A Novel Transadmittance-Type KHN-Biquad Employing DO-OTA with Only Two Grounded Capacitors

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Abstract – In this paper, a transadmittance (TA)-type Kerwin-Huelsman-Newcomb (KHN) biquad is proposed. The proposed circuit employs four dual-output operational transadmittance amplifiers (DO-OTAs) as active elements together with two grounded capacitors as passive elements. The circuit simultaneously provides the three basic filter functions, namely bandpass (BP), highpass (HP) and lowpass (LP) functions. The proposed filter offers very high input and output impedances, which is important in the case of interface circuits connecting voltage-mode (VM) to current-mode (CM) circuits. SPICE simulation verification is performed.

Key-Words: - Transadmittance-Mode, KHN-Biquad, DO-OTA.

1 Introduction

In many applications voltage-mode (VM) and current-mode (CM) circuits must be interconnected, which causes some difficulties, and voltage to current converter (V-I) interface circuits are required to overcome these difficulties [1]. During V-I interfacing, it is also possible to perform signal processing at the same time, so that the total effectiveness of the electronic circuitry can be increased. For this purpose transadmittance type filters are needed, which are described as an interface filter circuits connecting VM circuits to CM circuits. One of the most important application areas of the transadmittance filters are in the receiver baseband (BB) blocks of modern radio systems [2].

On the other hand, the well known Kerwin-Huelsman-Newcomb biquad, or KHN-biquad, is a filter circuit, which consists of two integrator and a summing circuits. The KHN filters offer several advantages as low sensitivities, low component spread and good stability behavior [3]. Based on the active elements used in the integrator and summer circuits, several KHN-biquads have been presented in the literature [4-9]. Some of them employ current conveyors, which do not suffer from the limited gain-bandwidth products of the op-amps. Some of these circuits operate in VM. Considering the advantages of the CM circuits, such as relevant wider bandwidth, greater linearity, low power consumption and wider dynamic range [10], some CM KHN-biquads have been presented [6,8]. A Transadmittance- (TA) type single input and three outputs (SITO) multifunction filter is presented in the literature [2]. Although it employs minimum number of active elements (three current conveyors) and its output signals are taken from high impedance output ports, it has the following drawbacks: a) it can not produce notch response directly by adding proper outputs without using additional circuits, b) it has not high input impedance, c) all of its passive elements are not grounded. Another TA-type KHN-biquad filter recently has been reported in the literature that uses three dual-output differential difference current conveyors (DO-DDCCs) with three resistors and two capacitors [9].

In this work, a TA-type KHN-biquad filter employing only four dual-output operational transadmittance amplifiers (DO-OTAs) and only two grounded capacitors is presented. The filter produces its filter responses (bandpass (BP), highpass (HP) and lowpass (LP) responses) simultaneously at high impedance outputs. The notch and the allpass responses can be produced by adding proper outputs directly without using additional circuits. The high input and output impedances of the proposed filter enable easy interfacing between VM and CM circuits. Therefore, the proposed filter has superiorities over the one given in [2]. Another advantage of the proposed circuit is that using only two capacitors, which is the minimum number of capacitors necessary for a biquadretic filter, as passive elements. This makes the proposed filter to be an alternative to the one given in [9]. SPICE simulation results are given to verify the predictions.
2 The Proposed Circuit

The DO-OTA, whose electrical symbol is shown in Figure 1, can be characterized by

\[ I_o = g_m(V_1 - V_2) \]  

(1)

where \( g_m = \frac{I_{SS}}{2V_T} \) is the transconductance of the DO-OTA, \( I_{SS} \) is the bias current of the DO-OTA and \( V_T \) is the thermal voltage.

![Figure 1. Electrical symbol of DO-OTA](image)

A CMOS implementation for the DO-OTA can be given as shown in Figure 2 [11]. Using the terminal relation between the ports of the DO-OTA, the corresponding TA KHN-biquad filter can be implemented as illustrated in Figure 3. It can be observed from Figure 3 that the first and the second DO-OTAs constitute the summer circuit stage and the third and the fourth DO-OTAs are the integrator circuit stages.

