INT. J. ELECTRONICS, 1995, VOL. 79, NO. 1, 53–61

Theorem relating a class of op.-amp. and current conveyor circuits

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The generation of active circuits using the second-generation current conveyor (CCII) as the active building block instead of the operational amplifier can be easily achieved in some cases. A useful theorem which illustrates this conversion method and identifies the class of circuits that can be converted by replacing the op.-amp. by a CCII is given. Applications of the theorem to realize differential voltage amplifiers, first-order transfer functions and the generation of two integrator loop filters using CCII are given.

1. Introduction

The second-generation current conveyor (CCII) (Sedra and Smith 1970) is a powerful building block in active circuits. Basically there are three different methods to transform an op.-amp. circuit to its CCII equivalent circuit: the first method is based on the adjoint network theorem (Roberts and Sedra 1992); the second is based on the nullor equivalent circuit (Grimbleby 1992, Carlosena and Moschytz 1994, Wilson 1990, Svoboda 1989); and the third is based on the equivalent building blocks approach (Soliman 1994).

The purpose of this paper is to demonstrate the application of the third method in the realization of active circuits using CCIIs. First, a useful theorem relating a class of op.-amp. circuits to their CCII equivalents is given. Next, application of the theorem in the realization of three-port voltage controlled voltage source (VCVS) structures using CCIIs are given. The second application considered is the synthesis of first-order voltage-mode and current-mode transfer functions using CCIIs. Finally, the application of the building block approach in the realization of the Tow–Thomas two integrator loop filter using CCIIs is considered.

Theorem

An ideal op.-amp. circuit with a feedback impedance Z_f connected between the inverting op.-amp. input and its output as shown in Fig. 1(*a*) is equivalent to each of the following CCII circuits:

(*a*) the circuit shown in Fig. 1(*b*) with an impedance $2Z_f$ connected between the X and the Z terminals;
(*b*) the circuit shown in Fig. 1(*c*) which included two grounded impedances Z_0 and Z_i, each equal to Z_f .

This theorem is based on the assumption that port Z of the CCII is buffered (no loading on the output port of the CCII).

Received 8 November 1994; accepted 13 February 1995.

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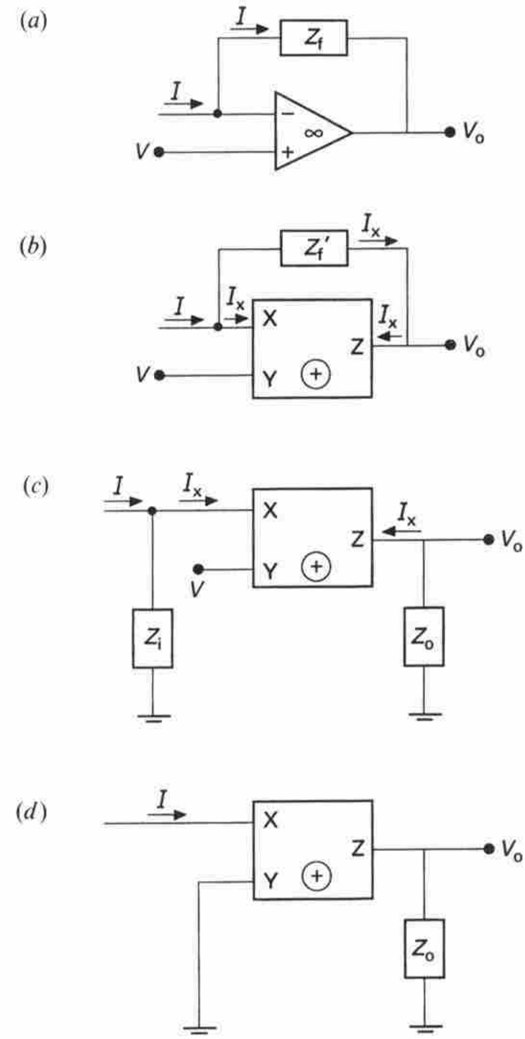

Figure 1. (*a*) Op.-amp. circuit; (*b*) first equivalent CCII circuit, $Z_f' = 2Z_f$; (*c*) second equivalent CCII circuit, $Z_0 = Z_i = Z_f$; (*d*) equivalent CCII circuit for the special case of $V = 0$.

