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CDTA-C current-mode universal 2nd-order filter

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Abstract: Transformation of the classical KHN (Kerwin-Huelsman-Newcomb) 2nd-order filter into the current mode structure containing the CDTA (Current-Differencing Transconductance Amplifier) active elements is described. The resulting structure consists of three CDTAs and two grounded capacitors. The proposed filter has a low-impedance current input and three current outputs, realizing three basic transfer functions (lowpass, highpass, and bandpass), which can easily be combined to implement transfer functions with various transfer zeros.

Keywords: - Active filter, KHN structure, CDTA, CDTA-C filter.

1 Introduction

The well-known voltage-mode 2nd-order KHN filter [1], [2] in Fig. 1 is preferred building block for cascade filter design. This circuitry can be understood as a single-input three-output device, generating three basic 2nd-order transfer functions (lowpass, bandpass, and highpass). In addition, as obvious from the flow-graph in Fig. 1, filter tuning without modifying the quality factor can be done by simultaneous modification of $R_5=R_6$. For identical values of R_1, R_2, R_3 and R_4 the DC gain of LP, high-frequency gain of HP, and maximum gain of BP filters are fixed to their unity-values while tuning, and thus the upper bound of the filter dynamic range remains unchanged.

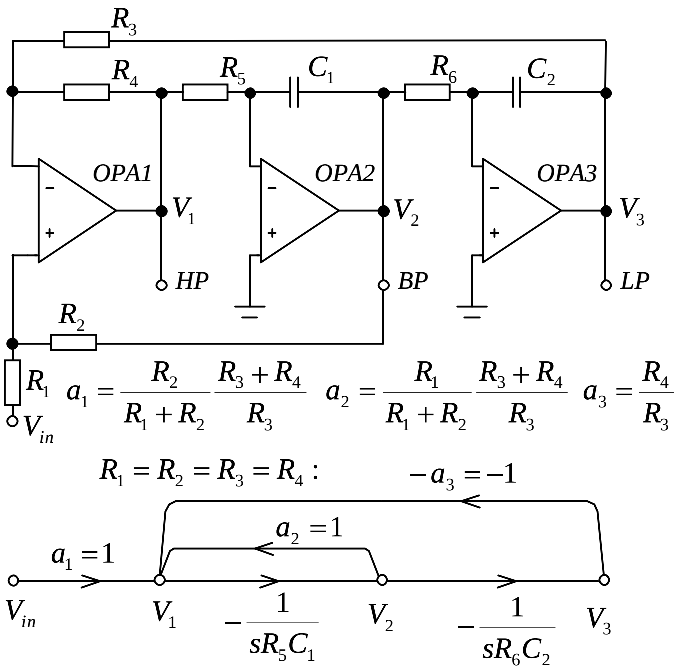

Fig. 1: Classical structure of the KHN filter and the corresponding flow-graph.

The relatively high number of resistors can be a disadvantage of this classical structure. Resistors R_1 to R_4 together with OpAmp No. 1 form a common summing amplifier, which can be done more easily in the current mode.

Recently, more ways were published how to implement the KHN structure by means of active elements other than voltage OpAmps, in particular by current conveyors [3], [4], [5], but also by CDBA (Current-Differencing Buffered Amplifier) [6], [7] or DO-DDCC (Differential-Output Differential Difference Current Conveyor) elements [8]. The last mentioned implementation uses three DO-DDCCs and five grounded passive components, namely three resistors and two capacitors, which represents some simplification in comparison with the original KHN structure. On the other hand, transforming the classical structure into the popular „gm-C“ filter is problematic. The input summing amplifier must be implemented by summing the currents. However, this means a voltage-to-current conversion of signals V_{in}, V_1, V_2, and V_3 in Fig. 1 by using additional OTA elements, and summing these currents on auxiliary resistance, which is implemented by one OTA. The resulting biquad then consists of 6 OTAs and two capacitors [9], [10].

