Universal Active Current Filter Using Single Third-Generation Current Conveyor

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Abstract: - The realization of the second-order universal (low-pass, band-pass, high-pass, band-reject, and all-pass) active current filter using a single third-generation current conveyor (CCIII), two grounded capacitors, and two resistors is proposed in this paper. Three input signals and one tunable resistance determine the five generic filtering output signals. H-Spice simulations with 0.35μm process are used to validate the theoretical predictions of the filtering output signals, and show the low sensitivities to the passive components, and the sensitivity frequency responses.

Key-Words: analog circuit design, active filters, continuous-time filters, low-pass filters, band-pass filters, high-pass filters, band-reject filters, all-pass filters

1 Introduction
In 1989, it was presented that circuits based on current amplifiers operate at higher signal bandwidths, greater linearity and larger dynamic range, than their voltage-based circuit counterparts [1]. Current-mode circuits have emerged over the last two decades as an important class of analogue circuits. A universal (low-pass, band-pass, high-pass, band-reject, and all-pass) current-mode (current input and current output) biquad which employs seven second-generation current conveyors (CCIs) in addition to two grounded capacitors and three grounded resistors was presented [2]. This biquad suffers from the following two disadvantages: requirement of one matching condition to realize an all-pass signal, and no orthogonal control of ω0 and Q. The improved universal filter does not need any component matching conditions and enjoys the orthogonal control of ω0 and Q although with the same structure complexity [3]. The condensed universal filter employs only five CCIIs in addition to two grounded capacitors and three grounded resistors [4] was proposed which enjoys the advantageous features: (i) no component matching, and (ii) the independent control of ω0 and Q. The active component count of the universal filter was reduced to four but with the addition of one more grounded capacitor [5, 6], or using two floating capacitors and two floating resistors [7], or employing two grounded capacitors and two grounded resistors [8]. Then, a high output impedance multifunction filter employing three CCIIs, two grounded/floating capacitors and three grounded/floating resistors was presented [9] which cannot enjoy low active sensitivities as high quality factor is necessary. And then, a versatile multi-input-multi-output universal biquad structure was supplied using three current conveyors, two grounded capacitors, and two grounded resistors, which still has the two advantages: no orthogonal control of ω0 and Q and the limitation for high frequency operation [10]. The last universal filter was improved to be an insensitive one using three dual output current conveyors, two grounded capacitors, and three grounded resistors which, again, suffered from the limitation for high frequency operation [11]. The current-mode universal biquad without any matching conditions was condensed to the three-input and three-output structure with the minimum number of components, two plus type CCIIs, two grounded capacitors, and two grounded resistors [12]. The single-current conveyor-based universal biquads with low quality factor [13] or high quality factor [14] were proposed using three capacitors and four/five resistors. The five generic filter (low-pass, band-pass, high-pass, band-reject, and all-pass) signals are obtained by adjusting the values of one grounded capacitor and one grounded resistor appropriately. In this paper, a new current-mode universal biquad employing a single third-generation current conveyor (CCIII) [15], two grounded capacitors, and two grounded/floating resistors is presented whose structure is much simpler than the previous two single-current conveyor-based universal biquads [13, 14]. Three input signals and the variable grounded R2 determine the five different generic filtering signals obtained from the output terminal. H-Spice simulation using 0.35μm process is used to validate the theoretical predictions of the new simple universal biquad including its five generic filtering output signals, low individual component sensitivities, and show the sensitivity frequency responses for the five generic filtering signals.

2 Universal Active Current Biquad
The universal active current filter with a single third-generation current conveyor (CCIII), two grounded capacitors, and two grounded/floating resistors is shown in Fig. 1. The dual output terminal Z can be easily realized using current mirror technique.

