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Using SINH-Z Building Blocks in Linear Applications

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Abstract – The SINH building block is used in the design of hyperbolic circuits. In this paper, starting from an existing lossy integrator structure with hyperbolic circuits, an alternative connection of the SINH block is proposed. The connection involves the high-impedance output pin of the block. In order to apply easier the proposed connection, two modified blocks are proposed, a noninverting one, called SINHZ and its inverting version, called SINHZ-. Simulations show that the lossy integrator based on the SINHZ- block provides better large signal responses. A lossless integrator is proposed, based onto a pair of SINH and SINHZ- cells.
Keywords: SINH building block, current conveyor, exponential-space-state circuits

I. INTRODUCTION

Hyperbolic blocks are used in the design of exponential state-space circuits, taking part from the family of ELIN (Externally Linear, Internally Nonlinear) circuits. These types of circuits are built from nonlinear building blocks and are characterized with an overall input-output linear transfer function, while the internal transfer functions are nonlinear. Among the advantages offered by these circuits we should highlight the signal companding function and the high electronic adjustability of the exponential space-state circuits.
The family of exponential space-state circuits has mainly two categories: the log-domain and the hyperbolic domain circuits. The sinh cell comes from the second category, where circuits realizing hyperbolic functions like sh, th, ch are combined to obtain the overall linear transfer function.
The sinh cell were analysed in [1]. In this paper, another connection of the sinh cell, in the lossy integrator presented in [1], based on the specifications in [2], is proposed. Comparison of the effect of the proposed connection on the integrator performance is carried out by simulations in OrCAD, using standard BJT models. It is shown that the lossy integrator with the proposed connection presents lower THD at higher amplitudes of input signals.
Using of the lossless integrators is required in many standard biquad structures [3]. To solve the DC biasing issues, in this paper a structure of a lossless integrator is proposed. based on a SINH-SINHZ-building block pair.

II. LOSSY INTEGRATOR

The lossy integrator was developed taking into account the method proposed by Frey [2]. Starting from the space-state equation of a lossy integrator,

$$\tau\frac{d_{io}}{dt}+i_o=ki_{in} \tag{1}$$

and taking into account that

$$i_o=kI\ \mathrm{th}\frac{v_c}{2V_T}\ ;\ i_{in}=I\ \mathrm{th}\frac{v}{2V_T} \tag{2}$$

results in

$$kI_0\mathrm{th}\left(\frac{v_{in}}{2V_T}\right)=kI_0\tau\frac{1}{2V_T}\frac{1}{\mathrm{ch}^2\left(\frac{v_c}{2V_T}\right)}+kI_0\mathrm{th}\left(\frac{v_c}{2V_T}\right) \tag{3}$$

Note that the time constant τ is in the form of

$$\tau=\frac{CV_T}{I_0} \tag{4}$$

that highlights one of the greatest advantages of the exponential space-state circuits, their highly adjustability. Finally, it results [1]

$$C\frac{dv_c}{dt}=I_0\left(1+\mathrm{ch}\frac{v_c}{V_T}\right)\mathrm{th}\frac{v}{2V_T}-I_0\mathrm{sh}\frac{v_c}{V_T} \tag{5}$$

The structure of a sinh cell for implementing the above equation is shown in Fig. 1.a, and the sinh cell block implementation, with the external biasing sources is shown in Fig. 1.b. The structure basically is a second order positive current-conveyor (CCII+), but used without feedback in the X node, i.e. without an R_X resistance [1].

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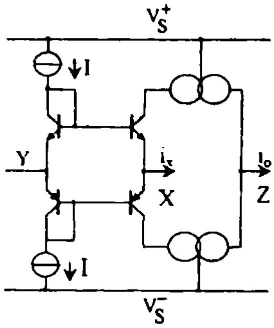


$$i_o = 2I\,\mathrm{sh}\frac{V_{yx}}{V_T}$$

$$\mathrm{sh}\ x = \frac{e^x - e^{-x}}{2}$$

$$i_o = i_x$$

Fig 1a. The Sinh building block structure

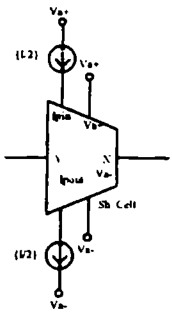


Fig 1.b. The block implementation of the sinh cell

Note that the Z output in the figure above is not used, as it is not necessary to implement the equation (5).

