Implementing a Direct Thermocouple Interface With the MSP430F4xx and ADS1240

ABSTRACT

This application report describes how to implement a direct thermocouple interface without using the signal conditioning circuitry normally required for thermocouples. The thermocouple interfaces directly to the ADS1240 24-bit analog-to-digital converter (ADC). An MSP430F413 ultra-low-power microcontroller (MCU) is used to communicate with the ADC, read the conversion values, convert them to temperature, and display them on an LCD. Although an MSP430F413 is used for this application report, any MSP430™ MCU could be used to implement this application.

This document includes a complete schematic and code listing. The code can also be downloaded from http://www.ti.com/lit/zip/slaa125.

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1 Introduction

Thermocouples typically require signal conditioning to amplify the thermocouple voltage into the ADC range and to provide any offset that is required. This application report describes how a high-resolution ADC, such as the 24-bit ADS1240, can be used to implement a direct thermocouple interface without the need for signal conditioning. The thermocouple is connected directly to the inputs of the ADC. An MSP430F413 MCU communicates with the ADS1240 to read the ADC values, convert the ADC values into temperature, and display the temperature on the LCD. For this application report, a type K thermocouple was used, and the temperature range was limited to 0°C to 99.9°C.

2 Thermocouples

Thermocouples are constructed of two dissimilar metals welded at one end. They produce a voltage at the nonwelded end that is relative to the temperature difference between the two ends of the thermocouple. There are many types of thermocouples and much has been written on thermocouples and thermocouple usage. A simple search on the Internet can provide a host of useful information for anyone wanting to learn the intricate details of thermocouples and thermocouple usage that are not covered in this report.

The voltage produced by thermocouples depends on the temperature difference between the ends of the thermocouple. It is not enough to simply measure the voltage to determine the temperature. That measurement gives only the temperature difference between the two ends of the thermocouple. The temperature of the cold junction (the connection of the thermocouple to the measuring device) affects the voltage produced at the thermocouple end. As a result, some type of cold junction compensation is required. Often, circuits are employed to produce a voltage proportional to the cold junction temperature. This voltage is injected into the circuit and is part of the typical thermocouple signal conditioning circuitry.

Another technique of cold junction compensation involves measuring the temperature of the junction with a thermistor or some other type of temperature sensor. This is the technique employed in this report. In this technique, the temperature of the welded end of the thermocouple can be determined from knowing the cold junction temperature and measuring the thermocouple voltage. For accurate results, this technique requires the use of an isothermal block to assure the temperature of the cold junction temperature sensor is the same as the temperature of the cold junction.

The voltage that thermocouples produce is standardized by the National Institute of Standards and Technology. Data tables for thermocouple voltages are available from the NIST.
3 Application Circuit

Figure 1 shows the circuit diagram for the circuit used in this application report. Section 5 includes a complete schematic.

- A thermistor is used to provide cold junction compensation.
- Several pins from port P1 on the MSP430F413 are used to implement serial communication with the ADS1240.
- A voltage divider is used to bias the negative terminal of the thermocouple.
- The ADS1240 is clocked from the MCLK output of the MSP430F413.
- The clock frequency is set at 1.5 MHz.
4 Implementation and Code Details

Figure 2 shows the program flow. The following sections describe this program flow.

![Program Flow Diagram](image)

Figure 2. Program Flow
4.1 Initialization and Setup

The MSP430F413 and the ADS1240 are both initialized after a reset. On the MSP430F413, the watchdog timer is disabled. The FLL+ and DCO are configured to generate an MCLK of 1.507 MHz. This frequency is used for the CPU and is used externally to clock the ADS1240. This frequency was chosen for the ADS1240 because it is fast enough for the application but allows some power savings over the nominal 2.4576-MHz reference in the ADS1240 data sheet. The Basic Timer and LCD modules are configured for the LCD, and the LCD memory is cleared. The I/O ports are configured for desired function, direction and interrupt edge. The unused I/O ports are set to the output direction. A delay is implemented before calling the ADC setup routine. The delay allows the FLL+ time to adjust the DCO to the desired frequency of 1.507 MHz. For more information on the FLL+, DCO, or any other MSP430F413 peripheral, refer to the MSP430x4xx Family User’s Guide. For more information on the MSP430F41x devices, see the MSP430x41x Mixed-Signal Microcontrollers data sheet.

To setup the ADS1240, a reset command is issued first. Then the input multiplexer is set for channel 0 and 1 for the plus and minus inputs, respectively. These are for the plus and minus sides of the thermocouple. The data rate is selected for the ADS1240 as the slowest it offers. This results in approximately 2.3 conversions per second, rather than the 3.75 listed in the data sheet, because the values in the data sheet assume a clock of 2.4576 MHz, but this application uses a clock of 1.5 MHz. When writing to successive registers of the ADS1240, it is not necessary to send the WREG command each time (see the ADS1240 24-Bit Analog-to-Digital Converters data sheet for more details).

