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A LOW VOLTAGE CURRENT MIRROR WITH A HIGH OUTPUT VOLTAGE SWING

A circuit of the current mirror is proposed providing 85% precise current copying even in the linear region of the transistor operation. It can copy currents in power supply low voltage cases when transistors enter the triode region due to less overdrive voltages. Compared with the classic current mirror, the proposed structure provides about 0.94 *V* (normalized to power supply value) voltage range operation without degrading process variations related mismatches of currents. These are possible to be used in low voltage and low power analog and mixed-signal designs where they can provide a higher accuracy than the conventional current mirror.

Keywords: low voltage, current mirror, CMOS.

Introduction. The current mirror is fundamental building block in analog and mixed signal IC design which is used for biasing to provide active loads in differential amplifiers and for current-mode signal processing. In many circuits, the performance of the elementary current mirror is sometimes improper, because of a systematic gain error and comparably low output resistance [1]. In low voltage corners, these types of issues appear when devices operate out of the saturation region and the solution of these problems require structural changes. For example, in biasing and some other structure current mirrors used in the big part of a design, when the transistor is going out of the saturation region, the current variation depending on voltage becomes bigger causing a big error during current mirroring [2].

To achieve low power consumption and a high speed performance in modern analog and mixed-signal integrated circuits, devices are supplied by low voltages so as to provide low transition time and low current consumption. As CMOS technology is scaling power supply voltage scales down as well, but the threshold of transistors are not scaled by the same scaling factor as the power supply does [3]. But this scaling gives rise to some limitations and problems which require structural solutions. One of the main problems is that analog structures have exact operation voltage ranges in which transistors operate in the saturation region and when the supply voltage is going down, this region is becoming smaller and keeping these structures in a good operation mode is becoming more difficult [4].

Current mirrors which are mostly used in analog and mixed-signal designs as a building block, operate in some limited voltage range, because when transistors are going out of the saturation region, the accuracy of current copying is becoming smaller.

The idea of the proposed technique is to keep the current copying accuracy as much as possible not only in the transistor's saturation region, but also in linear region by giving some structural solutions in active current mirror structures.

The general approach is to embed in conventional architecture of current mirrors, negative feedback which can keep the current copying in the operation region 30% more when compared with the standard mirror transistors switching from saturation to triode region due to low supply voltages.

General parameters of linear region operated active current mirror architecture. In [5] reference parameters definitions are introduced for the passive and active current mirrors. These parameters completely describe the mirror behavioral small signal parameters. In this section, analytical expressions will be solved out for the proposed solution.

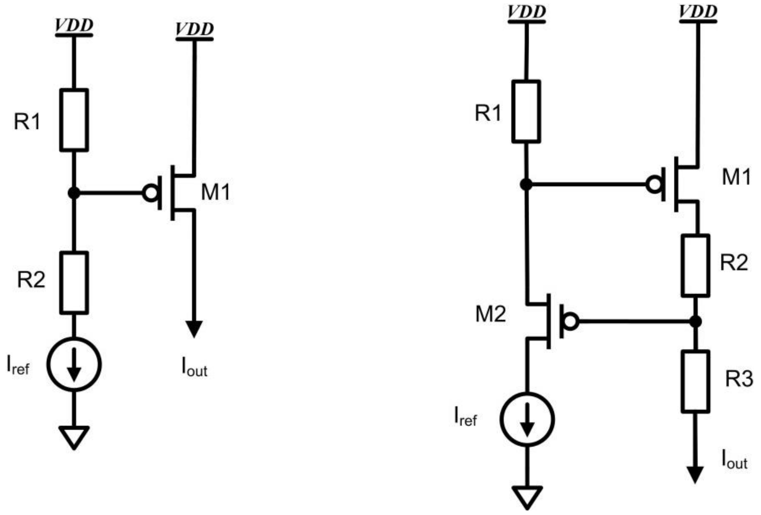

Fig. 1. Conventional and proposed current mirrors

The first parameter which is introduced is the output current for both conventional (1) and proposed (2) current mirrors (Fig. 1). The output current defines the amount of the current which is a result of copying from the reference one. The equation of the output current can be written as

$$I_{out} \approx \frac{1}{2}\mu_p C_{ox} \frac{W}{L}\left(\frac{R_2}{R_1+R_2}V_{DD}-V_{THp}\right)^2 \approx I_{ref}\,, \tag{1}$$

$$I_{out} \approx \frac{1}{2}\mu_p C_{ox} \frac{W_1}{L_1}\left(\frac{1/g_{m2}}{R_1+1/g_{m2}}V_{DD}-V_{THp}\right)^2 \approx I_{ref}\ , \tag{2}$$

where I_{out} is the mirror output currents, μ_p is the hole's mobility of the PMOS transistor, C_{ox} is the unit capacity of the MOS transistor under-gate isolator and g_{m2} is the M2 transistor conductivity.

