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Versatile universal electronically tunable current-mode filter using CCCIIs

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Abstract: A new versatile universal electronically tunable current-mode filter with three inputs and three outputs using three multiple-output current-controlled conveyors (MO-CCCIIs) and two grounded capacitors is proposed. The proposed configuration can be used as either a single-input three-output or three-input single-output. It can simultaneously realize all five different generic filtering signals: lowpass, bandpass, highpass, bandreject and allpass, unlike the previously reported works. It still maintains the following advantages: (i) the employment two grounded capacitors ideal for integrated circuit implementation, (ii) high output impedance good for cascadability for the current-mode circuits, (iii) no need to impose component choice, (iv) no need to employ inverting-type current input signals, and (v) low active and passive sensitivity performances. H-Spice and MATLAB simulations results are provided to demonstrate the theoretical analysis.

Keywords: active filters, current conveyors, analog electronics

Classification: Integrated circuits

References

[1] B. Wilson, "Recent developments in current conveyor and current-mode circuits," *Proc. IEE*, vol. 137, no. 2, pp. 63–77, 1990.

[2] G. W. Roberts and A. S. Sedra, "All current-mode frequency selective circuits," *Electron. Lett.*, vol. 25, no. 12, pp. 759–761, 1989.

[3] C. M. Chang, "Current mode allpass/notch and bandpass filter using single CCII," *Electron. Lett.*, vol. 27, no. 20, pp. 1812–1813, 1991.

[4] A. Fabre, O. Saaid, F. Wiest, and C. Boucheron, "Current controlled bandpass filter based on translinear conveyors," *Electron. Lett.*, vol. 31, no. 20, pp. 1727–1728, 1995.

[5] A. Fabre, O. Saaid, F. Wiest, and C. Boucheron, "High frequency applications based on a new current controlled conveyors," *IEEE Trans. Circuits Syst. I, Fundam. Theory Appl.*, vol. 43, no. 2, pp. 82–91, 1996.

[6] M. T. Abuelma'atti and N. A. Tasadduq, "A novel single-input multiple-output current-mode current-controlled universal filter," *Microelectron. J.*, vol. 29, no. 11, pp. 901–905, 1998.

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[7] I. A. Khan and M. H. Zaidi, "Multifunctional translinear-C current-mode filter," *Int. J. Electron.*, vol. 87, no. 9, pp. 1047–1051, 2000.
[8] S. Minaei and S. Turkoz, "New current-mode current-controlled universal filter with single input and three outputs," *Int. J. Electron.*, vol. 88, no. 3, pp. 333–337, 2001.
[9] E. Altuntas and A. Toker, "Realization of voltage and current mode KHN biquads using CCCIIs," *Int. J. Electron. Commun. (AEÜ)*, vol. 56, no. 1, pp. 45–49, 2002.
[10] M. Sagbas and K. Fidanboylu, "Electronically tunable current-mode second-order universal filter using minimum elements," *Electron. Lett.*, vol. 40, no. 1, pp. 2–4, 2004.
[11] R. Senani, V. K. Singh, A. K. Singh, and D. R. Bhaskar, "Novel electronically controllable current-mode universal biquad filter," *IEICE Electron. Express*, vol. 1, no. 14, pp. 410–415, 2004.
[12] N. Pandey, S. K. Paul, A. Bhattacharyya, and S. B. Jain, "A novel current controlled current mode universal filter: SITO approach," *IEICE Electron. Express*, vol. 2, no. 17, pp. 451–457, 2005.
[13] W. Tangsrirat and W. Surakampontorn, "High output impedance current-mode universal filter employing dual-output current-controlled conveyors and grounded capacitors," *Int. J. Electron. Commun. (AEÜ)*, vol. 61, no. 2, pp. 127–131, 2007.
[14] W. Tangsrirat, "Current-tunable current-mode multifunction filter based on dual-output currnet-controlled conveyors," *Int. J. Electron. Commun. (AEÜ)*, vol. 61, no. 8, pp. 528–533, 2007.

1 Introduction

Current-mode active elements offer the main advantages like greater linearity, low power consumption and wider bandwidth over their voltage-mode counterparts [1, 2, 3]. The current-controlled current conveyor based circuits introduced by Fabre et al. [4, 5] can be made a wide range of electronic tunability of the circuit parameters and a wider frequency range of operation. Many configurations for the realization current-mode universal biquadratic filter using current-controlled current conveyors (CCCIIs) have been reported in the literature [6, 7, 8, 9, 10, 11, 12, 13, 14]. In 1998, Abuelma'atti et al. [6] proposed a single-input multiple-output current-mode universal filter. This proposed configuration requires six active components. In 2000, Khan et al. [7] proposed a multifunction translinear-C current-mode filter. The proposed circuit suffers from high output impedance. Thus, it cannot be cascaded in current-mode. In 2001, Minaei et al. [8] proposed a single input and three outputs current-mode filter. Unfortunately, it needs three grounded capacitors to realize lowpass, bandpass and highpass filter responses. In 2002, Altuntas et al. [9] proposed two current-mode Kerwin-Huelsman-Newcomb (KHN) circuits. However, the proposed two configurations require five active components. In 2004, Sagbas et al. [10] proposed an electronically tunable current-mode filter. However, it still suffers from high output impedance. In the same year, Senani et al. [11] proposed a single input and three outputs current-mode filter. However, both single-input three-output and three-input

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single-output cannot be realized in the same configuration. In 2005, Pandey et al. [12] proposed another single input and three outputs current-mode filter. Both single-input three-output and three-input single-output still cannot be realized in the same configuration. In 2007, Tangsrirat et al. [13] proposed a good high output impedance current-mode universal filter. However, the proposed circuit needs a minus input current signal to realize all-pass filter. Thus, it needs one more active component to obtain the minus input current signal. Recently, Tangsrirat [14] proposed another current-tunable current-mode multifunction filter. However, it still needs a minus input current signal or double input current signal to realize allpass filter. In this paper, a versatile three-input three-output universal current-mode filter is proposed. Either applications single-input three-output or three-input single-output can be realized in the same configuration. Unlike the previously works [6, 7, 8, 9, 10, 11, 12, 13, 14], it is highly flexible and easy to design. In the application of single-input three-output, the lowpass, bandpass and bandreject can be realized simultaneously while the highpass and allpass responses can be easily obtained by connecting appropriated output currents directly without using additional active elements. In the application of three-input single-output, the lowpass (LP), bandpass (BP), highpass (HP), bandreject (BR) and allpass (AP) can be realized from the same configuration without any inverting-type current input signals or double input current signals.

2 Circuit description

The proposed versatile universal electronically tunable current-mode filter is show in Fig. 1 using three MO-CCCIIs and two grounded capacitors attractive for integrated circuit implementation. It can be seen that it is necessary to increase the number of terminals of the original three-terminal CCCII proposed in [4, 5] by two in order to produce two more current outputs which are taken from outputs Z_{2+}/Z_{2-}, Z_{3+}/Z_{3-}, all of which are simply reconstructed by using current mirrors. By using standard notation, the port relations of the CCCII can be characterized by $I_Y = 0$, $V_X = V_Y + I_X R_X$, and $I_Z = \pm I_X$ [4, 5], where the parasitic resistance $R_X = V_T/2I_o$, V_T is the thermal voltage, I_o is bias current of CCCII, the sign $\pm$ refers to plus or

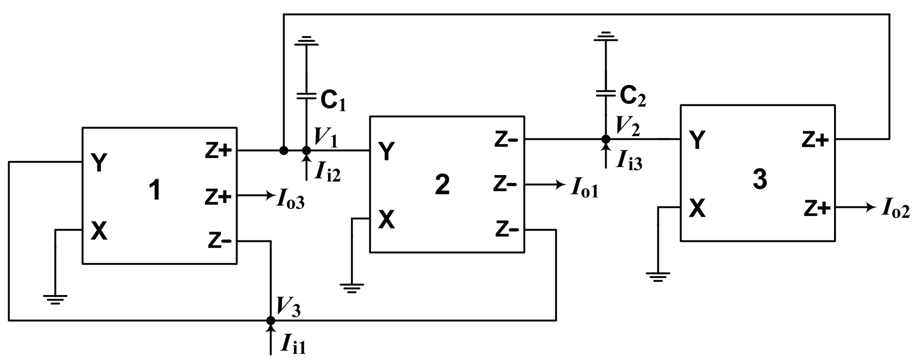

Fig. 1. Proposed versatile current-mode universal filter.

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minus type CCCII, respectively.

