AN940

Interfacing the TC72 SPI™ Digital Temperature Sensor to a PICmicro® Microcontroller

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INTRODUCTION

The TC72 is a digital CMOS silicon temperature sensor that provides an accurate digital temperature measurement. Data is converted from an internal diode temperature-sensing element to a digital format that can be directly interfaced to a microcontroller. The TC72 sensor offers many system-level advantages, including the integration of the sensor and signal-conditioning circuitry in a small integrated circuit (IC) package. The TC72 also has an One-shot Conversion mode, which performs a single temperature measurement and then goes into power-saving Shutdown mode. The One-shot Conversion mode makes this sensor a good choice for power-critical, portable applications.

The TC72 digital temperature sensor is especially suited for embedded systems due to its SPI interface, which serves to provide a straightforward and easy way to interface to a microcontroller. This application note will discuss system integration, firmware implementation and PCB layout techniques for using the TC72 in an embedded system.

The techniques for integrating the TC72 into an embedded systems environment will be demonstrated by using the PICkit™ 1 FLASH Starter Kit and a TC72 PICtail™ daughter board. The TC72 PICtail daughter board plugs into the PICkit 1 FLASH Starter Kit expansion header J3, as shown in Figure 1. The TC72 demonstration is designed to measure and display temperature in binary coded decimal (BCD) with the PICkit 1 LEDs.

Gerber files for the printed circuit board (PCB), source code and hex file to program a PIC16F676 are included in the companion zip file, 00940.zip.

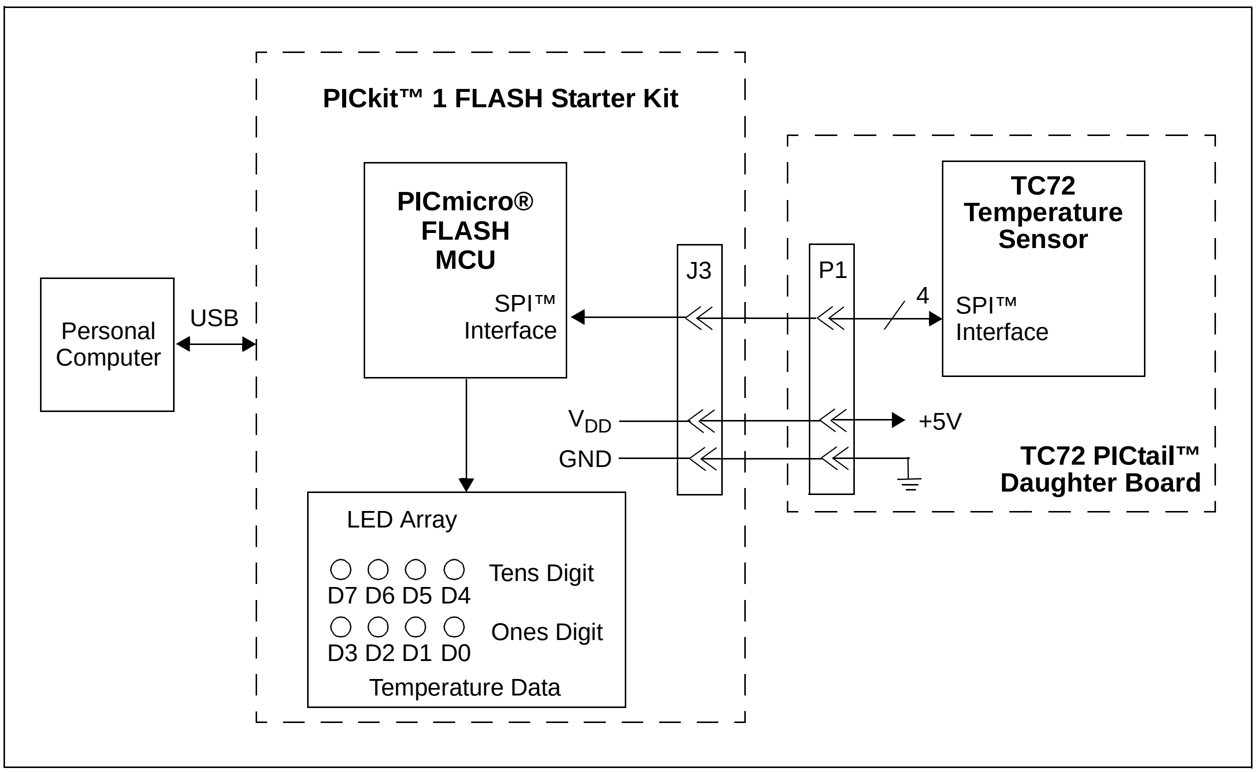

FIGURE 1: *Block Diagram of the TC72 Digital Temperature Sensor Demonstration.*

TC72 FUNCTIONAL DESCRIPTION

The TC72 consists of an internal diode temperature sensor, a 10-bit sigma delta analog-to-digital converter (ADC), digital registers and a SPI communication port. Figure 2 provides a simplified block diagram of the TC72. A schematic of the TC72 to PICmicro® MCU interface is shown in Figure 3.

