LOW-SENSITIVITY ACTIVE FILTER REALIZATION USING ALL-PASS FIRST-ORDER SECTIONS

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Abstract – **The direct synthesis procedure for low-sensitivity analog and filters in the form of cascade interconnection of first order three-ports is presented. Any kind of transfer functions can be realized by proposed method. Illustrative example is given.**

Index terms: **Analog filters, Digital filters.**

I. Introduction

The design of low-sensitivity active RC and digital filters has resived considerable attention during the last two decades. Traditionally the synthesis procedure is based on simulation of passive LC filters [1, 2]. In [3-5] it has been shown that low-sensitivity analog and digital filters can also be designed directly, without starting from a passive prototype network. Direct synthesis of low-sensitivity active RC filters has a considerable advantages, because it does not needs the design of LC prototype network.

Another class of low-sensitivity digital filters are the Gray and Markel lattice structures and orthogonal digital filters [6, 7]. Similar structures may be obtained for active RC-filters too. In this correspondence a general synthesis procedure of analog filters, based on the extraction of first-order all-pass sections, is presented. The proposed procedure can be considered as an extension of the Gray and Markel method to analog domain.

II. The realization procedure

Consider the synthesized filter as a three-pair (Fig. 1). It can be characterized by the transfer matrix $\mathbf{T}$

$$\begin{bmatrix} y_1 \\ y_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} t_{11} & t_{12} & t_{13} \\ t_{21} & t_{22} & t_{23} \\ t_{31} & t_{32} & t_{33} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ y_3 \end{bmatrix}, \qquad (1)$$

or, equivalently, by the chain matrix $\mathbf{B}$

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}. \qquad (2)$$

In (1) and (2) x_1, x_2, y_3 are inputs and $y_1, y_{2,} x_3$ are outputs of the three-pair, s is a complex frequency variable.

The relation between the two types of two-pair parameters can be readily established as

$$b_{11} = t_{11} - t_{13}\frac{t_{31}}{t_{33}};\ b_{12} = t_{12} - t_{13}\frac{t_{32}}{t_{33}};$$

$$b_{13} = \frac{t_{13}}{t_{33}};\ b_{21} = t_{21} - t_{23}\frac{t_{31}}{t_{33}};\ b_{23} = \frac{t_{23}}{t_{33}}. \qquad (3)$$

$$b_{31} = \frac{t_{31}}{t_{33}};\quad b_{32} = \frac{t_{32}}{t_{33}};\quad b_{33} = \frac{1}{t_{33}}.$$

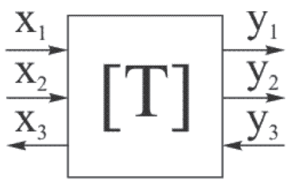

Fig. 1

The synthesis procedure amounts to factoring the chain matrix $\mathbf{B}$ into a product of first-order chain matrixes. The resulting structure is the interconnection of cascade of first-order three-pairs (Fig. 2).

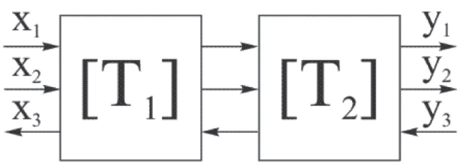

Fig. 2

The basic step of a synthesis procedure is the extraction of the first-order section, such that the chain matrix $\mathbf{B}_{i+1}$ is of low order. The lower index is the number of the extraction step. Extraction of a three-pair is equivalent to multiplication of $\mathbf{B}_{i-1}$ by $\mathbf{b}_i^{-1}$:

$$\mathbf{B}_i = \mathbf{B}_{i-1}\mathbf{b}_i^{-1}, \qquad (3)$$

where $\mathbf{b}_i$ is a chain matrix of the extracting section.

The realization algorithm is as follows.

