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New Current Mode Low-Pass Filter Using Identical Single Output Current Conveyors

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A new current mode low-pass filter using three single output inverting second generation current conveyors (ICCII) is introduced. The circuit uses three, ICCII+ and realizes an inverting low-pass response. The same circuit can also use three ICCII− and realizes a non-inverting low-pass response. The proposed circuit employs four grounded resistors and two grounded capacitors and has independent control on Q and on the DC gain by varying a single grounded resistor. It is found that the proposed circuit can not be used with three CCII+ or with three CCII−. Two modified configurations using four identical single-output CCII and having very low input impedance are defined. It is found that the ICCII+ and the ICCII− are suitable for one of the two modified configurations. The CCII+ can be used with both of the modified configurations and the CCII− can not be used with any of the proposed circuits with the same conveyor numbers. Spice simulation results using 0.5 µm CMOS transistors are included to support the theoretical analysis.

Keywords: Current mode filters; Current conveyors, low-pass filters.

1 INTRODUCTION

The Current Conveyor (CCII) family includes four types the CCII+, the CCII− [1] and the two inverting CCII (ICCII) [2–4] namely ICCII+ and ICCII−. The symbolic representation of the CCII is shown in Fig. 1(a). The relation between terminal voltages and currents is given by the following matrix equation:

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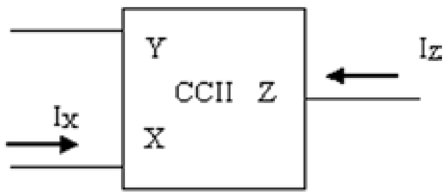

FIGURE 1A
Symbol of the CCII.

$$\begin{bmatrix} I_Y \\ V_X \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ \pm 1 & 0 & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} V_Y \\ I_X \\ V_Z \end{bmatrix} \tag{1}$$

The positive sign in the second row applies to the two CCII and the negative sign applies to the two ICCII. The ± 1 in the third row specifies the Z polarity of the current conveyor. By convention, the positive sign is taken to mean that the currents at the X and Z terminals are both flowing inwards to the conveyor or outwards from the conveyor.

Fig. 1(b) represents the CMOS circuit of the ICCII+ as special case from the DVCC given in [2–3]. Fig. 1(c) represents the CMOS circuit of the ICCII− given in [4], which is based on using the floating current source [5] to avoid the use of current mirrors in transferring current from port X to port Z of the conveyor. Fig. 1(d) represents the CMOS circuit of the CCII+ given in [6].

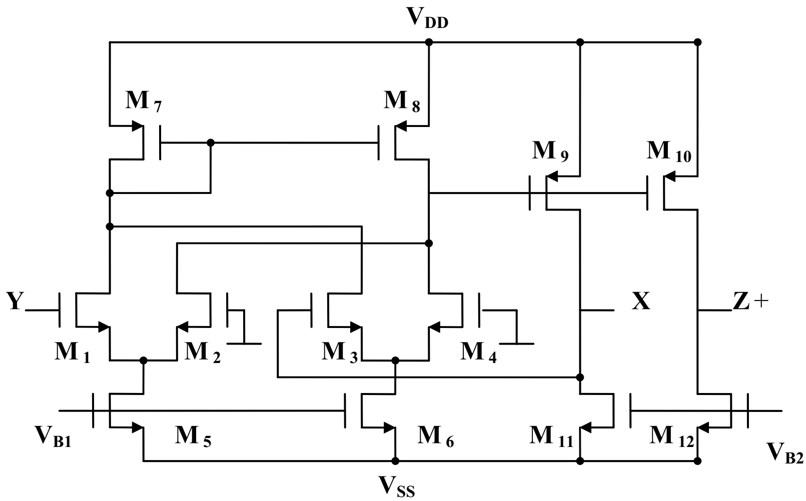

FIGURE 1B
The CMOS circuit of the ICCII+ [2-3].