Interrupts are enabled on the MSP430F413, and the SELFGCAL command is issued to the ADS1240. The SELFGCAL command works best when the PGA = 1, and it requires some time to complete. The DRDY line of the ADS1240 goes low to signal the completion of the SELFGCAL process. Interrupts are enabled on the MSP430F413 to allow the MSP430F413 to enter low-power mode 0 (LPM0) while the SELFGCAL process is being executed and to be interrupted by the ADS1240 when the process completes. Finally, the programmable gain amplifier (PGA) is set to a gain of 16 and the SELFOCAL command is issued. For more information on the ADS1240, refer to the ADS1240 24-Bit Analog-to-Digital Converters data sheet.

4.2 Mainloop

The mainloop is a succession of calls to other routines with a statements to enter LPM0. The first instruction of the mainloop puts the MSP430F413 into LPM0. The MSP430F413 stays in LPM0 until the DRDY line from the ADS1240 goes low, signaling that data is ready to be read. When the DRDY line goes low, the MSP430F413 receives the P1.0 interrupt and awakens to service it. The interrupt service routine then clears the appropriate status register bits so the MSP430F413 returns from the interrupt in active mode. Next, a call is made to the routine that reads the ADS1240. This value is for the thermocouple. Upon return from that routine, the MSP430F413 is again put into LPM0 to wait for the next DRDY. After the next DRDY, the ADS1240 is ready to be read again, so a call is made to the routine to read the thermistor value (see Figure 2). Upon return from reading the thermistor value, the MSP430F413 is ready to determine the temperature. Interrupts are disabled and calls are made to routines that convert the thermistor and thermocouple ADC values into their respective temperatures and then a call is made to determine the absolute temperature based on the thermistor and thermocouple temperatures. After the temperatures are determined, interrupts are re-enabled and a call is made to display the absolute temperature on the LCD. Then the mainloop starts over.

4.3 ReadTC and ReadTR Routines

The ReadTC and ReadTR routines read the thermocouple and thermistor values, respectively, from the ADS1240. Each routine sends the RDATA command and then clocks the data out of the ADS1240. Then, each routine sets up the PGA and multiplexer settings of the ADS1240 for the next conversion. The routine to read the thermocouple value sets up the ADS1240 to perform a conversion on the thermistor. The thermistor ADC value is then available at the next assertion of DRDY. Likewise, the routine to read the thermistor value sets up the ADS1240 to perform a conversion on the thermocouple.
4.4 Get_TR_Temp – Determining the Thermistor Temperature

To read the thermistor in this application a resistor divider is formed with a 10-kΩ resistor and 10-kΩ thermistor. The top of divider is connected to the reference and bottom to ground. This provides a voltage input to the ADC that varies with temperature. Thermistor values decrease as temperature increases, so the voltage from this divider decreases with temperature as well (see Figure 1). Perhaps a more common way of measuring a thermistor is with a slope analog-to-digital conversion. A slope conversion was not employed in this application, because a high-performance precision ADC was already available, and performing the slope analog-to-digital conversion would have unnecessarily complicated the application and the code. A complete application report with code examples are available to show how to perform a slope analog-to-digital conversion with the MSP430F4xx MCUs (see the MSP430 Based Digital Thermometer application report).

To determine the thermistor temperature from the ADC value, first a table lookup is performed to determine the temperature to the nearest degree. Then, an interpolation is done to determine the temperature to the nearest tenth of a degree. To do this, first the nearest whole degree temperature is multiplied by 10 and saved to RAM. Then, the tenths are determined from Equation 1.

\[
\text{higher} - \text{ADCvalue} \times 10 \over \text{higher} - \text{lower}
\]

where
- ADCvalue = ADC conversion value of thermistor voltage
- higher = the next higher value in the table
- lower = the next lower value in the table

(1)

After the tenths are interpolated, they are added to the nearest whole temperature that was multiplied by ten previously. Now the thermistor temperature is stored in the form of XX.X in binary format.

The table of thermistor values shown in the code in Section 6 is specific to this application. This table uses measured values for the 10-kΩ resistor and for the ADC reference and uses only 16 of the 24 ADC bits. Equation 2 shows the general formula for computing the table.

\[
\text{ADCvalue} = \text{hex} \left( 2^N \times \frac{\text{voltage}}{2 \times \text{Vref}} \right)
\]

where
- N = Desired resolution of the analog-to-digital conversion (the ADS1240 is a 24-bit ADC, but for this application only the upper 16 bits are used, so in this case, N is 16).
- voltage = Resulting voltage from the voltage divider
- Vref = Reference for the ADS1240

(2)

For this application, Equation 3 shows the equation for the voltage divider.

\[
\text{voltage} = \frac{V \times Rt}{Rt + 10k}
\]

where
- Rt = Thermistor resistance
- V = Voltage source for the divider – Vref in this application

(3)

Combining the two equations results in Equation 4.

\[
\text{ADCvalue} = \text{hex} \left( \frac{2^N \times \text{Vref} \times Rt}{2 \times \text{Vref} \times \left( \frac{Rt}{Rt + 10k} \right)} \right)
\]

(4)

Which reduces to Equation 5.

\[
\text{ADCvalue} = \text{hex} \left( \frac{2^{N-1} \times Rt}{Rt + 10k} \right)
\]

(5)
4.5 **Get_TC_Temp – Determining the Thermocouple’s Relative Temperature**

Converting a thermocouple voltage measurement into temperature can sometimes be a difficult task, depending on the application, because of the nonlinearity of thermocouples. However, this application report simplifies the task by limiting the measurable temperature range and by using a table lookup rather than a mathematical calculation. A type K thermocouple was used for this application report.

Determining the thermocouple relative temperature is done with a lookup table and tenths interpolation, the same as was described in Section 4.4 for the thermistor temperature. If the temperature of the thermocouple tip is less than the cold junction temperature, the voltage from the thermocouple will be negative and the ADC value will be negative. At the completion of the routine, the thermocouple temperature is stored in RAM in the form of XXX.X and has the appropriate sign.

As with the thermistor, the table of values used for the thermocouple temperature lookup is specific to this application and incorporates measured values. Equation 6 shows the general formula for computing the table.

\[
\text{ADCvalue} = \text{hex} \left( \frac{2^N \times \text{PGA} \times \text{Vtc}}{2 \times \text{Vref}} \right)
\]

where
- \( N \) = Desired resolution of the analog-to-digital conversion (the ADS1240 is a 24-bit ADC, but for this application only the upper 16 bits are used, so in this case \( N \) is 16)
- \( \text{PGA} \) = Gain from the programmable gain amplifier
- \( \text{Vref} \) = Reference for the ADC
- \( \text{Vtc} \) = Thermocouple voltage

\[ (6) \]

4.6 **Get_ABS_Temp – Determining the Absolute Temperature**

The Get_ABS_Temp routine adds the thermistor (cold junction) temperature to the relative thermocouple measurement to produce the absolute temperature of the thermocouple tip. After adding, the result is checked to determines if it is negative. If so, it falls outside of the range of this application report (0°C to 99.9°C). However, the range checking is performed in the display routine, not in this routine. Therefore, if the absolute temperature is negative, then it is simply stored in RAM as a negative value. If the temperature is positive, it is converted to the BCD format and stored in RAM in BCD format.

4.7 **DISPLCD – Display the Absolute Temperature on the LCD**

The DISPLCD routine checks the absolute temperature to make sure it is within the specified range. If it is not, either an L or an H is displayed on the LCD to indicate the out-of-range temperature. If the measured temperature is within range, the bits are manipulated appropriately for display on the LCD. The code in this application report is written for demonstration purposes and must be modified for the LCD of your choice.
5 Circuit Schematic

Figure 3 shows a schematic of the circuit used in this application.
6 Application Code

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#include "msp430x41x.h"

**************************************************************************

Implement a direct thermocouple interface with the ADS1240 and
MSP430.

Mike Mitchell

MSP430 Applications
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; Other Definitions
#define ADC_HI R14
#define ADC_LO R10
#define TXBUF R7
#define RXBUF R6
#define BITCNT R5

; LCD segment Definitions
a EQU 001h
b EQU 002h
c EQU 010h
d EQU 004h
e EQU 080h
f EQU 020h
g EQU 008h
h EQU 040h

; ADS1240 serial communication definitions
Dout EQU 004h
Din EQU 008h
SCLK EQU 010h
CS EQU 040h

; ADS1240 Register Definitions (Not complete list, see ADS1240 data sheet)
SETUP EQU 000h
MUX EQU 001h
ACR EQU 002h

; ADS1240 Commands (Not complete list, see ADS1240 data sheet)
RDATA EQU 001h
WREG EQU 050h ; The opcode for WREG is <0101 reg xxxx number>
RREG EQU 010h ; The opcode for RREG is <0001 reg xxxx number>
SELFCAL EQU 0F0h
SELFGCAL EQU 0F1h
SYSOCAL EQU 0F3H
SYSGCAL EQU 0F4h
RST EQU 0FEh

;***********************************************************************************
; RAM Locations
;***********************************************************************************
RSEG UDATA0

;***********************************************************************************
; Thermocouple ADC reading, high word
TC_ADC_HI DS 2
; Thermocouple ADC reading, low byte
TC_ADC_LO DS 1
; Thermistor ADC reading, low byte
TR_ADC_LO DS 1
; Thermistor ADC reading, high word
TR_ADC_HI DS 2
; Thermocouple temperature
TC_TMP DS 2
; Thermistor temperature
TR_TMP DS 2
; Absolute temperature (TR_TMP+TC_TMP)
ABS_TMP DS 2
; Used for keeping track of negative TC value
TC_NEG DS 1

;***********************************************************************************
DS 0

RSEG CODE

; Setup uC and ADC
RESET mov #SFE(CSTACK),SP ; define stackpointer
SetupWDT mov #WDTPW+WDTHOLD,&WDTCTL ; Stop Watchdog Timer
SetupFLL mov.b #02Dh,&SCFQCTL ; Set N=45. 46x32KHz = 1.5Mhz
; Set clock for ADS1240 to be above
; min of 1MHz for some margin.
SetupLCD mov.b #LCDON+LCD4MUX+LCDP2,&LCDCTL ; LCD 4Mux, S0-S17
SetupBT mov.b #BTDIV+BTFRFQ1,&BTCTL ; LCD freq.
ClearLCD mov #15,R15 ; Clear 15 bytes of LCD RAM
Clear1 cl.r #15,R15 ; Clear LCD RAM
dec R15 ; All 15 bytes of LCD RAM?
jnz Clear1 ; Not done?
SetupIO mov.b #0ffh,&P5SEL ; Select LCD functions
mov.b #BIT0+BIT1,&P5DIR ; Set output direction
mov.b #BIT1,&P1SEL ; Select MCLK output for pin
mov.b #BIT0,&P1IES ; Select H/L transition for interrupt
; DRDY\ is connected pin P1.0.
mov.b #0,&P1IFG ; The previous instruction could have
; set the P1.0 IFG, so clear it.
mov.b #BIT0,&P1IE ; Enable interrupt on P1.0
mov.b #BIT1+BIT0+BIT2,&P1DIR ; Set direction for serial comm. pins
; MCLK used as OSC input to ADS1240
mov.b #CS,&P1OUT ; Set CS High, everything else low

SetupIO2 ; Set all unused IO ports to output direction
bis.b #BIT5+BIT6+BIT7,&P1DIR
bis.b #0ffh,&P2DIR
bis.b #BIT0+BIT1+BIT2,&P3DIR
bis.b #0ffh,&P6DIR

Delay1 mov #0fffh,R15 ; Delay to allow FLL+ to
loop1 dec R15 ; sync up MCLK
jnz loop1

Call #SetupADC ; Call setup routine for ADC

Mainloop bis.w #LPM0,SR ; Enter LPM0
call #ReadTC ; Read Thermocouple
bis.w #LPM0,SR ; Enter LPM0
call #ReadTR ; Read Thermistor
call #Get_TR_temp ; Determine temperature with tables
; and interpolation
call #Get_TC_temp ; Determine temperature with tables
; and interpolation
call #Get_ABS_temp ; Determine absolute temperature
call #DISPLCD ; Display
jmp Mainloop ; Return to low power mode

; SetupADC ; Routine to setup the ADS1240 ADC
;******************************************************************************
bic.b #CS,&P1OUT ; Take CS\ low to select the ADC.

; Issue reset command
mov.b #RST,TXBUF ; Move Reset command to TX buffer (R15)
mov.b #08h,BITCNT ; Set bit count value
call #TXLoop ; Shift out the Reset command
call #SCLKdlay ; Delay for SCLK

; Set PGA to 16X to amplify thermocouple voltage
mov.b #WREG+SETUP,TXBUF ; Move write register command plus reg
mov.b #08h,BITCNT ; Set bit count value
call #TXLoop ; Shift out command
mov.b #02h,TXBUF ; Second part of write reg command
; Denotes going to write 3 registers total:
; Setup, Mux, and ACR
mov.b #08h,BITCNT ; Set bit count value
call #TXLoop ; Shift out command
mov.b #004h,TXBUF ; Set PGA to 16X
mov.b #08h,BITCNT ; Set bit count value
call #TXLoop ; Shift out command
call #SCLKdlay ; Delay for SCLK

; Select channels 0,1,common for +,- inputs. This is for the thermocouple
mov.b #01h,TXBUF ; Select analog channels for conversion
mov.b #08h,BITCNT ; Set bit count value
call #TXLoop ; Shift out command
call #SCLKdlay ; Delay for SCLK

; Setup up Data rate with ACR register
mov.b #002h,TXBUF ; Select slowest data rate for DRDY\.
mov.b #08h,BITCNT ; Set bit count value
call #TXLoop ; Shift out command
call #SCLKdlay ; Delay for SCLK

; enable interrupts
eint ; Enable interrupts
; Interrupts needed at this point to
; delay for SELFCAL command.

; Issue SELFCAL command
mov.b #SELFCAL,TXBUF ; Move Self cal command to TX buffer
mov.b #08h,BITCNT ; Set bit count value
call #TXLoop ; Shift out the command
bis #LPM0,SR ; Go to sleep until DRDY\ goes low.
; At that point the selfcal is done.
bis.b #CS,&P1OUT ; Take CS\ back high again
ret ; Done setting up ADC.

;******************************************************************************
ReadTC ; Routine to read thermocouple value
;******************************************************************************
bic.b #CS,&P1OUT ; Take CS\ low to select ADC.

; Transfer read data command
mov #RDATA,TXBUF ; Move read command to TX buffer
mov.b #08h,BITCNT ; Set bit count value
call #TXLoop ; Shift out the read command
call #SCLKdlay ; Delay for SCLK
; Get the data from the ADC
  mov    #10h,BITCNT   ; Set bit counter to 16 bits to shift
  call   #RXLoop      ; Call shift routine
  mov    RXBUF,TC_ADC_HI   ; Save off high word of data.
  mov    #08h,BITCNT   ; Set bit counter to 8 to shift in
    ; lower 8 bits of ADC data.
  call   #RXLoop      ; Call shift routine
  mov.b  RXBUF,TC_ADC_LO   ; Save off low byte of ADC data

; Now set mux and gain for thermistor for next ADC read.
  mov.b  #WREG+SETUP,TXBUF   ; Move write register command plus reg
  mov.b  #08h,BITCNT   ; Set bit count value
  call   #TXLoop      ; Shift out command
  mov.b  #08h,TXBUF   ; Second part of write reg command
  mov.b  #01h,TXBUF   ; Shift out command
  mov.b  #08h,BITCNT   ; Set bit count value
  call   #TXLoop      ; Delay for SCLK
  mov.b  #00h,TXBUF   ; Set PGA to 1X. The Thermistor needs no amp.
  mov.b  #08h,BITCNT   ; Set bit count value
  call   #TXLoop      ; Delay for SCLK

; Select channels 2,common for +,- inputs.
  mov.b  #028h,TXBUF   ; Select analog channels for conversion
  mov.b  #08h,BITCNT   ; Set bit count value
  call   #TXLoop      ; Delay for SCLK

; Done reading values, set CS\ high and return
  bis.b  #CS,&P1OUT   ; Take CS\ back high.
  ret

;*****************************************************************************
ReadTR  ; Routine to read thermistor value
;*****************************************************************************
  bic.b  #CS,&P1OUT   ; Take CS\ low to select ADC.

; First read the data for the thermistor
; Transfer read data command
  mov    #RDATA,TXBUF   ; Move read command to TX buffer
  mov.b  #08h,BITCNT   ; Set Bit count value
  call   #TXLoop      ; Shift out the read command
  call   #SCLKdlay    ; Delay for SCLK;

; Get the data from the ADC
  mov    #10h,BITCNT   ; Set bit counter to 16 bits to shift
  call   #RXLoop      ; Call shift routine
  mov    RXBUF,TR_ADC_HI   ; Save off high word of data.
  mov    #08h,BITCNT   ; Set bit counter to 8 to shift in
    ; lower 8 bits of ADC data.
  call   #RXLoop      ; Call shift routine
  mov.b  RXBUF,TR_ADC_LO   ; Save off low byte of ADC data

; Now set mux and gain for thermocouple for next ADC read.
  mov.b  #WREG+SETUP,TXBUF   ; Move write register command plus reg
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```assembly
mov.b #08h,BITCNT ; Set bit count value
call #TXLoop ; Shift out command
mov.b #01h,TXBUF ; Second part of write reg command.
mov.b #08h,BITCNT ; Set bit count value
call #TXLoop ; Shift out command
call #SCLKdlay ; Delay for SCLK

; Set PGA to 16X to amplify thermocouple voltage.
mov.b #004h,TXBUF ; Set PGA to 16X
mov.b #08h,BITCNT ; Set bit count value
call #TXLoop ; Shift out command
call #SCLKdlay ; Delay for SCLK

; Select channels 0,1,common for +,- inputs.
mov.b #01h,TXBUF ; Select analog channels for conversion
mov.b #08h,BITCNT ; Set bit count value
call #TXLoop ; Shift out command
call #SCLKdlay ; Delay for SCLK

; Done reading values, set CS\ high and return
bis.b #CS,&P1OUT ; Take CS\ back high.
ret

TXLoop ; Routine to transmit to the ADS1240 ADC
*****************************************************************************
bis.b #SCLK,&P1OUT ; Set SCLK high
rla.b TXBUF ; Rotate TXBUF through C
jc Set_H ; Jump if C is High
Set_L bic.b #Din,&P1OUT ; Set Dout Low
jmp A
Set_H bic.b #Din,&P1OUT ; Set Dout High
A bic.b #SCLK,&P1OUT ; Set SCLK Low to latch data into ADC
dec.b BITCNT ; Decrement Bit counter
jnz TXLoop ; Continue if not done
ret

