FOUR QUADRANT ANALOG CURRENT MODE MODULAR MULTIPLIER DESIGNED WITH DIFFERENTIAL AMPLIFIERS

Lorant Andras SZOLGA Lelia FESTILA Mihaela CIRLUGEA
Basis of Electronics Department, Faculty for Electronics and Telecommunications, Technical University of Cluj-Napoca,26. Baritiu Street, 400027, Romania,Tel/fax:0040-264-591340, lorant.szolga@bel.utcluj.ro

<u>Abstract:</u> In this paper we propose two and four quadrant analog current mode multipliers, implemented with bipolar differential amplifiers. The simplicity, low power consumption and high frequency operation recommend them for real time applications.

Key words: *analog multilplier, hyperbolic tangent domain, FF^{-1}functions*

I. INTRODUCTION

Nonlinear operations on continuous-valued analog signals are often required in instrumentation, communication, control and computing system design. Very important are VLSI signal processing systems based on neuron-like circuits (artificial neuronal networks, cellular nonlinear networks, support vector machines). In such analog-signal processors there is a need for circuits that take two analog inputs and produce outputs proportional to their product. Such circuits are termed analog multipliers.[1][2]

We present in this paper an original modular analog multiplier realized with hyperbolic tangent cells. These ones are simple differential amplifiers used on their large signal nonlinear input-output characteristics.

Such modular circuits can be used as real-time multipliers in ELIN circuit design[3] based on hyperbolic tangent domain.

After examining the two basic cells in the first section, in next section we propose modular two and four quadrant multiplier schematics. In each of the cases we proved by Pspice simulation the circuit validity and functionality.

III. HYPERBPLIC TANGENT AND ARCTANGENT CELLS

a) Hyperbolic arctangent cell (inverse th function)

Fig 1.a presents a circuit that implements the inverse function of a hyperbolic tangent.[3] The library symbol is given in Fig 1.b. In fact this cell has differential amplifier structure having a total negative feedback.

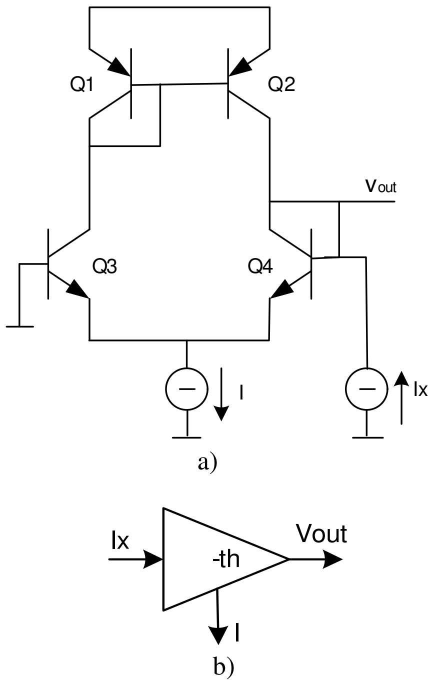


Figure 1. Hyperbolic arctangent cell
a) schematic b) library symbol

The current mirror loaded emitter-coupled pair Q_3-Q_4 , shown in figure 1.a has as input the bidirectional current i_x and the output is voltage v_{out}. The system equations which define the circuit in figure 1.a are:

$$\begin{cases} I_{C_4} + I_{C_3} = I \\ I_{C_4} - I_{C_3} = I_X \\ V_{out} = V_{BE_4} - V_{BE_3} \end{cases} \quad (1)$$

where

$$V_{BE} = V_T \ln \frac{I_C}{I_S} \quad ; \quad |I_X| < I \quad (2)$$

The output voltage from system (1) and (2) will be:

$$V_{out} = V_T \ln\left(\frac{I + I_X}{I - I_X}\right) \quad (3)$$

Equation (4) defines the hyperbolic tangent function.

$$\frac{e^x - 1}{e^x + 1} = \tanh\left(\frac{x}{2}\right) \quad (4)$$

In order to determine the inverse form of the logarithmic function, we transformed equation (3) as shown below:

$$\frac{e^{\frac{V_{out}}{V_T}} - 1}{e^{\frac{V_{out}}{V_T}} + 1} = \frac{I_X}{I} \quad (5)$$

It can be easily observed that equations (4) and (5) have a similar form. Identifying the terms between the two equations we deduced the expression of the output voltage of the form of the hyperbolic arctangent function performed by circuit 1.a:

$$V_{out} = 2V_T \tanh^{-1}\left(\frac{I_X}{I}\right) \quad (6)$$

Fig. 2 proves the correct operation of this circuit in DC_sweep analysis made with the Orcad Pspice simulator.

