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Design of a Compact Hexagonal Monopole Antenna for Ultra—Wideband Applications

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Abstract This paper presents two design compact hexagonal monopole antennas for ultra-wideband applications. The two antennas are fed by a single microstrip line . The Zeland IE3D version 12 is employed for analysis at the frequency band of 4 to 14 GHz which has approved as a commercial UWB band. The experimental and simulation results exhibit good agreement together for antenna 1. The proposed antenna1 is able to achieve an impedance bandwidth about 111%. The proposed antenna2 is able to achieve an impedance bandwidth about (31.58%) for lower frequency and (62.54%) for upper frequency bandwidth. A simulated frequency notched band ranging from 6.05 GHz to 7.33 GHz and a measured frequency notched band ranging from 6.22 GHz to 8.99 GHz are achieved and gives one narrow band of axial ratio (1.43%). The proposed antennas can be used in wireless ultra-wideband (UWB) communications.

Keywords UWB applications · Monopole patch antenna · Circular polarization · Axial ratio · Notch band

1 Introduction

Ultra Wideband (UWB) technology has become a major interest to researchers and scientists. The commercial usages of frequency band from 3.1 GHz to 10.6 GHz, was approved by Federal Communications Commission (FCC) in 2002 [1]. However, there is always an increasing demand for smaller size, and greater capacities and transmission speeds, which will certainly require more operating bandwidth in the near future. In the last few years, researchers have investigated several kinds of microstrip slot and printed antennas for UWB applications [2–17]. Ultra-wideband (UWB) communication systems are currently under investigation and have been widely adopted in commercial and military

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domains. Because of its attractive features, such as low cost, small size and easy fabrication; the printed ultra-wideband monopole antenna has received more and more attention with the development of communication technology.

In this paper, a compact planar monopole antennas for UWB applications are proposed, which exhibits better UWB operating characteristics. The proposed antennas not only occupy a small size but also preserve a very single structure which is easy to be fabricated. The input impedance matching over a wide frequency range is achieved. It can cover a wide frequency range (4 GHz–14 GHz) and satisfy the VSWR≤2.0.

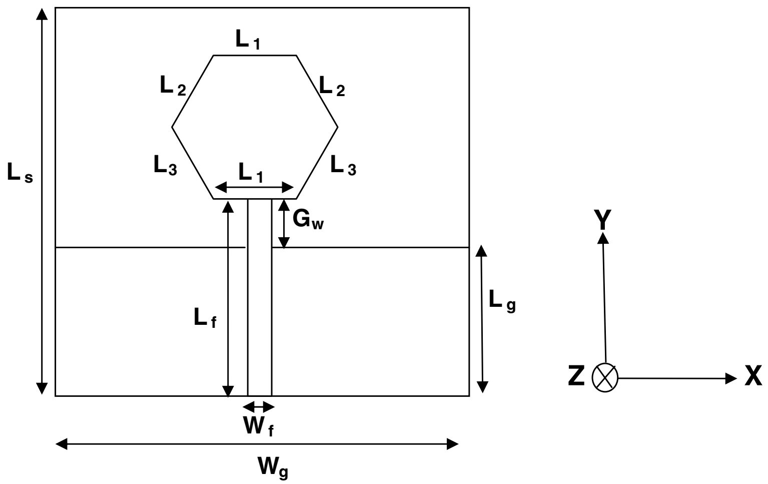
Two design compact hexagonal monopole antenna for ultra-wideband applications are:

1- **Antenna 1: Hexagonal monopole antenna.**
2- **Antenna 2: Hexagonal monopole antenna with asymmetrical U-slot**

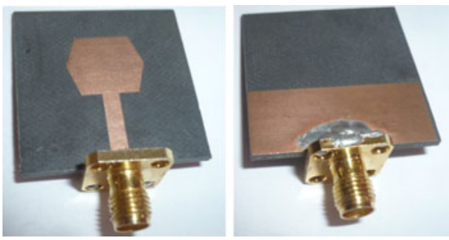
The detailed design and experimental results are presented and discussed below.