The expression for the output current will be calculated based on equations (1) and (2). Fig. 1 presents the proposed current mirror which consists of the additional M_2 transistor biasing by R_2 and R_3 resistive divider. This structure takes the role of negative feedback which can keep the current copying accuracy even when M_1- the main mirror transistor is out of the saturation region and can change its drain-source resistance linearly depending on the branch current.

The main mechanism providing the linear region operation. The idea of that mechanism is to add a negative feedback sensitive circuit to the mirror architecture. That mechanism can keep the whole mirroring system in the operational region dynamically in case of different overdrive voltages for the mirror device.

Starting from the one of low overdrive voltage the mirror can go out of the well-operating condition. The proposed method can sense that and keep a good performance which in case of mirrors means current high accuracy copying. The block diagram on Fig. 2 is proposed to copy the reference current and have a high accuracy of current duplication in case of low supply voltage and hence overdrive voltages. In this structure, to avoid unequal distribution, the system which is in the negative feedback condition is used.

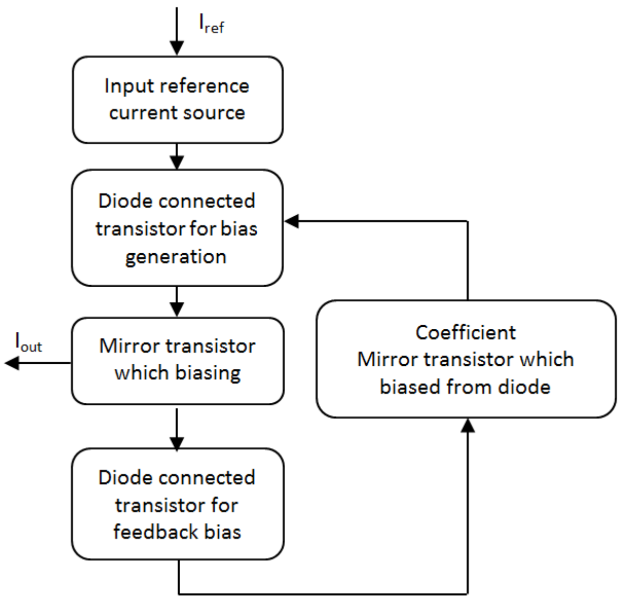

Fig. 2. A block diagram of the proposed linear region operation method

The reference current of the circuit followed through the diode-connected transistor generates bias voltage for the M1 transistor the operation condition of which depends on its drain-source voltage. Due to this dependence, different operations can be obtained hence different current copying accuracy. For this reason, it is necessary to create some negative feedback to dynamically stabilize the overdrive voltage on the M1 device. In the proposed circuit (Fig. 3), the negative feedback is composed by the M2 and M4 transistors creating vice dependency between the two branches of this architecture. The coefficient of the negative feedback depends on the proportionality of the M2 and M4 transistor W/L ratios which can be manipulated to match the currents in the two branches.

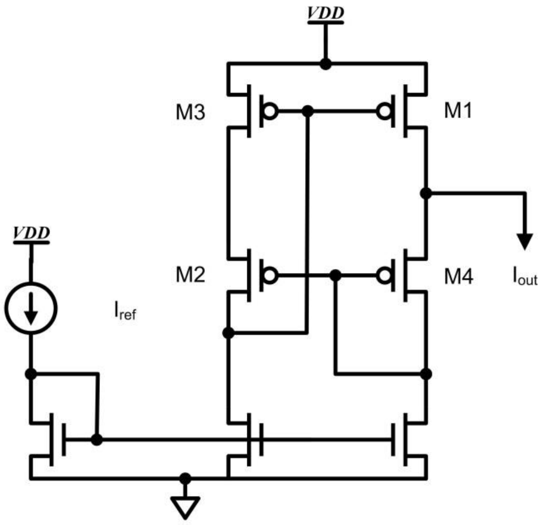

Fig. 3. The proposed current mirror

The simulation results. The conventional and proposed current mirror architecture has been designed with “SAED32nm” library and studied with HSPICE simulator. The simulation results show (Fig. 4) that in the proposed current mirror, the voltage swing on the output increases by about 0.2 *V* versus conventional. When the drain-source voltage of the M1 transistor is close to 1.6 … 1.8 *V*, it enters into the linear region of operation causing the output current to drop drastically, but in the proposed current mirror, it is seen that the current remains constant even in the linear region.

Also, the conventional and proposed current mirrors have been simulated with MONTE CARLO analysis (the number of samples is 100, e.g. the accuracy is about 98%) to check the process variability. As seen from Fig. 5, the standard deviation of the current is similar for both architectures and equal to 1.12 *uA* and 1.4 *uA* for the conventional and proposed current mirrors respectively.