In this paper, the classical KHN structure is transformed into the current mode by utilizing the CDTA (Current Differencing Transconductance Amplifier) circuit elements [11], whose input and output signals are currents. The final filter consists of only 3 CDTAs and two capacitors, and thus it can be classified as so-called CDTA-C filter, an analogy with the well-known gm-C filters. The current outputs of CDTAs provide formally the same transfer functions as the outputs of voltage OpAmps in the classical KHN structure on the assumption of identical resistances R_1 to R_4. Below, the results of computer simulations are discussed and some requirements as to the real properties of CDTA elements that have to be taken into account in the design of this interesting filter structure are defined.

2 „CDTA-C“ KHN filter

The CDTA element with its possible schematic symbol in Fig 2 (a) has been introduced in [11]. The difference of input currents, flowing into a pair of low-impedance current inputs *p* and *n*, flows out of an auxiliary terminal *z*. The voltage across *z*-terminal is transferred through internal transconductance g_m to current I_x, which is copied to a general number of output current terminals *x*. The direction of these currents can be arbitrary. It is designated by arrows directly in the schematic symbol.

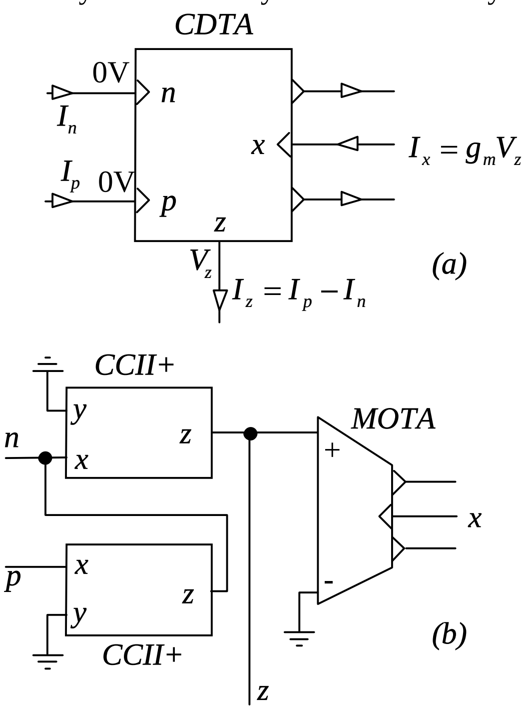

Fig. 2: (a) Example of the schematic symbol of CDTA CDTA, (b) possible CDTA realization by two current conveyors and a multiple-output OTA (MOTA).

A possible CDTA implementation using current conveyors and an OTA amplifier is in Fig. 2 (b).

The signal-flow graph in Fig. 1 can be redrawn for currents as shown in Fig. 3, together with the corresponding CDTA-based biquad. In contrast to conventional OpAmp, the CDTA enables an easy implementation of the non-inverting integrator. The non-inverting integrators in the feedback loops require the signs of gains of the feedback branches to be modified, as follows from a comparison of the graphs in Figs. 3 and 1.

CDTAs No. 1 and 2 together with transconductances g_{m1} and g_{m2} implement the integrators, while CDTA No. 0 provides the summing of currents I_{in}, I_1, I_2, and I_3: Since the *z* – outlet is open, the input current I_{in} flowing into the *p* terminal is equal to the current flowing to the *n* terminal. However, this is the sum of currents I_1, I_2, and I_3.

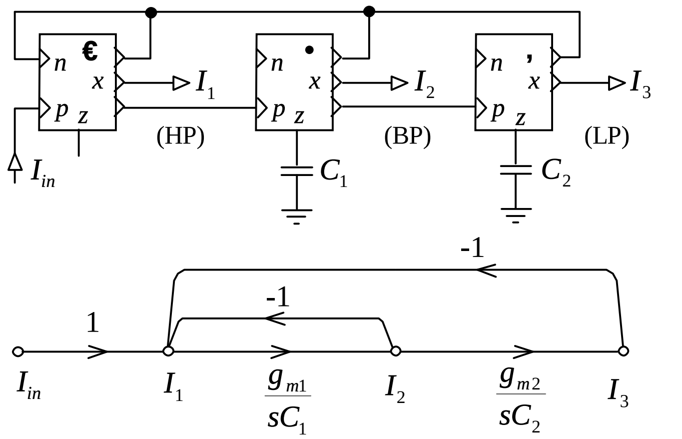

Fig. 3: CDTA-based KHN structure.

