Design of Dome Shape Slot Antenna for UWB Applications

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ABSTRACT

In this paper, a compact micro strip fed dome shape slot antenna for Ultra Wide Band (UWB) applications is proposed. The dome shape is obtained by rounding (blending) the corners of a hexagonal slot. To excite the slot, a micro strip feed and a rectangular shape tuning stub is used. One of the corners of the rectangular patch is chamfered while the others are blended for better impedance matching and return loss. The patch and the ground plane are printed on the opposite sides of an inexpensive FR4 substrate with overall dimensions of 24 mm × 35 mm. The experimental result shows that the proposed antenna has good impedance bandwidth of 10.9 GHz from 2.14 GHz to 13 GHz (143%) which covers the entire UWB Band. The stable radiation patterns which are nearly Omni directional in H-plane and dumbbell shape in E-plane have been achieved.

Keywords

Antennas, Slot antenna, CPW-feed, Ultra wideband (UWB) and UWB Systems

1. INTRODUCTION

UWB is a short distance radio communication technology which is having many advantages like wider bandwidth, low power output and high data rate (more than 100 Mbps) when compared with traditional communication systems. Because of these advantages, a lot of interest has been generated in researchers and engineers for the development of UWB antennas for short-range wireless, imaging radar and remote sensing applications. Also various characteristics of ultra wideband (UWB) technology like low cost, low complexity, low spectral power density, high data resolution, very low interference, and extremely high data transmission rates have made it a potential candidate in various wireless communications. Researchers have proposed many slot antennas for UWB applications. Among the planar UWB antennas, the printed slot antenna is one of the most suitable candidates for UWB applications. The wide-slot antenna always gives wider impedance bandwidth it is seen that large antenna slot dimension makes impedance bandwidth wider [1]. Study and optimization of microstrip feed lines of various shape exciting Rectangular slot is proposed in [2-5]. CPW fed UWB wide slot antennas are optimizes and proposed in [6-9]. In an approach presented in [10],. A Effect of similar ground and Patch shapes is studies and a wide band antenna using this approach is proposed in [10] E shaped Patch and E shaped ground slot is studied and optimized in this antenna which achieves an impedance bandwidth of 120% (2.8–11.4 GHz). However, Due to large dimensions 85mm × 85 mm. this antenna cannot provide compact profile

Different tuning techniques, various patch shapes and their Applications is studied and optimized in [11]- [12] and introduction of new but unconventional shape , a rhombus shaped slot is presented in [13].

The antenna proposed in this paper has the advantage of compactness in size with wide bandwidth. It uses a dome shape slot which is excited by a micro strip feed line with a rectangular tuning stub. Suitable blending and chamfering of the slot and patch corners gives the ultra wideband characteristics.

2. ANTENNA DESIGN

The antenna geometry and configuration is shown in Fig. 1. The antenna consists of a dome shaped slot etched in the ground plane and a micro strip line fed, chamfered rectangular patch for excitation. The slot and rectangular patch are printed on opposite sides of an inexpensive FR4 substrate of thickness 1.6 mm and relative permittivity 4.3. The slot in the ground plane has a strong coupling to the feeding structure. Therefore, by properly selecting the shape of the slot and patch, good impedance bandwidth and radiation characteristics can be achieved. The optimized parameters of the proposed antenna are mentioned in Table 1. The overall size of the antenna is 24 mm × 35 mm. The feed line has a width of 2.8 mm. The development of the dome shape slot is shown in Fig. 2. The slot is initially hexagonal in shape, rectangular patch .the patch was taken symmetric in shape as shown in figure 2(Reference antenna) laterally for improvement in return loss the asymmetric design (Reference Antenna 1) of patch is chosen which has an advantage of better return loss characteristics as shown in figure 3, The radius of the blend in ground plane is denoted by equal to 6mm. Similarly, the rectangular patch has its edges blended by arcs of radii 3mm. Also one of the corners of the patch is chamfered. This parameter is denoted by Pc in Fig. 1 and has an optimized value of 9.2 mm. The improvement in the return loss with these modifications is shown in Fig. 3 where a comparison with the antenna with unblended slot and patch (Reference Antenna) is made.

