

## New Simple Flower Shaped Reconfigurable Band-Notched UWB Antenna Using Single Varactor Diode

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**Abstract**—In this paper, a new flower-shaped microstrip line feed reconfigurable band-notched UWB monopole antenna using single varactor diode is introduced and fabricated. Different notch frequencies can be obtained using different capacitance values. The effect of changing the varactor position is also examined. The flower shape is first optimized to obtain UWB characteristics. Then, a slot is made in the microstrip line to be loaded later with a single varactor diode. A wide range of notch frequencies can be obtained using this simple configuration which covers most of the narrow band coexistence systems. The notch frequency can be lower by increasing the capacitance value. The notch frequency covers the WLAN band when  $C = 0.8$  pF and covers the WiMAX band when the capacitance is changed to 0.7 pF for the same antenna configuration and varactor position. Two prototypes of the proposed antenna using two different single capacitor elements with capacitances 0.6 pF and 1.5 pF are fabricated, and their reflection characteristics are measured and compared with the simulated ones. Notch frequencies at 6.1 GHz and 4.3 GHz are obtained respectively in both simulated and measured antenna structures. The proposed antenna has a directive radiation pattern in  $E$ -plane and omnidirectional pattern in  $H$ -plane. Also, the gain is suppressed in the notched frequencies. The group delay is nearly stable in the UWB frequency range with very little variations, but it is distorted sharply at the notch frequencies. So, the proposed antenna is a good candidate for the modern UWB systems.

### 1. INTRODUCTION

The need for high data transmission rate in communication systems is more and more important according to the development of wireless technology [1]. Hence, ultra-wideband (UWB) radio technology has attracted researchers' attention due to its advantages such as high-speed data rate, low cost, small size, and more security [2]. Planar monopole antenna is characterized by low cost, ease of fabrication, low profile, wide bandwidth, and high radiation efficiency, so it is one of the most common UWB antennas [1]. A band of 7.5 GHz between 3.1 and 10.6 GHz has been allocated for UWB applications by FCC [3]. WLAN and WiMAX and other narrow band systems coexist in the same UWB frequency band [4]. Recently, a lot of UWB monopole antennas with single or multiple notch frequencies to avoid this interference have been introduced. The band-notch characteristics can be achieved through various slots or slits in the radiating patch [5–11], slots in the feed line [12–15], slots in the ground plane [16–19], or using parasitic patches [20–26]. However, these antennas have fixed band-notch characteristics, and in the cases that there is no interference, they are unable to utilize all the UWB frequency range. Hence, using reconfigurable band-notch structure can improve the performance of the UWB system. In reconfigurable band-notch UWB antennas, changing the notch frequency is achieved by using lumped elements such as PIN diodes or varactor diodes [27–29]. PIN diodes are used as a switch by applying

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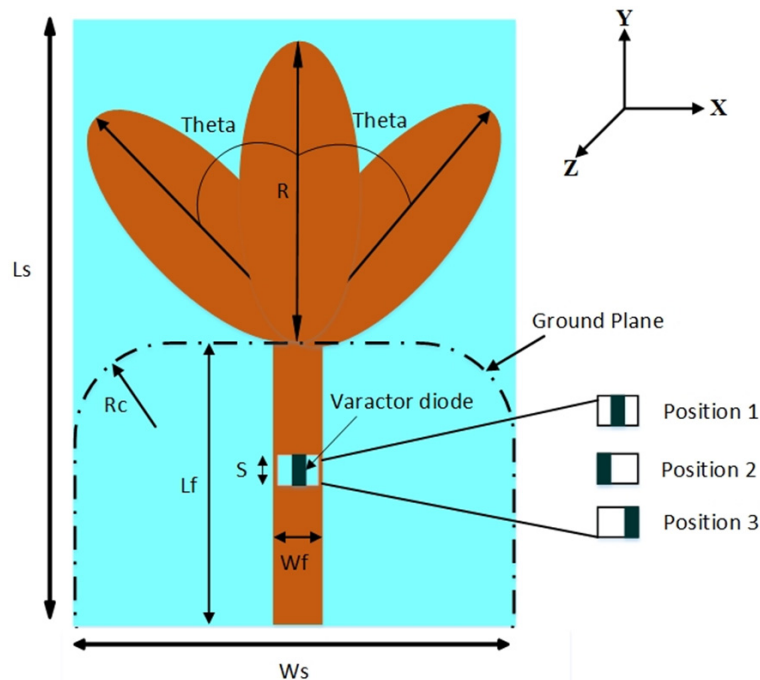
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a dc voltage on its terminals [27, 29]. UWB antennas with PIN diodes have only two different notch frequencies or less. Varactor diodes are used as a variable capacitance depending on the applied reverse bias DC voltage [28], to achieve different notch frequencies.

