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Design of Variable-Gain Current Conveyors

Alfonso Carlosena and George S. Moschytz

***Abstract*— Several possible implementations of variable-gain current conveyors are proposed. They can be designed with two opamps and current mirrors and exhibit constant bandwidth property. Their configuration as differential-output current amplifiers is straightforward.**

I. Introduction

Although the first current conveyor was conceived more than two decades ago [1], due to the lack of an appropriate technology, commercial circuits capable of implementing the current conveyor functions became available only recently [2], [3]. In the meantime, a number of implementations were suggested, making use of other readily available active devices, such as OTA's or opamps [4], [5]. This approach allowed many current-conveyor–based circuits to be tested in the laboratory, however, the results obtained in this way were only tentative at best. This was because those inherent limitations of the OTA's or opamps, which were used to build the current conveyors, manifested themselves again in the conveyors. Thus very little seemed to be gained from trying to design new current-mode active elements containing precisely those voltage-mode active elements whose limitations the new devices were supposed to overcome.

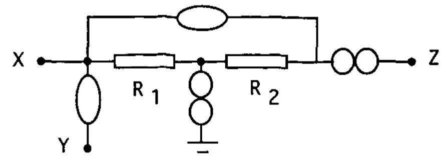

Fig. 1. Nullor representation of a variable-gain current conveyor.

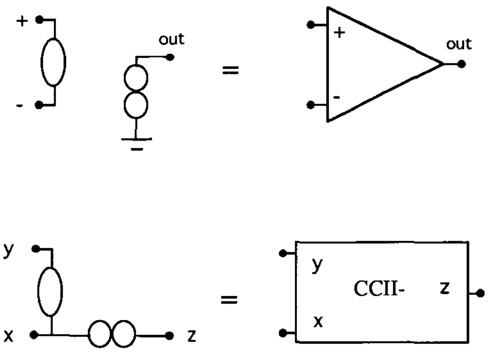

Fig. 2. Nullor representation of voltage opamp and CCII-.

Recently [6], however, it has been made clear that this conclusion is not entirely correct, in view of some ingenious schemes suggested in the literature. They are based on the use of opamps in a rather nonconventional way, in which a high amount of negative feedback is combined with supply current sensing to obtain a wideband current output. A representative example [7], [8] is the current conveyor built around an opamp with 100% feedback and supply current sensing providing excellent performance.

In this paper we take this last approach to propose several new opamp implementations of a current conveyor with an arbitrary current gain. Such blocks may be useful for the realization of the current-mode counterparts of the classical voltage-mode filters. They contain one opamp, one CCII (second-generation current conveyor), and two resistors. Constant feedback around the opamp provides constant bandwidth, whereas the gain is controlled by a single resistor.

It must be pointed out that these topologies are not suitable for monolithic implementation. To achieve variable current gains with a wide range and using integrated technology is a very difficult task. Our circuits are intended for discrete designs, such as biquads, oscillators, and so forth. As the CCII can be realized by one opamp and a current mirror, a full opamp realization of our variable-gain current conveyors would contain a total of two opamps, two resistors, and a couple of cross-coupled current mirrors. We believe that this is still worthwhile, considering that comparable circuits (e.g. "actively compensated amplifiers") require approximately the same number of components but perform far less well in terms of bandwidth, gain dependence, and stability.

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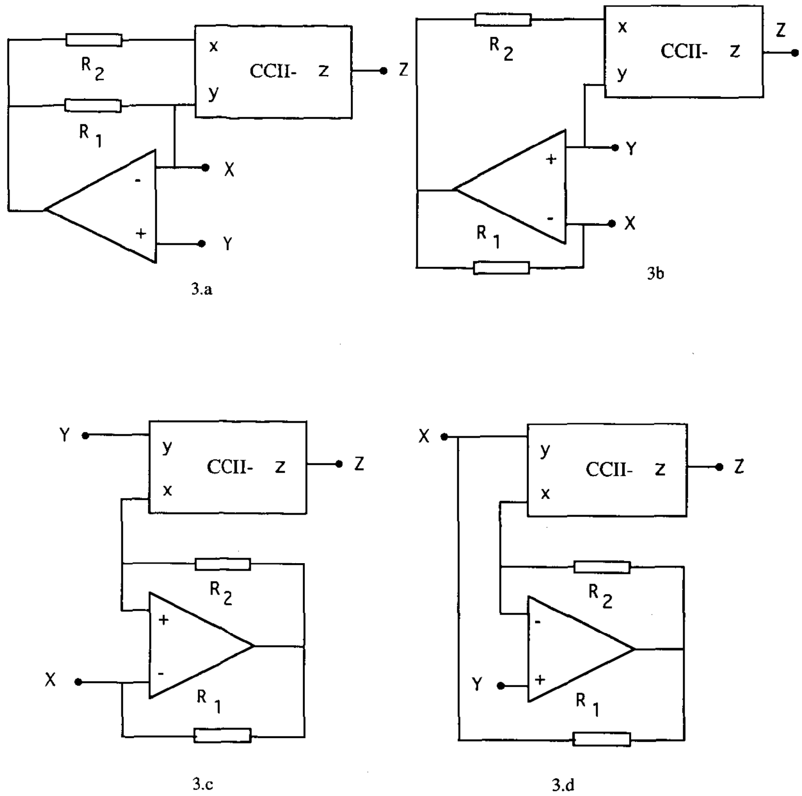

