Current-Mode Electronically Tunable Universal Filter Using Only Plus-Type Current Controlled Conveyors and Grounded Capacitors

Shahram Minaei and Sait Türköz

In this paper we present a new current-mode electronically tunable universal filter using only plus-type current controlled conveyors (CCCII+s) and grounded capacitors. The proposed circuit can simultaneously realize lowpass, bandpass, and highpass filter functions—all at high impedance outputs. The realization of a notch response does not require additional active elements. The circuit enjoys an independent current control of parameters ω_o and ω_o / Q. No element matching conditions are imposed. Both its active and passive sensitivities are low.

Keywords: Current controlled conveyors, filters, current-mode.

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I. Introduction

Current-mode filters using second-generation current conveyors (CCII) have received considerable attention owing to the fact that their bandwidth, linearity, and dynamic range performances are better than those of their Op-amp based counterparts [1]. Therefore, a number of universal current-mode filters based on CCII have been presented [2]-[12]. Universal filters are able to achieve more than one basic filter function simultaneously with the same topology. The presented topologies in the literature can be classified considering the number of active/passive elements (grounded or floating), the number of simultaneously realized functions, the possibility of a realization of other filter functions by a slight modification of the circuit, component matching constraints, an independent electronic adjustability of the resonant angular frequency and quality factor, active/passive sensitivities, component spread, and output impedance. A current-mode filter theoretically should exhibit high output impedance to enable easy cascadability and to enable additional filter responses by a simple connection of the outputs.

Most of the circuits presented in the literature suffer from a lack of electronic tunability [2]-[8]. By using the second-generation current controlled conveyor (CCCII) introduced by Fabre and others [13], current conveyor applications can be extended to the domain of electronically tunable functions. While the circuits reported in [9]-[11] employ CCCIIs, they suffer from the use of dual-output positive/negative type CCCIIs, which complicates the filter implementations [14]. Also, the realizations of highpass responses in [9] and [10] are not in high output impedance.

On the other hand, while the circuit in [12] proposed by the authors presents all of the lowpass, bandpass and highpass responses at high impedance outputs, it suffers from the use of both the positive and negative types of the CCCII in the structure of the filter.

In this paper, we modified the circuit given in [12] to propose a new current-mode current-controlled universal filter using only plus-type CCCIIs, which is advantageous in view of integrated circuit implementation. The proposed circuit can simultaneously realize lowpass, bandpass and highpass filters all at high impedance outputs, thus permitting easy cascadability. The realization of a notch function does not require additional current conveyors as such a realization can simply be achieved by connecting the appropriate nodes. The circuit enjoys independent current-control of parameters ω_o and ω_o/Q.

II. Proposed Circuit

The terminal relations of a CCCII, as shown in Fig. 1, can be characterized by

$$\begin{bmatrix} I_y \\ V_x \\ I_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & R_x & 0 \\ 0 & \pm\alpha & 0 \end{bmatrix} \begin{bmatrix} V_y \\ I_x \\ V_z \end{bmatrix}, \quad (1)$$

where the positive sign denotes a positive current-controlled conveyor (CCCII+) and the negative sign denotes a negative current-controlled conveyor (CCCII–), $\alpha = 1 - \varepsilon$, $|\varepsilon| \ll 1$ represents the current tracking error,

$$R_x = \frac{V_T}{2I_o} \quad (2)$$

is the input resistance at terminal x, where V_T is the thermal voltage, and I_o is the bias current of the CCCII. The proposed universal filter is constructed with five CCCII+s and three grounded capacitors as shown in Fig. 2. The use of grounded capacitors is particularly attractive for integrated circuit implementation [15].

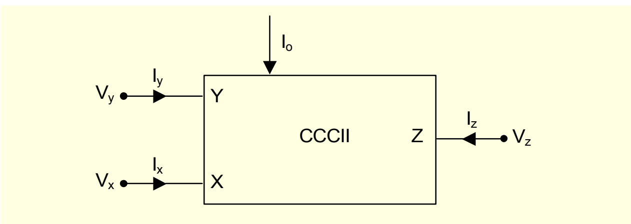

Fig. 1. An electrical symbol of the CCCII.

