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Ultra-Wide Band Printed Microstrip Patch Antenna with Two Band Rejection Feature

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Abstract
This work presents a new design idea for a UWB printed micro strip patch antenna with two band-rejection features. The patch has an elliptical shape and its feeding using micro strip feeding line. To achieve the UWB, an elliptical slot was etched on a ground plane. The rejection of two-band is achieved with the addition of two different slots on the radiating patch, the first slot is inverted U shaped slot and the other is U-shaped slot, so there is no need for antenna's additional size. The radiation pattern of the suggested antenna has an omnidirectional shape for the frequency band from $3.168\ GHz$ ***to over*** $15\ GHz$***. There is a two rejection bands, the first one covering*** $4.87-5.79\ GHz$ ***with a center frequency of*** $5.42\ GHz$***, and the other covering*** $7.2-8.45\ GHz$ ***with a center frequency of*** $7.8\ GHz$***. The chosen substrate for the current work is FR-4 having permittivity of*** 4.3 ***and thickness of*** $1.43\ mm$ ***and the suggested antenna has a small size of*** $24.5\times24.5 mm^2$***. The Experimental results of the manufactured antenna showed agreement with those results of the simulated one.***

Keywords
UWB, Single Rejection Band, Two Rejection Bands, Patch Antenna.

I. INTRODUCTION

Ultra-wide band (UWB) antennas are essential components of many systems, including radar systems, electronic warfare, medical imaging, and broadband wireless communications. Among their many appealing advantages is that they frequently just need a basic RF front-end [1,2]. A frequency range of UWB is often quite wide. The specifics, however, are determined by the system specifications and the band's center frequency [2].

Patch antennas, which have the benefits of being lightweight, inexpensive, and easily fabricated, have been used in UWB systems to satisfy the need for small antennas for portable devices. To expand the bandwidth, a variety of patch shapes, including elliptical, triangular, and circular disks, have been employed [3,4]. In order to provide a better matching throughout a larger band, the antenna ground plane was additionally reshaped from its original rectangular shape by tapering and notching [5]. However, more research is currently being driven by the need for wider bandwidths and smaller antennas. Typically, the antenna's radiating patch is positioned above a ground plane that is printed in a rectangle on the substrate's opposite side. Other designs had slots etched in the antenna ground plane and in the radiating patch [6].

Owing to their broad frequency range, UWB systems frequently interact with the X-band satellite systems as well as the current narrow band wireless communication systems [7]. Using band-reject filters is an easy way to reduce the interference mentioned above. But this strategy, nevertheless, will introduce more devices into the system that are relatively small in size as an example portable devices [8].

To reduce interference with aforementioned systems, it is preferable to use band-rejection features in UWB antenna [9]. Notch loading is an effective way to reduce interference and improve impedance matching. Nevertheless, the additional

band-notching techniques shouldn't require the current antenna to be any bigger or function any differently [7].
This work presented a small-size UWB patch antenna with an elliptical radiating patch on the substrate's front side and an ellipse-shaped slot etched on the substrate's back side. The dimensions of both elliptical shape patch and ground plane elliptical slot were selected to provide the possibility for more bandwidth. The proposed antenna includes two rejected bands 4.89–5.79GHz (WLAN) and the 7.2–8.45GHz (X-band satellite system) in order to avoid interfering with these systems. In order to reject these two frequency bands, a radiating patch is etched with two slots, an inverted U shape slot and a U shape slot. Since the extra two slots are integrated into the radiating patch, they provide the necessary band-notching without requiring any additional space, allowing the antenna to remain the same size. Section II. provides an explanation of the antenna's design mythology, Section III. presents the experimental results of the manufactured prototypes, and Section IV. lists the final conclusions.

