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Integrated Filtering Antenna with High Selectivity Band Rejection for UWB Applications

***Abstract**. In this paper, a new design composed of an UWB monopole antenna integrated with bandstop filter (BSF) has been proposed. The bandstop filter is constructed by using a defected microstrip structure (DMS). The proposed design covers frequency bandwidth from 3 GHz to 14 GHz (129.5%), with single band rejection from 5.1 GHz to 5.8 GHz (12.8%). The new integration of filter and antenna shows a high level of rejection, wide impedance bandwidth, realized peak gain of 5.23 dB and stable omnidirectional azimuth pattern. Therefore, the proposed design is suitable to be used in reducing the possible interference problem for the UWB applications.*

Streszczenie.** W artykule opisano projekt anteny UWB ze zintegrowanym filtrem. Filtr został wykonany z wykorzystaniem struktury mikropaska . Antena umożliwia wykrywanie sygnałów w paśmie 3 – 14 GHz z możliwością usuwania pasma 5.1 – 5.8 GHz. Umożliwia to rozwiazywanie problemu interferencji fal. **Antena UWB ze zintegrowanym filtrem do selektywnego usuwania wybranego pasma.

Keywords: Bandstop filter, defected microstrip structure, filtering-antenna, ultra-wideband (UWB).
Słowa kluczowe: antenna UWB, filtr pasmowy.

Introduction

Nowadays, ultra-wideband (UWB) technology received a major boost for use in several present and future applications that required transmitting and receiving data with very high data rates over short-range wireless communication systems using the existing communication standards. One of the problems that the UWB technology is facing the interference with other narrow band technologies (e.g., WLAN, HIPERLAN) operating in a frequency band occupied by the UWB bandwidth. Therefore, in order to overcome this problem band rejected technique is used to remove undesired signals and reduce the possible interference. Currently, most research improvements trend towards miniaturization and simplicity, thus it is great interest to combine a microwave antenna and filter into a single device that provides radiating and filtering functions at the same time, known as filtering antenna or filtenna.

There is a growing interest to achieve filtering and radiating functions within a single design. Therefore, many different methods and techniques were proposed to provide radiating and filtering functions within a single component. Various researchers achieved filtering function by using the band rejected technique in order to produce notched characteristics. Defected microstrip structure (DMS) is considered as one of these techniques. The DMS is implemented by inserting a slot structure in the microstrip feed line in order to produce the band rejection [1-3]. The conventional methods include inserting a slot structure on the radiation patch of the antenna design [4]. However, the structure of the produced notch on the radiation patch influences the radiation characteristics. Moreover, band rejection characteristics can be generated by integrating straight open stub in the feed line [5]. However, the disadvantage of this technique is the wide band rejection which leads to reject frequencies out of the desired range.

In this paper, a single band-notched filtering-antenna for UWB applications has been designed and simulated. In order to provide high level of rejection and stable omnidirectional azimuth pattern the single notched band is realized by using a DMS etched on the feed line of an optimized UWB monopole antenna design. The created band notch is controlled by adjusting the parameters of the DMS. Table 1 shows some of the recent published topologies in comparison to the proposed design. It can be seen that the proposed design provides wider impedance bandwidth and greater gain than those reported topologies.

Table 1: Some of the recent published topologies in comparison to the proposed design

Ref	Bandwidth (GHz)	Peak Gain	Size (mm^2)
[1]	5-10	4.72 dBi	38×44
[2]	2.5 -11	1.51dB	60×50
[3]	2.5 - 12	4.4 dB	40×40
[4]	3.07-10.9	4.13 dB	52×28
[5]	2.91-10.46	4dB	40×30
Proposed	3-14	5.23 dB	40×30

UWB Antenna Design

The printed monopole antennas are fit for UWB applications due to their attractive features such as low profile, ease of fabrication, omnidirectional radiation pattern and wide frequency bandwidth which is sufficient for many applications, printed monopole antennas are currently under consideration for use in UWB systems [6].

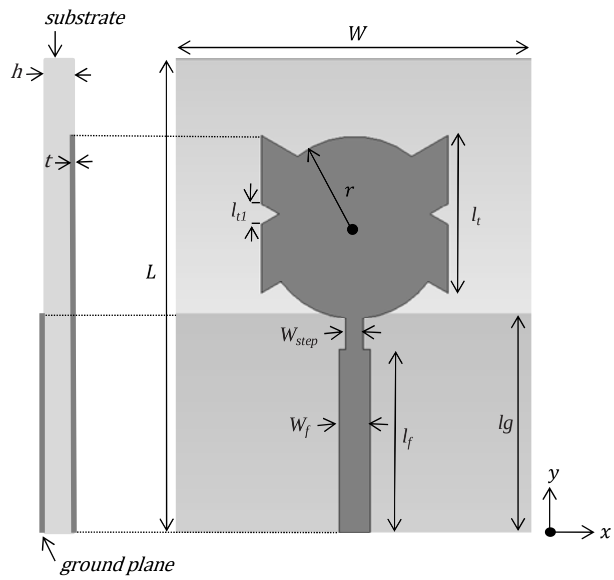


Fig.1. Structure of the proposed UWB monopole antenna with dimensions of W=30mm, L=40mm, r=7.7mm, l_f=15.5mm, l_g=18.3mm, w_{step}=1.5mm, w_f=2.6mm, l_t=15.4mm, l_{t1}=2mm, h=0.787mm, t=0.0175mm

An optimized monopole antenna is designed and simulated as illustrated in Fig. 1. The proposed antenna provides ultra-wideband response from 3 to 14 GHz as shown in Fig. 2. The proposed antenna is simulated in CST using Roger RT/Duroid 5880 substrate with a relative permittivity of ε_r = 2.2 mm and thickness of h=0.787 mm. A circular disc monopole with a radius of r = 7.7 mm and a 50 ohm microstrip feed line are printed on the same side of the dielectric substrate. L = 40 mm and W = 30 mm denote the length and the width of the dielectric substrate, respectively.

The width of the microstrip feed line, which has the stepped feed line width W_{step} = 1.5 mm, and feed line width W_f = 2.6 mm to achieve 50 ohm impedance. On the other side of the substrate, the conducting ground plane with a length of l_g = 18.3 mm only covers the section of the microstrip feed line. A block with triangular-shape slot is placed on both sides of the circular patch to improve the return loss of the antenna. The block has dimensions of 15.4 x 4 mm^2.

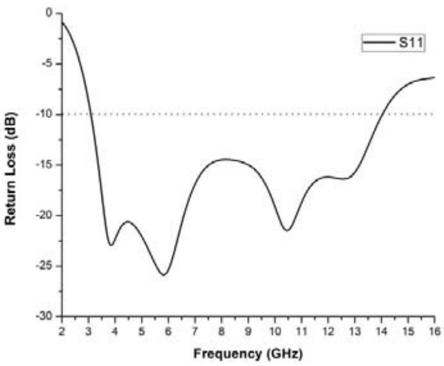


Fig. 2. Return loss of the UWB monopole antenna

Bandstop Filter Design

To produce a band notch characteristic at resonant frequency of 5.45 GHz, a U-shaped slot has been inserted in a microstrip transmission line to perform as a bandstop filter. The resonant frequency can be varied according to the change in the length of the U-shaped slot. The length of the U-shaped slot is about a quarter of the wavelength. The wavelength can be calculated according to the resonant frequency by using the following equations [7]:

(1) $$\lambda = \frac{c}{f_o\sqrt{\varepsilon_e}}$$

(2) $$f_o = \frac{1}{2\pi\sqrt{LC}}$$

where λ and f_o are the wavelength and the resonant frequency respectively.

Fig. 3 shows the equivalent circuit of the BSF, it shows the current distribution areas in the microstrip transmission line.