RXLoop ; Routine to shift in ADC data
*****************************************************************************
mov #0,RXBUF ; Clear buffer
L1 bis.b #SCLK,&P1OUT ; Set SCLK high.
nop ; Short delay
bic.b #SCLK,&P1OUT ; Set SCLK low
bit.b #Dout,&P1IN ; Latch data into Carry bit
rlc RXBUF ; C -> Receive buffer
dec BITCNT ; Decrement bit counter
jnz L1 ; Continue if not done
ret

SCLKdlay ; Delay loop to meet spec. for SCLK inactive
*****************************************************************************
mov #0Fh,R7 ; load delay value
L2 dec R7 ; decrement
jnz L2 ; repeat until zero
ret

Get_TR_temp ; Determine temperature of thermistor
```
; using tables and interpolation

;******************************************************************************

dint ; Disable interrupts.
mov TR_ADC_HI,R14 ; Move high word of TR data to R14
    ; Not using low byte in this app.
    ; Only using upper 16-bits.
mov #0h,R5 ; Use R5 as table pointer
mov #0h,R13 ; Use R13 for temperature value
cmp TR_Temps(R5),R14 ; Compare A/D high word to table
jge End_TR_Temp ; If Thermistor value is greater than
    ; first value in table, then it's temp
    ; is too low, so end. If equal, then
    ; then temp is = 0.

incl R5 ; Point to second value in table
CMPloop1 cmp TR_Temps(R5),R14 ; Compare again
    ; If equal, need to add one to temp
    ; value then end.
jge End_TR_lookup ; If greater, then end routine
incl R5 ; Point to next value in table
inc R13 ; Add one to temp value
jmp CMPloop1 ; Repeat loop

End_LU_1 incl R13 ; Add one to temp value
incl R5 ; Also need to increment pointer

End_TR_lookup ; Resolved to nearest degree, now multiply by 10 and interpolate tenths.
; After tenths are determined, simply add it. Then will have temp to nearest
; tenth in binary format.

rla R13 ; rotate left
mov R13,R12 ; copy
rla R12 ; rotate the copy two more times
rla R12 ;
add R12,R13 ; then add.
mov R13,TR_TMP ; Save off to RAM

; Interpolate to tenths. Tenths = ((higher-ADCvalue)x10)/(higher-lower)

mov TR_Temps(R5),R13 ; Move table value to R13
decd R5 ; Point to previous value in table
mov TR_Temps(R5),R15 ; Now, the higher is in R15
    ; the ADC value is in R14
    ; and the lower is in R13
sub R13,R15 ; Get delta between lower and higher
mov TR_Temps(R5),R13 ; Move higher table value to R13
sub R14,R13 ; Get delta between ADC value and higher

; Multiply delta between ADC value and higher table value by 10

rla R13 ; rotate left
mov R13,R12 ; copy
rla R12 ; rotate the copy two more times
rla R12 ;
add R12,R13 ; then add.
mov R13,TR_TMP ; Done with x10. Now need to divide

; Divide (higher-ADCvalue)x10 by delta between lower and upper to get tenths
; Dividend = (higher-ADCvalue)x10, which is in R13
; Divisor = (higher-lower), which is in R15

mov #0,R12 ; Use R12 as counter for subtractions
cmp R15,R13 ; Compare to see if R13>R15.
```
jl remainder ; If not, no division, just remainder
Divide1 sub R15,R13 ; Dividend-Divisor -> dividend
inc.b R12
cmp R15,R13 ; Is Dividend>Divisor?
jge Divide1 ; Yes, subtract and increment again
remainder rla R13 ; Multiply remainder by two
cmp R15,R13 ; Is Dividend>Divisor?
jl EndDiv1 ; If not, return
inc.b R12 ; If so, increment counter to round up
EndDiv1 ; Division now done, so Add tenths (R12) to the whole number (TR_TMP)
add R12,TR_TMP ; Now have xx.x (in binary) for the thermistor temperature.
ret ; Done with TR temp. Note interrupts not re-enabled until end of Get_ABS_temp

End_TR_Temp
mov #0h,TR_TMP ; If get here, TR temp is 0 or too low; So store 00.0 as the temp.
ret ; Return. Note interrupts not re-enabled until end of Get_ABS_temp

