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DESIGN AND SYNTHESIS OF QUASI-ELLIPTIC TRIPLE MODE FILTER

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Abstract—The design and synthesis of quasi-elliptic triple-mode filter with three transmission poles and three transmission zeros are presented in this paper. The transfer and reflection filtering functions are obtained to get the even- and odd-mode admittances. The synthesized admittances give the even- and odd-mode networks, routing structure and coupling matrix of the filter. The microstrip prototype of the quasi-elliptic triple-mode filter is designed and realized to prove the feasibility of the approach. The filter is realized by having a capacitive coupling between the input and the output of a proposed triple mode resonator. The results show an excellent agreement with the theories.

1. INTRODUCTION

Elliptic and pseudo-elliptic filters offer optimal solutions to filtering function with high selectivity and low in-band insertion loss. This is achieved by shifting the transmission zeros of a N-degree filter network from infinite frequencies to finite frequencies [1–3]. Various cross-coupled filter networks with non-adjacent resonator couplings have been introduced to implement such transmission zeros at finite frequencies; however only a maximum number of N-2 transmission zeros could be realized with N-degree resonators [4–6]. It has recently been shown that N finite transmission zeros can be generated with N resonators with additional couplings between the source and load of the filter [7–9]. The synthesis of canonical folded filter topology with source-load coupling was presented for N-even order symmetric filters based on coupling extraction techniques which also give N finite

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transmission zeros [10, 11]. Recently, the synthesis of N-odd order filter with N zeros was first presented based on adaptive technique [12]. The present work shows an alternative filter topology for N-odd order filter realization which allows the introduction of N transmission zeros, yielding the optimum selectivity filtering function close to elliptic response. Synthesis and derivation of filter network based on the prescribed quasi-elliptic function response are shown in this paper where an experimental prototype is realized and presented to demonstrate the feasibility of the approach. As miniaturization is one of the key requirements for a filter, a novel stepped impedance triple mode resonator is adopted where a compact design is shown.

2. TRANSMISSION AND REFLECTION POLYNOMIALS

Let's synthesize a degree $N = 3$ transfer function with N transmission zeros located at $\omega = +5, -5, +3$ (rad/sec).

The transfer and reflection functions can be defined in term of the rational polynomials as discussed in [13]. For the filter with return loss level of 20 dB, the filtering function and corresponding reflection function are:

$$S_{21}(p) = \frac{M(p)}{D(p)} \tag{1}$$

$$S_{11}(p) = \frac{N(p)}{D(p)} \tag{2}$$

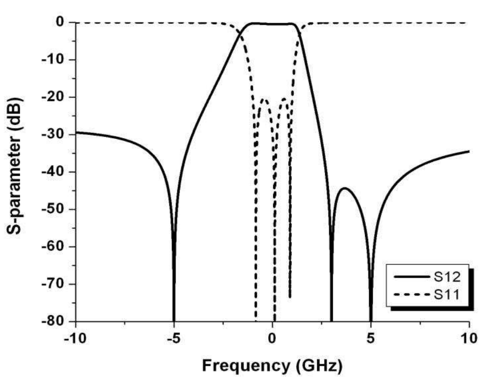

Figure 1. Transmission and reflection responses.

where

$$M(p) = j0.035\,(p - j5)\,(p + j5)\,(p - j3) \tag{3}$$
$$N(p) = 0.999(p - j0.116)(p - j0.897)(p + j0.841) \tag{4}$$
$$D(p) = (p + 1.21 - j0.299)(p + 0.392 - j1.28)(p + 0.716 + j1.404) \tag{5}$$

The transmission and reflection responses of S_{12} and S_{11} in dB are shown in Fig. 1, which clearly shows three resonant frequencies at the passband and three transmission zeros beyond the passband, i.e., one is at the lower side and two at the high side of the passband.

3. ODD- AND EVEN-MODE ADMITTANCE NETWORKS

From the expressions of S_{11} and S_{12}, with respect to the even- and odd-mode admittances as shown in [14], the expressions of even- and odd-mode admittances of the network will be obtained as the following

$$Y_{odd}\,(p) = j0.0175 + \frac{1.208}{p - j0.278} \tag{6}$$

and

$$Y_{even}\,(p) = -j0.0175 + \frac{1.109}{p + j0.435 + \frac{1.928}{p - j0.331}} \tag{7}$$

The synthesized odd- and even-mode admittances give the odd- and even-mode networks as shown in Fig. 2 and Fig. 3, respectively. Here $K_1 = 0.0175$, $K_2 = -0.278$, $K_3 = 0.435$, $K_4 = -0.331$ and

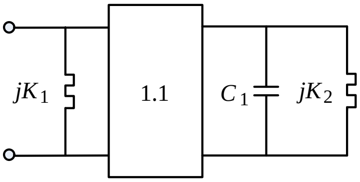

Figure 2. Odd-mode network.

