Generation of Current Conveyor-Based All-Pass Filters From Op Amp-Based Circuits

Ahmed M. Soliman

***Abstract*—In this brief, it is shown that two of the recently reported voltage mode and current mode current conveyor-based all-pass circuits can be generated from the well known single input op amp all-pass configuration. It is also found that two other voltage mode current conveyor-based all-pass circuits are related directly to the differential input op amp all-pass structure. Several new grounded capacitor all-pass circuits are introduced. A new universal biquad circuit which realizes complex poles and employs a single current conveyor is also given. PSpice simulation results are included.**

***Index Terms*—All-pass filters, current conveyor circuits.**

I. Introduction

The first realization of the all-pass transfer function using the operational amplifier (op amp) as the active building block was given by Genin [1], and the basic structure is shown in Fig. 1(a). Shortly thereafter, an equivalent configuration which employs a single input op amp which is shown in Fig. 1(b) was independently reported by Aronhime-Budak [2], and Bhattacharyya [3]. Although the two configurations are theoretically equivalent, they have different frequency limitations due to the finite gain bandwidth of the op amp [4].

Few years after the second generation current conveyor (CC II) was introduced by Sedra and Smith [5], it was used as the active element in realizing the second-order all pass transfer function [6], [7] and the basic configuration is shown in Fig. 2(a). Of course, the same configuration can also be used to realize the first-order all-pass transfer function [8], [9]. Recently several realizations of the all-pass current transfer function (current mode) [10]–[13] and the all-pass voltage transfer function (voltage mode) [14] using the CC II have been reported. All these realizations are limited to real axis poles.

The purpose of this paper is to provide a brief summary of the all-pass circuits using the CC II and to show how they can be generated from the two well-known op amp-based all-pass circuits shown in Fig. 1.

A new generalized single CC II configuration realizing a second-order all-pass transfer function having complex poles is also introduced. PSpice simulations are given.

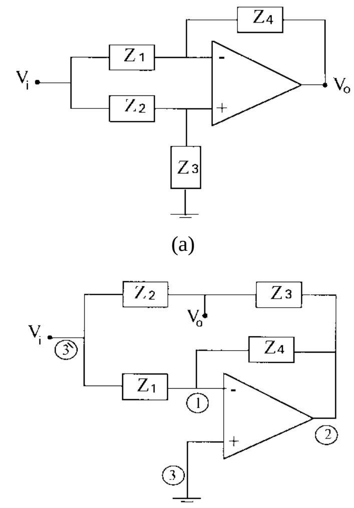

Fig. 1. (a) The differential input op amp circuit [1] and (b) the single input op amp circuit [2], [3].

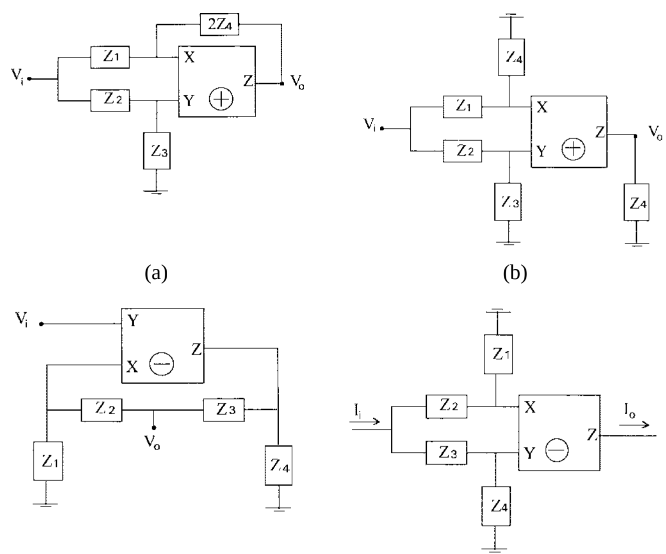

Fig. 2. (a) The CC II(+) all-pass circuit [6], (b) an equivalent CC II(+) all-pass circuit [15], (c) the CC II(−) all-pass voltage mode circuit [14], and (d) the CC II(−) all-pass current mode circuit [10].

II. Generation of the Generalized CC II Circuits

The basic configurations for realizing the voltage or the current all-pass transfer functions using the CC II are shown in Fig. 2. All these four circuits have the same expression for the transfer function which is given by

$$T(s) = \frac{Z_3 - \dfrac{Z_2 Z_4}{Z_1}}{Z_3 + Z_2} \tag{1}$$

where $T(s)$ represents a voltage transfer function for the circuits of Fig. 2(a)–(c) and it represents a current transfer function for the circuit of Fig. 2(d). The above expression represents also the voltage transfer function for each of the two op amp circuits of Fig. 1 (assuming ideal op amps).

