F « G TRANSFORMATION OF CDTA-BASED FILTERS

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Abstract: *Rules of mutual transformation of equivalent CDTA-based circuit structures are described. After the transformation into the so-called grounded structure, several optimization methods can be applied. Then it is possible to pass to a simpler circuit, applying backward transformation. The procedures are demonstrated on an example of the current-mode LeapFrog structure.*

Introduction

The CDTA (Current-Differencing Transconductance Amplifier) building block has been introduced in [1]. It consists of a difference-input current amplifier and a multi-output OTA. Fig. 1 shows an example of the DICO (Differential-Input Common-Output) type [2]. The input-to-output behavior can be described as shown in the figure. The current gain b is usually equal to 1. However, it can be controlled electronically, the same as the transonductance g_m.

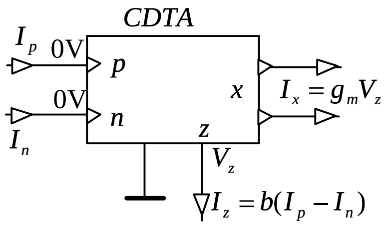

Fig. 1: Schematic symbol of CDTA, DICO type.

In this paper, the basic rules for a potential optimization of DCTA-based circuits will be given. The rules and procedures will be demonstrated on active structures which simulate passive ladder filters.

Equivalent CDTA-based circuits

Circuits containing CDTA elements usually have to be optimized according to various criteria, e.g. maximum dynamic range, minimum spread of capacitances or transconductances, optimum impedance levels, etc. Certain circuit structures exist where the given optimizations can be performed with various degrees of freedom. That is why it is desirable to know the rules of transformation between equivalent circuit structures. The so-called grounded structures (GS) are appropriate for optimization. In general, these structures consist of CDTA elements, current amplifiers and immittances with one outlet either grounded or connected to ground potential (i.e. to some current input of CDTA or virtual ground of OpAmp). Other structures will be named floating (FS).

The equivalence of the circuits in Fig. 2 can be checked by a simple computation: If a current amplifier with gain K_I exists in the negative feedback loop of CDTA element, the loop can be removed and replaced by a grounded admittance bg_mK_I, connected to the z- terminal.

Both structures in Fig. 2 belong to grounded structures. The equality of input currents I results in the equality of currents I_x and voltages V_z. Note that both structures differ in currents I_n and I_z.

Another equivalence is given in Fig. 3. By means of this equivalence, floating immittances can be transformed into grounded immittances.

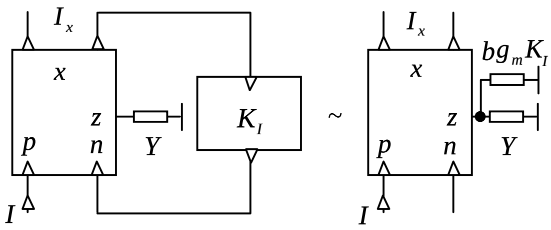

Fig. 2: Removal of the feedback path.

In Fig. 3, only the second circuit belongs to the class of grounded structures. The equality of

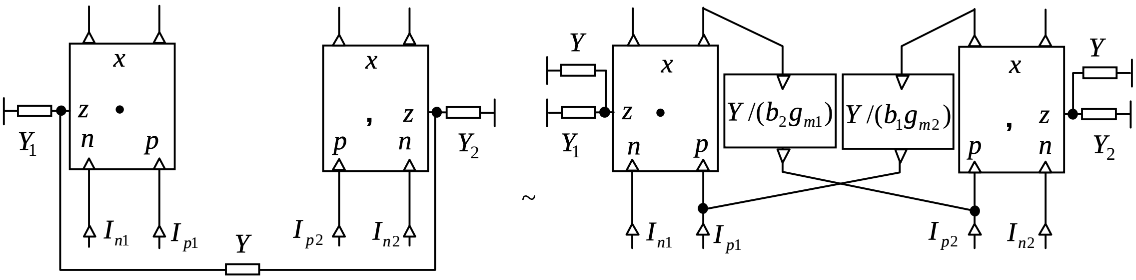

Fig. 3: Removal of the floating immittance.

currents I_{n1}, I_{p1}, I_{n2}, and I_{p2} in both structures results in the equality of voltages V_z and currents I_x, not the equality of currents I_z.

Optimization procedure

More Propositions could be stated which can generally be used to optimize grounded structures. Two of them are given below. To apply them, a floating-to-grounded structure transformation (F→G) has been performed. After the optimization, the grounded structure is transformed back (F←G) into the simpler floating structure.

