**INTRODUCTION**

Silicon temperature sensors offer an easy-to-use alternative to traditional temperature sensors, such as thermocouple, thermistors and RTDs. The TC77 SPI™ Thermal Silicon Sensor is especially suited for embedded systems, due to its SPI interface. This serves to provide a straight-forward and easy way to interface to a microcontroller. This application note will discuss system integration, firmware implementation and PCB layout techniques for the TC77 in an embedded system.

Microchip has developed a hardware platform called the PICkit™ 1 FLASH Starter Kit, allowing the designer to quickly begin their system development. Additionally, Microchip has developed a TC77 PICtail™ Daughter Board that interfaces directly to the PICkit 1 FLASH Starter Kit. These two boards are used to demonstrate the techniques for integrating the TC77 into an embedded systems environment. Both of these development boards are available on the Microchip web site at www.microchip.com.

The TC77 SPI™ Thermal Sensor PICtail™ daughter board is designed to demonstrate the ease of integrating a digital silicon IC temperature sensor to a PICmicro® microcontroller unit (MCU). The TC77 PICtail daughter board plugs into the PICkit 1 FLASH Starter Kit expansion header J3, as shown in Figure 1. The PICkit 1 FLASH Starter Kit is a low-cost development kit with an easy-to-use interface for programming Microchip's 8-pin and 14-pin FLASH family of microcontrollers.

The TC77 demonstration is designed to measure and display temperature in binary coded decimal (BCD) with the PICkit 1 LEDs. The TC77 is a CMOS silicon digital temperature sensor particularly suited for low cost and small form-factor applications. Temperature data is converted from the internal thermal sensing element and made available as a 13-bit two's compliment digital word. The TC77 offers many system-level advantages, including the integration of the temperature sensor and signal conditioning circuitry on a single chip that is connected to the PICkit 1 through the SPI compatible interface.

Gerber files for the Printed Circuit Board (PCB), source code and hex file to program a PIC16F676 are included in the companion zip file "00913.zip".

**FIGURE 1:** Block Diagram of the TC77 Thermal Sensor Demonstration.
TC77 FUNCTIONAL DESCRIPTION

The TC77 consists of an internal diode temperature sensor, a 13-bit Delta-Sigma, Analog-to-Digital Converter (ADC), three digital registers and a SPI compatible interface. The SPI compatible interface provides for serial communication with microcontrollers, such as a PICmicro microcontroller. Figure 2 provides a simplified block diagram of the TC77 sensor.

The temperature measurement data is stored in the Temperature register, while the Configuration register is used to select the operating mode of the sensor. The Manufacturer’s Identification (ID) register is used to identify the sensor as a Microchip component. Table 1 provides the bit definitions of the TC77 registers.

Operating Modes

The user-configured operating modes of the TC77 include a Continuous Temperature and a Shutdown mode that are selected via the Configuration register. In the Continuous Temperature mode, an ADC conversion is performed approximately every 300 ms, with the data being stored in the Temperature register. If a Temperature register read operation is requested while an ADC conversion is in progress, the previously completed ADC conversion data will be outputted via the sensor’s serial I/O port.

Shutdown mode can be used to minimize the power consumption of the TC77 sensor when active temperature monitoring is not required. While Shutdown mode disables the temperature conversion circuitry, the SPI compatible interface remains active. The current consumption of the sensor will be less than 1 µA when Shutdown mode is activated.

FIGURE 2: Block Diagram of the TC77 Thermal Sensor.

TABLE 1: TC77 DIGITAL REGISTERS

| Register               | Bit 15 | Bit 14 | Bit 13 | Bit 12 | Bit 11 | Bit 10 | Bit 9  | Bit 8  | Bit 7  | Bit 6  | Bit 5  | Bit 4  | Bit 3  | Bit 2  | Bit 1  | Bit 0  | Value at Power-up/Reset |
|------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|------------------------|
| Configuration          | C15    | C14    | C13    | C12    | C11    | C10    | C9     | C8     | C7     | C6     | C5     | C4     | C3     | C2     | C1     | C0        | Continuous Temperature Conversion Mode ** |
|                        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        | Value at Power-up/Reset |
| Temperature            | T15    | T14    | T13    | T12    | T11    | T10    | T9     | T8     | T7     | T6     | T5     | T4     | T3     | T2     | T1     | T0        | Temp. = -2°C |
|                        | (2^15)| (2^14)| (2^13)| (2^12)| (2^11)| (2^10)| (2^9)  | (2^8)  | (2^7)  | (2^6)  | (2^5)  | (2^4)  | (2^3)  | (2^2)  | (2^1)  | (2^-1)    | |
| Manufacturer ID        | 0      | 1      | 0      | 1      | 0      | 1      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | x         | Bit 15 to Bit 8 = 54 hex |

Legend:

* Temperature Bit 2 = 0 during power-up; otherwise, bit 2 = 1

** C15:C0 = xxxx/xxxx 1111/1111 (Shutdown mode)

C15:C0 = xxxx/xxxx 0000/0000 (Continuous Conversion mode)

*** Temperature Register Bit 15 is the sign bit. If Bit 15 is equal to ’1’, the temperature is negative (T < 0°C). If Bit 15 is equal to ’0’, the temperature is positive (T ≥ 0°C).
SPI Compatible Interface

The TC77’s SPI compatible interface consists of the Chip Select (CS), Serial Clock (SCK) and bidirectional Serial Input/Output (SI/O) data signals. Figure 3 provides a timing diagram of a read operation of the Temperature register.

Communication with the TC77 is initiated when the CS goes to a logic ‘0’. The SI/O signal then transmits the first bit of data. The SCK input is provided by the PICmicro microcontroller and data is transferred on the rising edge of SCK. The SI/O line is then tri-stated once 14 bits of data have been transmitted.

The CS input is used to select the TC77 when multiple devices are connected to the SPI lines. The CS line is also used to synchronize the data, which is written to, or read from, the device when CS is equal to a logic ‘0’. The SCK input is disabled when CS is a logic ‘1’. The falling edge of the CS line initiates communication, while the rising edge of CS completes the communication.