II. Design Mythology

A. The Fundamental Antenna

The elliptical patch utilized as the active antenna, with major and minor radii of a and b, respectively, is seen in Fig. 1. This design, which will undergo band-notching in later stages of the design process, is referred to as the fundamental antenna and it should provide UWB characteristics in addition to sufficient gain. The ground plane is etched with a slot of elliptical shape with a upper radius slx and lower radius sly. In order to enhance bandwidth, an elliptical shape was chosen for both of patch and ground plane slot. The antenna is mounted on a FR4 substrate with a permittivity of $\varepsilon_r = 4.3$ and thickness of 1.43 mm. The substrate's final dimensions are $24.5 \times 24.5 \times 1.43$ mm^3 to achieve a small antenna. A 50 Ω micro strip line is used to feed the antenna; its width is determined by applying the widely recognized micro strip line design formulae [10]. The micro strip feed line dimensions are 2.82 mm in width and 7.2 mm in length.

The CST microwave studio version 2020 is used to design and simulate the construction of the proposed antenna. For the intended antenna to provide the necessary extremely wide bandwidth, every design parameter has been optimized. The parameters (a, b, slx, sly) are carefully optimized in this instance. The simulation results for the realized gain and reflection coefficient obtained for the fundamental antenna are displayed in Figs. 2 and 3. These figures show that the fundamental antenna has a maximum gain of 4.11 dBi and covering UWB from 3.168 GHz to over 15 GHz, or 131% of the relative bandwidth.

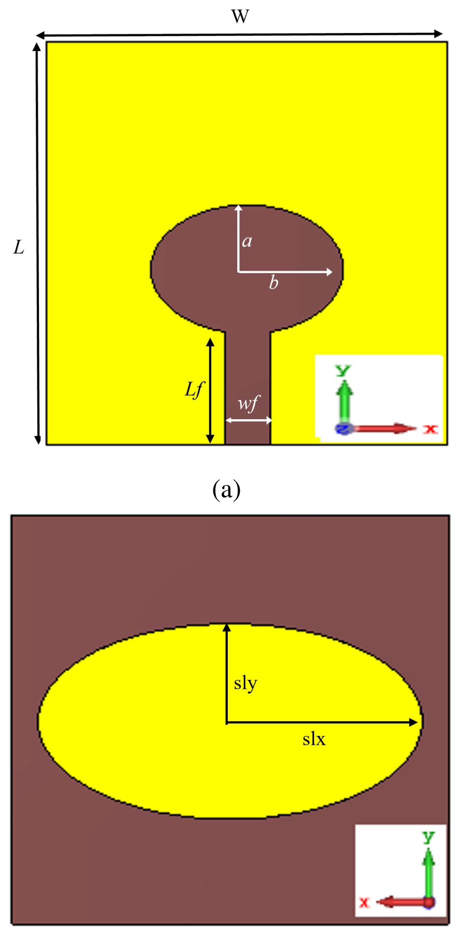


Fig. 1. The proposed fundamental antenna geometry, (a) Front view, (b) Back view.

1) The Single Rejection Band Phase:

By etching slots of a specific length in a radiating patch or in a feed line, a specific band rejection can be accomplished [11–13]. As seen in Fig. 4, this design entails etching an inverted U-shaped slot in the radiating patch. By adjusting the slot's length to half of its effective wavelength, it can be used as a two short-circuited ends resonator. This is the second step of design, and the achieved antenna is called a single rejection band antenna. The rejected band is significantly influenced by the slot's length. To calculate the notch frequency, use [6]:

$$f_{notch} = \frac{c}{2L_{slot}\sqrt{\varepsilon_{eff}}} \quad (1)$$

where c is the speed of light in free space,L_{total} is the inverted U slot total length and $\varepsilon_{eff}$is the effective permittivity.

