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# The Survey Of Historical - Technical Development In Current Conveyors and Their Applications

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## ABSTRACT
Current conveyors are unity gain active building block having high linearity, wide dynamic range and provide higher gain-bandwidth product. The current conveyors operate at low voltage supply and consume less power. It has high input impedance, low output impedance, high CMRR and high slew rate. The working principle of Current Conveyors is very simple and similar to the bipolar transistors. That can easily be explained with help of emitter follower and current mirrors. Now-a-days current conveyors are available in integrated circuit forms. Both BJT and MOS technology is used for developing current conveyor ICs.

This paper highlights on historical and technical development of current conveyors right from CCI, CCII and CCIII to recent developments and their linear, nonlinear circuit applications.

## Keywords
current conveyor, current-mode circuits, integrated circuit, linear and nonlinear circuits

## 1.INTRODUCTION
The current mode circuits such as Current conveyors (CCs) have emerged as an important class of circuits in the field of analog electronics. It has excellent properties that enable them to rival their voltage-mode counterparts (Op-Amps) in a wide range of applications. Since the gain-bandwidth product of Op-Amp is finite; thus higher the gain it realizes, the less bandwidth it possesses. In CCs, the use of current rather than voltage as the active parameter can result in higher usable gain, accuracy and bandwidth due to reduced voltage excursion at sensitive nodes [1]. The current conveyors are not only useful for current processing, but also offer certain important advantages in voltage processing circuits.
Recently, second generation current conveyors (CCII) have become very useful for implementation of analog signal processing circuits such as amplifiers, oscillators, filters and nonlinear circuits.

## 2.HISTORY OF CURRENT CONVEYOR
In 1968 Smith and Sedra [2] firstly introduced a new building block current conveyor CCI in the field of Analog Electronics. Subsequently in 1970, they had reformulated it as second generation CCII [3]. The current conveyor is functionally flexible and versatile in nature as it has precise unity voltage gain between X and Y; unity current gain between Z and X (fig. 1), rather than the high ill-defined open loop gain Op-Amps. Because of this fact, CCII is generally used without feedback in amplifier applications [4, 5].

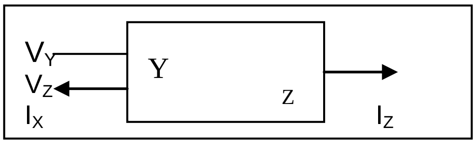



**Fig 1: Current conveyor**

The current conveyor is a grounded three-port network represented by the black box (fig 1) with the three ports denoted by X, Y, and Z. Its terminal characteristics can be represented best by a hybrid matrix giving the outputs of the three ports in terms of their corresponding inputs [3].
For CCI this relationship can be stated as

$$\begin{pmatrix} i_y \\ v_x \\ i_z \end{pmatrix} = \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & \pm1 & 0 \end{pmatrix} \begin{pmatrix} v_y \\ i_x \\ v_z \end{pmatrix} \quad (1)$$

While for CC II

$$\begin{pmatrix} i_y \\ v_x \\ i_z \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & \pm1 & 0 \end{pmatrix} \begin{pmatrix} v_y \\ i_x \\ v_z \end{pmatrix} \quad (2)$$

That is vx = vy and iz = ± ix
It should be noted that all currents and voltages in (1) and (2) are total instantaneous quantities rather than incremental values [2].

Later in 1995, Fabre, published Third generation current conveyor [6] CCIII which has similar characteristics to CCI with exception that the current in port X and Y flows in opposite directions. In 1999, Awad and Soliman, introduced concept of voltage mirror and used together with the current mirror, to ideally represent the current and voltage inverting properties of some analogue building blocks called inverting second generation current conveyors ICCII [7]. The generalized current conveyor (GCC) [8] is defined by universal characteristics represented best by a hybrid matrix equation 3, which satisfies functionality of CC I, II, III and their inverted modes.

$$\begin{pmatrix} i_y \\ v_x \\ i_z \end{pmatrix} = \begin{pmatrix} 0 & a & 0 \\ b & 0 & 0 \\ 0 & c & 0 \end{pmatrix} \begin{pmatrix} v_y \\ i_x \\ v_z \end{pmatrix}$$

