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Analysis of Double U-Shaped Slot Loaded Patch Antenna For Uwb Applications

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***Abstract* - In this paper a microstrip antenna loaded with double U-slot is designed. Here, the shape of patch is rectangular and partial ground plane is used. The antenna designing is done by using HFSS simulation tool. Feeding is done by using microstrip feed line. After designing antenna the effect of variation in the dielectric material of substrate, width and length of U-shaped slot, feed position and ground plane variation on antenna bandwidth is analyzed. Finally, the proposed antenna design gives optimum impedance bandwidth of 10 GHz operating over a frequency range of 4.1 to 14.1 GHz with VSWR < 2. These characteristics make the designed antenna suitable for various ultra wideband applications.**

Keywords
Microstrip Antenna, U-shaped slot, Partial ground plane, Ultra wide band.

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I. INTRODUCTION

Antennas are very important component in wireless communication system. There are different types of antennas exits practically which we used for transmit and receive EM waves. Out of these microstrip antenna is one of the most important antenna nowadays due to their attractive features such as low profile, light weight, low cost and ease in fabrication. Therefore, they are compatible with wireless communication integrated circuitry. But it has some disadvantages such as narrow bandwidth, low gain and low efficiency. There are some drawbacks in order to reduce these drawbacks such as slot loading over patch, reduction in length of ground plane etc. [1] [2].

Federal Communication Commission (FCC) allocated a bandwidth of 7.5 GHz i.e. from 3.1 GHz to 10.6. It is generated by very short duration pulses generally in picoseconds therefore it provides very high data rate in the range of Mbps. There are several advantages of short duration pulses like it avoids multi path fading etc. This is widely used in radars and remote sensing applications. UWB antennas having return loss (S11< -10dB) high radiation efficiency over ultra wide band from 3.1 GHz to 10.6 GHz.

In the present paper, a double U-shaped slot loaded rectangular microstrip antenna is designed and analyzed. Two U-shaped slots reduce the overall impedance of antenna. The slot reduces the area of copper sheet which leads to less value of quality factor hence bandwidth increases. The microstip line is used for feeding because of its ease in fabrication and simple to match by controlling inset positions. A VSWR< 2 and S11< -10 dB is achieved for a frequency range of 6.5-14.8 GHz with stable E- and H-plane radiation patterns. Now, figure 1 shows the antenna design.

II. ANTENNA DESIGN

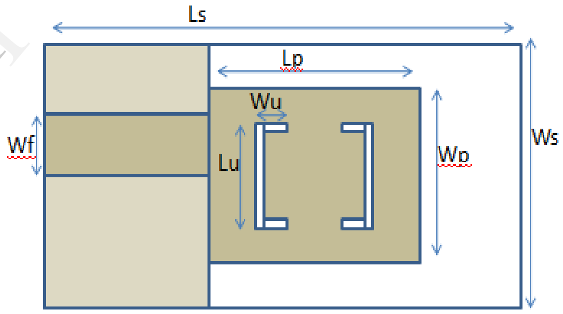

Fig. 1 Design of Double U-slot loaded Microstrip Antenna

Table 1 shows the dimension of various parameters of antenna.

Table 1. Dimensions of Antenna

S.No	Parameters	Dimensions	Material
1	Substrate	W_s=30 mm L_s=30 mm H_s= 1.6mm	Varying
2	Rectangular patch	L_p= 16 mm W_p= 11.964mm	Copper
3	Ground Plane	W_g= 16 mm L_g= varying	Copper
4	U-Slot	L_u= Varying W_u= Varying	-
5	Feed line	W_f= 3.01mm L_f = 8 mm	Copper

III. MATHEMATICAL FORMULATION

Width of microstrip antenna is simply given as

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}} \qquad (1)$$

Where,

W= Width of Patch

ε_r = Dielectric constant of the substrate

Actual length of microstrip antenna is given as

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

Where,

L_{eff} = Effective length of the patch.

