DIRECT SYNTHESIS OF CASCADED QUADRUPLET (CQ) FILTERS

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ABSTRACT

Previous designs for CQ filters have required matrix rotation operations on the coupling matrix of the canonic form of the cross-coupled filters. This is a rather awkward and not entirely satisfactory process since the theory is not general, requiring the application of equations specific to each order of filter, and in fact has been developed only as far as even order 10. A new direct CQ synthesis has now been discovered having no such limitations.

INTRODUCTION

A CQ filter consists of cascaded groups of 4 cavities or nodes, each with one cross coupling. This is illustrated by the 8th-order coupling diagram of Fig. 1, which

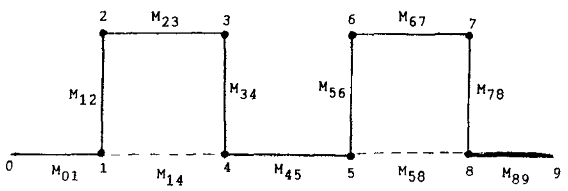


Fig. 1 Coupling diagram of an eighth order CQ filter

contains two CQ sections separated by one normal main coupling, M_{45}. Restrictions on the form of transfer function for this type of network are well documented, e.g. [1]. In particular the transmission zeros must be on either the real or imaginary axes, and no complex transmission zeros are allowed. The CQ structure has the advantage that each CQ section is entirely responsible for producing one transmission zero. This is not the case for other realizations such as the canonic structure where each cross coupling affects all the transmission zeros, making the filter more difficult to tune. The simpler tunability of CQ filters makes them attractive for commercial applications where cost is a prime consideration.

Previously the only known method for designing CQ filters has been by applying matrix rotations to the canonic form of the network for which synthesis techniques exist [1]. A method for extracting CQ sections directly from the transfer function has now been formulated as described in the following sections.

DIRECT CQ SYNTHESIS

Initially the extraction of a CQ section from a low pass transfer funcion would seem to be an impossible task because the CQ section is of such high degree and contains several independent parameters. Each of the nodes shown in the example of Fig. 1 has a capacitor to ground as well as main line and possibly cross couplings. However actually a shunt capacitor may be extracted, and the remaining portion of the CQ section is shown in Fig. 2. The capacitor at node 4 may be disregarded, being extracted after the CQ portion has been dealt with.

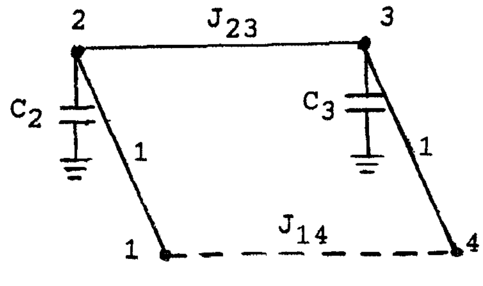


Fig. 2 Partial CQ section equivalent to a Brune or C section

In Fig. 2 the lines joining the nodes are admittance inverters, and inverters J_{12} and J_{34} may be set to unity admittance without loss of generality. The transfer matrix of this partial CQ section may be derived as

$$\frac{1/(1-J_{14}J_{23})}{1-\omega^2/\omega_o^2)} \begin{bmatrix} C_2\omega/J_{23} & j(C_2C_3\omega^2/J_{23}-J_{23}) \\ j[J_{14}^2C_2C_3\omega^2 - (J_{14}J_{23}-1)^2]/J_{23} & C_3\omega/J_{23} \end{bmatrix} \qquad \ldots\ldots\ldots\ldots(1)$$

where

$$\omega_o^2 = J_{14}C_2C_3/[(J_{14}J_{23}-1)J_{23}] \qquad (2)$$

This is a matrix of degree 2 in ω. The proof that it is extractable from the overall transfer matrix of the network follows from the fact that apart from a trivial rotation of the matrix parameters due to having an odd number of admittance inverters in the main path and also the inclusion of an ideal transformer, matrix (1) is exactly that for either a Brune section or C-section, e.g. [2].

Appropriate extraction techniques for such sections are well known, and in fact necessary and sufficient conditions which guarantee that such extractions are always possible have been published [2]. The extraction process for CQ sections using matrix (1) need not be detailed here since an alternative procedure which requires no new synthesis programming has been obtained, as described below.

