# Insensitive High-Output Impedance Current-Mode Biquad with a Single Current Follower Transconductance Amplifier

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***Abstract*—The circuit configuration for realizing a canonical current-mode biquad filter with three inputs and one output is introduced. The introduced filter employs a single current follower transconductance amplifier (CFTA) and a minimum of passive components, i.e., one resistor and two grounded capacitors. It is capable of generating all the five standard biquadratic filtering functions and suitable for current-mode cascading by possessing high-output impedance. Also, the proposed filter can be tuned electronically by an external bias current of the CFTA. The circuit is analyzed for the non-idealities of the used CFTA and possesses attractive low sensitivity performance. PSPICE simulation results are found to be in good agreement with the presented theory.**

***Keywords*— current follower transconductance amplifier (CFTA); biquad filter, current-mode circuit; high-output impedance; electronically tunable.**

## I. Introduction

Recently, the relatively new active device so-called current differencing transconductance amplifier (CDTA) was introduced in 2003 [1]. This device is emerging as a flexible and versatile active building block for the synthesis of analog signal processing circuits, especially in current-mode operation. Accordingly, many different applications based on CDTAs as the major active elements have already been reported in the technical literature, particularly in the areas of active filters and oscillators [1]-[12]. However, the earlier configurations reported in [5]-[8] do not exploit the full capacity of the used CDTAs, since one of the input terminals (p or n terminals) of the CDTA is not used. This may cause some noise injection into the monolithic circuit [13]. Moreover, most of them also involve more than one CDTA [1]-[6]. From the point of view of the low power consumption and manufacturing cost, it is important in circuit design to keep the number of active component at minimum. A careful survey of the available technical literature reveals that a few current-mode filters using single CDTA have been reported in [7]-[12]. However, these solutions suffer from the disadvantage features of either inability to provide high-output impedance terminals [7]-[11] or inability to realize all the five standard types of filtering functions from the same configuration [8]-[9], [11]-[12].

More recently, the newly introduced active device named current follower transconductance amplifier (CFTA) has been reported as the slight modification of the original CDTA [14]. This device can be thought of as a combination of the current follower and the multi-output operational transconductance amplifier. Its behavior is quite similar to the CDTA element, in which the current follower is used instead of the current differencing unit at the front-end. Although, the current-mode biquad filter using single CFTA has been recently reported in [15], it is not in high output impedance.

In this study, a high-output impedance current-mode biquadratic filter with three inputs and one output is presented. The presented circuit is constructed with a single CFTA, one resistor and two grounded capacitors, which is canonical structure [16]. By selecting the appropriate input current terminals, the circuit can realize all the standard types of universal filter functions, i.e. lowpass (LP), bandpass (BP), highpass (HP), bandstop (BS) and allpass (AP). It also permits orthogonal electronic adjustment of the natural angular frequency ($\omega_o$) and the bandwidth (BW) with externally applied bias current of the CFTA. The presented filter is a cascadable circuit due to its high-output impedance characteristic. Non-ideal analyses along with performance verifications by PSPICE simulations are given.

## II. Description of the CFTA

An electrical symbol of the CFTA is shown in Fig.1. Assuming the standard notation, the terminal defining relations of the CFTA device can be characterized by the following set of equations .

$$v_f = 0 \;,\; i_z = i_f \quad \text{and} \quad i_x = g_m v_z = g_m Z_z i_z \qquad (1)$$

where $g_m$ is the transconductance gain of the CFTA and $Z_z$ is an external impedance connected to the z-terminal. The CFTA consists essentially of the current follower at the input part and the multi-output transcondcutance amplifier at the output part. According to equation (1), the f-terminal forms the current input terminal at ground potential ($v_f$ = 0) and the output current at the z-terminal ($i_z$) follows the

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current ($i_f$) through the f-terminal. The voltage drop at the z-terminal ($v_z$) is then converted to a current at the x-terminal ($i_x$) by a $g_m$-parameter. In general, the $g_m$-value is adjustable over several decades by a supplied bias current/voltage, which lends electronic controllability to design circuit parameters.

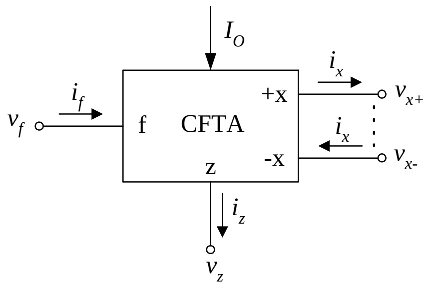


Fig.1 Electrical symbol of the CFTA.

