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A miniaturized Monopole Antenna with Triple-Notch Filters for UWB Applications

***Abstract**. This work focuses on the miniaturized ultra wide-band (UWB) monopole antenna with triple notch filters.(The designing process of the proposed antenna starts from analyzing the circular patch antenna followed by modified slot structures with cutting four triangle shapes at the patch edges. The triple notch filters are designed based on the U-shape resonator placed on the antenna patch to obtain triple-band rejection. The proposed triple-notch filters are located at both sides of the dielectric substrate, meaning that two of them are placed at both sides of the microstrip feed line, and the last notch is arranged at the ground plane of the substrate. The triple U-shaped notch filters exhibited a filtering response covering various frequencies, including WLAN ((5.15 GHz - 5.35 GHz and 5.725 GHz - 5.825 GHz), uplink of X-band satellite communication systems from 7.9 GHz up to 8.4 GHz)*

Streszczenie.** Ta praca koncentruje się na zminiaturyzowanej ultraszerokopasmowej antenie monopolowej (UWB) z potrójnymi filtrami wycinającymi. (Proces projektowania proponowanej anteny rozpoczyna się od analizy okrągłej anteny krosowej, a następnie zmodyfikowanych struktur szczelinowych z wycięciem czterech trójkątnych kształtów na krawędziach plastra. Filtry z potrójnym wycięciem są zaprojektowane w oparciu o rezonator w kształcie litery U umieszczony na plastrze anteny w celu uzyskania potrójnego tłumienia pasma.Proponowane filtry z potrójnym wycięciem znajdują się po obu stronach podłoża dielektrycznego, co oznacza, że dwa z nich są umieszczone po obu stronach po bokach linii zasilania mikropaskowego, a ostatnie wycięcie jest umieszczone na płaszczyźnie uziemienia podłoża. Potrójne filtry wycinające w kształcie litery U wykazywały odpowiedź filtrowania obejmującą różne częstotliwości, w tym WLAN ((5,15 GHz - 5,35 GHz i 5,725 GHz - 5,825 GHz), uplink systemów komunikacji satelitarnej w paśmie X od 7,9 GHz do 8,4 GHz)* (Zminiaturyzowana antena jednobiegunowa z potrójnymi filtrami do zastosowań UWB)***

Keywords: ultra wide-band (UWB), monopole antenna, band notched filter, WLAN
Słowa kluczowe: antena UWB, antena kjednobiegunowa

Introduction

The Federal Communication Commission certified the used of ultra wide-band (UWB) that covers from 3.1 GHz to 10.6 GHz. Starting in 2012, the UWB antenna has a high attention from the research because of its potential for future very high data rates over short-range wireless communication systems applications [1-7]. Monopole type antennas are one of the extensive antenna in UWB technology because of its wide frequency bandwidth effect [8], omnidirectional radiation [9], and low in cost.

However, UWB technology is facing interference problem with other narrowband systems. These UWB antennas are important for the provision of wireless wideband communications based on the use of very narrow nanosecond pulses, covering a very wide bandwidth in the frequency domain and at very low power densities over very short distances.

Consequently, to eliminate interfering signals and decrease potential interference, it is beneficial to incorporate a band stop filter into the UWB system. In addition, it increases loss, complexity, cost and weight by incorporating a band stop filter into the UWB system [10]. A small UWB antenna with numerous notched bands is therefore needed, for which several approaches have been proposed and shown. The example of the filtering UWB antenna with three band rejection that using for 3.5 GHz (WiMAX), 5.8 GHz (WLAN) and 8.4 GHz (X-Band) by Pate [11]. Li, in his paper also create a designed MIMO antenna that covers frequency band starting from 2.9 GHz to 11.6 GHz with two notched bands covering 5.3 GHz to 5.8 GHz and at 7.85 GHz - 8.55 GHz [12].

