Current Conveyor CCII as the Most Versatile Analog Circuit Building Block

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Abstract – **The second generation current conveyor CCII is introduced in this paper as a most versatile analog building block for realization of many other active circuits and applications. Short overview of interesting connections, using modular approach of design, with CCII are presented here, as well as two topologies of the conveyor, realized in CMOS technology, including their measured parameters.**

Keywords – **Current conveyor, design, modular approach**

I. INTRODUCTION

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 gain over a larger signal bandwidth under small or large signal conditions than a corresponding op-amp circuit in effect of the higher gain-bandwidth-product [2].

A. CCII behavior description

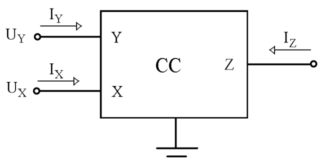

Fig. 1. Current Conveyor schematic symbol

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.

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

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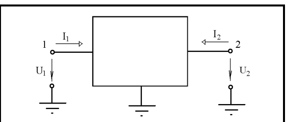
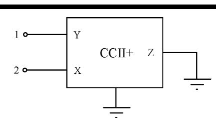
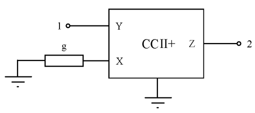
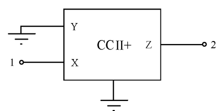
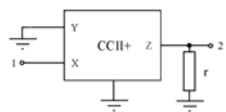
II. CCII APPLICATIONS

The current conveyor CCII allows us to build very easy a very large set of applications as the more complex building blocks, controlled sources, special blocks providing mathematic operations, transformation blocks and frequency filters working in classical voltage mode and in current mode as well.

A. Controlled sources

By the current conveyor CCII we are able to create very simply the basic set of the controlled sources. The four most important ones, built from CCII+ are presented in Table 1. Circuits with voltage output are limited by maximum possible load. It can be improved by simple voltage follower (see subsection B, circuit CFA).

TABLE 1. CONTROLLED SOURCES BY CCII

Source type	Matrix description	
Voltage follower	$K = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}$	
Voltage controlled current source	$Y = \begin{bmatrix} 0 & 0 \\ -g & 0 \end{bmatrix}$	
Current follower	$H = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}$	
Current controlled voltage source	$Z = \begin{bmatrix} 0 & 0 \\ -r & 0 \end{bmatrix}$	

B. Active devices

The CCII, as a basic building block, is very suitable for realization of the most complex active devices. As an example we could remind the possibility of realization of the transimpedance amplifier, commercially well known as the current feedback amplifier CFA or new modern active device for real current mode circuits called CCIITA.

Transimpedance amplifier - CFA

This circuit can be created by the cascade connection of the CCII+ current conveyor and simple voltage follower (that can be also realized by CCII+). The internal block connection, including the passive devices representing parasitics, is shown in Fig. 2.

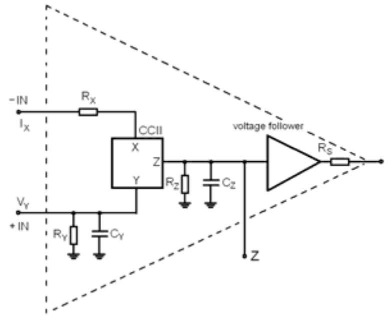


Fig. 2. Block realization of transimpedance amplifier CFA

The brought-out internal terminal Z (output of the CCII) makes possible to work with the device like with voltage buffered current conveyor CCII and allows us to realize all above mentioned voltage output circuits without critical load limitation.

CCIITA

This new current mode active device was derived from the already known CCTA [5] substituting the CCIII conveyor by CCII and it was designed for usage mostly in current mode circuits but it is also good choice in case of hybrid (voltage-current) circuits. Both circuits have many common applications like filters [4,5], controlled sources, current amplifiers etc., but each of them has also some unique advantages. Block CCIITA internal schematic is presented in Fig 3 and its behavior model and symbol is shown in Fig. 4.