The node analysis of the circuit shown in Figure 3 yields the following transadmittance transfer functions for \( g_{m1} = g_{m2} \)

\[
\begin{align*}
I_{HP} &= -\frac{g_{m1}S^2}{V_{in}} + \frac{g_{m1}g_{m3}}{C_1C_2} \quad (2a) \\
I_{BP} &= -\frac{g_{m1}g_{m3}}{C_1} \quad (2b) \\
I_{LP1} &= -\frac{g_{m1}g_{m3}g_{m4}}{C_1C_2} \quad (2c) \\
I_{LP2} &= -\frac{g_{m1}g_{m3}g_{m4}}{C_1C_2} \quad (2d)
\end{align*}
\]

The natural angular frequency and the quality factor of the filter can be expressed respectively as

\[
\omega_o = \sqrt{\frac{g_{m1}g_{m3}}{C_1C_2}}, \quad Q = \sqrt{\frac{g_{m3}C_1}{g_{m1}C_2}}
\]

It should be noted that \( \omega_o \) and \( Q \) are orthogonally adjustable. In addition, the three basic filter functions, namely HP, BP and LP filter functions are obtained simultaneously, all at high impedance outputs. Having high input and output impedances the proposed filter enables easy interfacing between VM and CM circuits. Also, note that the notch and the allpass filter responses can be produced by adding the appropriate output currents (\( I_{HP} \), \( I_{BP} \), \( I_{LP1} \) for the notch response and \( I_{HP} \), \( I_{BP} \), \( I_{LP1} \) for the allpass response) without using additional circuits.

The sensitivity analysis of the proposed circuit show that

\[
S_{g_{m1}} = S_{g_{m2}} = -S_{C_1} = -S_{C_2} = 0.5,
\]

\[
S_{C_1} = -S_{C_2} = -S_{C_3} = 0.5
\]

Thus, the entire sensitivities are low.

3 Simulation Results

The proposed TA KHN-biquad filter circuit is simulated using SPICE program to verify the given theoretical analysis. The DO-OTAs are simulated using the CMOS structure of Figure 2 [11]. The aspect ratios of the MOS transistors of the CMOS DO-OTA are given in Table 1. The device model parameters used for the SPICE simulations are taken from MIETEC 0.5 µm CMOS process. The supply voltages are selected as \( V_{DD} = -V_{SS} = 2.5V \) and the bias current is selected as \( I_{SS} = 50 \mu A \). Simulated gain responses of the basic filter functions (HP, BP and LP) of the proposed TA KHN-biquad circuit are given in Figure 4. For the simulation, equal transconductance values of 270µA/V are taken and the capacitance values of \( C_1 \) and \( C_2 \) are taken as \( C_2 = 2C_1 = 20 \) pF for a natural frequency of \( f_o \approx 3 \) MHz and a quality factor of \( Q = 0.707 \). Thus, the filter realizes the Butterworth type filter response.
Table 1. Transistor aspect ratios of the DO-OTA circuit given in Figure 2

<table>
<thead>
<tr>
<th>TRANSISTOR</th>
<th>W (µm)</th>
<th>L (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1-M2</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>M3-M22</td>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>

From Figure 4 it can be recognized that the theoretical and simulation results are in good agreement. To test the input dynamic range of the filter, the simulation has been repeated for a sinusoidal input signal at $f_o = 3$ MHz. Figure 5 shows that the input dynamic range of the BP response extends up to an amplitude of 0.3 V (peak to peak) without significant distortion in the output current signal that swings approximately between ±40 µA for the DO-OTAs biasing currents of $I_{SS} = 50$ µA.

### 4 Conclusion

In this work, a TA KHN-biquad circuit has been presented. The filter employs four DO-OTAs, and only two capacitors. The proposed filter has the following advantages: a) all the passive elements are grounded, which is important with respect to integrated circuit implementation, b) it provides the basic three filter functions (BP, HP and LP) simultaneously and the notch and the allpass filter responses can be produced directly by adding appropriate outputs without additional circuits, c) the input and all the outputs are taken from high impedance terminals, which is important in interface connection point of view between the VM and CM circuits, d) it enjoys low sensitivities and e) it has a high input dynamic range. The simulation results confirm the theoretical predictions.
Figure 4. Simulated gain responses of the basic filter functions (BP, HP and LP) of the proposed TA KHN-biquad

Figure 5. The output waveform of the BP response for a 3 MHz sinusoidal input voltage of 0.3 V (peak to peak)

References