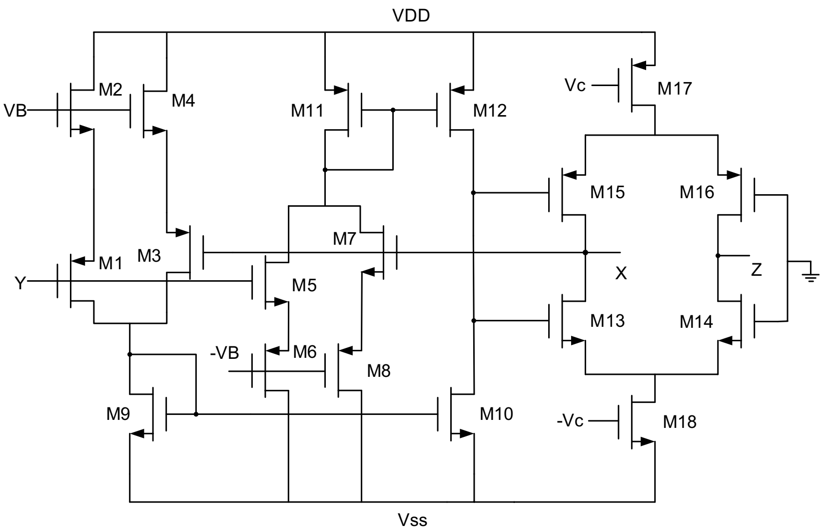

FIGURE 1C
The CMOS circuit of the ICCII− [4].

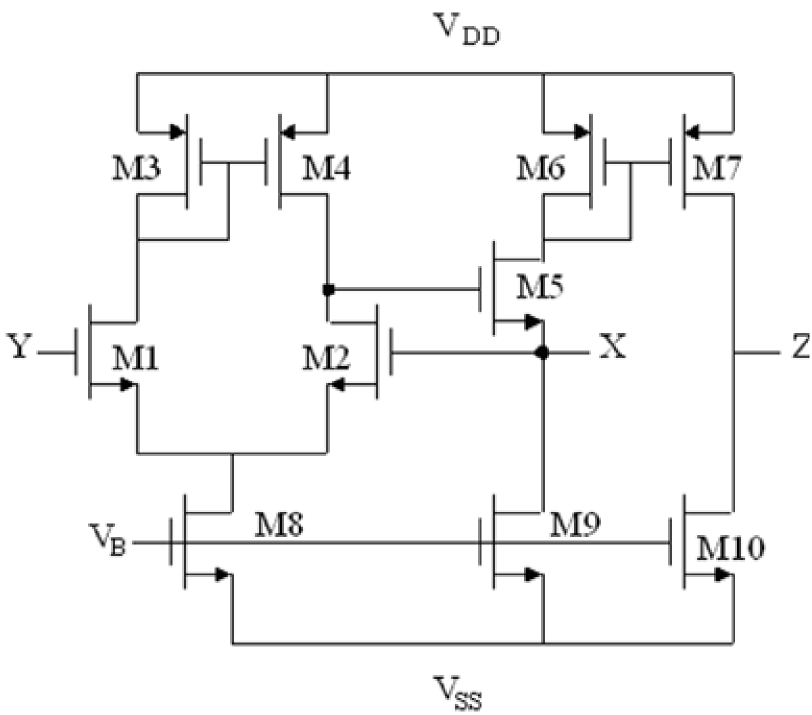

FIGURE 1D
The CMOS circuit of the CCII+ [6].

Current mode filters have been introduced in the literature using two-output CCIIs [7–10] or single output CCIIs [11–12]. The circuit reported in [11] uses five CCII+ and has two floating resistors, and the circuit in [12] has the advantage that all passive elements are grounded and it uses three CCII+ and one CCII−.

A current mode filter which uses three single output ICCII+ was given in [13]. The circuit suffers however from having all resistors and capacitors being floating, besides the capacitors are connected to the X terminals of the ICCII+ which limits the operating frequency of the circuit. Also there is no independent control on the gain or on the filter pole Q. It is desirable in many cases to use identical single output conveyors as has been recently done in the realization of voltage mode filters [14–15]. The voltage mode filter reported most recently in [15] has no independent control on the gain or on the filter pole Q.

In this paper a novel current mode low-pass filter using three, ICCII+ or three ICCII− is introduced. The circuit avoids all the disadvantages of the filter in [13] and employs four grounded resistors and two grounded capacitors and has independent control on Q and on DC gain.

2 THE NEW THREE ICCII LOW-PASS FILTER

Fig. 2(a) represents the proposed current mode low-pass filter using three ICCII+ with all grounded passive elements. The circuit block diagram is shown in Fig. 2(b) with a current to voltage lossless integrator followed by a lossy integrator which is in a reverse order from the Tow-Thomas well known filter [16–17].

