Single GCFDITA and Grounded Passive Elements Based General Topology for Analog Signal Processing Applications

Norbert Herencsar, Jaroslav Koton, Kamil Vrba
Department of Telecommunications
Brno University of Technology
Purkynova 118, 612 00 Brno, Czech Republic
{herencsn, koton, vrbak}@feec.vutbr.cz

Abhirup Lahiri
36-B, J and K Pocket
Delhi-110095
India
lahiriabhirup@yahoo.com

***Abstract*—In this paper, a novel topology using generalized current follower differential input transconductance amplifier (GCFDITA), which is suitable to realize several current-mode (CM) analog functions is presented. The topology is created using a single GCFDITA, a maximum of two grounded passive elements and can realize CM amplifier, integrator, first-order low-pass, high-pass, and all-pass filtering functions. The workability of one of the GCFDITA variants, namely the current inverter differential input transconductance amplifier (CIDITA) is proved by SPICE simulation results, based on the commercially available ICs OPA860 by Texas Instruments, and is in good accordance with theoretical predictions.**

Keywords-current-mode circuit; GCFDITA; CIDITA; general topology; all-pass filter.

I. Introduction

Analog frequency filters are widely used as anti-aliasing video filters in the analog sections of high-speed data communication systems defined by ITU BT 601 standard, for signal processing in wireless LANs described by IEEE 802.11 standard, measurement systems, etc. [1]–[3]. One of the most often used versatile modern current-mode (CM) active building blocks (ABBs) is the current differencing transconductance amplifier (CDTA) [4]. In the current technical literature, numerous publications providing several simple circuit solutions using CDTA can be found. These include CM biquadratic filters [4], [5], first-order all-pass filters [6], [7], higher-order filters [1], [8], full-wave CM precision rectifiers [9], or sinusoidal oscillators [10]. However, many of the aforementioned circuits only partially utilize the input p or n terminals of the CDTA. In such cases, the input current differencing unit (CDU) is reduced to a current follower (CF) or current inverter (CI). This fact has been the first time noticed in [11] and later in [12], and which led to the evolution of a generalized current follower transconductance amplifier (GCFTA) [13]. Depending on the value of the conveyance coefficients, six types of CFTA variants can be defined. In general, these are the CFTA and the inverted CFTA (ICFTA) [13]–[19]. In one of more recent article [20], Biolek and Biolkova introduced a modified version of GCFTA with buffered voltage outputs and transconductance of conventional CDTA or GCFTA changed to differential input transconductance amplifier. Limiting this work to the circuits with only current inputs and current outputs, in this paper, we provide a new ABB called generalized current follower differential input transconductance amplifier (GCFDITA), which as compared to [20] does not have a buffered voltage output terminal. This modification leads to simpler internal structure, and subsequently, less power consumption of its applications. An important advantage of GCFDITA is also that it can be easily created using commercially available ICs OPA860 [21].

II. Proposed circuit

A generalized current follower differential input transconductance amplifier (GCFDITA) has positive or negative current follower input that transfers the input current at terminal f to the z terminal and a balanced-output differential input transconductance amplifier (BO-DITA) stage, which is used to convert the difference voltage between the z and v terminals to balanced output currents. The transconductance parameter g_m corresponds for the positive output and $-g_m$ for the negative output. The circuit symbol of GCFDITA is shown in Figure 1. In general, the equations characterizing an ideal GCFDITA are:

$$V_f = 0,\ I_z = aI_f,\ I_v = 0,\ I_{x+} = -I_{x-} = g_m(V_z - V_v), \tag{1}$$

where $a \in \{1, -1\}$. Depending on the values of a, two variants of GCFDITA are possible, namely current follower differential input transconductance amplifier (CFDITA) for

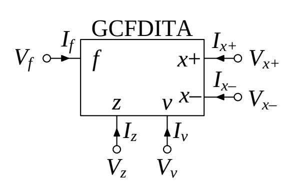

Figure 1. Circuit symbol of GCFDITA

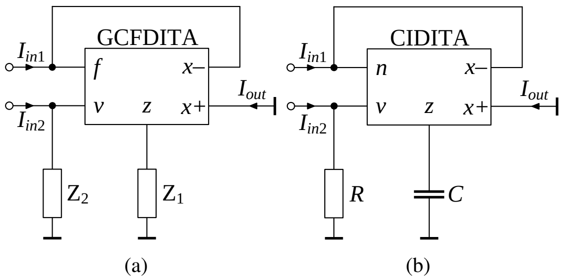

Figure 2. (a) Proposed circuit topology for realizing CM analog functions, (b) derived all-pass filter

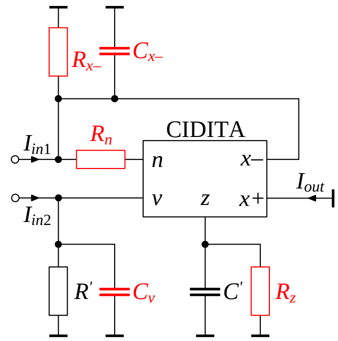

Figure 3. The all-pass filter in Figure 2(b) including dominant parasitics

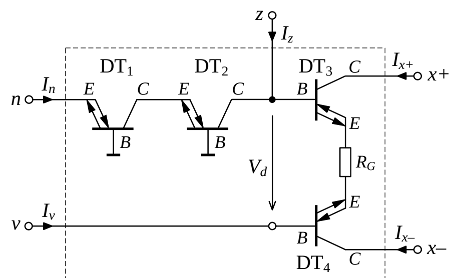

Figure 4. CIDITA implementation by ICs OPA860

$a = 1$ (let us label the input terminal as p) and current inverter differential input transconductance amplifier (CIDITA) for $a = -1$ (its input terminal is labeled as n).

The proposed general circuit topology used to realized several CM analog functions is shown in Figure 2(a). Recently, a similar general topology for realizing multiple voltage-mode (VM) analog functions using differential voltage current conveyor (DVCC) has been proposed in [22]. However, it is worth mention that the circuit in [22] does not provide a low-pass and high-pass filtering functions that can also be realized by here proposed general topology.

Considering the used ABB to be a CIDITA (i.e. $a = -1$) and doing routine circuit analysis using (1), the output current can be expressed as follows:

$$I_{out} = \frac{g_m(I_1Z_1 - I_2Z_2)}{g_mZ_1 + 1}. \quad (2)$$

By appropriately choosing different impedances (Z_1 and Z_2 - as combinations of resistor and capacitor) and current inputs (I_1 and I_2), various CM analog functions can be derived. For example, with $I_1 = I_2 = I_{in}$, $Z_1 = 1/sC$ and $Z_2 = R$, the transfer function (TF) becomes:

$$T(s) = \frac{I_{out}}{I_{in}} = -\frac{g_m(sCR - 1)}{sC + g_m}. \quad (3)$$

The above TF represents an all-pass (AP) filter under the condition $g_mR = 1$. If it is satisfied, the phase response of the filter is given as:

$$\varphi(\omega) = -2\tan^{-1}(\omega CR) = -2\tan^{-1}\left(\frac{\omega C}{g_m}\right). \quad (4)$$

It is worth noting that here proposed AP circuit uses all grounded passive elements, a feature which is absent in previously reported CDTA based APF in [6].

III. Non-idealities of the CIDITA

For a complete analysis of the AP filter, it is important to take into account the non-idealities of CIDITA shown in Figure 3:

- $I_z = -\alpha I_n, I_{x+} = \beta_1 g_m V_d, I_{x-} = -\beta_2 g_m V_d$, where $V_d = V_z - V_v$, $\alpha = 1-\varepsilon_1$, $\beta_1 = 1-\varepsilon_2$ and $\beta_2 = 1-\varepsilon_3$. The parameters ε_1, ε_2 and ε_3 $(|\varepsilon_1|, |\varepsilon_2|, |\varepsilon_3| \ll 1)$ denote the current tracking error of the current inverting stage and of BO-DITA, respectively.
- The non-zero parasitic input resistance at terminal n of the CIDITA is represented by R_n, which typical value in case of implementation by ICs OPA860 in Figure 4 is 10.5 Ω.
- The parasitic resistance R_z and parasitic capacitance C_z appear between the high output impedance z terminal of the CIDITA and ground and their typical values are 455 kΩ||2.1 pF. The parasitic capacitance C_z is absorbed into external capacitor C as it appears in shunt with it and in Figure 3 labeled as C'.
- The parasitic resistance R_v and parasitic capacitance C_v appear between the high input impedance v terminal of the CIDITA and ground and their typical values are equal to z terminal parasitics. The parasitic resistance R_v is absorbed into external resistor R as it appears in shunt with it and labeled as R'.
- The parasitic impedances appearing between the high-impedance x terminals of the CIDITA and ground. For the circuit in Figure 3, these impedances are modeled at terminal $x-$ by R_{x-} and C_{x-} that represent the parasitic resistance and parasitic capacitance, respectively, and their typical values are 54 kΩ||2 pF.

