Three-Input Single-Output Current-Mode Biquadratic Filter with High-Output Impedance Using 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 single 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.**

***Index Terms*— current follower transconductance amplifier (CFTA); current-mode circuit; biquadratic filter; high-output impedance; electronically tunable.**

I. Introduction

In 2003, the newly defined active device so-called current differencing transconductance amplifier (CDTA) was first introduced [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, a number of various applications based on CDTAs as the major active elements has 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. In the literature, a number of CFTA-based current-mode active filters has been developed [15]-[20]. Although, the current-mode biquad filter using single CFTA has been recently reported in [20], it is not in high output impedance.

In this study, a high-output impedance current-mode biquadratic filter with three inputs and single output (TISO) is presented. The presented circuit is constructed with a single CFTA, one resistor and two grounded capacitors, which is canonical structure [21]. 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 (ω_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. CFTA Operation and Realization

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 .

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

In above equations, the parameter g_m refers to the transconductance gain of the CFTA and Z_z is an external

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impedance connected to the terminal z. 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 terminal f forms the current input terminal at ground potential (v_f = 0) and the output current at the terminal z (i_z) follows the current (i_f) through the terminal f. The voltage drop at the terminal z (v_z) is then converted to a current at the terminal x (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.

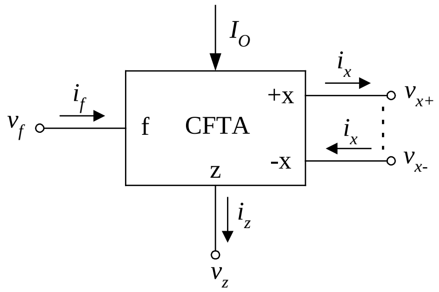

Fig. 1. Circuit representation of the CFTA.

Fig.2 shows the schematic bipolar realization of the CFTA [17], which mainly consists of the current follower circuit (transistors Q_1-Q_6, and bias current sources I_B) followed by the dual-output transconductance amplifier (Q_7-Q_{29}, and external bias current source I_O). In this realization, the effective small-signal transconductance (g_m) can be derived as :

$$g_m = \frac{I_O}{2V_T} \tag{2}$$

where $V_T \cong$ 26 mV at 27°C is the thermal voltage. It may be easily visualized that the g_m-value is tunable linearly and electronically by an external DC bias current I_O.

III. Proposed Single CFTA-Based TISO Current-Mode Biquadratic Filter

Fig.3 shows the proposed current-mode universal biquadratic filter. The circuit is canonical in the number of active and passive components, since it employs only one CFTA, one resistor and two grounded capacitors. Routine circuit analysis using defined relation in equation (1) shows that the proposed circuit in Fig.3 has the following output current :

$$I_{out} = \frac{D(s)I_1 + (1 + sR_1C_2)I_2 + I_3}{D(s)} \tag{3}$$

where

$$D(s) = \left(\frac{R_1C_1C_2}{g_m}\right)s^2 + \left(\frac{C_1 + C_2}{g_m}\right)s + 1 \ . \tag{4}$$

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 filtering function can be obtained with $I_1 = I_2 = 0$ and $I_{in} = I_3$ (an input current signal).
2) The BP filtering function can be obtained with $I_1 = 0$, $I_{in} = I_2 = -I_3$ and $g_mR_1 = (C_1+C_2)/C_2$.
3) The HP filtering function can be obtained with $I_3 = 0$, $I_{in} = I_1 = -I_2$ and $g_mR_1 = (C_1+C_2)/C_2$.
4) The BS filtering function can be obtained with $I_{in} = I_1 = -I_2 = I_3$ and $g_mR_1 = (C_1+C_2)/C_2$.
5) The AP filtering function can be obtained with $I_{in} = I_1 = -I_2 = I_3$ 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.

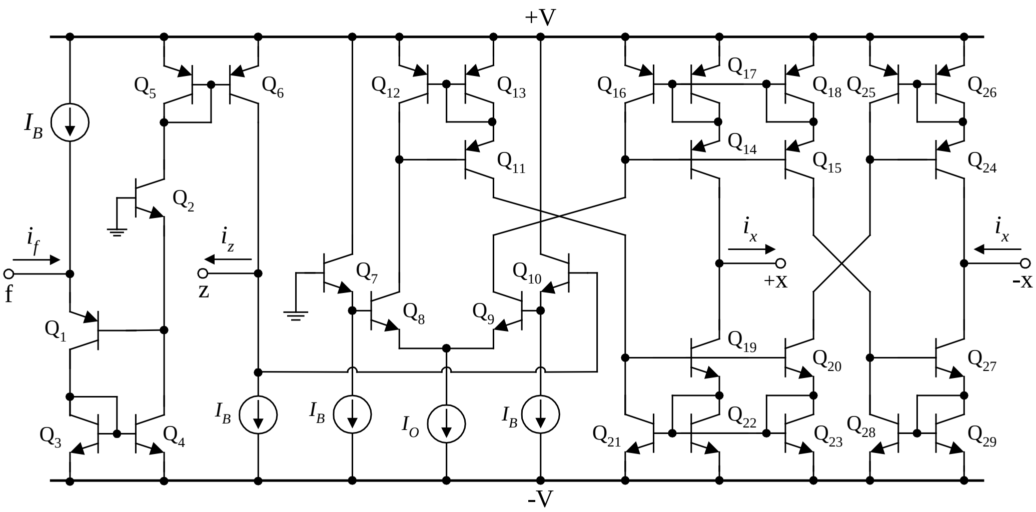

Fig.2 Particularly bipolar realization of the CFTA used in this work.

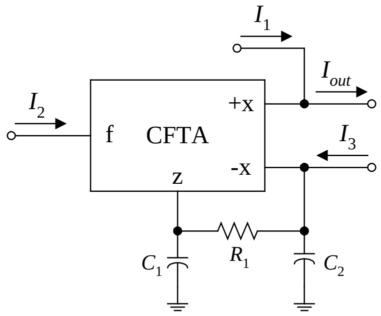

Fig. 3. Proposed TISO current-mode biquadratic filter with a single CFTA.

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

$$\omega_o = \sqrt{\frac{g_m}{R_1 C_1 C_2}} \tag{5}$$

and

$$BW = \frac{C_1 + C_2}{R_1 C_1 C_2} \quad . \tag{6}$$

From equations (5) and (6), it can be observed that the resultant frequency filter provides the possibility of electronic tuning the characteristic frequency ω_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 :

$$v_f = 0 \quad , \quad i_z = \alpha i_f \quad \text{and} \quad i_x = g_m v_z = \beta g_m Z_z i_z \tag{7}$$

where $\alpha = 1- \varepsilon_i$ and ε_i ($|\varepsilon_i| << 1$) is the current tracking error from terminal f to terminal z, and β is the transconductance inaccuracy factor from terminal z to terminal x. Therefore, taking the non-idealities of the CFTA into account, the modified parameters ω_o and BW of the proposed filter given in Fig.3 turn to :

$$\omega_o = \sqrt{\frac{\beta g_m}{R_1 C_1 C_2}} \tag{8}$$

and

$$BW = \frac{C_1 + C_2}{R_1 C_1 C_2} \quad . \tag{9}$$

It can be seen from equations (8) and (9) that the ω_o- and BW-parameters of the proposed filter are not influenced by the current tracking error α of the CFTA. The transconductance inaccuracy factor β has only effect on the ω_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 ω_o-value of equation (8) compared to equation (5) can be compensated by re-tuning the value of g_m properly.

Normalized active and passive sensitivities of the parameters ω_o and BW are calculated for the proposed filter as below :

$$S_{\beta}^{\omega_o} = S_{g_m}^{\omega_o} = \frac{1}{2} \quad , \tag{10}$$

$$S_{R_1}^{\omega_o} = S_{C_1}^{\omega_o} = S_{C_2}^{\omega_o} = -\frac{1}{2} \quad , \tag{11}$$

$$S_{\alpha}^{\omega_o} = 0 \quad , \tag{12}$$

$$S_{\alpha}^{BW} = S_{\beta}^{BW} = 0 \quad , \tag{13}$$

$$S_{R_1}^{BW} = -1 \quad , \tag{14}$$

$$S_{C_1}^{BW} = -\frac{C_2}{C_1 + C_2} \quad , \tag{15}$$

and

$$S_{C_2}^{BW} = -\frac{C_1}{C_1 + C_2} \quad . \tag{16}$$

Sensitivity analyses show that all magnitudes of ω_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 α and β of the CFTA, while the parameter ω_o is independent on α.

V. Performance Simulations and Discussions

To confirm the theoretical prediction, the proposed filter of Fig.3 has been simulated with PSPICE program. To implement the CFTA active device in simulations, the bipolar technology structure given in Fig.2 has been performed. The PNP and NPN transistors in CFTA implementation were simulated using the typical parameters of bipolar transistor model PR100N (PNP) and NP100N (NPN) [22]. The DC supply voltages and bias currents were respectively selected as : +V = -V = 1.5 V and I_B = 100 μA.

The proposed filter of Fig.3 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., $I_O \cong 104$ μA), 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.3. 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.

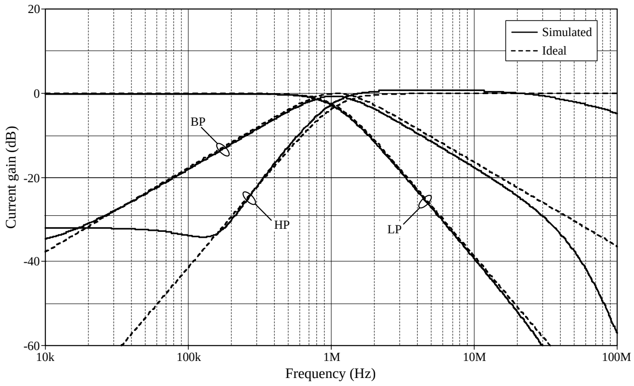

Fig. 4. Simulation results for the LP, BP and HP current responses of the proposed filter in Fig.3.

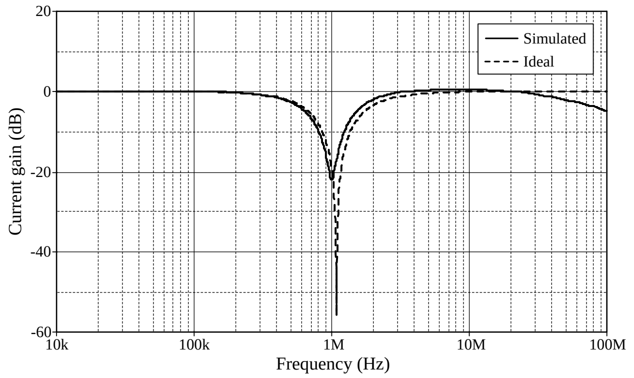

Fig. 5. Ideal and simulated frequency characteristics for the BP response of the proposed filter in Fig.3.

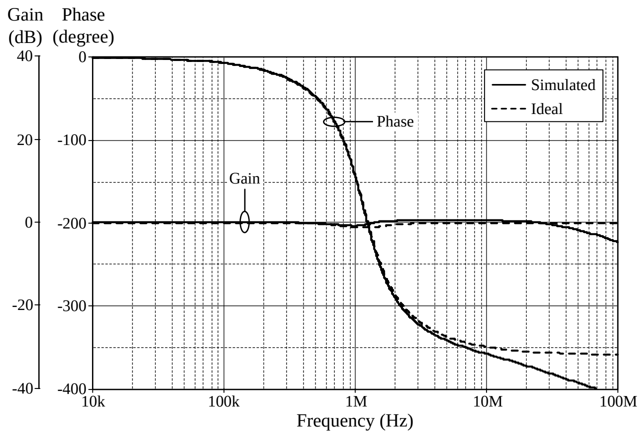

Fig. 6. Magnitude and phase frequency responses for the AP filter.

In order to demonstrate the controllability of the f_o-frequency by varying the biasing current I_O while the Q-factor is kept to be constant at unity, the resultant phase characteristics of the AP filter are shown in Fig.7. From the simulated results, we obtain f_o about at 0.37 MHz, 0.73 MHz, 1.06 MHz and 1.40 MHz, respectively.

The simulated transient responses for the input and output currents of the BP filter are given in Fig.8, in which the 1.12-MHz sinusoidal input current signal with 100-μA peak value was injected to the proposed filter. The total power consumption of the circuit is found as : 2.13 mW.

Furthermore, the simulations have also been demonstrate the dependence of the total harmonic distortion (THD) of the BP response on input signal amplitude and the results are shown in Fig. 9 for three different values of I_O. As it can be recorded from the results, the values of THD for a sinusoidal input signal with peak value of 150 μA at 1.12 MHz and 2.16 MHz are respectively obtained as: 7.95% and 1.23%.

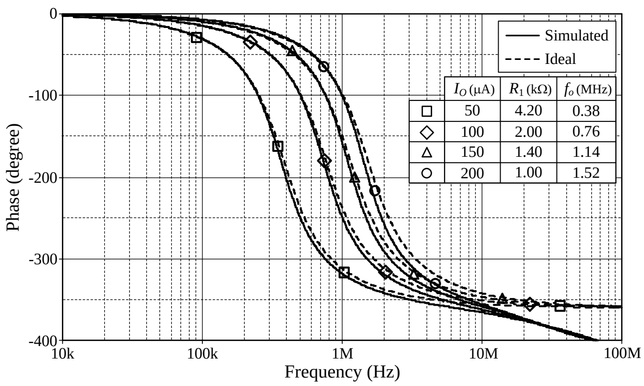

Fig. 7. Magnitude-frequency responses for the AP filter with tuning f_o.

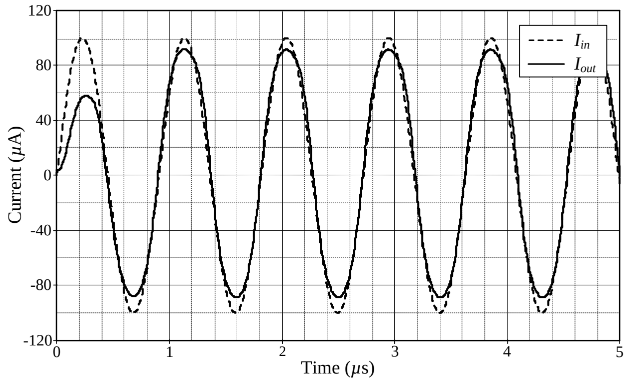

Fig. 8. Simulated transient responses for input current and output current of the BP filter at 1.132 MHz.

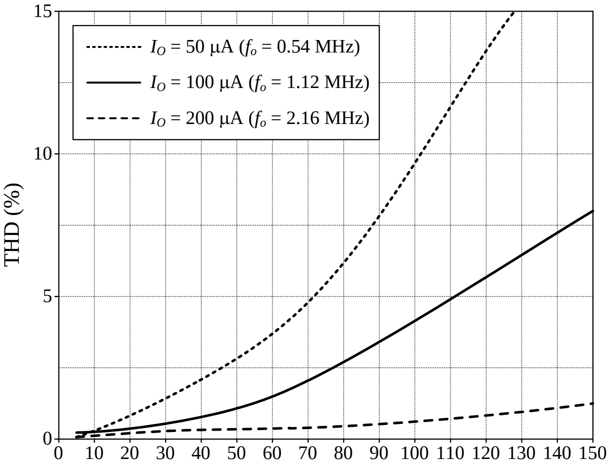

Fig. 9. THD variations of BP output on input signal amplitude.

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 ω_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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