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Pentaband Slotted Microstrip Patch Antenna for Wireless Applications

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***Abstract*—** A pentaband slotted microstrip patch antenna for wireless applications operating in the frequency range of 2-25GHz is designed and simulated. Four pentagonal slots in radiating patch and a square slot in ground plane are introduced to get improved antenna parameters. The proposed antenna resonated at five resonant frequencies 11.373GHz with return loss -42.63dB, 16.85GHz with return loss -13.52dB, 18.67GHz with return loss -11.75dB, 21.56GHz with return loss -16.72dB and 24.28GHz with return loss -45.26dB resulting in five frequency bands. Transmission line model is used to calculate initial dimensions and IE3D simulation software based on method of moments is used for optimization of proposed antenna. The simple structure of proposed antenna makes its fabrication easy and multiband operation makes it suitable for X-band, Ku-band and K-band applications.

***Keywords*—**Pentaband; Patch; Resonant Frequency; Slot.

I. INTRODUCTION

In the last few decades, the requirement of low-profile antenna for wireless communication operating in higher frequency range has increased as the electromagnetic spectrum in the lower frequency range is saturated. Along with small size, multiband operation is highly desirable as it helps in achieving multiple applications through a single wireless terminal. Microstrip antennas satisfy such requirements as they are low-profile, light weight, conformable to surfaces, inexpensive to manufacture and mechanically robust. Apart from various advantages, narrow bandwidth is one of the major limitations of microstrip patch antennas.

Bandwidth of antenna can be improved by varying substrate parameters such as dielectric constant (εr) and thickness, by selecting suitable patch shape and proper feeding technique or by using multiple patches and coplanar parasitic elements [1]. Air substrate may be used to increase the bandwidth of an antenna but the size of antenna increases [2]. A small size antenna can be designed by increasing dielectric constant of substrate used in antenna [3].Various approaches to improve bandwidth of an antenna includes introduction of parasitic element, increasing substrate thickness and introduction of slots of various shapes in the radiating patch. Introduction of slots in the radiating patch is an attractive approach for better bandwidth development while maintaining a single layer structure so as to maintain thin profile characteristic of antenna [4,5]. Slots of various shapes and sizes have been introduced by different researchers for improving antenna characteristics [6-9].

Introduction of slots in ground plane also have various effects on antenna parameters [10-13]. Datta et al. proposed an antenna structure formed by cutting two hexagonal and a circle like shape slots in the radiating patch covering C, X and Ku band used for wireless applications [5]. The substrate used was PTFE of thickness h=1.6mm and dielectric constant εr= 4.4.

In this paper, a coaxial fed rectangular microstrip antenna with four pentagonal slots in the radiating patch and a square slot in the ground plane has been presented. The aim is to design a pentaband antenna that can operate in X, Ku and Ka bands with simultaneous reduction in the size of antenna and improved antenna characteristics by using various techniques.

The pentagonal slots have been introduced in the radiating patch to increase the number of frequency bands with improved return loss, bandwidth and gain. Further improvement in return loss has been obtained by introduction of square slot in the ground plane. Transmission line model is used for calculating the initial dimensions of radiating patch. Microstrip antenna is simulated using IE3D software [17] and modifications such as changing dimensions of ground plane, changing feed locations, cutting slots in the radiating patch and cutting slot in ground plane are applied to traditional rectangular patch antenna to improve various antenna parameters.

II. DESIGN OF ANTENNA

A. *Transmission Line Model*

In the transmission line model, the microstrip patch antenna is considered as a transmission line of length L and is represented by the two slots of width W and substrate thickness h separated by that length. The transmission line section is a non-uniform line of the air and substrate dielectrics. The electric field lines mostly reside in the substrate region and a part of some lines resides in the air.