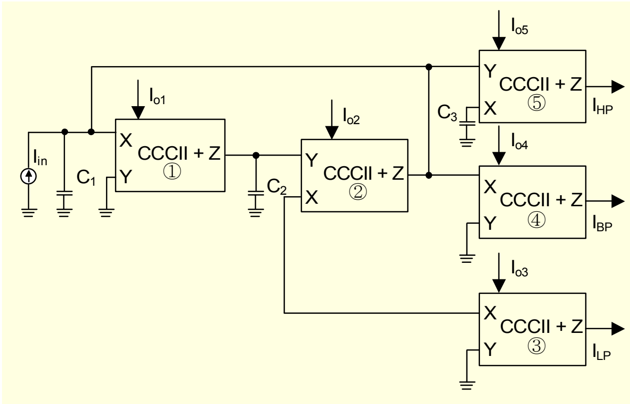

Fig. 2. Proposed current-mode current-controlled universal filter.

By taking I_{o5} too high, the fifth CCCII operates as a CCII in which R_{x5} is negligible, where R_{x5} is the input resistance at terminal X of this current conveyor. The transfer functions of the proposed filter can then be given by

$$\frac{I_{LP}}{I_{in}} = \frac{\dfrac{\alpha_1\alpha_3}{R_{x1}C_1C_2(R_{x2}+R_{x3})}}{s^2 + \dfrac{R_{x1}+R_{x4}}{R_{x1}R_{x4}C_1}s + \dfrac{\alpha_1\alpha_2}{R_{x1}C_1C_2(R_{x2}+R_{x3})}} \quad (3)$$

$$\frac{I_{BP}}{I_{in}} = \frac{-\dfrac{\alpha_4}{R_{x4}C_1}s}{s^2 + \dfrac{R_{x1}+R_{x4}}{R_{x1}R_{x4}C_1}s + \dfrac{\alpha_1\alpha_2}{R_{x1}C_1C_2(R_{x2}+R_{x3})}} \quad (4)$$

$$\frac{I_{HP}}{I_{in}} = \frac{\dfrac{\alpha_5 C_3}{C_1}s^2}{s^2 + \dfrac{R_{x1}+R_{x4}}{R_{x1}R_{x4}C_1}s + \dfrac{\alpha_1\alpha_2}{R_{x1}C_1C_2(R_{x2}+R_{x3})}}, \quad (5)$$

where R_{xi} and $\alpha_i, i = 1, \cdots, 4$ are the input resistance at terminal X and the current tracking error of the i-th CCCII, respectively. Then, the filter simultaneously realizes lowpass, bandpass, and highpass responses. From (3), (4), and (5), we can see that the gains of the lowpass, bandpass and highpass responses are as follows:

$$G_{LP} = \frac{\alpha_3}{\alpha_2},\ G_{BP} = \frac{-\alpha_4 R_{x1}}{R_{x1}+R_{x4}},\ G_{HP} = \frac{\alpha_5 C_3}{C_1}. \quad (6)$$

By adding current outputs I_{LP} and I_{HP}, one can obtain a regular notch filter for C_1=C_3. Note that since zero and pole frequencies can take different values, one can also obtain lowpass notch and highpass notch filters for C_1>C_3 and C_1<C_3, respectively. Parameters ω_o and $\dfrac{\omega_o}{Q}$ can be given as follows:

$$\omega_o = \sqrt{\frac{\alpha_1\alpha_2}{R_{x1}C_1C_2\left(R_{x2}+R_{x3}\right)}} \tag{7}$$

$$\frac{\omega_o}{Q} = \frac{R_{x1}+R_{x4}}{R_{x1}R_{x4}C_1}. \tag{8}$$

From (2), (7), and (8), we can see that parameter ω_o can be controlled electronically by adjusting bias current I_{o2} and/or I_{o3} without disturbing parameter ω_o/Q. Furthermore, parameter ω_o/Q can be controlled by adjusting bias current I_{o4} without disturbing parameter ω_o.