ΔL = Extended electrical length

Effective length of the patch is simply given by

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \quad (3)$$

Where,

ε_{reff} = Effective dielectric constant

For low frequencies the effective dielectric constant is essentially constant. At intermediate frequencies its values begin to monotonically increase and eventually approach the values of dielectric constant of the substrate. Its value is given by,

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (4)$$

h = thickness of the substrate

In microstrip antenna, radiation occurs due to the fringing effects. Due to fringing effects electrical length of patch is greater than its physical length. This fringing depends on the width of patch and height of substrate [2].Now the extended electric length is given by

$$\Delta L = 0.412h\,\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.8)} \quad (5)$$

The width of microstrip line in microstrip antenna is given as follows:

For

$$\frac{W_{eff}}{h} \geq 2$$

$$W_{eff} = \frac{2h}{\pi}\left\{\frac{\varepsilon_r-1}{2\varepsilon_r}\left[\ln(B-1)+0.39-0.\frac{61}{\varepsilon_r}\right]+B-1-\ln(2B-1\right.$$

and for

$$\frac{W_{eff}}{h} \leq 2$$

$$W_{eff} = \frac{8he^{A}}{e^{2A}-2}$$

$$W_f = W_{eff} - \frac{t}{\pi\left[1+\ln\left(\frac{2h}{t}\right)\right]}$$

Where, A and B are given as follows

$$A = \frac{Z_{ol}}{60}\left(\frac{\varepsilon_r+1}{2}\right)^{0.5} + \frac{\varepsilon_r-1}{\varepsilon_r+1}(0.23+0.11/\varepsilon_r)$$

$$B = \frac{377\pi}{2Z_{ol}\sqrt{\varepsilon_r}}$$

IV. RESULT AND DISCUSSION

In this paper, antenna is designed by using ANSOFT HFSS (High Frequency Structural Simulator) [4]. Method of finite element solver is used. Rectangular patch is 11.964 mm wide and 16 mm long. Dielectric material of substrate is varying and it is 30 mm wide and 30 mm long and height of the substrate is 1.5 mm. Different types of substrate such as glass, FR4 epoxy, mica and Bakelite is taken. Feeder position is varied at 0 mm, 1.5mm, 2.5 mm from the symmetrical position. . Ground plane is partial providing good impedance match with width 30mm mm and varying length. At different lengths of partial ground plane i.e. 7mm, 7.4mm, 7.8mm, 8mm, 8.4mm, 8.8mm and 9mm, effect on antenna bandwidth is observed. Double U-shaped slot is used to decrease the overall impedance. It provides good impedance matching and higher bandwidth. In HFSS, rectangular patch and partial ground plane are made up of PEC (Perfect Electrical Conductor) and air or vacuum can be used for the radiation box.

Firstly, the effect of varying length of partial ground plane on bandwidth of antenna is analyzed. Return loss gives us amount of power being reflected by the input port. For UWB antenna, return loss below -10 dB is considered to be quite efficient.Figure2 shows return loss v/s frequency curve at different length of ground plane.

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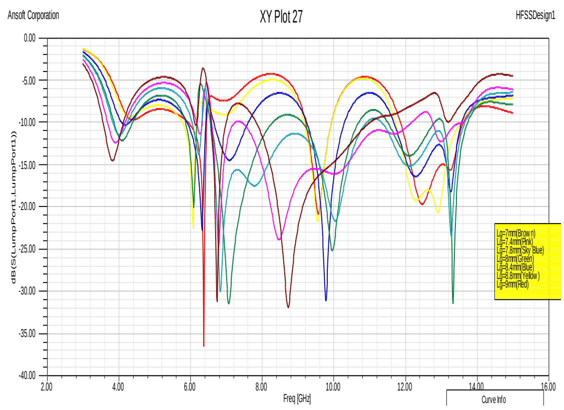

Fig. 2 Return loss Vs frequency curve for varying length of ground plane

Table 2. Bandwidth at Different Length of Ground Plane

Length of Ground Plane	Frequency Range	Bandwidth	Fractional Bandwidth
7mm	7.8-11.01 GHz	3.21 GHz	44.58%
7.4mm	6.5-12.22GHz	5.72GHz	79.44%

7.8mm	6.5-13.6GHz	7.1GHz	98.6%
8mm	6.5-13.7GHz	7.2GHz	100%
8.4mm	9.2-10.33GHz	1.13GHz	15.69%
8.8mm	9.17-9.94GHz	0.77GHz	10.69%
9mm	9.22-9.92GHz	0.7GHz	9.72%

From the figure 2 and table 2 it is clear that optimum bandwidth is achieved when length of ground plane is 8mm.

Now, we see the effect of U-slot width on bandwidth of antenna. Figure 3 shows return loss v/s frequency curve at different width of ground plane.

