ADJOINT VOLTAGE-CURRENT MODE TRANSFORMATION FOR CIRCUITS BASED ON MODERN CURRENT CONVEYORS

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Abstract: *The paper deals with the transformation of networks in the familiar voltage signal processing mode (VM) into the equivalent current mode (CM). The adjoint VM-CM transformation of the circuits, containing several modern multi-port current conveyors, is given. An example of adjoint VM and CM biquadratic ARC filters, using differential voltage current conveyors (DVCC), illustrates this transformation.*

1. INTRODUCTION

Current mode (CM) signal processing circuits have received increasing attention in recent years, due to their many advantages [2]. One way how to obtain the CM circuits straightforwardly from standard and well-explored voltage signal processing networks (VM) is the adjoint transformation. The adjoint network theorem was originally defined in [1] to facilitate the computation of network sensitivity. This can be applied to a class of op.amp-based circuits [2], [3] to simplify the design of the CM circuits. Furthermore the adjoint transformation can be used in other ARC networks based on novel modern functional blocks too. We turn our attention to several types of the current conveyor in this paper.

2. CURRENT CONVEYORS

Since 1968 several types of the current conveyor have been published (CCI, CCII, CCIII, ICCII, CCII+/-, DVCC, FDCC, UCC etc.), namely three-port, four-port, five-port, and eight-port conveyors. All of them can be taken as a special case of the generalized n-port current conveyor. Furthermore every n-port current conveyor is a special case of n-terminal immittance converter with one independent node current and (n-1) independent node voltages. The independent current (I*) is assumed to enter the terminal labelled (x). It is also assumed that the independent voltages are transformed into port (x), independently of the transformation of currents. There the transformation coefficients of voltages (α_i) and currents (β_i) have only values of (0, +1, -1) for all types of the conveyors.

Let us denote the (non-zero) voltage gains with serial numbers 1, 2, ... , k (k < n-1) and label their corresponding ports y. These ports (x, y) will be taken as input ports, herewith the following voltage relation

$$V_x = \alpha_1 V_{y1} + \alpha_2 V_{y2} + \ldots + \alpha_k V_{yk}. \qquad (1)$$

The remaining nodes (there are $m = n - k - 1$ of them) will be labelled (z) and taken as output ports.

If the coefficients of the current transformation into the ports y_i are zero, i.e.

$$I_{y1} = I_{y2} = \ldots = I_{yk} = 0, \qquad (2)$$

then the current conveyor under consideration is included in the **current conveyors of the null class** (CCNC). If one of the above currents is non-zero, then it is in class 1, in the case of two non-zero currents in class 2, etc. The output currents are defined as follows

$$I_{z1} = \beta_1 I^*,\ I_{z2} = \beta_2 I^*, \ldots\ I_{zm} = \beta_m I^*,\ (m = n - k - 1). \qquad (3)$$

The coefficients β_i can have a value of +1 or –1.

Note that, from among the existing conveyors, the following functional blocks belong to the CCNC: CCII+, CCII-, ICCII+, ICCII-, CCII+/-, CCII+/+, DVCC, and UCC.

3. ADJOINT CURRENT CONVEYORS

All of the CCNC, both familiar and as novel ones, have their adjoint current conveyors of the CCNC again, but interchanging terminals y+ ↔ z- and y- ↔ z+, which is briefly given in the following compendious table (Tab. 1).

If we want to obtain an adjoint equivalent to the current conveyor of other than null class, firstly a certain model of this CC must be taken, using the CCNC and connecting some ports. Then the model can be transformed using Tab. 1, what will be described in detail in following illustrative examples.

Some simple example of three-port conveyors is given in Fig. 1. There in Fig. 1a is the well known and often used conveyor CCII+. Its adjoint equivalent is from Tab. 1 evidently the ICCII- (Fig. 1b). In the right part of Fig. 1 we can see that the CCII− (Fig. 1c) has as its adjoint equivalent again the CCII− (Fig. 1d), but with interchanged ports, as was given above (Tab. 1).