Our goal is to achieve a simple reconfigurable band-notch UWB antenna using single varactor diode. A slot in the microstrip line is made and optimized to be loaded later by a single varactor diode. The frequency band notch is achieved simply by using a single capacitor element. There are no slots or slits in the radiating patch or parasitic patches with specific wavelength related resonant lengths. A wide range of frequency band-notches, which cover almost all the narrow band coexistence systems, can be obtained simply by changing the capacitance value. The reconfigurability can be done by using a variable capacitor or a varactor diode instead of using single capacitor element. Hence, the notch frequency tuning is achieved by applying a different reverse DC voltage on the varactor terminals. The effect of changing the varactor position is also examined. Finite element method (FEM) in the frequency domain and finite integration technique (FIT) in the time domain are used to simulate the proposed structures using Ansys HFSS [30] and CST MWS [31], respectively. Two prototypes of the proposed antenna with a rectangular slot are fabricated, each with a different single capacitor element. Their return losses are measured and compared with the simulated ones. To ensure tunability, two different capacitor elements with capacitances 0.6 and 1.5 pF are used, which are available in our laboratory. Two notch frequencies are obtained at 6.1 and 4.3 GHz, respectively. Very good agreement between measured and simulated results has been obtained. Far field and time domain characteristics are also examined. The proposed antenna with and without the varactor diode has nearly stable radiation pattern across the entire bandwidth, with a directive radiation pattern in  $E$ -plane and omnidirectional pattern in  $H$ -plane. Also, the gain is suppressed in the notched frequencies. The group delay is stable in the UWB frequency range with very little variations, but it is distorted sharply at the notch frequencies. The proposed design is a simple reconfigurable band-notch UWB antenna with good radiation characteristics and suitable for up-to-date UWB systems.



**Figure 1.** Flower shaped UWB planar monopole antenna loaded by a single varactor diode.

## 2. ANTENNA DESIGN

The proposed UWB antenna configuration is shown in Figure 1. The antenna is printed on an FR4 dielectric substrate having a thickness of 1.6 mm with a relative permittivity of 4.5. The flower shape has three ellipses with major radius  $R$ . The antenna is excited through a microstrip line of width ' $W_f$ ' and length ' $L_f$ '. The ground plane which is on the back side has curved corners with radius  $R_c$ . Rectangular slot with length ' $S$ ' is made in the microstrip line to fit a varactor diode. An SMV2019-040LF varactor diode is used, and its capacitance can be varied from 0.3 pF to 1.4 pF depending on the applied reverse DC voltage. The varactor has three different positions as shown in Figure 1. Table 1 shows the design parameters used for the prototype structure.

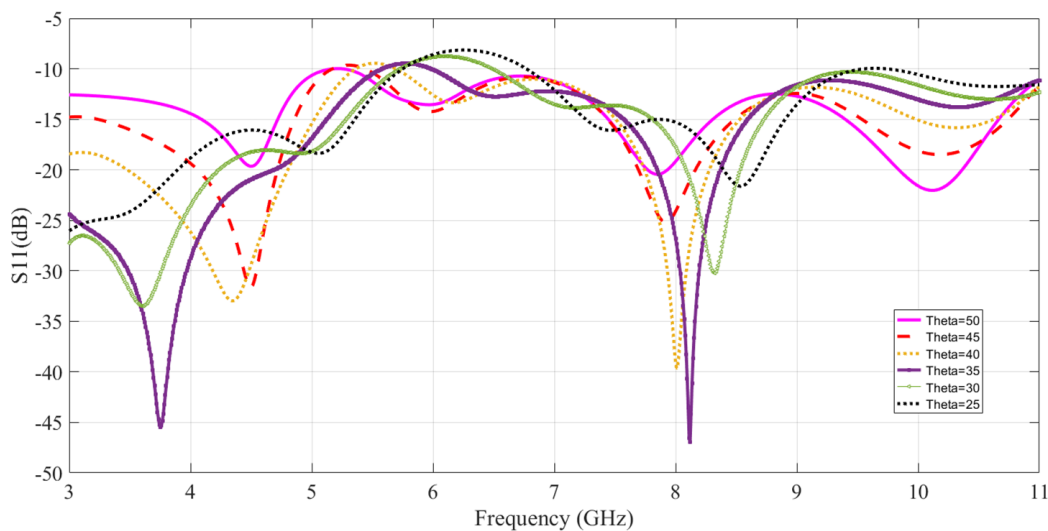
**Table 1.** The design parameters of the proposed antenna.

