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SPECIFICATIONS ABOUT USING THE SINH BUILDING BLOCK FOR LINEAR APPLICATIONS

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Abstract: We analysed in this paper the **sinh cell** in order to put into evidence its connection with other linear universal building blocks based on the same basic schematic (current conveyor CCII+, Diamond transistor, Diamond current source, OTA). Some limits and requirements for the linear operation have been deduced. We also concluded that the sh cell is a general universal structure that can be used in both linear and nonlinear applications. Examples and simulations proved the validity of our analysis.

Keywords: Sinh building block, current conveyor, Diamond transistor, exponential state space circuits.

1. Introduction

We analyse in this paper the **sinh cell**, an exponential building block, used in the design of low voltage-low power ELIN (Externally Linear Internaly Nonlinear) filters [1] [4]. This circuit has a nonlinear large signal characteristic and is used with other nonlinear exponential-type building blocks (**th, ch**) to realise the overall linear transfer function [1]. On the other hand you can find the same structure of this circuit as linear **universal building blocks having different names and symbols** in technical literature. Thus, it is more known in fully linear applications as a transconductor, current conveyor CCII, Diamond (ideal) Transistor or Diamond current source [2] [3] [5] [6]. We put into evidence the connection between the **sh** structure and this linear blocks and deduced some operating regions and conditions for using this basic cell in different linear or nonlinear applications. Our analysis led to the conclusion that actually the conveyor CCII+ and its "synonym" circuits represent sh cells optimized for linear small signal operation. Therefore the analized sh structure is a more general universal building block. Some examples and simulations are given for proving our conclusions.

2. Sinh basic building block.

The circuits in figure 1, a are basic building blocks given in technical literature for both linear and nonlinear applications. The same basic structure is called **sh cell** (b) [1], **current conveyor CCII+** (c) [2], **Diamond Transistor (ideal transistor), Diamond current source** [3].

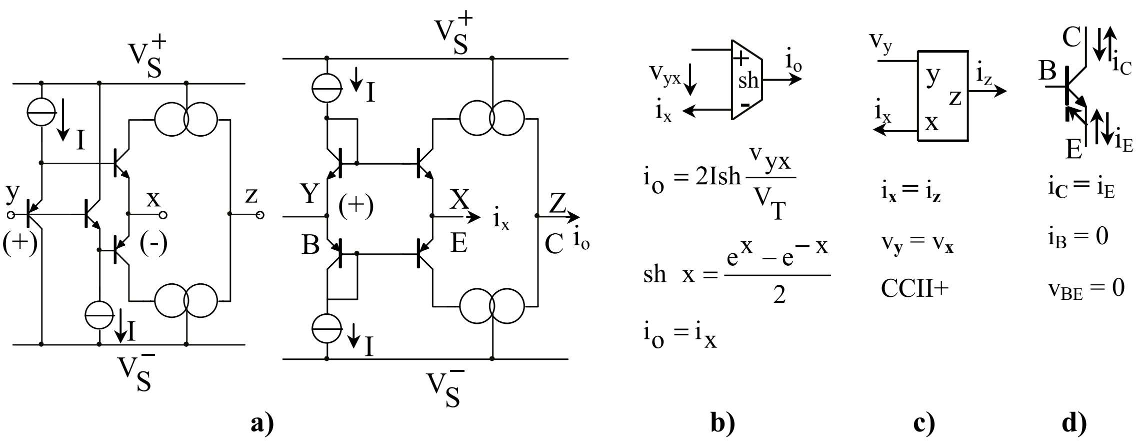


Figure 1. A basic building block with different functions.**a**) schematics ; **b**) symbol and large signal model ; **c**) current conveyor ideal model ; **d**) ideal (Diamond) transistor

