MODELING OF CURRENT AND VOLTAGE CONVEYORS BY FLOW GRAPH TECHNIQUE

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Abstract – *The so-called n-port generalized conveyor (GC) is presented. This conveyor models a number of various active devices, depending on the choice of the number of its corresponding ports, on the type of circuit equations, and on the values of conveyance coefficients. Equations of two possible types describe so-called generalized current or voltage conveyor (GCC, GVC) as a generalization of the familiar CCI, CCII, CDBA, DVCC and other active elements. Modified Mason-Coates (M-C) flow graphs for fast analysis of circuits containing these elements are proposed. Some advantages of this approach are shown on illustrative examples.*

Keywords: voltage conveyor, current conveyor, generalized conveyor, flow graphs, Mason-Coates´ flow graph.

1 Introduction

The evolution of current-mode and mixed-mode analog signal processing led to rediscovering the current conveyor, which was introduced into circuit theory by Smith and Sedra in 1968 [1]. Together with various types of current conveyors (*CCI*, *CCII* and others) [2], voltage conveyors and other elements have appeared, for example *CDBA* (Current-Differencing Buffered Amplifier) [3], *DVCC* (Differential Voltage Current Conveyor) [4] and others.

Verifying the basic function of small-signal linearized models of circuits containing the elements mentioned above is not as easy as for classical *OpAmp* circuits. That is why we introduce a special circuit element. Its model includes models of all the above elements and other elements. Then we compile a flow graph model of this element. Specifying it, we obtain a modified Mason-Coates (*M-C*) flow graph of a concrete element [5], [6]. In this manner, we obtain a universal tool for fast reference analysis of circuits with a broad spectrum of modern and promising active elements.

In the paper, the so-called *n*-port generalized conveyor [7] is described. Three types of its ports and two types of circuit equation – for the current/voltage conveyor – are defined. The terms: conveyor *order*, *kind*, and *class* are introduced. That sets down the conditions for unified universal classification of present conveyor-based active elements. Some frequently used elements are shown as special cases of *n*-port conveyor. Then the *M-C* flow graphs of generalized *n*-port current/voltage conveyors are compiled. Some examples of analysis are included.

2 *n*-port conveyor

The schematic symbol of *n*-port conveyor, $n \geq 3$, is in Fig. 1(a). There are three types of conveyor port: input ports (x), auxiliary ports (y) and output ports (z). The number of individual ports is m, I and J, respectively. Nodal currents and nodal voltages are considered as variables.

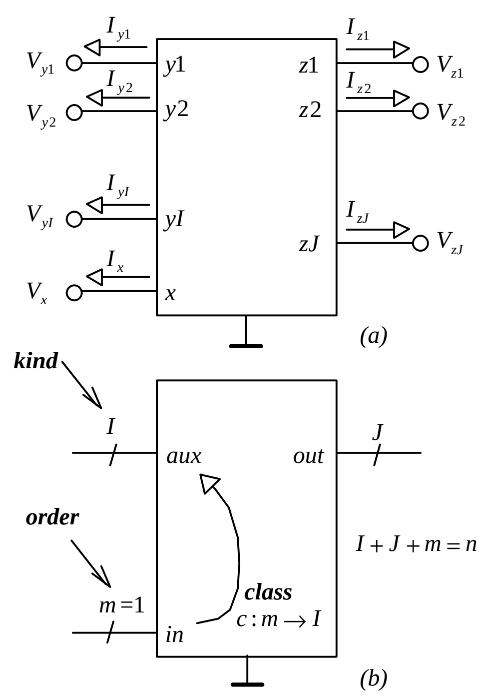


Fig. 1. (a) Schematic symbol of *n*-port conveyor, (b) illustration of the terms conveyor *kind*, *order*, and *class*.

Let number m be called the conveyor *order*. The order is equal to the number of independent exciting quantities. In the following we will confine ourselves to the practically exploitable case $m = 1$ (so-called *first-order* or *classical conveyors*). The exciting quantity (current or voltage) is applied to the input port and can be conveyed to the auxiliary ports. Number c of such auxiliary ports is called the *conveyor class*, whereas the total number I of auxiliary ports classifies the *conveyor kind*. Very important for practical use is the case when no input quantity is conveyed to the auxiliary ports, i.e. $c = 0$. Then we say that the conveyor in question is of class zero. Formerly, such a conveyor was called second-generation conveyor. Nearly all the conveyors published up to date are zero-class conveyors.

