Single-Input Three-Output Current-Mode Filter Using Dual-Output Current Conveyors

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Abstract

In this paper we present a new universal current-mode frequency filter using only three dual-output second-generation current conveyors (DO-CCII) and five grounded passive elements. Simultaneously a low-pass, high-pass and band-pass can be realized – all with high output impedance. Using the proposed structure the quality factor *Q* can be via single passive element changed independently of the natural angular frequency ω_0. The PSpice simulations are given, which confirm the theoretical analysis results.

1. Introduction

Current-mode frequency filters using current conveyors as active elements are still under considerable attention mainly because of their bandwidth, linearity and dynamic range [1], [2]. Mostly second-generation current conveyors or their modifications with one [3-7] or more current outputs [8-15] are used. Using such active elements, a number of multifunction or universal filters have been designed that simultaneously realize more than one frequency response without changing the circuit topology, [4-10], [12], [14], [15]. Although the structures in [4], [6], [10] use only two or three active elements, some of the outputs are not of a high impedance. In the case of [4] and [6] another disadvantage is the necessity of using floating passive elements. This drawback is removed in the universal filter in [7]. However, five active elements have to be used. It is possible to reduce the number of active elements using dual-output current conveyors. As an example a structure in [12] can be given, which realizes a low-, a band-pass and a band-reject filter. Frequency filters with high output impedance realizing a high-, low- and band-pass response are presented in [8], [9], [14] and [15]. Nevertheless, the use of up to four current outputs of active elements sets considerable demands on the realization in integrated form.

In this letter we present a new topology of a universal filter realizing high-, low- and band-pass responses at the same time. The advantages of this circuitry can be seen in the usage of the most required number of active and passive elements, while the structure is driven in a terminal X of the active element and all current outputs are of high impedance.

2. Dual-output second-generation current conveyor

The relation between the port currents and voltages of the DO-CCII active element (Fig. 1.) can be described by the following hybrid matrix

$$\begin{bmatrix} v_X \\ i_Y \\ i_{Z1} \\ i_{Z2} \end{bmatrix} = \begin{bmatrix} 0 & \alpha & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \beta & 0 & 0 & 0 \\ \gamma & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} i_X \\ v_Y \\ v_{Z1} \\ v_{Z2} \end{bmatrix}, \qquad (1)$$

where $\alpha = 1 - \varepsilon$, $\beta = \pm(1-\sigma)$, and $\gamma = \pm(1-\eta)$ are the voltage or current transfer coefficients, whereas $|\varepsilon| << 1$, $|\sigma| << 1$, and $|\eta| << 1$ represent the voltage or current tracking errors. The ±sign refers to the positive or negative types of the current conveyor.

3. Proposed circuit

The proposed universal frequency filter using the DO-CCII elements is shown in Fig. 2. The circuit analysis yields to following current transfer functions

$$\frac{I_{\mathrm{OUT1}}}{I_{\mathrm{IN}}} = -\frac{s^2\gamma_1 C_1 C_2}{s^2 C_1 C_2 - s\alpha_1\beta_1 C_2 G_1 + \alpha_2\alpha_3\beta_1\beta_2\beta_3 G_2 G_3}, \qquad (2a)$$

$$\frac{I_{\mathrm{OUT2}}}{I_{\mathrm{IN}}} = -\frac{\alpha_2\alpha_3\beta_1\beta_3\gamma_2 G_2 G_3}{s^2 C_1 C_2 - s\alpha_1\beta_1 C_2 G_1 + \alpha_2\alpha_3\beta_1\beta_2\beta_3 G_2 G_3}, \qquad (2b)$$

$$\frac{I_{\mathrm{OUT3}}}{I_{\mathrm{IN}}} = -\frac{s\alpha_3\beta_1\gamma_3 C_2 G_3}{s^2 C_1 C_2 - s\alpha_1\beta_1 C_2 G_1 + \alpha_2\alpha_3\beta_1\beta_2\beta_3 G_2 G_3}, \qquad (2c)$$

and hence the filter provides the high-, low-, and band-pass responses simultaneously. The gain of the high-, low- and band-pass (2) in the pass band is as follows

$$G_{\mathrm{HP}} = -\gamma_1, \quad G_{\mathrm{LP}} = -\frac{\gamma_2}{\beta_2}, \quad G_{\mathrm{BP}} = \frac{\alpha_3\gamma_3 G_3}{\alpha_1 G_1}. \qquad (3a,b,c)$$

For the second-generation current conveyors it holds $\alpha_i = 1$, *i* = 1, 2, 3. For the filter to be stable, all terms in the denominator of the transfer function have to be positive. Therefore $\beta_1 = -1$ and $\beta_2\beta_3 = -1$, and hence, two possible variant solutions can be described.