Coefficients in this equation can take values a={-1;0;1}, b={-1;1}, c ={-1;1}. Specific values of these coefficients determine the variations of current conveyors [9].
Second Generation Current Controlled Conveyor, CCCII was introduced by Fabre in 1996 [10]. This CCCII allows current conveyor applications to be extended to the domain of electronically adjustable functions [11] and it remains linear

over wide range of current [12]. In 1996, the advantages of CCII and DDA (Differential Difference Amplifier) had combined and extended to a new building block, called a Differential Difference Current Conveyor (DDCC) [13]. The main restriction of DDCC is lacks in tunability feature and requires the resistor connections. The new active building block for analog signal processing, named as current-controlled differential difference current conveyor (CCDDCC) is presented in 2010 [14]. The Dual Output Current Conveyor (DOCCII) based on second generation current conveyors (CCIIs) was proposed in [15, 16]. The differential voltage current conveyor (DVCC) building block is proposed in 1997. This DVCC is a novel building block specially defined to handle differential signals [17]. In 2005, the DCFDCC (Digitally Controlled Fully Differential Current Conveyor) is developed [18].

## CURRENT CONVEYORS CIRCUITS AND ICS

Smith and Sedra [2] themselves produced the first conveyor circuit implementation, based on an emitter driven current mirror approach, followed closely by an improved version using a greater number of transistors in 1969 [19]. The first implementation to use an operational amplifier was reported by Black in 1971 where the uncommitted output transistors were configured with additional transistors to produce a current output [20]. Both positive and negative conveyors were available using their approach, but with restricted frequency response and accuracy. Later in 1980, Senani proposed Current Conveyors Circuit Implementation Using an Op-Amp [21] and Huertas also proposed Current Conveyor Circuit in 1980 [22]. Vimal Singh designed CCII- using Op-Amp in 1989 [23]. The current conveyor integrated circuit PA630 and PA630A was presented by Wadsworth [24, 25]. The first commercially available current conveyor based on the current-feedback op-amp is the CCII01 from LTP Electronics [26, 27]. Initially, current conveyor designs had mainly using BJT due to their high transconductance values compared to their CMOS counterparts. They are used as current-feedback operational amplifiers like the MAX477 high-speed amplifier and the MAX4112 low-power amplifier, which both feature current feedback rather than the conventional voltage feedback used by standard operational amplifiers [28].

A class AB CMOS current conveyor is developed for wideband current-mode signal processing [29, 30]. It consists of a differential stage for the voltage input, a single-ended push-pull stage for the current input, and current mirrors for the current output. The differential and push-pull stages form a unity-gain buffer, to realize the exact voltage- following action and the low impedance at the current input node. The class AB current conveyor exhibits low harmonic distortion and reduced values for its parasitic input resistance [31, 32].

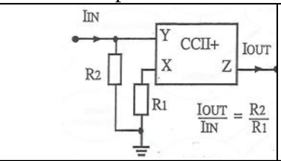
The low voltage CMOS technology is used for realization of CCII [33, 34, 35], CCIII [36], DVCC [37], DDCC [38], CCDVCC [39]. These designs provide high frequency operation and high slew rate [35]. The CCII and DOCCII are simulated using Op-Amp [40]. Field Programmable Analog Array is also available for current conveyor implementation [41]. In 2006, a CMOS electronically tunable CCII [42] and DDCC [43] was proposed by Kuntman.

## 1.LINEAR CIRCUIT APPLICATION

The CCII is a convenient building block that provides a simplified approach to the design of linear analog systems than the Op-Amp as it offers many advantages over Op-Amp [3, 5].

### A. Amplifiers

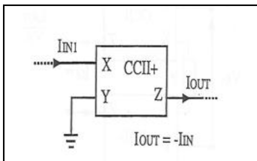
a) **Current Amplifier**: The CCII can easily be configured into current output amplifier as shown in fig.2 which acts as current amplifier.




| |
|---|
| For CCII+<br>Iout = Iz = Ix<br>Ix = Vx/R2=Vy/R2<br>Vx = Vy = Iin*R1<br>Iout = (R1/ R2) Iin |