We presented our proposals concerning the conveyor terminology in [7].

3 Conveyor types

The above *n*-port conveyor can be either of the *current* or the *voltage* type.

The current conveyor is described by the following set of equations:

$$V_x = \sum_{i=1}^{I} a_i V_{yi} ,$$

$$I_{yi} = b_i I_x ,\ i = 1...I, \tag{1}$$

$$I_{zj} = c_j I_x ,\ j = 1...J .$$

Here the independent current I_x is the main variable. The conveyor class is given by the number of non-zero conveyance coefficients b_i.

The voltage conveyor is described by the adjoint equations

$$I_x = \sum_{i=1}^{I} a_i I_{yi} ,$$

$$V_{yi} = b_i V_x ,\ i = 1...I, \tag{2}$$

$$V_{zj} = c_j V_x ,\ j = 1...J .$$

In this case the main variable is the independent voltage V_x.

The above equations containing general coefficients *a*, *b*, and *c* represent the model of *generalized conveyor*. Replacing the coefficients by their numerical values, which are typical of a given circuit element, yields the model of *concrete conveyor*. The sets of typical coefficients of currently used conveyors are as follows:

$$a_i \in \{+1, -1\},\ b_j \in \{0, +1, -1\},\ c_i \in \{+1, -1\},$$

$$i = 1...I,\ j = 1...J .$$

Behavioral models of the generalized current/voltage conveyor, shown in Fig. 2, can be compiled from equations (1) and (2). From these models, the principle of signal transmission between the individual ports is apparent.

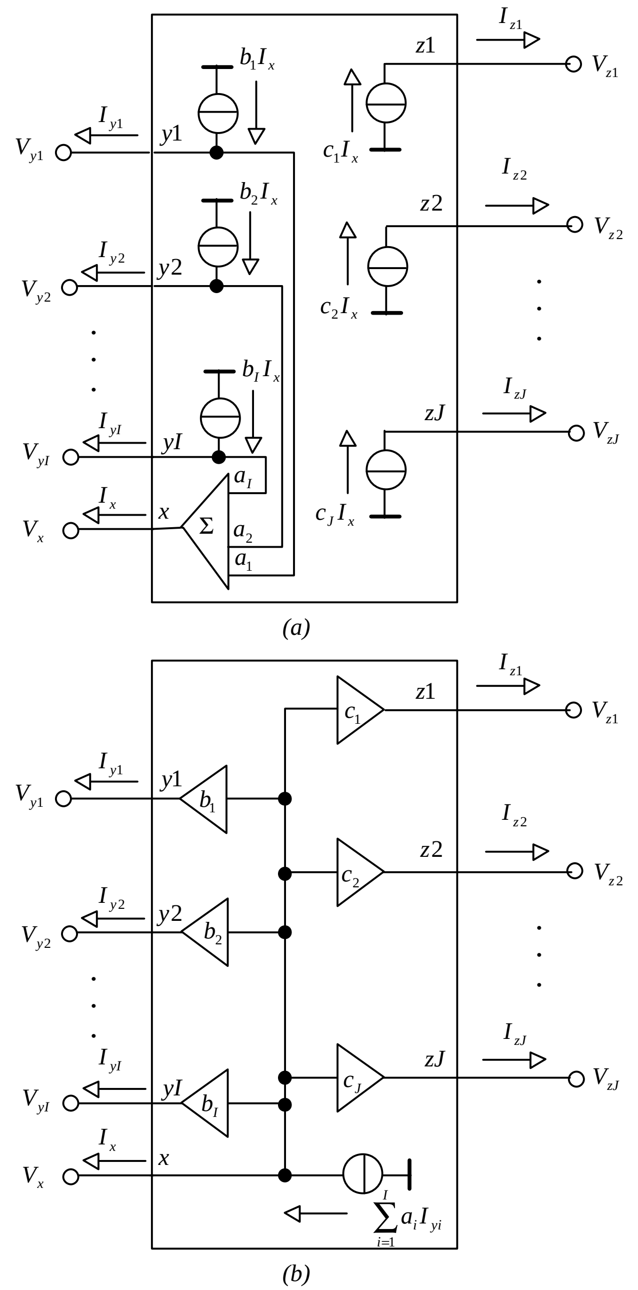


Fig. 2. Behavioral model of *n*-port generalized current (a), voltage (b) conveyor.

