

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

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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  $\omega_o$  and  $\omega_o/Q$ . No element matching conditions are imposed. Both its active and passive sensitivities are low.**

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

## 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 cascability 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

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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 CCCII, 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 cascability. 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  $\omega_o$  and  $\omega_o/Q$ .

## 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].

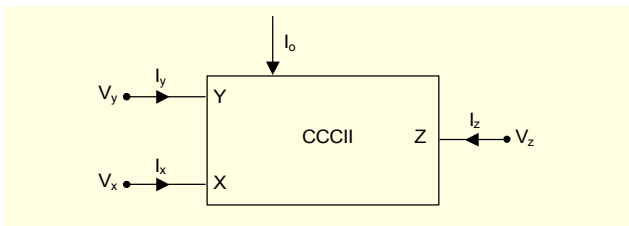


Fig. 1. An electrical symbol of the CCCII.

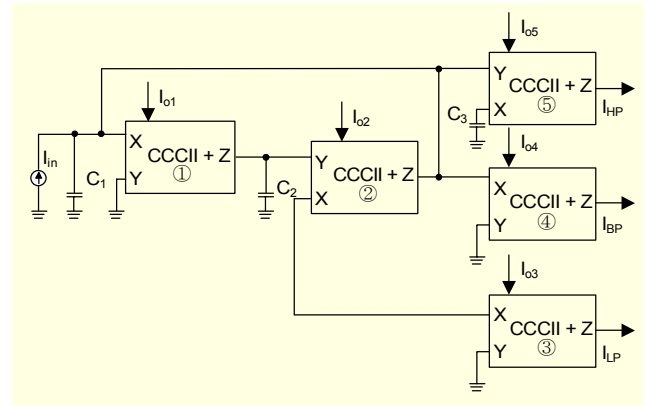


Fig. 2. Proposed current-mode current-controlled universal filter.

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

$$\frac{I_{LP}}{I_{in}} = \frac{\frac{\alpha_1 \alpha_3}{R_{x1} C_1 C_2 (R_{x2} + R_{x3})}}{s^2 + \frac{R_{x1} + R_{x4}}{R_{x1} R_{x4} C_1} s + \frac{\alpha_1 \alpha_2}{R_{x1} C_1 C_2 (R_{x2} + R_{x3})}} \quad (3)$$

$$\frac{I_{BP}}{I_{in}} = \frac{-\frac{\alpha_4}{R_{x4} C_1} s}{s^2 + \frac{R_{x1} + R_{x4}}{R_{x1} R_{x4} C_1} s + \frac{\alpha_1 \alpha_2}{R_{x1} C_1 C_2 (R_{x2} + R_{x3})}} \quad (4)$$

$$\frac{I_{HP}}{I_{in}} = \frac{\frac{\alpha_5 C_3}{C_1} s^2}{s^2 + \frac{R_{x1} + R_{x4}}{R_{x1} R_{x4} C_1} s + \frac{\alpha_1 \alpha_2}{R_{x1} C_1 C_2 (R_{x2} + R_{x3})}}, \quad (5)$$

where  $R_{xi}$  and  $\alpha_i$ ,  $i = 1, \dots, 4$  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:

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

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  $\omega_o$  and  $\frac{\omega_o}{Q}$  can be given as follows:

$$\omega_o = \sqrt{\frac{\alpha_1 \alpha_2}{R_{x1} C_1 C_2 (R_{x2} + R_{x3})}} \quad (7)$$

$$\frac{\omega_o}{Q} = \frac{R_{x1} + R_{x4}}{R_{x1} R_{x4} C_1} \quad (8)$$

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

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

$$f_{\max} = \frac{1}{2\pi R_{x5} C_3} \quad (9)$$

A sensitivity analysis shows that

$$S_{R_{x1}}^{\omega_o} = S_{C_1}^{\omega_o} = S_{C_2}^{\omega_o} = -S_{I_{o1}}^{\omega_o} = -S_{\alpha_1}^{\omega_o} = -S_{\alpha_2}^{\omega_o} = -\frac{1}{2}$$

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

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

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

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

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  $\pm 2.5$  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  $Q = 0.707$ :  $I_{o1} = I_{o4} = 10$   $\mu$ A,  $I_{o2} = I_{o3} = 40$   $\mu$ A,  $I_{o5} = 600$   $\mu$ A,  $C_1 = C_2 = C_3 = 1$  nF.