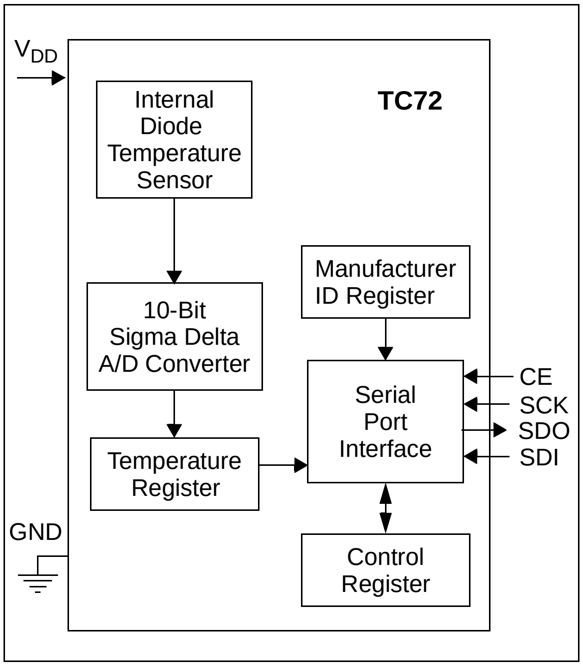

FIGURE 2: *TC72 Block Diagram.*

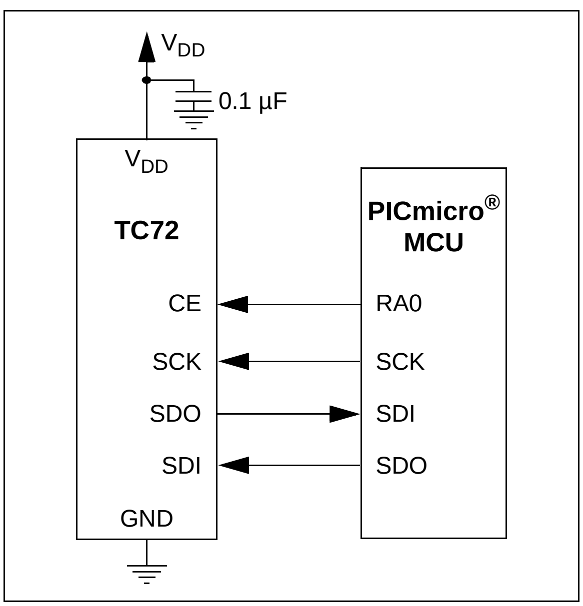

FIGURE 3: *TC72 to PICmicro® MCU Interface.*

Temperature Data Format

Temperature data is represented by a 10-bit two's complement word with a resolution of 0.25°C per bit. The temperature data is stored in the temperature registers in a two's complement format, as shown in Table 1.

Example:

Temperature	=	41.5°C
MSB Temperature Register	=	`00101001b`
	=	$2^5 + 2^3 + 2^0$
	=	32 + 8 + 1 = 41
LSB Temperature Register	=	`10000000b` = 2^{-1}
	=	0.5

TABLE 1: TEMPERATURE REGISTER

D7	D6	D5	D4	D3	D2	D1	D0	Address/ Register
Sign	2^6	2^5	2^4	2^3	2^3	2^1	2^0	02H Temp. MSB
2^{-1}	2^{-2}	0	0	0	0	0	0	01H Temp. LSB

Power-Up And Power-Down

The TC72 is in the low-power consumption Shutdown mode at power-up. The Continuous Temperature Conversion mode is selected by performing a write operation to the control register.

Serial Bus Interface

The serial interface consists of the Chip Enable (CE), Serial Clock (SCK), Serial Data Input (SDI) and Serial Data Output (SDO) signals. The serial interface is compatible with the SPI bus specification.

The CE input is used to select the TC72 when multiple devices are connected to the serial clock and data lines. The CE is active-high, and data is written to (or read from) the device when CE is equal to a logic-high voltage. The SCK input is disabled when CE is low. The rising edge of the CE line initiates a read or write operation, while the falling edge of CE completes a read or write operation.

