ANALYSIS OF CIRCUIT STRUCTURES CONTAINING BEHAVIORAL MODELS OF CDTA ELEMENT

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Abstract: *The behavioral model of ideal CDTA element (Current-Differencing Transconductance Amplifier) is described. Its matrix and flow-graph descriptions are proposed for algorithmic and "hand-and-paper" analyses of linear applications of CDTAs.*

Introduction

A novel circuit element, namely CDTA (Current-Differencing Transconductance Amplifier), we introduced in [1]. Its behavioral model contains current source which is controlled by a difference of two input currents, and two-output transconductance OpAmp – BOTA. This element seems to be appropriate for the synthesis of current-mode circuits, especially analogue frequency filters [2], [3].
For the purposes of symbolic and semisymbolic analyses of applications containing CDTAs, proper MNA (Modified Nodal Analysis) -compatible matrix forms of circuit equations have been compiled. These equations were then transformed into Mason-Coates (M-C) flow-graphs for fast "hand-and-paper" analysis and as an efficient tool for the synthesis of frequency filters.

CDTA and its behavioral model

An behavioral model of CDTA is in Fig. 1. It has difference current inputs p and n. The difference of these currents flows from terminal z into an outside load. The voltage across the z terminal is transferred by a transconductance g_m to a current, which is taken out as a current pair to x terminals. This last element part is the familiar transconductance operational amplifier (OTA). In general, the transconductance is controllable electronically through an auxiliary port that is not referred in Fig. 1.

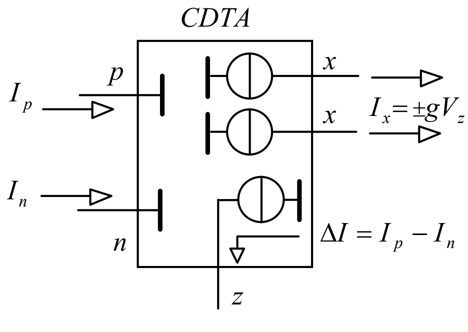

Fig. 1: Behavioral model of CDTA element.

The pair of the output currents from x terminals, referred in Fig. 1, may have three combinations of directions: 1. Both currents can flow out. 2. The currents have different directions. 3. Both currents flow inside the CDTA element. Then we talk about the CDTA++, CDTA+-, and CDTA-- elements. It is suitable to mark the current directions in the circuit symbol by the signs + (outside) and – (inside) as shown in Fig. 2 (a).

The proposed symbol of CDTA is in Fig. 2 (a). Also in Fig. 2 (b) is given a possible implementation of CDTA using the familiar CCII+ and double-output OTA (i.e. BOTA) components.

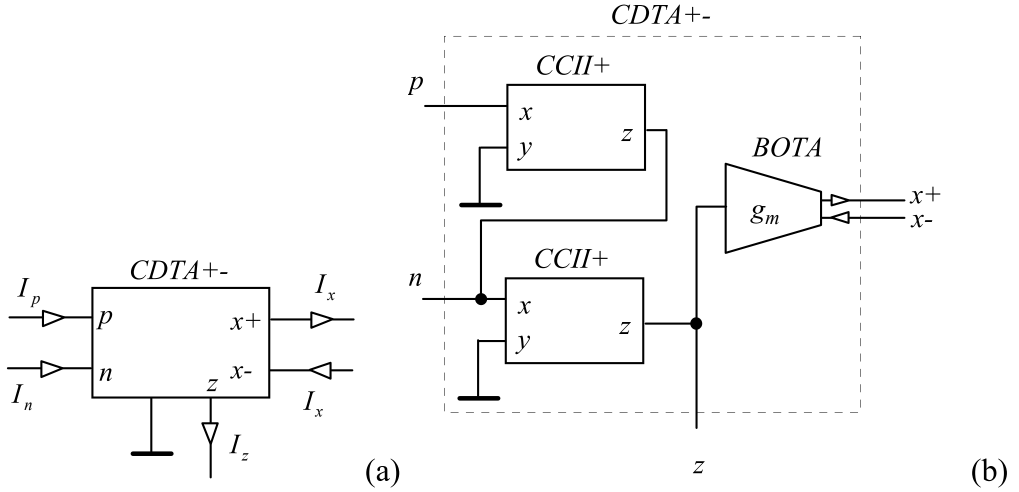

Fig. 2: (a) Symbol of the CDTA+- element, (b) its implementation by current conveyors and by BOTA.

