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Realizations of DVCC Based Current Transfer Functions

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Abstract - *Kacar and Mahmut have proposed a single DVCC based configuration to realize first-order current-mode all-pass filters only. This paper has exploited this configuration to realize a wider class of current transfer function T(s), which has a pattern of poles and zeros of 1-T(s) as one of the four permissible patterns. Bilinear and biquadratic functions are dealt with in detail. It is shown that only bilinear functions can be realized with all the four passive elements grounded. The First-order all-pass function is a special case that needs only three elements (2R, 1C) or (1R, 2C). A biquadratic function requires (2R, 2C) elements and has all the capacitor grounded. The design of the second-order all-pass function is also given.*

Keywords—*Active realizations, Current transfer functions, Current mode, DVCC, Synthesis*

I. INTRODUCTION

There has been much interest in realizing all-pass functions since long [1]-[19]. While Rathore [1] deals with an *n*th order all-pass functions, others first order only. Some realizations focus on a minimum number of active and passive components, while some have few or all grounded passive elements. Some of them are voltage mode, while others are current-mode realizations.

Current-mode circuits are attractive because of their wider bandwidth, wider dynamic range, and lower power consumption than voltage-mode counterparts [19]. A current differencing buffered amplifier (CDBA) [14] and a current operational amplifier (COA) [15] based first-order current-mode all-pass filter configurations have been proposed.

Kacar and Mahmut [19] have presented a *current-mode* circuit using one DVCC for first-order all-pass filter only. We propose a *systematic synthesis procedure for realizing a wider class of current transfer functions by the same circuit topology.*

II. REALIZATION OF A GENERAL VOLTAGE TRANSFER FUNCTION

The symbol of a DVCC is shown in Fig. 1, and its terminal characteristics are [19] given by

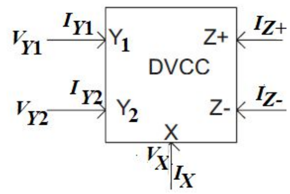

Fig. 1 Block representation of a DVCC.

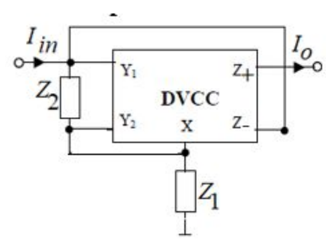

Fig.2 Proposed topology.

$$\begin{bmatrix} V_x \\ I_{Y1} \\ I_{Y2} \\ I_{Z+} \\ I_{Z-} \end{bmatrix} = \begin{bmatrix} 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_{Y1} \\ V_{Y2} \\ V_{Z+} \\ V_{Z-} \end{bmatrix} \tag{1}$$

The circuit topology of Fig. 2 has the current transfer function

$$T(s) = K\frac{N(s)}{D(s)} = 1 - Z_1 Y_2 \tag{2}$$

From (2),

$$Z_1 Y_2 = \frac{D(s) - KN(s)}{D(s)}. \tag{3}$$

Note that the poles of Z_1Y_2 are the same as those of T, but zeros are given by D-$KN = 0$. Impedances Z_1 and Z_2 can be identified as *RC* driving point functions (DPIs) from (3) if the poles and zeros of Z_1Y_2, arranged in pairs starting from the rightmost pair; each pair consists of a pole and a zero in either order [~~10~~7 or]. The four admissible pole-zero patterns are shown in Fig. 3. $T(s)$, so also Z_1Y_2, must have poles distinct negative real. Zero loci of Z_1Y_2 start from the poles when $K = 0$ and terminate on the zeros of $T(s)$ when $K = \infty$. Hence it is possible to choose K sufficiently small so that the zeros are negative real. Thus, if the poles and zeros of Z_1Y_2

fit into one of the patterns shown in Fig. 3, $T(s)$ is realizable; otherwise, not.

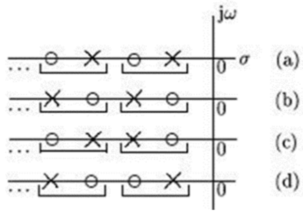

Fig. 3 Admissible pole-zero patterns.