Design parameters	Dimensions in (mm)
$W_s$	42
$L_s$	50
$W_f$	3
$L_f$	3
$R$	7
$S$	1.5
$R_c$	10

## 3. RESULTS AND DISCUSSIONS

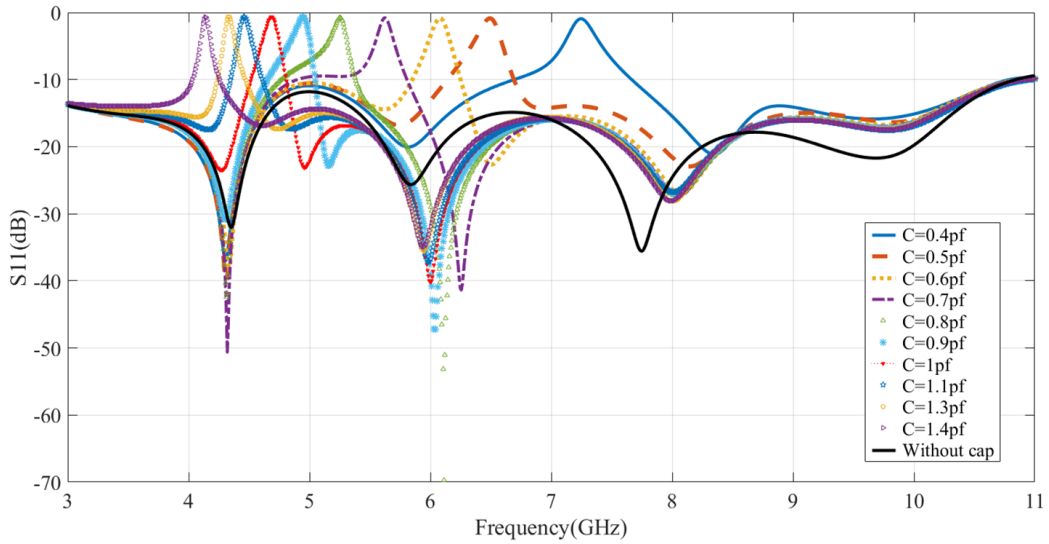
### 3.1. Simulated Results

In the beginning, the flower shape is optimized without any slots or varactors to achieve UWB characteristics. Three ellipses are used to construct the flower shape. The angles between the three ellipses are varied, and its effect on the reflection coefficient is examined. Figure 2 shows the reflection coefficient  $S_{11}$  with different angles. As the angle Theta decreases, the antenna has two wide bandwidths,