Circuit analysis yields the following current transfer functions:

$$I_{o1} = \frac{1}{\triangle}[-(sC_2G_{X2})I_{i1} - (sC_2G_{X2})I_{i2} - (G_{X2}G_{X3})I_{i3}]. \tag{1}$$

$$\begin{aligned} I_{o2} &= \frac{1}{\triangle}[-(G_{X2}G_{X3})I_{i1} - (G_{X2}G_{X3})I_{i2} \\ &\quad +(sC_1G_{X3} + G_{X2}G_{X3})I_{i3}]. \end{aligned} \tag{2}$$

$$\begin{aligned} I_{o3} &= \frac{1}{\triangle}[(s^2C_1C_2 + G_{X2}G_{X3})I_{i1} - (sC_2G_{X2})I_{i2} \\ &\quad -(G_{X2}G_{X3})I_{i3}]. \end{aligned} \tag{3}$$

where $\triangle = s^2C_1C_2 + sC_2G_{X2} + G_{X2}G_{X3}$, $G_{X2} = \frac{1}{R_{X2}}$, and $G_{X3} = \frac{1}{R_{X3}}$.

Depending on the status of the three biquad input currents, I_{i1}, I_{i2}, and I_{i3}, numerous filter functions are obtained. There are two cases shown as follows.

Case I. If $I_{i2} = I_{i3} = 0$, and $I_{i1} = I_{in}$ (the input current signal), then

$$\frac{I_{o1}}{I_{in}} = \frac{-sC_2G_{X2}}{s^2C_1C_2 + sC_2G_{X2} + G_{X2}G_{X3}}. \tag{4}$$

$$\frac{I_{o2}}{I_{in}} = \frac{-G_{X2}G_{X3}}{s^2C_1C_2 + sC_2G_{X2} + G_{X2}G_{X3}}. \tag{5}$$

$$\frac{I_{o3}}{I_{in}} = \frac{s^2C_1C_2 + G_{X2}G_{X3}}{s^2C_1C_2 + sC_2G_{X2} + G_{X2}G_{X3}}. \tag{6}$$

It can be seen from (4) to (6) that an inverting bandpass filter response is obtained from I_{o1}, an inverting lowpass filter response is obtained from I_{o2}, and a non-inverting bandreject filter response is obtained from I_{o3}. A non-inverting highpass filter response is easily obtained by connecting the I_{o2} with the I_{o3} output terminals. We obtain the current-mode highpass transfer function

$$\frac{I_{HP}}{I_{in}} = \frac{s^2C_1C_2}{s^2C_1C_2 + sC_2G_{X2} + G_{X2}G_{X3}}. \tag{7}$$

Similarly, by connecting the I_{o1} with the I_{o3} output terminals, we obtain the current-mode allpass transfer function

$$\frac{I_{AP}}{I_{in}} = \frac{s^2C_1C_2 - sC_2G_{X2} + G_{X2}G_{X3}}{s^2C_1C_2 + sC_2G_{X2} + G_{X2}G_{X3}}. \tag{8}$$

Obviously, it is a single-input and five-output current-mode universal biquad. Note that no cancellation constraints are used in the design.

Case II. The specializations of the numerator in (3) result in the five generic filter function:

(i) LP: $I_{i1} = I_{i2} = 0$, and $I_{i3} = I_{in}$;

(ii) BP: $I_{i1} = I_{i3} = 0$, and $I_{i2} = I_{in}$;

(iii) HP: $I_{i2} = 0$, and $I_{i1} = I_{i3} = I_{in}$;

(iv) BR: $I_{i2} = I_{i3} = 0$, and $I_{i1} = I_{in}$;

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(v) AP: I_{i3}= 0, and $I_{i1} = I_{i2} = I_{in}$.

Note that there are not any component-matching conditions, inverting-type input current signals, and double input current signals to realize the above five generic filter signals in the design. Obviously, it is a three-input and signal-output current-mode universal biquad, too. In all cases the resonance angular frequency ω_o, quality factor Q, and ω_o/Q are given by

$$\omega_o = \sqrt{\frac{G_{X2}G_{X3}}{C_1C_2}}, \quad Q = \sqrt{\frac{C_1G_{X3}}{C_2G_{X2}}}, \quad \frac{\omega_o}{Q} = \frac{G_{X2}}{C_1}. \tag{9}$$

The resonance angular frequency ω_o can be adjusted by varying bias current I_{o3} without disturbing ω_o/Q. The ω_o and Q are orthogonally adjustable if G_{X2} and G_{X3} are simultaneously adjusted by a common control bias current $I_{o2} = I_{o3} = I_o$ [12].