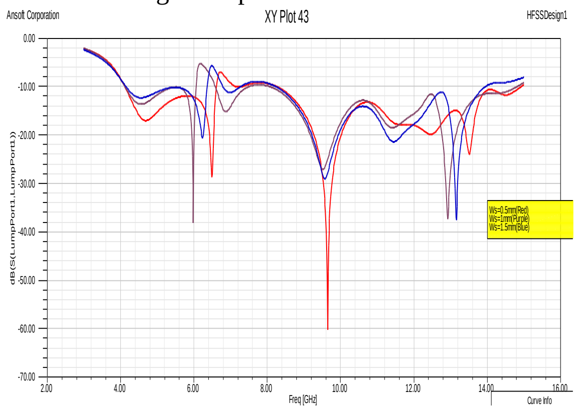

Fig. 3 Return loss Vs frequency curve for varying width of U-slot

Table 3. Bandwidth at Different width of U-slot

Width of Slot	Range of frequency	Bandwidth (GHz)	Fractional Bandwidth (%)
0.5mm	7.0-14.9GHz	7.9	109.72
1mm	6.5-14.8GHz	8.3	115.27
1.5mm	8.2-13.9GHz	5.7	79.16

From the figure 3 and table 3 it is clear that optimum bandwidth is achieved when width of U-slot is 1 mm. Dielectric constant of the substrate also creates the effect on the bandwidth of microstrip antenna. So, now we see the effect of substrate material on bandwidth. Figure4 shows return loss v/s frequency curve at different substrate materials.

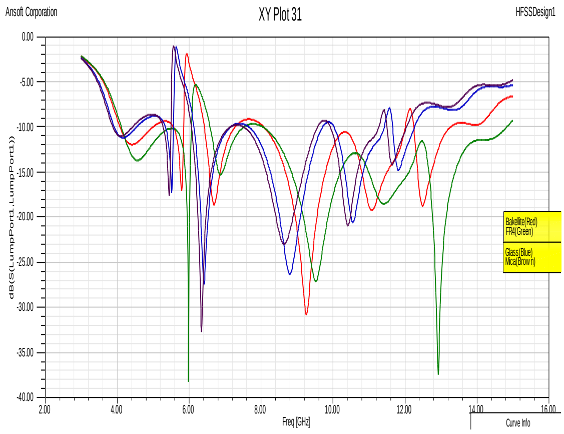

Fig. 4 Return loss Vs frequency curve for varying dielectric constant

Table 4. Bandwidth at Different Dielectric Material

Substrate Material and Dielectric constant	Range of frequency	Bandwidth	Fractional Bandwidth
Mica(5.5)	6.05-12.05GHz	6 GHz	83.33%
Glass(5.7)	6.15-11.4GHz	5.25GHz	72.91%
Bakellite(4.8)	6.42-13.98GHz	7.56GHz	105%
FR4(4.4)	6.5-14.8GHz	8.3GHz	115.28%

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From the figure 4 and table 4 it is clear that optimum bandwidth is achieved when substrate is FR4 epoxy and its dielectric constant is 4.4.

Now, we see the effect of varying feeding position on the bandwidth of antenna. Figure 5 shows return loss v/s frequency curve at different feeding positions.

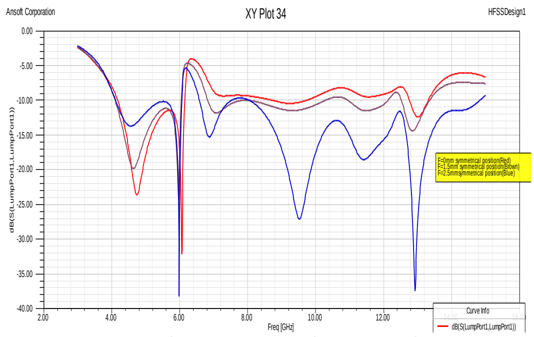

Fig. 5 Return loss Vs frequency curve for varying feeding position

Table 5. Bandwidth at Different Feeding Positions

Feeding position from symmetrical position (mm)	Range of Frequency (GHz)	Bandwidth (GHz)	Fractional Bandwidth (%)
1.5	6.8-12.5	5.7	79.16
2.5	6.5-14.8	8.3	115.27
0	8.6-9.8	1.2	16.67

From the figure 5 and table 5 it is clear that optimum bandwidth is achieved when feeding position is 2.5mm from symmetrical position.