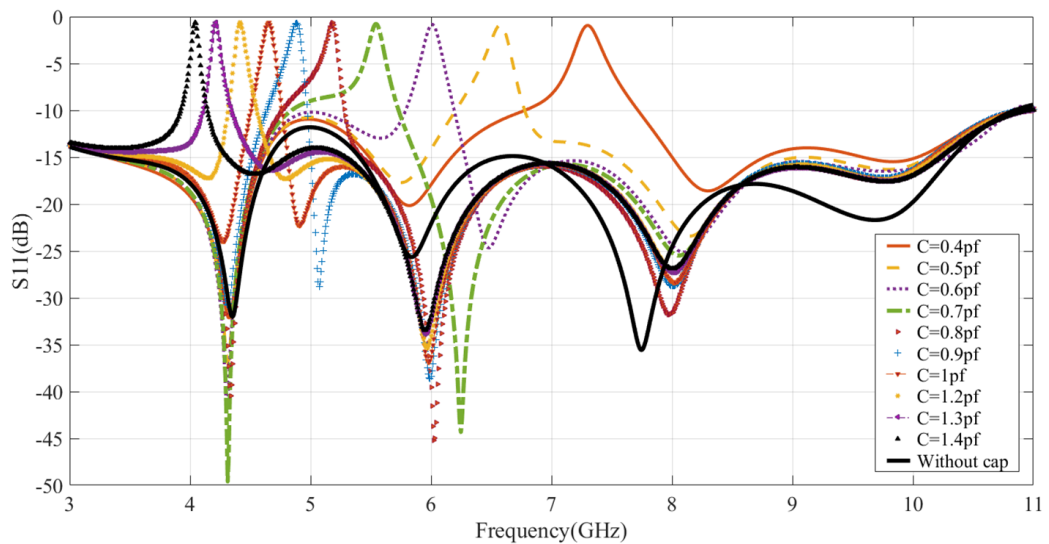


**Figure 2.** Simulated  $S_{11}$  characteristics of the proposed UWB flower monopole antenna without slots for different angles.

and a null is found between 5 and 7 GHz. At  $\Theta = 50^\circ$ , the antenna validates the UWB characteristics and has a continuous bandwidth between 3 and 11 GHz. A slot is made in the microstrip line, and its dimensions and position are optimized. Results are not shown for simplicity. A single varactor diode is loaded in the slot. The varactor position is changed three times as shown in Figure 1. In each position, the capacitance is changed, and the corresponding reflection coefficient is stored. Figures 3–5 show the return loss versus frequency for the different capacitance values and positions. In each position, increase the capacitance value, and decrease the notch frequency. A wide range of notch frequencies can be obtained using this simple configuration, which covers most of the narrow band coexistence systems. For example, as shown in Figure 5 the notch frequency covers the WLAN band when  $C = 0.8 \text{ pF}$  and covers the WiMAX band when the capacitance is changed to  $0.7 \text{ pF}$ .



**Figure 3.**  $S_{11}$  characteristics of the proposed antenna for different capacitance values in position one.



**Figure 4.**  $S_{11}$  characteristics of the proposed antenna for different capacitance values in position two.

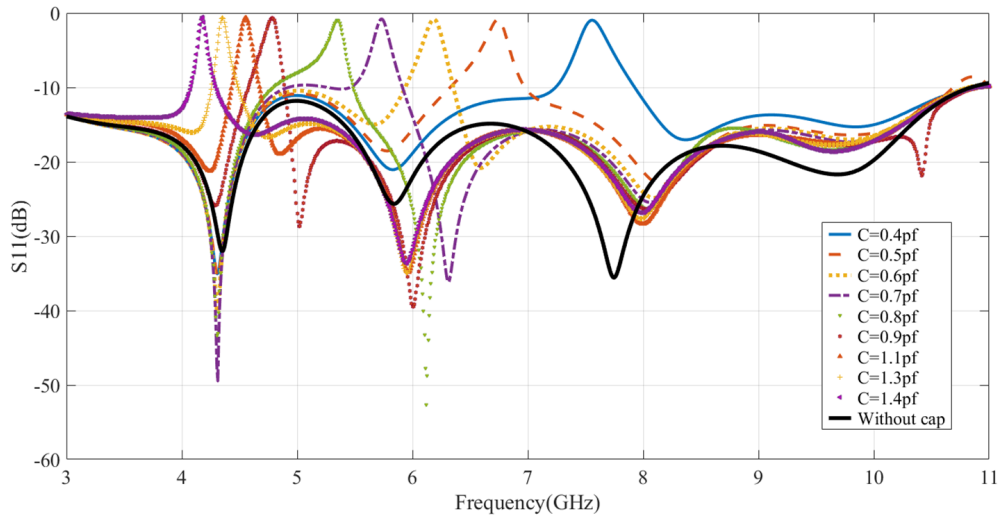


Figure 5.  $S_{11}$  characteristics of the proposed antenna for different capacitance values in position three.

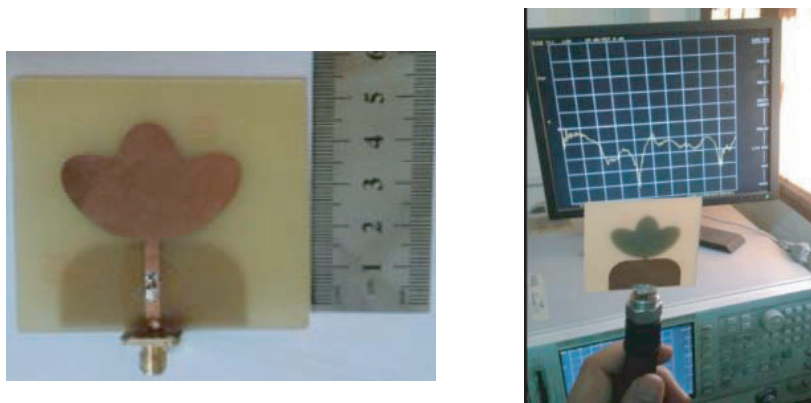


Figure 6. Photograph of the fabricated prototype antenna.

