

# A CPW-fed Irregular Shaped Hexagonal Patch Antenna with Elliptical Substrate for UWB Applications



P. Kartikeya, Ayyem Pillai. V

**Abstract:** A novel design of Ultra-Wideband (UWB) antenna with irregularly shaped hexagonal patch built on the elliptical-shaped FR-4 laminate with  $\epsilon_r = 4.3$  and  $\tan\delta = 0.025$  is presented. The feed mechanism utilized in the structure proposed is modified co-planar waveguide (CPW), the feeding microstrip is tapered near the connecting edge of the patch for better impedance matching. The proposed antenna is compared with the traditional rectangular substrate and found that the elliptical substrate enhances the radiation characteristics of the antenna and is capable of functioning effectively in the range of 3.1 GHz-11.7 GHz, accompanied by the total efficiency > 86% across the whole FCC allocated UWB operating band. The antenna can be used for wide range of UWB applications as it exhibits good omnidirectional characteristics with a realized peak gain of 4.178dB and an average realized gain of 3.063dB. The simulation work of the antenna is accomplished using CST Studio (v. 2014).

**Keywords :** Ultra-Wideband (UWB), Co-planar waveguide (CPW), Elliptical substrate, Tapered microstrip.

## I. INTRODUCTION

Since the commercial release of UWB band (3.1GHz - 10.6 GHz) by the FCC in the year 2002 [1], the developments in UWB technology are going at a remarkable pace as the UWB technology has several advantages like faster data rate, lower power requirements, data security, minimization of multipath fading. There are several applications for UWB technology, such as Ultra-wideband Pulse-Doppler radar, Automotive Radar, Ground Penetrating Radar, Precision geo-location, UAV data links, and many more. In the literature, several ways to expand the bandwidth were explored, such as the inclusion of slots on the radiating patch, on ground plane, on microstrip line, substrate truncation, printed and planar monopole antennas [2-6]. The cost and complexity of the antenna are greatly minimized with the use of CPW feeding method, as both the patch and ground are on the same side, a single layer copper clad is required instead of multi-layered copper clads [5-9]. In [5], Sharma et al., presents an innovative approach to reduce the footprint of the antenna by truncating the substrate in crown shape.

Revised Manuscript Received on December 30, 2019.

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In this paper, an antenna with an irregular hexagonal patch on an elliptical substrate for UWB operation is designed. The area of the ellipse is comparatively less than a rectangle; the proposed structure is built on an ellipse-shaped substrate to reduce the size of the antenna. The subsequent section describes the antenna's geometrical structure. The simulated results of the proposed structure are studied in section III. The summary of the proposed design work is stated in section IV.

## II. ANTENNA GEOMETRY

The antenna is built on the single-sided FR-4 laminate with  $\epsilon_r = 4.3$  and loss tangent  $\tan\delta = 0.025$ , The antenna is modeled in two variants, as illustrated in Fig. 1, one is with a common rectangular substrate, and the other is the proposed structure with an elliptical substrate. A height of  $h = 0.8\text{mm}$  is selected for the substrate, and the standard height of the copper film is  $t = 0.035\text{mm}$  or  $35\mu\text{m}$ .

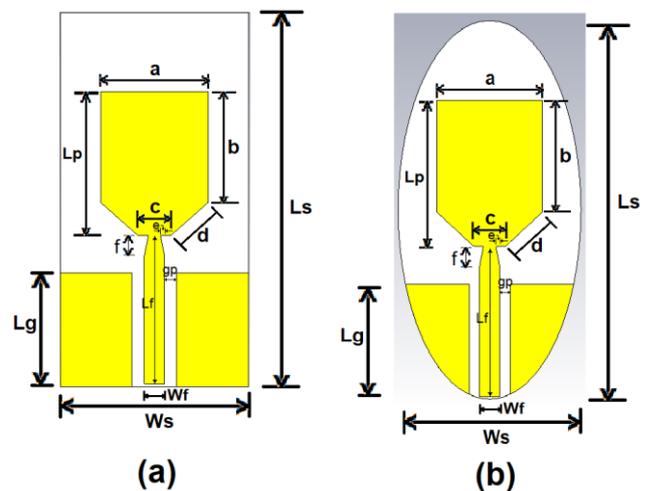


Fig. 1. Geometry of the antenna, (a) Rectangular Substrate, (b) Elliptical Substrate