DERIVATION OF CQ FILTERS FROM LOWPASS FILTERS - A NEW NETWORK TRANSFORMATION.

In the previous section the existence of a general CQ synthesis was demonstrated. However rather than having to write a special synthesis program, it has been convenient to transform simple cascaded lowpass filters of defined topology into CQ form using an interesting circuit transformation. As an example, the form of circuit to be transformed is shown in Fig. 3(a) for the 8th degree case. This has a 4th ordered attenuation pole at infinity and a pair of second degree finite poles, giving total degree 8. The synthesis of this filter was performed using an existing program for the synthesis of generalized lowpass filters, but may be carried out also using the commercially available program FILSYN [3].

The first step in the transformation of this circuit into a CQ filter is to replace each simple series inductor by a cascade of a shunt capacitor flanked on each side by admittance inverters, as shown in Fig. 3(b). At this stage it is convenient also to incorporate the non-unity terminating resistance into one of the inverters.

Less obvious is the fact that a similar operation may be performed in the case of the inductors within the pole sections as shown in Fig. 3(c). Here we make use of the identity

$$\begin{bmatrix} 1 & jL \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} 0 & j \\ j & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ jC & 1 \end{bmatrix} \begin{bmatrix} 0 & -j \\ -j & 0 \end{bmatrix} \qquad (3)$$

where

$$C = L \qquad (4)$$

(The exact equality of (4) would be modified by a factor J^2 if the immittance inverters were of admittance J rather than unity, i.e. $C = J^2L$, giving the correct dimensional relationship).

It is very important to have one of the inverters in (3) have negative admittance to avoid a 1:-1 transformer. In the case of the single series inductors of step (a) to (b) such transformers are of no consequence since they do not affect the amplitude of the transfer function.

The circuit section between nodes 1 and 4 of Fig. 3(c) has the admittance matrix

$$\begin{bmatrix} C_1s & -J_{12} & 0 & 0 \\ -J_{12} & (C_2+C_{24})s & -1 & -C_{24}s \\ 0 & -1 & C_3s & 1 \\ 0 & -C_{24}s & 1 & (C_{24}+C_4)s \end{bmatrix} \qquad (5)$$

where the complex frequency variable s is used rather than $j\omega$.

In order to eliminate the 24 coupling row 2 is multiplied by $C_{24}/(C_2+C_{24})$ and added to row 4, and a similar operation applied to columns 2 and 4. The J_{12} entries are made unity by multiplying row 2 and column 2 by $1/J_{12}$, giving the equivalent admittance matrix

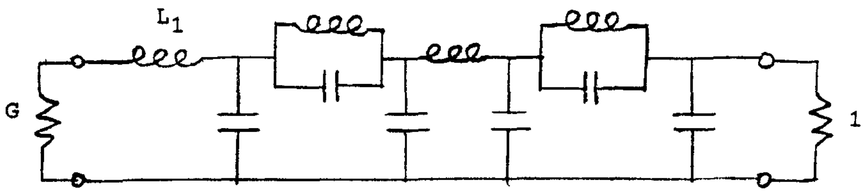
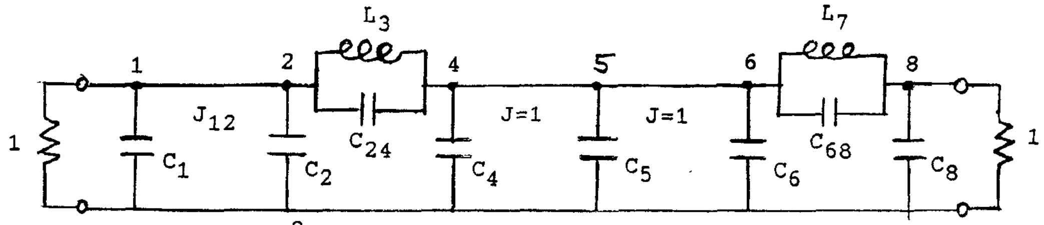