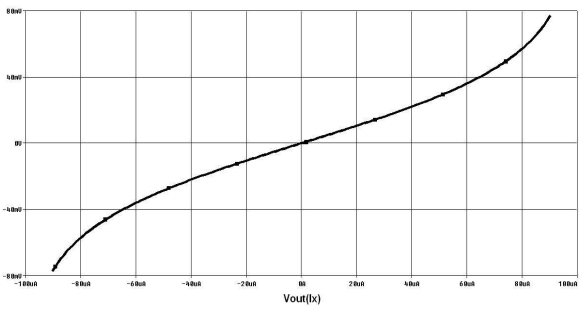


Figure 2. Hyperbolic Arctangent cell DC_sweep analysis

b) Hyperbolic tangent function

The th cell and its library symbol are given in Figures 3.a and 3.b respectively

Using the same procedure as in the case of the first circuit, for schematic in figure 3.a we obtain:

$$I_{out} = I \tanh\left(\frac{V_{in}}{2V_T}\right) \quad (7)$$

which is related to the differential input voltage $V_{in} = V_{BE7} - V_{BE8}$, where $I_{out} = I_{C7} - I_{C8}$.

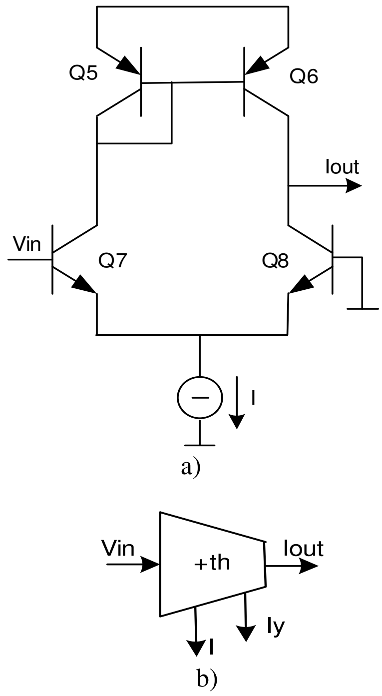


Figure 3. Hyperbolic Tangent cell
a) schematic b) library symbol

To have a good functioning of the circuit in Fig. 3.a strict positive bias current I is required.

The hyperbolic tangent characteristic of circuit 3.a, is put into evidence in figure 4, which presents the DC_sweep analysis of the circuit.

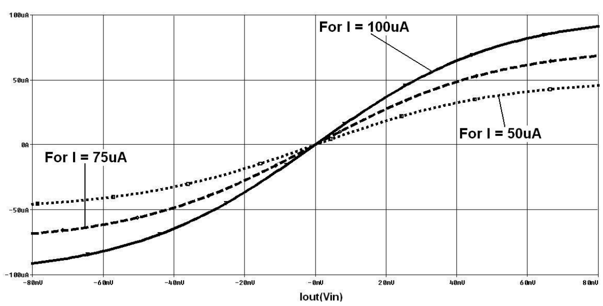
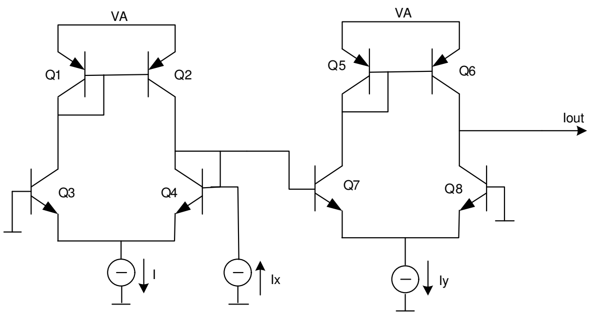


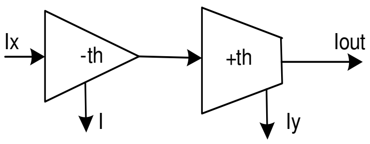
Figure 4. Hyperbolic Tangent cell DC_sweep analysis

III. TWO QUADRANT CURRENT MULTIPLIER

Combining the two cells presented in the first section, we got the circuit in Fig.5:



a)



b)