Since the four generalized CC II configurations shown in Fig. 2 have the same transfer function as the op amp-based circuits of Fig. 1, it is desirable to see how the CC II circuits of Fig. 2 are generated from the op amp-based circuits of Fig. 1.

A. Generation Methods

First, it is seen that the CC II circuits of Fig. 2(a) [6] and Fig. 2(b) can be generated directly from the op amp circuit of Fig. 1(a) by applying the recently reported transformation theorem which relates a class of op amp and CC II circuits [15].

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The author is with the Electronics and Communications Engineering Department, Cairo University, Egypt.

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TABLE I
FOUR REALIZATIONS OF THE FIRST-ORDER ALL-PASS TRANSFER FUNCTION

Realization	Z_1	Z_2	Z_3	Z_4	Design Equation	Gain Factor T(0)	Reference			
							Fig.2(a)	Fig.2(b)	Fig.2(c)	Fig.2(d)
I	R_1	R	$\frac{1}{sC}$	R_2	$R_1 = R_2$	1	8, 9	-	14	10
II	R_1	$\frac{1}{sC}$	R	R_2	$R_1 = R_2$	-1	9	-	14	10
III	$R+\frac{1}{sC}$	aR	R	bR	$b = \frac{2}{a}$	$\frac{1}{a+1}$	-	-	-	-
IV	bR	aR	R	$\frac{R}{sCR+1}$	$b = \frac{a}{2}$	$\frac{-1}{a+1}$	-	-	-	-

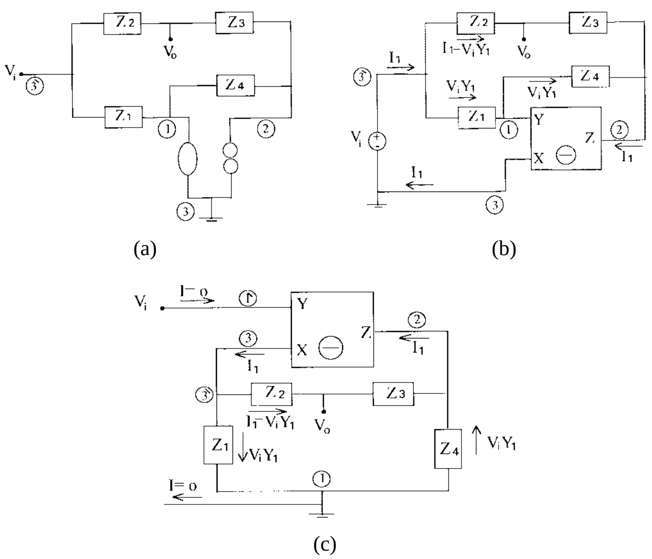


Fig. 3. (a) The nullor equivalent circuit to that Fig. 1(b). (b) The theoretical CC II equivalent circuit. (c) The practical CC II equivalent circuit [14].

Next, it is shown how the op amp circuit of Fig. 1(b) can lead to the generation of both of the circuits of Fig. 2(c) and (d).

B. Generation of the Circuit of Fig. 2(c)

Consider the single input op amp circuit of Fig. 1(b) and replace the op amp by its nullor model as shown in Fig. 3(a), hence replace the nullator and the norator by an inverting CC II [16] as illustrated in Fig. 3(b). This circuit is of theoretical interest only (since the X terminal of the CC II which is the current driven terminal should not be grounded). In order to transform this theoretical circuit to a practical one, it is desirable to relocate the ground terminal. Of course this is possible since node 3 can be floating as illustrated from the currents shown in Fig. 3(b). Setting $V_i = 0$, remove the ground from node 3, inject the input voltage at Y (node $1'$) and ground node 1, we obtained the circuit of Fig. 3(c). Observing the currents in all of the four impedances, it is seen that they are the same as in the circuit of Fig. 3(b), thus the two circuits have the same transfer function.

C. Generation of the Circuit of Fig. 2(d)

The steps for generating the current mode circuit of Fig. 2(d) from the op amp configuration of Fig. 1(b) are illustrated in Fig. 4. Applying the adjoint network theorem [17] to the circuit of Fig. 1(b) and replacing the infinite voltage gain amplifier by an infinite current gain amplifier, results in the circuit of Fig. 4(a). Next replace the op amp by its nullor model as shown in Fig. 4(b) which is equivalent to the CC II circuit of Fig. 4(c). Again this circuit is of theoretical interest only, and it is desirable to relocate the ground node. Taking node 1 as the ground, the circuit of Fig. 4(d) is obtained in which the currents in all impedances are shown to be the same as in the circuit of Fig. 4(c). The current entering port X of the CC II equals to I_0 which can be taken from port Z to any desirable load without affecting its value (since port Z has a very high output impedance).

