International Journal of Electrical and Computer Engineering (IJECE)
Vol. 9, No. 5, October 2019, pp. 3591~3598
ISSN: 2088-8708, DOI: 10.11591/ijece.v9i5.pp3591-3598

UWB elliptical patch monopole antenna with dual-band notched characteristics

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Article Info

Article history:

Received Dec 28, 2018
Revised Mar 24, 2019
Accepted Apr 3, 2019

Keywords:

Elliptical patch
Dual notch antenna
Single notch antenna
Slot antenna
UWB antenna

ABSTRACT

In this paper, a new approach to the design of an UWB monopole antenna with dual band-notched characteristics is presented. The antenna has the form of an elliptical monopole over a ground plane having an elliptical slot to achieve the UWB. The dual-band notch function is created by inserting a U-shaped and a C-shaped slots on the radiating patch, thus no extra size is needed. The proposed antenna shows a good omnidirectional radiation pattern across the band from 3.2 to more than 14 GHz. The dual band-rejection is for 4.88-5.79GHz centered at 5.4GHz and 7.21-8.46 GHz centered at 7.8 GHz. The antenna prototype using the FR-4 substrate with ε_r=4.3 has a compact size of 25mm×25 mm ×1.45mm. The fabricated prototype showed experimental results comparable to those obtained from the simulations.

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1. INTRODUCTION

The Ultra-WideBand (UWB) technology has become the most promising technology since the Federal Communication Commission approved the 3.1-10.6 GHz band for unlicensed radio frequency applications [1]. To comply with this huge range of frequencies and the need for compact antennas for portable devices, patch antennas have been used in UWB systems due to their favorable features like light-weight, ease of fabrication and low cost. Many shapes of the patch such as circular disks, rings, triangular, and elliptical have been used to increase the bandwidth [2-4]. The antenna ground plane was also modified from the conventional rectangle shape by tapering and notching to offer a solution for better matching across a wider band [2, 5, 6]. However, the need for larger bandwidths and compact antennas is still motivating further research. The radiating patch of the antenna is usually placed above a rectangular ground plane printed on the other side of the substrate. In other designs, the radiating patch was accompanied with a slot in a ground plane covering the whole size of the antenna [7].

Due to the wide frequency range of the UWB systems, they inevitably interfere with the existing narrowband wireless communication systems and the X-band satellite communication systems [8]. Such systems are like the WLAN system operating in the 5.15-5.825 GHz band (IEEE 802.11a), and X-band satellite communication system operating in the 7.2-8.4 GHz band (7.25-7.745 GHz for the uplink and 7.9-8.395 GHz for the downlink). The straightforward solution to mitigate the above interferences is to employ band-reject filters. However, this approach will add extra devices to the system, where the size is very limited as in portable devices. A better alternative is to implement band-notched characteristics in the UWB antenna to mitigate the interference with the mentioned systems [8-10]. Notch loading is a good solution to minimize the interference and enhance the impedance matching and bandwidth [8-13]. However, the added band-notching measures should neither demand further size nor alter the performance of the existing antenna.

