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Simulation and Analysis of Current Conveyor using 0.18um CMOS Technology

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Abstract: ***Current Conveyors have been used as a basic building block in a variety of electronic circuit in instrumentation and communication systems. Today they replace the conventional OPAMP in so many applications such as active filters, oscillators, analog signal processing and A/D, D/A Convertors. Current conveyor is a high performance analog circuit design block based on current mode and voltage mode approach. It is basically a unity gain element that exhibits high linearity, wide dynamic range, high bandwidth and better high frequency performance. The current conveyor is a combination of voltage as well as current follower. Current conveyor has the advantages of a wide current and voltage bandwidths. We use a translinear configuration for first, second and third generation current conveyor. CMOS process model show that the CCI CCII and CCIII perform good accuracy and frequency response at 1.8V supply voltage. The current conveyor is simulated in terms of voltage offset, current offset, current bandwidth and voltage bandwidth in 180nm CMOS technology using Mentor Graphics tools.***

Keywords: Current Mode Circuits, Current Mirror Circuits, CMOS Current Conveyor, CCI, CCII, CCIII.

1. Introduction

Current Conveyors represent the emerging class of high performance analog circuit design based on current-mode approach. The last decade, current mode circuits have become popular. Current mode circuits exhibit reliable high frequency response, have simpler architecture, provides better dynamic ranges and operate at lower voltages than their voltage mode counterparts[1]. Its performance is characterized by the voltage and current following behaviors. To exploit wideband and wide dynamic range capabilities under low power operation of current-mode signal CCI, CCII and CCIII based on the translinear loop has been designed. These translinear CMOS circuits exhibit an excellent current following behavior from port X to port Z over to rail input stage is designed to improve the dynamic range. With the reduction in the supply voltage and a wide bandwidth, but the voltage following property from port Y to port X is poor and the offset voltage is rather high. In this paper, a wideband CMOS realization of the CC based on the long tail differential pair with rail to rail input stage is designed to improve the dynamic range. With the reduction of the supply voltage and device threshold voltage of CMOS technology, the performance of CMOS voltage-mode circuits has greatly affected which results in a reduced dynamic range, an increased propagation delay and reduced low noise margins. The influence of supply voltage reduction on the performance of current-mode circuits, however, is less severe as compared with that of voltage-mode circuits. This is because the design emphasis of current-mode circuits is on branch currents rather than nodal voltages. The usefulness of CMOS current-mode circuits in overcoming the difficulties arising from the reduction of the supply voltage and the increase in the operation speed has received an increasing attention from the industry [5].

The current conveyor is a basic building block that can be implemented in analog circuit design. This was introduced by Sedra and Smith in 1968 but its real advantages and innovative impact was not clear at that time. In recent years, current-mode circuits have emerged as an important class of circuits with properties of accuracy, high frequency range and versatility in a wide range of applications. Current conveyor represents the emerging class of high performance analog circuit design based on current mode approach. It has simple architecture, wider bandwidth and capability to operate at low voltage.

In this the application of CCI± becomes difficult because both the ports X and Y have zero input impedance in order to sink currents. The port Y needs to control a current rather than to control a voltage, which is usually difficult to obtain in practical designs. This is the perhaps the greater limit of the CCI device and this reduces its flexibility and versatility.

Current conveyors can be used in variety of applications ranging from multifunction and universal filters [2], oscillators and immittance design to integrators and differentiators. Unlike operational amplifier, current conveyors do not have a low frequency dominant pole and their utilizable frequency range is much higher. The current conveyors can be classified into three generations.

- First Generation Current conveyor, CCI.
- Second Generation Current conveyor, CCII.
- Third Generation Current conveyor, CCIII.

