Ultra-wideband Bandpass Filter Using Step-Impedance Resonators (SIR)

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The proposed filter is constructed by combination of two highly compact wideband bandpass filters (BPFs) with different physical dimensions which are designed on the basis of a Folded-T-shaped stepped impedance resonator (SIR) and parallel coupling feed structure.

The wideband BPFs can be designed separately, and the design procedure is described. The narrow notched band with 3.8% 3 dB fractional bandwidth (FBW) from 5.15 to 5.35 GHz (IEEE 802.11a lower band) is created in order to eliminate interference from wireless local area network (WLAN) with the determined UWB passband. The center frequency and bandwidth of the notched band can be controlled by tuning the structural parameters. The full-wave EM simulated and measured results are in good agreement, showing that the proposed filter possesses good characteristics including wide passband, high selectivity, low insertion loss, large notch deep and sharp rejection.

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Index terms: Notch bandpass filters, microstrip filters, ultra-wideband, wideband filters.

Introduction

As The ultra-wideband (UWB) radio system has been receiving great attention from both academy and industry since the Federal Communications Commission (FCC)'s release of the frequency band from 3.1 to 10.6 GHz for commercial communication applications in February 2002 [1]. To realize such UWB radio system, an UWB bandpass filter is one of the key passive components, with the requirements to be ultra-wideband, to have low insertion loss over the band as a conventional filter, to have good performance at low frequency end outside the operating band to meet FCC's limit, and at the same time to have a good group delay performance, which is strongly required for an impulse radio system to keep the distortion of pulse shape of the short pulses minimum. Although developing such a filter is definitely a challenging work, we have successfully invented a novel simple and compact planar filter structure which exhibits very excellent UWB filtering performance [2].

Resonance characteristics of SIR

Figure 1 presents the evolution of Folded-T-shaped stepped impedance resonator from conventional model stage by stage, which for more compactness the narrow section in conventional SIR is converted to two parts as in Figure 1 and then is folded back towards the wider section. As discussed in [7], based on transmission line theory, the equivalent circuit for the conventional open-circuited stepped impedance resonator shown in Figure 2 can be approximated as a series LC resonator. As indicated in Figure 2, the conventional open-circuited SIR is constructed by two sections with different characteristic impedances, the narrower line section with characteristic impedance Z_1 length Θ_1 and wider line section with characteristic impedance Z_2 and electrical length Θ_2.

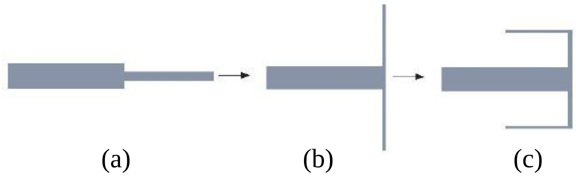

Figure 1. Evolution of Folded-T-shaped SIR from conventional model.

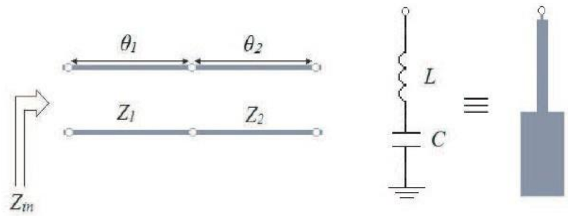

Figure 2. Equivalent circuit model of an open-circuited SIR

$$Z_{in} = jZ_1 \frac{Z_1 \tan\theta_1 \tan\theta_2 - Z_2}{Z_1 \tan\theta_1 + Z_2 \tan\theta_1} \quad (1)$$

