Current-mode and transimpedance-mode universal biquadratic filter using multiple outputs CCIIs

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A current-mode and transimpedance-mode universal biquadratic filter with single input and multi-outputs using three multiple outputs second-generation current conveyors (MOCCIIs), five resistors and two grounded capacitors is presented. The proposed circuit can realize current-mode notch, bandpass and lowpass responses, simultaneously. The current-mode highpass and allpass responses can be obtained by interconnection of relevant output currents. Moreover, the transimpedance-mode highpass, bandpass, lowpass, notch and allpass filters can also be obtained, simultaneously, from the proposed circuit.

Keywords: Current conveyor; Current-mode filter; Transimpedance-mode filter

Current conveyors have been received considerable attention due to the fact that they have better linearity, wider bandwidth and larger dynamic range than the voltage-mode counterparts, operational amplifiers. In analogue signal processing applications it may be desirable to have active filter with input currents and output currents or voltages, defined as current-mode or transimpedance-mode filters, respectively. If the filters employing grounded capacitors, it is attractive for monolithic IC implementation. Because the second-generation current conveyor (CCII) has a non-negligible output parasitic resistance on port $x$ ($R_x$), when the $x$ port of CCII is loaded by a capacitor, it leads to an improper transfer functions. Due to the effect of this parasitic resistance $R_x$, at the $x$ port of CCII, the filters with $x$ port loaded by a capacitor do not exhibit good performance at high frequency.

Several circuits realizing current transfer functions with single input and three outputs (SITO) have been presented in the literature. By interconnection of relevant output currents, the lowpass, bandpass, highpass, notch and allpass filters can be obtained from the same circuit configuration. Each of the SITO current-mode universal biquads in references requires at least four current conveyors. Abuelma’atti and Khan proposed a current-mode SITO universal biquadratic filter circuit using three multiple outputs second-generation current conveyors (MOCCIIs), one OTA, two grounded resistors and three grounded capacitors. The current-mode SITO universal biquad in Wang and Lee uses three MOCCIIs, two grounded resistors and two grounded capacitors. However, some $x$ ports of the MOCCIIs in references are connected to capacitors that degrade their high frequency performance. Each of the current-mode SITO universal biquads in references uses four current controlled conveyors and two floated capacitors. The current-mode SITO universal biquad in Horng et al. uses three MOCCIIs, four resistors and two grounded capacitors. However, it needs components matching condition in realizing the allpass response. Recently, Jerabek and Vrba present an interesting current-mode SITO universal biquad using three universal current conveyor (UCC), two resistors and two grounded capacitors.

Soliman presents two transimpedance-mode filters using four CCIIs, four resistors and two grounded capacitors. However, only highpass, bandpass and lowpass filters can be simultaneously obtained in the circuit configuration. Abuelma’atti et al. present a mixed-mode filter with multi-inputs and two outputs using seven CCIIs, eight resistors and two grounded capacitors. However, only one filter type can be obtained in each circuit realization.

In this paper, a new current-mode and transimpedance-mode universal biquadratic filter circuit with single current input terminal is presented. The proposed circuit requires three MOCCIIs, five resistors and two grounded capacitors. The current-mode notch, bandpass and lowpass filters can be

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obtained simultaneously. The realizations of current-mode highpass or allpass functions do not need additional current conveyors in either case as this can be simply achieved by connecting the appropriate nodes. Moreover, the transimpedance-mode highpass, bandpass, lowpass, notch and allpass filters can also be obtained, simultaneously, from the proposed circuit (the allpass filter needs component matching condition).

With respect to the current-mode universal biquads in references\(^5\)-\(^8\), the proposed circuit uses less active components. With respect to the current-mode universal biquads in references\(^9\),\(^10\), the \(x\) ports of the MOCCIIs in the proposed circuit are connected to resistors. With respect to the current-mode universal biquad in reference\(^11\),\(^12\), the proposed circuit uses less active components and using only grounded capacitors. With respect to the current-mode universal biquad in reference\(^13\), the proposed circuit needs not component matching condition in realizing the current-mode allpass filter. With respect to the current-mode universal biquad in reference\(^14\), another five typical transimpedance-mode filters can be simultaneously obtained from the proposed circuit configuration. With respect to the transimpedance-mode filters in references\(^2\),\(^3\), the proposed circuit can realize five kinds of standard filter functions, simultaneously, and employing less active components.

