OTA-BASED CURRENT DIFFERENCING UNIT

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ABSTRACT:

The CDU (Current Differencing Unit) which is a part of active elements such as CDBA (Current Differencing Buffered Amplifier) and CDTA (Current Differencing Transconductance Amplifier) is described. CDU is set up from a pair of grounded resistors and one OTA (Operational Transconductance Amplifier). The CDU characteristics are verified via PSpice simulation.

Keywords: Current Differencing Unit, OTA, transconductance, analysis

1 INTRODUCTION

The Current Differencing Unit (CDU) is a basic building block of several active elements for analog signal processing such as OTRA (Operational Transresistance Amplifier) [1], CDBA (Current Differencing Buffered Amplifier) [2], DCVC (Differential Current Voltage Conveyor) [3], or CDTA (Current Differencing Transconductance Amplifier) [4]. CDU (see Fig. 1 a) serves as an input block of these circuits. Its purpose is to receive input signals in the form of currents I_p and I_n, flowing into low-impedance terminals *p* and *n*, and deliver a difference of these currents through high-impedance output *z* for subsequent processing. There is a dual purpose of the claim to low, ideally zero input impedance of *p* and *n* terminals. First, it enables, in conjunction with an external circuit, utilizing the CDU input gates for a direct voltage-to-current conversion. Second, it eliminates the impact of parasitic impedances on current conduction into the CDU. A positive concomitant phenomenon consists in maintaining low, ideally zero voltage of *p* and *n* terminals. The high, ideally infinity impedance of the *z* terminal is required due to CDU desired behavior as an ideal current source for supplying independent load Z_L. In other words, value of the z-current should not depend on the loading impedance.

In reality, the CDU embodies internal impedances Z_p, Z_n, and Z_o according to Fig. 1 (b). In conjunction with external impedances Z_{ip}, Z_{in}, and Z_L, they cause a nonideal CDU behavior. The input impedances Z_p and Z_n have also inductive components, which negatively affect the circuit behavior by increasing the impedance at high frequencies [5]. The internal current source is other contributor of error because its current gain *b* is not equal to 1, it is frequency dependend, and it is extracted from nonlinear I/V characteristic. Also note that nonlinear properties of other internal blocks can come into effect, depending on a concrete implementation of the CDU.

Seeing that the CDU is not commercially available, its implementation from attainable integrated circuits should be discussed. Developed circuit solutions can became a starting point for the following chip design.

In next Sections, a simple circuit topology of the CDU on the basis of commercial OTA is proposed. The CDU properties are evaluated on the basis of the analysis of real influences and computer simulations.

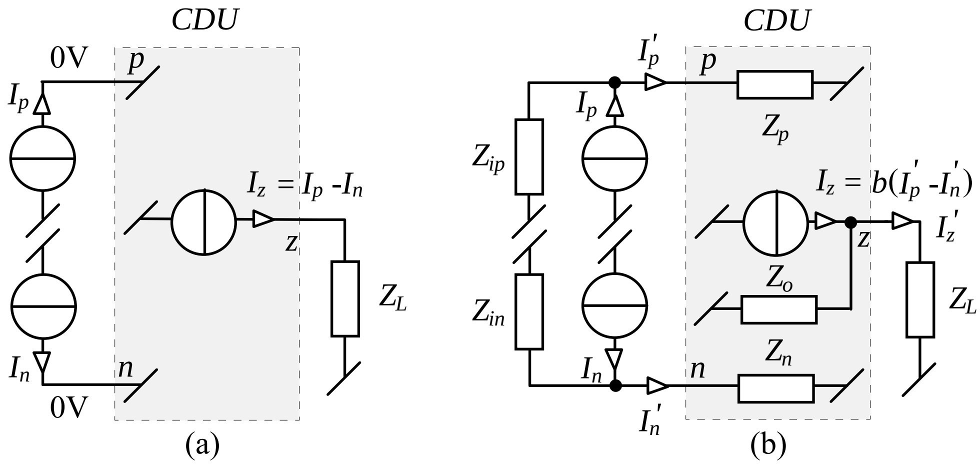

Fig. 1: CDU (a) ideal, (b) with parasitic impedances being considered.

2 CDU CONCEPTION

The CDU conception is shown in Fig. 2 (a). It is based on the fact that all the present CDUs show nonzero parasitic impedances of *p* and *n* terminals. In contrast to previous circuits, these impedances are purposely implemented here with the aim of their precise preset at least for low-frequency region. The circuit base is thus a pair of of grounded resistors R_1 and R_2 of equal resistances *R*. The currents I_p and I_n, flowing through them, cause voltage drops V_p and V_n. Their difference is sensed by a high-impedance differential OTA input. This voltage is then transferred into the output current I_z through the transconductance $g_m = 1/R$.

