Tunable ladder CDTA-based filters

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Abstract – A method of simulation of general-structure passive ladder filters by means of CDTA (Current-Differencing Transconductance Amplifier) elements is described. These elements with two current inputs and two kinds of current outputs facilitate realization of current-mode analog filters. The possibility of electronic tuning of such structures is illustrated by computer simulation of Tchebyshev 6^{th} order bandpass filter.

Key-Words: - CDTA, ladder filter, current mode.

1 Introduction

A new circuit element named CDTA (Current-Differencing Transconductance Amplifier) is introduced in [1]. This element converts currents into a pair of low-impedance inputs into a difference current, flowing from so-called *z*-terminal into an outside load. The z-terminal voltage is then converted into a couple of output currents into the *x*-terminals by internal operational transconductance amplifier (OTA). In general, its transconductance can be controlled electronically through an auxiliary port or it can be done by an outside two-port, for instance as in the commercial OTA amplifier MAX435/436 [2]. The current gain of the whole circuit will be given by the product of the outside z-terminal impedance and the OTA transconductance.

This principle has been already published in [3] as „differential-input, differential-output current-mode operational amplifier“. The CDTA element in Fig. 1 differs from it in two points:

1. The pair of output currents from the x terminals, shown 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 into the CDTA element. Then we speak 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. 1 (b).
2. The internal difference current can be (but it need not necessarily) electronically controlled by modifying the current gain *a*, analogous to commercial current multiplier EL2082C [4]. In certain circumstances, the resulting filter can be tuned by this current gain similarly as by changing the transconductance.

A universal 2^{nd} order CDTA-based block for cascade synthesis of high-order current-mode filters is described in [5]. In the following, the CDTA element will be used to SFG simulation of passive RCL ladder filters with a possibility to control frequency response electronically.

The paper is structured as follows: In Chapter 2, which follows the introduction, a principle of floating inductor simulation by CDTA elements is described. A concrete example of more complicated asymmetrically-terminated ladder filter is given in Chapter 3, together with demonstration of a methodology of CDTA-simulation. The Chapter 4 concludes results of computer simulation.

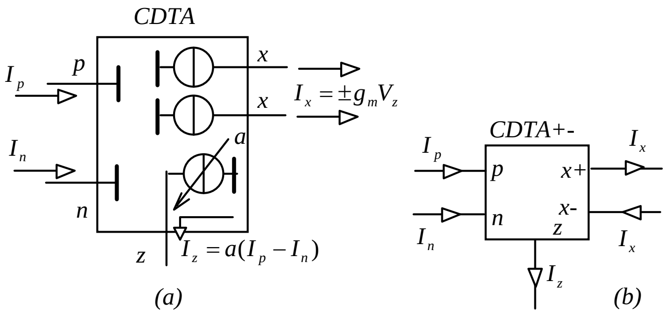

Fig. 1: (a) Behavioral model, (b) schematic symbol of CDTA+- element.

2 CDTA-based inductor simulation

The floating inductor in Fig. 2 (a) is described by Eq.

$$I_L = \frac{V_1 - V_2}{sL}, \tag{1}$$

where V_1 and V_2 are nodal voltages of nodes 1 and 2.

A circuit simulating this inductor is in Fig. 2 (b). The voltage across capacitor C is as follows:

$$V_{z2} = a_2 \frac{g_{m1}V_1 - g_{m3}V_2}{sC_L}, \qquad (2)$$

where a_2 is the current gain of current source inside the CDTA element No. 2, and g_{m1} and g_{m3} are transconductances of CDTA elements No. 1 and 3.
According to Fig. 2 (b), the currents I_L and I'_L will be