Evaluating the flow-graph in Fig. 3 yields the following transfer functions:

$$\frac{I_1}{I_{in}} = \frac{s^2}{s^2 + Bs + w_0^2},\ \frac{I_2}{I_{in}} = \frac{Bs}{s^2 + Bs + w_0^2},\ \frac{I_3}{I_{in}} = \frac{w_0^2}{s^2 + Bs + w_0^2}$$

where

$$B = \frac{w_0}{Q},\ w_0 = \sqrt{\frac{g_{m1} g_{m2}}{C_1 C_2}},\ Q = \sqrt{\frac{C_1}{C_2}\frac{g_{m2}}{g_{m1}}}.$$

It is obvious that the circuit in Fig. 3 provides all the LP, HP, and BP transfer functions, with the current low-impedance input and high-impedance outputs. The classical forms of the w_0 and Q formulae indicate the possibility of independent control of these parameters, and their low relative sensitivities, namely ±0.5, to variations in transconductances and working capacitances.

3 Simulation results

Before computer simulation, the filter in Fig. 3 was designed with the parameters f_0 = 10kHz and Q = 0.707. The corresponding component values are as follows: g_{m1} = g_{m2} = 0.1mS, C_1=113pF, C_2=225pF. The CDTA was modeled as a connection of the SPICE models of two AD844 operational amplifiers supplementing the current conveyors CCII+ in Fig. 2 (b), and two transconductance amplifiers MAX435, which realize the MOTA element with two current outputs. The SPICE model of MAX435 was completed with an input resistance of 800kΩ, which is not present in the official model of the MAXIM company.

It should be noted that such a construction of CDTA element is not optimal from the point of view of proper operation, in particular for the higher-frequency region. On the other hand, it offers for study the real properties of basic CDTA sub-blocks and their influence on the behavior of the filter, enabling us to define our requirements on CDTA features before its fabrication as a monolithic IC.

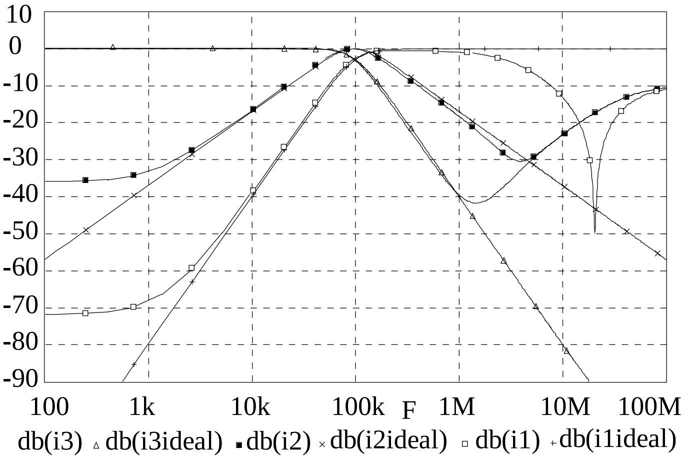

Fig. 4: Results of simulation in the MicroCap program. The CDTA element is modeled as a connection of AD844 and MAX 435.

