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An Improved Design of Slotted Microstrip Patch Antenna for X Band and Ku band Applications

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Abstract: **A comparative design of a rectangular shaped microstrip patch antenna for X band and Ku band application is analyzed in this paper. The proposed antenna of 7.5 * 10.50 square mm is placed over dielectric substrate of 15 * 15 * 1.5 mm having dielectric constant of 4.4. The proposed antenna is designed, optimized and analyzed with HFSS simulator.**

Keywords: Microstrip Patch Antenna, Return Loss, HFSS, X and Ku band.

I. INTRODUCTION

The microstrip antenna has attracted interest of researchers due to size compactness, light weight and low cost. The severe disadvantage of microstrip antenna is the narrow bandwidth. To overcome this problem without disturbing their principle advantage a number of methods and structures have been recently investigated. Most of the antenna is designed to improve upon bandwidth by Wideband patch antenna structures [1], multiband antenna [2], log periodic structures [3], Triple band (L shaped) patch antenna [4], resonator antenna, spiral antenna [5]. Further need of improvement in bandwidth is justified by various other designs of Dual Band X Shape Microstrip Patch Antenna for Satellite Applications [6], Microstrip Patch Antenna with an End Fire Radiation [7], Coaxial fed Micro strip Patch Antenna for 2.4GHz Bluetooth Applications [8], Inverted S-shaped compact antenna for X-band applications [9] and X band printed microstrip compact antenna with slots in ground plane and patch [10].

The purpose of this paper is to introduce the narrow bandwidth characteristics of patch antenna. The patch is feed by coaxial feed line.

The proposed antenna is simulated in X-band of frequency 8 to 12 GHz and Ku band of 12-18 GHz. These bands are popular radar frequency sub-bands used in civil, military, government institutions for weather monitoring, air traffic control, defence tracking and vehicle speed detection.

This paper consists of V Sections. Brief introduction is discussed in Section I. Section II describes the Analysis Model for microstrip antenna. Section III describes Antenna designs and its simulated results for Conventional Rectangular patch Antenna, Slotted Microstrip Patch Antenna-1 and 2. Comparative results for all structures are discussed in Section IV. Section V concludes the paper.

II. ANALYSIS MODEL FOR MICROSTRIP ANTENNA

There are several types of analysis model available for microstrip patch antenna in which transmission line model is simplest with good physical insight [12].

In the transmission line model, the microstrip patch antenna is represented by two slots of height h and width W and separated by a low impedance transmission line of length L as shown in figure 1.

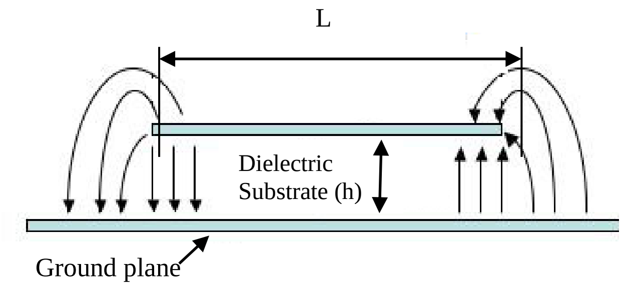

Figure1: Electric field lines between patch and ground plane.

The dimensions of the patch are finite with the length and width, so the fields at the edges of the patch undergo fringing. Due to this fringing effect an effective dielectric constant $\epsilon_{r\,eff}$ is introduced to account for this effect. The expression for $\epsilon_{r\,eff}$ is

$$\epsilon_{r\,eff} = \frac{1+\epsilon_r}{2} - \frac{1-\epsilon_r}{2}\left(1+12\frac{h}{w}\right)^{-1/2} \quad (1)$$

Where $\epsilon_{r\,eff}$ = Effective dielectric constant, ϵ_r = Dielectric constant of substrate, h = Height of dielectric substrate, W = Width of the patch

The resonating length of the patch is not exactly equal to the physical length due to the fringing effect. The fringing effect makes the effective length of the patch longer than its physical length as shown in the figure 2 below. A very popular and practical approximate relation for the normalized extension of the length is calculated as follows[11].

$$\Delta L = 0.412h - \frac{\epsilon_{r\,eff}+0.30}{\epsilon_{r\,eff}-0.258}\left(\frac{0.264+W/h}{0.813-W/h}\right) \quad (2)$$

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Now the effective length of the patch L_{eff}

$$L_{eff} = 2\Delta L + L \quad (3)$$

For a given resonance frequency f_r, the effective length is the width W is represented in equation 4.

$$W = \frac{c}{2\,fr}\left(\frac{1+\varepsilon r}{2}\right)^{-\frac{1}{2}} \quad (4)$$

Expression makes the width W equal to about half a wavelength. It leads to good radiation efficiency and acceptable dimension [13].

