CMOS Temperature Sensor Applied in an RF-Powered Biomedical Device

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1. Abstract

This paper presents the design and simulation of a low-power CMOS temperature sensor suitable for human body temperature range measurements, using the IBM 130 nm fabrication process. The sensor was designed to be part of a biomedical wireless sensor system, powered by radio-frequency signals. It consists of a CTAT current source that is used to bias an oscillator, which provides a signal with temperature-dependent frequency. In addition, a calibration circuit was added in order to compensate for process, voltage and temperature variation effects (PVT). Simulations on the circuit were performed in the Cadence Spectre environment and we could observe the circuit worked as expected up to a minimum voltage of 0.6 V. At this voltage the current source provides 0.6 μA nominal reference current, a temperature coefficient of -1.22 %/^{o}C and a power supply dependence of 3.47 %/V.

2. Introduction

Recent advances in the microtechnology area have provided great opportunities for innovation in the biomedical sector. In particular, the deployment of Wireless Body Area Network (WBAN) allows for many applications, such as remote health monitoring, through biological parameters sensors, as body temperature, blood pressure, heart rate [1]–[3]. The temperature sensors are one of the most utilized sensors in healthcare, since temperature is an important parameter for the diagnosis of many diseases [5]. CMOS sensor designs can be found in literature [5], [6] and are preferred due to their low power and low cost. These kind of sensors are very convenient to monitor temperature, and thus can be used in biomedical devices to monitor human health.

This paper proposes a low-power temperature sensor, based on a complementary to absolute temperature (CTAT) threshold-referenced current source, as shown in [4]. It also presents a calibration circuit that is used to regulate the source output current. The temperature sensor presented is part of a larger system powered by RF, which uses RFID-based techniques to communicate and receive power from a reader device, as the systems in [5]–[7].

3. Circuit Description

In the chosen topology, see Fig. 1, the output current I_{ref} depends directly on the value of threshold voltage V_t of transistor T1 and on the resistance R. A power-supply with low sensitivity can be obtained through the bootstrap bias technique [4], whereupon the input current of the circuit depends directly on the output current, of the current source itself. Using this technique, minimum start-up supply voltage is traded off with lower power-supply sensitivity through the cascode current mirror composed by the transistors T3-T6. The transistors T1 and T2 have the width and length of 18 μm and 1.2 μm respectively, transistors T3-T6 have same length and width of 16 μm.

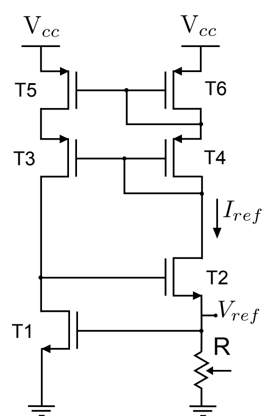

Fig. 1: Threshold referenced current source

The temperature variation is most conveniently expressed in terms of relative changes of output current per degree centigrade, called temperature coefficient TC_f. Assuming a very low power-supply sensitivity, the behavior can be understood from the following equation of TC_f [4]:

$$TC_f \simeq \frac{1}{V_t}\frac{\partial V_t}{\partial T} - \frac{1}{R}\frac{\partial R}{\partial T} = TC_{V_t} - TC_R, \tag{1}$$

where $\frac{dV_t}{dT}$ is a function of the technology parameters [1].

Since the resistor R has a positive temperature coefficient [9] and the threshold voltage decreases with temperature [4], with (1) we can observe that the TC$_f$ of the current source is negative. Using the output current to power a current-starved ring oscillator, we will obtain a signal with frequency that decreases with temperature. Thus the oscillator output can modulate the transmitted signal of the system aforementioned. The voltage reference V_{ref} is used in voltage regulation and mode selector, which are blocks of the same larger system aforementioned.

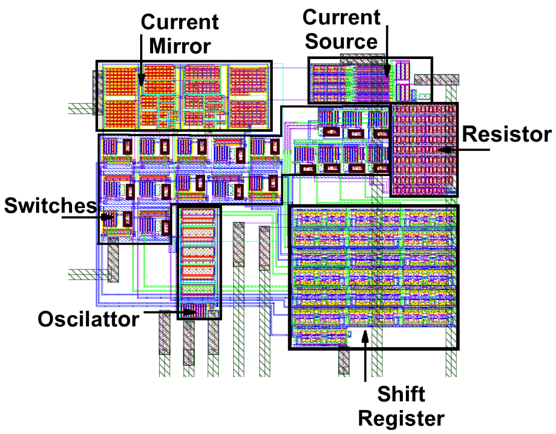

Fig. 2: Circuit layout

A. Calibration

In order to ensure proper operation over process variations, one optimal resistance value must be selected in order to produce a temperature coefficient equal to the nominal. Furthermore one optimal aspect ratio of the current mirror used to bias the oscillator must be also selected, in order to have the absolute value of the frequency. A sequence of switches enable or not the connections between different resistors in series, changing then the value of resistance R, and the aspect ratio by connecting transistors. To activate those switches one shift-register was designed. The mirror transistors were developed to have a good matching, using transistor of same size and just adding then in series or parallel to make the desired mirror.

The technology used to design the layouts was the IBM $130\,nm$. The layout of current source, current mirror, oscillator, switches, resistor and the shift register is presented in Fig. 2. The layout has an area of $0.015\,mm^2$.

4. Simulation Results

The graph in Fig. 3 presents the voltage and current references versus supply voltage. The minimum voltage required for correct operation of current source is 0.6 V. This is the voltage when those references get stable. The current consumption at 38.5^oC and $V_{dd} = 1V$ is 1.35 μA. From those graphics the value of the Power Supply Regulation (PSR) can be calculated, which is $3.47\%/V$ and attends to the system specifications. The simulations also have shown a quasi-linear curve of reference current versus temperature, at a range of 35^oC to 42^oC. The TC calculated for reference current was $-1.22\%/^oC$.

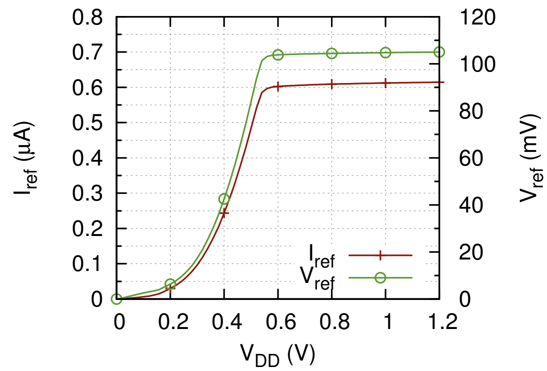

Fig. 3: References variation with supply voltage V_{dd}

5. Conclusion

A temperature sensor based on current source with a system application and calibration methods were presented. The current source has a TC$_f$ of $-1.22\%/^o$C and a PSR of 3.47%/V, the current consumption was $1.35\,\mu A$ without the oscillator and 2.55μA with the oscillator at $T = 38.5^o$C and $V_{dd} = 1V$. The power consumption was according to the power budget of our system.

Acknowledgment

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