Single Active Element Based Three input Single output Trans-admittance mode Biquad Universal Filter

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Abstract— **In this paper, a new three input single output trans-admittance mode biquad universal filter is proposed, which employs only single active element, namely modified differential voltage current conveyor trans-conductance amplifier (MDVCCTA) and four passive elements in the form of two capacitors and two resistors. Two of the passive elements used in the proposed structure (one resistor and one capacitor) are permanently grounded. The proposed circuit is capable of realizing trans-admittance-mode low pass (LP), high pass (HP), band pass (BP), band reject (BR) and all pass (AP) filtering responses. The two filter parameters such as quality factor and bandwidth are electronically tunable without effecting the pole frequency. In addition, the proposed filter circuit also enjoys the low active and passive sensitivities. PSPICE simulation results using 0.35um CMOS technology are shown to prove the performances of the proposed circuit.**

Keyword- Trans-admittance-mode, analog signal processing, filter, biquad, DVCCTA.

I. INTRODUCTION

In the last few decades, the current-mode approach of signal processing in designing of analog filters has offered an elegant solution due to their high performance attributes such as wider signal bandwidth, low power consumption, larger dynamic range, better linearity, simple circuitry and requirement of lesser on chip area [1]-[2] and hence, various current-mode active elements and their applications in analog filter design in various mode are proposed in the literature [3]-[24]. Among them, trans-admittance mode filter is one which convert input voltage signal into current signal as its output and can be effectively used as an interface circuit connecting a voltage-mode circuit to a current-mode circuit and find direct applications in some sensors, the receiver base band (BB) blocks of modern radio systems and D/A converters which provide a current as output signal [12]-[13].

A variety of works on realizing trans-admittance mode universal filters classified as single input multi output (SIMO) or multi input single output (MISO) are proposed in the available literature [13]-[24]. Among them, most of the trans-admittance-mode filter configurations require two ([13]-[14], [17], [22]) or more active elements (three in case of [15]-[16], [18], four in case of [19]-[20], five in case of [21]) in realization of various filtering functions.

As far as the topic of this paper is concerned, trans-admittance-mode biquad circuits using single active element are of great interest because circuits employing minimum (single) active components are more beneficial in terms of power dissipation and manufacturing cost point of view and also satisfy the supply related specifications of portable battery operated electronic gadgets. Two of the trans-admittance-mode filter circuits employing single active element as VDTA are also found in the available literature [23]-[24]. Each of the reported circuits uses one resistor and two capacitors. One of the circuits [23] realizes only two filtering functions (HP, LP) whereas other one realizes four filtering functions (LP, BP, HP, BR) with three of the filtering outputs were obtained on passive elements [24]. Hence, number of additional current conveyor(s) will be further required to implement all the standard universal filter functions (LP, HP, BP, BR and AP).

Keeping above discussion in the mind, a filter topology based on minimum number of active element as MDVCCTA is proposed in this paper which can realize all the five standard filtering functions in trans-admittance-mode. In addition to single active element, the proposed structure also consists of four passive elements in the form of two capacitors and two resistors. Moreover, the proposed filter circuit provides the feature of electronic tunability of filter parameters and low active passive sensitivity. The rest of the paper is organized as description of active element as MDVCCTA is given in section II. The description of proposed filter circuit followed by non ideal analysis and sensitivity analysis is given in section III and IV. Simulated results are shown in section V. Finally, the paper is concluded in section VI.

II. DESCRIPTION OF MDVCCTA

Recently DVCCTA have been extensively used as current-mode active element in designing of analog circuits [7], [25]-[26]. Modified DVCCTA (MDVCCTA) is the modified version of recently proposed DVCCTA and offers the additional electronic tunability option over conventional DVCCTA. The schematic symbol of MDVCCTA is shown in Fig. 1. The input port *X* is a low impedance port and transfers the copy of its current (I_X) to two auxiliary ports Z_1 and Z_2. The input ports Y_1 and Y_2 are input high impedance ports and ideally current in these ports is equal to zero. The voltages across auxiliary ports at Z_1 and Z_2 are transferred to currents I_{O1} and I_{O2} across high impedance output ports O_1 and O_2, respectively, by trans-conductance parameter g_{m1} and g_{m2}, respectively. Both trans-conductance parameters g_{m1} and g_{m2} are electronically controlled by biasing currents I_{S1} and I_{S2} of the MDVCCTA. The ideal equations governing relationship of voltages and currents between various input-output ports of MDVCCTA as shown in Fig. 1 can be described as

$$V_X = V_{Y1} - V_{Y2} \tag{1}$$

$$I_{Z1} = I_{Z2} = I_X \tag{2}$$

$$I_{-O1} = -g_{m1} V_{Z1} \tag{3}$$

$$I_{-O2} = -g_{m2} V_{Z2} \tag{4}$$

The internal circuit of MDVCCTA, implemented with CMOS technology is shown in Fig. 2. For the CMOS realization, the value of g_{m1} and g_{m2} as a function of biasing currents I_{S1} and I_{S2}, respectively, can be derived as following equations.