![Fig. 1 Universal active current filter](image)

A third-generation current conveyor (CCIII) is characterized by the following matrix equation [15].

\[
\begin{bmatrix}
V_x \\
I_y \\
I_z
\end{bmatrix} =
\begin{bmatrix}
0 & 1 & 0 \\
-1 & 0 & 0 \\
1 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
I_x \\
V_y \\
V_z
\end{bmatrix}
\]  
(1)

The new single-current conveyor-based universal active current filter is shown in Fig. 1 using one fewer capacitor and two/three fewer resistors than the previous ones [13, 14]. Circuit analysis for Fig. 1 gives the following output current

\[
I_{out} = \frac{s^2C_1C_2 + sC_1(G_1 + G_2)}{s^2C_1C_2 + sC_1(G_1 + G_2) + G_1G_2} - I_{in2} \left(\frac{sC_1(G_1 + G_2)}{G_1G_2} + I_{in1} \left(\frac{G_1C_1}{sC_1} \right)\right)
\]

\[
I_{in1} = \frac{s^2C_1C_2 + sC_1(G_1 + G_2) + G_1G_2}{s^2C_1C_2 + sC_1(G_1 + G_2) + G_1G_2}
\]

(2)

The specifications of (2) give the following five generic filtering signals.

(i) Low-pass: \(I_{in1} = 0\), and \(I_{in2} = I_{in1} = I_{in3}\), and \((G_1 + G_2)C_1 = C_2G_1\);  
(ii) Band-pass: \(I_{in2} = I_{in3} = 0\), and \(I_{in1} = I_{in3}\);  
(iii) High-pass: \(I_{in1} = 0\), and \(I_{in3} = I_{in2} = I_{in1}\);  
(iv) Band-reject: \(I_{in3} = I_{in1} = I_{in3}\), and \(I_{in2} = 0\) and \((G_1 + G_2)C_1 = C_2G_1\);  
(v) All-pass: \(I_{in3} = I_{in1} = I_{in3}\), \(I_{in2} = 0\) and \(2(G_1 + G_2)C_1 = C_2G_1\).

Note that the grounded resistor \(R_2\) is much easier to be tuned than the floating resistor \(R_1\) in the integrated circuit. The non-ideal characteristic of the input-and-output relationship of a CCIII is shown in the following matrix equation.

\[
\begin{bmatrix}
V_x \\
I_y \\
I_z
\end{bmatrix} =
\begin{bmatrix}
0 & \alpha_0 & 0 \\
-\alpha_0 & 0 & 0 \\
\alpha_0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
I_x \\
V_y \\
V_z
\end{bmatrix}
\]  
(3)

Hence, the non-ideal denominator of the output current signal (2) is

\[
\Delta = s^2\alpha_0 \alpha_0 C_1C_2 + (C_1 + C_2)G_2 + \alpha_0 \alpha_0 C_1C_2G_2\]

\[
\alpha = \frac{(C_1 + C_2)G_2 + \alpha_0 \alpha_0 C_1C_2G_2}{(C_1 + C_2)G_2 + \alpha_0 \alpha_0 C_1C_2G_2 - \alpha_0 \alpha_0 C_1C_2G_2\alpha_0 \alpha_0 C_1C_2G_2}
\]

(4)

The resonant angular frequency and the quality factor are

\[
\omega_0 = \frac{G_1G_2}{\sqrt{\alpha_0 \alpha_0 C_1C_2G_2}}
\]

(5)

\[
Q = \frac{\alpha_0 \alpha_0 C_1C_2G_2}{(C_1 + C_2)G_2 + \alpha_0 \alpha_0 C_1C_2G_2 - \alpha_0 \alpha_0 C_1C_2G_2\alpha_0 \alpha_0 C_1C_2G_2}
\]

(6)

The sensitivities of \(\omega_0\) to the passive component, \(C_1, C_2, G_1,\) and \(G_2,\) and the active parameter are ±0.5, a very low value. The sensitivities of \(Q\) are shown as follows.

\[
S_{\omega_0} = \frac{C_1G_2}{2(C_1 + C_2)G_2 + C_1G_2\alpha_0 \alpha_0 C_1C_2G_2}
\]

(7)

\[
S_{\omega_0} = \frac{C_1G_2}{2(C_1 + C_2)G_2 + C_1G_2\alpha_0 \alpha_0 C_1C_2G_2}
\]

(8)

\[
S_{\omega_0} = \frac{C_1G_2}{2(C_1 + C_2)G_2 + C_1G_2\alpha_0 \alpha_0 C_1C_2G_2}
\]

(9)

\[
S_{\alpha_0} = \frac{C_1G_2}{2(C_1 + C_2)G_2 + C_1G_2\alpha_0 \alpha_0 C_1C_2G_2}
\]

(10)

\[
S_{\alpha_0} = \frac{C_1G_2}{2(C_1 + C_2)G_2 + C_1G_2\alpha_0 \alpha_0 C_1C_2G_2}
\]