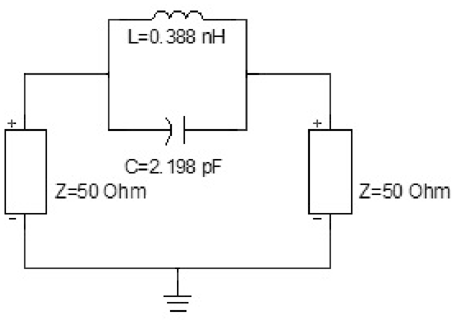


Fig. 3. Equivalent circuit of the BSF

The parallel inductance and capacitance of the BSF can be evaluated by using the following equations [8]:

(3) $$L = \frac{1}{4\pi^2 f_o^2 C}$$

(4) $$C = \frac{f_c}{200\pi\left(f_o^2 - f_c^2\right)}$$

where f_c is the cutoff frequency.

By applying frequency band rejected technique using DMS, it reduces the possible interference problem in the UWB applications. The DMS is produced by etching a U-shaped slot embedded in a microstrip line, which may influence the behaviour of the current flow in the transmission line and leads to produce notch band characteristics. This structure provides a single band notch with higher selectivity in order to filter out wireless local area network (WLAN) within the UWB bandwidth. The created notch can be varied by changing the width g and the length ls of the U-shaped slot. The main advantages of the DMS are more easily to integrate with the antenna, has small size and high band rejection.

Fig. 4 shows the structure of the proposed filter. This structure is simulated using CST software and shows a resonant frequency at 5.45 GHz as illustrated in Fig. 5. The DMS is simulated using Roger RT/Duroid 5880 substrate with a thickness of h = 0.787 mm and dielectric permittivity of εr = 2.2. The simulated results show a good response with narrower bandwidth, higher selectivity and Q-factor. The unloaded Q-factor (Qu) is calculated according to the bandwidth (BW) by using the following equation:

(5) $$Q_u = \frac{2f_o}{BW}$$

The created band notch can be controlled by optimizing the U-shaped slot length and width. Fig. 6(a) shows different resonant frequencies with different slot lengths, it can be seen that as the length increases the resonant frequency decreases, thus when the length is 11.5 mm the resonant frequency appears at 5 GHz while when the length is 9.5 mm the resonant frequency appears at 6 GHz. Fig. 6(b) shows different frequency bandwidths with different slot widths, it can be observed that as the width increases the bandwidth increases also. Therefore, it can be said that the change in the U-shaped slot diminutions leads to change in the capacitance and inductance; this change can be appeared in the scattering parameters behaviour.

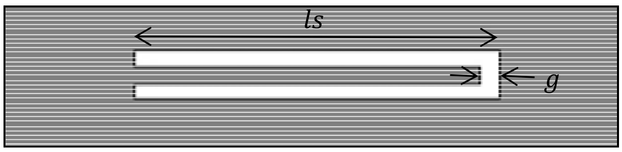


Fig. 4. Proposed BSF

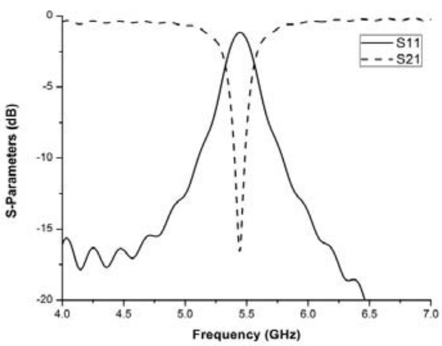
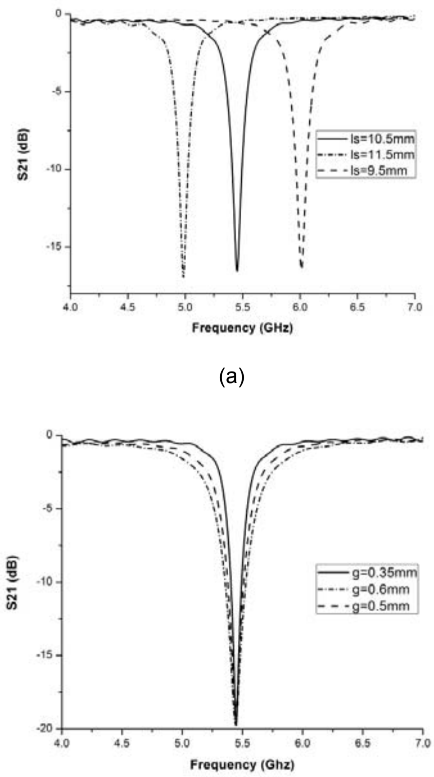


