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 circuits that are used as an interface connecting a 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:

$$\begin{bmatrix} v_p \\ v_n \\ i_y \\ i_z \\ v_w \\ i_x \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & g_m & 0 & 0 \end{bmatrix} \begin{bmatrix} i_p \\ i_n \\ v_y \\ v_z \\ i_w \\ v_x \end{bmatrix}. \quad (1)$$

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

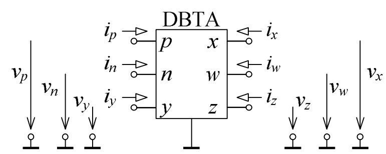

Fig. 1. Schematic symbol of DBTA

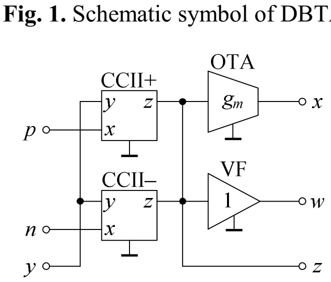

Fig. 2. Internal structure of DBTA

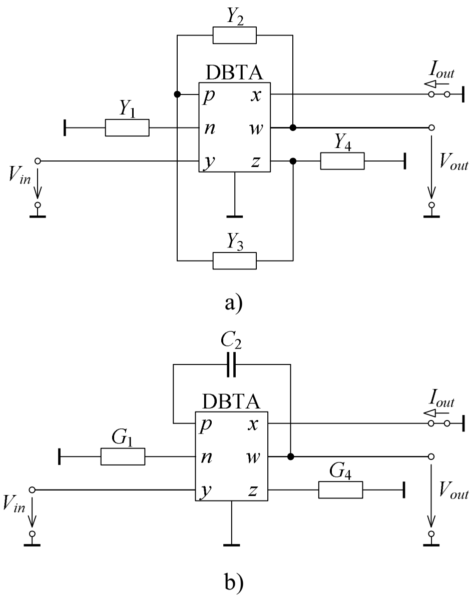

Fig. 3. a) The proposed general configuration for realizing all-pass filters, b) filter design example no. 3 for analysis

it is reduced to another active building block called modified differential current conveyor (MDCC) [21], which is a simplification of the DCC. In very few publications the MDCC is also called current differencing unit (CDU) [22].

In other meaning the DBTA is a "universal" active element. By connecting or grounding suitable terminals it helps to realize other foregoing active elements such as the current differencing buffered amplifier (CDBA) [23] also known as the plus-type differential current voltage conveyor (DCVC+) [24], or the differential-input current feedback amplifier (DCFA) [25], which is a slight modification of CDBA, the current differencing transconductance amplifier (CDTA) [26], or the plus-type first- and second-generation voltage conveyors (VCI+, VCII+) [16, 27], and also their inverting versions IVCI+, IVCII+ [27], and others. In the future we expect that the DBTA helps to define novel types of voltage conveyors, especially the first-generation differential current voltage conveyors (DCVCIs).

The proposed general configuration for realizing all-pass filters is shown in Fig. 3a. The circuit is composed of a DBTA and four passive admittances. Routine analysis yields the trans-admittance (TA) and voltage (V) transfer functions that can be expressed in following forms:

$$T_{TA}(s) = \frac{I_{out}}{V_{in}} = g_m \frac{Y_1 - Y_2 - 2Y_3}{Y_2 + 2Y_3 + Y_4}, \tag{2a}$$

$$T_V(s) = \frac{V_{out}}{V_{in}} = -\frac{Y_1 - Y_2 - 2Y_3}{Y_2 + 2Y_3 + Y_4}. \tag{2b}$$

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:

$$\varphi_{TA3}(\omega) = -2\mathrm{arctg}\left(\frac{\omega C_2}{G_1}\right), \tag{3a}$$

$$\varphi_{V3}(\omega) = 180° - 2\mathrm{arctg}\left(\frac{\omega C_2}{G_1}\right). \tag{3b}$$