A. Realization of bilinear current transfer functions

Let the bilinear current transfer function be

$$T(s) = \frac{K(s+z)}{(s+p)} = 1 - Z_1Y_2 \quad (4)$$

If z is positive, i.e., it lies on the negative real axis, $T(s)$ can be realized by RC *passive elements*. Therefore, we shall consider the case when z is *negative,* i.e., $0 \le z \le \infty$. Then

$$Z_1Y_2 = \frac{(1-K)s + (p+Kz)}{(s+p)}. \quad (5)$$

The zero-locus with K as a variable is shown in Fig. 4. It starts from pole at $-p$ when $K = 0$ and reaches $-\infty$ when $K = 1$ and again from $+\infty$ to zero at z from $K = 1$ to $K = \infty$. Thus choosing $0 < K \le 1$, the zero of Z_1Y_2 can be made negative real. Thus, it will follow the pattern shown in Fig. 3(a) and (d). Now (5) can be written as

$$Z_1Y_2 = \mu\frac{(s+\alpha)}{(s+p)},\ p<\alpha \le \infty. \quad (6)$$

where $\mu = (1-K), \alpha = \frac{p+Kz}{1-K}$.

The only possible identifications are

$$Z_1 = \frac{\mu_1}{(s+p)},\quad Y_2 = \mu_2(s+\alpha) \quad (7)$$

$$Z_1 = \mu_1\frac{(s+\alpha)}{s},\quad Y_2 = \mu_2\frac{s}{(s+p)} \quad (8)$$

$$Z_1 = \mu_1\frac{(s+\alpha)}{(s+p)},\quad Y_2 = \mu_2 \quad (9)$$

Where $\mu=\mu_1\mu_2$, the possible canonic realizations of Z_1 and Z_2 in Foster and Cauer forms from (7) are given in Fig. 5(a), from (8) in Fig. 5(b), from (9) in Fig. 5(c), and 5(d), respectively.

Minimum 4 elements (2C, 2R) or (1C, 3R) are required for realizing $Z_{1,2}$, as shown in Fig. 5. However, one element can be reduced by choosing $K = 1$, which forces the zero of Z_1Y_2 at ∞ (see (5)). The reduced realizations of $Z_{1,2}$ are shown in Fig. 6. The complete realizations of $T(s)$ given by (4) are obtained by inserting $Z_{1,2}$ of Fig. 6 in Fig. 2. They reduce to all-pass functions when $p = z$. Thus, we get (2R, 1C) and (1R, 2C) realizations for first-order all-pass function.

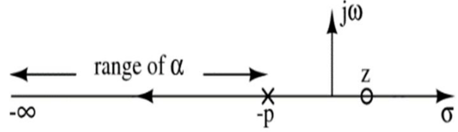

Fig. 4 Root locus with *K* as a variable.

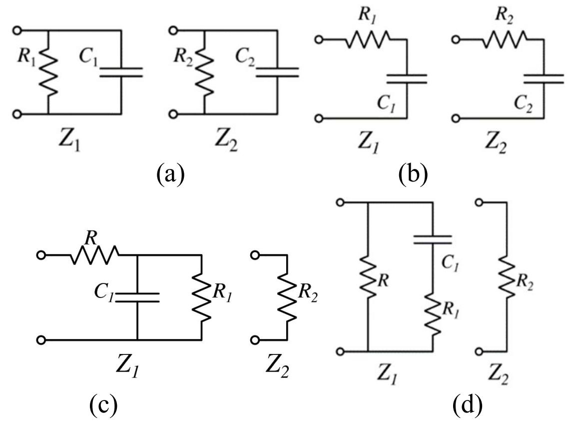

Fig. 5 Realizations of Z_1 and Z_2 given by (a) (7), (b) (8) and (c) and (d) by (9).

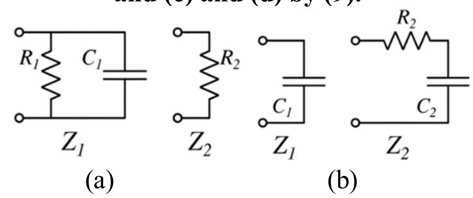

Fig. 6. Two realizations of $Z_{1,2}$.