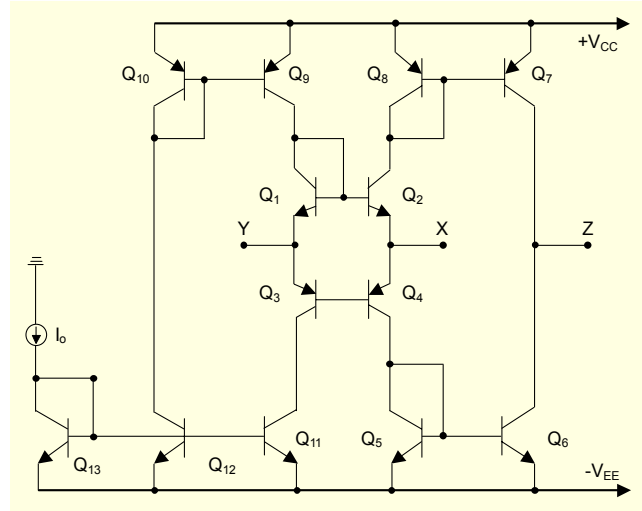


Fig. 3. The realization circuit of CCCII+.

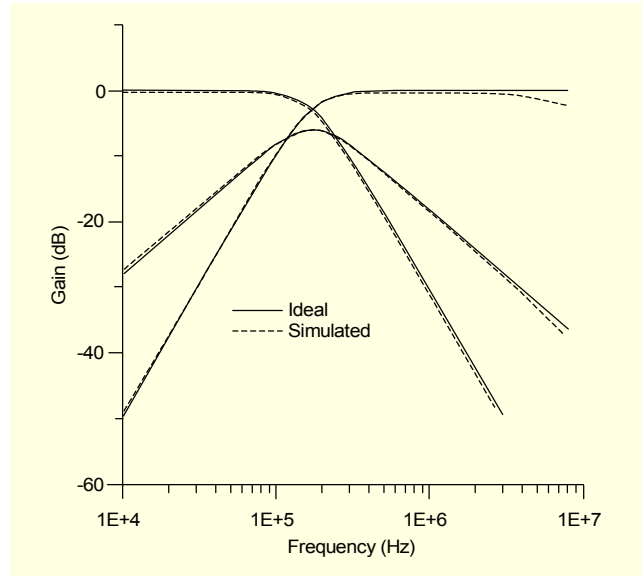


Fig. 4. The ideal and simulated lowpass, bandpass and highpass responses of the proposed circuit.

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

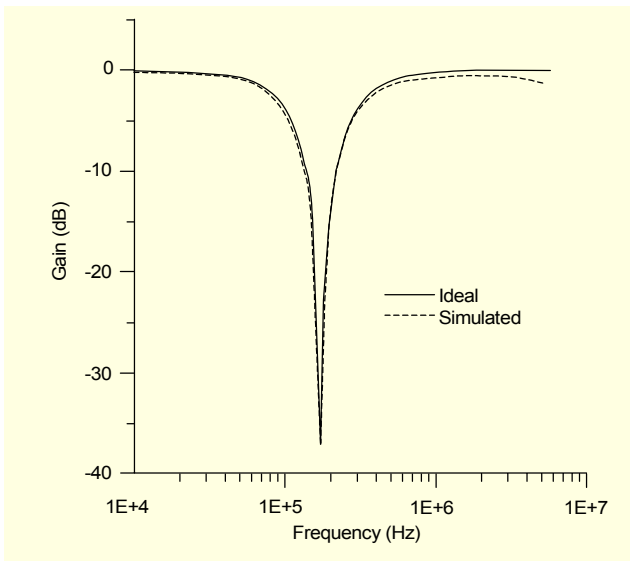


Fig. 5. The ideal and simulated notch responses of the proposed circuit.

