PROGRAMMABLE CF-OTA-BASED LOWPASS AND BANDPASS FILTERS

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A new circuit is proposed for realizing lowpass and bandpass filter responses. The circuit uses one current-follower and one operational transconductance amplifier. The circuit enjoys low temperature sensitivities, high input impedance and its important parameters are electronically programmable. The use of grounded capacitors is an additional attractive feature for integration. Simulation results confirming the theory presented are included.

INTRODUCTION

At present there is a growing interest in designing current-follower (CF)-based biquad filters [1,2]. This is attributed to their wide bandwidth and accurate performance. Moreover, the CF has only the current tracking error. This makes CF-based realizations more attractive than second-generation-current-conveyor (CCII)-based realizations which, in addition to the current-tracking error, suffer also from the voltage tracking error. However, the CF-based biquad filter realizations available in the literature [1,2] can not be cascaded to produce higher-order filters. Moreover, the important parameters, such as the pole frequency (ω_o) and the pole-Q (Q_o) are not programmable. On the other hand, the operational-transconductance-amplifier (OTA) can be utilized for the realization of active filters with electronic tunability over a wide range of control current (or voltage) [3,4]. This is attributed to the dependence of the OTA-transconductance (g_m) on the auxiliary bias current. However, the resulting active-filter structures, usually using a pair of OTAs, suffer from relatively high temperature-sensitivities [3,4].

In this paper, an OTA-CF-based lowpass and bandpass biquad filter circuit is proposed. The circuit uses a single OTA and enjoys relatively low temperature sensitivity. The circuit has a high input-impedance and, therefore, is cascadable to produce higher-order filters. Moreover, the important parameters ω_o and Q_o are programmable. Furthermore, the proposed circuit uses two grounded capacitors. These are attractive features for integration.

PROPOSED CIRCUIT

Consider the circuit shown in Fig. 1. Assuming ideal CF with $i_x = i_y$ and ideal OTA with $i = g_m(v_+ - v_-)$ where $g_m = \frac{I_{ABC}}{2V_T}$ is the transconductance of the OTA, I_{ABC} is the auxiliary bias current of the OTA, V_T is the terminal voltage, and v_+ and

v_- are the positive and negative input voltages of the OTA, routine analysis of the circuit of Fig. 1 shows that

$$\frac{V_{o1}}{V_i} = \frac{Gg_m/C_1C_2}{s^2 + sG/C_1 + Gg_m/C_1C_2} \quad (1)$$

and

$$\frac{V_{o2}}{V_i} = \frac{sg_m/C_1}{s^2 + sG/C_1 + Gg_m/C_1C_2} \quad (2)$$

Equation (1) corresponds to the transfer function of a lowpass filter and equation (2) corresponds to the transfer function of a bandpass filter. From (1) and (2) one can see that the important parameters of the filters are given by

$$\omega_o^2 = Gg_m/C_1C_2 = \frac{GI_{ABC}}{2C_1C_2V_T} \quad (3)$$

$$Q_o = (g_mC_1/GC_2)^{1/2} = (I_{ABC}C_1/2GC_2V_T)^{1/2} \quad (4)$$

and

$$Bandwidth = \frac{\omega_o}{Q_o} = G/C_1 \quad (5)$$

From (3)-(5), one can see that ω_o and Q_o can be tuned by adjusting the parameters g_m without affecting the bandwidth. This is an attractive feature in bandpass filter realization. It is interesting also to note that a similar result can be obtained by adjusting the grounded capacitor C_2 .

Sensitivity Analysis

By defining the passive sensitivity of a parameter F to the element of variation x_i by

$$S_{x_i}^F = \frac{dF}{dx_i} \frac{x_i}{F}$$

it is easy to show that the sensitivity of the parameters ω_o and Q_o to the variations in passive elements are given by

$$S_R^{\omega_o} = S_{C_1}^{\omega_o} = S_{C_2}^{\omega_o} = -\frac{1}{2}$$

$$S_{C_1}^{Q_o} = S_R^{Q_o} = S_{C_2}^{Q_o} = \frac{1}{2}$$

Similarly, the temperature-sensitivity of ω_o and Q_o can be expressed by

$$S_T^{\omega_o} = S_T^{Q_o} = \frac{1}{2}$$

Thus the ω_o and Q_o sensitivities to passive-elements and temperature are low.