Figure 4 provides a timing diagram of a multi-byte communication operation consisting of a read of the Temperature Data register, followed by a write to the Configuration register. The first 16 SCK pulses are used to transmit the TC77’s temperature data to the microcontroller. The second group of 16 SCK pulses are used to receive the microcontroller command to place the TC77 either in Shutdown or Continuous Temperature Conversion mode. Note that the TC77 is in the Continuous Temperature Conversion mode at power-up.

The data written to the TC77’s Configuration register should be either all 0’s or all 1’s, corresponding to either the Continuous Temperature Conversion or Shutdown mode, respectively. The TC77 is in Shutdown mode when bits C0 to C7 are all equal to 1’s. The TC77 will be in the Continuous Conversion mode if a ‘0’ in any bit location from C0 to C7 is written to the Configuration register.

Temperature Data Format

The TC77’s temperature data is represented by a 13-bit two’s complement digital word as shown in Table 1 and Table 2. The Least Significant bit (LSb) is equal to 0.0625°C. Note that the last two bits (bit T0 and T1) are tri-stated and are represented as a logic ‘1’ in the table. bit T2 is set to logic ‘1’ after the completion of the first temperature conversion following a power-up or voltage reset event.

Listed below is an example of the TC77’s Temperature Register bit definition for a temperature of 85.125°C.

Example:

Temperature = 85.125°C
Temperature Register = 00101010 10010111b
= 2^6 + 2^4 + 2^2 + 2^0 + 2^-3
= 64 + 16 + 4 + 1 + 0.125
= 85.125°C

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Bit 15</th>
<th>Bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>+125°C</td>
<td>0011 1110 1000 0111</td>
<td></td>
</tr>
<tr>
<td>+25°C</td>
<td>0000 1100 1000 0111</td>
<td></td>
</tr>
<tr>
<td>+0.0625°C</td>
<td>0000 0000 0000 1111</td>
<td></td>
</tr>
<tr>
<td>0°C</td>
<td>0000 0000 0000 0111</td>
<td></td>
</tr>
<tr>
<td>-0.0625°C</td>
<td>1111 1111 1111 1111</td>
<td></td>
</tr>
<tr>
<td>-25°C</td>
<td>1111 0011 1000 0111</td>
<td></td>
</tr>
<tr>
<td>-55°C</td>
<td>1110 0100 1000 0111</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 2: TC77 TEMPERATURE OUTPUT DATA

---

**FIGURE 3:** Temperature Read Timing Diagram.

---
TC77 Application Guidelines

It is recommended that a decoupling capacitor of 0.1 µF to 1 µF be provided between the power supply and ground pins to provide effective noise protection to the sensor. Also, the user should select a TC77 sensor that has a calibration voltage that is as close as possible to the system voltage on the PCB. The TC77’s temperature accuracy is tested and calibrated at either 3.3V or 5.0V, with the accuracy being degraded if a different voltage is used than the calibration V_DD. Please refer to the TC77 data sheet (DS20092) for further details on the specifications of the sensor.

Silicon digital temperature sensors measure temperature by monitoring the voltage of a diode located on the die. The TC77’s substrate of the die is grounded and connected to the PCB’s ground plane via a bonding wire and package lead. The ground pin provides a low-impedance thermal path between the die and the PCB, allowing the sensor to effectively monitor the temperature of the PCB board.

The thermal path between the top of the package to the ambient air, and between the bottom of the package and the PCB, is not as efficient because the plastic 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 temperature sensor.

TC77 PICTAIL DAUGHTER BOARD

The TC77 PICtail daughter board is plugged to the PICkit 1 FLASH Starter Kit via expansion header J3. Figure 5 shows a picture of the TC77 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 TC77 PICtail daughter board consists of a TC77 temperature sensor and a bypass capacitor. The bypass capacitor (C1) 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. The Bill of Materials (BOM) is given in Table 3. Gerber files for the TC77 PICtail daughter board are available in the companion zip file “00913.zip”.

TABLE 3: TC77 THERMAL SENSOR PICtail™ DAUGHTER BOARD (112-00004) BILL OF MATERIALS (BOM)

<table>
<thead>
<tr>
<th>Component</th>
<th>Symbol</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Sensor</td>
<td>U1</td>
<td>TC77-5.0MCT</td>
</tr>
<tr>
<td>5V, SOT-23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacitor, 0.1 µF,</td>
<td>C1</td>
<td>ECJ-2VBIE104K (Panasonic®)</td>
</tr>
<tr>
<td>±10%, 25V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connector, 14-pin</td>
<td>P1</td>
<td>800-99-014-20-001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Mill-Max™)</td>
</tr>
<tr>
<td>Connector, 14-pin</td>
<td>P2, P3</td>
<td>Not Used</td>
</tr>
<tr>
<td>Printed Circuit</td>
<td></td>
<td>102-00004</td>
</tr>
<tr>
<td>Board</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FIGURE 5: TC77 PICtail™ Daughter Board and PICkit™ 1 FLASH Starter Kit.

FIGURE 6: TC77 PICtail™ Daughter Board Schematic.

FIGURE 7: TC77 PICtail™ Daughter Board PCB Layout.
TC77 Interface Software

A flow diagram for the PICkit 1 software is given in Figure 8. The TC77 thermal sensor is read by the PICmicro microcontroller. Bit T2 of the Temperature register is tested to ensure that the TC77 sensor is powered up and ready. The value read from the TC77 is right-adjusted in the register as a 12-bit temperature value in degrees Celsius. The temperature value is tested for a negative temperature reading by checking the status of bit T15. If the value is negative (T < 0°C), the state is saved in a flag bit and the value is 2's complemented.

The TC77's Temperature register provides a temperature measurement in Celsius. A provision in the software is provided to display the temperature in either Fahrenheit or Celsius by testing the status of the PICkit 1 push button switch (SW1). If SW1 is not depressed, the temperature value is converted to Fahrenheit. Otherwise, if the push button is depressed, 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.

