Modified Buffered Transconductance Amplifier for analog signal processing

Dalibor BIOLEK[1], *Viera BIOLKOVÁ*[2]

[1] Dept. of Electrical Engineering/Microelectronics, University of Defence/Brno University of Technology, Kounicova 65/Údolní 53, 612 00 Brno, Czech Republic
[2] Dept. of Radio Electronics, Brno University of Technology, Purkyňova 118, 612 00 Brno, Czech Republic

dalibor.biolek@unob.cz, biolkova@feec.vutbr.cz

Abstract. *A new active element for analog signal processing, namely the Current Inverter Buffered Differential Input Transconductance Amplifier (CIBDITA), is proposed. It combines some features of the well–known current differencing buffered and transconductance amplifiers, simplifies their current input stage, and increases their universality by introducing an additional voltage–type input. The usefulness of this new element is demonstrated on the example of a 2nd–order filter which employs only one active element, two grounded capacitors, and one resistor.*

Keywords

Current Differencing Buffered Amplifier, Current Differencing Transconductance Amplifier, Current Inverter Buffered Transconductance Amplifier, voltage mode.

1. Introduction

In the last decade, the number of publications, dealing with new circuit principles of active blocks for analog signal processing, has continuously been growing. In addition to the Current Differencing Buffered Amplifier (CDBA) [1], the Current Differencing Transconductance Amplifier (CDTA) has been proposed [2]. The versatility of these circuit elements consists in their identical input stage, the so-called Current Differencing Unit (CDU), which provides the difference of two input currents I_p and I_n, flowing to the low-impedance terminals *p* and *n*. This difference current $I_z = I_p - I_n$ flows out of the device through the high-impedance *z* terminal. The corresponding voltage drop on the external impedance is subsequently processed by voltage buffer for the CDBA or by multi-output Operational Transconductance Amplifier (OTA) for the CDTA. In this way, either the output voltage or currents are available, but not both of them simultaneously.

The versatility of the CDU consists in the possibility of easy implementation of both non–inverting and inverting integrators which are the building blocks of active filters, as well as in the elegant selection of the type of the feedback (negative or positive). However, in some applications, the capabilities of CDBA or CDTA are not fully utilized in the cases when one of the *p* and *n* terminals is not used [3–8]. The CDU could then be simplified to a current follower (CF) or inverter (CI). As shown in [9], the absence of differential input can be compensated by utilizing the *x*–currents of the conventional CDTA with both polarities. The transformation of CDU into CF or CI can then be of high practical importance, since the resulting topology of the active element is more economical. Such elements are called CFBA (Current Follower Buffered Amplifier), CIBA (Current Inverter Buffered Amplifier), CFTA (Current Follower Transconductance Amplifier), and CITA (Current Inverter Transconductance Amplifier) [9].

This paper starts from the above idea of replacing the CDU by CF or CI. To improve the universality of the active element towards an easy implementation of frequency filters operating in the mixed voltage–current modes, both the current– and the voltage–types of output signals should be available. This requirement is solved via combining the OTA and voltage follower as the output devices. The second requirement consists in the possibility of processing both the current– and voltage–type input signals. It can be easily accomplished by utilizing the inverting input of the internal OTA, which is grounded in the conventional CDTA, as an additional terminal. According to the methodology introduced in [9], let us call this element CFBDITA (Current Follower Buffered Differential Input Transconductance Amplifier) or CIBDITA (Current Inverter Buffered Differential Input Transconductance Amplifier). As shown below, the latter implementation from commercial integrated circuits (ICs) is more economical. That is why the following text is focused on CIBDITA. The conclusions are also valid for CFBDITA accordingly.

2. Circuit description

The schematic symbol and behavioral model of the CIBDITA are shown in Figs 1 (a) and (b). Note that the number of x–type current outputs of the internal OTA as well as the directions of the output currents are arbitrary, depending on the concrete application.

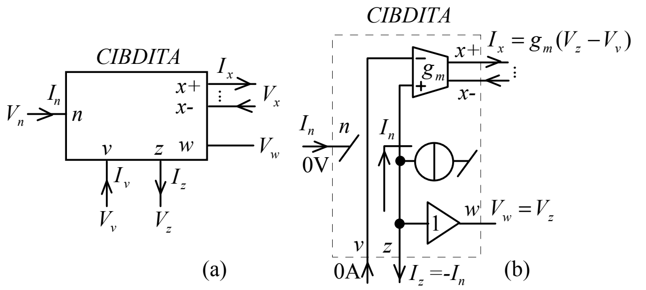

Fig. 1. Current Inverter Buffered Differential Input Transconductance Amplifier: (a) schematic symbol, (b) behavioral model.

