THE PRECISE RAIL-TO-RAIL CURRENT CONVEYOR CCII FOR MEASUREMENT APPLICATIONS

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A CMOS07 precise current conveyor CCII was designed as a part of the chemical sensor current sensing and preprocessing system on chip. Reached signal achieves very small values of current, so the measuring chain must be very accurate. The precise conveyor CCII is used as a transconductance stage in amplifying and range switching system.

Keywords: Current conveyor, offset, transconductance

1. INTRODUCTION

As the electro-chemical measurement system on chip is not the main topic of the paper, here there is only brief description of part of the system to illustrate the CCII usage in the measuring chain.

1.1 System description using CCII as the transconductance circuit

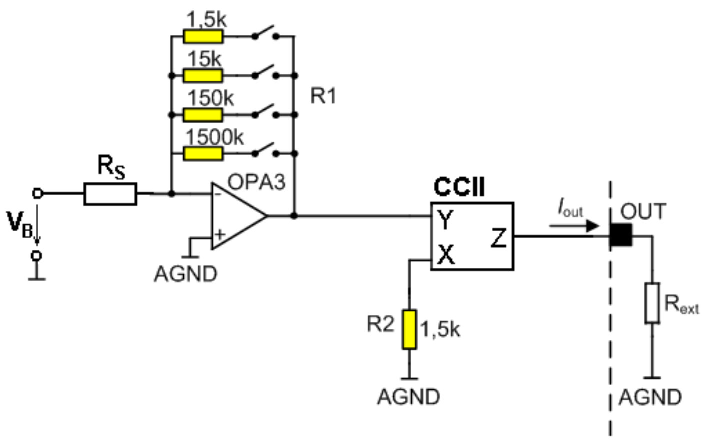


Figure 1: Part of the measurement system using CCII

The main part of the measurement chain is shown in Fig.1. The target is to sense and process current through the sensor R_S. The negative input of the OPA3 is held on the virtual AGND by the resistive feedback R1 and make reference potential for the sensor which the input voltage V_B is applied on. Sensor current flows through the selected resistor (defined by measured current range) and makes corresponding voltage at the OPA3 output. The CCII connected as the transconductance stage convert the voltage to the output current by R2 resistor. Full circuit works as a current amplifier with switchable gain, defined just by ratio of resistors R1/R2 with no influence of process or temperature. The current signal is also much more resistive to interference. Out of the chip the signal is converted to digital by current mode A/D converter or by precise external resistor and classical voltage A/D converter

2. CCII DESCRIPTION

A current conveyor is a four terminal device which when arranged with other electronic elements in specific circuit configurations can perform many useful analog signal processing functions [1, 2, 3]. In many ways the current conveyor simplifies circuit design in much the same manner as the conventional operational amplifier.

It was discovered that the current conveyor offers several advantages over the conventional op-amp; specifically a current conveyor circuit can provide a higher voltage gain over a larger signal bandwidth under small or large signal conditions than a corresponding op-amp circuit in effect a higher gain-bandwidth-product [2]

2.1 CCII behavior description

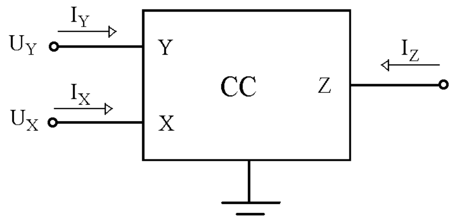


Figure 2: Current Conveyor schematic symbol

The current conveyor CCII was introduced by Sedra [1] as the new more versatile circuit against the older CCI. The operation of the CCII current conveyor is such that if a voltage is applied to high impedance input terminal Y, an equal potential will appear on the input terminal X. In a similar fashion, an input current I being forced into terminal X will result in an equal amount of current flowing into terminal Z with high output impedance. As can be seen, the potential of X, being set by that of Y, is independent of the current being forced into port X. Similarly, the current through input Z, being fixed by that of X, is independent of the voltage applied at Z. Ideally the terminal X exhibits short circuit input. In mathematical terms, the input-output characteristics of CCII can be described by the hybrid matrix equation (1). Depending on the polarity of the current Iz we know CCII+ and CCII- conveyors.

$$\begin{bmatrix} I_Y \\ U_X \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} U_Y \\ I_X \\ U_Z \end{bmatrix} \quad (1)$$

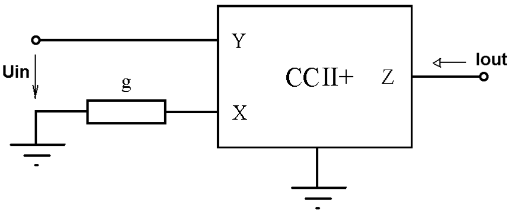
2.2 CCII applications

The current conveyor CCII allows us to build very easy a large set of applications as the building blocks, special blocks providing mathematic operations and filters working in classical voltage mode as well as in the current mode. The main building blocks overview is introduced in [4]. The circuit connection of the CCII working as the transconductance stage (voltage controlled current source) with transconductance given by externally connected admittance is shown in Fig.3.

The external admittance, determining the "g" transconductance parameter can be realized by net of the resistors or by some MOS transistor working as a voltage controlled resistance. In our application the fix resistor is used.

$$Y = \begin{bmatrix} 0 & 0 \\ -g & 0 \end{bmatrix}$$

a)



b)

Figure 3: Voltage controlled current source using CCII conveyor
a) admittance matrix
b) schematic

3. CMOS DESIGN OF THE PRECISE CCII

3.1 The basic CCII topology and principle

Many possible topologies of CCII exist, but just that one based on the operational amplifier structure is the most suitable for precise design of the conveyor that is not demanding high frequency bandwidth. The functionality of the circuit is demonstrated at the simple Miller-OTA opamp structure given in Fig. 4.

The negative feedback loop ensures the X terminal potential is equal to the Y terminal one. Simultaneously the feedback gives very low impedance to that terminal. Current flowing through the X terminal is given by externally connected admittance and it is supplied by transistors M5 and M6. When the transistors M5, M6 have their mirror in M7, M8 then ideally the current of the terminal Z is exact copy of terminal X current. It must be guaranteed by high output impedance of the output transistors. In real design the cascode connection must be used for precise circuit.

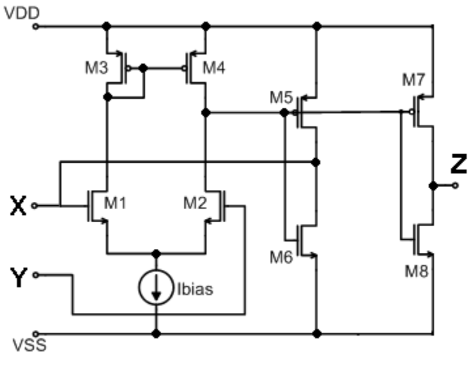


Figure 4: CCII based on simple Miller-OTA structure

3.2 Precise design of the CCII in technology AMIS CMOS07

As the application demands large input voltage common mode range, the input structure with both NMOS and PMOS input transistors was chosen together with folded cascode and input stage bias current compensation when one of the pairs is out of operation due to the common mode voltage.

The significant problem of this type of current output (especially for low processed currents) is the output current offset given mostly by output transistor matching and output stage bias current. Because of the reason the output stage working in class AB was used to ensure low quiescent bias current together with ability to process high output currents. In the presented design the quiescent output stage bias current is 40 µA, but maximum processed current is about 1.5 mA as it can be visible in Fig. 6c

