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A Novel Current-Mode SIMO Type Universal Filter Using CFTAs

Norbert Herencsar*, Jaroslav Koton, Kamil Vrba, and Jiri Misurec

Department of Telecommunications
Faculty of Electrical Engineering and Communication
Brno University of Technology, Purkynova 118, 612 00 Brno, Czech Republic
*Corresponding author: herencsn@feec.vutbr.cz

Abstract

In this paper a new active element for the realization of current-mode analog blocks Current Follower Transconductance Amplifier (CFTA) is presented. The element is a combination of the Current Follower (CF) and the Balanced Output Transconductance Amplifier (BOTA). In the paper we also document another extended active element CFTA which has more current outputs than can be realized by the UCC-N1B circuit, which was developed at our workplace. The application of this active element is shown on the realization of current-mode second-order universal frequency filters of the type SIMO (single-input-multi-output). The circuit structure consists of three active and three passive elements. The circuit was analyzed using signal-flow graphs. The properties of the proposed universal filter were subjected to a sensitivity analysis and AC analysis using PSpice software.

Keywords: Current Follower Transconductance Amplifier (CFTA), current-mode circuit, universal filter, signal-flow graph, Universal Current Conveyor (UCC), BOTA

1 Introduction

In current technical literature the main trend noticed in the area of analog filter design concerns reducing the supply voltage of integrated circuits with VLSI, which results in the ever greater popularity of the current-mode [1], [2]. In current-mode circuits it is possible to decrease the supply voltage to maintain a sufficient signal-to-noise ratio, which is better than in the case of voltage-mode circuits. Circuit structures are often presented that can realize several circuit functions simultaneously such as low-pass filter (LP), band-pass filter (BP), high-pass filter (HP) and possibly also band-reject filter (BR) and all-pass-filter (AP). Structures such as these are decided as multifunction or universal frequency filters.

The goal of this work is to define a novel building block, the Current Follower Transconductance Amplifier (CFTA), for current-mode analog frequency filter design, and the presentation of a novel second-order universal frequency filter structure using up to three passive and three active elements CFTA. The designed universal filter satisfies these four criteria: (i) the circuit can be used to realize all filter types (LP, BP, HP, BR, AP), (ii) the circuit contains low number of active and passive elements, (iii) all passive elements are grounded for easy integration and (iv) output responses can be taken directly from current outputs.

2 Description of CFTA and MO-CFTA

The ideal behavioural model of the CFTA element is shown in Fig. 1 (a). The element is a combination of the Current Follower (CF) [3], [4], which is the input part of the designed element, and the Balanced Output Transconductance Amplifier (BOTA) [5], [6], which forms the output part of the element. The schematic symbol of the CFTA element is shown in Fig. 1 (b) and a realization using the CF and BOTA blocks is shown in Fig. 1 (c). The element has been defined in compliance with network convention i.e. all currents are flowing into the circuit. The element has one low-impedance current input *f*. Current from the terminal *f* is transferred by the Current Follower to auxiliary terminal *z*. The voltage V_z on this terminal is transformed into current using the transconductance g_m, which flows into output terminals *x*+ and *x*-. Relations between the individual terminals of the CFTA+- element can be described in matrix form as follows:

$$\begin{pmatrix} I_z \\ I_{x+} \\ I_{x-} \\ V_f \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 1 \\ g_m & 0 & 0 & 0 \\ -g_m & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} V_z \\ V_{x+} \\ V_{x-} \\ I_f \end{pmatrix}. \quad (1)$$

The possible equivalent realization using commercially available active elements AD844 and MAX435 is shown in Fig. 1 (d).

In 1968 and 1970 Smith and Sedra introduced in [7] and [8] first- (CCI) and second-generation (CCII) current conveyors. The third-generation current conveyors (CCIII) were introduced by Fabre in 1995 [9].

