Design and Analysis of A Compact UWB Antenna based on Super-Formula

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Abstract In this paper, compact ultrawideband(UWB) antennas (1-Element and 2-Element) are presented for UWB application. The contour profile of the antenna is obtained by setting the six different parameters of the *super-formula*. The antenna is microstrip-fed and mounted on compact size FR4 substrate of dimensions of $25 \times 35 \times 1.6mm^3$. To improve the impedance bandwidth, a notch is cut from the ground plane and the edges are chamfered with specific dimensions. The antenna is simulated using a full-wave simulator HFSS. Results showed that the antenna works in the UWB range(3.3-10.3GHz) with VSWR less than 2,and having almost constant gain and group delay.Also,in paper 2-Element antenna array are designed and simulated. Proposed antenna are used for applications such as WPAN,WBAN,etc.

Keywords Ultra-Wideband (UWB) antenna , Super-formula,antenna array

1. Introduction

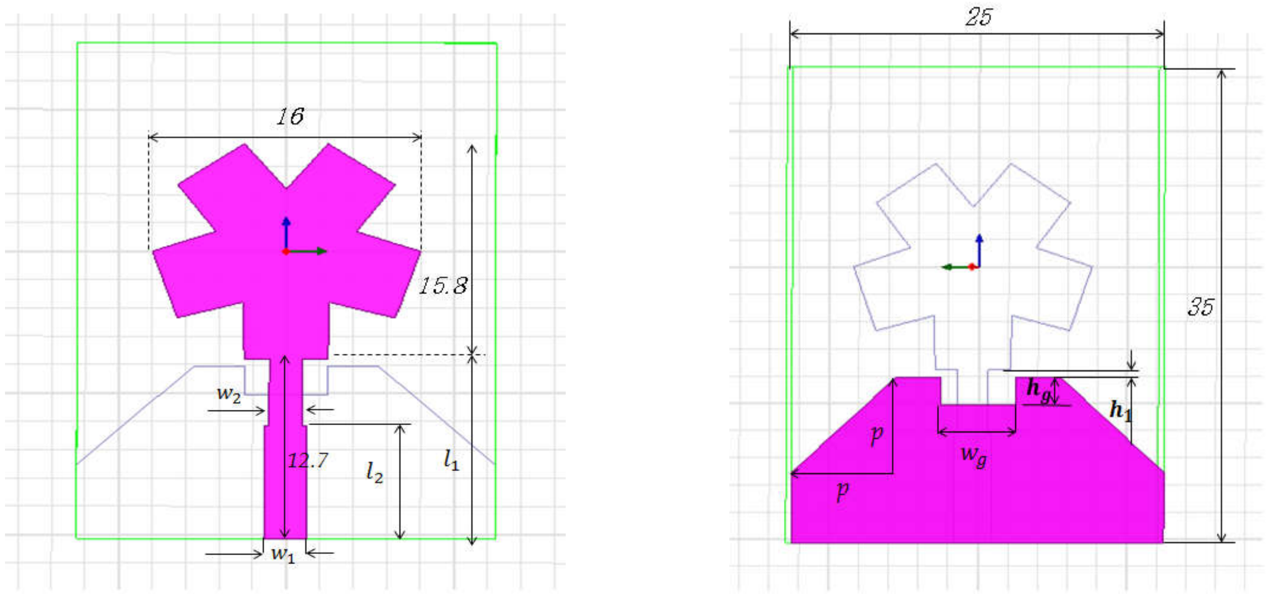
The rapid development in modern wireless communication system put several challenges to the researchers to design multiband or wideband antennas in order to accommodate wireless data user with more bandwidth. Thus, the design of a compact wideband antenna becomes very difficult with several advantages such as high data transmission capability at very low power level, low cost, ease in fabrication, wide operating bandwidth, etc. The above listed issues can be resolved up to some extent by using fractals in ultrawideband (UWB) antenna design. The UWB offer above 200 Mbps data transmission capacity in the limited range of few meters. Moreover, it transmits data using very low level of power because of absence of any carrier signal and it spreads the transmitted signal in the operational bandwidth of UWB spectrum[1]. Thus, the battery life of the device can be increased significantly. Such improvements in antenna design in case of indoor communication help to achieve several advantages over conventional wire- less data transmission. Recently, the advancement in UWB technology focusses on compactness in the design, which eases in the integration of the device with other components of the system. In [2], an egg shaped monopole UWB antenna of dimension $40 \times 40mm^2$ was designed. While in [3], a finite ground flag-shaped monopole UWB antenna was presented, which consisted of a finite ground CPW-fed monopole asymmetrically loaded with a rectangle strip. In [4], a CPW-fed hexagonal microstrip fractal UWB antenna was designed. A stepping fed structure was used to improve the characteristics of the antenna in the UWB range. In 2003, Gielis presented a geometrical approach to describe many abstract , naturally occurring and man-made geometrical shapes and forms with one simple generic formula called the super-formula [5]. A large number of shapes generated by the super-formula can be controlled by setting the values of six key parameters. Although a large number of shapes can be generated using the super-formula, a few of them can be used for antenna design due to symmetry requirement and limited edge diffraction and other requirements [6]. In this paper, the design of nature inspired shape using the super-formula is carried out. The contour profile of the shape is used to build a microstrip-fed UWB antenna.All simulations are carried out using the full-wave simulator HFSS[10].

2. UWB Antenna Design

The super-ellipse equation in polar form is illustrated in Eq. (1). By considering different exponents and introducing the parameter m/4 to divide the polar coordinates into m sectors, the super-formula is obtained in Eq. (2) [7]. The parameters n_i (i = 1, 2, 3) and m are positive real numbers. The parameter m determines the number of points, corners, sectors, or hollows fixed on the shape and their spacing. On the other hand, n2 and n3 determine if the shape is inscribed or circumscribed in the unit circle.

$$r = \left(\left| \frac{\cos\theta}{a} \right|^{n} + \left| \frac{\sin\theta}{b} \right|^{n} \right)^{-1/n} \qquad (1)$$

$$r = \left(\left| \frac{\cos(\frac{m}{4}\cdot\theta)}{a} \right|^{n_2} + \left| \frac{\sin(\frac{m}{4}\cdot\theta)}{b} \right|^{n_3} \right)^{-1/n_1} \qquad (2)$$



(a) (b)

Fig. 1 The structure of the proposed super-formula-based UWB antenna
Obtained with(a=1,b=1, m =10, n_1=1, n_2=0.3, n_3=0.3).All dimensions are in mm.

Figure 1 illustrates the structure of the proposed super-formula-based UWB antenna.The antenna is mounted on compact size FR4 substrate of dielectric constant of 4.4 and thickness of 1.6 mm. The patch contour profile follows the polar function in Eq. (2). Then, the size of the patch was changed to get good return loss in the UWB range. The antenna is fed with 50Ω microstrip line of width W_1 and length of 12.7 mm. The ground plane on the bottom side of the substrate has dimensions of $11.8 \times 25 mm^2$ with a notch cut near the feeding point to improve the impedance bandwidth. Also, the edges were chamfered to further improve the impedance bandwidth.

