Z i L O G

Technical Note

Technique for Measuring System Temperature Using the On-chip Temperature Sensor of the Z8 Encore! XP®

TN004201-0905

Introduction

The Z8 Encore! XP® is a high performance 8-bit microcontroller with a unique set of analog and digital peripherals, including an integrated on-chip temperature sensor (ITS). This sensor measures the surface temperature of the silicon die, therefore it is required to account for the difference between the actual system temperature and ITS temperature across the entire operating temperature range.

This technical note discusses a technique to measure the system temperature using the ITS.

The source code associated with this technical note is in the TN0042-SC01.zip file, available on the ZiLOG website.

Overview of the Z8 Encore! XP® On-Chip Temperature Sensor

The ITS is based on the proportional to absolute temperature (PTAT) topology, with its output directly coupled to the integrated analog to digital converter. The ITS's output can also be linked to the input of the on-chip comparator. In this mode of operation, the accuracy is substantially less, as compared to the implementation using the ADC.

For the ITS to operate or to be routed to the comparator, the ADC must be enabled. If the ITS is routed to the ADC, the ADC must be configured to unity-gain buffered mode (See *Input buffer stage* in the product specification document - PS0228). The output of the ADC is a signed number, although it is always positive. The ADC is calibrated at the factory based on the internal reference voltage. Though it is possible to use external reference voltage, more accurate readings are obtained using internal reference voltage.

Process Flow

The difference between the system temperature and the ITS temperature arises due to various factors:

- The thermal characteristics of the microcontroller package and its bonding interface to the board,
- The board topology (number of layers, copper content, vias, etc.),

- Air flow characteristics in the system.

In addition to all these, during normal operation the silicon die also experiences certain degree of heat.

The technique detailed in this technical note is based on National Semiconductor's LM35 precision temperature sensor. This sensor is used as the external (system) temperature reference for the initial correlation between the system temperature and the values obtained using the ITS.

The process flow is outlined below:

- Use the ADC control register to link the ADC to the ITS and LM35.
- Read the ADC output data from ITS and LM35 at different temperatures.
- Prepare a look-up table correlating the measured temperatures.
- Store the look-up table in the non-volatile data storage (NVDS) area of the Z8 Encore! XP®'s Flash memory
- Display the look-up table on the HyperTerminal.

Hardware and Software Details

The following sections discusses the hardware details and the associated software used for obtaining the temperature correlation technique.

Hardware Details

The hardware platform is based on the Z8 Encore! XP® *Development Board*, with the ITS of the Z8 Encore! XP® MCU (Z8F04A08100) used as the on-chip temperature sensor and the LM35 used as the off-chip reference temperature sensor.

For the purpose of heating and cooling, a lamp and a fan are provided. *Figure 1* shows the hardware set-up with lamp and fan mounted and *Figure 4* shows the block diagram of the hardware setup.

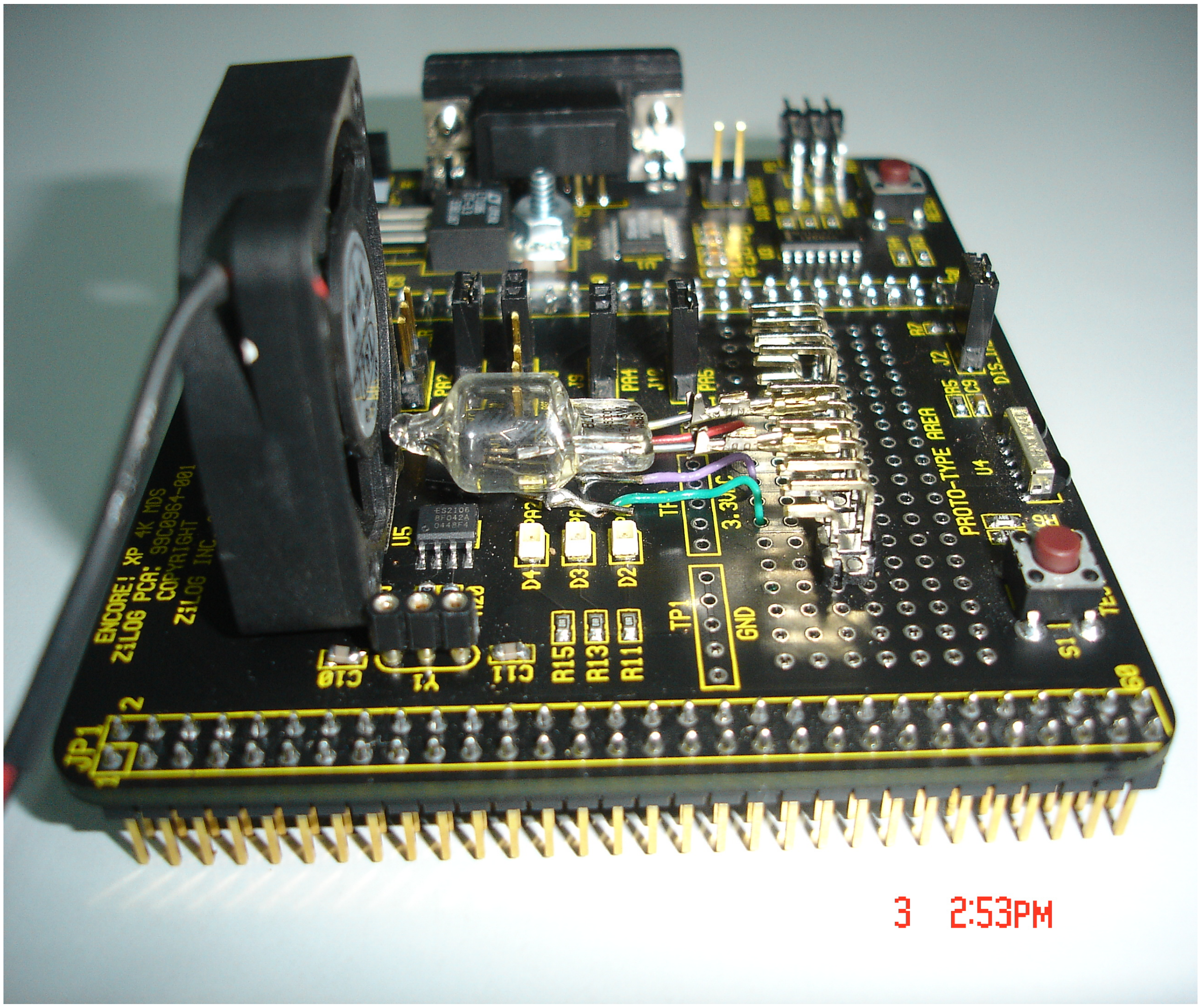

Figure 1. Hardware set-up with lamp and fan mounted

Software Details

The source code associated with this technical note is in the TN0042-SC01.zip file, available on the ZiLOG website.

The software is used for the following functionalities:

- Read the data from both temperature sensors via the ADC.
- Calculate temperatures at definite intervals.
- Prepare the look-up table and display the resulting values.

The following peripherals are used along with this hardware:

- *Analog to Digital Converter*

- *Timer*
- *Universal asynchronous receiver/transmitter (UART)*

Analog to Digital Converter

The input to the ADC is switched between the ITS and the LM35 in the ADC interrupt service routine. The switching is done by selecting alternatively the on-chip temperature sensor and analog input ANA2 (for LM35) in the ANAIN field of ADCCTL0 register. The ADC data registers are read in the ADC interrupt service routine. The ADC is configured for single shot conversion.

Timer

The Timer is used to set the time delays for each temperature calculations. The time delays are configured depending on how fast the temperature is expected to change. Timer0 is configured in continuous mode to generate an interrupt every second. Temperature calculations are done in the timer interrupt service routine with the latest ADC values for both devices.

Universal asynchronous receiver/transmitter (UART)

The UART is used to display the look-up table on the HyperTerminal, and is initialized with the following settings:

- 38400 baud rate
- 8 data bits
- No parity
- One stop bit

Temperature Measurements

The following equation defines the relationship between the ADC reading and the ITS temperature:

$T = (25/128)*ADC - 77$

where,

T is the temperature in C

ADC represents the 10-bit compensated ADC register value

In this application the ADC data register value is processed using a compensation algorithm. See technical note *TN0040-Computing ADC output in Z8 Encore! XP® MCU* for the details on ADC compensation.

