MULTI-INPUT MULTI-OUTPUT CDTA-BASED KHN FILTER

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ABSTRACT

In this study, a new KHN filter topology based on a recently reported active building block, Current Differencing Transconductance Amplifier (CDTA), is given. A CMOS realization of the CDTA element and related simulation results are supplied. The filter has two inputs and three outputs which realize low-pass, high-pass, band-pass and notch filter responses simultaneously with low passive element sensitivities. Moreover, it does not require any passive element matching conditions. All the passive elements in the proposed filter are grounded which is desirable in view of parasitics and process dependent realization issues. SPICE simulations of the filter are conducted. Both theoretical and simulated filter responses are in close harmony with each other.

I. INTRODUCTION

Current-mode circuits have received much attention since their introduction, because of their good features such as wide bandwidth and high linearity. Many current-mode circuits have been given in the literature and new current mode alternatives to voltage-mode circuits have been proposed [1-5].

Current Differencing Transconductance Amplifier is a recently reported current mode active element which has already been used in some current mode applications [6-7]. Section II deals with this active element. Its previously reported CMOS realization [7] and SPICE simulations are shown in this section. In section III, the proposed KHN filter topology is shown and passive element sensitivities are calculated. Results and the important features of the proposed filter topology are discussed in the last section.

KHN filter, with its low passive element sensitivities and with its topology simultaneously realizing multiple transfer functions, is an efficient filter for many circuit solutions. So far, many alternative realizations of this filter have been reported [8-10]. Current conveyor and CDBA (Current Differencing Buffered Amplifier) - based versions are available in the literature but there is no CDTA-based KHN filter topology in the literature. Using CDTA element in design of the KHN filter topology. it is possible to employ only grounded and less number of passive elements which is as an advantage over [8] and [9].

This paper presents a CDTA-based KHN filter topology with multiple inputs and multiple outputs realizing, numerous relevant filter transfer functions. In simulations CDTA is realized by using the previously reported CMOS structure based on the 0.5µm MIETEC process parameters.

II. CDTA ELEMENT

Current Differencing Transconductance Amplifier (CDTA) is a recently reported, promising active building block. CDTA basically consists of a current differencing input stage which accepts the input signal differentially and converts it to voltage at the z terminal via a load impedance. Then, this voltage is converted to balanced current outputs with a transconductance parameter g of the dual output transconductance stage. Symbol of CDTA element is shown in Figure 1 and its defining equations are given below.

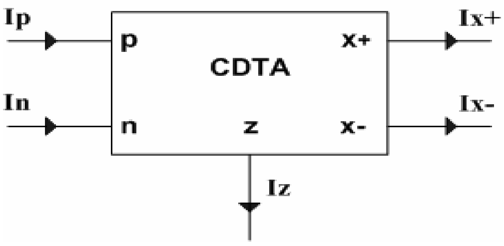

Figure 1. Symbol of CDTA element

$$\begin{aligned} V_p &= V_n = 0 \\ I_z &= I_p - I_n \\ I_{x+} &= gV_z \\ I_{x-} &= -gV_z \end{aligned} \qquad (1)$$

