NOVEL CCI-OTA-BASED GROUNDED CAPACITOR CURRENT-MODE BIQUADRATIC BANDPASS AND LOWPASS FILTERS

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A novel current-mode active filter topology using a first generation current conveyor (CCI) and an operational transconductance amplifier (OTA) is presented. Using this topology, grounded-capacitor biquadratic bandpass and lowpass filter sections, with at most five one-port passive elements, are realized. In these realizations, the parameter ω_o can be adjusted without disturbing the parameter ω_o/Q_o.

1. INTRODUCTION

In active-RC circuits, it is highly desirable to have all the capacitors grounded [1–8] for several reasons. First, grounded capacitors are suitable for monolithic IC technology [9–11] and thin film fabrication [2]. In thin film fabrication, if the capacitors are grounded, the etching process is eliminated and the number of contacts is reduced. Also, the parasitic capacitors surrounding the capacitors can be easily accounted for or tuned out as they are now in parallel with the grounded capacitors [3]. Secondly, in CMOS technology, the use of grounded capacitors is an advantage as the bottom plate parasitic capacitor is eliminated altogether and the top plate parasitic capacitor can be accounted for easily as it becomes parallel to the main capacitance [12]. This explains the considerable interest in designing active-RC circuits with grounded capacitors [1, 3, 5, 6, 13].

On the other hand, at present there is a growing interest in designing analog current-mode signal processing circuits. This is attributed to the higher bandwidth, greater linearity, and larger dynamic range obtainable compared to their voltage-mode counterparts. The current-conveyor (CC), a powerful analog building block with a current-mode capability and the operational transconductance amplifier (OTA) is basically a differential voltage-controlled current source. CCs are, therefore, highly potential candidates for implementing current-mode filter sections, and recently a number of realizations using the first-generation current-conveyor (CCI), the second-generation current-conveyor (CCII), and the OTA have been presented [14–25].

In most of the CC-based realizations, bandpass and lowpass biquadratic filters require at least two capacitors; one of them floating [14–19]. Moreover, in most of these realizations, the output current exhibiting bandpass/lowpass realization

has to be taken out through another CC. Thus, at least two active elements are required. In some CC-based realizations, bandpass and lowpass biquadratic filters are realized using at least two grounded capacitors [20–24]. The circuit proposed by Fabre et al [20] requires four, one-port passive RC elements; two grounded capacitors and two resistors, and two CCs. An additional CC is required to take out the output current. Moreover, the CCs are different; one CCI and the other CCII. The circuit proposed by Chang [21] requires six one-port passive RC elements; two grounded capacitors and four resistors, and one CCII. An additional CC is also required to take out the output current. The circuit proposed by Cang and Chen [22] requires eight one-port passive EC elements; two grounded capacitors and six resistors, and five CCIIs. The circuit proposed by Chang and Chen [23] requires eight one-port passive RC elements; three grounded capacitors and five resistors, and five CCIIs. The circuit proposed by Senani [24] requires six passive one-port elements; two grounded capacitors and four grounded resistors, two CCII−, four CCI− and one CCII+.

The OTA-based bandpass and lowpass realizations [25] requires three grounded one-port passive elements; two capacitors and one resistor, and five OTAs.

In the available literature no attempt has been reported to combine CC and OTA in a current-mode biquadratic filter realization.

It is the major intention of this paper to present a CCI-OTA-based low-component current-mode lowpass and bandpass biquadratic filter realizations. The proposed realizations use at most five one-port passive elements; two (or three) grounded capacitors and three (or two) resistors, one CCI+ and one OTA.

2. PROPOSED CIRCUIT

Consider the circuit shown in Fig. 1. Assuming ideal CCI and OTA with

$$I = g_m(V^+ - V^-), \qquad I_x = I_y = I_z, \qquad V_x = V_y$$

routine analysis yields

$$\frac{I_o}{I_i} = \frac{Z_2 Z_3 (1 + g_m Z_1)}{Z_3(Z_1 + Z_2 + g_m Z_2 Z_4) - Z_4(Z_1 + Z_2 + Z_3)} \tag{1}$$

where the current $I_o = -I_z$ is directly obtained through the z-port of the CCI.