Let *Zin* to zero, the resonance condition can be derived by:

$$R_z - \tan\theta_1 \tan\theta_2 = 0 \quad (2)$$

where $Rz = Z2/Z1$ is the impedance ratio of the SIR

The fundamental and higher order resonant frequencies can be adjusted over a wide frequency range with tuning of the *Rz* and length ratio *U* defined as

$$U = \frac{\theta_2}{\theta_1 + \theta_2} \quad (3)$$

When $\theta_1 = \theta_2 = \theta_0$, it can be obtained from (2)

$$\theta_1 = \theta_2 \equiv \theta_0 = \arctan\sqrt{R_z} \quad (4)$$

And the ratio of fundamental and second harmonic resonance frequencies f_0, f_{s1} with corresponding electrical lengths θ_0 and θ_{s1} respectively, can be defined as [7]

$$\frac{f_{s1}}{f_0} = \frac{\theta_{s1}}{\theta_0} = \frac{\pi - \theta_0}{\theta_0} = \frac{\pi}{\arctan\sqrt{R_z}} - 1 \quad (5)$$

This implies that by appropriately determining the impedance ratio *Rz*, it is possible to achieve two resonant frequencies with any desired ratio for applications such as dual-band filter. However, dependent on the choice of *U* and *Rz*, it is feasible to couple different resonant modes to obtain a wide passband. For instance, it was found that when considering that f_0 = 4 GHz and f_{s1} = 5.8 GHz with *Rz* = 0.25, the length ratio U can be explicitly determined as nearly 0.65 to achieve the desired wideband [5, 6].

Ultra-wide Band Bandpass filter including narrow notched band

By utilizing the proposed wideband BPF discussed in the previous section, an ultra-wideband bandpass filter with good performances and highly rejected notched band can be designed and simulated. The configuration of the designed notched band UWB filter is shown in Figure 3. To achieve very wide passband with bandstop notch characteristics, the proposed wideband BPFs.

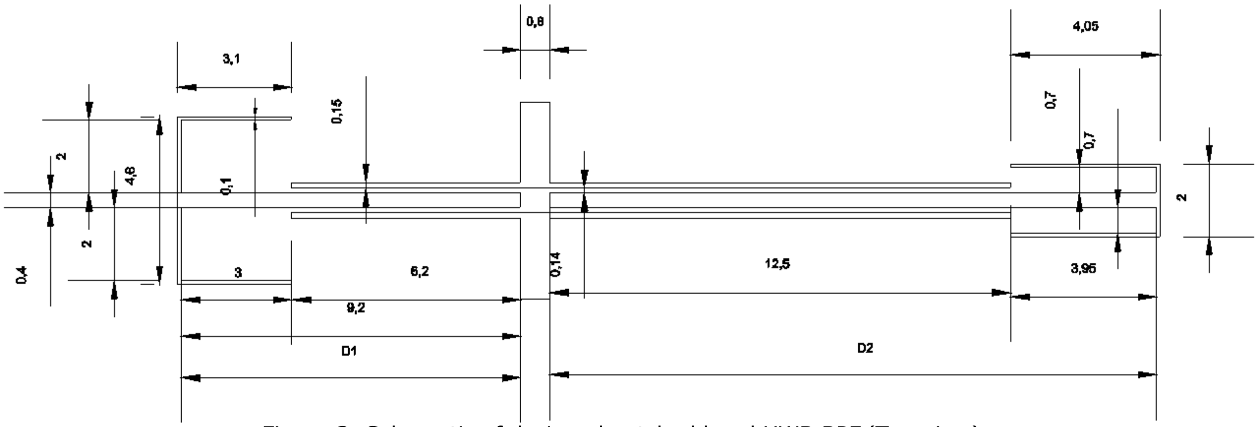

Figure 3. Schematic of designed notched band UWB BPF (Top view)

Dielectric substrate	Relative Permittivity = 3 Thickness of substrate = 0.787 mm
Copper sheet	Thickness of copper sheet = 0.001 mm
Dimensions	All dimensions are in mm

