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New Grounded Capacitor Current Mode Band-Pass Low-Pass Filters Using Two Balanced Output ICCII

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Four new grounded capacitor current mode filters with high output impedance and using two balanced output Inverting Current Conveyors (ICCII) are introduced. The circuits are classified to two classes, in class one the input current is injected at port X of the ICCII .In class two the input is applied to port Y of the ICCII. All reported circuits employ grounded resistors also except one minimal passive component circuit which uses one floating resistor. Spice simulation results for all reported circuits using technology: SCN 05 feature size 0.5 micronsMOSISVendor: AGILENT are given.

Keywords: Active filters, Inverting current conveyors.

1 INTRODUCTION

The balanced out Differential Voltage Current Conveyor (DVCC) was introduced in [1], and has also been independently introduced and defined in [2] as a single output Differential Difference Current Conveyor (DDCC).

The inverting second generation current conveyor (ICCII) introduced in [3] is considered to be a special case from the DVCC or the DDCC. The symbolic representation of the balanced output ICCII is shown in Fig. 1(a). The relation between terminal voltages and currents is given by the following

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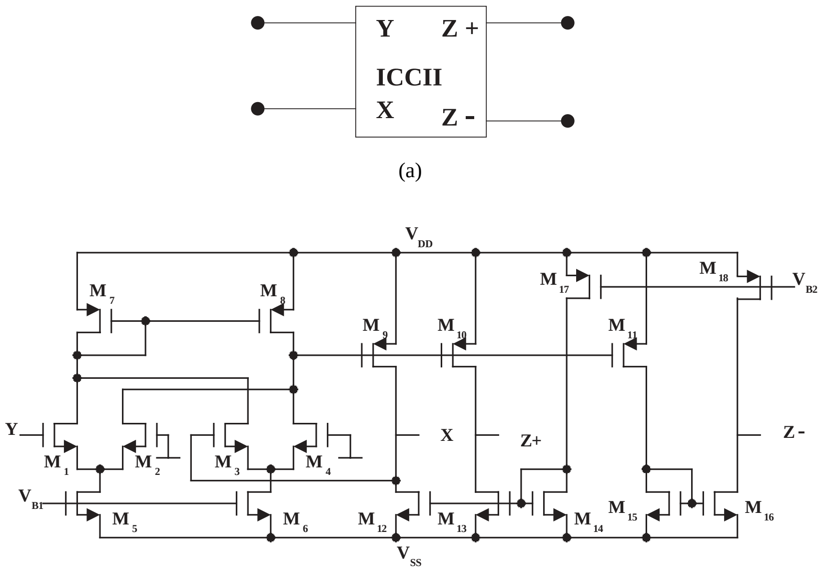


(b)

FIGURE 1
(a) Balanced output ICCII and (b) the CMOS circuit of the balanced output ICCII [2].

matrix equation:

$$\begin{bmatrix} V_x \\ I_y \\ I_{z+} \\ I_{z-} \end{bmatrix} = \begin{bmatrix} 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_{z+} \\ V_{z-} \end{bmatrix} \tag{1}$$

The voltage at terminal X is the inversion of the voltage at terminal Y. The current at each of the Z terminals follows the current at terminal X in magnitude. By convention, if I_x enters port X then I_{z+} also enters port $Z+$ and I_{z-} leaves port $Z-$.

This active circuit can be easily implemented with CMOS technology as given in [1–3] and Fig. 1(b) represents the CMOS realization of the balanced output ICCII [1]. Several current mode filters using the classical CCII have been introduced in the literature [4–10].

The first current mode filters using the DVCC or the DDCC were introduced in the literature in [1,2]. The filter given in [1] is a MOS-C filter and it employs two DVCC, two MOS transistors and two grounded capacitors and realizes band-pass and low-pass current responses. In [2] however a current mode active RC filter was proposed which is non-canonic as it uses three capacitors. The circuit in [2] is based on R, C in parallel with an active one port circuit which was identified in [2] as a simulated inductor. It is in fact a simulated frequency dependent negative resistance. The circuit realizes two output currents of low-pass and band-pass nature. Of course to utilize the two output currents I_{LP} and I_{BP} two additional current followers are needed. The current mode filter in [10] using electronically tunable CCII has the two output currents I_{HP} and I_{BP} flowing in capacitors so to use these currents two additional current followers are needed, in this case the capacitors used are becoming floating thus all passive circuit components become floating since it uses also two floating resistors. In integrated circuits it is desirable to have a grounded capacitor circuits as they can compensate for the stray capacitances at their nodes [11].