In the following subsections it will be shown that bandpass (BP) and lowpass (LP) biquadratic filter transfer functions can be obtained from eqn. (1).

2.1. Bandpass Realization

If we choose

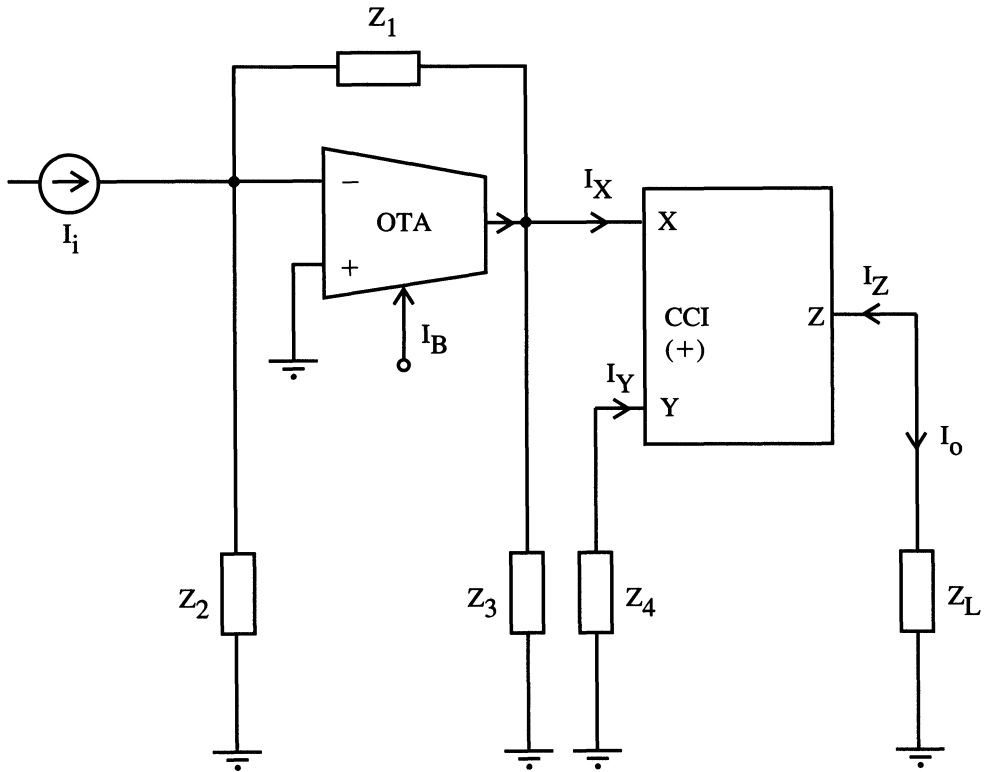$$Z_1 = R_1, \qquad Z_2 = \frac{1}{sC_2}, \qquad Z_3 = \infty, \qquad Z_4 = \frac{1}{sC_4}$$

FIGURE 1   Proposed current-mode achre filter using OTA and CCI.

Eqn. (1) reduces to

$$H_1(s) = \frac{I_o}{I_i} = \frac{sC_4(1 + g_mR_1)}{g_m + s(C_4 - C_2) + s^2C_2C_4R_1} = \frac{\alpha s}{s^2 + \frac{\omega_o}{Q_o}s + \omega_o^2} \qquad (2)$$

which corresponds to the transfer function of a bandpass filter with the parameters

$$\omega_o^2 = \frac{g_m}{C_2C_4R_1} \qquad (3)$$

$$\alpha = \frac{1 + g_mR_1}{C_2R_1} \qquad (4)$$

and

$$\frac{\omega_o}{Q_o} = \frac{C_4 - C_2}{C_2C_4R_1} \qquad (5)$$

This bandpass filter realization requires only three one-port passive elements; two grounded capacitors and one resistor. Also, the parameter ω_o can be tuned by adjusting g_m without disturbing the parameter ω_o/Q_o. By choosing $C_4 \gg C_2$ it is easy to show that the sensitivities of ω_o and ω_o/Q_o to the active and passive components are given by