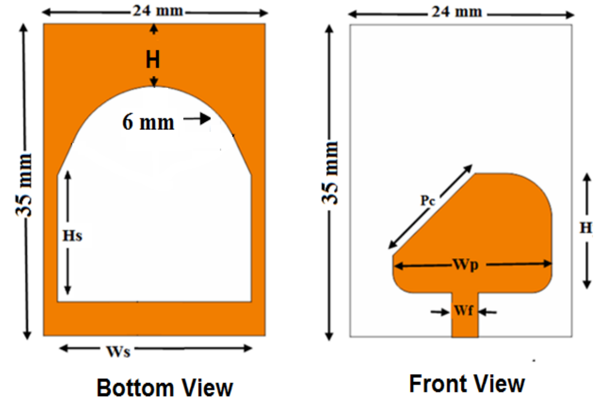


Fig 1: Geometry of Proposed Antenna

Table 1 Optimized Value of Antenna Parameters

S. NO.	Parameter	Dimensions (mm)
1	H	7
2	Hs	14.2
2	Ws	21
4	Wf	2.8
5	Wp	17.2
6	Hp	13.4
7	Pc	9.2

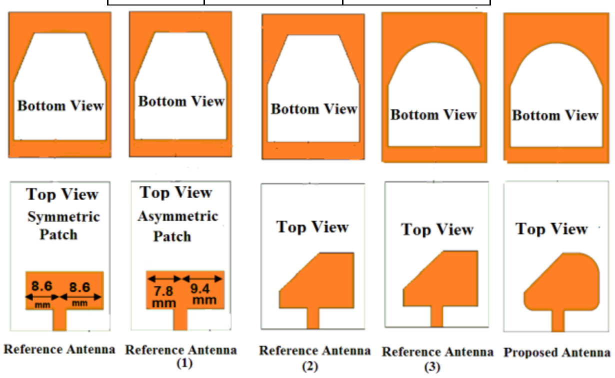


Fig 2: Development of the Dome Shape Slot and Chamfered Patch

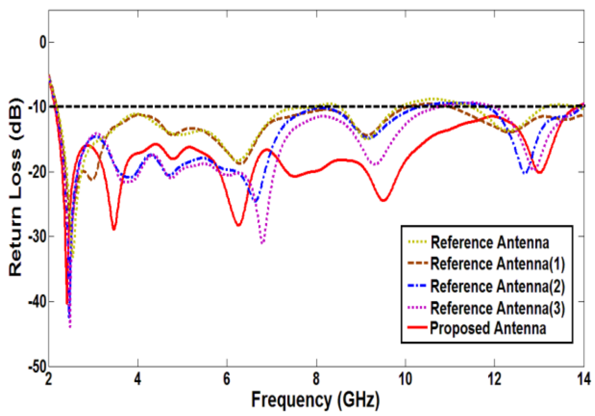


Fig 3: Improvement in return loss with blending of edges and chamfering

3. SIMULATED AND MEASURED RESULTS

The proposed antenna is designed and simulated using 3D-electromagnetic software CST Microwave Studio based on Finite Integration Technique (FIT). The antenna is then fabricated with the optimized dimensions as given in Table 1. A photograph of the fabricated antenna is shown in Figure 4. The measurements for the fabricated prototype were taken on a Rohde & Schwarz Vector Network Analyzer (ZVA-40). As show in Figure 5, the proposed antenna has good impedance bandwidth of about 10.9 GHz which is from 2.14 – 13 GHz (143%). The difference between the simulation and measurement results are mainly due to the effects of the SMA connector, cable and fabrication tolerances.