Adding up the currents I_{OUT1} and I_{OUT2} a band-reject can be realized in case $\gamma_1 = \gamma_2 / \beta_2$. Adding up the currents I_{OUT1}, I_{OUT2}

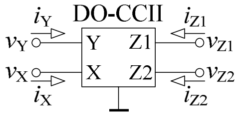


Fig. 1. Electrical symbol of the DO-CCII

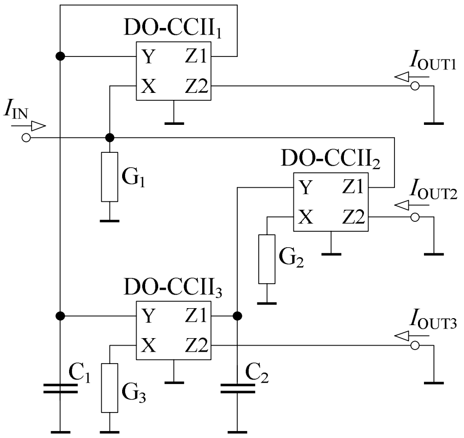


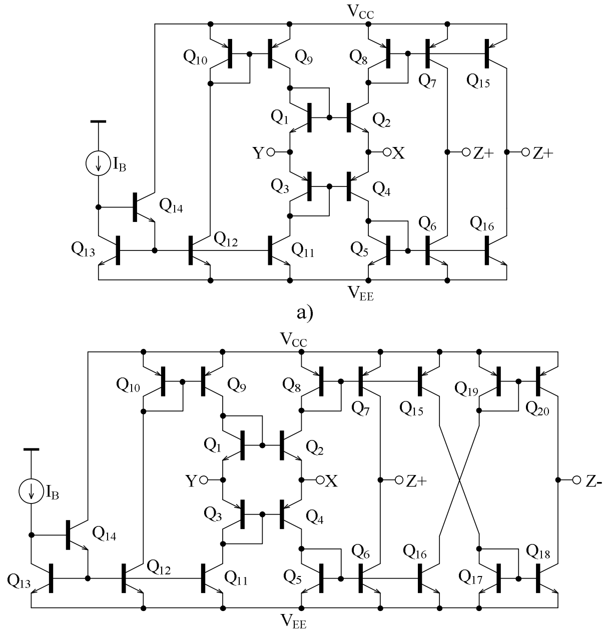
Fig. 2. Proposed current-mode universal filter

and I_{OUT3} an all-pass filter can be designed, if $\gamma_3 = -\gamma_1$ and $G_3 = G_1$. For the given conditions a suitable combination of the current transfer coefficients β and γ can be found. It should be mentioned that the most suitable are those combinations that yield to the usage of positive current outputs, because of maximal simplicity of the internal structure of the DO-CCII (Fig. 3), and consequently, final circuit solution.

For chosen coefficients $\beta_2 = 1$, $\beta_3 = -1$, $\gamma_1 = \gamma_2 = \gamma_3 = 1$ the natural angular frequency ω_0 and quality factor Q can be expressed as

$$\omega_0 = \sqrt{\frac{G_2 G_3}{C_1 C_2}}, \quad Q = \frac{1}{G_1}\sqrt{\frac{C_1 G_2 G_3}{C_2}}. \qquad (4a,b)$$

From (4) it can be seen that the quality factor can be by G$_1$ adjusted independently of the natural angular frequency. The natural frequency can also be independently adjusted, but since only five passive elements are used, the control of f_0 can be done via the capacitors C$_1$ and C$_2$ ($C_1 = C_2$). If it is required to control the natural frequency via resistors, it is necessary to use a structure employing at least seven passive elements (two capacitors, five resistors) [16].



a)

b)

Fig. 3. Internal structure of the DO-CCII with a) two positive, b) one positive and negative current outputs

Even if the proposed circuit is driven into the low-impedance terminal X of the DO-CCII$_1$, the input impedance of the filter is not ideally zero, but is given as follows

$$Z_{IN}(s) = \frac{sC_2}{s^2 C_1 C_2 + sC_2 G_1 + G_2 G_3}. \qquad (5)$$

The relative sensitivities of the ω_0 and Q parameters of the designed circuit are

$$S_{\alpha_2}^{\omega_0} = S_{\alpha_3}^{\omega_0} = S_{\beta_1}^{\omega_0} = S_{\beta_2}^{\omega_0} = S_{\beta_3}^{\omega_0} = \frac{1}{2},$$

$$S_{G_1}^{\omega_0} = S_{G_2}^{\omega_0} = -S_{C_1}^{\omega_0} = -S_{C_2}^{\omega_0} = \frac{1}{2},$$

$$S_{\alpha_2}^{\omega_0} = S_{\alpha_3}^{\omega_0} = -S_{\beta_1}^{\omega_0} = S_{\beta_2}^{\omega_0} = S_{\beta_3}^{\omega_0} = -\frac{1}{2},$$

$$S_{G_1}^{\omega_0} = -1, \quad S_{G_2}^{\omega_0} = S_{G_3}^{\omega_0} = S_{C_1}^{\omega_0} = -S_{C_2}^{\omega_0} = \frac{1}{2},$$

and so the influence of all passive and active elements on the proposed filter is small.

4. Simulation Results

The behaviour of the designed frequency filter in Fig. 2 was verified by the simulations in the PSpice program. The DO-CCII active element considered was realized using the topology shown in Fig. 3. [13], where the supply voltage is ±2.5 V and the bias current is I_B = 400 µA. Transistors PNP and NPN were simulated using the NUHFARRY and PUHFARRY models [17], which simulate UHF transistor arrays HFA3046 and HFA3096.

We designed a universal frequency filter with natural

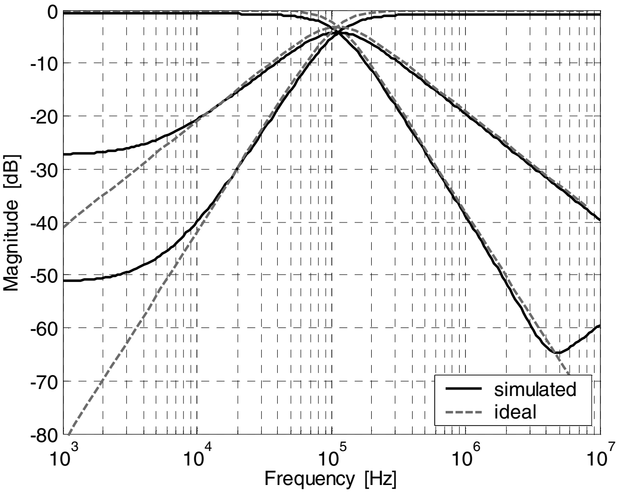
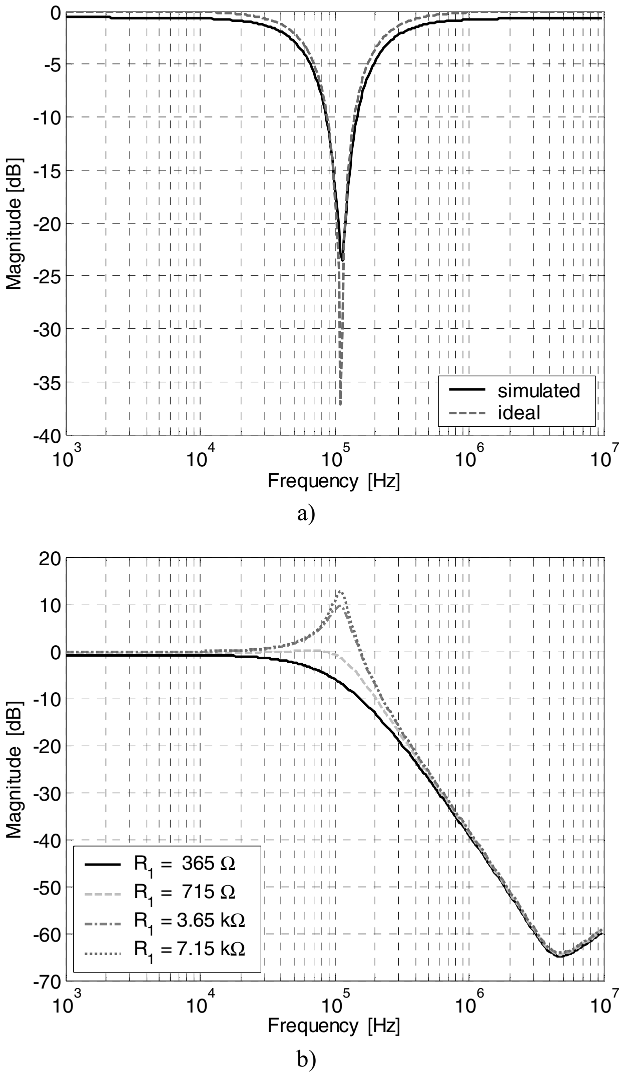