$$|S_{x_i}^{\omega_o}| = |S_{x_i}^{\omega_o/Q_o}| = \tfrac{1}{2}$$

2.2. Bandpass and Lowpass Realizations

If we choose

$$Z_1 = \infty, \qquad Z_2 = R_2, \qquad Z_3 = \frac{R_3}{1 + sC_3R_3}, \qquad Z_4 = R_4 + \frac{1}{sC_4}$$

eqn. (1) reduces to

$$H_2(s) = \frac{I_o}{I_i} = \frac{-sC_4g_mR_2R_3}{1 + s(C_3R_3 + C_4R_4 - C_4R_3) + s^2C_3C_4R_3R_4}$$

$$= \frac{\beta s}{s^2 + \dfrac{\omega_o}{Q_o} s + \omega_o^2} \tag{6}$$

which corresponds to the transfer function of a bandpass filter with the parameters

$$\omega_o^2 = \frac{1}{C_3C_4R_3R_4} \tag{7}$$

$$\beta = \frac{g_mR_2}{C_3R_4} \tag{8}$$

$$\frac{\omega_o}{Q_o} = \frac{C_3R_3 + C_4R_4 - C_4R_3}{C_3R_3C_4R_4} \tag{9}$$

If we choose $R_3 = R_4$ eqn. (9) reduces to

$$\frac{\omega_o}{Q_o} = \frac{1}{C_4R_4} \tag{10}$$

This bandpass filter realization requires five one-port passive elements; two grounded capacitors and three resistors. From eqn. (7) and eqn. (10), it is obvious that the parameter ω_o can be tuned by adjusting C_3 without disturbing the parameter ω_o/Q_o. The gain of this bandpass realization can be adjusted by changing the parameter g_m and/or the resistance R_2 without disturbing the parameters ω_o and ω_o/Q_o. It is easy to show that the sensitivities of the parameters ω_o and ω_o/Q_o to passive components are low.

If we choose $Z_2 = 1/sC_2$ instead of $Z_2 = R_2$, eqn. (1) reduces to

$$H_3(s) = \frac{I_o}{I_i} = \frac{C_4 g_m R_3/C_2}{1 + s(C_3 R_3 + C_4 R_4 - C_4 R_3) + s^2 C_3 C_4 R_3 R_4}$$

$$= \frac{\gamma}{s^2 + \dfrac{\omega_o}{Q_o} s + \omega_o^2} \tag{11}$$

which corresponds to the transfer function of a lowpass filter with the parameters ω_o^2 and ω_o/Q_o the same as in eqn. (7) and eqn. (8) and the parameter γ is given by