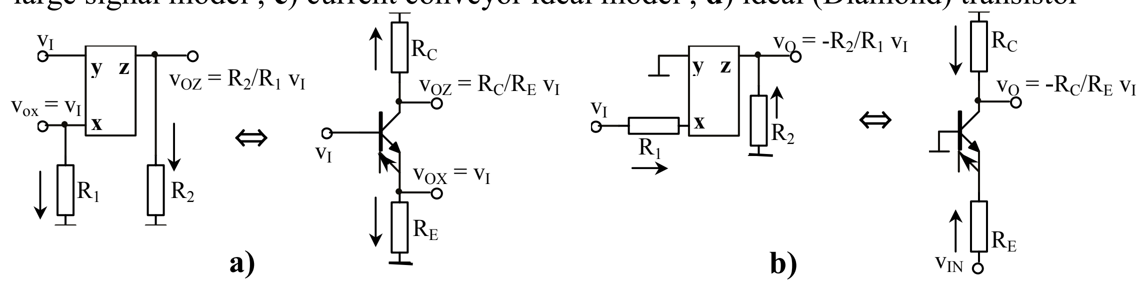


Figure 2. Basic voltage amplifier configuration based on structure 1,a (c,d) ; **a**) non inverting amps (v_{OZ}) ; voltage followers (v_{OX}) ; **b**) inverting amps

We would like to see what the difference is when using this structure as a sh or other functional blocks. The correspondence between Diamond transistor and CCII+ is direct and obvious (figure 2), both structures have the some functions [3].

Actually at large signals, over a large domain of signal variations the basic circuits, from figure 1,a whatever were their names, are characterized by the **sinh** input/output characteristic.

For small signals around the origin the transfer characteristic of the sh cell can be approximated with a linear function:

$$sh \cong x \tag{2.1}$$

with an error $\varepsilon < 10^{-3}$ for $|x| \le 0.18$, that is $|v_{yx}| < 5mV$. The linearity of the sh function domain can be extended over the above mentioned domain but with lower precision.

This linear operation close to the origin is used in fully linear applications such as **CCII+** and its equivalent circuits.

3. Sinh building blocks and the current conveyor

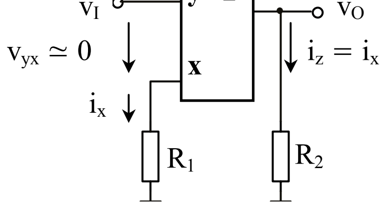


Figure 3. Basic amplifier configuration with CCII

We will analyse the basic amplifier linear configuration in figure 3 in order to determine some conditions for sh cell to operate as a CCII+.

An ideal current conveyor is characterised by the relations:

$$v_y = v_x;\ i_z = i_x,\ \text{so that}\ v_{yx} = 0 \tag{3.1}$$

$$\Rightarrow v_o = \frac{R_2}{R_1}v_I;\ G = \frac{R_2}{R_1} \tag{3.2}$$

The real conveyor has the structure in figure 1,a so that it actually is a sh cell and the amplifier in figure 3 (with the specifications from figure 1,b) can be described by the following more accurate equations:

$$v_I = v_{yx} + R_1 \cdot 2I \text{ sh } v_{yx}/V_T \tag{3.3}$$

$$v_o = R_2 \cdot 2I \text{ sh } v_{yx}/V_T \tag{3.4}$$

The real amplifier gain is therefore:

$$G = \frac{dv_o}{dv_I}\Big|_Q = \frac{R_2}{R_1} \cdot \frac{R_1}{R_1 + \frac{V_T}{2I} \cdot \frac{1}{ch(V_{yx}/V_T)}} \tag{3.5}$$

The requirement to get a gain G close to the ideal one (R_2/R_1) will be:

$$R_1 >> \frac{V_T}{2I} \cdot \frac{1}{ch(V_{yx}/V_T)} \tag{3.6}$$

If the **quiescent point Q is in origin** $\Rightarrow$ $V_{yx} = 0$, and the condition (3.6) becomes:

$$R_1 >> \frac{V_T}{2I} = R_{inx}\Big|Q \to 0 \tag{3.7}$$

Larger R_1 (or smaller input resistance R_{inx} at the terminal x) closer to an ideal CCII+ the sh cell is.