2. Motivation for Current and Voltage Mode Design

The current-mode design technique is a good alternative for the high performance analog circuit design as it offers voltage independent high bandwidth. In current-mode design, the stress is more on the current levels for the operation of the circuits and the voltage level at various

nodes are immaterial. In Voltage-mode circuits (VMCs), such as operational amplifiers (op amp), the performance of the circuit is determined in terms of voltage levels at various nodes including the input and the output nodes. But all these circuits suffer from the following disadvantages:

- Output voltage cannot change instantly when there is a sudden change in the input voltage due to stray and other circuit capacitances.
- Bandwidth of the op amp based circuits is usually low because of finite unity gain bandwidth.
- Slew rate is dependent on the time constants associated with the circuit.
- Circuits do not have high voltage swings.

Require higher supply voltages for better signal-to-noise ratio. Therefore, VMCs are not suitable for high frequency applications.

When signals are widely distributed as voltages, the parasitic capacitances are charged and discharged with the full voltage swing, which limits the speed and increases the power consumption of voltage-mode circuits. Current-mode circuits cannot avoid nodes with high voltage swing either but these are usually local nodes with less parasitic capacitances [6]. Therefore, it is possible to achieve higher speed and lower dynamic power consumption with current-mode circuit techniques.

When the signal is conveyed as a current, the voltages in MOS transistor circuits are proportional to the square root of the signal, if the devices are assumed to be operating in saturation region. Therefore, a compression of voltage signal swing and a reduction of supply voltage are possible. This feature is utilized in log domain filters, switched current filters and in non-linear current-mode circuits [7]. However, as a result of the device mismatches, this non-linear operation may generate an excessive amount of distortion and cannot be used for the applications where high linearity is required. Thus, linearization techniques are utilized in current-mode circuits to reduce the nonlinearity of the transistor transconductance and in this case the voltage signal swing is also not reduced. An ideal voltage-mode circuit has infinite input impedance, zero output impedance and a constant voltage gain. The best example of voltage mode circuit is an ideal operational amplifier. The infinite input impedance and a zero output impedance of Operational amplifiers enable an easy cascade without loading effect and also ensure that the characteristics of these circuits are determined by the external elements [5].

Unlike ideal voltage-mode circuits, an ideal current-mode circuit has the characteristics of zero input impedance, infinite output impedance and a constant current gain. The current amplification will result in a high level of static power consumption; therefore, the current gain of ideal current-mode circuits is set to unity. This constant current gain up to large frequency range enables current-mode circuits to be used for high frequency applications. On the contrary, the gain of voltage-mode circuits falls at high frequencies [6].

The comparison between voltage-mode and current-mode circuit with respect to input/output impedance, bandwidth, propagation delay, slew rate, power supply sensitivity and electrostatic discharge.

- A voltage-mode circuit is characterized by large input impedance and low output impedance. On the other hand, a current-mode circuit is characterized by low input impedance and high output impedance.
- The comparison of the bandwidth of voltage and the current mode circuits can be done by using their basic building blocks because a current mode circuit has large output impedance and small input impedance, therefore the condition of load impedance is holds.
- For digital circuits, the average propagation delay is used as a figure-of-merit in depicting the transient behavior of the circuits. It is directly related to the swing of the signal [5].

1) Minimizing the voltage swing of the node.
2) Maximizing the current charging and discharging the capacitance of the node.

- For voltage mode circuits, the slew rate is usually determined by the output stage because of the large width of transistors in the output stage and the large load capacitance.
- The effect of VDD and ground fluctuations on the output voltage or current of CMOS circuits is of a great concern in mixed-mode circuits because both analog and digital circuits often share the same supply voltage and ground. Supply voltage sensitivity, defined as is a measure of the effect of the variation of the supply voltage on the response of the circuits.
- The oxide thickness tox is scaled down aggressively in deep submicron CMOS processes. This results in large number of ESD (electrostatic discharge) induced damages of MOSFETs mainly due to the breakdown of the gate oxide insulator.

3. First Generation Current Conveyor

The first ideal current mode circuits were first generation current conveyors introduced by Sedra and Smith in 1968. These are denoted by CCI±, where polarity specify the direction of the output current is same as that of current flowing into port X or not. It is basically a three terminal device as shown in figure 1.