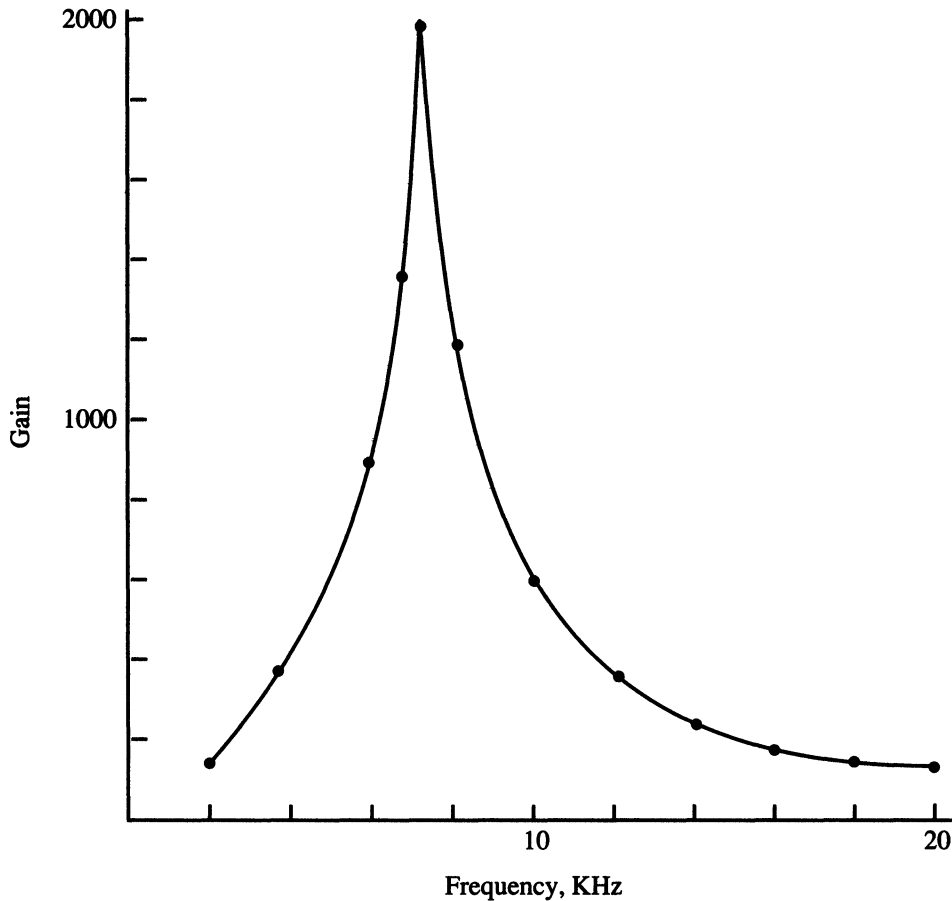$$\gamma = \frac{C_4}{C_2} g_m R_3 \tag{12}$$

FIGURE 2 Characteristics of the BPF of Eqn. (2) ————: Calculated (eqn. (2)), ●: Simulated.

This lowpass filter realization requires three grounded capacitors and two resistors. By selecting $R_3 = R_4$ or $C_3 = C_4$, it is easy to see that the parameters ω_0^2 and ω_0/Q_0 are not interdependent; that is, the parameter ω_0^2 can be tuned without disturbing the parameter ω_0/Q_0. The gain of this lowpass realization can be adjusted by changing the parameter g_m and/or the capacitance C_2 without disturbing the parameters ω_0 and ω_0/Q_0.

4. SIMULATION RESULTS

All the current transfer functions presented in this paper have been verified using IS-SPICE simulations based on the translinear CC implementations of Fabre et al. [20]. Fig. 2 shows the simulated and calculated current transfer functions of the bandpass filter realization of eqn. (2). From Fig. 2, it is obvious that the agreement between simulated and calculated results appears to be good.
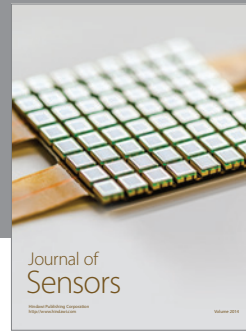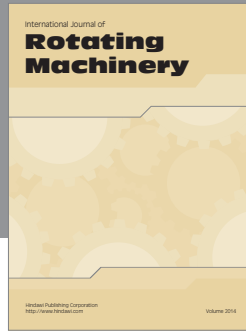
5. CONCLUSION

In this paper a new topology for realizing current mode bandpass and lowpass biquadratic filters has been presented. This topology uses an operational trans-conductance amplifier, a first generation current conveyor, and five one-port passive elements at most. In the resulting lowpass and bandpass realizations, the parameters ω_0^2 can be tuned without disturbing the parameter ω_0/Q_0. In one of the realizations, the gain of the lowpass and bandpass filters can be adjusted without disturbing the other parameters of the filters. The proposed lowpass and bandpass realizations enjoy low active and passive sensitivities. In all the proposed realizations, the capacitors are grounded; this is an attractive feature for integration.

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