Effect of CF Non-idealities

The effect of CF-non-idealities on the performance of the biquad filter circuit of Fig. 1 can be studied by assuming that the characteristic of a CF with current tracking error can be described by

$$i_y = ki_x, k = 1 - \epsilon, |\epsilon| \ll 1$$

Reanalysis of the circuit of Fig. 1 shows that

$$\frac{V_{o1}}{V_i} = \frac{kGg_m/C_1C_2}{s^2 + sG/C_1 + kGg_m/C_1C_2} \quad (6)$$

and

$$\frac{V_{o2}}{V_i} = \frac{sg_m/C_1}{s^2 + sG/C_1 + kGg_m/C_1C_2} \quad (7)$$

From (6) and (7), one can see that, due to the current-tracking error, the important parameters ω_o and Q_o of the lowpass and the bandpass filters become

$$\omega_o^2 = kGg_m/C_1C_2 \quad (8)$$

$$Q_o = (kGg_m/C_1C_2)^{1/2} \quad (9)$$

FIGURE 1 Proposed lowpass and bandpass biquad filter.

and

$$bandwidth = \frac{\omega_o}{Q_o} = G/C_1 \quad (10)$$

From (8)-(10), one can see that while the parameters ω_o and Q_o are slightly affected by the current-tracking error, the bandwidth is not affected.

SIMULATION RESULTS

The biquad filters proposed in this paper have been checked using PSPICE Evaluation Version 5.4. Although there are several ways to simulate the CF required, the simulation was performed using a second-generation current-conveyor (CCII). The CF can be obtained using a CCII with its high impedance terminal grounded. The CCII was simulated using the circuit proposed by Senani [5] because of its simplicity. The kernel of the work presented here is independent of the particular simulation selected. The CCII was simulated using one OTA, one resistor and one operational amplifier (OA) as shown in Fig. 2. The OA was simulated using the uA741 model contained in the file called EVAL.LIB available in the PSPICE Evaluation Version. The OTA was simulated assuming a finite input resistance of 2 M Ω . Figs. 3 and 4 show the simulated results obtained from a lowpass and a bandpass filter realization. The simulation results appear to be in good agreement with the theory presented.

CONCLUSION

In this paper, a new CF-OTA-based lowpass and bandpass filter realization has been presented. The proposed circuit uses one CF, one OTA, one floating resistor, and two grounded capacitors. The circuit has a high input impedance and is, therefore, cascadable to produce higher order filter realizations. The important parameters of the filters, ω_o and Q_o are programmable by adjusting the transconductance of the OTA. Thus, current(voltage) digital programming of these

FIGURE 2 CF realization used in simulation, $g_{mo} R_O = 1$.

FIGURE 3 Simulated and calculated response of a BPF designed with: $g_m = 3.9$ mmho, $R = 998.3$ ohm, $C_1 = 10.414$ nF, $C_2 = 10.031$ nF • Calculated, eqn. (2) ----- simulated.

FIGURE 4 Simulated and calculated response of a LPF designed with: $g_m =$ mmho, $R = 998.3$ ohm, $C_1 = 10.03$ nF, $C_2 = 42.17$ nF • Calculated, eq. (1) ----- simulated.

parameters is feasible. The use of grounded capacitors is another attractive feature for integration. The CF current-tracking error has a slight effect on the parameters ω_o and Q_o and does not affect the bandwidth (ω_o/Q_o).

It is worth mentioning here that the proposed circuit can realize lowpass and bandpass biquad filter responses. Other responses, such as highpass, allpass, and notch, are also realizable by using an additional summing circuit [6].

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