Fig. 3(a) Lowpass prototype filter



$C_1 = J_{12}^2 L_1$

$J_{12} = \sqrt{G}$

Fig. 3(b) First stage of transformation

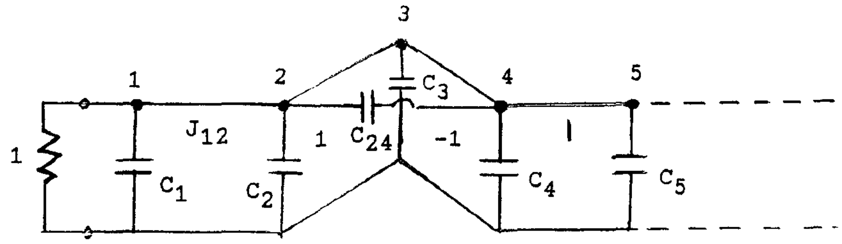


Fig. 3(c) Second stage of transformation

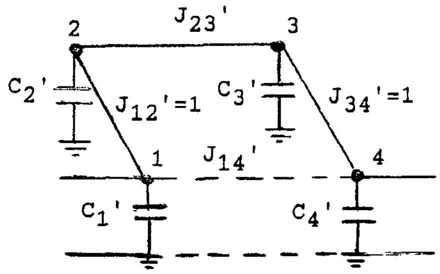


Fig. 3(d) Final conversion into CQ format:

$C_1' = C_1$ $\qquad C_2' = (C_2 + C_{24})/J_{12}^2$

$C_3' = [(C_2 + C_{24})/C_2]^2 . C_3$ $\qquad (C_3 = L_3)$

$C_4' = C_4 + C_2 C_{24}/(C_2 + C_{24})$

$J_{23}' = (C_2 + C_{24})/(C_2 J_{12})$ $\qquad J_{14}' = -C_{24} J_{12}/(C_2 + C_{24})$

$$\begin{bmatrix} C_1 s & -1 & 0 & \dfrac{-C_{24}J_{12}}{(C_2+C_{24})} \\ -1 & \dfrac{(C_2+C_{24})s}{J_{12}^2} & \dfrac{-1}{J_{12}} & 0 \\ 0 & \dfrac{-1}{J_{12}} & C_3 s & 1-\dfrac{C_{24}}{(C_2+C_{24})} \\ \dfrac{-C_{24}J_{12}}{(C_2+C_{24})} & 0 & 1-\dfrac{C_{24}}{(C_2+C_{24})} & C_4+\dfrac{C_2C_{24}}{(C_2+C_{24})}s \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

The process of making the off-diagonal elements 12 and 34 equal to -1 is completed by multiplying row and column 3 by the factor $(C_2+C_{24})/C_2$. The 34 terms could be transformed to unity only by introducing a multiplication factor to row and column 4 which would change the admittance looking to the right, and it is simpler not to carry this out.

The final step is the necessary and rather interesting one of multiplying row and column 4 by -1, which gives the 34 terms the correct negative sign and also changes the sign of the 14 terms. The final matrix is given below, and the resulting CQ section shown in Fig. 3(d).

$$\begin{bmatrix} C_1 s & -1 & 0 & \dfrac{C_{24}J_{12}}{(C_2+C_{24})} \\ -1 & \dfrac{(C_2+C_{24})s}{J_{12}^2} & \dfrac{-(C_2+C_{24})}{J_{12}C_2} & 0 \\ 0 & \dfrac{-(C_2+C_{24})}{J_{12}C_2} & \dfrac{(C_2+C_{24})^2}{C_2^2}C_3 s & -1 \\ \dfrac{C_{24}J_{12}}{(C_2+C_{24})} & 0 & -1 & C_4+\dfrac{C_2C_{24}}{(C_2+C_{24})}s \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots(7)$$

Note that if C_{24} is positive, corresponding to an attenuation pole, then the 14 term correctly represents a negative admittance inverter, whereas if C_{24} is negative, corresponding to a real axis pole, then the cross coupling inverter is positive.

The transformation is applied to each pole-producing section of the original lowpass filter, e.g. to nodes numbered 5,6 and 8 in Fig. 3(b), resulting in the complete CQ filter.

The element values have been compared to those obtained using matrix rotations, with identical results. The theory has been checked also by direct analysis of the derived CQ networks.

REFERENCES

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