SIMULATION OF PASSIVE LADDER LC STRUCTURES BY ACTIVE FILTERS CONTAINING CDBA ELEMENTS

Dalibor Biolek*) and Viera Biolková**)

*) K301 VA Brno, Kounicova 65, 612 00 Brno, Czech Republic,
tel. (+420) 5 4118 2487, fax (+420) 5 4118 2888, dalibor.biolek@vabo.cz
**) ÚREL FEKT VUT Brno, Purkynova 118, 612 00 Brno, Czech Republic,
tel. (+420) 5 4114 9152, fax (+420) 5 4114 9244, biolkova@feec.vutbr.cz

Abstract: *Simulation of passive ladder LC filters by active circuits with CDBA (Current-Differencing Buffered Amplifier) elements is presented. The procedure of non-cascade active filter synthesis is described, including some possibilities of its subsequent optimization.*

Introduction

The CDBA (Current-Differencing Buffered Amplifier) circuit element, in [1], is a special type of generalized voltage conveyor [2]. It is particularly appropriate for the synthesis of voltage-mode active filters because it enables easy realization of inverting and non-inverting multiple-input integrators.

A synthesis of non-cascade FLF (Follow-the-Leader Feedback) [3] topology filter is described in [1]. We will show in this paper how to utilize CDBA elements in active filter synthesis by the familiar „integrator“ simulation of ladder cells. The procedure is explained on examples of lowpass filters with and without transmission zeros. However, it can also be applied to other ladder structures.

CDBA – a versatile building block of active filters

The behavioral model of ideal CDBA is shown in Fig. 1. This element has two 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 to the *w* terminal by a unity-gain buffer.

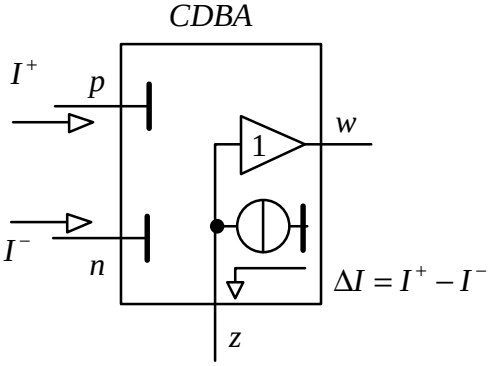

Fig. 1. Behavioral model of CDBA element.

The basic CDBA connection is given in Fig. 2 (a), where currents flow into the *p* and *n* terminals from voltage sources through general impedances. The difference current flows from the *z* terminal into an impedance *Z* and generates the voltage

$$V_w = Z\left(\sum_{i=1}^{m} Y_i^+ V_i^+ - \sum_{j=1}^{n} Y_j^- V_j^-\right), \qquad (1)$$

which can be taken from the low-impedance *w* terminal. Symbols *Y* denote admittances which correspond to individual impedances *Z*.

Equation (1) is expressed in the form of simple signal flow graphs (SFG) in Fig. 2 (b). These are so-called „*VIV*“ graphs, originally introduced in [4] for the analysis of OpAmp circuits. Note that admittances serve as input voltage/current converters, whereas impedance *Z* is a difference current/voltage converter. When impedance *Z* is realized by a capacitor, then the circuit is a multiple-input universal integrator.

Signal-Flow-Graph simulation of ladder filter

Consider the ladder filter in Fig. 3 (a). To realize the effect of both inductors and capacitors via integrators, let us draw the following familiar equations [3]:

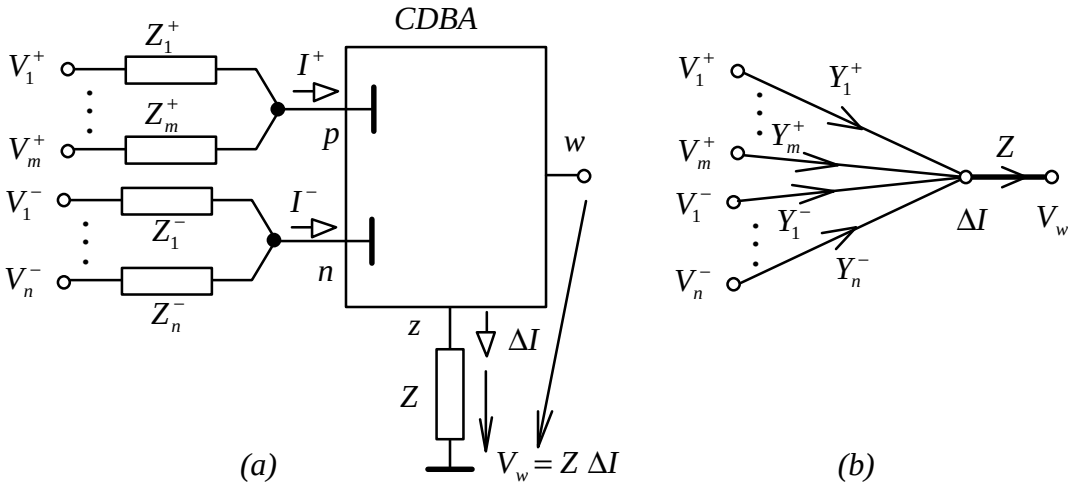

Fig. 2. (a) Basic connection of CDBA element, (b) corresponding signal flow graph.

$$I_{1,2} = G_1(V_1 - V_2),\ V_2 = \frac{1}{sC_1}(I_{1,2} - grI_{2,3}),$$

$$rI_{2,3} = \frac{1}{sL_1/r^2}(gV_2 - gV_3),\ V_3 = \frac{1}{sC_2}(grI_{2,3} - grI_{3,4}), \qquad (2)$$

$$\vdots$$

$$rI_{n-1,n} = \frac{1}{sL_{n-2}/r^2}(gV_{n-1} - gV_n),\ V_n = \frac{1}{sC_{n-1}}(grI_{n-1,n} - G_2V_n).$$

The symbols r and g=1/r denote auxiliary resistances and conductances, respectively, which convert currents into voltages for active SFG simulation. As shown below, these voltages will be realized as w-terminal voltages of individual CDBAs.

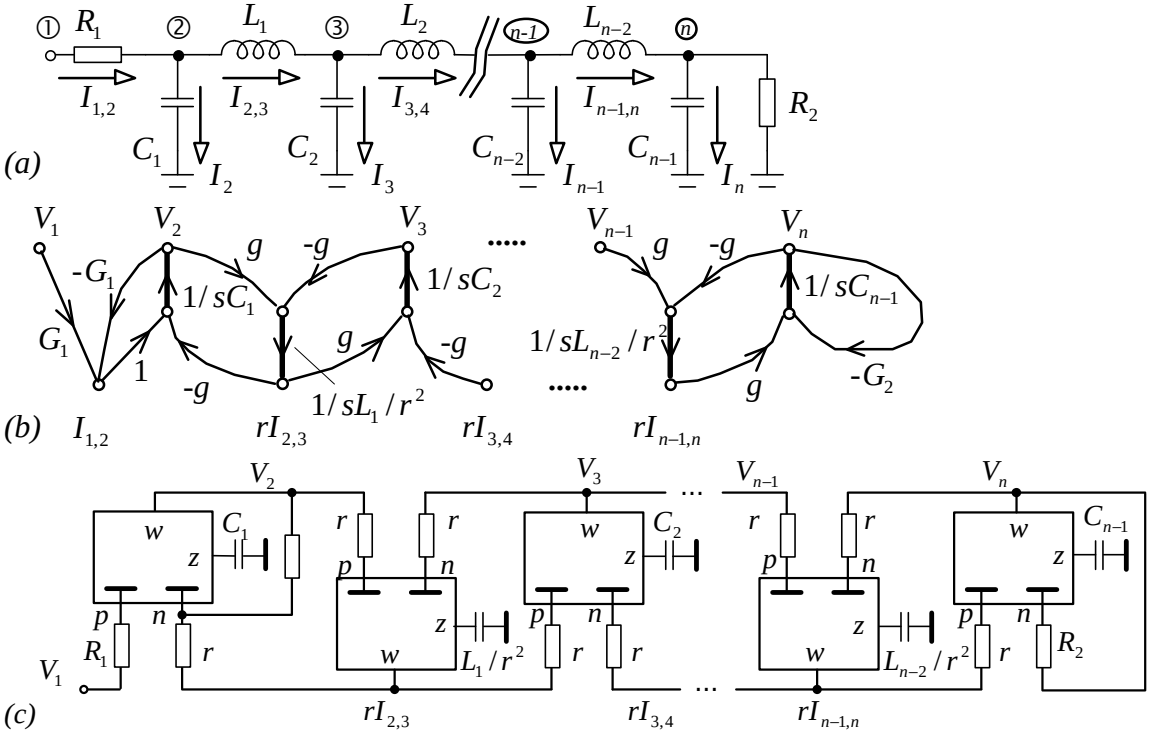

Fig. 3. (a) Lowpass ladder filter, (b) SFG, accordant with equations (2), (c) active filter implementation.