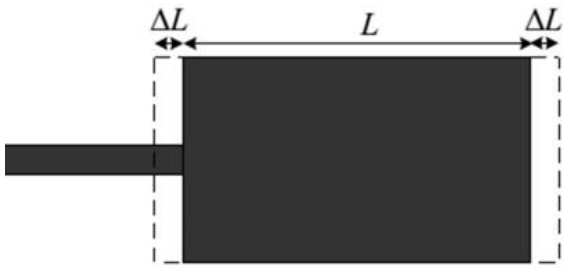

Figure 2: Top view

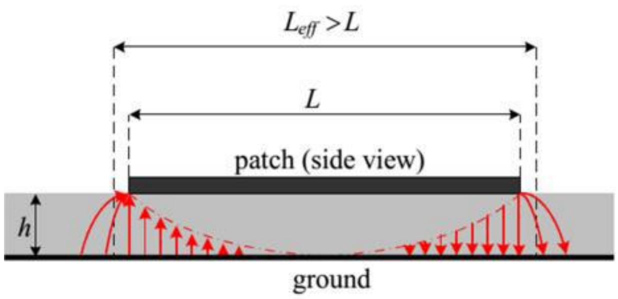

Figure 3: Side view

As shown in figure 3, the normal components of electric field has equal amplitude but opposite phase at the edges, so cancel out each other in perpendicular direction [14].

III. ANTENNA DESIGNS AND SIMULATED RESULTS

A. Conventional Rectangular Patch Antenna

The conventional rectangular patch of 7.5 * 10.5 square mm is placed over dielectric substrate (FR4) of 15 * 15 * 1.5 cubic mm and has dielectric constant of 4.4. The proposed geometry is as shown in figure 4. The coaxial feeding technique is used.

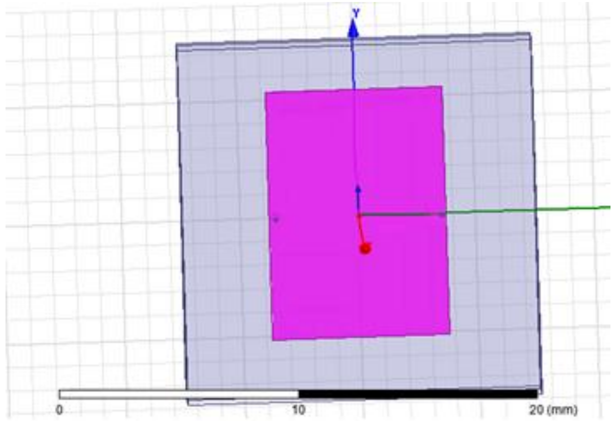

Figure 4: Geometry of Structure1 (Conventional Rectangular Patch antenna)

Simulation results obtained by this conventional Rectangular Patch are given in figure 5. It is observed that rectangular patch antenna has -10dB return loss from 8.5 GHz to 9.3 GHz and resonates at 8.7 GHz frequency which is close to the desired frequency of 9 GHz. The gain is 2.15 dB as seen in radiation pattern of figure 6.