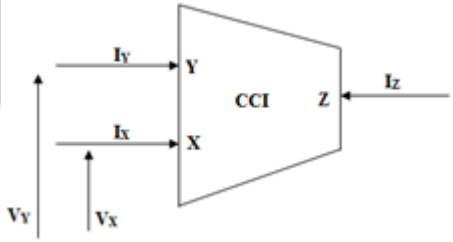

Figure 1: Block representation of CCI [6]

The relation between the terminal voltages and current of CCI can be given by the following matrix relation,

$$\begin{bmatrix} I_Y \\ V_X \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} V_Y \\ I_X \\ V_Z \end{bmatrix}$$

Matrix representation of CCI

From the above matrix description it is found that, if a potential is applied on port Y then equal voltage will appear at port X and this voltage is independent of current supplied to port X. Thus circuit exhibits a virtual short circuit at port X. Also, the current flows through port Y is equal to the current supplied to port X and this current is independent of voltage at port Y. Thus circuit exhibits a virtual open at port Y. Finally, the current supplied to X is also conveyed to the output port Z which is at a high impedance level. The impedance level at different ports of first generation current conveyor is listed in table 1.

Table 1: Impedance level at ports of CCI[6]

CCI Ports	Impedance Level
X	Low (ideally zero)
Y	Low (ideally zero)
Z	High (ideally infinite)

The application of CCI becomes difficult because both the port X and Y have zero input impedance in order to sink currents. The port Y needs to control a current rather than to control a voltage, which is usually difficult to obtain in practical designs. This is the perhaps the greater limit of the CCI device and this reduces its flexibility and versatility.

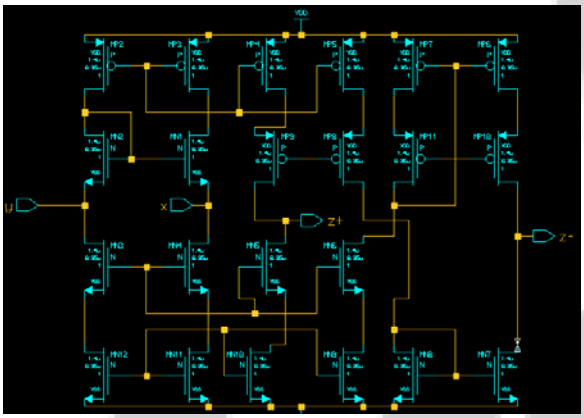

Figure 2: CMOS implementation of the proposed CCI [4]

The simple CMOS implementation of first generation current conveyor is shown in figure 2. To overcome this drawback, a novel first-generation current conveyor (CCI) which consists of a "half" class-AB input stage and wide-swing current mirror is presented. Simulation using Cadence Spectre with TSMC 0.18µm standard CMOS process shows that the proposed CCI performs good accuracy and frequency response at 1.8V supply voltage.

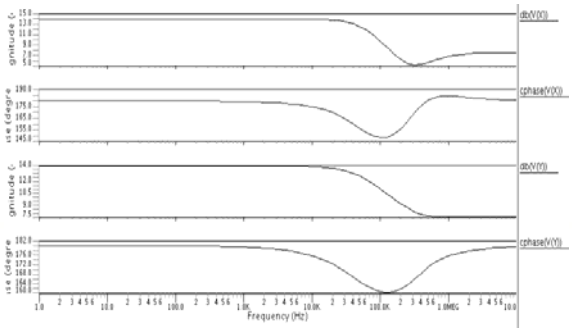

Figure 3: Simulation result of proposed CCI

The first generation current conveyor, CCI is a basic building block can be used for variety of applications. The following are the application of CCI:

- The low impedance at the input terminal allows this current conveyor to be used as a current amplifier.
- The DC-voltage level at the current input port X can be easily set to a desired value by the voltage at the Y-terminal and input voltage-

Current conversion is easier than in the case of a current-mirror. This is shown in figure 4.

