

MSP430

This application report describes the hardware and software interface between the Texas Instruments MSP430F413 16-bit micro-controller and TMP100 digital temperature sensor, implementing an ultra-low power temperature measurement system (Figure 1) capable of operation from a single 3-V battery for over 10 years. The following sections demonstrate how to interface the two devices in hardware as well as implementation of the communication protocol via a two-wire I2C bus in software. While demonstrated here specifically for the TMP100, the software interface described can be applied to any MSP430 micro-controller and I2C-compatible slave peripheral device.

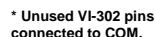


Figure 1. MSP430F413 and TMP100 Schematic

Introduction

Many systems across a vast array of applications require some implementation of temperature sensing and measurement. Often, these measurements must be performed remotely requiring battery-powered implementations and consequently, low power consumptions for increased system life. A host of measurement solutions exist including the use of discrete transistors, thermistors or thermocouples and system-on-a-chip (SoC) integrated circuits. The TMP100 represents the latter option and when combined with the ultra-low power MSP430 micro-controller as shown in Figure 1, becomes a full function temperature measurement system capable of achieving an operational life in excess of 10 years from a single coin-cell battery.

Theory of Operation

The MSP430-TMP100 measurement system is designed to operate on as little power as possible while continuously displaying real-time temperature of the TMP100 sensor's environment. When operated in one-shot mode, the TMP100 goes into shutdown mode after each conversion is completed and consumes a typical current of 0.1uA between conversions. Coupled with the energy efficient stand-by modes of the MSP430, which consumes a typical 0.9uA in low power stand-by (LPM3), along with a 3.5 digit static LCD, these two devices create a complete temperature monitor and display system capable of 0.5°C resolution and consumes less than 2.45uA total average current. The current profile of the system is shown in Figure 2.

