# SPC58xx temperature sensor

## Introduction

The aim of this document is to detail the usage of the temperature sensor on SCP58xx microcontroller family.

The document provides the necessary information about the hardware and a reference code to calculate the temperature.

All the microcontrollers (MCU) listed in Table 1. Devices list include a temperature sensor (TSENS) that monitors device junction temperature.

More details about the TSENS can be found in the device's reference manual (see Section  Appendix B  Reference documents).

*Note: SPC582Bx MCU does not support TSENS.*

**Table 1. Devices list**

| Device | Part number |
|---|---|
| SPC584Bx | SPC584B60x, SPC584B64x, SPC584B70x |
| SPC584Cx/SPC58ECx | SPC584C70x, SPC584C74x, SPC584C80x, SPC58EC70x, SPC58EC74x, SPC58EC80x |
| SPC584Gx/SPC58EGx | SPC584G80x, SPC584G84x, SPC58EG80x, SPC58EG84x, SPC58NG80x, SPC58NG84x |
| SPC58EHx/SPC58NHx | SPC58EH84x, SPC58EH90x, SPC58EH92x, SPC58NH84x, SPC58NH90x, SPC58NH92x |

# 1 Overview

SPC58xx MCUs include an onboard temperature sensor that monitors device temperature and delivers two analog outputs signals and three digital output signals. The analog outputs consist of two voltage signals which vary linearly with the internal junction temperature:

- a voltage signal that is linearly increasing (PTAT: Proportional to absolute temperature)
- a voltage signal that is linearly decreasing (CTAT: Complementary to absolute temperature).

The analog outputs are connected to an input channel of an ADC on the device. The internal junction temperature must be calculated by software based on the converted temperature values. The three digital outputs, connected to the PMC module, are used to signal under- and over-temperature operating conditions. These signals notify the device to take action to appropriately adjust the device temperature in response to an out of specification low or high temperature operating condition. Calibration parameter values, associated with the temperature threshold detection feature, are determined and stored in internal flash memory during production testing at the factory.

## 1.1 Linear temperature sensor (analog output generation)

The temperature sensor outputs two voltage proportional and complementary proportional to the internal junction temperature of the chip. These analog voltage signals are converted into digital values by an on-chip ADC (SAR_ADC_12bit_B0). The temperature value is obtained from a linear voltage-temperature relation with coefficients adjusted by calibration parameters. These are extracted during factory test and programmed into flash memory.

# 2 Temperature formula

The Table 2. Calibration constants shows the addresses of the calibration parameters associated to the temperature sensor in the internal UTEST memory.

**Table 2. Calibration constants**

| Constant | Description | UTEST Address |
|---|---|---|
| P1 | Code from the ADC converting PTAT output voltage at 150ºC | 0x400004 |
| P2 | Code from the ADC converting PTAT output voltage at -40ºC | 0x400000 |
| C1 | Code from the ADC converting CTAT output voltage at 150ºC | 0x400006 |
| C2 | Code from the ADC converting CTAT output voltage at -40ºC | 0x400002 |

In the equations below:

- Pn and Cn are the calibration constants described in Table 2. Calibration constants .
- T is the unknown device temperature in ºC
- Px is the code from the ADC converting PTAT output voltage at the temperature T with any ADC reference voltage Vref
- Cx is the code from the ADC converting CTAT output voltage at the temperature T with the same ADC reference voltage Vref
- T2 = -40 ºC
- T1 = 150 ºC

The temperature T is calculated as:

$$T = T2 + (A*(T1-T2))/(A+B)$$

Where:

$$A = Px*C2-(Cx*P2)$$
$$B = Cx*P1-(Px*C1)$$

Please, note that it is mandatory to have the same value as the ADC reference while measuring Px and Cx.

The monitoring of on-chip analog signals coming from temperature sensor is managed by the SARADC SUPERVISOR (SAR_ADC_12bit_B0) through some specific test channels. The Table 3. SAR_ADC analog test channels for TSENS shows the test channels for temperature sensor.

**Table 3. SAR_ADC analog test channels for TSENS**

| Test channel | Description |
|---|---|
| 120 | PTAT (Proportional to absolute temperature) |
| 121 | CTAT (Complementary to absolute temperature) |

After the conversion is performed on a test channel the converted data is stored at two CDR locations at the end of conversion, first location is the CDR belonging to the test channel on which conversion is performed and second location is the CDR belonging to internal channel on which test channel is mapped.

# 3 Example code for temperature calculation

The C code below is a part of the SPC5Studio temperature sensor component and shows how to calculate the junction temperature in SPC58xx devices.

```
int16_t p1,p2,c1,c2;
uint16_t px,cx;
float a,b;
float t1 = (float)150;
float t2 = (float)-40;

/* get calibration constants from flash */
caddress = tsens_config.constants_address;
p2 = *((vuint16_t*)(caddress));
caddress = tsens_config.constants_address + 2UL;
c2 = *((vuint16_t*)(caddress));
caddress = tsens_config.constants_address + 4UL;
p1 = *((vuint16_t*)(caddress));
caddress = tsens_config.constants_address + 6UL;
c1 = *((vuint16_t*)(caddress));

/* get current vbg and tsens values from saradc channels */
cx = saradc_lld_readchannel(tsens_config.saradc_driver, tsens_config.vbg_channel);
px = saradc_lld_readchannel(tsens_config.saradc_driver, tsens_config.tsens_channel);

/*calculate and b values */
a = ((float)px * (float)c2) - ((float)cx*(float)p2);
b= ((float)cx*(float)p1) - ((float)px*(float)c1);

/* calculate temperature */
temperature = t2 + (((t1-t2)*a)/(a+b));
```

where:

```
tsens_config.constants_address = 0x00400000
tsens_config.vbg_channel = 121U
tsens_config.tsens_channel = 120U
```

# Appendix A Acronyms and abbreviations

Table 4. **Acronyms**

| Abbreviation | Complete name |
|---|---|
| MCU | Microcontroller unit |
| TSENS | Temperature sensor |
| UTEST | User test Flash |
| ADC | Analog to digital converter |
| SARADC | Successive approximation register analog to digital converter |
| PMC | Power management controller |

# Appendix B Reference documents

- SPC58xx 32-bit power architecture microcontroller reference manuals.

# Revision history

Table 5. **Document revision history**

| Date | Version | Changes |
|---|---|---|
| 16-Jul-2020 | 1 | Initial release. |

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