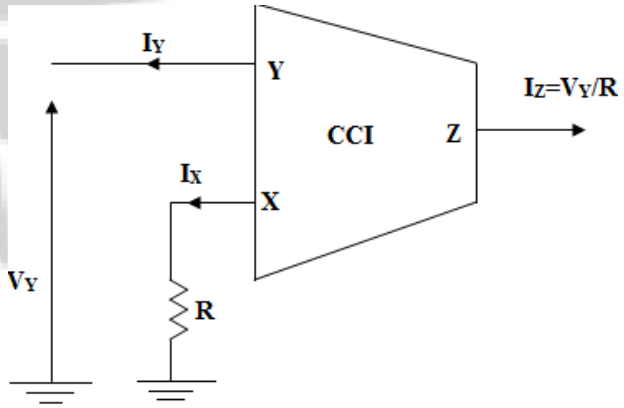

Figure 4: Voltage-to-Current Conversion [6]

4. Second Generation Current Conveyor

The second generation current conveyor (CCII) is one of the most versatile current-mode building blocks. For many applications, a high impedance input port is preferable in order to avoid loading effect. So, second generation current conveyor was developed to fulfill this requirement. It has one high and one low impedance input port rather than the two low impedance input ports of CCI. Since its introduction in 1970, it has been used in a wide range of applications and several circuits have been realized using this block. The CCII can be considered as the basic analog circuit design block because all the active devices can be made of a suitable connection of one or two CCIIs. It is a three terminal device and the block representation of this conveyor is shown in figure 5.

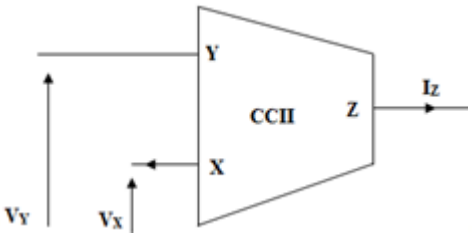

Figure 5: Block representation of CCII [6]

The relation between the terminal voltage and current of CCII can be given by the following matrix relation,

$$\begin{bmatrix} I_Y \\ V_X \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} V_Y \\ I_X \\ V_Z \end{bmatrix}$$

Matrix representation of CCII

This current conveyor differs from the first generation Current conveyor in a sense that the port Y is a high Impedance port i.e. there is no current flowing into Port Y. The port Y of the second generation current Conveyor is used as a voltage input and port Z is used as a current output port. Whereas, the port X can be used as a voltage output or as a current input port. Therefore, this current conveyor can be used to process both voltage and current signals. There are two types of second generation current conveyors:

- Positive current conveyor (CCII+) in which the Currents i_X and i_Z have the same direction as in a current mirror.
- Negative current conveyor (CCII-) in which currents i_X and i_Z have the different direction as in a current buffer

These two conveyors are shown in figure 6.

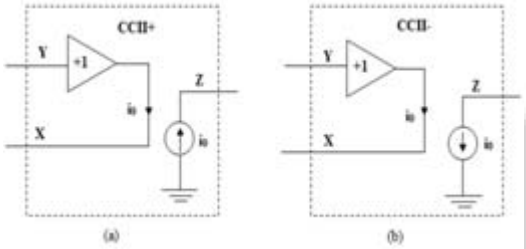

Figure 6: (a) Positive CCII+, (b) Negative CCII-[6]

The impedance level at various ports of second generation current conveyor is shown in the table 2. Impedance at input and output ports of current conveyors plays an important role in determining its characteristics.

Table 2: Impedance level at ports of CCII [6]

CCII Ports	*Impedance Level*
X	Low (ideally zero)
Y	High (ideally infinite)
Z	High (ideally infinite)

An implementation of the second generation current Conveyor using a mixed (NMOS and PMOS) translinear loop is shown in figure 7.