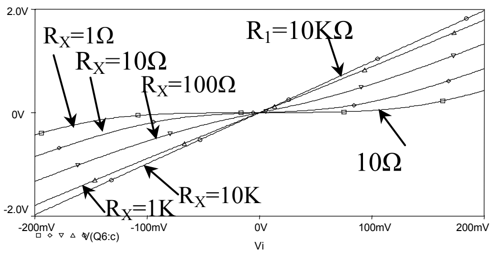


Figure 4. Amplifier Transfer characteristics

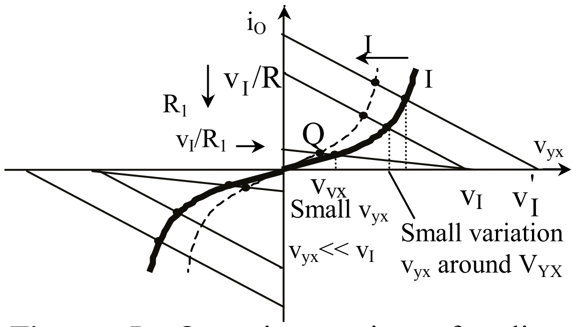


Figure 5. Operating regions for linear applications.

Figure 4 shows some in/out simulated characteristics of the schematic in figure 3. The basic circuit from figure 1,a is connected for G =10 and biased with I=100μA R_1 is the parameter and the condition (3.7) gives: $R_1 >> 130\Omega$. Characteristics from figure 4 show a good large domain linearity and the desired gain only for $R_1 = 10k\Omega$.

The requirements for resistance R_1 become less restrictive by increasing the bias current I (A) as it is usual for the most CCs. You can see in figure 5 the quiescent point on the linear region of the sh curve. Voltage v_{yx} decreases by increaseing R_1 and I.

We could extend our analysis for other regions of the transfer characteristic that have a higher slope, corresponding to a lower R_{inx}. They are evident in figure 5 and also examining condition (3.6). Taking into account that $chx \geq 1$, for relative large V_{yx}, R_{inx} is low and the variation of V_{yx} could be negligible ($V_{yx} \cong 0$). This is a case similar to a transistor biased for relative large currents and having $V_{BE} \cong ct$. We could obtain a relative constant slope $G=R_2/R_1$ for small R_1 but larger bias $V_{yx} \neq 0$. You can see in figure 4 that the slopes of each curve increase. They end to reach the ideal value (G=10) but only for relative large V_I. This domain coresponds more to the exponential characteristic ($shx \to e^x/2$ or $e^{-x}/2$) when only one half of the circuit is on and the circuit is similar to an exponential cell, used in log-domain [1] [2] It could also be compared with a BT transistor but in this case the "threshold" is positive or negative and much smaller than 0.6V. We can conclude tha relative large input signals (positive or negative) could preserve small variations in v_{yx} with less restrictive conditions for R_1. This is not a specific case for a current conveyor, but could explain some good results for large signals.

4. Examples.

a) AD846 is a monolithic very high speed current feedback amplifier (80MHz@A=1, S=450V/µs). The internal schematic from the inputs (3 and 2) to the output (5) coresponds to figure 1, a, that is a **sh cell**. Output 5 is buffered at terminal 6. Inverting treminal input resistance is R_{inx} = 50 Ω, I = 1 mA. The application from figure 6 is given in [5] for the linear operation and coresponds to our conclusion. (R_1 = 10 KΩ >> 50 Ω, large bias I and v_I)

b) OPA660 contains a Diamond transistor (Fig. 1,a) between terminals 2,3 and 8. The feedback amplifier in figure 7 has $R_{inx} \approx 8$ Ω for a quiescent current of 20 mA (G = 3, BW > 350 MHz) [6]. Therefore the equivalent resistance connected at terminal 3 (80 Ω) can be much lower than in the previous example (10 kΩ).

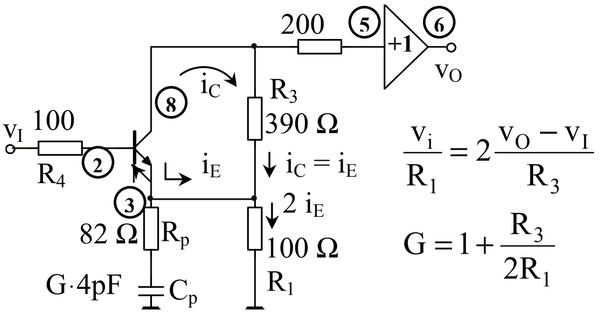


Figure 7 Fast high frequency amplifier

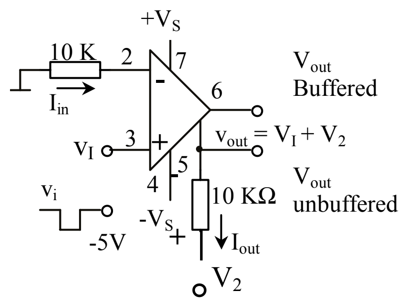


Figure 6 Level Shift Amplifier

c) An ELIN applications with nonlinear building blocks (sh, th, ch) which compensate each other the nonlinearities introduced by the large signal operation was developed taking into account the method proposed by Frey [1].