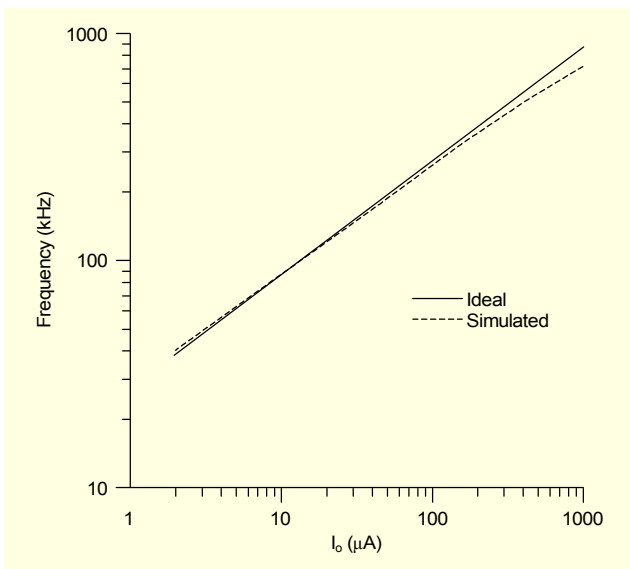


Fig. 6. Variation of natural frequency  $f_o$  with bias current  $I_{o2}=I_{o3}=I_o$  for the bandpass response.

is increased beyond 150  $\mu\text{A}$  for the chosen CCCII realization. For input signal levels of lower than 150  $\mu\text{A}$ , the total harmonic distortion remains in acceptable limits of the order of  $\text{THD} = 2.5\%$ . The results prove that the circuit operates properly even at larger signal levels in the order of 150  $\mu\text{A}$ . The dependence of the output current of the filter on load resistor  $R_L$  for a bandpass response is simulated for an input signal level of  $I_{in(\text{peak})} = 50 \mu\text{A}$  and a signal frequency of  $f = 173.1 \text{ kHz}$ . 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

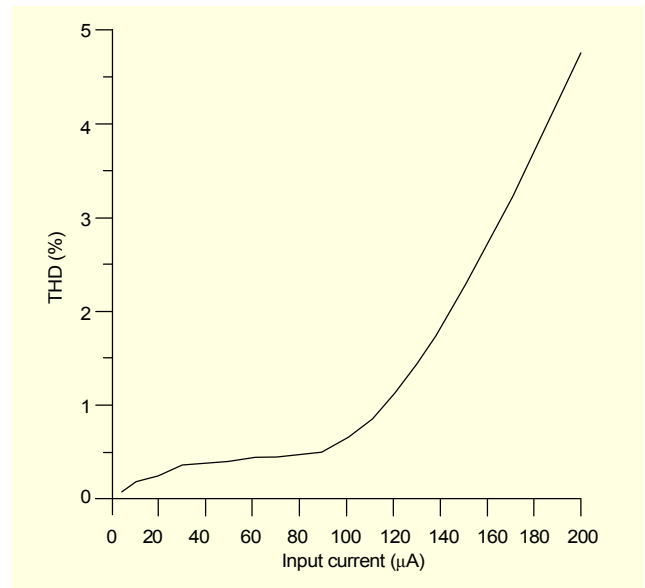


Fig. 7. Dependence of the output harmonic distortion of the bandpass filter on an input signal amplitude.