(11)

\[
S_{\alpha_0} = \frac{C_1G_2}{2(C_1 + C_2)G_2 + C_1G_2\alpha_0 \alpha_0 C_1C_2G_2}
\]

(12)

\[
S_{\alpha_0} = \frac{C_1G_2}{2(C_1 + C_2)G_2 + C_1G_2\alpha_0 \alpha_0 C_1C_2G_2}
\]

(13)

It is clear that the sensitivities of \(Q\) to the passive component, \(C_1, C_2, G_1,\) and \(G_2,\) and the active parameter...
α, are lower than 0.5, very small value, but the sensitivity of Q to the active parameters, αy and αz, depends on the magnitudes of the numerator and the denominator of (12) and (13). The universal active current filter shown in Fig. 1 is then insensitive to the passive component.

3 H-spice Simulations

The filtering performance of the new universal active current filter shown in Fig. 1 is shown in Figs. 3 to 7 by the TSMC035 level-49 H-Spice simulation (using the CMOS implementation of the CCIII [15], shown in Fig. 2, with the supply voltages Vdd=1.65V, and Vss=-1.65V, and W/L=5μ/1μ and 10μ/1μ for NMOS and PMOS transistors, respectively), and with element values R1=9kΩ, R2=9kΩ, and C1=50 pF, C2=25 pF (but 12.5pF for all-pass realization) for the 3dB frequency at 500kHz and C1=25 pF, C2=12.5 pF (but 6.25pF for all-pass realization) for the 3dB frequency at 1MHz, respectively. The simulation results of the 3dB frequency of the low-pass, band-pass, high-pass, band-reject, and all-pass output signals are 567kHz (error 13.5%) and 1.107MHz (error 10.7%); 513kHz (error 2.57%) and 0.956MHz (error -4.41%); 513kHz (error 2.57%) and 1.047MHz (error 4.7%); and 733kHz (error 46.6%) and 1.46MHz (error 46%), respectively. As we increase (resp. decrease) the capacitance value, the resonant frequency is lower (resp. higher). The low-pass, band-pass, high-pass, band-reject, and all-pass responses are shown in Figs. 8 to 12 with the frequency range from 10Hz to 51MHz (low-pass), 10Hz to 151MHz (band-pass), 10Hz to 127MHz (high-pass), 10Hz to 115MHz (band-reject), and 10Hz to 15MHz (all-pass). The higher the operation frequency, the larger the distortion (such as the higher the peak) due to the parasitic effect.
Fig. 7 All-pass simulations at 500kHz and 1MHz

Fig. 8 Low-pass responses from 10Hz to 480MHz

Fig. 9 Band-pass responses from 10Hz to 302MHz.

Fig. 10 High-pass responses from 10Hz to 174MHz

Fig. 11 Band-reject responses from 10Hz to 107MHz

Fig. 12 All-pass responses from 10Hz to 295MHz

Fig. 13 Component sensitivity simulations (LP)

Fig. 14 Component sensitivity simulations (BP)
The sensitivity simulations of the resonant-frequency to each passive component for low-pass, band-pass, high-pass, band-reject, and all-pass output signals are shown in Figs. 13 to 17, respectively. The sensitivity frequency responses of the 3dB or central frequency of the low-pass, band-pass, high-pass, band-reject, and all-pass output signals are shown in Figs. 18 to 22. As can be seen, the sensitivities of the low-pass, band-pass, band-reject, and all-pass signals are very low (lower than 0.5), and only the high-pass (resp. low-pass) sensitivity of the 3dB frequency to the capacitance C₂ (resp. C₁) is a little bit larger (the absolute value is about 0.95 and 0.8, respectively). Moreover, the component sensitivities are nearly fixed at a constant from 10Hz to 100kHz, and varied as the operating frequency is higher than 100kHz.
4. Conclusion
The single current conveyor based universal active current-mode filter using one fewer capacitor and two/three fewer resistors than the previous ones is proposed. The five generic filtering (low-pass band-pass, high-pass, band-reject, and all-pass) signals can be obtained by proper choice of the three input current signals and the adjustment of one grounded resistance. TSMC 0.35 μm process H-Spice simulations are included to validate the theoretical predictions of output filtering signals, component sensitivities, and sensitivity frequency responses.

References: