Design Feature

HAIRONG LIN | Master CHUNHUA WANG | Professor
College of Information Science and Engineering, Hunan University, Changsha 410082, People's Republic of China; e-mail: 806351940@qq.com, e-mail: wch1227164@hnu.edu.cn

Single CDTA Powers Universal Bi-Quad Filter

A low-voltage current-differencing transconductance amplifier provides the basis for a relatively simple universal bi-quad filter.

Filters come with many responses. Fortunately, a simple design based on a current differencing transconductance amplifier (CDTA) and a few additional passive circuit elements can produce all standard filter functions without significant changes in the basic structure. The filter is well suited for use in integrated-circuit (IC) designs, with natural frequency (ω_0) and quality factor (Q) that can both be tuned electronically via changes of CDTA bias current.

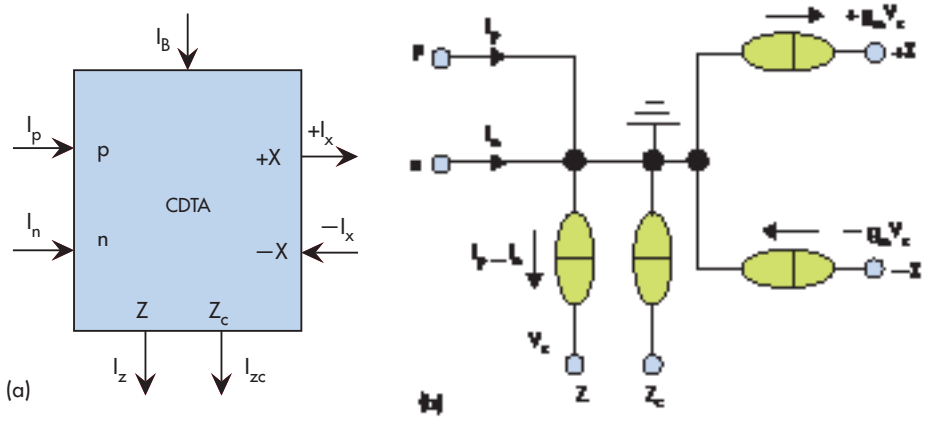
Current-mode circuits are gaining attention for analog signal-processing chores—specifically, for their wider bandwidths, larger dynamic ranges, and lower power consumption compared to their voltage-mode counterparts.[1] An analog filter is a key building block and is widely used in many fields, such as control systems, measurement, and instrumentation and communication systems. In 2003, D. Biolek proposed the CDTA as a new form of active component.[2] It is a really a current-mode device, with two inputs and two outputs all in current form.

In addition, it is equipped with low- and high-impedance input and output terminals, respectively. A CDTA can also adjust the output current gain by means of its bias current. As a consequence, a large number of circuit realizations for current-mode filters using CDTA have been published.[3-13] Unfortunately, these reported circuits have one or more of the following weaknesses:

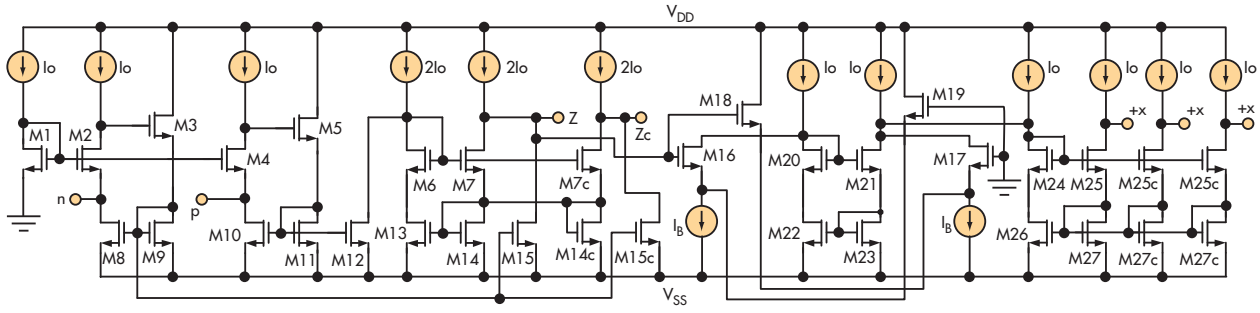
- The use of more than one active element;
- The use of floating resistors;
- A lack of high-output impedance ports;
- A lack of electronic adjustability; and
- An inability to realize completely standard filter functions.

To overcome these weaknesses, a CDTA-based current-mode universal biquad filter with grounded resistor is proposed. This filter contains only one CDTA, one grounded resistor, and two capacitors, and it is appropriate for monolithic integration. The circuit can realize second-order lowpass (LP), bandpass (BP), highpass (HP), bandstop (BS), and all-pass (AP) filter responses. According to the above analysis, a comprehensive comparison of the proposed filter and previously published realizations from refs. 3-13 based on the above-mentioned disadvantages is provided in the *table*. The new design makes up for all the disadvantages in the best ways among all other filters.

The symbol and equivalent circuit for a CDTA are shown in *Figs. 1(a) and (b)*, respectively. The CDTA's terminal char-



1.The CDTA is shown here by means of (a) its symbol and (b) its equivalent circuit



2. This schematic diagram was used as the basis for a CDTA fabricated in silicon CMOS technology.b

acteristics can be described by Eq. 1:

$$v_p = v_n = 0, i_{zc} = i_z = i_p - i_n, i_x = g_m v_z = g_m z_z i_z \quad (1)$$

where p and n are positive and negative current input terminals, respectively; z and x are current output terminals; g_m is the transconductance gain; and z_z is an external impedance connected to terminal z. According to Eq. 1 and the equivalent circuit of *Fig. 1(b)*, current flowing out of terminal z(i_z) is the difference between the input currents through the terminals p and n ($i_p - i_n$). The voltage at terminal z is transferred to a current at terminal x (i_x) through a transconductance gain (g_m) which can be adjustable by an external bias current, I_B.

Usually this circuit element can be realized with bipolar-junction-transistor (BJT) or CMOS techniques. By way of example, a possible NMOS-based, low-voltage, wide-bandwidth CDTA circuit realization is shown in *Fig. 2*. It is accomplished through the modification of a low-input-impedance, high-output-impedance current-differencing cascaded transconductance amplifier (CDCTA)[14] and the proposed NMOS CDTA can operate with a minimum supply voltage of ±0.8 VDC. The signals pass through only the NMOS transistors, greatly extending the circuit's bandwidth.

Figure 3 shows the proposed current-mode filter configuration with three inputs and two outputs using a single CDTA. According to Eq. 1 and *Fig. 3*, a routine circuit analysis of the structure shows that the transfer functions realized by the configuration can be expressed by Eqs. 2-4:

$$I_{o1} = \frac{s^2(I_1 - I_2 + I_3) + \frac{s}{C_1 R}(I_3 - I_2) + \frac{g_m}{C_1 C_2 R} I_3}{\Delta(s)} \quad (2)$$

$$I_{o2} = \frac{g_m \left[\frac{s}{C_2}(I_1 - I_2) - \frac{1}{C_1 C_2 R} I_2 \right]}{\Delta(s)} \quad (3)$$

COMPARING CURRENT WORK WITH VARIOUS CURRENT-MODE FILTERS BASED ON CDTA

Topology/ reference	Number of CDTA	Number of R + C	b	c	d	e
[3](2003)	2	1 + 2	Yes	Yes	No	Yes
[4](2005)	3	0 + 2	--	No	Yes	Yes
[5](2006)	2	0 + 2	--	No	Yes	Yes
[6](2007)	2	0 + 2	--	No	Yes	No
[7](2008)	1	1 + 2	Yes	Yes	Yes	Yes
[8](2008)	2	0 + 2	--	No	Yes	Yes
[9](2009)	3	0 + 2	--	No	No	No
[10](2009)	1	2 + 2	Yes	Yes	Yes	Yes
[11](2011)	2	0 + 2	--	Yes	Yes	Yes
[12](2012)	4	2 + 2	No	No	No	No
[13](2013)	2	0 + 2	--	No	Yes	No
This work	1	1 + 2	No	No	No	No

$$\Delta(s) = s^2 + \frac{1}{C_1 R} s + \frac{g_m}{C_1 C_2 R} \quad (4)$$

Through the use of Eqs. 2-4, the five filter functions can be achieved as follows:

1. The lowpass response can be realized from I_{o2}, when $I_1 = I_2 = I_{in}$.

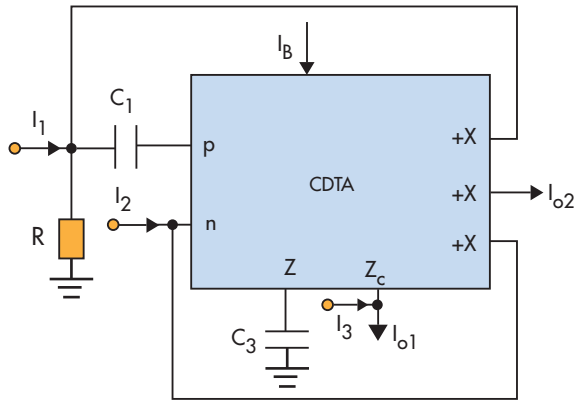
2. The bandpass response can be realized from I_{ol}, when $I_3 = 0$ and $I_1 = I_2 = I_{in}$.

3. The highpass response can be realized from I_{o1}, when $I_1 = I_{in}$ and $I_12 = I_3 = 0$.

4. The bandstop response can be realized from I_{o1}, when $I_1 = I_2 = I_3 = I_{in}$.

5. The all-pass response can be realized from I_{o1}, when $I_3 = I_{in}$ and $I_1 = I_2 = 2I_{in}$.

With a single CDTA, this simple filter can obtain all five filter



3. This is the proposed single CDTA-based current-mode filter.

functions at its high output impedance terminals.

Equations 5 and 6 can be used to find the natural frequency (ω_o) and Q of the proposed filter:

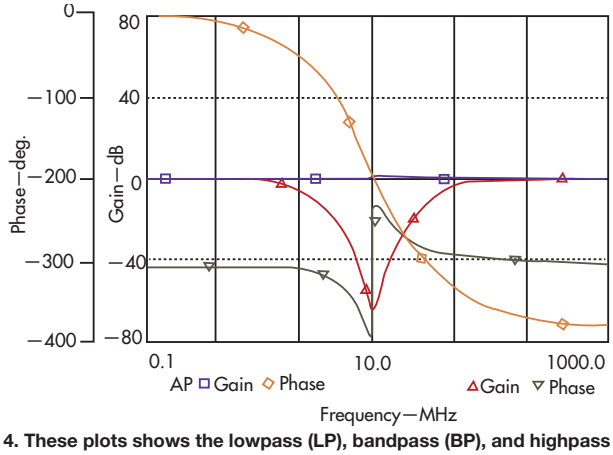
$$\omega_o = \sqrt{\frac{g_m}{C_1 C_2 R}} \quad (5)$$

$$Q = \sqrt{\frac{g_m C_1 R}{C_2}} \quad (6)$$

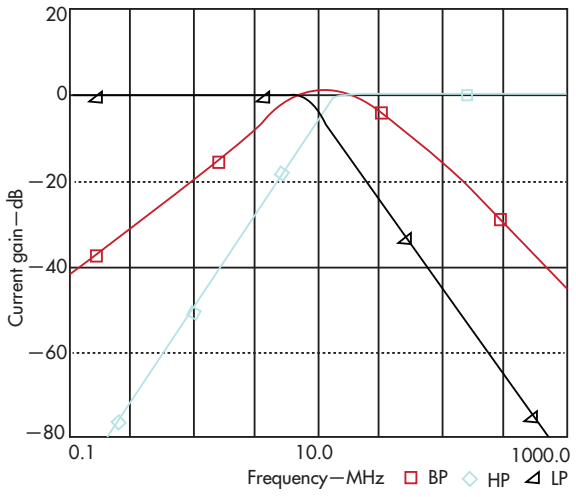
while the filter's bandwidth (BW) can be described by Eq. 7:

$$BW = \frac{\omega_o}{Q} = \frac{1}{C_1 R} \quad (7)$$

From Eqs. 5 and 6, it can be seen that ω_o and Q for the proposed filter are electronically adjustable by means of the bias current to the CDTA. Also, ω_o, the natural frequency of the filter, can be independently tuned by varying g_m through the bias current, I_B, without affecting the bandwidth (BW).



4. These plots shows the lowpass (LP), bandpass (BP), and highpass (HP) responses of the proposed filter.

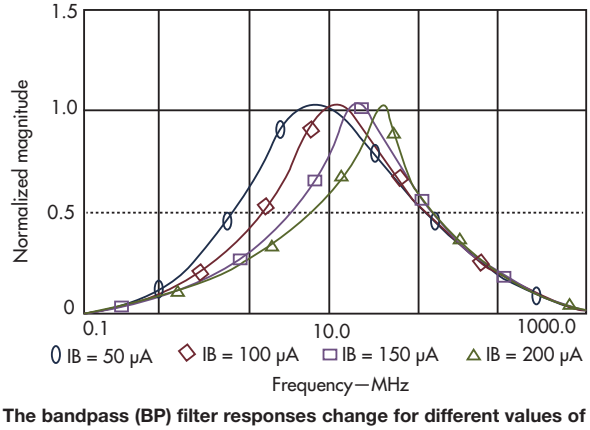


5. The plots reveal gain and phase responses for the bandstop and all-pass filters.

For a look at realistic applications, the performance of the presented circuit may deviate from the ideal by the nonideal characteristics of the CDTA being used. These characteristics are detailed in terms of tracking errors and parasitic impedances, respectively. For analysis of transfer errors, the terminal relations of the CDTA described in Eq. 1 can be further described in Eq. 8:

$$i_z = a_p i_p - a_n i_n,\ i_x = \beta g_m V_z \quad (8)$$

where αp (with $\alpha_p = 1 - \varepsilon_p$, $|\varepsilon_p| << 1$) denotes the current tracking error from terminals p to z, α_n(with $\alpha_n = 1 - \varepsilon_n$, $|\varepsilon_n| << 1$) denotes the current tracking error from terminals n to z, and β (with $\beta_p = 1 - \varepsilon_d$, $|\varepsilon_d| << 1$) denotes the transconductance inaccuracy factor from the z to the x terminals of the CDTA, respectively. In this case, the configuration of *Fig. 3* was reanalyzed, permitting the characteristic transfer functions of the proposed filter to be



6. The bandpass (BP) filter responses change for different values of bias current, I_B.

calculated by Eq. 9:

$$\Delta(s) = s^2 + \frac{1}{C_1 R}s + \frac{\beta\alpha_n g_m}{C_1 C_2 R} \quad (9)$$

The mathematical expressions for the filter parameters ω_o and Q are subsequently changed to Eqs. 10 and 11:

$$\omega_o = \sqrt{\frac{\alpha_n \beta g_m}{C_1 C_2 R}} \quad (10)$$

$$Q = \sqrt{\frac{\beta\alpha_n C_1 R g_m}{C_2}} \quad (11)$$

The sensitivities of the active and passive elements to ω_o and Q can be seen by applications of Eqs. 12 and 13, respectively:

$$S^{\omega_o}_{\beta,\alpha_n,g_m} = \frac{1}{2}, S^{\omega_o}_{C_1,C_2,R} = -\frac{1}{2}, S^{\omega_o}_{\alpha_p} = 0 \quad (12)$$

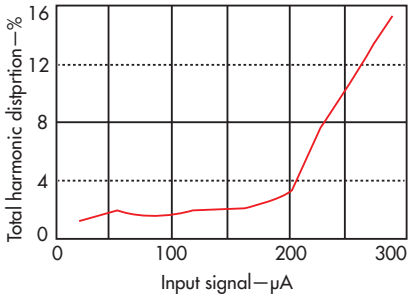
$$S^{Q}_{\beta,\alpha_n,g_m,C_1,R} = \frac{1}{2}, S^{Q}_{C_2} = -\frac{1}{2}, S^{Q}_{\alpha_p} = 0 \quad (13)$$

From Eqs. 10 and 11, it is clear that the tracking errors of the active and passive elements in the filter circuit may cause small deviations of the values of the filter parameters. Additionally, from the above calculations, all the sensitivities of the active and passive elements of the filter with respect to the CDTA tracking errors are less than unity.

The biquad filter represented by *Fig. 2* was simulated in the PSPICE software simulator from OrCAD using Taiwan Semiconductor Manufacturing Co.'s 0.18-µm silicon CMOS semiconductor process for the circuit of *Fig. 2*. The aspect ratios (W/L) for the NMOS transistors are W/L = 24 µm/1 µm for M1-M15c and M20-M27c; W/L = 1 µm/0.6 µm for M16-M17; W/L = 32 µm/0.6 µm for M18-M19. The supply voltages of $V_{DD} = V_{SS}$ = +0.8 VDC and external bias currents (I_o) were chosen as 30 µA. In this case, the NMOS CDTA provides very low-input and high-output impedances at the p, n, and z terminals ($R_p = R_n \approx 1.62\ \Omega$, $R_z = 300\ k\Omega$), respectively, and very high-frequency operation. Passive components with the following values were used: I_B = 200 µA; $C_1 = C_2$ = 10 pF; and R = 285 Ω.

According to Eqs. 5 and 6, this setting has been designed to obtain the LP, BP, HP, BS, and AP filter functions with f_o = 10 MHz and Q = 1. *Figure 4* shows the simulated responses of the prop2osed filter used as LP, BP, and HP filters. A natural frequency of 9.88 MHz was obtained. *Figure 5* shows the simulated frequency responses of the gain and phase characteristics of the BS and AP filters. It is evident from *Figs. 4 and 5* that both the natural frequency and the Q are in accordance with the proposed values.

Figure 6 shows a simulated BP filter response when the biasing current, I_B, was adjusted with values of 150, 200, 250, and 300 µA, respectively, while maintaining $C_1 = C_2$ = 10 pF and R = 285 Ω. The natural frequency and bandwidth of the filter response can be adjusted by means of the CDTA's input bias current. *Figure 7* shows the total harmonic distortion (THD) of the filter.



7. The total harmonic distortion (THD) of the proposed universal filter is very low.

In short, this CDTA-based current-mode universal biquad filter is relatively simple, with one CDTA, one grounded resistor, and two capacitors—ideal for monolithic implementations. mw

ACKNOWLEDGMENTS

The authors would like to thank the reviewers for valuable comments and helpful suggestions. This work is supported by the National Natural Science Foundation of China (No. 61274020) and the Natural Science Foundation of Hunan Province (No. 14JJ7026) and the Open Fund Project of the Key Laboratory in Hunan University (No. 13K015).

REFERENCES

1. C. Toumazou, F.J. Lidgey, and D.G. Haigh, Analogue IC Design: The Current-Mode Approach, Peter Peregrinus, London, 1990.
2. D. Biolek, "CDTA-Building block for current-mode analog signal processing," Proceedings of the ECCTD'03, Vol. III, Krakow, Poland, 2003, pp. 397-400.
3. D. Biolek and V. Biolková, "Universal biquads using CDTA elements for cascade filter design," Contribution to the book Computational Methods in Circuits and Systems Applications," WSEAS Press Electrical and Computer Engineering Series, 2003, p. 232-236.
4. D. Biolek and V. Biolkova, "CDTA-C Current-Mode Universal 2nd-Order Filter," in Proceedings of the 5th WSEAS International Conference on Applied Informatics and Communications, 2005, pp. 411-414.
5. A. U. Keskin, D. Biolek, E. Hancioglu, and V. Biolkova, "Current-Mode KHN Filter Employing Current Differencing Transconductance Amplifiers,", International Journal of Electronic Communications (AEÜ), Vol. 60, 2006, pp. 443-446.
6. Tangsrirat W, Dumawipata T, Surakampontorn W. "Multiple-input single-output current-mode multifunction filter using current differencingtransconductance amplifiers", International Journal of Electronic Communications (AEU), Vol. 61, 2007, pp. 209-214.
7. N.A. Shah, Q. Munazah, and S.Z. Iqbal, "Realization of CDTA Based Current-Mode Universal Filter," Indian Journal of Pure Applied Physics, Vol. 46, 2008, pp. 283-285.
8. D. Biolek, R. Senani, V. Biolkova, and Z. Kolka, "Active Elements for Analog Signal Processing: Classification, Review, and New Proposals," Radioengineering, Vol. 17, 2008, pp. 15-32.
9. W. Tangsrirat, "Cascadable Current-Controlled Current-Mode Universal Filters Using CDTAs and Grounded Capacitors," Journal of Active and Passive Electron Devices, Vol. 4, 2009, pp. 135-145.
10. D. Prasada, D.R. Bhaskara, and A.K. Singh, "Universal Current-Mode Biquad Filter Using Dual Output Current Differencing Transconductance Amplifier," International Journal of Electronic Communications (AEU);63, 2009, pp. 497-501.
11. F. Kacar and H.H. Kuntman, "A New, Improved CMOS Realization of CDTA and its Filter Applications, "Turkish Journal of Electronic Engineering and Computing Sciences, Vol. 19, 2011, pp. 632–42.
12. M. Kumngern, P. Phatsornsiri, and K. Dejhan, "Four Inputs and One Output Current-Mode Multifunction Filter using CDTAs and All-Grounded Passive Components," 10th International Conference on ICT and Knowledge Engineering, Vol. 5, 2012, pp. 9-62.
13. J. Jin and C. Wang, "Current-Mode Universal Filter and Quadrature Oscillator Using CDTAs,"Turkish Journal of Electronic Engineering and Computer Sciences, 2013.
14. J. Xu, C. Wang, and J. Jin, "Current Differencing Cascaded Transconductance Amplifier (CDCTA) and Its Applications on Current-mode Nth-order Filters," Circuits Systems & Signal Processing, 2013, pp. 1-17.