Proof

Assume that the voltage at the non-inverting input of the ideal op.-amp. is V and the current flowing in Z_f is I, then the voltage V_0 is given by

$$V_0 = V - IZ_f \tag{1}$$

Consider the CCII circuit shown in Fig. 1(*b*) and assume no loading on port Z, thus

$$I = 2I_x \tag{2}$$

The voltage V_0 is given by

$$V_0 = V - I_x Z_f' \tag{3}$$

From (2) and (3) and comparing with (1), therefore Z_f' must equal $2Z_f$ for the op.-amp. and the CCII circuits to be equivalent, which completes the proof of part (*a*) of the theorem. To prove part (*b*) consider the circuit of Fig. 1(*c*) and assume no loading on port Z other than the impedance Z_0, therefore

$$V_0 = \frac{Z_0}{Z_i} V - I Z_0 \tag{4}$$

From (1) and (4) it is seen that the two circuits of Fig. 1(*a*) and (*c*) are equivalent if

$$Z_0 = Z_i = Z_f$$

It should be noted that part (*b*) of the theorem can also be proved by showing that the CCII circuits of Fig. 1(*b*) and (*c*) are equivalent. This is easily achieved by reflecting the impedance Z_f' in Fig. 1(*b*) to two impedances Z_i and Z_0 at the input and the output ports, respectively. It can easily be seen that the two circuits of Fig. 1(*b*) and (*c*) are equivalent if

$$Z_0 = Z_i = \frac{1}{2} Z_f'$$

The special case of a grounded non-inverting input op.-amp. ($V=0$) results in an equivalent CCII circuit shown in Fig. 1(*d*) with $Z_0 = Z_f$.

The above theorem is useful for generating CCII circuits from well-known op.-amp. realizations. The first application of the theorem presented here is the realization of generalized three-port VCVS structures.

2. Three-port VCVS circuits

Figure 2 represents two alternative realizations for the differential VCVS. The output voltage V_0 in the circuits of Fig. 2(*a*) and (*b*) are given respectively by:

$$\begin{aligned} V_0 &= (K+1)V_2 - KV_1 \\ V_0 &= K(V_2 - V_1) \end{aligned} \tag{5}$$

It is seen that with $V_i = 0$ ($i = 1$ or 2), the circuit of Fig. 2(*a*) simplifies to the non-inverting VCVS and the inverting VCVS given by Wilson (1989 an 1990), respectively. The circuit of Fig. 2(*b*) has equal gains for the non-inverting and the inverting inputs and it has the additional advantage of using a grounded resistor for the gain control. Again, in the special cases where $V_i = 0$, the circuit has the same structure as the non-inverting and the inverting VCVS circuits reported by Carlosena and Moschytz (1994). their intention, however, was to realize a variable-gain CCII, that is, the non-inverting and the inverting VCVS circuits given by Carlosena and Moschytz employ equal resistors and the amplifier gain is controlled by the gain of the CCII.

With $V_1 = 0$, the non-inverting VCVS obtained using the circuit of Fig. 2(*b*) has both resistors grounded. It is worth noting that it is also possible to have an inverting VCVS using grounded resistors by applying the input signal to port Y and interchanging the polarity of the CCII as shown in Fig. 2(*c*).

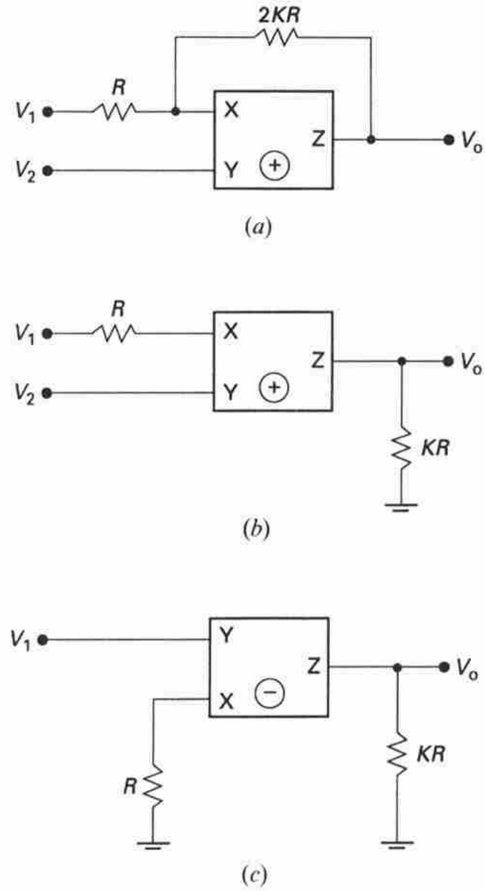

Figure 2. (*a*) First three-port VCVS; (*b*) second three-port VCVS; (*c*) inverting VCVS with grounded resistors.