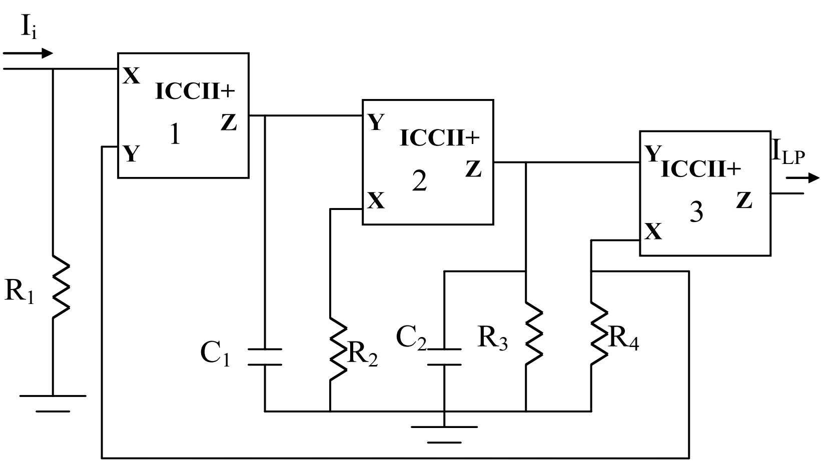

FIGURE 2A
The new inverting low-pass filter using three single-output ICCII+.

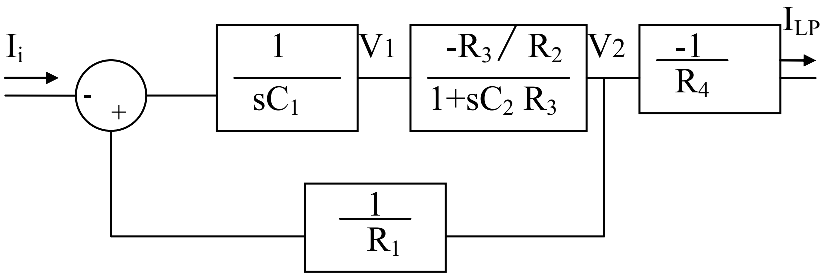

FIGURE 2B
The block diagram of the circuit shown in Fig 2(a).

The current transfer function of the filter is given by:

$$\frac{I_{LP}}{I_i} = \frac{\dfrac{-1}{C_1 C_2 R_2 R_4}}{s^2 + \dfrac{s}{C_2 R_3} + \dfrac{1}{C_1 C_2 R_1 R_2}} \tag{2}$$

The ω_o and Q are given by:

$$\omega_o = \frac{1}{\sqrt{C_1 C_2 R_1 R_2}}, \quad Q = R_3 \sqrt{\frac{C_2}{C_1 R_1 R_2}} \tag{3}$$

The magnitude of the DC gain is given:

$$K = \frac{R_1}{R_4} \tag{4}$$

For a specified DC gain, ω_o and Q the design equations are given by:

$$C_1 = C_2 = C, \quad R_3 = R_1 Q. \tag{5-a}$$

$$R_1 = R_2 = \frac{1}{\omega_o C}, \quad R_4 = \frac{R_1}{K} \tag{5-b}$$

The circuit has very low sensitivities to all circuit components.

Figure 3(a) represents an equivalent circuit using three ICCII− having the block diagram of Fig. 3(b) which differs from that of Fig. 2(b) in four signs.

All the above equations apply also to the circuit of Fig. 3(a) except equation (2) which will have a positive sign.