The CIBDITA is described by the following set of circuit equations:

$$\begin{pmatrix} I_z \\ V_w \\ I_x \\ V_n \\ I_v \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & -1 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ g_m & 0 & 0 & 0 & -g_m \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} V_z \\ I_w \\ V_x \\ I_n \\ V_v \end{pmatrix} \quad (1)$$

It can be concluded from Eq. (1) that CIBDITA has low–impedance terminals n and w and high-impedance terminals z and x. The input terminals n and v serve potentially for driving the circuit by current and voltage types of input signals whereas the output terminals x and w provide the outputs of current and voltage types. An external circuitry, connected to the z terminal, which is largely a two-terminal passive component, co–defines the input–to–output gains.

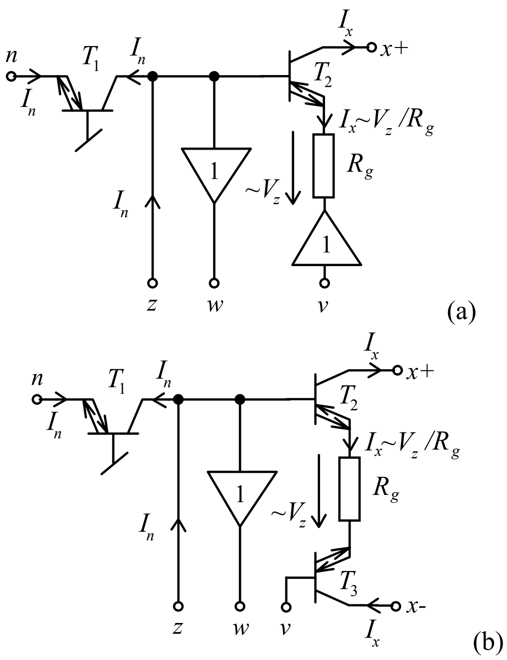

Fig. 2. CIBDITA implementations using diamond transistors OPA860 with: (a) single, (b) differential x–type outputs.

A possible implementation of single x–output CIBDITA using diamond transistors OPA860 [10] is shown in Fig. 2 (a). Each OPA860 contains one diamond transistor, which behaves like the current-controlled current conveyor CC–CCII+ [11], and one unity-gain buffer. The input conductivity of the n terminal is equal to the internal transconductance of T_1, which is approximately $g_{mT1} \approx 100$ mA/V for a proper biasing current [10]. The current I_n is transferred by T_1 to the collector as shown in Fig. 2. T_2 together with the voltage buffer in its emitter area serves as differential–input OTA. Its transconductance can be controlled either electronically via g_{mT2} or it can be decreased by adding degeneration resistor $R_g >> 1/g_{mT2}$ as shown in Fig. 2 (a), in order to increase the OTA linearity. The differential x–output can be implemented by an additional diamond transistor T_3 as indicated in Fig. 2 (b).

3. Application example

An example of universal 2nd–order filter employing only one active element is shown in Fig. 3. Four potential kinds of input signal, namely V_1, V_2, I_1 and I_2 are denoted here. A routine analysis leads to four equations, which define 16 transfer functions:

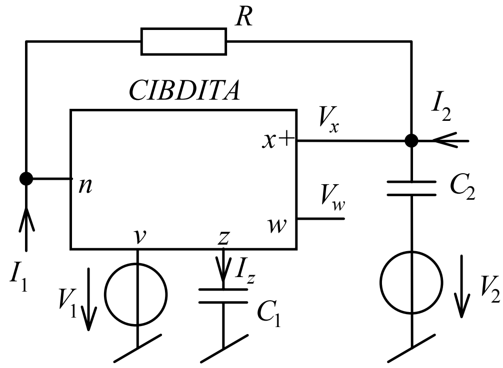

Fig. 3. An example of 2nd–order filter based on single CIBDITA.