In the following section, the realization of the all-pass transfer functions having real axis poles is considered.

III. THE ALL-PASS CIRCUITS

A. First-Order All-Pass Circuits

There are four alternative realizations of the first-order all-pass transfer function that can be obtained using any of the four CC II configurations given in Fig. 2. Table I summarizes these four realizations. It is seen that realization I results in grounded C (capacitor) circuits when used with the configurations of Fig. 2(a) and (b). Both of the first two realizations result in floating C circuits when employed with the configurations of Fig. 2(c) and (d).

It is desirable to have grounded C all-pass circuits using the configurations of Fig. 2(c) and (d). Here four new grounded C first-order all-pass circuits are reported. Consider realization III described in Table I, this results in the two new voltage mode and current mode grounded C circuits shown in Fig. 5(a) and (b), respectively. It is seen that the design equation given in Table I includes one degree of freedom. For equal R design, take $a = 1$, hence $b = 2$. The current mode circuit may employ a CC II(+) as shown in Fig. 5(b) with the direction of I_0 taken inwards to port Z in order to keep the same equation for $T(s)$ which is given by

$$T(s) = -\frac{1}{2}\left[\frac{sCR-1}{sCR+1}\right]$$

and

$$T(0) = \frac{1}{2}. \tag{2}$$

Fig. 5(c) and (d) represents the PSpice simulation results for the circuits of Fig. 5(a) and (b), respectively, using the AD844A/AD biased with ±12 V and taking $R = 10$ kΩ and $C = 10$ nF. It should be noted that for the circuit of Fig. 5(a) two AD844A are used to realize the CC II(−).

From the simulation results it is seen that the circuit of Fig. 5(a) has a larger phase error than that of the circuit of Fig. 5(b), this is mainly due to the parasitic impedances of the CC II.

It should also be noted that the phase of the voltage mode circuit is sensitive to the current transfer of the CC II (I_z/I_x), whereas the

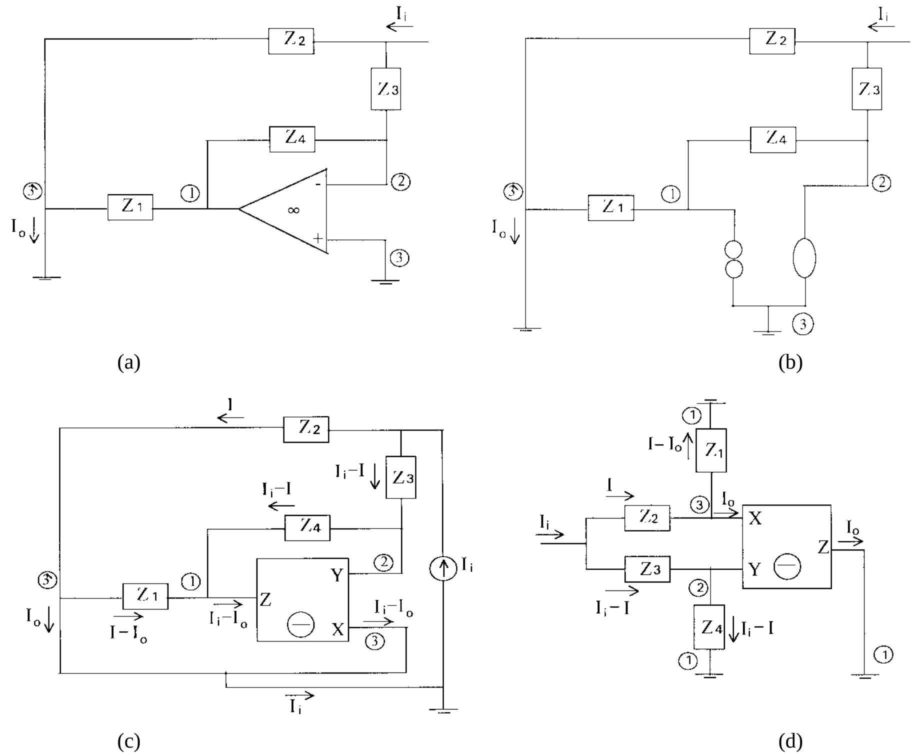


Fig. 4. (a) The adjoint current mode circuit obtained from Fig. 1(b). (b) The nullor equivalent circuit. (c) The theoretical CC II equivalent circuit. (d) The current mode CC II circuit [10].