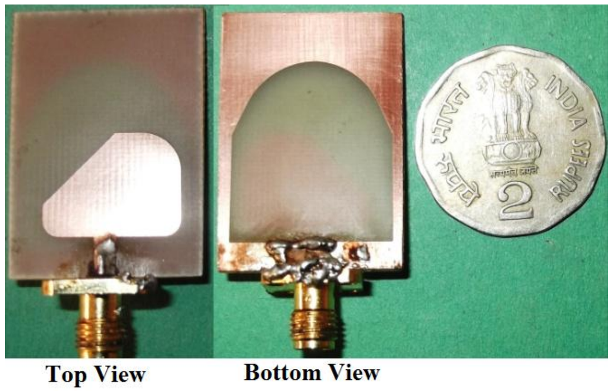


Fig 4: Photograph prototype of proposed antenna

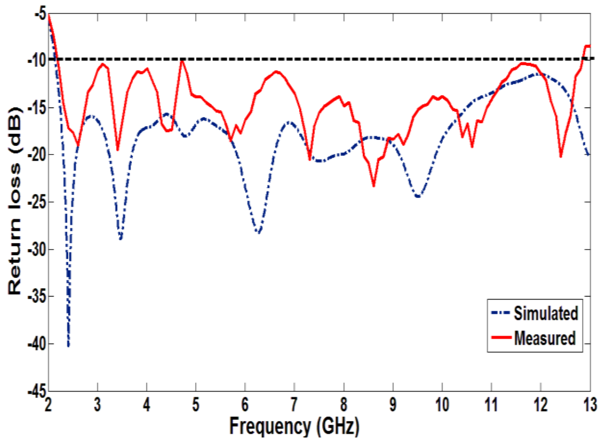


Fig 5: Measured and simulated return loss of proposed antenna

4. DESIGN EXPRESSION FOR RESONANT FREQUENCIES

The resonant frequencies are calculated and simulated using the following expresions, equations(1-4) gives the first and second resonance frequencies f_1 and f_2 .

$$f_1 = \frac{c}{4l\sqrt{\varepsilon_{reff}}} \quad (1)$$

$$l = 2Hs + Ws + R \quad (2)$$

$$\varepsilon_{reff} = \frac{\varepsilon_{r+1}}{2} \quad (3)$$

$$f_2 = \frac{c}{4H_p\sqrt{\varepsilon_{reff}}} \quad (4)$$

Table 2. Calculated and Simulated resonance frequencies

S. No	Ws (mm)	Hs (mm)	Hp (mm)	Calculated (GHz)	Simulated (GHz)
f_1	21	14.2	-	2.27	2.4
f_2		-	13.4	3.41	3.51

Considering the CST simulated RL characteristic of proposed Antenna, we can note four dip resonances in the curve located at 2.41Hz, 3.5 GHz, 6.3 GHz and 9.5 GHz. The first (lowest) resonance is due to the dome shape slot and an expression for the resonance frequency is given by equation (1). Here c stands for the velocity of light and l is the perimeter of the slot approximately given by equation (2). In equation (2), R is the length of the arc forming the dome and equal to 31mm. εr,eff is the effective relative permittivity and taken here as the average of substrate permittivity and permittivity of free space. Using equations 1-3, the calculated first resonance comes out to be 2.27 GHz which matches well with the simulated value of 2.4 GHz. Similarly as proposed in equation (4), the second resonance is found to be due to patch height (Hp), this effect is due to coupling between the ground slot and the radiating patch. The calculated and simulates resonance frequencies of proposed antenna are mentioned in Table (2).The slight difference between calculated and simulated frequencies is due to the ε_{reff} calculation , the effective permittivity cannot be calculated exactly as most of the electric field are in air so the value of ε_{reff} is very close to 1 but the exact calculation is complex . The surface current distribution at the various resonant frequencies is shown in Figure 6. It can be seen that the current distribution at 2.41GHz is more on the ground slot periphery and the feed line indicating the resonance of the ground slot structure. The current distribution at 3.5 GHz is reduced on the ground plane and slightly increases on the patch surface. The surface current at 6.3 GHz is concentrated more on the patch indicating the resonance of the patch at this frequency. Finally, the current distribution at 9.5 GHz shows a higher order resonance on the ground plane.

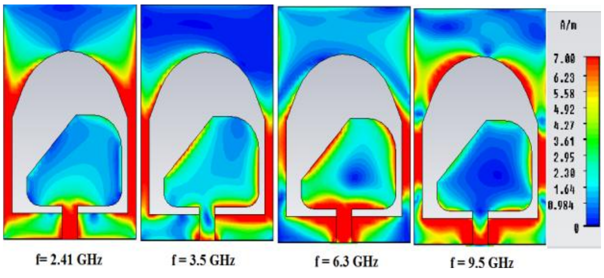


Fig 6: Surface current distribution of proposed antenna

5. PARAMETRIC STUDIES

Based on the performance of the proposed design, some sensitive parameters were studied in order to investigate the influence of the parameters on the antenna characteristics. The wide-slot antenna is well known to have wide impedance bandwidth, though its operating bandwidth is limited due to the degradation of the radiation patterns at higher frequencies. The ground plane consists of hexagonal slot etched from the metallic surface. The changes in the ground slot parameters such as its width and height are studied and optimized for better impedance bandwidth, likewise ground plane, patch parameters such as patch height and width, feed width and chamfering of patch corner are also studied and optimized. In the simulation, only one parameter was varied each time, whereas the others were kept constant. All simulations are carried out using CST Microwave Studio.