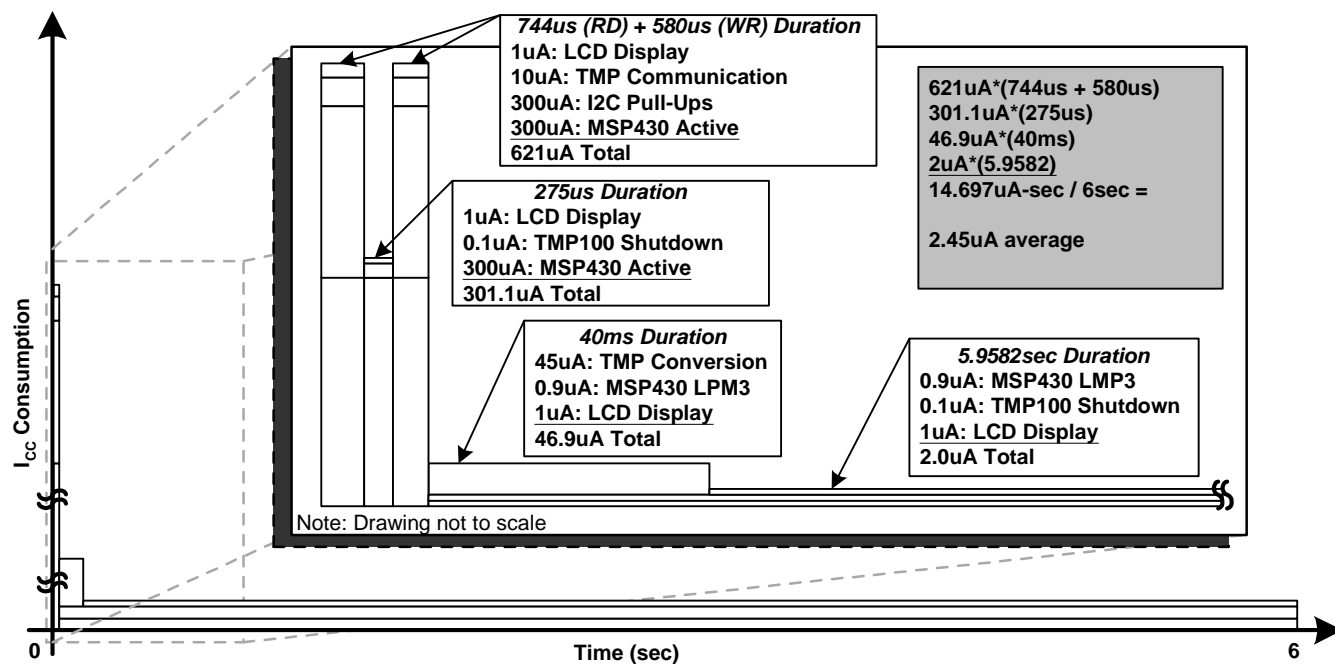


Figure 2. Current Consumption Profile

Power for the system is supplied by a 3-V CR-2032 lithium coin-cell battery and is rated at providing a minimum of 220-mA hours of operation. With the total system average current consumption of 2.45 μ A from Figure 2, a complete measurement and display platform capable of continuous operation in excess of 10 years from a single battery becomes a reality. This calculation is given in Equation 1.

$$1 \quad 220\text{mAh} / 2.45\mu\text{A} = 89,796 \text{ hours} = 10.25 \text{ years}$$

In order to achieve such a low average current, care must be taken to develop the MSP430 software with a minimum number of active clock cycles in mind. The fast 6- μ s wake-up time of the MSP430 DCO and CPU from low-power sleep mode along with the one-shot operation of the TMP100 provides the flexibility to create such a software flow. Figure 3 details the software flow of the MSP430 through a complete conversion and display cycle.

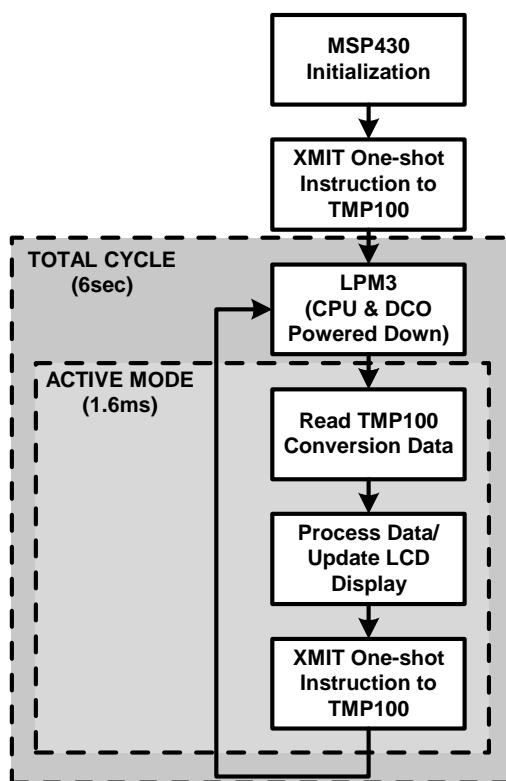


Figure 3. MSP430F413/TMP100 Software Flow

By minimizing the active time of the MSP430 to 1.6 ms per conversion cycle, the total system power consumption can be controlled. The fast wake-up of the CPU and DCO from LPM3 allow the MSP430 to perform the required tasks and re-enter low-power mode as quickly as possible. The CPU then awaits the next timer-generated interrupt and repeats the cycle. Further description of the system operation is given in the following sections as well as the provided MSP430 assembly code. Note that additional code optimizations exist such as straight-line techniques to reduce subroutine calls. For clarity of the software flow, the subroutines are broken out from the main loop. In addition to the software flow as shown in Figure 2, additional routines can easily be added such as multiple peripheral support or Celsius-to-Fahrenheit conversion.

Hardware Interface

The system interface between the MSP430 and TMP100 as shown in Figure 1 requires few discrete components or connections. System power is provided via the 3-V lithium battery and recommended 0.1-uF decoupling capacitor. A 68-kohm pull-up resistor is recommended on the reset (RST) input and a 32.768-kHz watch crystal provides the sleep-mode clock source for the MSP430 during CPU power-down. Two additional 10-kohm pull-up resistors are required on the SCL (clock input) and SDA (data I/O) of the TMP100 as required by the Phillips I2C specification.

Temperature readout is provided using a 3.5 digit static liquid crystal display (LCD). The built-in LCD driver on the MSP430F413 supports up to 24 segment drive outputs and 4 common outputs giving a total display support of 96 possible segments. The implementation shown uses a static LCD, available from Varitonix, using a single common line and a total of 24 segment drive outputs. Although this example uses the MSP430F413, the same segment implementation can be applied to any of the 4xx series MSP430 micro-controllers.