**Proposed Circuit**

The circuit symbol of the MOCCII is shown in Fig. 1, which shows the two types of output terminals, the positive outputs represented by terminal \(z^+\) and the negative by terminal \(z^-\). The terminal characteristic of the MOCCII can be described by the following matrix equation:

\[
\begin{bmatrix}
i_y \\
v_x \\
i_{z1+} \\
\vdots \\
i_{zn+} \\
i_{z1-} \\
\vdots \\
i_{zn-}
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & 0 & \ldots & 0 & 0 & \ldots & 0 \\
1 & 0 & 0 & \ldots & 0 & 0 & \ldots & 0 \\
0 & 1 & 0 & \ldots & 0 & 0 & \ldots & 0 \\
\vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\
0 & 1 & 0 & \ldots & 0 & 0 & \ldots & 0 \\
0 & -1 & 0 & \ldots & 0 & 0 & \ldots & 0 \\
\vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\
0 & -1 & 0 & \ldots & 0 & 0 & \ldots & 0
\end{bmatrix}
\begin{bmatrix}
v_y \\
i_x \\
v_{z1+} \\
\vdots \\
v_{zn+} \\
v_{z1-} \\
\vdots \\
v_{zn-}
\end{bmatrix}
\]

\[
\ldots (1)
\]

One possible implementation of the MOCCII is shown in Fig. 2\(^15\). The multiple current outputs can be easily implemented by simply adding output branches. The proposed circuit comprises three MOCCIIs, five resistors and two grounded capacitors is shown in Fig. 3. The use of grounded capacitors is particularly attractive for integrated circuit implementation\(^4\). The output voltages and currents for the circuit at Fig. 3 are given by the following equations:

\[
V_{o1} = \frac{s^2 C_1 C_2 + G_3 G_1}{s^2 C_1 C_2 G_1 + s C_2 G_1 G_2 + G_1 G_2 G_3} I_m \quad \ldots (2)
\]

\[
V_{o2} = \frac{s C_2 G_1}{s^2 C_1 C_2 G_1 + s C_2 G_1 G_2 + G_1 G_2 G_3} I_m \quad \ldots (3)
\]

\[
V_{o3} = \frac{-G_2}{s^2 C_1 C_2 G_1 + s C_2 G_1 G_2 + G_1 G_2 G_3} I_m \quad \ldots (4)
\]

\[
V_{o4} = \frac{s^2 C_1 C_2 G_1 R_4}{s^2 C_1 C_2 G_1 + s C_2 G_1 G_2 + G_1 G_2 G_3} I_m \quad \ldots (5)
\]

\[
V_{o5} = \frac{s^2 C_1 C_2 - s C_2 G_1 G_3 R_5 + G_2 G_3}{s^2 C_1 C_2 G_1 + s C_2 G_1 G_2 + G_1 G_2 G_3} I_m \quad \ldots (6)
\]

\[
I_{o1} = \frac{s^2 C_3 + G_2 G_3}{s^2 C_1 C_2 + s C_2 G_2 + G_2 G_3} I_m \quad \ldots (7)
\]

\[
I_{o2} = \frac{-s C_2 G_2}{s^2 C_1 C_2 + s C_2 G_2 + G_2 G_3} I_m \quad \ldots (8)
\]

\[
I_{o3} = \frac{-G_2 G_3}{s^2 C_1 C_2 + s C_2 G_2 + G_2 G_3} I_m \quad \ldots (9)
\]

![Fig. 1—MOCCII circuit symbol](image)
From Eqs (2)-(6) it can be seen that the transimpedance-mode notch, bandpass, lowpass and highpass filters are obtained from \( V_{o1} \), \( V_{o2} \), \( V_{o3} \), and \( V_{o4} \), respectively. If \( R_5 = R_1 \), a transimpedance-mode allpass response is obtained from \( V_{o5} \). Moreover, a non-inverting notch current output signal can be obtained at \( I_{o1} \), an inverting bandpass current signal can be obtained at \( I_{o2} \) and an inverting current lowpass signal can be obtained at \( I_{o3} \). A current-mode highpass signal is easily obtained by connecting the \( I_{o1} \) and \( I_{o3} \) output terminals. Let \( I_{\text{highpass}} = I_{o1} + I_{o3} \). We obtain the current-mode highpass output current:

\[
I_{\text{highpass}} = \frac{s^2 C_1 C_2}{s^2 C_1 C_2 + s C_2 G_2 + G_2 G_3} \quad \ldots (10)
\]

Similarly, by connecting the \( I_{o1} \) and \( I_{o2} \) output terminals (\( I_{\text{allpass}} = I_{o1} + I_{o2} \)), a current-mode allpass output current can be obtained by

\[
I_{\text{allpass}} = \frac{s^2 C_1 C_2 - s C_2 G_2 + G_2 G_3}{s^2 C_1 C_2 + s C_2 G_2 + G_2 G_3} \quad \ldots (11)
\]

Because the output impedances of the currents \( I_{o1} \), \( I_{o2} \) or \( I_{o3} \) are very high, the three output terminals, \( I_{o1} \), \( I_{o2} \) and \( I_{o3} \), can be directly connected to the next stage, respectively. The three resistors \( R_1 \), \( R_2 \) and \( R_3 \) are connected to the three \( x \) terminals of the three MOCCIIIs, respectively. This design offers the feature of a direct incorporation of the parasitic resistance at the \( x \) terminal of the MOCCII (\( R_x \)) as a part of the main resistance.

