

# 3 Input/ 2 Output Current-Mode Universal Biquad Filter Using Single DO-CCCDTA

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**Abstract-** This article presents a three-input two-output current-mode universal biquadratic filter performing completely standard functions: low-pass, high-pass, band-pass, band-reject and all-pass functions, based on Dual-Output Current Controlled Current Differencing Transconductance Amplifier (DO-CCCDTA). The features of the circuit are that: the quality factor and pole frequency can be tuned orthogonally via the input bias currents: the circuit description is very simple, consisting of merely one DO-CCCDTA, one voltage buffer and 2 grounded capacitors. Additionally, each function response can be selected by suitably selecting input signals in digital method. Without any external resistors and using only grounded elements, the proposed circuit is very suitable to further develop into an integrated circuit. The PSPICE simulation results are depicted. The given results agree well with the theoretical anticipation. The maximum power consumption is approximately 1.81mW at  $\pm 1.5V$  power supply voltages.

**Index Terms-** biquadratic filter, DO-CCCDTA, current-mode

## I. INTRODUCTION

In electrical engineering works, as well-known, an analog filter is an important block and widely used for continuous-time signal processing. It can be found in many fields: for instance, communication, measurement and instrumentation, and control systems [1-2]. One of most popular analog filters is a universal biquadratic filter since it can provide several functions. Nowadays, a universal filter working in current-mode has being been more popular than voltage-mode one. Since the last decade, on the other hand, there has been much effort to reduce the supply voltage of analog systems. This is due to the command for portable and battery-powered equipment. Since a low-voltage operating circuit becomes necessary, the current-mode technique is ideally suited for this purpose. Actually, a circuit using the current-mode technique has many other advantages: for example, larger dynamic range, higher bandwidth, greater linearity, simpler circuitry and lower power consumption [3-4].

The literature surveys show that a large number of circuit realizations for current-mode universal filters have been reported [5-19]. Unfortunately, these reported circuits suffer from one or more of following weaknesses

- a) excessive use of the active and/or passive elements and require changing circuit topologies to achieve several functions [5-9]
- b) lack of electronic adjustability [6-13], [16]

- c) the outputs of the filter responses are not in high output impedance [18-19]
- d) use of floating capacitor, which is not convenient to further fabricate in IC [6-13]
- e) cannot provide completely standard functions [5, 7-8, 10-12, 15-16]

This work is arranged to propose a new three-input two-output current-mode universal biquadratic filter, emphasizing on use of DO-CCCDTA. The features of proposed circuit are that: the proposed universal filter can provide completely standard functions without changing circuit topology by appropriately selecting the input signals in digital method: the circuit description is very simple, it consists of one DO-CCCDTA and 2 grounded capacitors, which is suitable for fabricating in monolithic chip: the filter does not require any external resistor and passive parameter matching conditions. In addition, the quality factor and pole frequency can be tuned orthogonally via the input bias currents. The performances of proposed circuit are illustrated by PSPICE simulations, they show good agreement as mentioned.

## II. PRINCIPLE OF OPERATION

### A. The Dual-Output Current Controlled Current Differencing Transconductance Amplifier (DO-CCCDTA)

Since the proposed circuit is based on DO-CCCDTA, a brief review of DO-CCCDTA is given in this section. Basically, the DO-CCCDTA is composed of translinear element, mixed loops and complementary current mirrors. Generally, the DO-CCCDTA properties are similar to the conventional CDTA, except that input voltages of DO-CCCDTA are not zero and the DO-CCCDTA has finite input resistances  $R_p$  and  $R_n$  at the  $p$  and  $n$  input terminals, respectively. These parasitic resistances are equal and can be controlled by the bias current  $I_{B1}$  as shown in the following equation

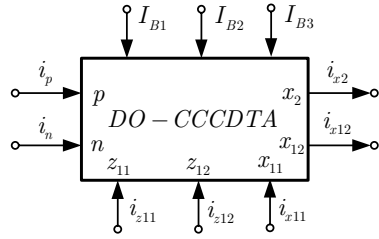
$$\begin{bmatrix} V_p \\ V_n \\ I_{z11,12} \\ I_{x11,12} \\ I_{x2} \end{bmatrix} = \begin{bmatrix} R_p & 0 & 0 & 0 & 0 \\ 0 & R_n & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -g_{m1} & 0 \\ 0 & 0 & 0 & 0 & g_{m2} \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ V_x \\ V_{z1} \\ V_{z1} \end{bmatrix}. \quad (1)$$