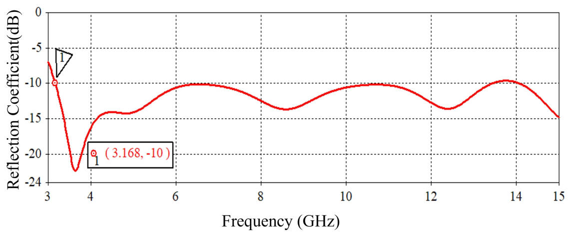


Fig. 2. The fundamental antenna's reflection coefficient fluctuation with frequency

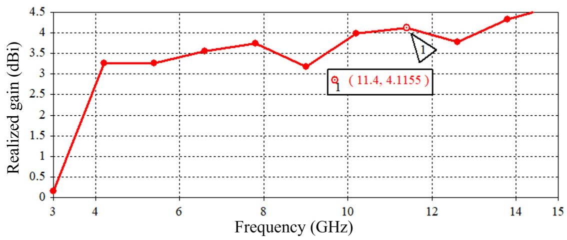


Fig. 3. The fundamental antenna's gain fluctuation with frequency

The following formula yields the whole length of inverted U slot's shown in Fig. 4:

$$L_{total} = d + 2e + f \quad (2)$$

where d, e, and f stand for the horizontal length, vertical length, and the width of the inverted U slot respectively. To attain the accurate notched center frequency, the inverted U slot dimensions (d, e, f) are adjusted and optimized.It should be noted that the designed UWB antenna in section 2.1 need to have its dimensions altered in order to accommodate this slot.

As shown in Fig. 4, the slot size was selected using (1) and (2) to produce a notch at 5.47GHz. The results of the simulations indicate that the notch frequency estimated by the aforementioned method was quite accurate; furthermore, CST simulation can be used to fine-tune this value.

Fig. 5 and Fig. 6 provide a comparison of the optimized performance with and without a notch in terms of the gain and reflection coefficient. Both figures show that a band of frequency from $5.09 - 6.18\ GHz$ is rejected with a decreasing in the gain. The gain stays nearly constant over the whole band, guaranteeing that the additional slot won't change the fundamental antenna's intended characteristics, but it only reduces the gain in the rejoin of rejected band.

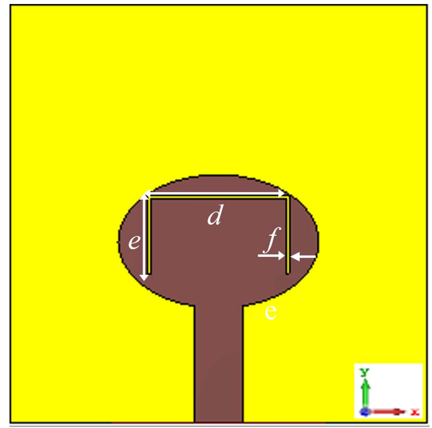


Fig. 4. The single rejection band antenna front view

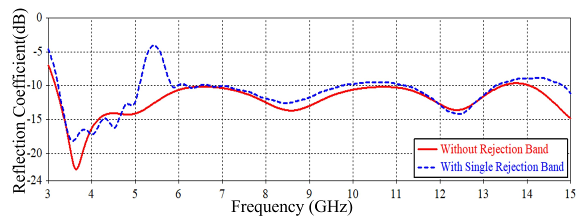


Fig. 5. Variation of reflection coefficient versus frequency for without and with single rejection band cases.

2) The Two-Bands Rejection Phase:

To reduce interference from many sources, it is also highly desirable to have notch features at two bands. In order to achieve this, the single-notch antenna's radiating patch is chopped to create a U-shaped slot; the resultant antenna, as seen in Fig. 7, is called a dual-notch antenna. The design process ends with this phase.

The overall length of the U slot can be computed using the following formula:

$$LL_{total} = dd + 2ee + ff \quad (3)$$

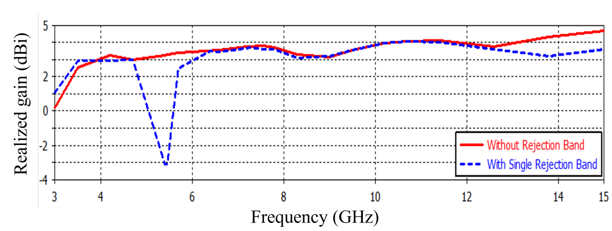


Fig. 6. The variation of realized gain with frequency for without and with single rejection band cases.