2 Antenna geometry

The configuration and the photo of the proposed UWB antennas are illustrated in Figs. 1 and 2, respectively. The proposed antenna have a compact size of 30× 30 mm and it is printed on conventional RT5880 substrate with thickness of 1.57 mm, and relative permittivity=2.2.



(a)



(b)

Fig. 1 Antenna 1: Hexagonal monopole antenna (**a**) Antenna geometry (**b**) Photograph.

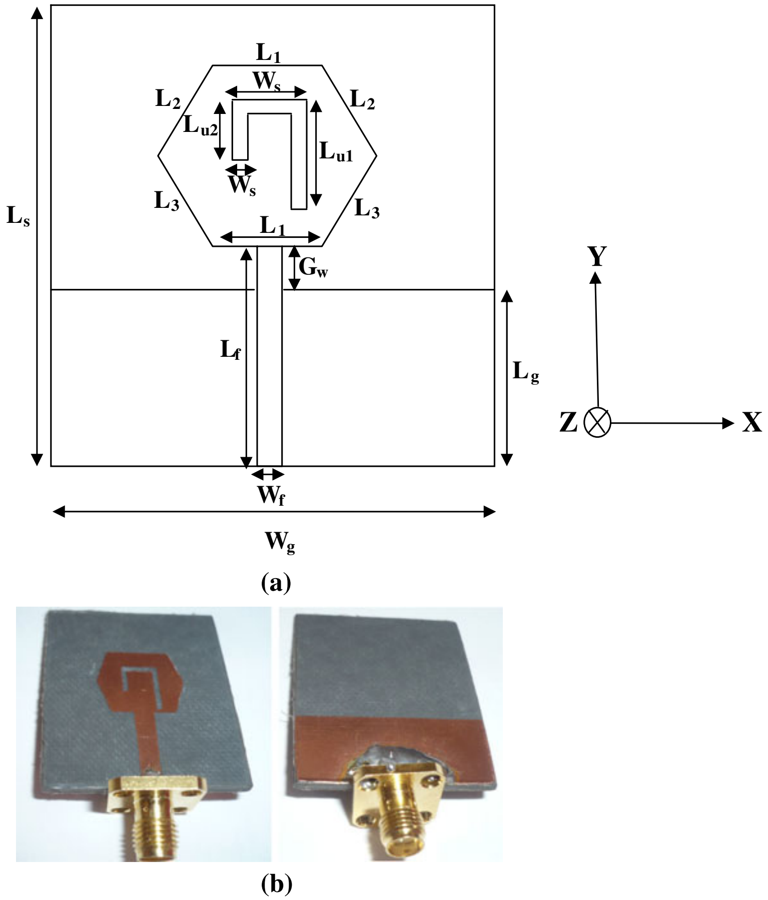


Fig. 2 Antenna 2: Hexagonal monopole antenna with asymmetrical U-slot (**a**) Antenna geometry (**b**) Photograph.

The radiating element is a hexagonal patch and the ground is a rectangular. The radiator and the 50Ω feed line are printed on the same side of the substrate and the ground plane is located on the other side. An asymmetrical U-slot is used to obtain dual circular polarization for ultra wideband applications.

The geometry and photograph of the proposed antenna1 with its parameters is depicted in Fig. 1. The antenna is located in the xy plane and the normal direction is parallel to the z axis. The dimensions of the proposed antenna1 including the substrate L_s X W_g=30 mm× 30 mm ,The radiation element is a hexagonal patch with dimensions L_1=10 mm, L_2=5.5 mm, L_3=6 mm, A 50Ω microstrip feed line with width of W_f=3 mm and the length of L_f=13 mm, The gap G_w=1 mm is the distance between the ground plane on the back side and the hexagonal patch on the front size. The ground plane size of L_g x W_g=12 mm×30 mm.

