CFTA Based MISO Current-mode Biquad Filter

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Abstract: - This article presents a four-inputs single output biquadratic filter performing completely standard functions: low-pass, high-pass, band-pass, band-reject and all-pass functions, based on single current follower transconductance amplifier (CFTA). The features of the circuit are that; the quality factor and natural frequency can be tuned electronically via the input bias current; the circuit description is very simple, consisting of merely 1 CFTA, 1 resistor and 2 grounded capacitors; the filter does not require inverting-type input current signal. Additionally, each function response can be selected by suitably selecting input signals with digital method. Using only single active element and grounded capacitors, the proposed circuit is very suitable to further develop into an integrated circuit. The PSPICE simulation results are depicted. The given results agree well with the theoretical anticipation. The total power consumption is approximately 2.01mW at ±1.25V supply voltages.

Key-Words: - analog filter, current mode, CFTA, multiple-inputs single-output.

1 Introduction

Recently, current-mode circuits have been receiving considerable attention due to their potential advantages such as inherently wide bandwidth, higher slew-rate, greater linearity, wider dynamic range, simpler circuitry and lower power consumption [1]. One of the standard research topics in current-mode circuit design is an analog filter. This circuit is important in electrical and electronic applications, widely used for continuous-time signal processing. It can be found in many fields: including, communications, measurement, and instrumentation, and control systems [2-3]. One of most popular analog current-mode filters is a multiple-input single-output biquadratic filter (MISO) which different output filter functions can be realized simply by different combinations of switching on or off the input currents where the selection can be done digitally using a microcontroller. Moreover, the high-output impedance of current-mode filters are of great interest because they make it easy to drive loads and they facilitate cascading without using a buffering device [4-5].

From our survey, it is found that several implementations of MISO current-mode filters have been reported [6-21]. Unfortunately, these reported circuits suffer from one or more of following weaknesses:

- Use more than one active element [7, 9, 13, 14, 16, 17, 18, 19, 20, 21].
- Excessive use of the passive elements, especially external resistors [7, 9, 10, 11, 14, 15, 16].
- Requirement of inverting-type input current signal(s) to realize all the responses [6, 14, 15, 17, 18, 20].
- Lack of electronic adjustability [7, 10, 11, 15, 16].
- Requirement of changing circuit topologies to achieve several functions [10].
- Requirement of element-matching conditions [10, 11, 15, 18].
- Use of floating capacitor which is not desirable for IC implementation [15].

The current follower transconductance amplifier (CFTA) is a recently reported active component. It seem to be a versatile component in the realization of a class of analog signal processing circuits, especially analog frequency filters [22-23]. It is really current-mode element whose input and output signals are currents. In addition, it can also adjust the output current gain.

This work is arranged to propose a new MISO current–mode biquadratic filter, emphasizing on use of single CFTA. The features of proposed circuit are that: the proposed universal filter can provide...
completely standard functions without changing circuit topology by appropriately selecting the input signals: the circuit description is very simple, it consists of single CFTA, single resistor and 2 grounded capacitors, which is suitable for fabricating in monolithic chip: the filter does not require inverting-type input current signal(s). In addition, the natural frequency and the bandwidth can be tuned electronically by adjusting the bias currents. Its performances are illustrated by PSPICE simulations, they show good agreement as mentioned.

2 Principle of Operation

2.1 Basic concept of CFTA
Since the proposed circuit is based on CFTA, a brief review of CFTA is given in this section. The schematic symbol and the ideal behavioural model of the CFTA are shown in Fig. 1(a) and (b), respectively. It has one low-impedance current input port. The current flows from port to terminal. In some applications, to utilize the current through terminal, an auxiliary terminal (z-copy) terminal is used [22]. The internal current mirror provides a copy of the current flowing out of the terminal to the terminal. The voltage on terminal is transferred into current using transconductance , which flows into output terminal. The gm is tuned by . In general, CFTA can contain an arbitrary number of terminals, providing currents of both directions. The characteristics of the ideal CFTA are represented by the following hybrid matrix:

\[
\begin{bmatrix}
V_f \\
I_{zx} \\
I_z
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & 0 \\
1 & 0 & 0 \\
0 & 0 & g_m
\end{bmatrix}
\begin{bmatrix}
I_f \\
V_z \\
V_x
\end{bmatrix}, \quad (1)
\]

For CMOS CFTA, the gm is written as

\[
g_m = \sqrt{k I_B}, \quad (2)
\]

where \( k = \mu_o C_{ox} (W/L) \). Here \( k \) and \( I_B \) are the physical transconductance parameter of the MOS transistor and input bias current, respectively.

