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LETTER TO THE EDITOR

Current mode filters using two output inverting CCII

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SUMMARY

Current mode Tow Thomas filter using two-output inverting second-generation current conveyor is given, the circuit has low input impedance, employs two grounded capacitors and three grounded resistors and has independent control on Q. A universal current mode filter capable of realizing the five filter functions is also given. Both circuits have low sensitivities to all circuit components. Spice simulation results are included. Copyright © 2007 John Wiley & Sons, Ltd.

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1. INTRODUCTION

The inverting second-generation current conveyor (ICCII) was first introduced in [1] as a new block to be added to the current conveyor family. The ICCII is considered to be a special case from the differential difference current conveyor introduced in [2] which has also been independently introduced and defined in [3] as the differential voltage current conveyor (DVCC). This active three-port circuit can be easily implemented with CMOS technology as given in [1–3].

The symbolic representation of the ICCII is shown in Figure 1. The relationship between terminal voltages and currents is given by the following matrix equation [1]:

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

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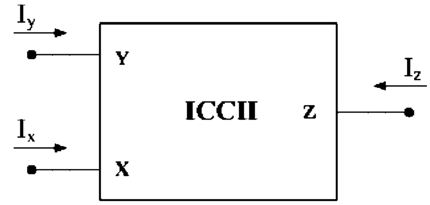

Figure 1. The symbolic representation of the ICCII.

The voltage at terminal X is the inverted version of the voltage at terminal Y. The current at terminal Z follows the current at terminal X in magnitude. In Equation (1), the ± 1 specifies the type of the current conveyor (ICCII+ or ICCII−). 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.

2. THE CURRENT MODE FILTER USING THE DVCC [2]

The first current mode filters using the DVCC were introduced in the literature in [2, 3].The filter given in [3] 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, an RC-active filter was proposed which is non-canonic as it uses three capacitors. It is of interest to review briefly this current mode filter which is shown in Figure 2(a). In [2], the circuit inside the dotted box was identified as simulated inductor. It is in fact a simulated frequency-dependent negative resistance (FDNR) as indicated in Figure 2(a). It can be easily seen that the input impedance of the FDNR at port X of the first DVCC is given by

$$Z_{\text{in}} = \frac{1}{s^2 C_2 C_3 R_2} \tag{2}$$

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 current followers are needed. Note also that the current in C_2 is of high-pass nature. To keep the capacitor C_2 grounded, this current cannot be utilized unless a two-output DVCC is used. The Q factor is independently controlled by the capacitor C_1.

It is of interest to return back to this circuit and to apply the RC:CR transformation [4] to obtain the original parallel RCL circuit which is shown here in Figure 2(b). This circuit also realizes band-pass and low-pass currents as shown and also needs additional current followers for practicality. Note also that the current in C_1 is of high-pass nature. To keep the capacitor C_1 grounded this current cannot be utilized.

It is important to consider the gyrator circuit that realizes the inductance; it is shown separately in Figure 2(c), for which the gyrator open circuit impedance matrix equation is given by

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} 0 & -R_3 \\ R_2 & 0 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \tag{3}$$

The simulated inductance obtained when port 2 of the gyrator is terminated by the capacitor C_2 given by $L = C_2 R_2 R_3$.