Where  $R_p = R_n = \frac{V_T}{2I_{B1}}$ , (2)

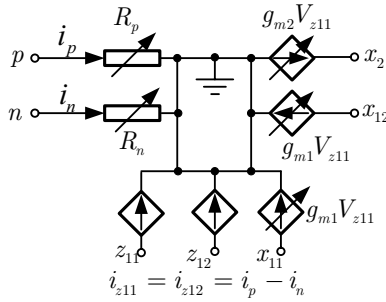
$$g_{m1} = \frac{I_{B2}}{2V_T}, \quad (3)$$

and  $g_{m2} = \frac{I_{B3}}{2V_T}$ . (4)

Where  $g_m$  is the transconductance gain of the CCCDTA and  $V_T$  is the thermal voltage. The symbol and the equivalent circuit of the CCCDTA are illustrated in Fig. 1(a) and (b), respectively.



(a)



(b)

Figure 1. DO-CCCDTA (a) Symbol (b) Equivalent circuit

### B. Proposed universal biquad filter

The proposed current-mode universal biquad filter is shown in Fig. 2. From routine analyzing the circuit in Fig. 2, we will get the output currents as

$$I_{O1} = \frac{1}{D(s)} [g_{m1} I_{in1} - sC_2 R_p g_{m1} I_{in2} + D(s) I_{in3}], \quad (5)$$

and  $I_{O2} = \frac{1}{D(s)} (g_{m2} I_{in1} - sC_2 R_p g_{m2} I_{in2})$ . (6)

Where  $D(s) = s^2 C_1 C_2 R_p + sC_2 R_p g_{m1} + g_{m2}$ . From Eqs. (5) and (6), the magnitudes of input currents;  $I_{in1}$ ,  $I_{in2}$  and  $I_{in3}$  are chosen as Table. 1 by digital method to obtain a standard function of the 2<sup>nd</sup>-order network. From Eq. (5), the pole frequency ( $\omega_0$ ) and quality factor ( $Q_0$ ) of each filter response can be expressed as

$$\omega_0 = \sqrt{\frac{g_{m2}}{C_1 C_2 R_p}}, \quad (7)$$

and  $Q_0 = \frac{C_1}{g_{m1}} \sqrt{\frac{g_{m2}}{C_1 C_2 R_p}}$ . (8)

For simple consideration, if we set  $C_1 = C_2 = C$  and  $I_{B1} = I_{B3} = I_B$ , Eqs. (7) and (8) are subsequently modified to

$$\omega_0 = \frac{I_B}{CV_T}, \quad (9)$$

and  $Q_0 = \frac{2I_B}{I_{B2}}$ . (10)

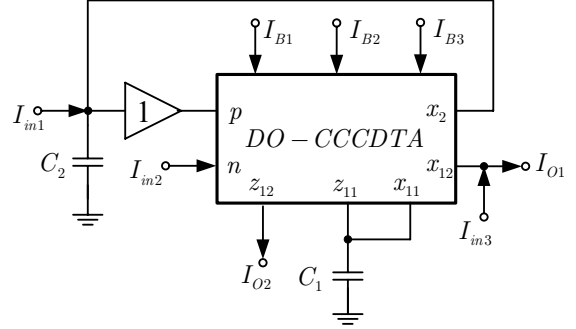


Figure 2. Proposed current-mode universal filter

TABLE I

The  $I_{in1}$ ,  $I_{in2}$  and  $I_{in3}$  values for each filter function response

Filter Responses		Input		
$I_{O1}$	$I_{O2}$	$I_{in1}$	$I_{in2}$	$I_{in3}$
-	LP	1	0	0
HP	-	-1	1	1
BP	-	0	1	0
BR	-	0	1	1
AP	-	0	2	1

It is obviously found that, from Eqs. (9) and (10), the quality factor can be adjusted by  $I_{B2}$  without affecting the pole frequency. Reversely, the pole frequency can be controlled via  $I_B$ . In addition, bandwidth ( $BW$ ) of the system can be expressed by

$$BW = \frac{\omega_0}{Q_0} = \frac{I_{B2}}{2CV_T}. \quad (11)$$

We found that the bandwidth can be linearly controlled by  $I_{B2}$ . Moreover, the quality factor can be much high by controlling  $I_{B2}$  to be much less than  $I_B$ . This differs from the conventional current-controlled universal filters in such that they use an input bias current to control the quality factor. However, it has a limited value of current in the circuits, the quality factor is then restricted.

