Novel structure of current amplifier and its application

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Abstract: - The paper deals with a novel structure of current amplifier and its application in filters working in the so-called pure current mode. It introduces a novel CDCOA element (Current Differencing Current Operational Amplifier). Its bipolar structure is designed. The new element is verified in the universal multifunction filter working in the pure current mode. Because of the better frequency properties of the current mode and because of the dynamic range decreasing in the voltage mode due to decreased supply voltages enabled by present day technology, a universal filter is designed that operates in the pure current mode. It is a circuit where the active elements are only current controlled current sources. The CDCOA elements designed were used as active elements.

Key-Words: - Filters, current mode, current conveyors

1 Introduction

Currently, we can ever more often meet with circuits working in the current mode. This is due to the usually wider bandwidth of these circuits. The next argument for using circuits in the current mode is their greater dynamic range. With decreasing supply voltage the dynamic range of circuits working in the voltage mode falls. The value of the supply voltage has no influence on the dynamic range of circuits in the current mode, which is another indisputable advantage.

Up to the present time a current follower or a current mirror has been used as the active element working in the pure current mode. These elements however have unity gains. Higher gain requirements had to be solved by connecting two corresponding outputs like in [1]. That is why a novel active element - operational current amplifier with symmetrical current input and symmetrical current output was - designed. In ideal case it will have an infinite current gain. By establishing the proper current feedback we obtain a current amplifier with a defined current gain

2 Current operational amplifier CDCOA (Current Differencing Current Operational Amplifier)

The current operational amplifier designed starts from the idea of creating an amplifier with ideally infinite current gain and, by establishing a proper feedback, obtain the desired value of gain. The block structure of the element designed starts from the CDBA element [2] (Current Differencing Buffered Amplifier) extended with a current buffer with two inverting and two non-inverting outputs – see Fig. 1.

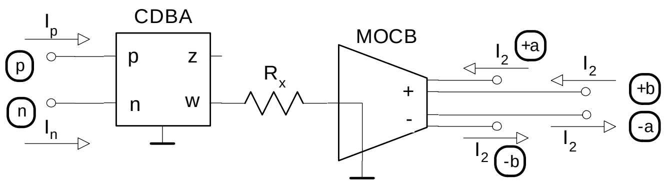
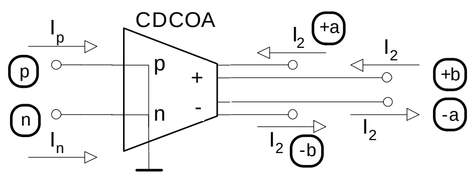
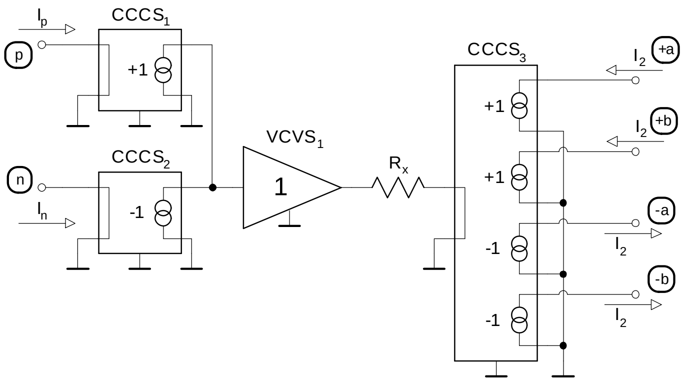


Fig. 1. *Current operational amplifier realized by extending CDBA with multi-output current buffer*

We can then imagine the current operational amplifier as two current-controlled current sources with unity current gains between which a unity-gain voltage-controlled voltage source (voltage buffer) is inserted, see Fig. 2. Thanks to this inserted voltage buffer (at the input the current source works into the high impedance while at the output the voltage source works into the low impedance) the current gain of the open loop is very high.



a)



b)

Fig. 2. *Schematic symbol of the current operational amplifier* ***a)*** *and its structure based on controlled sources* ***b)***

Resistor R_x is used only as a protective element preventing the overloading of the voltage buffer output stage (current limiting) for the case when the amplifier is connected without the feedback. The amplifier can be described by the relationship:

$$I_2 = -A_i (I_p - I_n), \quad (1)$$

where in ideal case:

$$A_i \rightarrow \infty . \quad (2)$$

The real value of current gain is given by the following ratio:

$$A_i = \frac{R_P}{R_S}, \quad (3)$$

where the value R_P is given by parallel combination of the output resistances of sources $CCCS_1$ and $CCCS_2$ and the input resistance of source $VCVS_1$. The value R_S is then given by the sum of the output resistance of source $VCVS_1$, the input resistance of source $CCCS_3$ and resistance R_X.

