



# uM-FPU Application Note 6

## Measuring Temperature using Thermocouples

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This application note describes how to use the uM-FPU floating point coprocessor to calculate temperature using a thermocouple.

### Introduction

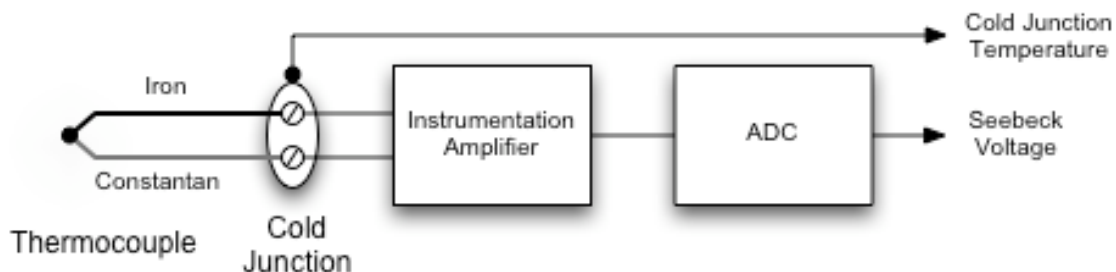
Thermocouples are widely used as an inexpensive and fairly accurate way to measure temperature over a wide range of temperatures. In 1821, Thomas Seebeck discovered that if two dissimilar metals are joined at one end, a voltage will be generated proportional to the temperature difference between the joined and open ends. This voltage is referred to as the Seebeck voltage, and it is typically a few millivolts or less. Several combinations of metals have been chosen as industry standards and each standard thermocouple type is referred to by a capital letter.

**Figure 1 – Thermocouple types**

Thermocouple Type	Metals	Temperature Range
B	Platinum / Rhodium	250 to 1820
E	Chromel / