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For acceptance, fully registration, and presentation of the paper with the title of

Compact UWB Bandpass Filter based on Crossed Dumbbell-Stub with Notch Band using Defected Microstrip Structure

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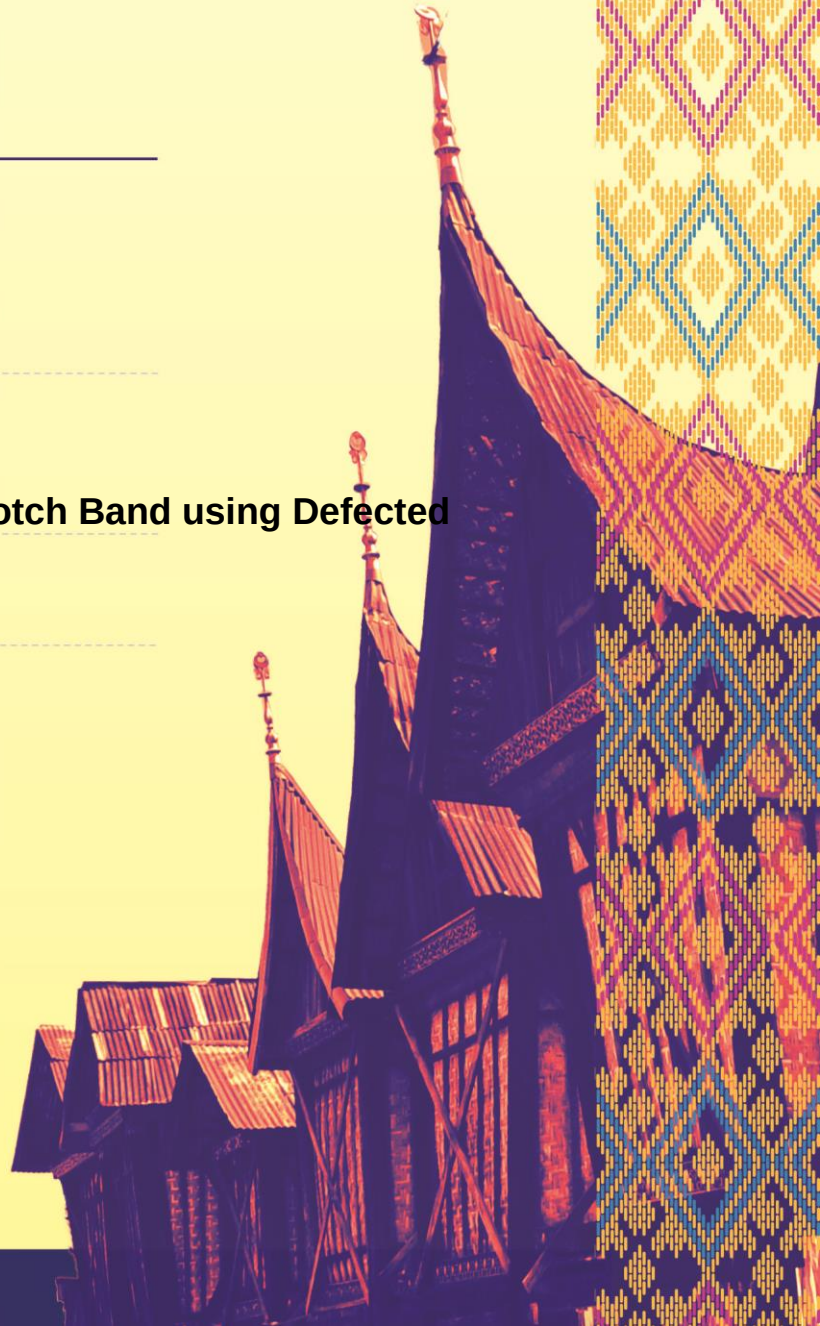

Compact UWB Bandpass Filter based on Crossed Dumbbell-Stub with Notch Band using Defected Microstrip Structure