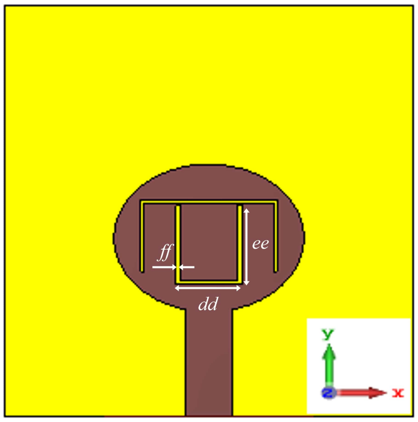


Fig. 7. The dual rejection band antenna front view.

where dd, ee and ff stands for the horizontal length, the vertical length, and the width of the U-shaped slot respectively.

Eq. 1 and Eq. 3 were used to design the U-shaped slot such that it would display a notch at 7.8 GHz.
Figs. 8 and 9, respectively, compare the three antennas optimal performance in terms of gain and reflection coefficient. Fig. 8 illustrates the rejection of the two-bands, the first band covers $4.87 - 5.79$ GHz and the other covers $7.2 - 8.45$ GHz without impacting the first band. It was found that, depending on the precise need, both rejected bands may be independently moved to the right or left utilizing variations in length of slot. According to Fig. 9, the first notched band achieves a minimum gain of -1.72 dBi at frequency of 5.42 GHz, whereas the second notched band achieves a minimum gain of 0.83 dBi at frequency of 7.8 GHz. According to the aforementioned gain values, there was a decrease of 4.97 dB and 2.89 dB, respectively, from the situation before the additions of the notches.

III. Experimental Results

Using the optimized dimensions listed in Table **??**, the antenna geometry depicted in Fig. 7 was manufactured and

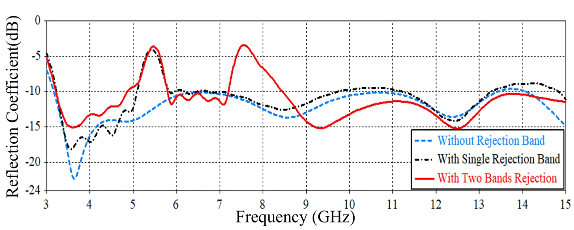


Fig. 8. Variation of reflection coefficient with frequency comparison for without, with a single rejection band and with dual rejection band cases.

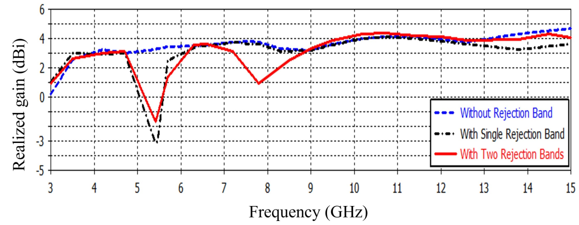


Fig. 9. Comparison of gain variations with frequency for without rejection band, with single rejection band, and with two rejection bands cases.

TABLE I.
The Suggested UWB Antenna's Optimized Dimensions with Dual-Rejection Bands Properties.

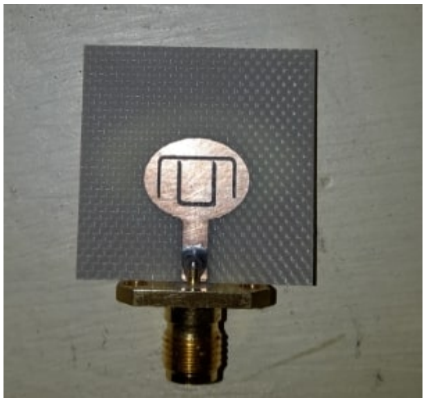
Parameter	Value(mm)	Parameter	value(mm)
L	2.45	e	3.87
W	2.45	f	0.19
slx	10.9	dd	4.3
sly	5.9	ee	3.9
a	4.65	ff	0.22
b	5.4	Lf	6.96
d	7.96	Wf	1.97

tested experimentally to confirm the suggested antenna design and assess the dual rejection antenna functionality. Fig. 10 shows a photo of constructed suggested UWB antenna of dual rejection bands features.

