Cascadable Three-Input Single-Output Current-Mode Universal Filter Using CDBAs

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Abstract-This paper presents the three-input single-output current-mode universal filter using three current differencing buffered amplifiers (CDBAs), two resistors, and two grounded capacitors. By properly selecting the input signals, the filter can realize five standard biquadratic functions, i.e. lowpass, bandpass, highpass, bandstop and allpass current responses from the same circuit topology. The natural frequency $\omega_n$ and the bandwidth $BW$ are independently controllable. No critical matching condition is required for realizing all the filter responses, and all the incremental parameter sensitivities are also low. The performances of the proposed circuit are confirmed by PSPICE simulations.

Keywords: current differencing buffered amplifier (CDBA), universal filter.

I. INTRODUCTION

In recent years, a new active building block, which is called a current differencing buffered amplifier (CDBA), has received much attention. Many applications in active filter design based on CDBA were reported in the literature [1]-[9]. They have been demonstrated that the CDBA is a versatile active building block for voltage- and current-mode signal processing applications. Despite the fact that the current-mode filter with multiple-input and single-output terminals concerning CDBA’s is now available. To the best of our knowledges, only one work proposes a current-mode Kerwin-Huelsman-Newcomb (KHN) biquad circuit using three CDBAs and eight passive elements [8]. Actually, the number of the passive elements employed in this filter realization is rather high. Moreover, the filter does not exhibit a high output impedance, which cannot be cascaded to the next stage directly. Although a cascadable CDBA-based current-mode filter has been proposed recently [9], it requires an additional CDBA and component matching conditions for realizing a highpass response. Therefore, a few applications on the cascadable multiple-input single-output (MISO) current-mode universal filter using CDBAs as active components are available.

In this paper, the CDBA-based MISO current-mode universal biquadratic filter is proposed to show versatility of CDBA in current-mode operation. The proposed circuit configuration with three input and single output terminals employs only three CDBAs, two virtually grounded resistors and two grounded capacitors, which provides the advantage of an integrated circuit (IC) implementation [10]-[11]. The filter can realize five standard biquadratic filtering functions, i.e., lowpass (LP), bandpass (BP), highpass (HP), bandstop (BS) and allpass (AP) from the same configuration by properly selecting the input signals. The circuit also provide the low-impedance inputs and high impedance output which is no problem for the input signal current source and easily cascadable to the next stage without needing additional buffers. For the realization of all the filter responses, no critical component matching condition is required, and both active and passive sensitivities are low. PSPICE simulation results are used to verify the performances of the proposed circuit.

Figure 1. Electrical circuit symbol of the CDBA
II. CIRCUIT DESCRIPTION

An electrical circuit symbol of the CDBA is shown in Fig.1, where p and n are input terminals, and z and w are output terminals. The characteristic equation of this device can be expressed by the following matrix equation.

\[
\begin{bmatrix}
    i_z \\
    v_w \\
    v_p \\
    v_n
\end{bmatrix}
= \begin{bmatrix}
    0 & 0 & 1 & -1 \\
    1 & 0 & 0 & 0 \\
    0 & 0 & 0 & 0 \\
    0 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
    v_z \\
    i_w \\
    i_p \\
    i_n
\end{bmatrix}
\]  \quad (1)

According to above equation, the difference of the input currents \(i_p\) and \(i_n\) at the terminals p and n, respectively, is converted to the output voltage \(v_w\) at the terminal w through an impedance connected at the terminal z. It can be further inferred that the terminal impedances of the p and n terminals are internally grounded.

Fig.2 illustrates the proposed three-input single-output (TISO) cascadable current-mode universal filter, which consists of only three CDBA, two resistors and two grounded capacitors. Since all the capacitors are grounded, thus the circuit is beneficial to an IC implementation \([10]-[11]\). By routine circuit analysis based on equation (1), the current transfer function of the proposed CDBA-based filter can be given by:

\[
I_{\text{out}} = \frac{D(s)I_{\text{in}3} - sR_1C_1I_{\text{in}2} - I_{\text{in}1}}{D(s)} \quad (2)
\]

where \(D(s) = s^33R_1R_2C_1C_2 + sR_1C_1 + 1\).