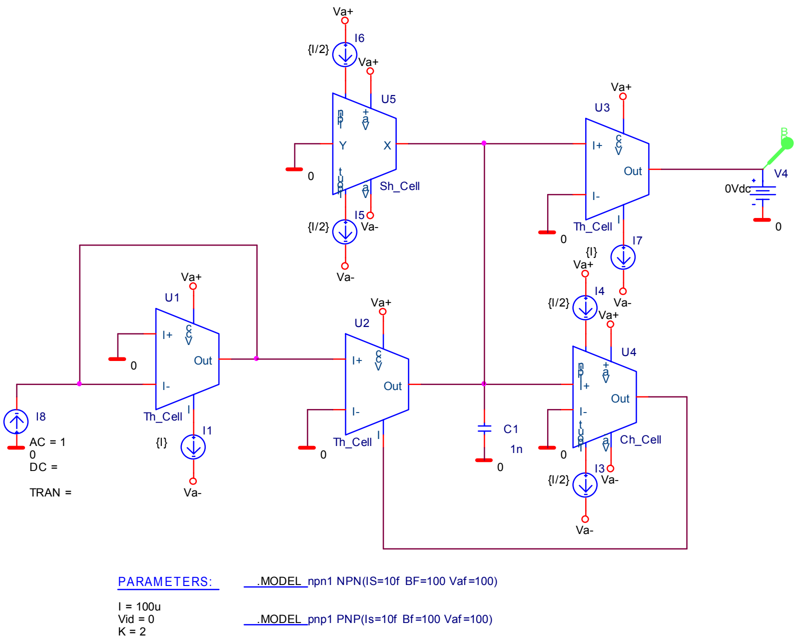
We designed a high frequency lossy integrator described by the relation:

$$\tau\frac{d_{io}}{dt} + i_o = ki_{in} \qquad \text{Substituting} \qquad (4.1)$$

$$i_o = kI\ \text{th}\frac{v_c}{2V_T}\ \ ;\ \ i_{in} = I\ \ \text{th}\frac{v}{2V_T} \qquad \text{results in:} \qquad (4.2)$$

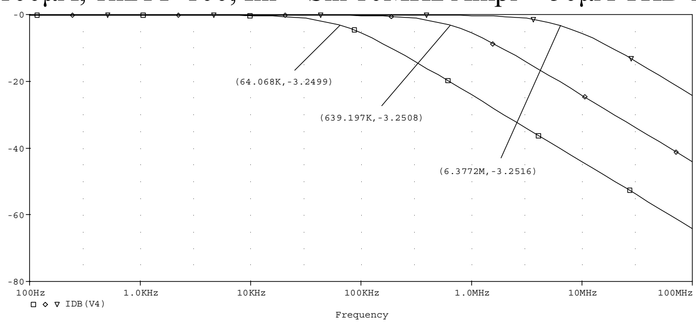
$$C\frac{dv_c}{dt} = I_O\left(1 + \text{ch}\frac{v_c}{V_T}\right)\text{th}\frac{v}{2V_T} - I_O\text{sh}\frac{v_c}{V_T}\ \ ;\ \ I_O = \frac{CV_T}{\tau} \qquad (4.3)$$

You can see the circuit in figure 8 that sh block is used only with its input stage in order to have the desired polarity from relation (4.3). The ch cell is a modified form of the sh building block [1] and the th is a current mirror loaded differential transistor pair [1]. Figure 9,b shows frequency characteristics for different bias currents I_O. Figure 9,c and d display some time domain diagrams for in–out signals in the case of a sine input function and a high frequency corresponding to an integration task. One can see internal nonlinear signal forms (displayed here only for signal v), but a good linear in-out behaviour with small distorsions (fig 9,d). In these applications all the cells can be used on the full input range a)