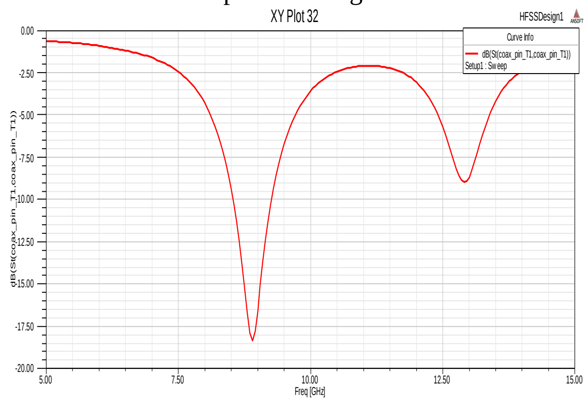

Figure 5: Return loss versus Frequency Plot for Conventional Rectangular Patch antenna (Structure 1)

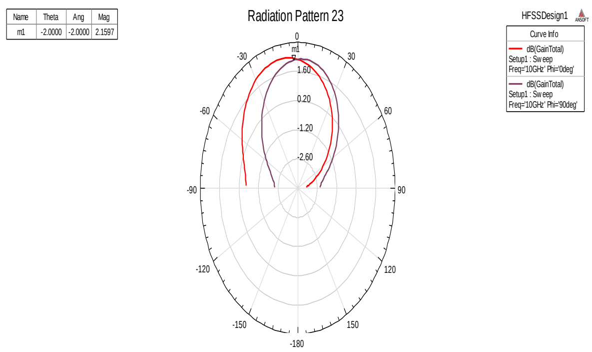

Figure 6: Radiation pattern of Structure 1 for Conventional Rectangular Patch antenna

Return loss is logarithmic ratio which is measured in dB that compares the power reflected by the antenna to power that is fed into antenna. The optimal feed location is found out to be at (x ,y) of (-3.5, 0) with a S11 of -18.5 dB. The % Bandwidth obtained is 8.62%.

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TABLE I. EFFECT OF FEED LOCATION WITH CENTER FREQUENCY, S11 AND PERCENT BANDWIDTH

S No.	Feed location (X,Y) mm	Center Frequency (GHz)	S11 (dB)	%BW
1.	(0 , -5)	7	-11	5.71
2.	(0, -2)	7	-11	5.71
3.	(0, -2.5)	6.5	-20	9.2
4.	(0 ,-3)	6.3	-17	9.5
5.	(-1 ,0)	13.5	-14	3.7
6.	(0.2, 0)	13.4	-12	2.98
7.	(0.75, 0)	13.4	-13	3.73
8.	(-3, 0)	8.6	-14	5.81
9.	(-3.2, 0)	8.4	-17	8.33
10.	(-3.5, 0)	8.7	-18.5	8.62

Table I shows the result obtained from observing the different feed point locations. After identification feed point remains same for all the geometries.

B. Slotted Microstrip Patch Antenna-1

For increasing the bandwidth, four semicircular cuts of 1.5 mm radius are cut in the conventional patch at the four corners. Figure 7 (a) shows the geometry of resultant patch antenna. The similar semicircular cut of radius of 2 mm, 2.5 mm and 2.8 mm obtained at the four corners of patch are shown in figure 7 (b), (c) and (d) respectively.

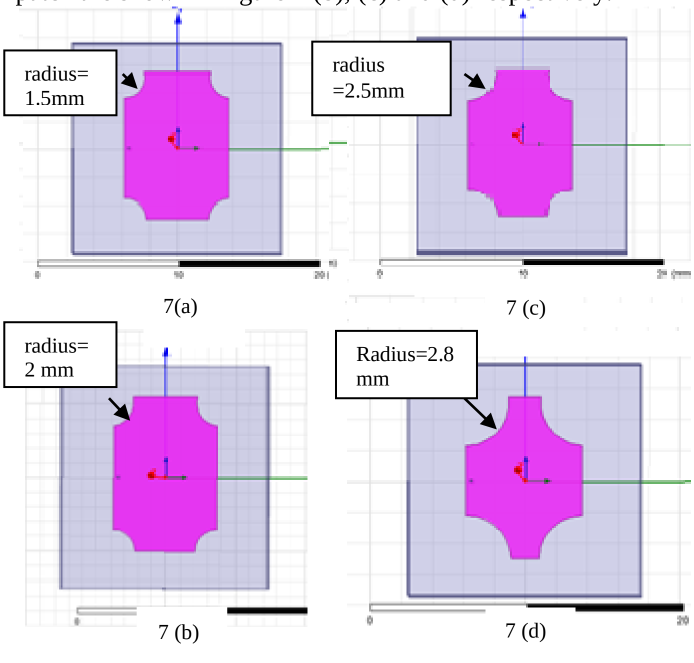

Figure 7 (a): Geometry of Structure 2 Slotted Microstrip Patch Antenna-1 with four semicircular slots of radius 1.5 mm (b) 2 mm (c) 2.5 mm (d) 2.8 mm