Finally, we see the effect of varying length of U-slot on the bandwidth of antenna. Figure 6 shows return loss v/s frequency curve at different length of U-slot.

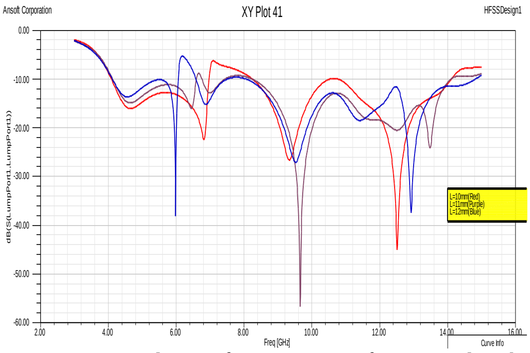

Fig. 6 Return loss Vs frequency curve for varying length of U-slot

Table 6. Bandwidth at Different length of U-slot

Length of slot	Range of frequency	Bandwidh(GHz)	Fractional Bandwidth(%)
10mm	8.2-14.1GHz	5.9	81.94
11mm	6.4-14.11GHz	7.71	107.08
12mm	6.5-14.8GHz	8.3	115.27

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From the figure 6 and table 6 it is clear that optimum bandwidth is achieved when length of U-slot is 12mm. We design antenna having ground plane length 8mm, U-slot width 1mm, length of U-slot 12mm, feeding position 2.5 mm from symmetrical position, substrate material is FR-4 epoxy. For this antenna design return loss is less than -10 dB in frequency range 4.1-14.1 GHz. Figure 7 shows return loss v/s frequency curve.

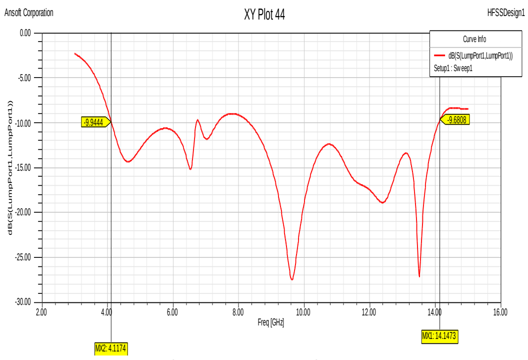

Fig. 7 Return loss Vs frequency curve for optimum antenna design

The E-plane is defined as the plane containing the electric field vector and the directions of maximum radiation while the H-plane is the plane containing the magnetic field vector and the direction of maximum radiation. The x-z plane elevation plane with some particular azimuth angle φ is the principle E-plane. While for the x-y plane azimuth plane with some particular elevation angle θ is principle H-plane.

Figure8 shows 2D E-plane radiation pattern at different frequencies within the band 4.1-14.1 GHz.

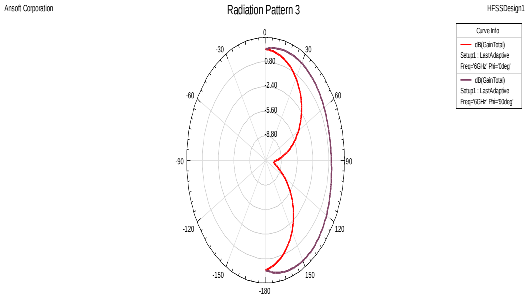

Fig.8a 2D E-plane Radiation Pattern at 6 GHz

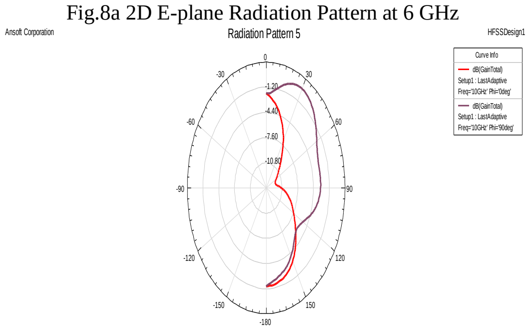

Fig.8b 2D E-plane Radiation Pattern at 10 GHz

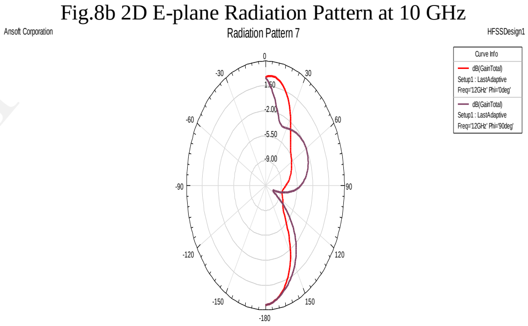

Fig.8c 2D E-plane Radiation Pattern at 12 GHz

Figure9 shows 2D H-plane radiation pattern at different frequencies with in the band 4.1-14.6 GHz.