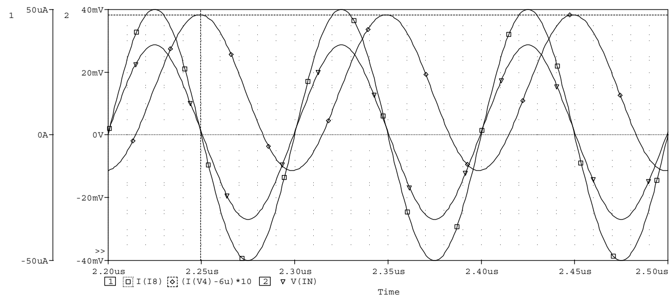
I=10μA, 100μA, 1mA I=100, Iin = Sin 10MHz Ampl = 50μA THD for I_{Out}= 0.51% = -45dB

b)



I=100μA, Iin = Sin 10MHz Ampl = 50μA THD for I_{Out}= 0.51% = -45dB

c)



I=100μA, Iin = Sin 10MHz Ampl = 100μA THD for I_{Out}= 1.03% = -39dB

d)

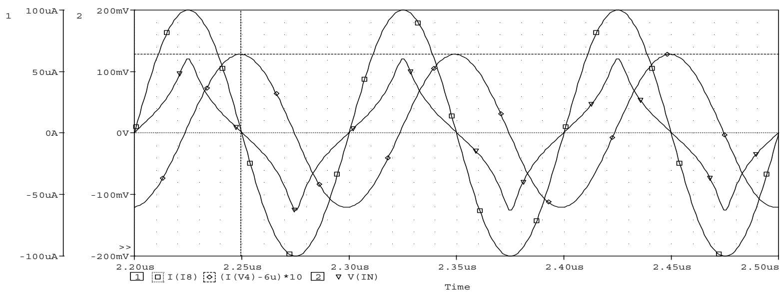


Fig. 8 Lossy integrator ; **a)** Schematic ; **b)** Frequency i_{out} / i_{in} characteristics ; **c) d)** Time diagrams

Conclusions.

Sinh building blocks can be considered as universal circuits that could be used in both linear or nonlinear applications. Conveyors CC II+, Diamond transistors and their "synonyms" are in fact sh cells which operate in the vecinity of the origin. They are optimized and biased for low input offsets and X resistances. For the linear operation, the equivalent resistance R_{1eq} connected to the X terminal must be much larger than the input X resistance.

A good linearity less dependent on R_{1eq} is achieved only for large bias currents I. For actual DTs large I is a also demand of high frequency applications. [6]. In low voltage - low power VLSI applications low bias currents are needed. Therefore using CC II+ structure would result in the need of high R_{1eq}. In that case the use of the "pure" nonlinear sh cell is prefered. This technique uses only low biased exponential cells and no passive resistances so that the input signals v_{yx} can vary in the large signal domain. [1].

We presented unitarily a class of nonlinear and linear circuits. As we know they were separately considered and treated in technical literature so far.

Clearing up their inter connectivity permitted understanding the reason and limits for their use in different applications with various tasks.

References.

1. D. Frey (1996) – Exponential State Space Filters IEEE, *Trans. On CS I*, vol 43, No.1, Ian 1996, pp 34-42.
2. M. Ismail, T. Fiez editors - Analogue VLSI Signal and Information Processing Mc Graw Hill 1994
3. Ch. Henn (1990), New Ultra High-Speed Circuit Techniques With Analog IC`s Application Handbook, Burr Brown International GmbH, AB-183, pp 249-256.
4. Y. Tzividis (1997) – Externally Linear, Time – Invariant Systems and Their Application to Companding Signal Processing, *IEEE Trans. On CS II,* vol 44, No 2, Feb 1997, pp 65-84
5. Analog Devices Linear Product Data Book, (1990/91), Analog Devices Inc., pp (2-307) – (2-317)
6. Burr Brown Integrated Circuits Data Book , Linear Product (1996-1997), Burr Brown Corporation, pp (2-326) – (2-328)