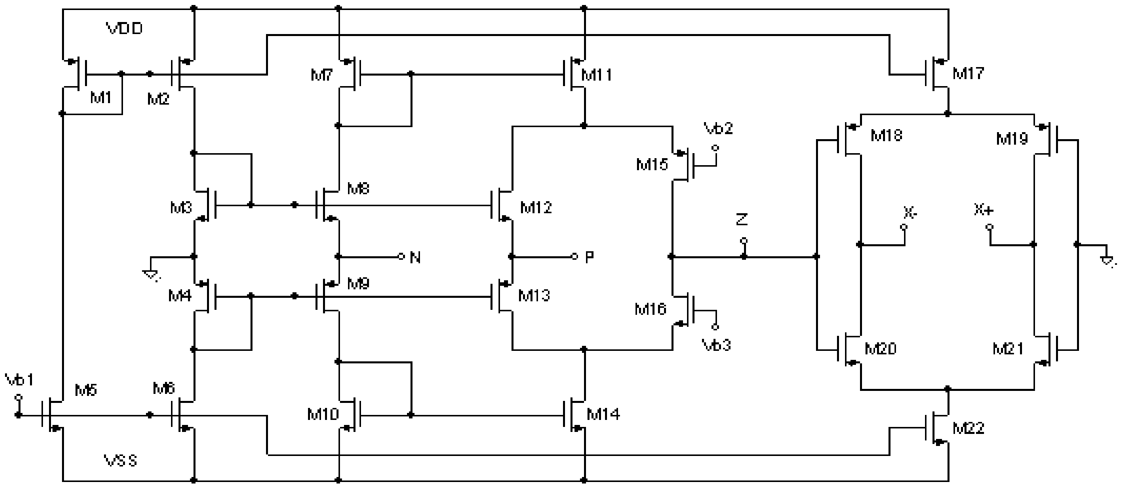

Figure 2. CMOS realization of CDTA element

Usually the z output terminal is loaded with a grounded impedance and difference current outputs are transferred to the transconductance stage over this impedance.

The CDTA element can be directly realized by replacing the buffer output of a CDBA with a dual-output balanced transconductor stage. It is also possible to realize this element using a dual output current operational amplifier where the z terminal is not taken outside [13]. The CDTA element, in this study, is designed using a DCCCS (Differential Current Controlled Current Source) [14] as the input stage, followed by a FCS (Floating Current Source) [15] which realizes the dual-output transconductor.

Figure 2 shows a CMOS realization of the CDTA element [7]. The transistors M1 to M16 form the input DCCCS stage and M17 to M12 form the dual-output transconductor stage. Quiescent current of the circuit flowing over M5 are chosen as 125µA. Aspects of the transistors in the Figure 2 are given in Table 1.

Table 1. Aspect ratios of the transistors

M1=12µm/1µm	M12=100µm /1µm
M2=12µm/1µm	M13=100µm /1µm
M3=100µm /1µm	M14=40µm /1µm
M4=100µm /1µm	M15=40µm /1µm
M5=12µm /1µm	M16=40µm / 1µm
M6=12µm /1µm	M17=40µm /1µm
M7=40µm /1µm	M18=230µm / 1µm
M8=200µm /1µm	M19=230µm /1µm
M9=200µm /1µm	M20=50µm /1µm
M10=40µm /1µm	M21=50µm /1µm
M11=40µm /1µm	M22=40µm /1µm

SPICE simulations are carried out using 0.5µm MIETEC process parameters with symmetric ±2.5V supply voltages. Simulation results are tabulated in Table 2. Both n and p ports' current transfer characteristics are shown in Fig. 3 and 4. As seen from the figures current tracking errors from n to z and p to z are small.

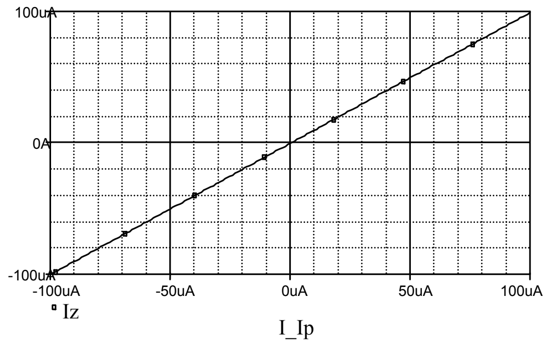

Figure 3. Current transfer from p to z

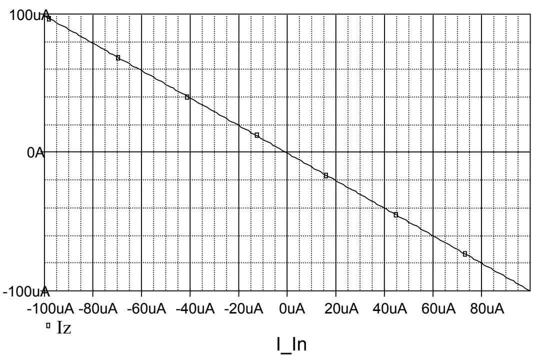

Figure 4. Current transfer from n to z

In Fig. 5 and 6, frequency response of current transfer ratios from p to z and n to z are given. 3dB bandwidth of those characteristics are quite large, 392MHz for I_z/I_p and 236MHz for I_z/I_n. Large signal behavior observed at the x+ and x- outputs are also given in Fig. 7.