Proposition 1:
We increase *k*-times the transconductance g_m of CDTA and decrease *k*-times all the impedances connected to the *z* – terminal of this CDTA. Then the voltages and currents in the whole circuit remain unchanged, excepting the voltage V_z, which decreases *k*-times.

This Proposition can be used to modify voltage at the *z* –terminal of a given CDTA without affecting the remaining voltages and currents in the circuit.

Proposition 2:
We increase *k*-times the transconductance g_m of CDTA and decrease *k*-times all the current transfers from the *x* –terminals of this CDTA into the other circuit nodes. Then the voltages and currents in the whole circuit remain unchanged, excepting the current I_x, which increases *k*-times.

Note 1: When the *p* or *n* input of another CDTA is connected to the *x* – terminal of CDTA, then the above current gain from the *x* – terminal will be decreased by lowering the current gain *b* of the connected CDTA.

Note 2: When the *p* or *n* input of another CDTA is connected to the *x* – terminal of CDTA and the connected CDTA is simultaneously fed by input current, it is necessary to amplify this current *k*-times.

Note 3: When a passive current divider is fed from the *x* – terminal, the voltage V_x can also be changed. For a CDTA-based current divider, the voltage V_x is zero.

This Proposition can be used to modify the level of currents I_x of a given CDTA without affecting the remaining voltages and currents in the circuit.

Demonstration

Consider the 10MHz CDTA-based bandpass filter in Fig. 4 (a), which has been preliminarily designed from the ladder RCL prototype. According to the principle in Fig. 2, CDTAs No. 1', 2' and 3' model grounded inductances connected to the *z*-terminals of CDTAs No. 1, 2, and 3. As follows from SPICE simulation, the filter in Fig. 4 (a) exhibits a large spread of maximum current transfers into the *x*-terminals of individual CDTAs, as well as transfers from input I_{in} into outputs V_z. That is why we should focus the optimization on the following:

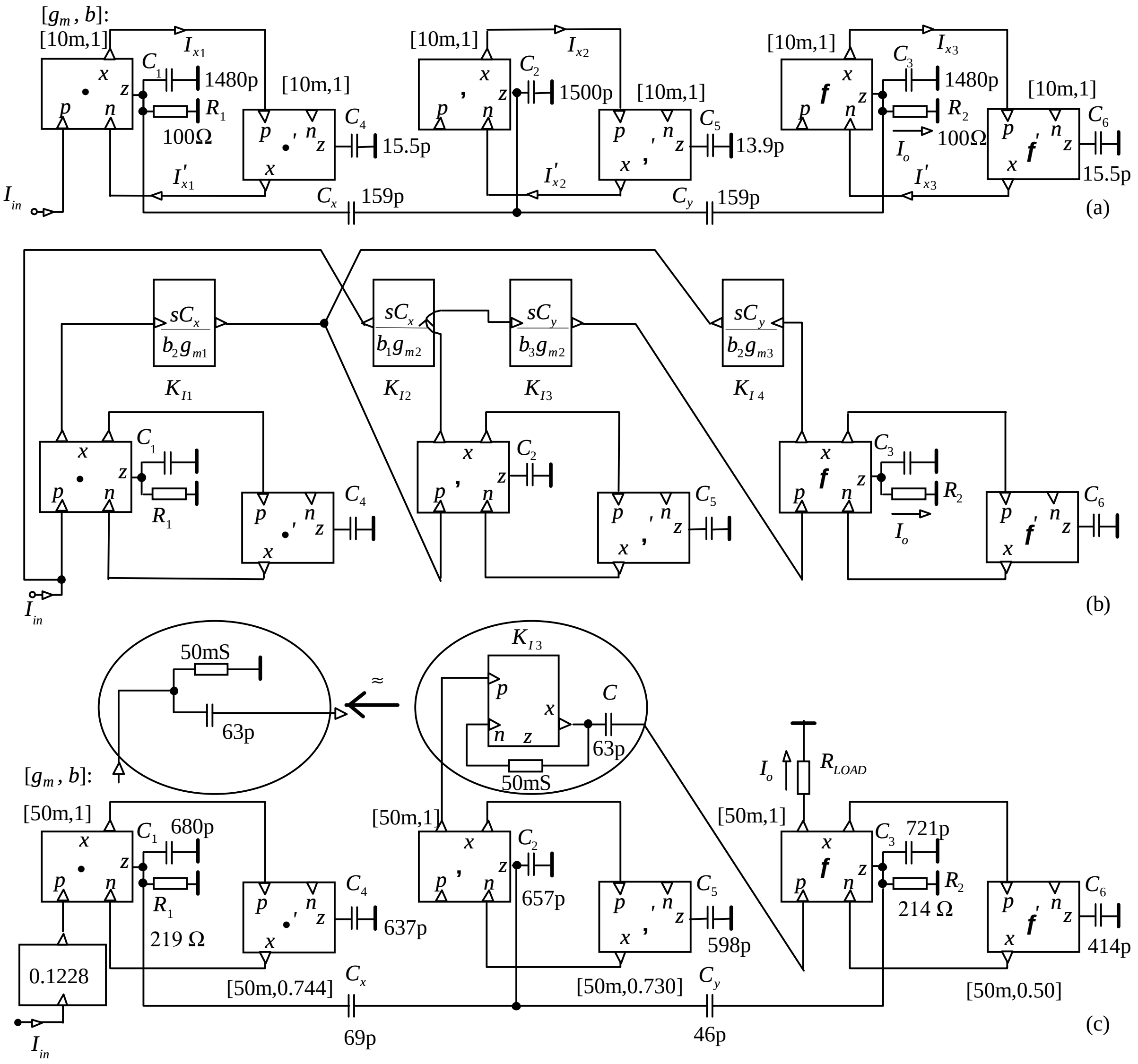

Fig. 4: 6th-order current-mode Chebyshev bandpass filter with a central frequency of 10MHz, 1.4MHz bandwidth and 0.1dB passband ripple; CDTA-based structure (a) preliminary designed, (b) after F←G transformation, (c) final floating structure.

- Decreasing the impedance levels at the z-terminals of CDTAs No. 1‘, 2‘, and 3‘. Then the voltages across these terminals will be lowered to the levels at the z-terminals of the remaining CDTAs. Simultaneously, capacitances C_4, C_5, and C_6 will increase and the undesired shift of the frequency response will be reduced. In other words, it is necessary to optimize the upper bound of the dynamic range of voltages V_Z, applying **Proposition 1**.
- Equalizing the current transfers from input into the *x*-outputs of individual CDTAs. In other words, it is necessary to optimize the upper bound of the dynamic range of currents I_x, applying **Proposition 2** including **Notes 1** and **2**.

To apply the **Propositions**, the floating structure is transformed into the grounded one in Fig. 4 (b). After its optimization, simulation confirms that both the voltage and current dynamic ranges are optimized.

After backward F←G transformation, utilizing the rule in Fig. 3, computer simulation verified that 3 from 4 current amplifiers K_{I1} to K_{I4} can be removed due to their zero or negligible current transfers. The block K_{I3} can be implemented either by a single CDTA or as a passive current divider, as shown in Fig. 4 (c).

Finally, according to **Proposition 1**, the impedance levels at the *z*-terminals were decreased 5 times to increase the working capacitances. It caused lowering the voltage levels 5 times compared with the original design. That is why voltages of up to 200mV across the *z*-terminals will now correspond to an input current of 10mA, as shown from the final results of SPICE simulation in Fig. 5. CDTA is modeled here as a connection of CDBA [3] and OTA elements. The corresponding SPICE models are provided from [4] and [5].

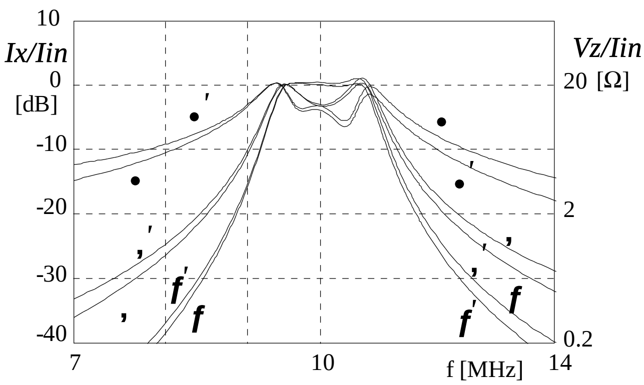

Fig. 5: Frequency responses of filter in Fig. 4 (c) after optimization.

Conclusion

The CDTA circuit element enables easy current-mode applications providing for fast analog signal processing. The described circuit equivalences and rules can serve for optimizing the designed circuits according to various criteria, applying more degrees of freedom.

Acknowledgement

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