N-TH ORDER FILTERS USING BALANCED-OUTPUT CCII+/- CONVEYORS

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Abstract

A novel second-generation current conveyor is defined. A special three-port cell containing the above element is presented. A method for nth-order multifunction circuit realization is described. Two universal networks illustrate the described procedure.

Keywords
circuit theory, filters, balanced-output conveyors, multifunction networks

1. Introduction

Recently [1,2] the family of active circuit elements has been enriched with a second-generation current conveyor with two outputs, which will be denoted CCII+/-. It is a four-port immittance converter with one independent current $I_x=I^*$ and three independent voltages. Its schematic representation is shown in Fig.1. The element CCII+/- is described by the matrix equation

$$\begin{bmatrix} V_x \\ I_y \\ I_{z+} \\ I_{z-} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} I_x \\ V_y \\ V_{z+} \\ V_{z-} \end{bmatrix} . \tag{1}$$

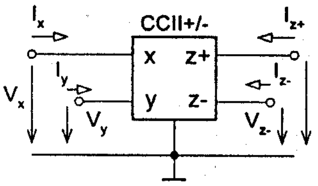

Fig. 1. Schematic symbol of CCII+/- conveyor

2. Cascade of special cells containing CCII+/- elements

Let there be a general three-port network (a cell) as shown in Fig.2, which contains one active element CCII+/- and two passive two-terminal elements. The terminals **a, b, c** specify the ports of the three-port with respect to the ground. The symbol **a** denotes the live terminal of the *input* port, symbol **b** the live port of the *output* port while symbol **c** denotes the *feedback* terminal of the cell.

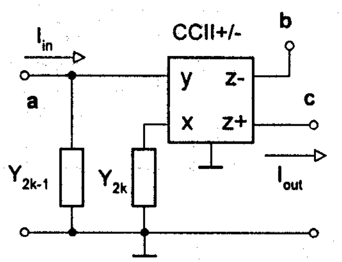

Fig. 2. Special cell using the CCII+/- element

As two-ports, these cells can be connected into a cascade. The symbol k in the subscripts in Fig.2 corresponds therefore with the sequence number of elementary cell in the cascade.

If only one cell is considered and if the feedback terminal **c** is connected to its input terminal, then we get a two-port whose current transfer function is given by the relation:

$$\frac{I_{out}}{I_{in}} = \frac{Y_{2k}}{Y_{2k} + Y_{2k-1}} . \tag{2}$$

The current transfer of the cascade of n cells considered is obviously:

$$\frac{I_{out}}{I_{in}} = \prod_{k=1}^{n} \frac{Y_{2k}(s)}{Y_{2k}(s) + Y_{2k-1}(s)} = \frac{P(s)}{Q(s)} . \tag{3}$$

In this case the general polynomial $Q(p)$ has 2^n terms ; for example, for $n=5$ the polynomial $Q(p)$ has 32 terms.

Grounding the output terminal $z+$ of the whole cascade we obtain an autonomous network whose characteristic equation is

$$Q(p) = 0. \tag{4}$$

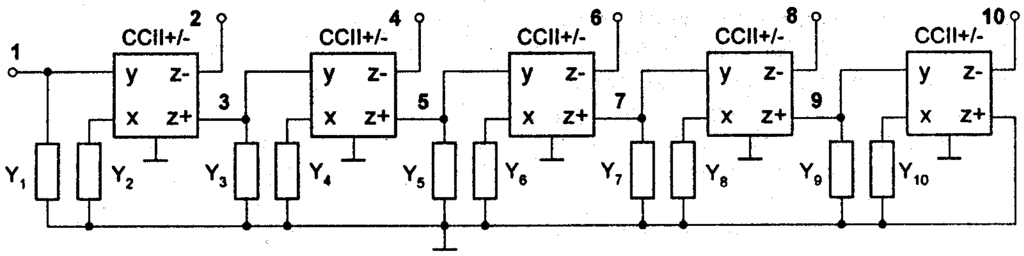

Fig. 3. Autonomous network consisting of a cascade of five special three-ports using CCII+/- elements

