Novel CMOS Current Follower Transconductance Amplifier Current-Mode universal Filter

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ABSTRACT
A current-mode universal biquad filter structure using two Current Follower Transconductance Amplifiers is proposed in this paper. It contains two grounded capacitors. The proposed structure can be configured into single input multiple outputs (MIMO). Using the proposed circuit, the realization of all the standard filtering responses such as low pass (LP), band pass (BP), high pass (HP), band reject (BR), and all pass (AP), can be done by choosing the output accordingly. The circuit does not require inverted current input signal(s) and it operates at lower supply voltage rails. The most important, component matching constraints are not required for the circuit. The proposed circuit offers an advantage of electronic tunability of pole-frequency independent to the quality factor. Performances of the proposed circuits were examined through P-SPICE programs on cadence tools using standard CMOS technology.

Keywords
Biquad, CFTA, Current-mode, Universal Filter

1. INTRODUCTION
Nowadays, the analog integrated circuits working in current mode are more popular due to their specific features such as higher slew-rate, considerable linearity, indigenous large bandwidth, broad dynamic ranges, low complexity and minimum power consumption [55]. Those current-mode (CM) continuous-time (CT) filter structures, capable to realize all the standard filtering responses, such as LP, BP, HP, BR and AP are having prominence in electronic industry. This type of filter structure is known as universal filters [55].

The designing of such type of filters with the concept, idea and availability of the components required for the circuit. The process of reducing the complexity of the circuit and make it operable at low power is being done, so that the device can be portable [57]. Further process of designing is to reduce the number of passive elements such as Capacitors and resistors used in the circuit and considering that there should be no floating elements, floating elements reduce the further integration[1-2].

Another big issue in the process of integrability is electronic tuning of the circuit and for highly accurate performance of any universal filter structure, first need is compatibility and adaptability of the filter parameters to compensate for unwanted variations due to various manufacturing imperfections, thermal drift, malfunctions, etc [3]. These structures are of many types either multiple-input multiple output abbreviate as MIMO or single-input multiple-output abbreviate as SIMO or multiple-input single output abbreviate as MISO configuration [56]. Single input multiple output filter structures [5-10] can realize many filtering functions without any modification requirement in the status of input signal. However, multi input multi output [56, 11-16] and Multi input single output filter structures [17-30] can perform multifunction filtering by modifying the input signals applied [56]. Since an introduction of the current differencing trans conductance amplifier (CDTA) in 2003, it has been acknowledged to be a versatile active building block for current-mode signal processing circuits [57]. Various analog signal processing/signal generation circuit solutions using this device have also been reported [57]. However, all of the previous works need more than one CDTA. In point of view of the low power dissipation and manufacturing cost, it is important to keep the active component count at minimum. Moreover, the earlier reported configurations 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. Thus, to avoid this problem, the modified version of the CDTA so-called current follower trans conductance amplifier (CFTA) has recently been introduced. [57]

A CFTA, a current-mode universal filter having single input and three outputs (SIMO) and electronically tunable is presented in this paper which provides all the desirable responses such as low pass, high pass band pass, band stop and all pass filter operation. The topology is Multiple-Input-Single-Output (MISO) and Single input and multiple output universal biquad, are having orthogonal adjustment facility of Q0 and Q [58].

In the literature, one input three output SIMO current-mode filter [59] consists of three CFTAs, three grounded passive elements (one resistor and two capacitors), but it realizes only three filtering functions (LP, BP and HP). The CIMO current-mode filters reported [58] employing two grounded capacitors and one floating resistor as passive elements and can realize all the standard filter functions i.e. LP, BP, HP, BR and AP. The structures in [60] realize one input three output biquad current-mode filters by employing CFTA and three Passive elements giving all five results. The structures in [61] realize one input three output biquad current-mode filters by employing two CFTA and two grounded capacitors and three grounded resistors elements giving all five results. The structures in [62] realize one input three output biquad mixed-mode filters by employing three VDTA and two grounded capacitors giving all five results.

This is just the literature review about the previous research to propose a current-mode biquad universal filter structure, which is configurable into SIMO (single input multiple output) structure and can realize all the standard filtering responses. The proposed circuit is a biquad filter consists of two CFTAs, two grounded capacitors as active and passive elements. This is a current mode SIMO circuit. This topology is a resistor less topology requires no matching conditions for the realization of all filter responses. In this circuit there is no requirement of inverted current input and operate at low power supply. All the filter responses are obtained at high impedance output terminal(s) which convince the cause of concern for circuit
The performance of the proposed circuit is verified through P-SPICE 16.3 Orcads programs using 0.25μm TSMC CMOS parameters [32], and various responses are included to verify the theory.

2. BASICS OF CFTA

Basic model and the ideal behavioral model of the CFTA are shown in Fig. 1. It has one I-port low-impedance current input port. The current I_in flows from port z. In some applications, to utilize the current through z terminal, an auxiliary Z_c (z-copy) terminal is used [57]. The internal current mirror provides a copy of the current flowing out of the z terminal to the zc terminal. The voltage V_z on z terminal is transferred into current using transconductance g_m, which flows into output terminal x. The g_m is tuned by I_S. In general, CFTA can contain an arbitrary number of x terminals, providing currents I_x of both directions. The characteristics of the ideal CFTA are represented by the following hybrid matrix:

$$\begin{bmatrix} V_f \\ I_{z, zc} \\ I_x \\ V_x \\ V_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & g_m & 0 \\ \end{bmatrix} \begin{bmatrix} I_f \\ I_x \\ V_x \end{bmatrix}.$$  

The use of CF (Current Follower) at the input stage sets a low impedance input terminal 'f' of CFTA. When an input current I_in is applied to the input terminal, it is transferred to the high impedance auxiliary Z-terminal as (I_Z = I_in). A copy of IZ current may also be conveyed to the Z-copy terminal (ZC). Mostly in the circuits, synthesized using CFTA, terminal Z is loaded with the grounded impedance. The voltage drop (V_Z) across grounded impedance is further transformed into current I_X+ and/or I_X- by the BOTA (Balanced output transconductance amplifier). The trans-conductance (g_m) of BOTA can be controlled by an external biasing current (I_S). Because of this feature CFTA can be extended for various electronically tunable current-mode applications [rt]. The schematic of CFTA is shown in Fig. 1. An ideal CFTA can be described mathematically by the following set of equations.

$$I_f = I_z, I_x = g_m V_z, V_f = 0$$  

From the given equations, it is shown that the proposed circuit can work as a universal current-mode filter as one input three outputs (SIMO) configuration and can perform LP, BP, HP, BR and AP filtering function. And there is no requirement of component matching condition(s). In Addition, there is no requirement of any type of inverting-type input current signal(s) in the design to realize all the responses.

With μ, COX and W/L are mobility of free electrons within the channel, gate-oxide capacitance per unit area and the aspect ratio of the NMOS transistors M_18-M_19 forming a differential pair in the trans-conductance stage of employed CFTA.

3. PROPOSED CURRENT MODE FILTER CIRCUIT

The proposed current-mode biquad filter with one input terminal (I_in1) and three output terminals (I_out1, I_out2 and I_out3) is shown in Fig. 2. It requires two ZC-CFTAs and two grounded passive elements (two grounded capacitors). The use of grounded capacitors is particularly attractive for integrability [31]. There is some output expressions obtained from the proposed circuit.

$$l_{out1} = \frac{s^2C_1G_{19}I_{in1}}{D(S)}$$

$$l_{out2} = \frac{sc_1gmi_{in1}}{D(S)}$$

$$l_{out3} = \frac{g_mgmi_{in1}}{D(S)}$$

$$D(S) = S^2C_1C_2 + SC_1Gm2 + Gm1Gm2$$

From equations (4) - (7) shows that various filtering responses can be obtained, which node providing the desired output is given in Table 2.

Table 2. Current-mode filter with one input and three outputs

<table>
<thead>
<tr>
<th>Filter type</th>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Pass</td>
<td>I_in 1</td>
<td>I_out1</td>
</tr>
<tr>
<td>Low Pass</td>
<td>I_in 1</td>
<td>I_out3</td>
</tr>
<tr>
<td>Band Pass</td>
<td>I_in 1</td>
<td>I_out2</td>
</tr>
<tr>
<td>Band Reject</td>
<td>I_in 1</td>
<td>I_out1-I_out3</td>
</tr>
<tr>
<td>All Pass</td>
<td>I_in 1</td>
<td>I_out1+I_out2+I_out3</td>
</tr>
</tbody>
</table>

From the given equations, it is shown that the proposed circuit can work as a universal current-mode filter as one input three outputs (SIMO) configuration and can perform LP, BP, HP, BR and AP filtering function. And there is no requirement of component matching condition(s). In Addition, there is no requirement of any type of inverting-type input current signal(s) in the design to realize all the responses.

The filter parameters such as pole frequency (ω_0), the quality factor (Q0) and bandwidth (BW) can be expressed as:

$$\omega_0 = \frac{g_mg_m}{\sqrt{C_1C_2}}$$  

$$Q0 = \frac{g_mg_m}{\sqrt{C_1C_2}}$$  

$$BW = \frac{1}{\omega_0}$$
Equation (9) shows that the BW can solely be controlled by $I_{S2}$ only. From equations (7) - (8), it is also clear that filter parameter $\omega_0$ and $Q_0$ can be adjusted electronically by adjusting bias current $I_{S1}$ without affecting BW.

4. NON-IDEAL ANALYSIS

In this section, the non-ideal aspects of the proposed biquad filter circuit are considered. For the non-ideal case, CFTA can be characterized by the following modified set of equations.

$$V_{f_0}=0, I_{Z_0}\approx\alpha_i I_{f_0}, I_{Z_0}\approx\beta_i I_{f_0}, I_{Z_0}\approx\gamma_i I_{G_m} V_Z$$

Where $\alpha_i=1-\epsilon_i$, with $|\epsilon_i|<1$, $\beta_i=1-6_i$, with $|6_i|<<1$

Represent the current tracking errors between $f$ to $Z$ terminal and $f$ to $Z$-copy terminal of the employed $i$th $ZC$-CFTA ($i=1, 2$), respectively. $\gamma_i$ is the trans-conductance inaccuracy factor between $Z$ to $\pm X$ terminal of the $i$th $ZC$-CFTA.

$$D(S) = S^2 C_1 C_2 + \gamma_y \alpha_2 S C_1 G_m + \gamma_x \alpha_2 G_m G_m$$

Considering these non-ideal parameters of the CFTA and reanalyzing the proposed filter of Fig. 2, we have the denominator of each current output expressions as:

$$\omega_0 = \frac{\alpha_2 \gamma_y C_1 G_m}{C_1 C_2}$$
$$Q_0 = \frac{1}{\gamma_x \alpha_2 G_m C_2}$$

It is seen from above equation that minor deviations are available in $\omega_0$ and $Q_0$ due to non-ideal analysis. But these deviations are negligible, because non-ideal parameters $\alpha$, $\beta$ and $\gamma$ are tends to unity at working frequency.

5. SIMULATION RESULTS

The proposed current-mode universal biquad filter in Fig. 2 was implemented using standard CMOS technology.
(TSMC 0.25μm) and examined using PSPICE simulation on cadence tools to verify the theoretical expectations. For this, CFTA was implemented using CMOS transistors as shown in Fig. 3. The dimensions of MOS transistors were taken as specified in Table 3. The proposed circuit was designed for $f_0 = \omega_0/2\pi = 10 MHz$ by selecting $I_{S1} = I_{S2} = 20 \mu A$ and $C_1 = C_2 = 10 pF$. The voltage supply rails were used as $V_{DD} = -V_{SS} = 1.0 V$ with bias $V_{BB} = -0.5V$. For SIMO (one input three outputs)
configuration of the proposed current-mode filter circuit, the
simulated gain and phase responses of HP, LP, BP, BR, AP output
is shown in Fig.4(a),4(b),4(c),4(d),4(e) respectively. Whereas, the simulated gain response of HP, LP, BP, BR and
AP filtering functions are illustrated in Fig. 5(a). And the
simulated gain response of HP, LP, BP, BR and AP filtering
functions are illustrated in Fig. 5(b).

| Table 3: Dimensions of MOS transistors MOS Transistors |
| Dimensions |
| NMOS W(μm)/L(μm) |
| M16-M17 2.5/25 |
| M18-M19 25/25 |
| M20-M31 7.5/25 |
| PMOS W(μm)/L(μm) |
| M1-M14 7.5/25 |
| M15 8.5/25 |

6. CONCLUSIONS
An electronic tunable universal biquad filter working in a
current mode is made up of two CFTAs and two grounded
capacitors are proposed. This circuit is having two grounded
capacitors as a passive elements only so they permits
cascadability for obtaining higher order filter functions as all
the output currents are available at high impedance output
terminals. There is no need of inverted current input of circuit
this is the advantage and operating at low power supply. All
the filter responses are obtained at high impedance output
terminal(s) which convince the cause of concern for circuit
cascading. Another advantage of the proposed circuits were
found is independent current tunability of ω0 and Q0 with bias
current(s) of CFTAs. Some other advantages are low active and
passive sensitivities and the versatility to realize LP, BP, HP,
BR and AP responses with one input and three output , without
requiring any matching conditions. The proposed universal
filter circuit was simulated using PSPICE with CMOS
implementation. The proposed circuit structure is expected to
be usable for different applications in communication,
instrumentation and measurement systems, specially at high
frequency range.

7. REFERENCES
[6] E. Yuce, S. Minaei and O. Cicekoglu, Universal current-mode active-C filter employing minimum number of
[19] J. W. Horng, High output impedance current-mode universal biquadratic filters with five inputs using multi-


[47] D. Biolek, V. Biolikova, Current-Input Current-Output 2nd-Order All-Pass Filter Employing Two ZC-CITAs, In proc. of the 20th International Conference


[59] Xinhua Nie Zhongming Pan, Multiple-input single-output low-input and high output impedance current-mode biquadratic filter employing five modified CFTAs and only two grounded capacitors. Pub. in Microelectronics Journal 44(2013), 802–806.


[61] Roam Sotner Josef Slezak Tomas dostal ,Tunable oscillator using two CCTA-s and only grounded passive elements pub.in Int.Conf. Environmental and Electrical Engineering, 2010, 447-450.