The temperature measurement is displayed using the red LEDs designated as D0 through D7 located on the PICkit board. The ten's digit of the temperature data is represented by bits D7 to D4, with D7 being defined as the Most Significant bit (MSb). The one's digit is defined by bits D3 to D0, with D3 serving as the MSb. Table 4 provides a list of the LED lamp annunciation that corresponds to the BCD coding representation of the temperature measurement. For example, a temperature reading of 70°F will be displayed by illuminating LEDs D4, D5 and D6. If the SW1 push button is activated, a measurement of 21°C will be shown by illuminating LEDs D0 and D5. A fractional temperature is rounded up if the tenths digit is determined to be either 0.5°F or 0.5°C.

Fully documented source code and a hex file ready to program into a PIC16F676 is available in the companion zip file “00913.zip”.

<table>
<thead>
<tr>
<th>Binary</th>
<th>BCD</th>
<th>LED Annunciation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0000</td>
<td>0</td>
<td>OFF OFF OFF OFF</td>
</tr>
<tr>
<td>0001</td>
<td>1</td>
<td>OFF OFF OFF ON</td>
</tr>
<tr>
<td>0010</td>
<td>2</td>
<td>OFF OFF ON OFF</td>
</tr>
<tr>
<td>0011</td>
<td>3</td>
<td>OFF ON ON ON</td>
</tr>
<tr>
<td>0100</td>
<td>4</td>
<td>OFF ON OFF OFF</td>
</tr>
<tr>
<td>0101</td>
<td>5</td>
<td>OFF ON OFF ON</td>
</tr>
<tr>
<td>0110</td>
<td>6</td>
<td>OFF ON ON ON</td>
</tr>
<tr>
<td>0111</td>
<td>7</td>
<td>OFF ON ON ON</td>
</tr>
<tr>
<td>1000</td>
<td>8</td>
<td>ON OFF OFF OFF</td>
</tr>
<tr>
<td>1001</td>
<td>9</td>
<td>ON OFF OFF ON</td>
</tr>
</tbody>
</table>

TABLE 4: LED LAMP ANNUNCIATION
FIGURE 8: TC77 PICtail™ Program Flow Diagram.
FIGURE 8:  TC77 PICtail™ Program Flow Diagram (Cont.)

1. Add 32
2. Round result to an integer
3. Convert value to BCD
4. Place value in LEDREG

A

B

C
CONCLUSION

The TC77 SPI™ Thermal Sensor PICtail™ daughter board demonstrates the ease of integrating a digital silicon IC temperature sensor to a PICmicro microcontroller unit (MCU). The TC77 is a CMOS silicon digital temperature sensor that provides an accurate digital temperature measurement to solve thermal management problems. The TC77 sensors offer 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

APPENDIX A: SOURCE CODE

; Filename:          TC77 PICtail.asm
; Date:              December 17, 2003
; File Version:      0.2
; Assembled using:
; Author:            Steven Bible
; Company:           Microchip Technology Inc.

;---------------------------------------------------------------------
; Files required:
; p16f676.inc

;---------------------------------------------------------------------

; Program Description
; This program demonstrates the Microchip TC77 Thermal Sensor with
; SPI(tm) compatible interface using the PICkit(tm) 1 FLASH Starter Kit.
; The temperature is read from the TC77 and displayed on LEDs
; D0 through D7 in Binary Coded Decimal (BCD).

;---------------------------------------------------------------------
list       p=16f676          ; list directive to define processor
#include    <p16f676.inc>    ; processor-specific variable definitions
errorlevel -302             ; suppress message 302 from list file

;---------------------------------------------------------------------
; Configuration Bits (Section 9.1 Configuration Bits)
;---------------------------------------------------------------------
; Data Memory Code Protection bit:
; _CPD = Enabled
; _CPD_OFF = Disabled
; Program Memory Code protection:
; _CP = Enabled
; _CP_OFF = : Disabled
; Brown-out Detection Enable bit:
; _BODEN = Enabled
; _BODEN_OFF = Disabled
; GP3/MCLR pin function select:
; _MCLRE_ON = GP3/MCLR pin function is /MCLR
; _MCLRE_OFF = GP3/MCLR pin function is digital I/O,       
; /MCLR internally tied to Vdd       
; 
; Power-up Timer Enable bit:         
; _PWRTE_ON = Enabled        
; _PWRTE_OFF = Disabled        
; 
; Watchdog Timer Enable bit:          
; _WDT_ON = Enabled          
; _WDT_OFF = Disabled          
; 
; Oscillator Selection bits:          
; _EXTRC_OSC_NOCLKOUT = CLKOUT function on GP4 pin, RC on GP5 pin. 
; _EXTRC_OSC_CLKOUT = I/O function on GP4 pin, RC on GP5 pin. 
; _INTRC_OSC_CLKOUT = Internal oscillator, CLKOUT function on GP4 pin, 
; I/O function on GP5 pin. 
; _INTRC_OSC_NOCLKOUT = Internal oscillator, I/O function on GP4 and GP5 pins. 
; _EC_OSC = I/O function on GP4 pin, CLKIN on GP5 pin. 
; _HS_OSC = High speed crystal/resonator on GP4 and GP5 pins. 
; _XT_OSC = Crystal/resonator on GP4 and GP5 pins. 
; _LP_OSC = Low power crystal on GP4 and GP5 pins. 
; 
; __CONFIG _CPD_OFF & _CP_OFF & _BODEN & _MCLRE_OFF & _PWRTE_ON & _WDT_OFF & 
; _INTRC_OSC_NOCLKOUT

; Variables (Section 2.2 Data Memory Organization)

; Data Memory Organization (Section 2.2) 
; The data memory is partitioned into two banks which contain 
; the General Purpose registers and the Special Function registers. 
; The Special Function registers are located in the first 32 
; locations of each bank. Register locations 0x20 to 0x5F (64 bytes) 
; are General Purpose registers, implemented as static RAM and are 
; mapped across both banks. 
; 
; RP0 (STATUS<5>) 
; 0 -> Bank 0 
; 1 -> Bank 1 
; 
; Refer to Section 2.2 of the data sheet for the organization of 
; the General Purpose Registers. 