Fig 2: current amplifier

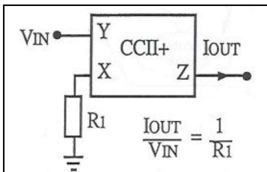
b) **Current Follower**: The CCII can be used as unity gain current amplifier i.e. current buffer or current follower as shown in fig 3. This is the most useful building block in current mode circuit implementation. Here current gain is unity; negative for CCII+ and positive for CCII-.




| | |
|---|---|
| For CCII+<br>Iout = Iz<br>Iz = Ix<br>Ix = - Iin<br>Iout = - Iin | For CCII-<br>Iout = Iz<br>Iz = Ix<br>Ix = Iin<br>Iout = Iin |

Fig 3: Current Follower

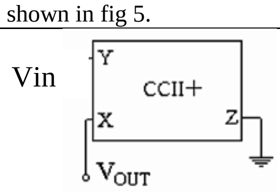
*c)* **Voltage to Current Converter**: The voltage to current converter circuit can be obtained using CCII as shown in fig 4.




| |
|---|
| For CCII+<br>Iout = Iz = Ix<br>Ix = Vx/$R_1$<br>Vx = Vy = Vin<br>**Iout = Vin/$R_1$** |

Fig 4 V to I converter

*d)* **Voltage Follower:** The CCII can be used as unity gain voltage amplifier i.e. voltage buffer or voltage follower as shown in fig 5.




| |
|---|
| For CCII+<br>Vout = Vx<br>Vx = Vy = Vin<br>**Vout = Vin** |

Fig 5: voltage follower

*e)* **Voltage Amplifier***:* Voltage amplifier can be designed using CCII as shown in fig 6.

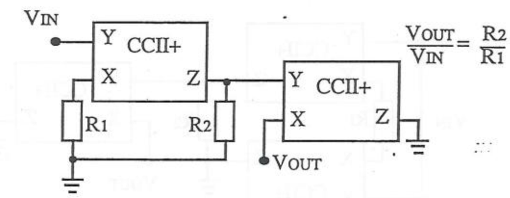



Fig 6: Voltage Amplifier

### *f) Differential V to I converter:*

Any differential input voltage appears across resistor R1 as shown in fig 7 to generate a current which is then conveyed to the two outputs. The common-mode gain of the circuit will be zero provided that both devices are well matched.

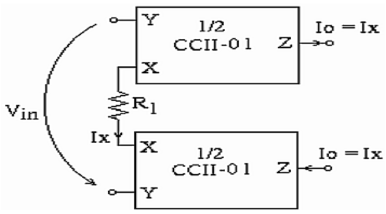



Fig. 7: Differential V to I converter

### *g)* **Instrumentation Amplifier**

By converting the output current back to a single-ended voltage, this differential transadmittance cell can be extended to produce a high performance instrumentation amplifier [44,45], as shown in Fig 8.

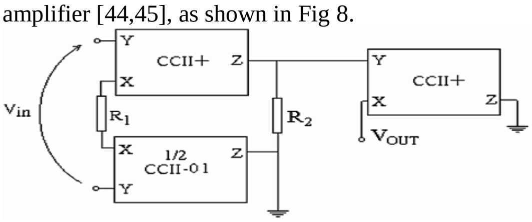



Fig 8: Instrumentation amplifier.

## B. Analog Computing

**a) Adder***:* The current summing amplifier can be implemented just by connecting n- number of input currents to X node of CCII in current follower mode as shown in fig 9.

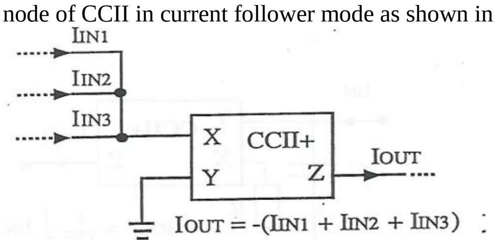



Fig 9: Current Adder

**b) Current integration***:* The time integral current input signal can be achieved using CCII as shown in fig 10.

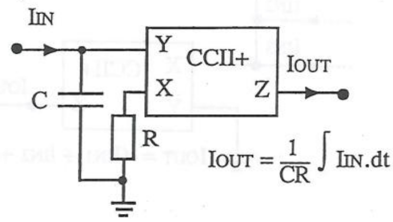



Fig 10: Current Integrator

**c) Current Differentiation***:* The time differentiation of current input signal can be achieved using CCII as shown in fig 11.