3 Current operational amplifier CDCOA working as non-inverting and inverting current amplifier

We verify features of current operational amplifier designed in the universal filter application. This filter was designed using current amplifiers with a gain of +/-1 or +/-2. Our aim is thus to find a proper connection of the current operational amplifier as a current amplifier with defined gain. This can be achieved by the establishing the current feedback. An example of inverting amplifier is in Fig. 3. The non-inverting current amplifier can be obtained simply by drawing the output current from the negative output terminals.

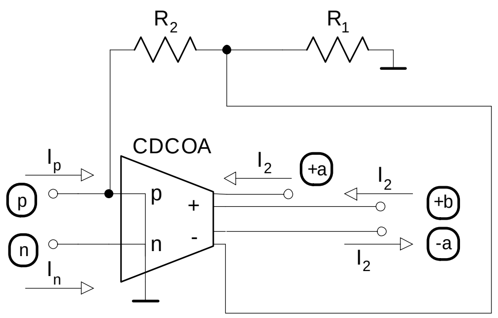


Fig. 3. *Obtaining the inverting current amplifier by establishing the current feedback in current operational amplifier CDCOA*

The current gain is given by the rate of the feedback. The relationship for current gain is then the following:

$$A_i = \frac{1}{\frac{R_1}{R_1 + R_2} - \frac{1}{A_0}} . \quad (4)$$

For ideal case, where $A_0 \rightarrow \infty$, relationship (4) can be simplified to:

$$A_i = 1 + \frac{R_2}{R_1} . \quad (5)$$

Relationships (4) and (5) are valid for the feedback lead from the output terminal to the opposite input terminal, i.e. from the **+** terminal to the **n** terminal or from the **–** terminal to the **p** terminal.

4 Bipolar structure of current operational amplifier CDCOA

The bipolar structure of this active current element has also been designed (Fig. 4).

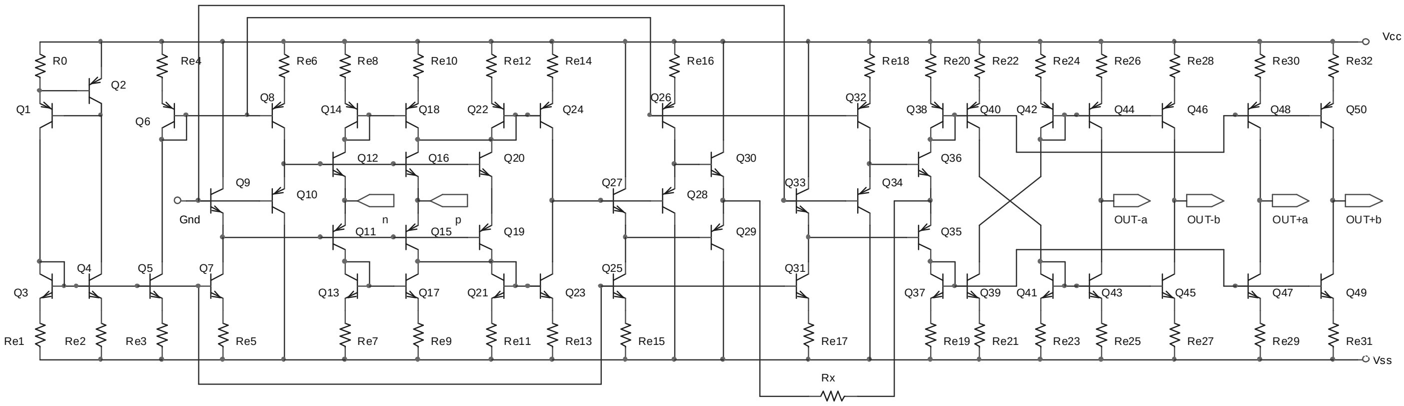


Fig. 4. *Bipolar structure of current operational amplifier CDCOA*

This structure starts from the bipolar structure of the CDBA element [3] and that of the current conveyor [4]. The inputs are the **p** and **n** terminals, which form part of the internal CDBA block, which is followed up with multi-output current buffer MOCB with output terminals **+a**, **+b**, **-a** a **-b**.