System Operation

The I2C communication to the TMP100 is provided entirely in software and uses two general-purpose I/O pins of the MSP430. The TMP100 addressing configuration supports up to 8 individual devices on a single I2C bus via two address pins. In this application, these two inputs are tied to ground setting the TMP100's 7-bit address to 1001000.

All access to the TMP100 first requires the proper address (7-bit + WR) to be sent followed by the desired 8-bit pointer address. The pointer address specifies one of three registers to be updated by the host controller. In this application, the TMP100 configuration register is updated each time through the main software loop in order to initiate a new conversion using one-shot mode. The same methods can also be used to write to the remaining registers of the sensor.

The communication required to read the temperature conversion data register of the TMP100 begins the same as for the write cycle instructions. First, device address and pointer data must be sent to the TMP100. Again, the 8-bit pointer specifies the desired register to be read by the MSP430. This is followed by a repeated start condition and re-sending of the TMP100 device address. During this second device address transmission, the RD/WR bit is set high indicating a read command of the register as specified by the previously sent pointer address.

Reading the temperature conversion data from the TMP100 requires 16-bits of data to be read by the host. Two 8-bit transfers from the TMP100, sent MSB first, accomplish this. The conversion result is dependent on the desired resolution of the conversion, which can be configured from 9 to 12 bits in 1-bit increments. The power-up default is a 9-bit conversion result providing a 0.5°C/LSB resolution. This is the configuration used for the implementation described within this application report. The trailing LSBs transferred by the TMP100 are read as zero and can be ignored.

For general-purpose temperature display such as in thermostat applications, a temperature resolution of 1°C is often adequate. In such an application, the second byte (8 LSBs) of the result can be ignored as the required 1°C resolution is contained in the first 8 data bits. The second byte can be read out and handled by the MSP430 in software or simply not read at all. This is accomplished by simply not acknowledging transfer of the first byte of data. While this method returns an 8-bit result, it will not allow for continuous temperature conversion into the Fahrenheit scale. However, reading only the first byte does slightly reduce the active time of both the MSP430 and TMP100 reducing the total system current and is adequate for displaying Centigrade temperature with 1°C resolution.

After acquiring the conversion result from the TMP100, the MSP430 performs the necessary data handling in order to display the calculated temperature to the LCD. This step involves handling of the MSB for negative temperature values, binary-to-BCD conversion, and updating of the necessary LCD registers driving the display.

Once the data is properly handled and the display is updated, the MSP430 returns to low power mode (LPM3), consuming 2.0 uA of total supply current (typical). Using a defined interrupt duration of 6 seconds, the CPU wakes up and begins the process again. For the purposes of this report, the Basic Timer is used to generate the interrupt waking up the MSP430. The software example provided uses the Basic Timer module set for a 2 second interval bringing the typical average current to 3.55 uA for an estimated battery life of 7.5 years. Multiple methods can be used to increase the interrupt frequency in order to increase battery life including the addition of multiple LMP3 calls or use of Timer A. In any case, the interrupt frequency is fully programmable and can be adjusted to meet the requirements of a given application.

Summary

As stated earlier, temperature measurement tasks can be accomplished in a number of different ways. The manner in which any task is completed is almost always a function of the physical constraints imposed on the system. With portability, and consequently, low power consumption a frequent and demanding parameter, the MSP430 and TMP100 offer an effective and efficient solution to this common task.

Using the hardware design and software methods described here, the ultra-low power combination of the MSP430 and TMP100 provide a complete temperature measurement and display system solution. Simple, small and low-cost, this system not only completes the temperature measurement task, but does so in a manner providing continuous operation in excess of 10 years from a single 3-V battery.

References

MSP430F413 Device Datasheet, Literature Number SLAS340C

MSP430 4xx User's Guide, Literature Number SLAU056B

TMP100 Datasheet, Literature Number SBOS231B

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VI-302 LCD Datasheet, Varitronix International Ltd

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Mailing Address:

Texas Instruments
Post Office Box 655303
Dallas, Texas 75265