## III. Proposed Single CFTA-based Current-Mode Biquad Filter

Fig.2 shows the proposed electronically tunable current-mode universal biquad filter. The circuit contains only one CFTA, one resistor and two grounded capacitors, thus it is canonical in the number of active and passive components. Routine circuit analysis using defined relation in equation (1) shows that the proposed circuit in Fig.2 has the following output current :

$$I_{out} = \frac{D(s)I_1 + (1+sR_1C_2)I_2 + I_3}{D(s)} \ , \quad (2)$$

where $$D(s) = \left(\frac{R_1C_1C_2}{g_m}\right)s^2 + \left(\frac{C_1+C_2}{g_m}\right)s + 1 \ . \quad (3)$$

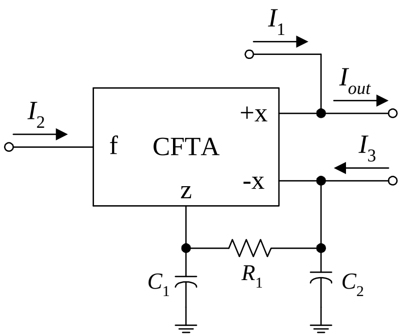


Fig.2 Proposed current-mode biquad filter with three inputs and single output using single CFTA.

The above expressions clearly indicate that the proposed filter can be used as a three-input single-output current-mode universal filter with the following specializations.

(1) The LP function is realized with $I_1 = I_2 = 0$ and $I_3 = I_{in}$ (an input current signal).

(2) The BP function is realized with $I_1 = 0$, $I_2 = -I_3 = I_{in}$ and $g_mR_1 = (C_1+C_2)/C_2$.

(3) The HP function is realized with $I_3 = 0$, $I_1 = -I_2 = I_{in}$ and $g_mR_1 = (C_1+C_2)/C_2$.

(4) The BS function is realized with $I_1 = -I_2 = I_3 = I_{in}$ and $g_mR_1 = (C_1+C_2)/C_2$.

(5) The AP function is realized with $I_1 = -I_2 = I_3 = I_{in}$ and $g_mR_1 = 2(C_1+C_2)/C_2$.

Obviously, the proposed filter can realize all five standard generic filtering functions with suitable choice of the input currents. In addition to the circuit configuration, the output current is directly taken from the x-terminal of the CFTA. Thus, the circuit possesses the feature of high-output impedance, which enables easy to cascade for current-mode system.

In all cases, the natural angular frequency ($\omega_o$) and bandwidth ($BW$) of the proposed filter are found as :

$$\omega_o = \sqrt{\frac{g_m}{R_1C_1C_2}} \ , \quad (4)$$

and $$BW = \frac{C_1+C_2}{R_1C_1C_2} \ . \quad (5)$$

From equations (4) and (5), it can be observed that the resultant frequency filter provides the possibility of electronic tuning the characteristic frequency $\omega_o$ by the value of transconductance $g_m$, independently of the parameter BW.

## IV. Non-Ideal Analysis and Sensitivity Performance

In this section, the effect of the non-idealities of the CFTA on the filter performance is discussed. In case of the non-ideal characteristic condition, the port relations of the CFTA given in equation (1) can be rewritten as :

$$v_f = 0 \ , \ i_z = \alpha i_f \ \text{ and } \ i_x = \beta g_m Z_z i_z \quad (6)$$

where $\alpha$ = 1- $\varepsilon_i$ and $\varepsilon_i$ ($|\varepsilon_i| << 1$) is the current tracking error from f to z terminals, and $\beta$ is the transconductance inaccuracy factor from z to x terminals. Therefore, taking the non-idealities of the CFTA into account, the modified parameters $\omega_o$ and BW of the proposed filter given in Fig.2 become :

$$\omega_o = \sqrt{\frac{\beta g_m}{R_1C_1C_2}} \ , \quad (7)$$

and $$BW = \frac{C_1+C_2}{R_1C_1C_2} \ . \quad (8)$$

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It can be seen from equations (7) and (8) that the $\omega_o$- and *BW*-parameters of the proposed filter are not influenced by the current tracking error $\alpha$ of the CFTA. The transconductance inaccuracy factor $\beta$ has only effect on the $\omega_o$-value and has no effect on the *BW*-value of the filter characteristic. However, in this case, it should not be seen as a drawback, as the small deviation in the $\omega_o$-value of equation (7) compared to equation (4) can be compensated by re-tuning the value of $g_m$ properly.