3. Realization of first-order transfer functions

In realizing odd transfer functions by factorization methods, one of the cascaded sections will be a first-order network. It is well known that the non-inverting op.-amp. configuration (which employs a single op.-amp. and two impedances) is only capable of realizing a class of first-order transfer functions, whereas the inverting op.-amp. configuration is capable of realizing any first-order voltage transfer function (Van Valkenburg 1982). The inverting op.-amp. configuration, however, has the disadvantage of having a finite input impedance. This section considers the realization of first-order transfer functions using the CCII as the active element instead of the op.-amp.

Consider the circuit of Fig. 3(*a*). The voltage transfer function is given by

$$T_v(s) \equiv \frac{V_0}{V_i} = \pm \frac{Z_2}{Z_1} \tag{6}$$

where the positive sign is obtained if the CCII is non-inverting and the negative sign if it is inverting. Of course it is seen that this configuration has an infinite input

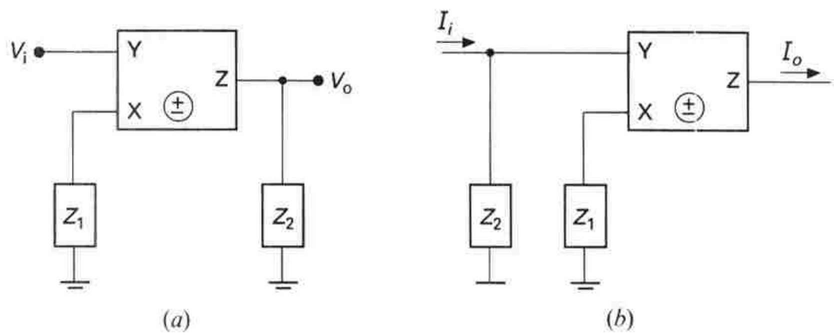

Figure 3. Generalized configurations for realizing first-order non-inverting or inverting transfer functions: (*a*) voltage transfer functions; (*b*) current transfer functions.

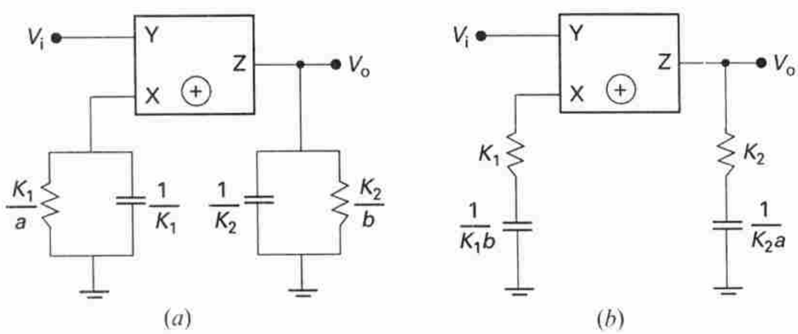

Figure 4. (*a*) Two alternative realizations of the first-order non-inverting voltage transfer function.

impedance and is capable of realizing any first-order non-inverting or inverting voltage transfer function with positive coefficients. Similarly, the circuit of Fig. 3(*b*) which has the current transfer function

$$T_i(s) \equiv \frac{I_o}{I_i} = \pm \frac{Z_2}{Z_1} \tag{7}$$

is capable of realizing the same class of first-order transfer functions. As an example, consider the transfer function

$$T_v(s) = K \frac{s+a}{s+b} \tag{8}$$

where K, a and b are positive coefficients. Figure 4 represents two alternative realizations using a CCII to realize the above voltage transfer function where K_1 and K_2 are two arbitrary positive constants such that $K_2/K_1 = K$.

It is worth noting that the two capacitors employed in each realization are grounded. It should also be noted that the non-inverting op.-amp. configuration can realize a function in the form of (8) only if

$$K \geq \max \left[1, \frac{b}{a} \right] \tag{9}$$

Thus it is seen that the CCII configuration of Fig. 3 is superior to the non-inverting op.-amp. configuration in many respects. Note also that if (8) is to be realized with a negative sign, then a negative-polarity CCII is used in Fig. 4. On the other hand, to realize this inverting first-order transfer function using the inverting op.-amp. configuration, the two capacitors will be floating and the input impedance of the circuit will not be infinite.