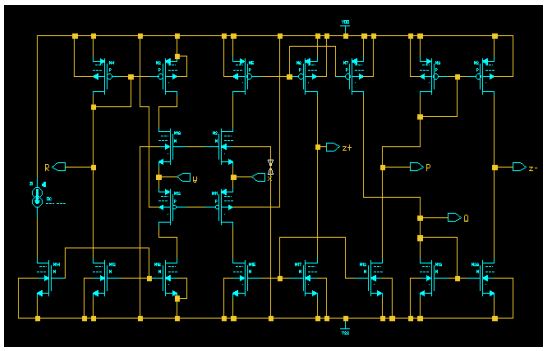

Figure 7: CMOS implementation of the proposed CCII [1]

$$\alpha = \frac{Vx}{Vy} = \frac{1}{1+\frac{1}{(gm2+gm4)(ro2//r04)}} \equiv 1$$

From the above equation it is clear that in order to maximize the voltage gain, the transconductance of the transistors M2 and M4 must be high so that the term in the denominator can be neglected. So for a given bias current I0 and length of transistor, the gm can only be increased by increasing the width of the transistors. Therefore, in order to maximize the voltage gain, the width of the transistors forming the translinear loop is kept large while designing the circuit [1]. The CCII can be considered as the basic circuit block because all the active devices can be made of a suitable connection of one or two CCIIs.

The various applications of CCII are:

- Voltage Controlled Current Source (VCCS)
- Current Controlled Voltage Source (CCVS)
- Current Amplifier
- Current Differentiator
- Current Integrator

The Simulation is obtained in 180nm.

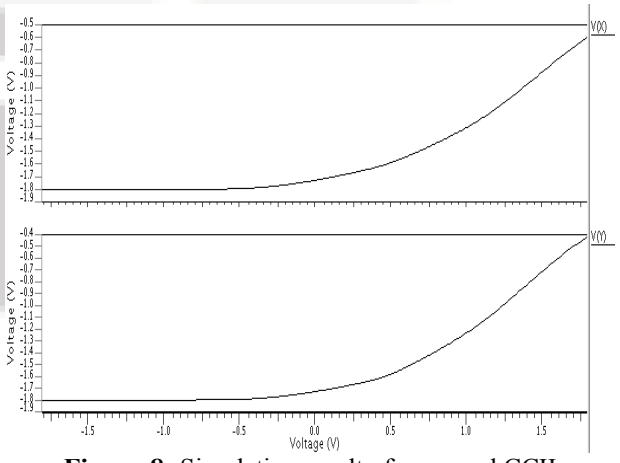

Figure 8: Simulation result of proposed CCII

5. Third Generation Current Conveyor

The third generation current conveyor can be considered as a current controlled current source device with a unity gain. This type of current conveyor is useful to take out the current flowing through a floating branch of a circuit and can be utilized in realization of various multifunction filters, inductance simulation and all pass sections [9] High performance current mirrors are required in the CMOS structure realization of CCIII in order to provide the good dynamic swing and high output resistance which enables cascadability [8].

The main features of the CCIII are:

- Low gain errors (high accuracy)
- High linearity
- Wide frequency response

The CCIII is a three port device and the relation between terminal voltages and currents of this current conveyor can be given by the following matrix relation,

$$\begin{bmatrix} I_Y \\ V_X \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} V_Y \\ I_X \\ V_Z \end{bmatrix}$$

Matrix representation of CCIII

That is, it has a +1 voltage gain between ports X and Y, a +1 current gain between ports X and Z and a -1 current gain between ports X and Y. The latter property enables the use of this circuit as an integrated floating current sensing device [10].

Besides showing the performance of the presented low voltage CCI, Table I summarize the performance of the proposed low voltage CCIII to compare with conventional CCIII and cascade CCIII citied from [9]. It can be seen that the proposed low voltage CCIII has the best current transfer accuracy even operated at 1.8V supply voltage. Resistance stem from better CMOS process. The voltage transfer accuracy is better than conventional CCIII although it is slightly worse than cascade CCIII [4].