The structure of the cosh cell is similar with the structure of the sinh cell in Fig. 1.a. The difference between the two cells is that the currents at the Z output are summed instead of being subtracted, in order to obtain the sum of the two exponential terms in the numerator of the ch function.

A tanh cell consists of a BJT differential transconductor, as the large signal transfer function of a BJT differential pair is implementing a th function.

The block schematic of the lossy integrator implementing eq. (5) is shown in Fig. 2.

An extra tanh cell is added at the input, to make the F^{-1} function, i.e. the $\frac{1}{\mathrm{th}}$ transfer function required at the input [2]. The frequency characteristics are shown in Figure 3a, for three different values of I_o: 10µA, 100µA and 1mA, respectively. The transient response of the circuit is shown in Figure 3b for a 10 MHZ, 100µA amplitude input sine wave.

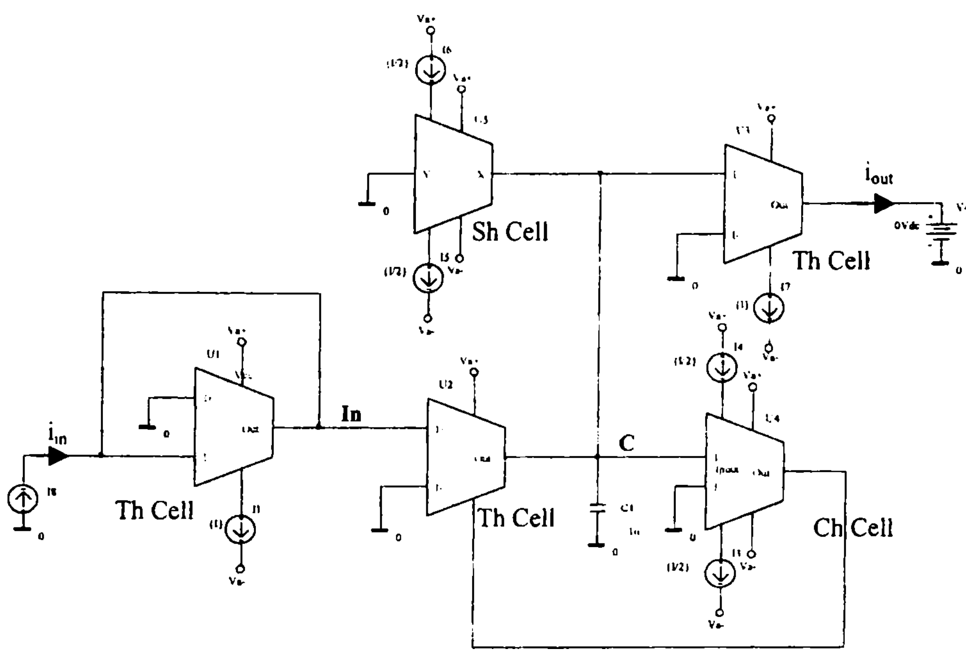
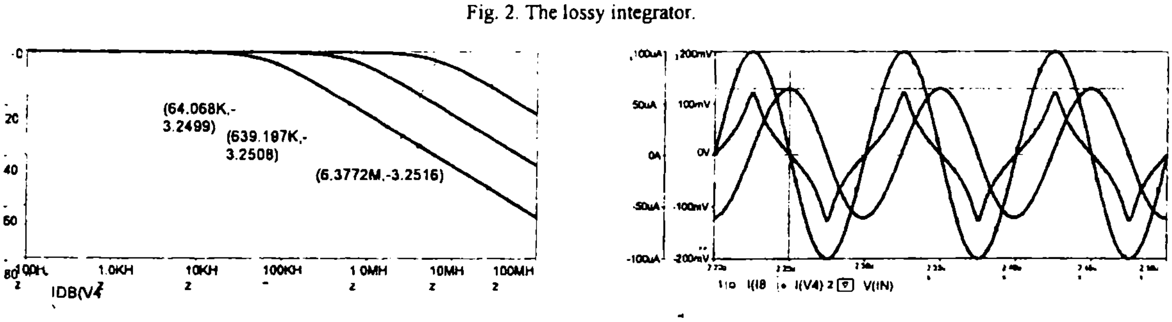


Fig. 2. The lossy integrator.