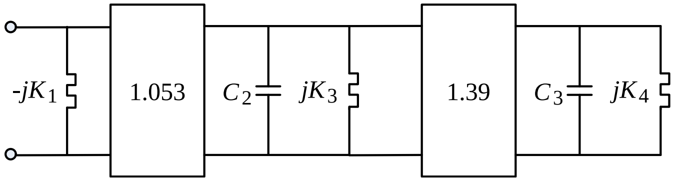

Figure 3. Even-mode network.

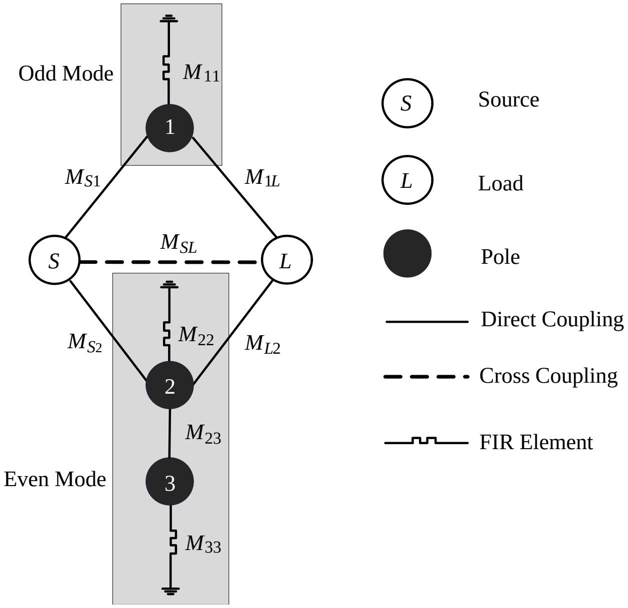

Figure 4. Routing structure of the quasi-elliptic triple mode filter.

$C_1 = C_2 = C_3 = 1$. Note that the elements of values jK_1, jK_2, jK_3, and jK_4 shown in the networks are the FIR (Frequency-Invariant Reactance) elements.

The routing structure of the quasi-elliptic triple mode filter is shown in Fig. 4.

Based on the routing structure in Fig. 4, the synthesized coupling matrix is obtained as

$$M = \begin{bmatrix} 0 & 1.1 & 1.053 & 0 & 0.0175 \\ 1.1 & -0.278 & 0 & 0 & 1.1 \\ 1.053 & 0 & 0.435 & 1.39 & -1.053 \\ 0 & 0 & 1.39 & -0.331 & 0 \\ 0.0175 & 1.1 & -1.053 & 0 & 0 \end{bmatrix} \tag{8}$$

4. QUASI-ELLIPTIC TRIPLE MODE FILTER PROTOTYPE

Shown in Fig. 5 is the microstrip circuit prototype of quasi-elliptic triple mode filter. The coupling between the input and output of the triple mode resonator is obtained by an interdigital capacitor of value 0.1 pF. The chip capacitors with the value of 0.7 pF are used

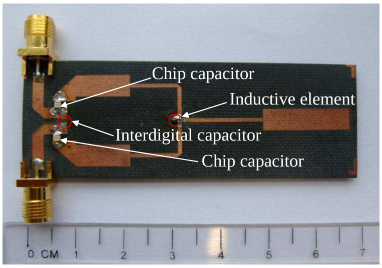

Figure 5. Microstrip prototype of the quasi-elliptic filter.

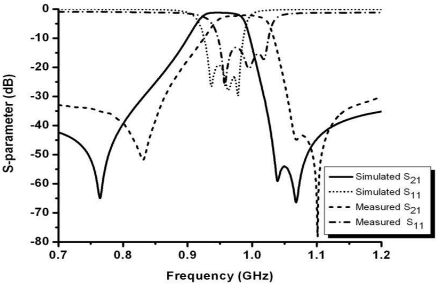

Figure 6. Simulated and measured transmission and reflection responses of the quasi-elliptic triple mode filter.

to couple the input and output to the resonator as shown. Note that the chip capacitor package's parasitic is relatively insignificant at low frequencies where the effect can usually be ignored. The filter prototype was fabricated on Roger RT Duroid 5880 substrate with a thickness of 787 µm and dielectric constant of 2.2. The inductive element is realized by a short circuit via hole shunted at the mid-point of the resonator. The dimension of the circuit is 7 cm × 2.8 cm.