5 Application of CDCOA in the universal filter

A second-order analog filter (biquad) working in the pure current mode the using current amplifiers has been designed. The autonomous circuit starts from the filter with MOCB element introduced in [1]. The filter is conceived as a universal eight-port. Choosing an appropriate output terminal and interconnecting suitably the other terminals we obtain a lowpass, highpass or bandpass filter. The schematic diagram of such a circuit is shown in Fig. 5.

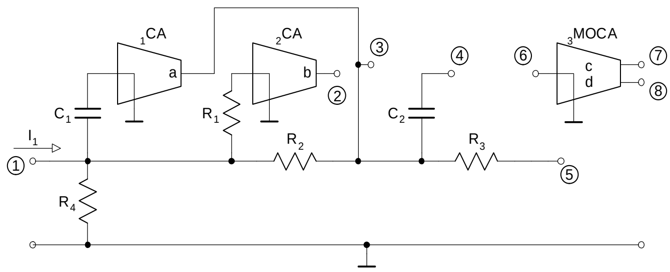


Fig. 5. *Universal eight-port in the pure current mode*

We replace individual blocks $_1$CA $_2$CA and $_3$MOCA representing current amplifiers with defined gain by current operational amplifiers with feedback established as shown in Fig. 3.

Table 1 gives the configurations for the lowpass, highpass or bandpass filter. It also contains information about which terminals should be interconnected and which terminal is the output terminal for the given type of filter. The input is always terminal 1. The Table also shows the current transfer for each configuration. For simplistic reason we consider $R_1 = R_2 = R$ and current transfer $d = -1$.

Table 1. Possible configurations of the universal eight-port working in the pure current mode

Filter type	Output terminal	Grounded terminals	Interconnected terminals	Current transfer
Lowpass	2	5	1-7, 3-8, 4-6	$H(s)=\frac{b\cdot(R+R_3)}{2R+R_3+(R+R_3)R/R_4+sR((1+a)R_3C_1+RC_1+cR_3C_2)+s^2(-ac)R^2R_3C_1C_2}$
Highpass	7	5	2-3, 4-6	$H(s)=\frac{s(1-b)cRR_3C_2+s^2(-ac)R^2R_3C_1C_2}{2R+(1+b)R_3+(R+R_3)R/R_4+sR((1+a)R_3C_1+RC_1+2R_3C_2)+s^2R^2R_3C_1C_2}$
Bandpass	7	4	2-3, 5-6	$H(s)=\frac{(1-b)cR+s(-ac)R^2C_1}{2R+(1+b)R_3+(R+R_3)R/R_4+sR((1+a)R_3C_1+RC_1+2R_3C_2)+s^2R^2R_3C_1C_2}$

By a detailed analysis of current transfer relationships we obtain the recommended coefficient values or intervals of coefficient values *a*, *b* and *c*, which should be observed in order to obtain proper filter functionality.

For the lowpass filter we choose $a \cdot c < 0$, while for the highpass and bandpass filters we choose coefficient $b = 1$.

For the lowpass filter we choose coefficients a = -2, b = 2 and c = 1. The passband current transfer can then be controlled by resistor R_4 in the range from 0 to 4/3.

For the bandpass filter we choose coefficients a = -2, b = 1 and c = 1. We omit the resistor R_4 ($R_4 \rightarrow \infty$).

For the highpass filter we choose coefficients a = -1 or a = -2, b = 1 and c = 1. We again omit the resistor R_4 ($R_4 \rightarrow \infty$). By choosing the a coefficient we choose the passband current transfer.

6 Simulations of filters working in the current mode

For the MicroCap program simulation requirements a simple model of current operational amplifier was designed. Parasitic capacitances, inductances and input and output impedances of controlled sources start from the experience of the CDBA [3] and CCIII [4] elements, whose parts are used in CDCOA and whose models were previously examined.

The model designed is shown in Fig. 6.