$$g_{m1} = \sqrt{\beta_n I_{S1}} \text{ and } g_{m2} = \sqrt{\beta_n I_{S2}} \tag{5}$$

where

$$\beta_n = \mu_n C_{OX} \frac{W}{L} \tag{6}$$

Here, μ is the electron mobility, C_{OX} is the gate oxide capacitance per unit area and W/L is aspect ratio of NMOS transistors M_{17}-M_{18} and M_{23}-M_{24}.

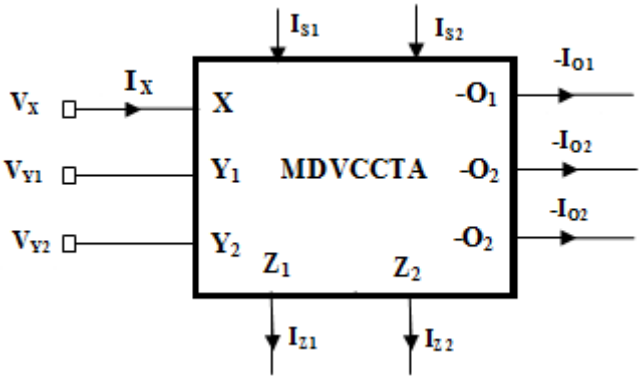


Fig. 1. Schematic symbol of DVCCTA

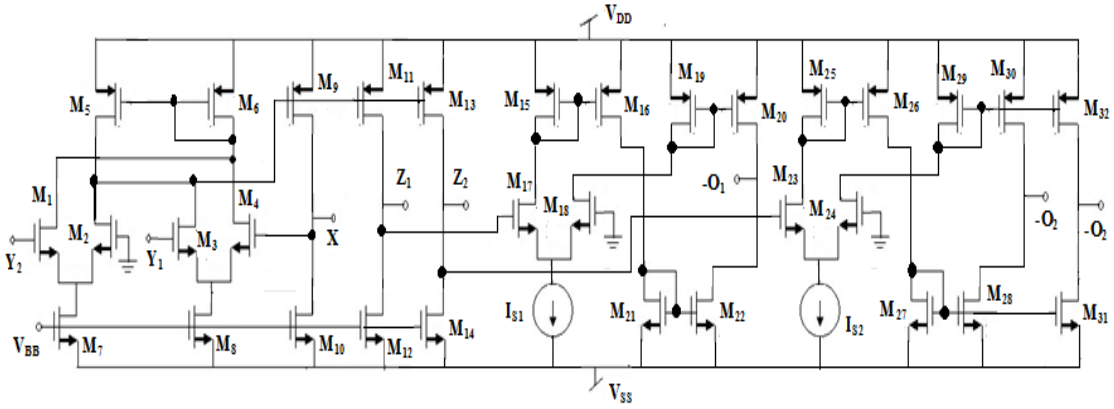


Fig.2. CMOS implementation of MDVCCTA

III. PROPOSED TRANS-ADMITTANCE MODE BIQUAD FILTER

The proposed trans-admittance biquad filter is shown in Fig.3. It consists of only single MDVCCTA, two capacitors (C_1 and C_2) and two resistors (R_1 and R_2) with one capacitor (C_1) and one resistor (R_2) are being permanently grounded. By applying V_1, V_2, and V_3 as voltage input signals to the appropriate positions in the circuit as shown in Fig. 3 and re-analysing the circuit, the following expression for the output current I_{OUT} can be obtained.

$$I_{OUT} = -g_{m2}\frac{V_3 D(s) - R_1(V_2 s^2 C_1 C_2 + V_1 s g_{m1} C_2 + V_3 s g_{m2} C_2)}{D(s)} \quad (7)$$

Where $$D(s) = s^2 C_1 C_2 R_2 + s C_2 R_1 g_{m2} + g_{m1} \quad (8)$$

It is evident from above equations that the following trans-admittance-mode filtering responses can be obtained at I_{OUT} by the appropriate selection of V_1, V_2 and V_3.

i. LP filtering response when $V_2 = V_3 = 1$, $V_1 = 0$ and $R_1 = R_2$.

ii. BP filtering response when $V_1 = 1$ and $V_2 = V_3 = 0$.

iii. HP filtering response when $V_2 = 1$ and $V_1 = V_3 = 0$.

iv. BR filtering response when $V_3 = 1$ and $V_1 = V_2 = 0$.

v. AP filtering response when $V_1 = V_3 = 1$, $V_2 = 0$ and $g_{m1} = g_{m2}$.