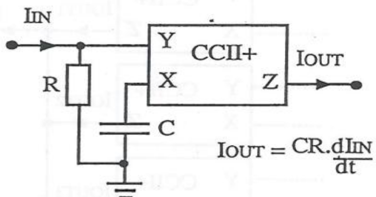



Fig 11: Current Differentiator

**d) Voltage integration***:* The time integral voltage input signal can be obtained using CCII as shown in fig 12.
Here, $V_{out} = 1/RC\int V_{in}\,dt$

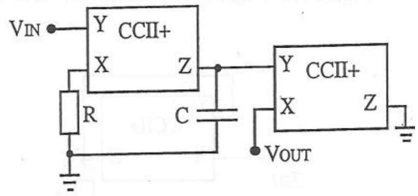



Fig 12: Voltage Integrator

**d) Voltage Differentiation***:* The time differentiation of voltage input signal can be obtained using CCII as shown in fig 13. Here, $V_{out} = RC*dV_{in}/dt$

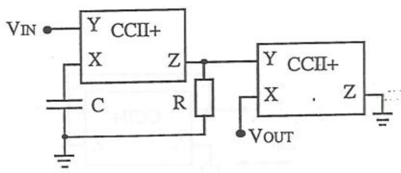



Fig 13: Voltage Differentiator

## C. Impedance Converter

### a) Negative Impedance Converter

There are three types NIC, those can designed using CCII as shown in fig 14.

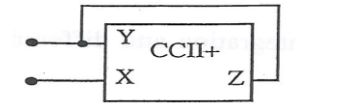
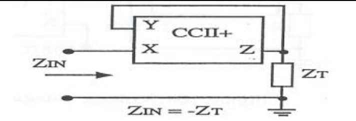
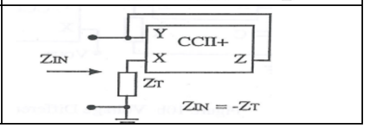
| | |
|---|---|
| Negative Impedance Converter (NIC) |   |
| Current Controlled NIC |   |
| Voltage Controlled NIC |   |

Fig 14: Impedance Converter

### b) Generalized Impedance Converter

The GIC (Generalized Impedance Converter) is capable of simulating frequency dependent elements such as Inductor, FDNR (frequency dependent negative resistance), Capacitor and resistor multiplier. The GIC using CCII- and CCCII- was presented by Khan and Zaidi in 2003 [46] and floating GIC based on difference I/O trans-admittance cell was described by Grigorescu in 2008 [47].

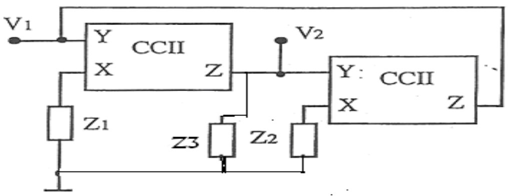



Fig 15: GIC

The GIC using two CCII is implemented as shown in fig. 15. In this circuit:

If both CCII of same type then $Z_{in}=Z_1Z_2Z_3$

If both CCII of opposite type then $Z_{in}=-Z_1Z_2Z_3$

**c) Simulation of Inductor***:* Circuit of fig 15, can be modeled as grounded inductor [48] as shown in fig 16.

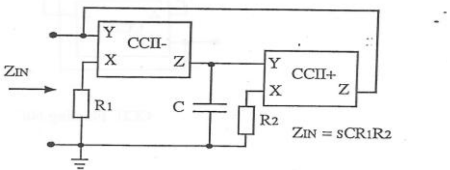



Fig 16: Grounded Inductor

If $Z_1 = R_1$ $Z_2=R_2$, $Z_3 = C$ and its value is

$L= R_1R_2C$ seen at the input.

An active grounded inductance using a single CCII and three passive components was proposed by Nandi in 1978 [49] and it used for bandpass filter realisation.

**d) Frequency Dependent Negative Resistance** *(FDNR):* In 2010, Soliman and Saad, highlighted the use of current conveyor (CCII) in realizing FDNR. The 13 different FDNR realizations were reported which include two new families introduced by them. [50].

