Differential-Input Buffered and Transconductance Amplifier (DBTA)-Based New Trans-Admittance- and Voltage-Mode First-Order All-Pass Filters

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Abstract

A new general configuration for realization of trans-admittance- and voltage-mode first-order all-pass filters based on differential-input buffered and transconductance amplifier (DBTA) is presented. The proposed generalized configuration is composed of single DBTA and four passive elements, however, the presented four different cases of all-pass filters, derived from the presented general circuit, employ only a single active and three passive elements. It is a first report of trans-admittance- and voltage-mode first-order all-pass filters at the same configuration in the literature. The DBTA is ideal for both modes first-order all-pass filter realizations because of its current and voltage outputs. The proposed circuits are cascadable and suitable for wideband applications. PSPICE simulation results are given to verify the theoretical analysis.

1. Introduction

First-order all-pass filters are widely used to shift the phase of an input signal while keeping the amplitude constant over the frequency range of interest. Therefore, many current- or voltage-mode first-order all-pass filters were researched and reported since 1966 [1-7]. These filters can be utilized for synthesis of high-Q band-pass filter [5] and quadrature [6] or multiphase oscillators [7]. Currently however, more interesting are the trans-admittance filters that are used as an interface connecting oscillator [7]. Currently however, more interesting are the trans-admittance circuits that are used as an interface connecting voltage-mode circuit to a current-mode circuit [8]. One of the most important application areas of trans-admittance-mode filters are the receiver baseband (BB) blocks of modern radio systems. There is no all-pass filter structure in the current technical literature that operates in trans-admittance- and voltage-mode simultaneously. Such filter could be operated in dual mode at the same time.

In [9] and [10] are presented general configurations that have been used for systematic generation of all-pass filters. Six [9] and eight [10] different current-mode all-pass filters have been derived from the presented configurations. This kind of approach requires an exhaustive analysis and time-consuming algebraic manipulations on complicated equations. In this paper, a new general configuration to realize trans-admittance- and voltage-mode first-order all-pass filters using a single differential-input buffered and transconductance amplifier (DBTA) and four passive admittances is presented. By systematic generation mentioned above four various circuits using one capacitor and two conductors has been derived from the proposed configuration. The theoretical results are verified with PSPICE simulations.

2. Proposed DBTA-Based All-Pass Filters

The schematic symbol of the differential-input buffered and transconductance amplifier (DBTA) is shown in Fig. 1 [11, 12]. The element has low-impedance current inputs p, n and high-impedance voltage input y. The difference of the i_p and i_n currents flows into auxiliary terminal z. The voltage v_z on this terminal is transferred into output terminal w using the voltage follower (VF) [13] and also transformed into current using the transconductance g_m of operational transconductance amplifier (OTA) [14], which flows into output terminal x. Relations between the individual terminals of the DBTA can be described by following hybrid matrix:

\[
\begin{bmatrix}
v_p \\
v_z \\
i_p \\
i_n \\
v_r \\
i_r \\
0
\end{bmatrix} =
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
i_p \\
i_n \\
v_r \\
v_z \\
i_r \\
i_r
\end{bmatrix}
\]

The internal structure of DBTA using two second-generation current conveyors (CCII) [11], one VF and one OTA is shown in Fig. 2. It can be also realized by modification of the universal voltage conveyor (UVC) [16-20]. In fact, the input circuitry of the DBTA is the differential current conveyor (DCC) defined by Elwan and Soliman in 1996 [21]. By grounding the y terminal
Expressed in following forms: admittance (TA) and voltage (V) transfer functions that can be given as:

\[ T_{a} (s) = \frac{I_{\text{out}}}{V_{\text{in}}} = g_{m} \frac{Y_{1} - Y_{2} - 2Y_{3}}{Y_{1} + 2Y_{3} + Y_{4}} , \quad (2a) \]

\[ T_{v} (s) = \frac{V_{\text{out}}}{V_{\text{in}}} = \frac{Y_{1} - Y_{2} - 2Y_{3}}{Y_{1} + 2Y_{3} + Y_{4}} . \quad (2b) \]

Selecting of different components for \( Y_{1} \) to \( Y_{4} \) ideally realizes twelve different all-pass filter realizations. Table 1 presents only four most interesting cases in the meaning of integration. From Table 1 it can be seen that all proposed circuits employ three passive elements. All circuits require at least one component-matching condition that might be disadvantage of the proposed circuits, however in current technical literature most of presented first-order all-pass filters also require component-matching such as presented in [2-4, 6, 7, 9, 10]. Other eight possible cases are not presented in this paper since they employ two capacitors or two component-matching conditions are required and they are not attractive for integration.

For further analysis from the Table 1 the circuit no. 3 has been chosen. The selected filter is shown in Fig. 3b. Transfer functions, natural pole frequency, and the matching condition are shown in Table 1 and phase responses of this filter can be given as follows:

\[ \phi_{\omega_1} (\omega) = -2\arctg \left( \frac{\alpha_{C_1}}{G_{1}} \right) , \quad (3a) \]

\[ \phi_{\omega_2} (\omega) = 180^{\circ} - 2\arctg \left( \frac{\alpha_{C_1}}{G_{1}} \right) . \quad (3b) \]

Taking into account the non-idealities of DBTA, the relationship of the terminal currents and voltages given in (1) can be rewritten as:

\[ \begin{bmatrix} v_p \\ v_n \\ i_p \\ i_n \\ v_y \\ v_z \\ i_y \\ i_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & \beta_y & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \beta_y & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \gamma & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \gamma & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} v_p \\ v_n \\ i_p \\ i_n \\ v_y \\ v_z \\ i_y \\ i_z \end{bmatrix} , \quad (4) \]

where \( \beta_{y} = 1 - \epsilon_{v_y} \), \( \alpha_{y} = 1 - \epsilon_{v_y} \) for \( j = p, n \) and \( \gamma = 1 - \epsilon_{v_y} \). Here, \( \epsilon_{v_y} \) and \( \epsilon_{i_y} \) (\( \epsilon_{v_y}, \epsilon_{i_y} \ll 1 \)) denote voltage tracking errors and current tracking errors of DBTA, respectively.

### Table 1. Transfer functions and properties of the circuits

<table>
<thead>
<tr>
<th>Circuit no.</th>
<th>( Y_{1} )</th>
<th>( Y_{2} )</th>
<th>( Y_{3} )</th>
<th>( Y_{4} )</th>
<th>Transfer function ( \frac{V_{\text{out}}}{V_{\text{in}}} )</th>
<th>Transfer function ( \frac{I_{\text{out}}}{V_{\text{in}}} )</th>
<th>Natural pole frequency, ( \omega_{0} )</th>
<th>Matching conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( G_{1} )</td>
<td>( G_{2} )</td>
<td>( sC_{3} )</td>
<td>( \frac{2sC_{3} - G_{3}}{2sC_{3} + G_{3}} )</td>
<td>( \frac{-2sC_{3} - G_{3}}{2sC_{3} + G_{3}} )</td>
<td>( \frac{G_{1}}{2C_{3}} )</td>
<td>( G_{1} = 2G_{2} )</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>( G_{1} )</td>
<td>( sC_{2} )</td>
<td>( G_{3} )</td>
<td>( \frac{sC_{2} - 2G_{3}}{sC_{2} + 2G_{3}} )</td>
<td>( \frac{-2sC_{2} - 2G_{3}}{sC_{2} + 2G_{3}} )</td>
<td>( \frac{2G_{1}}{C_{3}} )</td>
<td>( G_{1} = 4G_{3} )</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>( G_{1} )</td>
<td>( sC_{2} )</td>
<td>( \frac{G_{3}}{sC_{2} + G_{3}} )</td>
<td>( sC_{2} - G_{3} )</td>
<td>( \frac{-G_{1}}{sC_{2} + G_{3}} )</td>
<td>( \frac{G_{1}}{C_{3}} )</td>
<td>( G_{1} = G_{4} )</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>( G_{1} )</td>
<td>( \frac{2sC_{3} - G_{3}}{2sC_{3} + G_{3}} )</td>
<td>( \frac{-2sC_{3} - G_{3}}{2sC_{3} + G_{3}} )</td>
<td>( \frac{G_{1}}{2C_{3}} )</td>
<td>( G_{1} = G_{4} )</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The proposed all-pass filter transfer functions become:

\[ T_{pa1}(s) = \frac{I_{out}}{V_n} = \frac{\alpha_2 \beta_2 C_2}{\alpha_p \gamma C_p + G_i}, \]  