$$V_w = K_{vwv1}V_1 + K_{vwv2}V_2 + K_{vwi1}I_1 + K_{vwi2}I_2 \quad (2)$$

$$I_x = K_{ixv1}V_1 + K_{ixv2}V_2 + K_{ixi1}I_1 + K_{ixi2}I_2 \quad (3)$$

$$V_x = K_{vxv1}V_1 + K_{vxv2}V_2 + K_{vxi1}I_1 + K_{vxi2}I_2 \quad (4)$$

$$I_z = K_{izv1}V_1 + K_{izv2}V_2 + K_{izi1}I_1 + K_{izi2}I_2 \quad (5)$$

12 of them are of the low-pass, band–pass or high–pass types:

$$K_{vwv1} = \frac{\omega_0^2}{D},\; K_{vwv2} = \frac{-sB}{D}\frac{C_2}{C_1},\; K_{vwi2} = \frac{-R_g\omega_0^2}{D}$$

$$K_{ixv2} = \frac{-sC_2\omega_0^2}{D},\; K_{ixi2} = \frac{-\omega_0^2}{D} \quad (6)$$

$$K_{vxv1} = \frac{-s\frac{R}{R_g}B}{D}, K_{vxv2} = \frac{-s^2}{D}, K_{vxi1} = \frac{-R\omega_0^2}{D}, K_{vxi2} = \frac{sRB}{D}$$

$$K_{izv1} = \frac{sB/R_g}{D}, \; K_{izv2} = \frac{-s^2/R}{D}, \; K_{izi2} = \frac{-sB}{D}$$

Here

$$D = s^2 + sB + \omega_0^2 \tag{7}$$

Bandwidth B is the ratio of natural frequency ω_0 and quality factor Q, where

$$B = \frac{1}{RC_2}, \; \omega_0 = \frac{1}{\sqrt{R_g R C_1 C_2}}, \; Q = \sqrt{\frac{R}{R_g}\frac{C_2}{C_1}} \tag{8}$$

and $R_g = 1/g_m$ is resistance from Fig. 2, forming the transconductance of the OTA stage.

The transfer functions (6) indicate that the filter can provide all four types of input-to-output operation modes, namely voltage mode (K_{vwv1}, K_{vwv2}, K_{vxv1}, K_{vxv2}), current mode (K_{ixi2}, K_{izi2}), transimpedance mode (K_{vwi2}, K_{vxi1}, K_{vxi2}), and transconductance mode (K_{ixv2}, K_{izv1}, K_{izv2}). Note that not all the above transfer functions can be utilized directly without any additional circuit arrangements: For example,

