Development and Applications Current Driven Bulk Current Mirrors

Abedalhakem Alkowash[1], Imhammad Abood[2], Abdualbaset Asahi[3]

(1) University of Sabratha, Faculty of Engineering, Sabratha
(2) University of Gharyan Faculty of Engineering ,Gharyan
(3) University of Sabratha, Faculty of Engineering, Sabratha

Abstract

My work starts with designing a current mirror for low-voltage low power applications. The current source/sink is a basic building block in capacitance Metal-Oxide-Semiconductor-Transistors Integrated Circuit (CMOS IC) design and is used extensively in analog integrated circuit design. Ideally, the output impedance of a current source/sink should be infinite and capable of generating or drawing a constant current over a wide range of voltages. However, finite values of output resistance(r_0)and a limited output swing required to keep devices in saturation will ultimately limit the performance using the conventional gate-driven current mirror and the low-voltage low-power bulk-driven current mirrors and comparative study between them.

Keywords: current mirror, Metal-Oxide-Semiconductor-Transistors (MOSTs)**,** The Bulk-driven and Gate-Driven MOSFTs

1 Introduction

1.1 Ideal Current Mirror:

A current mirror can be used as an active load in the differential stage of the op-amp. It is a circuit that must mirror the current. After the differential stage of the op-amp, it is the most important circuit block. Therefore, it will be discussed in detail. The current mirror is represented in ideal form in Fig.1a. Its most simple realization is shown Fig. 1b. It consists of $two\ transistors$ with identical v_{GS}.
One is connected as a diode and is driven by i_{IN} . The other one provides output current i_{OUT} at a high impedance level. Since their v_{GS} are the same, the ratio of their currents is given by.

$$\frac{i_{OUT}}{i_{IN}} = B = \frac{(W/L)_2}{(W/L)_1} \qquad (1.1)$$

By choosing this ratio, the output current can be set on the required value with high precision. Usually the channel length L is kept the same for both transistors to achieve good matching [1-2]. Then the ratio B is set by the transistor widths W. Several errors occur, however, that cause deviations from ideal behavior. The requirements of an ideal current source are the following:

1- The current ratio B is precisely set by the (W/L) ratio, independent of temperature.
2- The output impedance is very high, i.e., high R_{OUT} and low C_{OUT} . As a result, the output current is independent of the output voltage, DC and AC.
3- The input resistance R_{IN} IS very low.
4- The compliance (voltage) is low, i.e., the minimum output voltage V_{OUTc}, for which the output acts as a current source, is low.

These requirements now considered for the simple CMOS current mirror.

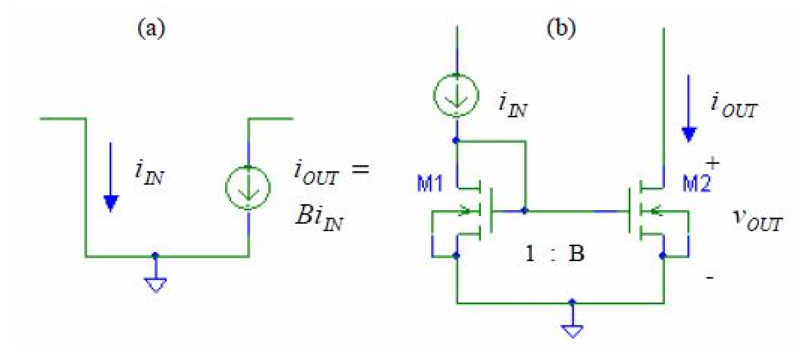

Figure 1: a) principle of current mirrors and 1 b) a simple MOST current mirror.

One of the problems with MOST current mirrors is that a significant voltage must be dropped across the input device. If I design the MOST so that it is operating with the bulk-source slightly forward biased, it can be avoided the requirement for this voltage drop by using the MOSTs from the bulk as the input devices with the gate at a constant voltage. This technique permits the transistor to operate in strong inversion and result in dc currents equivalent to higher voltage designs [3].

1.2 Simple MOST Current Mirror

A N-type version of the proposed low-voltage current mirror` is shown in Figure 2. Instead of the gate-drain diode connection used in the conventional simple current mirror, this new current mirror has a bulk-drain connection. Also, the bulks of M_1 and M_2 are tied together rather than the gates. Instead, the gates of M_1 and M_2 for the N-type version go to the most positive voltage available V_{DD}.

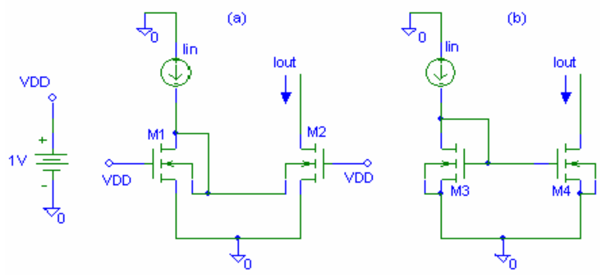

Figure.2. Simple current : a) Bulk-driven, b) Gate-driven.