Wang in his paper introduce the UWB antenna integrated with triple-notch filter based on SRSSLR structure that provides triple notched-bands [13]. The other work on UWB with band rejection is shown in several techniques such as using Rectangular Split loop resonator (RSLR) [14], metamaterial resonator [15], plus shape radiating patch [13] and circular monopole antenna with fractal slots [16].

The microwave antenna and filters are therefore desirable to be combined into a single component where the antenna offers radiating function and the band stop filter provides band rejection to filter out unwanted signals. Different band rejected structure techniques have been recently published, but the most common structure is the technique of microstrip structure. In [17], U-shaped slots notch filter are design by using the below equation:

$$x_2 + 2y_2 - 2t_2 \approx L_2 = \frac{\lambda_g}{2} \quad (1)$$

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

λ_g is the guided wavelength of the desired notch frequency, L_2 is the approximated length of the U-shaped slot. Three U-shaped slots are designed and located on the antenna to act as triple band rejection. The design then is optimizing by using parametric study to increase the performance of filtering antenna. The band rejection structures on the ground plane and radiation patch influence the radiation characteristics. Therefore, in this research U-shaped notch filter are avoiding that area.

In this paper, the miniaturized size of ultra wide-band (UWB) monopole antenna with three notch filters are designed. The modified monopole antenna is designed and applied using microstrip transformation and cutting shape s on each side of the monopole shaped antenna, which has a miniaturized design, large impedance bandwidth with high frequency skirt selectivity, high gain and omnidirectional radiation pattern, making it suitable for UWB applications. Three different location U-shaped slots are added into the microstrip antenna to give the triple-band rejection effect.

Research Method

The work begins with the simulation of basic antenna designs and followed by the improvement development stage of antenna design using CST Microwave Studio's software simulation. In the production laboratory, until the fabrication can be carried out. Then, the antenna and rectifying circuit combination is performed. Optimizing the fundamental development of parameters for the antenna such as return loss (S11), resonant frequency, bandwidth, surface current, Voltage standing wave ratio (VSWR) and antenna gain can be done in simulation work.

From the basic rectangular monopole antenna, a rectangle has four identical corners that have single degree of freedom controlled of 90^0 with similar two dimensions are joined to each other by these corners. From the basic structure, it goes to the next monopole antenna. Fig. 1 describe the schematic diagram of development for proposed monopole antenna. It started with three variation of basic circular monopole antenna (Antenna *A1*), followed by circular monopole with feedline modification (Antenna *A2*) and last is circular monopole antenna with cutting corner circular modification (Antenna *A3*). The proposed compact monopole size of 26 mm width x 40 mm length of substrates antennas. The antenna is design using the Roger Duroid 5880 with thickness of 0.787 mm while it has dielectric constant of 2.2. Then, it shows that also the thickness of the copper is 0.0175 mm.

Fig. 1(a) shows the basic circular monopole antenna structure. It contains a circular shaped that linked with the feedline and have a ground plane at the backside of the antenna. The radius of the antenna is 7.9 mm while the feedline is 17.9 mm length. At other side, the ground Figure 2(a) introduced a U-shaped element at the left part of the feedline while Figure 2(b) has moved its U-shaped element at the right location of the feedline. The last configuration is done by located the U-shaped structure at the upper part on the ground plane at the back side of the antenna. This U-shaped element has a capability to create a notch or a band rejection frequency for the proposed filtering antenna. The plane of copper is made of by 26 mm width x 18 mm length.

