Utility of Bulk Driven MOSFET for Low Voltage Analog Design

[1]Ashita Anand, [2]Kuldeep Rana

[1]M-Tech Student, [2]Asst. Professor
[1]ECE Department
[1]Maharishi Ved Vyas Engineering College, Jagadhri, Haryana, India

Abstract: ***The industry of electronics has developed fabulously in the last few years and the need for low voltage and low power consuming devices is reflected with its growth. This paper is focused on the bulk driven technique for low voltage, low power integrated circuits, having close attention on circuits suitable for analog devices. We have compared and observed simple and the bulk driven MOSFET and then used the current mirror for reducing the threshold voltage with 0.13µm CMOS technology at 1V supply voltage using PSpice orcad.***

Index Terms - MOSFET; bulk driven; low power; low voltage; threshold voltage; current mirror.

I. INTRODUCTION

Reviewing back at the history of the microelectronics, we find that the low power microelectronics was apprehended with the invention of transistor which took place in 1947 and the approved by the introduction of the integrated circuit in 1958. Over the following 39 years, the low power model is one of the maximum progressive research areas [1]. The Integrated circuits model in recent times has gone towards the LV and LP designs, specifically in the environment of convenient systems where a low supply voltage, given even by a single cell battery, is used [2]. The downturn of the transistor threshold voltage over the years is less symbolic in contrast to that of the power supply voltage which persuade towards a lower voltage swing and poor on/off characteristics [3].

There is requirement for the systems with high-performance and low-power and has significant consequences at the circuit level. We know that the reason for the progress of ICs, there is always a driving factor imposed with the technology limitations, and also with driving factor according to the market demand [4]. So, bulk driven MOSFET is an assuring technique to attain a better conduct in low-voltage circumstances along with the low-power ICs [3].

In this paper we have studied the simple MOSFET, Bulk Driven MOSFET, Current Mirror and its bulk circuit in Section II and III. After that we have compared the results of simple circuits with their bulk circuits and analyzed their performances.

II. SIMPLE MOSFET AND BULK DRIVEN MOSFET

The MOSFET (Metal Oxide Semiconductor Field Effect Transistor) transistor is a semiconductor device that is mostly used for the purpose of switching and amplifying electronic signals in the electronic devices. MOSFET is a root of the integrated circuit which can be fabricated and designed in a single chip because of these small sizes. It is a four terminal device with source(S), gate (G), drain (D) and body (B) terminals. It is said that the MOSFET is the most common transistor and it can be used in both analog and the digital circuits. The affiliation between transition frequencies (f_T) of a conventional gate driven MOSFET with a bulk-driven MOSFET is given as follows [5]:

$$f_{T,bulk-driven} \approx \frac{\eta}{3.8} f_{T,gate-driven} \quad (2.1)$$

2.1 Simple MOSFET

The simple MOS circuit for is shown in Fig. 1 with 1 MOSFET M_1.

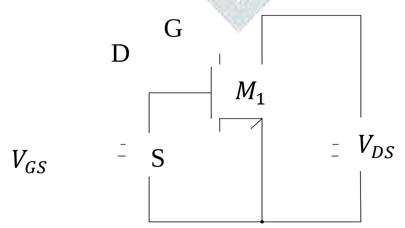

Fig 1 NMOS Simple MOSFET

2.2. Bulk Driven MOSFET

Bulk driven technique can remove the limitation of the threshold voltage adequately by controlling the weak positive bias between the bulk and the source of transistors, thus by reducing the total supply voltage of circuits. Moreover, this is completely compatible with the standard CMOS process. So, we have studied the basic bulk driven circuit with 1 MOSFET M_1 in Fig. 2. The I_{in} passes from the drain of M_1 and V_{in} come from the bulk of M_1.

