UWB dual notch implementation using folded bi-section stepped impedance resonator

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Abstract. This paper proposes a method for dual notch implementation in ultra wideband (UWB) using a simple stepped impedance resonator (SIR). The impedance ratio and electrical length ratio of a bi-section stepped impedance resonator (BSIR) are optimized to have the transmission zeros in the UWB. The high impedance section is folded producing multipath leading to the formation of notches. Transmission zero frequencies are at which the differential phase becomes equal to 180°. Simulations are carried out using ANSOFT HFSS and are fabricated using conventional FR4 PCB board. Prototype developed is tested and the obtained results are used to validate the simulations. Designed filter can be transformed into bandpass filter (BPF) in UWB by enhancing the widths of lower and upper rejection bands.

Keywords: Ultra wideband; Bandpass filter; Dual notch; Multimode resonator; Bi-section stepped impedance resonator.

1. Introduction

Federal Communications Commission (FCC) legitimized the use of license free UWB signals in 2002 [1]. UWB has emerged as an alternate technology for the IEEE 802.15.3a (TG3a) standard and is defined as any signal that has a bandwidth of 500 MHz in the 3.1 To 10.6 GHz band [2]. The purpose of this standard is to provide a specification for a less complex, low cost, low power consuming wireless connectivity with high data rate among devices within or entering the personal operating space. Significant advantages of UWB include large throughput, low power requirement, along with wide bandwidth in the range of GHz. As per FCC standard, the indoor and hand held UWB system operation must be strictly contained in the UWB band ranging from 3.1 to 10.6 GHz.

A variety of methods are available in the literature for the design of UWB filters. A simple UWB BPF using co-planar waveguides at the broadside is proposed in [3]. In the ground plane an open ended coplanar waveguide (CPW) is formed. Zhu and Wang [4] presented a BPF based on an aperture in the ground plane. It functions as a non-uniform resonator and its first three resonances constitute the UWB band. In [5] a UWB filter is designed using a transition structure between CPW and microstrip. The multimode resonator (MMR) includes a wide central strip and two identical narrow side strips. A UWB filter with extended stopband is reported in [6] combining two lowpass filters on both sides of a BPF. UWB BPF using SIR is developed in [7], which uses the first four resonant modes of SIR for wide bandwidth. The resonator has five high-low impedance quarter wavelength sections. In [8] a stub loaded MMR is used for designing a UWB BPF. Three open ended stubs are loaded on an SIR to form the MMR.

This paper proposes a very simple structure using a single Bi-section SIR. The high impedance sections on both sides are folded to form the filter. Multimode resonant characteristics of the SIR is applied to get a wideband response. Folding of SIR introduces multiple travelling paths for the signal
from input to output and transmission zeros are generated in the frequency response. The filter designed has two transmission zeros and can be used as a basic building block for the design of UWB BPFs.

2. Stepped impedance resonator

SIR is a logical extension of uniform impedance resonator (UIR) which was originally proposed by Makimoto and Yamashita in 1980 [9]. Simple BSIR has a single step discontinuity with two impedance sections $Z_1$ and $Z_2$ having electrical lengths $\theta_1$ and $\theta_2$ connected together as shown in Figure 1.

![Figure 1. Structure of BSIR.](image)

The two important attributes of an SIR are $k$ the impedance ratio and $\alpha$ the electrical length ratio expressed as,

$$k = \frac{Z_1}{Z_2}$$  
$$\alpha = \frac{\theta_1}{\theta_1 + \theta_2}$$

Electrical length ratio $\alpha$ is different from physical length ratio. It is due to the fact that, the two impedance sections are of different widths resulting in different effective dielectric constants. Input admittance of SIR is expressed as,

$$Y_{in} = j \frac{Z_2 \tan \theta_1 \tan \theta_2 - Z_1}{Z_1(Z_1 \tan \theta_1 + Z_2 \tan \theta_2)}$$

Resonance condition is obtained by setting $Y_{in}$ to zero. From (1), (2) and (3), it is clear that the SIR resonances are greatly dependent on $k$ and $\alpha$, the two key SIR parameters.

A folded BSIR is shown in Figure 2. Both high impedance sections of the SIR are folded and are kept anti-parallel to the body. When input is applied to one side, the signal can travel through multiple paths towards the output. Multipath signal leads to phase difference between received signals, altering the insertion loss (IL) response. SIR folding leads to an added advantage of structure compactness.