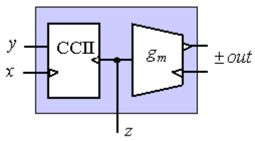


Fig. 3. Block internal schematic of the CCIITA

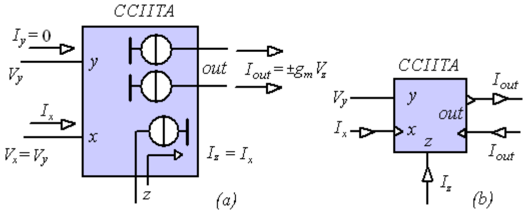


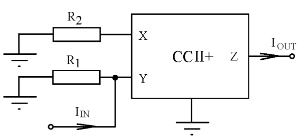
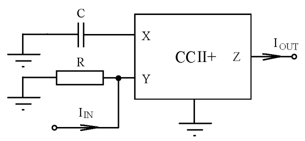
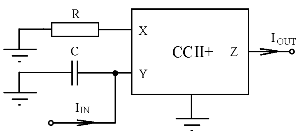
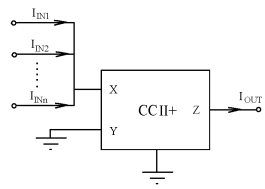
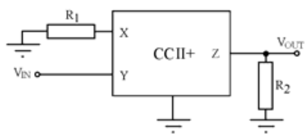
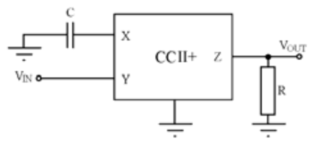
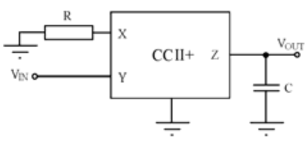
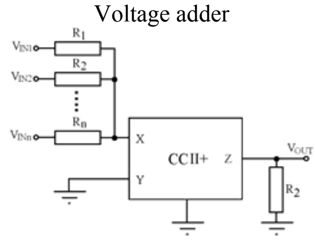
Fig. 4. CCIITA - a) behavior schematic description
b) schematic symbol

The CCIITA consists from two basic blocks. The first stage is represented by the current conveyor CCII that is followed by double output transconductance "gm" stage. The input behavior is mostly given by properties of the CCII conveyor. Conveyor output current flows out of the CCIITA terminal "z" into an outside load. The voltage across the z-terminal is converted through a transconductance gm into a current that is generally led in two output currents with opposite polarity. The transconductance can be either fixed or given by external component or controlled electronically from an auxiliary terminal as well.

C. Circuits providing mathematic operations

The current conveyor CCII allows us to develop a large set of circuits realizing many of mathematic operations in classical *voltage mode* and in *current mode* signal processing as well. Realizations of the most used operations by circuits using CCII+, including the corresponding transfer function, are introduced in Table 2.

TABLE 2. MATHEMATIC OPERATIONS REALIZED BY CCII

Current amplifier  $I_{OUT} = (R_1 / R_2) I_{IN}$	Current derivator  $I_{OUT} = CR\, dI_{IN} / dt$
Current integrator  $I_{OUT} = 1/CR \int I_{IN} dt$	Current adder  $I_{OUT} = -\sum_{j}^{n} I_{INj}$
Voltage amplifier  $V_{OUT} = (R_1 / R_2) V_{IN}$	Voltage derivator  $V_{OUT} = CR\, dV_{IN} / dt$
Voltage integrator  $V_{OUT} = 1/CR \int V_{IN} dt$	Voltage adder  $V_{OUT} = -R_2 \sum_{j}^{n} V_{INj} / R_j$

D. Transformation blocks

The probably most known transformation block is the *gyrator*, which is the special case of positive *immitance inverter*.

Ideal immitance inverter

Function of the ideal immitance inverter can be characterized by equation

$$Z_1 = \frac{U_1}{I_1} = v_0\left(\frac{-I_2}{U_2}\right) = v_0\,\frac{1}{Z_2} \tag{2}$$

where the index 1 and 2 means input or output terminal respectively and $v_0 = v_1 v_2$, if $U_2 = v_1 I_1$, $I_2 = \pm v_2^{-1} U_1$. The polarity sign determines the positive or negative immitance inverter.

