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ACCURACY IMPROVEMENT TECHNIQUE FOR ON-CHIP CURRENT SOURCES WITH NO EXTERNAL COMPONENTS

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ABSTRACT

A new design technique for accuracy improvement of on-chip reference current sources is proposed in this paper. A mathematical model has been developed describing the operation of the proposed technique. Based on the obtained equations the variation of the reference current resulted by the operating conditions' changes and process deviations should reach to 5%. The proposed technique has been implemented in the design of on-chip reference current source circuit in 14nm FinFet technology. Spice simulations performed for the developed circuit shown less than ± 7% variation of the reference current in the -40..125^{0}C temperature range considering the process variations in ±3 sigma range. Circuit keeps that accuracy for the supply voltage drop up to 0.66V.

Keywords: on-chip current source, current generators, reference current sources, aging.

Introduction

In modern electronic systems, the demand for accurate and stable current sources has become increasingly critical, particularly in applications such as sensor interfacing, analog signal processing, and precision measurement systems [1],[2]. High precision current sources are essential components that provide a constant current output with minimal variation, ensuring reliable performance in sensitive electronic circuits. One of the technical specifications to modern complementary metal-oxide-semiconductor (CMOS) ICs is to ensure high stability of the main parameters, regardless of ambient temperature, supply voltage, and technology deviations [3],[4]. Main parameters of the elements in relation to the typical characteristics may deviate from values reaching tens of percent to multiple [5]. These current sources are designed to maintain a consistent output despite fluctuations in load resistance or supply voltage, thereby enhancing the overall accuracy of the system. High precision current sources are characterized by their low noise, high stability, and excellent temperature coefficients, making them suitable for applications in instrumentation, telecommunications, and industrial automation. With the advent of portable devices, the energy consumption and requirements for the IC surface have also tightened, limiting the use of circuits with a large surface area and high energy consumption [2],[3]. The design of high precision current sources can be achieved through various methods, including the use of operational amplifiers, transistor-based configurations, and integrated circuit solutions. Each approach offers unique advantages and challenges, depending on the specific requirements of the application [5],[6]. The availability of precision voltage source doesn't ensure the design of stable current sources. Since the combination of resistance and a reference voltage source in the MOS structure depends on resistance variation [6],[7]. As technology advances, the integration of high precision current sources into compact and efficient designs continues to evolve, enabling new possibilities in the fields of electronics and instrumentation. This introduction sets the stage for a deeper exploration of the principles, designs, and applications of high precision current sources, highlighting their significance in achieving high-performance electronic systems. In the realm of electronic circuit design, achieving high precision in current sourcing remains a significant challenge. Many applications, such as precision measurement systems, sensor interfaces, and analog signal processing, require current sources that can deliver stable and accurate output currents under varying conditions. However, several factors contribute to the difficulties in designing high precision current sources:

1. Load Variability: Fluctuations in load resistance can lead to significant deviations in output current, affecting the accuracy of measurements and the performance of connected devices.
2. Supply Voltage Fluctuations: Variations in supply voltage can introduce errors in current output, necessitating robust designs that can maintain stability across a range of operating conditions.
3. Temperature Sensitivity: Many electronic components exhibit temperature-dependent characteristics, which can lead to drift in output current as environmental conditions change.
4. Noise and Interference: External electromagnetic interference and inherent noise in electronic components can compromise the precision of current sources, particularly in sensitive applications.
5. Integration Challenges: As the trend toward miniaturization continues, integrating high precision current sources into compact designs without sacrificing performance poses additional engineering challenges.

Addressing these issues is critical for the development of reliable high precision current sources that meet the stringent requirements of modern electronic systems. This problem statement underscores the need for innovative design approaches and technologies that can enhance the accuracy, stability, and overall performance of current sources in various applications.

Architecture and Operation Principle

The block diagram of the current source consists of the following blocks: Start-up circuit, voltage generator which generates voltage with positive temperature coefficient and reference current generator (Fig. 1). The start-up circuit is responsible for initializing the current source upon power-up. It ensures that the system transitions from a non-operational state to a fully functional state in a controlled manner. The voltage generator is designed to produce a voltage output with a positive temperature coefficient (PTC). This characteristic is crucial for compensating for temperature variations that can affect the performance of the current source. As the temperature increases, the output voltage from this generator will also increase, which helps to counteract the effects of temperature-induced drift in the reference current.