The drain current versus the bulk-source voltage for a fixed gate-source voltage of the bulk-driven MOST is shown in Figure 2 (a).The drain current versus the gate-source voltage of the Bulk-source voltage is also shown. It is observed that the bulk-driven MOST is equivalent to a Junction Field Effect Transistor (JEFT) where both drain-source current saturation (I_{DSsat}) and Threshold voltage (V_T) are dependent on the fixed gate-source voltage.
There are big similarity between MOST driven from the gate and from the bulk, the following several equations show the drain current in linear and saturation reign for both of gate-driven and bulk-driven MOST.

First order theory gives the drain current i_{DS} of Gate-Driven MOST as

Table 1. The Bulk-driven drain current

Reign	Gate-Driven	Bulk-driven
Linear $v_{DS} < v_{GS} - v_T$	$i_{DS} = \beta\left(v_{GS} - v_T - \frac{v_{DS}}{2}\right) v_{DS}$	$i_{DS} = \beta\left(v_{GS} - v_{TO} \mp \gamma\left(\sqrt{2\lvert\delta\Phi_F\rvert - v_{BS}} - \sqrt{2\lvert\Phi_F\rvert}\right) - \frac{v_{DS}}{2}\right) v_{DS}$
Saturation $v_{DS} \geq v_{GS} - v_T$	$i_{DS_{sat}} = \frac{\beta}{2}(v_{GS} - v_T)^2(1 + \lambda v_{DS})$	$i_{DS_{sat}} = \frac{\beta}{2}\left(v_{GS} - v_{TO} \mp \gamma\left(\sqrt{2\lvert\delta\Phi_F\rvert - v_{BS}} - \sqrt{2\lvert\Phi_F\rvert}\right)\right)^2 (1 + \lambda v_{DS})$

Where

$$KP_{n,p} = \mu_{n,p} C_{OX} \quad \text{transconductance parameter} \left({}^{A}/_{V^2} \right)$$

$$\beta = \frac{W}{L} KP_{n,p}$$

$\mu_{n,p} = \frac{v}{E}$ mobility in the channel $(cm^2/V.s)$. $\mu_n \approx 3\mu_p$

The small signal input resistance and output resistance of Figure 3 can be found as

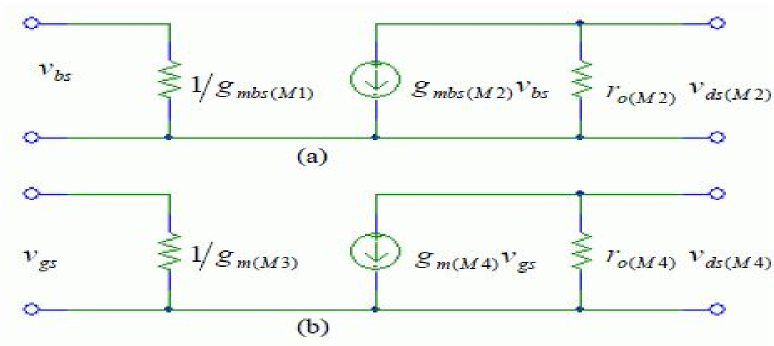

Figure 3: Small signal equivalent circuit of Simple current mirror: a) Bulk-driven, b)Gate-driven

Table 2: The bulk-driven and gate-driven input-output resistance

	The bulk-driven (a)	**The gate-driven**
r_{in}	$= \frac{1}{g_{mbs}} = \frac{dv_{BS}}{di_D} = \left(\frac{dv_{GS}}{di_D}\right)\left(\frac{dv_{BS}}{dv_{GS}}\right) = \frac{2\sqrt{2\emptyset_F - V_{BS}}}{\gamma g_{ms}}$	$= \frac{1}{g_{m(M3)}}$
r_{out}	$= \frac{1}{\lambda I_{DS(M2,M4)}}$	

Where I_{DS} is proportional to $\left(V_{GS(M2,M4)} - V_T\right)$. These values are in the same range as gate-driven mirrors.

2 Characteristics of Bulk-Driven Current mirror:

The most important characteristic of a current mirror is its current ratio. Therefore it is investigated.

2.1 Current Ratio

The current ratio is given by Eq.(1.1) .An error occurs because the finite output resistance of both transistors is present. Transistor M_1 operates at low $v_{DSI} = v_{BSI}$, whereas M_2 operates at another $v_{OUT} = v_{DS2}$, which is probably much higher [4-5]. Its value is determined by the load, which could be a resistor, a differential stage, etc. Thus, an error in current Δi_{OUT} occurs, as shown, as shown in Fig. 3.4. It is given by

$$\Delta i_{OUT} = \lambda(v_{DS2} - v_{DS1}) = \frac{v_{DS2}-v_{DS1}}{V_{En}-L_2} \qquad (1.2)$$

The error can be reduced by using large values of transistor length L_2 , but especially by enforcing equal v_{DS} values on both transistor. This can be realized by addition of more transistors.

