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New OTA-C Current-Mode Second-order and Fourth-Order Band-Pass Filters

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Abstract: In this paper, a general two-admittance current-mode circuit structure using Dual-Output OTA (DO-OTA) is explored to derive new second-order and fourth-order band-pass filters. The proposed second-order band-pass filtercircuits offer advantageous features like ease of design, good sensitivity and orthogonal tunability of pole-Q. The proposed fourth-order band-pass filtercircuit is attractive as it requires less number of OTAs and capacitors.PSPICE simulation results are given for the proposed circuits.

Keywords: Continuous-time (CT) filters, Current-mode circuits,SO-OTA,DO-OTA, OTA-C filters.

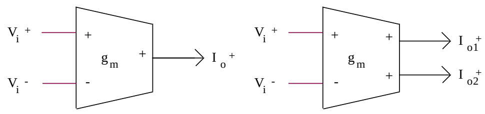
I. INTRODUCTION

Recently, the OTA-C current-mode (CM) continuous-time (CT) filterdesign approach [1]-[13] has received more attention. The design of current-mode OTA-C filters using Dual Output OTAs (DO-OTA) [2]-[8], TO-OTA[9], [10]and Multiple Output OTAs (MO-OTA) [5], [11]-[13] have been described. The different circuit configurations for realization of current-mode biquads using OTA have been describedi.e., a single DO-OTA and five admittance model [3], two-integrator loop structure [4]-[6]etc. The DO-OTA based general two-admittance circuit configuration with two/ one input current(s) has been discussed extensively in the literature [6], [8], [12], [14]. The realization of third-order OTA-C filters also has been researched in the literature [14]-[16].
The realization of OTA-C current-mode second-order band-pass filters are discussed [4], [5], [8], [12]. The third-order OTA-C current-mode band-pass filters with unsymmetrical amplitude response have been investigated [14]-[16]. The design of fourth-order band-pass Active-RC filters have been reported [17]-[19].
In this paper, the DO-OTA based general current-mode two-admittance circuit structure proposed in [6], [8], [12], [14] is presented in Section II. In Section III, the proposed general basic topology is used to explore second-order and fourth-order band-pass filters by considering proper admittances in place of $Y_n$and Y_p. In Section IV, the proposed fourth-order OTA-C current-mode band-pass filter is compared with the cascade band-pass filter arrangement using two identical band-pass biquads. PSPICE simulation results are presented in Section V. The concluding remarks are given in Section VI.

II. DO-OTA BASED TWO-ADMITTANCE CIRCUIT CONFIGURATION

The circuit symbol of single output OTA (SO-OTA) and dual output OTA (DO-OTA) used in this work are shown in Fig. 1(a) and (b) respectively. The two current outputs of DO-OTA are given by

$$I_{o1}+ = I_{o2}+ = g_m(V_i^+ - V_i^-) \qquad (1)$$



(a) (b)

Fig.1 Circuit symbol of (a) SO-OTA (b) DO-OTA

Here, I_{o1}^+, I_{o2}^- are the two output source currents, V_i^+andV_i^- denote non-inverting and inverting input voltages of the DO-OTA respectively.

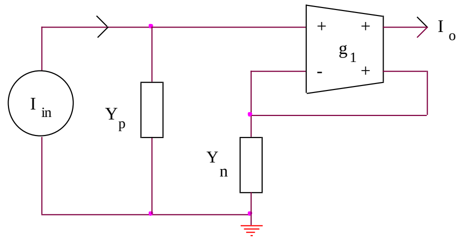


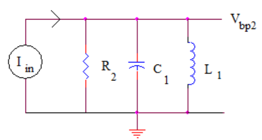
Fig.2 DO-OTA based general current-mode two-admittance circuit configuration with single input current

The DO-OTA based two-admittance general current-mode configuration with two input currents has been discussed in [7].The circuit configuration with single input current for realizing OTA-C third-order band-pass filters is shown in Fig. 2. The generalized current-input current-output (CICO) transfer function for this circuit can be shown to be

$$\frac{I_o}{I_{in}} = \frac{g_1 Y_n}{Y_p(g_1+Y_n)} \qquad (2)$$

III. REALIZATION OF CURRENT-MODE OTA-C SECOND-ORDERAND FOURTH-ORDER BAND-PASS FILTERS

A. Current-mode OTA-C second-order band-pass filter BP2



(a)