It is known that the current flowing through a N-MOS transistor in a linear mode is determined by the:

$$I_d = \beta\left[\left(V_{gs} - V_{th}\right)V_{ds} - 0.5{V_{ds}}^2\right]$$

where

$$\beta = \frac{(W/L)\mu_n\varepsilon_{ox}}{t_{ox}}$$

current flowing through a N-MOS transistor in a saturation mode is determined by the:

$$I_d = \frac{1}{2}\beta[\left(V_{gs} - V_{th}\right)^2]$$

Hence, it is obvious that if the transistor dimensions are large, then changes in the remaining parameters under the above influences can be ignored. If the temperature is constant, mobility is a fixed parameter.

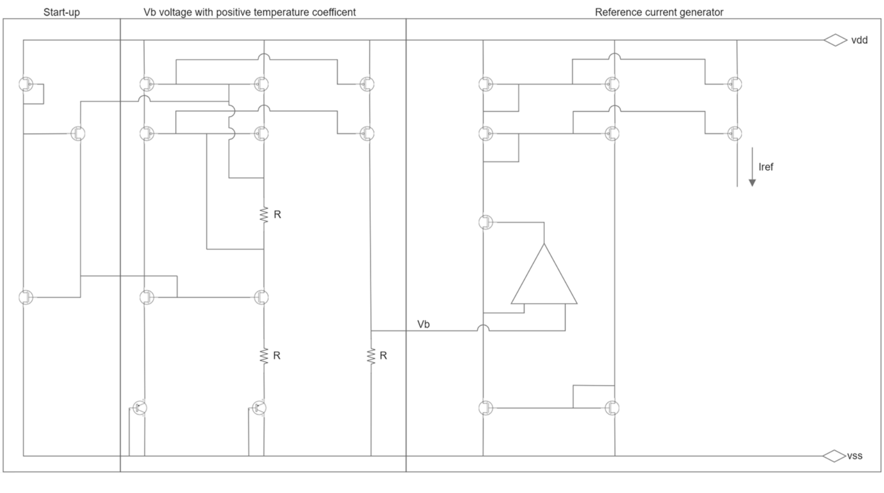

Fig. 1. The block diagram of a high-precision DC current source.

In cases of all possible processes, the thickness of the oxide layer t_{ox} varies approximately within ± 4.5..5 %. If assume the temperature is stable, then the change in β will be approximately within 5%. Imagine that the currents flowing through that two N-MOS transistors are the same.

$$I_{d1} = I_{d2}$$

$$\beta[(V_{gs1} - V_{th})V_{ds1} - 0.5V_{ds1}^2] = \frac{1}{2}\beta[(V_{gs2} - V_{th})^2]$$

Imagine that $V_{gs1} = V_{gs2}$.

$$(V_{gs} - V_{th}) = \frac{I_d + 0.5\beta V_{ds}^2}{\beta V_{ds}}$$

$$I_d = \frac{1}{2}\beta[\left(\frac{I_d + 0.5\beta V_{ds}^2}{\beta V_{ds}}\right)^2]$$

$$I_d^2 + \beta V_{ds}^2 I_d(1 - 2\eta) + \frac{\beta^2 V_{ds}^4}{4} = 0$$

where

$$\eta = \frac{W_1}{W_2}$$

If $\eta = \frac{W_1}{W_2} = 1$, then

$$I_d = \frac{\beta V_{ds}^2}{2}$$

$$\beta = \frac{(W/L)\mu_n \varepsilon_{ox}}{t_{ox}}$$

$$\beta(T) = \frac{W}{L}\mu(T_0)\left(\frac{T_0}{T}\right)^{-1.5} = bT^{-1.5}$$

The drain source voltage was designated as $V_{ds} = V_b$: V_b is directly proportional to temperature

$$V_b(T) = cT$$

To understand how the resulting expression depends on the temperature change, it is necessary to derive it in time and get the following expression:

$$\frac{\partial I_d(T)}{\partial T} = -1.5aT^{-2.5}bT^2 + 2bTaT^{-1.5}$$

From the graphical representation of the resulting expression, it can be seen that the current is in depended on the temperature variation (Fig. 2).

