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GENERAL THREE–PORT CURRENT CONVEYOR: A USEFUL TOOL FOR NETWORK DESIGN

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A new general current conveyor representing 12 concrete conveyors is defined. The procedure of network design using this general current conveyor is shown. Two examples illustrate the realization method described.

K e y w o r d s: current conveyors, RC-active networks, universal filters

1 INTRODUCTION

Let us introduce a general active element, which is in our case a *general three port current conveyor*. It is a three-port immittance converter with one independent current and two independent voltages. Its schematic symbol is shown in Fig. 1. The element has been denoted **GCC**. The port voltages and currents are node voltages and currents. The general conveyor is described by the following matrix equation:

$$\begin{bmatrix} V_x \\ I_y \\ I_z \end{bmatrix} = \begin{bmatrix} 0 & \alpha & 0 \\ \beta & 0 & 0 \\ \gamma & 0 & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \end{bmatrix}. \tag{1}$$

If in Eqn (1) $\alpha = 1$, we are considering a conventional (non-inverting) current conveyor, which is referred to by letters **CC**, while $\alpha = -1$ characterizes an inverting current conveyor **ICC** [1]. With ($\beta = 1$ we speak about a first-generation current conveyor [2] (**CCI** or **ICCI**), with $\beta = 0$ about a second-generation current conveyor [3] (**CCII** or **ICCII** but with $\beta = -1$ we have to do with a third-generation current conveyor [4] (**CCIII** or **ICCIII**. When the γ coefficient is 1, we are concerned with a positive current conveyor, which is denoted by the + sign following the schematic symbol (*eg* **CCII+**), when $\gamma = -1$, we are considering the so-called negative current conveyor, which is denoted by the $-$ sign. The **GCC** introduced has therefore the properties of twelve concrete current conveyors.

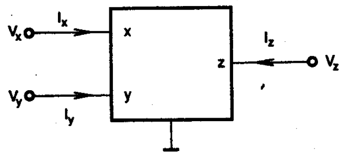

Fig. 1. General three port current conveyor

2 NETWORK FUNCTIONS OF CIRCUITS CONTAINING GCCs

In the design of the RC-active network we will start from a circuit containing only two-terminal passive elements and general three-port current conveyors. In the design we either choose an existing circuit with a concrete three-port current conveyor or we propose a suitable new circuit (prototype). For simplicity let us only consider in the following the immittance of a two-terminal network and the voltage transfer function of a no-load two-port network as the required circuit quantities. The input impedance of a one-port network is given by the relation $Z_{in} = A/D$, while the voltage transfer function of a no-load two-port network can be calculated from the following equation: $V_{out}/V_{in} = M/D$. The symbols A, D and M refer to cofactors of the system matrix. The equation $D = 0$ is called the characteristic equation (CE) of autonomous circuits (the circuit is driven neither by voltage source nor by current source). The procedure in the design of active networks with the aid of the GCC elements will be shown on two examples.

2.1 Desired admittance function realization

Let us have the general two terminal network shown in Fig. 2, whose input admittance is known to be

$$Y_{in} = Y_1 - Y_2 + \frac{Y_2 Y_4}{Y_3} = \frac{D}{A}, \tag{2}$$

when both conveyors are **CCI+**. If, however, we consider in Fig. 2 general conveyors **GCC**, we calculate the following cofactors:

$$D = \alpha_1\alpha_2\beta_1\beta_2 Y_1 Y_3 - \alpha_1\beta_1 Y_1 Y_4 + \alpha_1\gamma_1\gamma_2 Y_1 Y_4 - \alpha_2\beta_2 Y_2 Y_3 + Y_2 Y_4 \tag{3}$$

$$A = \alpha_1\alpha_2\beta_1\beta_2 Y_3 - \alpha_1\beta_1 Y_4 + \alpha_1\gamma_1\gamma_2 Y_4 . \tag{4}$$

