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Symmetrical Hexagonal Monopole Antenna with Bandwidth Enhancement Under UWB Operations

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Abstract
In certain a UWB applications, a hexagonal monopole antenna are desired but existing solutions have CPW fed structures. In this structure a compact simple symmetrical hexagonal shaped monopole antenna with defected ground plane is presented. Impedance, radiation and gain characteristics of the proposed structure are presented and discussed. The proposed antenna make use of a novel small microstrip antenna topology which consists of a symmetrical hexagonal shaped radiating patch using FR4 substrate for cost effectiveness and in case of fabrication whereas three rectangular slots are embedded in a ground plane. In addition, impedance bandwidth ($S_{11} < -10$ dB) of 9.03 GHz operates over a band of 3.1–12.18 GHz with a return loss of -10 dB or more and a maximum gain of 5.1 dBi is obtained and a good agreement is achieved in simulation and measured results. The proposed one is suitable for short band radio wave communications, land-mobile or other wireless applications.

Keywords Symmetrical hexagonal · Defected ground plane · Wave communications · Wireless applications

1 Introduction

A compact Microstrip antenna designs draws a lot of interest in a recent year. For data transmission, normally a microstrip antenna is used where gain is maximum. Designing more than one operating frequency or wide band frequency in a single antenna is challenging task for a researcher. Two operating frequencies or wideband frequency are required

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for the different microwave or radio wave applications [1, 2]. US-FCC released that 3.1–10.6 GHz frequencies cover the UWB applications [3]. Ultra Wide Band technology is one of the most promising solutions in present communication systems due to its high-speed data rate and excellent immunity to multi-path interference [4].

With the development of the high data rate wireless applications, the demand of smaller antennas increases which still retain broadband characteristics. Due to their appealing features, planar metal-plate monopole antennas have been proposed for such applications [5–7]. In recent years, many monopole structures have been designed employing various ground plane sizes and using radiating element of different shapes like squares, rectangular, circular and ellipses. A microstrip monopole antenna is thus suitable for integration with handheld terminal owing to its attractive features such as low profile, low cost and light weight [8–12].

In this paper, symmetrical hexagonal shape monopole antenna characteristics are proposed. The design initially begins with a printed regular hexagonal monopole antenna where rectangular shaped slot etched out of its ground plane. Further another rectangular shaped slot has been introduced in the ground plane and the study has been done. The proposed antenna has several advantages of low cost, compact and easy fabrication due to simple configuration. The features of the proposed structure are simple rectangular fed Microstrip antenna, electromagnetically excited by a co planner patch, low noise and easy fabrication.

Our main goal is to maintain the design specification and the antenna cover with wideband operation as well as to increase the operating bandwidth, which is cover radio wave frequencies and C-band frequencies. The simulation is carried out by IE3D™ simulator.

2 Antenna Design Procedure

There are four particular antennas which are examined, first one with a rectangular feed hexagonal radiating patch second and third one consists of two rectangular slots simultaneously which are embedded in a ground plane and last one embedded with another rectangular slot in a ground plane just below the feed line. The third one and proposed design has a size reduction of 36% and 45% for the UWB frequencies obtained respectively. For wideband antennas, lower band frequency becomes the design parameters, instead of resonance frequency. The design consist of a rectangular fed symmetrical hexagonal monopole antenna. The antenna element is designed on a FR4 substrate having dielectric constant (ε_r) = 4.4, thickness (h) = 1.6 mm and loss tangent = 0.02. The entire width (W) and length (L) of the proposed antenna is calculated by equation [1]. The diagram of the defected ground plane monopole antenna is shown in Fig. 1. Primary length and width of the structure is estimated as half of an effective wavelength of the lowest operating frequency. The precise value of the parameters is selected using optimizer tool and it's approximately 20 mm × 25 mm,