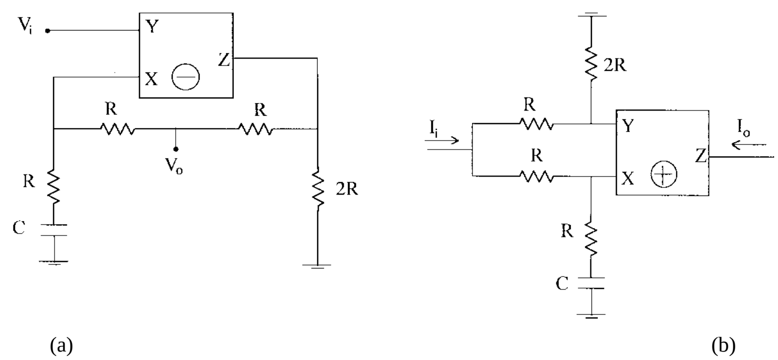


Fig. 5. (a) A new grounded C all-pass voltage mode circuit. (b) A new grounded C all-pass current mode circuit.

phase of the current mode circuit is sensitive to the voltage transfer of the CC II (V_x/V_y).

The two other grounded C all-pass circuits are shown in Fig. 6 and they are based on realization IV described in Table I. Again the recommended design is to take $a = 1$ and $b = \frac{1}{2}$. The circuit shown in Fig. 6(b) employs a CC II(+) and for both circuits of Fig. 6 the transfer function is given by

$$T(s) = \frac{1}{2}\left[\frac{sCR - 1}{sCR + 1}\right]$$

and

$$T(0) = -\frac{1}{2}. \tag{3}$$

Fig. 6(c) and (d) represents the simulation results for the circuits of Fig. 6(a) and (b), respectively, with $R = 10$ kΩ and $C = 10$ nF and using the AD844A.

From the simulation results, it is seen that among the four circuits of Figs. 5 and 6, the current mode circuit of Fig. 6(b) has the best frequency characteristics.

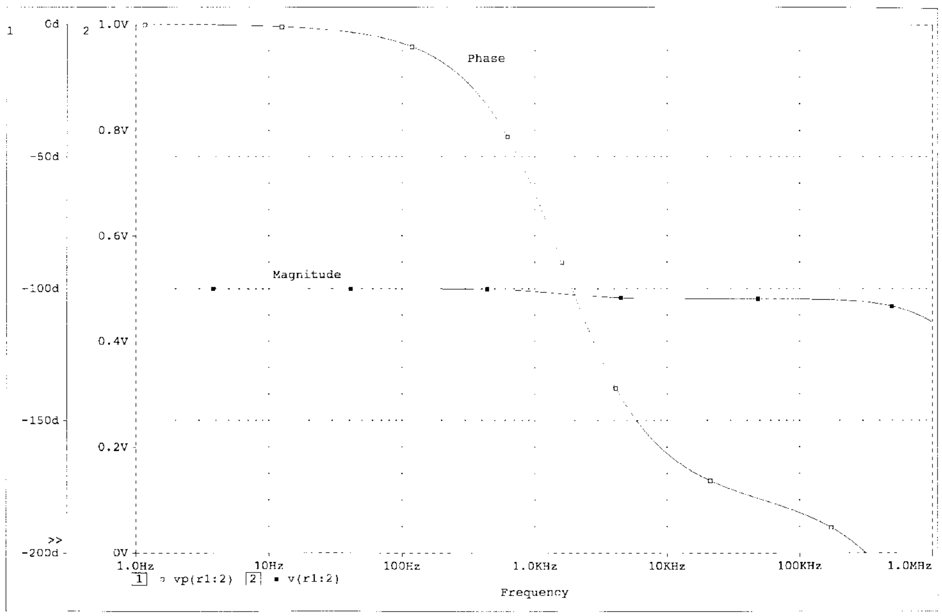
It should be noted that realizations III and IV employ one resistor more than realizations I and II and they are only attractive when applied to the configurations of Fig. 2(c) and (d).

It is worth noting that the four realizations using the configuration of Fig. 2(b) are new. In these realizations the desirable gain factor can be achieved by proper scaling of the impedance connected to port Z.

