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Compact Triple Band Patch Antenna for Cognitive Radio Applications Using Defected Ground Structure

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Abstract

A rectangular microstrip patch antenna with slots in the ground plane and the patch is presented. Three parallel slots are cut into the ground plane and two parallel slots of unequal length is cut into the patch resulting in a triple band antenna operating at 3.5 GHz, 4.8 GHz & 5.2 GHz with 174 MHz, 126 MHz & 116 MHz bandwidths respectively. The operating bands may be used for Wi-MAX, C band long distance radio communications and WLAN 802.11a (5.15-5.35GHz) applications suitable for cognitive radio system. The operating frequencies can be controlled by varying the length of the slots. The proposed design is then fabricated, tested and proper matching between the two results is observed.

Introduction

The day to day growth of wireless communication has brought the necessity of antenna to be compact and to operate at multiple bands of frequency. To diminish the antenna size and to use the same antenna for various purposes, recurring efforts are made. Thus a microstrip patch antenna is worthy of serving this purpose due to its cost effectiveness, low weight, low profile, etc.[1-4]. The patch antenna consists of a dielectric substrate with a metallic patch of any shape on one side and a ground plane on other side.

In this article FR4 substrate is used as the dielectric and various slots are cut into the ground plane and into the metallic patch to obtain triple band at 3.5 GHz (Wi-MAX) , 4.8 GHz (radio communications) & 5.2 GHz (WLAN IEEE 802.11a). By cutting three parallel slots into the ground plane [5] dual band frequencies are obtained at 3.5 GHz & 5.2 GHz, and by cutting two parallel slots into the patch the third band at 4.8 GHz is obtained as the path of the current is disturbed. The frequencies are obtained without increasing the overall dimension of the patch antenna, thus making the design compact [6-7]. Section 2 describes the patch antenna design, with and without slots to obtain the three operating bands. The simulated and fabricated results and their comparison are explained in section 3. It also includes the obtained radiation pattern at the three frequency bands.

Antenna Design

FR4 substrate of height 1.6mm and relative permittivity $({}_r) = 4.4$ and dielectric loss tangent of 0.02 is used. Firstly a simple rectangular patch antenna of length (L) = 12.1 mm and Width (W) = 15.8 mm is fed with the help of a quarter wave transformer operating at a resonant frequency of 5.5 GHz as shown in Figure 1(a). The patch antenna is designed using the formulas given below [2].

$$W=\frac{c}{2f_r}\sqrt{\frac{2}{{}_r+1}} \quad (1)$$

$$\in r_{eff} = \frac{\in_r+1}{2}+\frac{\in_{r-1}}{2}[1+12\frac{h}{W}]^{-1/2} \quad (2)$$

$$\frac{\Delta L}{h}=0.412\frac{(\in_{reff}+0.3)(\frac{W}{h}+0.264)}{(\in_{reff}-0.258)(\frac{W}{h}+0.8)} \quad (3)$$

$$L_{eff} = L + 2\Delta L \quad (4)$$

$$L = \frac{1}{2f_r\sqrt{\in_{reff}}\sqrt{\mu_0\in_0}} -2\Delta L \quad (5)$$

The length and width of the substrate is calculated by equation (6) & (7) by using [1].

$$W_g=6h + W \quad (6)$$

$$Lg=6h + L \quad (7)$$

50Ω microstrip is used to excite the microstrip patch. The width of the microstrip line is calculated from the equations given below [8].

$$W=\begin{cases} \frac{8e^A}{e^{2A}-2}\ for\ \frac{W1}{h}<2 \\ \frac{2}{\pi}\left[B-1-\ln(2B-1)+\frac{{}_r+1}{{}_r-1}\left\{\ln(B-1)+0.39-\frac{0.61}{{}_r}\right\}\right]\ for\ \frac{W1}{h}>2 \end{cases} \quad (8)$$

Where,

$$A=\frac{Z_0}{60}\sqrt{\frac{{}_r+1}{2}}+\sqrt{\frac{{}_r-1}{{}_r+1}}(0.23+\frac{0.11}{{}_r}) \quad (9)$$

$$B=\frac{377\pi}{2Z_0\sqrt{{}_r}} \quad (10)$$

Quarter wave transformer is a simple and useful technique to match real load impedance with various source impedances [9]. The length of the transformer is taken to be of quarter wavelength i.e. L= 6 mm & the characteristic impedance Z_c is given as $Z_c = \sqrt{Z_0Z_{in}}$.