Fig. 5. The simulated S-Parameters of the BSF



(a)

(b)

Fig. 6. The simulated S21 of the BSF with various U-shaped slot (a) lengths and (b) widths

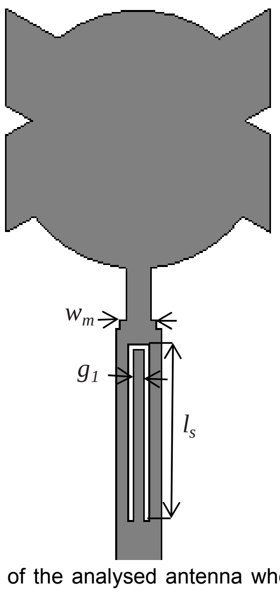


Fig. 7. Front pattern of the analysed antenna where W_m=2.16mm, l_s=9.9mm, g_1=0.6mm

Filtering-Antenna Design

The new combination of the bandstop filter and the UWB antenna provides an alternative solution for multifunction operation that can be used in many RF/microwave applications. In order to achieve filtering and radiating functions simultaneously the bandstop filter and the UWB antenna are combined into a single component. The antenna operates as ultra-wideband and the filter produce the notch band to remove the WLAN band. The bandstop filter is inserted in the microstip feed line of the UWB antenna to form the proposed filtering-antenna design as shown in Fig. 7. Fig. 8 shows the return loss of the proposed filtering-antenna. The simulated results show that the proposed design achieves UWB bandwidth from 3 to 14 GHz and provides a good band rejection to the WLAN band from 5.1 to 5.8 GHz.

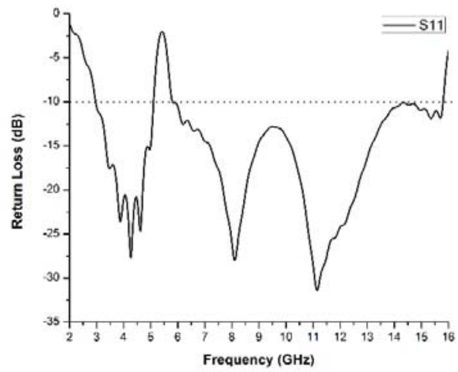


Fig. 8. The simulated return loss of the Filtering-Antenna

Results and Discussions

Evaluation and analysis using the CST software simulator have been done to investigate the performance of the proposed design. The return loss of proposed design without and with BSF are evaluated and simulated as shown in Fig. 9. It can be seen that the proposed design without BSF is an UWB antenna having bandwidth ranging from 3 GHz to 14 GHz. However, the proposed design with BSF has the same bandwidth with a single stop band ranging from 5.1 GHz to 5.8 GHz. The notched band is produced by DMS which influences the distributive capacitance and inductance of the microtrip transmission feed line. Therefore, a reasonable change occurred in the S-parameters behaviour due to the alteration of the current path in the microtrip feed line. These results show that the proposed design without BSF provides a return loss below -10 dB within the bandwidth from 3 GHz to 14 GHz. However, the proposed design with BSF has almost the same return loss except within the band rejection frequencies the return loss is above -3 dB, thus it provides a good level of rejection to the WLAN band frequencies within the UWB bandwidth.

Voltage standing wave ratio (VSWR) simulation has been carried out using CST software in order to evaluate the impedance matching of the proposed design along with the UWB bandwidth. The higher the VSWR, the greater the mismatch between antenna and transmission line and consequently, the more power is reflected from the antenna. Fig. 10 shows the simulated VSWR of the proposed design with and without BSF. The results show that the proposed design without BSF has a good impedance matching since the VSWR is less than 2. However, it can be observed that the proposed design with BSF has a VSWR less than 2 except in the band notch frequencies, it is more than 8, and thus it is well matched and provides a high band rejection to the band notch frequencies.