4 Modeling of generalized conveyors by flow graphs

In Fig. 3 (a), the behavioral model of generalized current conveyor is complemented with external exciting currents. The currents flowing into the input, auxiliary and output ports are indexed with *i*, *a*, and *o*, respectively. Equations (1) can be rewritten in the following form:

$$\sum_{i=1}^{I} a_i V_{yi} - V_x = 0.I_x , \tag{3}$$

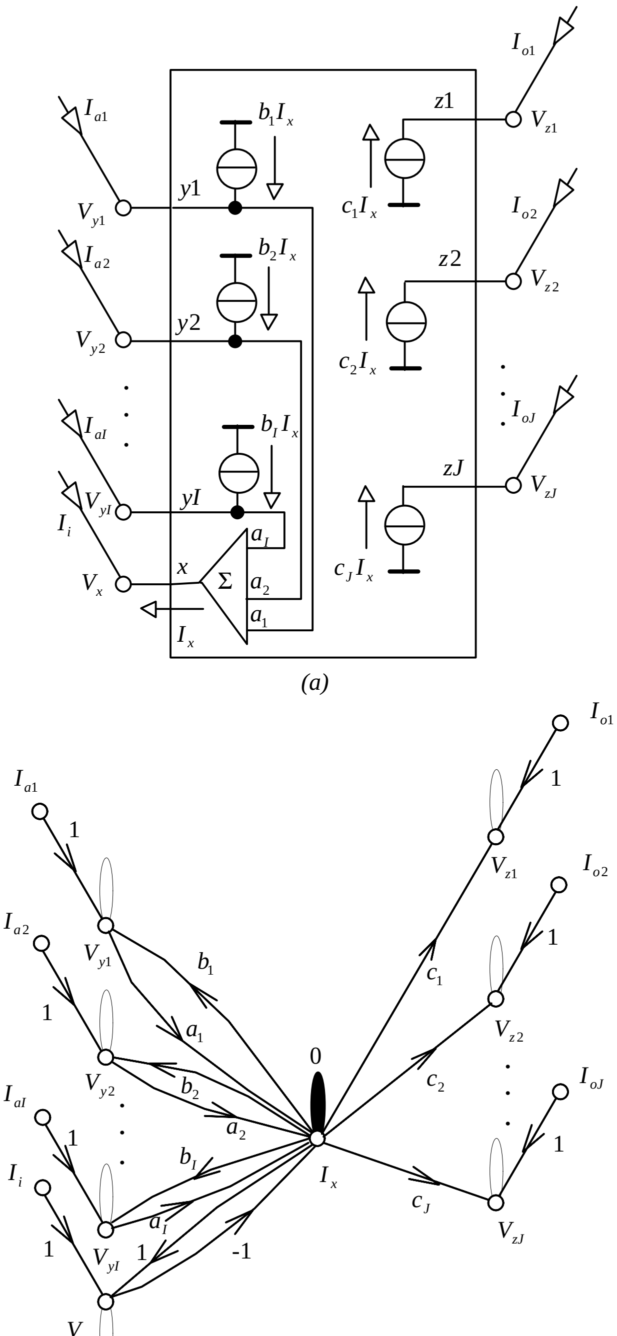


Fig. 3. (a) *n*-port generalized current conveyor, (b) its M-C flow graph.

$$Y_{yi}V_{yi} = I_{ai} + b_i I_x,\ i = 1...I, \tag{4}$$

$$Y_x V_x = I_i + I_x \tag{5}$$

$$Y_{zj}V_{zj} = I_{oj} + c_j I_x,\ j = 1...J\ . \tag{6}$$

The symbols Y_{yi}, Y_x, and Y_{zj} specify total admittances of elements, connected from outside to nodes *yi*, *x*, and *zj*. The dotted self-loops in the *M-C* flow graph in Fig. 3 (b) correspond to these admittances. Equation (3) is represented in the graph by the zero-gain self-loop of current node I_x. The paths from voltage nodes V_{yi}, having gains a_i, are directed into this node. Equations (4) are modeled by the self-loops of nodes V_{yi} and by paths which are directed into these nodes. Equations (5) and (6) are projected into the graph analogously.