The geometry of the proposed antenna 2 with its parameters is depicted in Fig. 2. The dimensions of proposed antenna in Fig. 2 is similar to dimensions of the proposed antenna in Fig. 1 except the radiation element is a hexagonal patch with asymmetrical U-slot with dimensions L_1=10 mm, L_2=5.5 mm, L_3=6 mm ,L_{u1}=8.5 mm, L_{u2}=5 mm, W_u= 6 mm, W_s=1 mm.

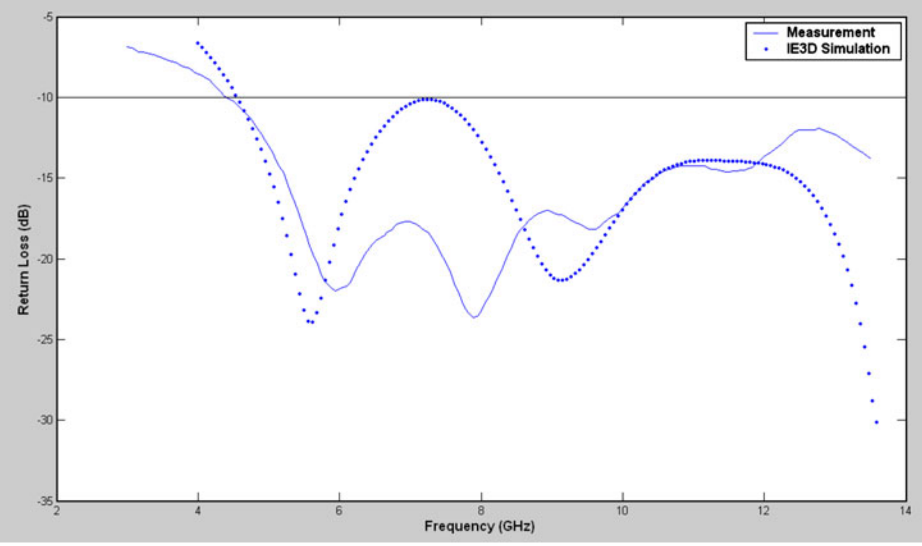


Fig. 3 Simulated and measurement return loss of Antenna 1.

3 Measurement and simulation results of antenna 1

The structures are simulated with IE3D which utilized the moment method for electromagnetic computation.

3.1 Return loss

The measured and simulated return loss S_{11} of antenna 1 are shown in Fig. 3. From the Figure, it is predicted that there is a good agreement between numerical and experimental

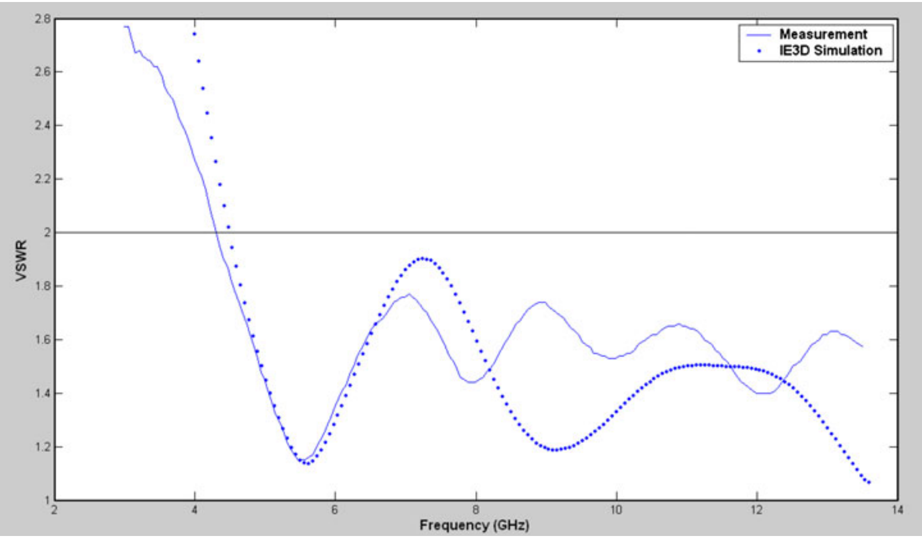


Fig. 4 Simulated and measurement VSWR of Antenna 1.