Where $Z_0 =$ characteristics impedance
Z_{in} = input impedance

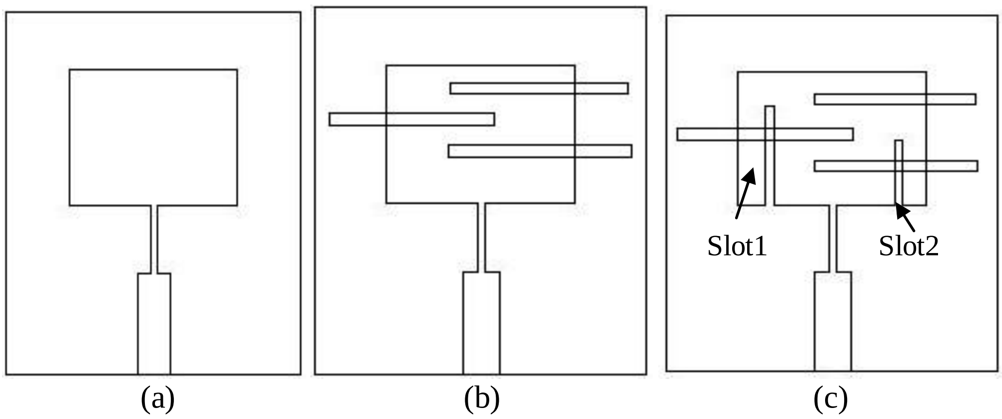

Figure 1: (a) Simple microstrip patch antenna (b) antenna with slots in ground plane, (c) antenna with slots in Ground plane and patch.

Further three parallel slots of width (w) = 0.8 mm are cut into the ground plane parallel to the radiating edge of the antenna to make it defected ground structure (DGS) as shown in figure 1 (b). Due to the slots present in the ground plane the slot gap behaves as capacitance and the equivalent circuit can be expressed as parallel LC circuit. The etched gap for all the slots in the ground plane being same, the equivalent capacitance remains the same and with the increase in the path of the current the equivalent inductance increases thus the resonant frequency is lowered [10]. With the perturbance in current path, the same antenna now behaves as a dual band antenna operating at 3.5 GHz & 5.2 GHz and the obtained simulated result is shown in figure 2(b).

Table 1: Simulation Parameter of Triple Band Antenna With Slots on Ground Plane and Patch

PARAMETERS	DIMENSIONS (mm)	
	Calculated	Measured
Patch width	15.7	15.8
Patch Length	11.9	12.1
Substrate width	25.8	25.8
Substrate length	40	40
Transformer length	6.16	6
Transformer width	0.69	0.6
Feed length	9	9
Feed width	2.91	2.91
Ground slot length	14.45	14.5
Ground slot width	optimized	0.8
Slot1 length		11
Slot2 length		7
Slot 1,2 width		0.8

Further two parallel slots of unequal length are cut into the patch, parallel to the non-radiating edge as shown in figure 1(c).due to which the path of the current is disturbed and a third band at 4.8 GHz is introduced. The result obtained is shown in figure 2(c). The length of slot 1 is fixed as 9 mm and the length of slot 2 is varied from 5.5 mm to 7 mm.The designed antenna simulation parameter is taken as per Table 1.

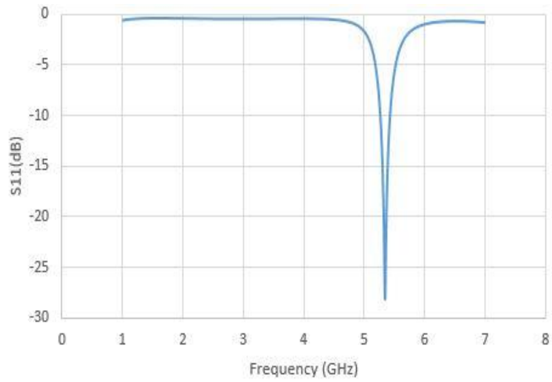

Figure 2: (a) S_{11} Vs frequency of simple patch antenna

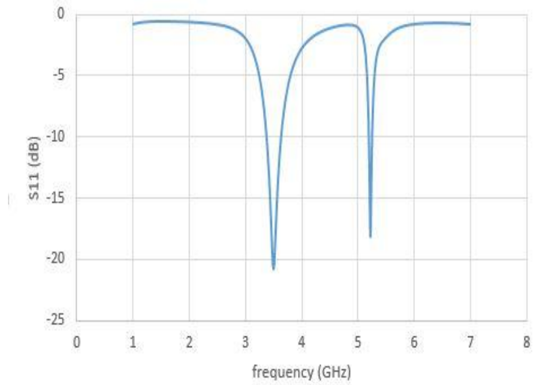

Figure 2: (b) S_{11} Vs frequency of patch antenna with slots on ground plane.