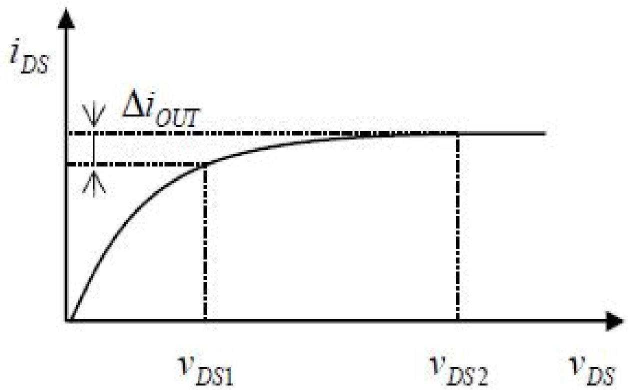

Figure 4: Current error because of different v_{DS}

At high frequencies the current the ratio is impaired as well. The small-signal equivalent circuit of the current mirror seen in Fig. 2a is given in Fig 5. All transistor capacitances are included. It is clear that the current mirror behaves as any other two-node amplifier. Thus it has two poles and one zero.

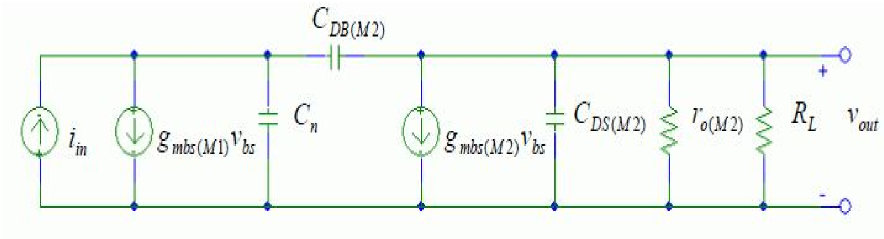

Figure 5: Small-signal high frequency circuit of bulk-driven current mirror

The input node is at an impedance level that is quite low, i.e., $1/g_{mbs(M1)}$. Therefore the effect of $C_{DB(M2)}$ IS usually negligible.
The dominant pole of the current ratio transfer characteristic is then given by

$$f_p = \frac{g_{mbs(M1)}}{2\pi C_n} \qquad (2.2)$$

In which $C_n = C_{bs(M1)} + C_{bs(M2)} + C_{DS(M1)}$.

This pole is normally situated at quit high frequencies because of the low value of $g_{mbs(M1)}$. Thus the current mirror operates well up to high frequencies.

2.2 Output Impedance

The output impedance is simply the output resistance r_{02} of the output transistor see Fig. 2 in parallel with an output capacitance. It is independent of the impedance of the current source with which the input transistor is driven. The value r_{02} can be made high by increasing the transistor length L. Very high values are difficult to realize, however. Therefore, other configurations are required, such as those used with cascades.

The output capacitance is simply $C_{DB(M2)} + C_{DS(M2)}$ see Fig. 5 in which $C_{DS(M2)}$ is are difficult to achieve; this can be a severe limitation at high frequencies.

2.3 Input Resistance

The input resistance of the bulk-driven is bigger than the input resistance of the gate-driven because it is given by $1/g_{mbs(M1)}$. Thus, it is easy to design a current source with value i_{IN}, which has an output resistance much higher than the resistance $1/g_{mbs(M1)}$ [6].

2.4 Compliance V_{OUT}

The compliance voltage V_{OUT} is the minimum output voltage at which the current mirror still provides a high output resistance. It is given by the value of $V_{GSI} - V_T$ can be decreased by taking large values of (W/L) [7]. In strong inversion it is given by

$$V_{OUT} = V_{GSI} - V_T = V_{DS_{sat2}} = \sqrt{\frac{I_{OUT}}{K(W/L)}} \qquad (3.2)$$

The current mirror of Fig. 2 is the simplest and thus it is used more often than any other. Nevertheless, for precision circuits there is a need for a current mirror with higher output resistance r_0 and with less error in current Δi_{OUT}. I will introduce other configurations that have less error.

I provided current mirrors using both bulk-driven and gate-driven MOSTs for low power applications. I provided the simulation by Orcad Pspice using model $0.7\ \mu m$ [8]. The results show that the input voltage drop for the bulk-driven mirrors can be much less as depicted on the following figure (6).