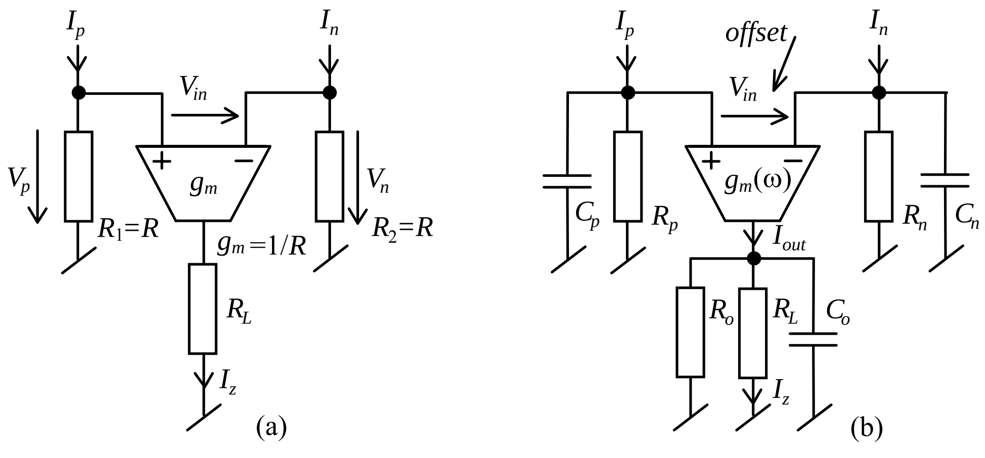

Fig. 2: (a) OTA-based CDU, (b) modeling of real influences.

Ideally, the circuit in Fig. 2 (a) is described by the equation

$$I_z = g_m (R_1 I_p - R_2 I_n) = I_p - I_n \,. \tag{1}$$

For a proper circuit operation, the following relationships between the parameters of circuit elements must be fulfilled:

Equality of resistances: $R_1 = R_2 = R$.; Equality $g_m R = 1$.

It is desirable to design relatively low resistance R, let us say its value should correspond to input resistances of CDU models, formerly designed in CMOS technology [6-8], i.e. tens Ohms to kiloOhms. Low value of R then results in utilizing OTA with adequately large transconductance.

3 OTA

Not all commercially available OTAs fulfill exacting demands on speed, accuracy and types of input and output. MAX435/436 [9] is 275/200MHz OTA with extremely linear characteristic $I=f(V)$ because its transconductance is determined by an external two-terminal device which is linear resistor in most cases. However, it has very low output resistance (about 3kΩ) and thus it is not suitable for DCU design. Some of fast OTAs have only single output such as variants of well-known "super-transistors" OPA660, OPA860, OPA615, SHC615, etc. [10]. OPA615 contains so-called current comparator or SOTA (Sampling OTA). This element, serving as an voltage input and current output comparator [11], can be used as OTA with bipolar inputs and relatively high transconductance. Below is a summary of its parameters which are significant for CDU design:

Transconductance g_m no less than 19mA/V in various temperature regimes, typically 25mA/V.
Input impedance: R_i=200kΩ, C_i=1.2pF.
Output impedance: R_o=500kΩ, C_o=1.2pF.
Current offset ΔI_{out} no greater than 50μA for 25 °C, typically 10μA. The corresponding typical voltage offset is ΔV_{in} = 0.4mV.
Maximum output current is 5mA, at least 2mA in various temperature regimes.
Cutoff frequency $f_{\text{-3dB}}$: typically 730MHz, in various temperature regimes at least 400MHz.

The SPICE model of OPA615 supplied by the manufacturer has been used for the computer simulation of the CDU.

4 CDU DESIGN

When a concrete type of OTA is chosen, one must design the sensing resistances R_1 and R_2. Considering typical value of g_m = 25mA/V, then $R_1=R_2=R$=40Ω. In reality, the OTA input resistance will work in parallel to each of these resistors, but with negligible influence on the resulting resistance.

For input current from the interval -1mA to +1mA, the OTA output current will be from an acceptable range from -2mA to +2mA [11], the voltages at sensing resistors will be from -40mV to +40mV, and OTA input voltage from -80mV to +80VmV. Referring to the characteristic $I_{out}=f(V_{in})$ from [11], the operating point will move within a relatively linear part of the characteristic.

Next Section describes a symbolic analysis of the CDU with the behavioral model of the OTA in order to analyze the influence of nonideal OTA parameters on the CDU operation. The final PSpice simulation will follow.

5 SYMBOLIC ANALYSIS OF THE CDU

Fig. 2 (b) displays behavioral CDU model, taking into account parasitic impedances and other real properties of the OTA.