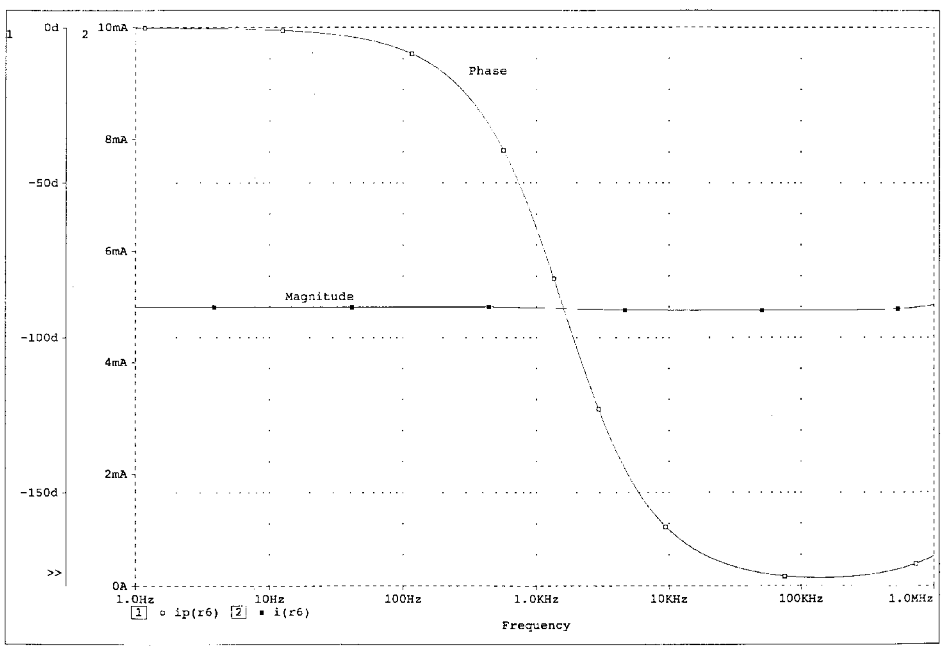
Of course realizations I, II, and III are well known when employed with the op amp circuit of Fig. 1(a) [18], however, it seems that realization IV was not described before (up to this author's knowledge) with the op amp configurations of Fig. 1(a) and (b).

B. Second-Order All-Pass Circuits

Three alternative realizations of the second-order all-pass transfer function are possible using any of the generalized configurations shown in Fig. 2. Table II summarizes these realizations together with the design equations and the gain factors. The only voltage mode grounded C circuit is obtained when realization III is used with the configuration of Fig. 2(c). This second-order all-pass grounded C



(c)



(d)

Fig. 5. *(Continued.)* (c) Simulation results for the circuit of (a) with $V_i = 1$ V. (d) Simulation results for the circuit of (b) with $I_i = 10$ mA.

circuit is new (although this configuration was used in [14] to realize a notch response, this grounded C realization was not mentioned).

It is worth noting that when realizations I and II are used with the configuration of Fig. 2(b) an independent control on the gain factor can be achieved by taking the grounded resistor at port Z equals to KR_4. Realization III however results in a nonconomic circuit when used with the configuration of Fig. 2(b).

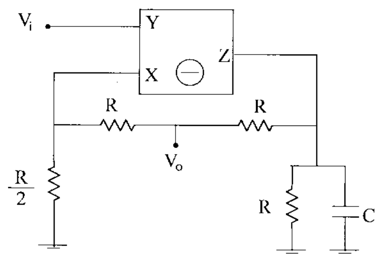
The three realizations discussed here are all well known when employed with the op amp-based configurations of Fig. 1 [19], [20].

IV. A New Biquad Circuit

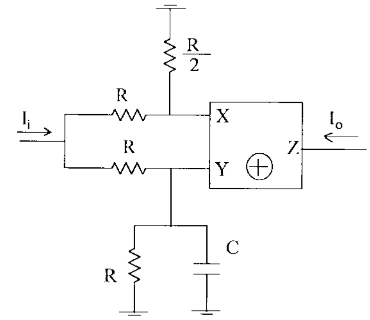
In this section, a new single CC II generalized biquad circuit is introduced. The proposed circuit is generated from the all-pass second-order circuit shown in Fig. 7(a), which employs the single input op amp, with N representing a passive RC bandpass circuit [21]. Replacing the op amp by its nullor equivalent and hence replace the nullor by an inverting CC II, the theoretical equivalent circuit is given in Fig. 7(b) in which N is also taken as in [21]. Examining the currents in this circuit, it is seen that node 3 can be floating, therefore it is desirable to relocate the ground node. As discussed before, remove the ground from node 3, set $V_i = 0$ and inject V_i at Y (node 1\) and ground node 1, the generalized practical CC II circuit is obtained as shown in Fig. 7(c).