5.1 Effect of Ground Slot Height 'Hs'.

The variation in the ground slot height is shown in Figure 7. It is seen that as the slot height is increased, the first resonance slightly shifts toward the lower side. The impedance matching improves over the lower frequencies but the return loss deteriorates at higher frequencies. Overall, an optimal height is found at 14.2 mm.

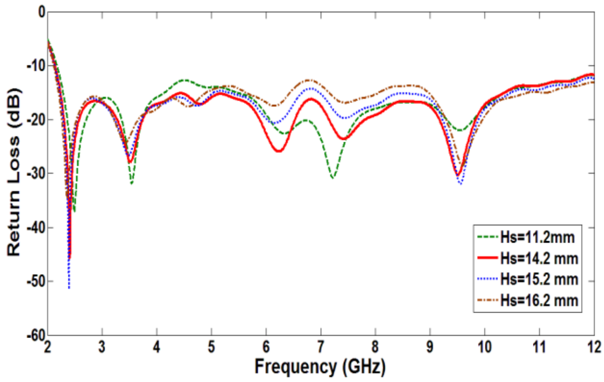


Fig 7: Effect of slot height 'Hs' on return loss

5.2 Effect of Ground Slot Width 'Ws'

The variation in the ground slot width 'Ws' affects all the resonant frequencies as also the return loss. The results are shown in Figure 8. With an increase in the slot width, the slot perimeter increases and hence the first resonance which is inversely dependent on the slot perimeter (Equation 1) reduces. The impedance matching improves in the initial part of the S11 characteristics but deteriorates over mid frequencies. Hence, as for the slot height, the slot width needs to be optimized and the optimal value is found out to be 21mm.

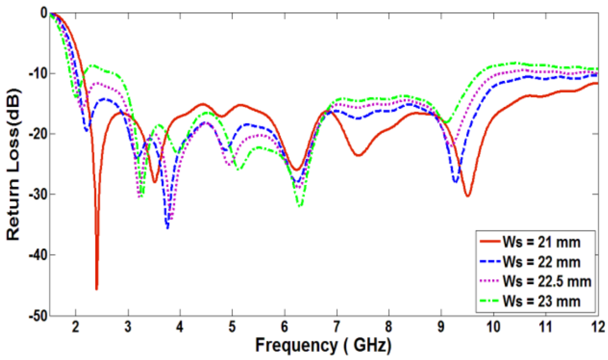


Fig 8: Effect of ground slot width 'Ws' on return loss.

5.3 Effect of Patch Height 'Hp'

The patch is a radiating element, the dimensions such as patch height and patch width will affect the return loss and the resonant frequencies and consequently the impedance bandwidth. The effect of varying the patch height on return loss is shown in Figure 9. The optimum value of patch height is found out to be 13.4 mm which gives the largest impedance bandwidth and improved return loss. With an increase in the patch height, there is a significant decrease in the third resonance near 6.3 GHz and this is because of the increased current in the patch as seen from the current distribution plot (Figure 9).

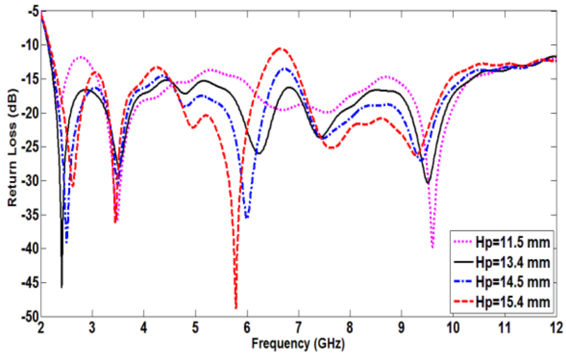


Fig 9: Effect of patch height 'Hp' on return loss.