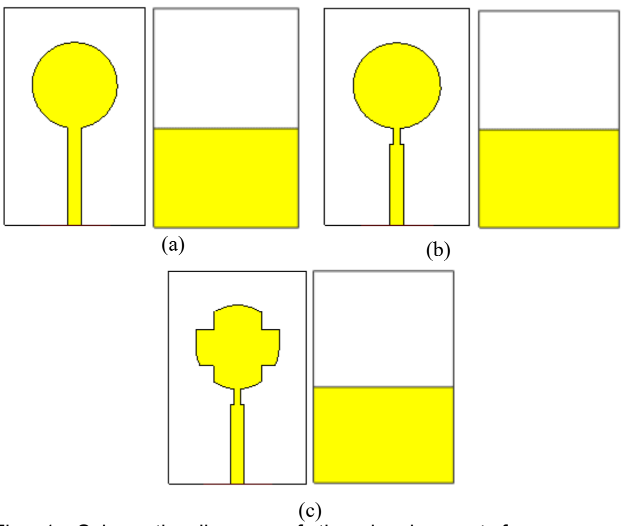


Fig. 1. Schematic diagram of the development for proposed monopole antenna (a) Antenna *A1* (b) Antenna *A2*, (c), Antenna *A3*

Then, the simple microstrip conversion feedline in Fig. 1(b) is done to increase the performance of several parameter of return loss, gain and bandwidth extension. In this case a 2.82 mm of length with only 1.14 mm of the width is modified at the upper part of the feedline. This adjustment of the usual circular antenna is referring on this paper of [18-20]. Besides that, based on the previous literature review from these papers [20-26], the impedance bandwidth can be enhanced by modification of the ordinary circular shaped. For the next step in Figure 1(c), the similar cutting size of four blocks with triangle shape slots on each side of the circular shaped antenna with feedline modification is done to increasing gain efficiency performance.

Fig. 2 represent the schematic diagram of monopole antenna with U-shaped element. It has three different configurations that has a different location of U-shaped element attached. Fig. 2(a) introduced a U-shaped element at the left part of the feedline while Fig. 2(b) has moved its U-shaped element at the right location of the feedline. The last configuration is done by located the U-shaped structure at the upper part than the ground plane at the back side of the antenna. This U-shaped element has a capability to create a notch or a band rejection frequency for the proposed filtering antenna.

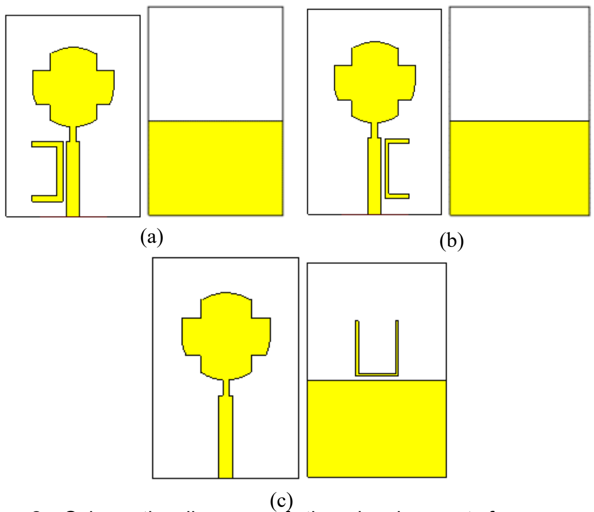


Fig. 2. Schematic diagram of the development for proposed monopole antenna with U-shaped element (a) Antenna *B1* (b) Antenna *B2*, (c), Antenna *B3*

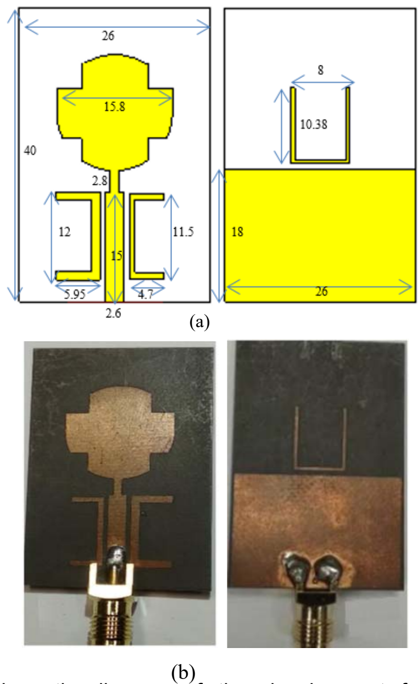


Fig. 3. Schematic diagram of the development for proposed monopole antenna of Antenna *C1* with combined three U-shaped elements, (a) simulation, (b) fabricated