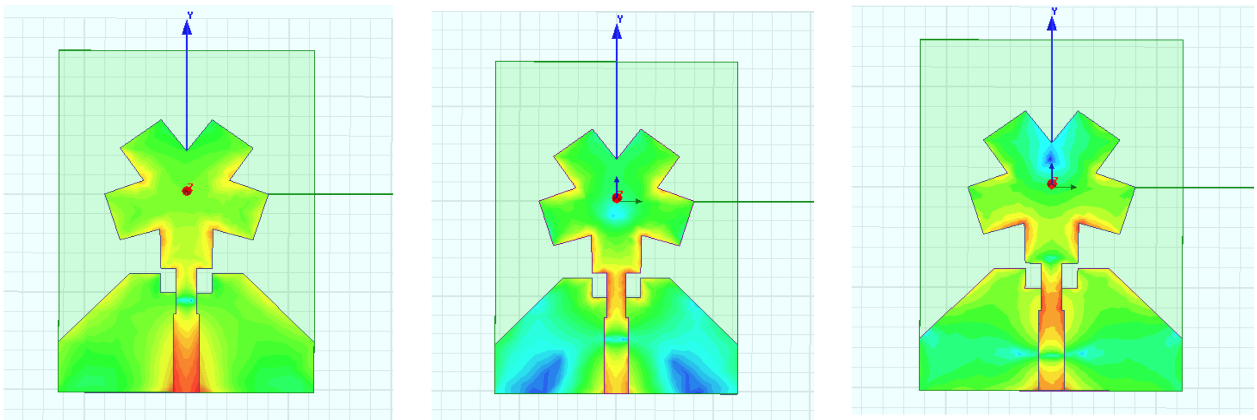
The initial parameters are as follows:

$$w_1 = 3mm, w_2 = 1.5mm, w_g = 5mm, h_g = 1.5mm, l_1 = 12.7mm, l_2 = 5mm$$

3. Antenna Performance Analysis

3.1 The current distribution of Antenna

Figure 2 shows the current distribution of antenna at frequencies 3.5, 6.8 and 9.5 GHz. It can be noticed from Fig. 2 that the current is highly distributed at the feeding line and along the edges of the patch at all frequencies. On the ground plane, the current is mainly distributed on the upper edge near the feeding point, which means that the portion of the ground plane close to the patch acts as a part of the radiating structure.



3.5GHz 6.8GHz 9.5GHz

Fig. 2 The current distribution of proposed UWB antenna

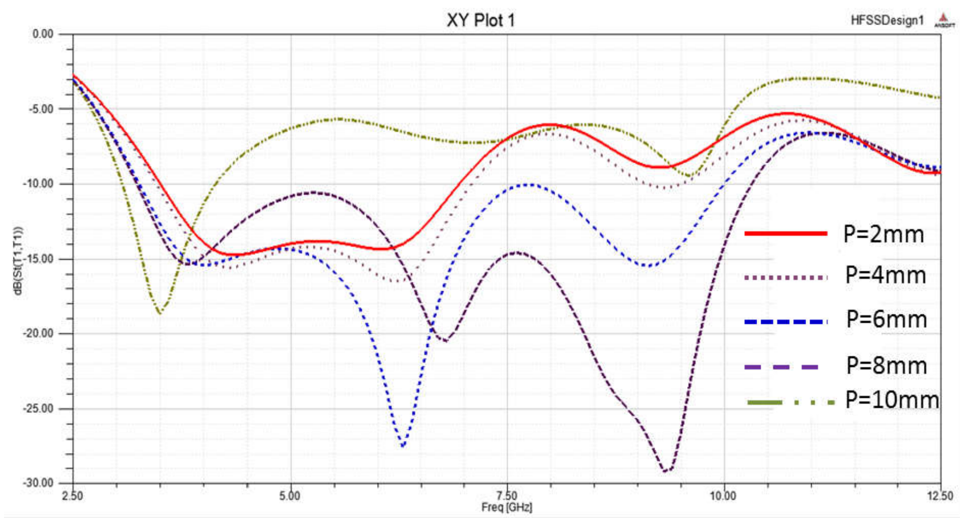


Fig.3 S_{11} Curves according to change of parameter P

3.2 Analysis of antenna S parameter

From Fig. 3 to Fig. 5 show the change curve of the S parameter according to the change of the structural variable. It can be noticed from Fig.3 that there is an optimum value that the VSWR is less than 2 in all bands when the parameter P changes from 2 mm to 10 mm. Figure 4 shows that VSWR is the smallest when $w_g = 5mm$. Figure 5 shows the S11 curves according to the parameter w_2 . The optimized parameters of the proposed UWB antenna are shown in **Table 1**. Then, the *voltage standing wave ratio*(VSWR) of the proposed UWB antenna as shown in Figure 6. It can be noticed from Fig 6 that the obtained parameters satisfy the design condition(VSWR<2) in the whole band.