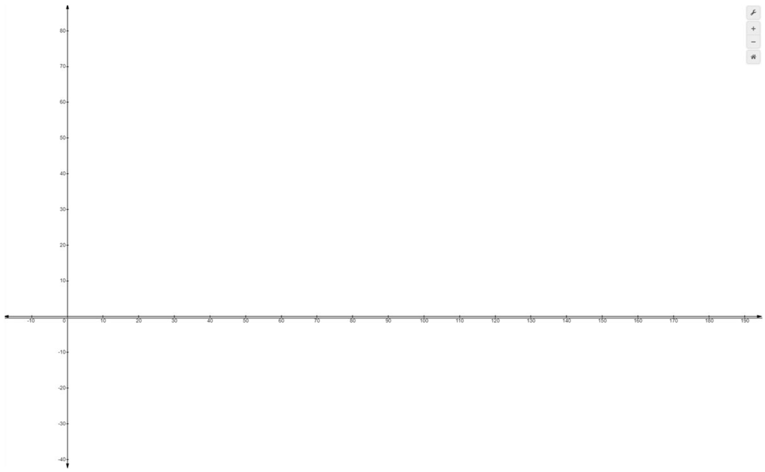

Fig.2. Graphical display of the obtained equality.

The graphical display likely includes a temperature axis alongside the reference current output, allowing for a direct visual correlation between temperature changes and the corresponding reference current values. The minimal deviation observed in the reference current across a wide temperature range underscores the effectiveness of the design in maintaining performance consistency.

Simulation Results

The dependency of the reference current on various stabilization factors has been thoroughly analyzed and evaluated. This investigation encompasses a detailed examination of the key parameters that influence the stability and accuracy of the reference current within the circuit design. Based on the simulation results it is possible to reach less than ± 4% current change from the temperature variation in range – 40..125^{0}C (Fig. 3).

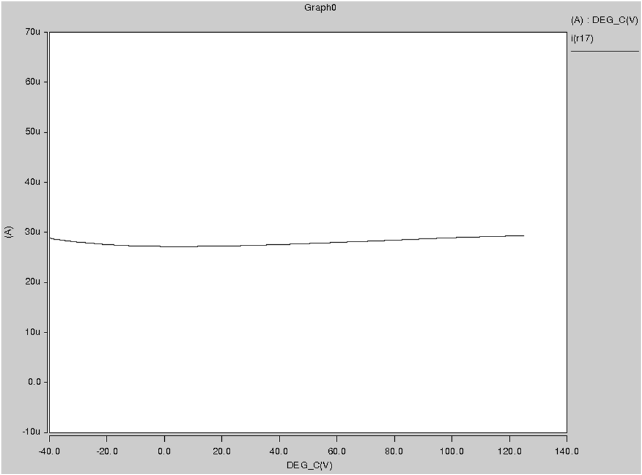

Fig. 3. The dependency of the reference current on the ambient temperature variation.

The results show that the reference current variation for the -40..125^{0}C temperature range considering the process variations in ±3 sigma range and supply voltage variation in ±10% range is less than ± 7% (Fig. 4).

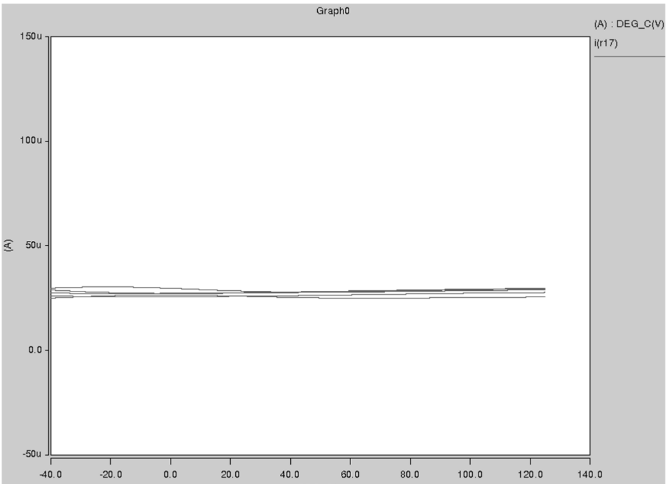

Fig. 4. The dependence of the output current on temperature, as well as supply voltage and technological changes.