The SCK input is provided by the external microcontroller and is used to synchronize the data on the SDI and SDO lines. The SDI input writes data into the TC72's control register, while the SDO outputs the temperature data from the temperature register and the status of the shutdown bit of the control register. The TC72 has the capability to function with either an active-high or active-low SCK input. The software developed in this demo uses an active-high SCK signal (CP=`0`). Each data bit is transferred at each clock pulse, with the data bits being clocked in groups of eight bits, as shown in Figure 4.

The address byte is transferred first, followed by the data. A7, the MSb of the address, determines whether a read or write operation will occur. If A7 = ‘0’, one or more read cycles will occur. Otherwise, if A7 = ‘1’, one or more write cycles will occur.

Data can be transferred either in a single byte or a multi-byte packet, as shown in Figure 4. In the 3-byte packet, the data sequence consists of the MSb and LSb temperature data, followed by the control register data. The multi-byte read feature is initiated by writing the highest address of the desired packet to registers. The TC72 will automatically send the register addressed and all of the lower address registers, as long as the Chip Enable pin is held active.

Read Operation

The temperature and control register data is outputted from the TC72 using the CE, SCK and SDO lines. Figure 4 shows a timing diagram of the read operation. Communication is initiated by the chip enable (CE) going high. The SDO line remains at the voltage level of the LSb bit that is outputted and goes to the tri-state level when the CE line goes to a logic-low level.

Write Operation

Data is clocked into the control register in order to enable the TC72’s power-saving Shutdown mode. The write operation is shown in Figure 4 and is accomplished using the CE, SCK and SDI lines.

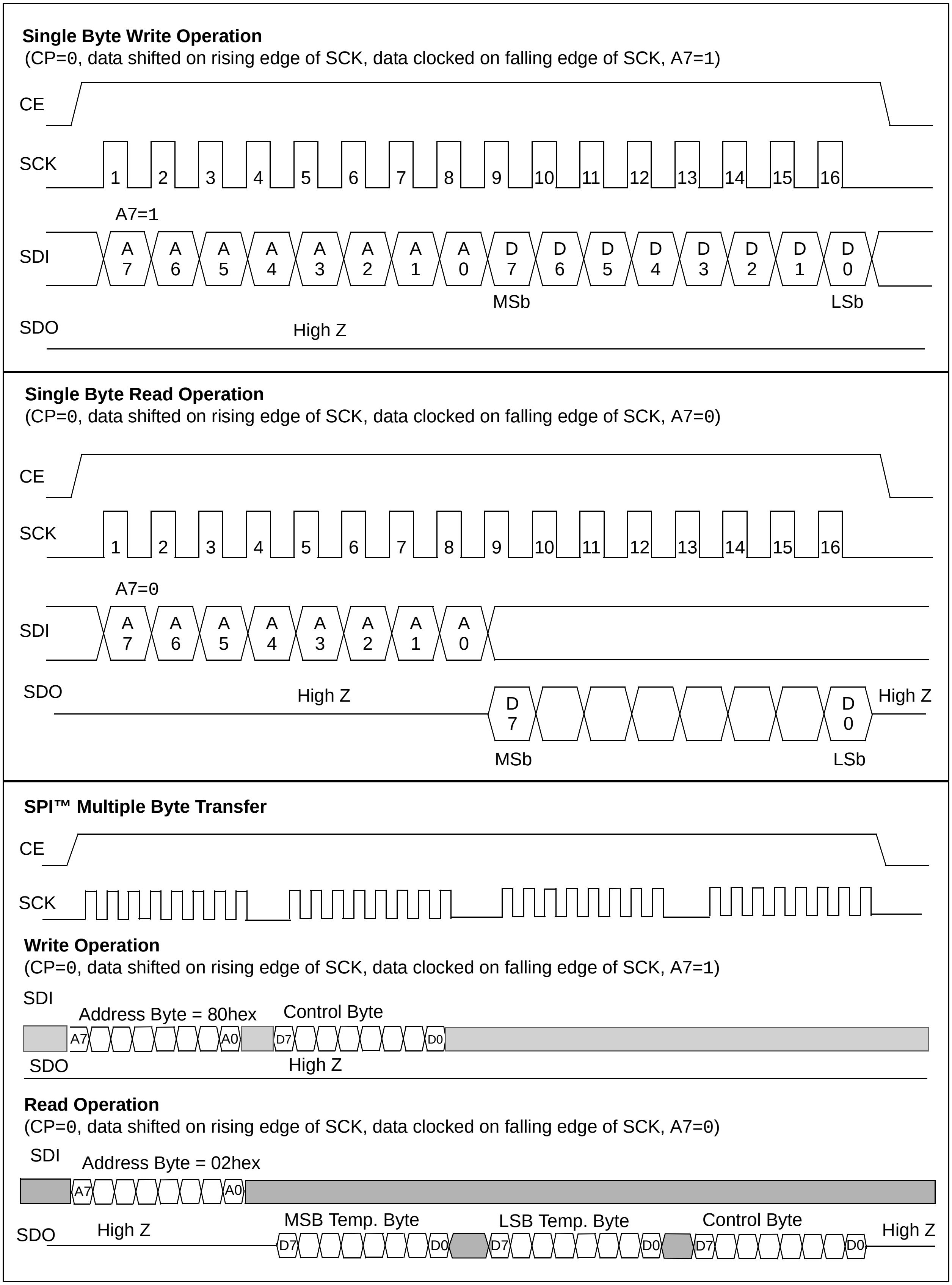

FIGURE 4: *Serial Interface Timing Diagrams (CP=0).*

Internal Register Structure

The TC72 registers are listed in Table 2.

TABLE 2: REGISTERS FOR TC72

Register	Read Address	Write Address	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on POR/BOR
Control	00hex	80hex	0	0	0	One-shot (OS)	0	1	0	Shutdown (SHDN)	05hex
LSB Temperature	01hex	N/A	T1	T0	0	0	0	0	0	0	00hex
MSB Temperature	02hex	N/A	T9	T8	T7	T6	T5	T4	T3	T2	00hex
Manufacturer ID	03hex	N/A	0	1	0	1	0	1	0	0	54hex

Control Register

The control register is both a read and write register that is used to select either the Shutdown, Continuous Temperature Conversion or One-shot Conversion mode. The Continuous Temperature Conversion mode selection logic is shown in Table 3.

The Continuous Temperature Conversion mode is selected by writing a ‘0’ to the SHDN bit of the control register. The Continuous Temperature Conversion mode measures the temperature approximately every 150 ms and stores the data in the temperature registers. The automatic temperature-sampling operation is repeated indefinitely until the TC72 is placed in Shutdown mode by a write operation to the control register. The TC72 will remain in the Shutdown mode until the shutdown bit in the control register is reset.

One-shot Conversion mode performs a single temperature measurement and returns to the power-saving Shutdown mode. This mode is especially useful for low-power applications. One-shot Conversion mode is selected by writing a ‘1’ into bit 4 of the control register. Upon completion of the temperature conversion, the One-shot bit (OS) is reset to ‘0’ (i.e., “off”). The user must set the One-shot bit to ‘1’ to initiate another temperature conversion.

Shutdown mode can be used to minimize the power consumption of the TC72 when active temperature monitoring is not required. Shutdown mode disables the temperature-conversion circuitry. However, the serial I/O communication port remains active. The shutdown (SHDN) bit is stored in bit 0 of the control register. If SHDN is equal to ‘1’, the TC72 will go into the power-saving Shutdown mode.

Temperature Register

The temperature register is a read-only and contains a 10-bit two’s complement representation of the temperature measurement. Bit 0 through bit 5 of the LSB temperature register are always set to a logic ‘0’.

Manufacturer ID Register

The manufacturer identification (ID) register is a read-only register used to identify the temperature sensor as a Microchip component.

TABLE 3: CONTROL REGISTER TEMPERATURE CONVERSION MODE SELECTION

Operational Mode	One-shot (OS) Bit 4	Shutdown (SHDN) Bit 0
Continuous Temperature Conversion	0	0
Shutdown	0	1
Continuous Temperature Conversion (One-shot Command is ignored if SHDN = ‘0’)	1	0
One-shot	1	1

APPLICATIONS INFORMATION

The TC72 does not require any additional components in order to measure temperature, though it is recommended that a decoupling capacitor of 0.1 µF to 1 µF be provided between the V_{DD} and GND pins. A high-frequency ceramic capacitor should be used. The capacitor should be located as close as possible to the IC power pins in order to provide effective noise protection to the sensor.

The TC72 measures temperature by monitoring the voltage of a diode located on the IC die. The IC pins of the TC72 provide a low-impedance thermal path between the die and the PCB, allowing the TC72 to effectively monitor the temperature of the PCB board. The thermal path between the ambient air is not as efficient because the plastic IC housing package functions as a thermal insulator. Thus the ambient air temperature (assuming that a large temperature gradient exists between the air and PCB) has only a small effect on the temperature measured by the TC72.