Matrix description of CDTA element

Let us mark nodal voltages, which correspond to the *p*, *n*, *z* and *x* outlets, by symbols V_p, V_n, V_z and V_x. For a transparency, consider only one current output *x*+. Currents flowing inside the CDTA from outside sources be marked by the superscript ^{0}. Then the matrix equation, implemented in SNAP program [4], is as follows:

$$\begin{array}{c} \\ \begin{bmatrix} I_p^0 \\ I_n^0 \\ I_z^0 \\ I_x^0 \\ \\ \\ \\ \end{bmatrix} \end{array} = \begin{array}{c} \begin{array}{ccccccc} V_p & V_n & V_z & V_x & I_p & I_n & I_x \end{array} \\ \begin{bmatrix} & & & & 1 & & \\ & & & & & 1 & \\ & & & & -1 & 1 & \\ & & & & & & -1 \\ 1 & & & & & & \\ & 1 & & & & & \\ & & g_m & & & & -1 \end{bmatrix} \end{array} \begin{array}{c} \\ \begin{bmatrix} V_p \\ V_n \\ V_z \\ V_x \\ I_p \\ I_n \\ I_x \end{bmatrix} \end{array} \qquad (1)$$

The second variant is reduction of unknown variables by current I_x, omitting the last equation, and modification the equation No. 4 to the form $I_x^0 = -g_m V_z$.

For fast "hand-and-paper" analysis, it is necessary to reduce given matrix-stamp to appropriate size. In reality, the voltages V_p and V_n are equal to zero and they need not be included in the vector of unknown variables. Together with the above reduction of current I_x, the economical set of equations has the following form:

$$\begin{array}{c} \\ \begin{bmatrix} I_p^0 \\ I_n^0 \\ I_z^0 \\ I_x^0 \end{bmatrix} \end{array} = \begin{array}{c} \begin{array}{cccc} V_z & V_x & I_p & I_n \end{array} \\ \begin{bmatrix} & & 1 & \\ & & & 1 \\ & & -1 & 1 \\ -g_m & & & \end{bmatrix} \end{array} \begin{array}{c} \\ \begin{bmatrix} V_z \\ V_x \\ I_p \\ I_n \end{bmatrix} \end{array} \qquad (2)$$

Flow-graph description of CDTA element

Two variants of Mason-Coates (M-C) flow-graphs [5] which are based on matrix equations (1) and (2), are given in Fig. 3. For fast evaluation of the graph, zero-value variables V_p and V_n are already excluded. The M-C graph is built for a couple of current outputs x+ and x-. In Fig. (b), the graph reduction is made for a case when we are not immediately interested in currents I_z, I_{x+}, and I_{x-}. The proper graph of CDTA element is drawn in bold. The dashed self-loops appear in the graph due to connected outside admittances.

