UNIVERSAL CURRENT-CONTROLLED CURRENT-MODE FILTER WITH THREE-INPUTS AND ONE-OUTPUT USING THE CURRENT CONTROLLED CONVEYOR

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A new current-mode universal filter is proposed. The filter uses five current-controlled current-conveyors (CCCII) and can realise lowpass, highpass, bandpass, notch and allpass responses. The parameters $\omega_0$ ($\omega_0/Q_0$) can be controlled by adjusting the bias currents of the CCCII. The proposed circuit enjoys low sensitivities.

Keywords: Current conveyors; current-mode filters

INTRODUCTION

Universal active filters using the operational transconductance amplifier (OTA) have many advantages such as simplicity, integrability and programmability [1–5]. However, they have some problems with dynamic range and at high frequencies of operation. On the other hand, current-mode current-conveyor based filters can offer wider signal bandwidths, greater linearity and larger dynamic ranges of operation [6–18]. However, they lack programmability. While programmability can be achieved by combining current conveyors and OTAs [19], the recently introduced second-generation current-controlled conveyor (CCCII) [20] allows current conveyor

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applications to be extended to the domain of electronically programmable functions. Figure 1(a) shows the electrical symbol of the CCCII+. Using two CCCII+ and two grounded capacitors, a voltage-mode bandpass filter was reported [20] and a current-mode bandpass filter was reported [21]. No attempt has been reported, so far, to present universal second-order current-mode filters using the

![Electrical symbol of the plus-type current-controlled current conveyor.](image)

![Universal current-controlled current-mode filter.](image)

**FIGURE 1** (a) Electrical symbol of the plus-type current-controlled current conveyor. (b) Universal current-controlled current-mode filter.
CCCII ± and grounded capacitors only. It is the purpose of this paper to present such a configuration.

**PROPOSED CIRCUIT**

The proposed circuit is shown in Figure 1(b). Using standard notations, the CCCII+ can be characterised by \( i_y = 0, V_x = V_y + R_x i_x \) and \( i_x = \pm i_y \), where \( R_x = V_T/2I_o \), \( V_T \) is the thermal voltage and \( I_o \) is the bias current of the CCCII. Routine analysis yields the current transfer function which can be expressed by

\[
I_{\text{out}} = \frac{s^2 I_3 + s(1/C_2 R_{x2}) I_2 + (1/C_1 C_2 R_x R_{x2}) I_1}{s^2 + s(1/C_2 R_{x2}) + ((1/C_1 C_2 R_x R_{x2})/(1/C_2 R_{x2} R_{x4} + ((1/C_1 C_2 R_x R_{x2})/(1/C_1 C_2 R_x R_{x2})))}
\]

(1)

Now, a current-mode bandpass filter is obtained if we choose \( I_1 = I_3 = 0 \), thus

\[
\frac{I_{BP}}{I_2} = \frac{s/C_2 R_{x2}}{s^2 + s(1/C_2 R_{x2}) + ((1/C_1 C_2 R_x R_{x2})/(1/C_1 C_2 R_x R_{x2}))}
\]

(2)

A current-mode lowpass filter is obtained if we choose \( I_2 = I_3 = 0 \), thus

\[
\frac{I_{LP}}{I_1} = \frac{(1/C_1 C_2 R_x R_{x2})}{s^2 + s(1/C_2 R_{x2}) + ((1/C_1 C_2 R_x R_{x2})/(1/C_1 C_2 R_x R_{x2}))}
\]

(3)

A current-mode highpass filter is obtained if we choose \( I_1 = I_2 = 0 \), thus

\[
\frac{I_{HP}}{I_3} = \frac{s}{s^2 + s(1/C_2 R_{x2}) + ((1/C_1 C_2 R_x R_{x2})/(1/C_1 C_2 R_x R_{x2}))}
\]

(4)

A current-mode notch (bandreject) filter is obtained if we choose \( I_2 = 0, I_1 = I_3 = I_i \) and \( R_{x3} = R_{x5} \), thus

\[
\frac{I_{\text{NOTCH}}}{I_i} = \frac{s^2 + (1/C_1 C_2 R_x R_{x2})}{s^2 + s(1/C_2 R_{x2}) + ((1/C_1 C_2 R_x R_{x2})/(1/C_1 C_2 R_x R_{x2}))}
\]

(5)
And a current-mode allpass filter is obtained if we choose \( I_1 = I_3 = -I_2 = I \) and \( R_{x3} = R_{x4} = R_{x5} \), thus

\[
\frac{I_{AP}}{I} = \frac{s^2 - s(1/C_2R_{x2}) + (1/C_1C_2R_{x1}R_{x2})}{s^2 + s(1/C_2R_{x2}) + (1/C_1C_2R_{x1}R_{x2})}
\]

From Eqs. (2–6) the parameters \( \omega_o \) and \( \omega_o/Q_o \) can be expressed as

\[
\omega_o^2 = \frac{R_{x3}/R_{x5}}{C_1C_2R_{x1}R_{x2}}
\]

and

\[
\frac{\omega_o}{Q_o} = \frac{R_{x3}}{C_2R_{x2}R_{x4}}
\]

From Eqs. (2–4) it can be seen that the high frequency gain of the highpass filter is equal to unity, the dc gain of the lowpass filter is equal to

\[
G_{LP} = \frac{R_{x5}}{R_{x3}}
\]

and the bandpass gain at \( \omega_o \) is equal to

\[
G_{BP} = \frac{R_{x4}}{R_{x3}}
\]