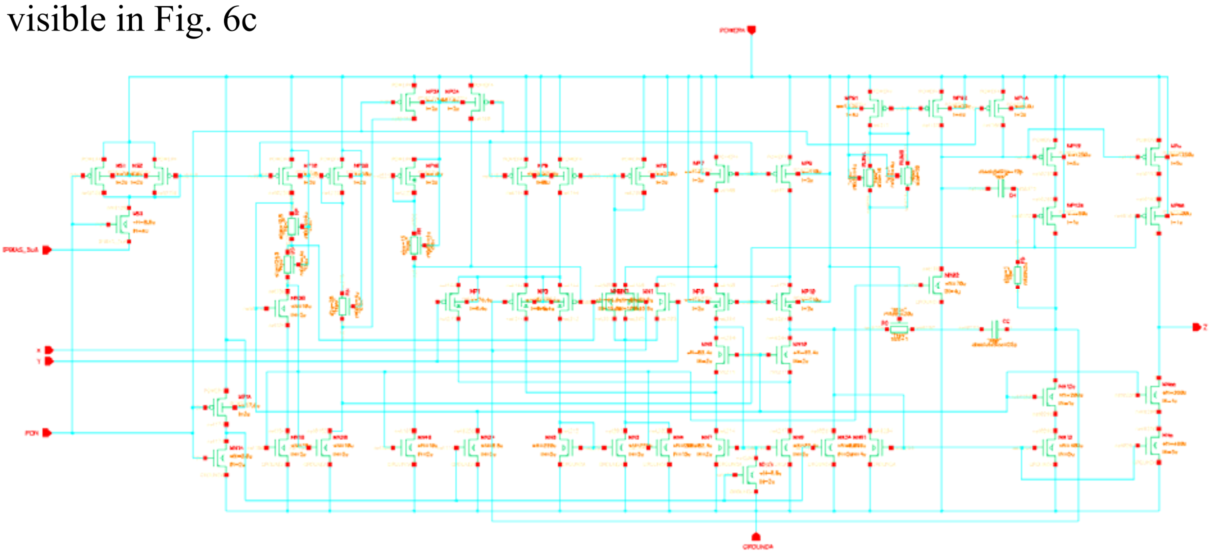
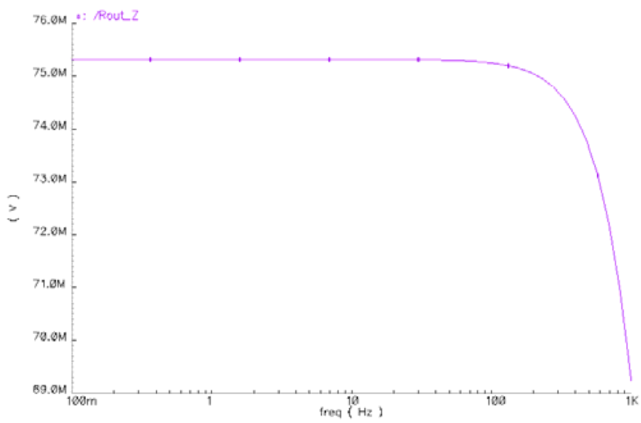
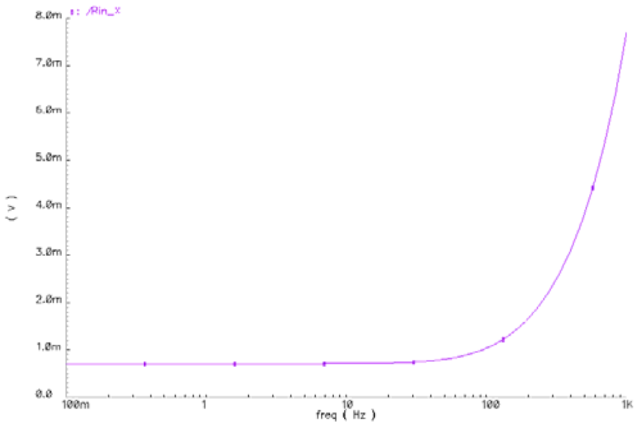


Figure 5: Cadence schematic of the realized CCII

The results of more significant simulations were done and their results are shown in figure 6. The simulated parameters are presented in Table 1.