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Due to this fact the transmission line cannot support pure transverse electro-magnetic (TEM) transmission mode. Since phase velocities are different in both the regions, the dominant mode of propagation becomes the quasi-transverse electro-magnetic mode. For such a component, any given phase of the electromagnetic wave will appear to travel at phase velocity. Therefore, an effective value dielectric constant εreff is obtained which accounts for the fringing and wave propagation in the transmission line. The value of εreff is slightly less than dielectric constant (εr) because fringing fields are around the periphery of the patch and are not confined to the dielectric substrate thus also spread in the air region. The proposed antenna employed RT/Duroid substrate as the dielectric material of height (h) =0.8mm between ground plane and the radiating patch. The permittivity (εr) of substrate used is 2.2 and loss tangent (tanδ) is 0.0009. The various equations used for calculating initial antenna parameters using transmission line model are as follows [13]:
The Width (W) of the microstrip patch antenna is given by (1) as:

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_{r+1}}{2}}} \quad (1)$$

c is light velocity.
The effective dielectric constant (εreff) of microstrip patch antenna is given by (2) as:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} - \frac{1}{\sqrt{1 + 12\frac{h}{w}}} \quad (2)$$

The Effective length (εeff) of microstrip patch antenna is given by (3) as:

$$L_{eff} = \frac{c}{2f_{0\sqrt{\varepsilon_{reff}}}} \quad (3)$$

The length extension (ΔL) of microstrip patch antenna is given by (4) as:

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

The actual length of patch (L) of microstrip patch antenna is obtained by (5) as:

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

The initial dimensions corresponding to resonant frequency f=13GHz are calculated using Eqn. (1) to Eqn. (5) and are listed in Table 1. The initial dimension of ground plane is 12mm × 12mm which has been optimized to 19mm× 8mm with feed location (-2,1) by using IE3D software [16].

Table 1: Initial antenna parameters

Parameter	Description	Value
W	Width of radiating patch	9mm
ε_{reff}	Effective permittivity of Dielectric constant	2.01734
L_{eff}	Effective length of the Radiating patch	8.124mm
ΔL	Change in length of the Radiating patch	0.415mm
L_{actual}	Actual length of the Radiating patch	7.3mm

Three resonant frequencies are obtained in the frequency range 2-22GHz which were initially two at 12.4531GHz and 17.0162GHz with return loss -10.5dB and -11.1dB, respectively. The return loss values obtained after optimization of ground plane are -12.23dB, -33.94dB and -14.77dB for three resonant frequencies 10.5GHz, 12.71GHz and 17.04GHz, respectively.

B. Optimizing the size of radiating patch

Simulations have been carried out for obtaining the optimum dimensions of the radiating patch. Radiating patch of dimensions, length Lp= 8 mm and width Wp = 7 mm provided three bands in frequency range 2-22 GHz. The return loss values obtained after optimization of radiating patch size are -10.28dB, -44.77dB and -24.37 dB for frequency bands at 12.46GHz, 13.63GHz and 19.07GHz, respectively. By changing the size of radiating patch there is an improvement in the values of return loss. There is also a shift in resonant frequencies by changing the size of radiating patch.

C. Introduction of slots in the radiating patch

Four pentagonal slots of equal size have been introduced in the radiating patch as shown in Fig.1, thus contributing in the improvement in resonance of the antenna. The parameters of radiating patch are given in Table 2. The pentagonal slots serve to increase the number of current paths.

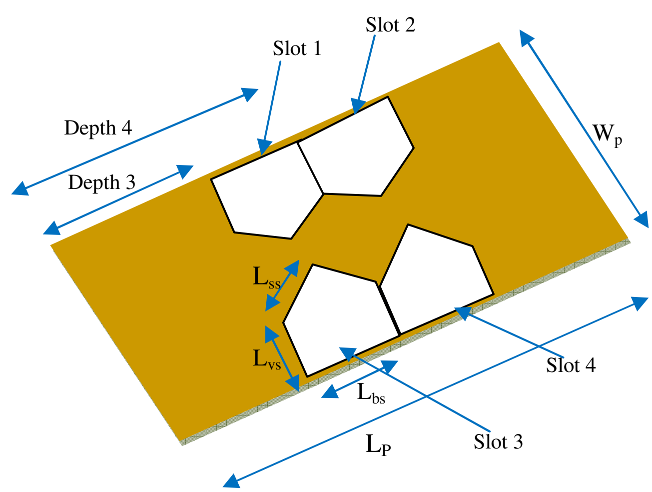

Fig.1. Detailed geometry of radiating patch

Table 2: Parameters of radiating patch

Parameter	Description	Value
L_p	Length of radiating patch	8mm
W_p	Width of radiating patch	7mm
Depth 3	Depth of slot 1 and slot 3 from left edge of patch	2mm
Depth 4	Depth of slot 2 and slot 4 from left edge of patch	2mm
L_{bs}	Length of base of pentagonal slot in radiating patch	2mm
L_{vs}	Length of vertical sides of pentagonal slot	1mm
L_{ss}	Length of slanted sides of pentagonal slot	1.41mm