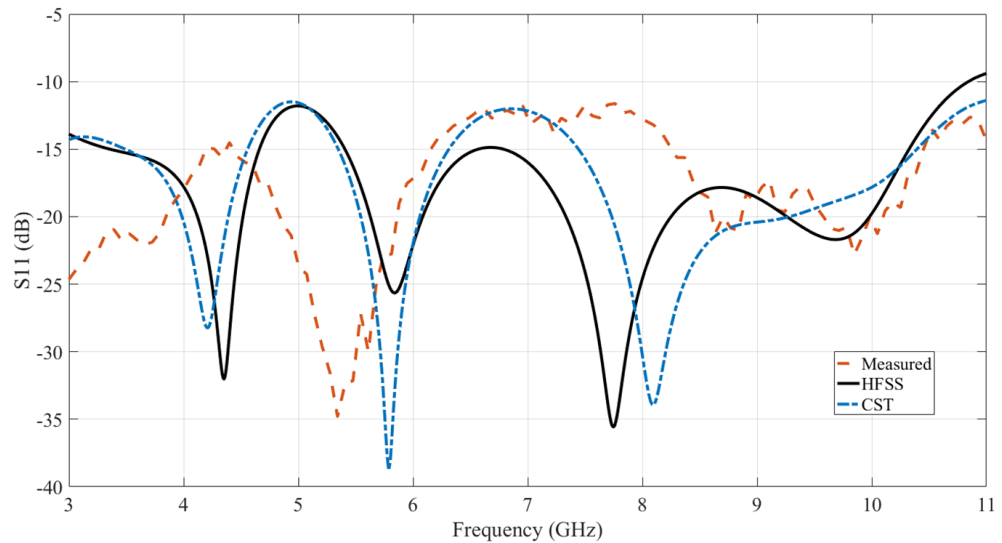
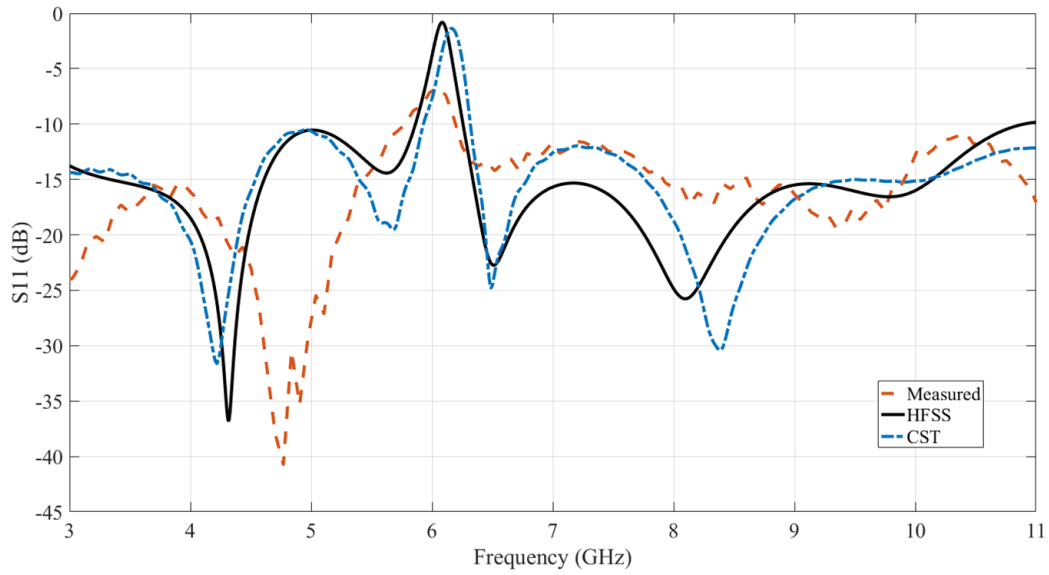


Figure 7. Simulated and measured return losses of proposed antenna without any capacitor.