Capacitor C_3 and input resistance R_{x5} at terminal X of the 5th CCCII result in a dominant pole in the highpass response, which restricts the frequency range of the filter. The maximum operating frequency of the filter can be calculated as

$$f_{\max} = \frac{1}{2\pi R_{x5}C_3}. \tag{9}$$

A sensitivity analysis shows that

$$S^{\omega_o}_{R_{x1}} = S^{\omega_o}_{C_1} = S^{\omega_o}_{C2} = -S^{\omega_o}_{I_{o1}} = -S^{\omega_o}_{\alpha_1} = -S^{\omega_o}_{\alpha_2} = -\frac{1}{2}$$

$$S^{\omega_o}_{R_{x4}} = S^{\omega_o}_{C_3} = S^{\omega_o}_{\alpha_3} = S^{\omega_o}_{\alpha_4} = S^{\omega_o}_{\alpha_5} = S^{\frac{\omega_o}{Q}}_{R_{x2}} = S^{\frac{\omega_o}{Q}}_{R_{x3}} = S^{\frac{\omega_o}{Q}}_{C_2} = S^{\frac{\omega_o}{Q}}_{C_3} = 0$$

$$S^{\frac{\omega_o}{Q}}_{\alpha_1} = S^{\frac{\omega_o}{Q}}_{\alpha_2} = S^{\frac{\omega_o}{Q}}_{\alpha_3} = S^{\frac{\omega_o}{Q}}_{\alpha_4} = S^{\frac{\omega_o}{Q}}_{\alpha_5} = 0$$

$$S^{\omega_o}_{R_{x2}} = -S^{\omega_o}_{I_{o2}} = -\frac{R_{x2}}{2\left(R_{x2}+R_{x3}\right)},\quad S^{\omega_o}_{R_{x3}} = -S^{\omega_o}_{I_{o3}} = -\frac{R_{x3}}{2\left(R_{x2}+R_{x3}\right)}$$

$$S^{\frac{\omega_o}{Q}}_{R_{x1}} = -S^{\frac{\omega_o}{Q}}_{I_{o1}} = -\frac{R_{x4}}{R_{x1}+R_{x4}},\quad S^{\frac{\omega_o}{Q}}_{R_{x4}} = -S^{\frac{\omega_o}{Q}}_{I_{o4}} = -\frac{R_{x1}}{R_{x1}+R_{x4}}.$$

Thus, all of the passive and active sensitivities are low.

III. Simulation Results

To verify the theoretical analyses, we simulated the circuit proposed in Fig. 2 using the SPICE circuit simulation program. We simulated the CCCII+s using the schematic implementation shown in Fig. 3 with a dc supply voltage of =±2.5 V. We simulated the PNP and NPN transistors in the CCCII+ implementation using the parameters of the PR100N and NR100N bipolar transistors [16]. We selected the following setting to obtain the lowpass, bandpass and highpass responses shown in Fig. 4 with a pole-natural frequency of f_o=173.1 kHz and a pole-quality factor of Q=0.707: $I_{o1}=I_{o4}$=10 µA, $I_{o2}=I_{o3}$=40 µA, I_{o5}=600 µA, $C_1=C_2=C_3$=1 nF.

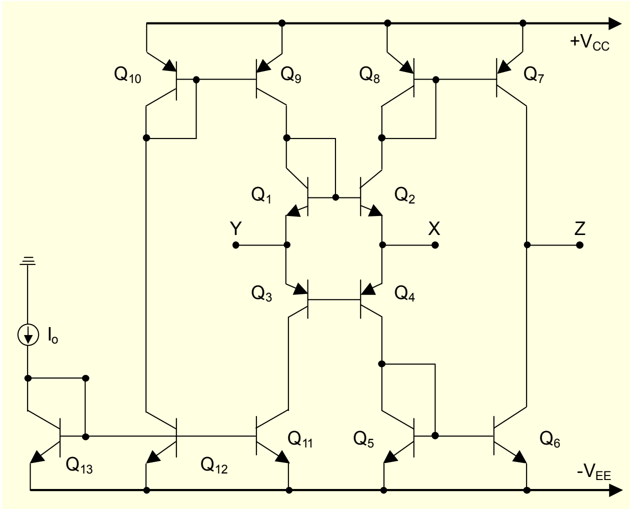

Fig. 3. The realization circuit of CCCII+.