Fig. 11 shows the simulated realized gain of the proposed design with and without BSF according to the frequency. The simulated realized gain of the proposed design without BSF is more than 1.6 dB with a peak value of 5.23 dB within the frequency bandwidth from 3 GHz to 14 GHz. However, the proposed design with BSF has almost the same gain except within the band rejection frequencies the gain decreased from 3.96 dB to -5.1 dB. The results show that the proposed design provides gradually more gain by increasing the frequency. This is an advantage of the monopole antennas, which contributes to increase the directivity in the radiation characteristics.

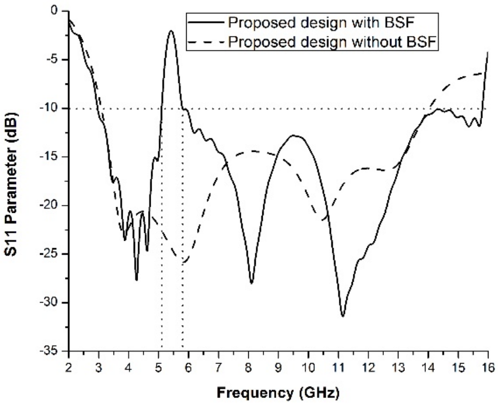


Fig. 9. The simulated return loss of the proposed design with and without BSF

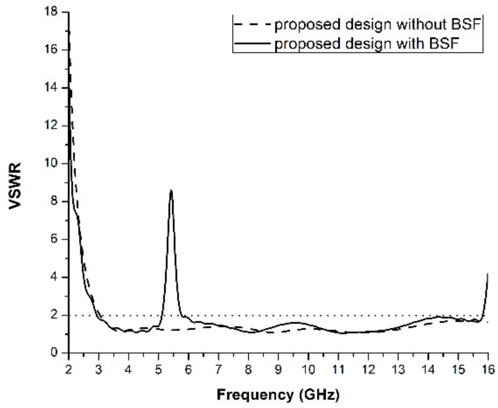


Fig. 10. The Simulated VSWR of the proposed design with and without BSF

The antenna is simulated in the x-y plane as shown in Fig. 1, and it is y-polarized because the antenna is in y-direction [9]. Thus, the H-plane for this antenna is x-z (θ = 0°) indicates as the azimuth plane, and the E-plane is y-z (θ = 90°) indicates the elevation plane. Fig. 10 shows the simulated radiation patterns of the proposed design with and without BSF in E-plane and H-plane at several frequencies. The results show the radiation pattern omnidirectional in the azimuth plane and dipole like in the elevation plane. It is observed that the radiation pattern remains the same for the proposed design with and without BSF. Therefore, the BSF does not influence the radiation pattern since it is embedded in the feed line of the antenna design.

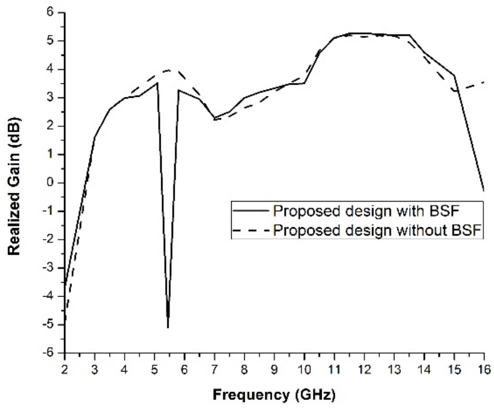


Fig. 11. The Simulated realized gain of the proposed design with and without BSF

Conclusion

A new topology of filtering-antenna design is proposed. The optimized monopole antenna is designed to provide UWB response ranging from 3 GHz to 14 GHz. The band rejected technique is achieved to reject the WLAN band by using DMS. The filtering-antenna is formed by embedding the BSF in the feed line of the antenna design. The created notch is controlled by adjusting the length and width of the U-shaped structure. The simulated results show that the proposed design has a high level of rejection to the WLAN frequencies within the UWB bandwidth, gradually more gain by increasing the frequency and stable omnidirectional radiation pattern in the azimuth plane. Also, the simulated results show that the band rejected structure has no effect on the radiation pattern since it is etched on the design feed line. Therefore, the proposed filtering-antenna is suitable to be used in the modern RF/microwave applications.