B. Realization of biquadratic transfer functions

Let the function be expressed as

$$T(s) = K\frac{(s+z_1)(s+z_2)}{(s+p_1)(s+p_2)} \quad (10)$$

Where poles $p_{1,2}$, as discussed above, have to be negative real and $z_{1,2}$ may lie anywhere in the s-plane. Then from (2)

$$Z_1Y_2 = \frac{(1-K)s^2 + [(p_1+p_2) - K(z_1+z_2)]s + (p_1p_2 -}{(s+p_1)(s+p_2)} \quad (11)$$

To realize a minimum number of elements, we choose $K = 1$. Then

$$Z_1Y_2 = \frac{[(p_1+p_2)-(z_1+z_2)]s + (p_1p_2 - z_1z_2)}{(s+p_1)(s+p_2)} = \mu\frac{(s+\alpha)}{(s+p_1)(s+p_2)} \quad (12)$$

where

$$\mu = (p_1+p_2) - (z_1+z_2)$$

and

$$\alpha = \frac{p_1p_2 - z_1z_2}{(p_1+p_2)-(z_1+z_2)}$$

If α and $p_{1,2}$ satisfy any of the pole-zero patterns shown in Fig. 3, then $Z_{1,2}$ can be identified as driving point impedances. Since there are many possible locations of $z_{1,2}$, we explain the procedure by taking the all-pass function for which $z_{1,2} = -p_{1,2}$. Then (12) reduces to

$$Z_1Y_2 = \mu\frac{s}{(s+p_1)(s+p_2)}. \quad (13)$$

where$\mu=2(p_1+p_2)$.

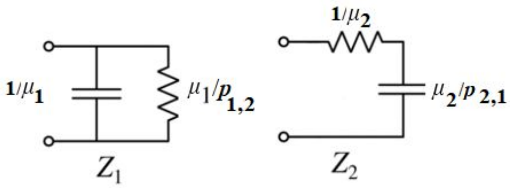

Fig. 7. Two realizations of $Z_{1,2}$ given by (14).

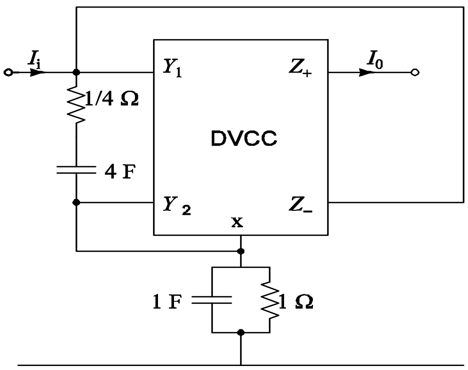

Fig. 8.Realization of all-pass function given by (16).

Now, $Z_{1,2}$ can be identified in two possible ways as

$$Z_1 = \frac{\mu_1}{(s+p_{1,2})}, Y_2 = \frac{\mu_2 s}{(s+p_{2,1})} \tag{14}$$

Where $\mu=\mu_1\mu_2$.

Two realizations of $Z_{1,2}$ given by (14) are shown in Fig. 7. It is interesting to realize an all-pass filter with double poles, *i. e.*, $p_1 = p_2 = p$. In this case,(14) reduces to

$$Z_1 = \frac{\mu_1}{(s+p)}, Y_2 = \frac{\mu_2 s}{(s+p)} \tag{15}$$

Example: Realize a second-order all-pass function

$$T(s) = K\frac{(s-1)^2}{(s+1)^2}. \tag{16}$$

Here

$$Z_1Y_2 = 1 - T(s)$$
$$= \frac{(1-K)s^2 + 2(1+K)s + (1-K)}{(s+1)^2} \tag{17}$$

Choosing $K = 1$, and then identifying

$$Z_1 = \frac{1}{(s+1)}, \quad Y_2 = \frac{4s}{(s+1)}, \tag{18}$$

The complete realization of $T(s)$ of (16) is given in Fig. 8.

$$\begin{bmatrix} V_x \\ I_{Y1} \\ I_{Y2} \\ I_{Z+} \\ I_{Z-} \end{bmatrix} = \begin{bmatrix} 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_{Y1} \\ V_{Y2} \\ V_{Z+} \\ V_{Z-} \end{bmatrix} \tag{19}$$

III. CONCLUSIONS

This paper has exploited the circuit proposed by Kacar and Mahmut for realizing any current transfer function $T(s)$ such that the location of the poles and zeros of 1 - $T(s)$ matches with any one of the four possible patterns. The First-order all-pass function is a special case that needs only three elements ($2R$, $1C$) or ($1R$, $2C$). Biquadratic functions require ($2C$, $2R$) passive elements. We have not attempted here the non-ideal analysis, simulation, and applications as Kacar and Mahmut very well document them.

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