According to equation (2), if the magnitudes of the input current \(I_{\text{in}1}, I_{\text{in}2}\) and \(I_{\text{in}3}\) are chosen as Table I, then all the standard biquad filtering functions can be obtained. This means that the proposed filter can realize five standard types of the biquadratic filtering functions without any component matching condition requirements.

**TABLE I**

<table>
<thead>
<tr>
<th>Function type</th>
<th>(I_{\text{in}1})</th>
<th>(I_{\text{in}2})</th>
<th>(I_{\text{in}3})</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP</td>
<td>0</td>
<td>(I_w)</td>
<td>(I_w)</td>
</tr>
<tr>
<td>HP</td>
<td>(I_{\text{in}1})</td>
<td>(I_w)</td>
<td>(I_{\text{in}2})</td>
</tr>
<tr>
<td>BP</td>
<td>0</td>
<td>(I_w)</td>
<td>0</td>
</tr>
<tr>
<td>BS</td>
<td>0</td>
<td>(I_w)</td>
<td>(I_{\text{in}2})</td>
</tr>
<tr>
<td>AP</td>
<td>0</td>
<td>2(I_{\text{in}1})</td>
<td>(I_w)</td>
</tr>
</tbody>
</table>

Figure 2. Proposed cascadable TISO current-mode universal filter employing CDBAs

Figure 3. Schematic bipolar implementation of CDBA used in simulations [4].
The natural frequency $\omega_n$ and the bandwidth $BW$ of the proposed filter are found to be

$$\omega_n = \frac{1}{\sqrt{3R Rc C_2}}$$  \hspace{1cm} (3)$$

and

$$BW = \frac{1}{3R C_2}$$  \hspace{1cm} (4)

From equations (3) and (4), it can readily be shown that the $\omega_n$ for all the filter responses can be adjusted by controlling the resistor $R_1$ and/or the capacitor $C_1$ without disturbing the parameter $BW$. Therefore, the filter parameters $\omega_n$ and $BW$ are independently controllable.

III. NON-IDEAL CONSIDERATIONS

The effects of CDBA non-idealities on the filter performance have been now considered in this section. By taking into consideration of the non-ideal CDBAs, the relationship of the terminal currents and voltages given with equation (1) can be rewritten as:

$$\begin{bmatrix} i_z \\ v_w \\ v_p \\ v_n \end{bmatrix} = \begin{bmatrix} 0 & 0 & -\alpha_p & -\alpha_n \\ \beta & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} v_z \\ i_w \\ i_p \\ i_n \end{bmatrix}$$  \hspace{1cm} (5)

where $\alpha_p = 1 - \epsilon_p$ and $\epsilon_p (|\epsilon_p| << 1)$ denotes the current-tracking error from p terminal to z terminal, $\alpha_n = 1 - \epsilon_n$ and $\epsilon_n (|\epsilon_n| << 1)$ represents the current-tracking error from n terminal to z terminal, and $\beta = 1 - \epsilon_v$ and $\epsilon_v (|\epsilon_v| << 1)$ is the voltage-tracking error from z terminal to w terminal of the CDBA. Therefore, considering into account the factors due to the non-idealities of the CDBA given in equation (5), the modified current transfer functions of the proposed filter can be expressed as:

$$I_{out} = \frac{(\alpha_{p3} D_p(s) v_{m3} - (s R C_1 \alpha_p \alpha_{p3} \beta_1) v_{m1} - (\alpha_{p3} \alpha_{p3} \alpha_{p3} \beta_1) v_{m1})}{D_p(s)}$$  \hspace{1cm} (6)

where $D_p(s) = s^3 R_1 R_2 C_1 C_2 + s R C_1 \alpha_{p3} \beta_2 + \alpha_{p3} \alpha_{p3} \beta_1$,

and $\alpha_{p3}$, $\alpha_{p1}$ and $\beta_1$ are the parameters $\alpha_p$, $\alpha_n$ and $\beta$ of the i-th CDBA ($i = 1, 2, 3$), respectively. In this case, the modified parameters $\omega_n$ and $BW$ are given by:

$$\omega_n = \frac{\alpha_{p3} \alpha_{p3} \beta_1 \beta_2}{3 R_1 R_2 C_1 C_2}$$  \hspace{1cm} (7)

and

$$BW = \frac{\alpha_{p3} \beta_1}{3 R_2 C_2}$$  \hspace{1cm} (8)

