

NON-CASCADE SYNTHESIS OF HIGH-ORDER VOLTAGE MODE ACTIVE FILTER USING NEW CDTA ELEMENT

Ing. Tomáš GUBEK, Doctoral Degree Programme (3)
Dept. of Microelectronics, FEEC, BUT
E-mail: gubek@feec.vutbr.cz

Supervised by: Prof. Dalibor Biolk

ABSTRACT

This paper presents a non-cascade synthesis of high-order maximally flat magnitude (MFM) highpass filter in voltage mode using a new CDTA element. The so-called frequency-dependent voltage divider with high-order synthetic immittance elements is used for non-cascade synthesis.

1 INTRODUCTION

Non-cascade synthesis of high-order active filters is known up to the present time but not very much using by electrical engineers in practice. Prime reason is more complicated calculation in comparison with cascade or RLC ladder filter simulation synthesis. One method how to get over is to find easier computation technique which would be more approachable for wide community of engineers. The other method is a finding of new versatile active element suitable for mixed mode active filters. Frequency-dependent voltage divider with high-order synthetic elements can easily carry out the first condition. A new circuit element named CDTA (Current-Differencing Transconductance Amplifier) firstly introduced in [1] can fulfill the other condition. The paper has the following structure: In Chapter 2 following the introduction the behavioral model of CDTA is presented. Chapter 3 describes the non-cascade synthesis of high-order active filter with the aid of frequency-dependent voltage divider. Practical realization of fourth-order highpass filter is presented in Chapter 4. The last Chapter 5 depicts simulation results and additional dynamic-range optimization.

2 BEHAVIORAL MODEL OF CDTA

The ideal behavioral model and symbol of the CDTA element are in Fig. 1. CDTA converts the differential currents I_p and I_n flowing into a pair of low-impedance inputs p and n to the voltage across the z -terminal with the aid of outside load. Grounded impedance Z denotes outside load in most cases. Subsequently this voltage V_z is transferred by a transconductance g_m to a current I_x flowing through the x -terminal. The output current I_x may have two directions. Either it can flow outside or inside of the CDTA element. As long as the current I_x flows out then we mark the current direction at the element symbol by the sign $+$. Contrariwise if the current I_x flows in we use the sign $-$. This behavior can be expressed by the following matrix equation

$$\begin{pmatrix} I_z \\ I_x \\ V_p \\ V_n \end{pmatrix} = \begin{pmatrix} 0 & 0 & 1 & -1 \\ \pm g_m & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} V_z \\ V_x \\ I_p \\ I_n \end{pmatrix}. \quad (1)$$

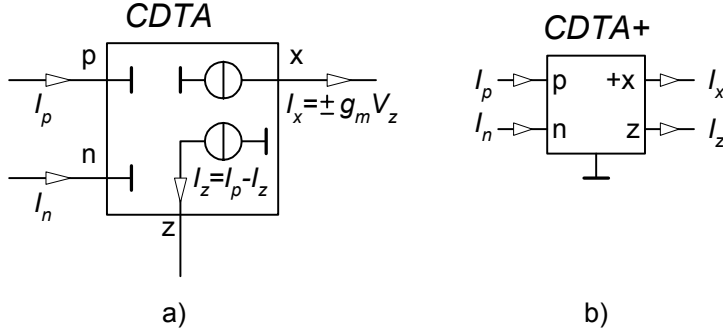


Fig. 1: Behavioral model (a) and circuit symbol (b) of the CDTA element.

Differential current source can be implemented by using two CCII+ [1] or by first stage of CDBA (Current-Differencing Buffered Amplifier) circuit element introduced in [2]. The other current source with transconductance g_m is familiar OTA (Operational Transconductance Amplifier). Both proposed implementations are in Fig 2.

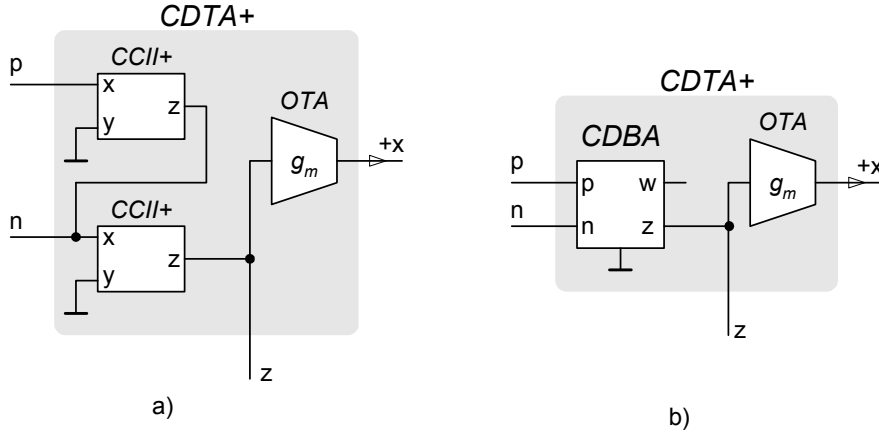


Fig. 2: Implementation of the CDTA by (a) CCII+ and (b) CDBA both with OTA.