For the structure of figure 7 (a) the S11 parameter obtained is -32 dB. It is observed that the dual frequency operation can be achieved by cuts of semicircular shape of radius 1.5 mm at the four corners of patch of the antenna. Two resonating frequencies at 9.65 GHz and 13.3 GHz with % BW of 9.3 % and 4.1% respectively are obtained as shown in figure 8. The gain of 3.2 dB was observed from figure 9.

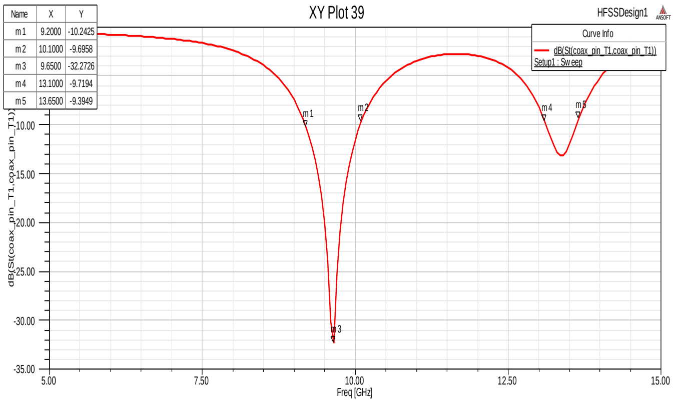

Figure 8 : Return loss versus frequency plot of Structure 2 for radius=1.5 mm

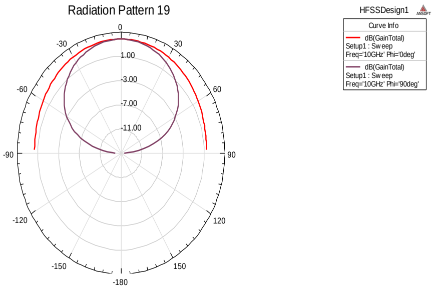

Figure 9: Radiation pattern of Structure 2 for radius=1.5 mm

The simulated results of the each the antenna geometries obtained by semicircular cut of radius of 1.5mm, 2 mm, 2.5 mm and 2.8 mm at the four corners of patch are listed in the table II. A comparison chart is shown in figure 10, 11 and 12 for resonant frequency, gain and percentage bandwidth.

TABLE II. COMPARISON RESULTS FOR DIFFERENT SEMICIRCULAR SLOTS

ircle Radius (mm)	Resonant frequency f1, f2 (GHz)	Gain (dB)	% BW BW1,BW2	S11 (dB)
1.5	9.65, 13.3	3.2	9.3, 4.1	-32,-13
2	10, 13.3	2.6	9.5, 5.2	-30,-20
2.5	10.3, 13.3	3.0	9.1, 5.9	-22,-24
2.8	10.6, 13.3	2.8	8.9, 5.6	-19,-15

