Chapter 3

Motivation

Fig. 3.1 illustrates the operational principle of an *absolute* temperature sensor. Diode-connected bipolar transistor at the left of Fig. 3.1, denoted as *BJT*, is applied to produce voltage V_{EB} with constant current. The block at the right of Fig. 3.1, denoted as *CORE*, consists of a constant current generator and an analog-to-digital converter to output digital values according to the temperature at the location of *BJT*. Ideally, *BJT* is supposed to be linearly sensitive to *absolute* temperature while *CORE* is insensitive to temperature fluctuation.

To understand the effect of process variations on the measured *absolute* temperatures as described in Fig. 3.1, we conduct a SPICE simulation. In this experiment, $45nm$ technology is used and $10uA$ constant current is pumped into *BJT* for different process corners at different specified actual temperatures. The estimated temperature is reported by *CORE* according to the measured voltage V_{EB}. The first experiment is conducted assuming process variations occur in *BJT* and do not in *CORE*.

Table 3.1 shows the measured *absolute* temperatures. The first column shows the actual temperature assigned in SPICE simulation. The second, third and fourth columns represent the measured temperatures in the slow, typical and fast process corners, respectively. All temperatures are represented in Celsius. Let us take the entry of (25, FF) as an example. It shows that when *BJT* is in the fast corner and *CORE* in typical one, the temperature sensor will report 29.8°C while the actual temperature is only 25°C. From this table, the measured

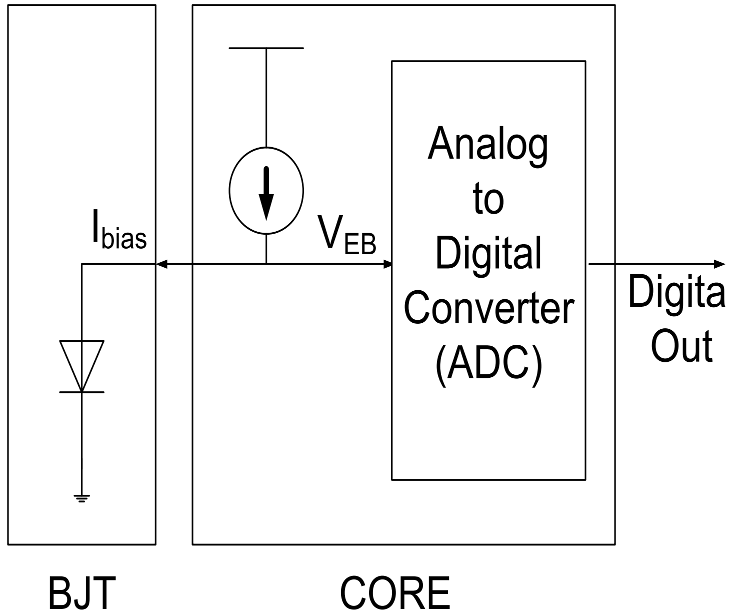

Figure 3.1: Block diagram of the temperature sensor

Table 3.1: Measured Temperature due to Process Variations in *BJT*

	Measured (°C)		
Actual (°C)	SS	TT	FF
-40.0	-41.7	-37.2	-33.7
0.0	-4.0	1.0	5.0
25.0	20.1	25.6	29.8
125.0	120.9	127.8	133.1

temperature is within one digit error as compared with the actual temperature when process variations occur only in *BJT*.

Similarly, we conduct our second experiment where we assume that process variations occur in *CORE* and do not in *BJT*. Table 3.2 shows the measured *absolute* temperature. In this table, the first column shows the actual temperature assigned in SPICE simulation. The second, third and fourth columns represent the measured temperature with $5uA$, $10uA$ and $20uA$ constant current, respectively, generated by *CORE* and driven into *BJT*. From this table, double-digit inaccuracy is observed when process variations occur only in *CORE*.

Judging from the results illustrated by the above two tables, it is difficult to assure the accuracy of *absolute* temperature under the process variations in both *BJT* and *CORE*.

Table 3.2: Measured Temperature due to Process Variations in *CORE*

	Measured (°C)		
Actual (°C)	5uA	10uA	20uA
-40.0	-28.7	-37.2	-45.8
0.0	11.0	1.0	-9.0
25.0	36.5	25.6	14.5
125.0	142.5	127.8	113.0

As to MOS devices, the primary temperature-dependent parameters are the mobility μ and the threshold voltage V_T. However, those two parameters have different temperature impacts on drain current. For example, both μ and V_T increase when temperature decrease. However, the increased μ increases drain current while the increased V_T decreases drain current. In other words, mobility sensitive circuitry and threshold voltage sensitive circuitry have different device behaviors caused by temperature fluctuation. Therefore, in order to avoid the complex temperature dependent behavior of circuitry and erroneous measurement, *CORE* should be placed at locations which have minimum temperature fluctuation.

To solve problems of the above-mentioned process variations and temperature fluctuation, we propose a *relative* temperature sensor. Our specific contributions in this paper will be:

- to propose a novel architecture of relative temperature sensor to alleviate the temperature errors from process variations and temperature fluctuation in a chip;
- to propose an efficient algorithm to allocate and place relative temperature sensors.