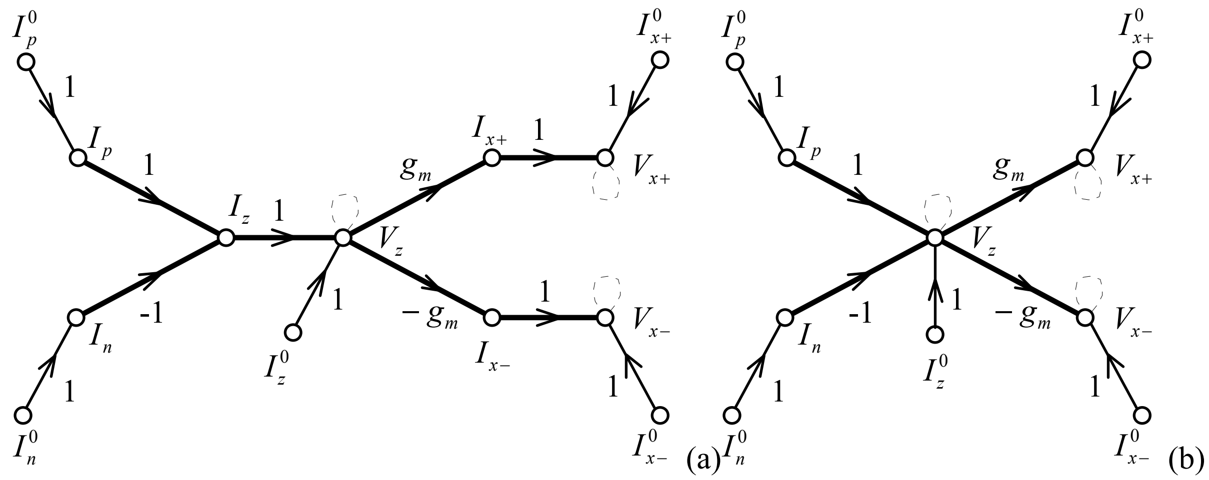

Fig. 3: (a) general, (b) reduced M-C graph of CDTA element.

Demonstration of the analysis

The active filter in Fig. 4 (a) simulates a passive RCL ladder filter. The corresponding flow-graph is in Fig. 4 (b).

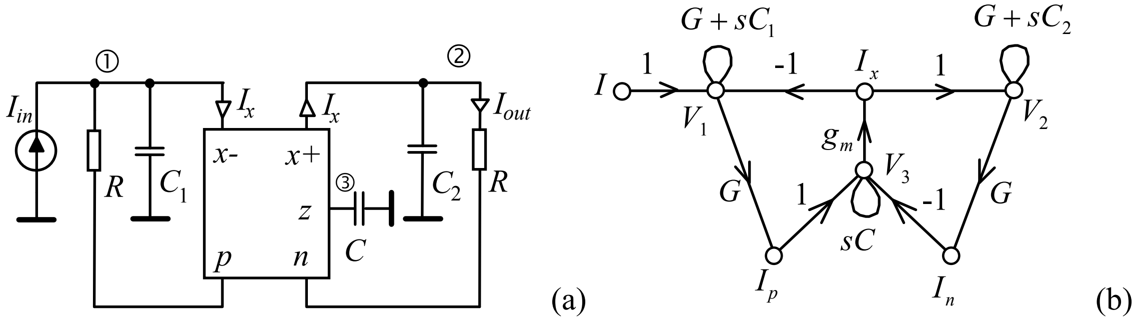

Fig. 4: (a) Simulation of passive RCL filter by CDTA-based structure, (b) the corresponding M-C graph.

Let us verify that the CDTA element behaves as a floating inductor between its x- and x+ terminals.
The set of equations can be compiled for the circuit in Fig. 4 (a):

	V_1	V_2	V_3	I_p	I_n	
I_{in}	sC_1		g_m	1		V_1
		sC_2	$-g_m$		1	V_2
			sC	-1	1	V_3
	$-G$			1		I_p
		$-G$			1	I_n

A rather tough computation leads to the final result

$$\frac{V_1 - V_2}{I_x} = \frac{V_1 - V_2}{g_m V_3} = \frac{1}{g_m} \frac{\Delta_{1:1} - \Delta_{1:2}}{\Delta_{1:3}} = sL \text{, where } L = \frac{RC}{g_m}. \tag{3}$$

The identical result can be obtained more quickly, evaluating the flow-graph in Fig. 4 (b):

$$\frac{V_1}{I_x} - \frac{V_2}{I_x} = \frac{sC(G + sC_2) + Gg_m - Gg_m}{Gg_m(G + sC_2)} = s\frac{RC}{g_m}.$$

The above results are also consistent with the results of symbolic analysis by SNAP program.

Conclusion

The above matrix and flow-graph models of the CDTA element were created primarily for symbolic and semisymbolic analyses of general linear applications of this element, in the frame of its ideal behavioral model in Fig.1. An implementation of matrix equations in SNAP program was made. The described flow-graphs are particularly appropriate for fast "hand-and-paper" analysis.

Acknowledgement

This work is supported by the Grant Agency of the Czech Republic under grant No. 102/03/1363, and by the research programmes of BUT MSM 262200022 & MSM 262200011.

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