Design and Analysis of Ultra-wide Band Bandpass Filter Using Spiral Stub-Loaded Triple-Mode Resonator with a Notched Band

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Abstract: An ultra-wide band band-pass filter using novel spiral stub-loaded triple-mode resonator (SSL-TMR) is presented. New spiral stub loaded resonator is analyzed with odd and even modes analysis for this class of BPF, achieving higher band wide and size reduction. In order to have a good response characterized, two (SSL-TMRs) and two quarter wavelength digital coupled lines are used. This new design filter produces triple modes, one odd mode and two even modes in the desired band and two transmission zeroes (TZs) out of band, providing sharp cut off, low insertion-loss and good return-loss characteristics. The measured results are in good agreement with the electromagnetic simulation.

1. Introduction

Various ultra-wide band bandpass filter have been extensively studied and developed to meet requirements in modern wireless communication systems(from 3.1 to 10.6 GHz) [1].

Much research works were conducted, and various design approaches were proposed. According to the requirements of the UWB filters, the UWB filters with steep passband selectivity and notched bands are desirable. For this purpose, several methods have been developed [2-6].

A compact UWB bandpass filter based on wave cancellation method with dual-band notch was proposed by authors in [2]. In the proposed structure, a couple of modified cross-shaped coupled lines (CCLs) is implemented between two ports, in order to omit the unwanted harmonic passbands. Controllable transmission zeroes (TZs) are introduced by adding CCLs, a pair of half-circle-shaped stubs and a stepped-impedance stub on the main resonator. Loading the CCLs and the stub loaded resonator (SLR) in this filter caused to reduce the total size of the plane. Although, this filter benefits from these features, etching two symmetrical T-shaped slots on the ground plane in order to enhancement the coupling degree

caused the fabrication trepan would become intricacy.

Authors in [3] in order to introduce another UWB bandpass filter, using E-shaped resonator based on variation of genetic algorithm (GA). Although, the structure of this filter is simple and flexible for omit undesired radio signals appeared in UWB band, the stop-band edges present low attenuation to raise the possibility of signal error rating.

In [4], an UWB bandpass filter is described so that three transmission nulls in the upper stop band and three transmission poles in the passband are generated using stepped-impedance parallel-coupled microstrip structure, including three subsections of different lengths and coupling factors. The UWB bandpass filter based on a simplified composite right/left-handed (SCRLH) resonator has also been presented in [5]. To eliminate interfered WLAN and satellite-communication systems signals, the SCRLH has produced dual notched bands in 5.8GHz and 8GHz respectively by employed folded shunt quarter-wavelength short-circuited stubs.

Another procedure to manufacture ultra-wideband bandpass filter is differential filter [6]. Based on this method, to get the 1800 phase shift out of band width, 1800 UWB phase shifters and 3600 transmission lines are used in the plan. According to the proposed filter, the differential-mode signals can propagate in the UWB frequency response, while the common-mode noises are cancelled in the related frequency band.

As known, in order to avoid the interference from the military satellite communication signals, the UWB filter with high passband selectivity and notch band is required. In this paper, we propose a new UWB filter using the spiral

stub-loaded multiple-mode resonator for achieving the high passband selectivity and a notched band simultaneously. The filter consists of two spiral stub loaded resonators to reduce the size of filter and two quarter wavelength digital coupled lines (QWL-DCL) to produce wide passband on FCC demand. The proposed filter generates triple modes, one odd mode and two even modes in desired passband and two transmission zeroes (TZs) near the upper and lower cut off frequencies.

2. Design and Analysis of the SSL-TMR

Fig. 1 shows the basic structure of the presented filter. It consists of two spiral stub loaded resonators emplaced between two quarter wave length digital coupled lines.

Since the proposed SSL-TMR has symmetrical structure, we can apply the even-odd mode method to analyse this filter. As depicted in Fig. 1, fundamental SSL-TMR shaped resonator splits into two equivalent circuits for even and odd modes along the symmetric plan of the filter.

In the odd mode excitation, voltages and currents on the two ports of the symmetric plan have the same amplitudes but opposite signs. For this reason, the middle point of the symmetric plan will connect the ground node. Based on this excitation, the transmission line with admittance Y_1 in Fig. 2a is kept and ignored two T-shaped stubs.

