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The conception of differential-input buffered and transconductance amplifier (DBTA) and its application

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Abstract: In this paper, a novel versatile active building block the differential-input buffered and transconductance amplifier (DBTA) is proposed. The application of the newly defined active function block is shown on the design of voltage-mode (VM), multi-input and single-output (MISO)-type multifunction biquad, employing single DBTA and five passive elements. Proposed VM filter structure can realize four filter functions i.e., low- (LP), band- (BP), high-pass (HP) and band-stop (BS) without changing the circuit topology and enables independent control of the quality factor Q using single passive element. Theoretical results are verified by PSPICE simulations using a BJT realization of DBTA.

Keywords: active filters, analog signal processing, DBTA, voltage-mode

Classification: Electron devices, circuits, and systems

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1 Introduction

With the increasing emphasis on the voltage-mode (VM) multifunction biquad filters using single element [1, 2, 3, 4, 5] (i.e. that can realize several circuit functions simultaneously such as low-, band-, high-pass, and band-stop filter response), there is a need to develop new biquad filters with new active elements that offer new advantages [6]. These blocks are the most often used as anti-aliasing filters in the analog sections of high-speed data communication systems defined by ITU standards or for signal processing in cable modems described by IEEE 802.11, 802.16 standards, in hard-drive communication interfaces, in regulation and measurement techniques, in electro acoustics, in automobile industry or in piezoresistive pressure sensors [7]. The structures discussed in [1, 2, 3, 4, 5] employ CFA (current-feedback amplifier), UVC (universal voltage conveyor), CDBA (current differencing buffered amplifier), OTRA (operational transresistance amplifier), and DDCC (differential difference current conveyor) as active element.

Here, we described a novel active element, the DBTA (differential-input buffered and transconductance amplifier), and its possible usage for the design of the voltage-mode (VM) multi-input and single-output (MISO)-type biquad. The proposed frequency filter has been simulated using PSPICE to verify the theoretical analysis.

2 Circuit description

The schematic symbol and the ideal behavioural model of the DBTA are shown in Fig. 1 (a)-(b). It has low-impedance current inputs p, n and high-impedance voltage input y. The difference of the i_{p} and i_{n} currents flows from auxiliary terminal z. The voltage v_{z} on this terminal is transferred into

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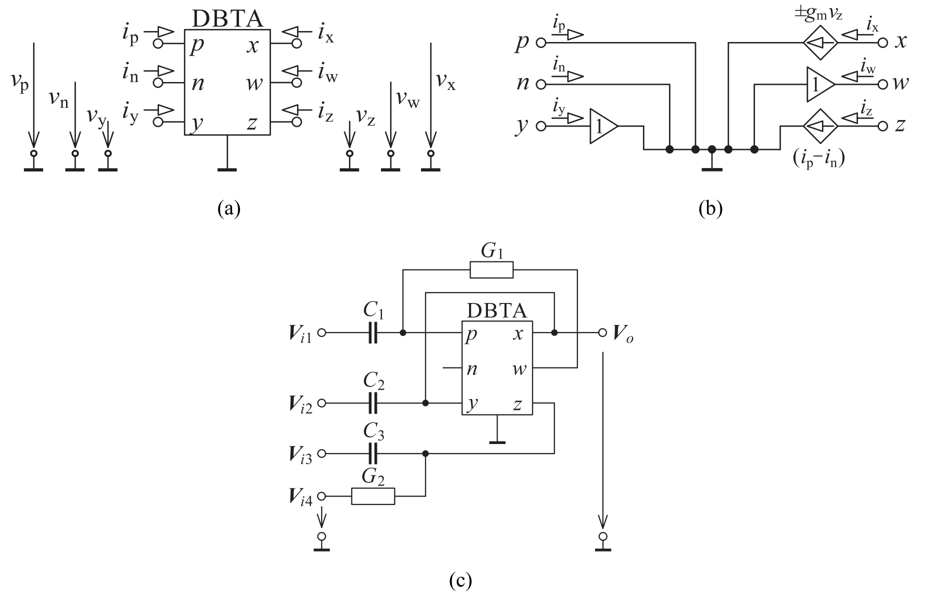

Fig. 1. (a) Schematic symbol and (b) behavioural model of the DBTA, (c) the proposed VM biquad.

output terminal w using the voltage follower (VF) [8] and also transformed into current using the transconductance g_{m}, which flows into output terminal x. Relations between the individual terminals of the DBTA can be described by following hybrid matrix:

$$\begin{bmatrix} v_{\mathrm{p}} \\ v_{\mathrm{n}} \\ i_{\mathrm{y}} \\ i_{\mathrm{z}} \\ v_{\mathrm{w}} \\ i_{\mathrm{x}} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & \pm g_{\mathrm{m}} & 0 & 0 \end{bmatrix} \begin{bmatrix} i_{\mathrm{p}} \\ i_{\mathrm{n}} \\ v_{\mathrm{y}} \\ v_{\mathrm{z}} \\ i_{\mathrm{w}} \\ v_{\mathrm{x}} \end{bmatrix}. \tag{1}$$

The application of the newly defined DBTA is shown on the design of MISO-type VM biquad, employing single DBTA and five passive elements. All capacitors in the structure are generally grounded. The use of grounded capacitors is ideal for integration [9].