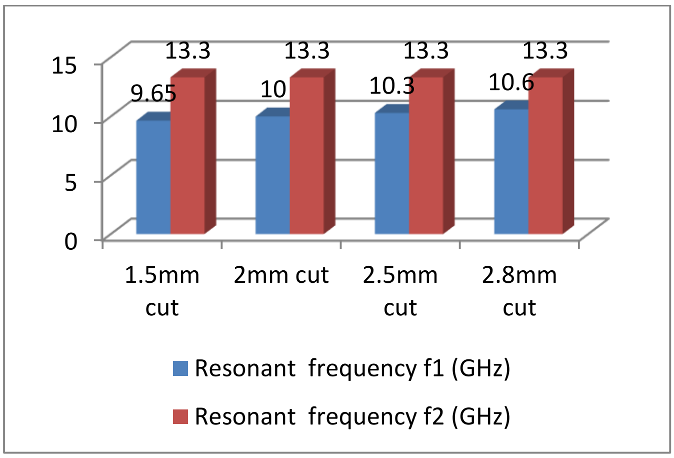

Figure 10: Resonant frequency Comparison chart for Structure 2

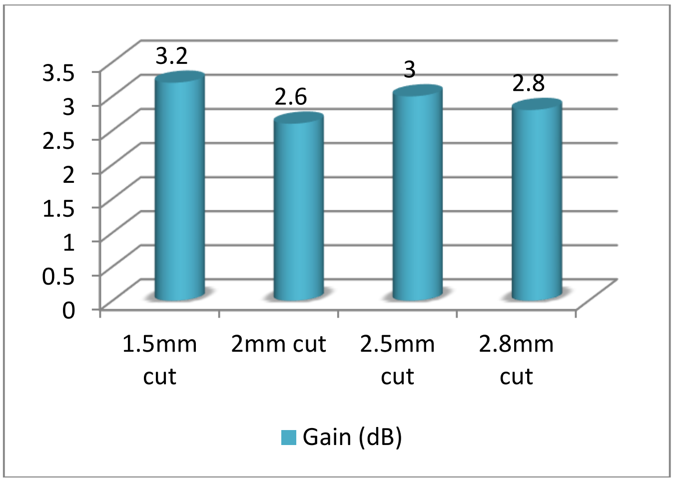

Figure11: Gain Comparison chart for Structure 2

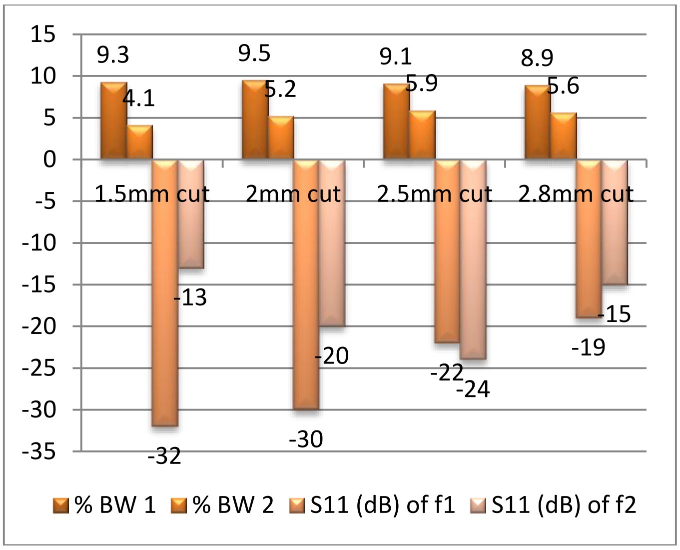

Figure12: % Bandwidth and resonant frequency Comparison chart for Structure 2

It is observed that the gain is above 2 dB for all geometries. A dual band is observed in each structure in the X and Ku band. The return loss of structure of radius = 1.5 mm cut at corners is less at -32 dB at resonant frequency of 9.3 GHz.

C. Slotted Microstrip Patch Antenna-2

For enhancing the bandwidth one rectangular slot of dimension (4mm * 2mm) is cut in the conventional patch at right side as shown in figure 13 (a). Four semicircular cuts of 2.5 mm radius at the four corners of the patch remain same for all the geometries of figure 13. Different slots of Rectangle of area (4 * 1) mm, (4 * 0.5) mm, (7 * 0.5) mm are shown in figure 13 (b), (c) and (d).

