Current-Mode Sixth-Order Elliptic Band-Pass Filter Using MCDTAs

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Abstract. *In this paper, a modified CDTA（MCDTA）is presented and the current-mode second-order band-pass, high-pass notch, and low-pass notch circuits using MCDTAs are given. Moreover, a current-mode sixth-order elliptic band-pass filter is realized by means of cascade method. Having used six MCDTAs, one CDTA, six grounded capacitors and two resistors, the circuit is easy to be integrated, of which the parameters can be electronically adjusted by tuning bias currents. It is noted that the results of circuit simulations are in agreement with theory.*

Keywords

Sixth-order elliptic band-pass filter, current mode, electronic adjusting, MCDTA.

1. Introduction

Current differencing transconductance amplifier (CDTA) is a new kind of active element, which combines the advantages of operational transconductance amplifier (OTA) and second-generation current conveyor (CCII). With its input terminals at virtual ground, output resistances infinite, transconductance tuned linearly and electronically, CDTA is a relatively ideal current-mode active component. Therefore, the circuits using CDTAs have found wide applications in electronics community. The current-mode oscillators in literature [1] – [15] and the universal current-mode filters in literature [16] – [27] have well explained this viewpoint. However, most of the filters mentioned in earlier works are only second order structures. Although higher order current-mode filters using CDTAs have been studied in literature [28] – [32], unfortunately, these reported circuits suffer from one or more of following weaknesses: interactive electronic control of ω_o and Q, excessive use of the passive elements, and use of floating capacitor, which is not desirable for IC implementation. Consequently, the circuits become more complicated.

The paper aims at presenting an economical current-mode sixth-order elliptic band-pass filter employing modified CDTA (MCDTA) elements. First, a traditional CDTA is modified into a MCDTA. Unlike the MCDTA in literature [13], this MCDTA consists of two well-known building blocks, one is a namely Z-Copy CDTA [1] and the other is an OTA. Second, the second-order circuit modes using MCDTAs are given, which include second-order band-pass filter, second-order high-pass notch filter and second-order low-pass notch filter. The last, on the ground of the circuit modes, a sixth-order elliptic band-pass filter employing MCDTAs is designed by means of cascade method. Having used canonic number of components and grounded capacitors, the circuit is easy to be integrated and its parameters can be electronically adjusted by tuning bias currents of MCDTAs. EWB simulations are included to verify the workability of the proposed circuit.

2. Circuit Description

2.1 MCDTA

By means of adding a transconductance amplifier and several current mirrors in the traditional CDTA, the number of x port and z port for the CDTA can be extended, and a modified CDTA (MCDTA) is realized. Its circuit representation and equivalent circuit are shown in Fig. 1. The terminal relation of MCDTA can be characterized by the following set of equations:

$$V_p = V_n = 0\ , I_{zc} = I_z = I_p - I_n \\ I_{x1} = g_{m1}V_z\ , I_{x2} = g_{m2}V_z. \tag{1}$$

Here, g_{m1} and g_{m2} represent transconductance gains of two different balanced operational transconductance amplifiers, respectively. For a MCDTA implemented with bipolar technology, g_{m1} and g_{m2} can be expressed as follows:

$$g_{m1} = \frac{I_{B1}}{2V_T}\ ,\ g_{m2} = \frac{I_{B2}}{2V_T}. \tag{2}$$

Here, I_{B1} and I_{B2} are bias currents of MCDTA. V_T is the thermal voltage.