Fig. 4. Simulation results of the high-, low- and band-pass responses of the current-mode filter

frequency $f_0 = 100$ kHz, and quality factor $Q = 0.707$, while $C_1 = C_2 = 2.2$ nF, $G_2 = G_3 = 1.4$ mS, and $G_1 = 1.9$ mS. The simulation results for the high-, low- and band-pass are shown in Fig. 4. The finite value of the attenuation of the band- and high-pass filter at low frequencies is caused by the finite value of the output impedance of the terminals Z of the current conveyors. The increase in the gain of the low-pass filter in the stop-band is caused by the parasitic input-impedance of the X-port of the DO-CCII$_1$ element. This feature can be also seen in other structures, e.g. [18-20].

The response of the frequency filter working as a band-reject is shown in Fig. 5a, with the value of passive elements being retained. The control of the quality factor Q, independent of the the natural frequency $f_0 = \omega_0/2\pi$, is depicted in Fig. 5b. The values of the resistor R$_1$ were chosen as 365 Ω, 715 Ω, 3.65 kΩ, and 7.15 kΩ, which according to (4b) corresponds with the values 0.5, 1, 5, and 10 of the quality factor Q. From the simulations one can see that the available value of the quality factor is about 5.

From (5) and Fig. 6 it can be seen that the input impedance is of a band-pass character and it changes if varying the quality factor.



a)

b)

Fig. 5. a) Ideal and simulated notch responses of the proposed filter, b) Simulated low-pass responses of the filter if R$_1$ is changed

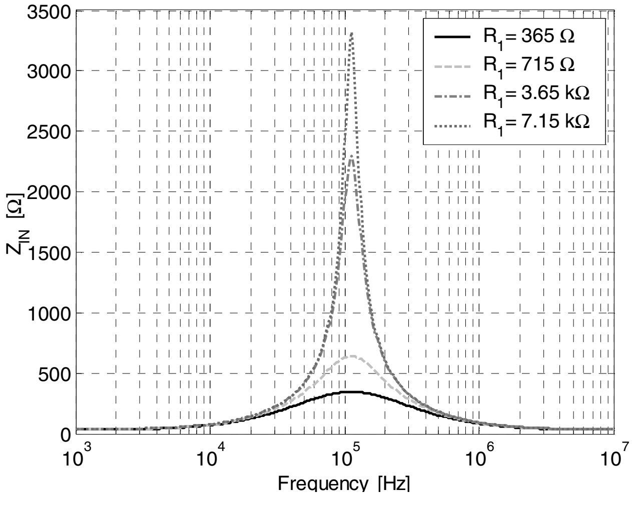


Fig. 6. Input impedance of the proposed filter vs. frequency

6. Conclusions

In this letter we presented a new universal current-mode frequency filter. The current conveyors were used as the active elements. The advantages of this structure are in that all current responses are at high impedances and, furthermore, all the passive elements are grounded, which is suitable for the implementation of the structure in the integrated form. Besides, the possibility of changing the quality factor Q via single passive element independently of pole angular frequency ω_0 can be used. The possibiliti of controlling the natural frequency independently of the quiality factor has been also discussed. The behaviour of the proposed structure has been verified using bipolar implementation of the active elements. The results fully suport the feasibilities of the frequency filter.

6. Acknowledgement

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7. References

[1] G. W. Roberts, and A. S. Sedra, “All Current-Mode Frequency Selective Circuits”, *Electronics Letters*, vol. 25, no. 12, pp. 759-760, 1989.

[2] S. Takagi, “Analog Circuit Designs in the Last Decade and Their Trends toward the 21st Century”, *IEICE Trans. Fundamentals*, vol. E84-A, no. 1, pp. 68-79, 2001.