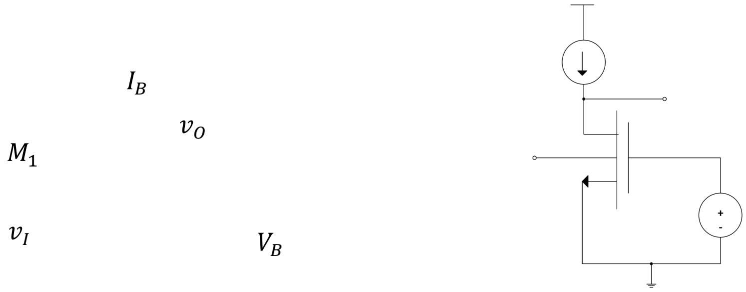

Fig 2 Bulk Driven MOSFET

The performance of the bulk-driven MOSFET is similar to the gate-driven MOSFET. The only exceptions are related to the physical size of the bulk which can be minimized through unique layout techniques. Normal current flow in the bulk terminal is in the pico ampere range and is insignificant in most applications where $V_{BS} \leq 0.3$ V. The l/f noise of the bulk-driven MOSFET is approximately equal to that of a gate-driven MOSFXT [6]. A slight increase in thermal noise occurs due to the resistance of the bulk. Modification of normal layout practice may allow the bulk resistance and input capacitance to be reduced. First-order theory gives the dependence of the drain current, i_D, as

$$i_D=\frac{K'W}{L}(v_{GS}\text{-}V_T\text{-}\frac{n}{2}v_{DS})v_{DS}, v_{DS} \leq v_{DS(sat)} \qquad (2.2)$$

and

$$i_D=\frac{K'W}{2nL}(v_{GS}\text{-}V_T)^2(1+\boldsymbol{\lambda v_{DS}}), v_{DS} \geq v_{DS(sat)} \qquad (2.3)$$

where

$$n=1+\frac{C_{BC}}{C_{ox}}+\frac{qNFS}{C_{ox}}=1+\frac{\gamma}{2\sqrt{\varphi_j-V_{BS}}} \qquad (2.4)$$

and

$$v_{DS(sat)}=\frac{v_{GS}-V_T}{n} \qquad (2.5)$$

The parameters in Eq. (2.4) are identical with standard SPICE parameters for MOSFETs. However, in bulk-source operation, the gate-source voltage becomes a constant and we re-express Eqs. (2.2) and (2.3) as

$$i_D=\frac{K'W}{L}(v_{GS}-V_{T0}-\gamma\sqrt{2\varphi_F-v_{BS}}+\gamma\sqrt{2\varphi_F}-\frac{n}{2}v_{DS}) \bullet v_{DS}, v_{DS} \leq v_{DS(sat)} \qquad (2.6)$$

and

$$i_D=\frac{K'W}{2nL}(v_{GS}-V_{T0}-\gamma\sqrt{2\varphi_F-v_{BS}}+\gamma\sqrt{2\varphi_F})^2 \bullet (1+\boldsymbol{\lambda}v_{DS}), v_{DS} \geq v_{DS(sat)}, \qquad (2.7)$$

respectively. The small signal transconductance in saturation is given by

$$g_{mbs}=\frac{di_D}{dv_{BS}}\frac{1}{V_{BSQ}}=\frac{\gamma g_m}{2\sqrt{2\varphi_F-V_{BS}}} \qquad (2.8)$$

where g_m, is the top-gate transconductancc. With the sourcc- bulk junction forward-biased, V_{BS} in the above expression is negative thereby reducing the magnitude of the denominator. For V_{BS} greater than zero, Eq. (2.3) shows how the bulk-driven (bottom-gate) transconductance can be equal or larger than g_m. The above equations have been used for the theoretical point of view of the bulk-driven MOSFET but the preliminary indications suggest that they need to re-examine to allow the better correlation between the experimental and the theoretical results [6].

2. 3. Comparison of Simple MOSFET and Bulk Driven MOSFET

The comparison of the simple and the bulk driven MOSFET circuit is shown below in Fig. 3. It can be seen from the graph that the bulk driven circuit (black line) has more efficient results as the current in simple MOSFET (blue line) starts increasing from 0.4 threshold value whereas in bulk driven it starts from 0.3 threshold value.

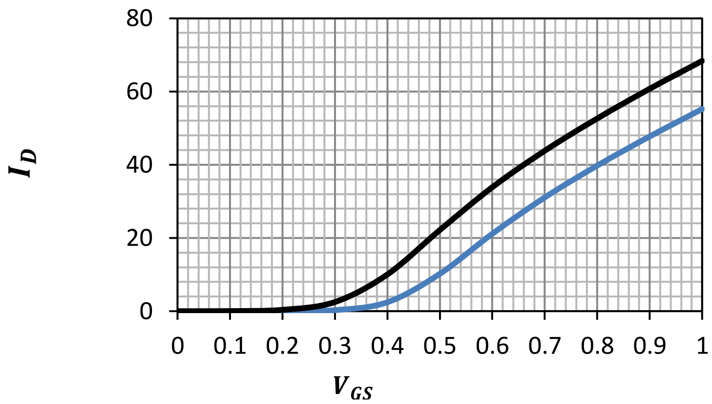

Fig 3 Comparison of transfer characteristics

From the transfer characteristics we have observed the power dissipation for the Simple MOSFET is 55.2µW and for the Bulk Driven MOSFET is 37.2µW. This comparison shows that Bulk Driven MOSFET is can be used for the low voltage design.

Further for preventing the use of Bulk Driven MOSFET we can use the current mirror as, the CM can also help in lowering the threshold voltage of the MOSFET.

III. CURRENT MIRROR

As we know that the current mirrors are important basic buildings blocks both in analog as well as in the mixed-signal VLSI circuits [7]. The current mirrors are important elements for performing current-mode in the analog signal processing. The current mirror consists of the two branches that are parallel to each other and divides the current into 2 equal parts. The basic principle of the Current Mirror is that if the gate-source potentials of the two identical CMOS transistors are equal, then the current flowing from their drain terminals should be the same.

3.1. Simple Current Mirror

Current mirrors are one of the most prevalent buildings Blocks in both analog and the mixed-signal VLSI circuits. A current mirror (CM) is a unity gain current amplifier that brings output current proportional to the input current at its high impedance output node. The current mirror (CM) circuits are generally used in the analog integrated circuits. It is understandable from its name that it copies the current [8].

The simplest form of a NMOS current mirror consisting of two transistors M_1 and $M_2$is shown in fig. 4. The gates of M_1 and M_2 MOSFETs are connected with each other. The voltage of the drain-gate of M1 is zero; so therefore, the channel does not exist at the drain, and then the transistor operates in the saturation or the active region if the threshold is positive. Current I_{in} is to be mirror by the M_2 through diode connected load M_1.For proper operation the aspect ratio of the both transistors is kept the same. Since gate to source voltage of M_1 is equal to that of M_2. So, for the same gate to source voltages their drain current also has to remain same.

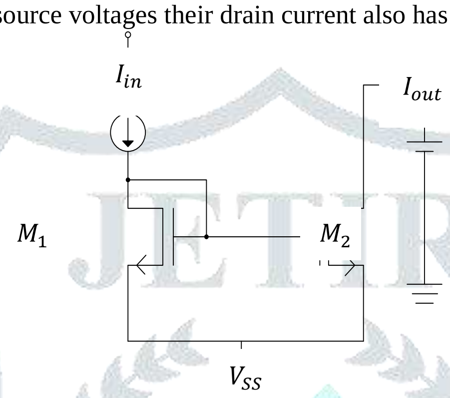

Fig 4 Simple Current Mirror

3.2. Bulk Driven Current Mirror

To overcome the issue of threshold voltage from signal path Bulk-driven Current Mirror is used. A NMOS type of the bulk-driven current mirror is shown in Figure 5. Rather than the gate-drain diode connection used in the standard simple current mirror; this circuit has a bulk-drain connection. The bulks of the M_1 and M_2 are tied together rather than the gates. The voltage potential between the each gate and source is l v in order to form an inversion layer beneath the gate [6]. In this the signal is imposed on the bulk terminal instead of the gate terminal and also keeping V_{GS} voltage of the MOSFET as constant, then that very device operates as the bulk-driven MOS transistor.

In bulk driven N type MOSFET, the body to source voltage is kept less than the switch on voltage of the diode, or else the large forward current will flow from the device. In Bulk-driven current mirror, acceptable voltage is provided to the gate terminal to create the inversion layer and input signal is applied to the bulk terminal of the MOSFET.

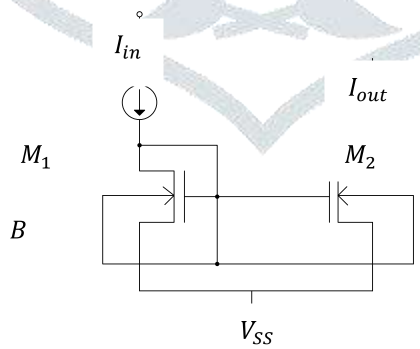

Fig 5 Bulk Driven Current Mirror

IV. RESULTS

The proposed circuits were simulated using 0.13µm CMOS technology. The circuits in the Fig. 4 and Fig. 5 are simulated using with W/L ratio of MOSFET as L= 0.26 and W= 3.9 for M_1, M_3 and L= 0.26 and W= 3.7 for M_2, M_4 and at 1V supply voltage in both the cases. From the simulation of the circuits the DC and AC characteristics are obtained and their comparison is shown under in Fig. 6 and Fig. 7.

We have compared the output results of the simple current mirror (blue line) and the bulk driven current mirror (black line) to observe whose performance is better. We have also analyzed the parameters offered from their DC and AC characteristics.

DC Characteristics

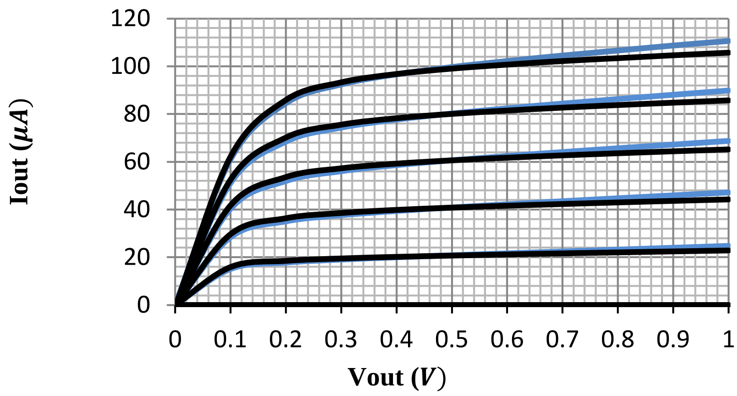

Fig 6 Comparison of Output voltage vs Output current characteristics of Current Mirror and Bulk Driven Current Mirror

AC Characteristics

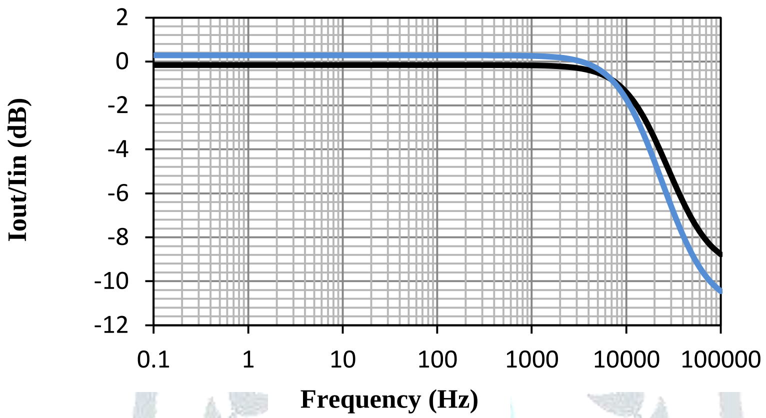

Fig 7 Comparison of Frequency response of Current Mirror and Bulk Driven Current Mirror

Based on these characteristics the CM offers some parameters and they are shown below in Table 1.

Table1. Parameters of Simple Current Mirror and Bulk Driven Current Mirror

Parameters	**Simple Current Mirror**	**Bulk Driven Current Mirror**
Power Dissipation	111µW	106µW
Bandwidth	10.328u	9.817u
Transfer Ratio	1.033	0.981
Input Impedance	1.016kΩ	0.895kΩ
Output Impedance	51.29kΩ	94.44kΩ

V. Conclusion

Circuits that operate with the low-power consumption are outstanding to assure the device reliability and also to avoid overheating caused by increasing the components density per unit area. Furthermore, the high performance low-voltage input stage is very much decisive for boosting up the input common-mode voltage range of the circuit. We have designed, analyzed, and simulated the high performance Low voltage circuits using the bulk driven technique with the unconventional CMOS techniques. The circuits were carried out in a standard 0.13µm CMOS technology with 1V of voltage supply in PSpice orcad. We have found that the bulk driven current mirror lowers the threshold voltage to some extent and give more accurate and good results than the simple current mirror.

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