TB3165

Temperature Indicator Module on 8-Bit PIC® Microcontrollers

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INTRODUCTION

This technical brief discusses the operation of the internal temperature indicator module found on the newer 8-bit PIC® Microcontrollers. This document also covers how to set up the module and estimate the temperature based on single-point calibration technique.

There are some applications that require measuring the internal operating temperature of the microcontroller. It is useful to monitor the temperature of the silicon die of the microcontroller to ensure that it is operating within its limits of thermal rating. In enclosed products, the microcontroller's internal temperature can be monitored for protection of other components that are part of the system.

TEMPERATURE INDICATOR MODULE OVERVIEW

The temperature indicator module consists of a temperature-sensing circuit that provides a voltage output to the Analog-to-Digital Converter (ADC) on the device. The analog voltage output (V_{MEAS}) varies inversely to the device temperature, which can be measured using the internal ADC.

The circuit's range of operating temperature falls between -40°C and +125°C. A one-point calibration allows the circuit to indicate a temperature closely surrounding that point. A two-point calibration allows the circuit to sense the entire range of temperature more accurately.

Figure 1 shows a simplified block diagram of the temperature indicator module. This temperature indicator module features a different internal voltage referencing, as compared to the legacy 8-bit PIC devices, thereby improving the overall accuracy and lowering the offset error between the measured and the actual temperature values. The operation of the module is controlled by the module enable and range selection bits (TSEN and TSRNG bits in the FVRCON register). Figure 2 shows an example of the voltage variation across temperature for a PIC18FXXK42 device. Details and operation of the previous temperature indicator module are further explained in AN2092 *"Using the Temperature Indicator Module"* (DS00002092).

FIGURE 1: TEMPERATURE INDICATOR MODULE BLOCK DIAGRAM

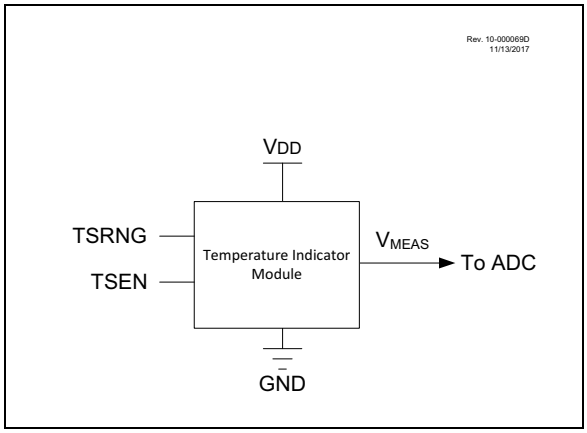
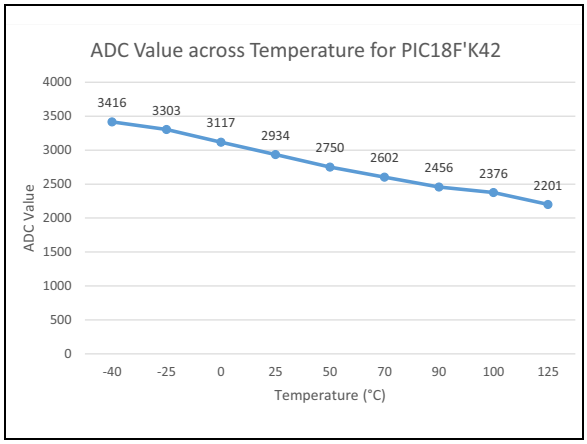


FIGURE 2: VOLTAGE VARIATION ACROSS TEMPERATURE FOR PIC18FXXK42



SINGLE-POINT CALIBRATION

This section describes the process of estimating the internal temperature using single-point calibration technique.

Note:	Single-point calibration is a quick method of calculating an estimate of the internal temperature within reasonable error limits. For applications requiring precise temperature measurement, a higher-order calibration is recommended, which is out of the scope of this document.