In this paper all of the four proposed circuits employ grounded capacitors. The proposed current mode filters employ two balanced output ICCII. The filters are classified to two classes based on the input current excitation port.

2 CLASS I CURRENT MODE FILTERS

In this section two new grounded capacitor band-pass filters using two balanced output ICCII are given. The first proposed circuit is shown in Fig. 2(a) which employs the minimum number of passive components namely two resistors and two capacitors. The current transfer function is given by:

$$\frac{I_{BP}}{I_i} = \frac{sC_1R_1}{s^2C_1C_2R_1R_2 + sC_1R_1 + 1} \tag{2}$$

The ω_o and Q are given by

$$\omega_o = \frac{1}{\sqrt{C_1C_2R_1R_2}}, \quad Q = \sqrt{\frac{C_2R_2}{C_1R_1}} \tag{3}$$

For a specified ω_0 and Q and for equal RC design, the design equations are given by:

$$C_2 = QC_1, \quad R_2 = QR_1 \tag{4}$$

$$R_1 = \frac{1}{\omega_0 C_2} \quad \text{and} \quad R_2 = \frac{1}{\omega_0 C_1} \tag{5}$$

This is an noninverting band-pass filter and the magnitude of the center frequency gain is unity. The circuit has no independent control on Q and the resistor R_2 is floating.

The next circuit with the current input applied to port X is shown in Fig. 2(b). It employs three grounded resistors and two grounded capacitors and two balanced output ICCII. The transfer function is given by:

$$\frac{I_{BP}}{I_i} = \frac{sC_2R_1R}{s^2C_1C_2R_1R_2R + sC_2R_1R_2 + R} \tag{6}$$

$$\omega_o = \frac{1}{\sqrt{C_1C_2R_1R_2}}, \quad Q = R\sqrt{\frac{C_1}{C_2R_1R_2}} \tag{7}$$

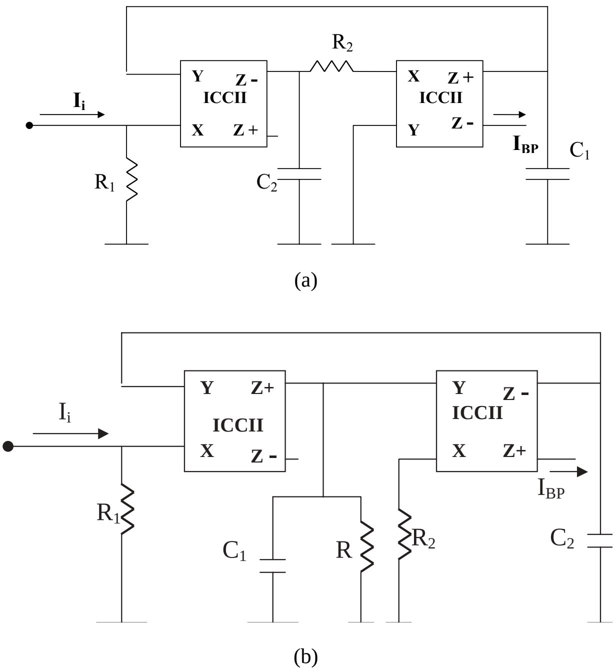


FIGURE 2
(a) Minimum passive component grounded capacitor band-pass filterand (b) grounded resistor grounded capacitor band-pass filter.

The design equations are given by:

$$C_1 = C_2 = C, \quad R_1 = R_2 = \frac{1}{\omega_0 C} \quad \text{and} \quad R = QR_1 \tag{8}$$

This is a non-inverting band-pass filter with a gain at the center frequency equal to Q.