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

$$\begin{bmatrix} v_p \\ v_n \\ i_y \\ i_z \\ v_w \\ i_x \end{bmatrix} = \begin{bmatrix} 0 & 0 & \beta_p & 0 & 0 & 0 \\ 0 & 0 & \beta_n & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ \alpha_p & -\alpha_n & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \gamma & 0 & 0 \\ 0 & 0 & 0 & g_m & 0 & 0 \end{bmatrix} \begin{bmatrix} i_p \\ i_n \\ v_y \\ v_z \\ i_w \\ v_x \end{bmatrix}, \tag{4}$$

where $\beta_j = 1 - \varepsilon_{vj}$, $\alpha_j = 1 - \varepsilon_{ij}$ for $j = p$, n and $\gamma = 1 - \varepsilon_v$. Here, ε_{vj} and ε_v ($|\varepsilon_{vj}|$, $|\varepsilon_v| \ll 1$) denote voltage tracking errors and ε_{ij} ($|\varepsilon_{ij}| \ll 1$) denote current tracking errors of DBTA, respectively.

Table 1. Transfer functions and properties of the circuits

Circuit no.	Y_1	Y_2	Y_3	Y_4	Transfer function V_{out}/V_{in}	Transfer function I_{out}/V_{in}	Natural pole frequency, ω_0	Matching conditions
1	G_1	G_2	sC_3	–	$\frac{2sC_3 - G_2}{2sC_3 + G_2}$	$-g_m \frac{2sC_3 - G_2}{2sC_3 + G_2}$	$\frac{G_2}{2C_3}$	$G_1 = 2G_2$
2	G_1	sC_2	G_3	–	$\frac{sC_2 - 2G_3}{sC_2 + 2G_3}$	$-g_m \frac{sC_2 - 2G_3}{sC_2 + 2G_3}$	$\frac{2G_3}{C_2}$	$G_1 = 4G_3$
3	G_1	sC_2	–	G_4	$\frac{sC_2 - G_1}{sC_2 + G_1}$	$-g_m \frac{sC_2 - G_1}{sC_2 + G_1}$	$\frac{G_1}{C_2}$	$G_1 = G_4$
4	G_1	–	sC_3	G_4	$\frac{2sC_3 - G_1}{2sC_3 + G_1}$	$-g_m \frac{2sC_3 - G_1}{2sC_3 + G_1}$	$\frac{G_1}{2C_3}$	$G_1 = G_4$

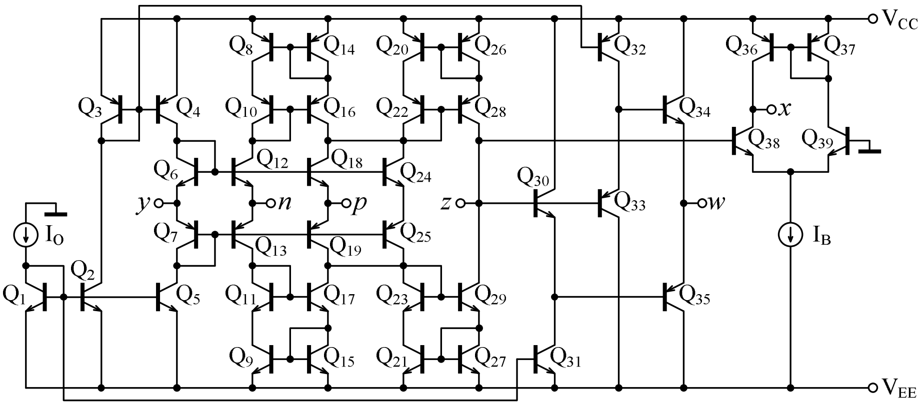

Fig. 4. Used bipolar implementation of the DBTA

The proposed all-pass filter transfer functions become:

$$T_{TA3}(s) = \frac{I_{out}}{V_{in}} = -g_m \frac{\alpha_p \beta_p s C_2 - \alpha_n \beta_n G_1}{\alpha_p \gamma s C_2 + G_1}, \tag{5a}$$

$$T_{V3}(s) = \frac{V_{out}}{V_{in}} = \frac{\alpha_p \beta_p \gamma s C_2 - \alpha_n \beta_n \gamma G_1}{\alpha_p \gamma s C_2 + G_1}. \tag{5b}$$