5.4 Effect of Patch Corner Chamfer 'Pc'

The patch is initially taken rectangular in shape but for optimization of return loss, the chamfering of one of the patch corners is done. In Fig. 10, the parameter 'Pc' denotes the chamfer value. The variations in the return loss with variations in Pc are shown in Figure 10. With different values for the chamfer, there is an improvement in different parts of the return loss characteristics. The chamfer is optimized at 9.2 mm.

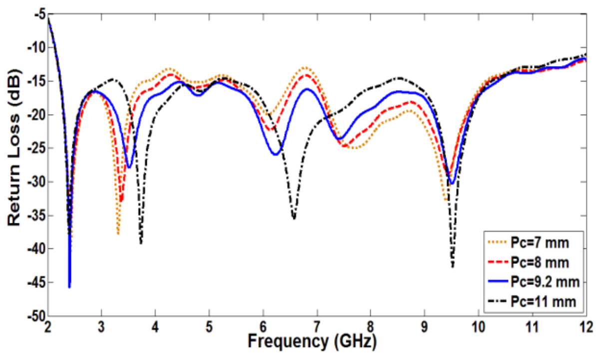


Fig 10: Effect of patch chamfering 'Pc' on return loss.

5.5 Effect of Feed Width 'Wf'

A micro strip feed line is used to excite the proposed antenna. The impedance of the feed line is primarily decided by the feed width. The feed width is optimized to get the real part near to 50 ohms and the imaginary part close to zero. This ensures the best impedance matching with the 50 ohm SMA connector and hence the maximum possible bandwidth. A change in the feed width from this optimized value (2.8 mm for the proposed antenna) changes the impedance and disturbs the impedance matching, thus increasing the return loss. Variation in feed width is studied with the constant gap between the patch and ground slot which has a fixed value of 1.2 mm .This is verified from the simulated S11 curves obtained for different values of Wf as shown in Figure 11.

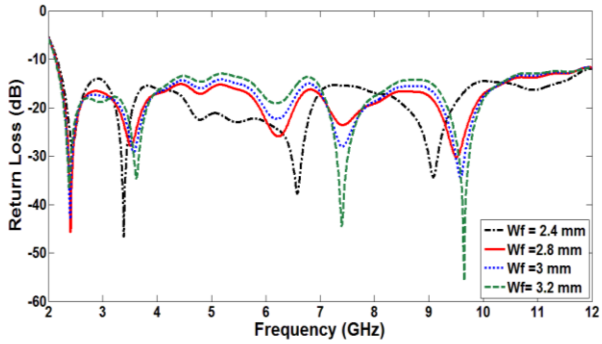
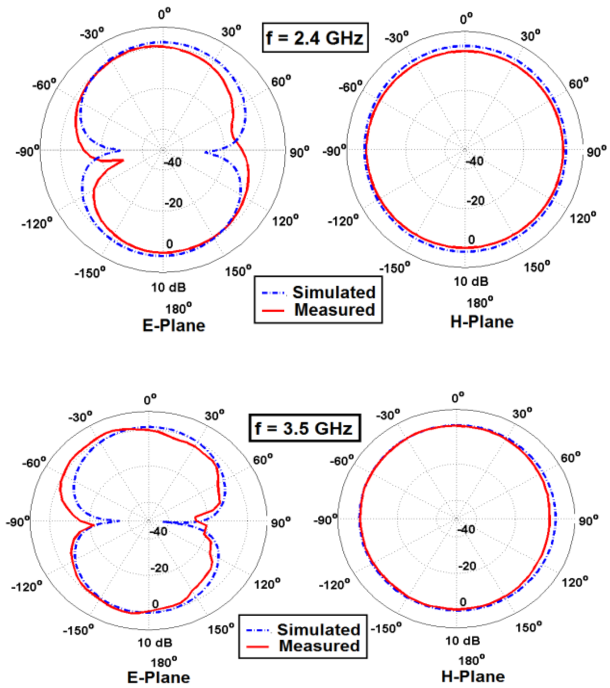


Fig 11: Effect of feed width 'Wf' on return loss

6. RADIATION PATTERNS, GAIN AND EFFICIENCY

The radiation patterns of the proposed antenna are studied at all the resonance frequencies. The measured and simulated plots are compared and shown in Figure 12. While the simulated results are obtained from CST MWS, the measured radiation patterns are obtained using Antenna Measurement System inside an Anechoic Chamber.