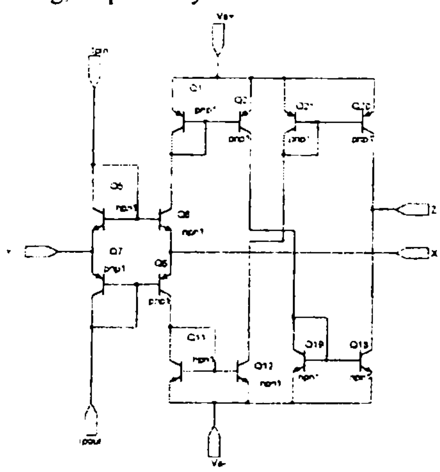
a.) b.)

Fig. 3. a.) Frequency response and b.) transient response of the lossy integrator from Fig. 2

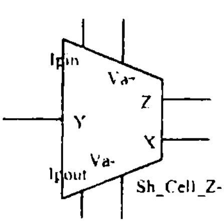
Fig. 3. a shows the adjustability of the passband of the circuit, over two decades. Fig. 3.b shows the other interesting feature of these circuits: while the output is not distorted, the overall input-output response being linear, the internal circuit is highly nonlinear, as, for example, the voltage on the internal node In is very distorted. The measured THD for the output current was -39dB.

III. SINH-Z AND SINH-Z- BLOCKS

Making the sinh term in equation (5) does not require the use of the high impedance output Z in the sinh cell, thus the Z terminal in the cell from Fig. 1 is internally connected to the ground. However, a sinh behavior is obtained also if the Z output is connected to the Y input. Additional current mirrors are added at the Z output, in order to obtain the – sign, transforming the CCII+ into a CCII-, (second order negative current conveyor). The internal structure is shown in Fig. 4 a.), and the block implementation in Fig. 4.b.) The cells created using this approach will be called SINHZ. and SINHZ-, according to the internal current conveyor structure used, noninverting, or inverting, respectively



a.)



b.)

Fig. 4 a.) Structure of the SINHZ- cell b.) The block schematic of the cell

In this way, the lossy integrator in Fig. 2 can be also obtained by replacing the SINH cell with the SINHZ- cell. The new structure was compared with the structure in Fig. 2, regarding the accuracy of the low-pass bandwidth versus the ideal bandwidth obtained from (4), and the THD in the pass band, for different amplitudes of input signals.

The passband gain of the integrator with the SINHZ- cell is lower than the passband gain of the integrator with SINH cell, being -0.82dB versus -0.24db. Therefore it is more relevant to compare the gain-bandwidth product of the two circuits, assuming that the ideal passband gain is 0dB. Table 1 shows comparatively the simulation results for different values of I_0, using a capacitor of C=1nF.

Table 1

I_0, μA	**GBW SINH (Hz)**	**GBW SINHZ-, (HZ)**	$B_{3dB}=\frac{1}{2\pi\delta}$ **(Ideal) (Hz)**
50	31.36K	31.4k	30.74K
100	62.42K	62.53k	61.49K
200	124.72K	124.95	122.9K
300	187.06K	187.39	184.4K

It is visible from Table 1 that both structures present a relative error less then 2% from the ideal characteristics. The error of the circuit with the SINHZ- block is slightly larger than the error of the circuit with the SINH, but also the differences are not important, the largest difference between the GBW of the two structures being under 0.2%.

Table 2 shows the comparison of the THD for the two types of lossy integrators in the passband, at I_0=100μA, applying an input sine wave of 10khz frequency, with the amplitude of I_{in}

Table 2

I_{in}, μA	THD Sinh, dB	THD Sinh_Z-, dB
10	-80	-72
50	-54	-52
90	-32	-40
100	-28	-35

Table 2 shows the advantages using the SINHZ- cell: while at lower amplitudes the THD of the structure with SINH cell is better, at higher amplitudes this advantage is lost against to the structure with the SINHZ-.

IV. LOSSLESS INTEGRATOR

Many biquad structures like Tow-Thomas or KHN require lossless integrators in their implementation structures. [3]. While at higher frequencies lossy integrators with lower time constants can be used as lossless ones, at lower frequencies, there is still a demand to build lossless integrators. From the space-state equation of a lossless integrator,