3 FREQUENCY-DEPENDENT VOLTAGE DIVIDER

Active filters consisting of frequency-dependent voltage dividers belong to the class of non-cascade filter synthesis working in voltage mode. Typical frequency-dependent voltage divider using high-order synthetic immittances is in Fig. 3 [3]. Voltage transfer function of two-port network depicting in Fig. 3 is as follows

$$K_v(p) = \frac{V_{out}(p)}{V_{in}(p)} = \frac{1}{Z_1(p)Y_2(p) + 1}. \quad (2)$$

The n th-order impedance function $Z_1(p)$ can be expressed as a serial interconnection

$${}^{(n)}Z_1(p) = {}^0Z(p) + {}^1Z(p) + {}^2Z(p) + \dots + {}^nZ(p). \quad (3)$$

There are two possibilities to express the individual terms of impedance in Eq. (3):

$$\text{a) } {}^m Z(p) = {}^m Z_X(p) = X_m p^m \quad \text{or} \quad \text{b) } {}^m Z(p) = {}^m Z_D(p) = \frac{1}{D_m p^m}, \quad (4)$$

where $m = 0, 1, 2, \dots, n$. The n th-order admittance function $Y_2(p)$ can be expressed as

$${}^{(n)} Y_1(p) = {}^0 Y(p) + {}^1 Y(p) + {}^2 Y(p) + \dots + {}^n Y(p). \quad (5)$$

There are again two possibilities to express the individual terms of admittance in Eq. (5):

$$\text{a) } {}^m Y(p) = {}^m Y_D(p) = D_m p^m \quad \text{or} \quad \text{b) } {}^m Y(p) = {}^m Y_X(p) = \frac{1}{X_m p^m}, \quad (6)$$

where $m = 0, 1, 2, \dots, n$. The individual realization of the above-mentioned terms by high-order immittance elements is highly uneconomical. Thus there is the aim to find a simple one-port network implementing the immittance functions in (3) or (5) in both possibilities.

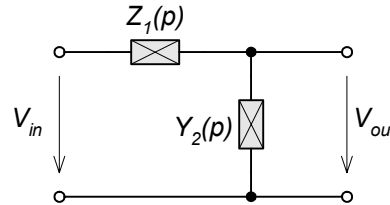


Fig. 3: Frequency-dependent voltage divider.

4 FOURTH-ORDER HIGHPASS FILTER REALIZATION

In order to get a highpass filter according to Eq. (2) there must be met these equations

$$Z_1(p) = Z_D(p) \quad \text{and} \quad Y_2(p) = Y_X(p). \quad (7)$$

Assume N th-order maximally flat magnitude (MFM) highpass filter. One possible solution is

$$Z_1(p) = Z_D(p) = \frac{1}{pC_0} \quad \text{and} \quad Y_2(p) = Y_X(p) = \frac{1}{X_0} + \frac{1}{X_1 p^1} + \dots + \frac{1}{X_{N-1} p^{N-1}}. \quad (8)$$

Particular implementation of one-port network with a 3rd-order admittance function $Y_X(p)$ using new CDTA element is proposed in Fig. 4. The input admittance function of this network is defined as

$$Y_{in} = \frac{I_{in}}{V_{in}} = \frac{1}{4} \left(g_{m1} + \frac{g_{m1} g_{m2}}{Y_2} + \frac{g_{m1} g_{m2} g_{m3}}{Y_2 Y_3} + \frac{g_{m1} g_{m2} g_{m3} g_{m4}}{Y_2 Y_3 Y_4} \right). \quad (9)$$

As long as we choose $Y_2 = pC_2$, $Y_3 = pC_3$ and $Y_4 = pC_4$, then the following formula of the voltage transfer function according to (2) and (9) will be valid (note $g_m \equiv g$)

$$K_v(p) = \frac{p^4 4C_0 C_2 C_3 C_4}{p^4 4C_0 C_2 C_3 C_4 + p^3 g_1 C_2 C_3 C_4 + p^2 g_1 g_2 C_3 C_4 + p g_1 g_2 g_3 C_4 + g_1 g_2 g_3 g_4}. \quad (10)$$

