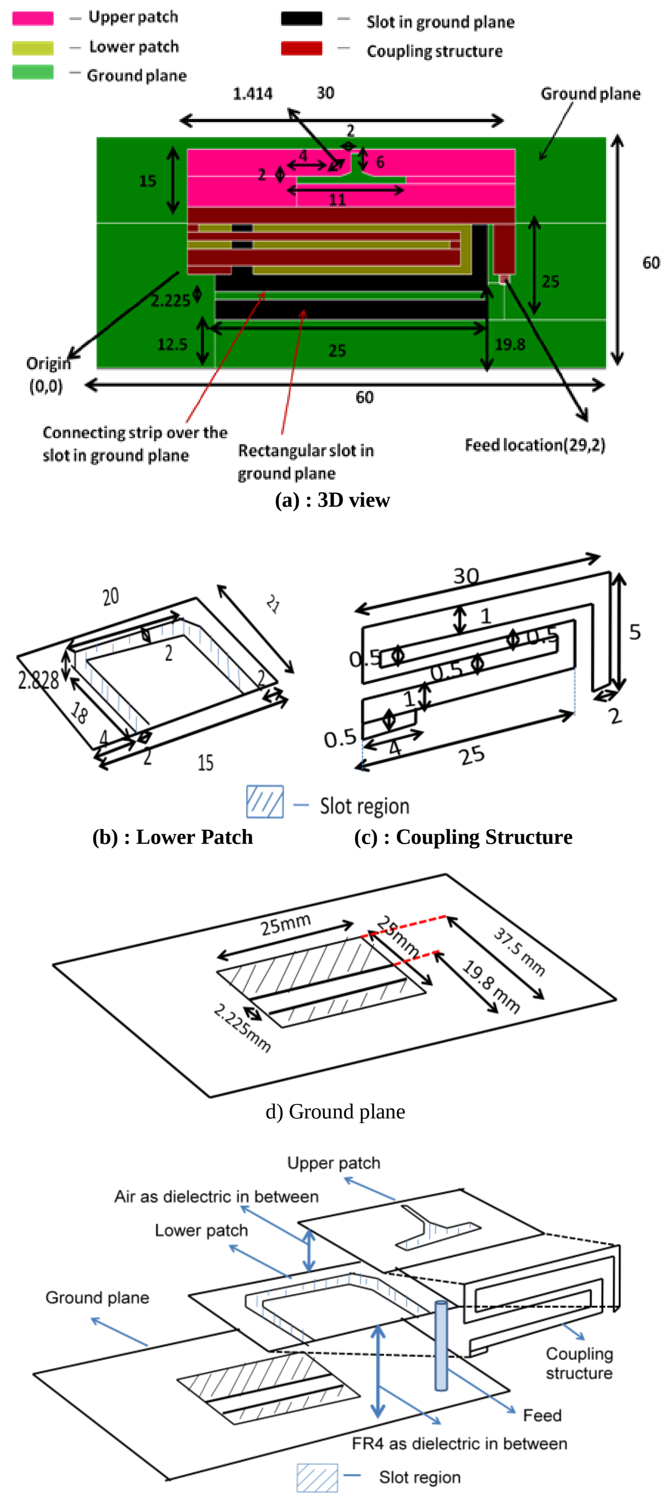
The proposed antenna is the dual stacked microstrip patch antenna. The upper patch consists of a T-shaped slot at the centre of the patch. The lower patch employs a U-shaped slot which is slightly shifted towards right from the centre. There exists an S-shaped coupling structure extending from lower patch, for feeding the upper patch indirectly, while the lower patch is being fed directly through the probe feed. Furthermore, the proposed antenna comprises of a wide slot in the ground plane. The ground slot has been modified by inserting a metallic strip over the slot which then divides the slot into two parts. The proposed antenna geometry is shown in Figure 1. The upper patch occupies the area of 30mm×15mm, lower patch has area of 30mm× 21mm and the ground plane has area 60mm×60mm with the antenna height to be of 5mm. Since instead of having a conventional direct feed structure, the proposed antenna employs an S–shaped coupling structure, this helps in matching the antenna impedance. The feed through coupling structure provides slow-wave high density structure to match the input impedance [4] and the antenna input impedance can also be controlled by tuning the distance between the feed point and the coupling structure.