Therefore, the odd mode resonance input admittance $Y_{in,odd}$ can be expressed as

$$Y_{in,odd} = \frac{Y_1}{j \tan \theta_1} \tag{1}$$

where $\theta_1 = \beta L_1$ is the electric length of the microstrip line and Y_1, L_1 denote the characteristic admittance and length of the microstrip line, respectively. From the resonance condition of $Y_{in,odd} = 0$, the odd mode resonant frequencies can be resulted as:
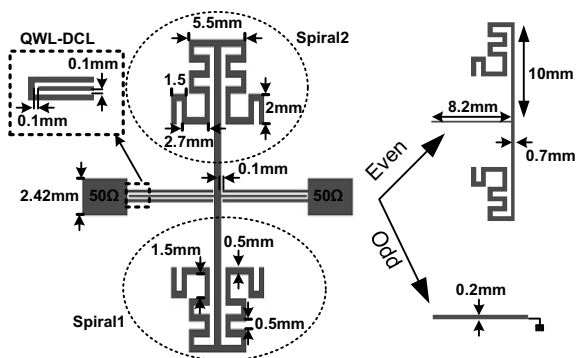

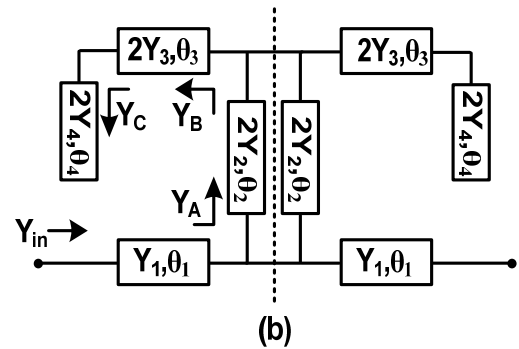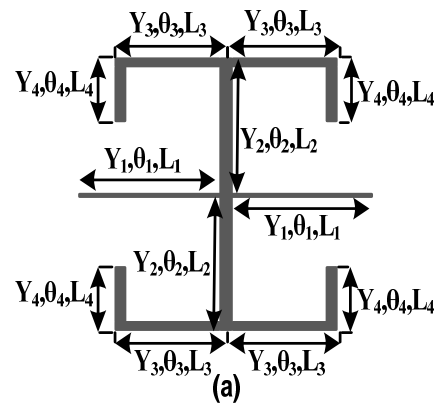**Fig. 1.** Configuration of the proposed UWB filter

Fig. 2. Configuration of the correspondence shape of the basic SSL-TMR (a) conventional resonator. (b) even-mode equivalent diagram

$$f_{odd} = \frac{(2n-1)C}{4L_1 \sqrt{\varepsilon_{eff}}} \tag{2}$$

where n=1, 2,…, c is the speed of light in free space, and εeff denotes the effective dielectric constant of the substrate. It can be observed that the odd mode resonant frequency is not affected by the T-shaped stubs.

Based on the method presented in [7], the equivalent diagram for even mode is used as exhibited in Figure 2b. Also as shown in Figure 2a, two T-shaped resonators by admittance lines (Y_2, Y_3, Y_4) are shunted. To get a new resonator with similar features, two shunt lines admittances are considered equal to admittance lines in Figure 2b $(2Y_2, 2Y_3, 2Y_4)$.

The input admittance for even-mode can be approximately obtained as [2]:

$$Y_{in,even} = jY \frac{\tan \theta_1 (1 - R - \tan \theta_2)}{1 - \tan \theta_2 (R + \tan \theta_3) - 2R \tan \theta_1 - 2 \tan \theta_1 \tan \theta_2 (1 - R)} \tag{3}$$

For simplicity, $Y_1 = Y_2 = Y_3 = Y_4 = Y$ and $R = \tan\theta_3 \tan\theta_4$ are assumed. According to the resonance condition
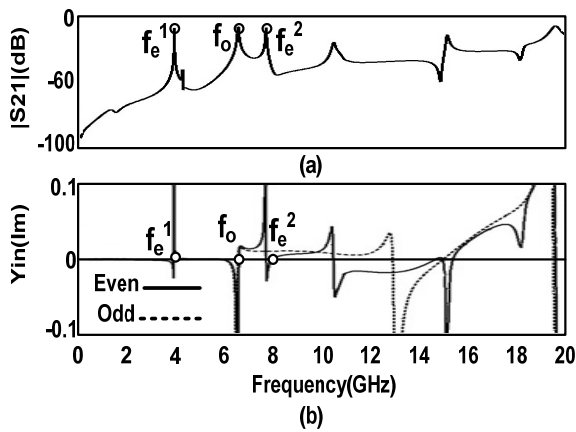
Fig. 3. Even and odd modes responses. (a) simulated frequency response of the proposed filter under tight coupled excitation. (b) odd and even modes input admittances against frequency

Fig. 4. Notch band location against the length of L5.