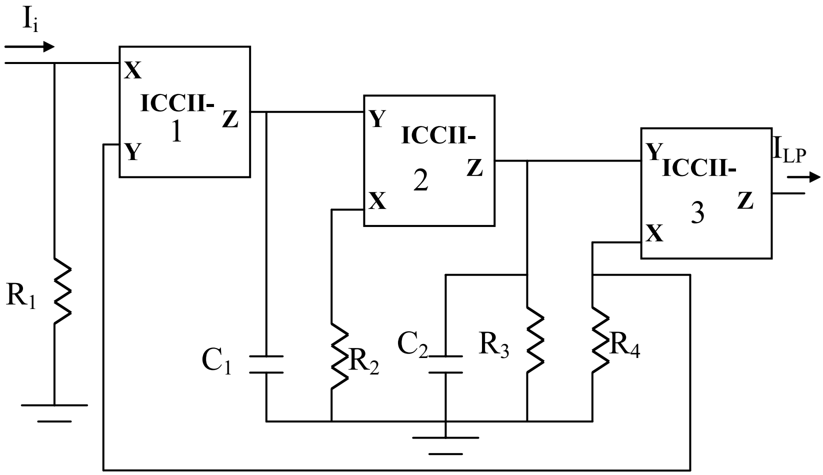

FIGURE 3A
The new non-inverting low-pass filter using three single-output ICCII−.

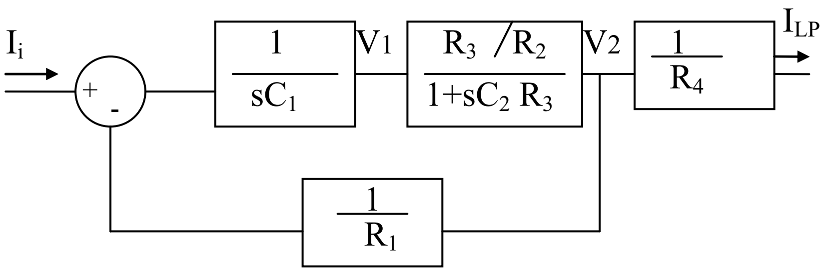

FIGURE 3B
The block diagram of the circuit shown in Fig. 3(a).

3 THE NEW FOUR CCII LOW-PASS FILTER

Fig. 4(a) represents a modified current mode low-pass filter using four ICCII+ with all grounded passive elements. The circuit has the advantage of having zero input impedance which is ideal for current mode filters. The circuit is equivalent to that of Fig. 2(a) and has the same block diagram in Fig. 2(b).

Fig. 4(b) represents a modified current mode low-pass filter using four ICCII− with all grounded passive elements. The circuit is equivalent to that of Fig 3(a) and has the same block diagram in Fig. 3(b).

Fig. 5(a) represents a new current mode low-pass filter using four CCII+ with all grounded passive elements. The circuit has the advantage of having zero input impedance which is ideal for current mode filters. The circuit realizes an inverting low-pass response and has the block diagram shown in Fig. 5(b).

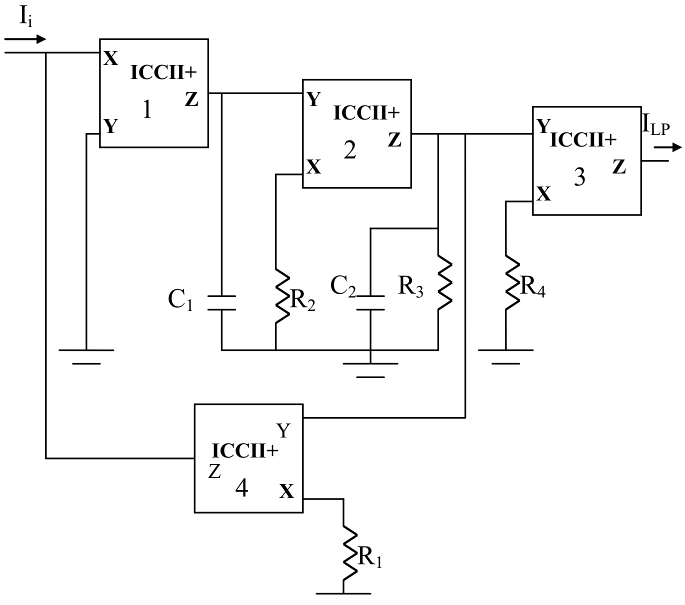

FIGURE 4A
The new inverting low-pass filter configuration II-a using four single-output ICCII+.