In the case of positive inverter and furthermore $v_1 = v_2 = S$, we get the ideal gyrator with impedance transfer function

$$Z_1 = \frac{U_1}{I_1} = S^2\left(\frac{-I_2}{U_2}\right) = S^2\,\frac{1}{Z_2} \tag{3}$$

and the S is then called as the *gyrator resistor* or *gyrator constant*.

Such circuit as the immitance inverter we can easy realize by connection of the CCII+ and transconductance building blocks (*the gm block can be also realized as the controlled source by CCII*), as shown in Fig. 5.

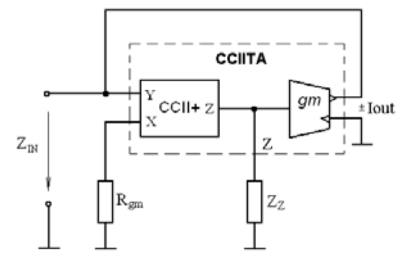


Fig. 5. Immitance inverter built from CCIITA

If the $R_{gm} = 1/gm$, then we have got the gyrator.

$$Z_{IN} = \frac{U_{IN}}{I_{IN}} = \frac{U_{IN}.R_{gm}}{I_{IN}.gm.Z_Z} = \frac{R_{gm}}{gm}\frac{1}{Z_Z} = S^2\,\frac{1}{Z_Z} \tag{4}$$

The most known and usable application of the immitance inverter or gyrator is the creation of the synthetic inductor, by loading the circuit output by capacitor. In this case the input impedance is following:

$$Z_{IN} = \frac{U_{IN}}{I_{IN}} = S^2\,\frac{1}{Z_Z} = S^2\,\frac{1}{1/j\omega C} = j\omega C S^2 \tag{5}$$

where the equivalent inductor is then $L_{eq} = CS^2$

Ideal immitance converter

Function of the ideal immitance converter can be characterized by equation

$$Z_1 = \frac{U_1}{I_1} = k_0\left(\frac{U_2}{-I_2}\right) = k_0\,Z_2 \tag{6}$$

where the k_0 is called conversion coefficient of the converter. Polarity of the coefficient determines positive or negative immitance converter.

Such circuit as the positive immitance converter can be realized in similar way like the converter and its schematic is presented in Fig. 6. The load impedance Z_Z is then converted to the input impedance Z_{IN} by equation

$$Z_{IN} = \frac{Z_Z}{Z_C\,.gm} = k.Z_Z \tag{7}$$

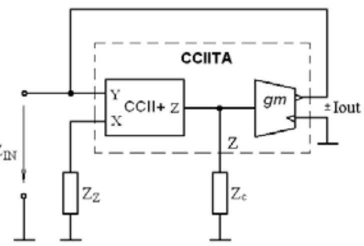


Fig. 6. Positive immitance converter built from CCIITA

The transconductance "*gm*" stage can be also realized by current conveyor CCII and depending on polarity of the conveyor it is possible to design positive or negative immitance converter. The negative immitance converter, created by two CCII+, can be seen in Fig. 7.

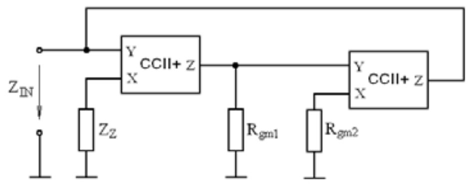


Fig. 7. Negative immitance converter built from two CCII+

The load impedance Z_Z is then trasformed by equation

$$Z_{IN} = -\,\frac{Z_Z.R_{gm2}}{R_{gm1}} \tag{8}$$

The special case of negative immitance converter, which can be realized just by one current conveyor CCII+, is the immitance converter with k_0= -1. In that case the transformation equation is

$$Z_{IN} = -Z_Z \tag{9}$$

that means the block just changes the sign of impedance. Connection of the circuit is shown in Fig. 8.

