REVIEW PAPER ON DESIGN OF COMPACT ULTRA-WIDEBAND BAND PASS FILTER

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ABSTRACT

This paper reviews the performance analysis of compact notched Ultra-Wideband (UWB) band pass filter using quasi electromagnetic bandgap structure [1], Quadruple mode ring resonator [2] and stepped-impedance stub-loaded resonator [3].

Keywords— Electromagnetic Band gap (EBG), Multiple Mode Resonators (MMR), Stepped Impedance Resonator (SIR), Stepped Impedance Stub-loaded Resonator (SISLR), Stepped-Impedance One-wavelength Ring Resonator (SORR)

INTRODUCTION

The U.S. Federal Communications Commission (FCC) has decided to authorize the unlicensed use of ultra-wideband (UWB) with a frequency range of 3.1 to 10.6 GHz in 2002. To satisfy the FCC's specifications, UWB filters should not only have low insertion loss and good selectivity but also good out-of-band rejection performance. In addition, compact size and easily-implemented structures are also demanded. UWB technologies have received great attention from academic and industrial field. Band pass filter is one of the essential passive components in the UWB technologies. In recent years various UWB band pass filters have been reported based on numerous design techniques [1]-[3]. Multiple mode resonator (MMR) was originally proposed in the form of a stepped impedance resonator (SIR) in [1]-[3]

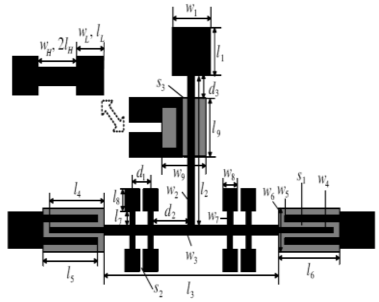

Fig. 1. Configuration of the notched UWB filter with upper stopband

The development in the compact notched Ultra-Wideband Band Pass Filter is focus area for this paper. The following review concentrates on the comparative study of three different research works.

In a recent study by M.J. Gao [1] a compact notched UWB band pass filter was designed based on stepped-impedance stub loaded resonator (SISLR) combined with quasi-EGB structures, which suppresses the undesired spurious bands to improve the out-of-band performance. In order to eliminate the interference caused by WLAN, a notched band was introduced at 5.2 GHz, which was implemented by adding a folded stepped-impedance resonator (SIR) near the stub of the SISLR.

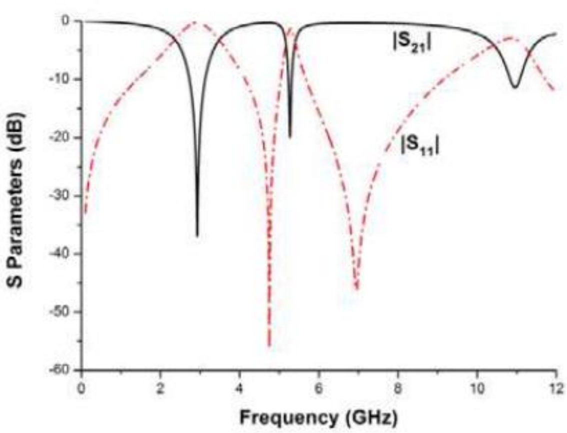

Fig. 2. The simulated module results of the model.

This notched UWB filter was fabricated on a F4B substrate, as shown in Fig. 1, which has a relative permittivity of 2.65 and thickness of 0.8 mm. The model of the filter was designed and optimized by Ansoft HFSS. The dimension were given by $w_1 = 4.8$, $w_2 = 1.5$, $w_3 = 0.8$, $w_4 = 0.5$, $w_5 = 0.2$, $w_6 = 1.6$, $w_7 = 0.3$,$w_8 = 0.7$, $w_9 = 4$, $l_1 = 2.8$, $l_2 = 9$, $l_3 = 7.1$, $l_4 = 7.7$, $l_5 = 7.7$, $l_6 = 8.1$, $l_7 = 1.1$, $l_8 = 1.3$, $l_9 = 5$, $d_1 = 0.9$, $d_2 = 1$, $d_3 = 1$, $s_1 = 0.2$ and $s_2 = 0.2$ (all in mm). The overall size of the fabricated filter prototype was about $0.87 \times 0.54\lambda_0^2$, where λ_0 is the wavelength in dielectric at 6.85 GHz.