The inverted U-shaped slot has been effective in directing the current towards the coupling structure by providing a high density region. The corners of U-shaped slot have been tapered to provide a smooth turn to the path of current rather than abrupt 90º turn. The proposed antenna employs FR4 substrate ($\varepsilon_r$=4.6, $tan\delta$= 0.025) as the dielectric material between ground plane and the lower patch for thickness of 1 mm, while for the region between the two patches air ($\varepsilon_r$=1) is used as the dielectric material for height of 4 mm. The proposed antenna geometry has been obtained after the optimizations of different antenna parameters.

## 3. Development of proposed antenna structure

### *3.1. Initial design without coupling structure*

The initial design consists of a ground plane, two stacked radiating patches and a shorting wall between the patches. The feeding is done only to the lower patch through the probe feed of radius 0.5 mm and the upper patch is coupled to the lower one through the wall. The initial length and width of lower patch are taken as calculated from transmission line model at resonant frequency 2.4 GHz i.e. 29mm and 37mm,respectively while that of upper patch are taken slightly less than the lower patch i.e. 29mm and 30mm, respectively. The design resonates at two resonant frequencies 1.8GHz and 2.35GHz for feed location (25,6) with radiation efficiency below 50% and the gain of 0.2dBi




(a) : 3D view
(b) : Lower Patch (c) : Coupling Structure
d) Ground plane
e) Layer-by-layer view of antenna

Fig. 1. Proposed antenna structure

and 1.5dBi, respectively. These values shows that the design is not efficient in terms of performance.

### *3.2. Introduction of coupling structure*

The structure has been modified by introducing an S-shaped coupling structure between the patches. For the initial dimensions of the patches and feed location (25,6), two resonant frequencies have been obtained at 2.3GHz and 3.2GHz with the gain of 0.5dBi and - 4dBi and the efficiency still below 50%. Thus the dimensions of the patches have been optimized after the introduction of coupling structure and are found to be 30mm and 15mm as length and width of the upper patch, respectively while 30mm and 21mm for the lower patch. The design now gives single band at 4.75GHz for feed location (14mm, 11mm) with efficiency 50% and the gain of 5dBi. This shows that antenna performance has improved with size reduction after introduction of coupling structure.

### *3.3. Introduction of U-slot in lower patch*

A U-shaped slot has been introduced in the lower patch which serves to increase the current path as current flows through the slot outline towards the other corner of the patch. For the feed location nearer to the coupling structure, i.e. (29,2), better results are obtained and this feed location is thus fixed for other variations in the antenna design. This configuration results in two resonant frequencies i.e., 4.25 GHz and 4.8 GHz with efficiency as 45% and 70%, respectively while the gain values obtained are 5dBi and 7.5dBi. Thus this modification shows an improvement in overall gain and efficiency.

### *3.4. Introduction of slot in ground plane*

The proposed antenna shows an improvement in bandwidth, gain and efficiency with the introduction of ground slot as this enlarges the path of current in the ground plane by forcing the current to flow through the slot outline. The location and size of ground slot has much influence on the proposed antenna performance. To analyze the antenna performance for variation in ground slot locations, size of ground slot is chosen to be 20mm×15mm after optimization. Figure 2 shows the variations in $S_{11}$ characteristics for different slot locations. Observing the simulation data, location (15 mm, 5 mm) is found to be suitable for better antenna performance. It has resulted in five operating bands covering DCS 1800, LTE 2600 and WiMax 2500. The antenna parameters corresponding to this slot location are listed in Table 1.