The purpose of two variants is to show that the shape of the substrate has the effects on the bandwidth and operating frequency, the proposed antenna has improvements in gain, total efficiency, and reduction in the antenna dimensions. The results of the simulation with a higher order of accuracy can be obtained with a standard 50Ω SMA connector included in the simulation model, as the SMA connector influences the antenna's performance characteristics. The CST models of the antennas shown in the Fig. 1 are depicted in Fig. 2.



The irregular hexagon is derived from the rectangular microstrip antenna which has been studied extensively in the literature, the length of the patch has a substantial effect on the bandwidth and resonances.

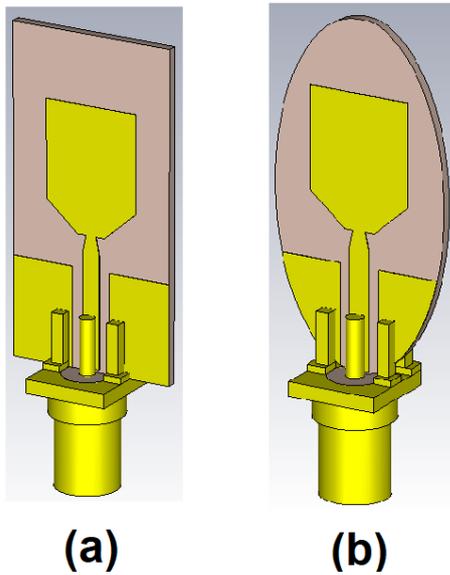


Fig. 2. CST models with standard 50Ω SMA connector, (a) Rectangular substrate, (b) Proposed Elliptical substrate

The length  $L_p = 11mm$  is computed with the help of design equations given in [10]:

Patch's width 'a' is evaluated by,

$$a = \frac{c}{2f_0 \sqrt{\frac{\epsilon_r + 1}{2}}} \quad (1)$$

Here,  $c = 3 \times 10^8 m/s$ ,  $\epsilon_r$  = relative permittivity of the dielectric/substrate material,  $f_0 = 6.8GHz$ .

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \sqrt{1 + 12 \frac{h}{a}} \quad (2)$$

Here,  $h$  = height or thickness of the substrate.

$$\Delta L = 0.412 \frac{\left(\frac{a}{h} + 0.264\right) (\epsilon_{reff} + 0.3)}{(\epsilon_{reff} - 0.258) \left(\frac{a}{h} + 0.8\right)} \quad (3)$$

$$L_{eff} = \frac{c}{2f_0 \sqrt{\epsilon_{reff}}} \quad (4)$$

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

The width of the microstrip is  $W_f = 1.5mm$  kept constant for  $Z_0 = 50\Omega$ , the air gap  $gp$  needs to be tuned to adjust the characteristics impedance of the feed. The parameter values for the antenna geometries shown in Fig. 1 are presented in Table-I.

For the antenna presented in Fig. 1(a), the substrate dimensions are  $W_s \times L_s$  and similarly for the elliptical substrate shown in Fig. 1(b), the diameter in X and Y-axes are also  $W_s \times L_s$ , these dimensions are selected such that the effects of changing the shape of the substrate can be studied. The area occupied by the rectangular variant is  $392mm^2$  and elliptical variant occupies  $307.7mm^2$ , it can be observed that

just changing the shape, the antenna dimensions are minimized by  $\approx 84mm^2$ .