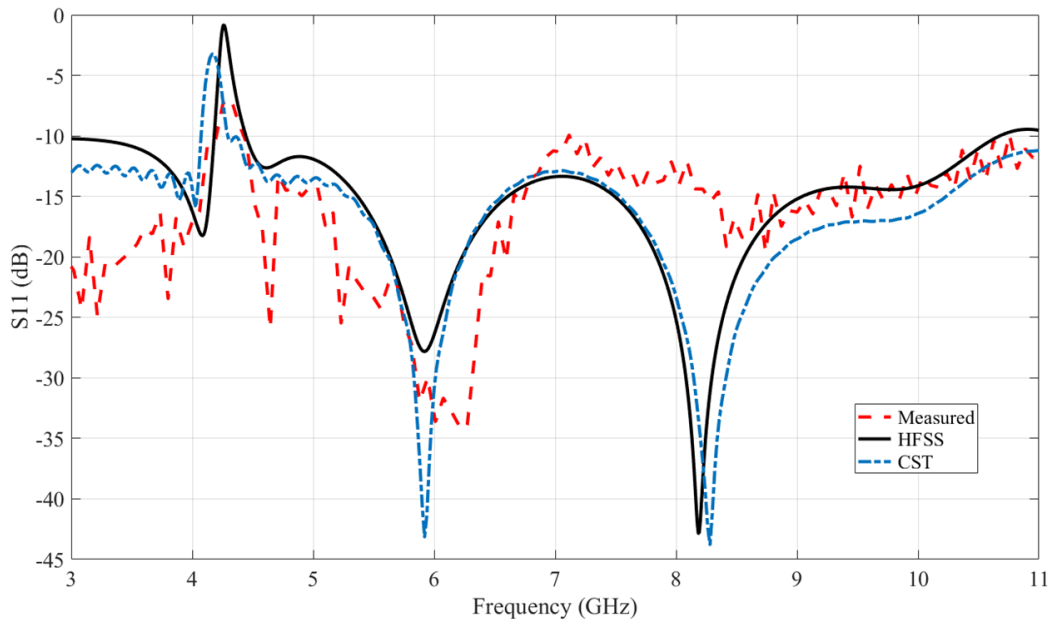
### 3.2. Measured Results

A prototype of the proposed antenna is fabricated using two different single capacitor elements instead of using a varactor diode because it is not available in our laboratory. The reflection coefficients of the proposed antenna with and without the capacitor are measured in the Electronics Research Institute in Egypt. Figure 6 shows photographs of the fabricated antenna loaded by a single capacitor. Figures 7–9 show the comparison between measured and simulated  $S_{11}$  results for the antenna without and with a single capacitor.

Very good agreement has been obtained between measured and simulated results in the three cases. The fabrication tolerance and/or hand welding inaccuracy causes these discrepancies. It can be