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Table 1: Adjoint current conveyors

PROTOTYPE ELEMENT in VM								ADJOINT EQUIVALENT in CM								Notes:
Passive subcircuit		Nodes						Passive subcircuit		Nodes						without changes
		A	B	C	D	E	G			A	B	C	D	E	G	
Current conveyor								Current conveyor								
Type	Ports							Type	Ports							
CCII-	X	*						CCII-	X	*						The same FB changing ports y ↔ z
	Y		*						Y			*				
	Z			*					Z		*					
	GND				*				GND				*			
CCII+	X	*						ICCII-	X	*						changing ports y ↔ z
	Y		*						Y			*				
	Z			*					Z		*					
	GND				*				GND				*			
ICCII+	X	*						ICCII+	X	*						The same FB changing ports y ↔ z
	Y		*						Y			*				
	Z			*					Z		*					
	GND				*				GND				*			
ICCII-	X	*						CCII+	X	*						changing ports y ↔ z
	Y		*						Y			*				
	Z			*					Z		*					
	GND				*				GND				*			
DVCC	X	*						DVCC	X	*						The same FB changing ports y(+/-) ↔ z(-/+)
	Y(+)		*						Y(+)					*		
	Y(-)			*					Y(-)				*			
	Z(+)				*				Z(+)			*				
	Z(-)					*			Z(-)		*					
	GND						*		GND						*	