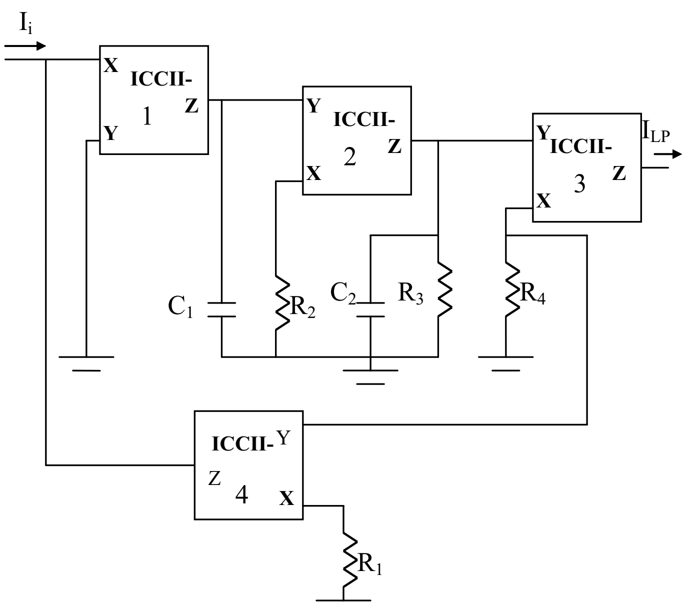

FIGURE 4B
The new non-inverting low-pass filter configuration II-b using four single-output ICCII−.

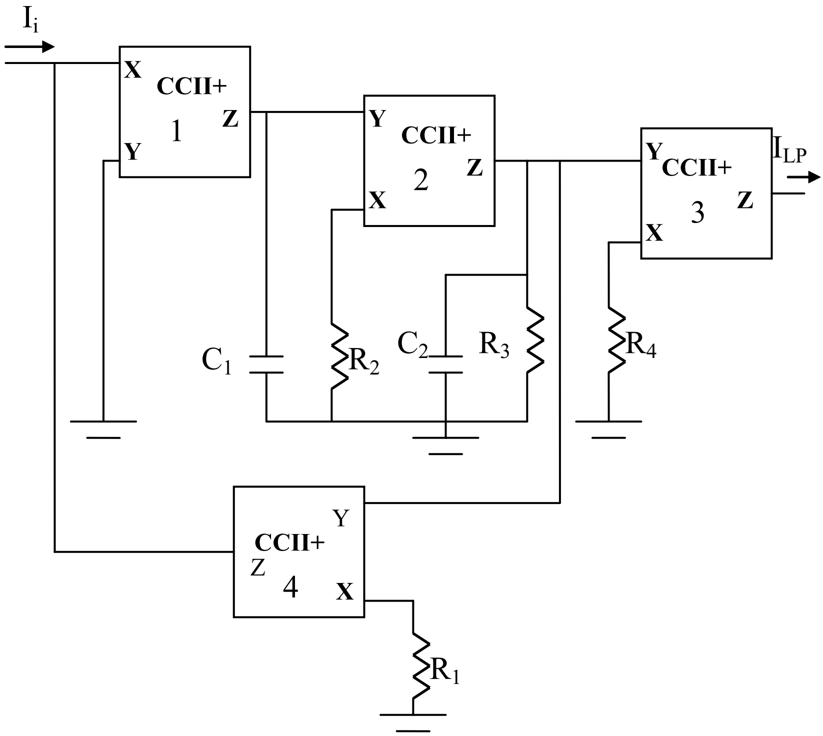

FIGURE 5A
The new inverting low-pass filter using four single-output CCII+.

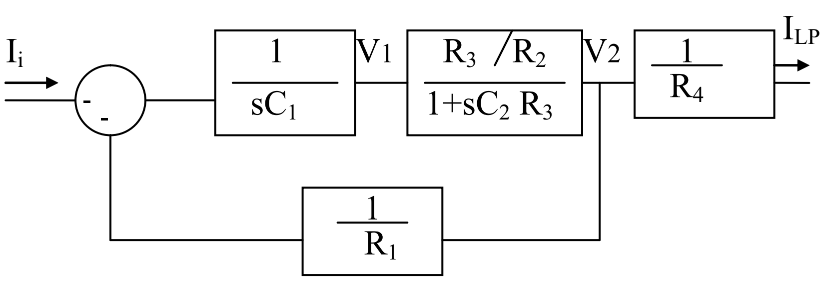

FIGURE 5B
The block diagram of the circuit of Fig. 5(a).

It should be noted that the circuit can not be used with four CCII− which demonstrates that the CCII family members are not interchangeable in some circuit configurations. Tables 1 and 2 summarize the results of the validity of using members of the CCII family in the two proposed configurations.

