Application Note

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

AN029401-1008

Z8 Encore! XP® Flash Microcontrollers

Introduction

Zilog's Z8 Encore! XP® is a high performance, 8-bit microcontroller unit (MCU), with a unique set of analog and digital peripherals. It also includes an integrated on-chip temperature sensor (ITS), that measures the surface temperature of the Silicon die. It is therefore required to account for the difference between the actual system temperature and ITS temperature, across the entire operating temperature range.

This Application Note discusses a technique to measure the system temperature using the ITS.

> **Note:** *The source code file associated with this application note,* `AN0294-SC01.zip` *is available for download at* www.zilog.com.

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

The ITS is based on proportional-to-absolute temperature (PTAT) topology, with its output directly coupled to the Integrated Analog-to-Digital Converter (ADC). 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. For more details refer to *Input buffer stage* in *Z8 Encore! XP® F082A Series Product Specification (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 the following factors:

- The thermal characteristics of the MCU 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 Application 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
- Create 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 section 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 heating and cooling, a lamp and a fan are provided. Figure 1 displays the hardware setup with lamp and fan mounted. Figure 4 on page 6 displays the block diagram of the hardware setup.

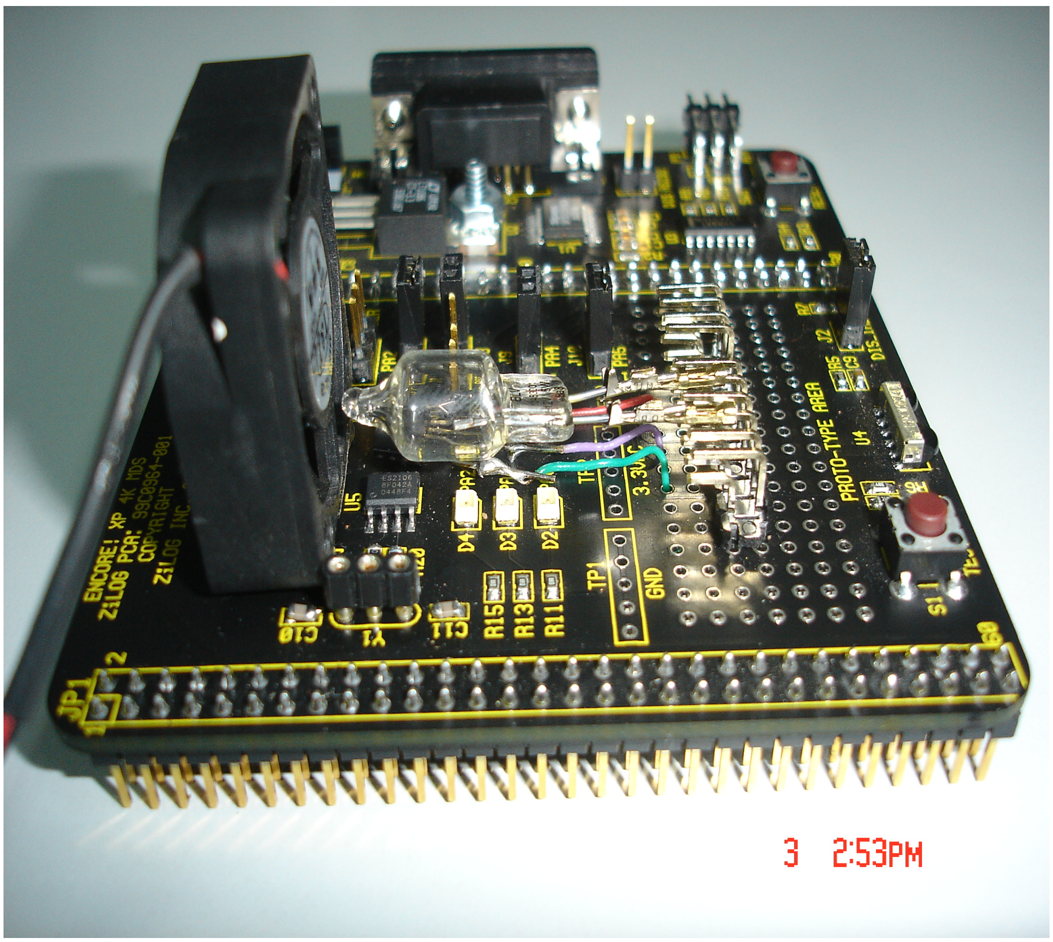

Figure 1. Hardware Setup with Lamp and Fan Mounted

Software Details

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:

- ADC
- 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

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 ^{O}C

ADC represents the 10-bit compensated ADC register value

In this application, the ADC data register value is processed using a compensation algorithm. For details on ADC compensation refer to *ADC Compensation in Z8 Encore! XP® MCUs Application Note (AN0284).*

You can define the interval at which the temperatures are calculated by setting 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. For details about these macros see Demonstration on page 5. Temperature measurements are spaced at $1^{O}C$ intervals. Temperatures measured by LM35 are stored at appropriate locations in an array in the timer interrupt service routine. 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 selectable through the `nvds_start_address` variable in the `main.c` file. It is your 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 `lookup_temperature()` API accepts the temperature measured by the ITS as the argument and returns the corresponding look-up table entry.