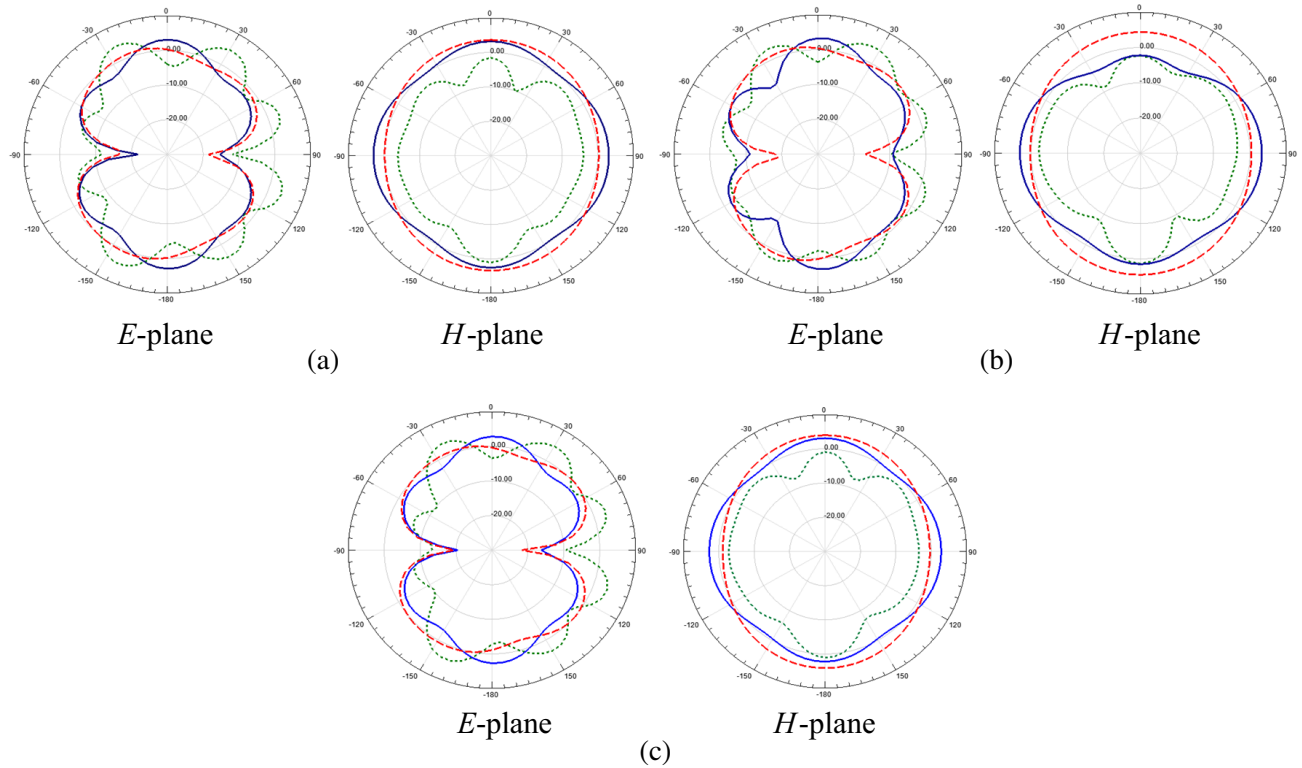


**Figure 8.** Simulated and measured return losses of proposed antenna with  $C = 0.6$  pF.

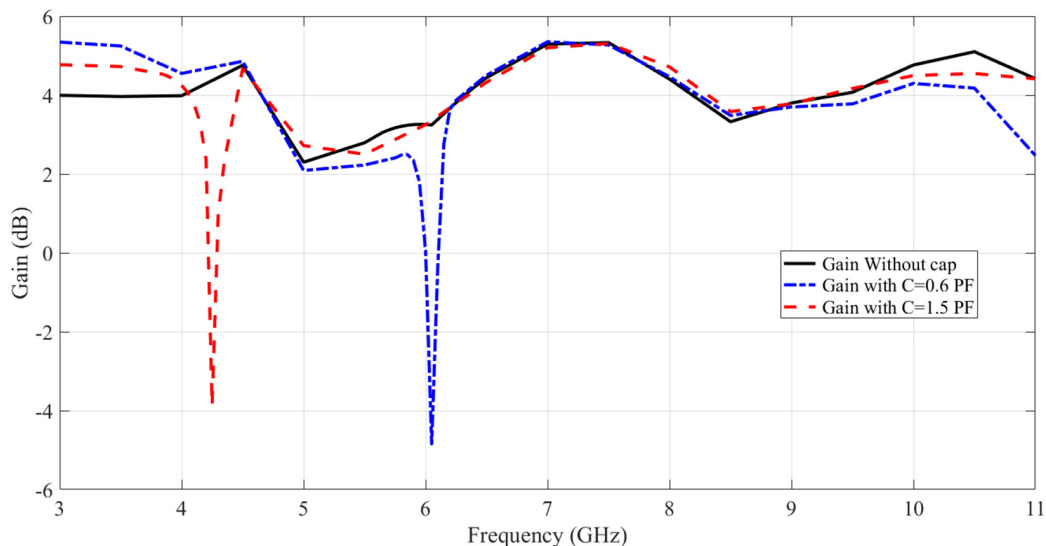


**Figure 9.** Simulated and measured return losses of proposed antenna with  $C = 1.5$  pF.

observed in Figure 7 that the proposed flower-shaped antenna has an UWB performance, covering the entire UWB frequency. As shown in Figure 8, the antenna with a capacitor with  $C = 0.6$  pF, introduces a notch frequency at 6.1 GHz, with a very good agreement with the simulated results. Also, in Figure 9, the antenna with a capacitor with  $C = 1.5$  pF introduces a notch frequency at 4.3 GHz, with a very good agreement with the simulated results.



**Figure 10.** The Radiation patterns of the UWB antenna without and with capacitor elements. (a) Without any capacitors, (b) with  $C = 0.6$  pF, (c) with  $C = 1.5$  pF [4 GHz (Red-long dashes), 6 GHz (Blue-solid), 10 GHz (Green-short dashes)].