After fixing the location of the ground slot, optimization of ground slot size is carried out. The slot size is varied slightly above and below the size chosen previously i.e. 20mm×15mm. By varying the size of slot on the ground plane a drastic change in the antenna parameters is observed. The varaitions in $S_{11}$ characteristics for different slot sizes is shown in Figure 3. For the proposed antenna, the larger ground slot provides better efficiency than smaller slot size. Comparing the results for the ground slot with different sizes, it is found that for larger ground slots, efficiency is improved but at the same time gain has been decreased slightly. For further increase in ground slot size after a particular value, there is no further improvement in efficiency and even the resonant characteristics have degraded. Thus the optimum solution out of the data obtained, for the size of ground slot has come out to be the slot of size 25mm×25mm at (15 mm, 5 mm) and simulated parameters corresponding to it are listed in Table 2. For this size the efficiency, gain and $S_{11}$ at 2.54 GHz have the best values among others and also covers 2.4 GHz frequency band. For this variation in the design, antenna covers Bluetooth, WLAN, WiMax 2500/3500 and LTE 2600.

### *3.5. Introduction of modified T-shaped slot in upper patch and tapering of U-shaped slot in lower patch*

With the introduction of T-shaped slot in upper patch, antenna performance is improved further. Better efficiency values are obtained and the design also provides the desired resonance at 2.4 GHz. The modified T-shaped slot gives slightly better $S_{11}$ characteristics (Figure 4), while the efficiency and gain remains unchanged as that for simple T-shaped slot. $S_{11}$ at 1.67 GHz and 4.5GHz got improved. The antenna parameters are compared for different U-shaped slots, in Figure 5, i.e. with tapering and without tapering. Again with the tapering of U-slot better $S_{11}$ is obtained, and also efficiency and gain gets improved.

**Table 1.** Simulated parameters for slot location (15mm,5mm)

| Frequency(GHz) | 1.74 | 2.54 | 3.2 | 4.28 | 4.8 |
|---|---|---|---|---|---|
| $S_{11}$(dB) | -25.6 | -26.5 | -12 | -13.5 | -25 |
| Radiation efficiency(%) | 55 | 58 | 57 | 31 | 60 |
| Gain(dBi) | 1.68 | 3.2 | 4.4 | 2.86 | 5.81 |

**Table 2.** Simulated parameters for slot size 25mm×25mm

| Frequency(GHz) | 1.74 | 2.54 | 3.25 | 4.28 | 4.8 |
|---|---|---|---|---|---|
| S11(dB) | -10 | -24 | -12 | -11 | -8 |
| Radiation efficiency(%) | 50 | 70 | 65 | 32 | 62 |
| Gain(dBi) | -3 | 3.5 | 4.75 | -0.6 | 3 |

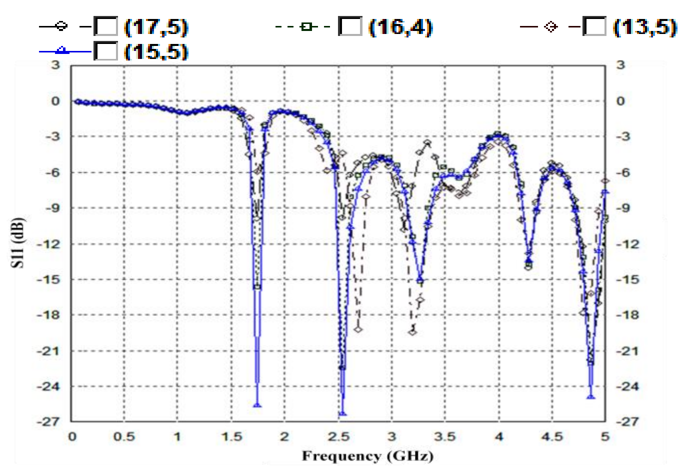



Fig. 2. $S_{11}$(dB) v/s frequency graph for different ground slot locations

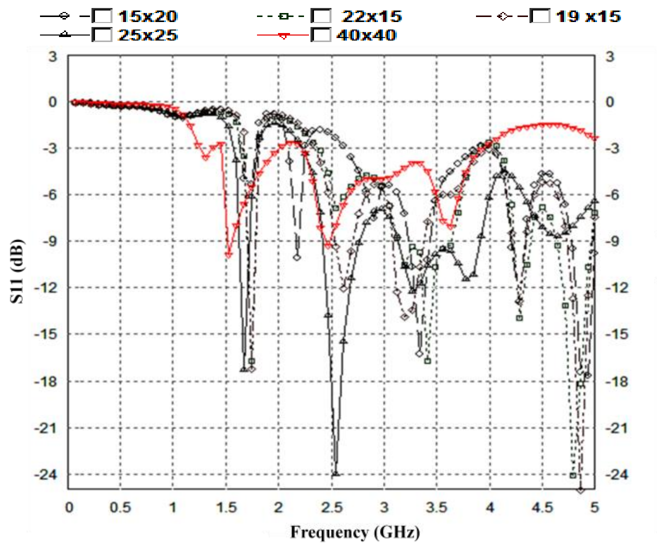



Fig. 3. $S_{11}$(dB) v/s frequency graph for different ground slot sizes

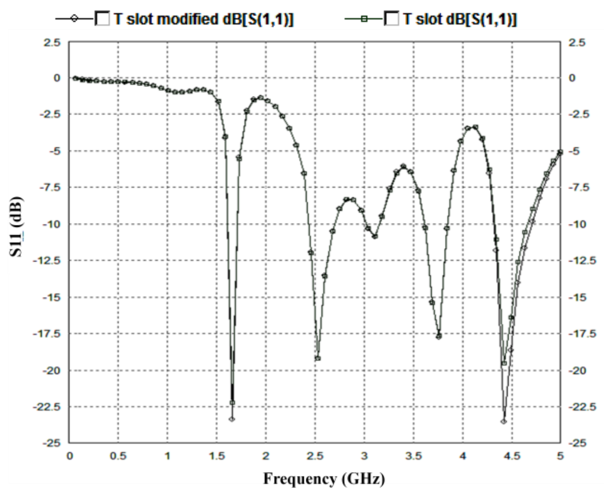



Fig. 4. $S_{11}$(dB) v/s frequency for different T-shaped slots

The graph shows that even for simple U-shaped slot five frequency bands are obtained ($S_{11}$< -10dB) but the $S_{11}$ values are low at frequencies 1.67GHz, 2.54 GHz, 3.76 GHz and 4.5 GHz. Thus, after comparison the variation in design employed in the proposed antenna is the modification of T-shaped slot in upper patch, while tapering or modification of U-slot in lower patch to obtain overall improvement in performance of the proposed antenna. The $S_{11}$ variation for modified T-shaped slot and tapered U-shaped slot is shown in Figure 6. The simulated parameters for this design are listed in Table 3 and shows that for this variation antenna covers WiMax 2500, Bluetooth, WLAN and LTE 2600.

**Table 3**. Simulated parameters for modified T-shaped slot in upper patch and tapered U-shaped slot in lower patch

| Frequency(GHz) | 1.67 | 2.54 | 3.15 | 3.76 | 4.5 |
|---|---|---|---|---|---|
| $S_{11}$(dB) | -23.5 | -19.5 | -10.9 | -17.8 | -20 |
| Radiation Efficiency (%) | 73 | 70 | 56 | 62 | 56 |
| Gain(dBi) | 2.56 | 3.54 | 3.3 | 3.36 | 3.55 |