Taking $C_1 = C_2 = C$ (the minimum passive sensitivity design), the transfer function is given by

$$\frac{V_0}{V_i} = a\,\frac{s^2C^2R^2b - sCR\left[\dfrac{(1-a)b}{a} - 2\right] + 1}{s^2C^2R^2b + 2sCR + 1}. \tag{4}$$

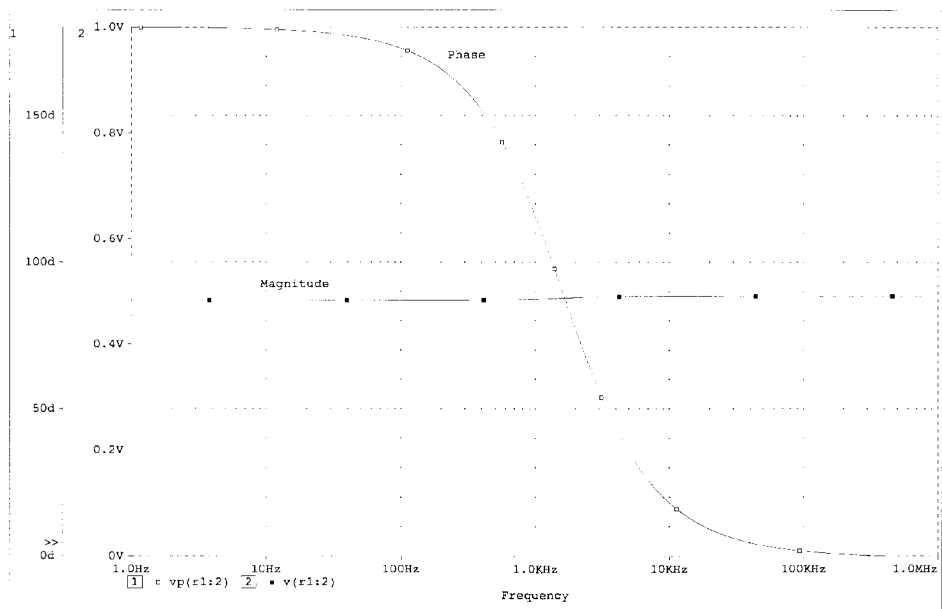


(a)

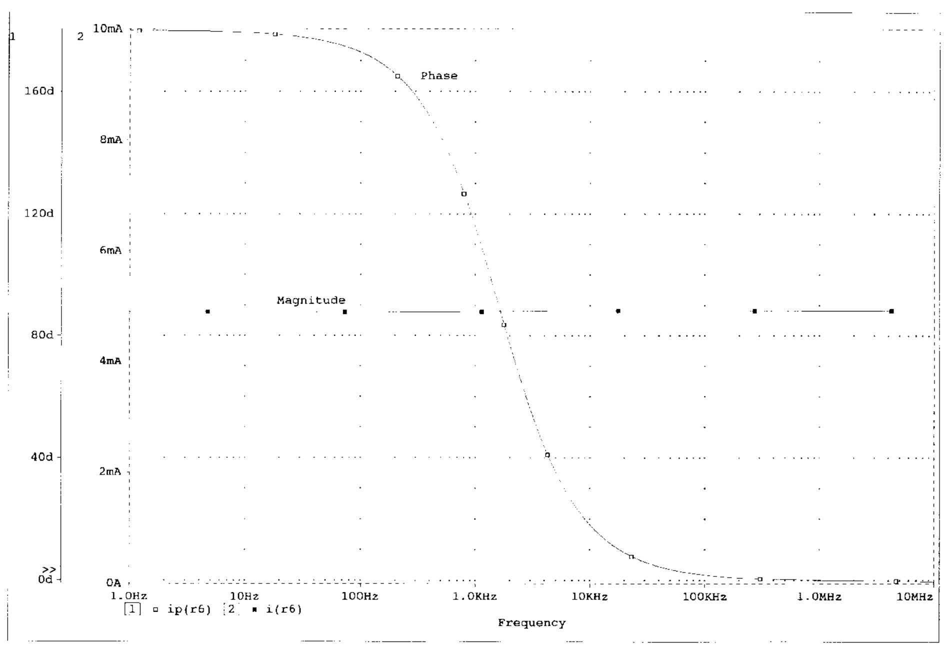


(b)

Fig. 6. (a) Another new grounded C all-pass voltage mode circuit. (b) Another new grounded C all-pass current mode circuit.