2.2 Proposed MISO current-mode filter
The proposed MISO current-mode filter is shown in Fig. 2. Straightforwardly analyzing the circuit in Fig. 2, the output current can be obtained as

\[
I_{out} = -\frac{1}{RC} (I_{in1} + I_{in2}) - \frac{g_m}{RC} C_2 I_{in2} + \left( s^2 + \frac{1}{RC} + \frac{g_m}{RC} \right) I_{in4}. \quad (3)
\]

Figure 1. CFTA (a) Symbol (b) Equivalent circuit.

From Eq. (3), the magnitudes of input currents \( I_{in1} \), \( I_{in2} \), \( I_{in3} \) and \( I_{in4} \) can be chosen as in Table I to obtain a standard function of the network. The circuit of digital selection can be seen in [24]. It is found that the proposed filter does not require inverting-type input current signal to synthesis all the filter responses. From Eq. (3), the natural frequency (\( \omega_0 \)) and quality factor (\( Q_0 \)) of each filter response can be expressed as

\[
\omega_0 = \sqrt{\frac{g_m}{C_2 C_z R}}, \quad (4)
\]

and

\[
Q_0 = \frac{C_z R g_m}{C_2}. \quad (5)
\]

It is found from Eqs. (4) and (5) that if \( g_m = \sqrt{k I_B} \), the natural frequency and quality factor can be electronically adjusted.

Figure 2. Proposed MISO current-mode biquadratic filter.
### 2.3 Circuit sensitivities

The sensitivities of the proposed circuit can be found as

\[
S_{C1, C2, r}^{00} = -\frac{1}{2}, \\
S_{r, C1}^{00} = -\frac{1}{2}, \\
S_{r, C2}^{00} = -\frac{1}{2}.
\]

and

\[
S_{C1, C2, r}^{11} = -\frac{1}{2}, \\
S_{C1, C2, r}^{11} = -\frac{1}{2}.
\]

Therefore, all the active and passive sensitivities are equal or less than unity in magnitude.

### 3 Simulation Results

To prove the performances of the proposed filter, the PSPICE simulation program was used for the examination. Internal construction of CFTA used in simulation is shown in Fig. 4. The PMOS and NMOS transistors have been simulated by respectively using the parameters of a 0.25µm TSMC CMOS technology [25]. The aspect ratios of PMOS and NMOS transistor are listed in Table II. The circuit was biased with ±1.25V supply voltages, \( V_{BB} = -0.55V \), \( C_1 = C_2 = 0.1\text{nF} \), \( I_B = 100\mu\text{A} \) and \( R = 1\Omega \). It yields the natural frequency of 1.71MHz. The results shown in Fig. 4 are the gain and phase responses of the proposed biquad filter from Fig. 2. There are seen that the proposed filter can provide low-pass, high-pass, band-pass, band-reject and all-pass functions dependent on selection as shown in Table I, without modifying circuit topology.

#### Table I

The \( I_{in1}, I_{in2}, I_{in3} \) and \( I_{in4} \) value selections for each filter function response

<table>
<thead>
<tr>
<th>Filter Responses</th>
<th>( I_{in1} )</th>
<th>( I_{in2} )</th>
<th>( I_{in3} )</th>
<th>( I_{in4} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>HP</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>BP</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BR</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>AP</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

#### Table II

Dimensions of the MOS transistors

<table>
<thead>
<tr>
<th>MOS Transistors</th>
<th>( W(\mu m) / L(\mu m) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1, M2</td>
<td>1/0.25</td>
</tr>
<tr>
<td>M15, M16</td>
<td>20/0.25</td>
</tr>
<tr>
<td>M14</td>
<td>4.5/0.25</td>
</tr>
<tr>
<td>Another PMOS</td>
<td>5/0.25</td>
</tr>
<tr>
<td>Another NMOS</td>
<td>3/0.25</td>
</tr>
</tbody>
</table>

![Figure 3. Internal construction of CFTA.](image)

![Figure 4. Gain and phase responses of the biquad filter in voltage-mode for (a) LP (b) HP (c) BP (d) BR (e) AP.](image)
proposed filter from band-pass function for center frequency of 1.71MHz can be seen in Fig. 6. Total power consumption is about 2.01mW.

Figure 5. Current-mode band-pass responses for different values of $I_B$.

Figure 6. Transient responses at center frequency of 1.71MHz obtained from the proposed filter for BP function.

4 Conclusion

The multiple-inputs single output biquadratic filter based on single CFTA is presented. The advantages of the proposed circuit are that: it performs low-pass, high-pass, band-pass, band-reject and all-pass functions dependent on an appropriate selection of three signals: the bandwidth and the natural frequency can be electronically controlled via input bias currents, it is easily modified to use in control systems using a microcontroller [1]. The circuit description comprises only 1 CFTA, 1 resistor and 2 grounded capacitors. With mentioned features, it is very suitable to realize the proposed circuit in monolithic chip to use in battery-powered, portable electronic equipments such as wireless communication system devices.

References:


