ASYMMETRIC CANONICAL DIELECTRIC RESONATOR FILTERS

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ABSTRACT

Miniature, high performance asymmetric canonical filters utilizing dual-mode dielectric resonators are discussed. Filter synthesis is accomplished by proper rotations of the canonical coupling matrix. As an example, performance of realized 6-pole asymmetric canonical (6-4) and 8-pole self-equalized (8-4-2) filters are presented.

Introduction

Canonical bandpass filters offer greater flexibility of response and improved electrical performance due to the fact that the maximum number of permissible independent crosscouplings is utilized (Fig. 1). Such filters implemented in a dual mode cavity configuration were introduced by Williams and Atia [1]. The coupling matrix of these filters is symmetrical. Consequently to provide necessary crosscouplings, the location or routing (numbering) of the individual resonators was such that input and output ports of the filter were located in the same physical cavity (Fig. 2a). Therefore, meeting input/output isolation requirements caused significant problems. For this reason, a novel 6-pole canonical filter was proposed by Pfitzenmaier [2], and later expanded to 8 or more pole filters [3]. In Pfitzenmaier's realization, like in the previous case, a maximum number of permissible independent crosscouplings is utilized. However the coupling matrix is asymmetrical and routing is such that input/output ports of the filter are located in adjacent physical cavities (Fig. 2b), eliminating the problem of out-of-band isolation. In this paper, the synthesis procedure of asymmetric canonical filters from a symmetric prototype will be outlined. Rotation formulas and proper pivots will be given for important 6 and 8-pole cases. It will be shown that only one rotation of the coupling matrix is necessary to achieve a 6-pole asymmetric canonical filter, and 2 rotations for 8-pole case. A novel miniature implementation utilizing dual-mode dielectric resonators will be also discussed.

Theoretical Basis

A symmetric canonical coupling matrix has a tridiagonal form presented in Fig. 3a (8-pole case). Coupling and routing diagram of the corresponding filter is shown in Fig. 3b. It can be seen that main couplings are those parallel to the main diagonal. The weaker crosscouplings are positioned antidiagonally and they are between n and 1, n-1 and 2 resonators, etc. Filters with such couplings can be realized in a folded single-mode configuration or a dual-mode configuration with input/output in the same cavity. To achieve the same transfer function, but with an asymmetrical coupling matrix, we will utilize the well known theory of similarity transformations of the matrices. Namely, if matrix M is premultiplied by a certain matrix A, and post multiplied by transpose of A, a resultant matrix M^1, will have the same eigenvalues and eigen vectors. The filter described by this new matrix will have the same transfer function [7]. Therefore we have

$$M' = AMA^T \qquad (1)$$

It is convenient to utilize matrix plane rotations as similarity transformations, and in such a case matrix A has a form of unit matrix except that for pivot (i, k) - matrix elements

$$A_{ik} = -\sin\psi$$
$$A_{ki} = \sin\psi \qquad (2)$$
$$A_{ii} = A_{kk} = \cos\psi$$

where; ψ - angle of rotation. Iterative procedure for rotations was outlined in [4]. However, in our case, it was difficult to implement and converge due to the fact that pivot selection and order of rotations is crucial in obtaining the desired result. Also there does not seem to be any pattern governing the pivotal positions or order of rotations for different orders of the filters [6]. For this reason, we will present very simple formulas derived analytically to obtain asymmetric coupling matrices from symmetric canonical matrix for 6 and 8-pole cases. According to [4], after rotation by pivot (i, k) (where i, k = 2, 3.....n-1), new elements of M matrix are given by

$$M'_{lk} = M_{lk}\cos\psi + M_{li}\sin\psi$$
$$M'_{li} = M_{li}\cos\psi - M_{lk}\sin\psi$$
$$M'_{ii} = M_{ii}\cos^2\psi + M_{kk}\sin^2\psi - 2M_{ik}\sin\psi\cos\psi$$
$$M'_{kk} = M_{kk}\cos^2\psi + M_{ii}\sin^2\psi + 2M_{ik} \times \sin\psi\cos\psi \qquad (3)$$
$$M'_{ik} = M'_{ki} = M_{ik}(\cos^2\psi - \sin^2\psi) + (M_{ii} - M_{kk})\sin\psi\cos\psi$$

In a 6-pole symmetric canonical case, the coupling matrix is presented in Fig. 4. Analyzing formulas (3) and form of matrix in Fig. 4, it is obvious that one of the pivot selection criteria should be that matrix M has 0 element in pivotal position (i, k). In such a case, we avoid creation of unwanted diagonal elements of new matrix M. Therefore, we have initial choice of pivot (4, 2) or (5, 3). It was found that the (4, 2) pivot creates desired coupling matrix, realizable in filter configuration of Fig. 2b, where coupling 2-5 was replaced by 1-4. Elements of the new coupling matrix after (4, 2) rotation are given by:

$$M'_{12} = M_{12}\cos\psi$$
$$M'_{32} = M_{32}\cos\psi + M_{34}\sin\psi$$
$$M'_{34} = M_{34}\cos\psi - M_{32}\sin\psi \qquad (4)$$
$$M'_{54} = M_{54}\cos\psi - M_{52}\sin\psi$$
$$M'_{14} = -M_{12}\sin\psi$$

$M'_{16} = M_{16}$ (original value)

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$$M'_{56} = M_{56} \quad \text{(original value)}$$

$$\psi = \operatorname{atan}\left(-\frac{M_{52}}{M_{54}}\right)$$

In the case of an 8-pole filter, the initial matrix has the form of Fig. 3a. Utilizing the same criterion as before for selecting pivots (0-i, k matrix element for i, k pivot), we have the following choice; (2-,4), (2,5), (2, 6) (3, 5), (3, 7), (4, 6), (4, 7), (5, 7). To achieve the desired form of coupling matrix and realize an asymmetric filter, we have to replace couplings 2-7 and 3-6 with couplings 3-8 and 4-7 (Fig. 5). It was found that two pivots; first (7, 3) and second (4, 6) give the desired result. Formulas for asymmetric coupling matrix are given by:

$$M'_{23} = M_{23}\cos\phi - M_{27}\sin\phi$$
$$M'_{45} = M_{45}\cos\Theta - M_{56}\sin\Theta$$
$$M'_{56} = M_{56}\cos\Theta + M_{54}\sin\Theta$$
$$M'_{67} = (M_{67}\cos\phi + M_{63}\sin\phi)\cos\Theta + M_{43}\sin\Theta\sin\phi$$
$$M'_{43} = M_{43}\cos\Theta\cos\phi - (M_{63}\cos\phi - M_{67}\sin\phi)\sin\Theta \qquad (5)$$
$$M'_{78} = M_{78}\cos\phi$$
$$M'_{83} = -M_{87}\sin\phi$$
$$M'_{74} = M_{43}\sin\phi\cos\Theta - (M_{67}\cos\phi + M_{63}\sin\phi) \times \sin\Theta$$

where

$$\phi = \operatorname{atan}\left(-\frac{M_{27}}{M_{23}}\right)$$

$$\Theta = \operatorname{atan}\left(\frac{M_{63}\cos\phi - M_{67}\sin\phi}{M_{43}\cos\phi}\right)$$

$$M'_{12} = M_{12} \quad \text{(original value)}$$

$$M'_{18} = M_{18} \quad \text{(original value)}$$

Formulas (4) and (5) give a fast and exact way to design asymmetric canonical 6 and 8-pole filters. They were successfully used to design filters described in the following section.

Experimental Results

Using formulas (4) and (5), a number of 6 and 8-pole, C-Band filters were designed and realized. Basic configuration of filters utilizes dual-mode dielectric resonator loaded cavities [5]. In this particular approach, a dramatic reduction in the weight and volume of the filters was achieved without significant reduction of the filter performance. Typical performance of a 6-pole asymmetric canonical filter (6-4) is presented in Fig. 6. An 8-pole filter performance (self equalized 8-4-2) is presented in Fig. 7 and shows an excellent correlation with theory.

Conclusion

An approach to design optimum performance, asymmetric canonical filters from symmetrical designs was presented. A simple formula for values of asymmetric coupling matrix in important 6 and 8-pole filter cases were given. Novel realizations utilizing dielectric resonators offer dramatic reduction in weight and volume of the filters while maintaining excellent electrical performance. This approach presents significant advancement in satellite transponder applications.

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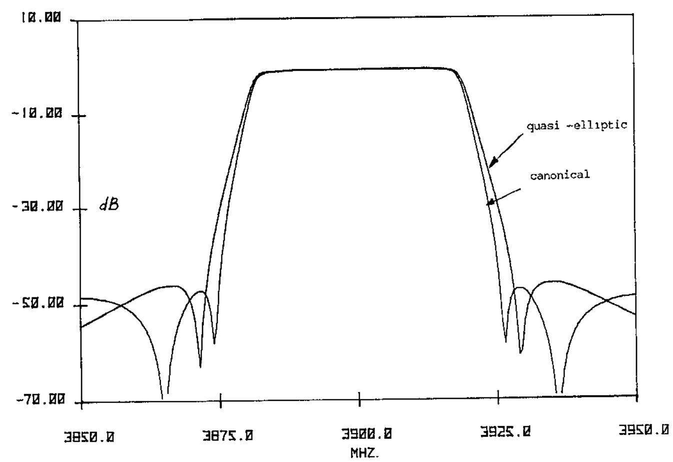


Fig. 1 Comparison (Rejection) Between a 6-pole Quasi-Elliptic Filter (6-2) and canonical 6-pole filter (6-4).

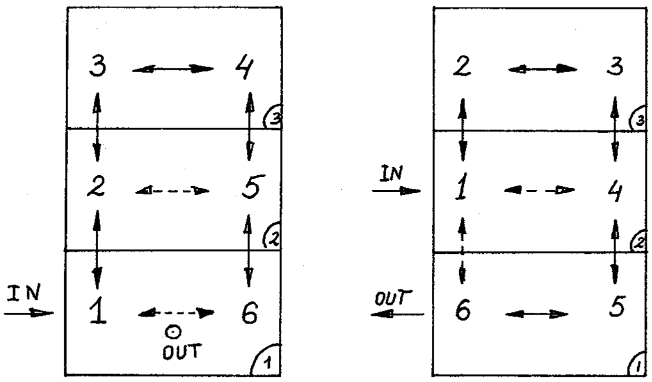


Fig. 2

main coupling
crosscoupling

a) A 6-pole Symmetric, Dual Mode, Canonical Filter Configuration

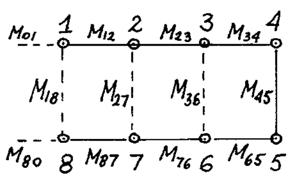
b) A 6-pole Assymmetric, Dual Mode Canonical Filter Configuration

(Left Side Number Describes Mode in a Cavity With E-Field Parallel to Plane of the Paper; Right Side Number - Looking Into Paper).

a)

	M_{12}						M_{18}
M_{21}		M_{23}				M_{27}	
	M_{32}		M_{34}		M_{36}		
		M_{43}		M_{45}			
			M_{54}		M_{56}		
		M_{63}		M_{65}		M_{67}	
	M_{72}				M_{76}		M_{78}
M_{81}						M_{87}	

b)



$M_{12} = M_{78}$ ... etc.

$M_{21} = M_{12}$ ... etc.

Fig. 3

a) A Symmetric Canonical Coupling Matrix of 8-Pole Filter

b) Routing Diagram for a Symmetric, 8-pole Canonical Filter

	M_{12}				M_{16}
M_{21}		M_{23}		M_{25}	
	M_{32}		M_{34}		
		M_{43}		M_{45}	
	M_{52}		M_{54}		M_{56}
M_{61}				M_{65}	

Fig. 4

Coupling Matrix of a Symmetric Canonical 6-Pole Filter

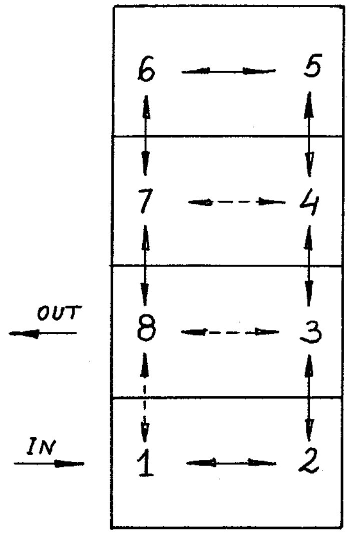


Fig. 5

Configuration of an 8-Pole Asymmetrical Canonical Filter.

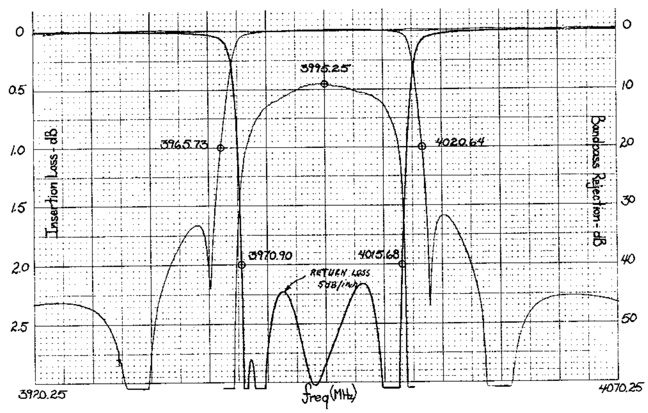


Fig. 6

Performance of a 6-Pole Asymmetric Canonical Filter (6-4) Utilizing Dielectric Resonators

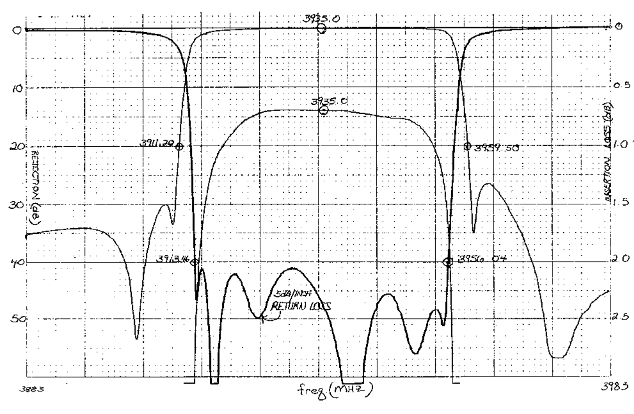


Fig. 7

Performance of an 8-Pole Asymmetrical Self. Eq. Filter (8-4-2) Utilizing Dielectric Resonators