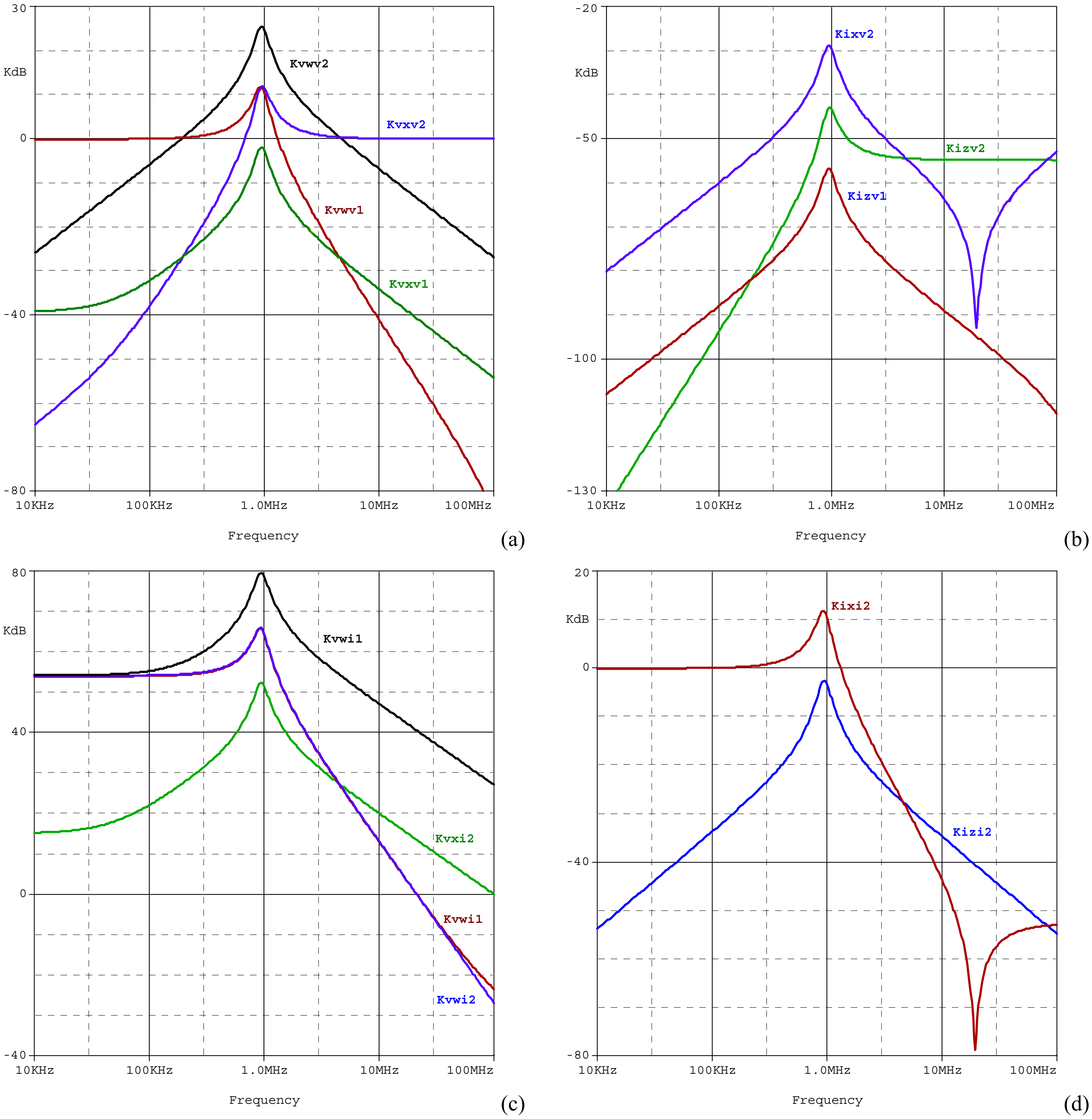

Fig. 4. Simulated frequency responses for (a) voltage, (b) transconductance, (c) transimpedance, (d) current modes.

utilization of output voltage V_x requires voltage buffering. I_x can be used when an additional x terminal is available. Utilization of I_z current is possible when an auxiliary circuitry for doing its copy is available [9].

4. PSpice simulations

The filter in Fig. 3 was designed for the parameters $f_0 = \omega_0/(2\pi) = 1$ MHz and $Q = 5$. The corresponding parameters of the passive components are as follows:

$R_g = R = 500\ \Omega$, $C_1 = 63.7$ pF, $C_2 = 1.59$ nF.

CIBDITA was implemented with the utilization of two OPA860, see Fig. 2 (a). According to the datasheet [10], a symmetrical supply voltage of ±5 V was used. The internal transconductance of each diamond transistor is set by an external resistor R_Q, which is connected between the "IQ Adjust" terminal and the negative supply voltage [10]. For $R_Q = 330\ \Omega$, which was used in the experiment, the g_{mT} is approximately 105 mA/V, which represents a resistance of about 9.5 Ω. That is why the values of external R_g in Fig. 2 (a) and R in Fig. 3 were decreased from 500 Ω to 490.5 Ω.

For PSpice simulations, the original SPICE model of OPA860 by Texas Instruments was used (Rev. B - Revised 4/25/06) [12]. According to the recommendations from [10], auxiliary resistors 100 Ω for impedance separation of parasitic base capacitance from the rest of the circuit were added in series to the bases of both diamond transistors. The results of AC analyses are shown in Fig. 4. The values measured for f_0 and Q are 953 kHz and 4.5. The error analysis reveals that these parameters are affected by the collector and base parasitic impedances of diamond transistors. The capacitances of transistors T_1 and T_2 in Fig. 2, namely $C_{c1} + C_{b2}$, increase the total capacitance of the z terminal. The corresponding resistances $R_{c1}\&R_{b2}$ form a parasitic damping resistance of the z terminal. The collector capacitance of T_2, C_{c2}, increases the value of C_2, and the parasitic resistance R_{c2} decreases the value of R. Taking into account the values of C_b, C_c, R_b and R_c from [10], the error analysis yields results that are close to the values measured.

5. Conclusions

The proposed Current Inverter Buffered Differential Input Transconductance Amplifier (CIBDITA) consists of three basic blocks: current inverter, multi–output differential–input operational transconductance amplifier, and unity–gain voltage buffer. In comparison to the conventional CDBA and CDTA, it offers a simplification of the input stage and also merges the output blocks into a single device. Introducing the differential input of the internal OTA also enables the circuit to be driven by voltage–type signals. The resulting element is thus suitable for implementing voltage–, current–, and mixed–mode operation. According to the methodology introduced in [9], the versatility of the CIBDITA can be further increased by adding the z–copy terminal.

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