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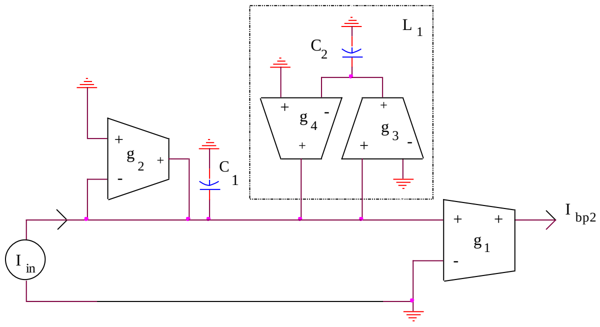

(b)

Fig. 3 (a) Second-order passive RLCtransimpedance band-pass filter circuit reported in [2] (b) Current-mode second-order band-pass filter circuit BP2 derived from the configuration of Fig. 2

The transfer function of passive RLC transimpedance band-pass biquadin Fig. 3(a) reported in [ ] is shown to be

$$\frac{V_{bp2}}{I_{in}} == \frac{s\left(\frac{1}{C_1}\right)}{s^2 + s\left(\frac{1}{R_2 C_1}\right) + \frac{1}{L_1 C_1}} \quad (3a)$$

A current-modesecond-order band-pass filter circuit in Fig. 3(b) is obtained by using the basic structure of Fig. 2 by replacing the admittance$Y_p$withaparallel RLC resonator (consisting of grounded inductor L_1, grounded OTA simulated resistor $1/g_2$and grounded capacitor C_1) and $Y_n = \infty$(grounding negative input of OTA g_1).Here the inductance$L_1$of value $C_2/g_3g_4$is realized by OTAs g_3 and g_4 and capacitor C_2.The transfer function of OTA-C current-mode band-pass biquadBP2 in Fig. 3(b) is given by

$$\frac{I_{bp2}}{I_{in}} == \frac{s\left(\frac{g_1}{C_1}\right)}{s^2 + s\left(\frac{g_2}{C_1}\right) + \frac{g_3 g_4}{C_1 C_2}} \quad (3b)$$

The expressions for pole-frequency and pole-Q are shown to be

$$\omega_o = \sqrt{\frac{g_3 g_4}{C_1 C_2}}\,; \quad Q_o = \frac{g_{3,4}}{g_2}\sqrt{\frac{C_1}{C_2}} \qquad (3c)$$

Note that current-mode band-pass OTA-C biquad BP2 in Fig. 3(b) is an extension of passive transimpedancebiquadusing an additional OTA $g_1$as a voltage-to-current converter.

B. Current-mode OTA-C second-order band-pass filter BP2*

The current-mode second-order band-pass filter circuit shown in Fig. 4 can be realized from the basic structure of Fig. 2 by replacing the admittance Y_p with grounded resistor $1/g_2$ and Y_n with C_3 in series with grounded inductor L_2. Here the grounded inductance L_2 of value $C_4/g_5g_6$is realized by OTAs g_5 and $g_6$and capacitor C_4.

The current-mode second-order band-pass transfer function realized by the BP2* filter circuit in Fig. 4 are given by

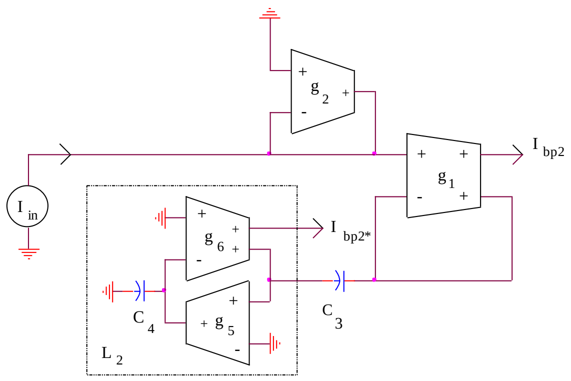

Fig. 4Current-mode second-order band-pass filter BP2/ BP2* derived from the configuration of Fig. 2

$$\frac{I_{bp2}}{I_{in}} = -\frac{I_{bp2*}}{I_{in}} = \left(\frac{g_1}{g_2}\right)\frac{s\left(\frac{g_5 g_6}{g_1 C_4}\right)}{s^2 + s\,\frac{g_5 g_6}{g_1 C_4} + \frac{g_5 g_6}{C_3 C_4}} \quad (4a)$$

The expressions for pole-frequency and pole-Q are shown to be

$$\omega_o = \sqrt{\frac{g_5 g_6}{C_3 C_4}}\,; \quad Q_o = g_1\sqrt{\frac{C_4}{g_5 g_6 C_3}} \qquad (4b)$$

C.Current-mode OTA-C fourth-order band-pass filter BP4/ BP4*

In this section we show that the general basic topology of Fig.2 can be used to realize fourth-order band-pass filter circuit.