You need 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, `lookup_temperature()` API 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. For details on the procedure to create the look-up table see Demonstration on page 5.

Results

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

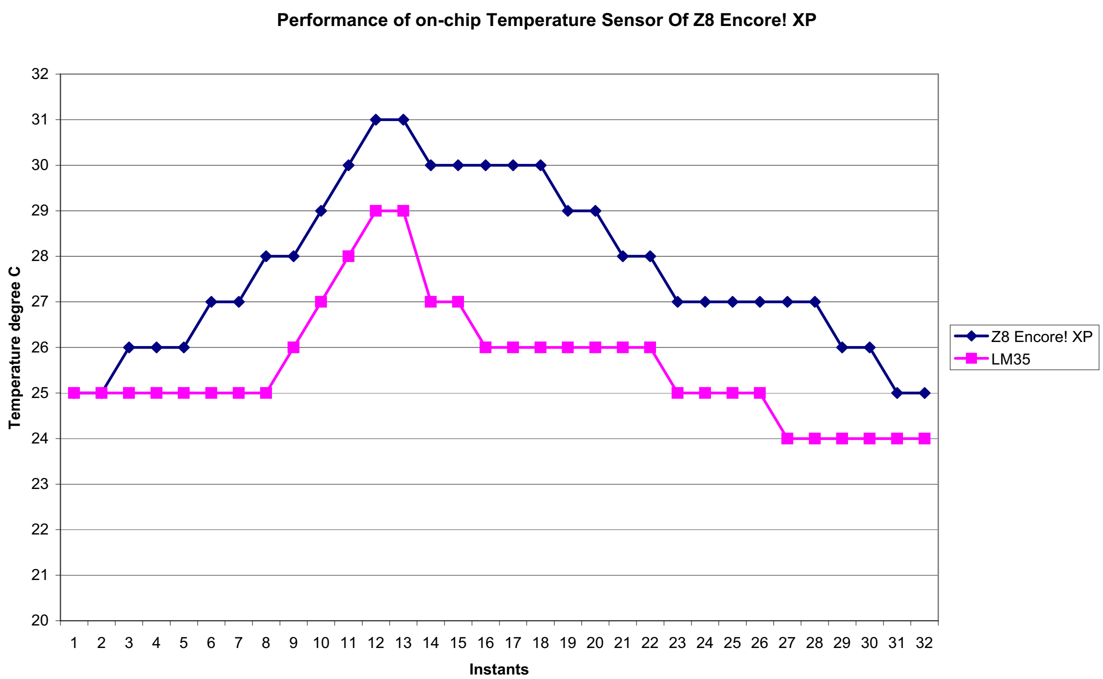

Figure 2. Temperature Data

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 displays the plot of the data with the offset correction included.