A similar procedure can be applied to yield graph representation of the voltage conveyor. Its behavioral model together with the external exciting currents is in Fig. 4 (a). The following equations result from the model:

$$Y_{yi}V_{yi} = I_{ai} + I_{yi},\ i = 1...I\ , \tag{7}$$

$$I_x = \sum_{i=1}^{I} a_i I_{yi}\ , \tag{8}$$

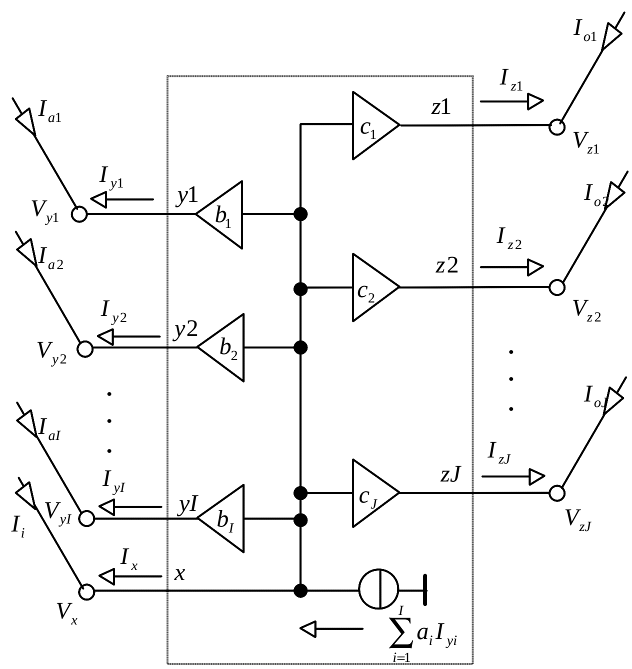
$$0.I_{yi} = b_i V_x - V_{yi},\ i = 1...I\ , \tag{9}$$

$$Y_x V_x = I_x + I_i\ , \tag{10}$$

$$0.I_{zj} = c_j V_x - V_{zj},\ j = 1...J\ , \tag{11}$$

$$Y_{zj}V_{zj} = I_{0j} + I_{zj},\ j = 1...J\ . \tag{12}$$

The *M-C* flow graph in Fig. 4 (b) results from the above equations. When neither the current I_x nor the currents through the output ports are the objects of analysis, the reduced graph in Fig. 4 (c) can be used. Because of ideal voltage sources in the output ports, no additional directed path can enter any voltage node V_{zj} [6].



(a)

