LETTER

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Behavioral model for emulation of ZC-CG-VDCC

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Abstract: This paper presents a proposal and an experimental analysis of behavioral emulator of so-called z-copy controlled-gain voltage differencing current conveyor (ZC-CG-VDCC) based on commercially available devices. Most of them are electronically (by DC voltage) controllable. This work represents a suitable example of preliminary stage of development of an active device before its fabrication on silicon. This approach of development provides certain and significant information about basic functionality of the active device or the whole application and proves expected theory. The particular results of tested ZC-CG-VDCC implementation in frequency domain (transfers, gains, impedances) and DC domain (dynamics, linearity) are shown.

Keywords: behavioral emulator, behavioral model, electronic control, ECCII, ZC-CG-VDCC

Classification: Electron devices, circuits, and systems

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1 Introduction

Fabrication of on-chip implementation of a new circuit is a very expensive procedure. Therefore, certain preliminary verification of functionality of the device (active element or application or both) is very useful. The main reason for such approach is a necessity to avoid future problems if the proposed device (and/or application) is not working properly or at all. Behavioral modeling (emulation of intended behavior and function) based on commercially available devices is the only way how to prove or disprove expected theory and behavior by real measurement. The next step can be IC implementation but with certain confidence that proposed system will be working as expected. A similar approach of modeling was used for instance in [1], where intentional control of the resistance of the current input terminal is possible.

2 Discussion of active devices based on voltage difference

Current conveyors with differential voltage inputs were investigated in the past. Chiu et al. [2] presented so-called differential difference current conveyor providing an operation of difference and sum of three voltages ($V_{Y1} - V_{Y2} + V_{Y3} = V_X$). Similarly Elwan et al. [3] introduced so-called differential voltage current conveyor (DVCC) for realization of function $V_{Y1} - V_{Y2} = V_X$. Note that Y_{1-n} are voltage terminals and X is current input/output terminal in accordance with basic definition of current conveyor [4, 5]. DVCC based filtering applications attract interest of many researches, for example [6, 7, 8]. The interesting features are also available in so-called fully differential current conveyor of second generation (FDCCII) presented by El-Adawy et al. [9] useful for many applications [10]. A definition of

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the voltage differencing current conveyor (VDCC) is different [11] in comparison to [2, 3, 6, 7, 8, 9, 10]. This device also contains current conveyor but difference of two input voltages V_{p} and V_{n} is provided by internal operational transconductance amplifier (OTA) [11, 12] connected to Y terminal of current conveyor forming the second stage of the circuit. The discussed principles spread also to other advanced active elements, see for example [13, 14].

3 Z-copy controlled-gain VDCC

Recently, VDCC with advanced controllable features has been reported as so-called z-copy controlled-gain voltage differencing current conveyor (ZC-CG-VDCC) [15] where the useful features of VDCC for applications are extended together with controllable properties. ZC-CG-VDCC is defined by the following equations:

$$I_{z\_TA} = -I_{zc\_TA} = (V_p - V_n)g_m, \tag{1}$$

$$V_x = V_{z\_TA} + R_x I_x, \tag{2}$$

$$I_{zp} = -I_{zn} = B \cdot I_x. \tag{3}$$

As we can see from (1)–(3), difference of two voltages V_{p} and V_{n} is transformed by OTA section to $I_{\mathrm{z\_TA}}$ and inverted copy $-I_{\mathrm{zc\_TA}}$. Current conveyor part of the ZC-CG-VDCC (electronically controllable current conveyor - ECCII [11, 16, 17, 18]) provides voltage transfer from z_TA to X terminal including voltage drop at the controllable intrinsic R_{X} [18, 19] resistance and controllable gain (B) [16, 17] of the current flowing through X (current input terminal with controllable R_{X}) to terminals zp and zn. This behavior is obvious from a basic block structure in Fig. 1(a). The detailed information about general principle of the ZC-CG-VDCC can be found in [15]. ZC-CG-VDCC has been discussed several times in several works also concerning its applications [20, 21, 22]. However, no practically manufacturable behavioral emulator allowing all directly controllable parameters was shown.

4 Proposed behavioral emulator of Z-copy controlled-gain voltage differencing current conveyor

Commercially available active elements are useful for behavioral modeling of complex systems. They can emulate behavior of future CMOS implementations of active devices sufficiently. ZC-CG-VDCC has behavioral emulator/model (including all parameters) given in Fig. 1(b). Note that current conveyors used for construction of the emulator have also designation ECCII- (designation with subscript) but their controllability includes current gain B only — they cannot directly serve as ECCII discussed in Fig. 1(a). When suitably interconnected, they can emulate function of important systems (R_{X} control for example). Current gain between X and zp and zn terminals is given by:

$$I_{zp} = -I_{zn} = \frac{B_2 R_j^{/}}{B_1 R_i^{/}} I_X \cong \frac{V_{SET\_B} R_j^{/}}{V_{SET\_Rx} R_i^{/}} I_X. \tag{4}$$

Voltage relation between X and z_TA terminal is of the following form:

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$$V_X = V_{z\_TA} + R_X I_X = V_{z\_TA} + \frac{R_j^{/}}{B_1} I_X \cong V_{z\_TA} + \frac{R_j^{/}}{V_{SET\_Rx}} I_X, \quad (5)$$

and relation between voltage terminals p, n and z_TA (zc_TA respectively) is:

$$I_{z\_TA} = -I_{zc\_TA} = (V_p - V_n)g_m \cong (V_p - V_n)\frac{B_3}{R_k^{/}} \cong (V_p - V_n)\frac{V_{SET\_gm}}{R_k^{/}}. \quad (6)$$

Additional weighting of voltage difference (V_pA–V_n) by voltage gain A is available for different V_{SET_A} (see VCA$_1$ in Fig. 1(b)) than −1 (range is 0 to −2 V leading to gain between −40 and 40 dB). This feature can be useful in some cases. All definitions of internal subparts were given in accordance with information from the producers of the used active elements (ECCIIs – EL2082, voltage buffers – LT1364, voltage buffer/amplifier VCA$_1$ – VCA810, current followers/inverters – EL4083). Emulator allows setting of global current gain (in accordance with Fig. 1(a)) B by V_{SET_B}, R_X by V_{SET_Rx} and transconductance g_m by V_{SET_gm}. All these control voltages are considered from 0 V to 3 V for proper operation of the whole circuit.

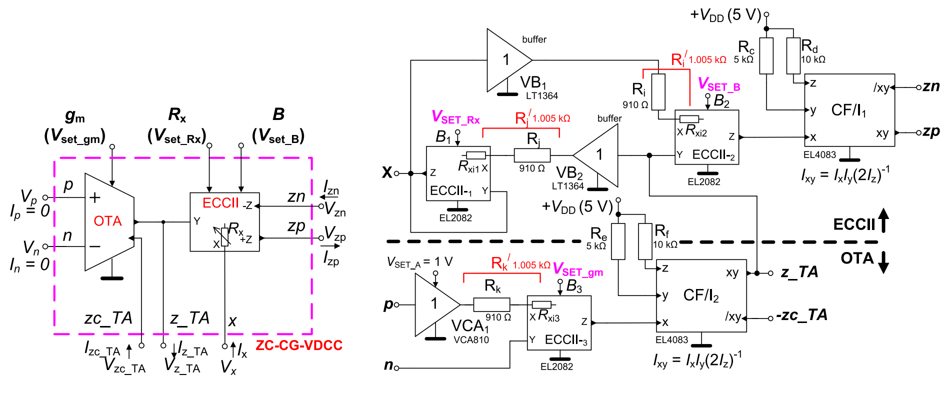

Fig. 1. (a) Ideal block structure of the ZC-CG-VDCC, (b) behavioral emulator of the ZC-CG-VDCC based on commercially available active devices.

5 Verification and practical limits of ZC-CG-VDCC emulator

Proposed ZC-CG-VDCC emulator was measured in lab (supply ± 5 V) to obtain and evaluate the available features (dynamics, frequency responses, ranges of adjustability of required parameters, etc.). Particular AC responses (transfer of current between X and zp,n terminals for several values of current gain V_{SET_B}; transconductance for several values of V_{SET_gm}; and impedance of X terminal for several values of V_{SET_Rx}) are shown in Fig. 2(a–c). All observed parameters were stepped for several values of their DC control voltages. All details about setting are included in Fig. 2. The main frequency limitation of used active device is given by frequency dependence of input impedance X.