3 CLASS II CURRENT MODE FILTERS

Two grounded resistor grounded capacitor circuits are given in this section. Figure 3(a) represents the first circuit which is the same as that of Fig. 2(b) except that the input current is applied to port Y of the first ICCII instead of port X.

$$\frac{I_{LP}}{I_i} = \frac{R}{s^2 C_1 C_2 R_1 R_2 R + sC_2 R_1 R_2 + R} \tag{9}$$

It has the same characteristic equation as the circuit of Fig. 2(b) and the design equations are the same. This is an noninverting low-pass filter with a unity DC gain.

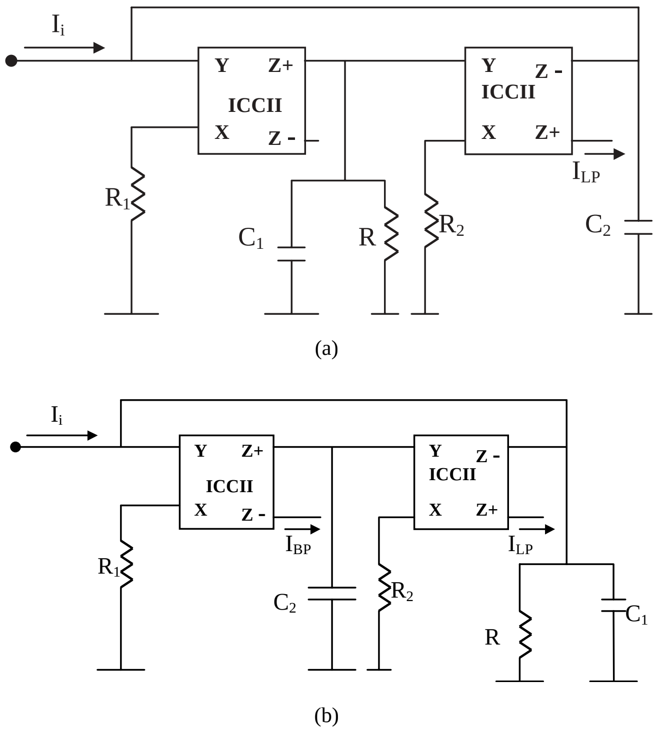


FIGURE 3
(a) Grounded resistor grounded capacitor low-pass filter and (b) grounded resistor grounded capacitor band-pass low-pass filter.

The circuit of Fig. 3(b) is slightly different and it realizes both low-pass and band-pass responses at two different outputs. The transfer function of the band-pass response is given by:

$$\frac{I_{BP}}{I_i} = \frac{sC_2R_2R}{s^2C_1C_2R_1R_2R + sC_2R_1R_2 + R} \tag{10}$$

The design equations are the same as given by equation (8). The band-pass and low-pass responses are both non-inverting with gain at ω_o given by Q.

4 SIMULATION RESULTS

Spice simulation results using technology SCN 05 feature size 0.5 µm from MOSIS vendor: AGILENT and using the CMOS ICCII of Fig. 1(b) [1] with the aspect ratios shown in Table 1 and with $V_{DD} = 1.5\,\text{V}$, $V_{SS} = -1.5\,\text{V}$, $V_{B1} = -0.52\,\text{V}$ and $V_{B2} = 0.33\,\text{V}$.

NMOS transistors	$W(\mu m)/L(\mu m)$
M_1, M_2, M_3, and M_4	25/0.5
M_5 and M_6	8/0.5
M_{12}, M_{13}, M_{14}, M_{15}, and M_{16}	20/2.5
PMOS Transistors	$W(\mu m)/L(\mu m)$
M_7 and M_8	10/0.5
M_9, M_{10}, M_{11}, M_{17}, and M_{18}	40/2

TABLE 1
Aspect ratios of the MOS transistors in the balanced output ICCII

All circuits are simulated with $f_o = 1\,\text{MHz}$, and $Q = 10$ for band-pass responses and $Q = 0.707$ for low-pass maximally flat magnitude response.

For the circuit of Fig. 2(a) the design values taken are $C_1 = 10\,\text{PF}$, $C_2 = 100\,\text{PF}$, $R_1 = 1.592\,\text{k}\Omega$ and $R_2 = 15.92\,\text{k}\Omega$.