$$I_L = a_1 g_{m2} V_{z2}, \; I'_L = a_3 g_{m2} V_{z2}. \qquad (3)$$

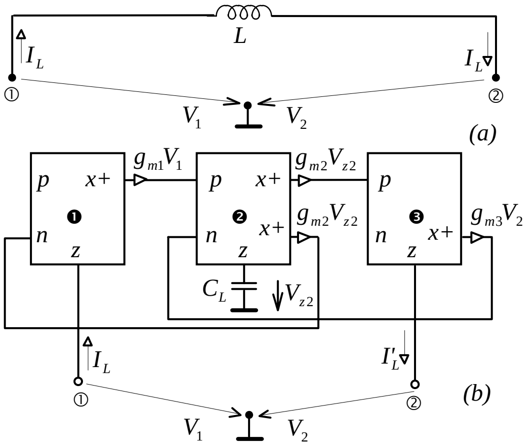

Fig. 2: (a) Floating inductor, (b) its simulation by three CDTA elements.

Equating

$$a_1 = a_3 = a, \; g_{m1} = g_{m3} = g_m \qquad (4)$$

and substituting (2) into (3) yields Eq. (1):

$$I_L = I'_L = \frac{V_1 - V_2}{sL}, \text{ where}$$

$$L = \frac{C_L}{a g_m a_2 g_{m2}}. \qquad (5)$$

Accordingly, a satisfactory matching of parameters of terminal CDTAs is required for correct circuit operation.
The circuit in Fig. 2 (b) can be simplified in case of grounded inductor. The existence of pairs of CDTA current outputs enables further simplifications of CDTA-based simulations of ladder structures, as shown below.

3 Example of ladder structure simulation

A current-mode ladder filter, designed by NAF program [5], is in Fig. 3 (a). It is Tchebyshev bandpass filter with 2dB ripple, with 100kHz central frequency, and with attenuation of more than 40dB below 80kHz and above 120kHz.

An active realization, simulating this filter, is in Fig. 3 (b). All the CDTA elements have set the parameters a = 1 and g_m = 1mS.
The input part of ladder filter with resistor R_1 and floating inductor L_1 is implemented by subcircuit with a pair of CDTA elements Nos. 1 and 2. The equation of K.L. I for node No. 1 is simulated by the connection of CDTA No 1:

$$I_{L1} = g_m V_{CL1} = g_m \frac{1}{sC_{L1}} (I_{in} - I_{L1} - g_m V_2).$$

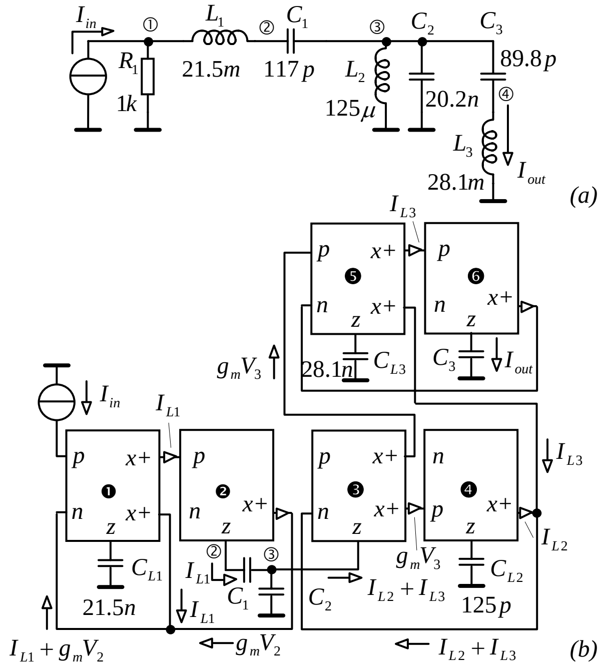

Fig. 3: (a) 100kHz bandpass ladder filter, (b) its CDTA-simulation.

However, according to Fig. 3 (a), the difference of currents I_{in} and I_{L1} is equal to the current of resistor R_1, thus G_1V_1. Assuming $G_1 = g_m$, the current flowing into C_1 will have inductance character, and the equivalent inductance will be as follows:

$$L_1 = \frac{C_{L1}}{g_m^2}.$$

The remaining subcircuits, comprising CDTA elements Nos. 3 and 4, or 5 and 6, simulate grounded inductors L_2 or L_3.

