Design and Application of Quasi-Elliptic Bandstop Filters

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Abstract— **In this paper, the design and implementation of a new type of band-stop filter having transmission zeros is presented. Detailed design aspects of 3 and 4 pole band-stop quasi-elliptic filters are discussed, where transmission zeroes are attained by a source-load cross coupling line. These filter topologies offers a sharp pass-band to stop-band transition due to the introduction of the pair of transmission zeros, compared to a conventional Chebyshev design.**

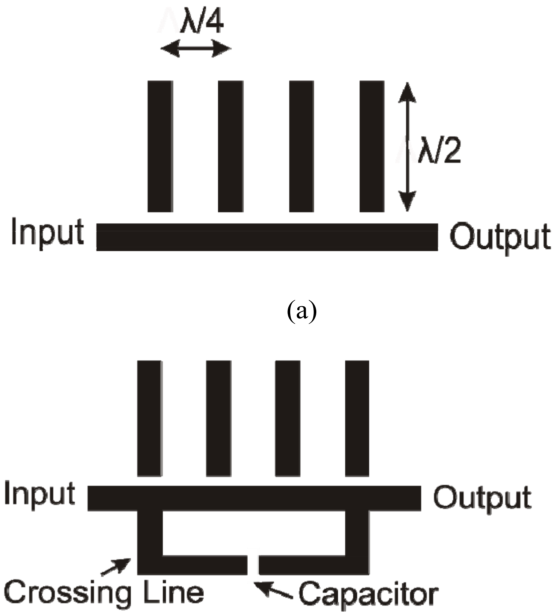
Keywords-component; Microwave filters, source-load cross coupling, transmission zeros.

I. INTRODUCTION

In the literature, extensive work has been found on Band-stop (BS) filters with Chebyshev configurations [1-6]. However, for applications such as mobile communications and radio astronomy receivers, high performance band-stop filters have been proposed to decrease interference with the addition of transmission zeros and therefore, increasing selectivity [7-10]. In this paper a detailed design procedure is provided for 4th order filters with extra transmission zeroes made on microwave laminates. Moreover, these design techniques are extended to a 3rd order filter which has only one transmission zero at the edge of the passband.

Fig.1 shows the two topologies under interest. Fig.1a is a traditional Chebyshev topology and Fig.1b contains the proposed band-stop filter topology.

Fig.2 shows the schematic of the BS filters, where decoupling resonators are interconnected by admittance inverters of value J=1, and J_a and J_b represent the admittance inverters for the center and source-load resonators. Fig.3 shows a circuit simulation, where it is apparent that the proposed filter design with a pair of transmission zeros has sharper passband to stop-band transition due to the source-load cross-coupled structure [11]. This letter presents full design procedure, simulations and experimental results of a 3rd and 4th order filters with extra transmission zeroes.



(b)

Fig.1. Narrowband band-stop filter topologies.
(a) Conventional Chebyshev topology, (b) Proposed topology

