# Current-Mode Active-C Biquad Filter Using Single MO-CCCFTA

R. S. Tomar[1], C. Chauhan[2], S. V. Singh[3] and D. S. Chauhan[4]

*Abstract*— **This paper presents a new current-mode active-C biquad filter employing single multi-output current controlled current follower trans-conductance amplifier (MO-CCCFTA). The proposed filter employs only two grounded capacitors. The proposed filter can simultaneously realize low pass (LP), band pass (BP) and high pass (HP) responses in current form by choosing appropriate current output branches. In addition, the pole frequency of proposed current-mode filter circuit can be tuned electronically and independent of quality factor, by simultaneous adjusting the external bias currents. The circuit possesses low sensitivity performance and low power consumptions. The validity of proposed filter is verified through PSPICE simulations.**

***Keywords*— CCCFTA, current-mode, biquad, active-C**

## Introduction

The current-mode filters, where information is represented by the branch currents of the circuits, are receiving significant attention owing to their large dynamic range, larger bandwidth, greater linearity, simple circuitry, low power consumption and less chip area over their voltage-mode counter parts, where information is represented by nodal voltage of the circuits[1-2]. They can be classified as single-input multiple-output (SIMO) or multiple-input single-output (MISO). There has been a great attention on the design and study of current-mode SIMO filter due to simultaneous realization of multi-function filtering outputs, without changing the connection of the input current signal and without current signal matching. During the last one decade and recent past a number of universal current-mode SIMO active filters have been reported in the literature [3-20], using different electronically tunable current-mode active elements such as current controlled current conveyor (CCCII) [3-6], operational transconductance amplifier (OTA)[7], current differencing transconductance amplifier (CDTA)[8,9,15,17,18], current follower transconductance amplifier (CFTA)[10-12], current conveyor transconductance amplifier (CCTA) [16], current controlled current conveyor transconductance amplifier (CCCCTA) [13-14 ], VDTA [19] and current controlled current follower transconductance amplifier (CCCFTA) [20]. The current-mode filters reported in Refs. [3-14] realize multi-filtering functions but they require excessive number of active elements (more than two). On the other hand, the active filter employing low active components is more beneficial from fabrication point of view. Moreover, it can also reduce the power consumption and the area of chip when it builds in the form as ICs. So several current-mode filters using single active element (minimum number of active element) have been proposed in the literature [15-20]. The filter circuits reported in Refs. [15-19] consists of at least three passive elements (two grounded capacitors and one or two resistors) and realize two or three filtering functions simultaneously. However, all the reported filter circuits [15-20] based on single active element provide only one filtering function in the form of explicit current output. Explicit current outputs are necessary for the cascading of current-mode filter. The current-mode filter circuit reported in ref. [20] uses single CCCFTA, two grounded capacitors and realizes three filtering functions (LP, BP, HP). However, it provides two current-mode filtering functions (BP, HP) through passive elements (capacitors).

In this paper, a new current-mode tunable biquad filter based on single MO-CCCFTA is proposed. The proposed filter employs only two grounded capacitors as passive elements. The proposed filter can simultaneously realize LP, BP and HP responses in current form in which two of the outputs (LP, BP) are explicitly available. The circuit possesses low sensitivity performance and low power consumptions. The validity of proposed filter is verified through PSPICE, industry standard tool.

## MO-CCCFTA and Proposed Current-Mode Active-C Filter

CCCFTA is relatively new proposed current mode active building block [20-21] which is the modified version of CFTA. The properties of ideal MO-CCCFTA can be characterized by the following set of equations

$$V_f = i_f R_f,\ I_{\pm Z} = \pm I_f,\ I_{\pm X} = \pm g_m V_Z \quad (1)$$

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where $g_m$ and $R_f$ are trans-conductance and input parasitic resistance of the MO-CCCFTA, respectively. The $g_m$ and $R_f$ depend upon the biasing currents $I_S$ and $I_B$ of the MO-CCCFTA, respectively. The schematic symbol of MO-CCCFTA is illustrated in Fig 1. For MOS model of CCCFTA [21], $R_f$ and $g_m$ can be expressed as

$$R_f = \frac{1}{\sqrt{8\beta_n I_B}} \quad \text{and} \quad g_m = \sqrt{\beta_n I_S} \tag{2}$$