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***Abstract*—A compact ultra-wideband (UWB) bandpass filter based on cross dumbbell stub with notch band structures is proposed and implemented. This bandpass filter (BPF) structure consists of directly feed line input/output. As the novelty, the cross dumbbell stub resonator was used and it was placed at the middle of the filter structure. By using this structure, the BPF not only has a compact size but also it has a wide-passband response. To remove unnecessary radio frequency (RF) signal, the rejection (notch) band was also proposed by using a novel technique which uses U-shaped defected microstrip structure (DMS). Moreover, the DMS is constructed at the center between crossed dumbbell resonators. This notch band structure has highly independent and it can be adjusted by modifying the U-shaped structure. Therefore, the specific frequency of the notch band can be selected independently without expanded number of resonator or stub. Furthermore, this BPF is fabricated on 2D - Duroid/RT 5880 substrate with permittivity (εr) of 2.2, thickness (h) of 1.57 mm, and loss tangent tand of 0.0009. Furthermore, the measured results show that the UWB-BPF has 3-dB passband from 3.0 – 12.2 GHz, with notch band at 6.7 GHz and the notch band has attenuation -22 dB. The design structure was verified by a good agreement between simulated and measured result. Overall, the proposed filter design has excellent performance in term of insertion loss, high independent notch-band, compact size, and implementable structures.**

Keywords— BPF, defected microstrip structure, crossed-dumbbell, notch, UWB.

I. INTRODUCTION

The ultra-wideband (UWB) wireless technology has great attention after the Federal Communications Commission (FCC) declare that the range of frequency 3.1–10.6 GHz can be used for a commercial purpose [1][2]. The critical subsystem of UWB wireless transceiver is UWB bandpass filter (BPF). High performance of UWB-BPF is needed to reduce noise and interference of radio signals simultaneously. The performance of UWB-BPF can be determined by a good value of insertion loss (S_{21}), compact size, and implementable structures. There are various approaches have been proposed to obtain an excellent performance of UWB-BPF.

The UWB-BPF using modified composite-right/left-handed (CRLH) unit cell is proposed by [3] and to control transmission zeros a cross coupling is used As the result, this UWB-BPF has good insertion loss (S_{21}) and compact size, but the BPF structure is complex. Furthermore, the cross-coupling with λ/4 short circuit-stub resonator was used by [4]. As a result, the proposed UWB-BFP has a compact size and high selectivity.

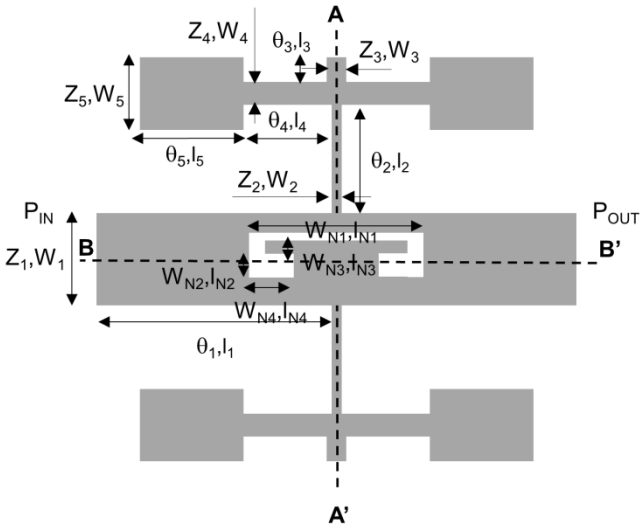


Fig. 1. The proposed UWB-BPF based on Crossed Dumbbell-Stub

The high selectivity response is produced by transmission zeros which are generated by coupling between input and output impedance. Furthermore, a stub-step impedance resonator (SIR) is proposed by [5]. The stub-SIR is connected at its center of filter structure symmetrically. This filter has frequency of 3.1–10.6 GHz. Furthermore, [6] proposed two rectangular stub resonators and single-stage parallel-coupled line and. The rectangular stub resonators create transmission zeros to extend stopband. Moreover, the short-circuited stubs with via-less resonator were investigated by [7]. The resonator structure was investigated by extracting all parasitic elements such as junction and discontinuity to generate UWB BPF. Moreover, Ref [8] presented four resonant modes based on multiple-mode resonator (MMR) with half-mode substrate integrated waveguide (HMSIW) structure. This resonator structure has successfully designed by this resonator structure. However, it has drawback such as complex resonator stucture.