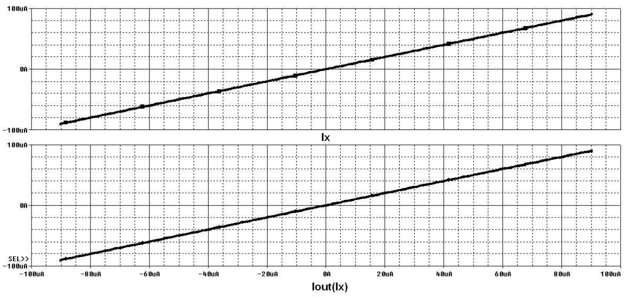
Figure 5. Two quadrant hyperbolic tangent domain analog current multiplier: a) schematic, b) block diagram

In this circuit configuration it is obvious that the input voltage V_{in}, of the tangent cell is equal to the output voltage V_{out} of the arctangent cell. Under this consideration we canceled the nonlinearity of de tangent and arctangent functions (equations (6) and (7)), obtaining for I_Y=ct a linear distribution output current of form:

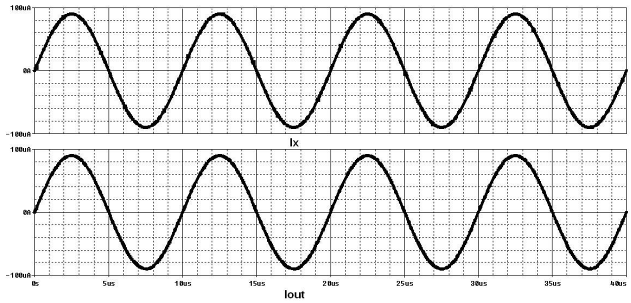
$$I_{out} = \frac{i_x I_y}{I} \qquad (8)$$

Equation (8) denotes the multiplication of currents scaled by the bias current I. Because of the positive direction of current I_y and the bidirectional values that current i_x may have, the circuit from figure 5.a will be a two-quadrant multiplier.

A particular case of the circuit is for the current follower I_y=I, when the output current will be equal with the I_x input. This particular case is a good example to prove the well functioning of this circuit. Figures 6.a and 6.b present the DC_sweep and Transient analysis of the circuit for this particular case.



a)



b)

Figure 6. Analysis of the two quadrant current mutiplier in the case of I_x=I
a) DC_sweep b) Transient analysis

Figure 7 proves a good operation of the two-quadrant multiplier in the non particular cases ($I_x \neq I_Y$), for different values of I_Y current and I=50μA.

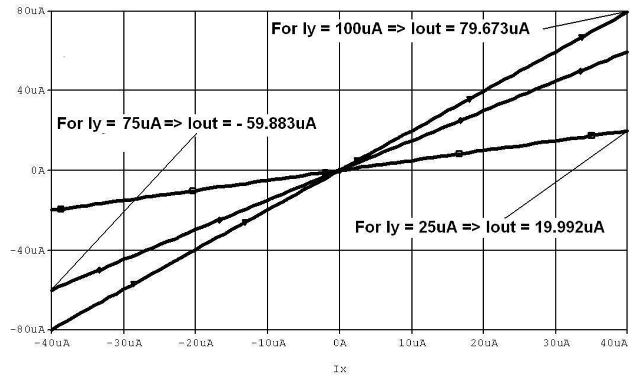


Figure 7. DC_Sweep simulation for the two quadrant current multiplier in the $I_x \neq I_Y$ case

IV. FOUR QUADRANT CURRENT MULTIPLIER

The restriction to two-quadrants of operation may be a severe one for many communications and neuronal network applications, and most practical multipliers have to allow a four-quadrant operation.

Adding a bidirectional current to the bias current of the tangent cell and considering the same bias currents in both cells the output of the figure 5.a circuit will be:

$$I_{out} = \left(I + i_y\right)\left(\frac{i_x}{I}\right) = i_x + \frac{i_x I_y}{I} \qquad (9)$$

Subtracting the current i_x from equation (9) the output current becomes:

$$I_{out} = \frac{i_x i_y}{I} \qquad (10)$$

The circuit which implement this multiplying function is the one from figure 8.a

It can be observed that equations (8) and (10) are of the same form, but the difference is made by the bipolar values that current i_Y could have in the circuit from figure 8.a.

Making this remarks we can conclude that the schematic from figure 8.a is one of a four quadrant multiplier.