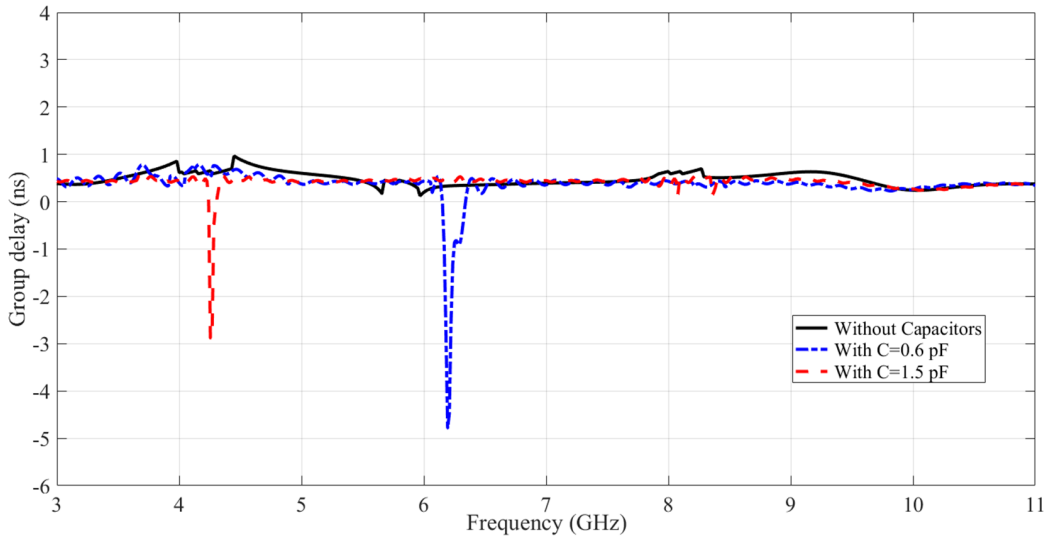
**Figure 11.** The proposed antenna gain versus frequency.



### 3.3. The Radiations Patterns, Gain, and Group Delay

In this section, the radiation patterns, gain, and group delay for the previously stated cases will be achieved. Figure 10 shows the different radiation pattern planes at different frequencies 4, 6, and 10 GHz for the proposed antenna without and with capacitor elements. In all cases, the antenna has a stable radiation across the operating frequency band with a directive radiation pattern in  $E$ -plane and omnidirectional pattern in  $H$ -plane.

The maximum gain for the three proposed cases, without and with capacitor elements, is shown in Figure 11. As shown in the figure, the gain is suppressed in the notched frequencies at 6.1 GHz and 4.3 GHz for the given capacitor values. The group delay is shown in Figure 12. The group delay has very little variations across the operating band within a range of 1 ns, but at the notch frequencies the group delay has very sharp changes.



**Figure 12.** The group delay.

## 4. CONCLUSION

The design of a new simple reconfigurable band-notch flower-shaped microstrip line fed UWB planar monopole antenna loaded with a single varactor diode is designed, tested, and fabricated. The flower shape is first optimized to achieve UWB characteristics. A slot is made and optimized in the microstrip line and loaded by a single varactor diode to achieve tunable notch frequencies. A wide range of notch frequencies can be obtained using this simple configuration, which covers most of the narrow band coexistence systems. The effect of the capacitance value and the position of the varactor diode on the notch frequency are investigated. FEM and FIT are used to simulate the proposed antenna structure using ANSYS HFSS and CST MWS respectively. The notch frequency covers the WLAN band when  $C = 0.8$  pF and covers the WiMAX band when the capacitance is changed to 0.7 pF for the same antenna configuration and varactor position. A prototype of the proposed antenna is fabricated using the available two single capacitor elements of 0.6 pF and 1.5 pF, and the return loss is measured and compared with the simulated ones. Very good agreement between them is obtained, and notch frequencies at 6.1 GHz and 4.3 GHz are obtained, respectively. The proposed antenna yields a directive radiation pattern in the  $E$ -plane and omnidirectional pattern in  $H$ -plane. Also, the gain is suppressed in the notch frequencies. The group delay is nearly stable in the entire UWB with sharp changes at the notch frequencies. The proposed antenna is a suitable candidate for the up-to-date UWB systems.



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