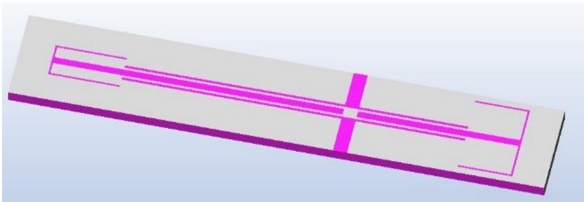

Figure 4. Copper part (shown in pink color) of designed notched band UWB BPF

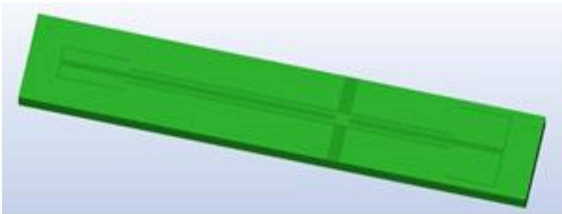

Figure 5. Substrate part (shown in Green color) of designed notched band UWB BPF

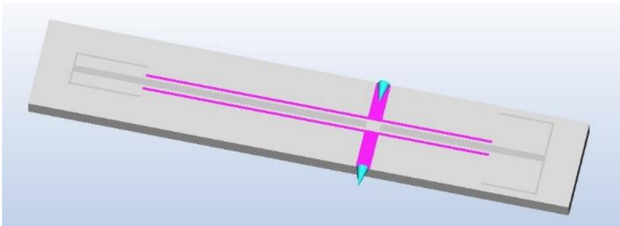

Figure 6. Assign a Line Voltage source (two ports) of 1Volt at a zero phase angle (shown in blue cones) to designed notched band UWB BPF

The simulated *S*21 for wideband BPF is shown in Figure 7 individually and as a whole structure, hence, the mechanism of creating UWB passband with bandstop notch and transmission zeros at the lower and upper sides of passband edges can be discovered. By tuning structural parameters and spacing *S*, the notch response can be adjusted. It can be seen in Figure 8 that as the D1 length increases from 8.5 to 10mm with steps of 0.5mm while D2 and *S* remain 16.5 and 0.14 mm, respectively, the notch 3 dB bandwidth slightly increases from 0.74% to 12.52% and notch shifts to lower frequency with larger rejection level.

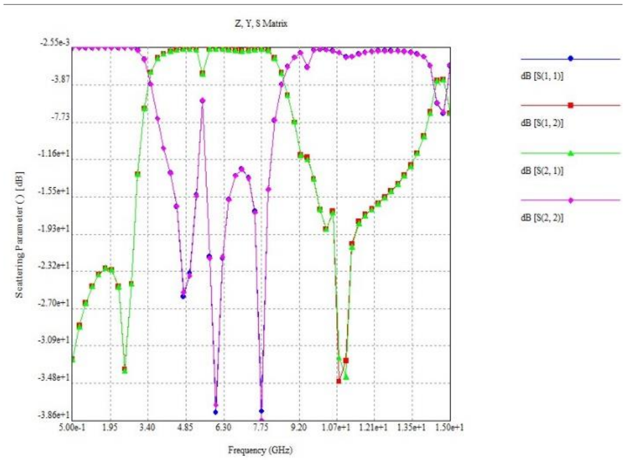

Figure 7. Simulated (S11, S12, S21 and S22) results of wideband BPF.

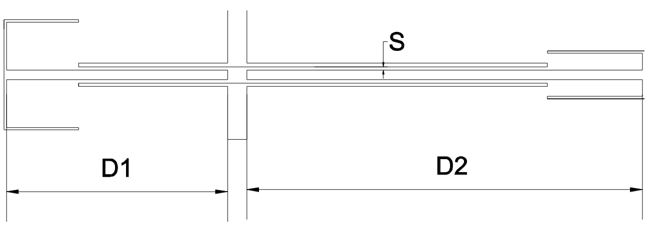

Figure 8. Tuning of structural parameters.

However, from Figure 8 as the D2 length decreases from 17.5 to 16mm with steps of 0.5mm while D1 and *S* remain 9.2 and 0.14 mm, respectively, the notch 3 dB bandwidth slightly increases from 1.02% to 6.54%, and the notch shifts to higher frequency with larger rejection level. The major reason for this behavior is that by tuning D1 and D2, the resonant frequencies of the Folded-T-shaped SIRs will change. The spacing *S* has considerable influence on the bandwidth and the rejection level of the notch. Figure 8 depicts the simulated results of the rejection characteristics as a function of S. By increasing S, as a result of weak coupling, the notch bandwidth decreases, and the rejection level becomes lower. In order to evaluate frequency performance of the designed notched band UWB BPF, the filter is simulated by Singula Software (http://www.integratedsoft.com/Products/Singula).