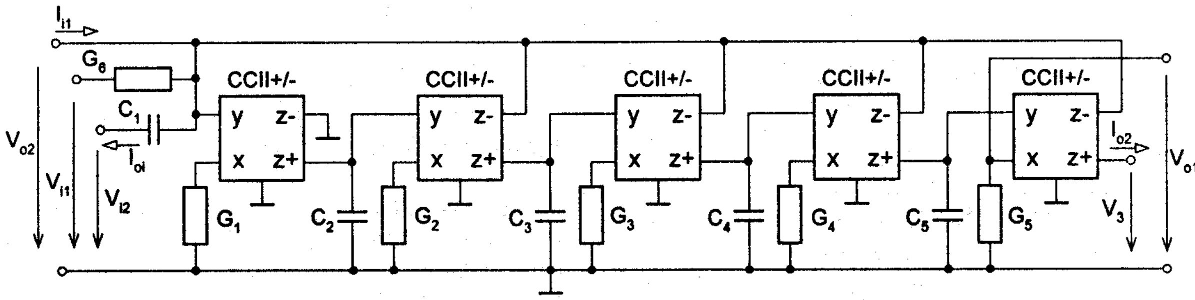

Fig. 4. Universal five-port for the realization of fifth-order filters

Connecting the feedback terminals of individual members in the cascade other than to the cell's own input terminal the number of polynomial terms will decrease. If all the feedback terminals were grounded, the polynomial $Q(p)$ would only have one term. Regarded as almost optimum can be the case when the feedback terminals of all members are connected to the input terminal of the *first* cell. Then, for instance, for n=5 (see Fig.3) there will be:

$$Q(s)=Y_1Y_3Y_5Y_7Y_9+Y_2Y_3Y_5Y_7Y_9+Y_2Y_4Y_5Y_7Y_9+ \\ +Y_2Y_4Y_6Y_7Y_9+Y_2Y_4Y_6Y_8Y_9+Y_2Y_4Y_6Y_8Y_{10}\ . \tag{5}$$

The number of polynomial terms can further be reduced by grounding terminal 4 in the network in Fig.3. In that case relation (5) changes to:

$$Q(s)=Y_1Y_3Y_5Y_7Y_9+Y_2Y_4Y_5Y_7Y_9+Y_2Y_4Y_6Y_7Y_9+ \\ +Y_2Y_4Y_6Y_8Y_9+Y_2Y_4Y_6Y_8Y_{10}\ . \tag{6}$$

3. Universal networks for filter realization

Any autonomous circuit (AC in the following) can be transformed into a two-port whose transfer functions have in the denominator the same polynomial as that of the characteristic equation of the AC considered. This was described in [3, 4]. If for the schematic diagram in Fig.3 we choose Y_1=sC_1+G_6, Y_2=G_1, Y_3=sC_2, Y_4=G_2, Y_5=sC_3, Y_6=G_3, Y_7=sC_4, Y_8=G_4, Y_9=sC_5, Y_{10}=G_5 , we obtain an autonomous network with the following characteristic equation:

$$Q(s)=s^5C_1C_2C_3C_4C_5+s^4C_2C_3C_4C_5G_6+ \\ +s^3C_3C_4C_5G_1G_2+s^2C_4C_5G_1G_2G_3+ \\ +sC_5G_1G_2G_3G_4+G_1G_2G_3G_4G_5=0 \tag{7}$$

Disconnecting the elements C_1, G_6 and the terminal $z+$ of the last conveyor from the ground in the considered network we obtain a five-port as shown in Fig.4. Here the input quantities are denoted as V_{i1}, V_{i2} and I_{i1} , while the output quantities are denoted V_{o1} , V_{o2} , I_{o1} and I_{o2}. If V_3=0, then the properties of the circuit can be described by the following relations:

$$\frac{V_{o1}}{V_{i1}}=\frac{G_1G_2G_3G_4G_6}{Q(s)}\quad (V_{i2}=0, I_{i1}=0), \tag{8}$$

$$\frac{V_{o2}}{V_{i2}}=\frac{s^5C_1C_2C_3C_4C_5}{Q(s)}\quad (V_{i1}=0, I_{i1}=0), \tag{9}$$

$$\frac{I_{o1}}{I_{i1}}=\frac{s^5C_1C_2C_3C_4C_5}{Q(s)}\quad (V_{i1}=V_{i2}=0), \tag{10}$$

$$\frac{I_{o2}}{I_{i1}}=\frac{G_1G_2G_3G_4G_5}{Q(s)}\quad (V_{i1}=V_{i2}=0). \tag{11}$$

The relations we have obtained show that the universal five-port in Fig.4 can be used as a highpass or lowpass filter of fifth order for both voltage and current transfer functions.