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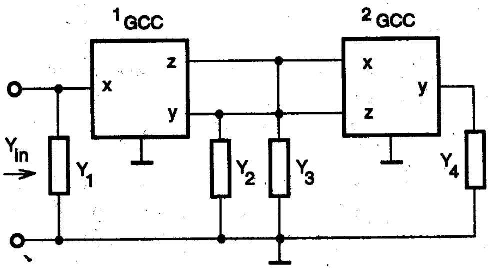

Fig. 2. Prototype of a general one-port network

Choosing $\beta_1 = \gamma_1\gamma_2$, we obtain for the input admittance of the one-port network the relation:

$$y_{in} = \frac{D}{A} = \frac{\alpha_1\alpha_2\beta_1\beta_2Y_1Y_3 - \alpha_2\beta_2Y_2Y_3 + Y_2Y_4}{\alpha_1\alpha_2\beta_1\beta_2Y_3}. \quad (5)$$

The required relation (5) for Y_{in}, will be obtained if $\alpha_1\alpha_2\beta_1\beta_2 = 1$ and $\alpha_2\beta_2 = 1$ and thus also $\alpha_1\beta_1 = 1$.

The above conditions are fulfilled in the case of the following coefficients and their corresponding current conveyors:

α_1	β_1	γ_1	α_2	β_2	γ_2	1GCC	2GCC
1	1	1	1	1	1	CCI+	CCI+
1	1	−l	1	1	−1	CCI−	CCI−
1	1	1	−1	−1	1	CCI+	ICCIII+
1	1	−1	−1	−1	−1	CCI−	ICCIII−
−1	−1	1	1	1	−1	ICCIII+	CCI−
−1	−1	1	−1	−1	−1	ICCIII+	ICCIII
−1	−1	−1	−1	−1	1	ICCIII−	ICCIII+
−1	−1	−1	1	1	1	ICCIII−	CCI+

Choosing $Y_1 = G_1$, $Y_2 = G_3$, $Y_3 = sC_l$, $Y_4 = G_2$, the input admittance of the one-port network in Fig. 2 will be given by the following relation, no matter which pair of the above active elements is used:

$$Y_{in} = G_1 - G_3 + \frac{G_3G_2}{sC_l}. \quad (6)$$

If $G_1 = G_3$, the one-port network in Fig. 2 represents a grounded synthetic inductor of inductance $R_1R_2C_1$. Connecting a capacitor to the input port of the circuit will yield an oscillator.

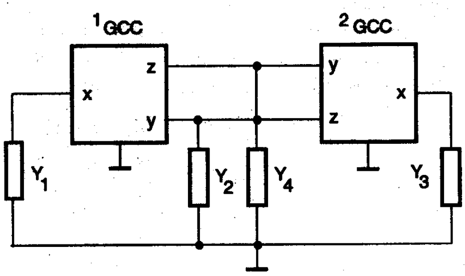

Fig. 3. General autonomous network

Choosing $Y_1 = sC_1$, $Y_2 = sC_1$, $Y_3 = G_1$, $Y_4 = sC_2$, we obtain a frequency-dependent negative resistor (FDNR), whose admittance is: $Y_{in} = s^2C_1C_2R_1$.

We have yet another possibility of simplifying the input admittance given by relations (3) and (4), namely by choosing the following conditions: $\beta_1 = 0$, $\alpha_1\gamma_1\gamma_2 = -1, \alpha_2\beta_2 = 1$. then $Y_{in} = Y_1 - Y_2 + \frac{Y_2Y_3}{Y_4}$. The above conditions can be realized as follows:

α_1	β_1	γ_1	α_2	β_2	γ_2	1GCC	2GCC
1	0	1	1	1	−1	CCII+	CCI−
1	0	1	−1	−1	−1	CCII+	ICCIII−
1	0	−1	1	1	1	CCII	CCI+
1	0	−1	−1	−1	1	CCII	ICCIII+

We obtain relation (6) if we choose: $Y_1 = G_1$, $Y_2 = G_3$, $Y_3 = G_2$, $Y_4 = sC_1$.