Table I. Parameter Values

Parameter	Value (in mm)	Parameter	Value (in mm)
$a$	8	$gp$	0.8
$b$	8.3	$L_s$	28
$c$	2.4	$W_s$	14
$d$	3.75	$L_g$	8.5
$e$	0.4	$L_f$	11.1
$f$	2	$W_f$	1.5
$L_p$	10.8		

### III. SIMULATION RESULTS AND DISCUSSION

The S11 or return loss plot for the antennas shown in Fig. 1 are depicted in Fig. 3, for the values  $L_s = 28mm$  and  $W_s = 14mm$ . The rectangular substrate has a return loss of  $8.5dB$  lower than the elliptical version at  $5.65GHz$ , but at the lower frequencies  $< 4.57GHz$ , the elliptical variant has a lower return loss, and also for frequencies  $> 6.45GHz$ . The elliptical version is more compatible than the rectangular version for operation in the UWB band. The overall response of the antenna with the elliptical substrate is more balanced than the rectangular substrate across the band.

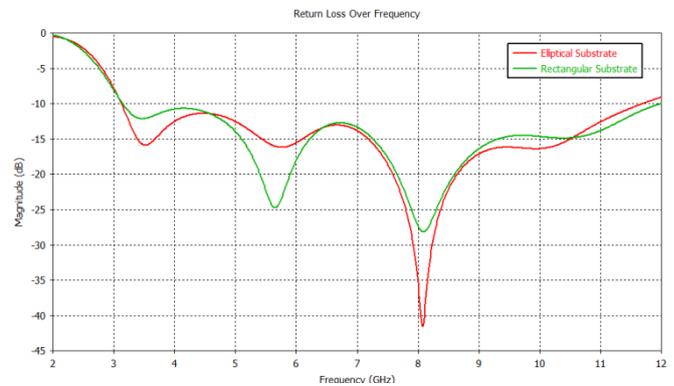


Fig. 3. Return loss comparison for ellipse and rectangular-shaped substrates

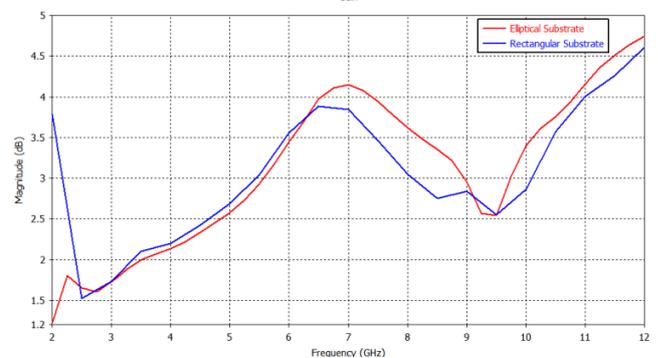


Fig. 4. Comparison of antenna gain

The gain plays a critical role in mobile and handheld applications as higher gain improves the range of wireless communication devices. The proposed antenna has higher gain at frequencies > 6.5GHz, and the comparison plot is depicted in Fig. 4.

The surface currents of the proposed antenna at 3.5GHz, 5.75GHz, and 8.08GHz are depicted in Fig. 5, it is observed that the stronger currents are present near the air gap and at the edges of the ground, and because of such distribution, there is a significant impact on the antenna's bandwidth.