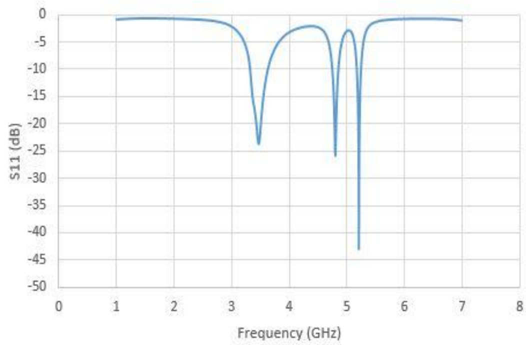

Figure 2: (c) S_{11} Vs frequency of patch antenna with slot on ground plane as well as patch

By varying the length of the ground slots we can see the resonant frequencies at 3.5 GHz & 5.2 GHz is shifted towards the lower frequencies as shown in figure 3. The frequency at 4.8 GHz is not much altered, by which it can be concluded that the slots in the ground plane is responsible for the two bands and doesn't affect the middle band. An optimized length of 14.5 mm is taken to obtain the two bands which can be useful for Wi-MAX and WLAN applications. Various lengths taken are distinguished by different colours and shift in frequencies is observed. The different lengths taken for slot 2 and their equivalent frequencies are given in table 2.

Again by varying the difference in length between the two slots on the patch the third band is shifted towards the lower side [9] i.e. by increasing the difference in length between the two slots, frequency gets lowered for the middle band without affecting the two side bands as shown in figure 4. The length of slot 1 is fixed as 9mm and the length of slot 2 is varied. The different lengths are shown in figure and distinguished by different colour and the equivalent frequencies obtained are tabulated in Table 3.

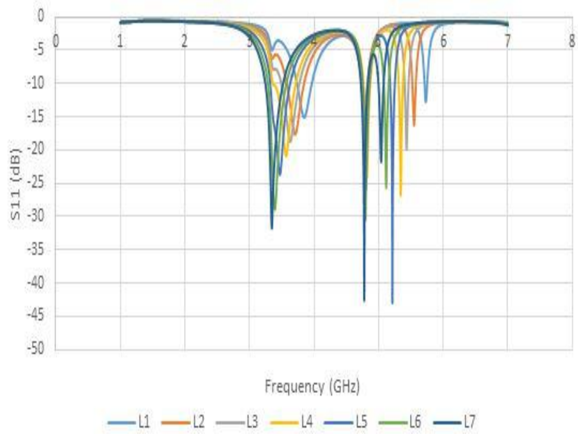

Figure 3: Variation of length of ground slots

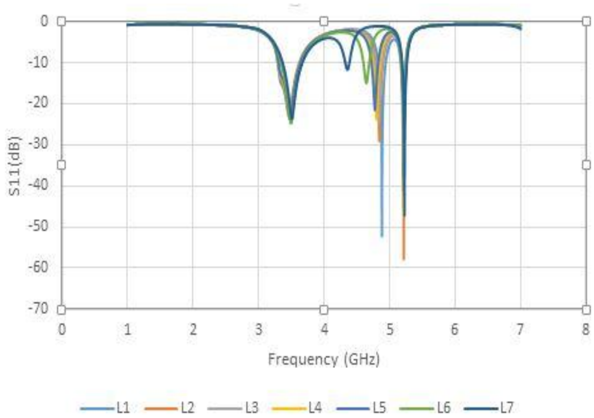

Figure 4: Variation of difference in length of slots in patch

Table 2: Varying length of ground slots

	LENGTH (mm)	FREQUENCY 1 (GHz)	FREQUENCY 2 (GHz)
L1	13	3.856	5.734
L2	13.5	3.717	5.548
L3	13.8	3.640	5.434
L4	14.1	3.562	5.342
L5	14.5	3.5	5.2
L6	14.8	3.39	5.116
L7	15.1	3.346	5.038

Table 3: Varying length of slot 1

	SLOT 2 LENGTH (mm)	FREQUENCY (GHz)
L1	5.5	4.882
L2	5.7	4.843
L3	5.8	4.832
L4	5.85	4.8
L5	6	4.75
L6	6.5	4.6
L7	7	4.48

Experimental Results

Using the dimensions given in table 1, the proposed antenna operating at the three frequencies is fabricated as shown in fig 5. The fabricated antenna is tested using vector network analyser. Figure 6 shows the comparison between the simulated and measured results. The observed return loss (S_{11}) in the aforesaid bands is well below -10dB and the matching between the simulated and measured results is found to be reasonably good. The operating bands observed are 3.446-3.61 GHz, 4.724-4.848 GHz &5.189-5.305 GHz with centre frequencies 3.521 GHz, 4.786 GHz & 5.247 GHz respectively.