### C. Sensitivities

The sensitivities of the proposed circuit are low and can be found as

$$S_{I_B}^{\omega_0} = 1; S_C^{\omega_0} = -1, \quad (12)$$

and  $S_{I_B}^{Q_0} = 1; S_{I_{B3}}^{Q_0} = -1$ . (13)

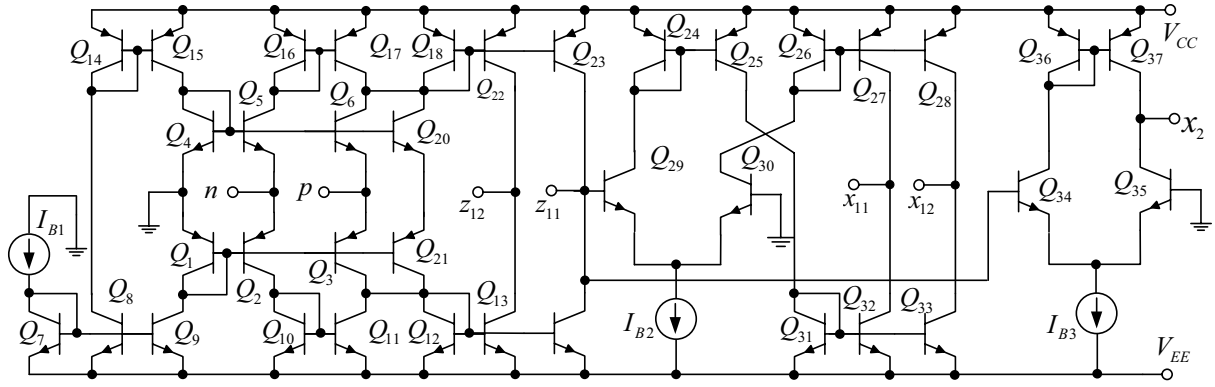


Figure 3. Internal construction of DO-CCCDTA

#### D. Non-ideal case

For non-ideal case, the  $I_z$  and  $I_x$  of DO-CCCDTA can be respectively characterized by

$$I_{z11} = \alpha_{p1} I_p - \alpha_{n1} I_n, \quad (14)$$

$$I_{z12} = \alpha_{p2} I_p - \alpha_{n2} I_n, \quad (15)$$

$$I_{x11} = \beta_{11} g_m V_{z11}, \quad (16)$$

$$I_{x12} = \beta_{12} g_m V_{z11}, \quad (16)$$

and

$$I_{x2} = \beta_2 g_m V_{z11}. \quad (18)$$

Where  $\alpha_p$ ,  $\alpha_n$  and  $\beta$  are transferred error values deviated from one. In the case of non-ideal consideration, reanalyzing the proposed filter circuit in Fig. 2 yields the denominator as

$$D(s) = s^2 C_1 C_2 R_p + s C_2 R_p g_{m1} \beta_{11} + g_{m2} \alpha_{p1} \beta_2. \quad (19)$$

In this case, the  $\omega_0$ ,  $Q_0$  and BW are changed to

$$\omega_0 = \sqrt{\frac{\alpha_{p11} \beta_2 g_{m2}}{C_1 C_2 R_p}}, \quad (20)$$

$$Q_0 = \frac{C_1}{\beta_{12} g_{m1}} \sqrt{\frac{\alpha_{p1} \beta_2 g_{m2}}{C_1 C_2 R_p}}, \quad (21)$$

and

$$BW = \frac{\omega_0}{Q_0} = \frac{\beta_{12} g_{m1}}{C_1}. \quad (22)$$

Eqs. (20)-(22) degrade the performances of proposed filter at high frequency applications in such restricted frequency response and temperature dependence because of the parasitic elements of active device used in the circuit.

Actually, if careful design technique is employed to design the CCDTA, these deviations are very small and can be ignored.

### III. SIMULATION RESULTS

To prove the performances of the proposed circuit, the PSPICE simulation program was used for the examination. The PNP and NPN transistors employed in the proposed circuit were simulated by respectively using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T [20]. The voltage buffer was used as an ideal voltage buffer. Fig. 3 depicts schematic description of the DO-CCCDTA used in the simulations.

