Universal Current-Mode Biquad Employing Dual Output Current Conveyors and MO-CCCA with Grounded Passive Elements

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Received May 17, 2012; revised November 6, 2012; accepted November 13, 2012

ABSTRACT

A new universal multiple input multiple output (MIMO) type current-mode biquad employing two dual output current conveyors (DOCCII), one multiple output current controlled current amplifier (MOCCCA) and four passive grounded elements is proposed which can realize all the five basic filtering functions namely, low-pass (LP), high-pass (HP), band-pass (BP), band-stop (BR) and all-pass (AP) in current mode from the same configuration. The centre frequency \( \omega _c \) can be set by the passive elements of the circuit and the quality factor \( Q_0 \) is electronically tunable through bias currents of the MOCCCA. Therefore, the biquad filter has independent tunability for the \( \omega _c \) and \( Q_0 \). The active and passive sensitivities of \( \omega _c \) and \( Q_0 \) are low. The workability of the new configuration has been demonstrated by PSPICE simulation results based upon a CMOS CCII in 0.35 \( \mu \)m technology.

Keywords: Current-Mode Filters; Current Conveyors; Analog Circuit Design; CMOS Circuits

1. Introduction

Recently, Chunhua, Hiaguang and Yan presented two new universal multiple input single output (MISO) current-mode (CM) biquadatic filters using one MOCCCA, two grounded capacitors (GC) and two grounded resistors (GR) and realize all the five generic filter responses in CM (i.e. with current as input and current as output) [1].

The purpose of this paper is to introduce a new configuration which although uses exactly same number of active and passive components but in contrast to the circuit of reference [1] realizes a MIMO-type biquad and hence, does not require any additional hardware to duplicate/invert current inputs which is required in case of MISO-type filters of [1].

In the literature there are SIMO-type filter circuits which have three active devices but suffer from the independent tunability as in [2-5] or have more passive or active elements as in [4-9]. The circuits in [10-12] need double inputs and outputs to realize all five generic filters. The circuit in [13] has two MO-CCCIIs and one DO-CCCI, the draw back of this circuit is the control currents \( I_{o1}, I_{o2}, I_{o3} \) are temperature dependent. The circuit in [14] has two MO-CCCIIs and one MOCCCA but realizes only SIMO-type biquad.

2. The Proposed Configuration

The proposed configuration is shown in Figure 1. Assuming the CCII to be characterized by

\[
\begin{bmatrix}
I_T \\
V_X \\
I_Z
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & 0 \\
1 & 0 & 0 \\
0 & \pm 1 & 0
\end{bmatrix}
\begin{bmatrix}
I_X \\
I_Y \\
V_Y
\end{bmatrix}
\]

(1)

The symbolic notation of MO-CCCA is given in Figure 2(a), where \( i \) represent input, \( (I_{o1} - I_m) \) are n outputs respectively, and \( I_d \) and \( I_b \) denote DC bias currents. Figure 2(b) is a CMOS realization of MO-CCCA. Here \( I_i \) denotes the input signal; \( I_{o1}, I_{o2}, I_{o3} \) are the three output currents, respectively.

If the channel lengths of \( M_5-M_8 \) are all \( n \) times of that of \( M_4 \) and the channel size of \( M_{17} \) is \( n \) times that of \( M_{18} \), namely

\[
(W/L)_{M_5}/(W/L)_{M_4} = (W/L)_{M_6}/(W/L)_{M_4} = (W/L)_{M_7}/(W/L)_{M_4} = (W/L)_{M_8}/(W/L)_{M_4} = n,
\]

the output current expressions can be obtained as

\[
I_{o1} = I_{o2} = \cdots = I_{on} = \frac{nI}{2I_d} = Kl
\]

(2)
where $K$ represents the current gain. It is clear from Equation (2) that the value of $K$ can be set by $I_B$ and $I_A$.

Consider now the following special cases:

2.1. MISO Type:

When $i_1, i_2, i_3, i_4$ and $i_5$ are input currents and taking $i_{o3}$ as output current, then a routine analysis of the circuit reveals the following expression of the output current $i_{o3}$ in terms of the five input currents $i_1, i_2, i_3, i_4$ and $i_5$:

$$i_{o3} = \frac{1}{\Delta} \left[ i_2 s^2 C_1 C_2 + i_4 G_1 G_2 + (i_1 - i_3 - i_4) s C_1 G_2 \right]$$

(3)

where $\Delta = s^2 C_1 C_2 + \frac{1}{K} s C_1 G_2 + G_1 G_2$, $G_1 = 1/R_1$ and $G_2 = 1/R_2$.

Then, the various filter responses can be realized from...
the circuit are:

LPF: when \( i_1 = i_{m} \) (non-inv.) and \( i_1 = i_2 = i_3 = 0 \).