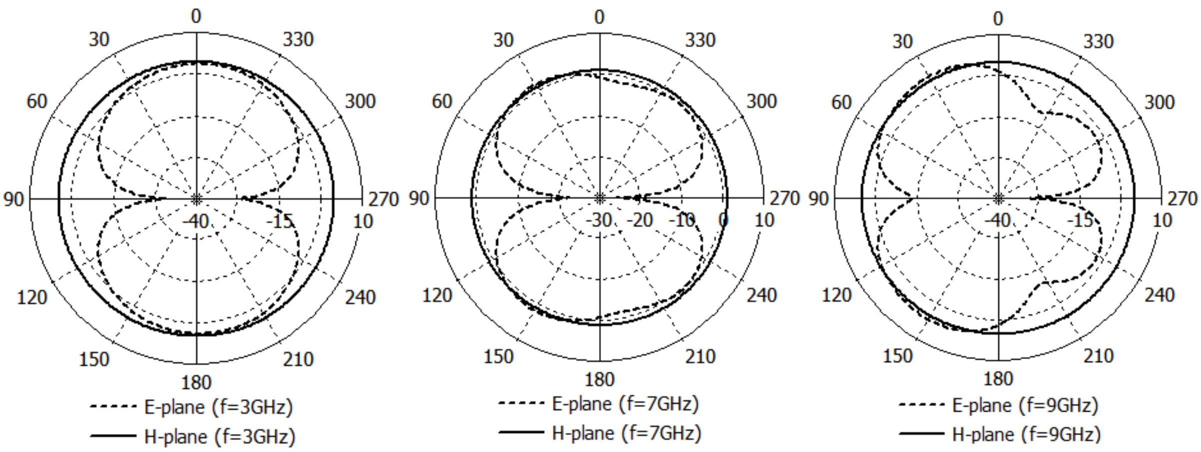


Fig. 12(a): The Simulated radiation patterns in E-Plane and H- Plane of the proposed design without BSF.

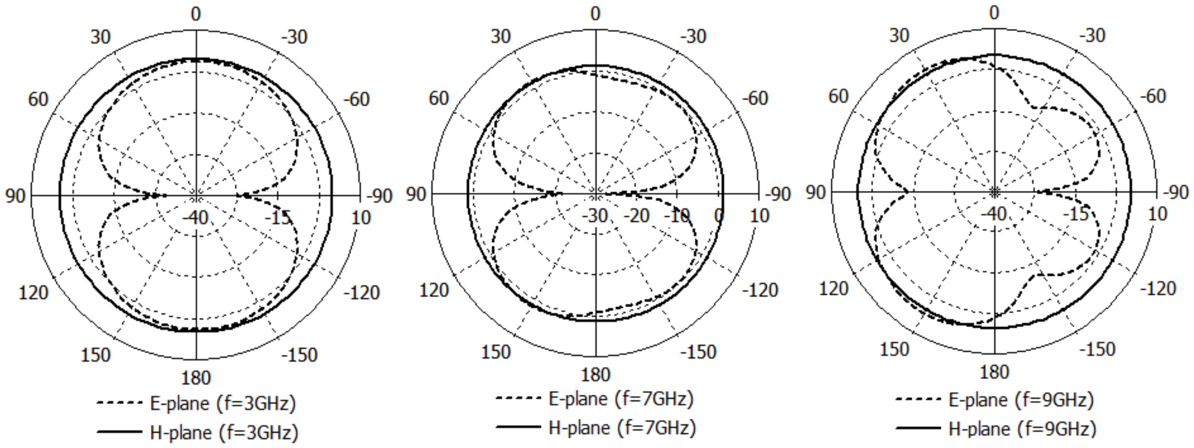


Fig. 12(b): The Simulated radiation patterns in E-Plane and H- Plane of the proposed design with BSF.

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