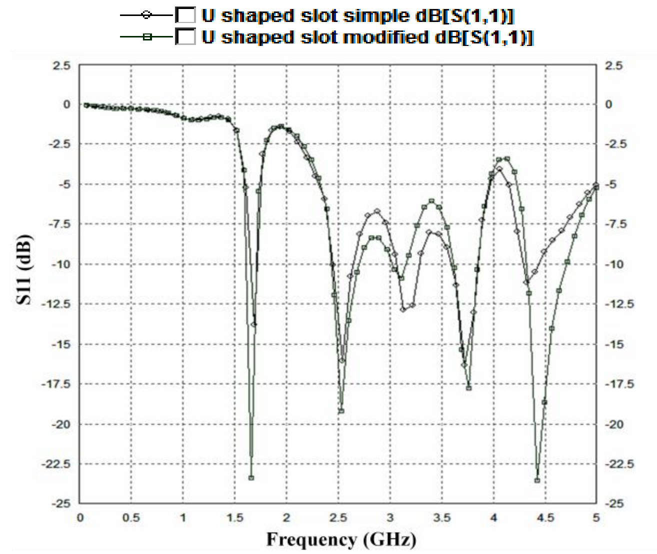



Fig. 5. $S_{11}$(dB) v/s frequency for different U-shaped slots

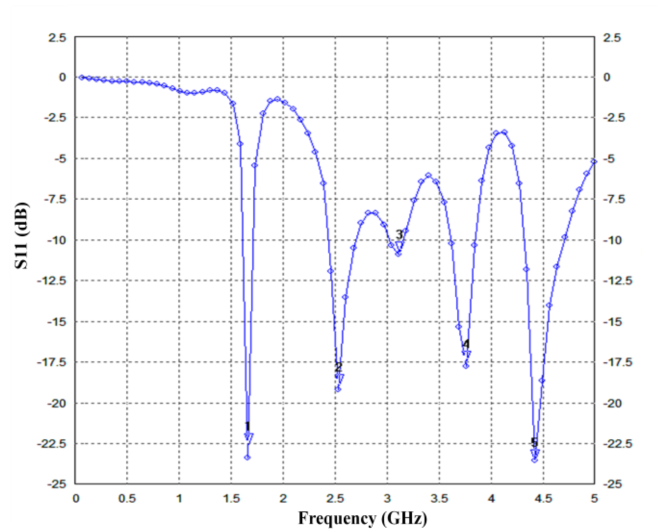



Fig. 6. $S_{11}$(dB) v/s frequency for modified T-shaped slot in upper patch and tapered U-shaped slot in lower patch

3.6. *Inserting metallic strip over the ground slot*

With the introduction of metallic strip over the ground slot of size 25mm×25mm, a drastic change in the antenna properties is observed. The required resonance at 2.4 GHz has been obtained and also the antenna covers DCS band and the higher range of WiMax, 3.5 GHz. Thus the resonance properties of the proposed antenna have been enhanced. The strip has area of 25mm×2.225mm. The depth of strip in the ground slot has been tuned to obtain the desired results and the value thus chosen is 19.8mm. Variation in $S_{11}$ characteristics for different depths of strip is shown in Figure 7. The proposed antenna design, thus obtained for strip with depth 19.8mm, (from bottom of ground plane) shows optimum results in all aspects. The $S_{11}$ characteristics, efficiency and gain of the proposed antenna are shown in Figures 8-10, respectively. In Figure 9, red curve shows radiation efficiency and blue curve shows total efficiency.

## 4. Results

The proposed multiband stacked microstrip antenna has been designed considering the size constraints and to be applicable for desired useful applications. The variations in the antenna structures have been effective in enhancement of antenna characteristics. These variations have been followed in steps to obtain the final geometry of proposed antenna. The antenna thus obtained, resonates at six frequencies i.e. 1.74, 2.38, 3.48, 3.7, 4.38 and 4.75 GHz. The $S_{11}$ values obtained are -22.5dB, -12.2dB, -14dB, -21dB, -28.5dB and -21.5dB, respectively, which is shown in Figure 8 and the corresponding VSWR values are 1.12, 1.65, 1.49, 1.2, 1.1, and 1.19. The bandwidths for the five bands obtained due to merging of bands at 3.48 GHz and 3.7 GHz, are 64, 232, 424, 176 and 248 MHz, showing broadband characteristics at resonant frequencies 2.38 GHz, 3.48-3.7 GHz and 4.75 GHz.