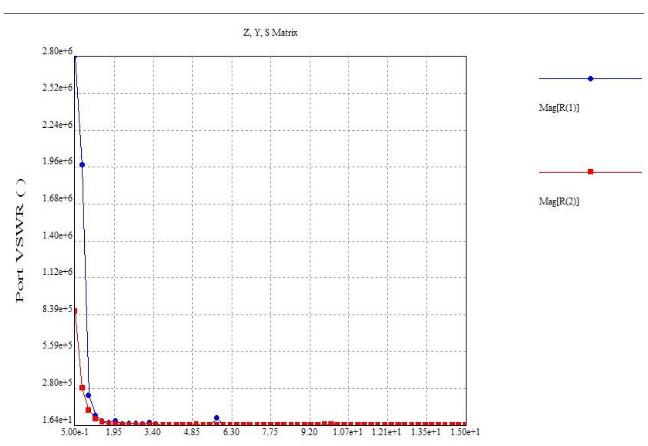

Figure 9. Simulated (VSWR Vs frequency for port1 and port2) results of wideband BPF

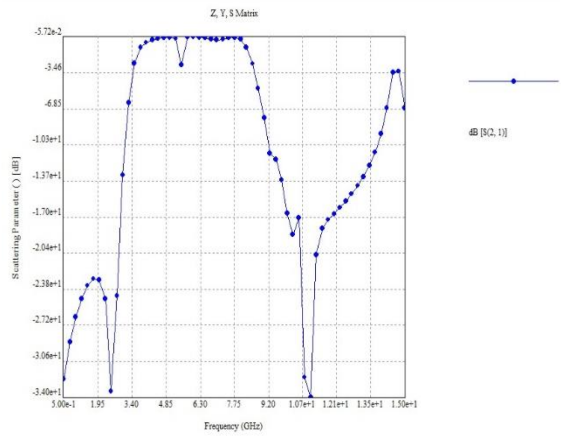

Figure 10. Simulated S21 results of wideband BPF

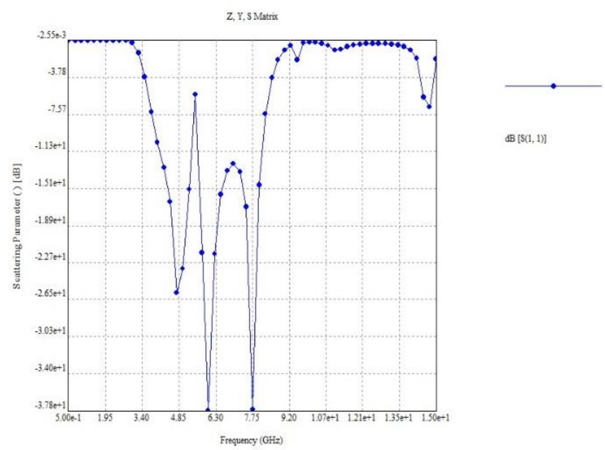

Figure 11. Simulated S11 results of wideband BPF

Conclusion

Utilizing folded-T-shape model of stepped-impedance resonator, a compact wideband bandpass filter has been developed and introduced. Combining the proposed wideband bandpass filters with different physical dimensions was used to corroborate ultra-wideband bandpass filter with notched band characteristics. The proposed filter realizes very wide passband with 101.95% 3 dB FBW including a narrowband stop notch with 3.8% 3 dB FBW at the center frequency of 5.25 GHz with large deep in order to eliminate interference from wireless local area network (WLAN) with the determined UWB passband. Compared to the existing notched band filter designs in the literature the proposed filter has simple structure, compact size, high performance, and easy fabrication. These attractive features make the design suitable for employing in advanced UWB wireless communication systems.

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