Furthermore, the utilizing short-circuited stubs with less-vias resonator structure was proposed by [9]. This paper has advantages such as via less resonator. Another attractive method is proposed by [10]. This paper is investigated UWB-BPF based on one-cell composite right- and left-handed-transmission line (CRLH-TL) resonator with optimized using particle swarm optimization (PSO) process.

However, the UWB-BPF design has drawback such as a complex structure and low selectivity.

In order to remove unnecessary radio frequency (RF) signal, some research proposes the notch band with various resonator structure. Asymetric open loop resonator with defected ground structures (DGS) was investigated by [11] to produce UWB BPF with notch band. Furthermore, to reduce filter size, the interdigital hairpin resonator unit with three fingers are proposed by [12]. Moreover, the multiple-mode resonators (MMR) and SIR are combined by [13]to increase bandwith. Another resonator structure to generate UWB BPF with notch band such as complementary split ring resonators (CSRR) [14], embedded SIR [15], radial stub loaded resonator [16], modified non-uniform resonator [17], meander H-shaped slot [18] and multilayer LCP technology [19]. All these methods propose a design UWB-BPF with notch band with good performance of S_{21}. However, the notch band is not independent. Besides that, majority the notch band structure has an impact to extend the filter size.

As novelty, this paper is proposed a compact UWB BPF based on crossed dumbbell-stub with notch band using defected microstrip structure as shown in Fig.1. The contribution of this paper such as: 1) The proposed resonator stucture is based on cross dumbbell stub resonator structure, this structure can generate ultrawide pass band, 2) the notch band could be adjusted independently, 3) the notch band resonator is based on U-shaped defected microstrip structure (DMS), so the additional resonator is not required, and 4) the proposed UWB-BPF has excellent performance in term of insertion loss, compact size, and implementable structures.

This paper is organized as follows: Section 2 briefly describes the design of the proposed compact UWB bandpass filter based on crossed dumbbell-stub with notch band using defected microstrip structure, Section 3 presents the simulated and experimental results, and finally, Section 4 concludes this paper.

II. Design of Crossed Dumbbell-Stub Resonator with Notch Band using Defected Microstrip Structure

A. Crossed Dumbbell-Stub Resonator

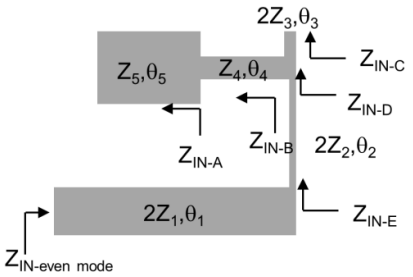
To generate ultra-wide pass band, the crossed dumbbell stub resonator is proposed, as shown in Fig 1. The crossed dumbbell stub resonator is constructed by dual-dumbbell stub and it is placed at the middle of the filter structure. The W_1, W_2, W_3, W_4, and W_5 represent the width of the resonator. The l_1, l_2, l_3, l_4, and l_5 represent the length of the resonator. Furthermore, the resonator structure consists of five transmission lines having different characteristic impedances Z_N (N = 1,2,3,4,5) with corresponding electrical lengths θ_N (N = 5 1,2,3), respectively.

Since the resonator is symmetrical to the *A-A'* plane and *B-B'* plane, the resonant frequencies for even-mode and odd mode can be determined from impedance condition $Z_{IN} = \infty$ or admittance condition $Y_{IN} = 0$ [20][21][22]. Equivalent circuit model for the even-mode of UWB-BPF is shown in Fig. 2(a) and equivalent circuit model for the odd-mode of UWB-BPF is shown in Fig 2(b).

