TUNABLE CURRENT-MODE TOW-THOMAS BIQUAD BASED ON CDTAs

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ABSTRACT

A new current-mode Tow-Thomas biquad filter based on employing current differencing transconductance amplifiers (CDTAs) is introduced. The filter circuit uses two grounded capacitors and realizes a lowpass (LP) and a bandpass (BP) responses, simultaneously. The proposed circuit is electronically tunable by adjusting the biasing current of the CDTAs. The circuit requires no component matching conditions for realizing the transfer functions listed above. Additionally, the circuit parameters Q and ω₀ can be tuned orthogonally by adjusting the bias currents of the CDTAs and grounded capacitors. It is clear from sensitivity analysis that the proposed biquad circuit has very low sensitivities with respect to the circuit components.

KEYWORDS

CDTA, Current-Mode, Tow-Thomas Biquad, Tunable Filter.

1. INTRODUCTION

In the last decade, there has been much effort to reduce the supply voltage of electronic circuits. This is due to the command for portable and battery-powered equipment. Since a low-voltage operating circuit becomes necessary, the current-mode (CM) technique is ideally suited for this purpose more than the voltage-mode (VM) one. Consequently, there is a growing interest in synthesizing the CM circuits because of more their potential advantages such as larger dynamic range, higher signal bandwidth, greater linearity, simpler circuitry and low power consumption [1],[2]. Many active elements that are able to function in CM such as OTA, current conveyor and current differencing buffered amplifier (CDBA), have been introduced to response these demands. Recently, a reported 5-terminals active element, namely current differencing transconductance amplifier (CDTA) [3], seems to be a versatile component in the realization of a class of analog signal-processing circuits, especially analog frequency filters [3],[4]. It is really CM element whose input and output signals are currents. It should also be noted here that, the CDTA offers wider frequency bandwidth advantages as compared to its close relative, the CDBA [5]. In addition, it can also be adjusted the output current gain.

This CM active building block (CDTA) has been found to be versatile for CM signal processing and its use has reportedly provided several circuit solutions. These primarily consist of the design of CM filters [6], [7], [8], [9] and sinusoidal oscillators (including quadrature and multi-phase oscillators) [10], [11], [12], [13], [14].

The Tow-Thomas biquad filter is a very useful second-order function block and it is also the more popular universal filter structure. Since this structure offers several advantages such as low passive and active sensitivity performance, low component spread and good stability...
behaviour, the Tow-Thomas biquad circuit [15], [16], employing various types of the current conveyors (CCs), operational transconductance amplifiers (OTAs) and other active elements has already been reported in the literature. Unfortunately, most of these reported circuits suffer from one or more of following weaknesses:

- Excessive use of the active and/or passive elements
- Lack of electronic adjustability (tunability)
- The pole frequency and quality factor cannot be tuned independently

Active filters with current controllable (tunable) frequency have a wide range of applications in the signal processing and instrumentation area. New advantageous filter topologies can be realized by introducing CDTAs in the filter design that leads to current controllability of the filters.

The motivation of this paper is to propose a minimum component CDTA based tunable CM biquad Tow-Thomas filter. The proposed biquad filter employs two CDTAs and two grounded capacitors. The circuit can realize low-pass (LP) and band-pass (BP) functions, simultaneously. The circuit requires no component matching conditions for realizing the transfer functions listed above. Additionally, the circuit parameters Q and $\omega_0$ can be tuned orthogonally by adjusting the bias currents of the CDTAs and grounded capacitors. PSPICE circuit simulations are included to verify the workability of the proposed circuit.

2. CIRCUIT CONFIGURATION

The CDTA, with a pair of bidirectional currents $I_{x+}$ and $I_{x-}$, whose symbol and equivalent circuit shown in Figure 1, can be characterized by the following matrix equation:

$$
\begin{bmatrix}
V_p \\
V_n \\
I_z \\
I_x
\end{bmatrix}
= 
\begin{bmatrix}
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 \\
1 & -1 & 0 & 0 \\
0 & 0 & 0 & \pm g_m
\end{bmatrix}
\begin{bmatrix}
I_p \\
I_n \\
V_x \\
V_z
\end{bmatrix}
$$

According to above equation and the circuit of Figure 1, the current through terminal $z$ follows the difference of the currents through the terminals $p$ and $n$ ($i_p - i_n$). The voltage drop at terminal $z$ is transferred to a current at terminal $x$ ($i_x$) by a transconductance gain ($g_m$), which is electronically controllable by a bias current ($I_B$) [17].

$$
\begin{align*}
I_{z+} &= I_{zp} + \frac{g_m}{C_2} s \frac{g_m}{C_2} s + \frac{g_m}{C_1 C_2} s + g_m \frac{g_m}{C_2} \\
I_{z-} &= I_{zp} - \frac{g_m}{C_2} s \frac{g_m}{C_2} s + \frac{g_m}{C_1 C_2} s + g_m \frac{g_m}{C_2}
\end{align*}
$$

The application potential of the CDTA can be increased by extending the circuit with an auxiliary $z_c$ (Z Copy) terminal, which provides a copy of current $I_z$. Such a CDTA is called ZC-CDTA (Z Copy-CDTA) [18].

Using the voltages and currents relationships of the CDTA given in (1) the corresponding transfer functions of the proposed Tow-Thomas filter employing ZC-CDTAs that is shown in Figure 2 are given below.
\[
\frac{I_{o2}}{I_{in}} = \frac{I_{LP}}{I_{in}} = -\frac{g_{m1}g_{m2}}{C_1 C_2} \quad (2b)
\]

Equations (2a) and (2b) represent the CM filter functions for BP and LP responses, simultaneously. The natural frequency \(\omega_o\) and the quality factor Q for the filter are given by:

\[
\omega_o = \sqrt{\frac{g_{m1}g_{m2}}{C_1 C_2}}, \quad Q = \sqrt{\frac{g_{m1}C_2}{g_{m2}C_1}} \quad (3)
\]

It is clear from (3) that \(\omega_o\) and Q can be electronically tuned by adjusting the bias currents of the CDBAs (changing \(g_{m1}\) and \(g_{m2}\)). In addition, it can be seen that the parameters \(\omega_o\) and Q are orthogonally controllable by adjusting the ratio \(g_{m1}\) to \(g_{m2}\), \(C_2\) to \(C_1\) or \(g_{m1}C_2\) to \(g_{m2}C_1\).

Sensitivity analysis of the filter parameters shows that

\[
S_{\omega_o}^o = S_{\omega_o}^o = -S_{\epsilon_1}^o = -S_{\epsilon_2}^o = \frac{1}{2}
\]

\[
S_{Q}^C = S_{Q}^C = -S_{\epsilon_1}^Q = -S_{\epsilon_2}^Q = \frac{1}{2}
\]

which are all low.

3. SIMULATION RESULTS

In order to confirm the theoretical validity of the proposed filter configuration given in Figure 2 it is simulated with PSpice simulation program. To implement the CDBAs the CMOS structure given in Figure 3 is used [18]. The aspect ratios of the MOS transistors are given in Table 1. The device model parameters from TSMC 0.25 \(\mu\)m CMOS process model parameters, given in Table 2, are used for the PSpice simulations and the supply voltages of \(V_{DD}=V_{SS}=1.2\) V and \(I_B=15\) \(\mu\)A are selected.

Figure 4 shows the characteristics of the proposed Tow-Thomas filter which can realize two standard filter functions (LP and BP), simultaneously. The filter in Figure 2 is assumed based on the following conditions, \(I_B=15\) \(\mu\)A and \(C_1=C_2=20\) pF as frequency response of the filter proposed to be 1 MHz.

![Figure 3. The CMOS ZC-CDTA circuit used for simulations adopted from [18]](image)

<table>
<thead>
<tr>
<th>Transistor</th>
<th>(W(\mu m))</th>
<th>(L(\mu m))</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1-M8</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>M4’, M8’</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>M9-M10</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>M11-M14</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>M15-M20</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2. 0.25 \(\mu\)m TSMC CMOS transistor parameters.

To show the electronically tunability of the proposed filter, different values of MOS bias currents of the CDTAs as 15 \(\mu\)A, 25 \(\mu\)A and 45 \(\mu\)A are selected to obtain different resonance frequencies for the BP response of the filter as shown in Figure 5.
REFERENCES