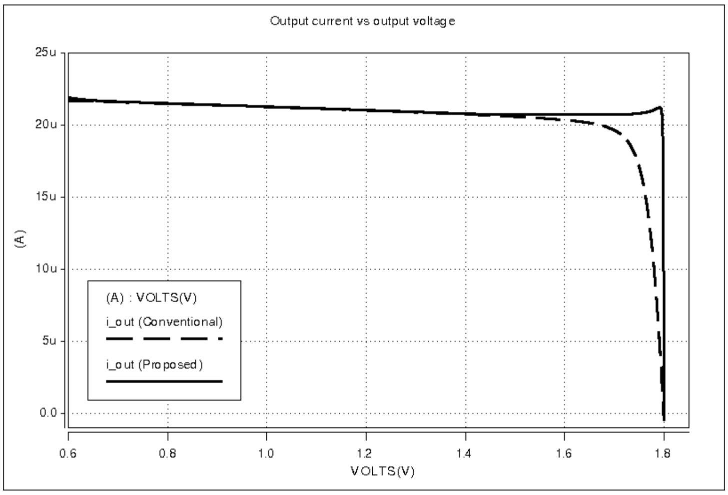

Fig. 4. The current vs output voltage for both conventional and proposed current mirrors

This means that introducing additional transistors in feedback does not cause more variation over the process mismatches.

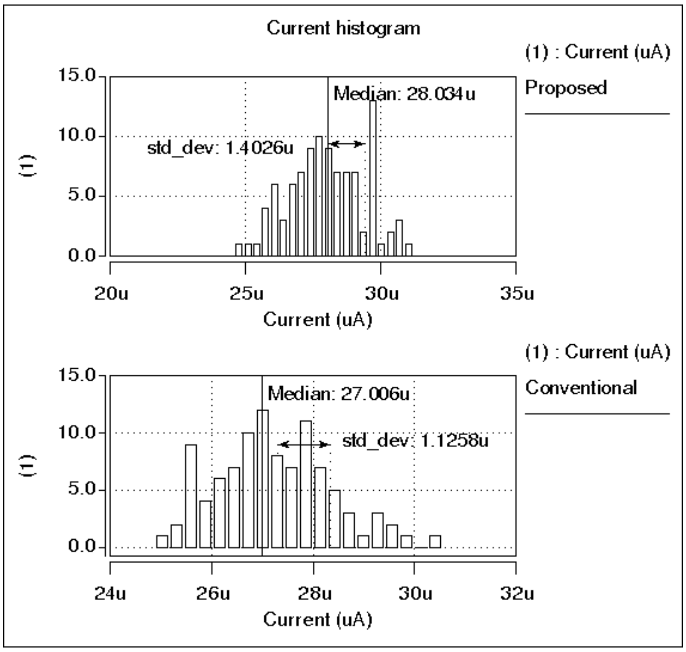

Fig. 5. The current historgram for both conventional and proposed current mirrors

The most important parameter for current mirrors is the “mirroring accuracy” from the reference current and the output current. So the summerized table with an accuracy relative to the drain-source voltage of M1 is presented in Table 1.

Table 1

Mirroring accuracy dependency on M1 overdrive voltage

	Conventional current mirror		Proposed current mirror	
M1 overdrive voltage, *mV*	Mirroring accuracy, %	M1 operating region	Mirroring accuracy, %	M1 operating region
400	98	Saturation	99	Saturation
200	87	Saturation	97	Saturation
100	80	Saturation	91	Saturation
50	20	Triode	89	Triode
25	5	Triode	85	Triode

Also, the comparative analysis has been carried out on the leakage current consumption which is presented in Table 2. It is seen that the leakage current decreases by about twice.

Table 2

Leakage current consumption comparison

Bounds Corner	Conventional current mirror		Proposed current mirror	
	Leakage current, *nA*	Leakage Power, *nW*	Leakage current, *nA*	Leakage Power, *nW*
TT/25	21	37.8	8	14.4
FF/-40	29	52.2	11	19.8
SS/125	14	52.2	6	10.8

The output resistance has also been measured versus voltage overdrive on the M1 transistor to show the improved region where the resistance is still linearly proportional to the drain source voltage of the M1 transistor (Fig. 6).