Next, it goes to the last design stages of the proposed antenna. Fig. 3 represents the schematic diagram of the development for proposed monopole antenna with combined three U-shaped elements, Antenna *C1.*

In Fig. 3(a), all three U-shaped elements are combined in a single monopole antenna at this stage to perform a triple-band notched antenna. From the study, each band notched element can perform operation separately and can be tuned independently. This UWB filtering-antenna is principally created by using a rejected band technique in the design of the antenna, where the antenna offers radiating purpose and the rejected band technique provides band notch features to reject undesirable signals. The width and length dimension of U-shaped element is not same among others. This is because to adjust the right frequency band rejection point. Fig.3(b) shows the fabricated version of the proposed antenna.

Results

This section discusses on the several parameter performance of the proposed antenna. Fig. 4 shows the return loss of the proposed antenna of Antenna of Antenna *A1,* Antenna *A2* and Antenna *A3.* From the graph, it shows that the bandwidth can be increase the return loss to by apply the feedline modification and with cutting corner modification technique. It shows that the maximum return loss value of - 14.86 dB, - 36.01 dB, - 38.03 dB at 9.61 GHz,7.22 GHz and 3.64 GHz for Antenna *A1*, Antenna *A2* and Antenna *A3*, respectively. It also shows the increasing of the bandwidth of Antenna *B2* compare of Antenna *A1*. Table 1: Parameter performance for the proposed monopole antenna of Antenna *A1*, Antenna *A2* and Antenna *A3*

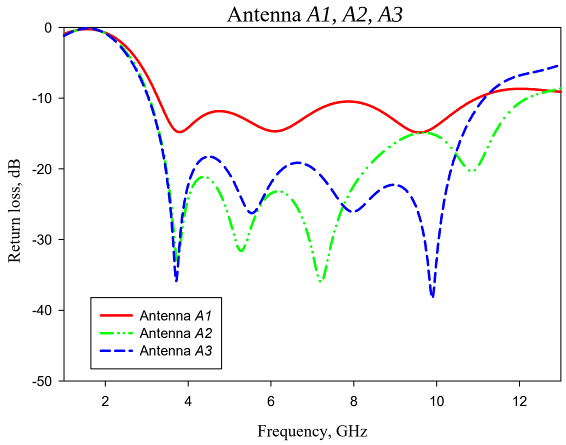


Fig. 4. Return loss of the for the proposed monopole antenna of Antenna *A1,* Antenna *A2* and Antenna *A3*

Table 1: Parameter performance for the proposed monopole antenna of Antenna *A1*, Antenna *A2* and Antenna *A3*

Antenna	Frequency range	Bandwidth	Maximum retuen loss, frequency
A1	3.28 – 10.99	7.71	- 14.87, 9.58
A2	3.06 – 12.22	9.16	- 36.01, 7.22
A3	3.02 – 11.19	8.17	- 38.03, 3.64

Fig. 5 represent the return loss of the for the proposed monopole antenna of Antenna *B1*, Antenna *B2* and Antenna *B3*. From the graph, it shows that the addition of the U-shaped element successfully acts as the band notch rejection. Different location such as left side, right side and back side of U-shaped elements provides a different band notch rejection frequency such as at 5.24 GHz, 5.84 GHz, 8.11 GHz, respectively.

Fig. 6 compare the return loss of the for the proposed monopole antenna of Antenna *C1* (simulation and measurement). Based on the graph, it shows both have a three band notches at nearly same point location. For simulation it achieved at 5.15 GHz – 5.31 GHz, 5.79 – 5.97 GHz and 7.91 GHz – 8.34 GHz compare with 5.21 – 5.54 GHz, 5.84 GHz – 6.07 GHz and 7.55 GHz – 8.29 GHz. Table 2 represents the parameter performance for the proposed monopole antenna of Antenna *A1*, Antenna *A2* and Antenna *A3*.