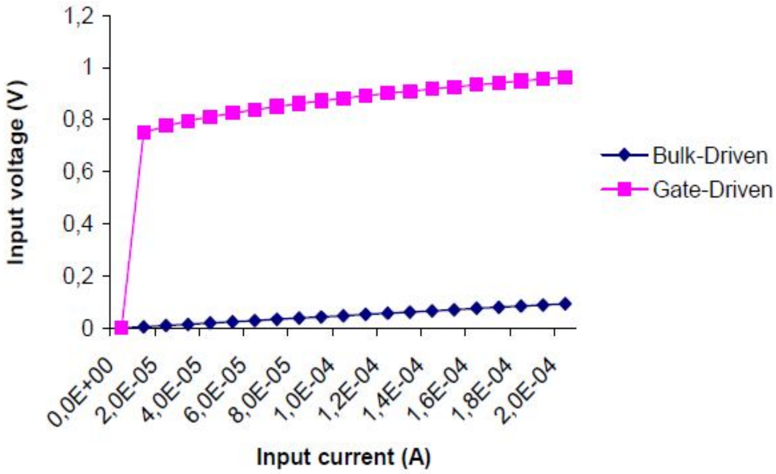

Figure 6: Input voltage vs. Input current characteristics

I can give an example, $200\mu A$ input current, the value of $V_{DS(M3)}$ for the gate-driven mirror was 0.96V and the bulk-driven mirror it was 0.09V. The small signal output resistances are approximately the same. The input-output current linearity of the gate-driven mirrors is absent in the bulk-driven mirror because the output transistor M_2 is operating in saturation see Figure 7and see Figure 8.

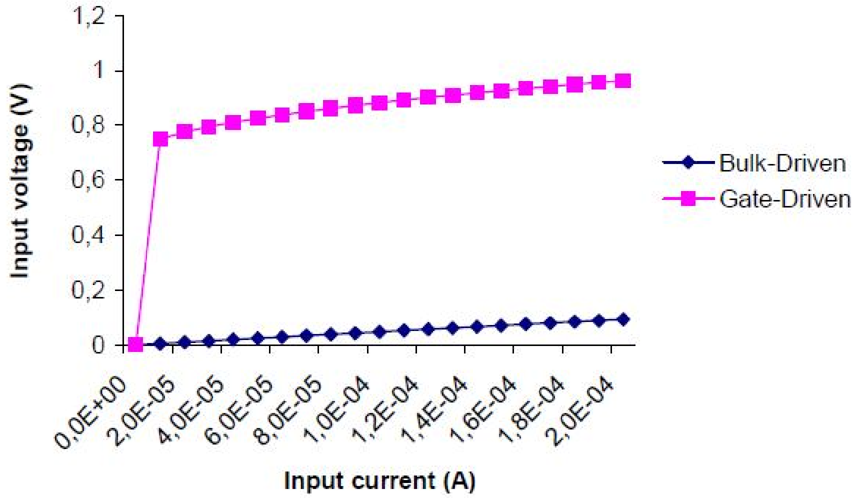

Figure 7: Input-output transfer characteristics.

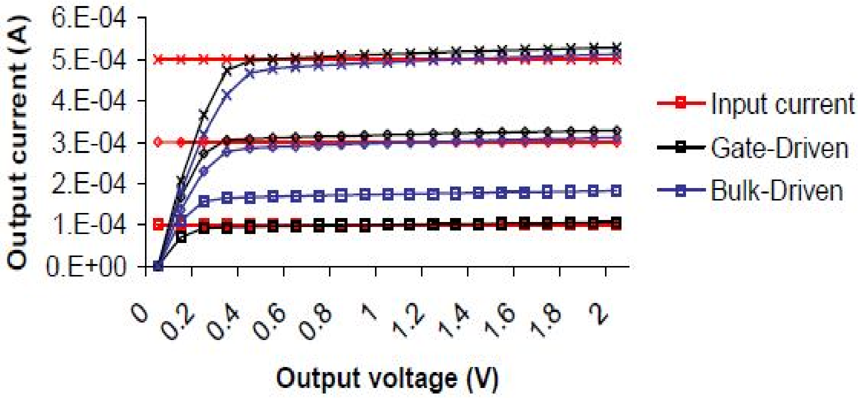

Figure 8: Drain current vs. Bulk-source voltage Characteristics.

3 Conclusions

The aim is to design low-voltage low- power bulk-driven current mirror and current source, explanation about the principle of the bulk-driven current mirror is provided, and current mirrors using both bulk-driven and gate-driven MOSTs have been designed. Since the output resistance is one of the most important performance parameters for a current mirror a folded cascade has been introduced too. Last subsection was the enhanced bulk-driven current mirror which remove the main drawback of the bulk-driven current mirror that occurred, and they are mainly the input-output current linearity of the gate-driven mirrors is absent in the bulk-driven mirrors.

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