HPF: when \( i_1 = i_{m} \) and \( i_1 = i_2 = i_3 = i_4 = i_5 = 0 \).

BPF: when \( i_1 = i_{m} \) and \( i_1 = i_2 = i_4 = i_5 = 0 \) or \( i_3 = i_{m} \) and \( i_1 = i_2 = i_4 = i_5 = 0 \) or \( i_2 = i_5 = i_3 = i_{m} \) and \( i_1 = i_2 = i_4 = i_5 = 0 \).

Note: when \( i_2 = i_4 = i_{m} \) and \( i_1 = i_3 = i_5 = 0 \).

APF: when \( i_1 = i_2 = i_{m} \) and \( i_1 = i_2 = 0 \) or \( i_2 = i_3 = i_4 = i_5 = i_{m} \) and \( i_1 = i_3 = i_5 = 0 \).

2.2. SIMO Type

If \( i_1 \) is input current, \( i_2 = i_4 = i_5 = 0 \) (open-circuited) then, the various filter responses realized are given by:

\[
\text{LPF: } \frac{i_{m}}{i_1} = -\frac{1}{\Delta} \left[ G_1 G_2 \right] \quad (4)
\]

\[
\text{HPF: } \frac{i_{m}}{i_1} = -\frac{1}{\Delta} \left[ s^2 C_1 C_2 \right] \quad (5)
\]

\[
\text{BPF: } \frac{i_{m}}{i_1} = \frac{1}{\Delta} \left[ s C_1 G_2 \right] \quad (6)
\]

\[
\text{Notch: } \frac{i_{m1} + i_{m2}}{i_1} = -\frac{1}{\Delta} \left[ s^2 C_1 C_2 + G_1 G_2 \right] \quad (7)
\]

\[
\text{APF: } \frac{i_{m1} + i_{m2} + i_{m3}}{i_1} = -\frac{1}{\Delta} \left[ s^2 C_1 C_2 - s C_1 G_1 + G_1 G_2 \right] \quad (8)
\]

The various parameters of the realized filters are given by

\[
\omega_0 = \frac{1}{\sqrt{C_1 C_2 R_1 R_2}}, \quad BW = \frac{1}{K C_2 R_2} \cdot Q_o = K \sqrt{\frac{C_1 R_3}{C_2 R_1}} \quad (9)
\]

From Equation (9), the centre frequency \( \omega_0 \) can be set by varying \( R_1 \) without disturbing \( \omega_0 / Q_o \). The \( Q_o \) can also be set by \( I_0 \) and \( I_1 \) without disturbing \( \omega_0 \). Therefore, the biquad filter has independent tenability for the \( \omega_0 \) and \( Q_o \).

From the above, the active and passive sensitivities of \( \omega_0 \) and \( Q_o \) are found as

\[
S_{\omega_0} = S_{\omega_0} = S_{\omega_0} = -\frac{1}{2}, S_{\omega_2} = S_{\omega_2} = \frac{1}{2}
\]

\[
S_{\omega_1} = S_{\omega_1} = -\frac{1}{2}, S_{\omega_2} = 1
\]

The active and passive sensitivities of \( \omega_0 \) and \( Q_o \) are found to be in the range \( -\frac{1}{2} \leq S_i \leq 1 \), and the circuit, thus, enjoys low sensitivities.

3. Simulation Results

To verify the validity of the various modes of operation of the proposed configuration, circuit simulation of the current mode filters (MISO and SIMO) have been carried out using the CMOS CCII implementation with multiple outputs shown in Figure 3 (as in [15], modified from [16]).

The model parameters of n-channel and p-channel MOSFETs are given in [17], whereas aspect ratios of the CCII MOSFETs are shown in Table 1, and aspect ratios of the MO-CCCA MOSFETs are shown in Table 2.

The CMOS CCII was biased with DC power supply voltages \( V_{DD} = +1.5 \text{ V}, V_{SS} = -1.5 \text{ V}, V_{i} = -0.5 \text{ V}, \) and \( V_{2} = -0.9 \text{ V} \).

To test the input dynamic range of the proposed filters, the simulation of the band-pass filter as an example has

\[
\begin{align*}
\omega_0 & = \frac{1}{\sqrt{C_1 C_2 R_1 R_2}}, \\
BW &= \frac{1}{K C_2 R_2} \cdot Q_o = K \sqrt{\frac{C_1 R_3}{C_2 R_1}} \\
\end{align*}
\]

Figure 3. CMOS realization of the CCII.

Table 1. Aspect ratios of CCII MOSFETs.

<table>
<thead>
<tr>
<th>MOS transistors</th>
<th>W/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M_1 - M_4 )</td>
<td>10/0.35</td>
</tr>
<tr>
<td>( M_5, M_6 )</td>
<td>16/0.35</td>
</tr>
<tr>
<td>( M_7, M_8, M_9 )</td>
<td>16/0.35</td>
</tr>
<tr>
<td>( M_{10}, M_{11}, M_{12}, M_{13}, M_{14}, M_{15}, M_{16}, M_{17}, M_{18} )</td>
<td>30/0.35</td>
</tr>
</tbody>
</table>

Table 2. Aspect ratios of MO-CCCA MOSFETs.