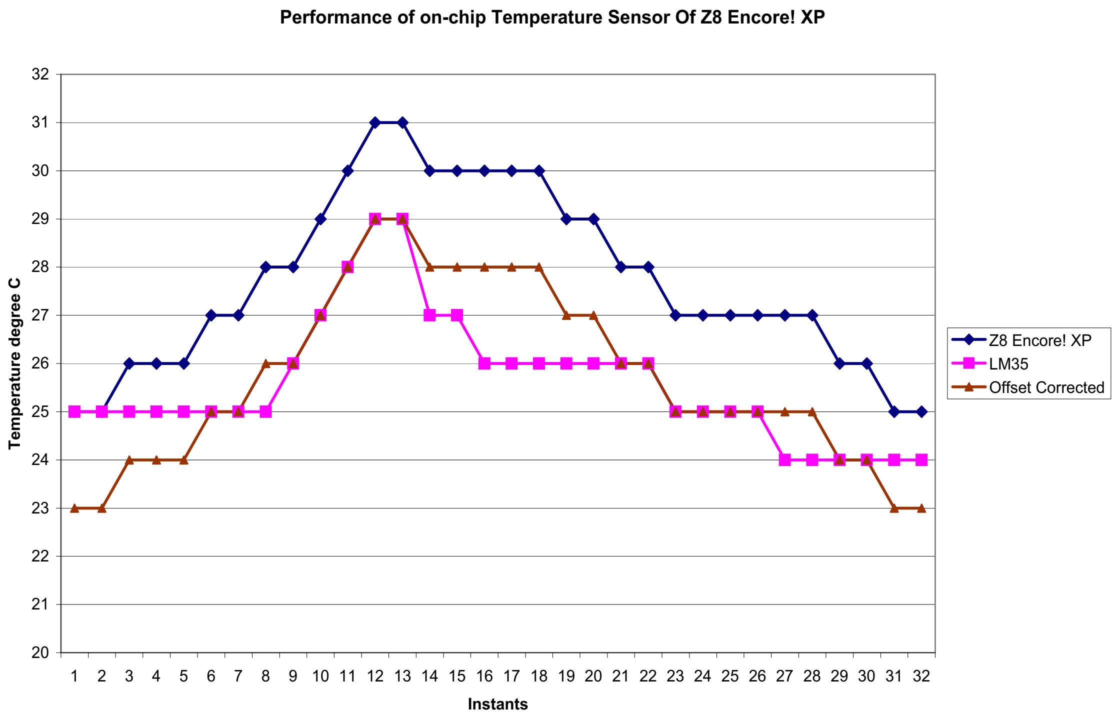

Figure 3. Temperature Data with Offset Calibration

Demonstration

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

1. Connect the external temperature sensor LM35 to the Z8 Encore! XP® Development board, as displayed in Figure 4 on page 6. The lamp and fan operate on external 9 V supply; while the LM35 operates on external 5 V supply.
2. Launch ZDS II for Z8 Encore! XP® and open the project file available in the `AN0294-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 °C (40 °C to 25 °C).

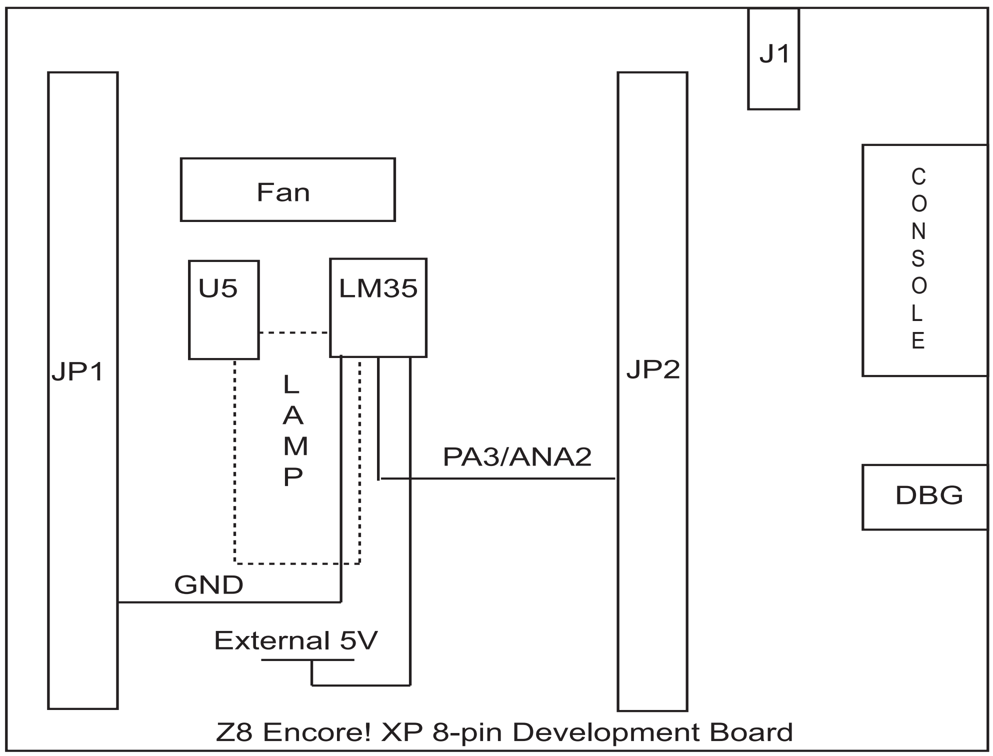

Figure 4. Z8 Encore! XP® 8-Pin Development Board with LM35, Lamp, and Fan Mounting

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® MCU provides unique advantages in temperature sensing and control applications. This Application Note addresses a method for correlating the temperature measured by the on-chip temperature sensor with the system temperature. You are required to initially run the application `AN0294-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, the on-board and ambient temperatures can be measured.

References

The documents associated with Z8 Encore! XP MCU available on www.zilog.com are provided below:

- Z8 Encore! XP® F082A Series Product Specification (PS0228)
- ADC Compensation in Z8 Encore! XP MCUs Application Note (AN0284)

Warning: DO NOT USE IN LIFE SUPPORT

LIFE SUPPORT POLICY

ZILOG'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS PRIOR WRITTEN APPROVAL OF THE PRESIDENT AND GENERAL COUNSEL OF ZILOG CORPORATION.

As used herein

Life support devices or systems are devices which (a) are intended for surgical implant into the body, or (b) support or sustain life and whose failure to perform when properly used in accordance with instructions for use provided in the labeling can be reasonably expected to result in a significant injury to the user. A critical component is any component in a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system or to affect its safety or effectiveness.

Document Disclaimer