From Eqs. (7–10) it can be seen that the parameter \( \omega_o \) can be adjusted by controlling the resistance \( R_{x1} \), that is the bias current \( I_{o1} \), without disturbing the parameters \( \omega_o/Q_o \), the lowpass gain \( G_{LP} \) and the bandpass gain, \( G_{BP} \). Moreover, the parameter \( \omega_o/Q_o \) can be adjusted by controlling the resistance \( R_{x2} \), that is the bias current \( I_{o2} \), without disturbing the parameter \( \omega_o \), the lowpass gain, \( G_{LP} \) and the bandpass gain \( G_{BP} \). Furthermore, the bandpass gain can be adjusted by controlling the resistance \( R_{x4} \), that is the bias current \( I_{o4} \), without disturbing the parameter \( \omega_o \). However, this will disturb the parameter \( \omega_o/Q_o \). Finally, the lowpass gain can be adjusted by controlling the resistance \( R_{x5} \), that is the bias current \( I_{o5} \), without disturbing the
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Parameter $\omega_0/Q_0$. However, this will disturb the parameter $\omega_0$. A possible strategy for adjusting the parameters $\omega_0, \omega_0/Q_0$ and the bandpass or the lowpass gains is therefore as follows: first the resistance $R_{x4}$ or $R_{x5}$, that is the bias current $I_{o4}$ or $I_{o5}$, is adjusted to control the bandpass gain $G_{BP}$ or the lowpass gain $G_{LP}$, then the bias current $I_{o1}$ is adjusted to control the parameter $\omega_0$, and finally the bias current $I_{o2}$ is adjusted to control the bandpass gain.

FIGURE 2 Simulated gain-frequency characteristics of the (a) BPF obtained from the circuit of Figure 1 with $C_1 = C_2 = 1000 \mu F$, $I_{o1} = I_{o2} = 1 \mu A$, $10 \mu A$, $100 \mu A$, $I_{o3} = 100 \mu A$, $I_{o4} = 50 \mu A$, $I_1 = I_3 = 0$, $I_2 = 1 \mu A$ (b) LPF obtained from the circuit of Figure 1 with $C_1 = C_2 = 1000 \mu F$, $I_{o1} = I_{o2} = 1 \mu A$, $10 \mu A$, $100 \mu A$, $I_{o3} = 100 \mu A$, $I_{o4} = 50 \mu A$, $I_2 = I_3 = 0$, $I_1 = 1 \mu A$ (c) HPF obtained from the circuit of Figure 1 with $C_1 = C_2 = 1000 \mu F$, $I_{o1} = I_{o2} = 1 \mu A$, $10 \mu A$, $100 \mu A$, $I_{o3} = 100 \mu A$, $I_{o4} = 100 \mu A$, $I_{o5} = 50 \mu A$, $I_1 = I_2 = 0$, $I_3 = 1 \mu A$. 

1: $I_{o1} = 1 \mu A$ 2: $I_{o1} = 10 \mu A$ 3: $I_{o1} = 100 \mu A$
From Eqs. (7 and 8) it is easy to show that the sensitivities of the parameters $\omega_o$ and $Q_o$ are

$$S_{\omega_o}^{\omega_o} = S_{R_{s1}}^{\omega_o} = S_{R_{s2}}^{\omega_o} = S_{R_{s3}}^{\omega_o} = S_{C_1}^{\omega_o} = S_{C_2}^{\omega_o} = -S_{R_{s3}}^{\omega_o} = -\frac{1}{2}$$

and

$$S_{R_{s2}}^{\omega_o/\omega_o} = -S_{R_{s3}}^{\omega_o/Q_o} = S_{R_{s4}}^{\omega_o/Q_o} = S_{C_2}^{\omega_o/Q_o} = -1$$

all of which are small.
The universal filter circuit of Figure 1(b) has been simulated using the ICAPS circuit simulation program. The CCCII± have been simulated using the schematic implementation of [20] with dc supply voltage = ±2.5 V. The results obtained are shown in Figure 2 for the bandpass filter with \( C_1 = C_2 = 1000 \text{pF}, I_{o1} = I_{o2} = 1 \text{µA}, 10 \text{µA}, 100 \text{µA}, I_{o3} = 100 \text{µA}, I_{o4} = I_{o5} = 50 \text{µA} \) and input current \( I_2 = 1 \text{µA} \), for the lowpass filter with \( C_1 = C_2 = 1000 \text{pF}, I_{o1} = I_{o2} = 1 \text{µA}, 10 \text{µA}, 100 \text{µA}, I_{o3} = I_{o4} = 100 \text{µA}, I_{o5} = 50 \text{µA} \) and input current \( I_1 = 1 \text{µA} \), and for the highpass filter with \( C_1 = C_2 = 1000 \text{pF}, I_{o1} = I_{o2} = 1 \text{µA}, 10 \text{µA}, 100 \text{µA}, I_{o3} = 100 \text{µA} = I_{o4} = 100 \text{µA}, I_{o5} = 50 \text{µA} \) and input current \( I_3 = 1 \text{µA} \). The results obtained by simulation are in fairly good agreement with the presented theory.
CONCLUSION

A new universal second-order current-mode filter has been presented. The proposed filter uses the current-controlled current-conveyor and enjoys the following advantages:

a. current control of the parameters $\omega_o$ and $\omega_o/Q_o$ of the filters and the gains of the bandpass and the lowpass filters.
b. independent control of the parameter $\omega_o$ without disturbing the parameter $\omega_o/Q_o$ and the bandpass and the lowpass gains.
c. independent current control of the bandpass gain without disturbing the parameter $\omega_o$.
d. independent current control of the lowpass gain without disturbing the parameter $\omega_o/Q_o$.
e. low sensitivities of the parameters $\omega_o$ and $\omega_o/Q_o$.

References