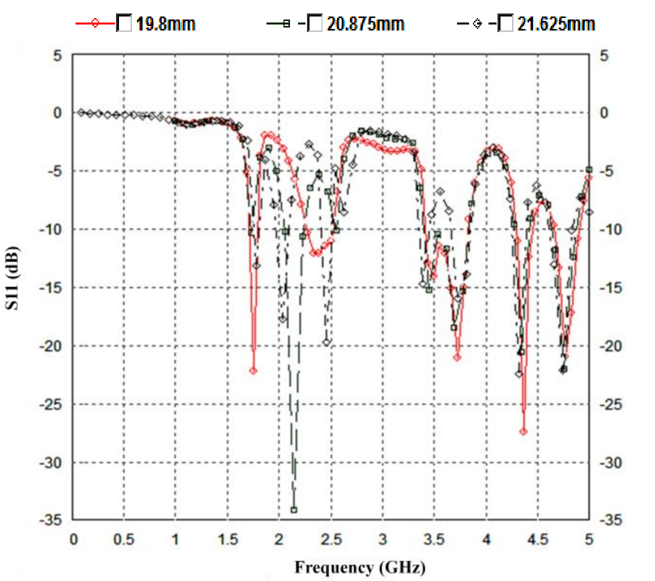



Fig. 7. v/s frequency graph for different depths of strip (from bottom of ground plane) over the ground slot

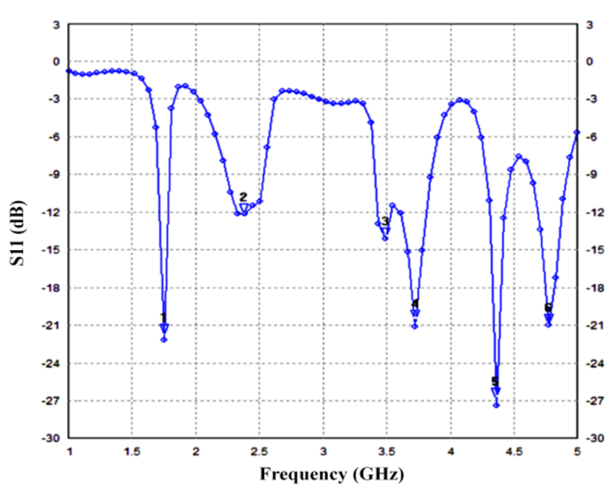



Fig. 8. $S_{11}$(dB) v/s frequency of proposed antenna

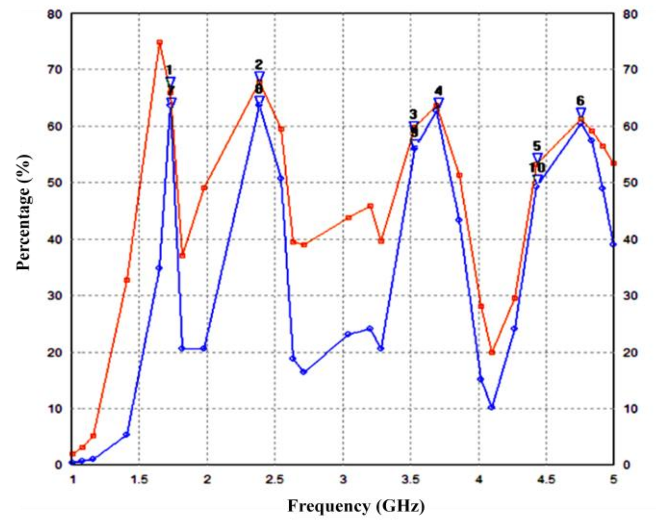



Fig.9. Efficiency v/s frequency of proposed antenna

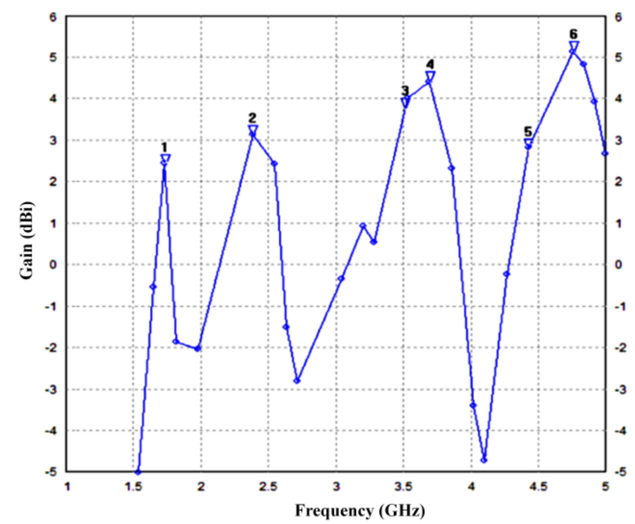
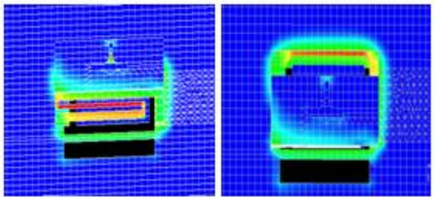