![Figure 2. Folded BSIR.](image)

3. Folded SIR Filter

Proposed structure is obtained by folding the SIR and connecting it to 50 $\Omega$ feedlines as shown in Figure 3. When the SIR is folded, one transmission zero each is formed at either sides of the frequency response, which is due to multiple signal path from input to output.
Figure 3. Filter using folded BSIR.

Filter dimensions are optimized using HFSS as follows, $L_1 = 4$ mm, $L_2 = 14$ mm, $L_3 = 0.75$ mm, $L_4 = 11$ mm, $L = 14$ mm, $W_1 = 3$ mm, $W_2 = 0.75$ mm, $W_3 = 2.75$ mm and $G = 0.2$ mm. Various SIR parameters are: $Z_1 = 98.04$ $\Omega$, $Z_2 = 53.48$ $\Omega$, $\theta_1 = 403.47^\circ$, $\theta_2 = 82.15^\circ$, $k = 1.83$ and $\alpha = 0.83$. The filter passband is realized based on the 2$^{nd}$ to 4$^{th}$ resonances of the SIR. Figure 4 shows the frequency responses of the above folded BSIR filter.

Figure 4. Frequency responses of filter using folded BSIR.

When the length of SIR folded arm is increased above 10 mm keeping all parameters constant, a pair of transmission zeroes are obtained. Under this condition, the multipath electrical length of the resonator will be equal to $180^\circ$. When $L = 14$ mm, two transmission zeroes are obtained at 3.19 and 9.71 GHz. The multipath electrical lengths at these frequencies are found to be $182^\circ$ and $181^\circ$ respectively. Differential phase becoming equal to $180^\circ$ causes cancellation of the signals leading to transmission zeroes. The lower and upper roll-off ratios of the filter are 41 and 70.5 dB/GHz respectively.

4. Results and discussions

Filter simulations are done using ANSOFT HFSS 3D full-wave electromagnetic field simulation software. For experimental demonstration, the proposed filter is fabricated using conventional FR4 substrate having a dielectric constant of 4.4, loss tangent 0.02 and thickness 1.6 mm. SMA connectors are connected to input and output ports for measurement. Photograph of the fabricated filter is shown in Figure 5. Area of the filter ground plane is 517 mm$^2$. Testing of fabricated filter is done using KEYSIGHT E5063A Series Network Analyzer (100 KHz – 18 GHz).

Figure 5. Photograph of the fabricated filter.
Frequency responses of simulated and validated filters are shown in Figure 6. Simulated filter passband is from 3.94 to 9.40 GHz (5.46 GHz) and that of validated filter is from 4.36 to 8.61 GHz (4.25 GHz).

![Figure 6. Responses of simulated and validated filters.](image_url)

Table 1 summarizes important parameters of both simulated and validated filters. Some of the reasons for validated filter performance deviation are tolerance in the filter fabrication method, radiation losses and the use SMA connectors. Another important reason is increased insertion loss at high frequencies due to substrate characteristic variation.

| Parameter                  | Simulated   | Measured   |
|----------------------------|-------------|------------|
| Lower 3 dB frequency       | 3.94 GHz    | 4.36 GHz   |
| Upper 3 dB frequency       | 9.40 GHz    | 8.61 GHz   |
| Center frequency           | 6.67 GHz    | 6.49 GHz   |
| Passband                   | 5.46 GHz    | 4.25 GHz   |
| First transmission zero    | 3.19 GHz    | 3.17 GHz   |
| IL at first transmission zero | 34.8 dB  | 34 dB      |
| Second transmission zero   | 9.71 GHz    | 9.89 GHz   |
| IL at second transmission zero | 27.8 dB  | 40 dB      |
| Maximum passband IL        | 0.62 dB     | 3.99 dB    |
| Minimum passband return loss | -9.4 dB | -7.8 dB    |

5. Conclusion
This paper proposes a simple method for the design of dual notch UWB filter using a folded BSIR. Ultra wide passband is obtained by tuning of SIR parameters. SIR folding leads to multiple signal path and results in transmission zeros. Differential phase difference at transmission zeros are found to be $180^\circ$. For experimental verification, the filter is fabricated and tested. Measured results justify the proposed design. Designed filter has the advantages of being simple, low cost, small size due to the use of folded SIR, steep passband selectivity, low insertion loss and wide passband. It is seen that, the filter performance is degraded by narrow lower and upper stopbands. This filter can be converted into UWB BPF by extending the widths of both lower and upper rejection bands.
6. References

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