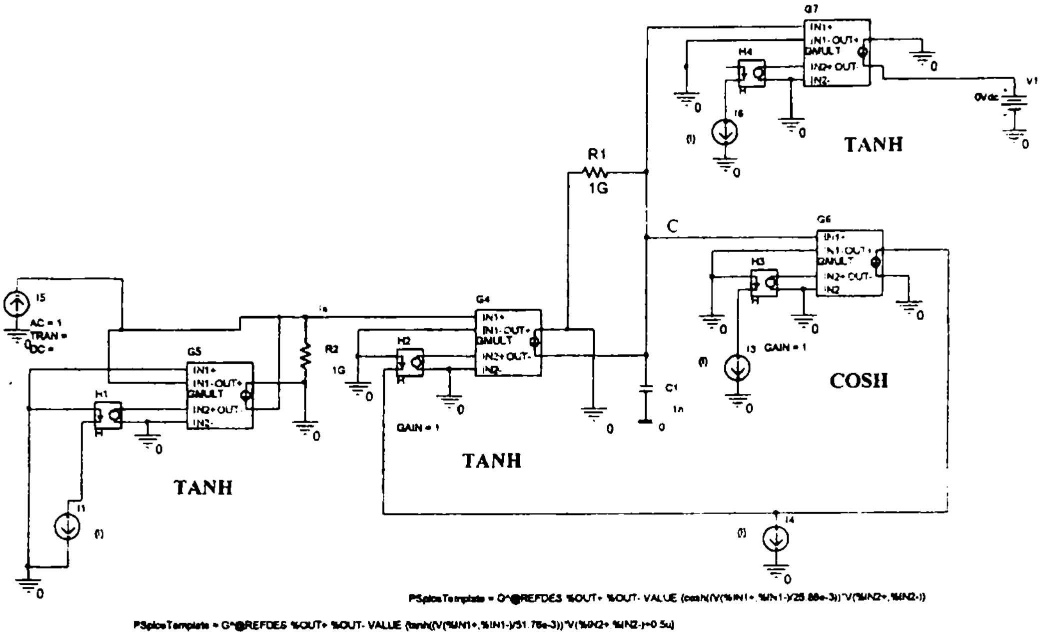


Fig. 5. Lossless integrator modeled with controlled sources.

$$\tau\frac{d_{io}}{dt} = ki_{in} \tag{6}$$

and taking into account equations (2), it will result

$$C\frac{dv_c}{dt} = I_0\left(1+ch\frac{v_c}{V_T}\right)th\frac{v}{2V_T} \tag{7}$$

Therefore, a lossless integrator can be obtained from the lossy integrator in Fig. 2 by simply removing the sinh block. This approach is used in Fig 5, where the lossless integrator is modeled with controlled sources. Note that, in order to follow the type of input-output variables, i.e. current at the input and output, respectively, each hyperbolic cell was modeled with a combination of an H (current controlled current source) and a GMULT (voltage controlled multiplying current source) controlled source.

Fig. 6 shows the amplitude and phase characteristics of the lossless integrator modeled with controlled sources. The low-frequency error is due to the small-signal resistance of the C node, modeled by R1, in the schematic in Fig.5. At the value of 1GΩ, the phase shift error is under 0.1 degrees at 100Hz. However, in practical implementation the phase error will be larger, as such high impedances are difficult to be achieved.

The implementation issues, however, are related to the biasing problems encountered. In the model in Fig. 5, all controlled sources are having zero offset voltages.

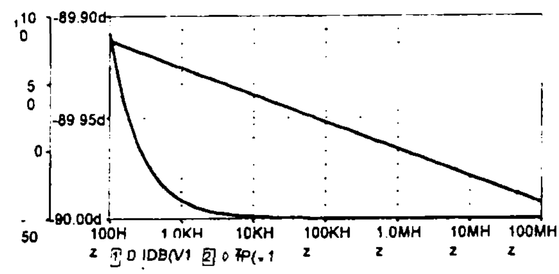


Fig. 6. Amplitude and phase response of the lossless integrator from Fig.5.

Considering just a 0.1mV offset voltage in any of the TANH or COSH cells, making the th(1+ch) product, leads to very high values of biasing currents like hundredths of amps and also to high values of node voltages, as the C node is of high impedance. These values of bias currents and voltages in a BJT circuit will not be achieved because of the finite Early and β effects. Though, the currents and voltages will increase until the transistors in the circuit will get into the saturation region.

A solution to this issue was found by not removing the SINH cell, implementing the –sh term in equation (5). Instead, its effect will be cancelled by the addition of a +sh term to the equation, that is, adding a SINHZ cell to the node C in Fig. 2. The schematic of the circuit is shown in Fig. 7. Note that the role of the I13 current source in the node C is to cancel completely the DC offset currents. The zero-value voltage sources are only used for current monitoring purposes.