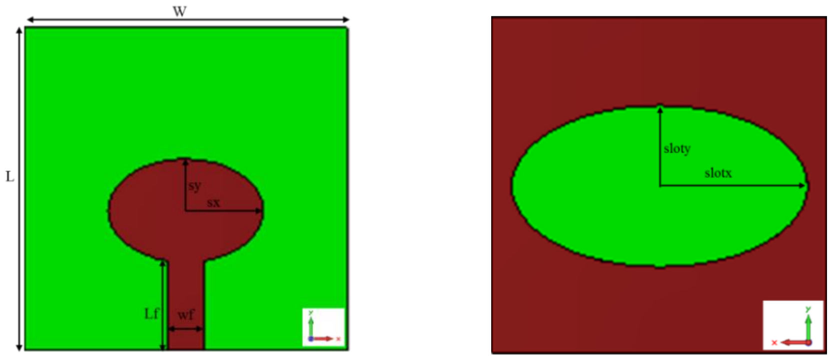
This paper proposes a compact UWB planar printed antenna where the elliptical radiating patch is placed inside an elliptical slot in the ground plane. The dimensions of the two elliptical shapes of the radiating patch and the slot in the ground plane were chosen to offer the capability of increased bandwidth. The antenna has dual notched bands for 4.88-5.79 GHz band (WLAN) and 7.21-8.46GHz band (X-band satellite communication system) to eliminate the interference with these systems. Two slots having C-shape and U-shape etched on the radiating patch, are used to obtain notching at these two frequency bands. The added two slots do not require any extra size as they are embedded in the radiating patch thus offer the required band-notching while keeping the same size of the antenna. The design development of the antenna is explained in section 2, while the test of the fabricated prototype is presented in section 3, and the conclusions are listed in section 4.

2. DESIGN CONCEPTS

2.1. The reference antenna

Figure 1(a) and 1(b) shows the geometry of an elliptical patch of major and minor radii *Sx* and *Sy* respectively that is used as the monopole antenna. This design is called here as the reference antenna that should offer the UWB characteristics as well as adequate gain and will be subjected to the band-notching in the next steps of the design. The rectangular ground plane has an elliptical slot of a major radius of *slotx* and a minor radius of *sloty*. The elliptical shape is used for both the radiating patch and the slot in the ground plane to increase the bandwidth. The antenna is assembled on an FR4 substrate with loss tangent = 0.025 and dielectric constant ε_r=4.3. The dimensions of the substrate are 25×25×1.45mm^3 to achieve a compact antenna. The thickness of the copper material for the patch and the ground plane is 0.035mm. The antenna is fed using a 50Ω microstrip line whose width is calculated using the well-known microstrip line design equations [14]. The width of the microstrip feed line is 2.84mm, and its length is 7mm.

The structure is designed and simulated using the CST microwave studio ver. 15. The proposed antenna is optimized for each design parameter to achieve the required ultra wide bandwidth. In this case, the parameters (*slotx*, *sloty*, *sx*, *sy*) are optimized rigorously. Figure 2 and Figure 3 show the simulation results of the reflection coefficient and realized gain obtained for the reference antenna. As can be seen from these figures, the reference antenna covers UWB starting from 3.204 GHz to 13.423GHz (123% relative bandwidth) with a maximum gain of 4.06dBi.



(a) (b)

Figure 1. The geometry of the reference antenna, (a) Top view, (b) back view with its dimensions

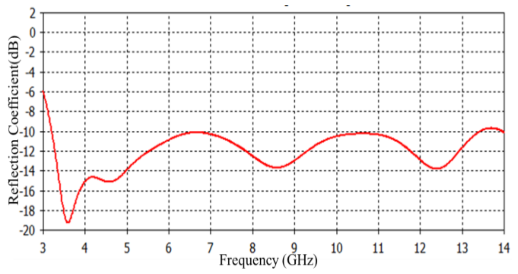


Figure 2. Reflection coefficient versus frequency for the reference antenna

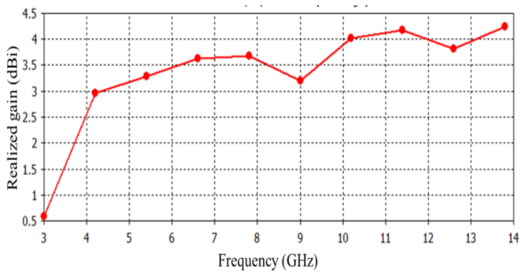


Figure 3. Realized gain versus frequency for the reference antenna

2.2. The single notch antenna

The band-rejection can be achieved by implementing slots of certain lengths in the radiating patch or the feed line [6, 15-20]. In this design, a rotated C-shape slot is etched in the radiating patch as shown in Figure 4. The length of the slot is adjusted to be half the effective wavelength in the slot so that the slot works as a resonator with two short-circuited ends. The resulting antenna is referred to as a single notch antenna, and this is the second step towards the final design. The length of the slot has a great influence on the notched band. The notch frequency is computed using [11]:

$$f_{notch} = \frac{c}{2L_T\sqrt{\varepsilon_{eff}}} \tag{1}$$

where L_T is the total length of the C-shaped slot, $_{eff}$ is the effective dielectric constant as given in [13], and c is the speed of light in free space. As shown in Figure 4 the total length of the C-shaped slot is given by:

$$L_T = a+2e+d \tag{2}$$

where *a* represents the horizontal length of the slot, *e* is the vertical length of the slot and *d* represents the width of the slot. The dimensions of the C-shaped slot (*a, d, e*) are optimized to obtain the correct notched center frequency. It is noted here that the addition of this slot does require any change in the dimensions of the UWB antenna that was designed in section 2.1. Using (1) and (2), the slot dimensions were chozen to obtain a notch at 5.4 GHz as can be seen in Figure 5. The simulations have shown that the above formula gave a very good estimate of the notch frequency, and a more precise value can be tuned with the help of CST simulation.

The optimized performance in terms of the reflection coefficient and gain without a notch and with a single notch is compared in Figure 5 and Figure 6. As seen from both figures, a frequency band along 5.11–6GHz is rejected and the gain at this band is reduced thus the interference at this frequency band is reduced by about 6.5 dB. The gain across the whole band remains almost the same ensuring that the added slot does not alter the desired properties of the reference antenna.

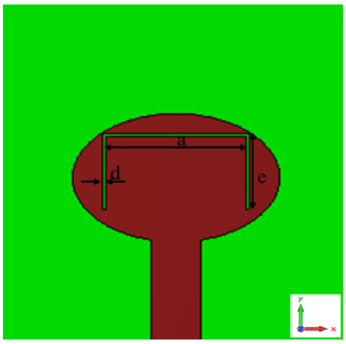


Figure 4. Front view of the single-notch antenna with the slot dimensions

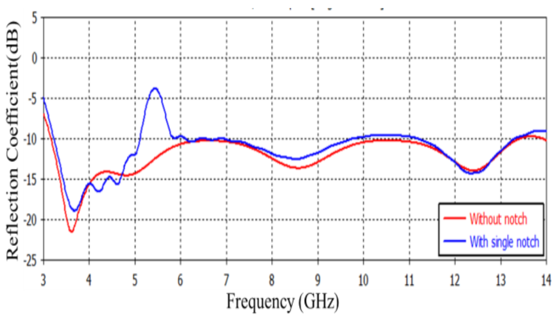


Figure 5. Reflection coefficient versus frequency without a notch and with a single notch

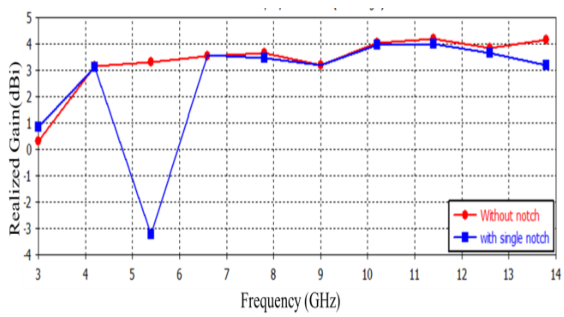


Figure 6. Realized gain versus frequency without a notch and with a single notch

2.3. The dual-notch antenna

The notch characteristic at two bands is also very desirable to reduce the interference from more than a single source. To fulfill this goal a U-shaped slot is cut from the radiating patch of the single-notch antenna, and the resulting antenna is referred to as dual-notch antenna as shown in Figure 7. This is the third and final step of the design. The total length of the U-shaped slot is calculated as:

$$L_T = aa + 2ee + dd \quad (3)$$

where *aa* represents the horizontal length of the slot, *ee* the vertical length of the slot and *dd* represents the width of the slot. Using (1) and (3), the U-shaped slot was designed to exhibit a notch at the frequency of 7.8 GHz.

The optimized performances in terms of the reflection coefficient and gain for the three antennas are compared as shown in Figure 8 and Figure 9 respectively. As it can be seen from Figure 8, the dual frequency bands are rejected, where the first band covers 4.88-5.79 GHz while the second band covers 7.21-8.46 GHz without affecting the first band. It was observed that both notched bands can be independently shifted either to the left or the right using slot lengths variations as per the exact requirement. Figure 9 shows that a minimum gain of -0.488dBi is achieved at the first rejected band of the frequency of 5.4GHz and a minimum gain of 0.769dBi is achieved at the second band of the frequency of 7.8GHz. These gain values represent a reduction of 3.8dB and 3.1dB respectively with respect to the case before introducing the notch characteristics.

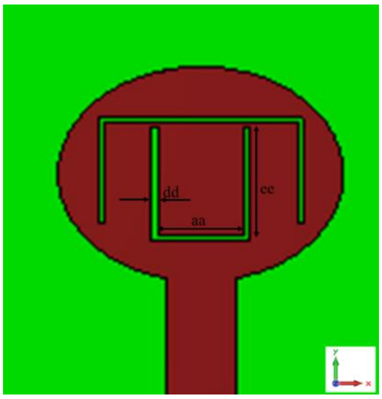


Figure 7. Front view of the dual notch antenna with its dimensions

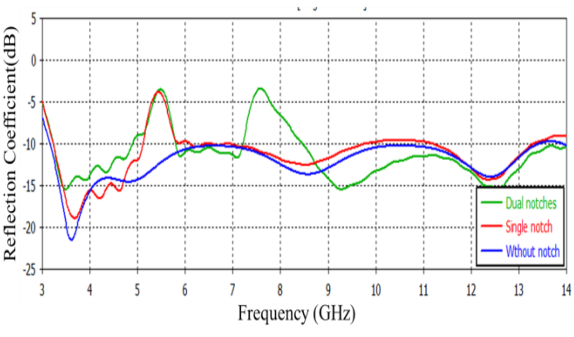


Figure 8. Reflection coefficient versus frequency without a notch, with a single notch and with dual notches

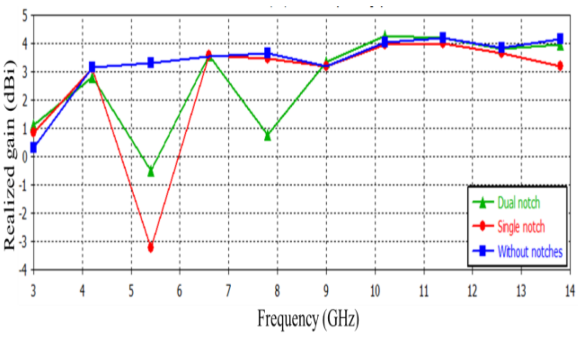


Figure 9. Realized gain versus frequency without a notch, with a single notch, and with dual notches

3. MEASURED RESULTS AND DISCUSSIONS

To validate the proposed design and to evaluate the performance of the dual-notch antenna, the geometry shown in Figure 7 with its optimized dimensions presented in Table 1 was fabricated and tested. A photograph of the fabricated proposed UWB antenna with dual-notch characteristics is shown in Figure 10.

The measured and simulated results of the reflection coefficients for the dual-notched antenna are compared in Figure 11. The fast variations in the measured results are caused by reflections from the connectors of the cables and the measurement environment. The figure shows that both the simulated and measured results are adequately close to verifying the design. The slight differences between measured and simulated values can be attributed to fabrication errors and the measurement environment. Figure 12 shows the simulated and measured realized gain variation with frequency of the proposed antenna. It is noted from the figure that the case with the two-slots added to the antenna, the realized gain at the two notch frequencies has decreased to small values.

Table 1. Optimized dimensions of the proposed UWB antenna with dual-notch characteristics

Parameter	Value(mm)	Parameter	Value(mm)
W	25.0	d	0.2
L	25.0	e	4.2
$slot_x$	11.0	aa	4.0
$slot_y$	6.0	dd	0.25
s_x	5.8	ee	4.8
s_y	4.5	W_f	2.84
a	8.3	L_f	7.0

(a) (b)

Figure 10. Photograph of the fabricated proposed UWB antenna with dual-notch characteristics. (a) Front view, (b) Back view

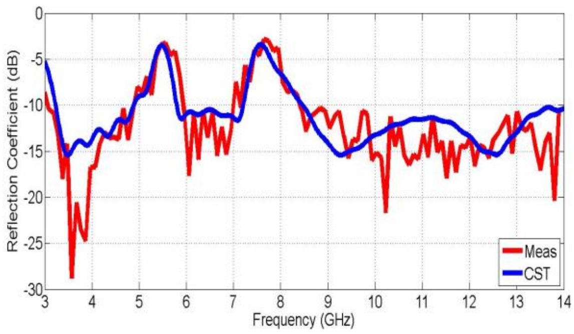


Figure 11. Reflection coefficient comparisons of the measured and simulated proposed UWB dual-band notch antenna

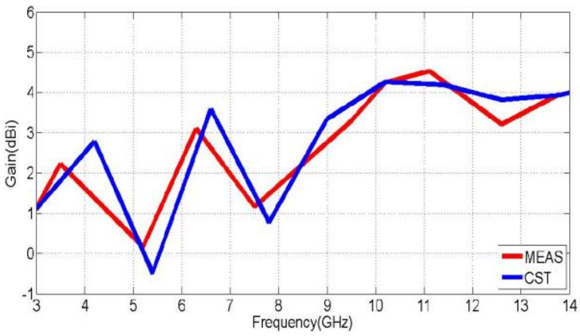
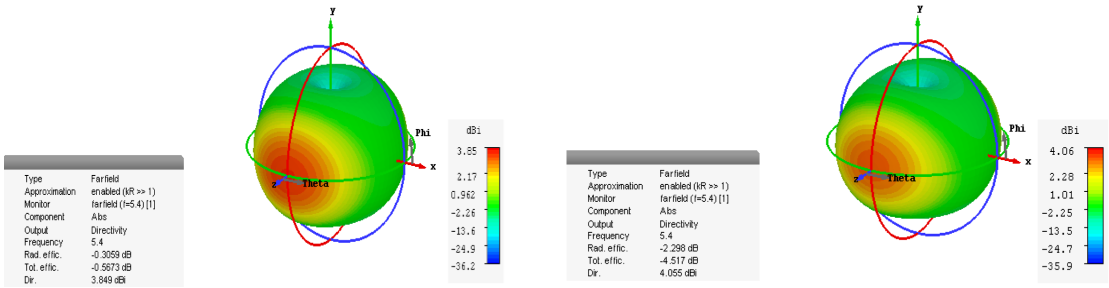


Figure 12: Gain comparisons of the measured and simulated proposed UWB antenna with dual-band notches characteristics

Figure 13 shows the three-dimensional far-field radiation patterns for the proposed antenna with and without notches. It can be seen that the radiation efficiency of the antenna at the first notched frequency of 5.4GHz without notches was -0.3059dB (93.2%) while with the dual notches the radiation efficiency went down to -2.298dB (58.9%). The radiation efficiency at the second notched frequency of 7.8GHz without notches was -0.6351dB (86.4%), while with the notched antenna the radiation efficiency went down to -1.521dB (70.4%).