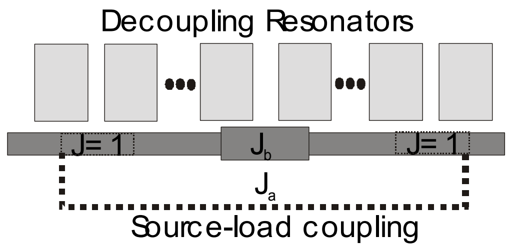


Fig.2. Source-coupled Band-stop filter

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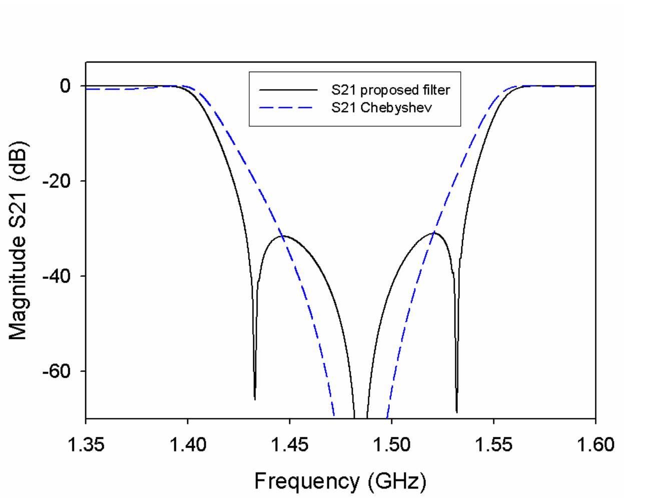

Fig.3. Circuit simulation of the filter topologies in Fig.1

This paper is divided in four parts, where filter design and synthesis is discussed in section II, section III shows the simulation and experimental results, and finally a conclusion on this work is given in section IV.

II. DESIGN PROCEDURE

A. *Bandstop Filter Synthesis*

In this section, a filter synthesis of the proposed filter is discussed. The design starts with a quasi-elliptic low pass filter prototype, with a angular frequency of 1 rad/sec, where the low pass element g, and J values used for this filter are given in table 1, where $J_1 = J_a$ and $J_2 = J_b$. The procedure to obtain these values can be found in [12]. The low pass quasi-elliptic prototype is shown in Fig. 4, where a circuit simulator is used to model the filter [13]. As a next step the capacitor in the low pass filter prototype is transformed to a series LC circuit, to produce a band-stop prototype, this is done using the following expressions [12].

$$C_i = \frac{g_i \Delta FBW}{\omega_0 Z_0} \quad (1)$$

$$L_i = \frac{Z_0}{\Delta FBW \omega_0 g_i} \quad (2)$$

Where Z_o is taken as 50 ohms, ΔFBW is the 3dB fractional bandwidth of the filter and g_i correspond to the quasi-elliptic low pass element g values in table 1.

Table 1. Quasi-elliptic low pass element values

Ω_a	g_1	g_2	J_1	J_2
1.85	0.9583	1.41	0.1969	1.1

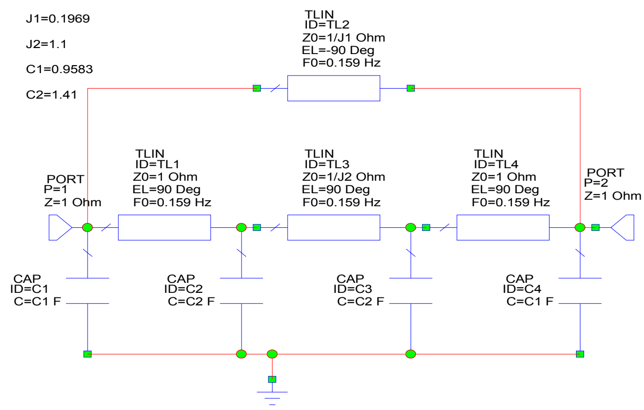

Fig.4. Quasi-elliptic low pass filter prototype

The band-stop filter in Fig.5 is centered at the design frequency and produces the band-stop response with a pair of transmission zeros, illustrated in Fig.3. Introduced by having the cross coupling between resonators, achieved using the crossing line. The quasi-elliptic band-stop filter circuit using [13] is shown in Fig.5, where the L-C circuits have been replaced by half wavelength resonators, which are coupled to the main transmission line by coupling capacitors. The equivalent circuit of the proposed quasi-elliptic band-stop filter is shown in Fig. 6.

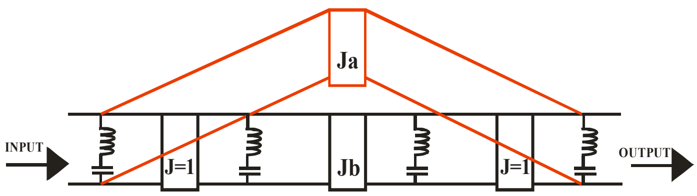

Fig.5. Quasi-elliptic band-stop filter circuit

B. *4-Pole Bandstop Filter Synthesis*

For the four pole quasi-elliptic filter, the design starts with a Chebyshev low pass filter prototype. In order to obtain the final filter layout, the J inverter used to achieve the cross coupling between resonators, is implemented using an interdigital capacitor, and by selecting an appropriate crossing line length [14], as shown in Fig. 7.

This is done because if the cross coupling was to be implemented by a section of transmission line, the resulting admittance of the *J* inverter becomes impractical for fabrication, since the impedance required for the crossing line would have an unpractical high impedance value. The value of the capacitance required and the length of the crossing lines are calculated using the following formulas [14].

$$Y = \frac{J}{\tan\left|\frac{\theta}{2}\right|} \tag{3}$$

$$B = \frac{J}{1-\left(\frac{J}{Y}\right)^2} \tag{4}$$

$$C = \frac{\frac{B}{Z_0}}{2\pi f_0} \tag{5}$$

Where, J is the admittance inverter value of the crossing line shown in Fig. 5, θ is the electrical length of the crossing line, shown in fig 6, and is chosen in such a way that the admittance Y of the crossing line corresponds to a 50 ohm impedance. Z_0 is chosen as 50 ohms, and f_o is the center frequency of the filter. C is the capacitance required for the interdigital capacitor.

The series capacitance for the interdigital capacitor can be calculated by using the following expressions [15].

$$C_{series} = \frac{\varepsilon_r + 1.0}{w} l\left[(N-3.0)A_1 + A_2\right] \tag{6}$$

Where,

$$A_1 = \left[0.3349057 - 0.15287116\left(\frac{t}{x}\right)\right]^2 \tag{7}$$

$$A_2 = \left[0.50133101 - 0.22820444\left(\frac{t}{x}\right)\right]^2 \tag{8}$$

Where, ε_r is the permittivity of the substrate, w is the width of the interdigital capacitor, N is the number of fingers of the interdigital capacitor, t is the thickness of the metal used to form the fingers of the interdigital capacitor, and x is the width of the fingers used for the interdigital capacitor, and l is length of the finger, this expression is valid for $h › w/N$, where h is the height of the substrate. The interdigital capacitor is then optimized using [15].The low pass element g, and J values used for this filter are: Ω_a=1.85, g_1 = 0.9583, g_2 = 1.41, J_a= 1.1 and J_b= 0.1969. The J=1 inverters are realized with 50Ω, λ/4 transmission lines. J_a and J_b have opposite signs hence they are implemented by 180° out of phase transmission lines (90° and 270°). The de-normalized impedance value for J_a= 1.1 is 45Ω and for J_b= 0.1969 it is 253Ω.