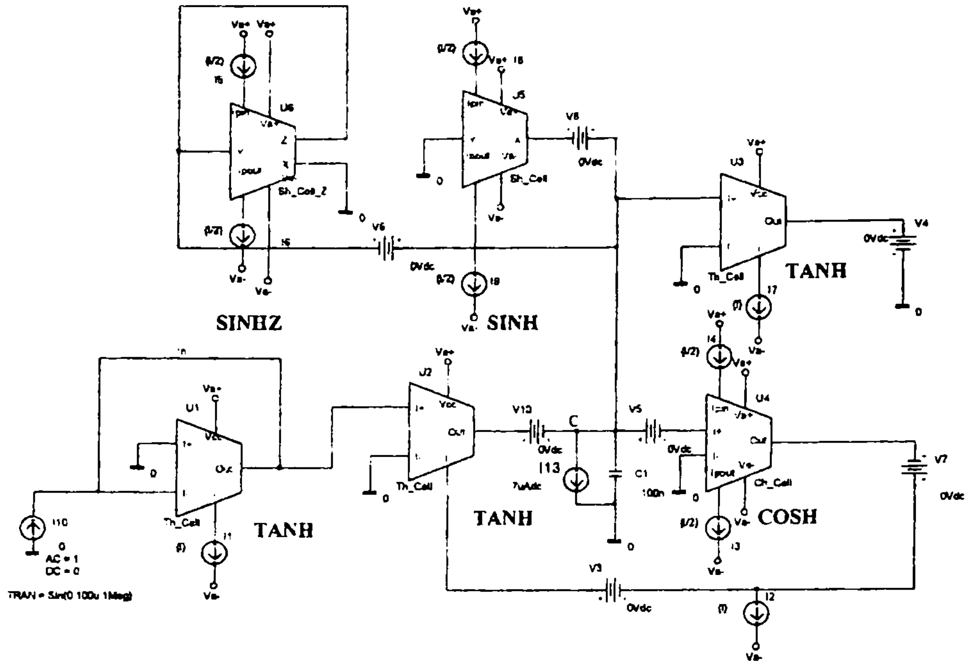


Fig. 7. Lossless integrator built by canceling the effect of the SINH cell with a SINHZ cell.

Fig. 8 shows the amplitude and frequency response of the lossless integrator from Fig. 7. Due to the finite input and output resistances of the TANH, SINH and COSH cells, the phase error is higher than in Fig. 6, being of 1 degree at the frequency of 1KHz. Obviously, the error can be lowered by increasing the output resistances of the cells, for example, by using enhanced mirrors like cascode at the outputs.

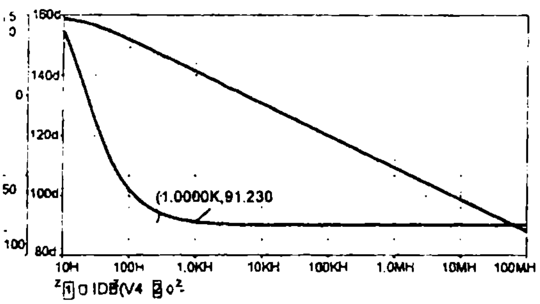


Figure 8. Amplitude and phase response of the lossless integrator from Figure 7.

V. CONCLUSIONS

In this paper, the usage of the SINH cell was presented. Starting from an existing lossy integrator structure, where the SINH cell was connected only by using its low impedance input terminal, another connection was proposed, involving the high-impedance output port. The modified cell was called the SINHZ. Its inverting version was also proposed and called SINHZ-.

The lossy integrator based on the SINHZ- cell was compared with the existing lossy integrator structure. While the precision of the frequency response of the integrator based on the SINHZ-cell is slightly lower, its large-signal response is much better for higher input amplitudes, giving lower THD.

Based on the equation of the lossy integrator with hyperbolic cells, a lossless integrator structure was proposed and modeled with controlled sources. To overcome the biasing problems in the BJT circuit, the lossless integrator with hyperbolic cells was built by using a pair of SINH–SINHZ circuits. The SINHZ cell cancels the –sh term, introduced by the SINH cell, in the equation of the lossy integrator.

The lossless integrator built with hyperbolic cells opens the possibility to build biquads in the low frequency domain, and to use the advantage of high adjustability provided by the ELIN circuits.

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