The results obtained after simulation of antenna for different locations of slots in the radiating patch have been observed, compared and then appropriate slot location has been chosen. The number of resonating frequencies has increased from three to four with the introduction of slots.

The return loss values of -28.29dB, -13.91dB, -10.53dB and -21.67dB has been obtained at resonant frequencies 11.38GHz, 16.78GHz, 18.63GHz and 21.15GHz, respectively.

After choosing the location of slots in the radiating patch, optimization of feed location has been carried out. The frequency range of the proposed antenna which was initially taken to be 2-22 GHz has been increased to 2-25GHz because the resonant frequency band with resonating frequency at 21.1586 cannot be covered upto 22 GHz.

By changing the feed location to (-3.8, 1), there is further increase in return loss of antenna. The return loss values for the five resonant frequencies at 11.37GHz, 16.85GHz, 18.67GHz, 21.56GHz and 24.28GHz are -28.91dB, -12.45dB, -15.07dB, -17.85dB and -28.86dB, respectively. It has been observed that there is an increase in the number of frequency bands after introduction of four pentagonal slots and optimization of feed location.

D. Introduction of square slot in ground plane

A square slot of size 1mm×1mm with centre at (-3, 2) has been introduced in the ground plane to enhance the resonance properties of the proposed antenna. The value of return loss for five bands obtained at resonant frequencies of 11.37GHz (X-band), 16.85GHz (Ku-band), 18.67GH (Ku-band), 21.56GHz (K-band) and 24.28GHz (K-band) are -44.75dB, -13.60dB, -11.85dB, -16.72dB and -46.68dB, respectively [14-15].

There is considerable increase in the return loss and no shift in resonant frequencies. The detailed geometry of ground plane is shown in Fig. 2 and its parameters are shown in Table 3. Fig.3 shows a comparison of simulated results of return loss in antenna structures with and without ground slot.

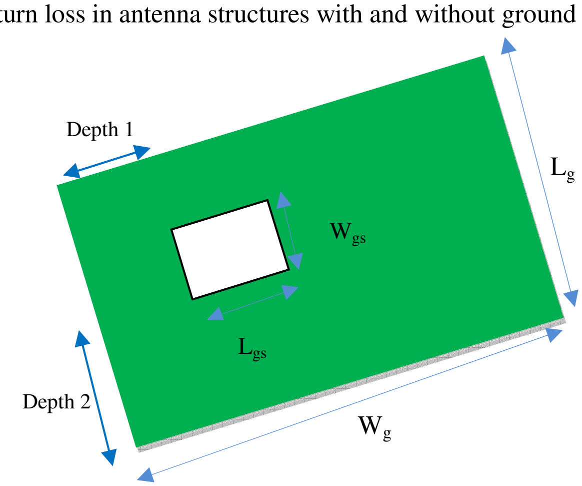

Fig.2. Detailed geometry of ground plane

Table 3: Parameters of ground plane

Parameter	Description	Value
L_g	Length of ground plane,	19mm
L_{gs}	Length of ground plane slot	1mm
W_g	Width of ground plane	8mm
W_{gs}	Width of ground plane slot	1mm
Depth 1	Depth of slot from right edge of patch	0.5mm
Depth 2	Depth of slot from lower edge of patch	5mm