4. Tow–Thomas biquad circuit

This section considers an important application of the theorem in the generation of new realizations of the Tow–Thomas biquad (Tow 1969, Thomas 1971) using CCIIs. Consider the well known three op.-amp. Tow–Thomas biquad shown in Fig. 5. Recently two alternative approaches have been used to realize a CCII Tow–Thomas biquad. The first approach is based on the adjoint network theorem (Sedra and Roberts 1990), and the second approach is based on the nullor network criteria (Svoboda 1989).

This section gives new realizations which are generated from the op.-amp. Tow–Thomas biquad using the two parts of the theorem. First, the lossy integrator of Fig. 5 is realized in Fig. 6(*a*), using a CCII by applying the first part of the theorem. The elements of the lossy integrator are taken as $2R_1$, $0{\cdot}5C_1$ so that the transfer functions are identical to the op.-amp. case. Next, consider the cascaded sections of the Tow–Thomas circuit which represent a non-inverting lossless integrator. This non-inverting integrator is realized by the second CCII together with R_2 and C_2. This realization is based on part II of the theorem and is desirable here so that this integrator does not load the first lossy integrator. The last CCII in Fig. 6(*a*) realizes a voltage follower and is connected to the first CCII by R_3. Figure 6(*a*) realizes the transfer functions given by:

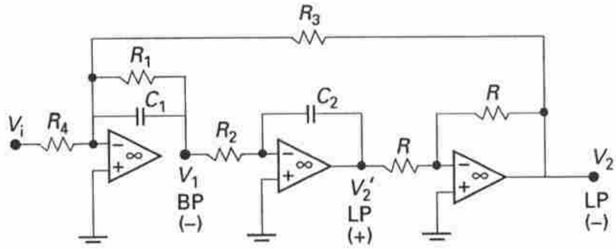

Figure 5. Three op.-amp. Tow–Thomas biquad circuit.

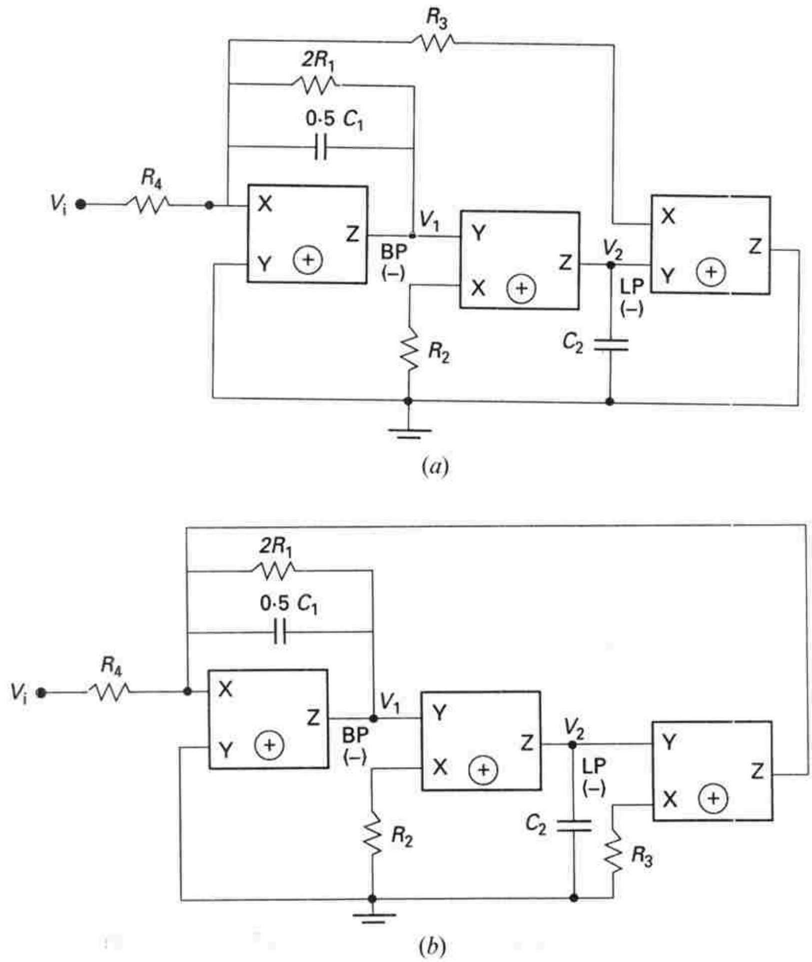

Figure 6. Two equivalent realizations of the Tow–Thomas biquad using CCIIs.

$$\frac{V_1}{V_i}=\frac{-\dfrac{s}{R_4C_1}}{s^2+\dfrac{s}{R_1C_1}+\dfrac{1}{R_2R_3C_1C_2}} \tag{10}$$

$$\frac{V_2}{V_i}=\frac{-\dfrac{1}{R_2R_4C_1C_2}}{s^2+\dfrac{s}{R_1C_1}+\dfrac{1}{R_2R_3C_1C_2}} \tag{11}$$

The above equations are identical with those obtained for the circuit of Fig. 5 with ideal op.-amps. Figure 6(*b*) is equivalent to Fig. 6(*a*) and also realizes V_1 and V_2 as given by (10) and (11).

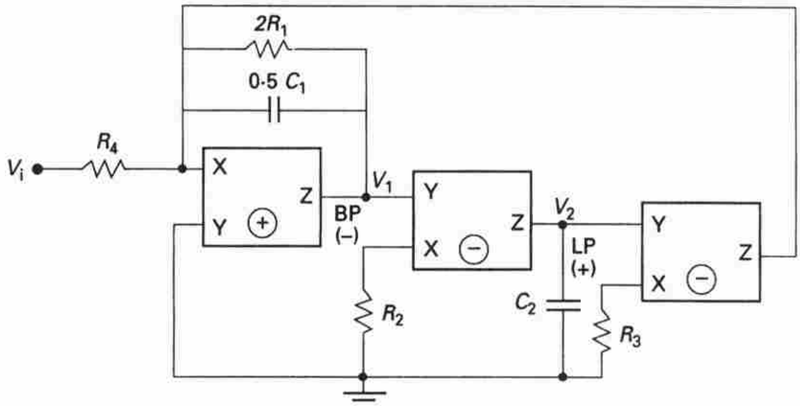

Figure 7. Tow–Thomas biquad using CCIIs to realize a non-inverting low-pass transfer function.

It is worth noting that the op.-amp. circuit of Fig. 5 realizes both non-inverting and inverting low-pass responses, whereas the CCII circuits of Fig. 6(*a*) and (*b*) realize only an inverting low-pass response. This is due to the fact that the two last sections of the circuit of Fig. 5 were combined in a single non-inverting integrator when the CCII realization was carried out. Of course if one is interested in a non-inverting low-pass response, the circuit of Fig. 6(*b*) can be modified by interchanging the polarities of the second and third CCIIs as shown in Fig. 7.

5. Conclusion

A theorem relating a class of op.-amp. circuits to their CCII equivalents has been given. The theorem is useful in generating active circuits, using the CCII as the active building block, from the op.-amp. circuits. Several applications were considered, including the realization of the three-port VCVS, the synthesis of first-order voltage or current transfer functions, and finally the realization of the Tow-Thomas biquad circuit using three-current conveyors.

References

Carlosena, A., and Moschytz, G. S., 1994. Design of variable-gain current conveyors. *IEEE Transactions on Circuits and Systems*—I, **41,** 79–81.

Grimbleby, J. B., 1992, Symbolic analysis of networks containing current conveyors. *Electronics Letters*, **28,** 1401–1403.

Roberts, G. W., and Sedra, A. S., 1992, A general class of current amplifier-based biquadratic filter circuits. *I E E E Transactions on Circuits and Systems—I*, **39,** 257–263.

Sedra, A., and Roberts, G. W., 1990, Current conveyor theory and practice. *Analog IC Design: the Current Mode Approach* (Stevenage, U.K.: Peter Peregrinus).

Sedra, A. S., and Smith, K. C., 1970, A second-generation current conveyor and its applications. *IEEE Transactions on Circuit Theory*, **17,** 132–134.

Soliman, A. M., 1994, Kerwin–Huelsman–Newcomb circuit using current conveyors. *Electronics Letters*, **30,** 2019–2020.

Svoboda, J. A., 1989, Current conveyors, operational amplifiers and nullors. *Proceedings of the Institution of Electrical Engineers*, Pt G, **136,** 317–322.

Thomas, L. C., 1971, The biquad: part I—some practical design considerations. *IEEE Transactions on Circuit Theory*, **18,** 359–357.

Tow, J., 1969, A step by step active filter design. *IEEE Spectrum*, **6** (12), 64–68.

Van Valkenburg, M. E., 1982, *Analog Filter Design* (New York: Holt, Rheinehart and Winston), pp. 87–99.

Wilson, B., 1989, Performance analysis of current conveyors. *Electronics Letters*, **25,** 1596–1598.

Wilson, B., 1990, Recent developments in current conveyors and current-mode circuits. *Proceedings of the Institution of Electrical Engineers*, Pt G, **137,** 63–77.