AMPLIFIERS BUILT WITH CURRENT-CONVEYORS★

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This paper shows the features of current-conveyors and their application in the amplifiers domain.

Key words: Circuits, current-conveyors, current-amplifiers.

1. INTRODUCTION

The current-conveyor has precise unity gain between Z and X (Fig. 1), rather than the high ill-defined open-loop gain of the voltage op-amp, therefore in amplifier applications the current-conveyor is generally used without any overall negative feedback.

The advantage of this approach is that the traditional closed-loop gain-bandwidth conflict of negative feedback voltage op-amp circuits is avoided.

The benefits of global negative feedback, for example noise reduction, improvement in input and output impedance levels, can no longer be exploited, but the absence of overall negative feedback generally results in wider bandwidths at higher levels of gain. However, to maintain a high level of accuracy without the use of negative feedback, a high quality current-conveyor integrated circuit realisation is required.

2. CURRENT OUTPUT AMPLIFIER

The CCII can easily be used to configure the two current output amplifiers, as shown in Fig. 1. In Fig. 1a, R_2 must be much less than the input impedance at node Y for current transfer accuracy, that is, $R_2 << R_{INY}$, and this factor will limit the maximum possible gain of the circuit.

$$I_0 = I_X, \quad I_X = \frac{V_X}{R_2}, \quad V_X = V_Y = R_1 \cdot I_1, \tag{1}$$

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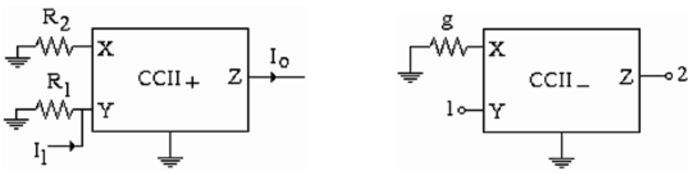

a. Current amplifier (CCCS) b. V to I convertor (VCCS)

Fig. 1 – Current output amplifiers.

$$I_0 = \left(R_1 / R_2 \right) \cdot I_1 \tag{2}$$

$$\begin{bmatrix} i_y \\ i_z \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ g & 0 \end{bmatrix} \cdot \begin{bmatrix} v_y \\ v_x \end{bmatrix} \tag{3}$$

with
$$Y = \begin{bmatrix} 0 & 0 \\ g & 0 \end{bmatrix} \tag{4}$$

$$i_z = g \cdot v_y, \quad g = \frac{1}{r}, \quad i_z = \frac{v_y}{r} \tag{5}$$

In both circuits R_1 forms a pole with parasitic capacitance to ground at node X, therefore the value of this resistor should be kept low to ensure that this parasitic pole does not dominate the frequency response.

3. CURRENT-BUFFER OR CURRENT-FOLLOWER

The current-conveyor can be used to advantage in current-mode circuits and probably the most useful utility building-block being the unity current gain current amplifier, shown in Fig. 2. The X node has a low input impedance and conveys the input current through to the high output impedance Z node. Hence the current gain is unity, negative for a CCII+ and positive for a CCII–. This circuit is the antithesis of a voltage-follower and is referred to as a current buffer or current-follower [3] and can be used to advantage as an interface between voltage and current-mode circuits. For example, adding a current-follower before the amplifier of Fig. 1a provides the circuit with a greatly reduced input impedance and improves the integrity of the current drive into the Y node of the second current-conveyor.

$$\begin{bmatrix} v_X \\ i_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} i_X \\ v_Z \end{bmatrix}, \quad v_X = 0 \tag{6}$$

$$i_Z = i_X \tag{7}$$

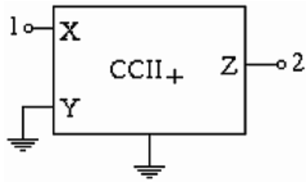

Fig. 2 – Current – buffer or current follower.

4. VOLTAGE AMPLIFIER

Voltage amplification can be obtained by adding a voltage buffer to the VCCS of Fig. 1b. The circuit of Fig. 3 is such an amplifier, with a second CCII+ being used as a voltage-follower. Using two CCIIs, described a differential voltage-to-current converter as shown in Fig. 4.

$$\frac{V_{OUT}}{V_{IN}} = \frac{R_2}{R_1} \tag{8}$$

$$\frac{V_{OUT}}{V_{IN}} = \frac{R_2}{R_1} \tag{9}$$

Any differential input voltage appears across resistor R_1 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 and have a

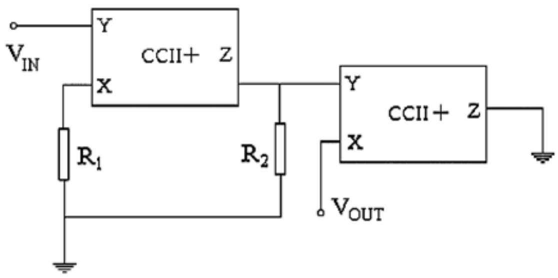

Fig. 3 – Voltage amplifier.