Module Configuration

To use the temperature indicator module with single-point calibration, the ADC and the Fixed Voltage Reference (FVR) modules need to be configured in addition to the temperature indicator module. The procedure for setting up the module is described in the following steps:

1. Enable the FVR (EN bit) and set the FVR Buffer 1 Gain (ADFVR bits) to 2x (2.048V) in the FVRCON register.
2. Enable the temperature indicator (TSEN bit) in the FVRCON register. Select the appropriate range of operation (high range or low range) using the TSRNG bit.
3. Set up the ADC module (or ADCC module, depending upon the device) as follows. Refer to the device data sheet for specific registers and instructions.
   a. Set the appropriate ADC clock using ADCS bits.
   b. Select FVR as the positive voltage reference using the ADPREF bits.
   c. Select the analog channel reserved for the temperature indicator using the ADPCH bits (or CHS bits, depending upon the device).
   d. The ADC must wait for a certain minimum acquisition time (parameter TS01 in device data sheet) for the analog channel to settle before the conversion can be performed. This can be done in the software or through ADACQ register (ADCC module only).
   e. There may be significant noise in the channel, which could be captured by the ADC. To reduce the noise, it is recommended to take the average of a few ADC readings. If the device is equipped with the ADCC module, it can be set to operate in averaging or low-pass filter mode to reduce noise from the channel.
4. Optionally, set up the UART to send the calculated temperature value to be displayed on the screen via a serial terminal window. Refer to the device data sheet for specific registers and instructions.

Temperature Calculation

The following steps are for calculating the die temperature (T_{MEAS}):

1. Obtain the ADC count value of the measured analog voltage. The analog output voltage from the temperature indicator module, V_{MEAS}, is converted to a digital count value by the ADC and is referred to as ADC_{MEAS}.
2. Obtain the ADC count value, ADC_{DIA} at 90°C, from the DIA table. This parameter is stored as TSLR2 for the low-range setting or TSHR2 for the high-range setting of the temperature indicator module. This value is the digital count value of the voltage output from the temperature indicator module, as measured at 90°C at the FVR 2x voltage reference, populated in the DIA table beforehand to assist with single-point calibration. Refer to the device data sheet for more information.
3. Obtain the output analog voltage (in mV) value of the Fixed Reference Voltage (FVR) for 2x setting from the DIA Table. This parameter is stored as FVRA2X in the DIA table. Refer to the device data sheet for more information.
4. Obtain the value of the temperature indicator voltage sensitivity (in mV/°C), parameter Mv, for the corresponding range setting. Refer to the Electrical Specifications section in the corresponding device data sheet.
5. Calculate the estimated die temperature (T_{MEAS}) using the following equation:

EQUATION 1: SENSOR TEMPERATURE

$$T_{MEAS} = 90 + \frac{(ADC_{MEAS} - ADC_{DIA}) \times FVRA2X}{(2^N - 1) \times Mv}$$

Where:

ADC_{MEAS} = ADC reading at temperature being estimated

ADC_{DIA} = ADC reading stored in the DIA

FVRA2X = FVR value stored in the DIA for 2x setting

N = Resolution of the ADC

Mv = Temperature Indicator voltage sensitivity (mV/°C)

Note:	It is recommended to take the average of ten measurements of ADC_{MEAS} to reduce noise and improve accuracy. This can be done by writing a code in the software to perform averaging function. Alternatively, if the device is equipped with the ADCC module, this can be achieved by operating the ADCC in averaging or low-pass filter mode. Refer to the device data sheet for more information.

EXAMPLE 1: TEMPERATURE CALCULATION ON A PIC18FXXK42 DEVICE AT ROOM TEMPERATURE

At room temperature, the following values were observed on a PIC18FXXK42 device by the temperature indicator module operating in high-range mode with FVR 2X as the voltage reference:

ADC_{MEAS} = 2948 (output from ADC)

ADC_{DIA} = TSHR2 = 0x0998 = 2456 (from DIA table)

FVRA2X = 0x0801 = 2049 (from DIA table)

N = 12 (K42 has 12-bit ADC)

MV = -3.684 (parameter TS02 from device data sheet)

Plugging these values in Equation 1, we get:

$$T_{MEAS} = 90 + \frac{(2948 - 2456) \times 2049}{4095 \times (-3.684)}$$

$$T_{MEAS} = 90 - 66.8 = 23.2^{\circ}C$$

A working demonstration of this module for a PIC18FXXK42 device is available in the Examples section of MPLAB® Xpress Cloud IDE.

CONCLUSION

The temperature indicator module helps determine the internal operating temperature of the silicon die, which can be extremely useful in certain applications. The module outputs an analog voltage inversely proportional to the variation in temperature, which can be measured by the ADC through a dedicated channel. This ADC value can then be used to estimate the temperature based on single-point or multiple-point calibration techniques.

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