The observed radiation patterns at different simulated frequencies are shown in fig.6. The observed gain at 3.5 GHz is 2.546 dB, 4.8 GHz is 1.903 dB and at 5.2 GHz is 1.0132 dB. Here different frequency bands are obtained by cutting slots into the ground plane and patch. Hence the patch antenna of same size which has been operating at a frequency of 5.4 GHz, is made to operate at three frequency bands after the inclusion of slots.

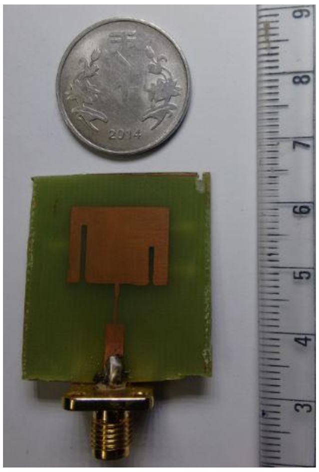

Figure 6: Top view of fabricated antenna

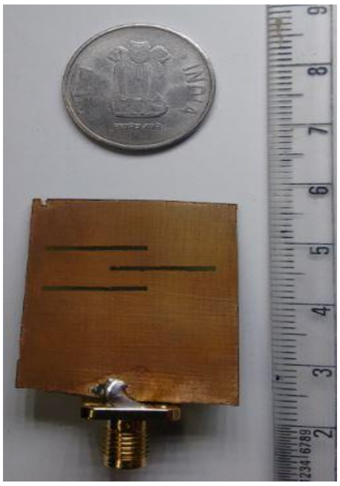

Figure 7: Bottom view of fabricated antenna

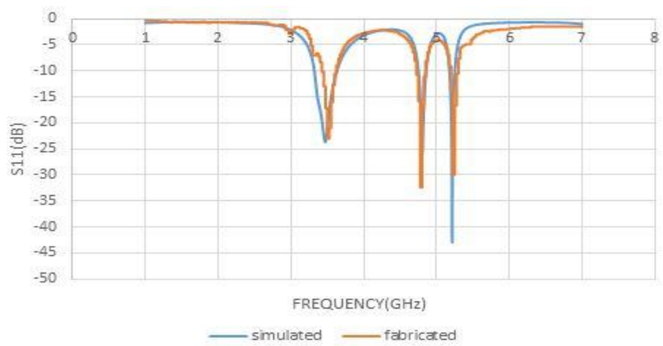

Figure 6: Comparison of simulated and fabricated results

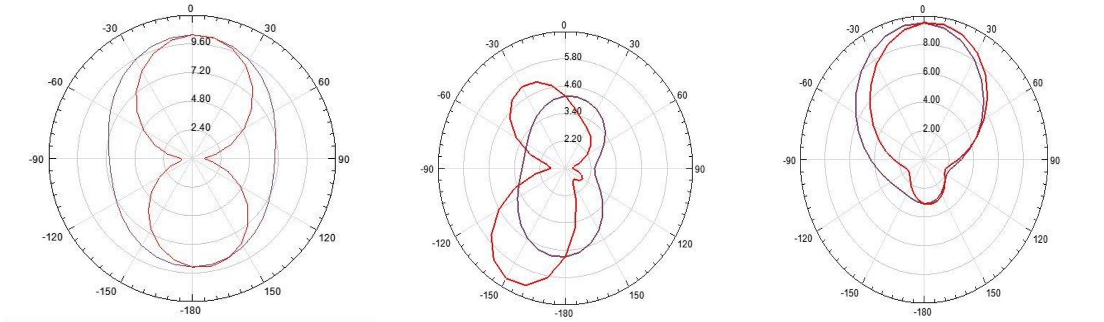

Figure 6: (a) Radiation pattern at 5.2 GHz (b) Radiation pattern at 4.8 GHz (c) Radiation pattern at 3.5 GHz

Conclusion

A microstrip patch antenna with parallel slots in ground plane and the patch is designed to operate at three frequency bands useful for Wi-MAX, radio communication and WLAN suitable for cognitive radio system. It is seen that by varying the length of the slots, the operating frequencies can be controlled. The antenna is simulated using HFSS (High Frequency Structure Simulator) software, fabricated and tested with the help of VNA (Vector Network Analyzer). The return loss (S_{11}) is obtained well below -10dB and reasonably good matching is seen between both the results. The gains obtained are 2.542 dB, 1.913 dB & 1.0132 dB at 3.5 GHz, 4.8 GHz & 5.2 GHz respectively. Further improvements may be made in future to improve the gain of antenna.

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