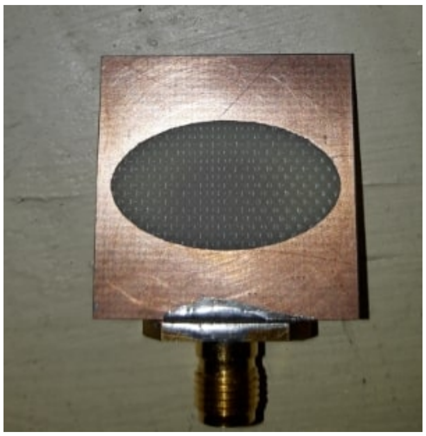
The reflection coefficients simulation and measurement results for the dual-band rejected antennas are compared in Fig. 11. Reflections from the cable connectors and the surrounding measuring environment are the source of the quick fluctuations in the measured results. The figure illustrates how well the measured and simulated outcomes match the design's validation. The little differences between the simulated and measured values can be attributed to both the fabrication errors and the measuring environment.

The gain's simulated and measurement results of the suggested antenna is displayed in Fig. 12. The figure shows that adding two slots to the patch causing decrease in the antenna gain to lower levels at two rejection frequencies.

The 3D radiation patterns of suggested antenna with and without notches are displayed in Figure 13. This figure shows that the radiation efficiency of the antenna decreased to -3.2598 dB at the first notch frequency of5.42 GHz when it had two notches, and to -0.3381 dB when it had none.At the second notch frequency 7.8 GHz, the radiation efficiency was -0.631 dB in the absence of notch, but with the existence of two notches, it dropped to -1.429 dB.



(a)



(b)

Fig. 10. Photo for the manufactured suggested printed patch antenna with two-bands rejection functionality (a) front view and (b)back view.

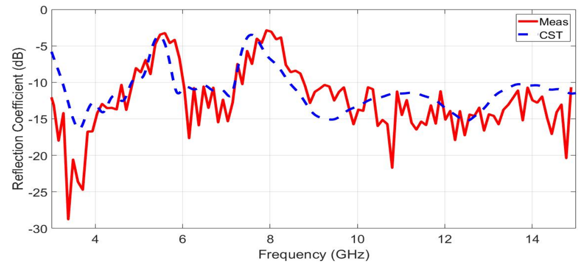


Fig. 11. Comparison of reflection coefficient variations against frequency for simulated and measured suggested UWB antenna with two-bands rejection functionality.

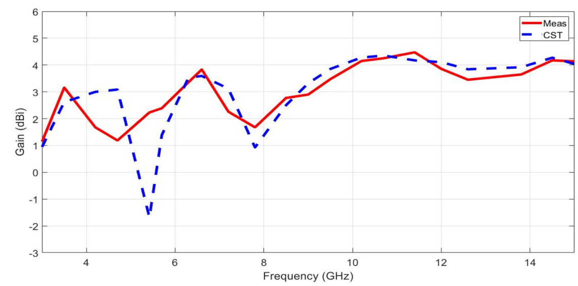


Fig. 12. Performance Comparison of gain variations with frequency for simulated and measured suggested UWB antenna with two-bands rejection functionality.

Together with these decreases in radiation efficiency, the corresponding gains also decrease by around 4.97 *dB* and 2.89 *dB*, and the reflection coefficient increases at the notched frequencies (Fig. 11). These findings demonstrate that for both rejection bands, the dual-rejection band antenna has a larger reflection coefficient, low gain and low radiation efficiency.

To evaluate the performance of the antenna even more, Table 2 compares the attributes of the suggested antenna with those of other antennas intended for UWB applications. The table makes it evident that the suggested antenna's size, gain, and operating bandwidth are competitive.

