



An accurate 1-V threshold voltage reference for ultra-low power applications



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ABSTRACT

An ultra-low power voltage reference circuit is presented, which is based on proportional (PTAT) and complementary (CTAT) to absolute temperature current generation and performs current-mode voltage reference with first-order temperature compensation. Thanks to the use of subthreshold CMOS transistors and an operational amplifier, the circuit achieves low sensitivity to power supply variations while providing low voltage capability. Measurements show that the proposed circuit provides a reference voltage of around 597 mV and correctly operates with a supply voltage ranging from 3.3 V to 1 V and temperature variations from -40 to 85 °C. The overall current consumption is below 1 μ A, thus making it suitable for RF-powered and ultra-low power sensor network applications. The chip was fabricated in a standard 0.13 - μ m CMOS technology and occupies a core area as low as 0.02 mm^2 .

1. Introduction

Low power and low voltage design techniques have become mandatory to meet the requirements of many integrated-circuit (IC) applications and also for technological reasons [1,2]. Indeed, low power design is essential in battery-operated systems to preserve operating time whereas in battery-less RF-powered systems guarantees fast start-up and better harvester sensitivity [3–6]. Moreover, low power and low voltage approach is of great importance in ICs with nanoscale technologies to avoid transistor breakdown and improve reliability.

By considering battery-less devices based on RF harvesting, the low power and low voltage design strategy involves all the functional blocks of the IC in both the analog and digital side, and mainly the power management unit (PMU) that greatly contributes to the overall power consumption. A key building block of a PMU is the voltage reference that sets the accuracy of the regulated power supply and determines its temperature behaviour.

Many approaches have been developed in the last decade to implement voltage references with low or even extremely low power consumption [7–17]. One of the most popular voltage references in CMOS technology for low voltage applications is shown in Fig. 1 [7]. It exploits a linear combination of proportional (i.e., PTAT) and complementary (i.e., CTAT) to absolute temperature currents to generate a reference voltage across resistance R_4 . The circuit uses parasitic bipolar

PNP transistors that have a poor performance in terms of current gain, β_F , and mainly suffers from the offset voltage due to the operational amplifier that greatly impacts accuracy.

To overcome the offset limitation, other types of current-mode voltage references are adopted [8,9]. However, they also employ parasitic bipolar transistors to perform PTAT and CTAT current generators.

There are also fully CMOS voltage references that make use of MOS transistors with different threshold voltages [10,11]. These circuits also avoid resistances, thus allowing to drastically reduce silicon area and power consumption. They can be designed with nano-ampere quiescent currents but exhibit a low accuracy, due to a high sensitivity to process variations, and require extra fabrication masks to implement different threshold voltages. Moreover, the reference voltage only depends on technology parameters and complex circuitry is needed to set a specific value.

In this paper, a fully standard CMOS threshold voltage reference is presented, which operates from 3.3 V down to a 1 V while exhibiting high accuracy against power supply variations. The circuit was designed for a battery-less transceiver based on RF energy harvesting [4,5]. It exploits MOS transistors operating in weak inversion for both PTAT and CTAT currents and an operational amplifier that improves accuracy of current matching and provides low voltage capability.

The paper is organized as follows. Section 2 deals with circuit description and design guidelines of the proposed voltage reference.

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