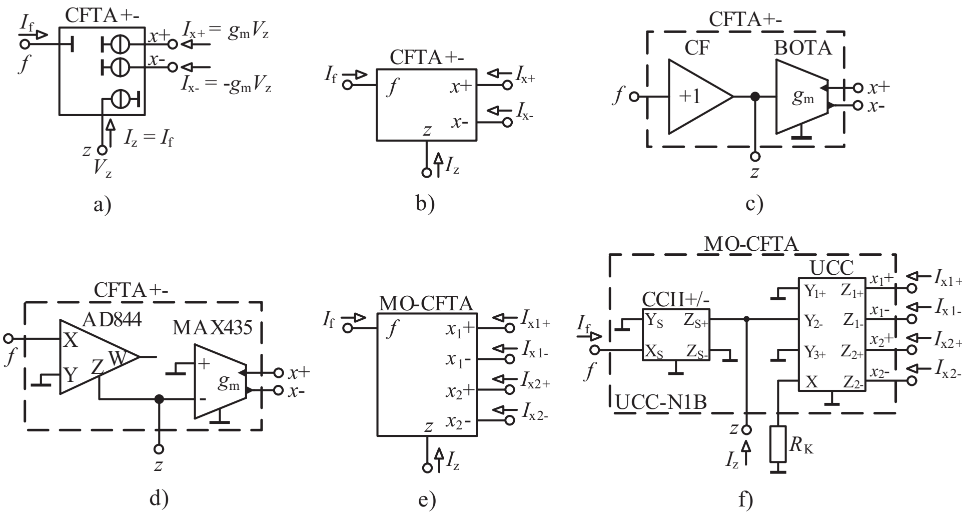

Fig. 1. (a) Behavioral model of the CFTA+- element, (b) schematic symbol of CFTA+-, (c) block diagram of the CFTA+-element, (d) possible realization of CFTA+- by commercially available amplifiers, (e) schematic symbol of MO-CFTA, (f) its realization by UCC-N1B.

In 2000 the Universal Current Conveyor (UCC) [10], [11] was designed and developed using CMOS 0.35 μm technology under the designation UCC-N1B at our workplace and in collaboration with AMI Semiconductor Design Centre. In addition to UCC, the UCC-N1B integrated circuit also includes the second-generation current conveyor CCII+/-. The UCC is defined as an eight-port active element which has three high-impedance voltage inputs (Y_{1+}, Y_{2-} a Y_{3+}) (one differencing - Y_{2-}, and two additive - Y_{1+}, Y_{3+}), one low impedance input X, and four current outputs (Z_{1+}, Z_{1-}, Z_{2+}, Z_{2-}). Outputs Z_{1-} and Z_{2-} are inverse to outputs Z_{1+}, Z_{2+}. The UCC helps to realize all types of current conveyors of all generations, which can be obtained by connecting or grounding suitable terminals [12], [13]. The UCC-N1B integrated circuit is so universal that we have used it for the realization of multi-output CFTA (MO-CFTA), whose schematic symbol is shown in Fig. 1 (e). The realization proper of the MO-CFTA using UCC-N1B is shown in Fig. 1 (f). The Current Follower is realized by using CCII+/-, and the Multi-Output Transconductance Amplifier is realized using UCC, with the transconductance g_m defined by resistor R_K [14]. Depending on the utilization of the x terminals we can realize, according to Fig. 1 (f), these elements: CFTA++, CFTA--, CFTA+-, CFTA+-+, CFTA-+- and CFTA+-+-.

3 Application Example

The application of the novel active CFTA element is shown in the design of a current-mode frequency filter using three active and three passive elements. The circuit of the filter type SIMO (single-input-multi-output) using CFTA is shown in Fig. 2 (a). In the structure, all passive elements are grounded which is advantageous because of the easy realization of grounded passive elements in integration. For the analysis the signal-flow graph method was used [15]. The M-C flow graph of the CFTA+- element is shown in Fig. 2 (b) and the M-C signal-flow graph of the designed universal filter is shown in Fig. 2 (c).