2.2 Second-Order Circuit Modes

Fig. 2 shows the second-order band-pass and high-pass notch filter using MCDTAs. The circuit has global and local feedback loops. The loop gains are $g_{m12} / sC_1 \times (-g_{m22} / sC_2)$ and $-g_{m11} / sC_1$, respectively. For $g_{m12} = g_{m22} = g_m$, $C_1 = C_2 = C$, using Mason's formula, the graph determinant of the circuit is

$$\Delta = 1 + \frac{g_{m11}}{sC} + \frac{g_m^2}{s^2C^2}\ . \tag{3}$$

Since the forward channel gain of I_i to I_{obp} is $-g_{m11} / sC$, the corresponding transfer functions can be easily derived as:

$$\frac{I_{obp}}{I_i} = \frac{-sg_{m11}/C}{s^2 + sg_{m11}/C + g_m^2/C^2}\ . \tag{4}$$

Obviously, if I_{obp} is an output of the circuit, the circuit should be a second-order band-pass filter. Combining (2) with (3), the pole frequency and Q-factor of the circuit are obtained respectively,

$$\omega_o = \frac{g_m}{C} = \frac{I_B}{2V_TC}\ , \tag{5}$$

$$Q = \frac{g_m}{g_{m11}} = \frac{I_B}{I_{B11}}\ . \tag{6}$$

The corresponding pass-band gain is

$$H_{BP} = -1\ . \tag{7}$$

(5) shows that ω_o can be linearly tuned by adjusting bias current I_B, whereas (6) indicates that Q can be independently tuned by tuning bias current I_{B11} without influencing ω_o. Thus the filter is tuned as follows: (a) adjust I_B to tune ω_o; (b) adjust I_{B11} to tune Q. This is the basis of realizing electronically tunable high order filter.

From Fig. 2, The forward transfers from I_i to I_{olp} and to I_{ohp} are $g_m g_{m21} / s^2C^2$ and 1, respectively. The corresponding transfer functions can be easily derived as:

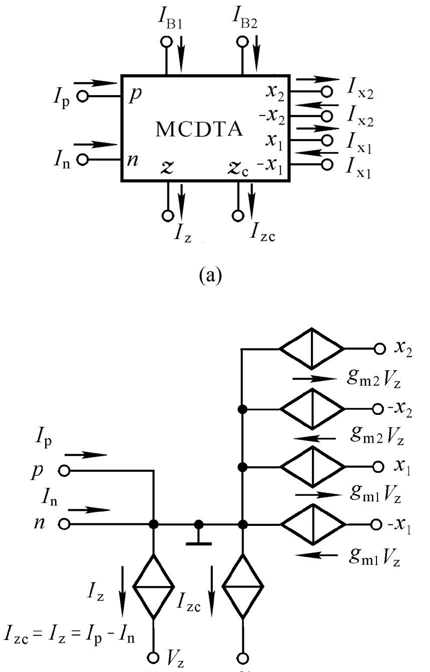
$$\frac{I_{olp}}{I_i} = \frac{g_m g_{m21}/C^2}{s^2 + sg_{m11}/C + g_m^2/C^2}\ , \tag{8}$$

$$\frac{I_{ohp}}{I_i} = \frac{s^2}{s^2 + sg_{m11}/C + g_m^2/C^2}\ , \tag{9}$$

$$\frac{I_{ohpn}}{I_i} = \frac{I_{ohp} + I_{olp}}{I_i} = \frac{s^2 + g_m g_{m21}/C^2}{s^2 + sg_{m11}/C + g_m^2/C^2}\ . \tag{10}$$

It is clearly shown that if I_{ohpn} is the output of the circuit, the circuit should be a second-order high-pass notch filter, whose pole frequency and Q-factor are the same as (5) and (6). Its zero frequency is

$$\omega_{n1} = \frac{\sqrt{g_m g_{21}}}{C} = \omega_o\sqrt{\frac{I_{B21}}{I_B}}\ . \tag{11}$$



(a)

(b)

Fig. 1. MCDTA: (a) symbol and (b) equivalent circuit.

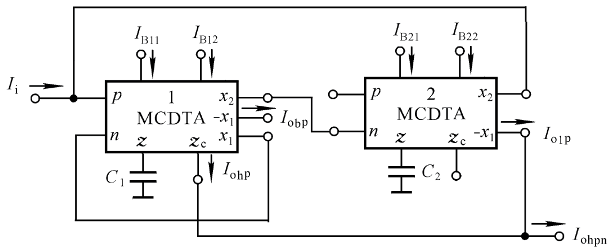


Fig. 2. Proposed second-order band-pass and high-pass notch filter.

The corresponding high-pass gain is

$$H_{HP} = 1 \tag{12}$$

and low-pass gain is

$$H_{LP} = \frac{g_{m21}}{g_m} = \frac{I_{B21}}{I_B}\ . \tag{13}$$

From (5) – (6) and (11) – (13), it is seen that more variables and degrees of freedom for design have provided due to using proposed MCDTA rather than the traditional CDTA. This is because one traditional CDTA can only provide one controlled variable rather than two controlled variables.

Fig. 3 shows the second-order low-pass notch filter using MCDTAs. The current follower in the circuit is realized by using a CDTA so that the output of the filter possesses high output impedance. The loop of the circuit is still the same as Fig. 2. The forward transfers from I_i to I_{olp} and to I_{ohp} are g_m^2 / s^2C^2 and $R_1 / (R_1 + R_2)$, respectively. The corresponding transfer functions can be easily derived as:

$$\frac{I_{\mathrm{olp}}}{I_{\mathrm{i}}}=\frac{g_m^2/C^2}{s^2+sg_{m11}/C+g_m^2/C^2}, \tag{14}$$

$$\frac{I_{\mathrm{ohp}}}{I_{\mathrm{i}}}=\frac{s^2R_1/(R_1+R_2)}{s^2+sg_{m11}/C+g_m^2/C^2}, \tag{15}$$

$$\frac{I_{\mathrm{olpn}}}{I_{\mathrm{i}}}=\frac{I_{\mathrm{ohp}}+I_{\mathrm{olp}}}{I_{\mathrm{i}}}=\frac{s^2R_1/(R_1+R_2)+g_m^2/C^2}{s^2+sg_{m11}/C+g_m^2/C^2}. \tag{16}$$

It is obviously seen that this is a second-order low-pass notch filter, of which the pole frequency and Q-factor are still the same as (5) and (6). Its zero frequency is

$$\omega_{\mathrm{n2}}=\sqrt{1+\frac{R_2}{R_1}}\cdot\frac{g_m}{C}=\omega_{\mathrm{o}}\sqrt{1+\frac{R_2}{R_1}}\,. \tag{17}$$

The corresponding low-pass gain is

$$H_{\mathrm{LP}}=1 \tag{18}$$

and the high-pass gain is

$$H_{\mathrm{HP}}=\frac{R_1}{R_1+R_2}\,. \tag{19}$$

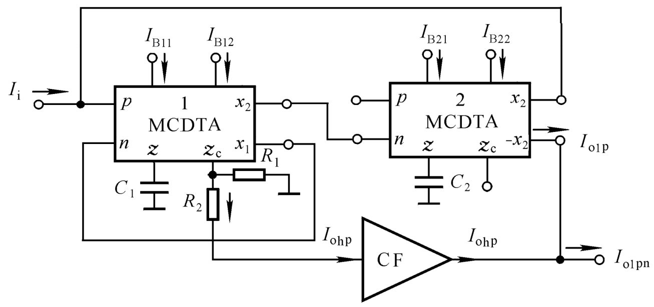


Fig. 3. Proposed second-order low-pass notch filter.

2.3 Sixth-Order Elliptic Band-Pass Filter using MO-CDTAs

Consider an elliptic band-pass filter with a central frequency of 1 MHz, 12.9 dB pass-band gain, 1 dB pass-band ripple, and with an attenuation of at least 37.1 dB for frequencies below 0.45 MHz and above 2.2 MHz.

The elliptic approximation leads to the sixth-order filter [28] – [30], which can be implemented as a cascade of biquads with the parameters according to Tab. 1. The cascade filter designed is shown in Fig. 4. Since the input terminal of any biquads in Fig. 4 is virtual ground, and the output terminals of biquad (1) and biquad (2) both have higher impedance, the output terminal of biquad (1) and the input terminal of biquad (2) are connected directly; the output terminal of biquad (2) and the input terminal of biquad (3) are also connected directly. Considering that the output terminal of biquad (3) has higher impedance, the output terminal of the filter can be directly connected with the output load.

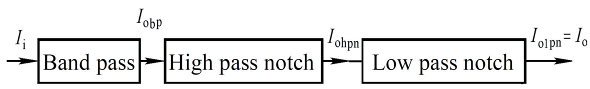


Fig. 4. Proposed current-mode sixth-order elliptic band-pass filter.

biquads	f_{o} / MHz	Q	f_{n} / MHz
1	1	3.939	
2	0.7860	8.656	0.4161
3	1.2723	8.656	2.4035

Tab. 1. Parameters of cascaded biquads of Fig. 4.

biquads	I_{B11} (μA)	I_{B} (μA)	I_{B21} (μA)	H_{LP}	H_{HP}	H_{BP}
1	83	327				-1
2	30	257	72	0.28	1	
3	48	415		1	0.28	

Tab. 2. Bias currents and pass-band gains of cascaded biquads.

The parameters of any biquads in Fig. 4, as shown in Tab. 1, could be adjusted by varying the bias currents of the MCDTAs. Substituting any group parameters in Tab. 1 into (5), (6), (7); (5), (6), (11), (12), (13); and (5), (6), (17), (18), (19), respectively, it yields the bias currents and pass-band gains of any biquads. This is shown in Tab. 2. In addition, if R_2 / R$_1$ = 2.568, R_1 = 1 kΩ, one obtains R_2 = 2.568 kΩ, and sixth-order elliptic band-pass filter is realized.

From (5) and (6), the ω_o and Q sensitivities for the filter are given by

$$S_{I_{B12}}^{\omega_o}=S_{I_{B22}}^{\omega_o}=-S_{C_1}^{\omega_o}=-S_{C_2}^{\omega_o}=0.5\,, \tag{20}$$

$$S_{I_{B12}}^{Q}=-S_{I_{B22}}^{Q}=-0.5\,,\ S_{I_{B11}}^{Q}=-1\,. \tag{21}$$

From (11) and (17), the ω_{n1} and ω_{n2} sensitivities for the filter are

$$S_{I_{B21}}^{\omega_{n1}}=-S_{C_1}^{\omega_{n1}}=-S_{C_2}^{\omega_{n1}}=0.5\,,$$

$$S_{I_{B12}}^{\omega_{n1}}=S_{I_{B22}}^{\omega_{n1}}=0.25\,. \tag{22}$$

$$S_{I_{B12}}^{\omega_{n2}}=S_{I_{B22}}^{\omega_{n2}}=-S_{C_1}^{\omega_{n2}}=-S_{C_2}^{\omega_{n2}}=0.5\,,$$

$$S_{R_2}^{\omega_{n2}}=-S_{R_1}^{\omega_{n2}}=\frac{0.5R_1}{R_1+R_2}\,. \tag{23}$$

From the above expressions, it is seen that all passive and active sensitivities of the proposed circuit are low.

3. Simulation Results

To prove the performances of the proposed circuit, the CDTA of literature [6] is modified into the MCDTA in Fig. 1, and the sub-circuit for MCDTA is created on transistor PR100N and NR100N by ELECTRONICS WORKBENCH 5.0 software (EWB5.0), then Fig. 2 and

Fig. 3 are created respectively. At last, the Fig. 4 circuit is simulated with ±1.5 V power supplies, $C = 1$ nF, $R_1 = 1$ kΩ, $R_2 = 2.5681$ kΩ, and the bias currents in Tab. 2. The simulation results are shown in Fig. 5 and Fig. 6. Using the pointer in EWB5.0, the parameters of the circuit are obtained: $f_o = 1$ MHz, $H(f_o) = 12.03$ dB, $BW = 0.5503$ MHz, $A_{max} = 1.42$ dB, attenuation > 42.25 dB when $f < 0.45$ MHz; attenuation > 38.85 dB when $f > 2.2$ MHz.

It is noted that the results of circuit simulations are in agreement with theory.

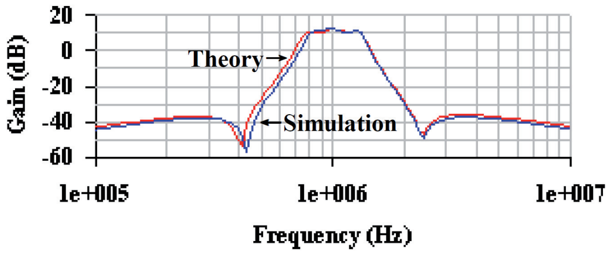


Fig. 5. Frequency responses of Fig. 4.

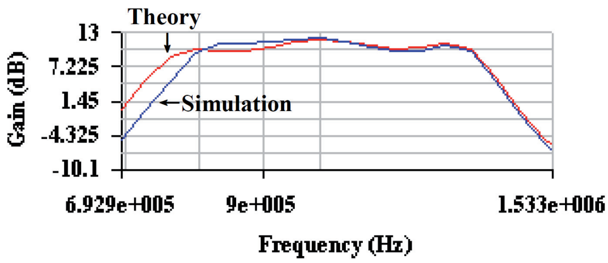


Fig. 6. Band-pass details of Fig. 4.

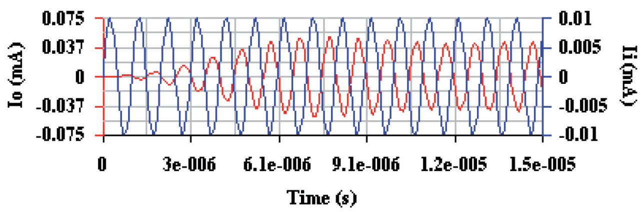


Fig. 7. Time-domain response of the proposed circuit when $I_i = 10$ µA, $f = 1$ MHz.

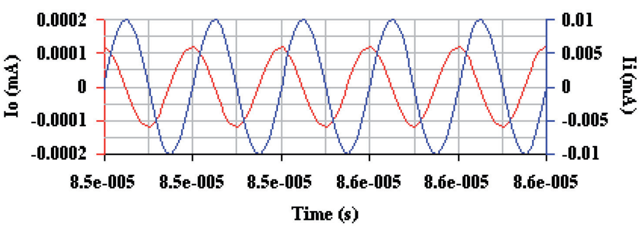


Fig. 8. Time-domain response of the proposed circuit when $I_i = 10$ µA, $f = 5$ MHz.

The time-domain response of the proposed sixth-order elliptic band-pass filter is shown in Fig. 7. After a sine wave of 10 µA amplitude and 1 MHz is applied as the input to the filter, the steady-state amplitude at the output is 40 µA, and phase shift is 183°. Fig. 8 shows the time-domain response when $I_i = 10$ µA, $f = 5$ MHz. The steady-state amplitude at the output is 0.12 µA, and phase shift is 90°, which is in correspondence with the theoretical values.

In fact, the time-domain response of the proposed circuit consists of two components, namely a transient component, and a steady-state component having the same frequency as the input, but differing in amplitude and phase. Because the circuit is stable, the transient component will die out, leaving only the steady-state component, as shown in Fig. 7. It should be noted that Fig. 8 shows only the steady-state component.

4. Conclusions

In this paper, a modified CDTA (MCDTA) is presented. It possesses two parameters controlled electronically, which are I_{B1} and I_{B2}. Second-order band-pass filter, second-order high-pass notch filter, and second-order low-pass notch filter were realized by using MCDTAs, respectively. Based on these biquads, sixth-order elliptic band-pass filter using MCDTAs was implemented by means of cascade method. It employs relatively few components and grounded capacitors and possesses high output impedance. Its parameters are electronically adjustable and its active and passive sensitivities are low. The proposed circuit structure is expected to be useful for applications in communications, instrumentation and measurement systems, especially at a high frequency range.

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References

[1] BIOLEK, D., SENANI, R., BIOLKOVA, V., KOLKA, Z. Active elements for analog signal processing: classification, review, and new proposals. *Radioengineering,* 2008, vol. 17, no. 4, p. 15 - 32.

[2] BIOLEK, D., HANCIOGLU, E., KESKIN, A, Ü. High-performance current differencing transconductance amplifier and its application in precision current-mode rectification. *AEU – International Journal of Electronics and Communication*, 2008, vol. 62, no. 2, p. 92 - 96.

[3] KESKIN, A. U., BIOLEK, D. Current mode quadrature oscillator using current differencing transconductance amplifiers (CDTA). *IEE Proceedings – Circuits, Devices and Systems*, 2006, vol. 153, no. 3, p. 214 - 218.

[4] LAHIRI, A. Explicit-current-output quadrature oscillator using second-generation current conveyor transconductance amplifier. *Radioengineering*, 2009, vol. 18, no. 4, p. 522 - 526.

[5] LAHIRI, A. Novel voltage/current-mode quadrature oscillator using current differencing transconductance amplifier. *Analog Integrated Circuits and Signal Processing*, 2009, vol. 61, no. 2, p. 199 - 203. Doi: 10.1007/s10470-009- 9291-0.

[6] LAHIRI, A. Resistor-less mixed-mode quadrature sinusoidal oscillator. *International Journal of Computer and Electrical Engineering*, 2010, vol. 2, no. 1, p.63 - 66.

[7] LAHIRI, A. New current-mode quadrature oscillators using CDTA. *IEICE Electronics Express*, 2009, vol. 6, no. 3, p. 135 - 140.

[8] TANGSRIRAT, W., TANJAROEN, W. Current-mode sinusoidal quadrature oscillator with independent control of oscillation frequency and condition using CDTAs. *Indian Journal of Pure & Applied Physics*, 2010, vol. 48, no. 5, p. 363 - 366.

[9] SIRIPRUCHYANUN, M., JAIKLA, W. CMOS current-controlled current differencing transconductance amplifier and applications to analog signal processing. *AEU-International Journal of Electronics and Communications*, 2008, vol. 62, no. 4, p. 277 - 287.

[10] PRASAD, D., BHASKAR, D. R., SINGH, A. K. Realisation of single-resistance-controlled sinusoidal oscillator: A new application of the CDTA. *WSEAS Transactions on Electronics*, 2008, vol. 5, no. 6, p. 257 - 259.

[11] TANGSRIRAT, W. Current differencing transconductance amplifier-based current-mode four-phase quadrature oscillator. *Indian Journal of Engineering and Materials Sciences*, 2007, vol. 14, no. 7, p. 289 - 294.

[12] TANGSRIRAT, W., TANJAROEN, W. Current-mode multiphase sinusoidal oscillator using current differencing transconductance amplifiers. *Circuits, Systems and Signal Processing*, 2008, vol. 27, no. 1, p. 81 - 93.

[13] LI, Y. A. Electronically tunable current-mode quadrature oscillator using single MCDTA. *Radioengineering,* 2010, vol. 19, no. 4, p. 667 - 671.

[14] JAIKLA, W., SIRIPRUCHYANUN, M., BAJER, J., BIOLEK, D. A simple current-mode quadrature oscillator using single CDTA. *Radioengineering*, 2008, vol. 17, no. 4, p. 33 - 40.

[15] BIOLEK, D., KESKIN, A. U., BIOLKOVA, V. Quadrature oscillator using CDTA-based integrators. *WSEAS Transactions on Electronics*, 2006, vol. 3, no. 9, p. 463 - 469.

[16] KESKIN, A. U., BIOLEK, D., HANCIOGLU, E., BIOLKOVA, V. Current-mode KHN filter employing current differencing transconductance amplifier. *AEU – International Journal of Electronics and Communications*, 2006, vol. 60, no. 6, p. 443 - 446.

[17] LAHIRI, A., CHOWDHURY, A. A novel first-order current-mode all-pass filter using CDTA. *Radioengineering,* 2009, vol. 18, no. 3, p. 300 - 305.

[18] KESKIN, A. U., BIOLEK, D. Current mode quadrature oscillator using current differencing transconductance amplifiers (CDTA). *IEE Proceedings – Circuits, Devices and Systems*, 2006, vol. 153, no. 3, p. 214 - 218.

[19] SHAHRAM, M., SAIT, T. New current-mode current-con-trolled universal filter with single input and three out-puts. *International Journal of Electronics*, 2001, vol. 88, no. 3, p. 333 - 337.

[20] BIOLEK, D., BIOLKOVA, V. Universal biquads using CDTA elements for cascade filter design. In *Proceeding of the 13th International Multiconference on Circuits, Systems, Communications & Computers (CSCC2003).* Corfu (Greece), 2003, p. 8 - 12.

[21] BIOLEK, D., BAJER, J., BIOLKOVA, V., KOLKA, Z., KUBICEK, M. Z copy - controlled gain - current differencing buffered amplifier and its applications. *International Journal of Circuit Theory and Applications*, 2010, vol. 40, no. 6, p. 225 - 235.

[22] BIOLEK, D., BIOLKOVA, V., KOLKA, Z. Current-mode biquad employing single CDTA. *Indian Journal of Pure & Applied Physics*, 2009, vol. 47, no. 7, p. 535 - 537.

[23] KESKIN, A. Ü., BIOLEK, D., HANCIOGLU, E. Current-mode KHN filter employing current differencing transconductance amplifiers. *AEU – International Journal of Electronics and Communications*, 2006, vol. 60, no. 6, p. 443 - 446.

[24] BIOLEK, D., BIOLKOVA, V., KOLKA, Z. Single-CDTA (current differencing transconductance amplifier) current-mode biquad revisited. *WSEAS Transactions on Electronics*, 2008, vol. 5, no. 6, p. 250 - 256.

[25] BIOLEK, D., BIOLKOVA, V. All-pass filter employing one grounded capacitor and one active element. *Electronics Letters,* 2009, vol. 45, no. 16, p. 807 - 808.

[26] BIOLEK, D., BIOLKOVA, V., KOLKA, Z., BAJER, J. Single-input multi-output resistorless current-mode biquad. In *Proceeding of the 19th European Conference on Circuit Theory and Design.* Antalya (Turkey), 2009, p. 225 - 228.

[27] PRASAD, D., BHASKAR, D. R., SINGH, A. K. Universal current-mode biquad filter using dual output current differencing transconductance amplifier. *AEU – International Journal of Electronics and Communications*, 2009, vol. 63, no. 6, p. 497 - 501.

[28] BIOLEK, D., BIOLKOVA, V. Tunable ladder CDTA-based filters. In *4th Multi-conference WSEAS.* Puerto De La Cruz (Tenerife, Spain), 2003, p. 1 - 3.

[29] FRANCO, S. *Design with Operational Amplifiers and Analog Integrated Circuits.* 3rd ed. Mc. Graw-Hill Science Engineering, 2001.

[30] BIOLEK, D., GUBEK, T., BIOLKOVA, V. Optimization of CDTA-based circuits simulating ladder structures. *WSEAS Transactions on Mathematics*, 2004, vol. 3, no. 4, p. 783 - 788.

[31] UYGUR. A, KUNTMAN, H. Seventh-order elliptic video filter with 0.1 dB pass band ripple employing CMOS CDTAs. *AEU – International Journal of Electronics and Communications*, 2007, vol. 61, no. 5, p. 320 - 328.

[32] LI, Y. A. Forth-order current mode band pass filter with coupled tuned by current using CCCDTAs. *Journal of Electron Devices*, 2010, vol. 7, p. 210 - 213.

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