1. Let $H(s) = \dfrac{N(s)}{D(s)}$ be the transfer function to be synthetized, $G(s) = \dfrac{D(-s)}{D(s)}$ - auxiliary allpass function. Determine the following elements of $\mathbf{T}$:
$$t_{31}(s) = \frac{N(s)}{D(s)};\ t_{32}(s) = \frac{D(-s)}{D(s)};\ t_{33}(s) = \frac{1}{D(s)}.$$
2. Find the elements of $\mathbf{B}$ according to (3):

$b_{31}(s) = N(s);\ b_{32}(s) = D(-s);\ b_{33}(s) = D(s).$

3. Order reduction of the chain matrix $\mathbf{B}$.
Apply (2) to $\mathbf{B}$. The first-order chain matrix is

$$[b]_i = \begin{bmatrix} 1 & 0 & 0 \\ \dfrac{-\nu \cdot k}{k^2-1} & \dfrac{-1}{k^2-1} & \dfrac{-k}{k^2-1} \\ \dfrac{\nu \cdot}{k^2-1} \cdot \dfrac{s+a}{s-a} & \dfrac{k}{k^2-1} \cdot \dfrac{s+a}{s-a} & \dfrac{1}{1-k^2} \cdot \dfrac{s+a}{s-a} \end{bmatrix}.$$

Corresponding transfer matrix is

$$[t]_i = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & k \cdot \dfrac{s-a}{s+a} \\ -\nu & -k & (k^2-1) \cdot \dfrac{s-a}{s+a} \end{bmatrix}. \quad (4)$$

In (4) $\nu = \dfrac{N(\infty)}{D(\infty)}$, $k = \dfrac{D(-a)}{D(a)}$, a is an arbitrary constant.

4. Repeat step 3 until order of $\mathbf{B}$ will reduce to zero.

The signal flow diagram of $\mathbf{t}_i$ defined by (4) is shown in Fig. 3.

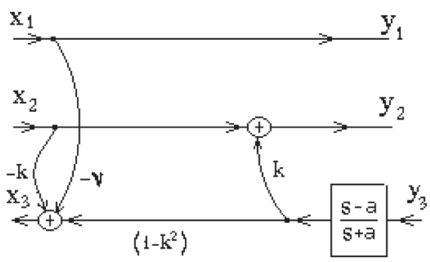

Fig. 3

Circuit realization of this three-pair using two operational amplifiers is shown in Fig. 4.

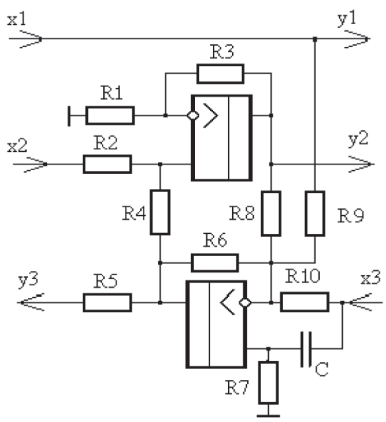

Fig. 4

III. Realization of second-order building blocks

The proposed method can be used for design both high order transfer functions and second order building blocks. As an illustrative example consider the realization of second-order bandpass filter. The signal flow diagram obtained by the proposed method is shown in Fig. 5.

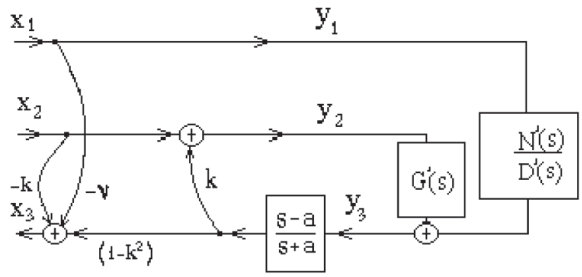

Fig. 5

Operational amplifier implementation of this structure is shown in Fig. 6. The transfer function of this network

$$H(s) = \frac{2 \cdot s}{C \cdot R_1 \cdot (\dfrac{R_4 + R_3}{R_3}) \cdot (s^2 + \dfrac{R_3 - R_4}{R_3 + R_4} \cdot \dfrac{2 \cdot s}{R_1 \cdot C} + \dfrac{1}{(R_1 \cdot C)^2})}$$

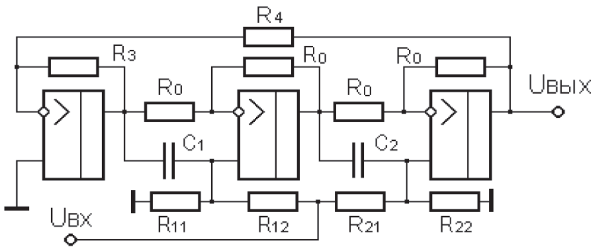

Fig. 6

It can be shown that proposed structure has extremely low sensitivity to component variations.

IV. Conclusion

A low-sensitivity active filter realization method has been presented. A method allows the design of an arbitrary transfer function. A connection with some known realizations was established.

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