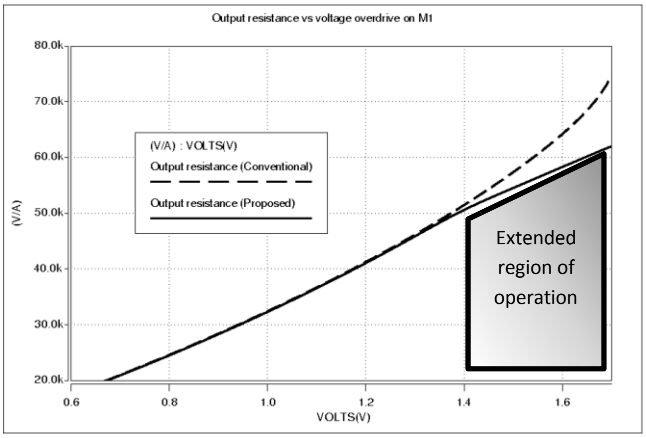

Fig. 6. The output resistance for both conventional and proposed current mirrors

Conclusion. This paper proposes a current mirror which can operate in the linear region of operation simultaneously providing a precise current copying. Negative feedback is embedded in the proposed current mirror which helps to have current mirroring even when the transistors enter the undesired region of operations (e.g. triode region). With this negative feedback, the output voltage swing increases by about 0.2 *V* relative to the conventional current mirror which is beneficial when analog and mixed signal circuits need to work properly in low voltage conditions. MONTE CARLO simulations also show that the variation is not degraded due to additional transistors used in the feedback path. The standard deviation of the current increases by 25% in the proposed current mirror.

REFERENCES

1. **Minch, B.A.** A low-voltage MOS cascode current mirror for all current levels // Circuits and System.- 2002.- Vol.2 .- P. 53-64.
2. **Aggarwal, B., Gupta, M., Gupta, A.K.** A low voltage wide swing level shifted FVF based current mirror // Advances in Computing, Communications and Informatics (ICACCI) International Conference.- 2013.- P. 880 – 885.
3. **Vajpayee, P., Srivastava, A., Rajput, S.S., Sharma, G.K.** Low voltage regulated cascode current mirrors suitable for sub-1V operation // Circuits and Systems (APCCAS) IEEE Asia Pacific Conference.- 2010.- P. 584 – 587.
4. **Laoudias, C., Psychalinos, C.** Low-voltage CMOS adjustable current mirror // Electronics Letters.- 2010.- P. 124 – 126.
5. **Sendi, M.S.E., Toosi K.N., Gatabi, I.R**. Improved low voltage all cascode mirror current source using the DC level shifter // Circuits and Systems.- 2007.- P. 171-172.

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ՑԱԾՐԱՎՈԼՏ ԵՎ ԵԼՔԱՅԻՆ ԼԱՐՄԱՆ ՄԵԾ ԱՇԽԱՏԱՆՔԱՅԻՆ ՏԻՐՈՒՅԹՈՎ ՀՈՍԱՆՔԻ ՀԱՅԵԼԻ

Առաջարկվել է տրանզիստորների՝ նույնիսկ գծային աշխատանքային տիրույթներում կրկնօրինակման մոտ 85% ճշտություն ապահովող հոսանքի հայելու սխեմա: Սնման լարման փոքր արժեքների դեպքում՝ այսինքն ակունք-արտաբեր լարման փոքր արժեքների պատճառով տրանզիստորների գծային աշխատանքային ռեժիմ անցնելու պարագայում, հայելին ունակ է կրկնօրինակելու հոսանքները: Չվատթարացնելով հոսանքների տեխնոլոգիական շեղումնե-րով պայմանավորված անճշտությունները՝ առաջարկված տարբերակը ավանդական հոսանքի հայելու սխեմային գերազանցում է ելքային լարման աշխատանքային տիրույթով՝ հասցնելով այն ընդհուպ մինչև 0,94 *Վ* (նորմավորված սնման լարման արժեքին): Հոսանքի հայելու ավան-դական սխեմայի համեմատ զգալիորեն ավելի մեծ ճշտություն ապահովելու շնորհիվ՝ մշակ-ված սխեման կարող է լայնորեն կիրառվել ցածրավոլտ և փոքր էներգասպառմամբ անալոգա-յին և խառը ազդանշանային համակարգերում:

Առանցքային բառեր. ցածր լարում, հոսանքի հայելի, ԿՄՕԿ:

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НИЗКОВОЛЬТНОЕ ТОКОВОЕ ЗЕРКАЛО С БОЛЬШИМ ВЫХОДНЫМ ДИАПАЗОНОМ НАПРЯЖЕНИЯ

Предложена схема токового зеркала, обеспечивающая даже в линейных рабочих областях транзисторов точность копирования ~85%. Схема способна копировать токи при небольших значениях напряжения питания, т.е. в случае перехода транзисторов в линейный рабочий режим из-за маленьких значений напряжения исток-сток. Предложенная схема превосходит традиционную схему с диапазоном выходного рабочего напряжения вплоть до 0,94 *В* (нормированное значение напряжения питания), не ухудшая при этом обусловленные технологическими разбросами точности токов. За счет обеспечения существенно высокой точности по сравнению с традиционными схемами предложенное решение может широко применяться в аналоговых и аналого-цифровых схемах с низким энергопотреблением.

Ключевые слова: низкое напряжение, токовое зеркало, КМОП.