The output voltage $\boldsymbol{V}_o$ of the proposed circuit in Fig. 1 (c) is given as follows:

$$\boldsymbol{V}_o = \frac{\boldsymbol{s}C_1 g_{\mathrm{m}} \boldsymbol{V}_{i1} + \left(\boldsymbol{s}^2 C_2 C_3 + \boldsymbol{s} C_2 G_2 - \boldsymbol{s} C_2 G_1\right) \boldsymbol{V}_{i2} + \boldsymbol{s} C_3 g_{\mathrm{m}} \boldsymbol{V}_{i3} + G_2 g_{\mathrm{m}} \boldsymbol{V}_{i4}}{\boldsymbol{s}^2 C_2 C_3 + \boldsymbol{s}\left(C_1 g_{\mathrm{m}} + C_2 G_2 - C_2 G_1\right) + G_1 g_{\mathrm{m}}}. \tag{2}$$

The proposed circuit requires component matching condition $G_1 = G_2$. From (2), we can see that:

(i) If $\boldsymbol{V}_{i2} = \boldsymbol{V}_{i3} = \boldsymbol{V}_{i4} = 0$ (grounded), a second-order band-pass filter (BP1) can be obtained with $\boldsymbol{V}_o/\boldsymbol{V}_{i1}$;

(ii) If $\boldsymbol{V}_{i1} = \boldsymbol{V}_{i3} = \boldsymbol{V}_{i4} = 0$ (grounded), a second-order high-pass filter (HP) can be obtained with $\boldsymbol{V}_o/\boldsymbol{V}_{i2}$;

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(iii) If $\boldsymbol{V}_{i1} = \boldsymbol{V}_{i2} = \boldsymbol{V}_{i4} = 0$ (grounded), a second-order band-pass filter (BP2) can be obtained with $\boldsymbol{V}_o/\boldsymbol{V}_{i3}$;

(iv) If $\boldsymbol{V}_{i1} = \boldsymbol{V}_{i2} = \boldsymbol{V}_{i3} = 0$ (grounded), a second-order low-pass filter (LP) can be obtained with $\boldsymbol{V}_o/\boldsymbol{V}_{i4}$;

(v) If $\boldsymbol{V}_{i1} = \boldsymbol{V}_{i3} = 0$ (grounded) and $\boldsymbol{V}_{i2} = \boldsymbol{V}_{i4} = \boldsymbol{V}_{in}$, a second-order band-stop filter (BS) can be obtained with $\boldsymbol{V}_o/\boldsymbol{V}_{in}$.

Thus, the circuit is capable of realizing low-, band-, high-pass, and band-stop filter responses. If the band-pass responses ($\boldsymbol{V}_{i1}$ or $\boldsymbol{V}_{i3}$) are inverted, than by adding up to $\boldsymbol{V}_{o2}$ and $\boldsymbol{V}_{o4}$ all-pass filters can be obtained. The circuit requires the minimum number of active and passive elements. For all filters the characteristic frequency ω_0 and quality factor Q derived from the denominator of (2) are:

$$\omega_0 = \sqrt{\frac{G_1 g_{\mathrm{m}}}{C_2 C_3}},\ Q = \frac{\sqrt{C_2 C_3 G_1 g_{\mathrm{m}}}}{C_1 g_{\mathrm{m}} + C_2\left(G_2 - G_1\right)}. \tag{3a, b}$$

In case of component matching condition $G_1 = G_2$, the (3b) changes to form:

$$Q = \frac{1}{C_1}\sqrt{\frac{C_2 C_3 G_1}{g_{\mathrm{m}}}}. \tag{4}$$

From the equations (3a) and (4) it is evident that the quality factor Q can be controlled independently of characteristic frequency ω_0 by adjusting the capacitor C_1, which is particular advantage of the proposed circuits.