Active and passive sensitivities of the parameters $\omega_o$ and *BW* are calculated for the proposed filter as below :

$$S_{\beta}^{\omega_o} = S_{g_m}^{\omega_o} = \frac{1}{2} \quad , \quad S_{R_1}^{\omega_o} = S_{C_1}^{\omega_o} = S_{C_2}^{\omega_o} = -\frac{1}{2} \quad , \tag{9}$$

$$S_{\alpha}^{\omega_o} = 0 \quad , \tag{10}$$

$$S_{\alpha}^{BW} = S_{\beta}^{BW} = 0 \quad , \tag{11}$$

$$S_{R_1}^{BW} = -1 \quad , \tag{12}$$

and

$$S_{C_1}^{BW} = -\frac{C_2}{C_1 + C_2} \quad , \quad S_{C_2}^{BW} = -\frac{C_1}{C_1 + C_2} \quad . \tag{13}$$

Sensitivity analyses show that all magnitudes of $\omega_o$ and *BW* sensitivities are found to be not more than unity. This also indicates that the parameter *BW* is practically insensitive to the non-ideal factors $\alpha$ and $\beta$ of the CFTA, while the parameter $\omega_o$ is independent on $\alpha$.

## V. Simulation Results and Discussion

To verify the theoretical analysis, the proposed circuit given in Fig.2 has been simulated with PSPICE simulation program. To implement the CFTA active device in simulations, the bipolar technology structure depicted in Fig.3 has been used [2]-[4]. The PNP and NPN transistors in CFTA implementation were simulated using the typical parameters of bipolar transistor model PR100N (PNP) and NP100N (NPN) [17]. The DC supply voltages and bias currents were respectively selected as : +V = -V = 3V and $I_B$ = 100 $\mu$A. In this case, the transconductance gain $g_m$ of the CFTA is directly proportional to the external bias current $I_O$, which is approximately equal to :

$$g_m = \frac{I_O}{2V_T} \quad , \tag{14}$$

and $V_T \cong 26$ mV at 27°C.

The circuit of Fig.2 was designed to obtain the filter responses with a natural angular frequency of $f_o = \omega_o/2\pi \cong$ 1.12 MHz and a quality factor of $Q = \omega_o/BW = 1$. To achieve this, the tuning bias current and the passive components were selected as: $g_m$ = 2 mA/V (i.e., $I_O \cong 104$ $\mu$A), $R_1$ = 1 kΩ and $C_1 = C_2$ = 0.2 nF. Fig.4 displays the simulation results for LP, BP and HP current responses of the proposed filter in Fig.2. In a similar way, the corresponding results showing a comparison between ideal and simulated frequency characteristics for BS and AP filter responses are also displayed in Figs.5 and 6, respectively. As are shown, one can see that the simulation results are in good agreement with the theory presented, and they confirm the workability of the proposed configuration.