Thus, the proposed circuit can realize all five filtering responses in trans-admittance-mode without requiring any inverted and/or scaled type voltage input signal(s). However, LP filtering and AP filtering responses require simple matching condition which can be justified in light of single active element used in the design of proposed biquad filter.

From $D(s)$ described in equation (6), the expression of filter parameters such as pole frequency (ω_0), quality factor (Q) and bandwidth (BW) can be derived as

$$\omega_o = \sqrt{\frac{g_{m1}}{C_1 C_2 R_2}} = \sqrt{\frac{1}{C_1 C_2 R_2}\sqrt{\beta_n I_{S1}}} \quad (9)$$

$$Q = \frac{1}{R_1 g_{m2}}\sqrt{\frac{C_1 R_2 g_{m1}}{C_2}} = \frac{1}{R_1}\sqrt{\frac{C_1 R_2}{C_2 I_{S2}}}\sqrt{\frac{I_{S1}}{\beta_n}} \quad (10)$$

and $$BW = \frac{\omega_o}{Q} = \frac{g_{m2}}{C_1}\frac{R_1}{R_2} = \frac{1}{C_1}\frac{R_1}{R_2}\sqrt{\beta_n I_{S2}} \quad (11)$$

It can be noted from (9)–(11) that the Q and BW can be electronically tunable without effecting ω_0 through single biasing current I_{S2} only.

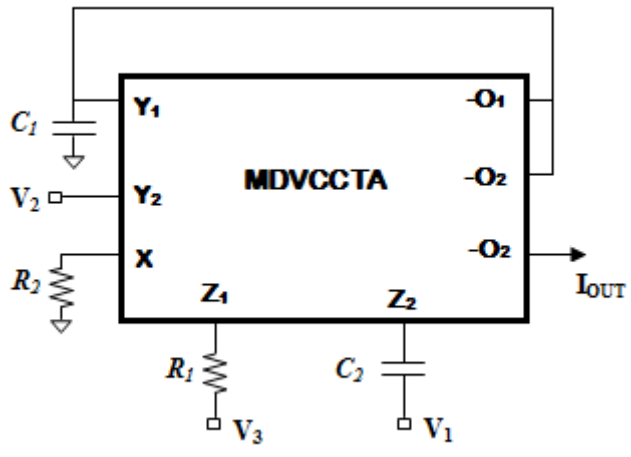


Fig. 3. Trans-admittance mode Biquad Filter

IV. NON IDEAL BEHAVIOUR AND SENSITIVITY ANALYSIS

In this section, the effect of non ideal errors on the performance of the proposed filter circuit of Fig. 3, which may occurred due to mismatching of the various MOS transistors used in CMOS implementation of MDVCCTA, is considered first.

Taking these non-ideal errors into consideration, the voltage-current port relationship of MDVCCTA will be modified as described below

$$V_X = \beta_1 V_{Y1} - \beta_2 V_{Y2} \tag{12}$$

$$I_{Z1} = \alpha_1 I_X \tag{13}$$

$$I_{Z2} = \alpha_2 I_X \tag{14}$$

$$I_{-O1} = -\gamma_1 g_{m1} V_{Z1} \tag{15}$$

$$I_{-O2} = -\gamma_2 g_{m2} V_{Z2} \tag{16}$$

Where α_1 and α_2 are the current tracking errors from X to Z_1 and Z_2, respectively. The β_1 and β_2 are the voltage tracking errors from Y_1 to X and Y_2 to X, respectively. The γ_1 and γ_2 are the trans-admittance gain tracking errors from Z_1 to O_1 and Z_2 to O_2, respectively, which may be deviated from unity. Taking above non-idealities into consideration, if we re-analysed the proposed circuit of Fig. 3, the following output equations for the I_{OUT} can be obtained.