<table>
<thead>
<tr>
<th>MOS transistors</th>
<th>W/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M_1 - M_7 )</td>
<td>9.5/0.55</td>
</tr>
<tr>
<td>( M_4 - M_6, M_{13}, M_{15}, M_{16}, M_{17}, M_{18} )</td>
<td>27.5/1.5</td>
</tr>
<tr>
<td>( M_{19}, M_{20}, M_{21}, M_{22}, M_{23}, M_{24}, M_{25}, M_{26}, M_{27} )</td>
<td>9.5/1.35</td>
</tr>
<tr>
<td>( M_{28}, M_{29}, M_{30}, M_{31} )</td>
<td>4.5/0.7</td>
</tr>
</tbody>
</table>

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been done for a sinusoidal input signal at $f_o = 1$ MHz.

**Figure 5** shows that the input dynamic range of the filter response extends up to amplitude of 105 $\mu$A without significant distortion. The dependence of the output harmonic distortion on the input signal amplitude is illustrated in **Figure 6**. For input signal amplitudes lower than 110 $\mu$A, the total harmonic distortion (THD) is of the order of less than 1% after that rapidly increasing is occurred. The obtained results show that the circuit operates properly even at signal amplitudes of about 120 $\mu$A and THD less than 4%.

To achieve the SIMO type filters with $f_o = 1$ MHz and quality factor of $Q_o = 2$, the component values were selected $K = 2 \left( n = 1, I_s = 25 \ \mu$A, $I_p = 100 \ \mu$A $\right)$, $R_s = R_p = 1 \ k\Omega$ and $C_1 = C_2 = 159 \ pF$. The circuit realizes LP, HP, and BP responses, respectively, at $i_{o1}$, $i_{o2}$ and $i_{o3}$ simultaneously. The frequency responses of Notch and AP can be realized by, respectively, $(i_{o1} + i_{o2})$ and $(i_{o1} + i_{o2} + i_{o3})$. Four filter responses are shown in **Figure 7**.

**Figure 8** shows the simulation results for control of $Q_o$ while keeping $f_o$ fixed (1MHz) with $C_1 = C_2 = 159 \ pF$ for different values of $Q_o$, as shown in **Table 3**. **Figure 9** shows the simulation results for control of $f_o$ while keeping $Q_o = 1$ with $C_1 = C_2 = 53 \ pF$ for different values of $f_o$ as shown in **Table 3**. The current mode band pass filter
Table 3. The $R_1$ and $R_2$ values for controlling of $Q_o$ and $C_1$ and $C_2$ values for controlling $f_o$.

<table>
<thead>
<tr>
<th>$Q_o$</th>
<th>$R_1$ kΩ</th>
<th>$R_2$ kΩ</th>
<th>$f_o$ MHz</th>
<th>$R_1$ kΩ</th>
<th>$R_2$ kΩ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>0.7</td>
<td>1.43</td>
<td>2</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>4</td>
<td>0.5</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 8. Simulation results for control of $Q_o$ while keeping $f_o$ fixed (1 MHz) for band pass filter.

Figure 9. Simulation results for control of $f_o$ while keeping $Q_o = 1$ fixed for band pass filter.

is tested for gain and quality factor tuning while keeping pole frequency constant at 1 MHz. $R_1 = R_2 = 1$ kΩ, $C_1 = C_2 = 159$ pF and $K = 1, 2, 4$ are taken for gain = quality factor = $1, 2, 4$, respectively. The simulated results are shown in Figure 10.

A very good correspondence between design values and values determined from PSPICE simulations is observed, which confirms the workability of the current mode filters realized from the proposed configuration.

4. Concluding Remarks

A new universal MISO/SIMO type current-mode biquad employing two DOCCII, one MOCCCA and four passive grounded elements is proposed in this paper. The purpose of this paper as to introduce a new configuration which although uses exactly same number of active and passive components but in contrast to the circuit of reference [1] realizes a MIMO-type biquad and hence, does not require any additional hardware duplicate/invert current inputs which is required in case of MISO-type filters of [1]. The centre frequency $\omega_o$ can be set by the passive elements of the circuit and the quality factor $Q_o$ is electronically tunable through bias currents of the MOCCCA. Therefore, the biquad filter has independent tenability for the $\omega_o$ and $Q_o$. The active and passive sensitivities $Q_o$ and $\omega_o$ are low.

The workability of the new configuration has been demonstrated by PSPICE simulation results based upon a CMOS CCII in 0.35 μm technology.

REFERENCES