2.2 Universal biguads

In the following we will conf ne ourselves to second-order networks (so-called biquads), considering only networks with general characteristic equations (CE) in the form: $Y_1Y_3 + Y_2Y_4 = 0$ or $Y_1Y_3 + Y_2Y_3 + Y_2Y_4 = 0$.

We have chosen as an example the autonomous circuit shown in Fig. 3. Its CE is defined by the relation:

$$D_1 = \alpha_1\alpha_2\beta_1\beta_2Y_1Y_3 - \alpha_1\beta_1Y_1Y_4 - D_1 = \alpha_1\alpha_2\gamma_1\gamma_2Y_1Y_3 - \alpha_2\beta_2Y_2Y_3 + Y_2Y_4 = 0. \quad (7)$$

There are three ways how to simplify the characteristic polynomial D_1. Because of circuit stability, all the terms in (7) must be positive since the last term, Y_2Y_4, is positive.

2.2.1 The first case

If in relation (7) we choose

$$\beta_1 = \beta_2 = 0 \text{and} \alpha_1\alpha_2\gamma_1\gamma_2 = -1, \quad (8)$$

we obtain the CE according to equation $Y_1Y_3+Y_2Y_4 = 0$. Let us now choose the following element parameters in Fig. 3:
$Y_1 = G_1$, $Y_2 = sC_1 + G_3$, $Y_3 = G_2$, $Y_4 = sC_2$. Polynomial D_1 will then be:

$$D_1(s) = s^2C_1C_2 + sC_2G_3 + G_1G_2. \quad (9)$$

The method of designing a multifunction n-port from an autonomous circuit with appropriate characteristic equation has been described in [5]. Using this method we have designed the four-port in Fig. 4. By analysis we can establish that if conditions (8) are fulfilled, the output voltage of the network shown in the Figure is:

$$V_{out} = \left(s^2\alpha_1 C_1 C_2 V_{i2} + s\alpha_1\alpha_2\gamma_2 C_2 G_2 V_{i3} - \alpha_1\alpha_2\gamma_1\gamma_2 G_1 G_2 V_{i1}\right)\left(D_1(s)\right)^{-1}. \quad (10)$$

To obtain the *universal* filter we set additional conditions: $\alpha_1 = 1$ and $\alpha_1\alpha_2\gamma_2 = -1$, *ie* $\alpha_2\gamma_2 = -1$ and, according to (8), $\gamma_1 = 1$, so that

$$V_{out} = \frac{s^2 C_1 C_2 V_{i2} + sC_2 G_2 V_{i3} + G_1 G_2 V_{i1}}{s^2 C_1 C_2 + sC_2 G_3 + G_1 G_2} \quad (11)$$

From the above conditions we will form a realization table:

α_1	β_1	γ_1	α_2	β_2	γ_2	^{1}GCC	^{2}GCC
1	0	1	−1	0	1	CCII+	ICCII+
1	0	1	1	0	−1	CCII+	CCII−

It follows from relation (11) that the four-por network in Fig. 4 can work in the voltage mode (V_{out}/V_{in}) as a universal filter, *ie* as

(i) a highpass filter if $V_{in} = V_{i1}$, $V_{i2} = V_{i3} = 0$,
(ii) a bandpass filter if $V_{in} = V_{i2}$, $V_{i1} = V_{i3} = 0$,
(iii) a lowpass filter if $V_{in} = V_{i3}$, $V_{i1} = V_{i2} = 0$,
(iv) a notch filter if $V_{in} = V_{i1} = V_{i3}$, $V_{i2} = 0$,
(v) an allpass filter if $V_{in} = V_{i1} = V_{i3} = V_{i3}$, $G_2 = G_3$.

