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A comparative study of various current mirror configurations: Topologies and characteristics

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ABSTRACT

Current mirror is a fundamental unit, widely used for current amplification, biasing and active load in various analog/mixed mode integrated circuits. Its efficient design plays a major role in deciding the overall performance of these circuits. In literature, various techniques have been developed and proposed to improve the performance parameters of a current mirror like accuracy, input resistance, output resistance and bandwidth etc. This paper is an effort to bring all these techniques on a single platform and compare their advantages and disadvantages. Here, a detailed survey of various current mirror topologies has been carried out and these topologies have been categorized on the basis of various characteristic parameters. The discussed circuits have been simulated using Mentor Graphics Eldo spice in TSMC 0.18 μm CMOS, BSIM3 and Level 53 technology. In order to get a fair comparison among these techniques, simulations under similar conditions using a supply voltage of 1.8 V have been performed.
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1. Introduction

A current mirror (CM) is a unity gain current amplifier which provides output current proportional to input current at its high impedance output node. It also maintains output current constant regardless of loading. Under ideal conditions, gain of a CM must remain independent of frequency and output current should be independent of voltage at the output node [1].

A CM can be used as a dc current source, current amplifier, active load and for biasing in most of analog and mixed signal circuits, such as operational amplifiers, operational transconductance amplifiers, second generation current conveyors, operational mirrored amplifiers, current feedback operational amplifiers, analog filters, analog-to-digital and digital-to-analog converters etc. [1–10]. Thus, CM being a fundamental unit, its efficient design affects the overall performance of these integrated circuits [2]. Important factors influencing performance of a CM are: (i) Accuracy, defined as precision of copying input current at the output node. (ii) Input/output compliance voltage, given as minimum voltage required at input/output node of a CM for its proper operation. (iii) Input resistance. (iv) Output resistance. (v) Bandwidth [2,3,11–15]. CMs with very high accuracy are required in several applications of critical importance like biomedical circuits, bio-amplifiers and implantable microstimulators etc. [9,10]. Low voltage applications like bluetooth filters, universal biquad filters, amplifiers, operational amplifiers and biomedical circuits etc. require CMs operating at low compliance voltages [6–8,16–18]. CMs with low input and high output resistances are required to minimize the loading effect. Such CMs are required as tail current sources to improve the common-mode rejection ratio, power supply rejection ratio and dc gain factor of differential pairs [1,19]. High bandwidth in a CM is desirable feature for increasing speed of the devices like current-steering digital-to-analog converters, high-speed current mode amplifiers and current conveyors etc. [2,5,15]. Moreover, due to increased demand of smaller portable devices, a lot of effort is being directed towards designing circuits (including CMs) operating at lower supply voltage [20–23].

In this paper, a survey of different CM configuration has been carried out. This survey as per author's knowledge broadly covers the CMs based on their performance characteristics, though it may not be exhaustive. The intention is to largely classify and categorize fundamental CM topologies available in literature that improve the characteristic parameters (mentioned above) of a basic CM.

The paper is organized as follows: In Section 2, basic CMs designed to improve the performance characteristics of a simple CM have been discussed. It also explains their operational principle along with main advantages and disadvantages. Section 3 consists