In this filter good frequency was achieved by locating two transmission zeros at the lower and upper band edges, which was generated by the stepped-impedance stub in the center. For good out-of-band rejection quasi-EGB-loaded lines substituting the middle section of SIR of UWB filter were introduced. In order to eliminate the interference caused by WLAN, a notched band was introduced at 5.2 GHz, which is implemented by adding a folded Stepped-impedance resonator (SIR) near the stub of the SISLR. The UWB filter has a 10 dB pass band from 3.07 to 10.69 GHz as per the measured results. The notched band was measured from 5.17 to 5.25 GHz with -10 dB rejection and the insertion loss was measured less than -1.7 dB within the pass band.

Design of UWB micro strip band pass filter by Jin Fan, [2] based on Quadruple Mode Ring Resonator Band-pass filter has advantages of low radiation loss, high-Q factor and compact size. A quadruple-mode ring resonator was developed by introducing a stepped impedance one-wavelength ring resonator (SORR) into a stepped-impedance half-wavelength resonator (SHR). Fig. 3 shows the proposed UWB filter consists of the quadruple-mode ring resonator and two band-stop sections.

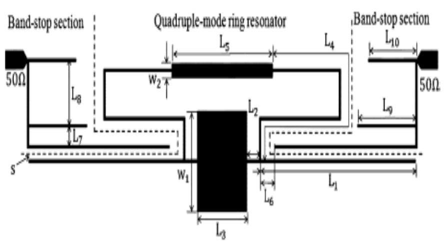

Fig. 3. Structure of filter using quadruple-mode ring resonator: L_1 = 19.16 mm, L_2 = 1.76 mm, L_3 = 6.30 mm, L_4 = 23.51 mm, L_5 = 12.87 mm, L_6 = 0.6 mm, L_7 = 0.74 mm, L_8 = 4.75 mm, L_9 = 7.39 mm, L_{10} = 6.03 mm, w_1 = 7.50 mm, w_2 = 1.13 mm, s = 0.37 mm.

The Quadruple-mode ring resonator has an excellent in-band performance and allows controlling resonant frequencies sensitively, thus achieves low return loss and insertion loss. Two band-stop sections with asymmetrical π-type structure were introduced to suppress the harmonic responses of the wide stop-band filter. Quadruple-mode ring resonator in the filter was the combination and modification of SORR and SHR as shown in Fig. 4.

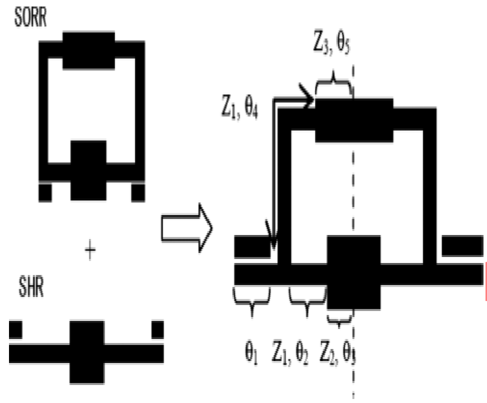

Fig. 4. The quadruple-mode ring resonator.

For even mode case, with ideal open-circuited terminals at two ends in Fig. 5(a), the resonant condition was derived as the following:

$Z_L^e + Z_R^e = 0$ (1)

$Z_L^e = -jZ_1 \cot\theta_1$ (2)

$Z_R^e = Z_M^e Z_N^e/(Z_M^e + Z_N^e)$ (3)

$Z_M^e = jZ_1(\tan\theta_4 \tan\theta_5 - R_s)/(\tan\theta_5 + R_s \tan\theta_4)$ (4)

$Z_R^e = jZ_1(\tan\theta_2 \tan\theta_3 - R_z)/(\tan\theta_3 + R_Z \tan\theta_2)$ (5)

Similarly, for odd mode circuit the resonant condition was derived as the following:

$Z_L^o + Z_R^o = 0$ (6)

$Z_L^o = -jZ_1 \cot\theta_1$ (7)

$Z_R^o = Z_M^o Z_N^o/(Z_M^o + Z_N^o)$ (8)

$Z_M^o = jZ_1(R_s \tan\theta_5 + \tan\theta_4)/(1 - R_s \tan\theta_4 \tan\theta_5)$ (9)

$Z_N^o = jZ_1(R_Z \tan\theta_3 + \tan\theta_2)/(1 - R_Z \tan\theta_2 \tan\theta_3)$ (10)

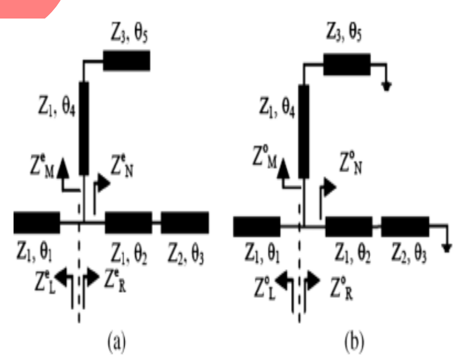

Fig. 5(a) & (b). Equivalent even- and odd-mode circuits of the quadruple mode ring resonator.