For the circuit of Fig. 2(b) the design values taken are $C_1 = C_2 = 100\,\text{PF}$, $R_1 = R_2 = 1.592\,\text{k}\Omega$ and $R = 15.92\,\text{k}\Omega$.

For the circuit of Fig. 3(a) same values as for the circuit of Fig. 2(b) except $R = 1.126\,\text{k}\Omega$.

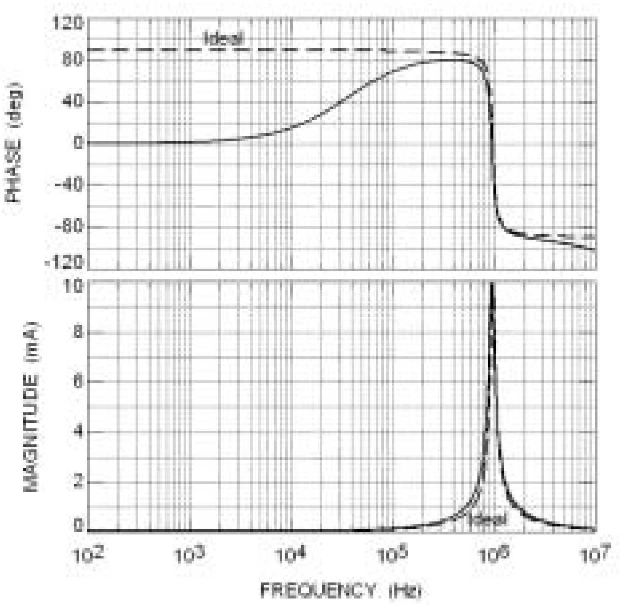
For the circuit of Fig. 3(b) same values as the circuit of Fig. 2(b) for band-pass response and same values as the circuit of Fig. 3(a) for low-pass response.

For all simulations it is seen that the simulated results agree well with the ideal responses.

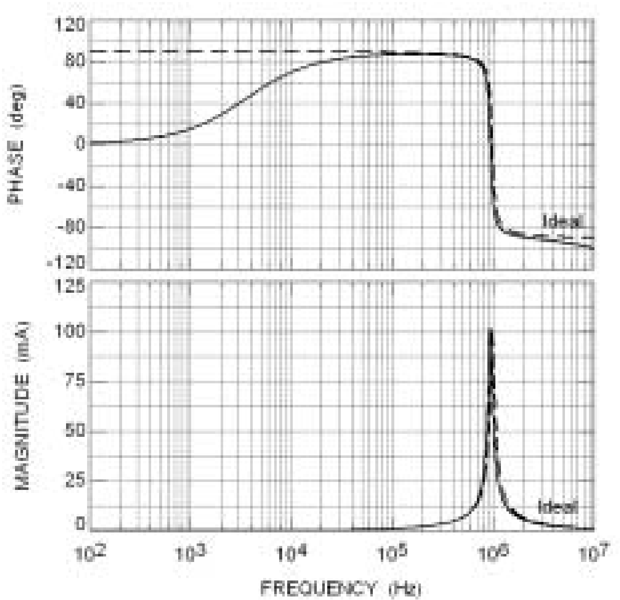
5 CONCLUSIONS

Four new grounded capacitor current mode filters with high output impedance and using two balanced output Inverting current conveyors (ICCII) are introduced. The circuits are classified to two classes, in class one the input current is injected at port X of the ICCII .In class two the input is applied to port Y of the ICCII. All reported circuits employ grounded resistors also except one minimal passive component circuit which uses one floating resistor. Spice simulation results for the four proposed circuits showing close agreement with the ideal responses are given.

It is worth noting that input currents can be injected at different ports of the proposed circuit of Fig. 3(b) resulting in desirable responses. Recently the current mode filter of Fig. 4(a) published in [7] using two output CCII with realization 3 in Table 2 of [7] was republished in [12,13] with multiple input currents to obtain different responses. Of course adding input currents to any circuit does not change the characteristic equation of the circuit which is its identity.