User can configure the interval at which the temperatures are calculated by defining the value of the macro SECONDS_COUNT in the header file timer.h. The range of temperature intended to be measured is decided by the values' of the macros BASE_TEMPERATURE and MAX_TEMPERATURE_UNITS defined in the temperature.h header file. See the *Demonstration* section for details about these macros. Temperature measurements are spaced at 1°C intervals. Temperatures measured by LM35 are stored at appropriate locations in an array in the timer interrupt service routine: that is; the temperature measured by LM35 for BASE_TEMPERATURE is stored at array location 0, that measured for BASE_TEMPERATURE+1 is stored at array location 1 and so on. Once the upper limit of temperature range is reached the array is stored into the NVDS as a look-up table. The starting address of NVDS for storing the look-up table elements is also user selectable through the `nvds_start_address` variable in the main.c file. It is the user's responsibility to traverse over the entire temperature range so that all the temperature readings of the Z8 Encore! XP®'s ITS have a corresponding value of the actual temperature in the look-up table. The API titled `lookup_temperature()` accepts the temperature measured by the ITS as the argument and returns the corresponding look-up table entry.

The user needs to run the demo application once in order to store the actual system temperature measurements (measured by LM35) in the NVDS area of the Z8 Encore! XP®'s Flash memory. Thereafter, the API titled `lookup_temperature()` can be used in the application to obtain the actual system temperature values using the ITS. The maximum temperature readings that can be stored are limited by the size of NVDS. The procedure to form the look-up table is detailed in the *Demonstration* Section.

Results

The following graph represents the temperature data recorded over the range of 25°C -30°C.

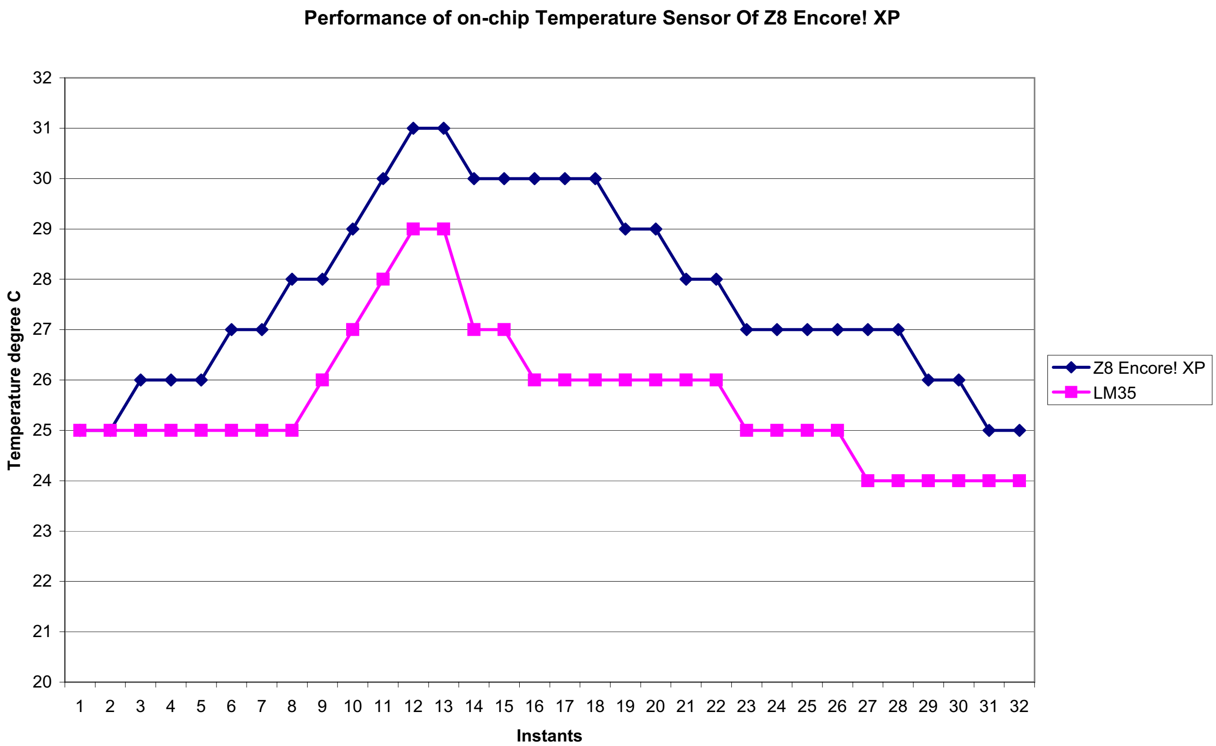

Figure 2. Temperature Data

In this temperature range, it is evident from the above plot that there is almost a constant offset between the temperature values measured using the ITS and the LM35. For example, from *Figure 2* the offset at 30 °C is -2 °C; that is; when the ITS reads 30 °C the LM35 reads 28 °C

In this range, based on implementation of a constant offset value, the temperature values measured using the ITS will closely replicate LM35's measured values. *Figure 3* is the plot of the data with the offset correction included.

