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New OTA-C universal current-mode/ trans-admittance biquads

D. R. Bhaskar,[1] **A. K. Singh,**[2] **R. K. Sharma,**[3] **and R. Senani**[3a)]

[1] *Electronics and Communication Engineering Department, Faculty of Engineering and Technology, Jamia Millia Islamia, Jamia Nagar, New Delhi 110 025*

[2] *Electronics and Communication Engineering Department. Inderprastha Engineering College, Sahibabad, Ghaziabad, U. P.*

[3] *Analog Signal Processing Research Lab., Division of Electronics and Communication Engineering, Netaji Subhas Institute of Technology (formerly, Delhi Institute of Technology), Sector 3, Dwarka, New Delhi 110 075, India*

a) *senani@nsit.ac.in*

Abstract: This letter introduces two new OTA-C universal Current mode biquads which offer almost all of the desirable features (expected from a good universal biquad) simultaneously, without any trade-offs. With first OTA removed and the input current source replaced by an input voltage source, both the new circuits can also realise trans-admittance-type universal biquad filters. The workability of the new circuits has been established by SPICE simulation results of their CMOS-implementable versions.

Keywords: Analog Circuit Design, Current Mode Filters

Classification: Integrated circuits

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1 Introduction

OTA-C structures are highly suitable for realising electronically-tunable continuous-time filters in a variety of technologies such as bipolar, CMOS and BiCMOS, and therefore, have been widely investigated for designing voltage-mode (VM) as well as current-mode (CM) filters. Although a number of CM OTA-C biquads are reported in earlier literature [1-10], those of [1-6] are of multiple-input-single-output type (as in [3]) or multiple-input-multiple-output type (as in [1, 2, 4-6]). Thus, only the circuits of [7-10] realise single-input-multiple-output (SIMO) type CM biquad filters, with which this paper is concerned.

A good SIMO type CM biquad filter should *simultaneously* exhibit the following desirable features, *without trade-offs*: (i) realisability of all the five standard filter functions namely, low pass (LP), band pass (BP), high pass (HP), notch and all pass (AP) (ii) realisability of all the five functions without requiring any design constraint/matching conditions (iii) availability of *explicit* current outputs (i.e. from high-output-impedance nodes) without requiring any additional active elements (iv) independent tunability of ω_0, ω_0/Q_o and H_o (v) either '*ideally zero or a resistive*' R_{in} (in the latter case, the finite source resistance of the input source can be easily absorbed/accounted in the R_{in}) (vi) employment of both grounded capacitors, and (vii) use of a small number of, and *only one type of*, active building blocks.

A careful inspection of the quoted earlier circuits of SIMO type OTA-C biquads of [7-10] (see Table I) reveals that none of these possess all the above desirable features (i)-(vii) *simultaneously*. The object of this communication

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Table I. Evaluation of performance parameters (i)-(vii) for previously reported OTA-based SIMO type CM biquads ('NA' denotes 'not applicable')

Features	Circuit reference			
	[7]	[8]	[9]	[10] [1]
(i) All five functions realisable	Yes	No	No	Yes
(ii) Any realisation constraints needed	No	NA	NA	No
(iii) Availability of explicit current output	Yes	Yes	Yes	Yes
(iv) Availability of independent tunability of all the three parameters	No	No	Yes	No
(v) Provides ideally zero or resistive R_{in}	Yes	No	Yes	No
(vi) Employs both grounded capacitors	Yes	No	Yes	No
(vii) Uses only one type of active elements	No	yes	No	No

is, therefore, to present two new OTA-C universal biquad structures which do possess all the above features *simultaneously*.

2 The proposed new structures

(a) Universal CM biquad realisation: The proposed new circuits are shown in Fig. 1. A straight forward analysis reveals the following transfer functions for the configuration of Fig. 1 (a):

$$\frac{I_{01}}{I_{in}} = \left(\frac{g_{m1}}{g_{m2}}\right)\left(\frac{\frac{g_{m3}g_{m4}}{C_1C_2}}{D(s)}\right) \tag{1}$$

$$\frac{I_{02}}{I_{in}} = \left(-\frac{g_{m1}}{g_{m2}}\right)\left(\frac{s\frac{g_{m3}}{C_1}}{D(s)}\right) \tag{2}$$

$$\frac{I_{03}}{I_{in}} = \left(\frac{g_{m1}}{g_{m2}}\right)\left(\frac{s^2}{D(s)}\right) \tag{3}$$

$$\text{where } D(s) = s^2 + s\left(\frac{g_{m3}}{C_1}\right) + \left(\frac{g_{m3}g_{m4}}{C_1C_2}\right) \tag{4}$$

