ADJOINT NETWORKS WITH INVERTING AND NONINVERTING CURRENT CONVEYORS

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Abstract

Four types of second-generation current conveyor are derived. Adjoint pairs of such conveyors are shown. The realisation of the above conveyors using differential voltage current conveyors (VDCC) is presented. Two examples illustrate the building of adjoint networks containing second-generation current conveyors.

Keywords

Current conveyors, adjoint elements, adjoint networks, universal filters

1. Second-generation current conveyors and their adjoint elements

The schematic symbol used for three-port second-generation current conveyors is shown in Fig. 1. Here, the port currents and the port voltages are node currents and node voltages. In the Figure, the live terminals are denoted by symbols x, y and z.

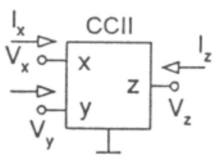

Fig. 1. General three-port second-generation current conveyor (CCII)

This is an immittance converter with one independent current I^*. Generally, second-generation current conveyors can be defined by the relations: $V_x = aV_y$, $I_x = I^*$, $I_y = 0$, $I_z = bI_x$. These relations describe four types of conveyor. If $a = 1$, we speak of conventional (noninverting) current conveyors **CCII** [1]. If, however, $a = -1$, we are concerned with inverting current conveyors **ICCII** [2]. Both types can be either positive ($b = 1$) or negative ($b = -1$). In this way we obtain conveyors that are usually denoted by abbreviations **CCII+, CCII–, ICCII+** and **ICCII–**.

Mutually adjoint are the following elements (the symbol ⇔ means adjointness):
CCII+ ⇔ **ICCII–** with terminals y and z interchanged,
CCII– ⇔ **CCII–** with terminals y and z interchanged,
ICCII+ ⇔ **ICCII+** with terminals y and z interchanged.

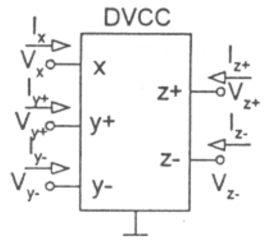

Fig. 2. Five-port differential voltage current conveyor (DVCC)

All the four types of second-generation current conveyor can be realised by the five-port differential voltage current conveyor with balanced output (**DVCC**) [3]. The schematic symbol of the **DVCC** element is shown in Fig. 2. It is an immittance converter with one independent current I^*, which is described by the following relations: $I_x = I^*$, $I_{y+} = I_{y-} = 0$, $I_{z+} = I^*$, $I_{z-} = -I^*$, $V_x = V_{y+} - V_{y-}$.

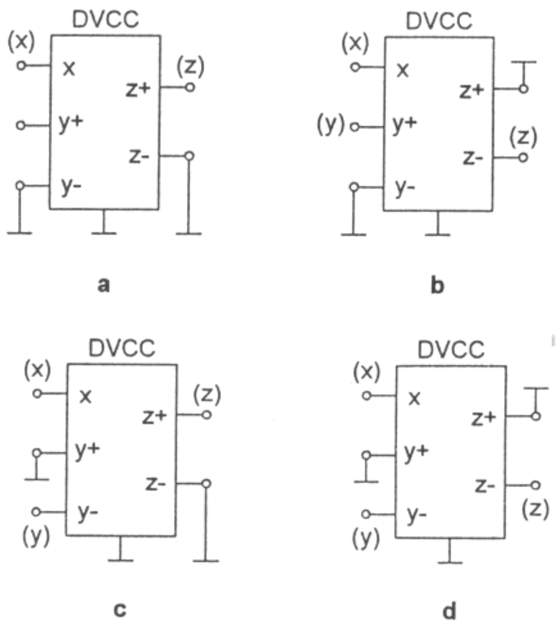

Fig. 3. DVCC element used as: a) a conventional positive CCII, b) a conventional negative CCII, c) an inverting positive CCII, d) an inverting negative CCII

The realisation of all types of second-generation current conveyors by means of the **DVCC** conveyors is shown in Fig. 3.

2. Adjoint networks with second-generation current conveyors

Consider an RC network that apart from the passive elements only contains the above current conveyors. Let this network have some exciting quantities and some output quantities. Let us refer to it as the *prototype*. Its *adjoint network* will result from considering output currents in place of input voltages, input currents in place of output voltages, output voltages in place of input currents, and input voltages in place of output currents. In addition, in place of prototype current conveyors the corresponding adjoint current conveyors are considered. The adjoint network thus has equivalent properties to those of the prototype if its currents and voltages are mutually interchanged, as mentioned above.