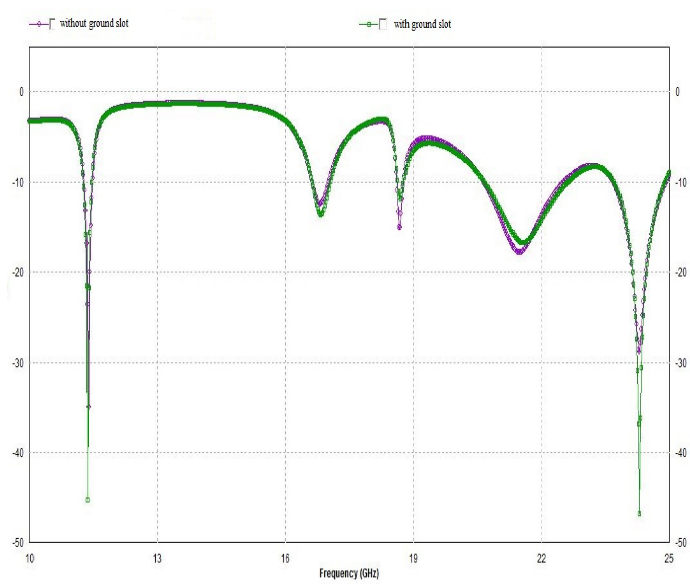

Fig.3. Comparison of return loss of antenna structure with and without ground slot

III. Result and Discussion

The proposed antenna design obtained is of single patch whose dimensions have been reduced than that calculated from the transmission line model after optimization of its dimensions. The optimization steps followed have thus helped in the reduction of antenna size and adjustment of antenna parameters resulting in multiband characteristics. The proposed antenna structure is shown in Fig.4.The dimension of final structure for the proposed antenna is 8×7mm^2 with substrate thickness of 0.8mm.

All the simulated results of the proposed antenna are summarized in Table 4. The gain reached upto 5.71dBi at resonant frequency 21.56GHz. The proposed antenna has five frequency bands with centre at 11.37GHz, 16.85GHz, 18.67GHz, 21.56GHz and 24.28GHz of -10db bandwidth. The bands covered are X-band, Ku- band and Ka-band. The return loss of -45.26dB has been obtained at frequency 24.28GHz. The radiation efficiency upto 81.82% is achieved at 11.37GHz. The 3D radiation patterns of the proposed antenna are shown in Fig. 5-9. Though the radiation pattern of proposed antenna are not purely omnidirectional but provides a wide coverage and is therefore suitable for X, Ku and Ka band applications.

Radiating
Patch Slot

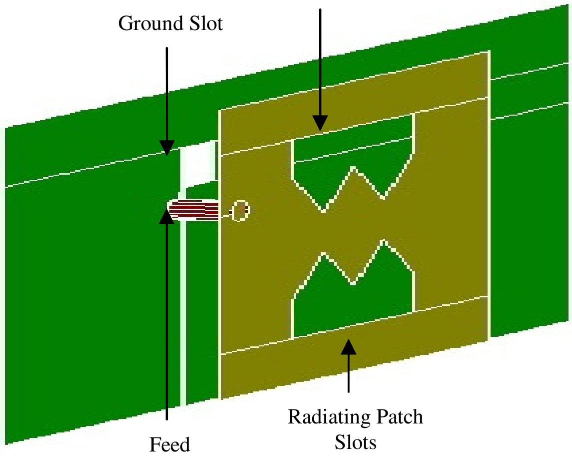

Fig.4. Proposed Antenna structure

Table 4: Simulated parameters of proposed antenna

Frequency (dB)		Return loss (dB)	Gain (dBi)	Efficiency (%)	Band-width (MHz)
f_1	11.37	-42.63	3.93	81.82	188.703
f_2	16.85	-13.52	3.69	66.38	423.811
f_3	18.67	-11.75	2.44	64.57	136.007
f_4	21.56	-16.72	5.71	67.67	1925.80
f_5	24.28	-45.26	3.71	56.37	1179.98