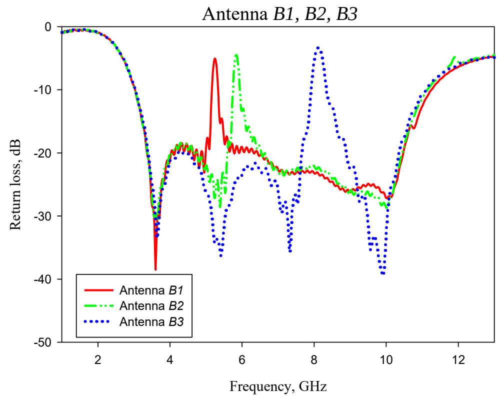


Fig. 5. Return loss of the for the proposed monopole antenna of Antenna *B1,* Antenna *B2* and Antenna *B3*

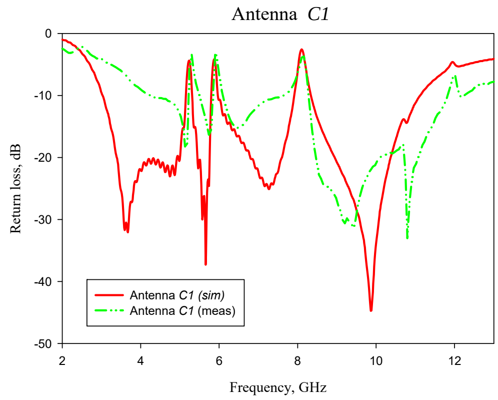


Fig. 6. Return loss of the for the proposed monopole antenna of Antenna *C1* (simulation vs measurement)

Table 2: Parameter performance for the proposed monopole antenna

Antenna	Frequency range (GHz)	Bandwidth (GHz)	return loss (dB), frequency (GHz)	Band rejection (GHz)
B1	3.28 – 10.99	7.71	- 14.87, 9.58	5.16 – 5.33
B2	3.06 – 12.22	9.16	- 36.01, 7.22	5.74 – 5.93
B3	3.02 – 11.19	8.17	- 38.03, 3.64	7.91 – 8.34
C1 (sim)	3.03 – 11.12	8.09	- 44.73, 9.87	5.15 – 5.31, 5.79 – 5.97, 7.91 - 8.34
C1 (meas)	4.43 – 11.83	7.40	- 33.94, 10.79	5.21 – 5.54, 5.84 – 6.07, 7.55 – 8.29

In order to test the impedance matching of the proposed monopole antenna design along with the UWB bandwidth, the voltage standing wave ratio (VSWR) simulation for Fig. 7 and Fig. 8 was carried out. Basically, in this graph shows the acceptable value of VSWR in the UWB range effect by the monopole antenna without a U-shaped element structure. Fig. 6 display the VSWR of the for the proposed monopole antenna of Antenna *A1*, Antenna *A2* and Antenna *A3.*

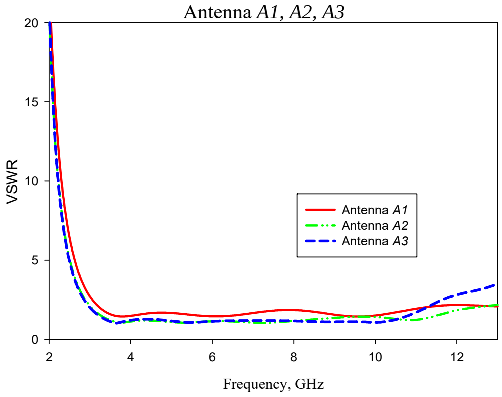


Fig. 7. VSWR of the for the proposed monopole antenna of Antenna *A1,* Antenna *A2* and Antenna *A3*

Next, it goes to the Fig. 8 that represents the VSWR of the for the proposed monopole antenna of Antenna *B1*, Antenna *B2* and Antenna *B3*. In this graph, the proposed monopole antenna of Antenna *B1*, Antenna *B2* and Antenna *B3* is done with at frequency of 5.25 GHz, 5.84 GHz and 8.12 GHz with VSWR value of 3.52, 3.93 5.29, respectively. For Antenna *C1*, it has spike at three different locations at 5.24 GHz, 5.87 GHz and 8.12 GHz with VSWR value of 4.05, 4.27 and 6.78, respectively.