A potential for self-heating errors can exist if the TC72 SPI interface communication lines are heavily loaded. Typically, the self-heating error is negligible because of the relatively small current consumption of the TC72. A temperature accuracy error will result from self-heating if the SPI communication pins sink/source the maximum current specified for the TC72. Thus to maximize the temperature accuracy, the output loading of the SPI signals should be minimized.

TC72 PICtail™ DAUGHTER BOARD

The TC72 PICtail daughter board is plugged to the PICkit 1 FLASH Starter kit via expansion header J3. Figure 5 shows the TC72 PICtail daughter board plugged into the PICkit 1 FLASH Starter Kit. For more information on the PICkit 1 FLASH Starter Kit, refer to the “PICkit™ 1 FLASH Starter Kit User’s Guide”, DS40051.

The TC72 PICtail daughter board consists of a TC72 temperature sensor and a bypass capacitor. The bypass capacitor C_1 is used to provide noise immunity on the +5 VDC power supply. Figure 6 shows a schematic of the board, while Figure 7 provides a layout drawing of the PCB.

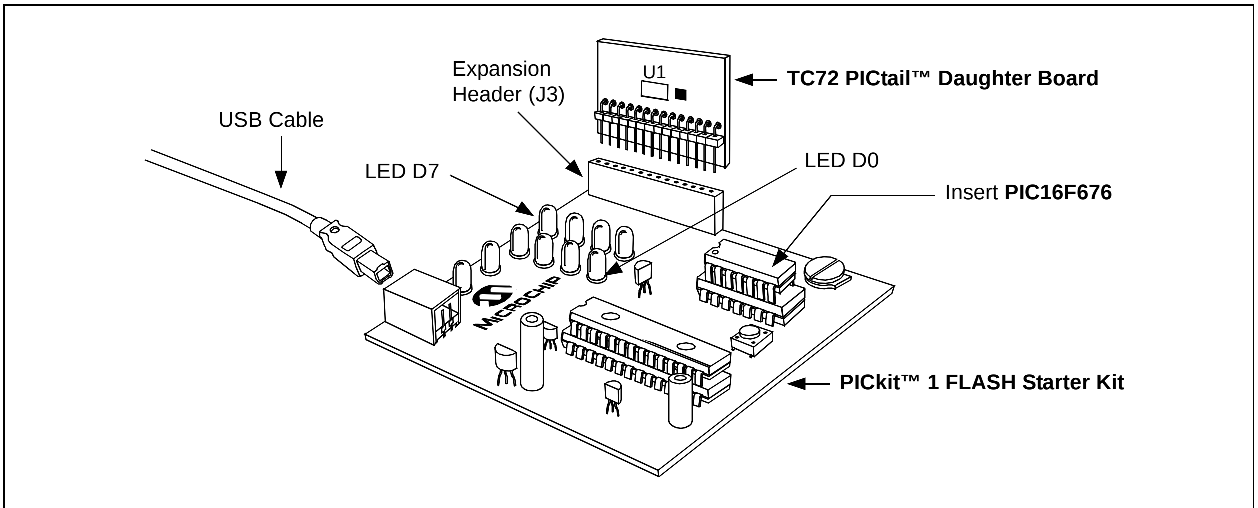

FIGURE 5: *TC72 PICtail™ Daughter Board and PICkit™ 1 FLASH Starter Kit.*

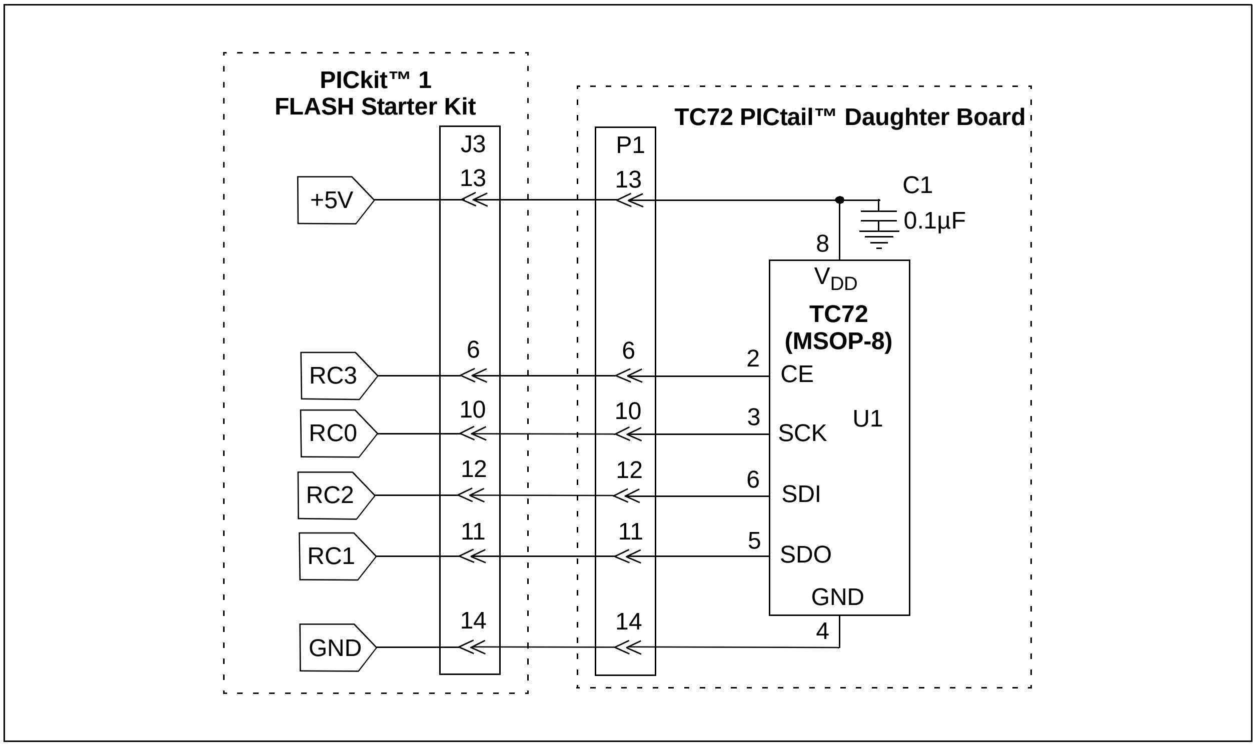

FIGURE 6: *TC72 PICtail™ Daughter Board Schematic.*

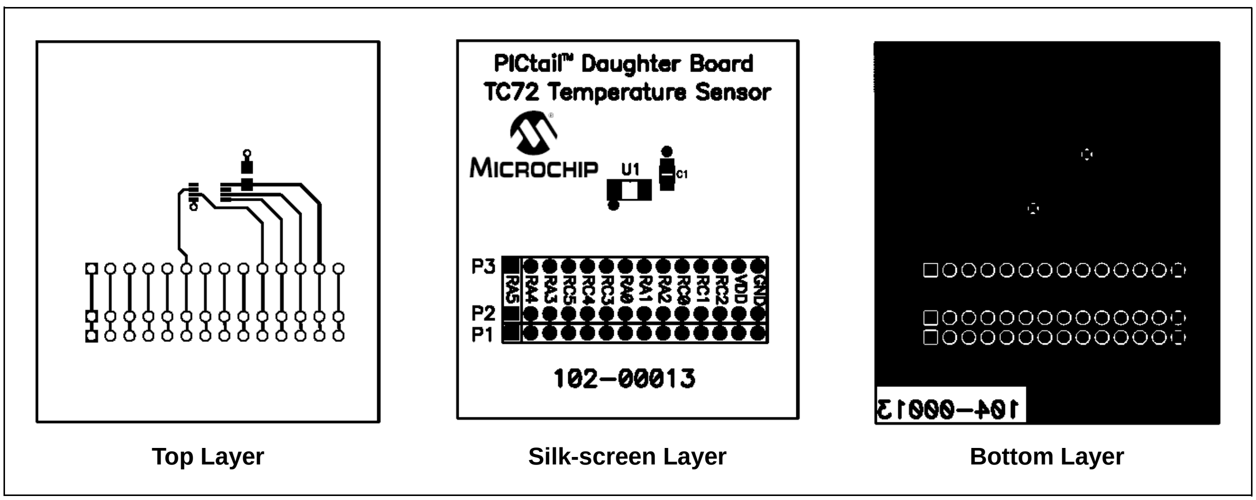

FIGURE 7: *TC72 PICtail™ Daughter Board PCB Layout.*

TC72 Interface Software

A flow diagram for the PICkit 1 software is given in Figure 8A. The TC72 thermal sensor is read by the PICmicro MCU. The value read from the TC72 is right-adjusted in the register as a 10-bit temperature value in degrees Celsius. The temperature value is tested for a negative temperature reading by checking the status of Bit 7 of the MSB of the temperature register. If the value is negative ($T < 0$°C), the state is saved in a flag bit and the value is two's complemented.