(c)

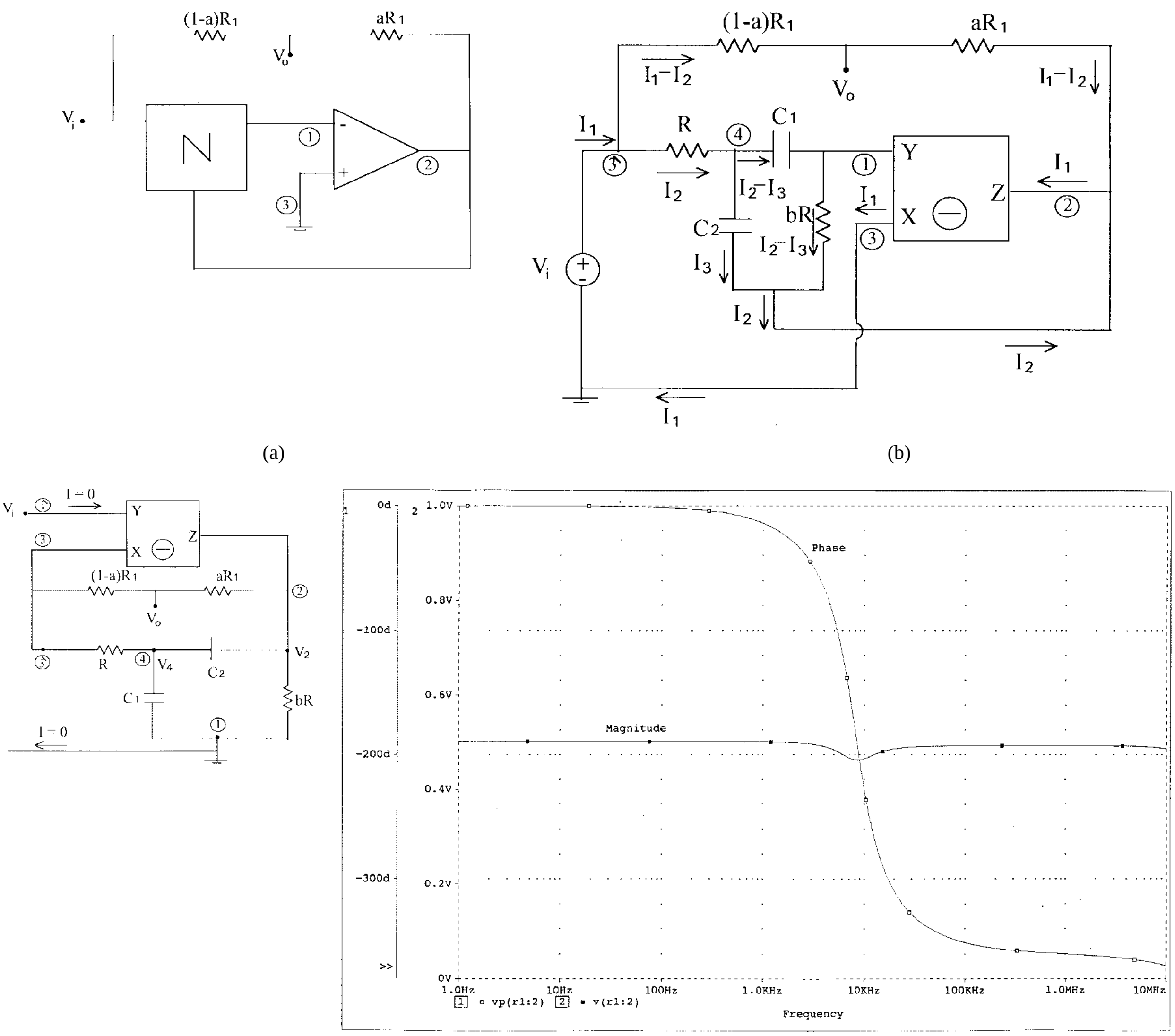


(d)

Fig. 6. *(Continued.)* (c) Simulation results for the circuit of (a) with $V_i = 1$ V. (d) Simulation results for the circuit of (b) with $I_i = 10$ mA.