TABLE 1
The low-pass filter polarity using the 3-CCII configuration.

CCII Type	Use with the current mode three CCII circuit	Low-Pass Polarity
ICCII+	Yes	Inverting
ICCII−	Yes	Non-inverting
CCII+	No	—
CCII−	No	—

TABLE 2
Summary of the two low-pass filter configurations.

CCII Type	Configuration I	Configuration II-a	Configuration II-b
ICCII+	Yes	Yes	No
ICCII−	Yes	No	Yes
CCII+	No	Yes	Yes
CCII−	No	No	No

4 SIMULATION RESULTS

Spice simulation results using technology SCN 05 feature size 0.5 μm from MOSIS vendor: AGILENT.

The circuit of Fig. 2(a) is simulated using the CMOS ICCII+ of Fig. 1(b) with the aspect ratios shown in Table 3 and with $V_{DD} = 1.5\,V$, $V_{SS} = -1.5\,V$. The circuit of Fig. 3(a) is simulated with the ICCII− of Fig. 1(c) with the aspect ratios shown in Table 4 and with $V_{DD} = 1.5\,V$, $V_{SS} = -1.5\,V$. The circuit

TABLE 3
Transistor aspect ratios of the ICCII+ shown in Fig. 1(b).

Transistor	W(μm)/L(μm)
M1,M2,M3,M4	25/0.5
M5, M6	8/0.5
M7, M8	10/0.5
M9, M10	40/2
M11, M12	20/2.5

TABLE 4
Transistor aspect ratios of the ICCII− shown in Fig. 1(c).

Transistor	**W(μm)/L(μm)**
M1,M2,M3,M4,M5,M6,M7,M8	50/1.5
M9, M10	12.5/1.5
M11, M12	37.5/1.5
M13, M14	25/0.5
M15, M16	50/0.5
M17	82.5/1.5
M18	39.5/1.5

TABLE 5
Transistor aspect ratios of the CCII+ shown in Fig. 1(d).

Transistor	**W(μm)/L(μm)**
M1, M2	20/1
M3, M4	60/2.5
M5	40/0.5
M6, M7	20/2.5
M8	50/2.5
M9, M10	20/2.5

of Fig. 5(a) is simulated using the CMOS CCII+ of Fig. 1(d) with the aspect ratios shown in Table 5 and with $V_{DD} = 1.5\,V$, $V_{SS} = -1.5\,V$.

The three circuits are simulated to realize a unity DC gain low-pass having $f_o = 10\,MHz$, and $Q = 0.707$ for maximally flat magnitude response and using a current source of 1 mA. For the three circuits the design values taken are $C_1 = C_2 = 10\,pF$, $R_1 = R_2 = R_4 = 1.59\,k\Omega$ and $R_3 = 1.125\,k\Omega$.

Fig. 6(a), Fig. 6(b) and Fig. 6(c) represent the magnitude and phase characteristics for the circuits of Fig. 2(a), Fig. 3(a) and Fig. 5(a) respectively, together with the ideal characteristics. From the simulations it is seen that the simulated results agree well with the ideal responses.

5 CONCLUSIONS

A new current mode low-pass filter using three single output inverting second generation current conveyors (ICCII) is introduced. The circuit uses three,

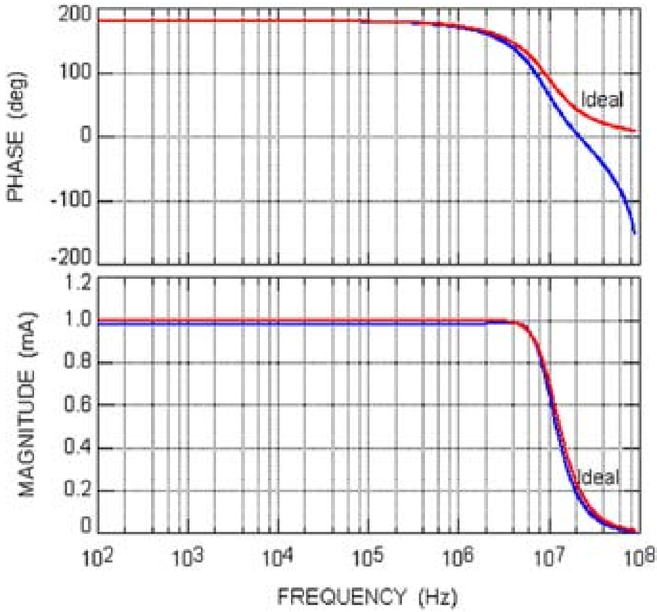

FIGURE 6A
Spice simulation results of the circuit of Fig. 2(a).