The designed circuit shown in Fig. 2 (a) can be used to realize the following current-mode transfer functions:

$$\frac{\boldsymbol{I}_{\mathrm{LP}}}{\boldsymbol{I}_{\mathrm{IN}}}=\frac{g_{\mathrm{m}1}g_{\mathrm{m}2}g_{\mathrm{m}3}}{\boldsymbol{D}},\quad \frac{\boldsymbol{I}_{\mathrm{BP}}}{\boldsymbol{I}_{\mathrm{IN}}}=-\frac{\boldsymbol{s}C_1g_{\mathrm{m}2}g_{\mathrm{m}3}}{\boldsymbol{D}},\quad \frac{\boldsymbol{I}_{\mathrm{HP}}}{\boldsymbol{I}_{\mathrm{IN}}}=\frac{\boldsymbol{s}^2C_1C_2g_{\mathrm{m}2}}{\boldsymbol{D}}, \tag{2}$$

where $\boldsymbol{D}=\boldsymbol{s}^2C_1C_2G_1+\boldsymbol{s}C_1g_{\mathrm{m}2}g_{\mathrm{m}3}+g_{\mathrm{m}1}g_{\mathrm{m}2}g_{\mathrm{m}3}=0$.

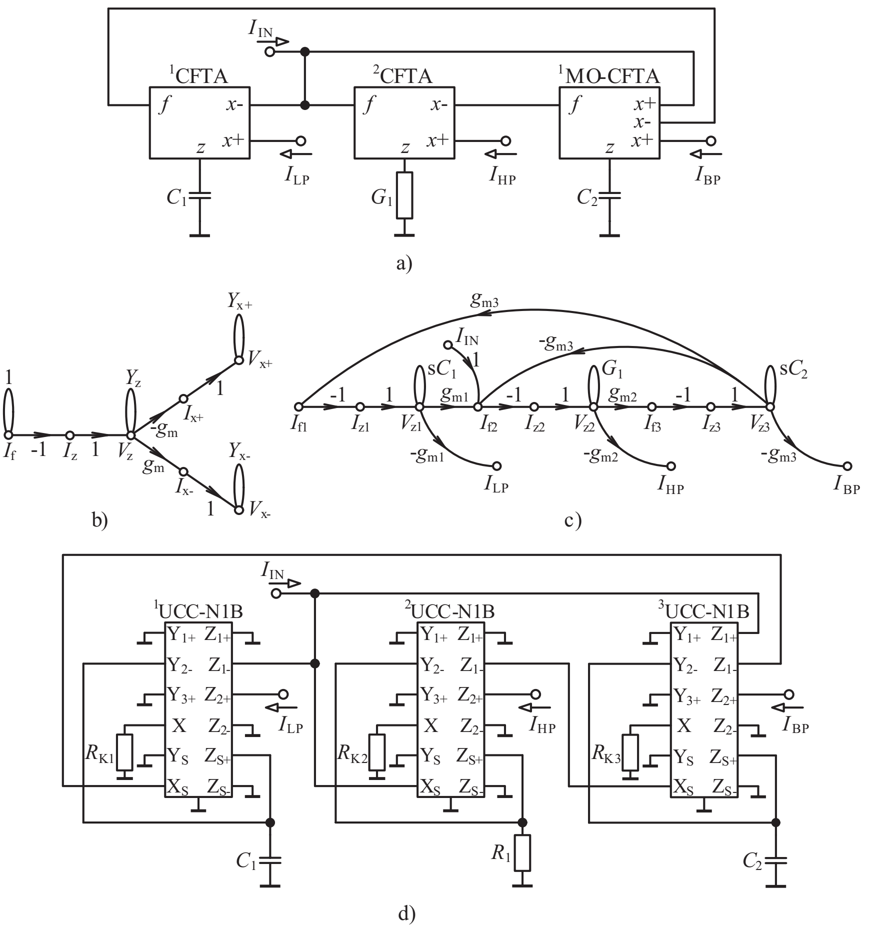

Fig. 2. (a) Universal filter using CFTAs, (b) M-C graph of CFTA+-, (c) M-C flow graph of proposed universal filter, (d) its realization using UCC-N1B.