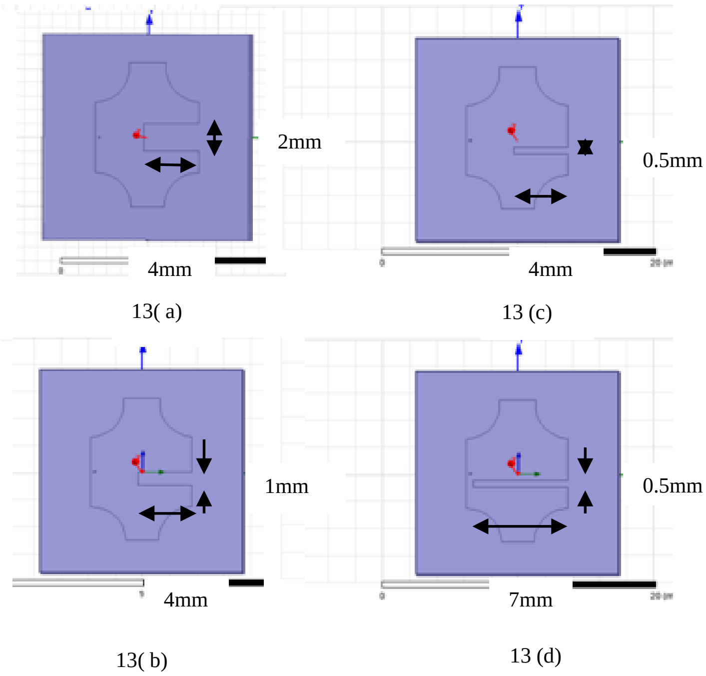

Figure 13: Geometry of Structure 3 of Slotted Microstrip Patch Antenna-2 with rectangular Slot at right side (a) 4mm * 2mm (b) 4mm * 1mm (c)4mm * 0.5mm (d) 7mm * 0.5mm

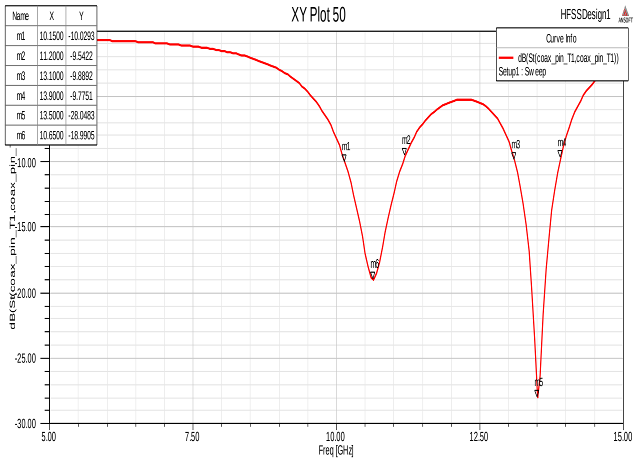

Figure 14: Return loss versus frequency plot for Structure 3 of (4 *2)square mm slot

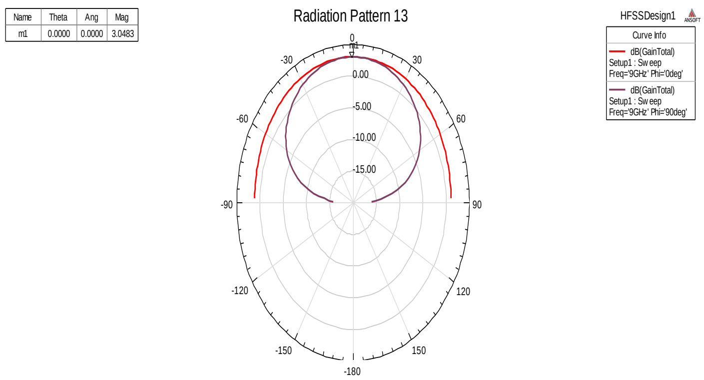

Figure 15: Radiation pattern of Structure 3 of (4 *2) square mm slot

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Dual Band is observed in this structure at 10.6 GHz and 13.5 GHz as shown in figure 14 of structure 3 of (4 * 2) square mm slot. Radiation pattern of figure 15 shows gain of 3.04 dB.

The table III shows the comparison results for different slots of Rectangle of area (4 * 2) mm, (4 * 1) mm, (4 * 0.5) mm and (7 * 0.5) mm in the patch. Figure 16, 17 and 18 shows the comparison chart for return loss, bandwidth and gain with frequency.

TABLE III. COMPARISON RESULTS FOR DIFFERENT RECTANGULAR SLOTS

Slot Area (square mm)	Gain (dB)	Resonant frequency (GHz) (fr1, fr2)	%BW (BW1,BW2)	S11 (dB)
4 x 2	3.04	10.6, 13.50	9.8, 5.9	-18, -28
4 x 1	3.07	10.45, 13.35	9.56, 5.99	-22, -29
4 x 0.5	3.08	10.4, 13.35	9.61, 6.36	-23, -27
7 x 0.5	3.08	10.3, 13.25	9.70, 6.03	-23, -24