The quadruple-mode ring resonator has an excellent pass-band performance but cannot avoid harmonic responses in the upper stop-band. To overcome this problem band-stop section was designed and was coupled with the ring resonator by parallel coupling lines. The band-stop section was an asymmetrical π-type structure composed of two micro strip stubs. The asymmetrical type structure contributed two transmission zeros at high frequency, forming a continuous stop-band and hence the filter was achieving a high cut- off band rejection. The filter model was also designed and optimized by Ansoft HFSS. The filter was fabricated on a 1.6 mm-thick micro strip substrate with a size of 2 cm × 6 cm. The relative dielectric constant and loss tangent were ε_r=11.2 and $\tan\delta$ = 0.001 respectively as shown in Fig. 3. The measured 3 dB fractional bandwidth was 57.9%, with the center frequency of 1.45 GHz. From 1.07 to 1.77 GHz, the insertion loss was less than 1 dB with the minimal insertion loss 0.6 dB and the return loss was larger than 18.8 dB.

The filter has four transmission poles, due to which the filter has low insertion loss and return loss with a small size. Two transmission zeros on both sides of the pass-band resulted in a high frequency selectivity of the filter.

As already mentioned this quadruple-mode ring resonator has an excellent pass-band performance but cannot avoid harmonic responses in the upper stop-band. Hence to suppress the second harmonic response of the filter, two asymmetrical type low-pass sections were used. The harmonic responses over the frequency range from 2.5 to 4.5 GHz were suppressed for more than 18 dB.

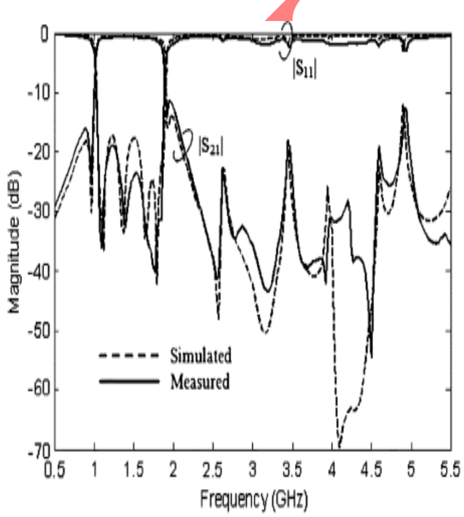

Fig. 6. Comparison between simulated and measured results of the filter based on quadruple mode ring resonator.

Qing-Xin Chu [3] designed an ultra-wideband (UWB) band pass filter (BPF) using stepped-impedance stub-loaded resonator (SISLR). The SISLR was able to provide more degrees of freedom to adjust the resonant frequencies; this was very convenient for relocating the required resonator modes within the UWB band. The Filter consists of conventional multimode resonator added with an extra stepped-impedance stub-loaded in the center. The structure of the SISLR is shown in Fig. 7(a) which consists of SIR with the characteristic Y_3, Y_4 admittance, and electrical lengths $2\theta_3$ and θ_4. SIR was tapped –connected to a stepped-impedance stub (SIS) in the center. SIS was constructed by using transmission-line sections of characteristic admittance $2Y_1$, $2Y_2$ and electrical lengths θ_1, θ_2. As SISLR was symmetrical in structure, odd and even mode analysis were adopted to characterize it.

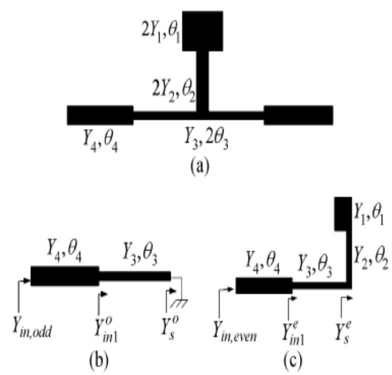

Fig. 7. (a) Basic structure of the SISLR, (b) odd-mode equivalent circuit, (c) even mode circuit.