Taking the tracking errors of the MOCCII into account, the relationship of the terminal voltages and currents of MOCCII can be rewritten as: \( i_y = 0 \), \( v_x = \beta(s) v_y \), \( i_z = \pm \alpha_i(s) i_x \), where \( \alpha_i(s) \) and \( \beta(s) \) represent the frequency transfers of the internal current and voltage followers of the MOCCII.
respectively. They can be approximated by first order lowpass functions, which can be considered to have a unity value for frequencies much less than their corner frequencies. Assuming the circuits are working at frequencies much less than the corner frequencies of $\alpha_k(s)$, $\beta(s)$, namely, $\alpha_k(s) = 1 - \varepsilon_{ak}$ and $\beta(s) = 1 - \varepsilon_b$ and $|\varepsilon_b| < 1$ denotes the current tracking error and $|\varepsilon_b| < 1$ denotes the voltage tracking error of the MOCCI. The denominator of the transfer functions in Fig. 3 becomes

$$D(s) = s^3 C_1 C_2 + s^2 C_2 G_2 \alpha_2 \alpha_3 \beta_1 \beta_3 + G_2 \alpha_3 \alpha_3 \beta_2 \beta_3$$

... (12)

The resonance angular frequency $\omega_0$ and the quality factor $Q$ are given by

$$\omega_0 = \frac{\alpha_2 \alpha_3 \beta_2 \beta_3}{C_1 C_2 R_2 R_3}$$

... (13)

$$Q = \frac{1}{\alpha_2 \alpha_3} \sqrt{\frac{C R_2 \alpha_3 \beta_3}{C_2 R_3 \beta_2}}$$

... (14)

The active and passive sensitivities of $\omega_0$ and $Q$ are

Fig. 4—Simulation results of the proposed transimpedance-mode filter (a) Notch filter, (b) Bandpass filter, (c) Lowpass filter, (d) Highpass filter and (e) Allpass filter
Simulation Results

HSPICE simulations were carried out to demonstrate the feasibility of the proposed circuit in Fig. 3. The MOCCI was realized by the CMOS implementation in Fig. 2 using 0.18 $\mu$m MOSFET from TSMC. The aspect ratios of the MOS transistors are shown in Table 1. Figures 4 (a)-(c) represent the simulated frequency responses for the transimpedance-mode notch ($V_{o1}$), bandpass ($V_{o2}$), lowpass ($V_{o3}$), highpass ($V_{o4}$) and allpass ($V_{o5}$) filters of Fig. 3, respectively, designed with $f_o = 281.35$ kHz, $Q = 0.707$, $C_1 = 40$ pF, $C_2 = 80$ pF and $R_1 = R_2 = R_3 = R_4 = R_5 = 10k\Omega$ with input sinusoidal current amplitude = 0.1 mA. The supply voltages are $V^+ = +1.25$ V, $V = -1.25$ V, $V_{b1} = -0.65$ V. Figures 5 (a)-(c) represent the simulated frequency responses for the current-mode notch ($I_{o1}$), bandpass ($I_{o2}$) and lowpass ($I_{o3}$) filters of Fig. 3, respectively, designed with $f_o = 281.35$ kHz, $Q = 0.707$, $C_1 = 40$ pF, $C_2 = 80$ pF and $R_1 = R_2 = R_3 = 10 k\Omega$ with input sinusoidal current amplitude = 0.1 mA. The MOCCI has parasitic resistor from the $z$ terminal to the ground ($R_z$). When the $z$ terminal load of the MOCCI is a capacitor ($C$), it introduces a pole produced by $R_z$ and $C$ at low frequency. This can explain why Fig. 4 (b), (d) and Fig. 5 (b) have non-ideal phase responses at low frequencies. This effect can be minimized by using larger loading capacitors or operating the filters in high frequencies.

Conclusions

A current-mode and transimpedance-mode universal biquadratic filter with single current input terminal using three MOCCIIs, five resistors and two grounded capacitors is presented. The new circuit offers several advantages, such as high output impedances from the current-mode outputs, five kinds of standard transimpedance-mode filter functions can be obtained simultaneously, very low filter sensitivities, the use of grounded capacitors and direct

\[-S_{C_1,C_2,R_3,R_5}^{o} = S_{\alpha_1,\alpha_3,\beta_2,\beta_3}^{o} = \frac{1}{2},\]
\[-S_{C_1,R_2}^{Q} = -S_{C_1,R_3}^{Q} = S_{\alpha_2,\alpha_3,\beta_2}^{Q} = -S_{\beta_2}^{Q} = \frac{1}{2},\]
\[-S_{\alpha_{12},\alpha_{21}}^{Q} = -1\]

all of which are small.

![Fig. 5](image)

Fig. 5—Simulation results of the proposed current-mode filters. (a) Notch filter; (b) Bandpass filter and (c) Lowpass filter
incorporation of the parasitic resistance at the $x$ terminal of the MOCCII as a part of the main resistance.

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