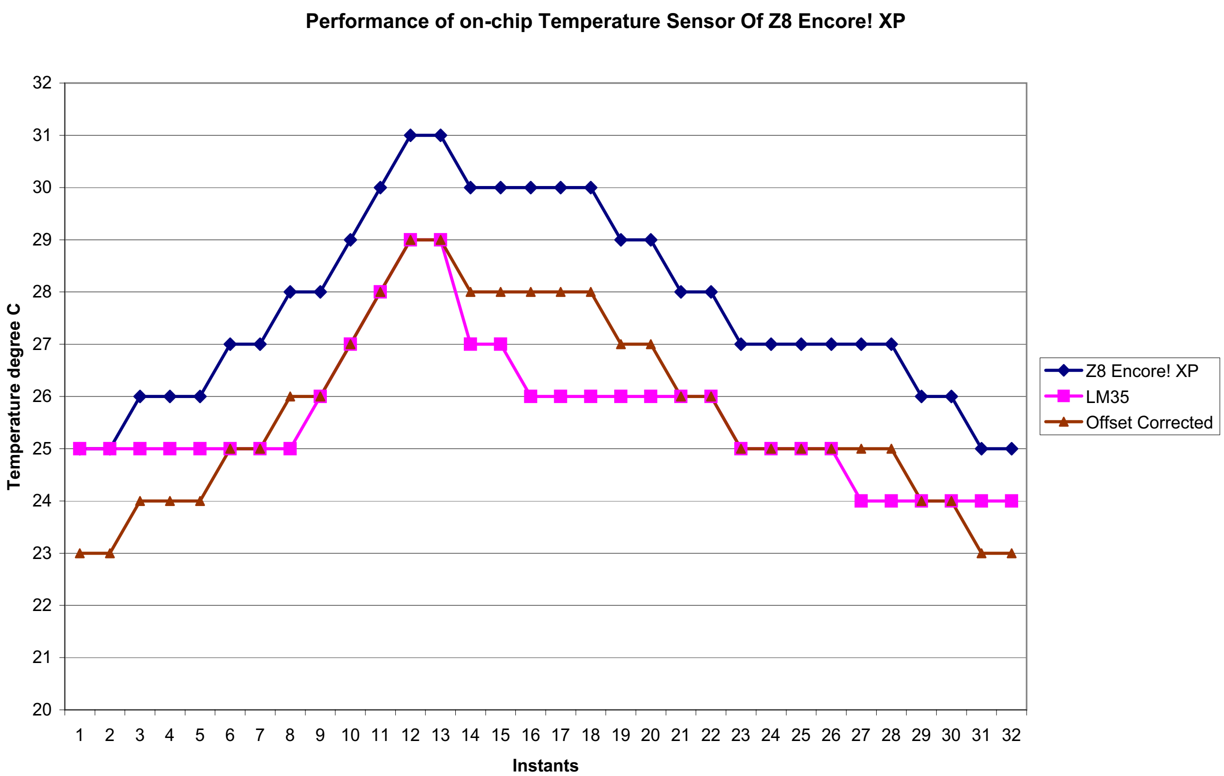

Figure 3. Temperature data with offset calibration

Demonstration

This section details the process of realizing a look-up table for the system temperature and storing it in the NVDS, with consequent correlation of the ITS measured temperature values to the system temperature, using the demo application:

1. Connect the external temperature sensor LM35 to the Z8 Encore! XP® Development board as shown in *Figure 4*. The lamp and fan operate on external 9V supply, while the LM35 operates on external 5V supply.
2. Launch ZDS II for Z8 Encore! XP® and open the project file available in the TN0042-SC01.zip file.
3. Define the BASE_TEMPERATURE and the maximum temperature of the intended temperature range in the defines.h file.

Example: If the intended range is 25 °C to 40 °C then BASE_TEMPERATURE would be 25 °C and MAX_TEMPERATURE_UNITS would be 15 (40-25).

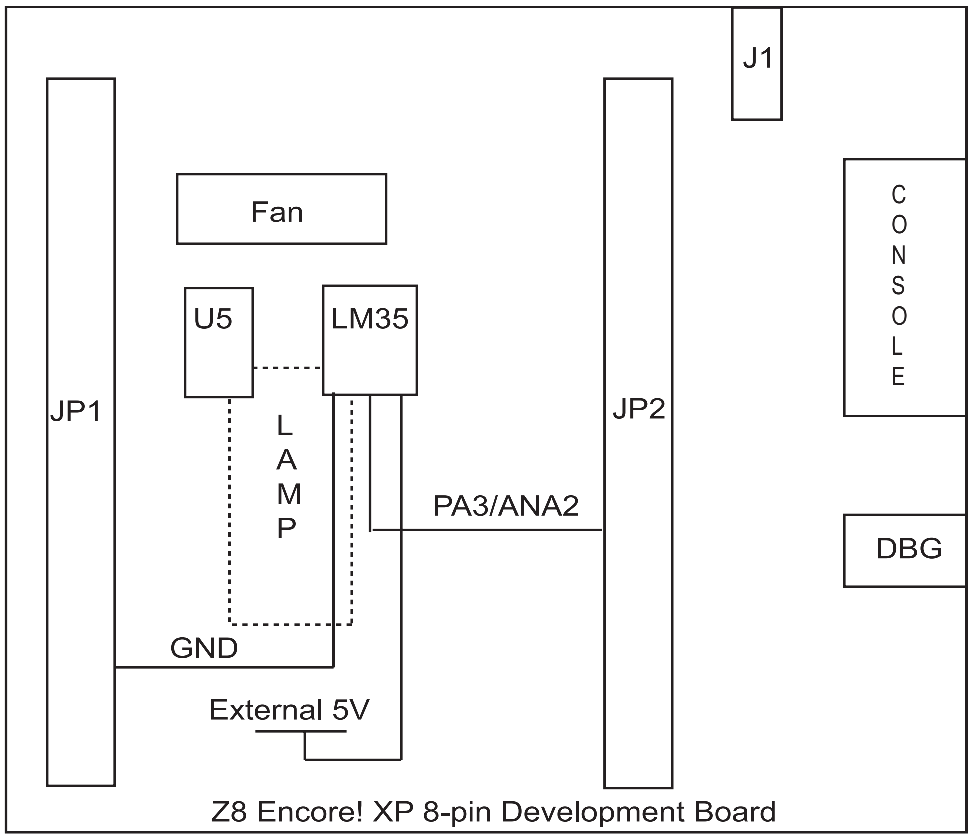

Figure 4. Z8 Encore! XP® 8-pin Development Board with LM35, Lamp and Fan Mounting

4. Define the starting address of NVDS for storing the look-up table elements through the variable `nvds_start_address` in the main.c file.
5. Launch HyperTerminal with following settings:
   - 38400 baud rate
   - 8 data bits
   - No parity
   - One stop bit
   - No flow Control
6. Build and download the code and then run the application.
7. Increase the temperature, covering the entire desired range.
8. The look-up table gets stored to the NVDS when the upper limit of the temperature range is recorded.

9. The look-up table is then displayed on the HyperTerminal along with the temperature measured by the ITS.

Once the look-up table is stored in the NVDS area, the need for an external reference temperature sensor is eliminated. User application needs the lookup_temperature() API to look up the corresponding system temperature.

Example: If the ITS measures temperature as 28 ^{o}C, then the actual temperature is obtained as

actual_temperature = `lookup_temperature(28)`

Summary

The on-chip temperature sensor of the Z8 Encore! XP® microcontroller provides unique advantages in temperature sensing and control applications. This technical note addresses a method for correlating the temperature measured by the on-chip temperature sensor with the system temperature. The user is required to initially run the application(TN0042-SC01.zip) to form the look-up table covering the intended temperature range. Following this process, the need for the external reference temperature sensor is eliminated. Also, by using this technique both the on-board and ambient temperatures can be measured.

References

1. PS0228 - Z8 Encore! XP® 4K Series Product Specification
2. TN0040 - Computing ADC Output in Z8 Encore! XP® MCUs Technical Note

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