The same properties in the current mode will be obtained if the network in Fig. 4 is transformed into an adjoint network. Mutually adjoint are these conveyors: **CCII+ ⇔ ICCII−** with the y and z terminals swapped, **CCII− ⇔ CCII−** with the y and z terminals swapped, **ICCII+ ⇔ ICCII+** with the y and z terminals swapped. The symbol ⇔ stands for adjointment.

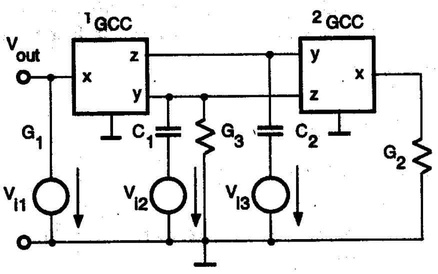

Fig. 4. Four-port network realizing the universal biquad filter

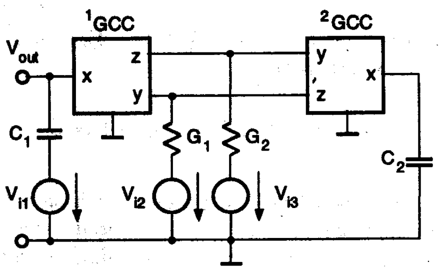

Fig. 5. Another four-port network representing universal filter

2.2.2 The second case

Characteristic equation (7) can be also rewritten differently, choosing

$$\beta_1 = 0, \quad \alpha_1\alpha_2\gamma_1\gamma_2 = -1, \quad \alpha_2\beta_2 = -1. \quad (12)$$

In this case $D = Y_1 Y_3 + Y_2 Y_3 + Y_2 Y_4 = 0$. Choosing $Y_1 = sC_1$, $Y_2 = G_1$, $Y_3 = sC_2$, $Y_4 = G_2$, we obtain the CE of a concrete network as follows:

$$D_2(s) = s^2 C_1 C_2 + sC_2 G_1 + G_1 G_2. \quad (13)$$

From the autonomous circuit we will form the four-port network in Fig. 5. For the output voltage $V - out$ we will establish the following relation:

$$V_{out} = \left(s^2 C_1 C_2 V_{i1} + (s\alpha_1 C_2 G_1 + \alpha_1 G_1 G_2)V_{i2} - s\alpha_1\alpha_2\gamma_2 C_2 G_2 V_{i3}\right)\left(s^2 C_1 C_2 + sC_2 G_1 + G_1 G_2\right)^{-1}. \quad (14)$$

This equation can be used to determine further conditions for the universal filter:

$$\alpha_1 = 1 \text{ and } \alpha_1\alpha_2\gamma_2 = -1, \; ie \; \gamma_1 = 1 \text{ and } \gamma_2 = -\alpha_1\alpha_2. \quad (15)$$

The realization table will then have this form:

α_1	β_1	γ_1	α_2	β_2	γ_2	^{1}GCC	^{2}GCC
1	0	1	1	−1	−1	CCII+	CCIII−
1	0	1	−1	1	1	CCII+	ICCI+

Again, the four-port network in Fig. 5 works in the voltage mode (V_{out}/V_{in}) as a universal filter, *ie* as

(i) a highpass filter if $V_{in} = V_{i1}$, $V_{i2} = V_{i3} = 0$,
(ii) a lowpass filter if $V_{in} = V_{i2} = V_{i3}$, $V_{i1} = 0$, $G_0 = G_2$,
(iii) a bandpass filter if $V_{in} = V_{i3}$, $V_{i1} = V_{i2} = 0$,
(iv) a notch filter if $V_{in} = V_{i1} = V_{i2} = V_{i3}$, $G_1 = G_2$,
(v) an allpass filter if $V_{in} = V_{i1} = V_{i2} = V_{i3}$, $G_2 = 2G_1$.

