TN1301
Technical note

SPC564Axx Temperature Sensor

Introduction

This document is intended for software and hardware developers who wants to understand how to use the SCP564Axx Temperature Sensor.

The aim of this document is to clarify the Temperature Sensor calculation, and to provide reference code to show how to calculate it.

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1 Scope

This document describes the Temperature Sensor integrated into SPC564Axx Automotive Microcontroller devices and the way to calculate the internal junction temperature.

The devices under analysis are listed in *Table 1*.

Table 1. Cores

Device	Name
SPC564A70xx	Andorra 2M
SPC564A74xx	Andorra 3M
SPC564A80xx	Andorra 4M

2 Overview

SPC564Axx MCUs include an on board temperature sensor that monitors device temperature and produces a voltage directly proportional to the internal junction temperature. Internal junction temperature must be calculated by software based on the sampled temperature sensor voltage, sampled bandgap voltage and calibration parameter values stored in internal flash memory.

The temperature sensor generates a voltage that increases linearly with temperature. Since the voltage is an amplified version of a ΔVBE voltage it is proportional to absolute temperature. This voltage, $V_{TSENS}(T)$, is read by software using the on board eQADC module and used with the bandgap voltage and constants stored in flash memory during factory test to calculate device junction temperature.

Five calibration parameters are stored in flash memory during factory test:

- T_{LOW} is the low temperature factory calibration temperature value.
- T_{HIGH} is the hot temperature factory calibration temperature value.
- $V_{BG\_CODE}(T_{LOW})$ is the bandgap voltage at low calibration temperature (T_{LOW}) sampled by the eQADC and converted to a 14-bit value.
- $T_{TSENS\_CODE}(T_{LOW})$ is the temperature sensor voltage at low calibration temperature (T_{LOW}) sampled by the eQADC and converted to a 14-bit value.
- $T_{TSENS\_CODE}(T_{HIGH})$ is the temperature sensor voltage at high calibration temperature (T_{HIGH}) sampled by the eQADC and converted to a 14-bit value.

3 Temperature formula

The temperature formula is the following:

$$T = T_{LOW} + \frac{T_{TSENS\_CODE}(T)*\beta - T_{TSENS\_CODE}(T_{LOW})}{T_{TSENS\_CODE}(T_{HIGH}) - T_{TSENS\_CODE}(T_{LOW})} * (T_{HIGH} - T_{LOW})$$

where:

$$T_{TSENS\_CODE}(T) = \frac{V_{TSENS}(T)}{V_{ref}} * 2^{14}$$

$$\beta = \frac{V_{BG\_CODE}(T_{LOW})}{V_{BG\_CODE}(T)}$$

$$V_{BG\_CODE}(T) = \frac{V_{BG}(T)}{V_{ref}} * 2^{14}$$

$$V_{ref} = V_{RH} - V_{RL}$$

- V_{RH} is ADC High Reference Voltage, V_{RL} is the ADC Low Reference Voltage, $V_{BG}(T)$ is the bandgap reference voltage and $V_{TENS}(T)$ is the output voltage of the device temperature sensor. Software must sample the voltages respectively from eQADC_A channel 40, 41, 45 and 128 (ADC0 and ADC1) (see *Table 2: ADC Temperature channels*).

Table 2. ADC Temperature channels

Function	ADC Channel Number
VRH	40
VRL	41
Bandgap (V_{BG})	45
Temperature Sensor (V_{TSENS}(T))	128

- T_{LOW} is the factory low calibration temperature, T_{HIGH} is the hot factory calibration temperature, $T_{TSENS\_CODE}(T_{LOW})$ is the sampled output voltage of the temperature sensor during low temperature factory calibration, $T_{TSENS\_CODE}(T_{HIGH})$ is the sampled output voltage of the temperature sensor during hot temperature factory calibration. These values are stored in internal flash memory during factory calibration, and accessible directly by the Temperature Calculation Constants Register 0 (TSENS_TCCR0, see *Figure 1: Temperature Calculation Constants Register 0 (TSENS_TCCR0)*).

Figure 1. Temperature Calculation Constants Register 0 (TSENS_TCCR0)

Address: 0xFFFE_C000

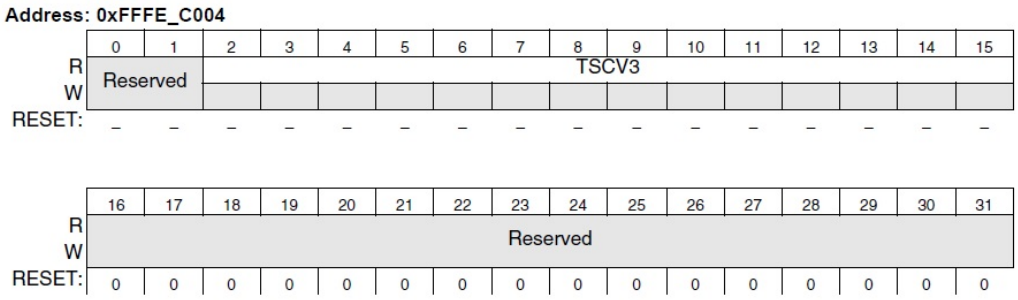
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	TSCV2															
W																
RESET:	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
R	TSCV1															
W																
RESET:	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Field	Bits	Description
TSCV2	0–15	Combination of encoded hot factory calibration temperature (T_{HIGH}) and the temperature sensor output at that temperature (TSENS_CODE(T_{HIGH})). Bits 0–1 contain a value representing the hot factory calibration temperature (T_{HIGH}). The values are as follows: – 00: T_{HIGH} = Reserved – 01: T_{HIGH} = Reserved – 10: T_{HIGH} = 145 °C – 11: T_{HIGH} = 150 °C Bits 2–15 are the temperature sensor voltage sampled and converted by the eQADC during factory test with device at hot temperature (T_{HIGH}). This is the T_{SENS_CODE}(T_{HIGH}) parameter value referenced in the temperature calculation formula. The reset value of this register is device-dependent. The value is set during factory test.
TSCV1	16–31	Combination of encoded low factory calibration temperature (T_{LOW}) and the temperature sensor output at that temperature (TSENS_CODE(T_{LOW})). Bits 16–17 contain a code indicating the value of T_{LOW}. The values are as follows: – 00: T_{LOW} = 25 °C – 01: T_{LOW} = 40 °C – 10: T_{LOW} = Reserved – 11: T_{LOW} = Reserved Bits 18–31 are the temperature sensor voltage sampled and converted by the eQADC during factory test with device at the low calibration temperature. This is the $T_{SENS\ CODE}$(T_{LOW}) parameter value referenced in the temperature calculation formula. The reset value of this register is device-dependent. The value is set during factory test.

- V_{BG_CODE}(T_{LOW}) is the value of the bandgap voltage sampled during low temperature factory calibration. This value is stored in internal flash memory during factory calibration, and accessible directly by the Temperature Calculation Constants Register 1 (TSENS_TCCR1, see *Figure 2: Temperature Calculation Constants Register 1 (TSENS_TCCR1)*).

Figure 2. Temperature Calculation Constants Register 1 (TSENS_TCCR1)



Field	Bits	Description
Reserved	0–1	Reserved
TSCV3	2–15	Bandgap voltage sampled and converted by ADC during factory test. This is the $V_{BG\_CODE}(T_{LOW})$ parameter value referenced in the temperature calculation formula. The reset value of this register is device-dependent. The value is set during factory test.
Reserved	16–31	Reserved

4 Example code for Temperature calculation

The following C code shows an example of a function that returns the junction temperature starting from the parameters *vrh* (ADC CH40), *vrl* (ADC CH41), *bandgap* (ADC CH45) and *tsens* (ADC CH128).

```
static float calculateSocTemperature(uint32_t vrh, uint32_t vrl, uint32_t
bandgap, uint32_t tsens) {

  uint32_t vref;
  uint16_t tscv1, tscv2;
  uint16_t t_sense_code_t_low, t_sense_code_t_high;
  int32_t t_low = 0;
  int32_t t_high = 0;
  uint16_t tscv3;
  float vbg_code;
  float beta;
  float t_sense_code_t;

  /* Vref calculation.*/
  vref = (vrh - vrl);

  /* TTSENS_CODE(TLOW) and TTSENS_CODE(THIGH) calculation.*/
  tscv1 = TSENS.TCCR0.B.TSCV1;
  tscv2 = TSENS.TCCR0.B.TSCV2;
  t_sense_code_t_low  = 0x3FFF & tscv1;
  t_sense_code_t_high = 0x3FFF & tscv2;

  /* TLOW calculation.*/
  switch(((0xC000 & tscv1) >> 14))
  {
    case 0:
      t_low = 25;
      break;
    case 1:
      t_low = 40;
      break;
    default:
      break;
  }

  /* THIGH calculation.*/
  switch(((0xC000 & tscv2) >> 14))
  {
    case 2:
```

```
      t_high = 145;
      break;
    case 3:
      t_high = 150;
      break;
    default:
      break;
  }

  /* VBG_CODE(TLOW) calculation.*/
  tscv3 = TSENS.TCCR1.B.TSCV3;

  /* VBG_CODE(T) calculation.*/
  vbg_code = (float)(bandgap * (1 << 14)) / vref ;

  /* BETA calculation.*/
  beta = ((float)tscv3 / (vbg_code));

  /* TTSENS_CODE(T) calculation.*/
  t_sense_code_t = (float)(tsens * (1 << 14)) / vref;

  /* SOC temperature calculation.*/
  return (t_low + ((((t_sense_code_t * beta) - t_sense_code_t_low) /
(t_sense_code_t_high - t_sense_code_t_low)) * (t_high - t_low)));
}
```

5 Revision history

Table 3. Document revision history

Date	Revision	Changes
27-Sep-2019	1	Initial release.

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