LOW-POWER CMOS BULK-DRIVEN WEAK-INVERSION ACCURATE CURRENT-MODE MULTIPLIER/DIVIDER CIRCUITS

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ABSTRACT

Two current mode multiplier/divider circuits using bulk-driven MOS transistors will be presented. Because of the operation of MOS transistors in subthreshold region, these computational circuits allow obtaining a very small current consumption, responding to the low-power requirements of newer computational circuit designs. The utilization of the bulk as the fourth active terminal reduces the circuit complexity and, in consequence, the silicon occupied area for the required function. The output currents of both versions of bulk-driven circuits are independent on the process parameters, so independent on temperature.

I. INTRODUCTION

Computational circuits and particularly multiplier/divider circuits are important building blocks for telecommunication applications, medical equipments, hearing devices and disk drives [1] - [5].

In the bipolar technology, the multiplication function could be easily obtained from the logarithmical characteristic [6] of the bipolar transistor. Important errors still remain because of the nonzero values of the base currents, especially for pnp transistors and of the temperature dependence of the bipolar transistor parameters (the thermal voltage is linear increasing with temperature and the saturation current has an exponential dependence on temperature).

Due to the rapid development of CMOS VLSI technology, many analog signal processing functions can be achieved by employing the square-law model of MOS transistors [7] – [15]. Analog circuits based on the square-algebraic identity can be easily realized from the well-known square-law model of the MOS transistors in the saturation region. Based on this principle, several basic building blocks, such as multipliers, active resistors and transconductors have been developed [7] – [15].

In order to respond to the low-power requirements of the newest CMOS designs, the subthreshold operation of the MOS transistor is an interesting choice. Based on the logarithmical law of a MOS transistor in weak inversion, the implementation of a CMOS current-mode multiplier/divider becomes very simple (even with respect

II. THEORETICAL ANALYSIS

CURRENT MULTIPLIER/DIVIDER USING BULK-DRIVEN MOS TRANSISTORS

The double drive of the MOS transistor (on gate and on bulk) allows the reduction of the complexity for the circuits that realize mathematical functions. The first proposed current multiplier/divider using bulk-driven MOS transistors is presented in Figure 1. Considering a weak inversion operation of all the transistors from Figure 1, the expressions of \( I_1 \) and \( I_2 \) currents will be:

\[
I_{1,2} = I_{D0} \exp \left( \frac{V_{GS1,2} + (n - 1)V_{BS1,2}}{nV_t} \right)
\]

where \( I_{D0} \) is a parameter with the following expression, resulted from the continuity between the strong inversion and weak inversion regions:

\[
I_{D0} = \frac{2 \mu_C}{e^2} \frac{C_{ox}(nV_t)^2}{e^2}
\]

\( V_{GS1,2} \) and \( V_{BS1,2} \) are, respectively, the gate-source and bulk-source voltages of the MOS transistor. \( C_{ox} \) is the oxide specific capacitance and \( V_t = kT / q \) is the thermal voltage. So:
\[
\frac{I_I}{I_2} = \exp\left(\frac{V_{X_2} - V_{Y_2}}{nV_t}\right) \exp\left[\frac{n-I}{nV_t} \left(V_{X_1} - V_{Y_1}\right)\right]
\]

(3)

\[
\frac{I_{X_I}}{I_{Y_I}} = \exp\left[\frac{n-I}{nV_t} \left(V_{BS_3} - V_{BS_4}\right)\right]
\]

(4)

Because \(V_{GS_3} = V_{GS_4}\) it results:

\[
\frac{I_{X_2}}{I_{Y_2}} = \exp\left[\frac{n-I}{nV_t} \left(V_{BS_7} - V_{BS_8}\right)\right]
\]

(5)

\[
\frac{I_1}{I_2} = \frac{I_{Y_1}}{I_{X_1}} \left(\frac{I_{Z_2}}{I_{X_2}}\right)^{\frac{1}{n-I}}
\]

(9)

Similarly, because \(V_{GS_7} = V_{GS_8}\) :

Knowing that:

\[
V_{X_1} - V_{Y_1} = V_{BS_4} - V_{BS_3}
\]

(6)

and:

\[
V_{X_2} - V_{Y_2} = V_{BS_8} - V_{BS_7}
\]

(7)

and using (2) and (3), the relations between the currents from Figure 1 could be written as:

\[
\frac{I_I}{I_2} = \frac{I_{Y_I}}{I_{X_I}} \left(\frac{I_{Y_2}}{I_{X_2}}\right)^{\frac{1}{n-I}}
\]

(8)

A generalization of relation (8) for different values of current sources \(I_0, I_{Z_1}, I_{W_1}\) and \(I_{Z_2}, I_{W_2}\), respectively) allow obtaining a more complex relation with currents as variables:

\[
I = \exp\left(\frac{V_{GS_1} - V_{GS_2}}{nV_t}\right) \times
\]

CURRENT-MODE MULTIPLIER/DIVIDER CIRCUIT USING A BULK-DRIVEN ACTIVE-LOAD DIFFERENTIAL AMPLIFIER

Another possible implementation of a current-mode multiplier/divider is referred to a bulk-driven active-load differential amplifier from Figure 2.

Considering a weak inversion operation of all the transistors from Figure 2, the ratio of \(I_1\) and \(I_2\) currents will be:

For the active-load differential amplifier it is possible to write:
\( \times \exp \left[ \frac{n-I}{nV_t} \left( V_{BS_j} - V_{BS_2} \right) \right] \) \quad (11) \[ \frac{I_{YL}}{I_{Y2}} = \exp \left( \frac{V_{GS_3} - V_{GS_4}}{nV_t} \right) \times \exp \left[ \frac{n-I}{nV_t} \left( V_{BS_j} - V_{BS_4} \right) \right] \] \quad (14)

From the two previous relations it results:

\( \frac{I_I}{I_2} = \exp \left[ \frac{I-n}{nV_t} \left( V_{X_1} - V_{X_2} \right) \right] \) \quad (12)

So, it results:

Similarly, the ratios of \( I_{X_1}, I_{X_2} \) and \( I_{Y_1}, I_{Y_2} \) are, respectively:

\[ \frac{I_{X_1}}{I_{X_2}} = \exp \left( \frac{V_{GS_3} - V_{GS_4}}{nV_t} \right) \] \quad (13)

From (12) and (15), using that \( V_{X_1} - V_{X_2} = V_{BS_d} - V_{BS_j} \), the relation between the currents from Figure 2 will be:

\[ \frac{I_I}{I_2} = \frac{I_{Y_1} I_{X_2}}{I_{Y_2} I_{X_1}} \] \quad (16)

Figure 2: Current-mode multiplier/divider using bulk-driven active-load differential amplifier
III. CONCLUSIONS

Two CMOS multiplier/divider circuits were presented. The reducing of the circuit complexities and, in consequence, of the silicon occupied areas is achieved by using the bulk as the fourth active terminal of the MOS transistors, making these computational circuits compatible with the latest VLSI designs. The proposed multiplier/divider circuits respond, also, to the low-power requirements due to the subthreshold operation of MOS transistors. The circuits’ output currents are independent on the process parameters, so independent on temperature variations.

REFERENCES