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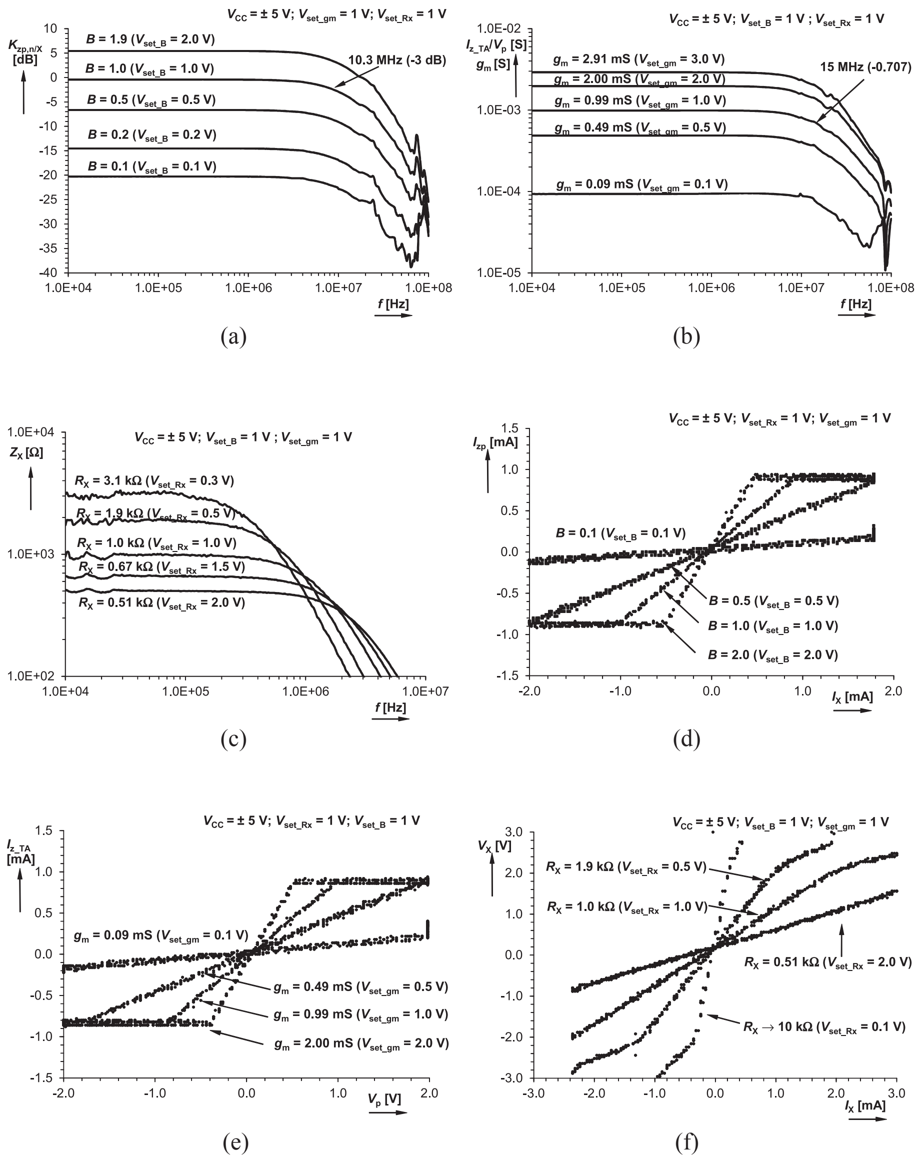

Fig. 2. (a) Measured dependence of current transfer between X and zp,n on frequency, (b) dep. of transconductance between p and z_TA terminal on frequency, (c) dep. of input impedance of X terminal on frequency, (d) measured transfer characteristic for current transfer between X and zp,n terminal, (e) transfer char. between p and z_TA terminal, (f) transfer char. between current through X and voltage drop across X terminal.

Bandwidth is about 100 kHz for $R_X = 3.1\,k\Omega$ ($V_{SET\_Rx} = 0.3\,V$) but for lower R_X values bandwidth overcomes 1 MHz. The dynamical features were also tested and the results are shown in Fig. 2(d–f) where very low frequency sawtooth impulse excitation was used (points in the figure indicates several repetitions). This analysis was also provided for several values of DC control voltages. The limitation at X terminal can be seen. Dynamics drops to low hundreds of μA for very high value of R_X where problems with linearity occur.

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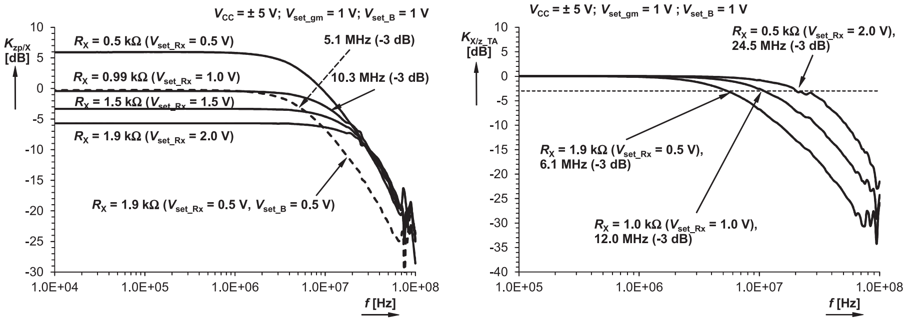

(a) (b)

Fig. 3. (a) Effect of R_X adjusting on current transfer between X and zp terminal, (b) effect of R_X adjusting on voltage transfer between z_TA and X terminal.

The last part of this analysis focuses on the possible problematic features. A setting of B is influenced by current R_X value (V_{SET_Rx}), see Fig. 3(a). If compensation of this impact by V_{SET_B} is applied, it reduces bandwidth (dashed line in Fig. 3(a)). Similar effect has R_X on voltage transfer between z_TA and X terminal. Parasitic capacitance (up to 10 pF in accordance with information from manufacturers of used active devices) is always present in node X and it creates real parasitic pole. This pole frequency decreases with higher value of intentionally adjusted R_X, see Fig. 3(b).

6 Conclusion

Proposed emulator provides valuable representation of ZC-CG-VDCC with intended behavior approximately up to 1 MHz whereas R_X has to be lower than 2 kΩ. Dynamical transfer responses are very good (several units of mA), certain limitation is observable for dynamics of X input (high R_X - 10 kΩ) where maximal current swing can be in low hundreds of μA. Negative effect of V_{SET_Rx} on current gain between X and zp,n terminal can be removed by using of additional adjustable current amplifier (subpart ECCII with grounded Y [1]) connected directly after ECCII-$_2$ which will be used for current gain control. All the tests confirmed theoretical expectations. The features of this behavioral emulator were partly tested in application of functional triangle and square wave generator presented in [22].

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