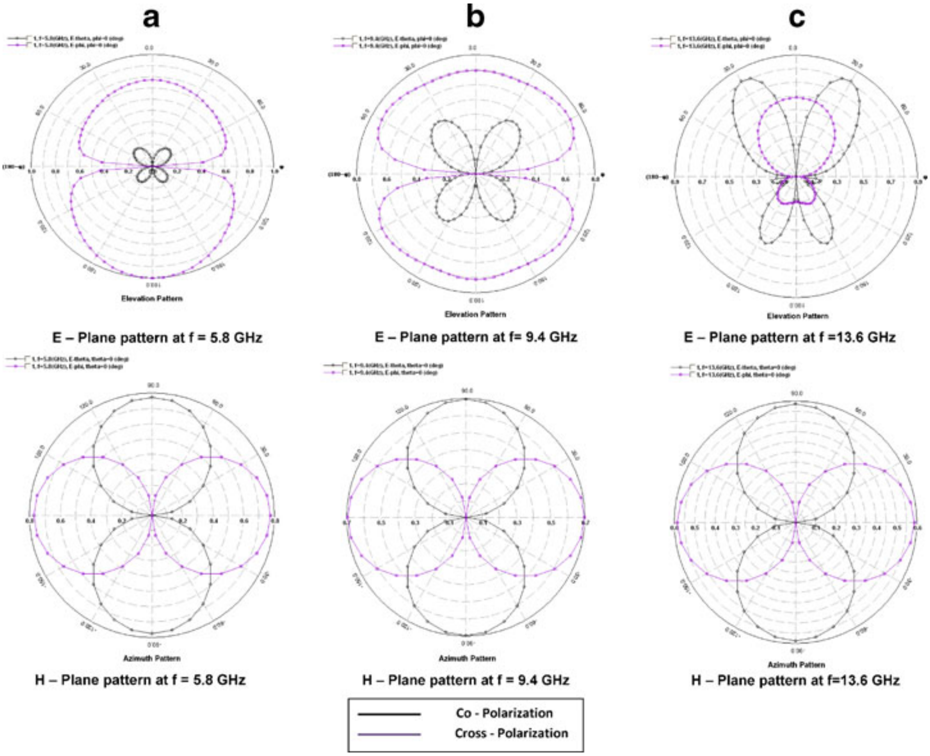


Fig. 5 Simulated radiation patterns of Antenna 1 at (**a**) 5.8 GHz , (**b**) 9.4 GHz, (**c**) 13.6 GHz.

results. The experimental and the simulated band frequencies from 3 GHz to 14 GHz are predicted, The slight frequency shift and discrepancy are achieved due to the probable deviation on the substrate permittivity at high frequency, Otherwise, a good agreement is achieved.

3.2 Voltage standing wave ratio

The measurement and simulated VSWR of antenna 1 are shown in Fig. 4. It is noticed from the Figure that antenna 1 provides a wide impedance bandwidth of 4.6 GHz to 14 GHz for VSWR$\leq$2.

3.3 Radiation patterns

The simulated radiation patterns of the proposed antenna 1 at 5.8 GHz, 9.4 GHz and 13.6 GHz along both *y-z* plane (E-plane) and *x-z* plane (H-plane) are illustrated in Fig. 5 (a,b,c) respectively. At lower frequencies, it is seen that our proposed design exhibits as an omnidirectional profile for the *y-z* plane and a bi-directional one for the *x-z* plane. With the increase of frequency, the proposed antenna becomes more directive, but still remains bi-directional.