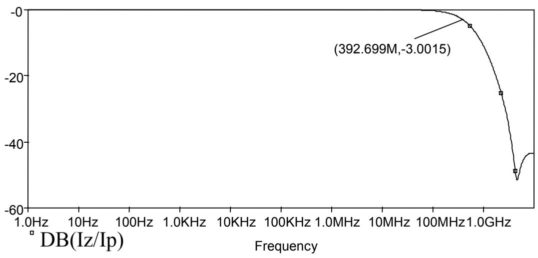

Figure 5. Change of I_z/I_p with frequency

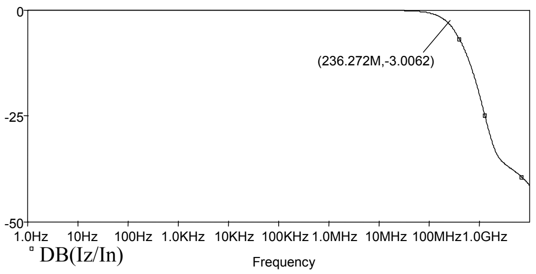

Figure 6. Change of I_z/I_n with frequency

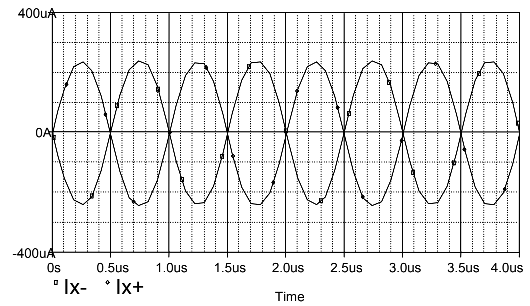

Figure 7. Large signal response of the circuit received form x+ and x- (when z is loaded with 10kΩ)

Table 2. Simulation results

Supply Voltages	±2.5V
I_z/I_p (-3dB) Bandwidth	392MHz
I_z/I_n (-3dB) Bandwidth	236MHz
P input resistance	654Ω
N input resistance	506Ω
Z output resistance	1GΩ
Slew rate	100uA/2ns
Power Consumption	4.4mW
Transconductance (g) from x terminal to z terminal	670μA/V

III. KHN FILTER TOPOLOGY

The state variable KHN (Kervin-Huelsman-Newcomb) Filter [12] is one of the most frequently used filter topology to obtain multiple filter outputs because of its low sensitivity and its feature of requiring less active elements. However, due to the limited bandwidth of operational amplifiers, its capacity is not fully exploited. Therefore, some current-mode alternatives which utilize the relatively wider bandwidth of current-mode circuits have been proposed [8-9].

In Figure 8, the proposed filter is given which is obtained from the classical KHN filter with the active element CDTA. As seen from the figure, all the passive elements are grounded. The proposed filter has two inputs and three outputs. According to the inputs, three outputs supply different biquadratic filter responses. To name it, when $I_{i1}=I_{in}$ and I_{i2} is open circuit, three outputs give simultaneously low-pass (4), band-pass (3) and high-pass (2) responses. When $I_{i2}=I_{in}$ and I_{i1} is open circuit, this time the filter realizes notch (6), low-pass (7) and high-pass (5) filter responses. It is also possible to obtain an all-pass response with a matching condition. All given filter functions require no passive element matching conditions and utilize the low passive element sensitivity feature of the KHN filter. Number of CDTA elements in the KHN filter topology can be reduced if a multi-output CDTA is used. So realization of low-pass high-pass and band-pass transfer functions with only three CDTA elements is also possible after a small modification in the CMOS realization of the CDTA element. Transfer functions of the filter outputs for two cases are given in (2-7).