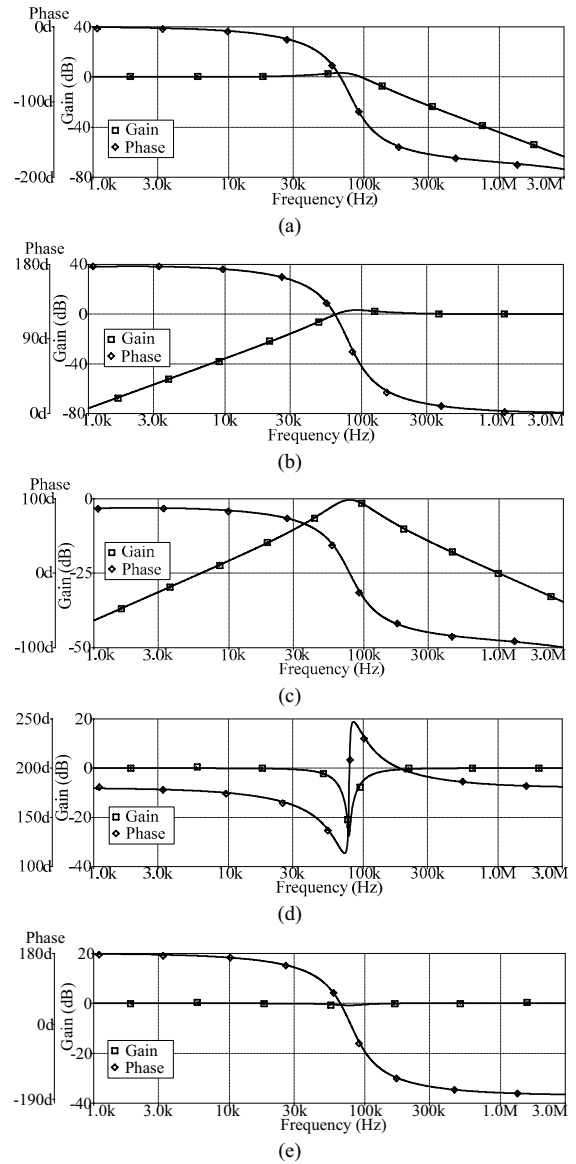


Figure 4. Frequency responses for different functions

The circuit was biased with  $\pm 1.5V$  supply voltages and  $C_1 = C_2 = 10nF$ . The results shown in Fig. 4 are the gain and phase responses of the proposed biquad filter obtained from Fig. 2 with different functions as shown Table 1, where  $I_{B1}$ ,  $I_{B2}$  and  $I_{B3}$  are equal to  $50\mu A$ ,  $200\mu A$  and  $200\mu A$ , respectively. There are clearly seen that the proposed biquad filter can provide low-pass, high-pass, band-pass, band-reject and all-pass functions dependent on selection as shown in Table 1, without modifying major circuit topology.

Fig. 5 displays gain responses of band-pass function with different  $I_{B2}$  values. It is obviously shown that the bandwidths of the responses can be linearly adjusted by the input bias current  $I_{B2}$  as depicted in Eq. (10) without affecting the pole frequency. Similarly, the results in Fig. 6 are phase responses of all-pass function. It confirms the performances of proposed filter in such controllability of the quality factor via  $I_{B2}$  without affecting the pole frequency as well. Maximum power consumption is about 1.81mW.

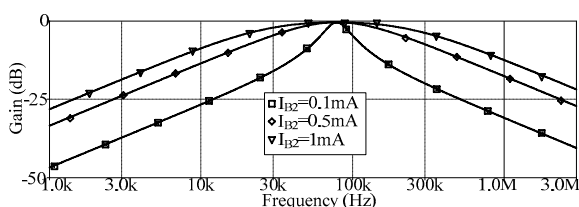


Figure 5. Bandwidth variation of band-pass function for different  $I_{B2}$

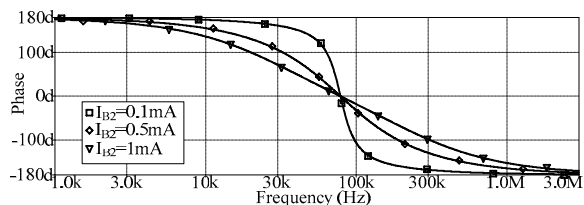


Figure 6. Phase responses of all-pass function for different  $I_{B2}$

#### IV. CONCLUSIONS

The current-mode universal biquadratic filter based on DO-CCCDTA has been presented. The advantages of the proposed circuit are that: it performs low-pass, high-pass, band-pass, band-reject and all-pass functions with two outputs depending on an appropriately selecting of three input signals: the quality factor and pole frequency can be tuned orthogonally via the input bias currents, this is easily modified to use in control systems using a microcontroller [3]. The circuit description comprises only one DO-CCCDTA and 2 grounded capacitors cooperating with one voltage buffer. With mentioned features, it is very suitable to realize the proposed circuit in a monolithic chip for use in battery-powered, portable electronic equipments such as wireless communication system devices.