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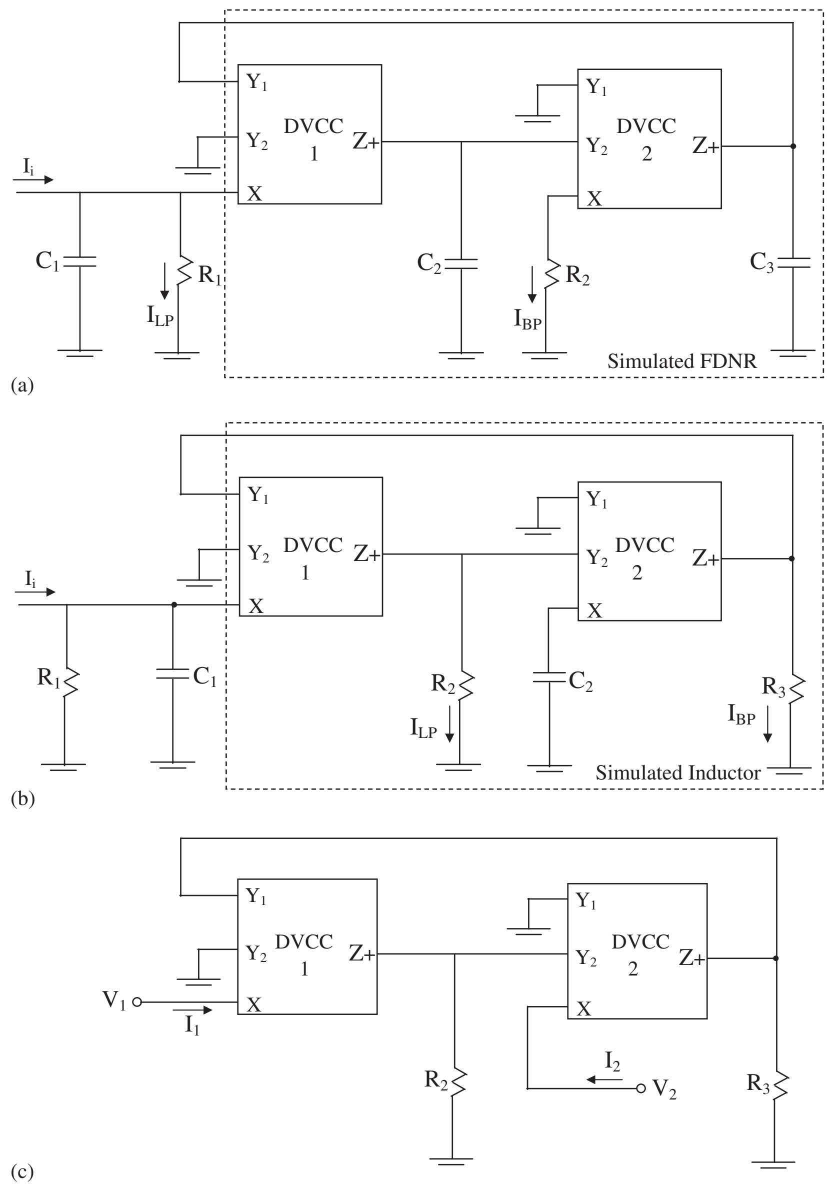

Figure 2. (a) DVCC-based current mode filter [2]; (b) DVCC-based current mode filter derived from (a) using RC:CR transformation; and (c) the gyrator circuit obtained from (b).

This gyrator uses the *X* terminals of the two DVCC as its two ports, this makes it limited to low-frequency applications [5]. It should be noted that this gyrator type is also realizable with two opposite polarity current conveyors [6].

Although the circuit of Figure 2(b) uses only two capacitors instead of three as in Figure 2(a), it has the disadvantage that the capacitors are connected to the *X* terminals of the DVCC which

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degrades the circuit performance at high frequencies since the parasitic resistance R_X of the X terminal will be in series with the capacitor C_2 thus affecting the circuit performance [5].

On the other hand, the RC:CR [4] transformed circuit from Figure 2(c) which is used in Figure 2(a) [2] is more practical. The circuit in this case provides a new realization of the D:R mutator [7] using two DVCC and two capacitors.

A disadvantage of both of the circuits of Figure 2(a) and (b) is that the input impedance is finite and is frequency dependent.

Although the realization of the well-known Tow Thomas (TT) [8, 9] voltage mode filter using the DVCC was given in [2], the current mode version, however, of the TT filter was not mentioned in [2]. Recently, a current mode TT using a single-output ICCII has been introduced [10]. In the next section a modified version of this current mode TT filter using two-output ICCII is given.

3. TT FILTER USING TWO-OUTPUT ICCII

Figure 3 represents the current mode non-inverting band-pass and non-inverting low-pass filter using one ICCII− and two balanced output ICCII. The circuit has the advantage of having low input impedance and high output impedance at both output Z ports.