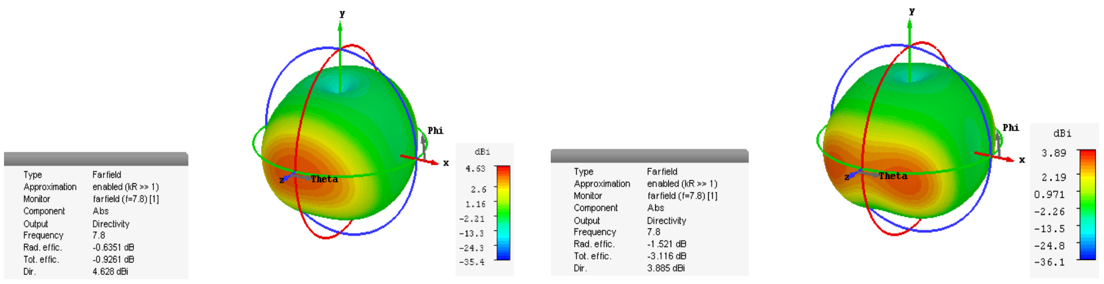
A reduction in the radiation efficiency from 93.2% to 58.9% was achieved in the first band and from 86.4% to 70.4% in the second band. These reductions in the efficiency are accompanied by other reductions of about 4dB and 3dB in the corresponding realized gains as well as an increase in the reflection coefficient at the notched frequencies as shown in Figure 11. These results show that the dual-notch antenna has low values of gain and radiation efficiency as well as larger reflection coefficients at both of the notched frequency bands.

For further assessment of the performance of the proposed antenna, its characteristics are compared with other antennas aimed for the UWB applications as depicted in Table 2. The table shows that the performance of the proposed antenna is very competitive regarding size, operational bandwidth, as well as gain.



Without notch With dual-notch

(a) 5.4GHz



Without notch With dual notches

(b) 7.8GHz

Figure 13. Simulated 3D radiation patterns of the proposed antenna without a notch and with dual notches at (a) 5.4 GHz, (b) 7.8GHz

Table 2. Comparison of performance of the proposed antenna with other designs for the UWB applications

Ref.	Dimensions [mm]	Frequency range [GHz]	% Bandwidth	Number of notches	Gain [dBi]
[1]	26x32x1.6	3.2-10.45	106	one	N.A.
[12]	27x34x0.8	3.1-10.6	109	three	4-5
[13]	26x40x0.8	3.1-10.6	109	three	NA
[15]	24x28x1.6	3.1-10.6	109	one	NA
[16]	15x18x1	3.1-14	127	one	3-5
[18]	28x43x1.6	3.3-10.3	103	one	3-6
[19]	31x31x1.5	3.1-10.6	109	one, and two	N.A.
[20]	15.2x31.4x	3.1-17.2	139	one	about 2.5
This work	25x25x1.45	3.2-14	126	one, and two	3 to 4

4. CONCLUSION

The design and analysis of a proposed UWB antenna covering a frequency range from 3.2 GHz to 14 GHz were demonstrated. Notching at a single band and dual bands were achieved by employing slots of C and

U shapes so that the UWB antenna can reject interfering signal at two designated bands. The notch frequency is controlled by the length of the slot. Fine-tuning of the notch characteristics can be achieved by varying the length and width of the slots. The fabricated prototype was tested and its measured results are compared with those obtained from the simulation. The prototyped antenna model shows excellent dual-band notch characteristics with strong rejection and stable gain in the passband. The simulated and measured results are in good agreement with each other's and give strong motivation that the proposed antenna is a good candidate for eliminating unwanted or disturbing frequency in the desired bands.

ACKNOWLEDGMENT

The authors wish to express sincere appreciation and thanks to the staff of the Communication Laboratory/Electronics and Telecommunication Engineering Department, College of Engineering, Al-Nahrain University, and to Dr. Ghassan/ Electronics and Telecommunication Engineering Department, College of Engineering, Baghdad University for their generous help throughout the testing of the antenna prototype.

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