Substituting $p = s\omega_c$ in Eq. (10) and after some algebraic manipulation we obtain

$$K_v(p) = \frac{s^4}{s^4 + s^3 c_{43} + s^2 c_{42} + s c_{41} + c_{40}}, \quad (11)$$

where coefficients are

$$c_{43} = \frac{1}{4} \frac{g_{m1}}{\omega_c C_0}, c_{42} = \frac{1}{4} \frac{g_{m1}g_{m2}}{\omega_c^2 C_0 C_2}, c_{41} = \frac{1}{4} \frac{g_{m1}g_{m2}g_{m3}}{\omega_c^3 C_0 C_2 C_3} \text{ and } c_{40} = \frac{1}{4} \frac{g_{m1}g_{m2}g_{m3}g_{m4}}{\omega_c^4 C_0 C_2 C_3 C_4}. \quad (12)$$

Equation (11) represents the fourth-order maximally flat magnitude (MFM) highpass filter. The corresponding circuit is in Fig. 5. As an example, the particular 4th-order highpass filter with Butterworth approximation and cut-off frequency $f_c = 100$ kHz is designed in the next step. Transfer function coefficients are [4]: $c_{43} = 2.6131$, $c_{42} = 3.4142$, $c_{41} = 2.6131$ and $c_{40} = 1.0000$. We choose the same value of 100 pF for all capacitors C_0 , C_2 , C_3 and C_4 . After some computation from formulas (12) we obtain: $g_{m1} = 657 \mu\text{S}$, $g_{m2} = 82 \mu\text{S}$, $g_{m3} = 48 \mu\text{S}$ and $g_{m4} = 24 \mu\text{S}$.

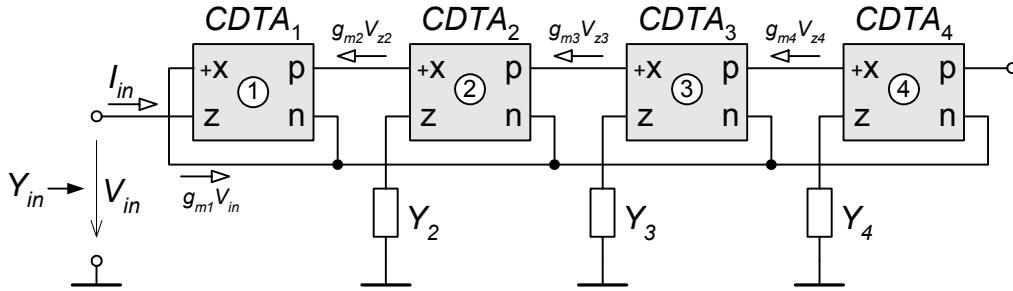


Fig. 4: One-port network with a 3rd-order admittance function using CDTA elements.

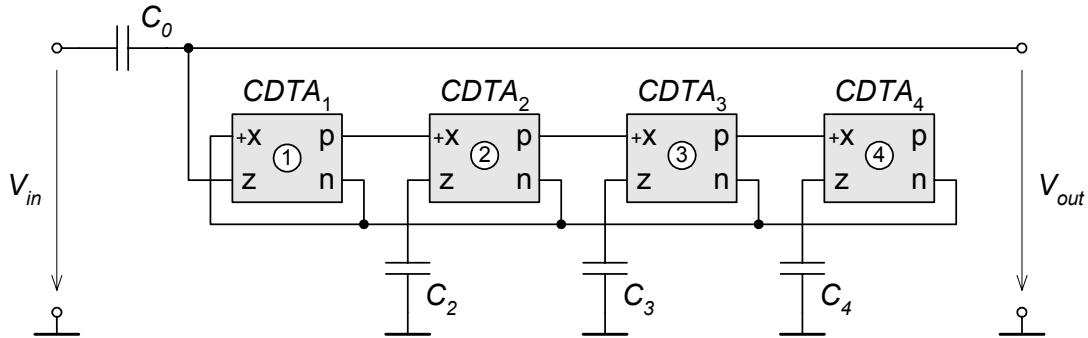


Fig. 5: The fourth-order MFM highpass filter using CDTA elements.

5 COMPUTER SIMULATION AND DYNAMIC-RANGE OPTIMIZATION

First of all, we have to create a SPICE model of CDTA element. The behavioral model of CDTA shown in Fig. 2(b) can be used as the groundwork. The bipolar implementation of CDTA element was recently published in [5]. Commercial wideband amplifier MAX436 models the OTA amplifier. The results of computer simulation of the active filter in Fig. 5 are depicted in Fig. 6(a). There are four frequency responses for all voltages across z -terminals. Voltage V_{z1} is equal to output voltage V_{out} of entire active filter. It is required to align the levels of all node voltages in circuit in practice (usually 0 dB). This requirement ensures the best dynamic range, which is limited by noise and distortion levels. We will formulate the following proposition to facilitate the optimization of CDTA-based filter.