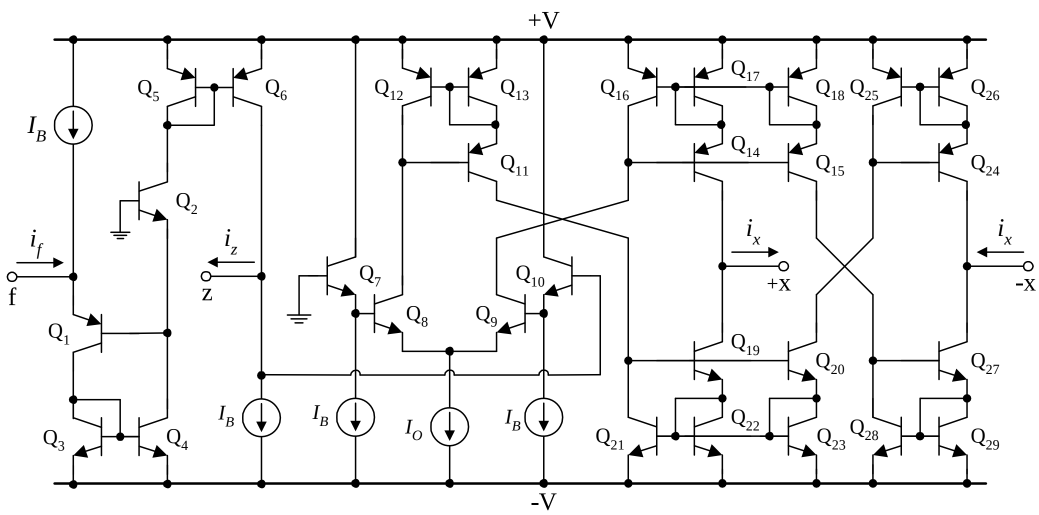


Fig.3 Bipolar implementation of the CFTA.

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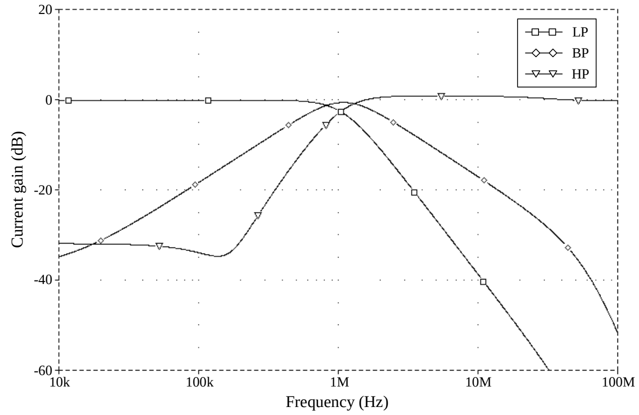


Fig.4 Simulation results for the LP, BP and HP current responses of the proposed filter in Fig.2.

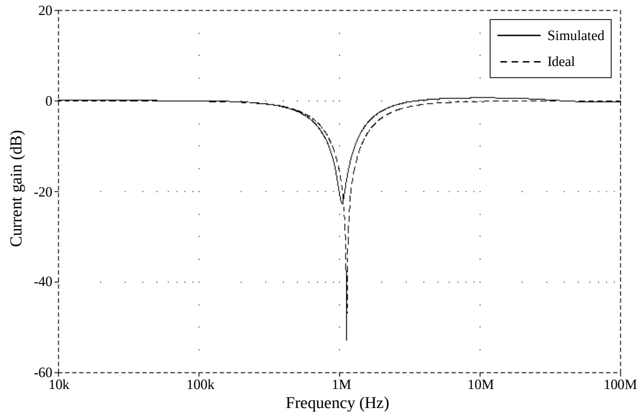


Fig.5 Ideal and simulated frequency characteristics for the BP response of the proposed filter in Fig.2.

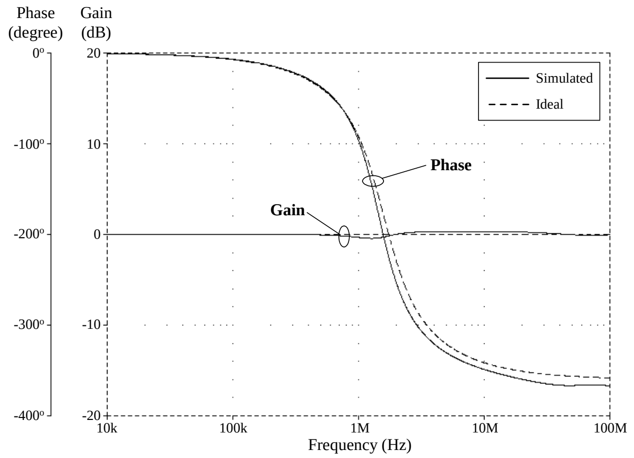


Fig.6 Magnitude and phase frequency responses for the AP filter.

## VI. CONCLUSIONS

In this work, an electronically tunable current-mode universal biquad filter with three inputs and single output employing only one CFTA and one resistor and two grounded capacitors is proposed. The proposed circuit can generate LP, BP, HP, BS and AP current responses all at the high-output impedance terminal. The important filter characteristics $\omega_o$ and BW can be tuned electronically and orthogonally by an external controlled current of the CFTA. The proposed circuit is canonical, insensitive to the current tracking error of the CFTA, and exhibits low active and passive sensitivities.

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