The current transfer functions are given by

$$\frac{I_{\text{BP}}}{I_i} = \frac{\frac{s}{C_1 R_1}}{D(s)}, \quad \frac{I_{\text{LP}}}{I_i} = \frac{\frac{1}{C_1 C_2 R_1 R_2}}{D(s)} \tag{4}$$

$D(s)$ is given by

$$D(s) = s^2 + \frac{1}{C_1 R} s + \frac{1}{C_1 C_2 R_1 R_2} \tag{5}$$

The ω_0 and the Q of the filter are given by

$$\omega_0 = \sqrt{\frac{1}{C_1 C_2 R_1 R_2}}, \quad Q = R\sqrt{\frac{C_1}{C_2 R_1 R_2}} \tag{6}$$

It is seen that the resistor R controls Q of the filter without affecting ω_0.

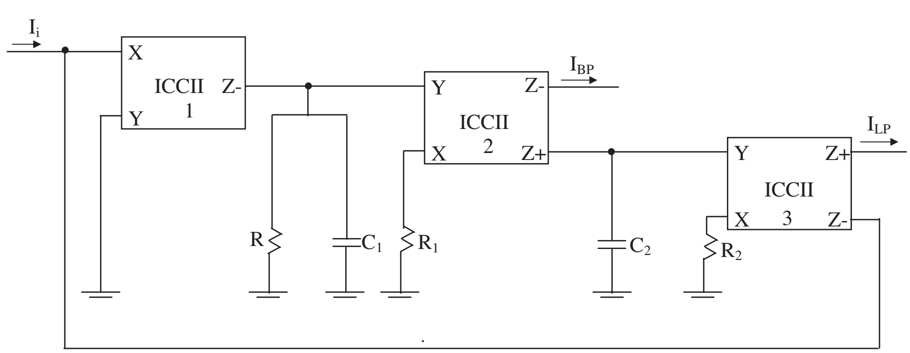

Figure 3. Current mode Tow Thomas biquad using three ICCII.

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The ω_0 and Q sensitivities to all circuit components are low.

Three more TT filters can be obtained from Figure 3 with different Z polarity combinations of the three ICCIIs.

It is worth noting that similar circuits with the CCII are available in the literature [11, 12]. Although the CCII circuits and the ICII circuits are equivalent and have identical block diagrams, the physical realization is different as the CMOS realization of the ICCII is different from that of the CCII.

The circuit of Figure 3, however, does not realize a high-pass response. If the RC:CR transformation is applied to the circuit of Figure 3 to realize a high-pass current in place of the low-pass current the circuit becomes limited to low frequencies as it will have two capacitors connected to the X ports of the second and third ICCII.

In the following section, a universal current mode filter is given.

4. UNIVERSAL FILTER USING TWO-OUTPUT ICCII

A current mode universal filter is given in this section. The proposed circuit has low input impedance, high output impedances at all output terminals and has independent control on Q. Figure 4 represents the universal current mode filter, it uses three balanced output ICCII and one double output ICCII and is canonic as it uses only two capacitors. The current transfer functions are given by

$$\frac{I_{\mathrm{HP}}}{I_i} = \frac{s^2}{D(s)}, \quad \frac{I_{\mathrm{BP}}}{I_i} = \frac{-\dfrac{s}{C_1 R_1}}{D(s)}, \quad \frac{I_{\mathrm{LP}}}{I_i} = \frac{\dfrac{1}{C_1 C_2 R_1 R_2}}{D(s)}, \quad \frac{I}{I_i} = \frac{-\dfrac{s}{C_1 R}}{D(s)} \tag{7}$$

$D(s)$ is the same as given by Equation (5).