IV. Conclusion

In this paper a suggested ultra-wide band antenna operating in a range of frequency from 3.168 GHz to over 15 GHz was designed and analyzed. By etching slots with inverted U and U shapes in the patch to achieve single-rejection band and two-rejection bands, the proposed UWB planar printed patch antenna rejects interfering signals at two defined bands. It is possible to adjust the notch characteristics by changing the width and length of the slots. The measured outcomes of the tests conducted on the manufacturing prototype are compared with the simulation's results. The suggested antenna model exhibits excellent two-band rejection characteristics, high rejection and steady passband gain. As a good agreement was yields between the measured and simulated results, so the antenna recommended in this work is an excellent option for removing undesired or bothersome frequencies from the intended bands.

Conflict of Interest

The author has no conflict of relevant interest to this article.

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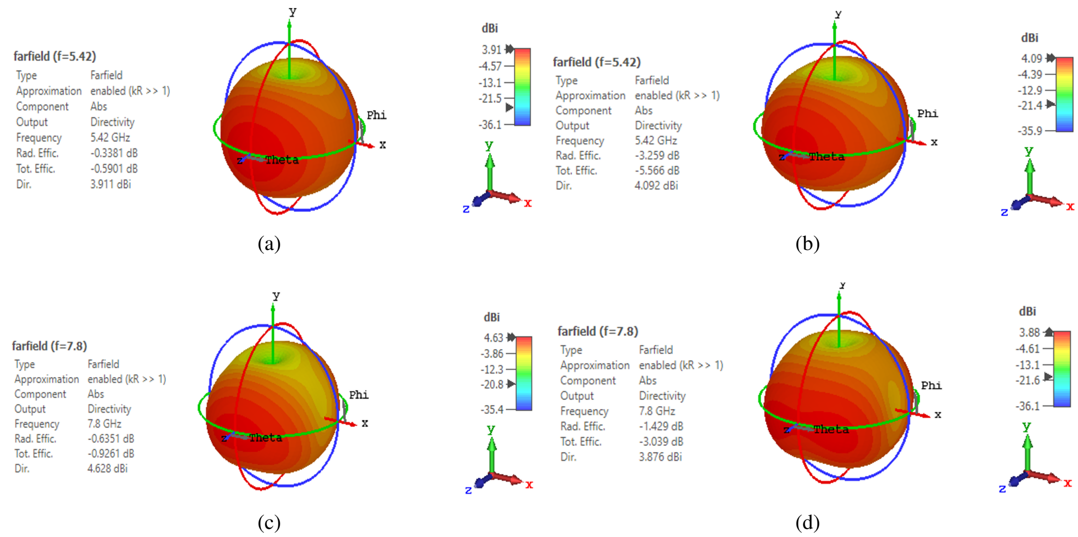

Fig. 13. The simulated 3-dimensional far field radiation patterns for suggested antenna for the cases with two and without notches at (a) Without of notch 5.42 GHz, (b) With two notches 5.42 GHz, (c) Without of notch 7.8 GHz, (b) With two notches 7.8 GHz

TABLE II.
PERFORMANCE COMPARISON FOR DIFFERENT DESIGNS OF UWB APPLICATIONS AND THE SUGGESTED ANTENNA

Reference	Dimension (mm)	FrequencyBand(GHz)	Bandwidth(%)	NotchNumber	Gain (dBi)
[1]	$26 \times 32 \times 1.6$	3.2-10.4	106	One	NA
[11]	$26 \times 40 \times 0.8$	3.1-10.6	109	Three	NA
[9]	$31 \times 31 \times 1.5$	3.1-10.6	109	One or Two	NA
[7]	$15.2 \times 31.4 \times 1.6$	3.1-17.2	139	One	About 2.5
[14]	$24 \times 24 \times 1.6$	3.1-10.6	109	One	NA
[15]	$45 \times 35 \times 0.6$	3.1-10.6	166.19	Three	NA
[16]	$40 \times 40 \times 0.6$	3.2-10.4	109	Two	5.35
[17]	$37.8 \times 27.1 \times 1.6$	3.17-11.61	125	Two	NA
[This work]	$24.5 \times 24.5 \times 1.4$	3.16– to over 15	131	One and Two	2.89 and 4.97

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