Considering the aforementioned tracking errors and parasitic capacitances, the ideal TF (3) turns to:

$$T(s) = \frac{I_{out}}{I_{in}} = -\frac{\beta_1 g_m[s(C' - \alpha C_v) - \frac{\alpha}{R}]}{(sC' + \alpha\beta_2 g_m)(sC_v + \frac{1}{R})}, \quad (5)$$

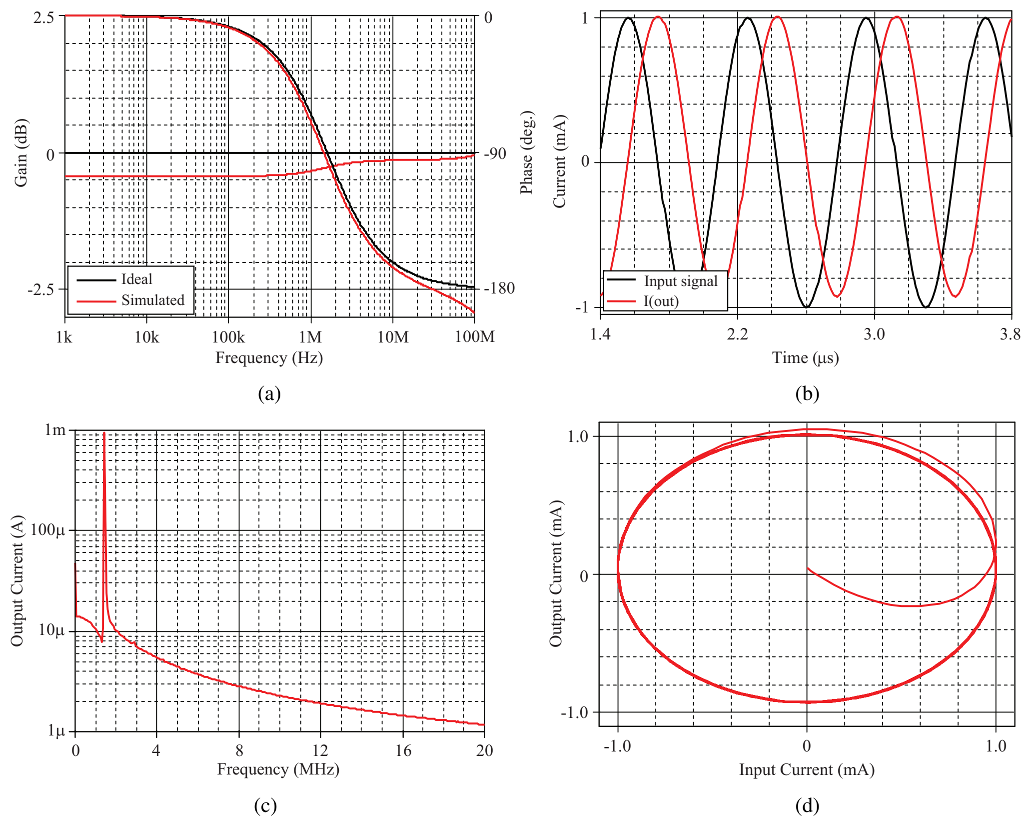

Figure 5. (a) Simulated gain and phase characteristics of the proposed CM all-pass filter, (b) time-domain responses at 1.44 MHz, (c) Fourier spectrum of the output signal, (d) Lissajous pattern showing $-90°$ phase shift at pole frequency

where $C' = C + C_z$. Assuming that the external capacitor C is much greater than C_v and C_z, the effects of these parasitics can be omitted and (5) changes to:

$$T(s) = \frac{I_{out}}{I_{in}} = -\frac{\beta_1 g_m (sCR - \alpha)}{sC + \alpha\beta_2 g_m}. \qquad (6)$$