; Bank 0 General Purpose Registers
cblock 0x20 ; File Address 0x20-0x5F (64 bytes)

  W_TEMP ; used for context saving
  STATUS_TEMP ; used for context saving
  PCLATH_TEMP ; used for context saving
  FSR_TEMP ; used for context saving
  TEMP ; General Purpose Temporary register
  FLAG ; A byte of binary flags (see Defines below)
  TICK ; Tick counter

; LED Display on PICkit 1 Flash Starter Kit
AN913

; TC77 Thermal Sensor variables
BIT_CNTR ; Bit counter
TC77_HI ; TC77 Temperature register high byte
TC77_LO ; TC77 Temperature register low byte
TEMP_HI ; Temporary Register high byte
TEMP_LO ; Temporary Register low byte

; Binary Coded Decimal (BCD) variables
BCD_H ; BCD Hundreds
BCD_T ; BCD Tens
BCD_O ; BCD Ones

endc

;------------------------------------------------------------------------
; Defines
;------------------------------------------------------------------------

;-----------------------------
; PORTA (Section 3.1)
;-----------------------------
#define POT PORTA, 0 ; (Analog Input) Potentiometer RP1
#define RA1 PORTA, 1 ; (Digital Input/Output) LEDs D6, D7
#define RA2 PORTA, 2 ; (Digital Input/Output) LEDs D2, D3, D4, D5, D6, D7
#define SW1 PORTA, 3 ; (Digital Input Only) Push Button SW1
#define RA4 PORTA, 4 ; (Digital Input/Output) LEDs D0, D1, D2, D3
#define RA5 PORTA, 5 ; (Digital Input/Output) LEDs D0, D1, D4, D5

#define PORTATRIS b'00111111'

; Define for TRISA Register (Section 3.1)

;-----------------------------
; PORTC (Section 3.3)
;-----------------------------
#define PORTC b'01111111'

; PORTC is a general purpose I/O port consisting of 6 bidirectional
; pins. The pins can be configured for either digital I/O or for analog
; input to an A/D converter. For specific information about individual functions
; such as the comparator or the A/D, refer to the appropriate section in the
; data sheet.
#define SCK PORTC, 0 ; (Digital Output) Serial Clock
#define SIO PORTC, 1 ; (Digital Input/Output) Serial I/O (initially set as input)
#define RC2 PORTC, 2 ; (Digital Input)
#define TC77_CS PORTC, 3 ; (Digital Output) TC77 Chip Select (active low)
#define RC4 PORTC, 4 ; (Digital Input)
#define RC5 PORTC, 5 ; (Digital Input)

; Define for TRISC Register (Section 3.3)

; PORTC Pins = xx543210
#define PORTCTRIS b'00110110'

;----------------------
; Program Defines
;----------------------

#define TRIP 0 ; Tick counter trip flag
#define SIGN_BIT 1 ; temperature sign bit
#define C_F_DISP 2 ; Display in C or F

; LEDs

; PORTA Pins = xx543210
#define LED0TRIS b'00001111'
#define LED1TRIS b'00001111'
#define LED2TRIS b'00101011'
#define LED3TRIS b'00101011'
#define LED4TRIS b'00101011'
#define LED5TRIS b'00101011'
#define LED6TRIS b'00111001'
#define LED7TRIS b'00111001'
#define LEDOFFTRIS b'00111111'

; PORTA Pins = xx543210
#define LED0ON b'00010000'
#define LED1ON b'00100000'
#define LED2ON b'00010000'
#define LED3ON b'00000100'
#define LED4ON b'00100000'
#define LED5ON b'00000100'
#define LED6ON b'00000100'
#define LED7ON b'00000010'

;----------------------------------------------------------------------

; Program Memory
;----------------------------------------------------------------------

; Program Memory Organization (Section 2.1)

ORG 0x0000 ; RESET Vector
nop ; for ICD use
goto MAIN ; goto MAIN Program

ORG 0x0004 ; Interrupt Vector
movwf W_TEMP ; save W register
swapf STATUS, W ; swap status to be saved into W
bcf STATUS, RP0 ; ----- Select Bank 0 ----- 
movwf STATUS_TEMP ; save STATUS register
movfw PCLATH
movfw PCLATH_TEMP ; save PCLATH_TEMP register
movfw FSR
movwf FSR_TEMP ; save FSR_TEMP register

;----------------------------------------
; Interrupt Service Routine (ISR) (Section 9.4)
;
; Description:
;
;----------------------------------------
bcf INTCON, T0IF ; clear TMR0 Interrupt Flag
call DISPLAY ; Update LED Array (light LEDs)
decf TICK, F ; decrement tick counter
btfsc STATUS, Z
bsf FLAG, TRIP

;----------------------------------------
movfw PCLATH_TEMP ; restore PCLATH_TEMP register
movfw PCLATH
movfw FSR_TEMP ; restore FSR_TEMP register
movfw FSR
swapf STATUS_TEMP, W ; swap status_temp into W, sets bank to original state
movwf STATUS ; restore STATUS register
swapf W_TEMP, F
swapf W_TEMP, W ; restore W register
retfie

;----------------------------------------------------------------------
; Initialize PICmicro(r) MCU (PIC16F630/676)
;----------------------------------------------------------------------
INITIALIZE

; Disable global interrupts during initialization

bcf INTCON, GIE ; disable global interrupts

;----------------------------------------------------------------------
; Calibrating the Internal Oscillator (Section 9.2.5.1)
; Oscillator Calibration Register (OSCCAL) (Section 2.2.2.7)
;
; A calibration instruction is programmed into the last location of
; program memory. This instruction is a RETLW XX, where the literal is
; the calibration value. The literal is placed in the OSCCAL register
; to set the calibration of the internal oscillator.

bsf STATUS, RP0 ; ---- Select Bank 1 -----
call 0x3FF ; retrieve factory calibration value
movwf OSCCAL ; update register with factory cal value
bcf STATUS, RP0 ;---- Select Bank 0 ----
; Store PORTATRIS and PORTCTRIS values defined above into the
; TRISA and TRISC direction registers
bsf STATUS, RP0 ; ---- Select Bank 1 -----
movlw PORTATRIS
movwf TRISA ; Write to TRISA register
movlw PORTCTRIS
movwf TRISC ; Write to TRISC register
bcf STATUS, RP0 ; ---- Select Bank 0 -----

;---------------------------------------------------------------------
; Comparator Module (Section 6.0)
;
; The PIC16F630/676 devices have one analog comparator. The inputs to
; the comparator are multiplexed with the RA0 and RA1 pins. There is
; an on-chip Comparator Voltage Reference that can also be applied to
; an input of the comparator. In addition, RA2 can be configured as
; the comparator output. The Comparator Control register (CMCON)
; contains bits to control the comparator. The Voltage Reference
; Control register (VRCON) controls the voltage reference module.