*The auxiliary voltage V_z of a given CDTA will be increased a -times without affecting output current I_x of the same CDTA as follows: **We increase a -times the impedances of all components that are connected to the z terminal and simultaneously we decrease a -times***

the transconductances g_m of a given CDTA.

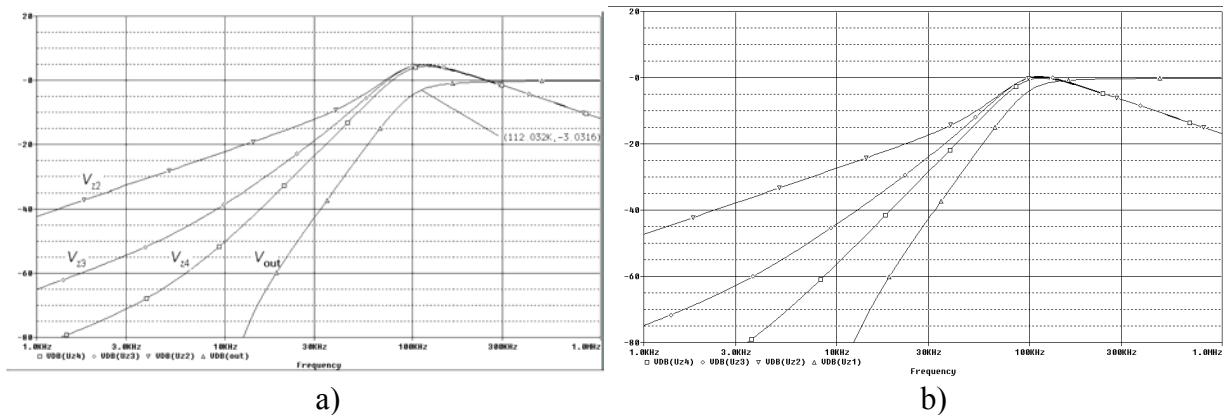


Fig. 6: (a) Initial frequency responses, (b) frequency responses of the optimized filter.

On the basis of this proposition we will optimize active filter in Fig. 5. We can see that the voltages V_{z2} , V_{z3} , and V_{z4} are shifted from 0 dB to about 4.86 dB, i.e. $a = 1/1.75$. The final optimized component values are summarized in column (b) in Tab. 1. The final responses of the optimized active filter in Fig. 5 are depicted in Fig. 6(b).

Tab. 1: Component values of filter in Fig. 5 (a) initial, (b) after dynamic-range optimization.

	C [pF]	g_{m1} [mS]	g_{m2} [μ S]	g_{m3} [μ S]	g_{m4} [μ S]
(a)	100	0.657	82	48	24
(b)	175	1.150	144	84	42

6 CONCLUSION

A method of non-cascade synthesis of high-order highpass voltage mode active filter based on the CDTA elements is described. The advantage of this synthesis is pretty easy computation. CDTA element is still only in a stage of behavioral model. Real CDTA parameters such as transconductance g_m , accuracy of differential current source, input impedance tolerance and their frequency responses will vary depending on particular monolithic realization on the chip. Unfortunately we are not in this stage yet. Sensitivity analysis of proposed highpass filter is presented in [6].

REFERENCES

- [1] Biolek, D.: CDTA-Building Block for Current-mode Analog Signal Processing. ECCTD2003, Kraków, 2003, Vol. III, pp. 397-400.
- [2] Acar, C., Ozoguz, S.: A New Versatile Building Block: Current Differencing Buffered Amplifier. Microelectronics Journal 30, 1999, pp. 157-160.
- [3] Vrba, K., Čajka, J.: Circuits with immittance elements of higher order. Research report, Brno, DTEL FECC BUT, 1999.
- [4] Ghausi, S.M., Laker, R.K., Schaumann, R.: Design of Analog Filters – Passive, Active RC and Switched Capacitor. New Jersey, Prentice-Hall Inc., 1990. ISBN 0-13-200288-4.
- [5] Lattenberg, I., Vrba, K., Biolek, D.: Bipolar Current Differencing Buffered Amplifiers and its Application. IASTED-SIP2001 Int. Conference, Honolulu, Hawaii, pp.376-379.
- [6] Gubek, T., Biolek, D.: New approaches to Gm-C filters using non-cascade synthesis and CDTA elements. <http://www.electronicsletters.com>, 2004, it will be published.