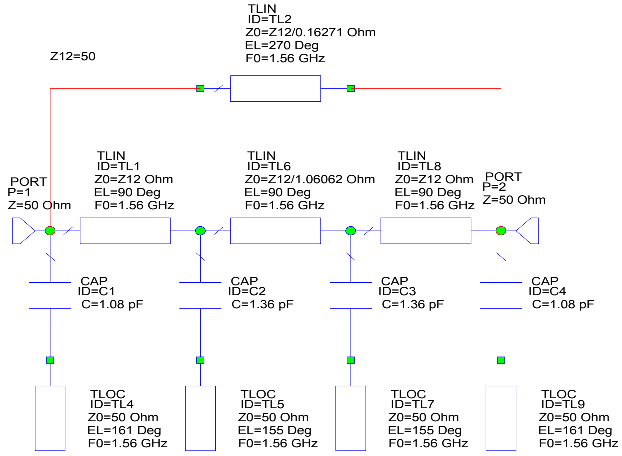

Fig.6. Quasi-elliptic band-stop filter circuit

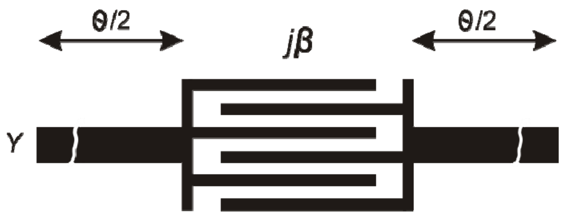

Fig.7. Crossing line practical implementation

The filter was designed in microstrip on a 0.787 mm thick RT/Duroid 5880 substrate, with ε_r = 2.2, and tanδ = 0.0002. The λ/2 resonators were miniaturized 50% from a length of 72 mm to 35 mm by adding a capacitive patch to ground as shown in Fig.8. The proposed resonators are coupled to the main transmission line using an interdigital capacitor. The normalized reactance-slope parameter related to the degree of coupling between the resonators and the main transmission line is given by (9) [17].

$$\frac{x_i}{Z_0} = \frac{1}{g_i \Delta FBW} \tag{9}$$

Where, Z_0 is the characteristic impedance of the main transmission line and ΔFBW is the 3dB fractional bandwidth of the filter. The reactance slope parameter can be calculated with equation (10) by varying the capacitive coupling between a single resonator and the main line on a full wave simulator [13].

$$\frac{x}{Z_0} = \frac{f_0}{2BW_{3dB}} \tag{10}$$

Where, f_0 is the resonator center frequency response and BW_{3dB} is the 3 dB response of the transmission line-resonator circuit. Since the 253Ω transmission line is not practical for fabrication it was replaced by a capacitance of 0.08 pF and a 50 Ω line with and electrical length of 365°. The final layout of the 4-pole band-stop filter is shown in Fig.8.

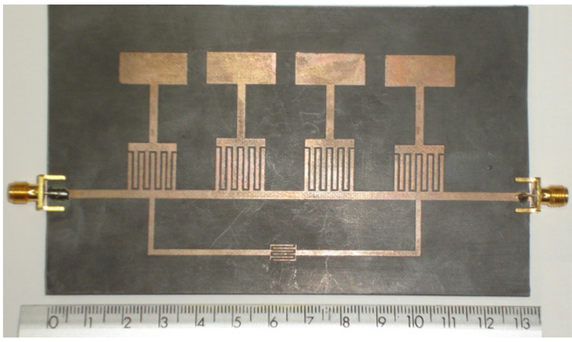

Fig.8. Photograph of the 4–Pole filter

C. *Triplet Filter Design*

Triplet BS filters require 3 decoupling resonators connected by J=1 immittance inverters and a cross coupling line of 180° out of phase to give negative coupling. As suggested in [17] CAD optimization can be utilized to obtain the parameter values. The procedure starts by designing a 3 pole Chebyshev filter to have the initial coupling matrix conditions for the optimizer. Then a 180° out-of phase cross-coupling line is added between the first and third resonators (Fig. 9). In this case, the transmission lines between resonators 1-2, and 2-3 are 270° long so the cross coupling line was chosen as 90°. The CAD optimization was carried out using [13], the goal was set to have a transmission zero at 1.49 GHz. The optimized coefficients correspond to the coupling capacitances (C_1, C_2, C_3) between the decoupling resonators 1, 2 and 3 respectively to the main transmission line, and the impedance (Z_c) of the cross-coupling line. The final values are C_1=C_3=0.9pF, C_2=0.98pF and Z_c=200 Ω.

Once the filter coupling parameters were acquired, the next step was to obtain the layout components of the circuit. The same miniaturized capacitive-patch resonators were used. The coupling capacitors were substituted by interdigital capacitors optimized in [13]. Finally, due to the manufacturing difficulty of implementing the 200Ω, 90° cross-coupling line, it was replaced by a capacitance of 0.49pF and a 50Ω, 320° transmission line. The filter structure is shown in Fig.9.