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

$R_L$	$I_{out(\text{peak})}$	THD (%)
100 $\Omega$	24.88 $\mu\text{A}$	0.82
1 k $\Omega$	24.85 $\mu\text{A}$	0.8
10 k $\Omega$	24.73 $\mu\text{A}$	0.75
50 k $\Omega$	23.88 $\mu\text{A}$	0.59
100 k $\Omega$	22.16 $\mu\text{A}$	1.11
120 k $\Omega$	19.9 $\mu\text{A}$	2.5

voltage is defined by

$$V_{out} = I_{out} R_L, \quad (10)$$

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  $V_{out} = 19.9 \mu\text{A} \times 120 \text{ k}\Omega = 2.38 \text{ V}$  even at a frequency of  $f = 173.1 \text{ kHz}$ , 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  $\omega_o$  and  $\omega_o/Q$ , v) use of grounded capacitors—attractive for integration, and vi) low sensitivities with respect to active and passive elements.

## References

- [1] G.W. Roberts and A.S. Sedra, "All Current-Mode Frequency Selective Circuits," *Electronics Lett.*, vol. 25, 1989, pp. 759-761.
- [2] C.M. Chang, "Universal Active Current Filter with Single Input and Three Outputs Using CCII's," *Electronics Lett.*, vol. 29, 1993, pp. 1932-1933.
- [3] C.M. Chang, "Novel Universal Current-Mode Filter with Single Input and Three Outputs Using Only Five Current Conveyors," *Electronics Lett.*, vol. 29, 1993, pp. 2005-2007.
- [4] A. Fabre and M. Alami, "Universal Current Mode Biquad Implemented from Two Second Generation Current conveyors," *IEEE Trans. Circuits Syst.-I: Fundamental Theory and Applications*, vol. 42, 1995, pp. 383-385.
- [5] S. Özoğuz and C. Acar, "Universal Current-Mode Filter with Reduced Number of Active and Passive Components," *Electronics Lett.*, vol. 33, 1997, pp. 948-949.
- [6] S. Özoğuz, A. Toker, and O. Çiçekoğlu, "New Current-Mode Universal Filters Using Only Four (CCII+)'s," *Microelectronics J.*, vol. 30, 1999, pp. 255-258.
- [7] R. Senani, "A Simple Approach of Deriving Single-Input Multiple-Output Current-Mode Biquad Filters," *Frequenz*, vol. 50, 1996, pp. 124-127.
- [8] R. Senani, "New Current-Mode Biquad Filter," *Int'l J. Electronics*, vol. 73, 1992, pp. 735-742.
- [9] M.T. Abuelma'atti and N.A. Tasadduq "New Current-Mode Current-Controlled Filters Using the Current-Controlled Conveyor," *Int'l J. Electronics*, vol. 85, 1998, pp.483-488.
- [10] M.T. Abuelma'atti and N.A. Tasadduq "Universal Current-Controlled Current-Mode Filter Using the Multiple-Output Translinear Current Conveyor," *Frequenz*, vol. 52, 1998, pp. 252-254.

- [11] M.T. Abuelma'atti and N.A. Tasadduq "A Novel Single-Input Multiple-Output Current-Mode Current-Controlled Universal Filter," *Microelectronics J.*, vol. 29, 1998, pp. 901-905.
- [12] S. Minaei and S. Türköz "New Current-Mode Current-Controlled Universal Filter with Single Input and Three Outputs," *Int'l J. Electronics*, vol. 88, 2001, pp.333-337.
- [13] A. Fabre, O. Saaid, F. Wiest, and C. Boucheron "Current Controlled Bandpass Filter Based on Translinear Conveyors," *Electronics Lett.*, vol. 31, 1995, pp.1727-1728.
- [14] M. Higashimura and Y. Fukui "Universal Filter Using Plus-Type CCII's," *Electronics Lett.*, vol. 32, 1996, pp. 810-811.
- [15] K. Pal and R. Singh "Inductorless Current Conveyor Allpass Filter Using Grounded Capacitors," *Electronics Lett.*, vol. 18, 1982, p. 47.
- [16] D.R. Frey "Log-Domain Filtering: an Approach to Current-Mode Filtering," *IEE Proc.-G, Circuits, Devices and Systems*, vol. 140, 1993, pp. 406-416.



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