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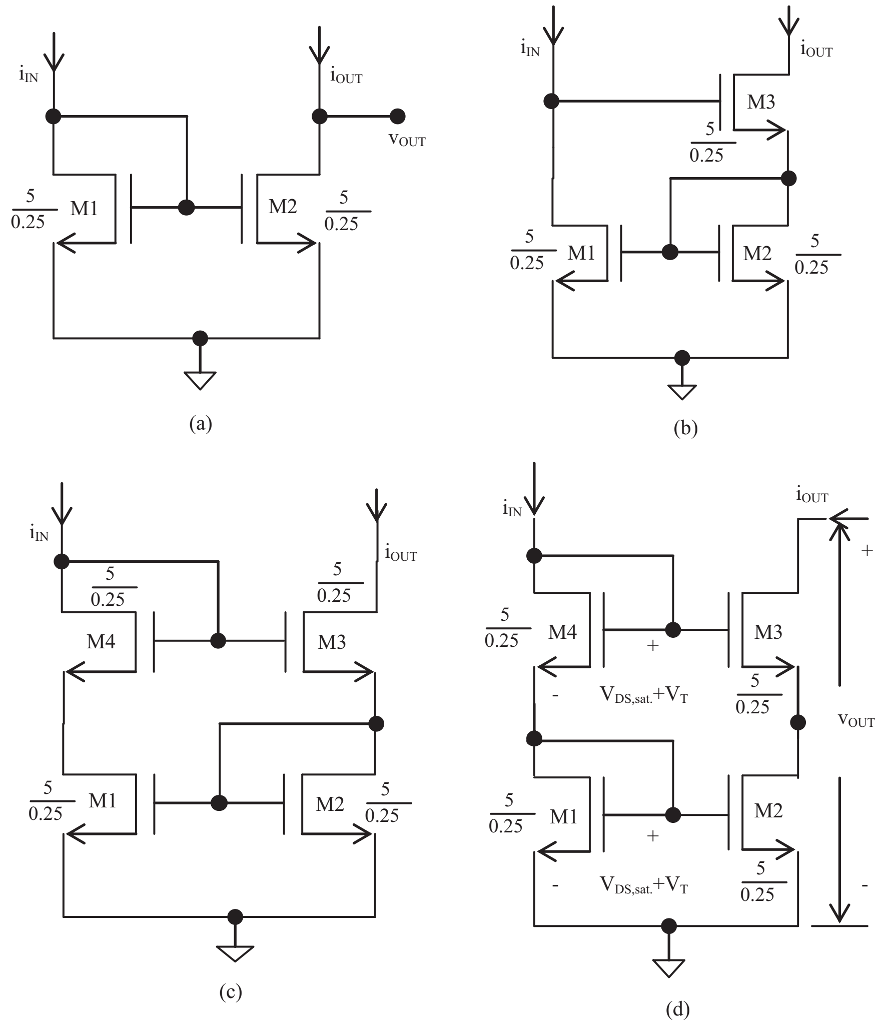

Fig. 1. Basic Current Mirrors (a–d). (a) Simple CM, (b) Wilson CM, (c) Improved Wilson CM, and (d) cascode CM.

of techniques that reduce the required compliance voltage, thereby reducing voltage headroom of the circuit. Structures suggested in literature to reduce input resistance for a CM are summarized in Section 4. In Section 5, CM topologies that provide high output resistance are explained. Techniques used to improve bandwidth of CMs are summarized in Section 6. Low voltage CM techniques available in literature along with their description are discussed in Section 7. Some of the very high performance CMs available in literature are described in Section 8. An effort has been carried out to simulate these circuits on similar platform to get a fair comparison amongst them. These simulated results are included in every section and finally Section 9 concludes the paper.

2. Basic current mirrors

MOSFET based simple CM is shown in Fig. 1(a). In this circuit, if MOSFETs $M1$ and $M2$ operate in saturation region, output current (i_{OUT}) is proportional to input current (i_{IN}) by the ratio of their aspect ratios. In case of identical MOSFETs, $i_{IN}=i_{OUT}$ and the circuit simply replicates or mirrors the input current at its output terminal and hence the name current mirror [1]. If the aspect ratio of $M2$ is greater than that of $M1$, the circuit behaves as current amplifier, whose gain is directly proportional to the ratio of their aspect ratios. However, gain of such circuits is fixed and has to be decided at the time of fabrication. Various programmable CMs [4,24–30] were proposed in literature that offer electronic tunability of the gain in current amplifiers.

In simple CM (Fig. 1(a)), due to channel length modulation effect, the replication of input current at output node is not perfect. Its current mirroring accuracy depends on the drain–source voltages of MOSFETs and channel length modulation parameter (λ). The input resistance (r_{in}), output resistance (r_{out}) and bandwidth (ω_0) of a simple CM are given as [1,3]:

$$r_{in} = 1/g_{m1}, \quad r_{out} = r_{02} = \frac{1}{\lambda i_{D2}}, \quad \omega_0 \approx g_{m1}/(C_{gs1} + C_{gs2}), \tag{1}$$

where g_m is transconductance, r_0 is incremental output resistance, i_D is drain current and C_{gs} is gate–source capacitance of respective MOSFET. Eq. (1) shows that performance parameters of a simple CM are limited by g_m, r_0 and C_{gs} of a MOSFET.

In case of short channel MOS devices used to design smaller, high frequency and low power consumption equipments, the error in output current due to channel length modulation effect increases further [1,18]. It has been noticed that a reduction in size of MOSFET leads to an increase in its transconductance along with decrease in its output resistance [1]. In short channel MOSFETs, the effect of reduction in output resistance is more prominent than increase in transconductance. Hence, simple CMs designed with these MOSFETs suffer from lower accuracy and lower output resistance, thereby adversely affecting overall circuit performance. Moreover, these CM circuits suffer from poor matching and

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