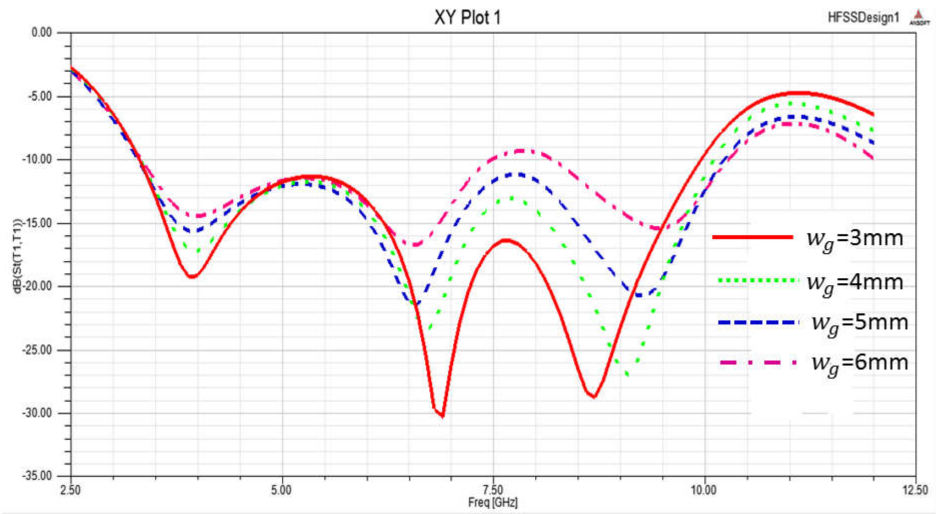


Fig.4 S_{11} Curves according to change of parameter w_g

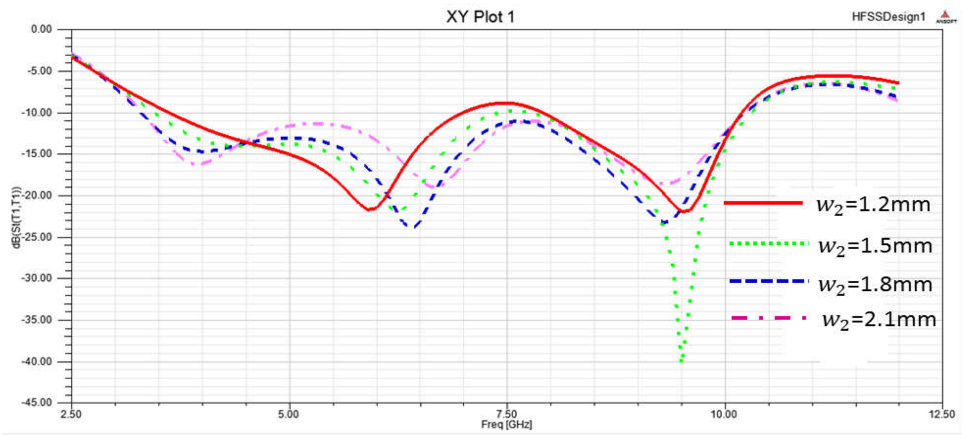


Fig.5 S_{11} Curves according to change of parameter W_2