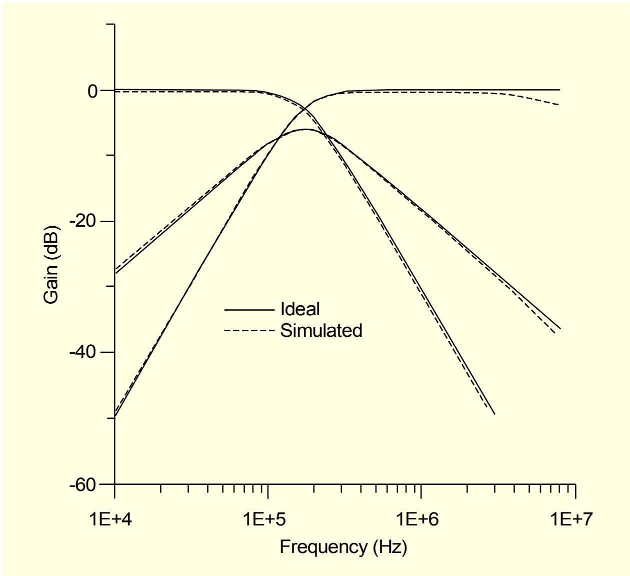

Fig. 4. The ideal and simulated lowpass, bandpass and highpass responses of the proposed circuit.

Figure 5 shows the notch response of a circuit with the same setting. The simulation results agree quite well with the theoretical analysis. The difference in the high frequency region of the highpass response stems primarily from the nonzero value of the R_{x5} resistance.

The variability of natural frequency f_o with bias current $I_{o2}=I_{o3}=I_o$ for the bandpass response is shown in Fig. 6. We can see that the circuit exhibits a large tuning range.

We tested the large signal behavior of the circuit by investigating the dependence of the output harmonic distortion of the bandpass response on the input signal amplitude. The obtained results are shown in Fig. 7. From Fig. 7, we can see that the harmonic distortion rapidly increases if the input signal

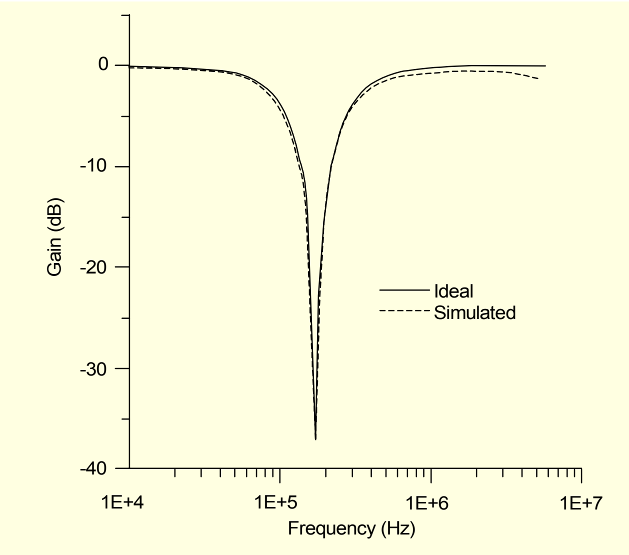

Fig. 5. The ideal and simulated notch responses of the proposed circuit.