The incremental passive and active sensitivities are calculated as:

$$S_{\omega_n}^{\omega_n} = \frac{\partial \omega_n}{\partial \alpha_{p3}} = -\frac{\partial \alpha_{p3}}{\partial \alpha_{p1}} = -\frac{\partial \alpha_{p1}}{\partial \alpha_{p2}} = -\frac{\partial \alpha_{p2}}{\partial \alpha_{p3}} = -\frac{\partial \alpha_{p3}}{\partial \beta_1} = -\frac{\partial \beta_1}{\partial \beta_2} = -\frac{\partial \beta_2}{\partial \beta_3} = -\frac{\partial \beta_3}{\partial \beta_1} = -\frac{1}{2}$$  \hspace{1cm} (9)

and

$$S_{BW}^{\omega_n} = \frac{\partial BW}{\partial \alpha_{p1}} = \frac{\partial \alpha_{p1}}{\partial \alpha_{p2}} = \frac{\partial \alpha_{p2}}{\partial \alpha_{p3}} = \frac{\partial \alpha_{p3}}{\partial \beta_1} = \frac{\partial \beta_1}{\partial \beta_2} = \frac{\partial \beta_2}{\partial \beta_3} = \frac{\partial \beta_3}{\partial \beta_1} = 0$$  \hspace{1cm} (10)

It is clearly observed from equations (9)-(12) that the absolute value of all $\omega_n$ and $BW$ sensitivities with respect to $\alpha_{p3}$, $\alpha_{p1}$ and $\beta_1$ are within unity. Thus, the proposed filter exhibits a low sensitivity performance.

IV. SIMULATION RESULTS

To confirm the theoretical analysis, the characteristics of the proposed filter in Fig.2 have been simulated with PSPICE program. For this purpose, PSPICE circuit simulations were performed with AT&T ALA 400-CBIC-R [12] process parameters for a bipolar CDBA realization shown in Fig.3 [4]. The DC supply voltages were chosen as $\pm 1V$ and the DC bias current was $I_B = 100 \mu A$.

![Figure 4. Simulated frequency responses of the proposed CDBA-based universal filter of Figure 2.](image-url)
Fig. 4 shows the simulated frequency responses of the proposed CDBA-based TISO current-mode universal filter with \( R_1 = R_2 = 1 \text{k} \Omega \) and \( C_1 = C_2 = 1 \text{nF} \). This setting leads to obtain the filter responses with \( f_o = \omega_o/2\pi \approx 91.88 \text{kHz} \). It was found from the simulation results that the frequency deviation is 0.78%. These results are found to be in good agreement with the critical values. Fig. 5 and Fig. 6 show the simulated frequency response and the theoretical behavior of the gain and phase characteristics of the AP and BS filters at \( f_o \approx 91.88 \text{kHz} \), which agree very well with the presented theory. It can be observed from all figures that the proposed filter performs all the standard biquadratic filtering functions well.

\[
\begin{align*}
\text{Figure 5. Gain and phase characteristics of the BS filter.} \\
\text{Figure 6. Gain and phase characteristics of the AP filter.}
\end{align*}
\]

V. CONCLUSION

This paper presents a TISO current-mode multifunction biquadratic filter using only three CDBAs, two resistors and two grounded capacitors, which is very suitable for IC implementation. The proposed filter can realize the LP, HP, BP, BS and AP filter responses all at the high impedance output terminal, which allows easy cascading in current-mode operation. The filter also requires no component matching conditions and has low passive and active sensitivities. An orthogonal control between the natural frequency \( \omega_o \) and the parameter \( BW \) is achieved.

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