Table 1

l_1	l_2	w_1	w_2	w_g	h_g	h_1	p
12.7	8	2.5	1.8	5	2.5	0.5	7

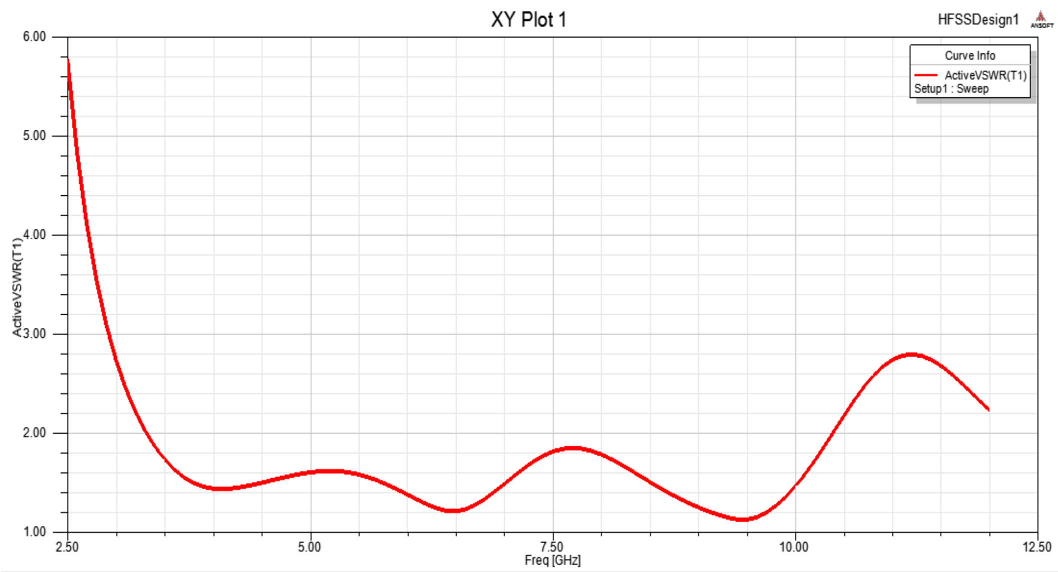
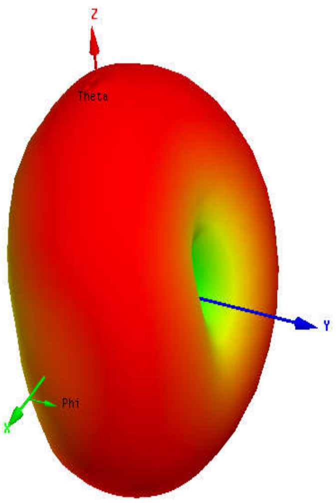
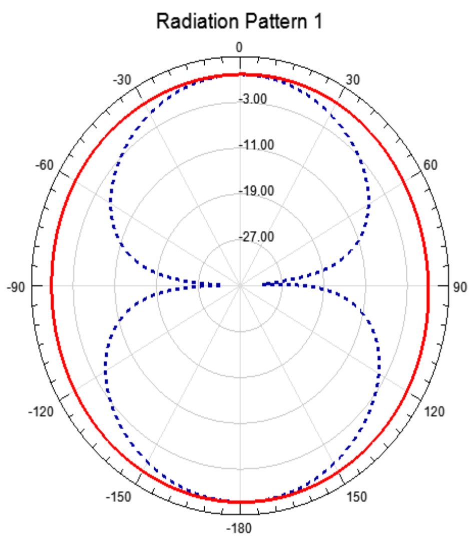


