Chapter 46
A Millimetre Size Wireless Temperature Sensor with Digital Conversion and Embedded 2.5 GHz Transmitter and Antenna

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Abstract The on-chip antenna concept is the actual trend in integrated wireless sensor systems because it is a practical solution to compact, small size and low cost devices for short range wireless applications, like RFID tags and biomedical sensor data transmitters and other related applications. Due to the typical small chip dimension, only high frequency bands can use these antennas in optimum, i.e., resonating, conditions. Although the chip dimension do not allow resonant radiating elements, nevertheless this does not seem to be a limit for the specific application in contactless sensing, where a short distance wireless link is sufficient. In this paper an improvement of a wireless temperature sensor with on-chip antenna is presented. This solution, realized in 0.35 μm CMOS technology, exploits a proportional to absolute temperature (PTAT) voltage scheme, where the difference between two base-emitter voltages under different bias current densities is constantly measured. The availability of bipolar transistors in CMOS technology allows to exploit their properties in temperature sensor applications. The signal is transmitted by a small loop antenna structure which is realized by aluminium deposition on the top surface of the chip.

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46.1 Introduction

The feasibility of wireless sensor devices has been fully demonstrated recently [1, 2] with a wide use of different interfaces and transmission standards and various antenna topologies. The link with the RFID technology can be a practical and low-cost solution to associate radio frequency identification with the measure of the temperature of product, animal or people with dynamic variable data acquisition from on-board sensors.

This study originates from a previous work, which deals with a wireless sensor with on-chip antenna for short range biomedical applications. A single-loop antenna is used in that case [3] and the device proves the possibility of realizing an on-chip antenna. When the RFID is combined with sensory systems, its application area can be extended to environmental monitoring such as temperature, humidity and pressure sensing. The new temperature sensor exploits the proportional to absolute temperature (PTAT) voltage, which is the difference between two base emitter voltages under different bias current densities. The availability of bipolar transistors, in CMOS technology, allows us to exploit their properties in temperature sensor applications. The sensitivity, signal level and linearity of the sensor interface were specially conditioned in order to simplify further Analog-to-Digital conversion (ADC). The idea is to convert the analog signal, i.e., PTAT voltage, to a N-bits digital signal, where each bit can modulate a Radio Frequency (RF) carrier generated, for example, by a ring oscillator, using the On–Off Keying (OOK) modulation.

46.2 The Temperature Sensing Principle

Many implementations of temperature sensors have been reported, relying on the well-known temperature dependency of bipolar devices. Considering CMOS technology, lateral as well as vertical substrate PNP transistors can be applied. The vertical substrate transistors have the better performance with respect to non-idealities of the characteristics $I_C(V_{BE}, T)$.

The PTAT temperature sensor uses the phenomenon that difference between voltages of two bipolar elements, which have different areas and conduct the same current (i.e., different current densities), is proportional to absolute temperature (PTAT). The base-emitter voltage of bipolar transistors or, more generally, the forward voltage of pn-junction diode exhibits a negative temperature coefficient ($\partial V_{BE}/\partial T \approx -1.5$ mV/°C). As well-know, if two different bipolar transistors (i.e., PNP substrate transistors for CMOS technology) operate at unequal current densities, then the difference between their base-emitter voltages is directly proportional to absolute temperature.

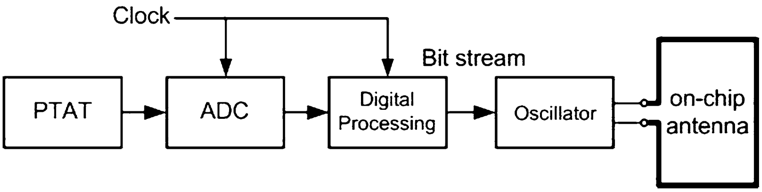

Fig. 46.1 Block diagram of the “RFID” temperature sensor

46.3 Chip Design

The electronic design of the RFID sensor has been carefully tuned to get a linear dependence of voltage versus temperature for a wide temperature range (room temperature to 100°C). This voltage, converted to a digital signal, is an output bit stream that can be used to drive a RF-oscillator, as shown in Fig. 46.1. The RFID temperature sensor comprises four major blocks: a proportional-to-absolute temperature (PTAT) voltage generator, an analog-to-digital converter (ADC) with a maximum resolution of 8-bits, a digital processing circuit and a RF transmitter.