Fig. 3. Practical realizations of variable-gain current conveyors.

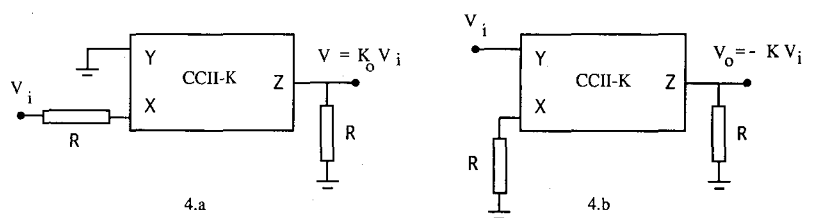

Fig. 4. Voltage amplifiers used in the parctical measurements: (a) noninverting; (b) inverting.

Finally, we show how our circuits can be readily modified as single-input, differential-output current amplifiers, which are very useful in various applications [9].

II. The Variable-Gain Current Conveyor

A current conveyor with arbitrary current gain can be represented by the nullor circuit shown in Fig. 1. Its input-output characteristic is as follows:

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

where $K = R_1/R_2$.

The nullators in Fig. 1 can be rearranged using well-known rules [10]; this results in two additional nullor representations. From the three nullor circuits, and using the identification shown in Fig. 2, four practical circuits, containing one opamp and one negative current conveyor (CCII−) are obtained. They are shown in Fig. 3. We have labeled the terminals of the CCII with small letters, whereas the capital letters are reserved for the external terminals of the variable-gain CC.

If positive current conveyors (CCII+) are used instead of CCII−, then negative variable-gain current conveyors result.

By simple inspection of the four circuits, it can be seen that resistor R_1, together with the impedance connected at node X, determines the feedback of the opamp and therefore its closed-loop response. For any given application, R_1 should be selected so as to meet the desired bandwidth. Here we assume that the bandwidth of the current conveyor section is at least the gain-bandwidth product (GB) of the opamp. R_2 has no influence on the opamp feedback, and can be modified to change the gain without affecting the bandwidth.

One important issue that has to be taken into consideration is stability. The polarity of the opamps in Fig. 3 has been chosen to meet the stability conditions when terminal "Y" is driven by a low-impedance source. This is the case in the example shown in the next section. If "Y" is not driven from a low-impedance source, then a more detailed analysis must be made for any given application. Our experience has shown that a simplified model using a single pole-

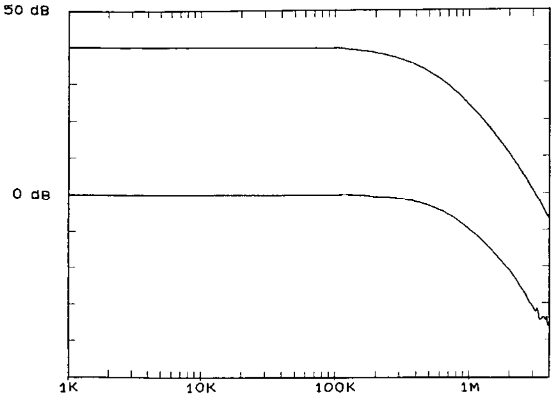

Fig. 5(a). Magnitude response of circuits in Fig. 4(a), with gains one and 100 (upper reference level: 50dB, div; 10 dB).