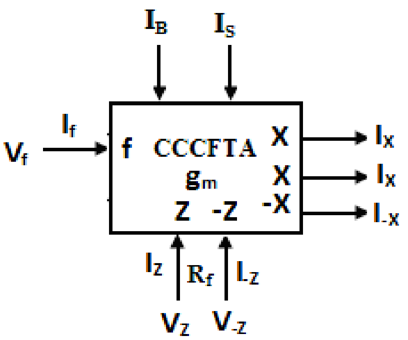



Fig. 1. MO-CCCFTA Symbol

Where $\beta_n$ is given by

$$\beta_n = \mu_n C_{OX}\left(\frac{W}{L}\right) \tag{3}$$

where $\mu_n$, $C_{OX}$ and W/L are the electron mobility, gate oxide capacitance per unit area and transistor aspect ratio of NMOS, respectively. The proposed current-mode biquad filter with single input and three outputs is shown in Fig. 2. It is based on only single MO-CCCFTA and two grounded capacitors. Routine analysis of the proposed circuit yields the following current transfer functions.

$$\frac{I_{LP}}{I_{in}} = \frac{g_m}{R_f C_1 C_2 s^2 + R_f g_m C_1 s + g_m} \tag{4}$$

$$\frac{I_{BP}}{I_{in}} = \frac{-R_f g_m C_1 s}{R_f C_1 C_2 s^2 + R_f g_m C_1 s + g_m} \tag{5}$$

$$\frac{I_{HP}}{I_{in}} = \frac{R_f C_1 C_2 s^2}{R_f C_1 C_2 s^2 + R_f g_m C_1 s + g_m} \tag{6}$$

It is clear from (4) – (6) that the proposed current-mode filter can realize LP, BP and HP responses. The pole frequency ($\omega_0$) and quality factor (Q) of the proposed circuit is given by

$$\omega_O = \sqrt{\frac{g_m}{R_f C_1 C_2}} = \sqrt{\frac{\beta_n (8 I_B I_S)^{\frac{1}{2}}}{C_1 C_2}} \tag{7}$$

$$Q = \sqrt{\frac{C_2}{R_f g_m C_1}} = \sqrt{\left(\frac{8 I_B}{I_S}\right)^{\frac{1}{2}} \frac{C_2}{C_1}} \tag{8}$$

From (7) and (8), it can be remarked that the $\omega_o$ can be electronically controlled without affecting Q, by simultaneously variations of biasing currents $I_B$ and $I_S$. The active and passive sensitivities of the proposed circuit as shown in Fig. 2, can be found as

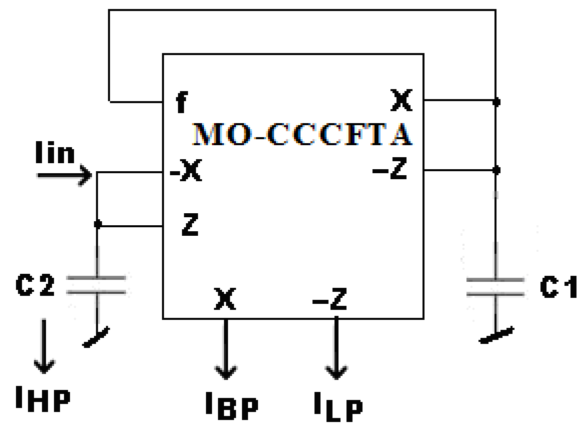



Fig. 2. Proposed MO-CCCFTA based current-mode biquad filter

$$S^{\omega_0}_{C_1,C_2} = -\frac{1}{2},\ S^{\omega_0}_{I_B,I_S} = \frac{1}{4},\ S^{\omega_0}_{\beta_n} = \frac{1}{2} \tag{9}$$

$$S^{Q}_{C_1} = -\frac{1}{2}, S^{Q}_{I_S} = -\frac{1}{4}, S^{Q}_{C_2} = \frac{1}{2}, S^{Q}_{I_B} = \frac{1}{4} \tag{10}$$

From the above results, it can be observed that all the active and passive sensitivities are low by being within half in magnitude.