A current-modefourth-order band-pass filter circuit is obtained by using the basic structure of Fig. 2 by replacing the admittance$Y_p$withaparallel RLC resonator (consisting of grounded inductor L_1,grounded OTA simulated resistor $1/g_2$and grounded capacitor C_1) andY_n with a series LC section (acapacitor C_3in series with grounded inductor L_2).Note that the inductance $L_1$of value $C_2/g_3g_4$is realized by OTAs $g_3$and g_4 and capacitor $C_2$and theinductance $L_2$of value $C_4/g_5g_6$is realized by OTAs g_5 and $g_6$and capacitor C_4.Theresulting circuit is presented in Fig.5.

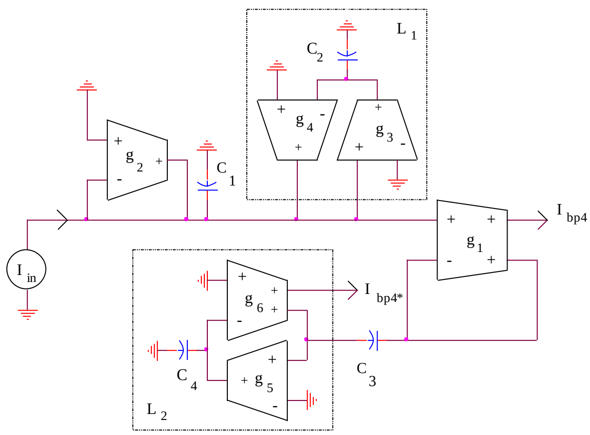

Fig.5 Current-mode DO-OTA based fourth-order band-pass filter BP4/ BP4* derived from the configuration of Fig. 2

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The current-mode fourth-order band-pass transfer function for the circuit of Fig. 5is shown to be

$$T_{bp4}(s) = \frac{I_{bp4}}{I_{in}} = -\frac{I_{bp4}*}{I_{in}} = \frac{s^2\beta_2}{s^4 + s^3\alpha_3 + s^2\alpha_2 + s\alpha_1 + \alpha_0} \quad (3a)$$

where

$$\beta_2 = \frac{g_5 g_6}{C_1 C_4}$$

$$\alpha_3 = \frac{g_2}{C_1} + \frac{g_5 g_6}{g_1 C_4}$$

$$\alpha_2 = \frac{g_3 g_4}{C_1 C_2} + \frac{g_5 g_6}{C_3 C_4} + \frac{g_2 g_5 g_6}{g_1 C_1 C_4}$$

$$\alpha_1 = \frac{g_2 g_5 g_6}{C_1 C_3 C_4} + \frac{g_3 g_4 g_5 g_6}{g_1 C_1 C_2 C_4}$$

$$\alpha_0 = \frac{g_3 g_4 g_5 g_6}{C_1 C_2 C_3 C_4}$$

But, the routine analysis shows an interesting observation that the fourth-order transfer function can be expressed as a cascade of two band-pass biquad sections having independent tunability of pole-Q and pole-frequency.

$$T_{bp4}(s) = K_{bp4} * T_{bp21}(s) * T_{bp22}(s) \quad (3b)$$

where

$$K_{bp4} = g_1/g_2$$

$$T_{bp21}(s) = \frac{s\left(\frac{g_2}{C_1}\right)}{s^2 + s\frac{g_2}{C_1} + \frac{g_3 g_4}{C_1 C_2}}$$

$$T_{bp22}(s) = \frac{s\left(\frac{g_5 g_6}{g_1 C_4}\right)}{s^2 + s\frac{g_5 g_6}{g_1 C_4} + \frac{g_5 g_6}{C_3 C_4}}$$