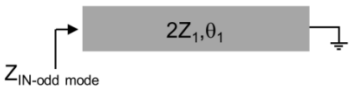
Analyzing the input impedance of even-mode $Z_{IN\text{-even mode}}$ can be derived:

$$Z_{INA} = -jZ_5 \cot\theta_5 \quad (1)$$

$$Z_{INB} = Z_4 \frac{Z_{INA} + jZ_4 \tan\theta_4}{Z_4 + jZ_{INA} \tan\theta_4} \quad (2)$$



(a)



(b)

Fig. 2. (a) Equivalent circuit model for the even-mode of UWB-BPF, and (b) Equivalent circuit model for the odd-mode of UWB-BPF.

$$Z_{INC} = -j2Z_3 \cot\theta_3 \quad (3)$$

$$\frac{1}{Z_{IND}} = \frac{1}{Z_{INB}} + \frac{1}{Z_{INC}} \quad (4)$$

$$Z_{INE} = 2Z_2 \frac{Z_{IND} + j2Z_2 \tan\theta_2}{2Z_2 + jZ_{IND} \tan\theta_2} \quad (5)$$

$$Z_{IN-even\ mode} = 2Z_1 \frac{Z_{INE} + j2Z_1 \tan\theta_1}{2Z_1 + jZ_{INE} \tan\theta_1} \quad (6)$$

Equation (6) can also be expressed as:

$$Z_{IN-even\ mode} = \frac{2Z_1 A + j4{Z_1}^2 B \tan\theta_1}{2Z_1 B + jA \tan\theta_1} \quad (7)$$

with:

$$A = 2Z_2 Z_{IND} + j4{Z_2}^2 \tan\theta_2 \quad (8)$$

$$B = 2Z_2 + jZ_{IND} \tan\theta_2 \quad (9)$$

and:

$$Z_{IND} = \frac{P - Q}{R + S + T - U} \quad (10)$$

where :

$$P = 2Z_3 Z_4 Z_5 \cot\theta_3 \cot\theta_5 \quad (11)$$

$$Q = 2Z_3 {Z_4}^2 \cot\theta_3 \tan\theta_4 \quad (12)$$

$$R = j2Z_3\, Z_4 \cot\theta_3 \quad (13)$$

$$S = j2Z_3\, Z_5 \cot\theta_3 \cot\theta_5 \tan\theta_4 \quad (14)$$

$$T = jZ_4 Z_5 \cot\theta_5 \quad (15)$$

$$U = j{Z_4}^2 \tan\theta_4 \quad (16)$$

The resonant frequencies can be obtained when:

$$2Z_1 B + jA \tan\theta_1 = 0 \quad (17)$$

Analyzing the input impedance of odd-mode $Z_{IN\text{-odd mode}}$ can be derived:

$$Z_{IN-odd\ mode} = j2Z_1 \tan\theta_1$$

The resonant frequencies odd mode can be determined from impedance condition $Z_{IN} = \infty$. The condition of the structure is found as follows

$$\tan\theta_1 = \infty \quad (18)$$

$$\theta_1 = \frac{(2n-1)}{2}\pi;\ \text{for n} = 1,2,3 \ldots \qquad (19)$$

Furthermore, the next step is to add the effect of the notch resonator.

B. Notch Band using Defected Microstrip Structure (DMS)

In order to remove unnecessary radio frequency (RF) signal, the rejection (notch) band was also proposed by using U-shaped defected microstrip structure (DMS). Moreover, the DMS is constructed at the center of crossed dumbbell resonator, as shown in Fig 3.

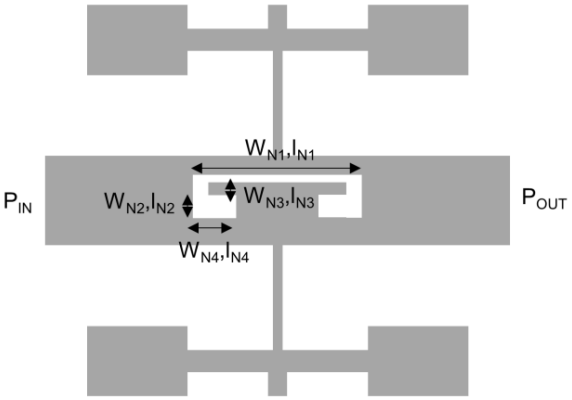


Fig. 3. The proposed defected microstrip structure (DMS) for notch band application

The W_{N1}, W_{N2}, W_{N3}, and W_{N4}, represent the width of the DMS resonator. The l_{N1}, l_{N2}, l_{N3}, and l_{N4} represent the length of the DMS resonator. The simulation and optimization is done by using The Momentum Advanced Design System (ADS). As a result, Fig 4 shows the insertion loss (S_{21}) response with varied W_{N3} (mm). Furthermore, Fig 5 shows the return loss (S_{11}) response with varied W_{N4} (mm). Fig 4. indicates that by increasing W_N, the frequency notch band is unchanged. However the value of S_{21} will increase slightly, but the attenuation is still lower than -15 dB.