In [2] a lowpass filter of fifth order with CCII+/- elements is presented which works in the current mode. The filter can be regarded as a special case of our circuit if in Fig.3 the nodes 2-1, 4-1, 6-3, 8-5 and 10-7 are short-circuited. In this case the polynomial $Q(s)$ has 13 terms.

In the following, let us only consider the first two cells from the cascade in Fig.4 and let us ground the feedback terminal of the first cell. We obtain a general autonomous circuit as shown in Fig. 5. The characteristic equation of this circuit has the typical form:

$$Y_1 Y_3 + Y_2 Y_4 = 0 . \tag{12}$$

Choosing, for example, $Y_1 = sC_1 + G_3$, $Y_2 = G_1$, $Y_3 = sC_2$, $Y_4 = G_2$, we obtain a concrete circuit with the characteristic equation

$$s^2 C_1 C_2 + sC_2 G_3 + G_1 G_2 = Q_1(s) = 0 \quad . \tag{13}$$

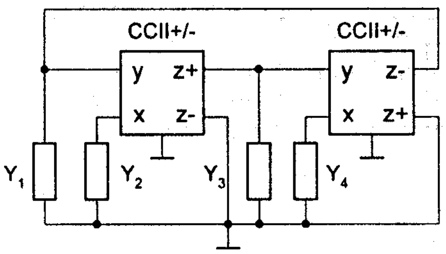

Fig. 5. Autonomous network consisting of two special cells

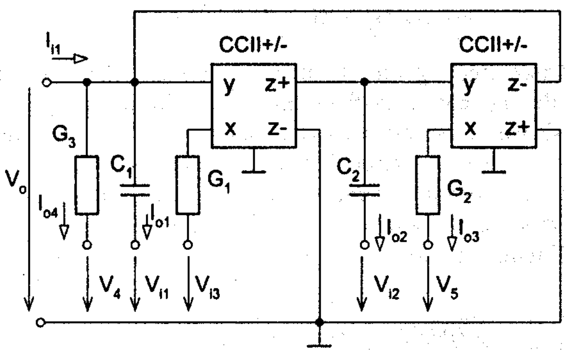

Fig. 6. Multifunction six-port network

Transforming this multifunctional circuit into a six-port, we obtain the circuit shown in Fig.6. Here, the input quantities are V_{i1}, V_{i2}, V_{i3} and V_{i3} while the output quantities are V_o, I_{o1}, I_{o2}, I_{o3}, I_{o4}. The complete circuit can be described by the following equations:

a) If $V_4 = V_5 = 0$ and $I_{i1} = 0$, then

$$V_o = \frac{s^2 C_1 C_2 V_{i1} - sC_2 G_2 V_{i2} + G_1 G_2 V_{i3}}{Q_1(s)} \tag{14}$$

and

$$I_{o4} = G_3 V_o . \tag{15}$$

b) For $V_{i1} = V_{i2} = V_{i3} = V_4 = V_5 = 0$, we have:

$$\frac{I_{o1}}{I_{i1}} = \frac{s^2 C_1 C_2}{Q_1(s)} , \tag{16}$$

$$\frac{I_{o2}}{I_{i1}} = \frac{sC_2 G_1}{Q_1(s)} , \tag{17}$$

$$\frac{I_{o3}}{I_{i1}} = \frac{G_1 G_2}{Q_1(s)} \tag{18}$$

and

$$\frac{V_o}{I_{i1}} = \frac{sC_2}{Q_1(s)} . \tag{19}$$

From relation (14) it follows that the eight-port in Fig.6 can work in the voltage mode (V_o/V_{in}) as:

(i) lowpass filter if $V_{in} = V_{i3}$, $V_{i1} = V_{i2} = V_4 = V_5 = 0$ and $I_{i1} = 0$
(ii) highpass filter if $V_{in} = V_{i1}$, $V_{i2} = V_{i3} = V_4 = V_5 = 0$ and $I_{i1} = 0$
(iii) bandpass filter if $V_{in} = V_{i2}$, $V_{i1} = V_{i3} = V_4 = V_5 = 0$ and $I_{i1} = 0$
(iv) notch filter if $V_{in} = V_{i1} = V_{i2}$, $V_{i2} = V_4 = V_5 = 0$ and $I_{i1} = 0$
(v) allpass filter if $V_{in} = V_{i1} = V_{i2} = V_{i3}$, $I_{i1} = 0$ and $G_2 = G_3$

The same possibilities exist if we are interested in the output current when the two-port is voltage driven (see relation 15).