$$\frac{I_{o1}}{I_{in}} = -\frac{R_1 g_1 s^2}{s^2 + s(R_1 R_2 g_1 g_2 g_3 / C_1) + R_1 g_1 g_2 g_4 / C_1 C_2} \quad (2)$$

$$\frac{I_{o2}}{I_{in}} = \frac{(R_1 g_1 g_2 g_3 R_2 / C_1) s}{s^2 + s(R_1 R_2 g_1 g_2 g_3 / C_1) + R_1 g_1 g_2 g_4 / C_1 C_2} \quad (3)$$

$$\frac{I_{o3}}{I_{in}} = -\frac{R_1 g_1 g_2 g_4 / C_1 C_2}{s^2 + s(R_1 R_2 g_1 g_2 g_3 / C_1) + R_1 g_1 g_2 g_4 / C_1 C_2} \quad (4)$$

$$\frac{I_{o1}}{I_{in}} = -\frac{R_1 R_2 g_3 g_1 s^2}{s^2 + s(R_1 R_2 g_1 g_2 g_3 / C_1) + R_1 g_1 g_2 g_4 / C_1 C_2} \quad (5)$$

$$\frac{I_{o2}}{I_{in}} = -\frac{R_2 g_3 (s^2 + R_1 g_1 g_2 g_4 / C_1 C_2)}{s^2 + s(R_1 R_2 g_1 g_2 g_3 / C_1) + R_1 g_1 g_2 g_4 / C_1 C_2} \quad (6)$$

$$\frac{I_{o3}}{I_{in}} = -\frac{R_2 g_3 (R_1 g_1 g_2 g_4 / C_1 C_2)}{s^2 + s(R_1 R_2 g_1 g_2 g_3 / C_1) + R_1 g_1 g_2 g_4 / C_1 C_2} \quad (7)$$

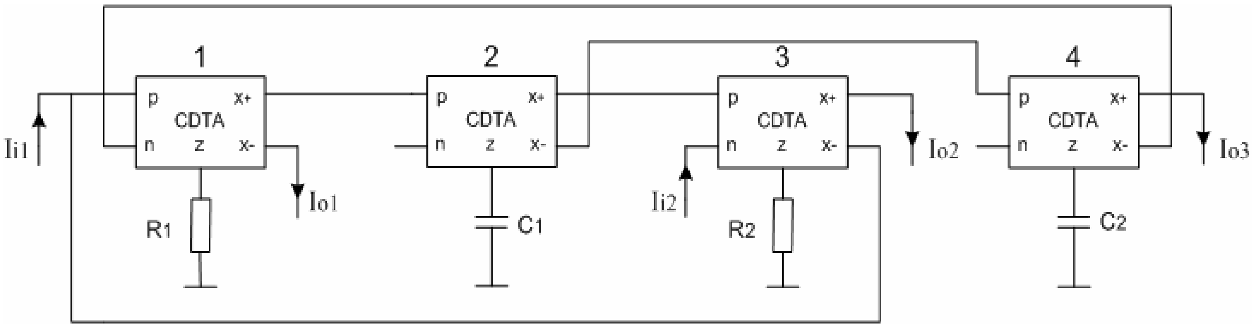

Figure 8. Proposed CDTA Based KHN Filter Structure

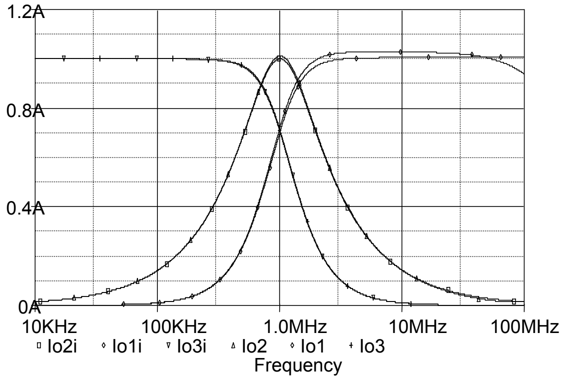

Figure 9. Ideal and simulated filter responses (Ii1=Iin)

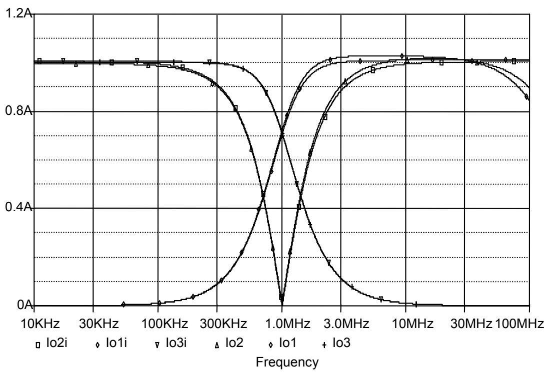

Figure 10. Ideal and simulated filter responses (Ii2=Iin)