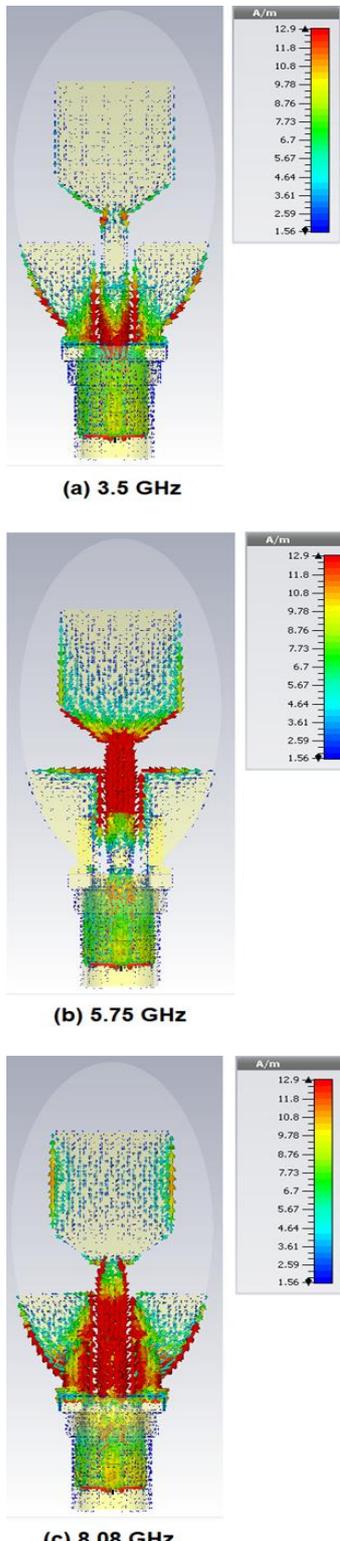


Fig. 5. Surface currents of the proposed antenna

The parametric study of the air gap  $gp$  and ground length  $L_g$  ascertains that these parameters do affect the impedance bandwidth, the results are shown in Fig. 6, and Fig. 7.

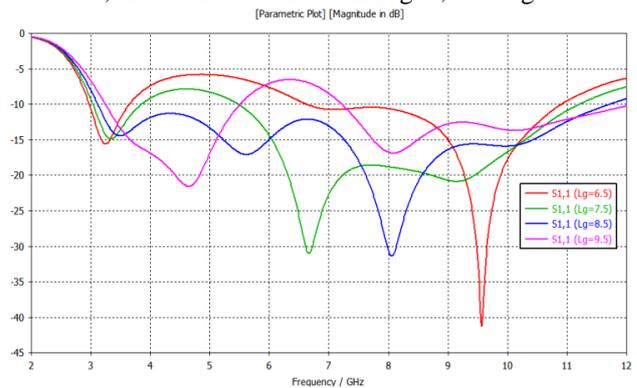


Fig. 6. Comparison of different values of  $L_g$

For  $L_g = 8.5mm$ , antenna has the widest bandwidth, and it is also observed that raising the length shifts the resonances towards the higher frequency, Fig. 6 also depicts that the proper optimization is needed as the response of the antenna appears to be improving until 8.5mm and quickly degrades after crossing that value.

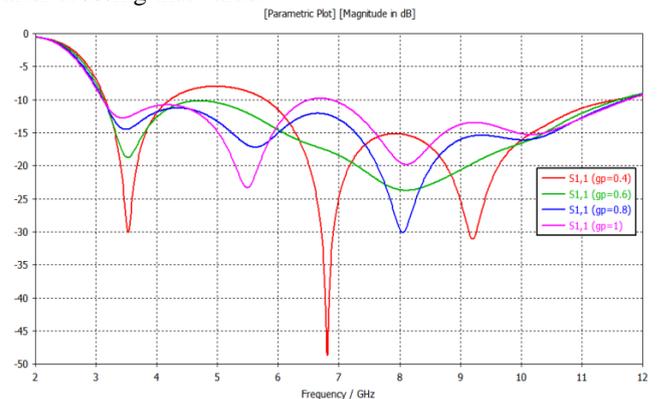


Fig. 7. Comparison of various values of  $gp$

The proposed antenna achieves a peak gain of 4.62dB at 11.7GHz, minimum gain being 1.86dB at 3.1GHz, and an average gain of 3.27dB, as shown in Fig. 4. The total efficiency is more than 86% across the UWB band as presented in Fig.8.