The eight-port can also work in the current mode (I_{out}/I_{i1}), as follows from eqns. (16)-(18), i.e. as:

(i) lowpass filter if $I_{out} = I_{o3}$,
(ii) highpass filter if $I_{out} = I_{o1}$,
(iii) bandpass filter if $I_{out} = I_{o2}$,
(iv) notch filter if $I_{out} = I_{o1} + I_{o3}$.

The network can also work in the hybrid mode (V_{out}/I_{in}) as a bandpass filter (see relation 19) .

4. Simulation results

The function of universal five-port from Fig.4 was verified by means of PSpice computer simulation. The network was used as a fifth-order lowpass filter and the values of components were proposed for the Chebyshev approximation and a cut-off frequency of 1 MHz. For the simulation, a computer model of CCII+/- was made, which starts from definition relation (1) and, moreover, takes into consideration the real parts of the impedance of input terminals x ($R_x = 50\Omega$) and y ($R_y = 1\text{M}\Omega$). From Fig. 7 the effect of these parameters on the shape of module-frequency characteristic is evident. In Fig. 8 both frequency characteristics of the filter with the above model of CCII+/- are illustrated. The waveforms given correspond to the voltage mode connection. For the current mode the results were almost identical that they are not given here.

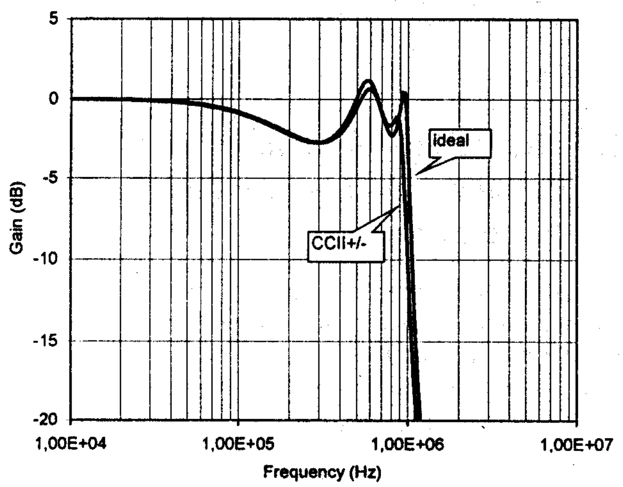

Fig. 7. Gain-amplitude characteristic with ideal and with simulated CCII+/- for the LPF in the voltage mode in Fig.4

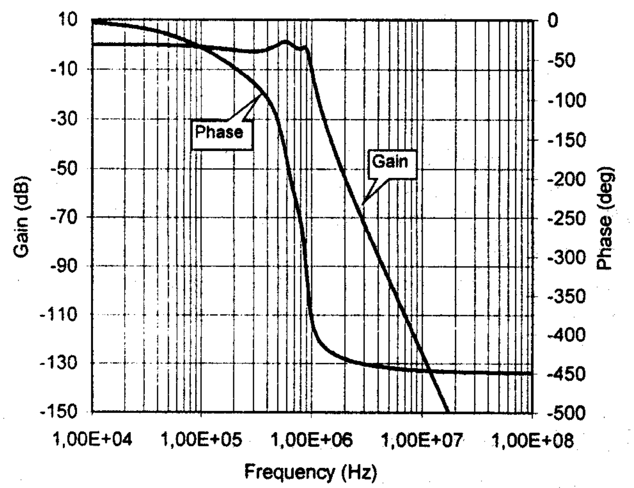

Fig. 8. Frequency characteristic for the LPF in the voltage mode in Fig. 4.

5. Conclusion

In the above manner we can design a multifunction *n*-port of arbitrary order for multi-purpose application as filters working in both the current and the voltage (or hybrid) modes.

Acknowledgment

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