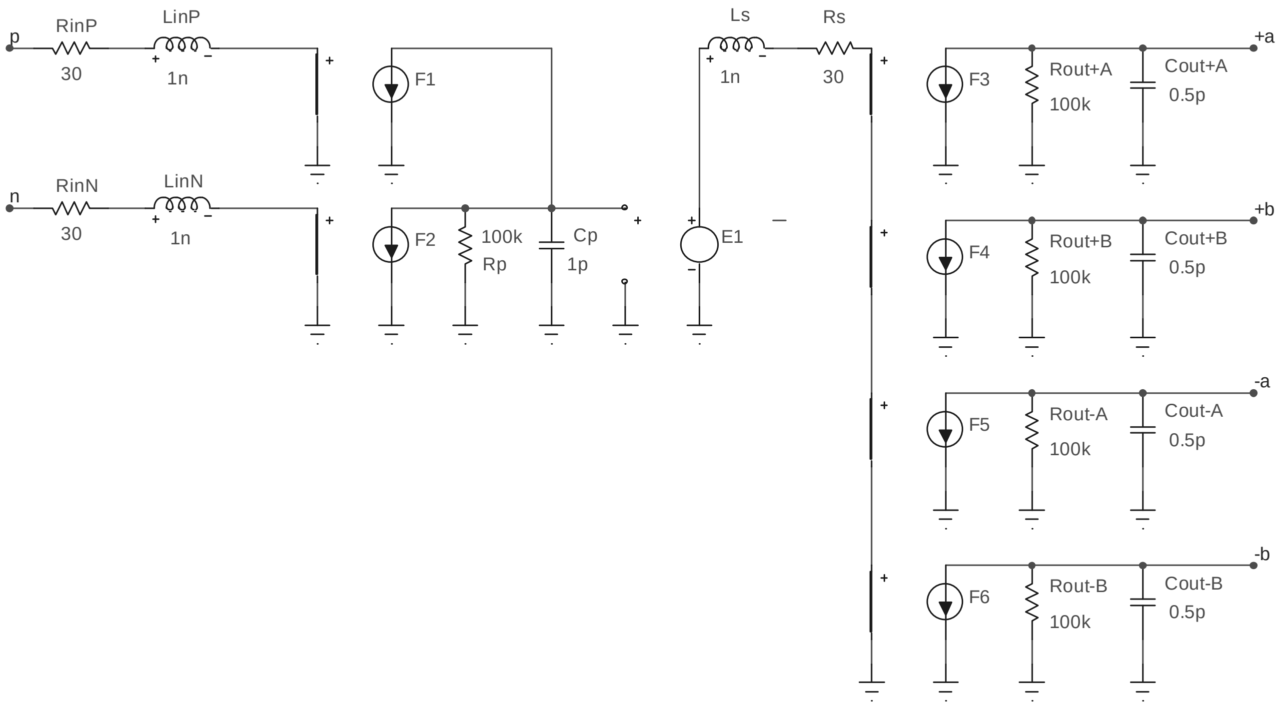


Fig. 6. *Simple model of the current operational amplifier*

Filters with a cut-off frequency of 10 MHz have been designed. Fig. 7 gives the frequency response of biquads in the current mode. The passband current transfer chosen was $|K_0| = 1$ and resistors $R_1 = R_2 = 1\text{k}\Omega$.

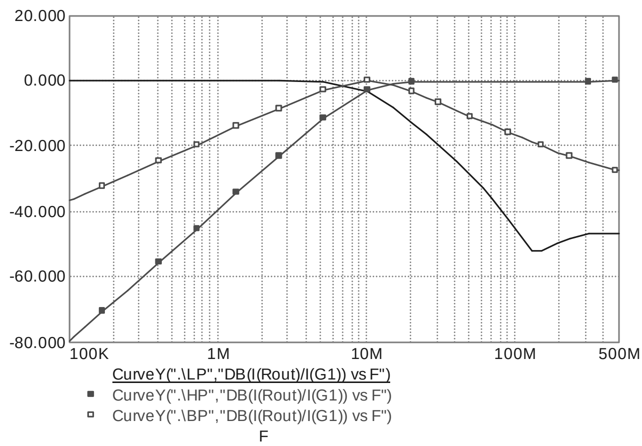


Fig. 7. *Frequency response of LP, HP and BP filters*

7 Conclusion

A novel active element – CDCOA (Current Differencing Current Operational Amplifier) suitable for filter realizations working in the so-called pure current mode was presented. Its bipolar structure starting from the bipolar structure of the CDBA element and the current conveyor was designed. It was shown how to establish the current feedback and thus to obtain a current amplifier with the gain given by the ratio of auxiliary resistor values.

Biquads with CDCOA elements connected as current amplifiers with defined current gain working in the pure current mode were designed. As far as the lowpass filter is concerned, we can control passband current transfer $|K_0|$ up to a value of about 1.3 by choosing the resistance of R_4. As far as the highpass filter is concerned, this passband current transfer is given by the value of coefficient *a*. And as far as the bandpass filter is concerned, we can set this passband current transfer arbitrarily by properly choosing the component values.

The simulations of the filters designed were performed in the MicroCap program using a simple model of the CDCOA element.

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