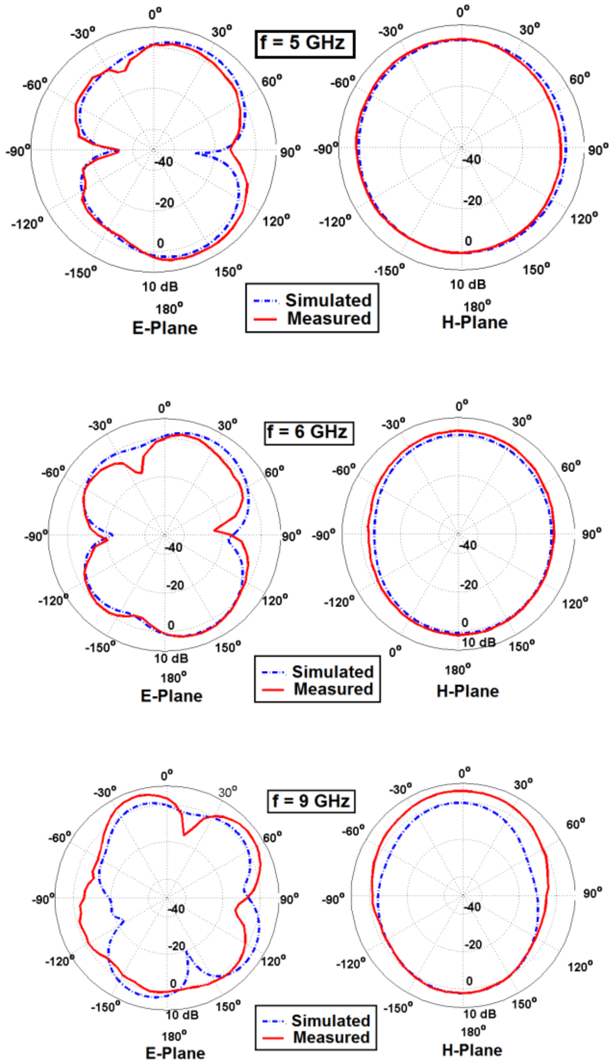


Fig 12: Radiation pattern of proposed antenna

From the figure 12, it can be seen that the radiation patterns of H–plane are Omni directional while the radiation patterns of the E-plane are bidirectional in nature. A slight difference is found between the simulated and measured radiation patterns due to alignment errors and to the characteristics of the reference horn antenna used in the measurement system.

The measured gain of proposed antenna is plotted and compared with the simulated gain in Figure 13. It is found that the measured gain has good agreement with the simulated gain and a maximum peak gain of 5 dBi is seen for the both. At lower frequencies, the measured gain is less due to the low gain of the reference horn antenna. The radiation efficiency is simulated and plotted in Figure 14. It is more than 80% throughout the band. The stable radiation patterns with a reasonable maximum gain and radiation efficiency more than 80% make the proposed antenna suitable for being used in UWB communication applications.