$$I_{OUT} = -\gamma_2 g_{m2} \frac{V_3 D(s) - R_1 \alpha_2 (V_2 s^2 \beta_2 C_1 C_2 + V_1 s \beta_1 \alpha_1 g_{m1} C_2 + V_3 s \beta_1 \gamma_2 g_{m2} C_2)}{D(s)} \tag{17}$$

where $$D(s) = s^2 C_1 C_2 R_2 + s\alpha_2 \beta_1 \gamma_2 C_2 R_1 g_{m2} + \alpha_1 \beta_1 \gamma_1 g_{m1} \tag{18}$$

The filters parameters of the circuit after considering tracking errors at various ports will be changed to

$$\omega_o = \sqrt{\frac{\alpha_1 \beta_1 \gamma_1 g_{m1}}{C_1 C_2 R_2}} \tag{19}$$

$$Q = \frac{1}{\alpha_2 \gamma_2 R_1 g_{m2}} \sqrt{\frac{\alpha_1 \gamma_1 C_1 R_2 g_{m1}}{\beta_1 C_2}} \tag{20}$$

It is clear from (19)-(20) that ω_0 and Q of the proposed filter of Fig. 3 will be deviated from the ideal case, due to the appearance of non-idealties. However, these deviations are very slight and can be neglected because non ideal parameters α_1, α_2, β_1, β_2, γ_1 and γ_2 can be found closed to unity at working frequency.

The sensitivities of the proposed circuit's pole frequency and quality factor with respect to various non ideal errors, active and passive components are determined as

$$S^{\omega_o}_{\alpha_1,\beta_1,\gamma_1,g_{m1}} = \frac{1}{2}, S^{\omega_o}_{C_1,C_2,R_2} = -\frac{1}{2}, S^{\omega_o}_{\alpha_2,\beta_2,\gamma_2,R_1} = 0 \tag{21}$$

$$S^{Q}_{C_2,\beta_1} = -\frac{1}{2}, S^{Q}_{C_1,\alpha_1,\gamma_1,R_2,g_{m1}} = \frac{1}{2}, S^{Q}_{\alpha_2,\gamma_2,R_1,g_{m2}} = -1 \tag{22}$$

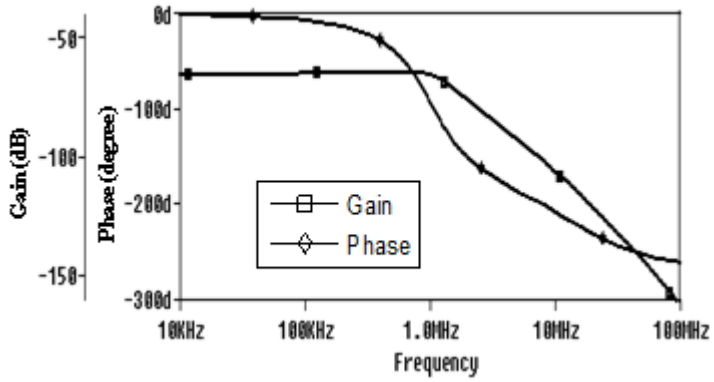
Evaluation of circuit in (21)-(22) for sensitivity shows that ω_0 and Q are less sensitive to non ideal errors, active and passive components and for them sensitivity value is less than or equal to unity in magnitude.

V. SIMULATION RESULTS

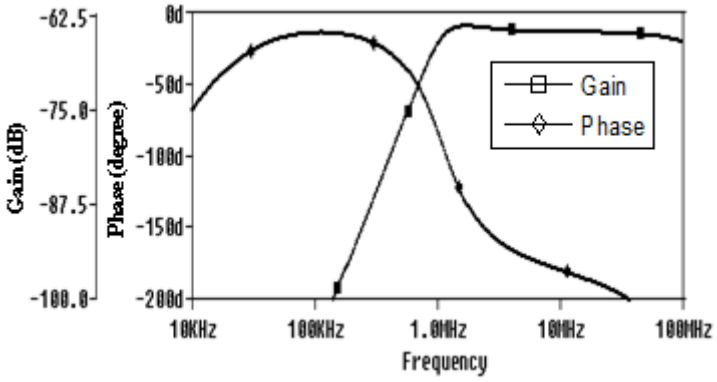
To verify the theoretical analysis of the proposed filter done in section II, PSPICE simulation on ORCAD tool was carried out. For this purpose, the circuit was designed by selecting the value of various active and passive elements as V_{DD}= -V_{SS}=1.85V, V_{BB}=−0.85V, I_{S1}=I_{S2}=110µA, C_1= C_2=80pF, R_1=R_2=2KΩ and simulated was performed based on CMOS structure of MDVCCTA as shown in Fig. 2, with transistor model of 0.35µm MOSFET from TSMC. Aspect ratio of each MOS transistors of MDVCCTA used for simulation is given in Table 1. Fig. 4 and Fig. 5 shows the simulation results in term of magnitude and phase response of LP, BP, HP, BR and AP for the proposed trans-admittance-mode filter of Fig. 3. From the simulation results shown in Fig. 4 and Fig. 5, the pole frequency was obtained as 1.0965 MHz which is very much closed to designed pole

