A new universal voltage-mode active-filter with single input and five outputs is presented. The parameters of the proposed filter are programmable and the filter uses grounded capacitors and resistors. The proposed circuit can simultaneously realize lowpass, highpass, bandpass, allpass, and notch biquadratic filter functions and enjoys low temperature sensitivities.

INTRODUCTION

At present, there is a growing interest in designing universal current-mode and voltage-mode active filters. Thus, a number of circuit realizations, for universal current-mode and voltage-mode filters, using current-conveyors or operational-transconductance-amplifiers (OTAs) were proposed [1–17]. A critical study shows that while some of the proposed circuits use grounded resistors and capacitors [1–6,11–13], other circuits use floating resistors and/or capacitors [7–10,15–17]. The majority of the proposed circuits can realize all the basic biquadratic filter functions, that is, lowpass, highpass, bandpass, allpass and notch. However, in most of the circuits, this can not be achieved simultaneously. Moreover, while the filter parameters in current-conveyor-based circuits are not programmable, in OTA-based circuits these parameters are programmable. This is attributed to the dependence of the OTA-transconductance ($g_m$) on the auxiliary bias-current $I_{ABC}$. However, because the auxiliary-bias-current is temperature-dependent, the parameters of the resulting active-filter structures suffer from relatively high temperature sensitivities.

As an illustrative example, consider the circuit proposed by Chang [1]. While the circuit can simultaneously realize lowpass, highpass, and bandpass functions, to obtain an allpass function it is necessary to connect the three output currents. Similarly, to obtain a notch function it is necessary to connect the highpass and the lowpass output currents. Thus, the five basic filter functions can not be realized simultaneously. While the circuit has the advantage of using grounded resistors and capacitors, its parameters are not programmable.

It is the major intention of this paper to explore the feasibility of designing programmable universal filters with relatively low temperature sensitivities. Also, it would be attractive for integration if a proposed implementation can be realized using grounded resistors and capacitors while enjoying high input impedance and independent control of the filter parameters.
PROPOSED CIRCUIT

The proposed circuit is shown in Fig. 1. Using the standard notation, the characteristics of the current conveyors can be described by \(i_x = \pm i_z, i_y = 0, v_x = v_y\) for the CCII± and \(i_o = g_m(v_+ - v_-)\) for the OTA, where \(g_m = I_{ABC}/2V_T\) is the transconductance of the OTA, \(I_{ABC}\) is the auxiliary bias-current of the OTA, \(V_T = kT/q\) is the thermal voltage, \(k\) is the Boltzman constant, \(T\) is the temperature, and \(v_+\) and \(v_-\) are the input voltages of the OTA. Routine analysis of the circuit yields the following transfer functions

\[
\frac{V_{BPF}}{V_i} = \frac{-(g_m/C_1)s}{s^2 + s/C_1 R_1 + g_m/C_1 C_2 R_1}
\]

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\]
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\[ V_{LPF} = \frac{g_m/R_1C_1C_2}{s^2 + s/C_1R_1 + g_m/C_1C_2R_1} \]  \hspace{1cm} (2)

\[ V_{HPF} = \frac{s^2g_mR_3C_3/C_1}{s^2 + s/C_1R_1 + g_m/C_1C_2R_1} \]  \hspace{1cm} (3)

If we choose \( R_4/R_6 = g_mR_3C_3/C_1 \) and \( R_5 = R_6 \) then

\[ \frac{V_{notch}}{V_i} = \frac{s^2 + g_m/C_1C_2R_1}{s^2 + s/C_1R_1 + g_m/C_1C_2R_1} \]  \hspace{1cm} (4)

And if we choose \( g_mR_1 = R_8/R_9 \) and \( R_7 = R_9 \) then

\[ \frac{V_{notch}}{V_i} = \frac{s^2s/R_1C_1 + g_m/C_1C_2R_1}{s^2 + s/C_1R_1 + g_m/C_1C_2R_1} \]  \hspace{1cm} (5)

Equation (1) corresponds to the transfer function of a bandpass filter, equation (2) corresponds to the transfer function of a lowpass filter, equation (3) corresponds to the transfer function of a highpass filter, equation (4) corresponds to the transfer function of a notch filter, and equation (5) corresponds to the transfer function of an allpass filter.

From (1)–(5), one can see that the parameters \( \omega_o^2 \) and \( \omega_o/Q_o \) of the proposed voltage-mode filter realizations are given by

\[ \omega_o^2 = g_m/C_1C_2R_1 \]  \hspace{1cm} (6)

and

\[ \frac{\omega_o}{Q_o} = 1/C_1R_1 \]  \hspace{1cm} (7)

From (6) and (7), one can see that the parameters \( \omega_o \) and \( \omega_o/Q_o \) can be adjusted by tuning the grounded resistor \( R_1 \). Moreover, \( \omega_o \) can be adjusted by tuning \( g_m \) without disturbing \( \omega_o/Q_o \). And since \( g_m \) is a function of \( I_{ABC} \), this opens the way for current/voltage control of the parameter \( \omega_o \).

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 $\omega_o$ and $\omega_o/Q_o$ to the variations in passive elements are given by

$$S_{C_i}^{\omega_o} = S_{C_z}^{\omega_o} = S_{R_i}^{\omega_o} = -\frac{1}{2}$$

$$S_{C_i}^{\omega_o/Q_o} = S_{R_i}^{\omega_o/Q_o} = -\frac{1}{2}$$

Similarly, the temperature-sensitivity of $\omega_o$ can be expressed by

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

Thus, the $\omega_o$ and $\omega_o/Q_o$ sensitivities to passive-elements and temperature are low.

SIMULATION RESULTS

To verify the theoretical analysis, the proposed circuit has been simulated using Pspice. The CCII+ has been simulated using the simplified nonideal model shown in Fig. 2(a) [18] with $C_y = 1pF, C_z = 1.5pF, R_y = 20M\Omega, R_z = 2M\Omega, R_{xy} = 50\Omega, h_1 = h_2 = 1.0$.

FIGURE 2 (a) Nonideal model for the current conveyor CCII+ and (b) Nonideal model for the OTA.
The OTA has been simulated using the simplified model shown in Fig. 2(b) with $R_{\text{input}} = 5\Omega, R_{\text{output}} = 10M\Omega, C_{\text{output}} = 1pF, g_{m} = 1mA/V$.

With $R_1 = 1k\Omega, R_3 = R_4 = R_5 = R_6 = R_7 = R_8 = R_9 = 10k\Omega, C_1 = C_2 = 10nF, C_3 = 1nF$, the results obtained from the LPF, HPF, BPF, APF and the notch filter are shown in Fig. 3. These results are in good agreement with the theory presented.

**FIGURE 3** (a) Simulated bandpass and notch characteristics and (b) Simulated lowpass, highpass and allpass characteristics obtained from Fig. 1.
CONCLUSION

In this paper, a novel universal programmable voltage-mode active filter using current conveyors has been presented. The circuit uses six current conveyors and one operational transconductance amplifier (OTA) and can simultaneously realize all the five standard biquadratic filter sections, the lowpass, the highpass, the bandpass, the allpass, and the notch. Values of ω₀ can be adjusted by tuning the transconductance of the OTA without disturbing ω₀/Q₀. This opens the way to programmable voltage(current)-control of the parameter ω₀.

REFERENCES

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