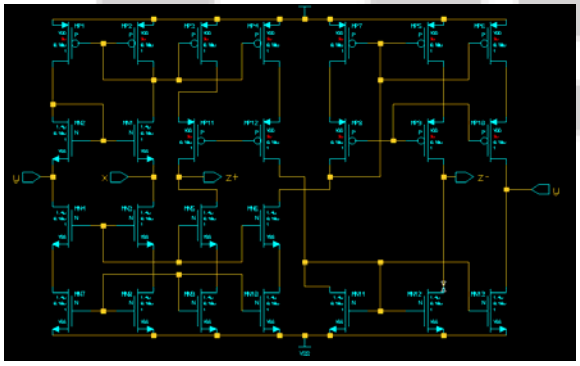

Figure 9: CMOS implementation of the proposed CCIII [4]

The third generation current conveyor can be used as an active current probe. The typical current measurement set-up is shown in figure 10, where the voltage drop over a small shunt resistor is amplified with a voltage amplifier, is problematic if a low shunt resistance is required. In such a case, a large voltage gain is needed to amplify this small voltage drop across the resistor *R,* which limits the measurement bandwidth and makes the measurement more sensitive to offset voltage, noise, and RF-interference [5].

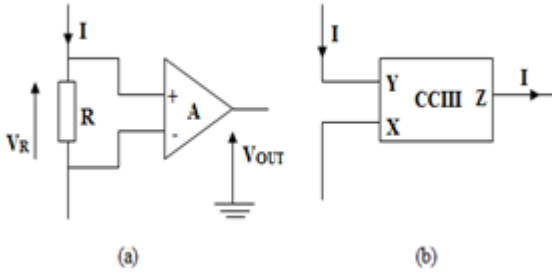

Figure 10: Current measurement (a) with a voltage amplifier (b) with a CCIII [7]

The simulation results are obtained in 180nm.

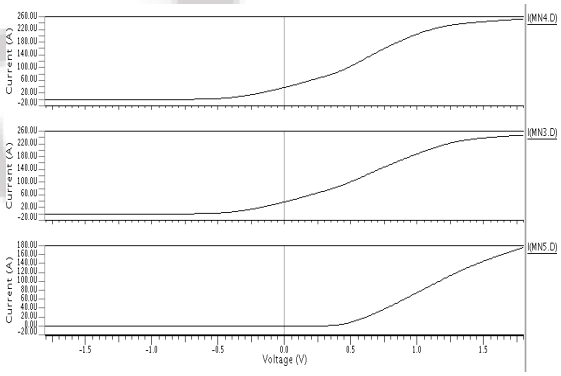

Figure 11: Simulation result of proposed CCIII

6. Conclusion

The parameter of Current Conveyor is as given in this table

Parameter	CCI	CCII	CCIII
CMOS process model	0.18um	0.18um	0.18um
Power supply	1.8V	1.8V	1.8V
Accuracy V_X/V_Y	0.95	0.99	0.95
Power dissipation	70uW	20uW	130uW
Bandwidth V_X/V_Y	12.5MHz	135MHz	21MHz
Accuracy I_Z/I_X	0.96	0.97	0.95
Dynamic Range	300mV,-300mV	600mV,-500mV	400mV,-400mV

In this thesis, CMOS Current Conveyors for high frequency applications have been presented. Current conveyor, namely, First, Second and Third Generation Current Conveyor (CCII) has been analyzed and designed using TSMC 0.18µm CMOS technology

process parameters. Current conveyors can provide better gain-bandwidth products than comparable op-amps, under both small and large signal conditions. In instrumentation amplifiers, their gain does not depend on the matching of pairs of external components, only on the absolute value of a single circuit element. Hence this circuit can be used for high frequency applications. The excellent current following action is also achieved from input port to the output port. In this paper a transitory overview of current conveyors has been revealed in terms of their different generations with their CMOS implementation and simulation results using TSMC 0.18µm. Due to its versatile characteristics and compatibility with several circuits we observe that current conveyor offers several advantages over the conventional op-amp such as removal of gain bandwidth limitation, improved slew rate etc. Due to its low voltage low power characteristics the current conveyors are going to define an era in the field of electronics.

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