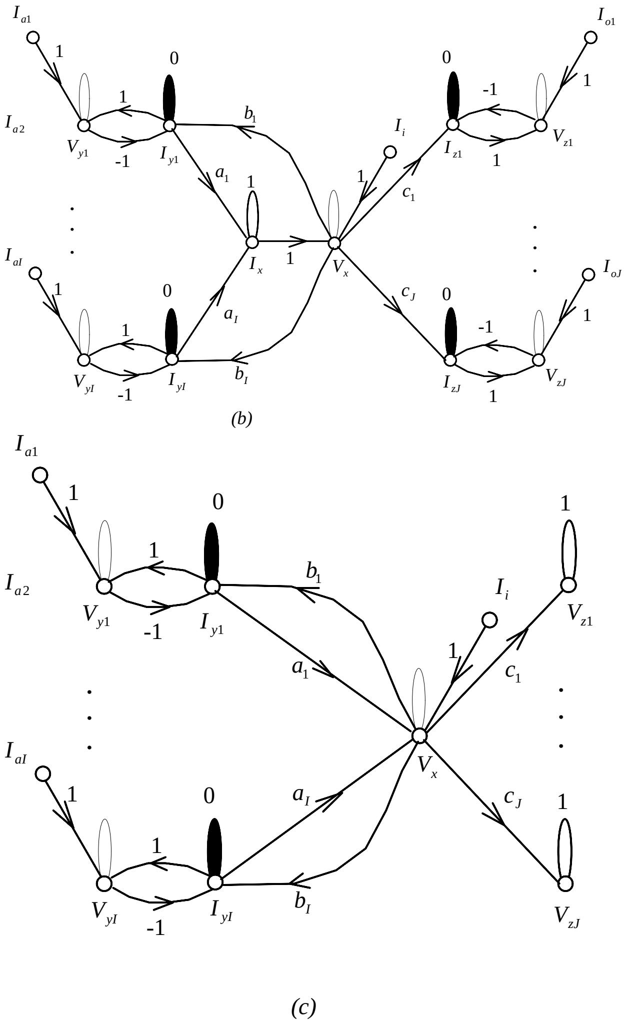
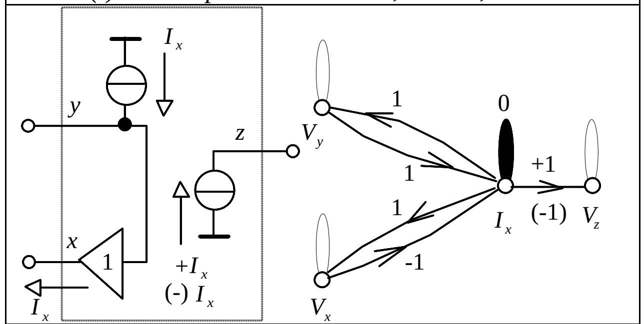


Fig. 4. (a) *n*-port generalized current conveyor, (b) total, (c) reduced *M-C* flow graph.

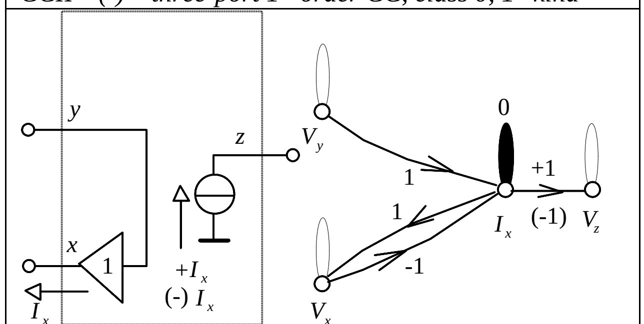
5 Some concrete conveyors

Some well-known circuit elements, their behavioral models and *M-C* flow graphs are in Table 1. It is evident that all the elements are special cases of the generalized *n*-port conveyor. Comparing with Fig. 2 yields the values of conveyance coefficients *a*, *b*, and *c*.

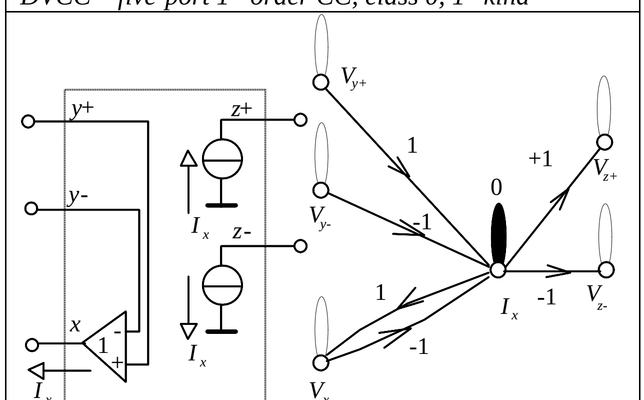
CCI+ (-) – three-port 1st-order CC, class 1, 1st kind