Now, the zero ω_z and pole ω_p frequencies are not equal and can be expressed as:

$$\omega_z = \frac{\alpha}{CR}, \qquad \omega_p = \frac{\alpha\beta_2 g_m}{C}. \qquad (7)$$

It should be noted that, the angular pole frequency ω_p differs from the corresponding angular zero frequency ω_z and thus this mismatch affects both the magnitude and phase response of the circuit. Hence, to receive $\omega_z = \omega_p$ precise matching condition $g_m R = 1$ and careful design of CIDITA with values of α, β_1 and β_2 close to unity are needed.

IV. Simulation results

In order to verify the workability of the designed AP filter shown in Figure 2(b), it has been simulated using SPICE software. Figure 4 shows the implementation of the CIDITA using commercially available ICs, e.g., the OPA860 by Texas Instruments [21]. The DC power supply voltages of OPA860 SPICE macromodels were equal to ± 5 V. The OPA860 contains the so-called 'diamond' transistor (DT) and fast voltage buffer (VB). In the output stage, in order to increase the linearity of collector currents versus input voltage V_d, the DT3 and DT4 are complemented with degeneration resistor $R_G \gg 1/g_{mT}$, added in series to the emitters, where the g_{mT} is the DT transconductance. Then the total transconductance decreases to the approximate value $1/R_G$. In simulations the passive element values were selected as follows: $C = 100$ pF and $R = R_G = 1$ kΩ, and hence, the above mentioned matching condition $g_m R = 1$ $(R = R_G)$ is fulfilled. In this case, a $90°$ phase shift is at pole frequency $f_p \cong 1.59$ MHz. Figure 5(a) shows the ideal and simulated gain and phase responses of the proposed filter, from which the obtained f_p is 1.44 MHz. Time-domain simulation result of the proposed filter is shown in Figure 5(b) in which a sinusoidal input current signal with 1 mA peak value at 1.44 MHz is applied to the filter. The total harmonic distortion at this frequency is found as 0.102%. The Fourier spectrum of the output signal, showing a high selectivity for the applied signal frequency, is shown in Figure 5(c). The Lissajous pattern for the circuit as $-90°$ phase shifter is shown in Figure 5(d). The total power dissipation of the circuit is found to be 204 μW. From the simulation results it can be seen that the final solution is in good agreement with the theory.

V. Conclusion

The paper presented a novel general topology suitable to realize several current-mode analog functions. It is created using single versatile ABB, namely the generalized current follower differential input transconductance amplifier (GCFDITA) and maximum of two grounded passive components. As an example, first-order all-pass filter has been derived and SPICE simulation results of the proposed filter have been provided. It is expected that GCFDITA would prove to be a versatile ABB for the general design of active filters and sinusoidal oscillators. It is worth mention that a similar general circuit is proposed for voltage-mode functions in [22], however, in [22] the low-pass and high-pass filtering functions are not provided.

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References

[1] A. Uygur and H. Kuntman, "Seventh-order elliptic video filter with 0.1 dB pass band ripple employing CMOS CDTAs," *Int. J. Electron. Commun. (AEU)*, vol. 61, pp. 320–328, 2007.

[2] T. Y. Lo, C. S. Kao, and C. C. Hung, "A Gm-C continuous-time analog filter for IEEE 802.11 a/b/g/n wireless LANs," *Analog Integrated Circuits and Signal Processing*, vol. 58, pp. 197–204, 2009.

[3] G. Ferri and N. C. Guerrini, *Low-voltage low-power CMOS current conveyors*, London: Kluwer Acad. Publ., 2003.

[4] D. Biolek, "CDTA - building block for current-mode analog signal processing," In *Proc. of the 16th European Conf. on Circuit Theory and Design - ECCTD'03*, Krakow, Poland, pp. 397–400, 2003.

[5] W. Tangsrirat, T. Dumawipata, and W. Surakampontorn, "Multiple input single-output current-mode multifunction filter using current differencing transconductance amplifiers," *Int. J. Electron. Commun. (AEU)*, vol. 61, no. 4, pp. 209–214, 2007.