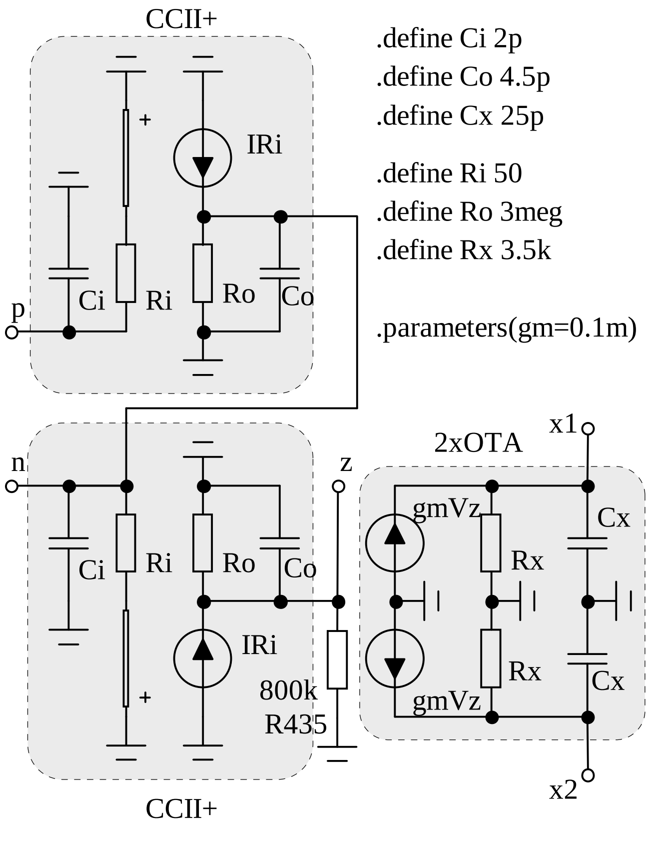

Fig. 5: CDTA macromodel based on the connection of the AD844 and MAX435 ICs according to Fig. 2.

Results of computer simulation are given in Fig. 4. Comparing them with the theoretical responses reveals the following anomalies:

1 Finite low-frequency attenuation for BP and HP outputs.
2 Finite high-frequency attenuation for LP and BP outputs.
3 Parasitic transmission zero for HP output.

The causes of these imperfections were analyzed by means of the CDTA macromodel in Fig. 5. Numerical values of individual circuit parameters correspond to the datasheet values of AD844 and MAX435. Results of the simulation using the above macromodel and of the SPICE model simulation exhibit perfect agreement. That is why the macromodel was implemented in the SNAP program [12] for symbolic analysis. Results of the symbolic analysis of the KHN filter lead to the following conclusions:

1. Finite low-frequency attenuation is caused by the finite value of parasitic resistance R_z of the *z* terminal. Concretely for the BP output, the attenuation is given by the product $g_m R_z$. Resistance R_z is formed by the transresistance R_o of AD844 and input resistance R_{435} of MAX435 in parallel, which is 632kΩ. For g_m = 0.1mS the parasitic attenuation is 63.2, i.e. 36dB. This is exactly the value obtained by computer simulation, see Fig. 4. To eliminate this phenomenon, R_z must be maximized. For instance, inserting an isolating amplifier between the *z* terminal and the OTA input, R_z will be increased to 3MΩ and the parasitic attenuation will increase to 50dB. Another increase can be accomplished by increasing the transconductance g_m, which must be followed by an adequate increase in the working capacitances.

The finite value of $g_m R_z$ seems to be the source of another negative effect, which can be significant in particular for higher Q values. Ideally, the maximum gain of BP filter is 1, i.e. 0 dB, independently of f_0 and Q. In reality, in filter tuning via modifying the g_m, this maximum is changed according to the formula

$$MAX \approx \frac{\sqrt{1+(g_m R_z/Q)^2}}{Q+g_m R_z/Q}.$$

This phenomenon will be insignificant when the condition $g_m R_z >> Q^2$ is met. Then MAX ≈ 1.

2. Finite high-frequency attenuation for LP and BP outputs. This effect is related to the appearance of the **parasitic transfer zero**. The notch frequency increases when g_m is increased, and R_i decreased, and when parasitic capacitances C_x and C_o are reduced. The finite attenuation can be increased, i.e. eliminated, by minimizing the capacitance C_x.

4 Conclusion

The described filter is an equivalent of the classical KHN biquad with voltage operational amplifiers. However, the current mode operation is used by virtue of active CDTA elements. From among all the KHN-based biquads, published so far, this CDTA-C biquad is the most economical, consisting only of three CDTAs and two grounded capacitors.

The computer simulation revealed some real effects which are known from similar classical filter structures. Their analysis results in concrete requirements on key parameters of the CDTA, in particular sufficiently high resistance of the *z* terminal and minimal parasitic capacitances, particularly the capacitances of the *x* terminals. The frequency of parasitic transfer zero can be moved up out of the operating frequency region by decreasing the input resistance R_i of terminals *p* and *n*, and by choosing higher values of transconductance g_m. Since the phenomena analyzed take place in the region of higher frequencies, the actual frequency responses will depend on concrete integrated implementation of the CDTA element.

Acknowledgments

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