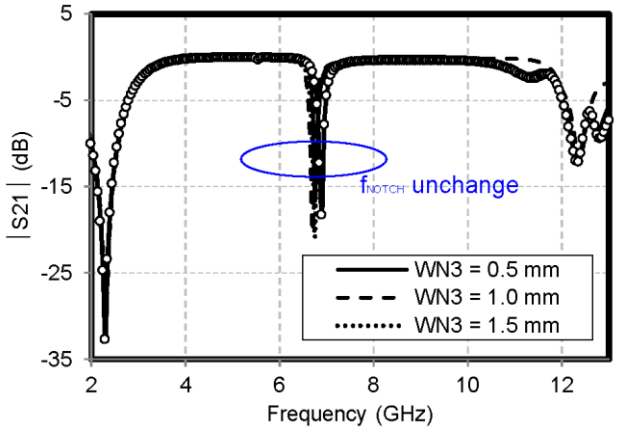


Fig 4. S_{21} (dB) response with varied W_{N3}

Fig 5 shows that by increasing W_{N3} the frequency notch band is still stable. However the frequency value at the lowest S_{11} will shift slightly, but the value of S_{11} has still lower than -30 dB. The figure also shows that the cutoff frequency at upper and lower band unchanged.

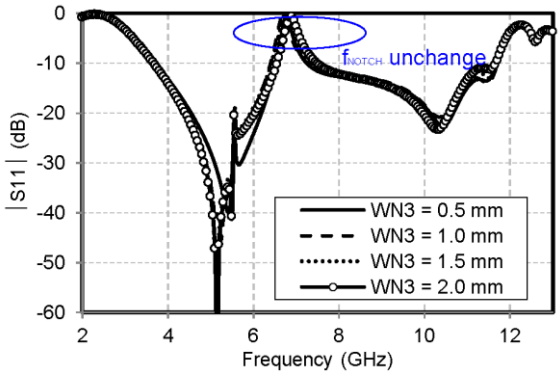


Fig 5. S_{11} (dB) response with varied W_{N3}

Furthermore, Fig 6 and Fig 7 show the S_{21} and S_{11} response with varied WN_4, respectively. The illustration from Fig 6, we can see that the frequency notch band is shifted independently. Although, there is a change in the notch band frequency, the upper and lower cut off frequency value remain stable. Therefore, the notch band frequency can be adjusted by modifying the U-shaped structure in term of W_{N4}. Moreover, the DMS method could produce the specific notch band without an expanded number of resonator or stub.

Moreover, Fig 7 shows the S_{11} (dB) response with varied W_{N4}. The data indicates that by increase a value of W_{N4}, the frequency of the notch band will be shifted to higher frequency. It is interesting to note that, the change in the value of frequency notch band by varied W_{N4}, was not accompanied by changes in the value of upper and lower frequency cutoff.