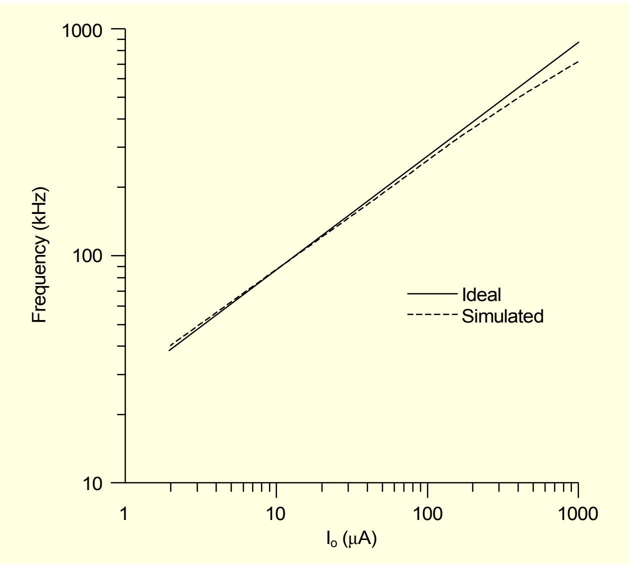

Fig. 6. Variation of natural frequency f_o with bias current $I_{o2}= I_{o3}=I_o$ for the bandpass response.

is increased beyond 150 μA for the chosen CCCII realization. For input signal levels of lower than 150 μA, the total harmonic distortion remains in acceptable limits of the order of THD =2.5%. The results prove that the circuit operates properly even at larger signal levels in the order of 150 μA. The dependence of the output current of the filter on load resistor RL for a bandpass response is simulated for an input signal level of $I_{in(peak)}=50$ μA and a signal frequency of $f=173.1$ kHz. The results are given in Table 1. From Table 1, we can easily observe that the output current level remains approximately constant, independent from the load resistor value. The output

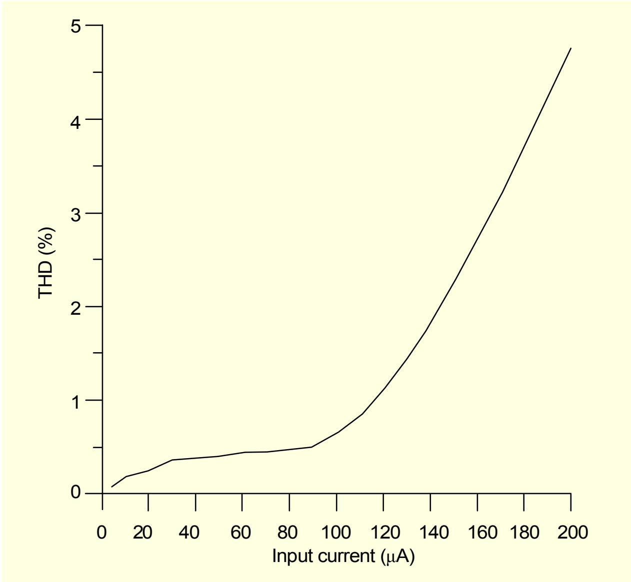

Fig. 7. Dependence of the output harmonic distortion of the bandpass filter on an input signal amplitude.

Table 1. The dependence of the output current of the bandpass filter on the load resistor R_L for an input signal of $f=173.1$ kHz, $I_{in(peak)}=50$ μA.

R_L	$I_{out(peak)}$	THD (%)
100 Ω	24.88 μA	0.82
1 kΩ	24.85 μA	0.8
10 kΩ	24.73 μA	0.75
50 kΩ	23.88 μA	0.59
100 kΩ	22.16 μA	1.11
120 kΩ	19.9 μA	2.5

voltage is defined by

$$V_{out} = I_{out} R_L, \tag{10}$$

which results in the output voltage increasing linearly with an increasing load resistor when the CCCII operates in the linear operation region. Note that the circuit yields output voltage levels of up to $V_{out}=19.9$ μA × 120 kΩ=2.38 V even at a frequency of $f=173.1$ kHz, where the harmonic distortion remains in acceptable levels. The power consumption of the filter is 17.1 mW.

IV. Conclusion

We presented a new current-mode current-controlled universal filter with a single input and three outputs. The proposed circuit uses the current-controlled conveyors and enjoys the following advantages: i) use of only plus-type current controlled conveyors, ii) simultaneous realization of lowpass, bandpass, and highpass filter functions without changing the circuit topology, iii) realization of the notch response does not require additional active elements, iv) an entirely independent current-control of parameters ω_o and ω_o/Q, v) use of grounded capacitors—attractive for integration, and vi) low sensitivities with respect to active and passive elements.

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