$$W = \frac{c}{2f_l\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (1)$$

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

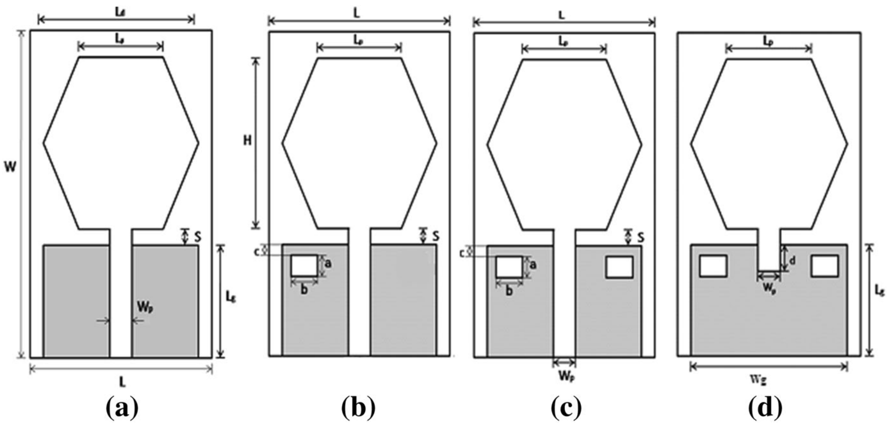

Fig. 1 **a** Reference antenna or Antenna 1. **b** Antenna 2 with a rectangular ground slot. **c** Antenna 3 with two rectangular ground slots with same dimension. **d** Proposed structure or Antenna 4 (back view when front view is same as Antenna 3) with another ground slot underneath the feed line

In [8] a CPW fed hexagonal monopole configurations was presented where bandwidth is very low where 'z' impedance is followed by 50 Ω. Also fabrication of coplanar waveguide is costlier. As gold ribbons are needed to suppress higher order modes at every quarter wavelengths. In this article a symmetrical hexagonal radiating patch is used as a radiating element whose dimensions are estimated by modifying the formula for a planar symmetricalhexagonal rectangular feed monopole antenna. The lower band frequency is f_l.

$$f_l = \frac{7.2}{\{(H + r + s) \times h\} \times k} \tag{3}$$

where H is the height from the end point of the feed line to the top of the hexagonal, r is the radius of an equivalent cylindrical monopole antenna and s is the length of the feed gap between patch and ground plane. Here, the value of h = 1.6 for a dielectric layer with dielectric constant 4.4, where k = 0.0128 cm consider for thermal expansion which is depended on the material. With reference to configurations in Fig. 1 with side length (Lp), height (H) and radius (r) are obtained by equating their areas as follows:

$$Wq = 2L_p \tag{4}$$

$$r = \frac{3L_p}{4\Pi} \tag{5}$$

$$H = \sqrt{3}L_p \tag{6}$$

In order to generate the lower band frequency fl using Eq. (1) the radiating patch is fixed at 16.18 mm × 14 mm × 1.6 mm. Where the diameter (L_d) is 16.18 mm, height (H) = 14 mm and side length (L_p) = 8.09 mm. It is fed via a 50 Ω microstrip line having a width, Wp = 2.8 mm. The dimension of a rectangular ground plane is 13 mm × 16 mm. In another form shown in Fig. 1 where the ground plane is defected by two rectangular shape slots and a simple rectangular slot underneath the feed line. The optimum dimension of c is 0.75 mm, d is 3.25 mm whereas that of 'a' and 'b' mm are found to be 3 mm

Table 1 All parameter of the proposed structure are summarized

Parameter	W	L	h	ε_r	H	Lp	Ld	Lg	Wg	Wp	S	a	b	c	d
Values (mm)	25	20	1.6	4.4	14	8.09	16.18	13	16	2.8	0.5	3	5.2	0.75	3.25

Table 2 Is presented to compare proposed antenna with recent reported antennas

Characteristics of antenna	Proposed antenna	Ref. [8].	Ref. [9].	Ref. [10]	Ref. [11]	Ref. [12]
Impedance bandwidth (− 10 dB)	3.1–12.18	2.9–18	4–14	3.1–13.43	2.9–14.75	2.71–12.62
Lower UWB band (3.1–5.2 GHz)	√	√	×	√	√	√
Max. return loss(dB)	55	45	23	35	25	33
Max. gain (dBi)	5	4.2	4.4	6.4	7	3.2
Fed-configuration	Rectangular	Trapezoidal	Rectangular	CPW	CPW	CPW
Dimensions in mm2	20×25	30×30	30×30	36×42	36×30	25×23

and 5.2 mm respectively by way of parametric study. The Zelend IE3D is used for further fine tuning and optimised to obtain maximum bandwidth. In Table 1 all parameter of the proposed structure are summarized.

Analytical studies has been perform and some basic characterise of the proposed antenna compare with recent reported antennas presented in Table 2. It is clear that the proposed structure is very small in size, low profile and does not require any lumped-element components. Therefore it is easy to fabricate using standard Protolithic graphic procedures at a very reasonable cost.

3 Results and Discussion

Figure 2 shows the simulated S_{11} (dB) of the proposed antenna followed by the all antennas. The S_{11} (dB) characteristics are observed with the variations of slots and positions of the ground plane. The ground plane parameters length, width, and positions are investigated to control the resonant frequency of the antenna. At first the reference antenna (antenna 1) is simulated then a small rectangle-shaped slot is cut at the upper edge of the ground plane right underneath the microstrip feed line. Further a rectangular slot is embedded in the ground plane towards the upper left side and upper right side separately. To get the promising result all the three slots are embedded altogether to improve matching at higher frequencies and hence to widen the operating bandwidth. Due to the cutting of slots at the ground plane in proposed antenna, resonant frequency operation is obtained with large values. The proposed antenna exhibits a measure S_{11} performance below − 10 dB from 3.1 to 12.18 GHz. In Table 3 all the simulated results are summarized as follows. In Fig. 3 gives the impact of ‘S’ on the impedance bandwidth.

This is one of the most important parameter controlling the impedance matching between the feed, slotted ground and radiating patch. The lower band frequency also

Fig. 2 Return loss versus frequency of all antennas

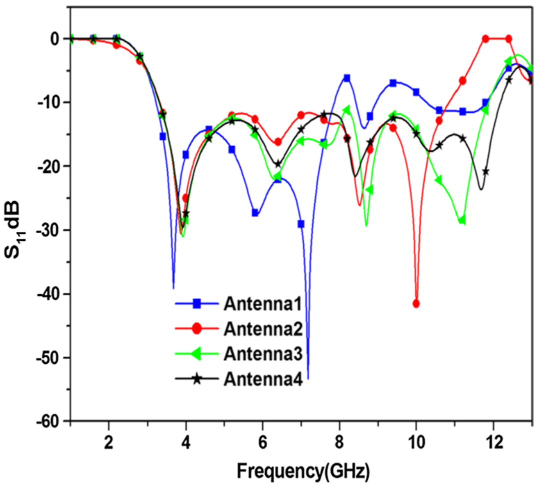

Table 3 Effect of the gap between patch and ground plane separation S are calculated using different dielectric substrate

Sl. no	S (mm)	Dielectric constant	h (mm)	fc (GHz)	λc (mm)	FBW %	Max gain (dBi) at 5.2 GHz
1	0.5	4.4	1.6	7.6	19.57	116	3.9
2		3.2	1.58	5.7	29.05	89	3.2
3		2.2	1.57	7.16	28.20	126	3.8
4	1	4.4	1.6	6.2	24.07	96	4.2
5		3.2	1.58	5.9	29.05	84	3.5
6		2.2	1.57	7.5	27.54	88	4.4
7	1.5	4.4	1.6	5.4	27.50	79	3.6
		3.2	1.58	5.8	30.32	76	4.93
		2.2	1.57	6.5	32.12	77	5.02

fc centre frequency, *λc* wavelength, *FBW* fractional bandwidth

depends on the parameter ‘S’. The f_1 will change if the value s parameter will change. A significant improvement of return loss is achieved in the proposed antenna by vary this simple parameter. It is evident from the following figure that the impedance matching deteriorates for the entire frequency band when the value of s increases from 0.5 to 2 mm where the optimal value of ‘s’ is 0.5 mm for maximum bandwidth. The resonant frequency tuning is presented in Table 3 where wavelength and fractional bandwidth will be established using different substrate and by changing s parameter. It is clear from the result that the proposed structure gives the best bandwidth and highest gain when s is fixed at 0.5 mm. In Fig. 4 the proposed structure simulated using three different dielectric materials. It is found that the maximum bandwidth is obtained when FR4 (with dielectric constant of 4.4) is used as a substrate for the proposed antenna structure.

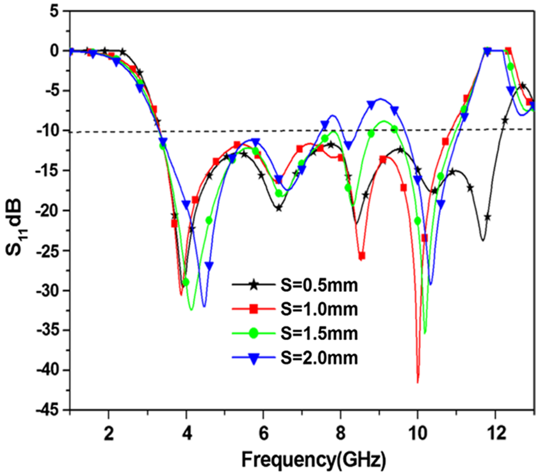

Fig. 3 Return loss of proposed antenna with different S

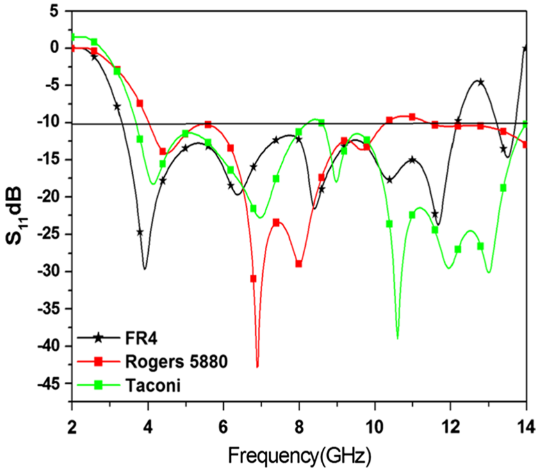

Fig. 4 Simulated result using different substrate when s = 0.5 mm

4 Simulated and Measured Results

Antenna4 and Antenna1 both are fabricated and tested which shown in Figs. 5 and 6. In Fig. 6 shows the finalized simulated and measured result of proposed antenna. The simulated maximum gain of Antenna4 is presented in Fig. 7. The antenna gain varies from 2 to 5.1 dB and not less than 1.8 dB over the entire frequency range from 3.1 to 12.18 GHz and the average gain as observed from the figure is equal to 3 dBi. The antenna gain is also depicted in the form of 'Elevation Pattern Gain Display'. In other words it is also called as the Radiation Pattern of the antenna.

For every transmitting antenna VSWR measuring and examining is an important task. If the antenna and feed line impedance is perfectly matched and transmitter is connected to an antenna then the maximum electrical energy transferred to the antenna via the feed line, otherwise it reflected back towards the transmitter. Impedance matching is

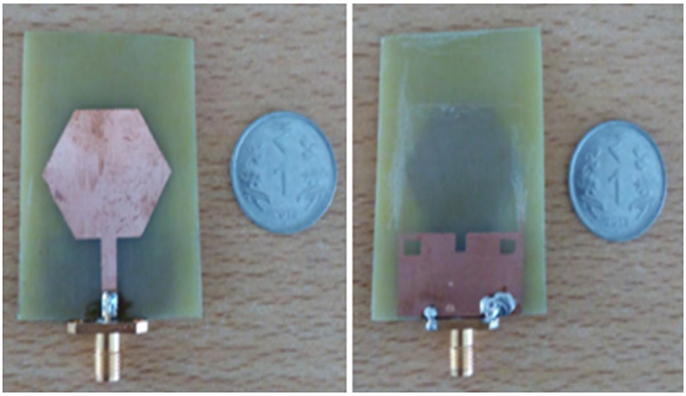

Fig. 5 Fabricated prototype of the reference antenna and proposed antenna (with slotted ground structure)