Fig 6. VSWR according to frequency

3.3 Antenna Directivity

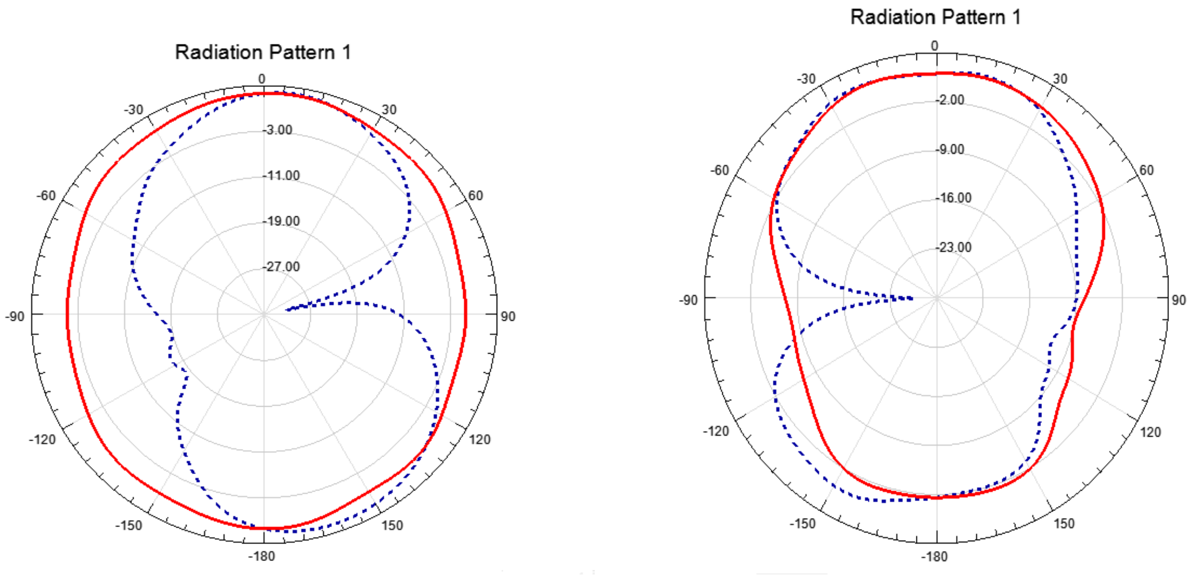
The simulated radiation patterns in the E-plane (yz-plane) and the H-plane (xz-plane) at 3.5, 6.5 and 9.5 GHz and 3D polar radiation patterns are illustrated in Fig. 6. It can be noticed that at low frequencies, the patterns in the E-plane have the figure-8 shape with small cross-polarization components which indicates that the antenna has a linear polarization. Also, the H-plane has non-directional patterns at low frequencies. But, as the frequency increases the patterns are no longer non-directional.





3D Polar Pattern(6.5GHz)

3.5GHz



6.5GHz 9.5GHz

Fig 7. Directivity patterns (in dB) of the proposed UWB antenna
(——— E-Plane, ------ H-Plane)

4. Design and Analysis of 2-Element Antenna Array

Figure 8 shows the design and configuration of the 2-Element antenna array.Here, single UWB antenna elements are used in the design of 2-Element antenna array. It is evident from Fig. 8 that the proposed structure is fed by 3-section 2-way wideband Wilkinson power divider [8,9]. The values of r_1, r_2 and r_3 are 120, 240 and 390Ω, respectively. The introduction of rectangular slot of dimensions $w_s \times L_s$ in the design help to achieve desired wideband performance.