Similarly, the various transfer functions of the configuration of Fig. 1 (b) are given by

$$\frac{I_{01}}{I_{in}} = \left(\frac{g_{m1}}{g_{m4}}\right)\left(\frac{s^2 + \left(\frac{g_{m2}g_{m3}}{C_1C_2}\right)}{D(s)}\right) \tag{5}$$

$$\frac{I_{02}}{I_{in}} = \left(\frac{g_{m1}}{g_{m4}}\right)\left(\frac{s\frac{g_{m2}}{C_1}}{D(s)}\right) \tag{6}$$

$$\frac{I_{03}}{I_{in}} = \left(-\frac{g_{m1}}{g_{m4}}\right)\left(\frac{\frac{g_{m2}g_{m3}}{C_1C_2}}{D(s)}\right) \tag{7}$$

$$\text{where } D(s) = s^2 + s\left(\frac{g_{m1}}{C_1}\right) + \left(\frac{g_{m2}g_{m3}}{C_1C_2}\right) \tag{8}$$

[1] Although not spelt out therein, the circuit of Fig. 1 of [10] can be synthesized from a parallel RLC resonator through the method of [11] by simulating each of these elements by OTAs (OTA-1 and OTA-3 along with C_2 simulating L, OTA-2 simulating R) and drawing out the currents flowing in them (i_L, i_R and i_C) as output currents (i_L as i_{LP} through OTA-3, i_R as i_{BP} through OTA-2 and i_C as i_{HP} through the CF).

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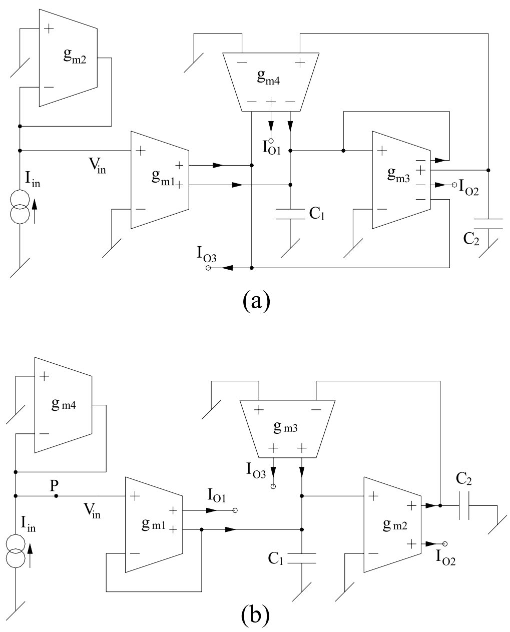

Fig. 1. The proposed new configurations

It is easy to verify that additional filter functions namely notch and all-pass in case of Fig. 1 (a) and highpass and allpass in case of Fig. 1 (b), are realizable by simply joining the appropriate terminals without requiring any design constraints/matching conditions. Furthermore, in both the cases, the various filter parameters can be electronically-tuned by varying the trans-conductances of the various OTAs as follows. In the circuit of Fig. 1 (a), ω_0/Q_o is tunable through g_{m3} after which ω_0 can be tuned with g_{m4} and finally, in all the five filters, H_o is tunable through g_{m1} and/or g_{m2}. On the other hand, in the circuit of Fig. 1 (b), ω_0 is tunable through g_{m2} and/or g_{m3}, ω_0/Q_o is tunable through g_{m1} and finally, in all the five filters, H_o is tunable through g_{m4}.

(b) Realization of trans-admittance–type biquads: It is interesting to note that both the circuits of Fig. 1 can be converted into a trans-admittance type biquad filter simply by removing the OTA-2 and OTA-4 along with current source I_{in} in Fig. 1 (a) and Fig. 1 (b), respectively and applying a voltage input V_{in} at the non-inverting input terminal of dual-output OTA-1. The resulting trans-admittance-type biquads are obviously superior to the recently repotted three-Current-Conveyor-based circuit of [12] (which employs three resistors and two floating capacitors), because of complete absence of any resistors and the use of both grounded-capacitors, as preferred for IC implementation (see [14] and references cited therein).