; Comparator Configuration (Figure 6-2)
; bcf CMCON, CINV ; Comparator Output Inversion: not inverted
; bcf CMCON, COUT ; Comparator Output bit: Vin+ < Vin-
; bcf CMCON, CIS ; Comparator Input Switch: Vin- connects to Cin-

; CM2:CM0 = 111 - Comparator Off (lowest power)
bsf CMCON, CM2 ; Comparator Mode bit 2
bsf CMCON, CM1 ; Comparator Mode bit 1
bsf CMCON, CM0 ; Comparator Mode bit 0

; VRCON (Register 6-2)
bsf STATUS, RP0 ; ---- Select Bank 1 -----
bcf VRCON, VREN ; CVref circuit: powered down, no Idd drain

; bcf VRCON, VRR ; CVref Range Selection: High Range
; bcf VRCON, VR3 ; CVref value selection bit 3
; bcf VRCON, VR2 ; CVref value selection bit 2
; bcf VRCON, VR1 ; CVref value selection bit 1
; bcf VRCON, VR0 ; CVref value selection bit 0

bcf STATUS, RP0 ; ---- Select Bank 0 -----

;---------------------------------------------------------------------
; Analog-to-Digital Converter (A/D) Module (Section 7.0) (PIC16F676 Only)
;
; The analog-to-digital converter (A/D) allows conversion of an analog
; input signal to a 10-bit binary representation of that signal. The
; PIC16F676 has eight analog inputs multiplexed into one sample and hold
; circuit. There are two registers to control the functions of the A/D
; module:
; A/D Control Register 0 (ADCON0)
; A/D Control Register 1 (ADCON1)
; Analog Select Register (ANSEL)
;
; Note: When using PORTA or PORTC pins as analog inputs, ensure the
; TRISA or TRISC register bits are set (= 1) for input.
bcf ADCON0, ADFM ; A/D Result Formed: left justified
bcf ADCON0, VCFG ; Voltage Reference: Vdd
bsf STATUS, RP0 ; ---- Select Bank 1 -----

; select A/D Conversion Clock Source: Fosc/8
bcf ADCON1, ADCS2 ; A/D Conversion Clock Select bit 2
bcf ADCON1, ADCS1 ; A/D Conversion Clock Select bit 1
bsf ADCON1, ADCS0 ; A/D Conversion Clock Select bit 0

; select GPIO pins that will be analog inputs: RA0/AN0
bcf ANSEL, ANS7 ; Analog Select RC3/AN7: digital I/O
bcf ANSEL, ANS6 ; Analog Select RC2/AN6: digital I/O
bcf ANSEL, ANS5 ; Analog Select RC1/AN5: digital I/O
bcf ANSEL, ANS4 ; Analog Select RC0/AN4: digital I/O
bcf ANSEL, ANS3 ; Analog Select RA3/AN3: digital I/O
bcf ANSEL, ANS2 ; Analog Select RA2/AN2: digital I/O
bcf ANSEL, ANS1 ; Analog Select RA1/AN1/Vref: digital I/O
bsf ANSEL, ANS0 ; Analog Select RA0/AN0: analog input

bcf STATUS, RP0 ; ---- Select Bank 0 -----

bcf ADCON0, ADON ; ADC is shut-off and consumes no operating current

;----------------------------------------

; TIMER1 Module with Gate Control (Section 5.0)
;
; The TIMER1 Control Register (T1CON) is used to enable/disable TIMER1
; and select various features of the TIMER1 module.

bcf T1CON, TMR1ON ; TIMER1: stopped
bcf T1CON, TMR1CS ; TIMER1 Clock Source Select: Internal Clock (Fosc/4)

bcf T1CON, NOT_T1SYNC ; TIMER1 External Clock Input Sync Control: Syncronize external
                      ; clock input
                      ; TIOSCEN only if INTOSC without CLKOUT oscillator is active, else ignored
bcf T1CON, TIOSCEN ; LP Oscillator Enable Control: LP oscillator off

; TIMER1 Input Prescale Select: 1:1
bcf T1CON, T1CKPS1 ; TIMER1 Input Clock Prescale Select bit 1
bcf T1CON, T1CKPS0 ; TIMER1 Input Clock Prescale Select bit 0

; TMR1GE only if TMR1ON = 1, else ignored
bcf T1CON, TMR1GE ; TIMER1 Gate Enable: on

;----------------------------------------

; PORTA Weak Pull-up Register (WPUA) (Section 3.2.1)
;
; Each of the PORTA pins, except RA3, has an individually configurable
; weak internal pull-up. Control bits WPUAx enable or disable each
; pull-up. Refer to Register 3-1. Each weak pull-up is automatically
; turned off when the port pin is configured as an output. The pull-ups
; are disabled on a Power-on Reset by the /RAPU bit (see OPTION Register
; below).

bsf STATUS, RP0 ; ---- Select Bank 1 -----

; PORTA Pins = x554x210
movlw B'00000000' ; no pull-ups enabled
movwf WPUA
bcf STATUS, RP0 ;---- Select Bank 0 -----  