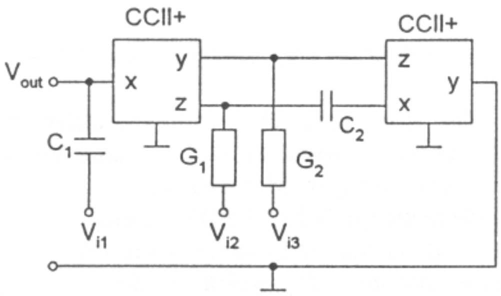

Fig. 4. Universal four-port biquad using CCII+ elements as prototype

As an example, let us consider the four-port in Fig. 4. This network was reported on in [4]. The following relations hold for this network

$$V_{out} = \frac{s^2 C_1 C_2 V_{i1} - sC_2 G_1 V_{i2} + (sC_2 G_2 + G_1 G_2) V_{i3}}{D(s)} , \quad (1)$$

where

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

It follows from the equations (1) and (2) that in the voltage mode (V_{out}/V_{in}) the four-port in Fig. 4 can operate 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 $V_{in} = V_{i2} = V_{i3}$, $V_{i1} = 0$, $G_1 = G_2$,
(iv) a notch filter, if $V_{in} = V_{i1} = V_{i2} = V_{i3}$, $G_1 = G_2$,
(v) an allpass filter, if $V_{in} = V_{i1} = V_{i2} = V_{i3}$, $G_1 = 2G_2$.

An adjoint filter, shown in Fig. 5, can easily be built up to the universal filter in Fig. 4 as a prototype. For the currents flowing through the short-circuited output port it then holds:

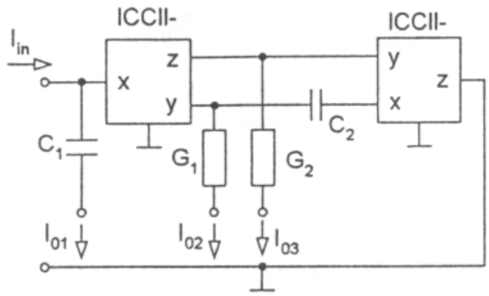

Fig. 5. Adjoint network to the prototype in Fig. 4

$$\frac{I_{o1}}{I_{in}} = \frac{s^2 C_1 C_2}{D(s)}, \quad (3) \qquad \frac{I_{o2}}{I_{in}} = \frac{-sC_2 G_1}{D(s)}, \quad (4)$$

$$\frac{I_{o3}}{I_{in}} = \frac{sC_2 G_2 + G_1 G_2}{D(s)} . \quad (5)$$

It is evident from the equations (3) to (5) that the four-port in Fig. 5 can in the current mode (I_{out}/I_{in}) be used as a universal filter of equivalent properties to those of the universal filter in Fig. 4 in the voltage mode.

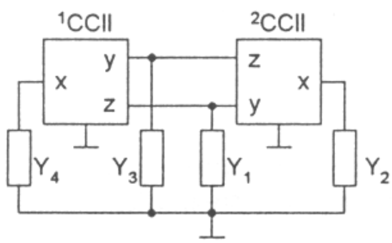

Fig. 6 An autonomous network containing two general second-generation current conveyors

As another example we have chosen the familiar autonomous circuit with two general second-generation current conveyors, for which we consider $I_z = bI_x$ (Fig. 6). Its characteristic equation is:

$$Y_1 Y_3 - b_1 b_2 Y_2 Y_4 = 0 \ . \quad (6)$$

For the network under consideration to be stable the product $b_1 b_2$ must be negative. This will be the case if one coefficient (no matter which) is positive and the other negative. Let us choose $b_1 = -1$, $b_2 = +1$, $Y_1 = sC_2 + G_3$, $Y_2 = G_2$, $Y_3 = sC_1$, $Y_4 = G_1$. This will yield a concrete network, from which the multifunction four-port can be derived as given in [5]. The network is shown in Fig. 7. Its characteristic equation is

$$s^2 C_1 C_2 + sC_1 G_3 + G_1 G_2 = D(s) = 0 . \quad (7)$$

It can be seen immediately that the following holds:

$$V_{out} = \frac{s^2 C_1 C_2 V_{i1} - sC_1 G_1 V_{i2} + G_1 G_2 V_{i3}}{D(s)} \quad (8)$$

$$\frac{I_{o1}}{I_{in}} = \frac{s^2 C_1 C_2}{D(s)}, \quad (9) \qquad \frac{I_{o2}}{I_{in}} = \frac{sC_1 G_2}{D(s)}, \quad (10)$$

$$\frac{I_{o3}}{I_{in}} = \frac{sC_1 G_2}{D(s)}, \quad (11) \qquad \frac{I_{o3}}{V_{i1}} = \frac{s^2 C_1 C_2 G_2}{D(s)} \ (V_{i2} = 0), \quad (12)$$

$$\frac{I_{o1}}{V_{i3}} = \frac{sC_2G_1G_2}{D(s)} \quad (V_{i2}=0) . \qquad (13)$$

Here we consider that the ports with output currents are short-circuited ($V_{i1}=V_{i2}=V_{i3}=0$).

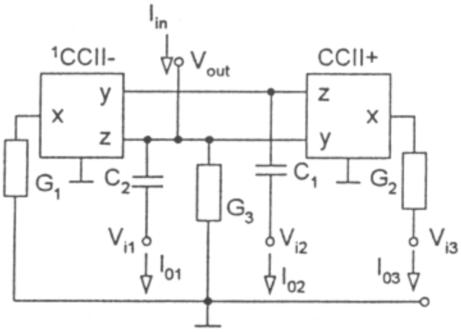

Fig. 7. A multifunction four-port biquad derived from the autonomous network in Fig. 6

It has been found that in the voltage mode the biquad in Fig. 7 can operate as a universal filter, in the current and transadmittance modes only as a highpass and bandpass filter. If we want to obtain an equivalent universal filter in the current mode, then to the prototype in Fig. 7 we build up an adjoint network as shown in Fig. 8. The properties of this network are described by the following equations:

$$V_{out} = \frac{s^2C_1C_2V_{i1} + sC_1G_2V_{i2} + sC_1G_2V_{i3}}{D(s)} , \qquad (14)$$

$$\frac{I_{o1}}{I_{in}} = \frac{s^2C_1C_2}{D(s)} , \quad (15) \qquad \frac{I_{o2}}{I_{in}} = \frac{-sC_1G_1}{D(s)} , \quad (16)$$

$$\frac{I_{o3}}{I_{in}} = \frac{G_1G_2}{D(s)} , \quad (17) \qquad \frac{I_{o3}}{V_{i1}} = \frac{sC_2G_1G_2}{D(s)} \quad (V_{i2}=0) , \quad (18)$$

$$\frac{I_{o1}}{V_{i3}} = \frac{s^2C_1C_2G_2}{D(s)} \quad (V_{i2}=0) . \quad (19)$$

In place of the second-generation current conveyors in Fig. 8 the five-port DVCC conveyors can be used, as shown in Fig. 9. This network, too, is described by equations (14) to (19).

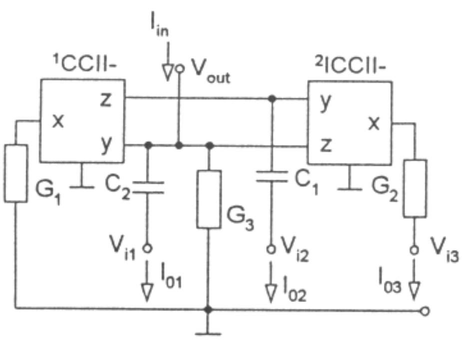

Fig. 8. A multifunction network adjoint to the prototype in Fig. 7

3. Filter realisation and simulation

To evaluate the performance of the above structures, the adjoint circuit of Fig. 9 was taken and studied in more detail, in particular in the current mode. The transfer functions of the currents are in this case given by equations (15), (16) and (17). From their denominator (7) a natural frequency (20) and a quality factor of poles (21) have been derived as follows:

$$\omega_0 = \frac{1}{\sqrt{C_1R_1C_2R_2}} , \quad (20) \qquad Q = \frac{R_3}{\sqrt{R_1R_2}}\sqrt{\frac{C_2}{C_1}} . \quad (21)$$

These design equations have been used for the ARC filter with the specification:

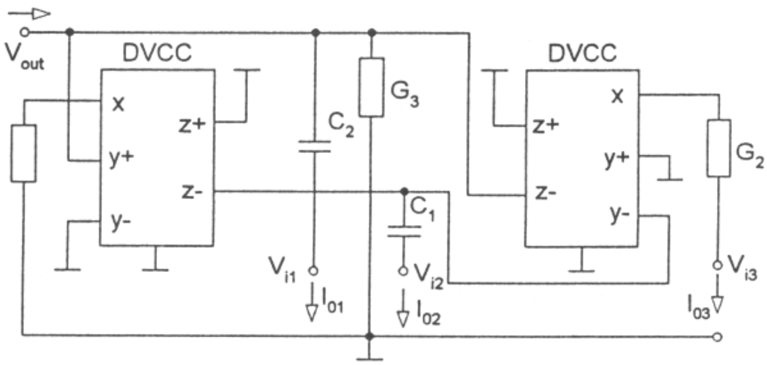

Fig. 9. Realisation of the network in Fig. 8 using DVCC elements

- the universal biquad (2nd order, LP, BP, HP),
- the Butterworth approximation (Q = 0.707) and
- the cut-off frequency f_0 = 500 kHz.

Then the resulting circuit (Fig. 9) has the following values of the components:

$R_1 = R_2 = 468\ \Omega$, $R_3 = 331\ \Omega$, $C_1 = C_2 = 680$ pF.

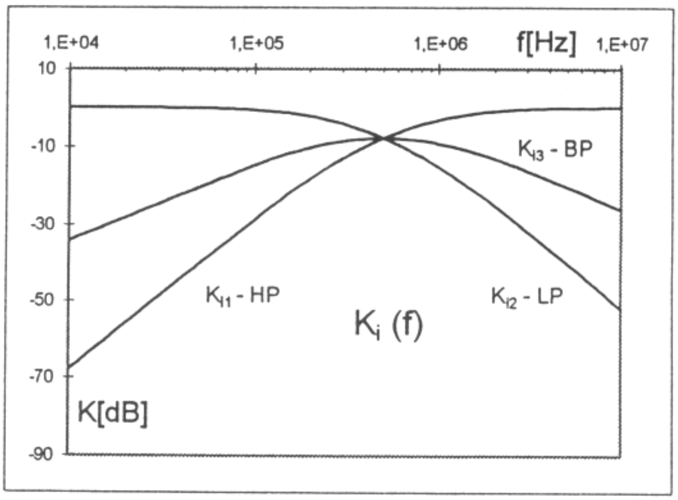

Fig. 10. Magnitude responses of the filter from Fig. 9

This filter was simulated by means of PSpice using a suitable model of the ideal DVCC, namely with controlled sources CCCS and VCVS only [6]. The resulting magnitude responses for all the outputs (LP, BP, HP) are shown in Fig. 10. This simulation confirms the symbolical analysis and theoretical assumptions.

4. Conclusion

The above adjoint elements can also be applied to the design of adjoint networks that also contain other elements, whose mutual adjointness is known (nullator-norator, controlled sources).

Acknowledgements

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Josef ČAJKA is a professor emeritus. He taught Electronic Circuit Theory at the Military Academy in Brno from 1951 to 1972 and at the Faculty of Electrical Engineering of the Technical University of Brno from 1972 to 1984. His field of professional interest was the analysis of linearized circuits, in particular with the aid of computer. Currently he collaborates on the design of universal RC networks containing modern active elements.

Kamil VRBA received the M.E. degree in electrical engineering in 1972 and the Ph.D. degree in 1977, both from Technical University Brno. He joined the institute of Telecommunications at the Faculty of Electrical Engineering and Computer Science of the TU in Brno and since 1997 is in a Full Professor position. His research work is concentrated to problems aimed to accuracy of analog circuits.

Tomáš DOSTÁL was born in Brno, in 1943. He received the CSc. (Ph.D) and DrSc. degree in electrical engineering from the Brno University of Technology in 1976 and 1989 respectively. From 1973 to 1978, and from 1980 to 1984, was with Military Academy Brno, from 1978 to 1980 with Military Technical College Baghdad. Since 1984 he has been with the Brno University of Technology, where he is now Professor of Radioelectronics. His present interests are in the circuit theory, filters, switched capacitor networks and circuits in current mode.