The TC72's temperature register provides a temperature measurement in Celsius. An option in the software is provided to display the temperature in either Fahrenheit or Celsius by testing the status of the PICkit 1 SW_1 push button switch. If SW_1 is not pressed, the temperature value is converted to Fahrenheit. Otherwise, if the push button is pressed, the conversion routine is skipped and the data is displayed in Celsius. Finally, the temperature value is loaded into the LEDREG variable to be displayed on the LEDs by the DISPLAY subroutine.

Fully-documented source code and a hex file ready to program into a PIC16F676 is available in the companion zip file, 00940.zip.

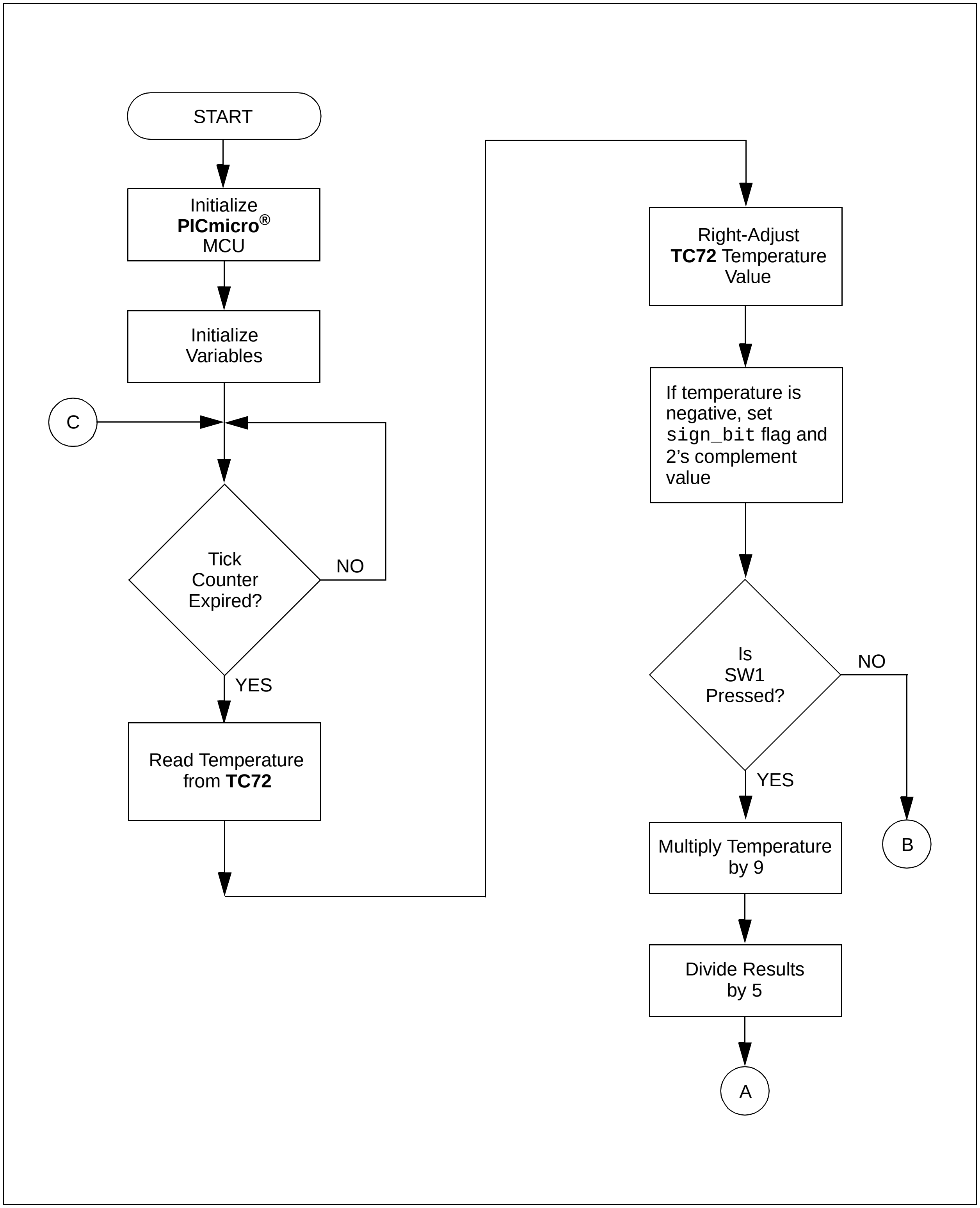

FIGURE 8A: *TC72 PICtail™ Program Flow Diagram.*

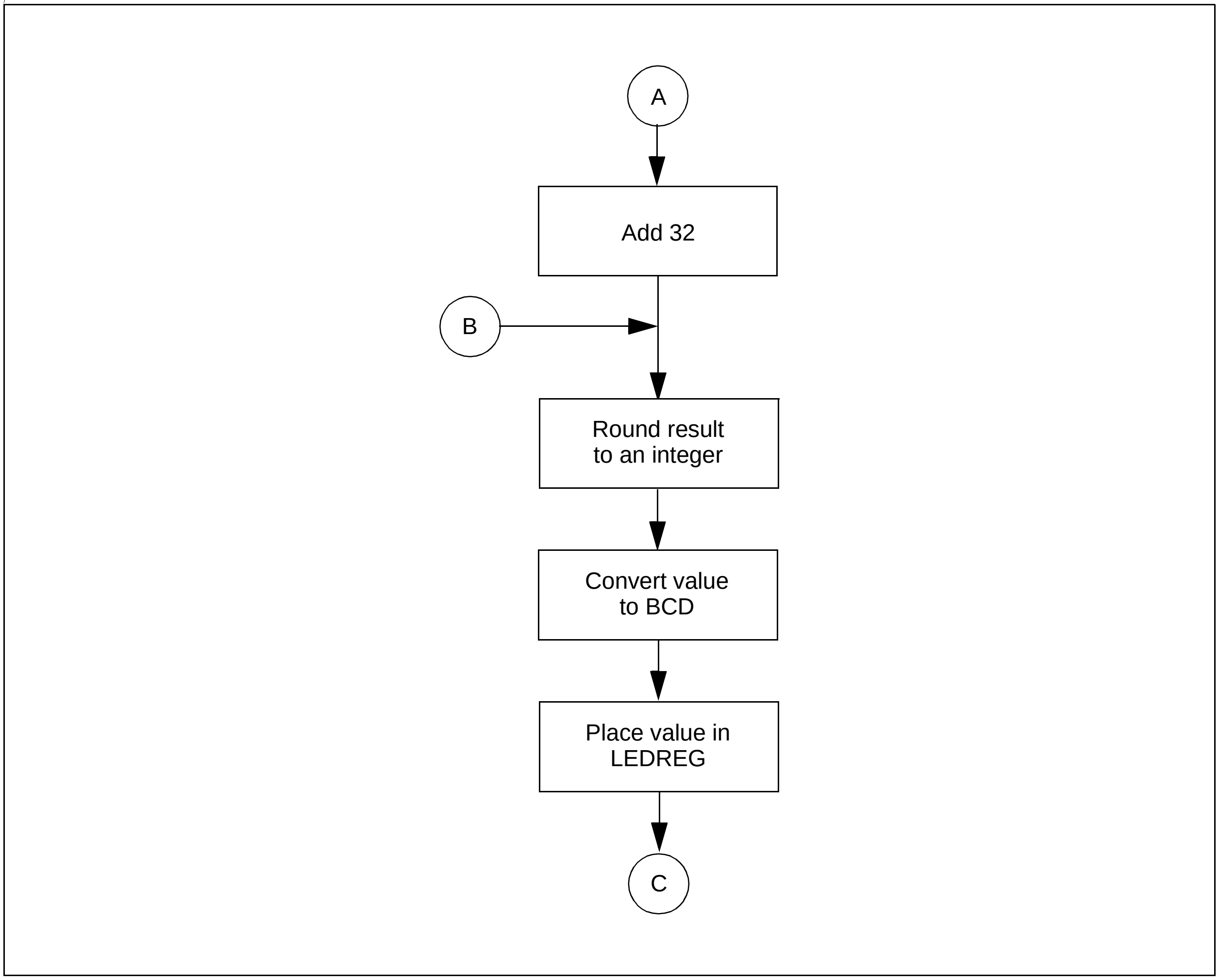

FIGURE 8B: *TC72 PICtail™ Flow Diagram (Cont.)*

CONCLUSION

The TC72 digital temperature sensor PICtail™ daughter board demonstrates the ease of integrating a digital output IC temperature sensor to a PICmicro® microcontroller. The TC72 is a CMOS silicon digital temperature sensor that provides many system level advantages, including the integration of the sensor and the signal conditioning circuitry in a small IC package. This provides for easy system integration and minimizes the required PCB space, component count and design time.

BIBLIOGRAPHY

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2. PICkit™ 1 FLASH Starter Kit User’s Guide, DS40051, Microchip Technology Inc.
3. TC72 Data Sheet, “Digital Temperature Sensor with SPI™ Interface”, DS21743, Microchip Technology Inc.

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