TABLE II
THE THREE ALTERNATIVE REALIZATIONS OF THE SECOND ORDER ALL-PASS TRANSFER FUNCTION, WHERE $H = 2(R_1/R_2 + C_2/C_1)$

Realization	Z_1	Z_2	Z_3	Z_4	Design Equation	Gain Factor	Reference			
							Fig.2(a)	Fig.2(b)	Fig.2(c)	Fig.2(d)
I	R_3	$R_1+\frac{1}{sC_1}$	$\frac{R_2}{sC_2R_2+1}$	R_4	$\frac{R_3}{R_4}=H+1$	$-\frac{R_4}{R_3}$	6	-	-	-
II	R_3	$\frac{R_2}{sC_2R_2+1}$	$R_1+\frac{1}{sC_1}$	R_4	$\frac{R_4}{R_3}=H+1$	1	6	-	-	12
III	$R_1+\frac{1}{sC_1}$	R_3	R_4	$\frac{R_2}{sC_2R_2+1}$	$\frac{R_3}{R_4}=H$	$\frac{R_4}{R_3+R_4}$	7	-	-	13



(c) (d)

Fig. 7. (a) The generalized all-pass filter using the single input op amp, (b) the theoretical CC II equivalent circuit, (c) the new generalized biquad circuit using a CC II(−), and (d) simulation results for the circuit of (c) with $V_i = 1$ V.

For an all-pass response the necessary condition is

$$a = \frac{b}{b+4}. \tag{5}$$

The circuit can be also realize a notch response if

$$a = \frac{b}{b+2}. \tag{6}$$

It is worth noting that this is the first single CC II universal biquad which realizes complex poles. For a specified ω_0 and Q the design equations for R and b are given by

$$R = \frac{1}{2Q\omega_0 C} \tag{7}$$

$$b = 4Q^2. \tag{8}$$

It should be noted that this circuit realizes also bandpass-lowpass responses at nodes 2 and 4, respectively, and it includes the circuit given in [14] as a special case. These transfer functions are given by

$$\frac{V_4}{V_i} = \frac{1}{D(s)}$$

and

$$\frac{V_2}{V_i} = \frac{-sCRb}{D(s)} \tag{9}$$

where $D(s)$ is the same as given by (4).

Of course if the second RC network N given in [21] is used, a highpass response is obtained at node 4.

Fig. 7(d) represents the simulation results for the magnitude and the phase of the circuit of Fig. 7(c) with $R = 10$ kΩ, $C = 1$ nF, $b = 4$, $a = 0.5$, $R_1 = 20$ kΩ, and using two AD844A to realize the CC II ($-$).

It is worth noting that a new current mode CC II-based all-pass circuit having a transfer function given by (4) can also be generated from the circuit of Fig. 7(a) following the same steps as described in Section II-C.

V. Conclusion

It is found that the CC II circuits of Fig. 2(a) and (b) are generated directly from the differential input op amp-based configuration of Fig. 1(a) by the transformation theorem given in [15]. It is also shown in details how the CC II-based configurations of Fig. 2(c) and (d) are generated from the single input op amp-based configuration of Fig. 1(b). Four new grounded capacitor first-order all-pass circuits are given.

A new universal biquad circuit which realizes all-pass (notch), lowpass (highpass), and bandpass responses at three alternative outputs is generated from a well-known single input op amp circuit [21]. This is the first single CC II voltage mode universal biquad circuit to be reported in the literature. PSpice simulation results are included. It should be noted that the generation methods described in this paper can be applied to many other op amp-based circuits leading to new equivalent CC II realizations.

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Further Simplifications to 2-D Filter Stability Test

Xiheng Hu

***Abstract*—A further simplification to the stability test of the characteristic polynomial $D(x_1, z_2)$ of a two-dimensional (2-D) filter is achieved by the following two modifications in the test procedure. At first, the modified Jury table is used to construct the polynomial array and then the real form of Siljak's theorem applied. Secondly, the positivity test on Δ_n, the last entry of the polynomial array, is further reduced to tests on its factors $D(x_1, 1)$, $D(x_1, -1)$ and $\Delta^-_{n-1}(x_1)$, which are of much lower orders in x_1.**

***Index Terms*—Two-dimensional (2-D) filters, polynomial array, stability.**

I. Introduction

The main concern in two-dimensional (2-D) filter stability test is the checking of the following condition

$$D(z_1, z_2) \neq 0, for |z_1| = 1, |z_2| \leq 1 \tag{1}$$

where $D(z_1, z_2)$ is the characteristic polynomial of a 2-D IIR filter.

The so-called indirect methods [1]–[5] examine the condition in (1) by first forming a real polynomial $\hat{D}(x_1, z_2)$ from $D(z_1, z_2)$ on $|z_1| = 1$, i.e.,

$$\hat{D}(x_1, z_2) = \tilde{D}(z_1, z_2)_{||z_1|=1} = [D(z_1, z_2)D(\bar{z}_1, z_2)]_{||z_1|=1} \tag{2}$$

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The author is with the Department of Electrical Engineering, The University of Sydney, NSW 2006 Australia.

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