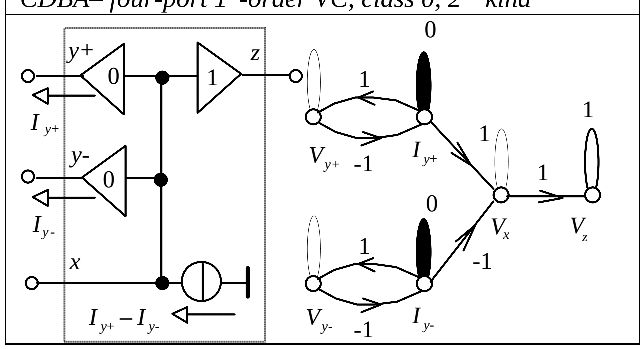
CCII+ (-) – three-port 1st-order CC, class 0, 1st kind



DVCC – five-port 1st-order CC, class 0, 1st kind



CDBA– four-port 1st-order VC, class 0, 2nd kind



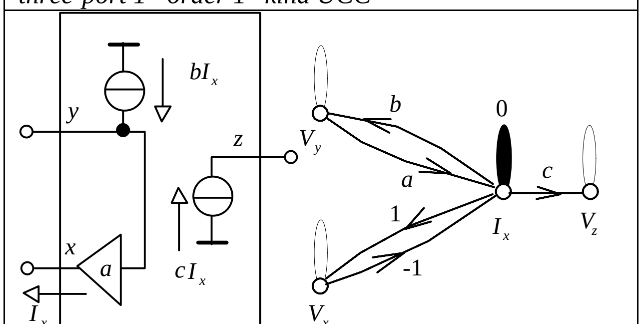
Tab. 1. Some concrete conveyors as special cases of generalized *n*-port conveyor.

6 Three-port universal conveyors

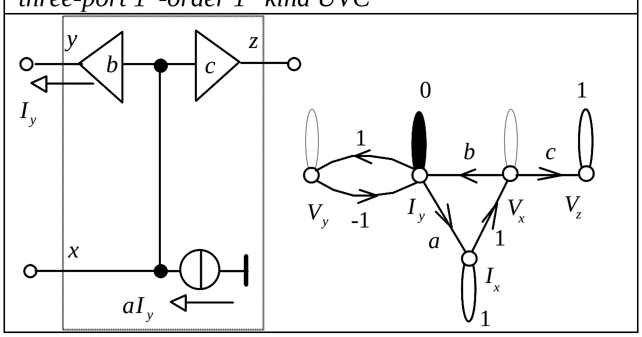
It is advantageous to compile flow graphs for the popular three-port conveyors, provided their conveyance coefficients will be taken for general symbols a, b and c. These models will enable an analysis of circuits with respect to real deflections of conveyor coefficients from their nominal values. Setting proper values instead of symbolic values, we can switch between models of several different conveyors. Moreover, this approach could also be useful for the synthesis of circuits. A concrete conveyor with symbolic values of conveyance coefficients could be called *universal conveyor* (*UC*).

Behavioral models and the corresponding flow graphs of three-port current and voltage *UCs* are in Table 2. In the case of current conveyor, its model includes the *CCI* and *CCII* types ($a = 1$ and 0), non-inverting and inverting types ($b = +1$ and -1), positive and negative types ($c = +1$ and -1) [8].

three-port 1st-order 1st kind UCC



three-port 1st-order 1st kind UVC



Tab. 2. Three-port universal current and voltage conveyors.

7 Examples of analysis

The 5th -order lowpass filter with *DVCC*s in Fig. 5 (a) was published in [9]. This filter can operate both in the voltage and the current mode, depending on the choice of input V_{in} or I_{in}.