The simulated and measured transmission and reflection responses of the filter are shown in Fig. 6. It is successfully demonstrated that the filter can achieve the quasi-elliptic triple mode response with three transmission zeros and three transmission poles. The filter has a center frequency of 0.98 GHz shifted slightly to the right compared to the simulated responses at 0.96 GHz, due to the presence of the chip capacitors which result in resonant frequency variation. Moreover, this shift is due also to the fabrication error. Besides, these chip capacitors also contribute to the passband loss.

It will also be noticed that one transmission zero of the filter is located at the lower side of the passband and the other two transmission zeros at the higher side of the passband.

5. CONCLUSIONS

Synthesis and derivation of filter network based on the prescribed quasi-elliptic function response are presented and discussed. In this synthesis, the transfer and its corresponding reflection polynomials are obtained. The transmission and reflection responses clearly show three transmission poles and three transmission zeros. From the polynomials, the even- and odd-mode admittances are obtained. The synthesized admittances give the corresponding even- and odd-mode networks. Consequently, the routing structure is also included along with the complete coupling matrix of the filter. The experimental prototype of the quasi-elliptic triple-mode resonator filter is designed and fabricated. It is realized by having a capacitive coupling between the input and output of a proposed triple mode resonator. The chip capacitors are used to achieve the coupling between the input and output to the resonator. As a consequence, the resonant frequency variation occurs, and the passband loss increases. It is successfully demonstrated that the filter can achieve the quasi-elliptic triple mode response with three transmission zeros and three transmission poles. The experimental work shows an excellent agreement with the theory.

REFERENCES

1. Zhu, Y.-Z. and Y.-J. Xie, "Novel microstrip bandpass filters with transmission zeros," *Progress In Electromagnetics Research*, Vol. 77, 29–41, 2007.
2. Mo, S.-G., Z.-Y. Yu, and L. Zhang, "Design of triple-mode bandpass filter using improved hexagonal loop resonator," *Progress In Electromagnetics Research*, Vol. 96, 117–125, 2009.
3. Kuo, J.-T., S.-C. Tang, and S.-H. Lin, "Quasi-elliptic function bandpass filter with upper stopband extension and high rejection level using cross-coupled stepped-impedance resonators," *Progress In Electromagnetics Research*, Vol. 114, 395–405, 2011.
4. Rosenberg, U. and S. Amari, "Novel coupling schemes for microwave resonator filters," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 50, No. 12, 2896–2902, Dec. 2002.
5. Cameron, R. J., A. R. Harish, and C. J. Radcliffe, "Synthesis of advanced microwave filters without diagonal cross-couplings," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 50, No. 12, 2862–2872, Dec. 2002.
6. Cameron, R. J., "General coupling matrix synthesis methods for Chebyshev filtering functions," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 47, No. 4, 433–442, Apr. 1999.
7. Cameron, R. J., "Advanced coupling matrix synthesis techniques for microwave filters," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 51, No. 1, 1–10, Jan. 2003.
8. Shaman, H. and J.-S. Hong, "A novel ultra-wideband (UWB) bandpass filter (BPF) with pairs of transmission zeroes," *IEEE Microwave and Wireless Components Letters*, Vol. 17, No. 2, 121–123, Feb. 2007.

9. Shaman, H. and J.-S. Hong, "Input and output cross-coupled wideband bandpass filter," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 55, No. 12, 2562–2568, Dec. 2007.
10. Montejo-Garai, J. R., "Synthesis of N-even order symmetric filters with N transmission zeros by means of source-load cross coupling," *Electronics Letters*, Vol. 36, No. 3, 232–233, Feb. 3, 2000.
11. Amari, S., "Direct synthesis of folded symmetric resonator filters with source-load coupling," *IEEE Microwave and Wireless Components Letters*, Vol. 11, No. 6, 264–266, Jun. 2001.
12. Amari, S., U. Rosenberg, and J. Bornemann, "Adaptive synthesis and design of resonator filters with source/load-multiresonator coupling," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 50, No. 8, 1969–1978, Aug. 2002.
13. Cameron, R. J., C. M. Kudsia, and R. R. Mansour, *Microwave Filters for Communication Systems*, 207–242, New Jersey, USA, 2007.
14. Hunter, I. C., *Theory and Design of Microwave Filter,* The Institution of Engineering and Technology, London, UK, 2001.