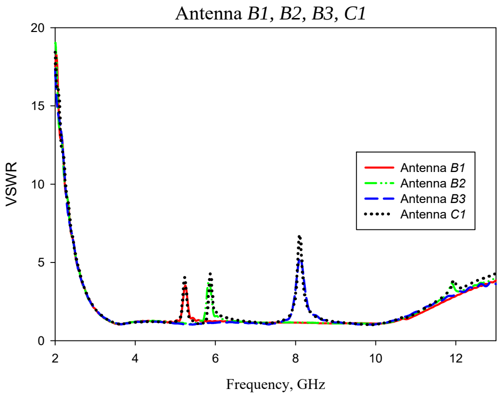
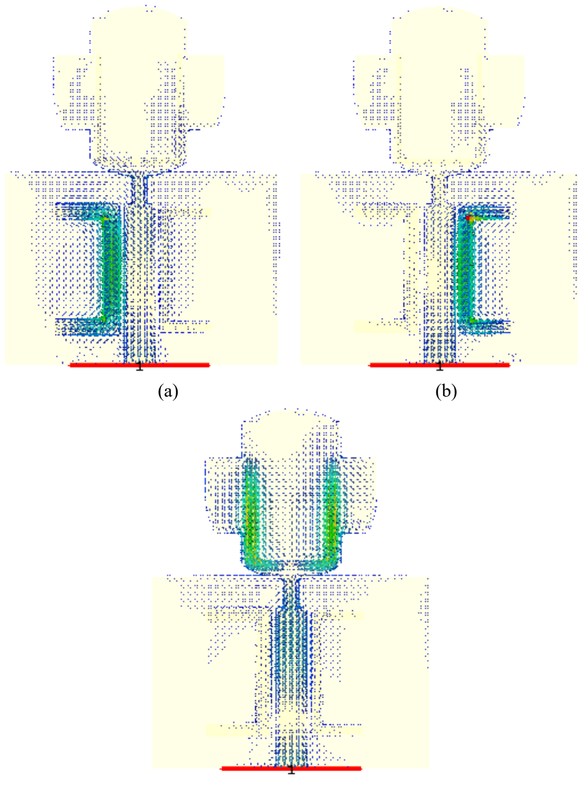


Fig. 8. VSWR of the for the proposed monopole antenna of Antenna *B1,* Antenna *B2,* Antenna *B3* and Antenna *C1*

Fig. 9 shows the simulated surface current distribution of proposed UWB antenna at three different point of 5.2 GHz, 5.8 GHz and 8.0 GHz Base on the observation, it can conclude that the currents are focused in the notch band, primarily over the corresponding U-shaped slot. The current is resonating on the left side of the feedline at 5.2 GHz, right side of the feedline at 5.8 GHz while on the back side of the monopole antenna part and above the field for 8 GHz. So, it can be said that the U shaped slots at three different spot on the antenna can offer three different notch bands at WLAN (downlink), WLAN (uplink) and X band (uplink), respectively.

Conclusion

In this work, the monopole UWB antenna with three notch filters is proposed that effect by three different location of U-shaped elements. It is satisfying the – 10 dB return loss requirement in frequency in the frequency 3.03 – 11.12 GHz, with rejecting the band notched performance in the frequency bands of 5.2 GHz, 5.2 GHz and 8.0 GHz.



(a) (b)

(c)

Fig. 9. Simulated surface current distribution of proposed UWB antenna of Antenna *C1* at (a) 5.2 GHz, (b) 5.8 GHz and (c) 8.0 GHz

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