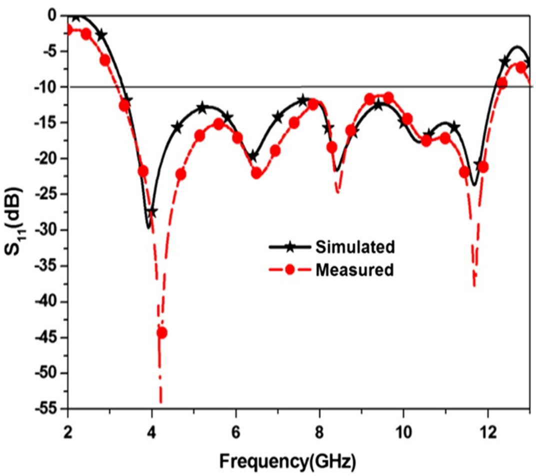

Fig. 6 Simulated and measured S_{11}(dB) characteristics of the proposed antenna

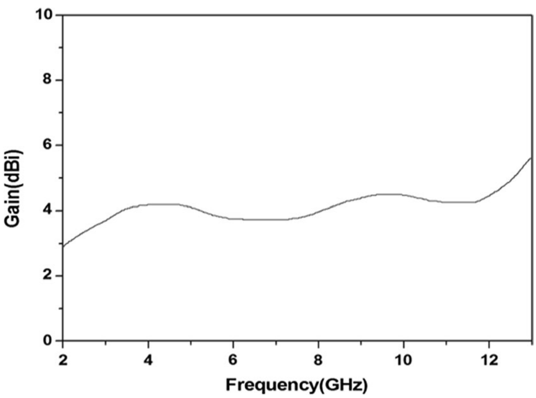

Fig. 7 Simulated gain of proposed antenna

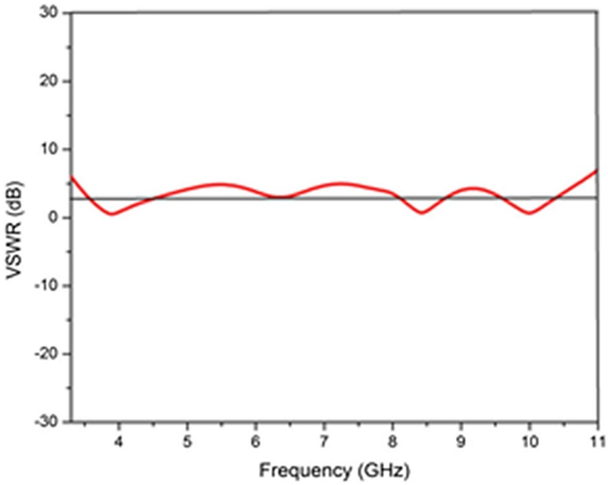

Fig. 8 Simulated VSWR of proposed antenna

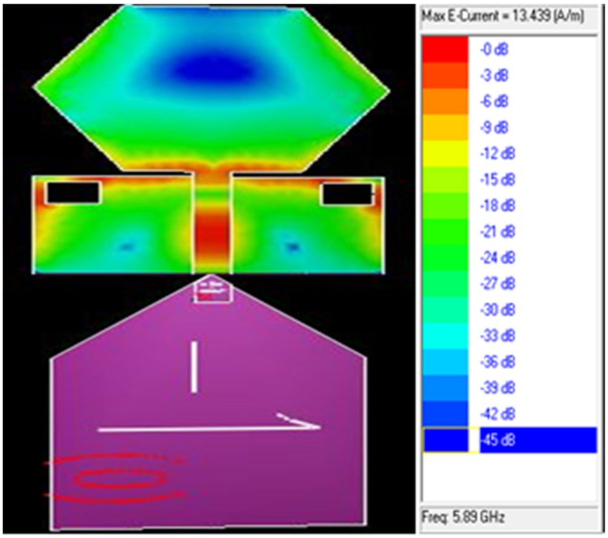

Fig. 9 Current distribution of proposed antenna at 5.8 GHz

done using a tuner and it works at a low VSWR. Ideally, VSWR must lie in the range of 2–2.5 which is achieved in Fig. 8 for the entire frequency band of UWB.

The simulated current distribution of proposed antenna is shown in Fig. 9. Antenna has a good current distribution over the entire frequency band. Here, distribution at one 5.8 GHz frequency is shown. It is clear from the result that current is flowing from the edge of the slots that are responsible for the formation of entire band. The antenna has almost identical radiation patterns throughout the 2:1 VSWR bandwidth.