Get_TC_temp ; Determine temperature of thermocouple
; ; using tables and interpolation
; ;******************************************************************************
mov TC_ADC_HI,R14 ; Move high word of TC data to R14
; Not using low byte in this app.
; Only using upper 16-bits.
mov #0h,R5 ; Use R5 as table pointer
mov #0FFD7h,R13 ; Use R13 for temperature value
; Preload it with -41 deg C.
cmp TC_Temps(R5),R14 ; Compare to table
jl End_TC2 ; Jump if A/D < 1st table value
jeq End_TC1 ; Jump if A/D = 1st table value
CMPloop2 incd R5 ; Point to next value in table
inc R13 ; Add one to temp value
cmp TC_Temps(R5),R14 ; Compare again
jge CMPloop2 ; If R14 greater or equal, loop
End_TC_lookup ; Resolved to nearest degree, now multiply by 10 and interpolate tenths.
; After tenths are determined, simply add it. Then will have temp to nearest tenth in binary format.
rla R13 ; rotate left
mov R13,R12 ; copy
rla R12 ; rotate the copy two more times
add R12,R13 ; then add.
mov R13,TC_TMP ; Save off to RAM
; Interpolate to tenths. Tenths = ((ADCvalue-lower)x10)/(higher-lower)
mov TC_Temps(R5),R15 ; Move table value to register
decd R5 ; decrement table pointer
mov TC_Temps(R5),R13 ; Now, the higher is in R15
; the ADC value is in R14
; and the lower is in R13
sub R13,R15 ; Get delta between lower and higher
sub R13,R14 ; Get delta between ADC value and lower
```

```
/**
 * Get_ABS_temp ; Calculate absolute temperature by adding the TC and TR temps.
 * ;
 * ;**************************************************************************
 */

; Add TR_TMP and TC_TMP to get ABS_TMP
Add_temps mov TC_TMP,R14 ; Put TC_TMP in R14
add TR_TMP,R14 ; Add TR_TMP to it
bit #08000h,R14 ; Test if result is negative
jge Bin_Dec ; If not, proceed with conversion
mov R14,ABS_TMP ; If so, store the negative temp
jmp End_Get_ABS_Temp ; and jump to end

; Now convert to BCD format
Bin_Dec rla R14 ; Shift out upper nibble,
rla R14 ; not used for this
rla R14 ; conversion
rla R14 ;
mov #0Ch,R15 ; Loop counter
clr R12 ; Result goes into R12
L3 rla R14 ; Shift MSB into C
dadd R12,R12 ; Add R14 to itself, plus C
dec R15
jnz L3 ; Jump if not done

; Done converting to BCD
Implementing a Direct Thermocouple Interface With the MSP430F4xx and ADS1240

```assembly
; Save absolute temp in BCD to RAM.
mov   R12,ABS_TMP

End_Get_ABS_Temp
    ; re-enable interrupts
eint
    ret

;******************************************************************************
DISPLCD ; Display temp on LCD.
;
;******************************************************************************
mov   ABS_TMP,R14 ; Get temperature from RAM
bit   #08000h,R14 ; Test if temp is negative
jn     Disp_L ; If so, display "low" on LCD
cmp   #01000h,R14 ; Test if temp >= 100
jge    Disp_H ; If so, display "high" on LCD

; display temp on LCD
mov.b R14,R11 ; Copy lower byte
mov.b R14,R12 ; copy lower byte
rra.b R12 ;
rra.b R12 ;
rra.b R12 ; Rotate right to expose nibble
rra.b R12 ;
swpb R14 ; Swap high and low bytes of data
mov.b R14,R13 ; Copy again
and   #0Fh,R13 ;
and   #0Fh,R12 ;
and   #0Fh,R11 ;
mov.b LCD_Tab(R11),&LCDM1
mov.b LCD.Tab(R12),&LCDM2
bis.b #040h,&LCDM2 ; Turn on decimal point
mov.b LCD_Tab(R13),&LCDM3
mov.b #0h,&LCDM4 ; Clear upper digit
ret

; Display "L" on LCD
Disp_L  mov.b #0h,&LCDM4
        mov.b #0h,&LCDM3
        mov.b #0h,&LCDM2
        mov.b #d+e+f,&LCDM1
        ret

; Display "H" on LCD
Disp_H  mov.b #0h,&LCDM4
        mov.b #0h,&LCDM3
        mov.b #0h,&LCDM2
        mov.b #b+c+e+f+g,&LCDM1
        ret

;******************************************************************************
TR_Temps DW 05DDEh ; 0C
          DW 05CE1h ; 1C
          DW 05BD5h ; 2C
          DW 05AB9h ; 3C
          DW 0598Ah ; 4C
          DW 05848h ; 5C
          DW 0573Dh ; 6C
          DW 05624h ; 7C
          DW 054FBh ; 8C
          DW 053C1h ; 9C
          DW 05274h ; 10C
```

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;**************************************************************************
;
;**************************************************************************