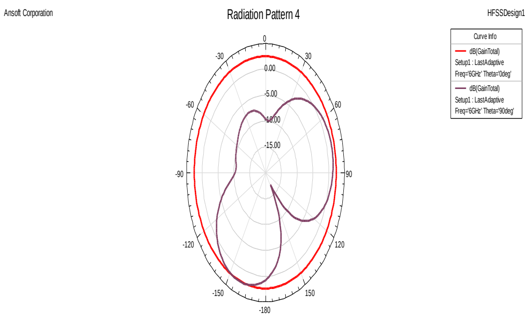

Fig.9a 2D H-plane Radiation Pattern at 6 GHz

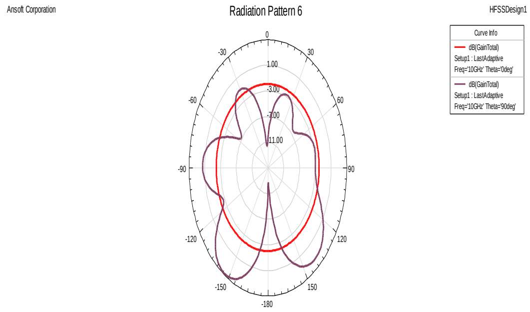

Fig.9b 2D H-plane Radiation Pattern at 10 GHz

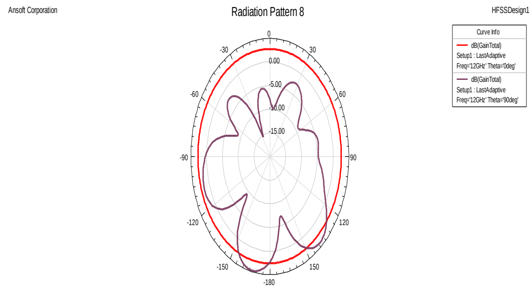

Fig.9c 2D H-plane Radiation Pattern at 12 GHz

Figure10 shows 3D radiation pattern at different frequencies within the band 4.1-14.6 GHz.

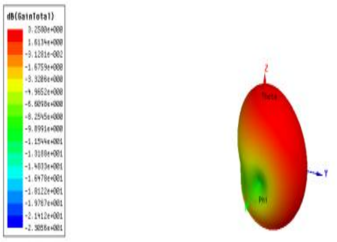

Fig.10a 3D Radiation Pattern at 6 GHz

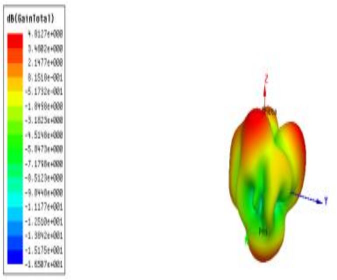

Fig.10b 3D Radiation Pattern at 12 GHz

V. CONCLUSION

It is observed that double U-slot loaded microstrip antenna provided optimum bandwidth when length of partial ground plane is 8mm (6.5-13.7 GHz i.e 7.2 GHz), U-slot width is 1mm (6.5-14.8 GHz i.e. 8.3GHz), and feeding position is 2.5mm from symmetrical position (6.5-14.8 GHz i.e. 8.3 GHz). Finally, we saw the effect of dielectric material on bandwidth and got optimum bandwidth by using FR-4 epoxy substrate (6.5-14.8GHz i.e. 8.3 GHz), and when length of U-slot is 12mm (6.5-14.8 GHz i.e. 8.3 GHz). Finally, we design antenna having ground plane length 8mm, U-slot width 1mm, feeding position 2.5 mm from symmetrical position, substrate material is FR-4 epoxy, length of U-slot is 12mm then we get bandwidth (S11<-10 dB) 10.5 GHz (4.1-14.6 GHz). The proposed design of the antenna can be used for a variety of UWB applications including high speed data transfers, wireless connectivity between UWB-enabled devices and a variety of medical applications.

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