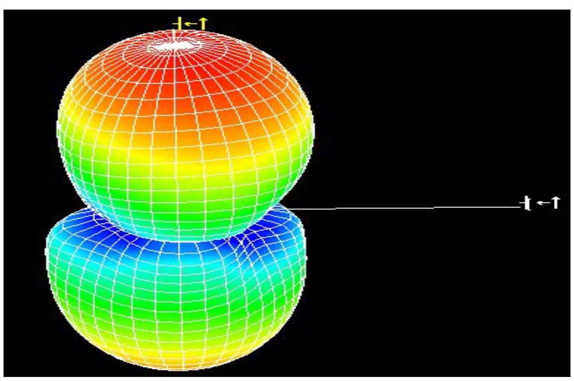

Fig.5. 3D radiation pattern of proposed antenna at 11.37GHz

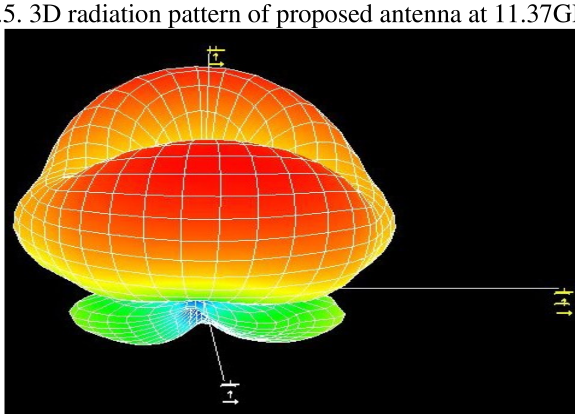

Fig.6. 3D radiation pattern of proposed antenna at 16.85GHz

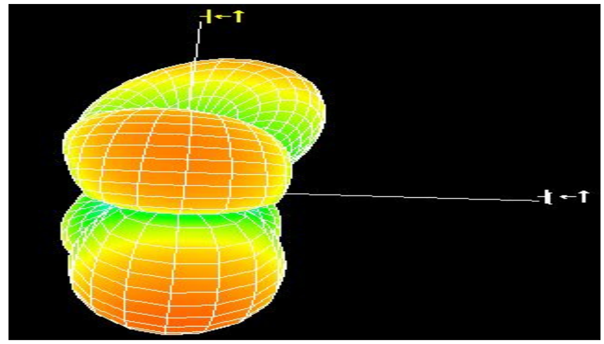

Fig.7. 3D radiation pattern of proposed antenna at 18.67GHz

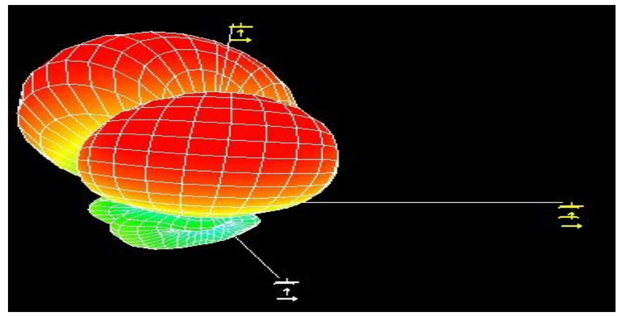

Fig.8. 3D radiation pattern of proposed antenna at 21.56GHz

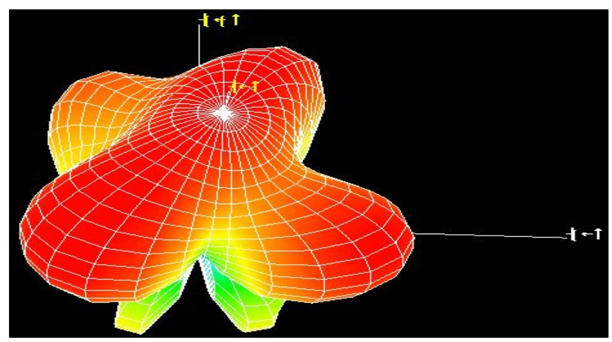

Fig.9. 3D radiation pattern of proposed antenna at 24.28GHz

IV. Conclusion

A detailed simulation study of a pentaband slotted microstrip antenna for wireless applications has been successfully carried out using procedure of transmission line model along with IE3D simulation software. Pentagonal slots in the radiating patch have been employed for increasing the number of resonant frequency band and for increasing the return loss. Simulated results show that with the introduction of square slot in the ground plane, there is considerable increase in the return loss of antenna at frequencies 11.37GHz and 24.28GHz. The proposed antenna has a volume 8×7×0.8 mm^3. The proposed antenna design shows nearly omnidirectional radiation pattern at some resonant frequencies. The proposed antenna is easy to fabricate due to its simple structure and can be used for X-band, Ku-band and K-band applications.

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