; OPTION Register (OPTION_REG) (Section 2.2.2)  
; TIMER0 Module (Section 4.0)  
;  
; The OPTION_REG contains control bits to configure:  
; Weak pull-ups on GPIO (see also WPU Register above)  
; External RA2/INT interrupt  
; TMR0  
; TMR0/WDT prescaler

bsf STATUS, RP0 ;---- Select Bank 0 -----  

;----------------------------------------

bsf OPTION_REG, NOT_GPPU ; PORTA pull-ups: disabled
bsf OPTION_REG, INTEDG ; Interrupt Edge: on rising edge of RA2/INT pin
bcf OPTION_REG, T0CS ; TMR0 Clock Source: internal instruction cycle (CLKOUT)
bcf OPTION_REG, T0SE ; TMR0 Source Edge: increment low-to-high transition on GP2/T0CKI pin

bcf OPTION_REG, PSA ; Prescaler Assignment: assigned to TIMER0

; TMR0 Prescaler Rate: 1:8
bcf OPTION_REG, PS2 ; Prescaler Rate Select bit 2
bsf OPTION_REG, PS1 ; Prescaler Rate Select bit 1
bcf OPTION_REG, PS0 ; Prescaler Rate Select bit 0

bcf STATUS, RP0 ;---- Select Bank 0 -----  

;----------------------------------------

; PORTA Interrupt-on-Change Register (IOCA) (Section 3.2.2)  
;
; Each of the PORTA pins is individually configurable as an interrupt-on-change pin. Control bits IOCAx enable or disable the interrupt function for each pin. Refer to Register 3-4. The interrupt-on-change is disabled on a Power-on Reset.
;
; Note: Global interrupt enables (GIE and GPIE) must be enabled for individual interrupts to be recognized.

bsf STATUS, RP0 ;---- Select Bank 1 -----  

; GPIO Pins = xx54x210
movlw B'00000000'
movwf IOCA ; Interrupt-on-change disabled
bcf STATUS, RP0 ;---- Select Bank 0 -----  

;----------------------------------------

; Peripheral Interrupt Enable Register (PIE1) (Section 2.2.2.4)  
;
; The PIE1 register contains peripheral interrupt enable bits.
;
; Note: The PEIE bit (INTCON<6>) must be set to enable any peripheral interrupt.

bcf STATUS, RP0 ;---- Select Bank 1 -----  

bcf PIE1, EEIE ; EE Write Complete Interrupt: disabled
bcf PIE1, ADIE ; A/D Converter Interrupt (PIC12F675 Only): disabled
bcf PIE1, CMIE ; Comparator Interrupt: disabled
bcf PIE1, TMR1IE ; TMR1 Overflow Interrupt: disabled
bcf STATUS, RP0          ;---- Select Bank 0 ----- 

;---------------------------------------------------------------
; Interrupt Control Register (INTCON) (Section 2.2.2.3)
;
; The INTCON register contains enable and disable flag bits for TMR0
; register overflow, GPIO port change and external GP2/INT pin
; interrupts.
    bsf INTCON, T0IE        ; TMR0 Overflow Interrupt: ENABLED
    bcf INTCON, INTE        ; RA2/INT External Interrupt: disabled
    bcf INTCON, RAIE        ; Port Change Interrupt: disabled
    bcf INTCON, PEIE        ; Peripheral Interrupts: disabled
                           ; (EEI, ADI, CMI, TMR1I)
    bcf INTCON, GIE         ; Global Interrupts: disabled
return                      ; return from INITIALIZE

; end INITIALIZE

;----------------------------------------------------------------------
; Subroutine: DATA_EEPROM_READ
;
; Description: To read an EEPROM data memory location, the address is
; written to the EEADR register and set control bit RD (EECON1<0>) to
; initiate a read. Data is available in the EEDATA register the next
; clock cycle.
;
; Constants: none
;
; Global Variables: none
;
; Initialization: W contains EEPROM address (EEADR) to be read
;
; Output: W contains EEPROM data (EEDATA)
;
;----------------------------------------------------------------------

DATA_EEPROM_READ
    bsf STATUS, RP0          ; ---- Select Bank 1 ----- 
    movwf EEADR               ; move EEPROM address in W to EEADR
    bsf EECON1, RD            ; initiate EEPROM read
    movf EEDATA, W           ; move data to W
bcf STATUS, RP0          ; ---- Select Bank 0 ----- 
return

;----------------------------------------------------------------------
; Subroutine: DATA_EEPROM_WRITE
;
; Description: To write an EEPROM data memory location, the address is
; written to the EEADR register, data to the EEDATA register, then
; execute a required sequence of instructions.
;
; CAUTION: Interrupts are disable and then re-enabled during this
; subroutine
;

; Constants: none
;
; Global Variables: none
;
; Initialization: Address = EEAR, Data = EEDATA
;
; Output: none
;
------------------------------------------------------------------

DATA_EEPROM_WRITE

bsf STATUS, RP0  ; ---- Select Bank 1 -----
                  
bsf EECON1, WREN ; EEPROM Write Enable: allow write cycles
bcf INTCON, GIE  ; disable global interrupts
                  ; *** required sequence, do not alter ***

movlw 0x55
movwf EECON2
movlw 0xAA
movwf EECON2
bsf EECON1, WR  ; initiate EEPROM write
                  ; *** end required sequence ***

btfsc EECON1, WR ; has write completed?
goto $-1

   bsf INTCON, GIE  ; enable global interrupts
   bcf EECON1, WREN ; EEPROM Write Enable: inhibit write cycles
   bcf STATUS, RP0  ; ---- Select Bank 0 -----

return

------------------------------------------------------------------

; Subroutine: READ_ANALOG_AN0
;
; Description: Read analog channel 0 (AN0).
;
; Constants: none
;
; Global Variables: none
;
; Initialization: none
;
; Output: ADRESH and ADRESL contain 10-bit A/D result justified
; according to ADCON0, ADFM bit.
;
------------------------------------------------------------------

READ_ANALOG_AN0

bsf ADCON0, ADON  ; Turn on ADC module

bcf ADCON0, CHS1  ; select analog channel AN0
bcf ADCON0, CHS0

; After selecting a new channel, allow for sufficient sample time.
; The amount of sample time depends on the charging time of the
; internal charge-holding capacitor (Section 7.2).