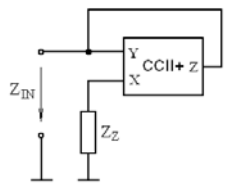
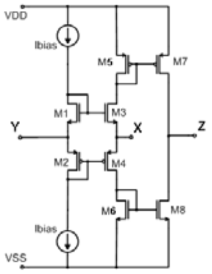


Fig. 8. Negative immitance converter from one CCII+

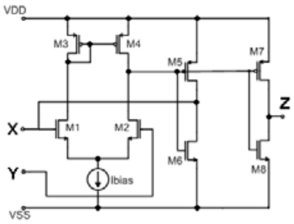
III. CCII Realization

For the current conveyor CCII the two basic topologies can be used. The first of them is based just on current mirrors (Fig. 9a) and the second one uses the operational amplifier feedback structure (Fig. 9b). Both of them have some advantages and some worse properties as well, of course.

The *current mirror topology* is convenient in high frequency applications due to the parasitic poles given just by current mirror low impedance nets. But its most important disadvantage is in very small input voltage swing, especially for low voltage technologies. The problem is raised by high threshold voltage of NMOS transistors M1, M3, caused due the "body effect of these MOSes, which have their sources connected at higher potential whereas their bulk are always connected to Vss (it is the problem of the most used n-well CMOS technologies, of course). It also limits using of cascode mirrors for more accuracy circuit. This topology also exhibits higher X-terminal input impedance, just given by transconductance of transistors M3 and M4.



a)



b)

Fig. 9. Internal topology of current conveyor CCII+
a) based on current mirrors
b) based on opamp structure

In contrast of that, the feedback of opamp structure copies the voltage from input "Y" to the input "X" and at the same time guarantees a *very low* impedance at the input "X" node. The current from the input "X" is then conveyed by the transistors M5, M6 and corresponding current mirrors M7, M8 to the output "Z". In the shown circuit the "push-pull" transistor branches were used. For better stability and property control the "current source-gm transistor" can be used.

TABLE 3. SIMULATED PARAMETERS OF CONVEYORS CCII DESIGNED IN CMOS07 TECHNOLOGY

Parameter	CCII - opamp structure	CCII current mirror
Supply voltage	0 ÷ 5V	0 ÷ 5V
Input voltage (V_{in}) range	VSS ÷ VDD	1.85V ÷ 3V
Output voltage (V_{out}) range	0.5V ÷ 4.5V	0.1V ÷ 4V
Max. output current I_{outmax}	±1.5mA	±150µA
Systematic current offset between I_X and I_Z	4nA	20nA
Matching current offset between I_X and I_Z	0.3µA at 1σ	0.4µA at 1σ
Systematic voltage offset between Vx and V_Y	100µV	200µV
Matching voltage offset between V_X and V_Y	2mV at 1σ	3mV at 1σ
Low frequency $Z_{IN}(X)$	10mΩ	240Ω
Low frequency $Z_{OUT}(Z)$ for $I_{OUT}=0$	75MΩ	5 MΩ
Z_{IN} (Y)	~ ∞	~ ∞
GBW	1 MHz	60 MHz

Using rail-to-rail opamp topology the rail-to-rail current conveyor, regarding the Y-terminal voltage, can be designed. The highest disadvantage appears the possibility to reach maximum current conveyor gain-bandwidth comparable with opamps for the technology is used.

Both topologies have been designed and realized in AMIS CMOS07 technology by EUROPRACTICE. The simulated parameters of the circuits can be find in Table 3. Measured results correspond to that simulated values.

IV. CONCLUSION

By the short overview of possible applications it is obvious the current conveyor CCII is really very versatile building block with wide utilization either as the active circuit element or as the building block for more complex active devices (e.g. CCIITA, CFA). Other applications like filters or even digitally controlled analogue circuits using CCII can be also developed by similar way. Parameters of the CCII conveyors designed in CMOS technology were presented.

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