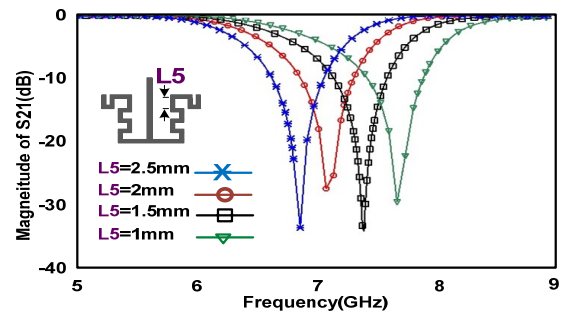$Y_{in,even}=0$, the even-modes resonant frequencies can be derived as:

$$f_{in,even} = \frac{nc}{2(L_1 + L_2 + L_3 + L_4)\sqrt{\varepsilon_{eff}}} \tag{4}$$

where n=1, 2, … . As seen in the equation (4), by replacing (L_1=8.55 mm, L_2=9.5 mm, L_3=6.35 mm, L_4=7 mm and ε_{eff} = 1.89), the second even mode frequency is obtained as 7.7 GHz, having good agreement with simulated frequency in Figure 3.

The transmission zeroes occur when the complex transmission coefficient $S_{21}=0$ in the two-port network. The S_{21} are given by [8]

$$S_{21} = \frac{Y_{in,odd}Y_0 - Y_{in,even}Y_0}{(Y_0 + Y_{in,odd})(Y_0 + Y_{in,even})} = 0 \tag{5}$$

where Y_0 is the characteristic admittance. From this equation, the condition of transmission zero frequencies are obtained when $Y_{in,odd} = Y_{in,even}$. So using equations (2)-(5), the even-odd mode frequencies are obtained. From simulation results, the first even mode resonance frequency is f_e^1= 3.94 GHz, the second one is f_e^2= 7.72 GHz and the only odd-mode frequency is located at f_0^1= 6.568 GHz, as depicted in Figure 3, being in close agreement with the results using above equations . As seen in Fig.4, the position of notched band frequency could be controlled by length of L5, making this filter applicable for many utilizations in new communication systems. It is clearly observed that with increasing length L5, the

notched band frequency is shifted to lower frequency and decreasing the L5 increases notched band frequency.

Figure 5 shows the simulated and measured results. As seen, from 3.3 GHz to 10.3 GHz, the measured return loss is greater than13dB and the measured insertion loss is less than 0.6 dB.

3. Simulation and Measurement
The measured results have a 3 dB fractional band width (FBW) of 120%. The UWB BPF is optimised by EM-Simulation using ADS and fabricated on the Rogers-RT-Duroid 5880 substrate with ε_r=2.2, h=31 mil and tanδ=0.0009. The physical dimensions were decided as L_1=8.2, L_2=10, L_3=6, L_4=7 all are in mm and electrical dimensions are θ_1=1.64, θ_2=2, θ_3=1.2, θ_4=1.4. Also, the total size of the proposed filter is 17.3*20.2 mm². Table 1 summarizes the UWB bandpass filter performance, such as 3 dB fractional bandwidth (FBW), relative stop band bandwidth (RSB), roll off (ROF), normalized circuit size (NCS), figure of merit (FOM) and its comparison with the other UWB works. These parameters are defined as follows:
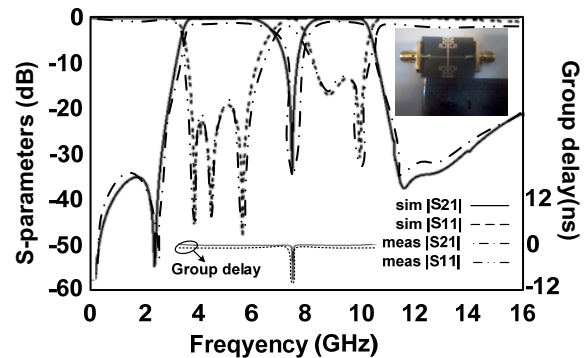
Fig. 5. Photograph of fabricated filter, Simulated and measured frequency responses and Group delay

Table 1 Comparisons with other works

Ref.	Notch (GHz)	B-W (GHz)	3dB FBW%	RSB	ROF	NCS (λ_g)²	FOM
[3]	5.9-8	3.91-10.11	108	7.1	12.2	0.42	26100
[4]	No	3.1-10.6	110	6.8	21.6	0.72	22440
[5]	5.8,8	2.8-10.9	118	6.84	17	0.7	19601
[6]	No	3.1-10.6	135	0.05	6.37	2.22	19.37
This work	7.4	3.36-10.32	103	6.8	34	0.33	72162

$$FOM = \frac{FBW.RSB.ROF}{NCS} \qquad (6)$$

As presented in Table 1, the proposed SSL-TMR has a good performance and figure of merit, as compared to the other UWB bandpass works.

4. Conclusion

In this paper, the proposed UWB filter with notch band using the spiral stub loaded triple modes resonator has been presented. The notch band at 7.4 GHz with insertion losses of 34.5 dB can be determined by the L5. This study provides a simple and effective method to design a compact UWB filter with notch band and high passband selectivity. Good agreement between the measurement and EM-Simulation has been observed. The proposed UWB BPF is actually suitable for modern ultra wideband communication systems.

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