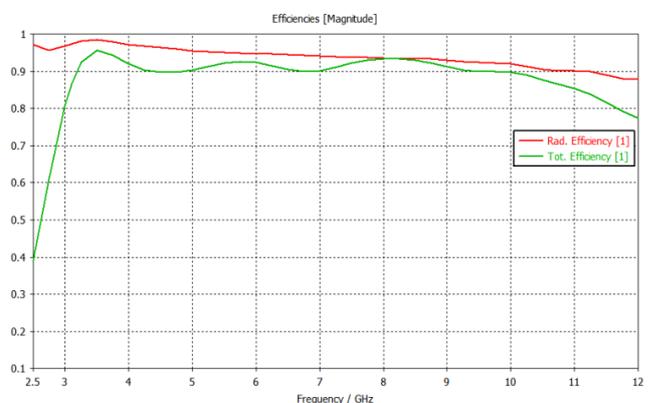


Fig. 8. Efficiency of the proposed antenna

In CPW feed the air gap affects the impedance matching significantly and the optimal value can be determined with the help parametric studies, for  $gp = 0.8mm$  has a better overall response comparatively. The proposed structure demonstrates good omnidirectional characteristics, the 3-D radiation patterns are presented in Fig. 9.

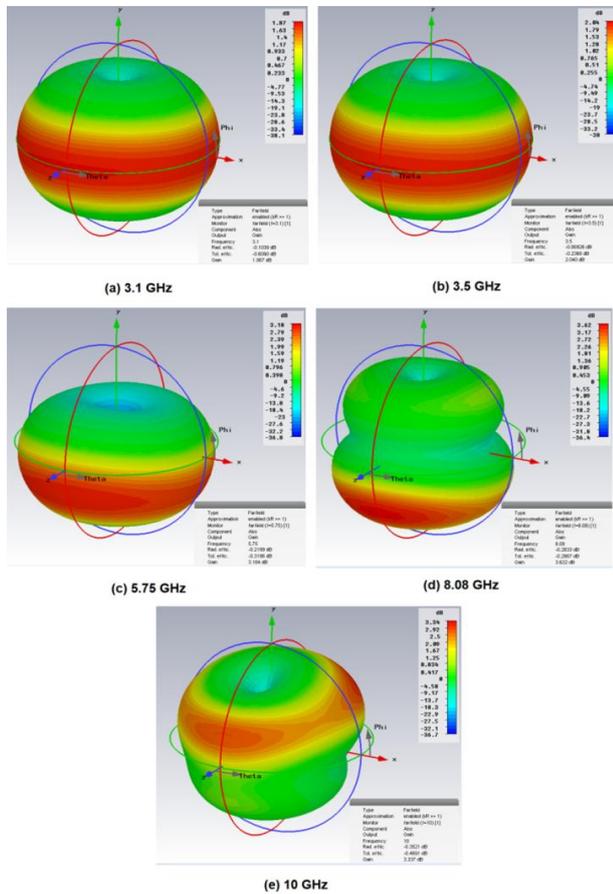


Fig. 9. 3D radiation patterns

The simulated results of the proposed antenna are listed in the Table II.

Table II. Simulated Results

Parameter	Value
$f_L$ , at $S_{11} = -10dB$	3.1 GHz
$f_H$ at $S_{11} = -10dB$	11.7 GHz
B.W	8.6 GHz
Fractional B.W	1.162
Peak Gain	4.62dB @ 11.7 GHz
Peak Realized Gain	4.178dB @ 11.7 GHz
Avg. Gain	3.27dB
Avg. Realized Gain	3.063dB
Radiation Pattern	Omnidirectional

IV. CONCLUSION

In this paper, a novel elliptical substrate ultra-wideband antenna is designed and simulated with a 50Ω SMA connector for UWB applications. The designed antenna delivers a respectable return loss with decent gain and

consistent omnidirectional radiation field pattern across the whole operating spectrum (3.1GHz – 11.7GHz) which is 115% of FCC’s UWB spectrum and with a peak efficiency of 95.6%, the footprint of the antenna is only 246.16mm<sup>3</sup>.

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