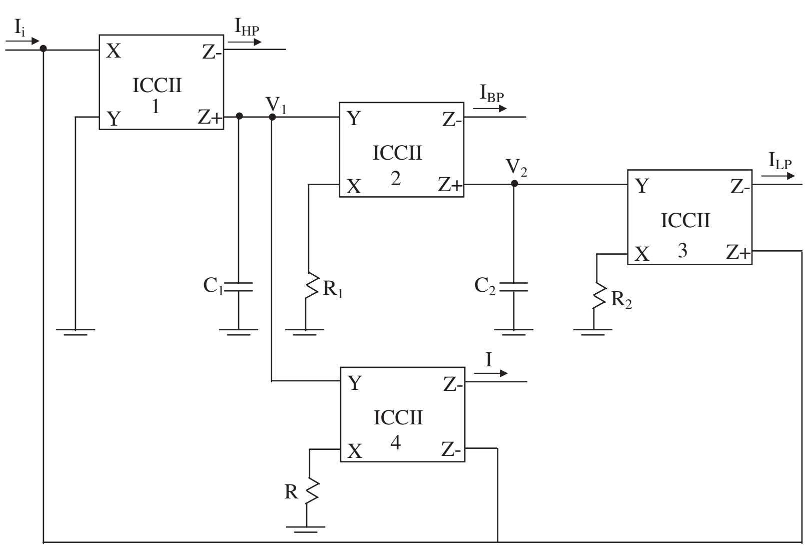

Figure 4. Current mode universal filter using four two-output ICII.

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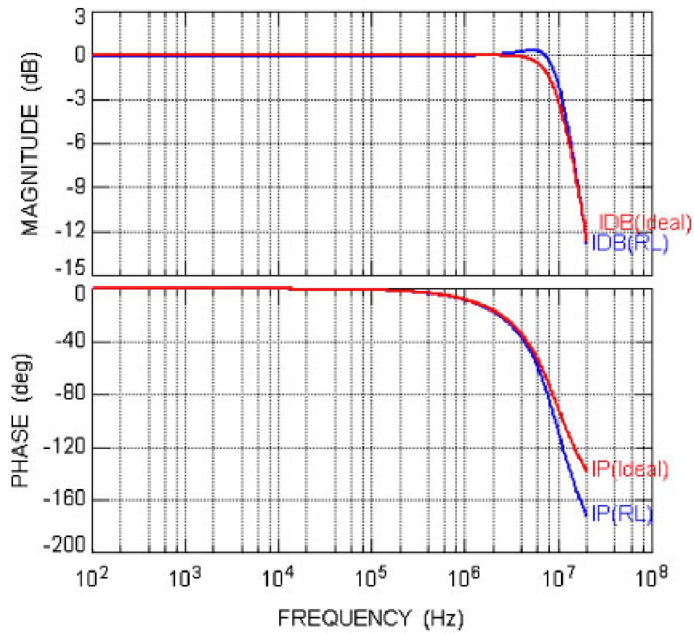

Figure 5. Magnitude and phase characteristics of the low-pass filter of Figure 3.

An equivalent current mode universal filter can be obtained from the circuit of Figure 4 by interchanging the Z terminals of the second ICCII and of the third ICCII as well.

5. SPICE SIMULATIONS

Spice simulations with 0.5 μm CMOS transistors model have been carried out for the circuit of Figure 3 using the ICCII given in [3] and biased with ±1.5 V. The low-pass filter is designed for $f_0 = 10\,\text{MHz}$ and $Q = 0.707$, taking $C_1 = C_2 = 10\,\text{pf}$, $R_1 = R_2 = 1.59\,\text{k}\Omega$ and $R = 1.125\,\text{k}\Omega$. Figure 5 represents the magnitude and phase responses that are very close to the ideal ones.

6. CONCLUSIONS

A current mode Tow Thomas (TT) filter is generated from the voltage mode TT circuit and uses three ICCIIs. The current mode circuit has low input impedance, employ grounded capacitors and has independent control on Q. The circuit uses one single output ICCII and two balanced output ICCIIs.

A universal current mode filter capable of realizing all the five filter functions and using four ICCIIs is also given. It is worth noting that all circuits reported in this paper employ grounded capacitors. Circuit configurations employing only grounded capacitors [13] are very attractive and are desirable for integrated circuit technology. Spice simulation results demonstrate good agreement with the ideal filter characteristics.

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