3.4 Gain

The Simulated maximum gain of the proposed antenna 1 is performed by using IE3D and presented in Fig. 6. The antenna gain varies from 2.32 dB to 4.4 dB over the operating

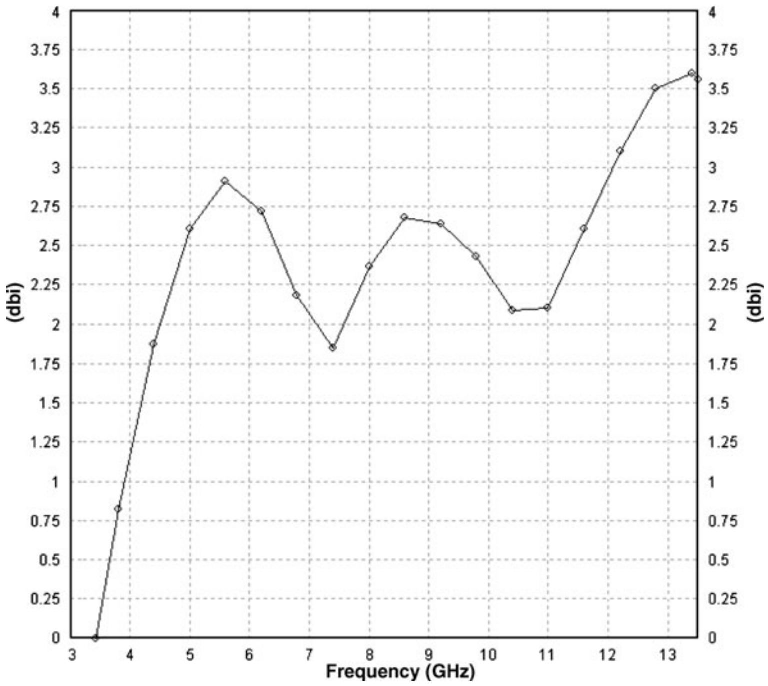


Fig. 6 Simulated maximum gain of Antenna 1.

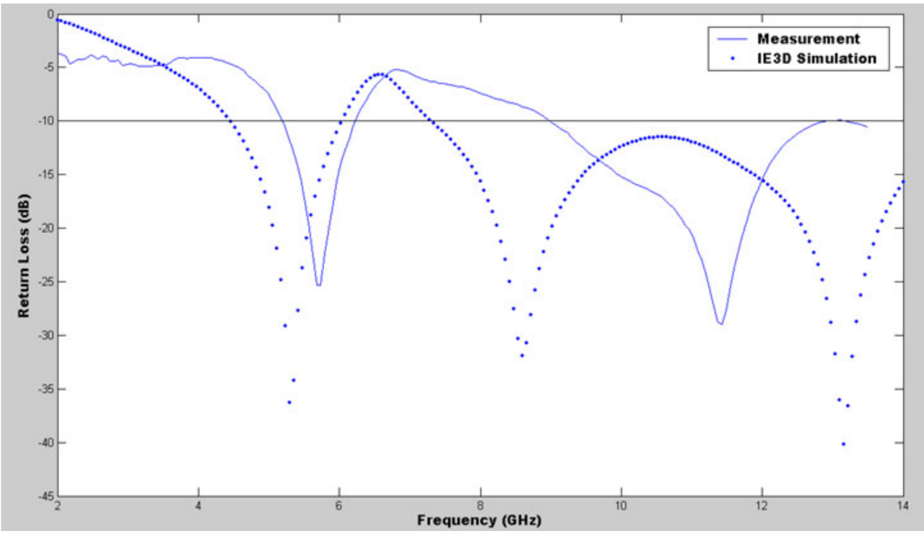


Fig. 7 Simulated and measurement return loss of Antenna 2.

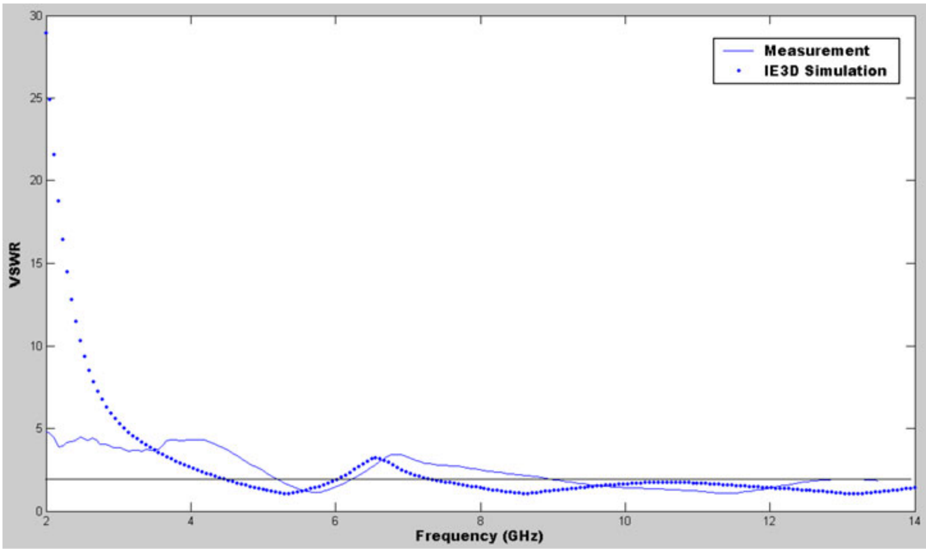


Fig. 8 Simulated and measurement VSWR of Antenna 2.

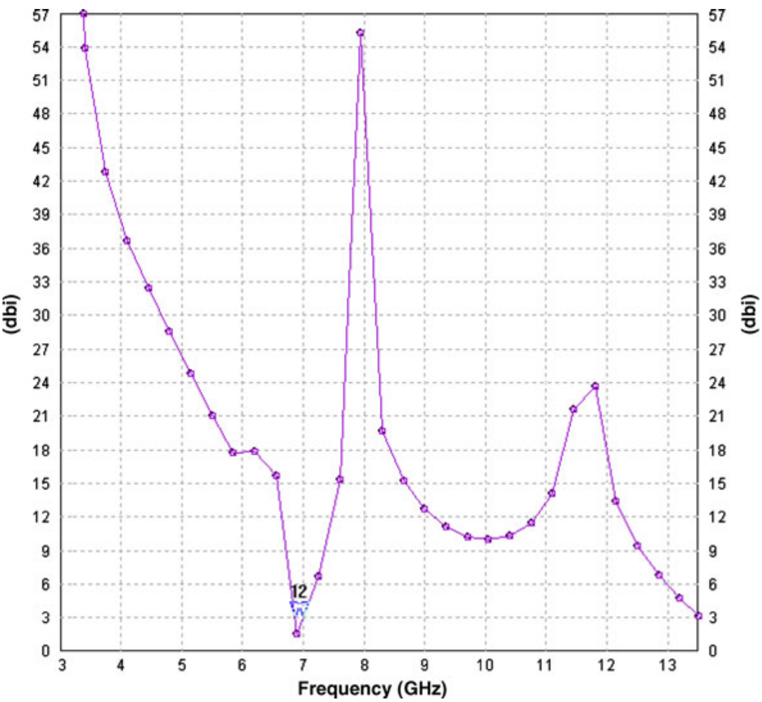


Fig. 9 Simulated AR vs. Frequency of Antenna 2.

UWB frequency range. It can be concluded that the gain variation is not less than 1.25 dB over the entire operating frequency range from 4 to 14 GHz.

4 Measurement and simulation results of antenna 2

4.1 Return loss

The measurement and Simulated return loss S_{11} of antenna 2 are shown in Fig. 7. The simulated impedance bandwidth for return loss (RL) less than−10 dB (|S11| ≤−10 dB) is

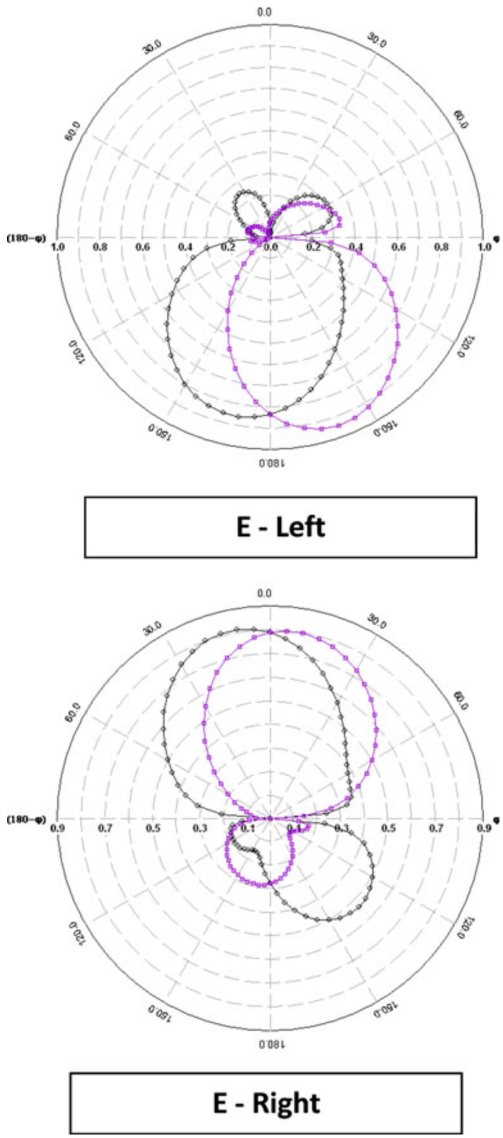


Fig. 10 Radiation Pattern at 6.9 GHz of Antenna 2.

obtained. It is seen that the impedance bandwidth for return loss of less than−10 dB ranges from 4.4 GHz to 14 GHz, in which a simulated frequency notched band ranging from 6.05 GHz to 7.33 GHz is achieved, a measured frequency notched band ranging from 6.22 GHz to 8.99 GHz is achieved. Due to this notch frequency, there are two bandwidth of the UWB antenna. The Simulated Lower frequency bandwidth (BW1) is starting from 4.4 GHz to 6.05 GHz and the simulated upper frequency bandwidth (BW2) is starting from 7.33 GHz to 14 GHz. The measured Lower frequency bandwidth (BW1) is starting from 5.19 GHz to 6.22 GHz and the measured upper frequency bandwidth (BW2) is starting from 8.99 GHz to 14 GHz.

4.2 Voltage standing wave ratio

The measurement and simulated VSWR of antenna 2 are shown in Fig. 8, the simulated VSWR shows that the proposed antenna 2 provides a wide impedance bandwidth of 4.37 GHz to 14 GHz with notched frequency band from 6.08 GHz to 7.26 GHz. The simulated results show that VSWR≤2 for frequency band (4.37–6.08) GHz and (7.26–15.5) GHz respectively. The simulated results show that VSWR≥2 for notched frequency band (6.08–7.26) GHz. The measured VSWR shows that the proposed antenna 2 provides a wide impedance bandwidth of 5.19 GHz to 14 GHz with notched frequency band from 6.22 GHz to 8.99 GHz. The measured results show that VSWR≤2 for frequency band (5.19–6.22) GHz and (8.99–14) GHz respectively. The measured results show that VSWR≥2 for notched frequency band (6.22–8.99) GHz.

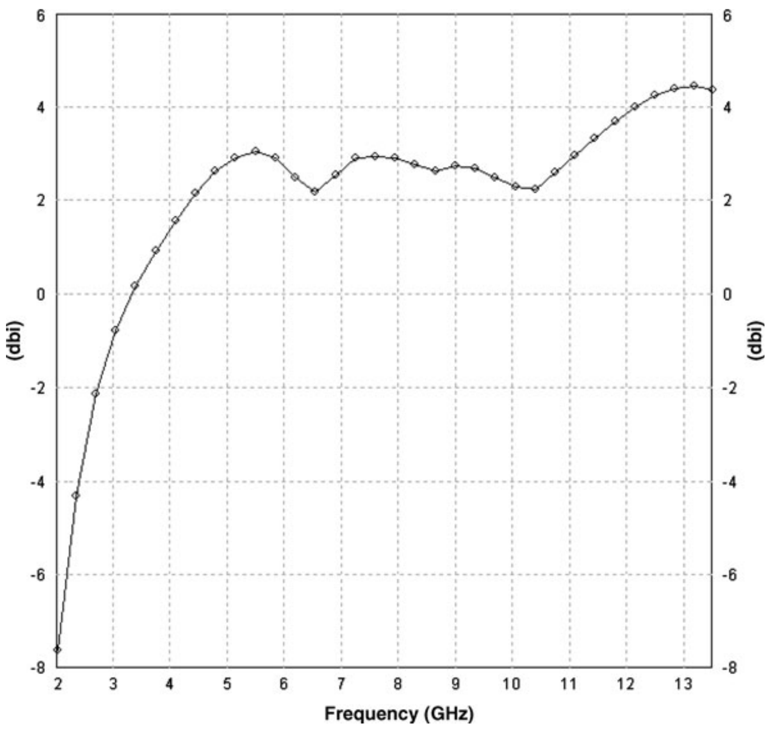


Fig. 11 Simulated maximum gain of proposed antenna 2.

4.3 Axial ratio

The simulated axial ratio (AR) of antenna 2 is shown in Fig. 9. The simulated axial ratio bandwidth (AR)≤3 dB provides single circular polarization. It is seen that the (AR) bandwidth have ranges (6.92–7.02) GHz , BW=(1.43%) .The circularly polarized (CP) antenna could have many different types and structures where the basic operation principle is to radiate two orthogonal field components with equal amplitude but in phase quadrature. The CP is generated by the unequal arms of the U-slot (Asymmetrical U-slot). Also Antenna 2 gives Left Hand Circular Polarization (LHCP) at one frequency 6.9 GHz which presented in Fig. 10, [18, 19].

4.4 Gain

The Simulated maximum gain of the proposed antenna 2 is performed by using IE3D and presented in Fig. 11. The antenna gain varies from 2.2 dB to 3.6 dB over the operating UWB frequency range. It can be concluded that the gain variation is not less than 1.38 dB over the entire operating frequency range from 4 to 14 GHz.

5 Conclusion

This paper presented two design of a compact hexagonal monopole antenna for ultra-wideband applications. Antenna 1 (Hexagonal monopole antenna) gives an return loss bandwidth about 111% with acceptable gain over the entire frequency band of operation. Antenna 2 (Hexagonal monopole antenna with asymmetrical U-slot) gives the lower frequency bandwidth (BW1) is starting from 4.4 GHz to 6.05 GHz (31.58%), the upper frequency bandwidth (BW2) is starting from 7.33 GHz to 14 GHz (62.54%) and the frequency notched band ranging from 6.05 GHz to 7.33 GHz. Antenna 2 gives single axial ratio (AR) band have ranges (6.92–7.02) GHz, BW=(1.43%). Antenna 2 gives Left Hand Circular Polarization (LHCP) at one frequency 6.9 GHz. Also, the gain of this antenna is presented. It is noticed that the gain is accepted for the band of operation.

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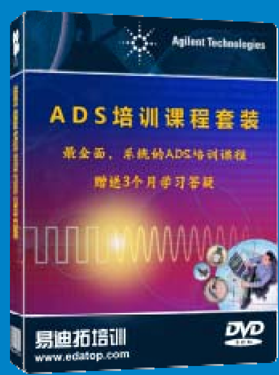

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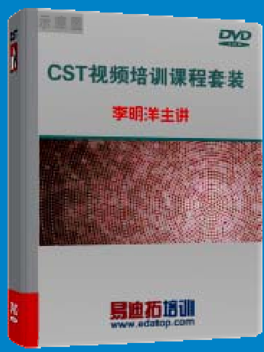

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