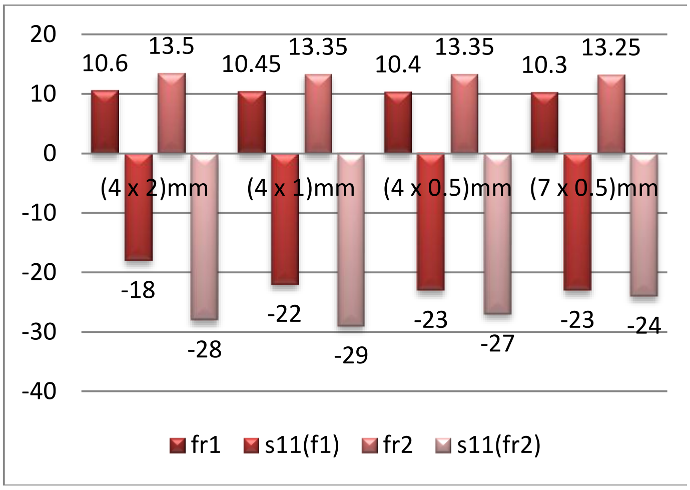

Figure16: Return loss and frequency chart for Structure 3

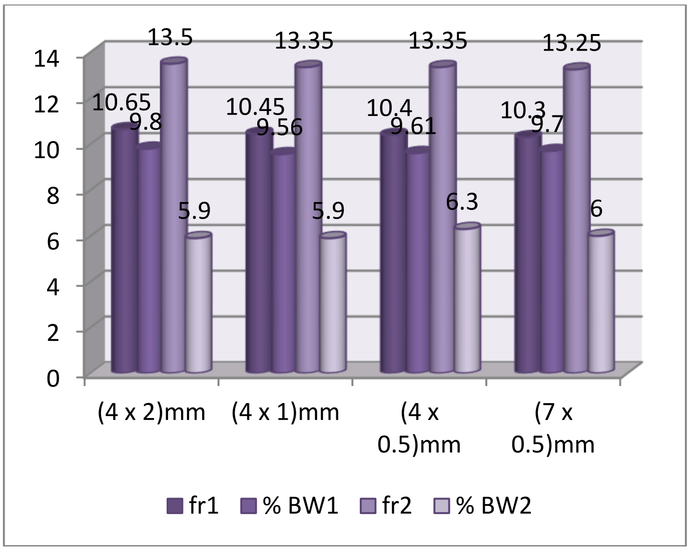

Figure 17: % Bandwidth and frequency chart for Structure 3

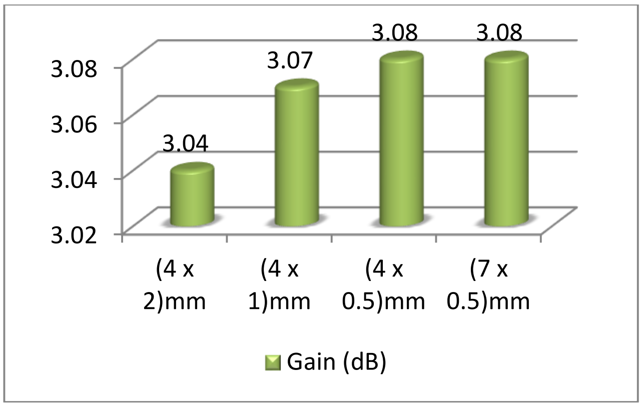

Figure18: Gain Comparison chart

It is observed that the gain is above 3 dB for all geometries. A dual band is observed in each structure in the X and Ku band with minimum return loss.

IV. COMPARATIVE ANALYSIS OF ALL STRUCTURES:

Bandwidth and Gain are the two important antenna performance parameters. It is observed that antenna has two resonant frequencies for structure 2 and structure 3. Gain is above 2 dB. Comparative results are more clearly shown by table IV below. Comparison of structure 2 with the basic patch of structure 1 shows a good improvement in the return loss from -18.5 dB to -32 dB with a dual band at 9.65 GHz and 13.3 GHz. Comparison of Structure 3 with structure 1 shows dual band at frequency 10.6 GHz and 13.50 GHz with return loss of -18 dB and -28 dB.