This finding underscores the effectiveness of the proposed current source design in achieving a high level of stability and accuracy under challenging operating conditions. The ability to limit the reference current variation to within ±7% is particularly significant, as it demonstrates the circuit's robustness against both environmental factors and manufacturing inconsistencies.

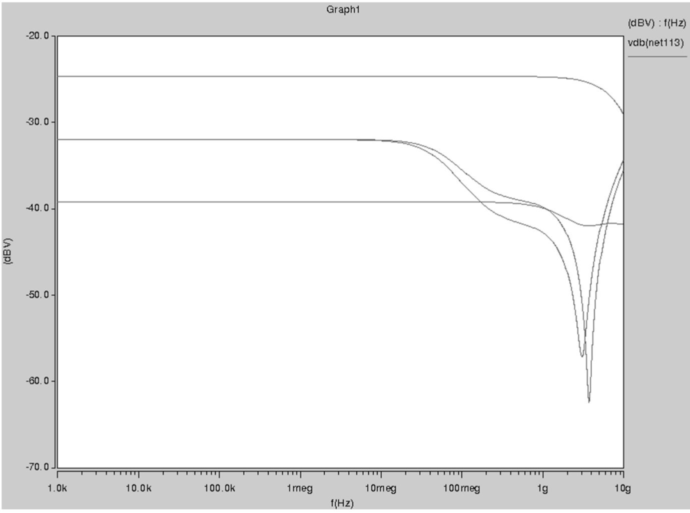

Fig. 5. The results of the frequency analysis.

The subsequent analysis focuses on evaluating the impact of power supply noise on the performance of the designed circuit. Power supply noise can significantly affect the stability and accuracy of electronic circuits, particularly in sensitive applications such as analog signal processing, precision measurement systems, and current sources. The PSRR analysis performed in $100..10^{10}$Hz ensure more than -10dB noise rejection and more than -35dB rejection in low frequencies range (Fig. 5).

Conclusion

In this paper, we present a novel design technique for on-chip current sources that has been proposed, meticulously designed, and rigorously simulated. This innovative approach aims to enhance the performance, accuracy, and stability of current sources used in integrated circuits, addressing common challenges associated with traditional designs. According to the simulation results, the newly developed circuit demonstrates the capability to deliver accurate reference currents while operating effectively within a temperature range of -40°C to 125°C and accommodating supply voltage variations of ±10%. Notably, the circuit maintains a variation in the reference current of approximately ±7% under these conditions. The main limitation of said techniques is the usage of biasing circuits as well as the estimated area increase by 25%. Both requirements are deemed acceptable, particularly in light of the critical need for high-precision current sources and the importance of mitigating performance degradation in various applications.

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СПОСОБ ПОВЫШЕНИЯ ТОЧНОСТИ ВНУТРИКРИСТАЛЛИЧЕСКИХ ИСТОЧНИКОВ ТОКА БЕЗ ВНЕШНИХ КОМПОНЕНТОВ

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АННОТАЦИЯ

В статье предложен новый способ повышения точности внутрикристаллических источников тока. Предлагаемый метод основан на разработанной математической модели. В результате полученных уравнений доказано, что отклонение тока, вызванное изменением условий работы и неточностями технологического процесса, не должно превышать 4%. Предлагаемый метод был реализован с использованием 14-нм технологического процесса FinFet для разработки внутрикристаллического эталонного источника тока. В результате экспериментального моделирования в диапазоне температур -40...125°C при отклонениях технологического процесса ±3 сигма разработанная схема обеспечивала ±7% отклонений от эталонного тока. Схема способна поддерживать указанную точность при падении напряжения питания до 0.66 В.

Ключевые слова: внутрикристаллический источник тока, генераторы тока, опорные источники тока.