(5a)

\[ T_{pa2}(s) = \frac{I_{out}}{V_n} = \frac{\alpha_2 \beta_2 C_2}{\alpha_p \gamma C_p + G_i}. \]  

(5b)

The non-ideal natural pole frequency \( \omega_0 \) can be expressed as:

\[ \omega_0 = \frac{G_i}{\alpha_p \gamma C_p}. \]  

(6)

The active and passive sensitivities of \( \omega_0 \) (6) for Fig. 3b are:

\[ S_{\omega_0}^a = S_{\omega_0}^p = 1, \quad S_{\omega_0}^{\alpha_2,\beta_2,\gamma} = 0. \]  

(7a,b)

From Eq. (7) it can be seen that all the active and passive sensitivities are not higher than unity in relative amplitude.

3. Simulation Results

The bipolar implementation of the DBTA is shown in Fig. 4 [11]. The DCC is formed by transistors \( Q_1 - Q_{29} \), transistors \( Q_{30} - Q_{35} \) form the VF, and the OTA consists of transistors \( Q_{36} - Q_{39} \). In the design the transistor model parameters NR100N (NPN) and PR100N (PNP) of bipolar arrays ALA400 from AT&T [28] were used with the DC supply voltages of \( +V_{CC} = -V_{EE} = 2 \) V. Bias current \( I_B = 400 \mu A \) has been chosen. The transconductance \( g_m \) of the DBTA can be adjusted by current \( I_B = 2g_mV_T \), where \( V_T \) is thermal voltage (approximately 26mV at 27°C).

The maximum values of terminal voltages and terminal currents without producing significant distortion are computed as \( \pm 365 \) mV and \( \pm 605 \) \( \mu \)A, respectively. The DC voltage gains \( \beta_p \equiv \beta_n \equiv 0.961 \) and \( \gamma \equiv 0.962 \) with bandwidths \( f_{bp} \equiv f_{bn} \equiv 381.1 \) MHz and \( f_i \equiv 417.1 \) MHz. The DC current gains \( \alpha_p \equiv \alpha_n \equiv 0.989 \) with bandwidths \( f_{mp} \equiv 170.9 \) MHz and \( f_{mn} \equiv 173.9 \) MHz. The OTA shows the transconductance \( g_m \equiv 0.951 \) mS with the bandwidth \( f_{gm} \equiv 85.8 \) MHz.

The behaviour of the proposed all-pass filter, shown in Fig. 3b, has been verified by PSPICE simulations. The passive element values were selected as: \( C_2 = 120 \) pF, \( R_1 = R_4 = 13.3 \) k\( \Omega \), and the transconductance \( g_m = 1 \) mS (\( I_B = 52 \) \( \mu \)A), which results in a 90° phase shift at \( f_0 \equiv 100 \) kHz. The magnitude and phase characteristics of the simulated circuit are shown in Fig. 5. From the results it can be seen that both the magnitude and phase
characteristics of the proposed trans-admittance- and voltage-mode all-pass filter are in good agreement with theory.

4. Conclusions

General configuration of a first-order filter using single DBTA has been presented. The advantage of the newly proposed structure is that it allows to realize trans-admittance- and voltage-mode responses simultaneously. Twelve different types of all-pass filters were derived from the presented general circuit, while only four most interesting in meaning of integration are presented. Moreover, they can be operated in cascaded form. The active and passive sensitivities of the filter example are low. PSPICE simulation results are in good agreement with the theoretical analysis and support the feasibility of the proposed circuit and also of the DBTA.

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6. References