2.2.3 The third case

When in relation (7) we choose

$$\alpha_1\alpha_2\beta_1\beta_2 = \alpha_1\alpha_2\gamma_1\gamma_2, \quad \alpha_1\beta_1 = -1, \quad \alpha_2\beta_2 = -1, (2 \quad (16)$$

we obtain the characteristic equation in the form:

$$Y_1 Y4 + Y_2 Y_3 + Y_2 Y_4 = D = 0. \quad (17)$$

Choosing $Y_1 = G_2$, $Y_2 = sC_2$, $Y_3 = sC_1$, $Y_4 = G_1$ the CE of this autonomous circuit will be identical with relation (13). Let us now consider the six-port network in Fig. 6. Having calculated the output voltages we get

$$V_{o1} = \left((-s^2\alpha_1\alpha_2\beta_2 C_1 C_2 + s\alpha_1 C_2 G_1)V_{i2} - s\alpha_1\gamma_2 C_1 G_1 V_{i4} + G_1 G_2 V_{i1}\right)\left(s^2 C_1 C_2 + sC_2 G_1 + G_1 G_2\right)^{-1} (V_{i3} = 0) \quad (18)$$

and

$$V_{o2} = \left(s^2 C_1 C_2 V_{i4} + s\alpha_1\alpha_2\gamma_1 C_2 G_2 V_{i2} + (s\alpha_2 C_2 G_1 + \alpha_2 G_1 G_2)V_{i3}\right)\left(D_2(s)\right)^{-1} \quad (V_{i1} = 0). \quad (19)$$

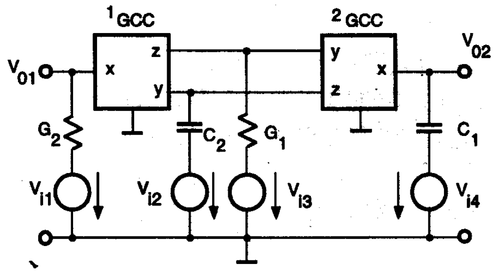

Fig. 6. Six-port network realizing two universal biquad filters

Relation (18) for V_{o1} gives rise to further conditions for the universal filter:

$$\alpha_1 = 1\,,\quad \beta_1 = -1\,,\quad \gamma_2 = 1\,,\quad \alpha_2\gamma_1 = 1\,. \qquad (20)$$

The cases satisfying all the conditions are listed in the following realization table:

α_1	β_1	γ_1	α_2	β_2	γ_2	1GCC	2GCC
1	−1	1	1	−1	1	CCIII+	CCIII+
1	−1	−1	−1	1	1	CCIII	ICCI+

Considering $V_{out} = V_{o2}$ according to (26), then for the universal filter the following further conditions must be fulfilled:

$$\alpha_1\alpha_2\gamma_1 = -1\,,\ \alpha_2 = 1\,,\ \alpha_1\gamma_1 = -1\,,\ \beta_2 = -1\ \gamma_2 = -1\,.$$

The realization table shows two further possibilities of filter realization:

α_1	β_1	γ_1	α_2	β_2	γ_2	1GCC	2GCC
1	−1	−1	1	−1	−1	CCIII−	CCIII−
−1	1	1	1	−1	−1	ICCI+	CCIII−

3 CONCLUSIONS

We have shown that the required input admittance function can be realized using 12 different networks with the same structure, and that 8 universal second-order filters in the voltage mode and 2 filters in the current mode can be derived from only one autonomous circuit.

Eight of the twelve current conveyors represented by the general three-port conveyor can be realized by a five port current conveyor with differential voltage input and balanced current output, denoted by the symbolic abbreviation **DVCC** [6]. The conveyors that cannot be replaced by the **DVCC** element are: **CCI+**, **ICCI+**, **CCI** and **ICCIII**. However, all the twelve conveyors can be realized using the universal current conveyor reported in [7].

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