Simulations regarding the radiating element has been conducted in Ansoft HFSS at a frequency of 2.4 GHz, for its tuning and for obtaining its characteristic values (to be used in Cadence). The stack-up refers to a 0.35 μm CMOS standard technology and consists of a 300 μm thick Si substrate ($\rho = 19\ \Omega\cdot\text{cm}$) and an Al metal layer on top. A 4 μm oxide layer ($\rho = 10^{10}\ \Omega\cdot\text{cm}$) between the metal layer and the lossy Si substrate acts as insulation. The typical dimensions of the metal cross-section are $20 \times 1\ \mu m^2$. Chip dimensions are about $2.5 \times 2.5\ mm^2$. The antenna structure is examined, investigating the effects in its behavior induced by varying the geometric and technological parameters. Inductive and radiation characteristics are calculated. Two sources of losses should be considered: losses due to the metal conductivity (these losses are in fact neglected) and losses in substrate volume. A lossy substrate decreases the radiation efficiency, which depends on the conductivity of the substrate material.

46.4 Results

Eddy currents are induced in the substrate as the effect of the current flowing in the antenna. Induced current causes poor values of the radiation efficiency. Comparing the simulations on air and on the substrate, the value of R_d remains substantially unaltered (about 0.16 Ω) but, more important, an increase in R_{loss} value is observed (it varies from 6.15 to 10.25 Ω with the introduction of the substrate). This implies an input impedance value $Z_{in} = 11 + j103$, with a radiation

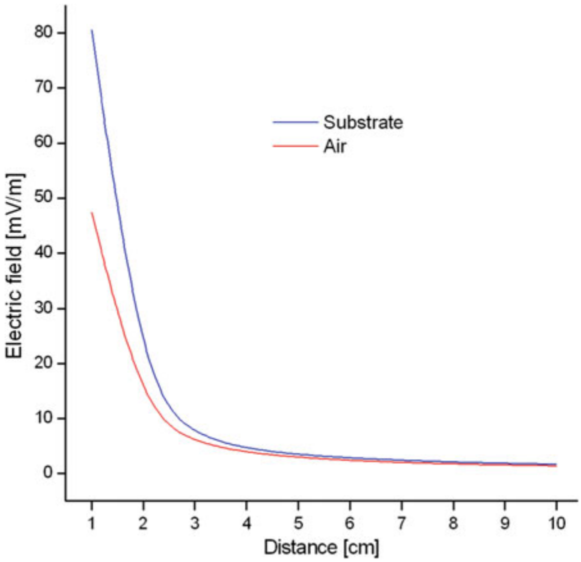

Fig. 46.2 Electric field versus distance on air and on substrate for the loop antenna

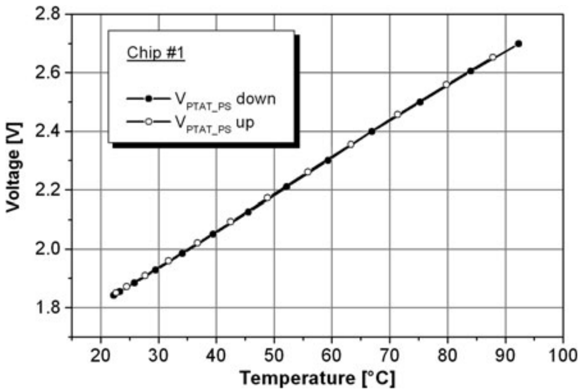

Fig. 46.3 Measured PTAT voltages versus temperature

efficiency value of 1.5% and a −41 dB gain in presence of the substrate. The electric field shows an inverse behaviour at a short distance, as can be observed in Fig. 46.2, where the fields on air and in presence of the substrate are reported.

The device showed a linear voltage versus temperature dependence for a wide temperature range: from room temperature to 100°C, applying both positive and negative temperature ramps (called up and down in Fig. 46.3). The voltage $V_{\text{PTAT-PS}}$, shows a linear dependence on the temperature changes, with temperature sensitivities equal to $\Delta V_{\text{PTAT-PS}}/\Delta T = 10.62$ mV/°C. After the temperature to voltage transduction, it is necessary to digitalize this signal with an ADC. We choose to implement an 8-bit ADC and thus the analog input voltage will be converted on 256 quantization levels. If we consider the interval between 20 and

100°C, we have a range of about 80°C. This means that the analog signal $V_{PTAT\text{-}PS}$, has a swing of 810 mV, with a resolution of about 3 mV, which translates into an error of 0.3°C.

The bias voltage for the device is 3.3 V with a low DC current consumption of about 70 μA for the PTAT sensor in continue operation mode. About the analog-to-digital conversion and digital processing, the dynamic power consumption does not represent a considerable value in terms of dissipated power because the temperature is periodically acquired with a very long time interval, for example at 1 Hz or less.

46.5 Conclusions

A fully integrated wireless temperature sensor, exploiting on-chip antenna for short range applications, has been presented. The sensor provides a voltage versus temperature sensitivity of 10.62 mV/°C, at 3.3 V bias voltage, for the PTAT sensing element. The sensor has been implemented in 0.35 μm CMOS technology. In consequence of its dimensions, antennas are far from resonance conditions and therefore their gain and radiation diagrams, although well far from being optimal, are still enough for enabling a short range RF communication channel.

References

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