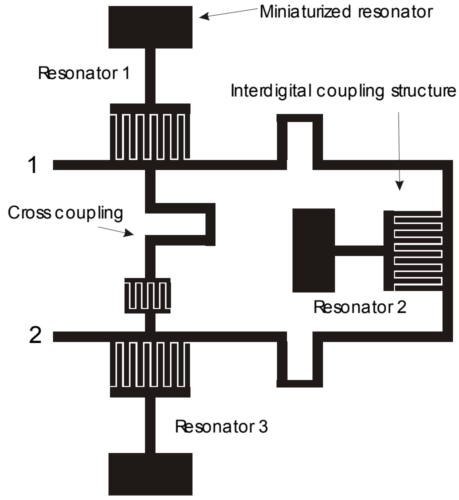

Fig.9. 3-Pole filter layout

III. SIMULATION AND MEASURED RESULTS

The simulated and measured responses of the 4-pole filter are shown in Fig.10. The bandwidth remained the same when comparing the simulations with the measurements both having a 5% fractional bandwidth. A slight frequency shift and mismatch in magnitude is observed that is believed to be caused by fabrication and substrate tolerances. The transmission zeros at the stop-band have been successfully demonstrated using the filter design technique discussed in this paper.

The simulated and measured responses of the 3-pole filter are shown in Fig.11. The experimental response was shifted 80MHz upwards due to manufacturing tolerances. As in the simulation response, the experiment shows an increased selectivity as a result of the transmission zero at the upper side of the band of 1.25dB/MHz, compared to 0.8dB/MHz at the lower side.

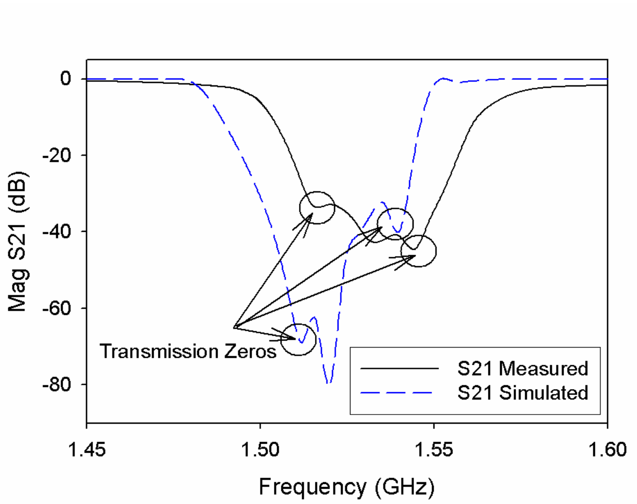

Fig.10. Simulated and experimental response of 4-pole filter

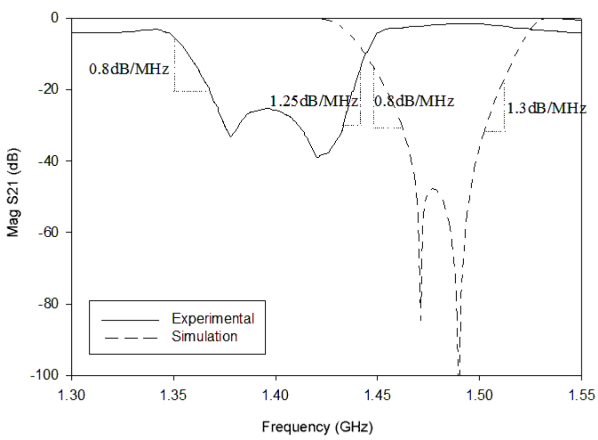

Fig.11. Simulated and experimental response of 3-pole filter

IV. CONCLUSIONS

A new quasi-elliptic band-stop filter design procedure and synthesis was demonstrated. The practical implementation of the proposed 4-pole and 3-pole filters using microstrip transmission lines was discussed, and experimental values were compared to simulation results, showing a good agreement. These filters have improved passband to stop-band transition, compared to conventional Chebyshev designs.

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