## Simulation Results

The PSPICE simulations are carried out to demonstrate the feasibility of the proposed circuit using CMOS implementation as shown in Fig. 3. The simulations use a 0.35µm MOSFET from TSMC whose model parameters are given in Table 1. The dimensions of PMOS are determined as W=3µm and L=2µm. In NMOS transistors, the dimensions are W=3µm and L=4µm. The circuit is designed for Q=0.91 and $f_o=\omega_o/2\pi$=1.05 MHz. The active and passive components are chosen as $I_B$=4µA, $I_S$=46.5µA $V_{DD}$ = $-V_{SS}$= 1.5V and $C_1=C_2$=10pF. Fig.4 shows the simulated current gain responses of the LP, BP and HP of the proposed filter. Fig. 5 shows the magnitude as well as phase responses of BP, LP and HP filtering functions. The simulation results show the simulated pole frequency as 1.01 MHz that is ~4% in error with the theoretical value. The power dissipations of the proposed circuit for the design values is found as 0.66 mW that is a low value.

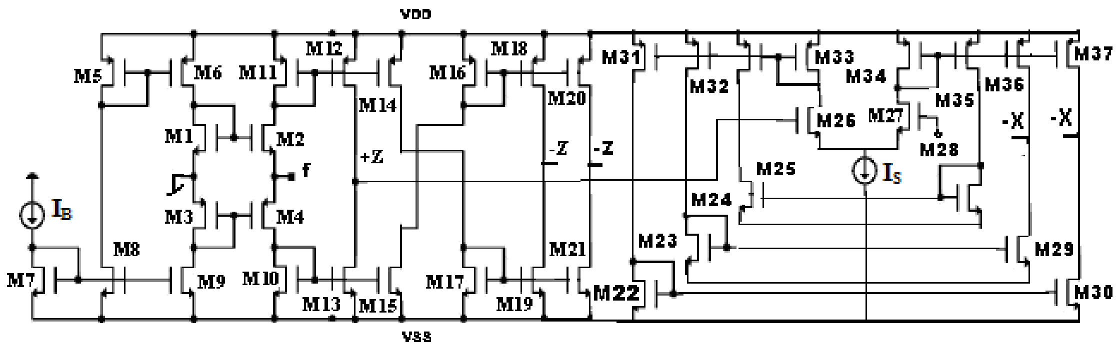



Fig. 3. CMOS Implementation of MO-CCCFTA

Table 1. The SPICE model parameters of MOSFET for level 3, 0.35 µm CMOS process from TSMC

| | |
|---|---|
| NMOS | LEVEL=3 TOX=7.9E-9 NSUB=1E17 GAMMA=0.5827871 PHI=0.7 VTO=0.5445549 DELTA=0 UO=436.256147 ETA=0 THETA=0.1749684 KP=2.055786E-4 VMAX=8.309444E4 KAPPA=0.2574081 RSH=0.0559398 NFS=1E12 TPG=1 XJ=3E-7 LD=3.162278E-11 WD=7.046724E-8 CGDO=2.82E-10 CGSO=2.82E-10 CGBO=1E-10 CJ=1E-3 PB=0.9758533 MJ=0.3448504 CJSW=3.777852E-10 MJSW=0.3508721 |
| PMOS | LEVEL=3 TOX=7.9E-9 NSUB=1E17 GAMMA=0.4083894 PHI=0.7 VTO=-0.7140674 DELTA=0 UO=212.2319801 ETA=9.999762E-4 THETA=0.2020774 KP=6.733755E-5 VMAX=1.181551E5 KAPPA=1.5 RSH=30.0712458 NFS=1E12 TPG=-1 XJ=2E-7 LD=5.000001E-13 WD=1.249872E-7 CGDO=3.09E-10 CGSO=3.09E-10 CGBO=1E-10 CJ=1.419508E-3 PB=0.8152753 MJ=0.5 CJSW=4.813504E-10 MJSW=0.5 |