R_p and R_n resistors include the sensing resistors R_1 and R_2 and the OTA input resistances R_i. Capacitances C_p and C_n are input capacitances of the OTA:

$R_p = R_n = R\&R_i \approx R_i = 40\Omega$, $C_p = C_n = C_i = 1.2\text{pF}$.

R_o and C_o are the above specified parameters of the OTA output impedance.

Frequency dependence of the transconductance is modeled by common single-pole model

$$g_m(s) = \frac{g_m}{1 + \frac{s}{\omega_{-3dB}}} . \tag{2}$$

The load resistance will be chosen in values of 0Ω, 10Ω, 100Ω, 1kΩ, and 10kΩ in order to evaluate the influence on the CDU behavior.

For DC analysis, the OTA linearized model will be used:

$$I_{out} = g_m(V_{in} + \Delta V_{in}) = g_m V_{in} + \Delta I_{out} , \tag{3}$$

which also includes the anticipated offset. DC analysis of model in Fig. 2 (b) gives the result

$$I_z = \frac{g_m R_o}{R_L + R_o}(R_p I_p - R_n I_n + \Delta V_{in}) = \frac{R_o}{R_L + R_o}(g_m R_p I_p - g_m R_n I_n + \Delta I_{out}) . \tag{4}$$

After evaluation,

$$I_z = \frac{500\text{k}\Omega}{R_L + 500\text{k}\Omega}(I_p - I_n + 10\mu A) . \tag{5}$$

For load resistances 0Ω, 10Ω, 100Ω, 1kΩ, and 10kΩ, the current gain (the first term in Eq. 5) is 1, 0.99998, 0.9998, 0.998, and 0.98, respectively.

Small-signal analysis of the model in Fig. 2 (b) provides the following formula for the output current:

$$I_z = \frac{R_o}{R_o + R_L} \frac{1}{(1 + s\frac{R_o R_L}{R_o + R_L}C_0)} \frac{g_m}{(1 + \frac{s}{\omega_{-3dB}})} \left[\frac{R_p}{1 + sR_p C_p} I_p - \frac{R_n}{1 + sR_n C_n} I_n \right] . \tag{6}$$

Note that the transfer function from the input I_p to the output I_z as well from the input I_n to the output I_z contains tree real poles. The first one (pole No. 1) is caused by the influence of current divider which takes effect due to nonzero load resistance. Its impact can be eliminated by selecting reasonable low load of the CDU. The pole No. 2 results from g_m frequency dependence. In reality, the corresponding model can be more complicated than in (2). The pole No. 3 exists due to the operation of parasitic RC cells at CDU inputs. Tab. 1 contains values of these poles for various load resistances, both in the common quantities [rad/s] and also in [Hz].

Tab. 1: Connection between the poles of the CDU transfer function and the load resistance.

R_L [Ω]	absolute value in [rad/s] /[Hz] of pole No.		
	1	2	3
0	∞	4.59G/730M	20.8G/3.32G
10	83.3G/13.3G		
100	8.34G/1.33G		
1k	835M/133M		
10k	85M/13.5M		

As results from the table, the g_m pole is a dominant pole, determining the character of the transfer function, when the load resistance is up to hundreds of Ohms. Larger load resistances will degrade both the frequency response and the corresponding step response of the CDU.

6 PSPICE SIMULATION

PSpice simulation has been performed on the basis of SPICE model of OPA615 by Texas Instruments (REV. A from Nov. 11, 2006). Main results are in Figs. 3 and 4.

Figure 3 (a) shows CDU current offset ca. 37μA. This value is in accordance with the datasheed [11]. Current gain is approximately 1.015. The Transient analysis under CDU excitation by 10MHz/1mA harmonic current and the subsequent Fourier analysis led to the output current THD of 0.4%. Fig. 3 (b) contains a detail of the CDU steady-state response to rectangular input current I_p or I_n, with the rise-time under 1ns at the output. Frequency responses in Fig. 4 confirm the conclusions from Table 1 that load resistances above ca 100 Ohms degrade the frequency characteristics due to pole No. 1 which becomes dominant.