TABLE IV. COMPARISON RESULTS FOR ALL STRUCTURES

Arrangement	Gain (dB)	Resonant freq. (GHz)	S11 (dB)	Bandwidth (%)BW
Structure 1	2.15	8.7	-18.5	8.6
Structure 2 (r=1.5mm)	3.2	9.65	-32	9.3
		13.3	-13	4.1
Structure 3 Slot area=(4*2) sq mm	3.04	10.6	-18	9.8
		13.50	-28	5.9

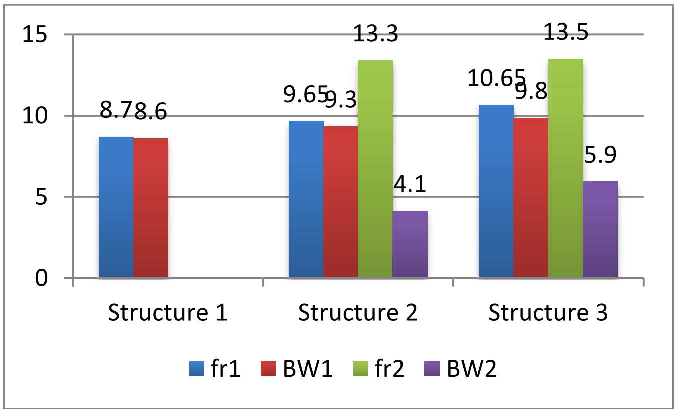

Figure 19: % Bandwidth and frequency comparision chart

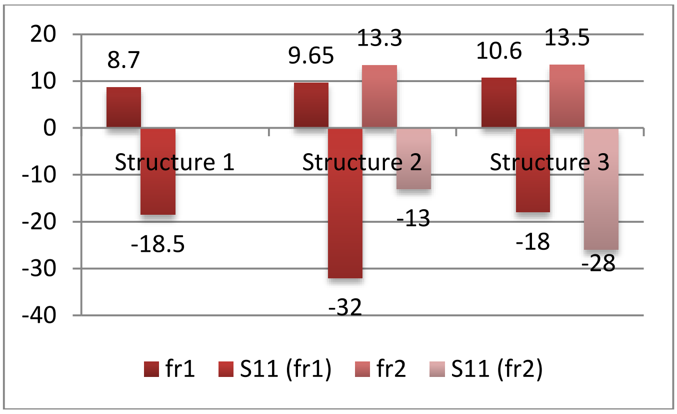

Figure 20: Return loss and frequency Comparison chart

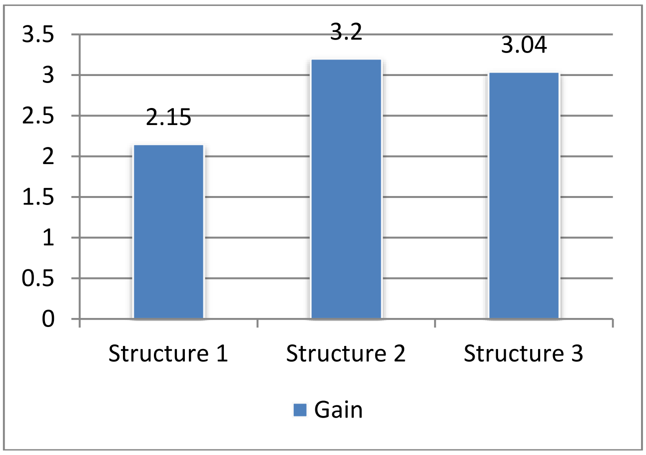

Figure 21 : Gain Comparison chart

Figure 19, 20 and 21 shows the comparison chart for return loss, bandwidth and gain with frequencies for all three structures.

V. CONCLUSION

In this paper a new low profile broadband antenna operating at X and Ku band has been proposed. A rectangular patch with different slots in different position is taken to achieve good performances like gain and percentage band width. This design provides several advantages. The first one is the gain of antenna structure 2 and structure 3 is more than 2 dB. The second is that the patch antenna has dual band operating at X and Ku band. The overall patch size is small of 7.5*10.5 square mm and helps in feeding the antenna with coaxial feed. Finally the proposed structure is simple and can be fabricated easily. This antenna can be employed for Broadband Wireless communication systems.

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