The designed circuit according to Fig. 2 (a) is universal, i.e. it allows a second-order non-inverted low-pass filter, inverted band-pass filter, non-inverted high-pass filter, non-inverted band-reject filter (if $\boldsymbol{I}_{\mathrm{OUT}}=\boldsymbol{I}_{\mathrm{LP}}+\boldsymbol{I}_{\mathrm{HP}}$), and an non-inverted all-pass filter (if $\boldsymbol{I}_{\mathrm{OUT}}=\boldsymbol{I}_{\mathrm{LP}}+\boldsymbol{I}_{\mathrm{BP}}+\boldsymbol{I}_{\mathrm{HP}}$) to be realized.

4 Tracking errors and sensitivity analysis

The real CFTA element can be characterized by:

$$V_{\mathrm{f}}=0, \quad I_{\mathrm{z}}=\alpha I_{\mathrm{f}}, \quad I_{\mathrm{x+}}=g_{\mathrm{m}}V_{\mathrm{z}}, \quad I_{\mathrm{x-}}=-g_{\mathrm{m}}V_{\mathrm{z}}, \tag{3}$$

where $\alpha = 1 - \varepsilon_{\mathrm{i}}$ and ε_{i} denotes the current tracking error of the current follower from the terminal f into the terminal z ($|\varepsilon_{\mathrm{i}}| \langle\langle\, 1$). Taking into account the non-ideal properties of CFTAs, the characteristic equation of the circuit according to Fig. 2 (a) has the form:

$$\boldsymbol{D} = \boldsymbol{s}^2 C_1 C_2 G_1 + \boldsymbol{s}\alpha_2\alpha_3 C_1 g_{\mathrm{m2}} g_{\mathrm{m3}} + \alpha_1\alpha_2\alpha_3 g_{\mathrm{m1}} g_{\mathrm{m2}} g_{\mathrm{m3}} = 0, \tag{4}$$

and for characteristic frequency ω_0, quality factor Q and ω_0/Q it holds:

$$\omega_0 = \sqrt{\frac{\alpha_1\alpha_2\alpha_3 g_{\mathrm{m1}} g_{\mathrm{m2}} g_{\mathrm{m3}}}{C_1 C_2 G_1}}, Q = \sqrt{\frac{\alpha_1 C_2 G_1 g_{\mathrm{m1}}}{\alpha_2\alpha_3 C_1 g_{\mathrm{m2}} g_{\mathrm{m3}}}}, \frac{\omega_0}{Q} = \frac{\alpha_2\alpha_3 g_{\mathrm{m2}} g_{\mathrm{m3}}}{C_2 G_1}. \tag{5}$$

The relative sensitivities [15] of these parameters for the constituent active and passive elements are:

$$S^{\omega_0}_{\alpha_1,\alpha_2,\alpha_3} = S^{\omega_0}_{g_{\mathrm{m1}},g_{\mathrm{m2}},g_{\mathrm{m3}}} = -S^{\omega_0}_{C_1,C_2,G_1} = \frac{1}{2}, \tag{6}$$

$$S^{Q}_{\alpha_1} = -S^{Q}_{\alpha_2,\alpha_3} = S^{Q}_{C_2,G_1,g_{\mathrm{m1}}} = -S^{Q}_{C_1,g_{\mathrm{m2}},g_{\mathrm{m3}}} = \frac{1}{2}, \tag{7}$$

$$S^{\frac{\omega_0}{Q}}_{\alpha_2,\alpha_3,g_{\mathrm{m2}},g_{\mathrm{m3}}} = -S^{\frac{\omega_0}{Q}}_{C_2,G_1} = 1, S^{\frac{\omega_0}{Q}}_{\alpha_1,C_1,g_{\mathrm{m1}}} = 0. \tag{8}$$

From the results it is evident that the sensitivities are low.