The simplest FDNR realization employs a single CCII+, two capacitors, and four resistors [51] but it requires conditions on the magnitudes of the passive elements. The other simplest FDNR requires two capacitors, one resistor, two CCII+ and one CCII-[52, 53].

## D. *Filter*

Many researchers published various filter realization using CCII [1]. Three different voltage mode universal filters using CCII were proposed by Liu and Lee in 1996 [54]. All these filters consist of 2 CCII, 3 resistors and 2 capacitors connected in differently.

## E. Oscillators

A single-resistance-controlled voltage-controlled sinusoidal oscillator using two current conveyors (CCs), two grounded capacitors and three grounded resistors is presented by Liu in 1995 [55] and in 2005, Khan, Bimal, Dey and Roy proposed RC Sinusoidal Oscillator Using CCII [56]. These oscillators provide the advantages such as independently controllable oscillation frequency by grounded resistors, easy conversion into a voltage-controlled oscillator, suitable for IC implementation and very good frequency stability. Two-amplitude matched anti-phase sine waveforms circuit was designed using CCII by Sharma and Pal in 2010 [57].

## F. Non-Linear Applications

The Op-Amp is basically a linear circuit building block but it has been used in many Non-Linear applications by forcing it into saturation (+/-) mode by means of positive feedback [58]. Nonlinear behavior can also be achieved with negative feedback by connecting nonlinear element in feedback path [59, 60]. Similarly Non-linear circuits can be developed using CCII though CCII is a linear circuit building block.

**a) Schmitt Trigger Circuit**

The CCII block can be used to implement a Schmitt Trigger, creating a regenerative feedback which takes part of the output voltage from the Z node and apply it to the Y node [61, 62]. A current-mode Schmitt trigger based on Multiple output current through transconductance amplifier (MOCTTA) is presented by Silapan and Siripruchyanun in 2009[63].

**b) Square and Triangular Waveform Generators**

A current-mode square wave generator circuit using Schmitt trigger circuit with grounded capacitor in place of input voltage [62]. The square wave generator based on CCII was proposed and integrated using CMOS analog VLSI [64]. A current-mode triangular wave generator circuit using two-CCII+ is proposed and implemented [65, 66]. The circuit consists of an astable multi-vibrator to generate a square wave followed by an integrator.

***c*) Diode Function Generators**

The diode function generators are used to approximate transfer curves, linearize transducers, limit the amplitude of signals, and perform mathematical operations such as multipliers, dividers, squarer, square rooter. The diode function generators are also used in precision rectifiers, nonlinear resistors and piecewise linear approximation circuits [59].

The diode function generators can be designed using CCIIs. Nonlinear buildings blocks such as multipliers, dividers, amplitude modulator, squarer, square rooter, nonlinear resistors, piecewise linear approximation [67] and vector summation [68] circuits have been developed using current conveyors.

## 2.CONCLUSION

The current-conveyor circuit being 40 years old concept emerged as potential candidate with numerous applications in the analog field. Commercially available current-conveyors such as CCII, CCIII, CCCII, DVCC, CCDVCC, DOCCII and electronically tunable CC's are welcomed by analog system developers as it provides valuable addition for the application engineer, complementing the omnipresent op-amp. The analog VLSI technology and Field Programmable Analog Array are available for implementation of current conveyors and current-feedback Op-Amps. The current-feedback Op-Amp is functionally close relative to the current-conveyor.

With this survey of historical and technical developments of current conveyors and related current mode developments, it is found that (i) the current conveyor based circuits provide much better performance characteristics than Op-Amps, (ii) the current-conveyor is versatile and convenient for many applications, (iii) the applications demonstrate the ease with which complex analog functions can be realized using current-conveyors, (iv) almost all the Op-Amp based circuits can be easily implemented using current conveyors, (v) there are many applications where op-amp realizations are significantly less practicable than the equivalent current-conveyor realization, (vi) The current conveyors including their applications can easily be configured into integrated circuits.

The current mode completions are having tremendous potential in the field of analog systems including nonlinear dynamics. A nonlinear dynamics using Current conveyor is the field where very less research work was carried out. Hence there is lot of scope in the development of nonlinear dynamics using current conveyor.

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