Equations are expressed by the SFG in Fig. 3 (b). The synthesis of the active filter in Fig. 3 (c) is performed from the SFG.
As shown in the following example, we can also simulate ladder elliptic filters by this procedure. However, any further details are beyond the scope of this contribution.

Example of elliptic filter design and optimization

Fig. 4 (a) shows a ladder lowpass filter, the Cauer approximation of magnitude frequency response, 3dB passband ripple, 1kHz cutoff frequency and 60dB attenuation above 1.5kHz. This filter has been designed using the NAF program.

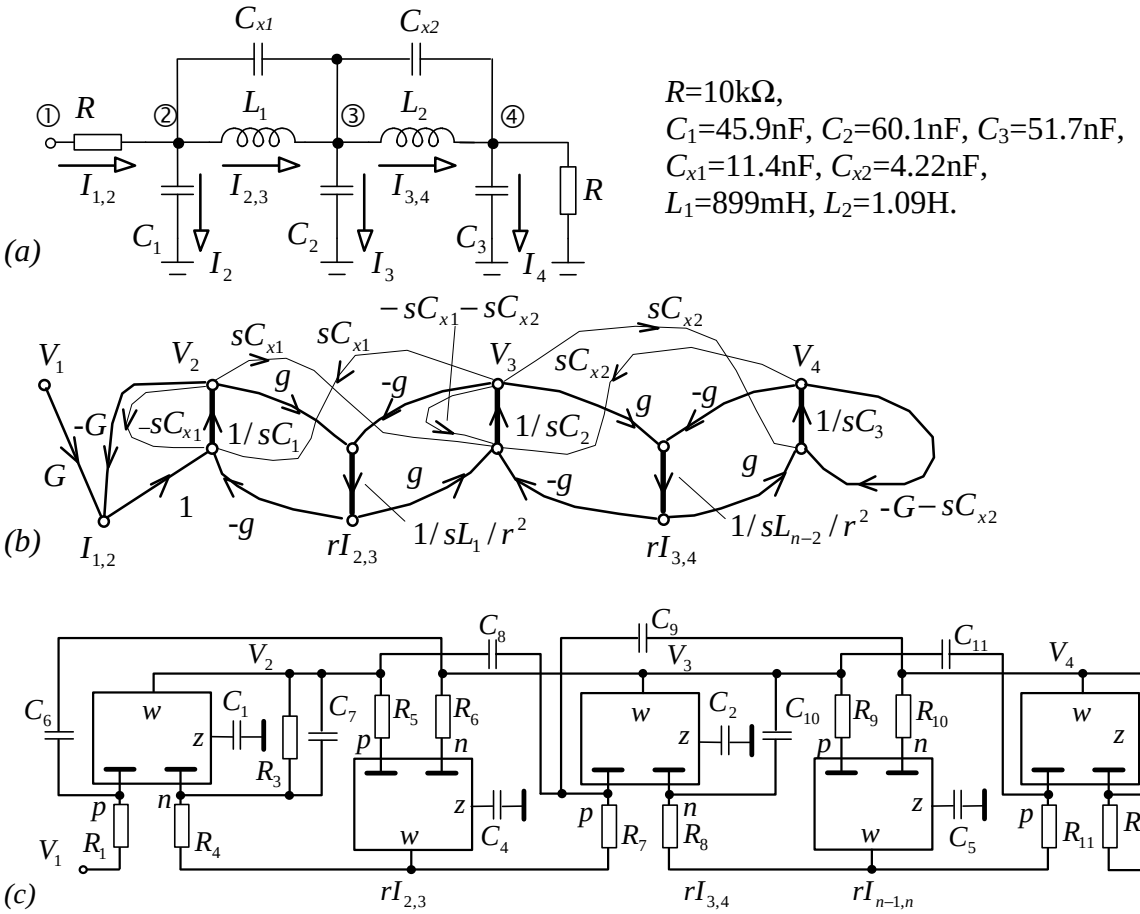

Fig. 4. (a) Ladder elliptic filter, (b) SFG, accordant with equations (3), (c) implementation of active filter.