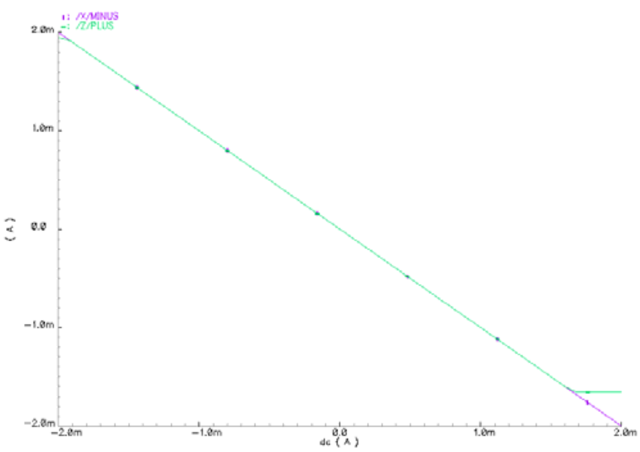


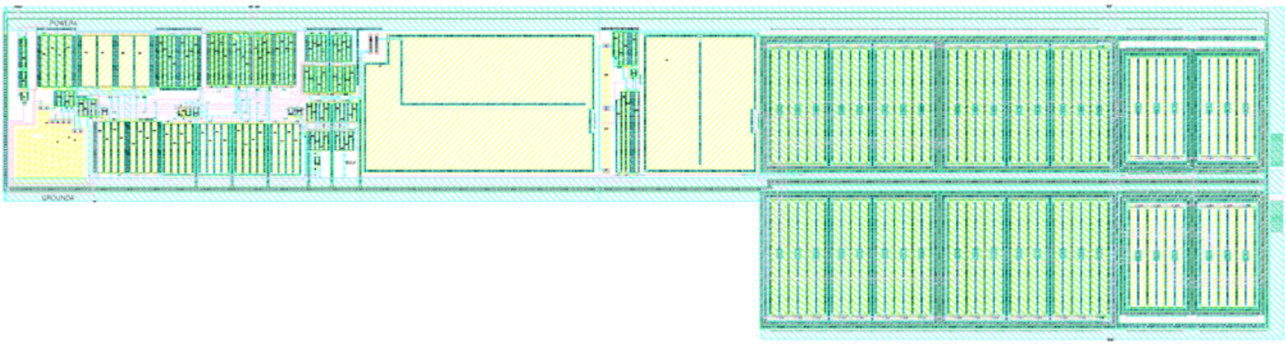
Fig. 6: Simulation results of precise CCI
a) output resistance of Z output
b) input resistance of X input
c) mutual characteristic $I_Z = f(I_X)$

Table 1. Simulated parameters of the designed CCII

Supply voltage	
Input voltage range V_{in}-range	VSS ÷ VDD
Output voltage range V_{out}-range (for used output current Iout= ±250μA)	VSS+0.5V ÷ VDD-0.5V
Max. output current I_{outmax}	±1.5mA
Systematic current offset between I_X and I_Z	4nA
Matching current offset between I_X and I_Z	0.3 μA at 1σ
Systematic voltage offset between Vx and V_Z	100 μV
Matching current offset between V_X and V_Z	2 mV at 1σ
Low frequency $Z_{IN}(X)$	1 mΩ
Low frequency $Z_{OUT}(Z)$ for $I_{OUT}=0$	75 MΩ
Z_{IN} (Y)	~ ∞
GBW	1 MHz
Phase margin (PM) – worst case	64°

4. Conclusion

The results of the design of precise current conveyor CCII with excellent DC properties was presented. The GBW was sacrificed to the high accuracy with comparison to the other current conveyor structures, but reached GBW = 1MHz satisfies certainly the used application demand. The discussed current conveyor was layouted as it is visible below and now it is processed in manufacture as the part of the full measurement system.



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5. References

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