A sensitivity study forms an important index of the performance of any active network. The active and passive sensitivities of the proposed circuit derived from (3a) and (4) are given as:

$$\begin{aligned} &S^{\omega_0}_{G_1, g_{\mathrm{m}}} = -S^{\omega_0}_{C_2, C_3} = \frac{1}{2},\ S^{\omega_0}_{C_1, G_2} = 0, \\ &S^{Q}_{C_2, G_3, G_1} = -S^{Q}_{g_{\mathrm{m}}} = \frac{1}{2},\ S^{Q}_{C_1} = -1,\ \ S^{Q}_{G_2} = 0. \end{aligned} \tag{5}$$

From the results it is evident that the sensitivities are low and not larger than unity in absolute value.

Taking into account the non-idealities of the DBTA, the (1) can be rewritten as $i_{\mathrm{y}} = 0$, $v_{\mathrm{p}} = \beta_{\mathrm{p}} v_{\mathrm{y}}$, $v_{\mathrm{n}} = \beta_{\mathrm{n}} v_{\mathrm{y}}$, $i_{\mathrm{z}} = \alpha_{\mathrm{p}} i_{\mathrm{p}} - \alpha_{\mathrm{n}} i_{\mathrm{n}}$, $v_{\mathrm{w}} = \gamma v_{\mathrm{z}}$, $i_{\mathrm{x}} = \pm g_{\mathrm{m}} v_{\mathrm{z}}$, where $\alpha_{\mathrm{p}} = 1 - \varepsilon_{\mathrm{i}}$, $\alpha_{\mathrm{n}} = 1 - \varepsilon_{\mathrm{i}}$ and ε_{i} ($|\varepsilon_{\mathrm{i}}| \langle\langle\ 1$) are the current tracking error from p and n terminals to z terminal, $\beta_{\mathrm{p}} = 1 - \varepsilon_{\mathrm{v}}$, $\beta_{\mathrm{n}} = 1 - \varepsilon_{\mathrm{v}}$ and ε_{v} ($|\varepsilon_{\mathrm{v}}| \langle\langle\ 1$) are the input voltage tracking error from p and n terminals to z terminal and $\gamma = 1 - \varepsilon_{\mathrm{v}}$ and ε_{v} ($|\varepsilon_{\mathrm{v}}| \langle\langle\ 1$) is output voltage tracking error from z terminal to w terminal of DBTA, respectively. The transconductance $g_{\mathrm{m}i}$ of the OTA with the non-idealities can be assumed as [10] $g_{\mathrm{m}i} = g_{\mathrm{m}i}\omega_{gi} \ / \ (\boldsymbol{s} + \omega_{gi}) \cong g_{\mathrm{m}i}\ (1 - \mu_i \boldsymbol{s})$, where ω_{gi} is the first-pole of the OTA and $\mu_i = 1/\omega_{gi}$. Taking into account non-idealities of the DBTA

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mentioned above, the denominator of (2) becomes:

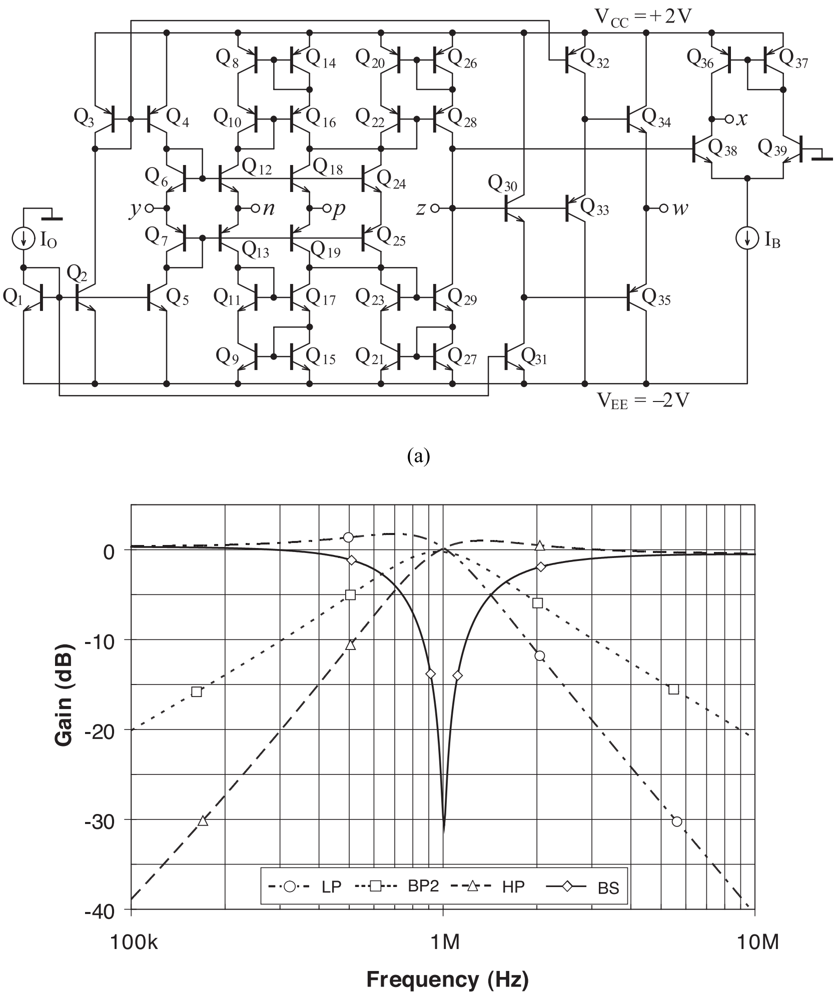
$$\boldsymbol{D} = \boldsymbol{s}^2 C_2 C_3 \left(1 - \frac{\mu C_1 g_{\mathrm{m}}}{\alpha_{\mathrm{p}} \alpha_{\mathrm{n}} \beta_{\mathrm{p}} C_2 C_3}\right) + \boldsymbol{s} C_1 g_{\mathrm{m}} \left[1 - \frac{\alpha_{\mathrm{p}} \alpha_{\mathrm{n}} G_1 (\gamma C_2 + \beta_{\mathrm{p}} \mu g_{\mathrm{m}}) - C_2 G_2}{\alpha_{\mathrm{p}} \alpha_{\mathrm{n}} \beta_{\mathrm{p}} C_1 g_{\mathrm{m}}}\right] + G_1 g_{\mathrm{m}} = 0. \tag{6}$$