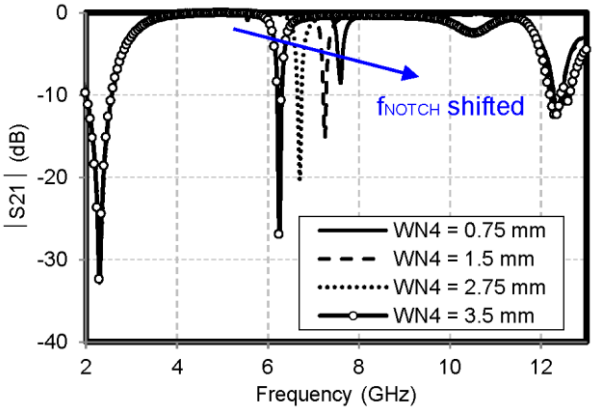


Fig 6. S_{21} (dB) response with varied W_{N4}

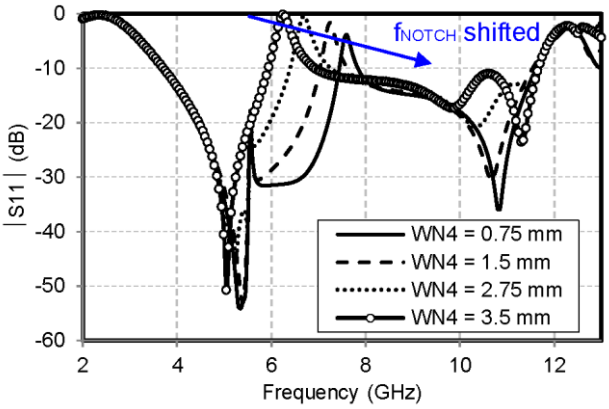
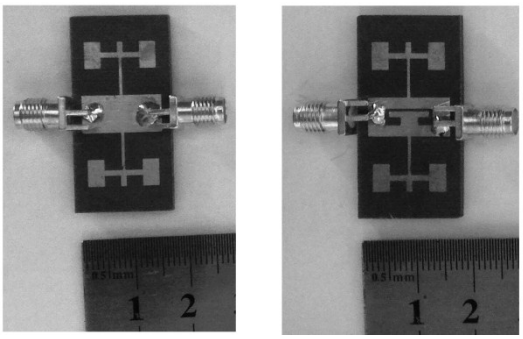


Fig 7. S_{11} (dB) response with varied W_{N4}

III. Implementation of Crossed Dumbbell-Stub Resonator with Notch Band using Defected Microstrip Structure

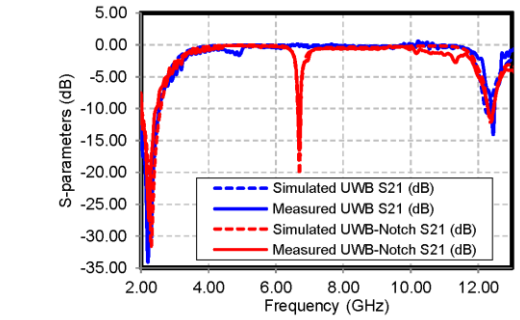
To validate the propose method, the prototype of BPF has been designed, built, and tested as shown in Fig 8a and 8b. Fig 8a and 8b show the photograph of UWB-BPF and UWB-Notch BPF, respectively. This BPF is fabricated on 2D - Duroid/RT 5880 substrate with permittivity εr of 2.2, thickness h of 1.57 mm, and loss tangen tand of 0.0009.



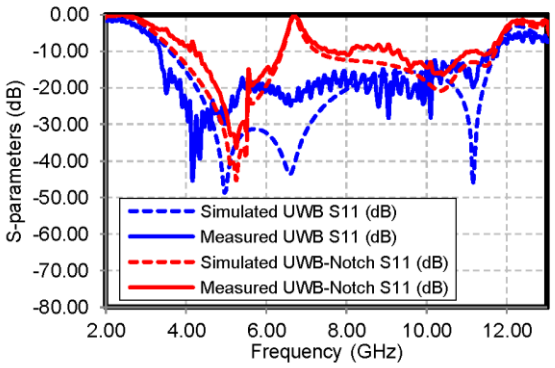
(a) (b)

Fig 8. The photograph of (a) UWB-BPF and (b) UWB-Notch BPF.

Furthermore, after optimization, the following dimension of filter structure was fabricated: W_1 = 7 mm, W_2 = 0.5 mm, W_3 = 1 mm, W_4 = 1 mm, , and W_5 = 5 mm. The l_1 = 7.25 mm, l_2 = 7 mm, l_3 = 2 mm, l_4 = 3.5 mm, and l_5 = 3 mm. Moreover, the size of W_{N1} = 0.5 mm, W_{N2} = 0.75 mm, W_{N3} = 1 mm, and W_{N4} = 1.5 mm, represent the width of the DMS resonator. The l_{N1} = 8.5 mm, l_{N2} = 1.5 mm, l_{N3} = 2 mm, and l_{N4} = 2.75.



(a)



Figs. 9. Comparison of imulation and measurement results of (a) S_{21}, and (b) S_{11}

Fig 9 (a) shows the comparison between simulation and measurement S_{21} results achieved by the UWB-Notch BPF. A VNA Rohde Schwarz ZVA67 was used to test the fabricated prototype. Both simulated and measured results of the UWB-BPF have accomplished UWB requirements with a frequency range of 3.0 – 12.2 GHz. The S-parameters is slightly shifted due to the imperfection of soldering and pabrication process. Moreover, the measured result of UWB-Notch BPF has addition the notch band at 6.7 GHz with attenuation more than -20 dB. This notchband can be adjusted independently.

Fig 10(a) and 10(b) show the surface current distribution of lower band UWB-NotchBPF and upper band UWB-Notch BPF, respectively. The important information for the RF signal flows can be determined by plotting the surface current distribution. The surface current of UWB-BPF has been investigated by Momentum-ADS. The surface current distribution at the lower frequency band has flowed at the lower resonator, as shown in Fig 10(a). Furthermore, the surface current distribution at the upper frequency band has flowed at the upper resonator as shown in Fig 10(b). Moreover, Table 1 summarizes the comparison of the proposed UWB-BPF.

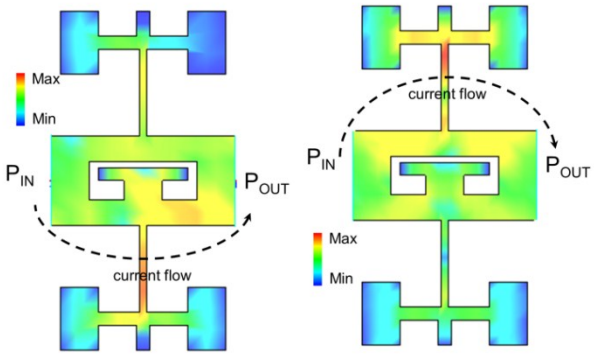


Fig. 10. Surface current distribution on of (a) lower band UWB-NotchBPF and (b) upper band UWB-Notch BPF.

Table 1. Summarizes the comparison of the proposed UWB-BPF

Ref	*3 dB Pass-band (GHz)*	*εr / h*	*Notch freq (GHZ)/ attenua-tion (dB)*	*Structure / Indepen-dent notch*	*Size λ_G x λ_G (λ_G : at 6.85 GHz)*
[15]	3.1 – 10.6	2.2 / 0.78	5.22 / 20	2-D / no	0.61 x 0.50
[16]	3.0 – 10.8	2.2 / 0.50	8.1 / 20	2-D / no	0.55 x 0.35
[17]	3.6 – 10.2	10.8 / 0.63	5.6 / 15	2-D / no	0.82 x 0.17
[18]	2.8 - 10.8	2.65 / 1.0	5.47 / 20	2-D / no	0.82 x 0.36
[19]	2.6 - 10	3.15 / NA	6.4 / 8.0	3-D / no	1.36 x 0.32
Proposed 1 UWB BPF	3.0 – 12.2	2.2 / 1.57	-	2-D / NA	0.42 x 0.84
Proposed 2 UWB Notch BPF	3.0 – 12.2	2.2 / 1.57	6.7 / 22	2-D / yes	0.42 x 0.84

NA = Not avaliable

IV. Conclusion

A compact ultra wideband (UWB) bandpass filter based on cross dumbbell stub with notch band structures is succesfully implemented, and measured. In order to remove unnecessary radio frequency (RF) signal, the rejection

(notch) band was also proposed by using DMS. This BPF is fabricated on 2D - Duroid/RT 5880. The measured results show that the UWB-Notch has 3-dB passband from 3.0 – 12.2 GHz, with notchband at 6.7 GHz and the nocth band has attenuation -22 dB. The design structure was verified by good agreement between simulated and measured result. In conclusion, the proposed filter design has excellent performance in term of insertion loss, high independent notch-band, compact size, and implementable structures.

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