3 Effect of Non-idealities

Taking the non-idealities of the MO-CCCII into account, the relationship of the terminal voltages and currents can be rewritten as $I_Y = 0$, $V_X = \beta V_Y + I_X R_X$, $I_{Z+} = +\alpha_P I_X$, and $I_{Z-} = -\alpha_n I_X$, where $\beta = 1 - \epsilon_v$ and ϵ_v ($|\epsilon_v| \ll 1$) represents the voltage tracking error from Y to X terminal, and $\alpha_P = 1-\epsilon_p$, and ϵ_p ($|\epsilon_p| \ll 1$) denote the current tracking error from X to +Z terminal, and $\alpha_n = 1-\epsilon_n$, and ϵ_n ($|\epsilon_n| \ll 1$) denote the current tracking error from X to -Z terminal of the MO-CCCII, respectively. The denominator of the transfer functions of Eqs. (4) to (8) is rewritten as

$$\begin{aligned} D(s) \;=\;& \alpha_{n11}\beta_1 s^2 C_1C_2 + \alpha_{n11}\alpha_{n23}\beta_1\beta_2 s C_2 G_{X2} \\ &+\alpha_{p31}\alpha_{n11}\alpha_{n21}\beta_1\beta_2\beta_3 G_{X2}G_{X3}. \end{aligned} \tag{10}$$

The non-ideal resonance angular frequency ω_o and quality factor Q are obtained by

$$\omega_o = \sqrt{\frac{\alpha_{p31}\alpha_{n21}\beta_2\beta_3G_{X2}G_{X3}}{C_1C_2}}. \tag{11}$$

$$Q = \frac{1}{\alpha_{n23}}\sqrt{\frac{\alpha_{p31}\alpha_{n21}\beta_3C_1G_{X3}}{\beta_2C_2G_{X2}}}. \tag{12}$$

A sensitivity study forms an important index of the performance of any active network. The formal definition of sensitivity is

$$S_x^F = \frac{x}{F}\frac{\partial F}{\partial x}. \tag{13}$$

where F represents one of ω_o, Q and x represents any of the passive elements $(G_{X2} - G_{X3}, C_1 - C_2)$ or the active parameters (α_i, β_i). Using the above definition the active and passive sensitivities of the proposed circuit shown in Fig. 1 are given as

$$\begin{gathered} S^{\omega_o}_{\alpha_{p31}} = S^{\omega_o}_{\alpha_{n21}} = S^{\omega_o}_{\beta_2} = S^{\omega_o}_{\beta_3} = S^{\omega_o}_{G_{X2}} = S^{\omega_o}_{G_{X3}} = -S^{\omega_o}_{C_1} = -S^{\omega_o}_{C_2} = \tfrac{1}{2}; \\ S^{Q}_{\alpha_{p31}} = S^{Q}_{\alpha_{n21}} = S^{Q}_{\beta_3} = -S^{Q}_{\beta_2} = -S^{Q}_{G_{X2}} = S^{Q}_{G_{X3}} = S^{Q}_{C_1} = -S^{Q}_{C_2} = \tfrac{1}{2}; \\ S^{Q}_{\alpha_{n23}} = -1. \end{gathered} \tag{14}$$

all of which are low and not larger than unity in absolute value.

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4 Simulation results

In order to verify the theoretical prediction of the proposed biquad filter, we use the H-Spice for the simulation part with TSMC 0.35 μm process and Mat-lab for the theoretical part to compare the results. The CMOS implementation of the DO-CCCIIs [9] is shown in Fig. 2. The aspect ratios (W/L) of the MOS transistors were taken as 20/0.35 for M1, M2; 60/0.35 for M3, M4, 30/2 for M5, M6, M7, 10/2 for M8, M9, 10/1 for M10, M11, M17, M18, M19, 30/1 for M12, M13, M14, M15, M16. The supply voltages are $V_{DD} = -V_{SS} = 1.65\,\text{V}$, and the biasing currents are $I_{o1} = 150\,\mu\text{A}$ and $I_{o2} = I_{o3} = 15\,\mu\text{A}$. The component values of Fig. 1 were given by $G_{X2} = G_{X3} = 800\,\mu\text{S}$, and $C_1 = C_2 = 100\,\text{pF}$, leading to a center frequency of $f_o = 1.27\,\text{MHz}$ and quality factor of $Q = 1$. Fig. 3 shows the simulated results of LP, BP and BR amplitude-frequency responses with $I_{i1} = I_{in}$, and