3 CMOS implementation and SPICE simulation results

To verify the workability of the proposed circuits, we have employed the CMOS multiple-output OTA (MOTA) structure shown in Fig. 2 (a) which was biased with ±2.5 V DC power supply, with gate bias voltages for the four OTAs taken as $V_{bias1} = V_{bias2} = V_{bias3} = V_{bias4} = -1V$. The aspect

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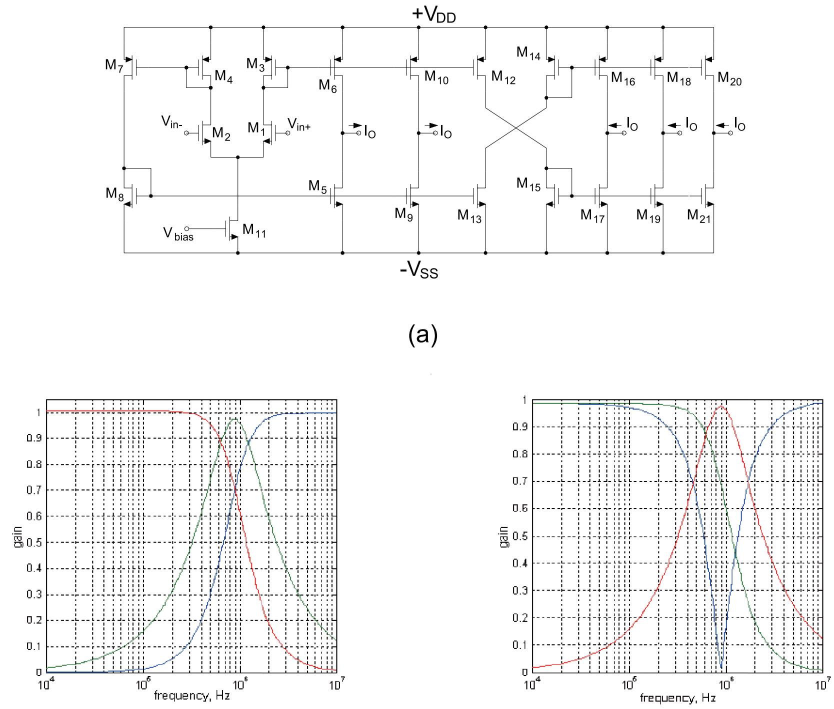

(a)

(b) (c)

Fig. 2. CMOS MOTA implementation and the SPICE simulation results
(a) CMOS MOTA implementation used in the simulations
(b) Frequency responses for the configurations of Fig. 1 (a)
(c) Frequency responses for the configurations of Fig. 1 (b)

ratios (W/L) for the various MOSFETs were taken as 10/1 for M_1, M_2; 4/1 for $M_3 - M_5$, M_8, M_9, M_{13}, M_{15}, M_{17}, M_{19}, M_{21}; 15/1 for M_{11}; 8/1 for M_6, M_7, M_{10}, M_{12}, M_{14}, M_{16}, M_{18}, M_{20}. The model parameters for 0.5 μm MIETEC CMOS process were adopted from [13]. Both the filter circuits employed $C_1 = 10\,\text{pF}$ and $C_2 = 20\,\text{pF}$ resulting in identical filter parameters as $f_0 = 0.884\,\text{MHz}$, $Q_0 = 0.707$ and $H_0 = 1$. Fig. 2 (b) shows the frequency responses of CM-based biquad of Fig. 1 (a) whereas Fig. 2 (c) shows the frequency responses of CM-based biquads derived from the circuit of Fig. 1 (b). Furthermore, the tunability properties of both the circuits have also been confirmed by SPICE simulations by changing the various trans-conductances through respective DC bias voltages. The SPICE-simulation results have been found to exhibit very close correspondence with the theoretical values which establishes the workability of the new circuits.

4 Conclusions

Two new OTA-C universal Current mode biquads have been introduced which offer all of the desirable features highlighted (in the introduction section) above *simultaneously*, without any trade-offs. With OTA-2 and OTA-4

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removed and the input-current source replaced by a voltage source, both the new circuits can also realise[2] trans-admittance type universal biquad filters. The workability of the new circuits has been established by SPICE simulation results of their CMOS-implementable versions. Because of their advantageous features, the proposed circuits appear to be eminently suitable for integrated circuit implementation in bipolar, CMOS and BiCMOS technologies.

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[2]Furthermore, it is worthwhile to point out that with one additional current output ($-I_{02}$) taken from the second OTA fedback to node P and with input current-source I_{in} removed, the circuit of Fig. 1 (b) gets converted into an electronically-controlled current-mode sinusoidal oscillator. For this oscillator, the condition of oscillation (CO) is given by $g_{m4} - g_{m2} < 0$ and frequency of oscillation (FO) is given by $\omega_o = \sqrt{\frac{g_{m2}g_{m3}}{C_1C_2}}$ and thus, both CO and FO are independently controllable through g_{m4} and g_{m3} respectively.

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