4 Computer simulation

To provide computer simulations, we have created a SPICE model of CDTA element. This model consists of two parts: The current source controlled by the difference I_p - I_n is modeled as a part of CDBA element which is published in [7], [8]. It is a model generated on transistor level (bipolar technology). The input resistances of p-and n-terminals are 2 ohms and the input capacitances are about 1 pF. The inner resistance of current outlet z is 10MΩ with a capacitance of 1pF The transconductance amplifier is modeled by SPICE model of 275MHz commercial amplifier MAX435.

The results of computer simulation of frequency responses of both filters in Fig. 3 are in Fig. 4. Note moderate shift of frequency response and its shape modification due to real properties of CDTA elements. Both the non-idealities can be rectified electronically by adjusting the transconductances or/and current gains a of the individual CDTAs.

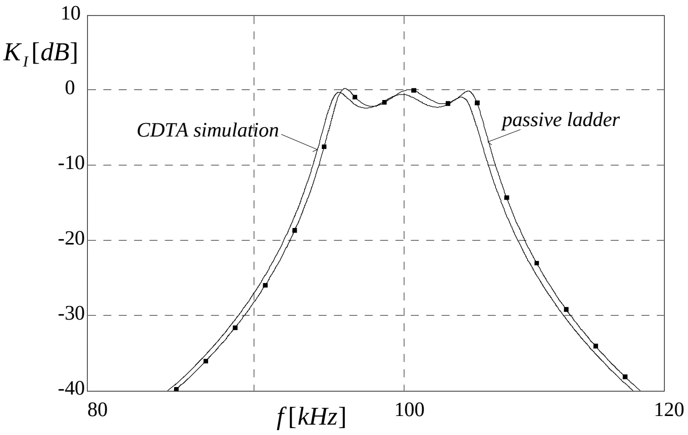

Fig. 4: Simulated frequency responses of filters in Fig. 3.

A demonstration of filter tuning by synchronous control of transconductances of all the CDTA elements is in Fig. 5. Increasing the central frequency is connected with moderate increasing the passband ripple. This phenomenon is related to the circuit approaching the instability region. However, within the existing circuit model, no unstable behavior has been observed for central frequencies up to 10MHz.

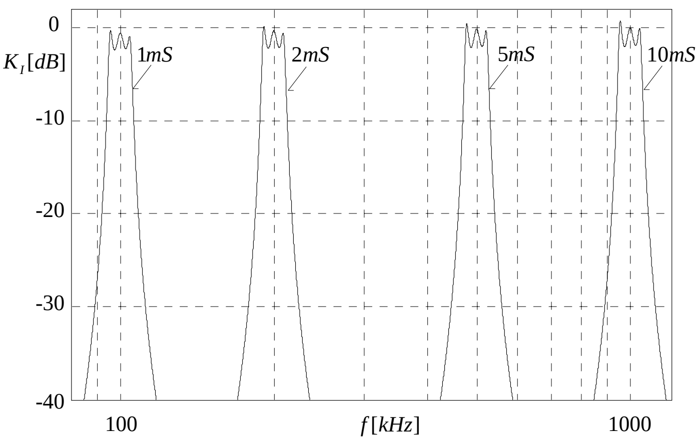

Fig. 5: Simulation of tuning the active filter by controlling the CDTA transconductances.

5 Conclusions

A methodology of the synthesis of active filters based on CDTA-simulation of passive ladder structures is described. The synthesis starts from the floating inductor simulation by current-mode circuit elements - CDTAs. In this way, we can simulate ladder structures of arbitrary topology without limitation. An interesting feature is to adjust/tune electronically frequency responses by controlling internal parameters of CDTAs. On the other hand, these parameters must be kept in required relationships with the accuracy better than 1%.

Acknowledgments

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