Fig. 10. Gain v/s frequency of proposed antenna

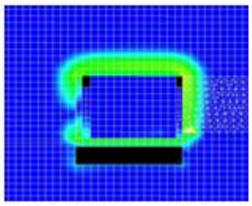
The area occupied by the proposed antenna (30mm×21mm) is less than the reference antenna [1] that is 50mm×14mm and also the overall volume is lesser as the height of proposed antenna is 5mm while that of reference antenna is 6mm. The peak current has the value of 47.063 A/m for the proposed antenna design and the corresponding current distribution is shown in Figure 11, which clearly shows the enlargement of the current path due to ground slot. The 3-dimensional radiation patterns at resonant frequencies are shown in Figure 12, which shows that the radiation is bidirectional at the resonant frequencies.

## 5. Conclusion

The proposed antenna design has been obtained with two stacked patches whose dimensions have been reduced than that calculated using the transmission line model after introduction of S-shaped coupling structure. The optimizations have helped in the adjustment of antenna parameters resulting in multiband and broadband characteristics of the proposed antenna.



(a) Front side



(b)Back side

Fig. 11. Current distribution of proposed antenna

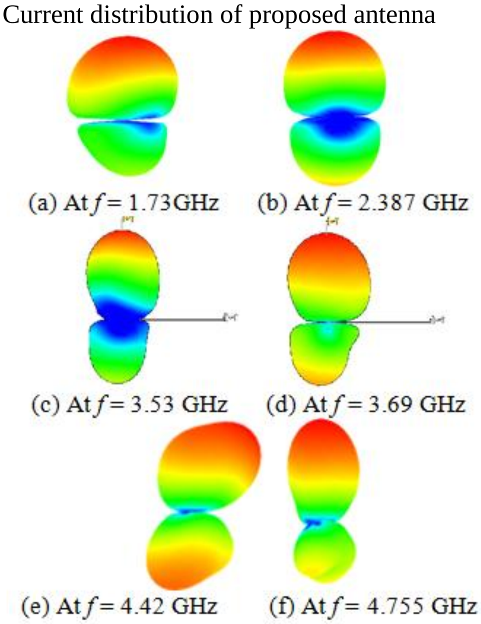



Fig. 12. 3D patterns for different frequencies of proposed antenna

The proposed antenna, thus obtained, can be used in wireless communications which includes DCS transmission band, Bluetooth, WiMax, WLAN, WiBro and the C-band applications covering satellite communications, weather radar systems, cordless devices, Wi-Fi devices, etc.

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**Biography of the Authors**

**Ankita (17-09-87)** has received her B.E. degree in Electronics and Communications engineering from Kumaun Engg. College Dwarahat in 2009. She joined the M.Tech programme at college of Technology G.B. Pant University Pantnagar in 2009 in Electronics and Communications and passed the M.Tech programme in 2011. Currently she is pursuing her PhD from Indian Institute of Technology Delhi in RF and Microwaves. Her research interests include analysis and characterisation of antennas and their applications, microwave imaging and analysis of antenna properties for imaging applications.

**R.P.S. Gangwar** is Professor and Head, Dept. of Electronics and Communication Engineering at College of Technology G.B. Pant University Pantnagar. He received his Masters Degree in Electronics and Communication Engineering from Indian Institute of Technology,Roorkee, and Doctor of Philosophy from G. B. Pant Univ. of Ag. & Tech., Pantnagar, Uttarakhand, India. He has guided a number of M.Tech. and Ph.D. students and published many research papers in reputed national/international journals.

**Paras**, is Assistant Professor, Dept. of Electronics and Communication Engineering at College of Technology G.B. Pant University Pantnagar. He has done his PhD from G. B. Pant University Pantnagar and has guided number of M.Tech and PhD students. His research areas include microstrip antenna design and metamaterials.