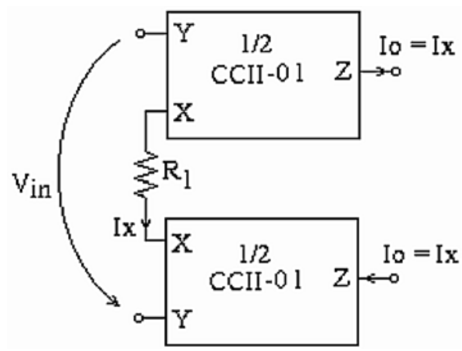

Fig. 4 – Differential V to I converter.

precise voltage-following action between their respective Y and X inputs. The circuit does not rely on any external resistor matching for high CMRR, however the CMRR will roll-off at higher frequencies due to parasitic capacitance to ground at the X nodes, which will then give rise to common-mode currents. The CMRR can be improved by increasing the differential gain, that is, by reducing the value of R_1. The ultimate limit on CMRR will be determined by the mismatch in open-loop bandwidth of the two conveyors.

$$\frac{I_0}{V_{IN}} = \frac{1}{R_1} \tag{10}$$

5. 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 [5, 6], as shown in Fig. 5.

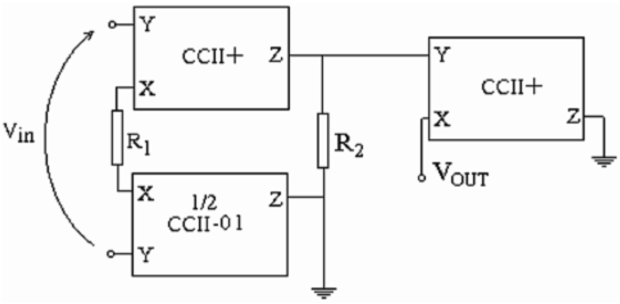

Fig. 5 – Instrumentation amplifier.

This instrumentation amplifier has a high CMRR, requires no external component matching and exhibits a bandwidth independent of gain.

This instrumentation amplifier has proved to be particularly suitable for the implementation of EMG amplifiers with shutdown control [7].

Shutdown control is necessary to isolate the EMG amplifier during the period that an electrical stimulation is applied to the muscles, since this large stimulus will otherwise saturate the amplifier.

$$\frac{V_{OUT}}{V_{IN}} = \frac{R_2}{R_1} \tag{11}$$

The amplifier would then require a recovery period before it is able to measure the much weaker EMG muscle response. This shutdown control is most easily implemented by providing a switch control at the amplifier inputs. Conventional EMG amplifiers based on voltage op-amp require switching at a high impedance node, and this tends to cause transient spikes which themselves can saturate the amplifier. Using the instrumentation amplifier of Fig. 5, the switching control can be moved to a low impedance node, so that resistor R_1 is either disconnected or connected between the two low impedance X inputs. This conveyor-based EMG amplifier demonstrates no saturation or recovery problems, and is able to measure the EMG signal accurately, immediately after the stimulation pulse.

6. CONCLUSIONS

Although 20 years old, the current-conveyor is a circuit concept whose time has now come. There is no doubt that the current-conveyor is both versatile and convenient for many applications. The applications demonstrate the ease with which complex analog functions can be realised using current-conveyors. There are many applications where op-amp realisations are significantly less practical than the equivalent current-conveyor realisation.

Commercially available current-conveyors are a welcomed and valuable addition for the application engineer, complementing the ubiquitious op-amp. The semiconductor industry has now recognised the potential of current-mode techniques, attested by the successful current-feedback op-amp which is a close relative to the current-conveyor. All the ingredients for a high performance current-conveyor realisation are already accessable to the semiconductor industry, so it is only a matter of time before the current-conveyor takes its place as a standard part in the application designers tool-kit.

REFERENCES

1. K. C. Smith, A. Sedra, *The Current-Conveyor – A New Circuit Building Block*, IEEE Proc., 56 pp. 1368–1369, 1968.
2. A. Sedra, K. C. Smith, *A second Generation Current-Conveyor and its Applications*, IEEE Trans., CT-17, pp. 132–134, 1970.
3. F. J. Lidgey, Toumazou, *Current-followers and a universal operational amplifier*, *Electronics World and Wireless World*, 90 (1577), pp. 40–43, 1984.
4. C. Toumazou, F. J. Lidgey, *Novel Current-Mode Instrumentation Amplifier*, Electron. Lett., 21 (15), pp. 640–642, 1985.
5. C. Toumazou, F. J. Lidgey, C.A. Makris, *Extending Voltage-Mode op-amps to Current-Mode Performance*, IEE Proc., Pt. G, 137 (2), pp. 116–130, 1990.
6. C. Toumazou, F. J. Lidgey, *Novel Current-Mode Instrumentation Amplifier*, Electron. Lett., 25 (3), pp. 228–230, 1989.
7. E. Bruun, E. U. Haxthausen, *Current-conveyor Based EMG Amplifier with Shutdown Control*, Electron. Lett., 27 (23), pp. 2172–2174, 1991.