The following equations are true for the ladder filter in Fig. 4 (a):

$$I_{1,2} = G(V_1 - V_2),\ V_2 = \frac{1}{sC_1}(I_{1,2} - grI_{2,3}) - \frac{C_{x1}}{C_1}(V_2 - V_3),$$

$$rI_{2,3} = \frac{1}{sL_1/r^2}(gV_2 - gV_3),\ V_3 = \frac{1}{sC_2}(grI_{2,3} - grI_{3,4}) + \frac{C_{x1}}{C_2}(V_2 - V_3) - \frac{C_{x2}}{C_2}(V_3 - V_4), \qquad (3)$$

$$rI_{3,4} = \frac{1}{sL_2/r^2}(gV_3 - gV_4),\ V_4 = \frac{1}{sC_3}(grI_{3,4} - GV_4) + \frac{C_{x2}}{C_3}(V_3 - V_4).$$

Both the SFG in Fig. 4 (b) and the active filter implementation in Fig. 4 (c) result from equations (3). In the first design stage, the value of auxiliary resistance was chosen to be r = 10kΩ. Then the designed parameters of filter elements summarized in Tab. 1, row *a* are:

	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}	R_{11}	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
a	10	10	10	10	10	10	10	10	10	10	10	46	60	51.7	9	11	11.4	11.4	11.4	4.2	15.6	4.2	4.2
b	10	20	14	3.4	14	10	3.4	4.5	10	20	4.5	33	60	30	27	24	11.4	8.2	8.2	2.1	15.6	4.2	2.1

Tab. 1. List of the designed parameters of filter elements from Fig. 4 (c) before (*a*) and after (*b*) the optimization of dynamic range. Resistances are in [kΩ] and capacitances in [nF].

output of CDBA No	max [dB]	multipl. factor *a*
1	-2.85	1.388
2	9.50	1/2.987
3	0	1
4	6.88	1/2.210
5	-6.03	2

Tab. 2. Maximum transfers from the input into the *w*–terminals of individual CDBAs.

A checking computer analysis by MicroCap 7 has verified the required frequency response, but the dynamic range of designed filter is not optimum, as shown in Tab. 2.

The last column in Tab. 2 shows how many times it would be necessary to increase/decrease the voltage gains from the input into the *w* –terminals of individual CDBAs to make the transfer peaks equal to 0 dB. The following rule can be derived from the SFG in Fig. 4 (b) or directly from the schematic in Fig. (c).

The gain from the input into the output of a given CDBA can be increased *a*-times without affecting the gains from the input into the outputs of the other CDBAs as follows:

> We decrease *a*-times the capacitance connected to the *z*- terminal. We increase *a*-times the resistances of all resistors and we decrease *a*-times the capacitances of all capacitors connected to the *w*- terminal.

Applying this rule successively to all CDBAs yields the optimum parameters of filter elements in Tab. 1, row *b*. The follow-up computer analysis verified that the optimization aims had been achieved.

Conclusion

Due to the easy implementation of multiple-input integrator, the CDBA element will find application in the synthesis of various forms of active filters. In the case of ladder filter simulation, the circuit topologies containing CDBAs offer more degrees of freedom, which can be used for optimization. In particular, the optimization of sensitivities is essential because of their deterioration as compared with the original passive ladder filters.

Acknowledgement

This work is supported by the Grant Agency of the Czech Republic under grants No. 102/01/0432 and No. 102/03/1181, and by the research programmes of BUT MSM 262200022 & MSM 262200011.

References

[1] ACAR,C.-OZOGUZ,S.: A New Versatile Building Block: Current Differencing Buffered Amplifier, Microelectronics Journal 30 (1999), pp. 157-160.

[2] CAJKA,J.-VRBA,K.: Conveyors – novel active device. In: Conference STO-8, MA Brno, Czech Republic, pp. 26-29, 2002.

[3] SCHAUMANN,R.-GHAUSI,M.S.-LAKER,K.R.: Design of Analog Filters. Prentice Hall, 1990.

[4] BIOLEK,D.-BIOLKOVÁ,V.: Modelling and Optimization of Active Filters by Hybrid "VIV-MMC"-graphs. "Systems and Control: Theory and Applications", World Scientific, Electrical and Computer Engineering Series, 2000, pp. 381-386.