In Figure 9 and 10, ideal and simulated filter responses for the two cases are given. From figures, it is seen that proposed filter responses behave very close to ideal filter responses. Cut-off frequency and quality factor for the filter are given in (8) and (9).

$$\omega_o = \sqrt{\frac{R_1 g_1 g_2 g_4}{C_1 C_2}} \quad (8)$$

$$Q = \sqrt{\frac{C_1}{C_2} \frac{g_4}{R_1 g_1 g_2 g_3^2 R_2^2}} \quad (9)$$

Sensitivity values for the filter are calculated and given below. As seen from those values, all sensitivities are low.

$$S_{R1}^{wo} = S_{g1}^{wo} = S_{g2}^{wo} = S_{g4}^{wo} = \frac{1}{2}, \quad S_{C1}^{wo} = S_{C2}^{wo} = -\frac{1}{2},$$

$$S_{g3}^{wo} = 0, \quad S_{C2}^{Q} = S_{R1}^{Q} = S_{g1}^{Q} = S_{g2}^{Q} = -\frac{1}{2},$$

$$S_{C1}^{Q} = S_{g2}^{Q} = \frac{1}{2}, \; S_{g3}^{Q} = S_{R2}^{Q} = -1, \quad S_{g4}^{Q} = 0 \quad (10)$$

In the filter, passive element values are chosen as $R_1=R_2=1.5k$, $C_1=75p$, $C_2=150p$ which gives a theoretical cut-off frequency of 1MHz. SPICE simulations show this value as 1.01MHz. It can be clearly said that both simulated and theoretical results are close agreement with each other.

In order to investigate the distortion performance of the proposed filter, THD of the low-pass section of the filter at 100 KHz are simulated through SPICE program and results are given in Figure 11. An input of 250µA yields THD value less than 2 percent. Also output voltage values when a load resistance, which is used to convert the current to voltage, ranged from 1Ω to 10kΩ are given in Figure 12.

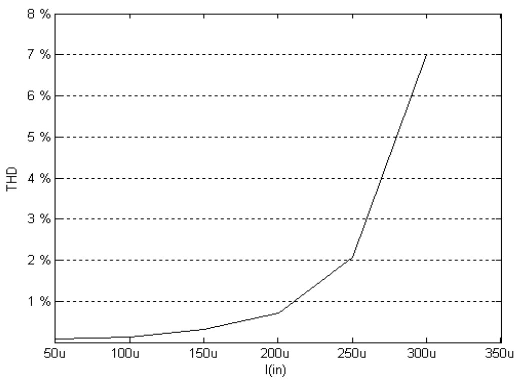

Figure 11. THD performance of the filter

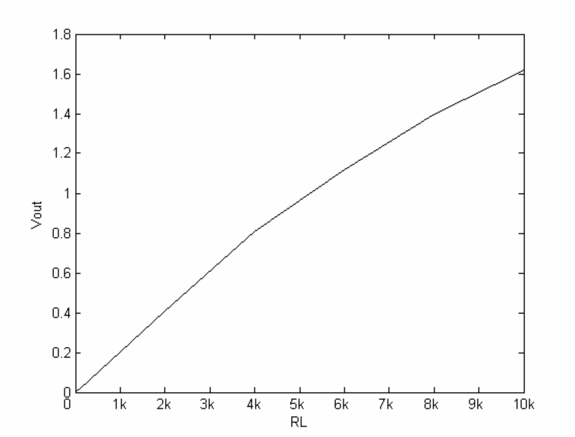

Figure 12 V_{out} versus R_L

IV. CONCLUSION

In this paper, a CDTA-based KHN filter topology with multiple inputs is presented. Its multiple outputs realize most relevant filter transfer functions. In simulations, a previously reported CMOS CDTA circuit is used. As it is apparent from the simulation results, the filter realizes the filter responses with low distortion. Theoretical and simulated results are in close agreement. The proposed filter structure employs only four and all-grounded passive elements with low sensitivity values.

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