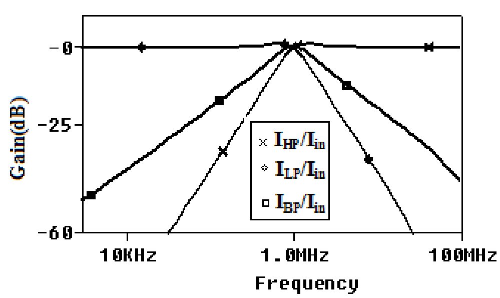
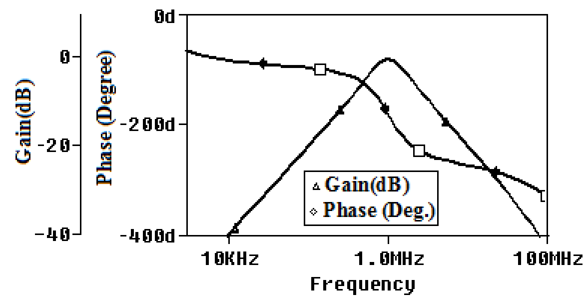
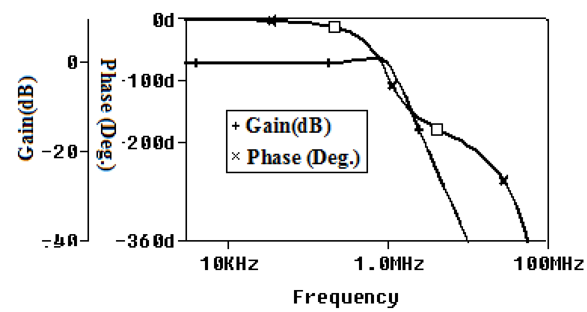



Fig. 4. Gain responses for LP, BP and HP for the proposed current-mode filter

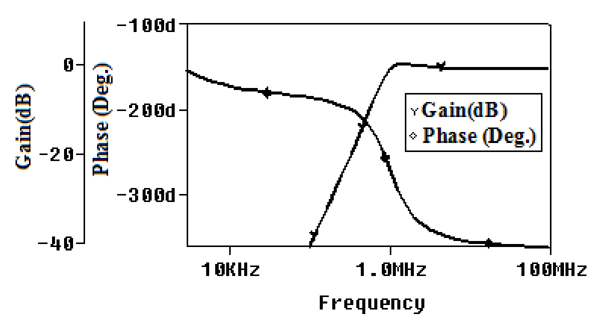
Further simulations are carried out to verify the total harmonic distortion (THD). The circuit is verified by applying a sinusoidal input ($I_{in}$) of varying frequency and amplitude of 25 µA. The THD measured at the LP output are found to be less than 3% while frequency is varied from 50 KHz to 600 KHz. The time domain behavior of the proposed current-mode filter is also investigated by applying a 500 KHz sinusoidal input current signal with peak to peak amplitude of 40 µA. Fig. 6 shows the time domain sinusoidal current input and corresponding LP output waveform for the proposed filter. Thus, both THD analysis and time domain response of LP output confirm the practical utility of the proposed circuit.




(a)




(b)




(c)

Fig. 5. Gain and phase responses for (a) BP, (b) LP and (c) HP for the proposed current-mode filter

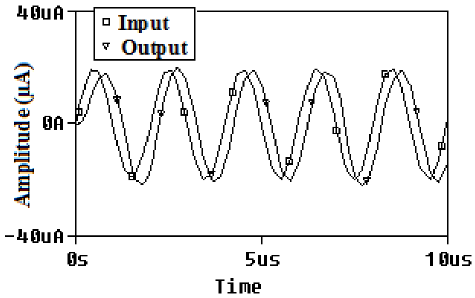



Fig. 6. The time domain sinusoidal current input and corresponding current-mode LP output

# IV. Conclusion

In this paper, a new current-mode biquad filter with single input and three outputs using only single MO-CCCFTA and two grounded capacitors has been presented. The proposed current-mode filter can realize LP, BP and HP responses. In additions, it also offers several advantages, such as current controlled of $\omega_0$ independent of Q through bias currents, the use of the grounded capacitors, low power consumptions, low active and passive sensitivities.

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