movlw D'6'        ; At 4 MHz, a 22 us delay
movwf TEMP         ; (22us = 2us + 6 * 3us + 1us)
derfza ADCON0, F
goto $-1
bsf ADCON0, GO ; start A/D conversion
btfsc ADCON0, GO ; has A/D conversion completed?
goto $-1
bcf ADCON0, ADON ; Turn off ADC module (consumes no operating current)
return

;----------------------------------------------------------------------
; Subroutine: DISPLAY
;
; Description: Displays Value Stored In LEDREG On LED Array
; 1 LED is displayed during each call
; D7..D4 LED'S show most significant nibble
; D3..D0 LED'S show least significant nibble
;
; Constants:
;
; Global Variables: LEDREG, LEDDISP, LEDSTATE
;
; Initialization:
;
; Output:
;
;----------------------------------------------------------------------

DISPLAY
clr PORTA ; turn off all LED's
bcf STATUS, C ; clear the carry bit
rlf LEDDISP, F ; rotate left the LED displayed bit
btfsc STATUS, C ; was the bit rotated into carry?
rlf LEDDISP, F ; yes, put it back into bit 0
incf LEDSTATE, F ; no, increment LED State
movfw LEDREG ; get LED Register, should the LED be lit?
andfw LEDDISP, W
btfsc STATUS, Z
return ; bit was a zero, do not light and return
movfw LEDSTATE
andlw B'00000111'
addwf PCL, F
goto LITELED0
goto LITELED1
goto LITELED2
goto LITELED3
goto LITELED4
goto LITELED5
goto LITELED6
goto LITELED7

LITELED0
bsf STATUS, RP0 ; ---- Select Bank 1 -----
movlw LED0TRIS
movwf TRISA
bcf STATUS, RP0 ; ---- Select Bank 0 -----
movlw LED0ON
movwf PORTA
return

LITELED1
bsf STATUS, RP0 ; ---- Select Bank 1 -----
movlw LED1TRIS
movwf TRISA
bcf STATUS, RP0 ; ---- Select Bank 0 -----
movlw LED1ON
movwf PORTA
return

LITELED2
bsf STATUS, RP0 ; ---- Select Bank 1 -----
movlw LED2TRIS
movwf TRISA
bcf STATUS, RP0 ; ---- Select Bank 0 -----
movlw LED2ON
movwf PORTA
return

LITELED3
bsf STATUS, RP0 ; ---- Select Bank 1 -----
movlw LED3TRIS
movwf TRISA
bcf STATUS, RP0 ; ---- Select Bank 0 -----
movlw LED3ON
movwf PORTA
return

LITELED4
bsf STATUS, RP0 ; ---- Select Bank 1 -----
movlw LED4TRIS
movwf TRISA
bcf STATUS, RP0 ; ---- Select Bank 0 -----
movlw LED4ON
movwf PORTA
return

LITELED5
bsf STATUS, RP0 ; ---- Select Bank 1 -----
movlw LED5TRIS
movwf TRISA
bcf STATUS, RP0 ; ---- Select Bank 0 -----
movlw LED5ON
movwf PORTA
return

LITELED6
bsf STATUS, RP0 ; ---- Select Bank 1 -----
movlw LED6TRIS
movwf TRISA
bcf STATUS, RP0 ; ---- Select Bank 0 -----
movlw LED6ON
movwf PORTA
return

LITELED7
bsf STATUS, RP0 ; ---- Select Bank 1 -----
movlw LED7TRIS
movwf TRISA
bcf STATUS, RP0 ; ---- Select Bank 0 -----
movlw LED7ON
movwf PORTA
return
Subroutine: READ_TC77_TEMP

Description:
The TC77 Temperature register is a 16-bit read-only register.
The temperature data format is a 13-bit two's complement digital word (bits 15:3). The Least Significant bit (LSb) is equal to 0.0625 degrees C. Bit 2 is set to a logic '1' after the completion of the first temperature conversion following a power-up or reset event. Bits 1:0 are tri-stated.

Constants:
None

Global Variables:
 TC77_HI = TC77 Temperature Register High Byte
 TC77_LO = TC77 Temperature Register Low Byte

Initialization:
The TC77_SIO TRIS bit is assumed to be set for input (=1)

Output:
TC77_HI and TC77_LO contain the 16-bit Temperature Register value

READ_TC77_TEMP

   movlw D'16'
   movwf BIT_CNTR
   bcf SCK
   bcf TC77_CS

READ_TC77_TEMP_LOOP

   bsf SCK
   btfsc SIO
   bsf STATUS, C
   btfss SIO
   bcf STATUS, C
   bcf SCK
   rlf TC77_LO, F
   rlf TC77_HI, F
   decfsz BIT_CNTR, F
   goto READ_TC77_TEMP_LOOP
   bsf TC77_CS

return
MAIN

;---------------------------------------------------------------
; Initialize PICmicro® MCU
;---------------------------------------------------------------
    call INITIALIZE

;---------------------------------------------------------------
; Initialize Variables
;---------------------------------------------------------------
    bcf FLAG, TRIP      ; clear tick counter trip flag.
    bsf TC77_CS         ; disable TC77 --> chip select high
    clrf LEDREG         ; initialize the LED display routine
    clrf LEDSTATE
    movlw D'1'          
    movwf LEDDISP
    bsf INTCON, GIE      ; enable global interrupts

MAINLOOP

; tick counter expired?
    btfss FLAG, TRIP       ; no, loop
    goto MAINLOOP
    bcf FLAG, TRIP      ; clear tick counter trip flag.