frequency of 1.07 MHz. The power dissipation of the proposed circuit is 2.65 mW. In order to show the electronic tuning feature of Q independent of pole frequency for the proposed filter, the circuit was further simulated to obtain various BP responses at different value of I_{S2} and corresponding simulation results was shown in Fig. 6. From the Fig. 6, Q value was found (at constant pole frequency of 1.0965 MHz.) as 2.1, 1.08, 0.768 and 0.56, respectively, at different values of I_{S2} = 20µA, 80µA, 160µA and 300µA, respectively, which proves the electronic tunable capability of the proposed circuit.

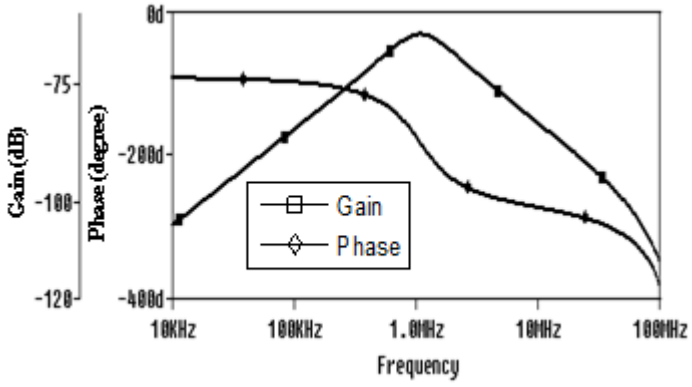
To examine the total harmonic distortion (THD) produce by the circuit, the circuit was again simulated for THD analysis at HP, by applying sinusoidal input voltage of varying amplitude and constant frequency. The THD values at frequency of 10 MHz are shown in Fig. 7 which clearly shows that for the input voltage signal having amplitude less than 160 mV, the THD remains in acceptable limits *i.e.* 3%. Lastly, the time domain behavior of HP response with respect to sinusoidal input voltage is shown in Fig. 8. It is clear from the simulations that 100 mV peak-to-peak sinusoidal input voltages are possible without significant distortions.



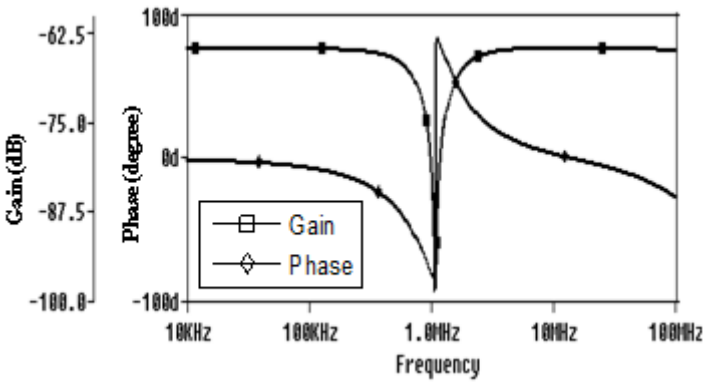
(a)



(b)



(c)



(d)

Fig .4 .Simulated gain and phase response of the proposed trans-admittance mode biquad filter : (a) LP, (b) HP, (c) BP (d) BR

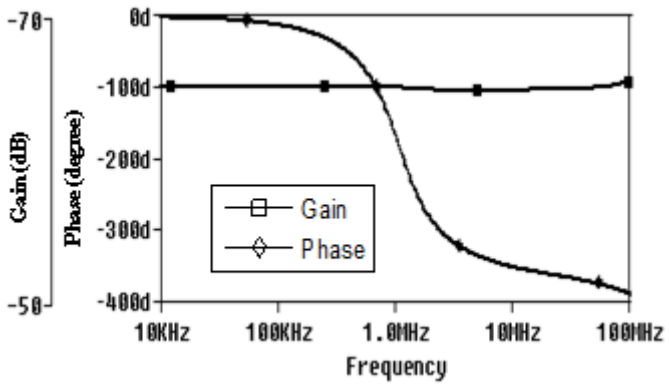


Fig. 5. Simulated gain and phase response of the proposed trans-admittance mode AP biquad filter.

