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CMOS Current-mode Operational Amplifier

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Abstract — **A fully differential-input differential-output current-mode operational amplifier (COA) is described. The amplifier utilizes three second generation current-conveyors (CCII) as the basic building blocks. It can be configured to provide either a constant gain-bandwidth product in a fully balanced current-mode feedback amplifier or a constant bandwidth in a transimpedance feedback amplifier. The amplifier is found to have a gain bandwidth product of 8 MHz, an offset current of 0.8 μA (signal-range $\pm$700 μA) and a (theoretically) unlimited slew-rate. The amplifier is realized in a standard CMOS 2.4 μm process.**

I INTRODUCTION

A current mode equivalent to the conventional voltage mode operational amplifier is a current mode operational amplifier (COA), i.e. a current amplifier with a current mode low impedance

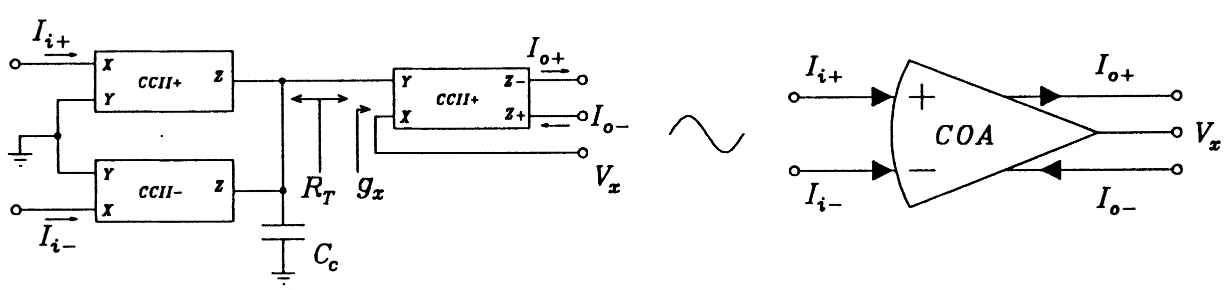


Figure 1: A current-mode op-amp

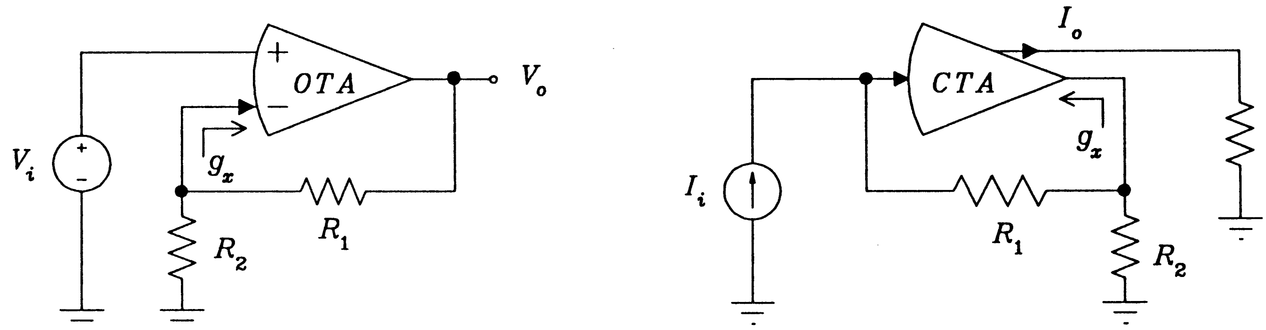


Figure 2: a: Voltage transimpedance amplifier. b: Current transimpedance amplifier (CTA)

input[1], a differential current mode high impedance output, and a high (ideally infinite) current gain.

Most current amplifiers described in the literature have only a limited gain. However, the structure described in the present paper is suitable for true COA operations, i.e. a current gain in the order of 80 dB.

The amplifier is based on the interconnection of second generation current conveyors [1]. Due to a flexible interconnection structure of the conveyors both a fully differential current mode opamp [2] and a current mode transimpedance opamp [3] can be configured from the present structure. Fig. 1 shows an equivalent diagram of the COA expressed in terms of second generation current conveyors. With the V_X-terminal connected to ground the circuit is inter-reciprocal to a conventional balanced voltage-mode operational amplifier. According to the theory of *Adjoint Networks* [1], it has a current transfer-function equal to the voltage transfer-function of the voltage-mode operational amplifier. The transfer-function is derived from Fig. 1 :

$$\frac{I_o(s)}{I_i(s)} = \frac{g_x R_T}{1 + sR_T C_c} \Rightarrow GBW = \frac{g_x}{C_c} \tag{1}$$

With the V_X-terminal used as a feedback-terminal (Fig. 2b[2]) the amplifier can be shown inter-reciprocal to a voltage domain transimpedance amplifier [3] shown in Fig. 2a [5]. In this configuration the amplifier therefore exhibits a nearly gain-independent bandwidth. The transfer-function is calculated from : $I_o = g_x(Z_T I_i + V_X)$ where $Z_T = R_T \parallel \frac{1}{sC_c}$ and $I_i = I_{i+} - I_{i-}$ and is the same for both circuits :

$$H(s) = \left.\frac{V_o(s)}{V_i(s)}\right|_{\text{Fig.2a}} = \left.\frac{I_o(s)}{I_i(s)}\right|_{\text{Fig.2b}} = (1 + \frac{R_1}{R_2})\frac{1}{1 + sR_1 C_c} \tag{2}$$

where it is assumed that $g_x[R_1 \parallel R_2] \gg 1$. Because the available current to charge and discharge C_c is not limited to a quiescent value of current (bias current source) but only limited by the current signal range of the input current conveyors, the amplifier does not suffer from slew rate limitation like the voltage mode opamp.