5 Simulation results

The circuit solution of the universal filter in Fig. 2 (a) using the UCC-N1B circuit is shown in Fig. 2 (d). In the computer verification of this filter the third-level model of UCC-N1B element was chosen, which is presented in [16]. The values of the capacitors and resistors were chosen as follows: $C_1 = C_2 = 0.5$ nF, $R_1 = 1/G_1 = R_{\mathrm{K1}} = 1/g_{\mathrm{m1}} = R_{\mathrm{K2}} = 1/g_{\mathrm{m2}} = R_{\mathrm{K3}} = 1/g_{\mathrm{m3}} = 1$ kΩ for the characteristic frequency $f_0 \approx 318$ kHz and quality factor of filters $Q = 1$. The simulated frequency characteristics of a current-mode low-, band-, high-pass and band-reject filter are shown in Fig. 3 (a). The resulting frequency characteristics of the all-pass filter are shown in Fig. 3 (b). The actual cut-off frequency was $f_0 = 309$ kHz. From the simulation results it is evident that the final solution corresponds to theoretical expectations. In the high-frequency region the filter characteristics are partly affected by the real properties of current conveyor UCC-N1B.

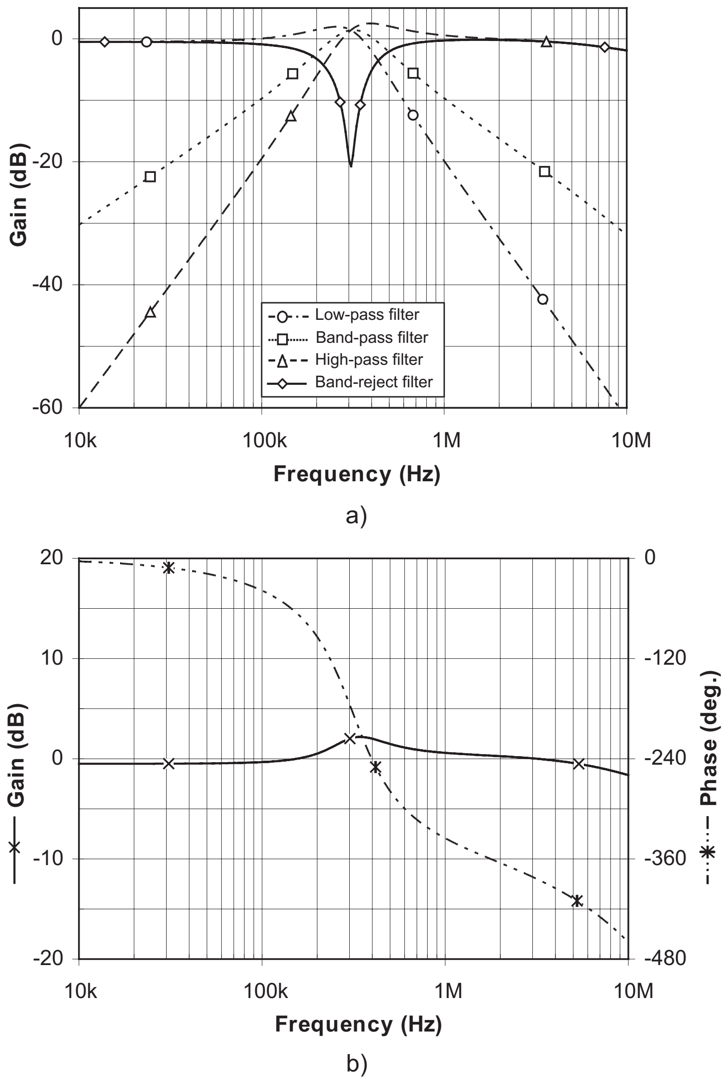

Fig. 3. Verification of the properties of current-mode universal filter according to Fig. 2 (d) using UCC-N1B: (a) low-, band-, high-pass, and band-reject filter, (b) all-pass filter.