(a)



(b)

FIGURE 4
(a) The magnitude and phase characteristics of the band-pass filter of Fig. 2a and (b) the magnitude and phase characteristics of the band-pass filter of Fig. 2b.

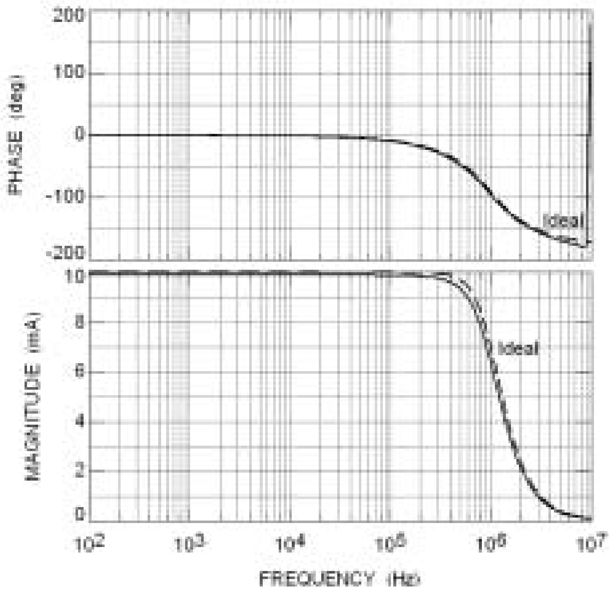
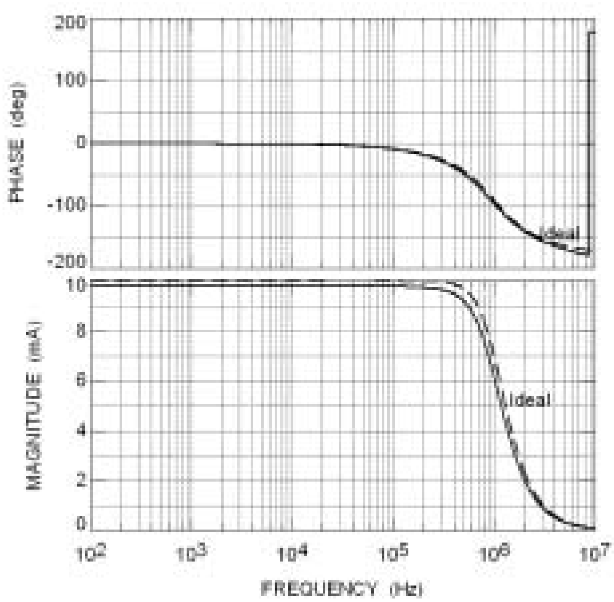
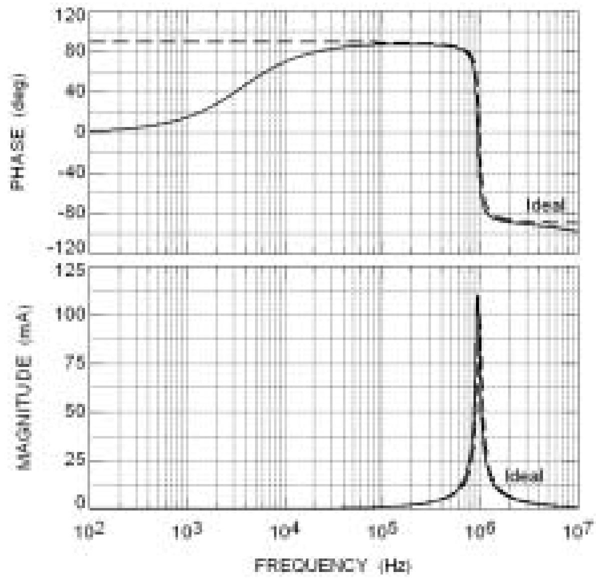


FIGURE 5
The magnitude and phase characteristics of the low-pass filter of Fig. 3a.



(a)

FIGURE 6
(Continued.)



(b)

FIGURE 6
(a) The magnitude and phase characteristics of the low-pass filter of Fig. 3b and (b) the magnitude and phase characteristics of the band-pass-pass filter of Fig. 3b.

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