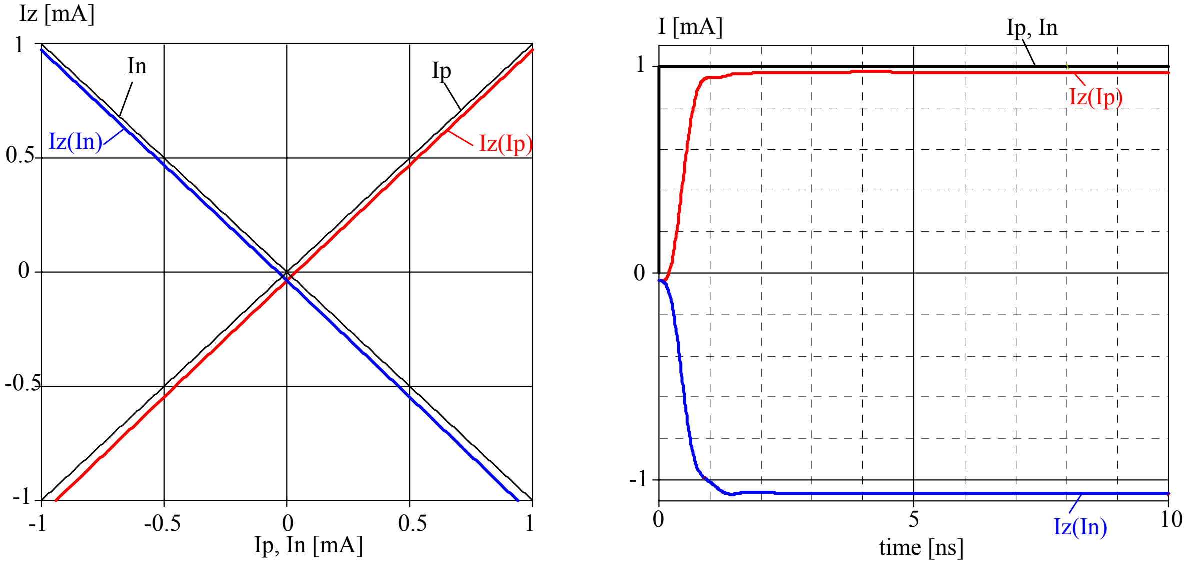

Fig. 3: Results of PSpice simulations, R_L=1Ω: (a) DC characteristics I_z=f(I_p, I_n), (b) CDU responses to step changes of input currents.

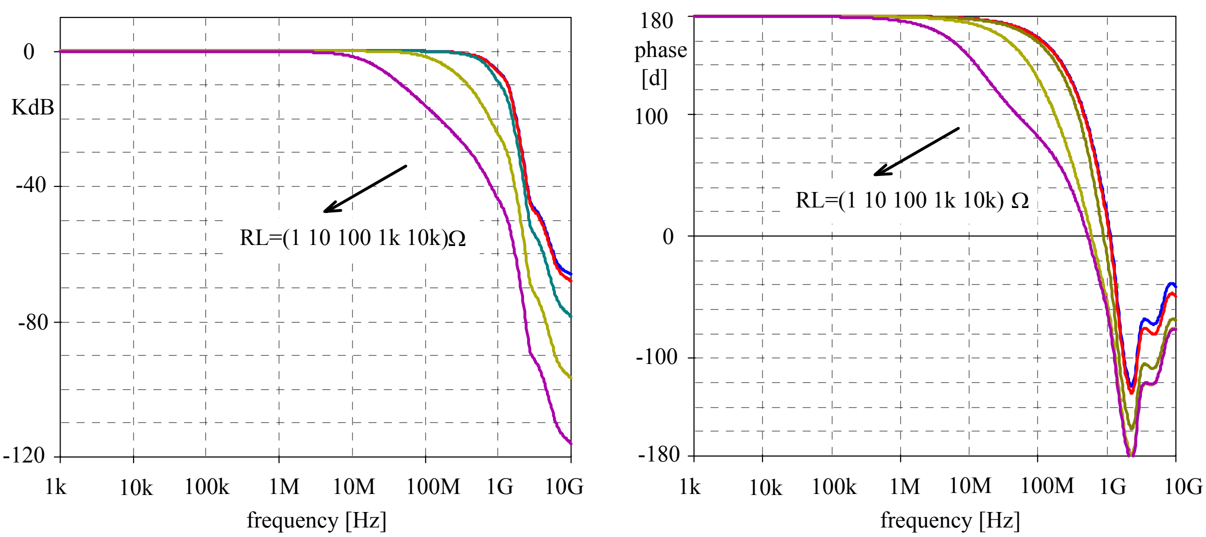

Fig. 4: Results of PSpice simulations: Frequency characteristics for various load resistances (identical for CDU excitation from *p* and *n* inputs).

7 CONCLUSIONS

The proposed CDU is very simple, consisting only of a pair of grounded resistors and of one commercial OTA. It works in a wider frequency range than for most till this time published CMOS structures of the CDU. The step response of the CDU is fast and without disturbing bouncing. A certain drawback is a necessity of precise setting values of sensing resistances in relation to the transconductance of concrete OTA. CDU linearity and temperature stability depend on OTA parameters.

8 ACKNOWLEDGMENT

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