[1] A differential current input is necessary if the amplifier has to be inter-reciprocal with a coventional balanced voltage mode opamp

[2] In Fig. 2b. the COA has been inserted with the I_{i-}-terminal left open and the I_{o-}-terminal grounded

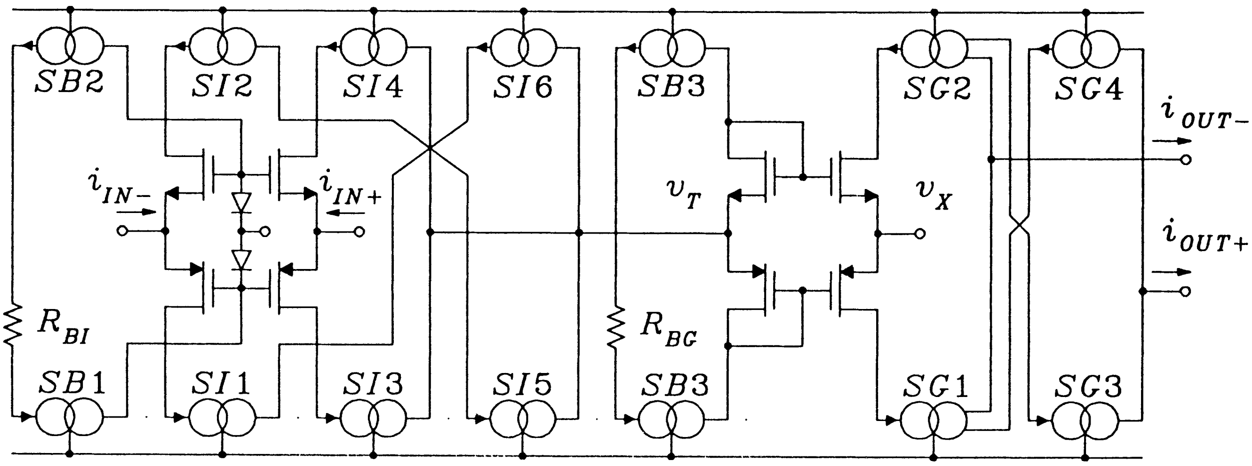


Figure 3: A CMOS current-mode op-amp

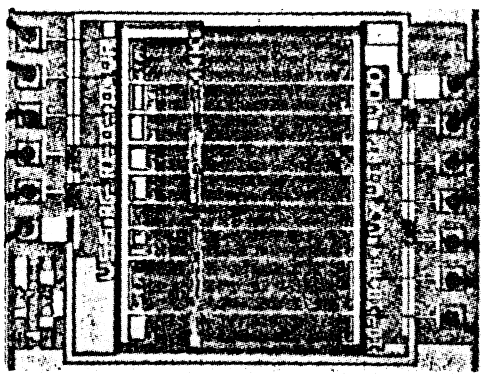


Figure 4: Die Photo of the current-mode operational amplifier

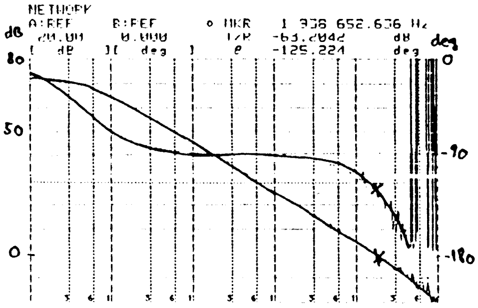
II REALIZATION

The current-mode op-amp has been realized as shown in the diagram of Fig. 3. The circuit is characterized by Eq. (3) and (4).

$$g_x = \frac{1}{g_{m6} + g_{mbs6} + g_{m8} + g_{mbs8}} \tag{3}$$

$$R_T = \frac{1}{g_{o2} + g_{o4} + g_{o5} + g_{o6} + g_{oi5} + g_{oi7}} \tag{4}$$

where g_{on} represent the output-conductance of current-mirrors or current-sources denoted by CMn and I_{Bn}. The input current offset errors are strongly dependent on the accuracy of the current-mirrors [2], and therefore all current-mirrors (and current-sources) have been realized as cascode current-mirrors. Each transistor in the amplifier needs to match one or two other transistors and in order to improve the matchning a finger-structure common centroid layout technique has been used for all transistors.



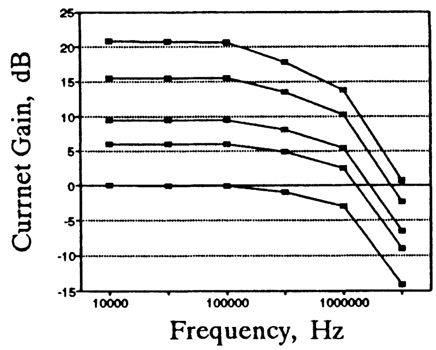


Figure 5: Transfer-functions of a. COA b. CTA

III Experimental Results

The COA has been implemented in a 2.4 μm industry standard analog CMOS proces. A chip photo is shown in Fig. 4. The COA was found to have a open loop current gain as shown in Fig. 5a. It is seen that the DC-gain is approximately 72 dB and the GB is 2 MHz . The offset-current was measured to about 0.8 μA compared to a signal range of $\pm$700 μA.

In Fig. 5b measured results from the feedback configuration of Fig. 2b are shown. The feedback resistor R_1 is 10 kΩ and different values of R_2 ranging from 1 kΩ to infinite have been used. The measurements confirm the expected constant bandwidth characteristics of the amplifier.

IV Conclusion

A CMOS current mode opamp has been analyzed and experimental results have been presented. With a structure based on three current-conveyors a versatile current-mode building-block has been achieved. The current-mode operational amplifier is found to have the current processing proporties as the traditional balanced voltage-mode operational amplifier as well as the transimpedance amplifier.

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