The pole frequency and quality factor of the two inherent band-pass biquad transfer functions (i.e., $T_{bp21}$and T_{bp22}) and their sensitivity valuesare shown to be

$$f_{o1} = \frac{1}{2\pi}\sqrt{\frac{g_3 g_4}{C_1 C_2}}; \quad Q_{o1} = \frac{1}{g_2}\sqrt{\frac{g_3 g_4 C_1}{C_2}}$$

$$f_{o2} = \frac{1}{2\pi}\sqrt{\frac{g_5 g_6}{C_3 C_4}}; \quad Q_{o2} = g_1\sqrt{\frac{C_4}{g_5 g_6 C_3}} \quad (3c)$$

$$S_{g_3}^{f_{o1}} = S_{g_4}^{f_{o1}} = -S_{C_1}^{f_{o1}} = -S_{C_2}^{f_{o1}} = 0.5$$

$$S_{g_5}^{f_{o2}} = S_{g_6}^{f_{o2}} = -S_{C_3}^{f_{o2}} = -S_{C_4}^{f_{o2}} = 0.5$$

$$S_{g_3}^{Q_{o1}} = S_{g_4}^{Q_{o1}} = S_{C_1}^{Q_{o1}} = -S_{C_2}^{Q_{o1}} = 0.5$$

$$S_{C_4}^{Q_{o2}} = -S_{g_5}^{Q_{o2}} = -S_{g_6}^{Q_{o2}} = -S_{C_3}^{Q_{o2}} = 0.5$$

$$S_{g_1}^{Q_{o2}} = -S_{g_2}^{Q_{o1}} = 1 \quad (3d)$$

IV. SUMMARY OF PROPOSED FOURTH-ORDERCURRENT-MODEOTA-C BAND-PASS FILTERS

Using the proposed DO-OTA based circuit configuration of Fig. 2, 4thorder band-pass filter circuit is shown to be realizable. In Table 1 the proposed 4thorder current-mode band-pass filter of Fig. 5 is compared with 4thorder cascade band-pass filter realized with two biquad sections of Fig. 3(b) and Fig. 4 in this paper. The proposed 4thorder band-pass filter BP4/ BP4* of Fig. 5 require six OTAs, one extra output, three grounded and one floating capacitors. The 4th order cascade band-pass filter realized with two biquad sections of Fig. 3(b) in this paper require eight OTAsandfour grounded capacitors. The 4th order cascade band-pass filter realized using two biquad sections of Fig. 4 in this paper require eight OTAs, one extra output, two grounded and two floating capacitors. The filter circuits are found to be attractive due to their features like ease of design, programmability, good sensitivity and independent pole-*Q*tunability.

Table 1 Comparative summary of various current-mode fourth-order band-pass filter circuits

Author/ Reference	No. of OTAs	No. of extra OTA outputs	No. of capacitors (grounded/ floating)
Fourth-order cascade band-pass filter realized with two biquad sections of Fig. 3(b)in this paper	8	0	4 grounded
Fourth-order cascade band-pass filter realized with two biquad sections of Fig. 4 in this paper	8	2	2 grounded 2 floating
Fourth-order band-passBP4/ BP4* of Fig. 5 in this paper	6	1	3 grounded 1 floating

V. SIMULATION RESULTS

The proposed current-mode second-order and fourth-order band-pass filter circuits in Fig. 3(b), Fig. 4 andFig. 5 have been simulated using PSPICE simulator using Level 3 0.5μm MOSIS model parameters and device dimensions (W = 4 μm and L = 2 μm) and supply voltages V_{dd}= +2V,V_{ss} = -2V. [6].

The proposed current-mode filter circuits were also simulated usingbehavioral voltage controlled current source (VCCS) model of OTA(i.e., ideal transconductor with infinite R_o and zeroC_o) to obtain the ideal characteristics.The schematic circuit ofDO-OTA used in our simulation is presented in Fig. 6.

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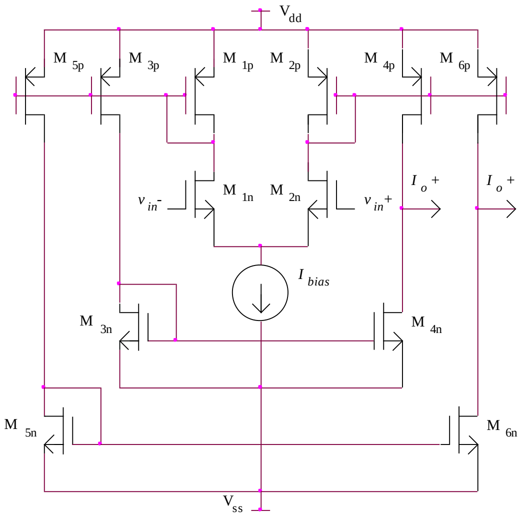
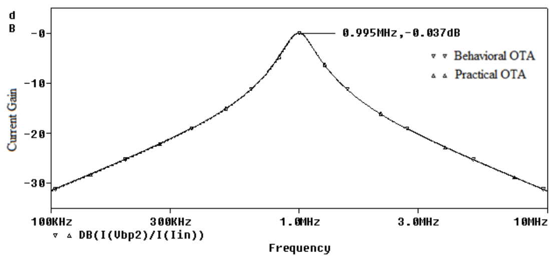