[6] A. U. Keskin and D. Biolek, "Current mode quadrature oscillator using current differencing transconductance amplifiers (CDTA)," *IEE Proc.-Circuits Devices Syst.*, vol. 153, no. 3, pp. 214–218, 2006.

[7] A. Lahiri and A. Chowdhury, "A novel first-order current-mode all-pass filter using CDTA," *Radioengineering*, vol. 18, pp. 300–305, 2009.

[8] T. Dostal, "All-pass filters in current mode," *Radioengineering*, vol. 14, no. 3, pp. 48–53, 2005.

[9] J. Koton, N. Herencsar, S. Minaei, and K. Vrba, "Precision full-wave current-mode rectifier using current differencing transconductance amplifier," In *Proc. of the Int. Conf. on Computer and Communication Device - ICCCD'11*, Bali Island, Indonesia, vol. 1, pp. 71–74, 2011.

[10] A. Lahiri, "Novel voltage/current-mode quadrature oscillator using current differencing transconductance amplifier," *Analog Integr. Circ. Signal Proc.*, 2009, vol. 61, pp. 199–203.

[11] N. Herencsar, J. Koton, I. Lattenberg, and K. Vrba, "Signal-flow graphs for current-mode universal filter design using current follower transconductance amplifiers (CFTAs)," In *Proc. of the Int. Conf. on Applied Electronics - APPEL'08*, Pilsen, Czech Republic, pp. 113–116, 2008.

[12] D. Biolek, R. Senani, V. Biolkova, and Z. Kolka, "Active elements for analog signal processing: classification, review, and new proposals," *Radioengineeing*, vol. 17, no. 4, pp. 15–32, 2008.

[13] N. Herencsar, J. Koton, K. Vrba, I. Lattenberg, and J. Misurec, "Generalized design method for voltage-controlled current-mode multifunction filters," In *Proc. of the 16th Telecommunications forum - TELFOR'08*, Belgrade, Serbia, pp. 400–403, 2008.

[14] N. Herencsar, K. Vrba, J. Koton, and A. Lahiri, "Realisations of single-resistance-controlled quadrature oscillators using generalised current follower transconductance amplifier and unity-gain voltage-follower," *International Journal of Electronics*, vol. 97, no. 8, pp. 897–906, 2010.

[15] N. Herencsar, J. Koton, K. Vrba, and I. Lattenberg, "Novel SIMO type current-mode universal filter using CFTAs and CMIs," In *Proc. of the 31st Int. Conf. on Telecommunications and Signal Processing - TSP'08*, Paradfurdo, Hungary, pp. 107–110, 2008.

[16] N. Herencsar, J. Koton, and K. Vrba, "Realization of current-mode KHN-equivalent biquad using current follower transconductance amplifiers (CFTAs)," *IEICE Trans. Fundamentals*, vol. E93-A, no. 10, pp. 1816–1819, 2010.

[17] W. Tangsrirat, "Novel current-mode and voltage-mode universal biquad filters using single CFTA," *Indian Journal of Engineering & Materials Sciences*, vol. 17, pp. 99–104, 2010.

[18] N. Herencsar, J. Koton, K. Vrba, and O. Cicekoglu, "New active-C grounded positive inductance simulator based on CFTAs," *Proc. of the 33th Int. Conf. on Telecommunications and Signal Processing - TSP'10*, Baden near Vienna, Austria, pp. 35–37, 2010.

[19] R. Sotner, J. Jerabek, N. Herencsar, T. Dostal, and K. Vrba, "Additional approach to the conception of current follower and amplifier with controllable features," In *Proc. of the 2011 34th Int. Conf. on Telecommunications and Signal Processing - TSP'11*, Budapest, Hungary, pp. 279–283, 2011.

[20] D. Biolek and V. Biolkova, "Modified buffered transconductance amplifier for analog signal processing," In *Proc. of the Int. Conf. Radioelektronika'09*, Bratislava, Slovak Republic, pp. 191–194, 2009.

[21] Datasheet OPA860 - Wide Bandwidth Operational Transconductance Amplifier (OTA) and Buffer. Texas Instruments, SBOS331C–June 2005–Rev. August 2008.

[22] S. Maheshwari, "Analogue signal processing applications using a new circuit topology," *IET Circuits Devices Syst.*, vol. 3, no. 3, pp. 106–115, 2009.

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