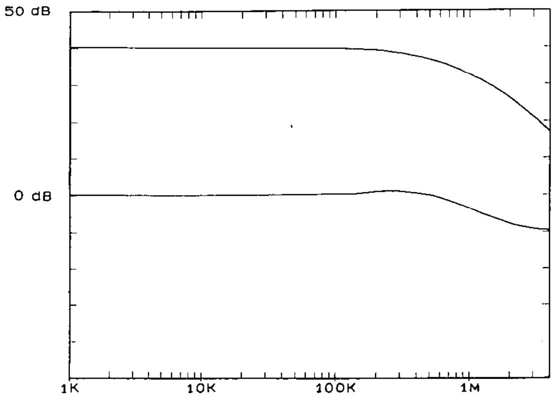

Fig. 5(b). Magnitude response of circuits in Fig. 4(b), with gains one and 100 (upper reference level: 50dB, div; 10 dB).

rolloff for the opamp and for the buffer connecting terminals "y" and "x" is enough to determine straightforward conditions for stability, making use of well-known stability criteria (e.g. Routh-Hurwitz).

III. Experimental Results

We have tested these circuits in simple voltage-amplifier configurations, both inverting and noninverting, as shown in Fig. 4. To implement our variable (negative)-gain current conveyor, we used a classical 741 opamp (GB $\sim$ 0.8 MHz) and a PA630 circuit (BW $\sim$ 6 MHz) configured as a positive current conveyor [2]. We deliberately used a PA630 instead of another 741 with supply sensing because in this way we can distinguish clearly the effects associated with the opamp closed-loop response.

In our laboratory measurements R and R_1 are fixed to 8K2 ohms. A bandwidth of about 400 KHz should be expected. The extreme values for R_2 were 82 and 8K2 ohms, providing gains of 100 and 1, respectively. The magnitude response corresponding to the two gains is shown in Figs. 5(a) and 5(b), respectively, for the inverting and noninverting configurations. Note that the constant bandwidth property anticipated above is apparent, retaining its value around the frequency predicted. It should be noted that the value of resistor R_2 cannot be arbitrarily reduced due to the finite and frequency-dependent opamp output impedance and also to the impedance of terminal x. If R_2 is too small, comparable to those impedances, this effect produces a behavior similar to that of the limited gain-bandwidth product familiar in opamp voltage-based circuits.

IV. Further Applications

The circuits proposed here are easily modified as variable-gain current amplifiers (Y grounded), exhibiting a virtual ground property

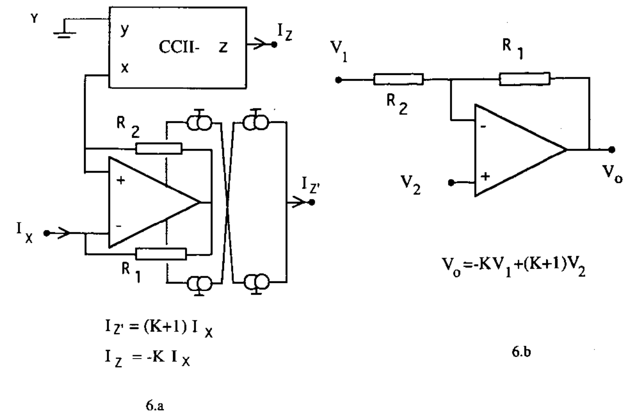

Fig. 6. Differential output current amplifier and its opamp voltage adjoint.

at node X, and a high output impedance. Furthermore, the output can be made differential. This is an interesting feature, because current-mode circuits can be easily obtained from their voltage-mode counterparts by means of the adjoint transformation, however in many cases, the practical use of this method is limited by the availability of an adjoint version of the opamp [9], [11]. Such an element can be designed from the circuits proposed in this paper by simply sensing the supply current of the opamp, as indicated in Fig. 6(a) for the circuit in Fig. 3(c). Its adjoint voltage amplifier, the closed-loop differential opamp, is also shown in Fig. 6(b). The authors recently reported an application employing this circuit [12].

V. Conclusions

In this paper, some circuits implementing a variable-gain current conveyor function are proposed. They contain voltage opamps, but provide variable gain with constant bandwidth by varying a resistor, as demonstrated experimentally. They are primarily intended for discrete high-frequency circuit design. It is also shown how these circuits can be modified as differential-output current amplifiers, which are the adjoint equivalents of the closed-loop differential opamp.

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