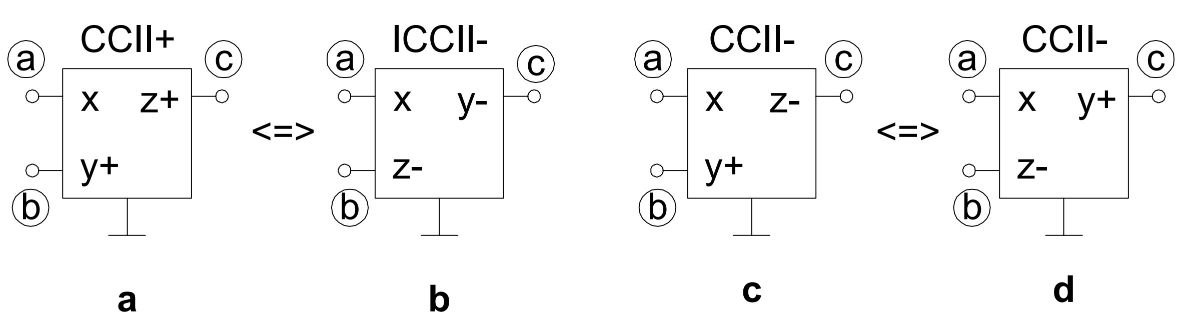

Fig. 1. Mutually adjoint equivalents of three-port current conveyors

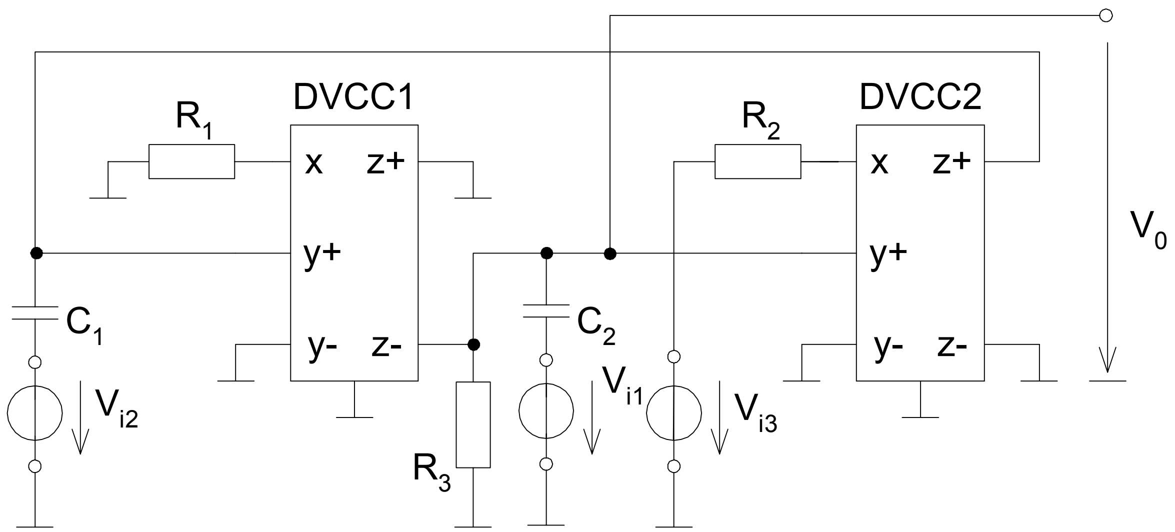

Fig. 2. Biquadratic current conveyor (DVCC) based filter working in the voltage mode

4. ADJOINT FILTER BASED ON DVCC'S

Another illustrative example is the multifunctional (LP, BP, HP, BR, APF) second-order ARC filter using two five-port conveyors DVCC (Fig. 2). The circuit realizes in the voltage mode the following transfer function

$$V_{out} = \frac{s^2 C_1 C_2 V_{i1} - s C_1 G_1 V_{i2} + G_1 G_2 V_{i3}}{s^2 C_1 C_2 + s C_2 G_3 + G_1 G_2}. \quad (4)$$

Now, using the adjoint transformation given above (Tab. 1), the network of Fig. 2 is ingeniously retransformed into the equivalent filter working in the current mode, which results in Fig. 3. The current transfer functions are now given by

$$\frac{I_{o1}}{I_{in}} = \frac{s^2 C_1 C_2}{D(s)} \quad (5)$$

$$\frac{I_{o2}}{I_{in}} = \frac{-s C_1 G_1}{D(s)} \quad (6)$$

$$\frac{I_{o3}}{I_{in}} = \frac{G_1 G_2}{D(s)} \quad (7)$$

where the denominator is

$$D(s) = s^2 C_1 C_2 + s C_1 G_3 + G_1 G_2. \quad (8)$$

From denominator (8) design equations can be derived, namely for the natural frequency

$$\omega_0 = \frac{1}{\sqrt{C_1 R_1 C_2 R_2}}, \quad (9)$$

and for the quality factor

$$Q = \frac{R_3}{\sqrt{R_1 R_2}} \sqrt{\frac{C_2}{C_1}}. \quad (10)$$

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

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

Then the resulting circuit (Fig. 3) has the following values of the components:

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

This filter was simulated by means of PSpice using a suitable model of the ideal DVCC, namely with controlled sources CCCS and VCVS only [7]. The resulting magnitude responses for all the current outputs (LP, BP, HP) are shown in Fig. 4. This simulation confirms the symbolical analysis and theoretical assumptions.

5. CONCLUSION

The above given adjoint VM-CM structures of the DVCC based biquadratic ARC filters are evidently a suitable choice for high frequency applications. The results simulated by PSpice have confirmed this conclusion.