Due to the parasitic effect, the characteristic departs from the ideal responses. But, the parasitic effect can be made negligible satisfying the following condition:

$$\frac{\mu C_1 g_{\mathrm{m}}}{\alpha_{\mathrm{p}} \alpha_{\mathrm{n}} \beta_{\mathrm{p}} C_2 C_3} \ll 1, \quad \frac{\alpha_{\mathrm{p}} \alpha_{\mathrm{n}} G_1 (\gamma C_2 + \beta_{\mathrm{p}} \mu g_{\mathrm{m}}) - C_2 G_2}{\alpha_{\mathrm{p}} \alpha_{\mathrm{n}} \beta_{\mathrm{p}} C_1 g_{\mathrm{m}}} \ll 1. \tag{7}$$

3 Simulation results

The behaviour of the proposed VM biquad has been verified by PSPICE simulations. Used internal structure of the DBTA is shown in Fig. 2 (a). The



(a)

(b)

Fig. 2. (a) Used bipolar implementation of the DBTA, (b) simulated frequency characteristics for LP, BP2, HP, and BS responses of the proposed circuit of Fig. 1 (c) in voltage mode.

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differential-input stage is formed by transistors $Q_1 - Q_{29}$, transistors $Q_{30} - Q_{35}$ represent a voltage follower (VF) [8], and the operational transconductance amplifier (OTA) [11] 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 [12] were used. Bias current $I_O = 400\,\mu$A has been chosen. The transconductance g_{m} of DBTA can be adjusted by current $I_{\mathrm{B}} = g_{\mathrm{m}}/20$.

For the characteristic frequency $f_0 = \omega_0/2\pi \cong 1\,$MHz and the quality factor of filters $Q = 1$ the following passive component values have been chosen: $C_1 = C_2 = C_3 = 60.4\,$pF, $G_1 = G_2 = 0.402\,$mS ($R_1 = R_2 = 2490\,\Omega$) and $g_{\mathrm{m}} = 0.4\,$mS ($I_{\mathrm{B}} = 20\,\mu$A). The simulation results of the low-, band-, high-pass, and band-stop filter working in voltage-mode are shown in Fig. 2 (b). From the simulation results it is evident that the final solution corresponds to the theoretical expectations.

4 Conclusion

A new versatile active function block for analog signal processing, namely the DBTA (differential-input buffered and transconductance amplifier) has been introduced. A new MISO-type VM biquad using single DBTA and five passive elements has been presented. All capacitors are virtually grounded in the structure. The use of only grounded capacitors is ideal for integrated circuit implementation [9]. The proposed circuit enables to realize the low-, band-, high-pass, and band-stop response without changing the circuit topology. The independent control of the quality factor Q using single grounded capacitor is possible, which can be advantageous in some applications. The behaviour of the proposed filter has been verified by PSPICE simulations. Corresponding bipolar implementation of the DBTA has been also presented.

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