; read temperature from TC77
    bcf INTCON, GIE      ; disable global interrupts
    call READ_TC77_TEMP
    bsf INTCON, GIE      ; enable global interrupts

; is temperature conversion complete?
    ; check bit 2
    ; if not complete, read TC77 again
    ; (be sure to include code in the event bit 2 is never true)
    btfss TC77_LO, 2     ; right adjust 13-bit 2's complement temperature value into TC77_HI:TC77_LO
    goto MAINLOOP

; right adjust 13-bit 2's complement temperature value into TC77_HI:TC77_LO
    bcf STATUS, C        ; clear carry bit
    rrf TC77_HI, F       ; rotate right TEMP_HI:TEMP_LO 3 bits
    rrf TC77_LO, F
    bcf STATUS, C        ; clear carry bit
    rrf TC77_HI, F
    rrf TC77_LO, F
    bcf STATUS, C        ; clear carry bit
    rrf TC77_HI, F
    rrf TC77_LO, F

; if temperature is negative, save the sign bit and complement
    btfsb TC77_HI, 4
    bbsf FLAG, SIGN_BIT
    btfsb TC77_HI, 4
    bccf FLAG, SIGN_BIT
btfss   FLAG, SIGN_BIT     ; temperature is positive, jump ahead
  goto   ML00
bsf    TC77_HI, 7          ; sign extend bits 15:13 in TEMP_HI
bsf    TC77_HI, 6
bsf    TC77_HI, 5
comf    TC77_HI, F         ; 2's complement
comf    TC77_LO, F
incf    TC77_LO, F
btfsc   STATUS, C
incf    TC77_HI, F

; display temperature in F (no push button press) or C (push button pressed)
ML00
btfss   SW1                  ; is push button SW1 pressed?
  goto   ML20
  ; no, jump ahead

to convert C to F:
; multiply temperature by 9
movfw   TC77_HI              ; move TC77_HI:TC77_LO to TEMP_HI:TEMP_LO
movwf   TEMP_HI              ; (save original temperature in TC77_HI:TC77_LO)
movfw   TC77_LO
movwf   TEMP_LO

; left shift 3 (multiply by 8)
bcf    STATUS, C            ; clear carry bit
rlf    TEMP_LO, F           ; rotate left TEMP_HI:TEMP_LO 3 bits
rlf    TEMP_HI, F
bcf    STATUS, C            ; clear carry bit
rlf    TEMP_LO, F
rlf    TEMP_HI, F
bcf    STATUS, C            ; clear carry bit
rlf    TEMP_LO, F
rlf    TEMP_HI, F

; add TC77_HI:TC77_LO (multiply by 9)
movfw   TC77_LO
addwf   TEMP_LO, F
btfsc   STATUS, C
  incf   TC77_HI
  addwf   TEMP_HI, F          ; result is in TEMP_HI:TEMP_LO

; divide results by 5
clrf    TC77_HI
clrf    TC77_LO
ML05
movlw   D'5'                ; subtract 5 from TEMP_LO
subwf   TEMP_LO, F
btfsc   STATUS, C
  goto   ML10
  ; no, jump ahead
movlw   D'1'
subwf   TEMP_HI, F          ; yes, borrow from TEMP_HI
btfss   STATUS, C
  goto   ML15
  ; yes, we are done, jump ahead
ML10
movlw   D'1'
addwf TC77_LO, F       ; no, increment TC77_HI:TC77_LO
btfsc STATUS, C        
incf TC77_HI, F        
goto ML05             ; do it again

; add 32 (0x0200)
ML15
movlw 0x02
addwf TC77_HI, F      ; result is in TC77_HI:TC77_LO

; end C to F conversion
; round result to integer value
ML20

; rotate right 3
bcf STATUS, C          ; clear carry bit
rrf TC77_HI, F         ; rotate right TC77_HI:TC77_LO 3 bits
rrf TC77_LO, F
bcf STATUS, C          ; clear carry bit
rrf TC77_HI, F
rrf TC77_LO, F
bcf STATUS, C          ; clear carry bit
rrf TC77_HI, F
rrf TC77_LO, F

; round
movlw D'1'
addwf TC77_LO, F
btfsc STATUS, C        
incf TC77_HI, F        

; rotate right 1
bcf STATUS, C          ; clear carry bit
rrf TC77_HI, F
rrf TC77_LO, F
bcf STATUS, C          ; clear carry bit
rrf TC77_HI, F
rrf TC77_LO, F

; convert into Binary Coded Decimal (BCD) format
clr BCD_H              ; clear the BCD registers
clr BCD_T
clr BCD_O

; hundreds digit
ML25
movlw D'100'
subwf TC77_LO, W       ; subtract 100 (result goes into W)
btfss STATUS, C        ; was result negative?
goto ML30
incf BCD_H, F          ; no, increment BCD_H register
movwf TC77_LO           ; save result
goto ML25               ; do it again
ML30
movlw D'10'
subwf TC77_LO, W       ; subtract 10 (result goes into W)
btfss STATUS, C ; was result negative?
goto ML35

incf BCD_T, F ; no, increment BCD_T register
movwf TC77_LO ; save result
goto ML30 ; do it again

ML35
movfw TC77_LO
movwf BCD_O ; save result as BCD_O

; display on PICkit 1 FLASH Starter Kit LED's D7:D0
movfw BCD_O ; move BCD Ones to TEMP
movwf TEMP

swapf BCD_T, W ; swap BCD Tens nibbles
iorwf TEMP, W ; inclusive or and store in TEMP

movwf LEDREG

goto MAINLOOP

;-------------------------------------------------------------------------------
; Data EEPROM Memory (Section 8.0)
;
; PIC12F630/676 devices have 128 bytes of data EEPROM with address
; range 0x00 to 0x7F.

; Initialize Data EEPROM Memory locations

; ORG     0x2100
; DE      0x00, 0x01, 0x02, 0x03

;-------------------------------------------------------------------------------
; Calibrating the Internal Oscillator (Section 9.2.5.1)
; Oscillator Calibration Register (OSCCAL) (Section 2.2.2.7)
;
; The below statements are placed here so that the program can be
; simulated with MPLAB(r) SIM or emulated with the ICD2 or ICE-2000.
; The programmer (PICkit(tm) or PRO MATE(r) II) will save the actual OSCCAL
; value in the device and restore it. The value below WILL NOT be
; programmed into the device.

org 0x3ff
retlw 0x80 ; Center Frequency

;-------------------------------------------------------------------------------
end ; end of program directive
;-------------------------------------------------------------------------------
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