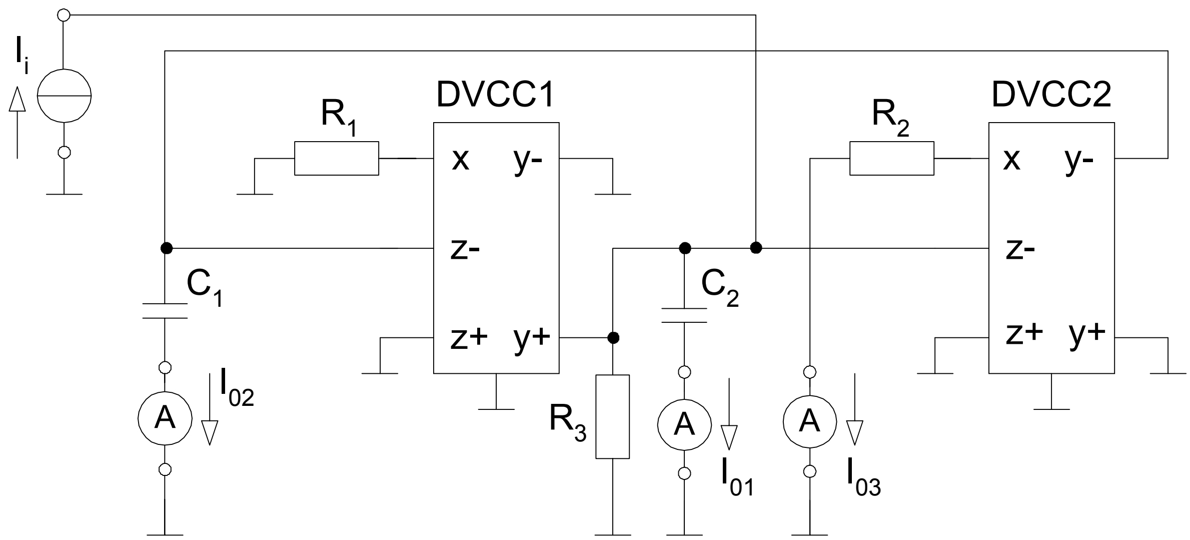

Fig. 3. Adjoint filter working in the current mode

The method of adjoint transformation is applicable to other elements, whose mutual adjointness is known as nullator-norator or V-I controlled sources, etc.

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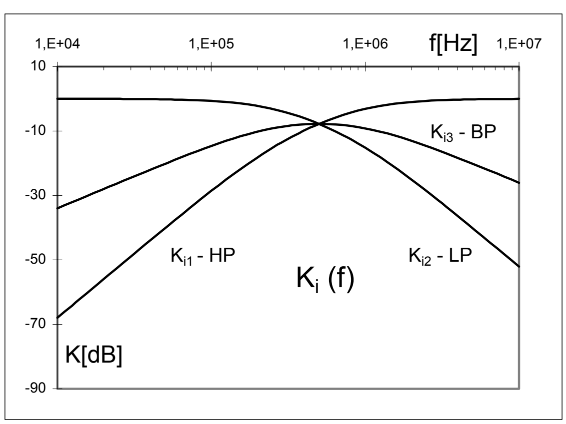

Fig. 4. Magnitude responses of the filter from Fig. 3 in the current mode

REFERENCES

[1] S. W. Director, R. A Rohrer, "The generalized adjoint network and network sensitivities", IEEE Trans. Circuit Theory, vol. CT-16, 1969, pp. 318-323.

[2] C. Toumazou, F. J. Lidgey, D. G. Haigh, "Analogue IC design: The current - mode approach, Peter Peregrinus Ltd., London, 1990.

[3] H. O. Elwan, A. M. Soliman, "Novel CMOS differential voltage current conveyor and its application", IEE Proc. - Circuits Devices Syst., vol. 144, No. 3, 1997, pp. 195-200.

[4] G. S. Moschytz, A. Carlosena, "A classification of current-mode single-amplifier biquads based on voltage-to-current transformation." IEEE Trans. on CAS-II, vol. 41, no. 2, 1994.

[5] C. A. Papazoglou, C. A Karybakas, "A transformation to obtain CCII-based adjoint of op.amp-based circuits. IEEE Trans. on CAS-II, vol. 45, no. 7, 1998, pp. 894-898.

[6] S. Celma, A. Martinez, J. Sabadell, "A transformation method for equivalent infinite-gain op.amp - based adjoint of CCII - based circuits", IEEE Trans. on CAS-II, vol. 45, no. 7, 1998, pp. 61-63.

[7] MicroSim, "Pspice – User's Guide", MicroSim corp., Irvine, 1996.