5 Conclusion

In the paper, a new active element for analog signal processing in the current-mode, namely the CFTA (Current Follower Transconductance Amplifier) is presented. The element is a combination of the Current Follower (CF) and the Balanced Output Transconductance Amplifier (BOTA). The method of implementing the CFTA+- element by commercially available active elements is shown. A potential application of the UCC-N1B integrated circuit as a suitable building block for a circuit realization of multi-output CFTA is also shown. The practical usage of the defined element is shown on a selected circuit. The advantages of the circuit are: (i) the circuit allows all types of filter, i.e. to be realized LP, BP, HP, BR and AP, (ii) low number of active and passive elements, in the structure here are three active and three (iii) grounded passive elements and (iv) the current responses are detected on direct current outputs.

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References

[1] C. Toumazau, F. J. Lidgey, and D. G. Haig, Analogue IC Design: The current-mode approach, Peter Peregrinus Ltd., London, 1990.

[2] S. Takali, Analog circuit designs in the last decade and their trends toward the 21st century, IEICE Trans. Fundamentals, **E84-A** (2001), 68-79.

[3] J. J. Chen, C. C. Chen, H. W. Tsao, and S. I. Liu, Current-mode oscillators using single current follower, Electronics Letters, **27** (1991), 2056-2059.

[4] R. Senani and S. S. Gupta, Novel sinusoidal oscillators using only unity-gain voltage followers and current followers, IEICE Electron. Express, **1** (2004), 404-409.

[5] R. L. Geiger and E. Sánchez-Sinencio, Active Filter Design Using Operational Transconductance Amplifiers: A Tutorial, IEEE Circuits and Devices Magazine, **1** (1985), 20-32.

[6] T. Tsukutani, M. Higashimura, Y. Sumi, and Y. Fukui, Electronically tunable current-mode biquad using OTAs and grounded capacitors, IEICE Trans. Fundamentals, **E84-A** (2001), 2595-2599.

[7] K. C. Smith and A. Sedra, The current conveyor: a new circuit building block, IEEE Proc., **56** (1968), 1368-1369.

[8] A. Sedra and K. C. Smith, A second generation current conveyor and its applications, IEEE Trans. Circ. Theory, **17** (1970), 132-134.

[9] A. Fabre, Third generation current conveyor: a new helpful active element, Electronics Letters, **31** (1995), 338-339.

[10] D. Bečvář, K. Vrba, V. Zeman, and V. Musil, Novel universal active block: A Universal Current Conveyor, Proc. IEEE Int. Symposium on Circuits and Systems - ISCAS 2000, Geneva, Switzerland, 471-474.

[11] G. Ferri and N. C. Guerrini, Low-Voltage Low-Power CMOS Current Conveyors, Kluwer Acad. Publ., London, 2003.

[12] J. Cajka, T. Dostal, and K. Vrba, General view on current conveyors, Int. Journal of Circuit Theory and Applications, **32** (2004), 133-138.

[13] J. Cajka, K. Vrba, and J. Misurec, New Universal Biquad Using UCCX Devices, Frequenz, **60** (2006), 138-141.

[14] N. Herencsar and K. Vrba, Current conveyors-based circuits using novel transformation method, IEICE Electron. Express, **4** (2007), 650-656.

[15] W. K. Chen, The VLSI Handbook, CRC Press, Boca Raton, 2000.

[16] R. Sponar and K. Vrba, Measurements and behavioural modelling of modern conveyors, Int. J. of Computer Science and Network Security, **6** (2006), 57-65.

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