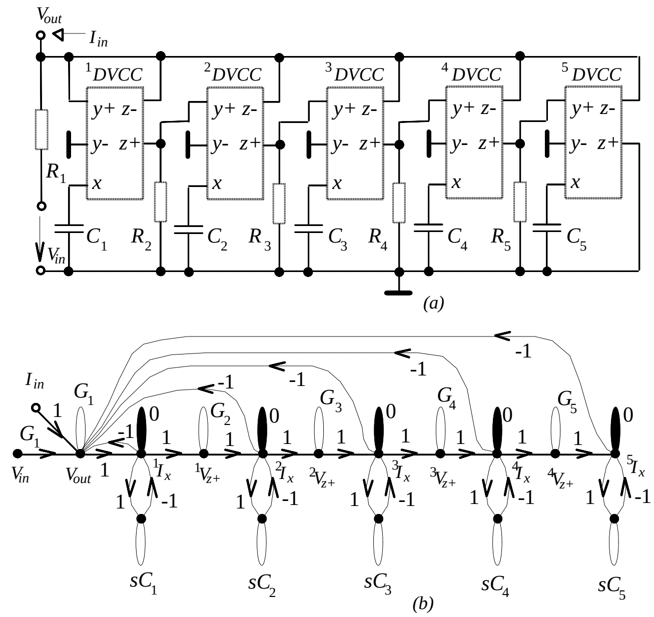


Fig. 5. (a) 5th -order lowpass filter, (b) its M-C graph.

To determine, for example, filter transfer function V_{out}/V_{in}, let us construct the *M-C* flow graph in Fig. 5 (b). The graph evaluation is considerably simplified by the presence of five zero-gain self-loops. Applying the generalized Mason's gain formula [10] yields the result

$$\frac{V_{out}}{V_{in}} = \frac{a_0}{\sum_{i=0}^{5} b_i s^i},$$

where

$$a_0 = \prod_{i=1}^{5} G_i,\ b_0 = G_1,\ b_k = \prod_{i=1}^{k} C_i \prod_{j=k+1}^{5} G_j,\ k = 1...5.$$

This is in accordance with [9].

The second sample circuit in Fig. 6 (a) [11] is compiled from two universal three-port voltage conveyors. Let us find a set of conveyance coefficients that will ensure the circuit operation as positive immittance inverter.
We draw the flow graph in Fig. 6 (b) and evaluate the input impedance:

$$Z_{in} = \frac{{}^1V_x}{I} = \frac{Y_L - {}^2a\ {}^2bY_2}{{}^1a\ {}^1bY_1({}^2a\ {}^2bY_2 - Y_L) - {}^1a\ {}^1c\ {}^2a\ {}^2cY_1Y_2}.$$

Relations

$${}^1b = {}^2b = 0 \text{ and } {}^1a\ {}^1c\ {}^2a\ {}^2c = -1$$

yield the required equation of positive immittance inverter:

$$Z_{in} = \frac{Y_L}{Y_1Y_2} = \frac{Z_1Z_2}{Z_L}.$$

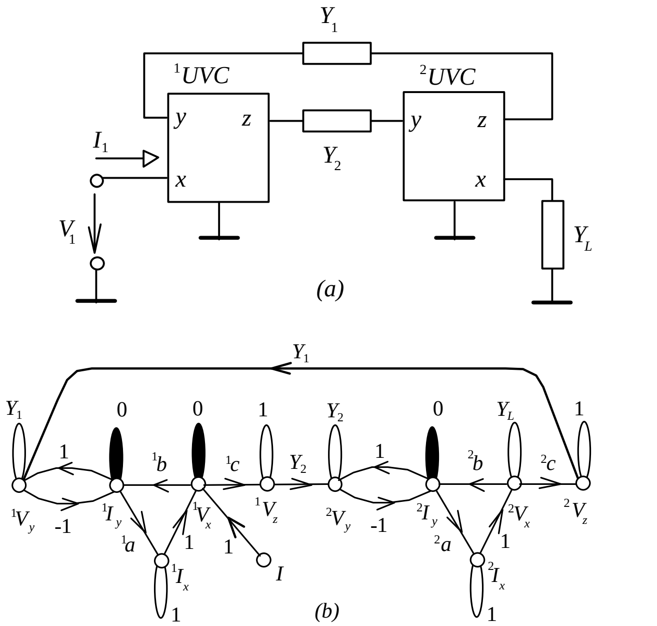


Fig. 6. (a) positive immittance inverter, (b) its *M-C* flow graph.

Conclusion

The concept of the generalized *n*-port current/voltage conveyors and their *M-C* flow graphs enables a simple analysis of small-signal linearized models of circuits, consisting of a number of active elements and operating in the voltage, current and mixed mode.

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