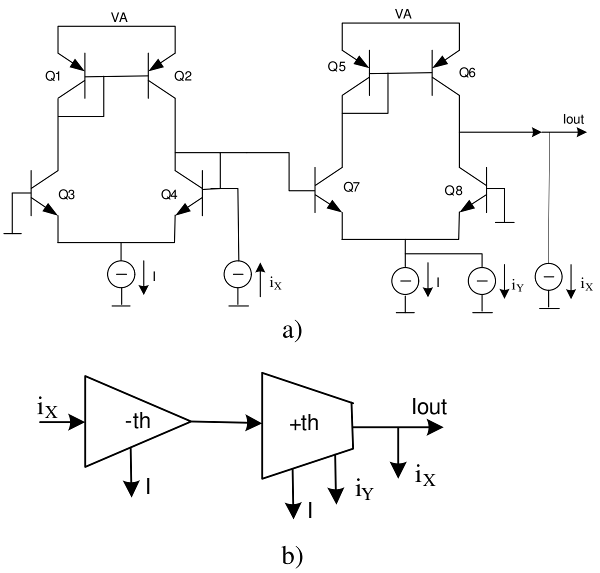
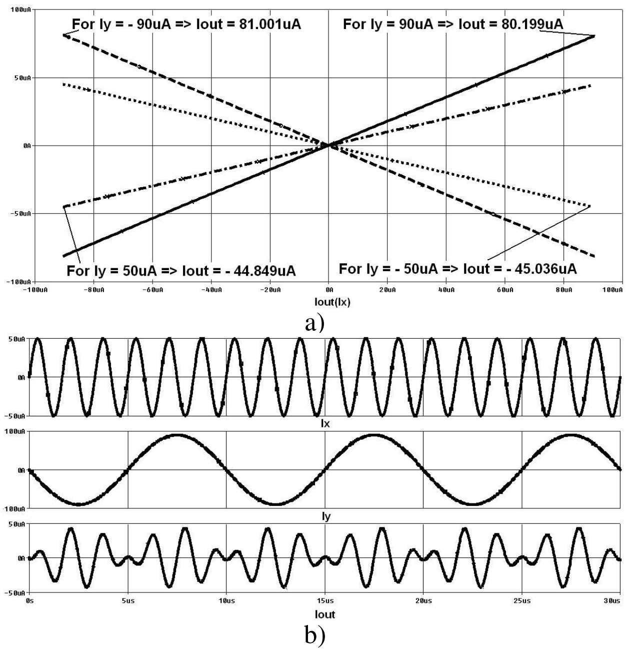


Figure 8. Four quadrant hyperbolic tangent domain analog current multiplier: a) schematic, b) block diagram

Figure 9.a shows a DC_sweep analysis of the schematic from figure 8.a for I_Y€{-90uA, -50uA, 50uA, 90uA}, I=100uA and I_X€[-90uA,90uA] . All the four cases prove the four-quadrant operation of the circuit.

Choosing I=100uA, I_x= 50sin(2π*600*10^3)uA, I_Y=100 sin(2π*100*10^3)uA we obtained the modulated output signal I_{out}=1/2(cos(2π*500*10^3)- cos(2π*700*10^3)) presented in figure 9.b. The frequency spectrum of the input currents and the modulated output signal are shown in figure 9.c
All these simulations prove the good functionality of the four quadrant circuit.



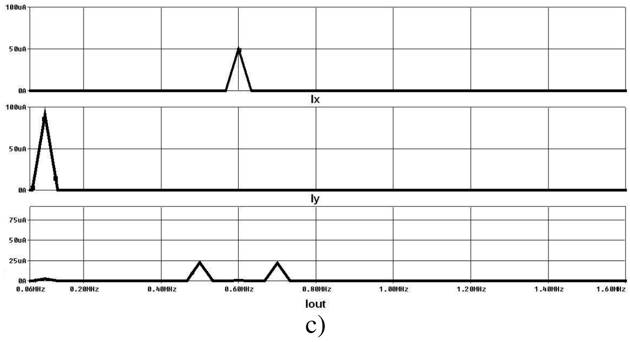


Figure 9. Analysis of the two quadrant current multiplier a) DC_sweep b) Transient c) FFT

CONCLUSIONS

The 2Q and 4Q modular multipliers proposed in this paper are very simple but functional ones.

They exhibit a good linearity on the whole domain of existence, and also a good accuracy. In high frequency bipolar or BiCMOS modular design these analog current-mode multipliers could be a good alternative to the classical ones.

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