TC_Temps DW 0FD78h ; -40C
DW 0FD87h ; -39C
DW 0FD97h ; -38C
DW 0FDA6h ; -37C
DW 0FDB6h ; -36C
DW 0FDC6h ; -35C
DW 0FDD6h ; -34C
DW 0FDE6h ; -33C
DW 0DF5h ; -32C
DW 0FE05h ; -31C
DW 0FE15h ; -30C
DW 0FE25h ; -29C
DW 0FE35h ; -28C
DW 0FE45h ; -27C
DW 0FE55h ; -26C
DW 0FE65h ; -25C
DW 0FE75h ; -24C
DW 0FE85h ; -23C
DW 0FE95h ; -22C
DW 0FEA6h ; -21C
DW 0FEB6h ; -20C
DW 0FEC6h ; -19C
DW 0FED6h ; -18C
DW 0FEE7h ; -17C
DW 0FEF7h ; -16C
DW 0FF07h ; -15C
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DW OFF18h ; -14C
DW OFF28h ; -13C
DW OFF38h ; -12C
DW OFF49h ; -11C
DW OFF5Ah ; -10C
DW OFF6Ah ; -9C
DW OFF7Bh ; -8C
DW OFF8Bh ; -7C
DW OFF9Ch ; -6C
DW OFFACh ; -5C
DW OFFBDh ; -4C
DW OFFCEh ; -3C
DW OFFD Eh ; -2C
DW OFFEFh ; -1C
DW 00000h ; 0C
DW 00011h ; 1C
DW 00022h ; 2C
DW 00033h ; 3C
DW 00043h ; 4C
DW 00054h ; 5C
DW 00065h ; 6C
DW 00076h ; 7C
DW 00087h ; 8C
DW 00098h ; 9C
DW 000A9h ; 10C
DW 000BAh ; 11C
DW 000CAh ; 12C
DW 000DBh ; 13C
DW 000ECh ; 14C
DW 000FDh ; 15C
DW 0010Eh ; 16C
DW 0011Fh ; 17C
DW 00131h ; 18C
DW 00142h ; 19C
DW 00153h ; 20C
DW 00164h ; 21C
DW 00175h ; 22C
DW 00186h ; 23C
DW 00198h ; 24C
DW 001A9h ; 25C
DW 001BAh ; 26C
DW 001CBh ; 27C
DW 001DCh ; 28C
DW 001E Eh ; 29C
DW 001FFh ; 30C
DW 00210h ; 31C
DW 00222h ; 32C
DW 00233h ; 33C
DW 00244h ; 34C
DW 00255h ; 35C
DW 00267h ; 36C
DW 00278h ; 37C
DW 0028Ah ; 38C
DW 0029Bh ; 39C
DW 002ACH ; 40C
DW 002BEh ; 41C
DW 002CFh ; 42C
DW 002E1h ; 43C
DW 002F2h ; 44C
DW 00303h ; 45C
DW 00315h ; 46C
DW 00326h ; 47C
DW 00338h ; 48C
DW 00349h ; 49C
DW 0035Bh ; 50C
DW 0036Ch ; 51C
DW 0037Eh ; 52C
DW 0038Fh ; 53C
DW 003A1h ; 54C
DW 003B3h ; 55C
DW 003C4h ; 56C
DW 003D5h ; 57C
DW 003E7h ; 58C
DW 003F9h ; 59C
DW 0040Ah ; 60C
DW 0041Ch ; 61C
DW 0042Dh ; 62C
DW 0043Fh ; 63C
DW 00451h ; 64C
DW 00462h ; 65C
DW 00474h ; 66C
DW 00486h ; 67C
DW 00497h ; 68C
DW 004A9h ; 69C
DW 004BAh ; 70C
DW 004CCh ; 71C
DW 004DEh ; 72C
DW 004EFh ; 73C
DW 00501h ; 74C
DW 00513h ; 75C
DW 00524h ; 76C
DW 00536h ; 77C
DW 00548h ; 78C
DW 00559h ; 79C
DW 0056Bh ; 80C
DW 0057Ch ; 81C
DW 0058Eh ; 82C
DW 005A0h ; 83C
DW 005B1h ; 84C
DW 005C3h ; 85C
DW 005D5h ; 86C
DW 005E6h ; 87C
DW 005F8h ; 88C
DW 00609h ; 89C
DW 0061Bh ; 90C
DW 0062Ch ; 91C
DW 0063Eh ; 92C
DW 00650h ; 93C
DW 00662h ; 94C
DW 00673h ; 95C
DW 00685h ; 96C
DW 00696h ; 97C
DW 006A8h ; 98C
DW 006B9h ; 99C
DW 006CBh ; 100C
DW 07FFFh ; Too high

;******************************************************************************
; LCD Table of definitions
; These use the bit definitions defined above
7 Conclusion

While traditional thermocouple circuits can be complex to design and implement, this report shows how new high-resolution ADCs and microcontrollers can simplify the task.

8 References

1. MSP430x4xx Family User’s Guide
2. MSP430x41x Mixed-Signal Microcontrollers data sheet
3. ADS1240 24-Bit Analog-to-Digital Converters data sheet
4. MSP430 Based Digital Thermometer
Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

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