[3] A. M. Soliman, “Equal-E, Equal-C Current Mode Butterworth Lowpass Filters”, *IEICE Trans. Fundamentals*, vol. E81-A, no. 2, pp. 340-342, 1998.

[4] A. Fabre, and M. Alami, “Universal Current Mode Biquad Implemented from Two Second Generation Current Conveyors”, *IEEE Trans. Circuits Systems I*, vol. 42, no. 7, pp. 383-385, 1995.

[5] S. Minaei, O. Cicekoglu, H. Kuntman, and S. Türköz, “High output impedance current-mode lowpass, bandpass

and highpass filters using current controlled conveyors", *Int. J. Electronics*, vol. 88, no. 8, pp. 915-922, 2001.

[6] S. Minaei, O. K. Sazin, and H. Kuntman, "A New CMOS Electronically Tunable Current Conveyor and Its Application to Current-Mode Filters", *IEEE Trans. Circuits Systems I*, vol. 53, No. 7, pp. 1448-1457, 2006.

[7] S. Minaei, and S. Türköz, "Current-Mode Electronically Tunable Universal Filter Using Only Plus-Type Current Controlled Conveyors and Grounded Capacitors", *ETRI Journal*, vol. 26, no. 4, 2004.

[8] A. Toker, S. Ozoguz and O. Cicekoglu, "A New Current-Mode Multifunctional Filter with Minimum Components Using Dual-Output Current Conveyors", *IEICE Trans. Fundamentals*, vol. E83-A, no. 11, pp. 2382-2384, 2000.

[9] R. Senani, V. K. Singh, A. K. Singh, and D. R. Bhaskar, "Tunable Current-Mode Universal Biquads employing only three MOCCs and all grounded passive elements: Additional New Realizations", *Frequenz*, vol. 59, no. 9-10, 2005.

[10] M. T. Abuelma'atti, and N. A. Tasadduq, "New current-mode current-controlled filters using the current-controlled conveyor", *Int. J. Electronics*, vol. 85, no. 4, pp. 483-488, 1998.

[11] S. Minaei, O. Cicekoglu, H. Kuntman, and S. Türköz, "Electronically tunable, active only floating inductance simulation", *Int. J. Electronics*, vol. 89, no. 12, pp. 905-912, 2002.

[12] C.-M. Chang, B. M. Al-Hashimi, and J. N. Ross, "Unified Active Filter Biquad Structures", *IEE Circuits, Devices and Systems*, vol. 151, no. 4. pp. 273-277, 2004.

[13] E. Yuce, S. Minaei, and O. Cicekoglu, "Resistorless floating immittance function simulators employing current controlled conveyors and a grounded capacitor", *Electrical Engineering*, vol. 88, no. 6, pp. 549-525, 2005.

[14] R. Senani, V. K. Singh, A. K. Singh, and D. R. Bhaskar, "Novel electronically controllable current-mode universal biquad filter", *IEICE Electronics Express*, vol. 1, no. 14, pp. 410-415, 2004.

[15] N. Pandey, S. K. Paul, A. Bhattacharyya, and S. B Jain, "A novel current controlled current mode universal filter: SITO approach", *IEICE Electronics Express*, vol. 2, no. 17, pp. 451-457, 2005.

[16] J. Koton, N. Herencsár, K. Vrba, and O. Cicekoglu, "Kerwin-Huelsman-Newcomb filters using DVCCs," in *Proc. Int. Conf. Applied Electronics 2009*, Pilsen, Czech Republic, pp. 161-164, 2009.

[17] HFA3046/3096/3127/3128 Transistor Array PSpice Models, www.intersil.com.

[18] J.-W. Horng, "High input impedance voltage-mode universal biquadratic filters with three inputs using plus-type CCIIs," *Int. J. Electronics*, vol. 91, no. 8, pp. 465-475, 2004.

[19] C.-L. Hou and C.-C. Lin, "A Filter with three Voltage-inputs and One Voltage-output and One Current-output using Current Conveyors," *Tamkang J. Science and Engineering*, vol. 7, no. 3, pp. 145-148, 2004.

[20] D. Biolek, M. Siripruchyanun, and W. Jaikla, "CCII and OTA based- Current-mode Universal Biquadratic Filter," in *Proc. 6th PSU Engineering conference*, Songkla, Thailand, pp. 238-241, 2008.