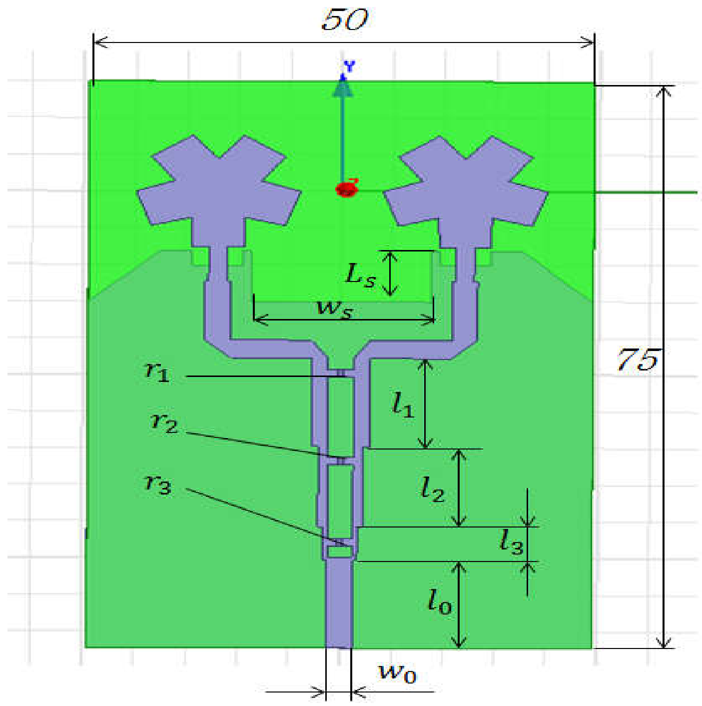


Fig 8. The configuration of the 2-Element antenna array

The application of slot in the design enhances the operating bandwidth and reduces mutual coupling between antenna elements. The VSWR of the 2-Element antenna array is displayefrd in Fig 9.It can be noticed from Fig 6 and Fig 9 that the bandwidth characteristics is improved for the 2-Element antenna array.The simulation results show the operational bandwidth from 2.8 to 11.5GHz with multiple resonant frequencies,which cover the whole UWB band. The optimized dimensions of the 2-Element antenna array are as follows:

$$l_0 = 12mm, l_1 = 5mm, l_2 = 11mm, l_3 = 12mm, w_0 = 2.5mm, w_s = 17.5mm, L_s = 7mm$$

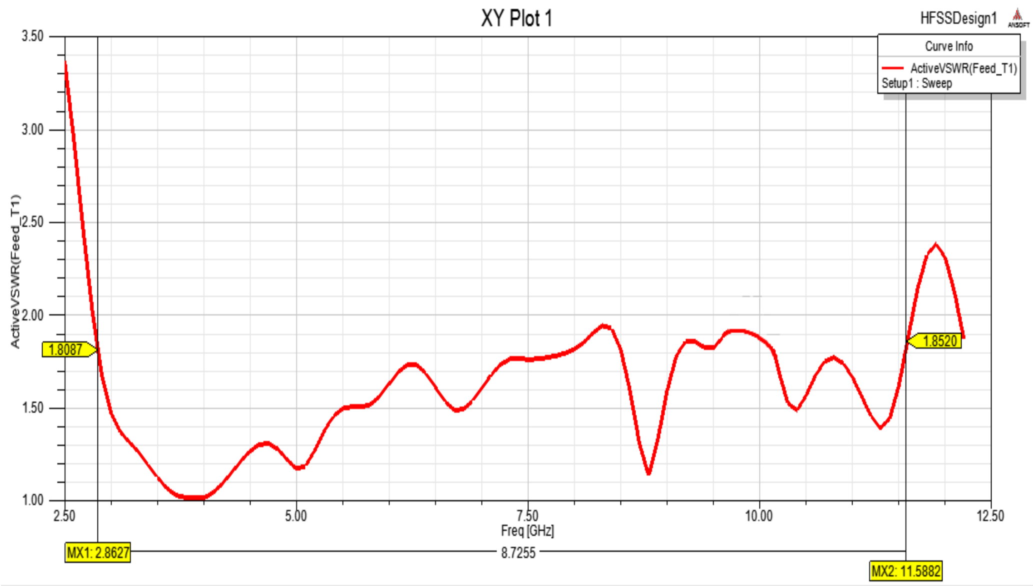


Fig 9. The VSWR of the 2-Element antenna array

4. Conclusion

In this paper,the design and analysis of a compact size UWB antenna based on the super-formula was carried out.Also, the 2-Element antenna array are designed by using 1:2 Wilkison power divider. The 2-Element antenna array works in the range 2.8~11.5GHz with VSWR<2.

The result of this study can be helpful to design the UWB antenna and the proposed antenna are used for various application.

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