Fig.6Schematic circuit of CMOS DO-OTA

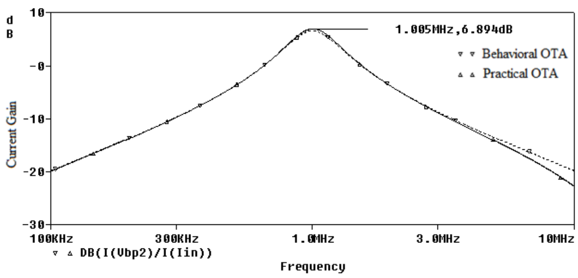
The DO-OTA based second-order band-pass filter of Fig. 3(b) has been simulated using $g_1 = g_2 = 53.9\ \mu S$ $(I_{bias1,2} = 10\ \mu A)$,$g_3 = g_4 = 206\ \mu S$ $(I_{bias3,4} = 200\ \mu A)$, $C_1 = C_2 32.79\ pF$ designed for a center frequency of 1 MHz, pole-Q of Q_o= 3.82, center frequency gain of 0 dB and the resulting amplitude response is shown in Fig. 7.



∇ …. usingbehavioral OTA, Δ __ using Tsukutani OTA

Fig. 7 Amplitude response of current-mode second-order band-pass filter of Fig. 3(b)

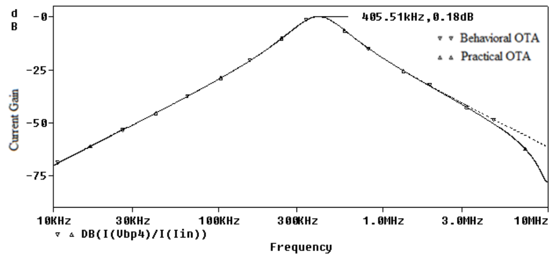
The band-pass biquad filter of Fig. 4 have been simulated using $g_1 = 114\ \mu S(I_{bias1} = 50\ \mu A)$,$g_2 = g_5 = g_6 = 53.9\ \mu S(I_{bias2} = I_{bias5} = I_{bias6} = 10\ \mu A)$, $C_3 = C_4 = 8.58$ pFdesignedfor a pole frequency of 1 MHz corresponding to pole-QQ_o= 2.12,center frequency gain of 6.506 dB and the resulting amplitude responses are shown in Fig. 8.



∇ …. usingbehavioral OTA, Δ __ using Tsukutani OTA

Fig. 8 Amplitude response of current-mode second-order band-pass filter of Fig. 4

The fourth-order band-pass filter BP4of Fig. 5 have been simulated using $g_1 = g_2 = g_3 = g_4 = g_5 = g_6 = 53.9\ \mu S(I_{bias1,2,3,4,5,6} = 10\ \mu A)$, $C_2 = C_3 = 15$ pF, $C_1 = C_4 = 30$ pFdesignedfor a centre frequency of 404.39 kHz corresponding to pole-$QQ_{o1} = Q_{o2}$= 1.414 and the resulting amplitude responses are shown in Fig. 9.



∇ …. usingbehavioral OTA, Δ __ using Tsukutani OTA

Fig. 9 Amplitude response of current-mode fourth-order band-pass filter of Fig. 5

From the simulatedamplitude responses, it isevident that the centre frequency and gain roll-off values are found to be in good agreement with theory.

VI. CONCLUSION

In this paper, a DO-OTA based general current-input current-output (CICO) two-admittance circuit configuration is used to realize second-order and fourth-order band-pass filter circuits. The proposed current-mode band-pass biquadsexhibit low sensitivity to component tolerances and provide independent tuning of pole-frequency and pole-Q.The proposed fourth-order current-mode band-pass filtercircuitrequires less number of OTAsand capacitors when compared withcascade band-pass filter realized using two biquad sections. The simulation results obtained are in good agreement with theory.

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BIOGRAPHY

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