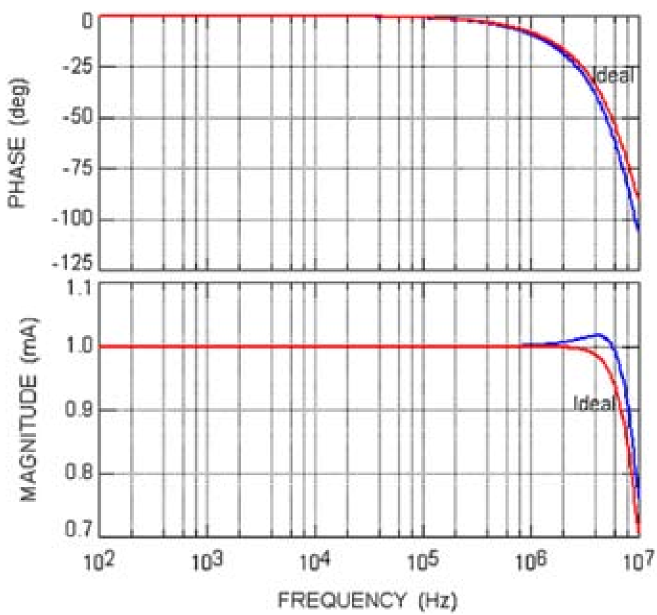

FIGURE 6B
Spice simulation results of the circuit of Fig. 3(a).

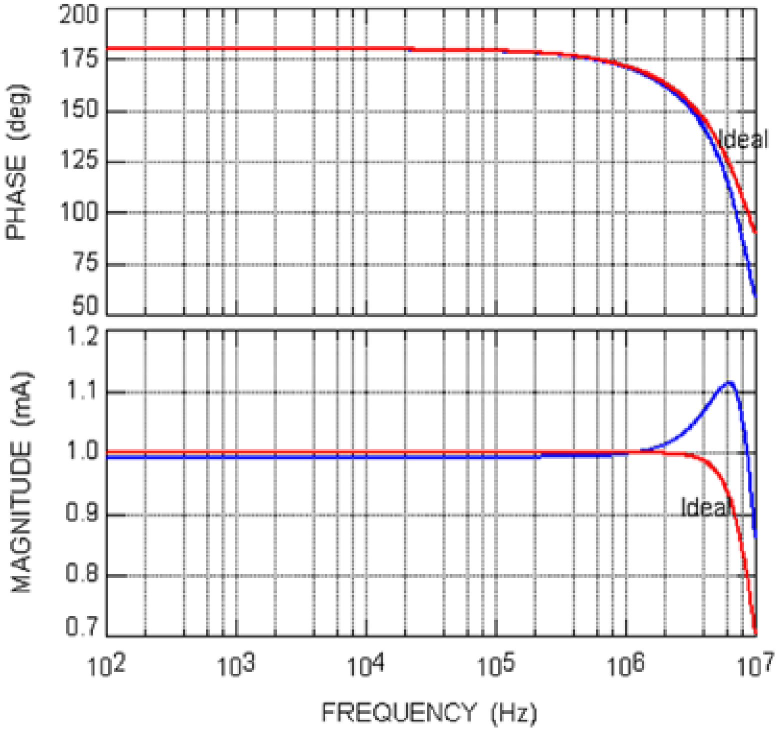

FIGURE 6C
Spice simulation results of the circuit of Fig. 5(a).

ICCII+ and realizes an inverting low-pass response. The same circuit can also use three ICCII− and realizes a non-inverting low-pass response. The proposed circuit employs four grounded resistors and two grounded capacitors and has independent control on Q and on the DC gain by varying a single grounded resistor. It is found that the proposed circuit can not be used with three CCII+ or with three CCII−. A second configuration using four identical CCIIs is also introduced Spice simulation results using 0.5 µm CMOS transistors are included to support the theoretical analysis. It is worth noting the low input impedance current mode low-pass filter reported most recently in [10] employs a two-output ICCII and has no independent control on gain.

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