The non-ideal natural pole frequency ω_0 can be expressed as:

$$\omega_0 = \frac{G_1}{\alpha_p \gamma C_2}. \tag{6}$$

The active and passive sensitivities of ω_0 (6) for Fig. 3b are:

$$S_{G_1}^{\omega_p} = -S_{\alpha_p,\gamma,C_2}^{\omega_p} = 1, \quad S_{\alpha_n,\beta_p,\beta_n,g_m}^{\omega_p} = 0. \tag{7a,b}$$

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 $I_O = 400$ µA 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 ±365 mV and ±605 µA, respectively. The DC voltage gains $\beta_p \cong \beta_n \cong 0.961$ and $\gamma \cong 0.962$ with bandwidths $f_{\beta p} \cong f_{\beta n} \cong 381.1$ MHz and $f_\gamma \cong 417.1$ MHz. The DC current gains $\alpha_p \cong \alpha_n \cong 0.989$ with bandwidths $f_{\alpha p} \cong 170.9$ MHz and $f_{\alpha n} \cong 173.9$ MHz. The OTA shows the transconductance $g_m \cong 0.951$ mS with the bandwidth $f_{gm} \cong 85.8$ 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, $R_1 = R_4 = 13.3$ kΩ and the transconductance $g_m = 1$ mS ($I_B = 52$ µA), which results in a 90° phase shift at $f_0 \cong 100$ 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

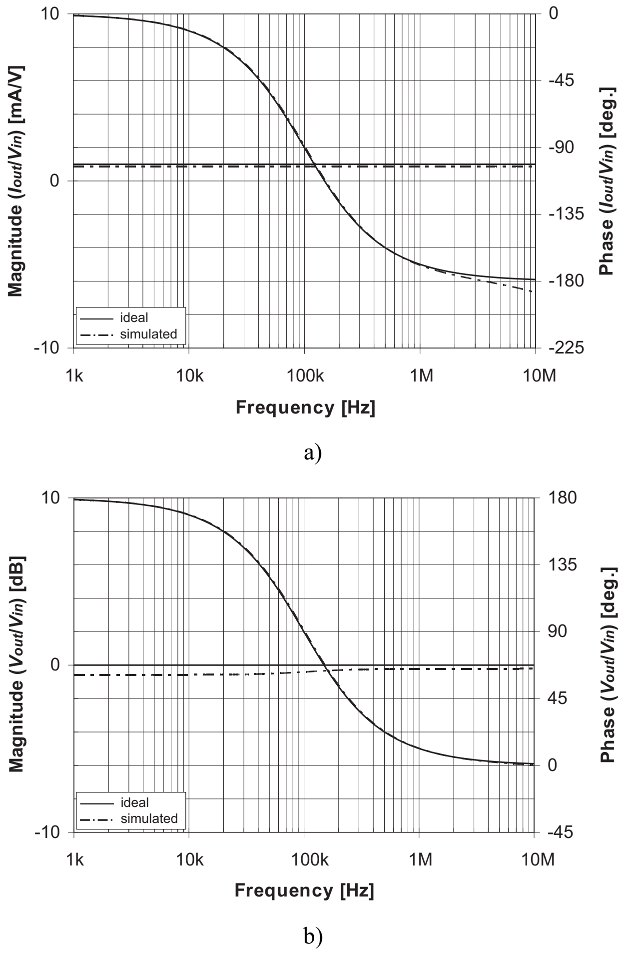

Fig. 5. The magnitude and phase characteristics of the proposed a) non-inverting type trans-admittance- and b) inverting type voltage-mode first-order all-pass filter

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.

5. Acknowledgment

This work has been supported by the Czech Science Foundation project GACR 102/09/1681 and Ministry of Education of the Czech Republic project No. MSM0021630513.

The authors also would like to thank the anonymous reviewer for his helpful comments, which substantially improved the quality of this paper.

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