The ratio of the first two odd-mode resonance frequency f_2^o / f_1^o can be determined by the length ratio α_1 and admittance ratio K_4 , as shown in Fig. 8. It was observed that when $\alpha_1 = 0.5$, f_2^o / f_1^o was maximum. Thus two odd mode frequencies were allocated more closely by tuning $K_4 < 1$.

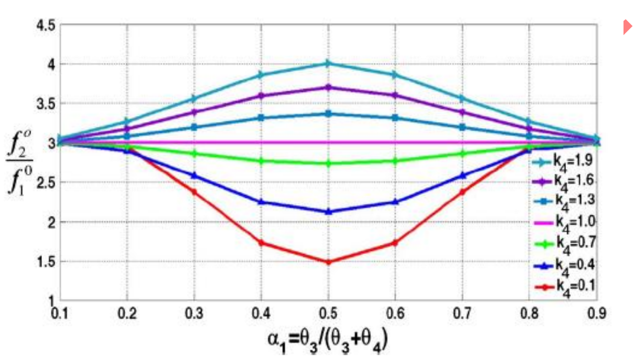

Fig. 8. Ratios of first two odd-mode resonant frequency f_2^o / f_1^o under different length ratio α_1 and admittance ratio K_4.

In proposed UWB filter the first two odd mode resonant frequencies (f_2^o, f_1^o) were set as 4.0 and 9.0 GHz ($f_2^o / f_1^o = 2.55$), and first three even mode resonant frequencies as $f_1^e = 3.1, f_2^e = 6.85, f_3^e = 10.6$ GHz

($f_2^e/f_1^e = 2.21$, $f_3^e/f_1^e = 3.42$). By setting $\alpha_1 = 0.5$, the admittance ratio $K_4 \approx 0.5, K_1 \approx 2$ and length ratio $\alpha_2 = 0.5$ were selected as shown in Fig. 8 and 9.

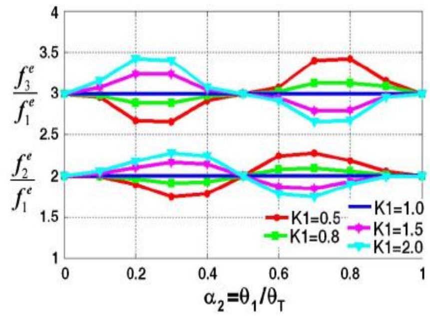

Fig. 9. Ratios of the second and third even-mode resonant frequencies to the first even-mode resonant frequency $f_2^e/f_1^e, f_3^e/f_1^e$ with different k_1 and α_2 setting $Y_3 = Y_4$.

The UWB pass band was satisfactorily realized with two transmission zeros produced in the lower & upper cutoff edges of pass band filter, which resulted in sharper roll-off.

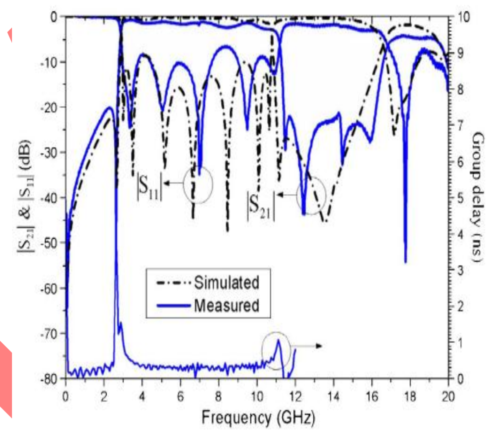

Fig. 10. Simulated and measured result of proposed UWB BPF.

Simulated and measured result of this UWB band pass filter was shown in Fig. 10.The pass band was measured from 2.90 to 10.90 GHz while pass band obtain by simulation was 2.92 to 10.72 GHz and the measured return loss was lower than -10 dB. The overall size of the fabricated filter was around $0.73\lambda_0 \times 0.35\lambda_0$

II. CONCLUSION

This review paper gives an insight of the design of UWB band pass filter based on quasi EBD structure, quadruple mode ring resonator and SISLR. The lowest return loss was obtained in filter based on quadruple mode ring resonator and was less than -18.8 dB. It has the measured 3 dB fractional bandwidth of 57.9% with the center frequency of 1.45 GHz. The value of insertion loss was also less than 1 dB with the minimum insertion loss 0.6 dB. The low insertion loss and return loss was due to four transmission poles. Two transmission zeros result in a high frequency selectivity of the filter.

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