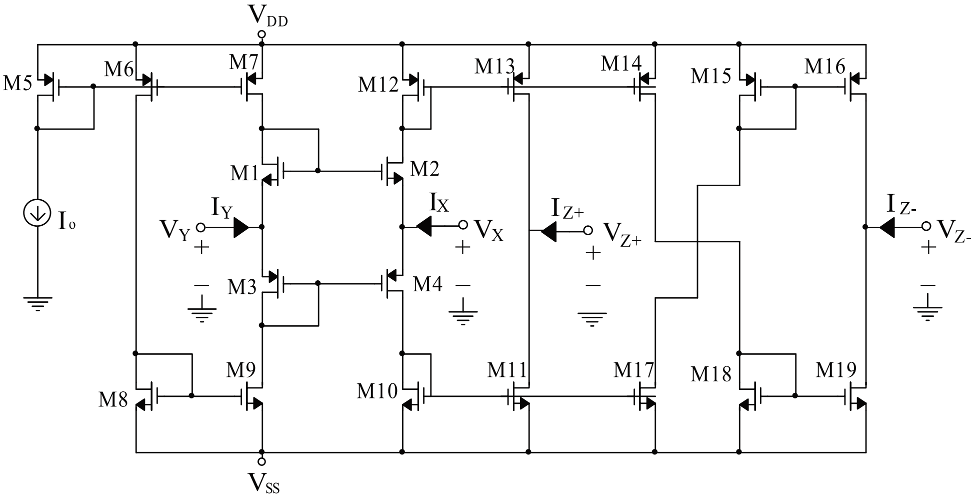

Fig. 2. CMOS implementation of DO-CCCII.

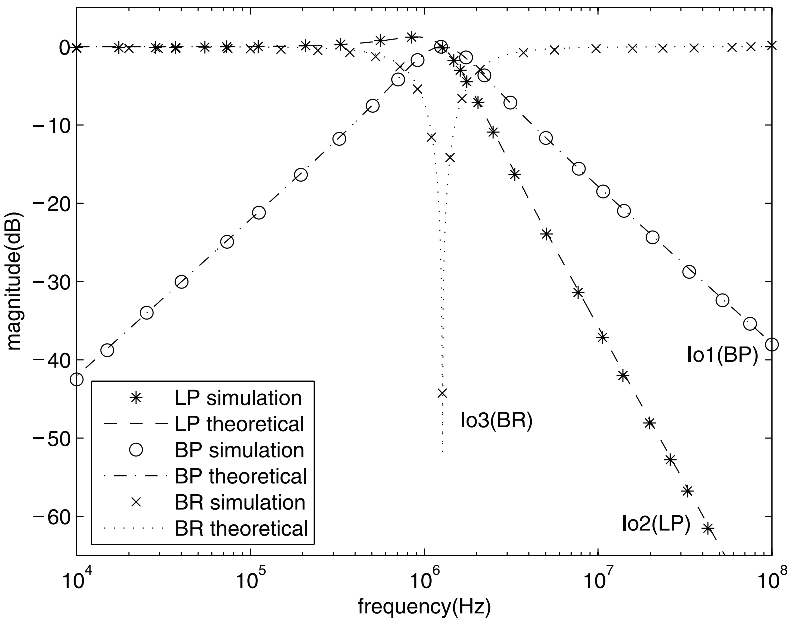

Fig. 3. Amplitude-frequency responses in case I of Fig. 1.

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Table I. Performance parameters of recently reported current-mode filters.

Circuits	Criteria					
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
The new circuit	yes	yes	yes	yes	yes	yes
Ref. [14] in 2007	no	yes	yes	yes	no	yes
Ref. [13] in 2007	no	yes	yes	yes	no	yes
Ref. [12] in 2005	no	yes	yes	yes	yes	yes
Ref. [11] in 2004	no	yes	yes	yes	yes	yes
Ref. [10] in 2004	no	no	no	yes	yes	yes
Ref. [9] in 2002	no	yes	yes	yes	yes	yes

$I_{i2} = I_{i3} = 0$. As can be seen, there is a close agreement between theory and simulation.

5 Conclusion

In this paper, a new universal current-mode filter was proposed. The proposed circuit can simultaneously realize of LP, BP, and BR filter responses without changing the circuit topology. The HP and AP can be easily obtained by connecting appropriated output currents directly without using additional active elements. It still maintains the following advantages: (i) simultaneous realization of LP, BP, HP, BR, and AP responses with the single-input three-output or three-input single-output in the same configuration, (ii) the employment two grounded capacitors ideal for integrated circuit implementation, (iii) high output impedance good for cascadability for the current-mode circuits, (vi) no need to impose component choice, (v) no need to employ inverting-type current input signals or double input current signals to realize all five generic filter, and (vi) low active and passive sensitivity performances. In Table I, the main features of the proposed new circuit are compared with those of previous works.

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