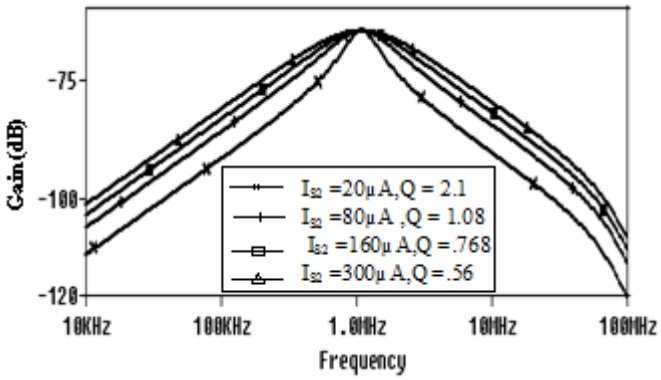


Fig.6. Band pass responses for different values of I_{s2}.

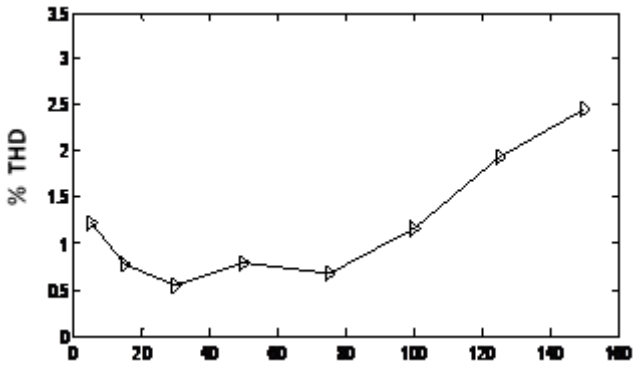


Fig. 7. Variation in THD of HP for input signal of frequency 10MHz.

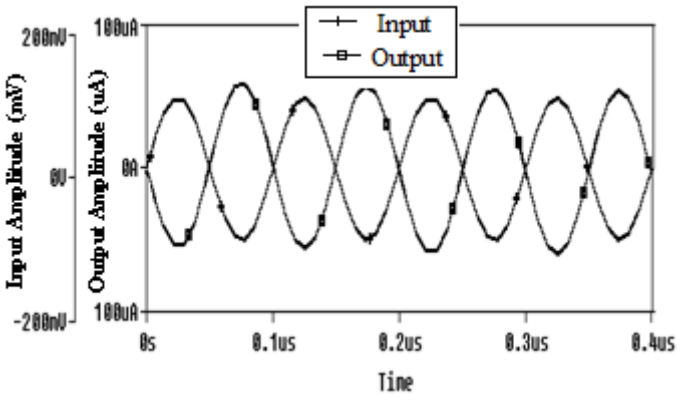


Fig.8. The time domain sinusoidal input waveform and corresponding response at HP output of Fig.3.

TABLE II. TRANSISTOR TYPE AND ASPECT RATIOS

Transistor Type	Transistor Number	Aspect ratio (W(μm)/L(μm))
nMOS	M1-M4, M7-M8,M10, M12, M14	5/1
	M17-M18, M21-M24, M27-M28, M31	20/1
pMOS	M5, M6, M9,M11, M13,M15- M16,M19-M20,M25- M26, M29-M30, M32	10/1

VI. CONCLUSION

A new three input single output trans-admittance mode biquad universal filter based on only single active element namely MDVCCTA is proposed in this work. It also uses two capacitors and two resistors as passive element with two of the passive elements (one capacitor and one resistor) are permanently grounded. In addition, the proposed circuit offers the following attractive features.

i. Capable of realizing LP, BP, HP, BR, AP filtering responses in trans-admittance-mode.
ii. The circuit is canonical by the way of using only two capacitors.
iii. The circuit does not require any scaled or inverted type voltage signal to realize any filtering response which makes the circuit simpler.
iv. The circuit provide the feature of electronic control of Q and BW independent of ω_0 through single biasing current and hence suited for practical applications.
v. Active and passive components sensitivity is low.
vi. Minimum number of active element.
vii. Low power consumptions.

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