#### REFERENCES

- [1] A. S. Sedra, and K. C. Smith, *Microelectronic circuits*, 5rd ed., Florida: Holt, Rinehart and Winston, 2003.
- [2] M. A. Ibrahim, S. Minaei, and H. A. Kuntman, "A 22.5 MHz current-mode KHN-biquad using differential voltage current conveyor and grounded passive elements," *Int. J. Electron. Commun. (AEU)*, vol. 59, pp. 311-318, 2005.
- [3] C. Toumazou., F. J. Lidgey, and D. G. Haigh, *Analogue IC design: the current-mode approach*, London: Peter Peregrinus, 1990.
- [4] D. R. Bhaskar, V. K. Sharma, M. Monis, and S. M. I. Rizvi, "New current-mode universal biquad filter," *Microelectronics Journal*, vol. 30, pp. 837-839, 1999.
- [5] N. A. Shah nad M. A. Malik, "Voltage/current-mode universal filter using FTFN and CFA," *Analog Integrated Circuits and Signal Processing*, vol. 45, pp. 197-203, 2005.
- [6] C. M. Chang, T. S. Liao, T. Y. Yu, E. S. Lin, C. H. Teng, and C. L. Hou, "Novel universal current-mode filters using unity-gain cells," *Int. J. Electronics*, vol.86, pp. 929-932, 2001.
- [7] H. Y. Wang and C. T. Lee, "Versatile insensitive current-mode universal implementation using current conveyors," *IEEE Trans. on Circuits and Systems II*, vol. 48, pp. 409-413, April 2005.
- [8] R. K. Sharma and R. Senani, "Universal current-mode biquad using a single CFOA," *Int. J. Electronics*, vol. 91, pp. 175-183, March 2004.
- [9] S. H. Tu, C. M. Chang, and K. P. Liao, "Novel versatile insensitive universal current-mode biquad employing two second-generation current conveyors," *Int. J. Electronics*, vol. 89, pp. 897-903, 2002.
- [10] N. A. Shah and M. A. Malink, "High impedance voltage and current-mode multifunction filters," *Int. J. Electron. Commun. (AEU)*, vol. 59, pp. 262-266, 2005.
- [11] M. Sagbas and K. Fidanboyulu, "Electronically tunable current-mode second-order universal filter using minimum elements," *Elec. Letters*, vol. 40, pp. 2-4, January 2004.
- [12] J. Wu and e. I. El-masry, "Universal voltage and current-mode OTAs based biquads," *Int. J. Electronics*, vol. 85, pp. 553-560, 1998.
- [13] J. W. Horng, "Current-conveyors based allpass filters and quadrature oscillators employing grounded capacitors and resistors," *Computers and Electrical Engineering*, vol. 31, pp. 81-92, 2005.
- [14] M. Bhusan, R. W. Newcomb, "Grounding of capacitors in integrated circuits," *Elec. Letters*, vol. 3, pp.148-149, 1967.
- [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, 451-457, 2005.
- [16] R. Senani, V. K. Singh, A. K. Singh, and D. R. Bhaskar, "Novel electronically controllable current-mode universal biquad filter," *IEICE Electronics Express*, vol1, 410-415, 2004.
- [17] Y. Maruyama, A. Hyogo, and K. Sekine, "A digitally programmable CMOS biquad filter using current-mode integrators," *IEICE trans. on fundamentals*, vol. E85-A, no. 2, pp. 316-323, 2002.
- [18] S. Celma, J. Sabadell and P. Martinez, "Universal filter using unity-gain cells," *Elec. Letters*, 31, pp. 1817-1818, 1995.
- [19] R. M. Weng, J. R. Lai and M. H. Lee, "New universal biquad filters using only two unity-gain cells," *Int. J. Electronics*, vol. 87, pp. 57-61, 2000
- [20] D. R. Frey, "Log-domain filtering: an approach to current-mode filtering," *IEE Proc. Circuit Devices Syst.*, vol. 140, pp. 406-416, 1993.