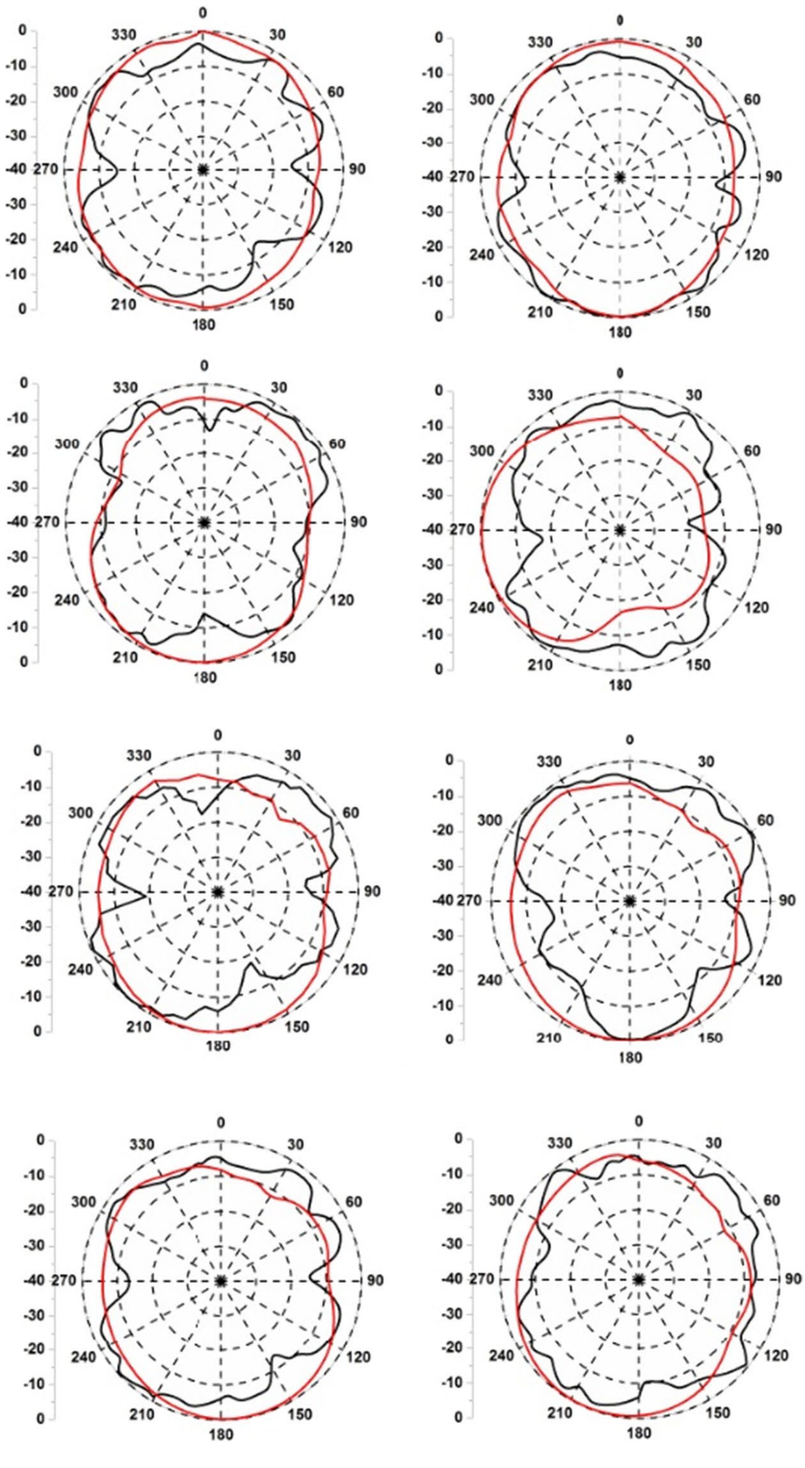

Fig. 10 Simulated elevation pattern gain display at 3.2 GHz, 4.5 GHz, 5.12 GHz, 5.5 GHz, 5.89 GHz, 7.39 GHz and 10.6 GHz

The Fig. 10 shows the Cartesian form of radiation pattern for frequencies 3.2 GHz, 4.5 GHz, 5.12 GHz, 5.5 GHz, 5.89 GHz, 7.39 GHz and 10.6 GHz.

5 Conclusion

A symmetrical hexagonal monopole antenna has been presented. Approximate calculation of lower frequency for symmetrical hexagonal monopole antennas have been presented. On the basis of the simulated and measured result, it completely covers UWB frequency. Parametric studies have been performed which shows that the frequency dependency of the feed gap between bottom part of the patch and the ground plane. The maximum bandwidth of the proposed structure is obtained at about 9.08 GHz. It is noted that the introduction of a rectangular slots in the ground plane can be used as a compact printed planar monopole antenna. The simulation results also yield improvement of impedance bandwidth from 3.09 to 12.2 GHz with respect to prototype antenna. Therefore the proposed antenna can be useful for various UWB applications.

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