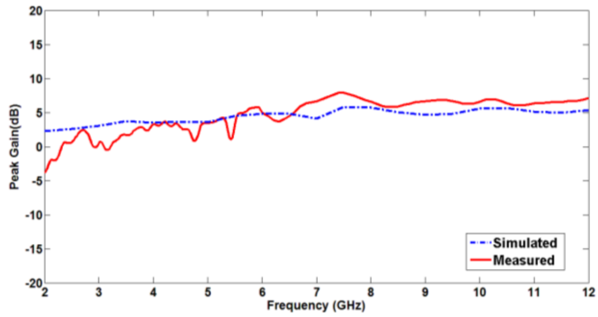


Fig 13: Simulated and measured gain of proposed antenna

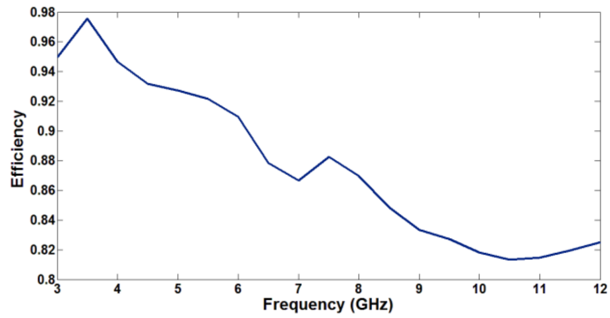


Fig 14: Simulated Radiation Efficiency

7. CONCLUSIONS

A compact, micro strip line-fed ultra wideband dome shape slot antenna has been proposed. The corners of a hexagonal slot are blended to get the dome shape. The slot is excited using a rectangular chamfered Patch. The antenna is fabricated on an inexpensive FR4 substrate with overall dimensions of 24 mm × 35 mm. Experiments show that the proposed antenna achieves good impedance matching, constant-gain, stable radiation patterns over an operating bandwidth of 2.14–12 GHz (143%), which covers the entire UWB. The radiation efficiency more than 80% makes the proposed antenna suitable for being used in UWB communication applications.

8. ACKNOWLEDGMENT

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9. REFERENCES

[1] M. K. Kim, K. Kim, Y. H. Suh, and I. Park, "A T-shaped microstripline- fed wide slot antenna," IEEE Antennas Propag. Soc., vol. 3, pp. 1500–1503, Jul. 2000.

[2] Y. Liu, K. L. Lau, Q. Xue, and C. H. Chan, "Experimental studies of printed wide-slot antenna for wide-band applications," IEEE Antennas Wireless Propag. Lett., vol. 3, pp. 273–275, Dec. 2004.

[3] G. Sorbello, F. Consoli, and S. Barbarino, "Numerical and experimental analysis of a circular slot antenna for UWB communications," Microw. Opt. Technol. Lett., vol. 44, pp. 465–470, Mar. 2005.

[4] P. Li, J. Liang, and X. Chen, "Ultra-wideband elliptical slot antenna fed by tapered microstrip line with U-shaped tuning stub," Microw. Opt. Technol. Lett., vol. 47, pp. 140–143, Oct. 2005.

[5] J. -Y. Sze and K. -L. Wong, "Bandwidth enhancement of a microstripline- fed printed wide-slot antenna," IEEE Trans. Antennas Propag., vol. 49, pp. 1020–1024, Jul. 2001.

[6] X. Ding and A. F. Jacob, "CPW-fed slot antenna with wide radiating apertures," Inst. Elect. Eng. Proc. Microw. Antennas Propagat., vol. 145, pp. 104–108, Feb. 1998.

[7] E. A. Soliman, S. Brebels, E. Beyne, and G. A. E. Vandenbosch, "CPW-fed cusp antenna," Microwave Opt. Technol. Lett., vol. 22, pp. 288–290, Aug. 1999.

[8] M. Miao, B. L. Ooi, and P. S. Kooi, "Broadband CPW-fed wide slot antenna," Microwave Opt. Technol. Lett., vol. 25, pp. 206–211, May 5, 2000.

[9] U. Bhobe, C. L. Holloway, and M. Piket-May, "CPW fed wide-band hybrid slot antenna," in Proc. 2000 IEEE Antennas Propagat. Soc. Int. Symp. Dig., pp. 636–639.

[10] Dastranj, A. Imani, and M. N. Moghaddasi, "Printed wide-slot antenna for wideband applications," IEEE Trans. Antennas Propag., v 56, no. 10, pp. 3097–3102, Oct. 2008.

[11] D. C. Chang, J. C. Liu, and M. Y. Liu, "Improved U-shaped stub rectangular slot antenna with tuning pad for UWB applications," Electron. Lett., vol. 41, no. 20, pp. 1095–1097, 2005.

[12] J. Y. Sze and C. C. Chang, "Circularly polarized square slot antenna with a pair of inverted-L grounded strips," IEEE Antennas Wireless Propag. Lett., vol. 7, pp. 149–151, 2008.

[13] J. Y. Jan and J. C. Kao, "Novel printed wide-band rhombus-like slot antenna with an offset microstrip-fed line," IEEE Antennas Wireless Propag. Lett. vol. 6, pp. 249–251, 2007.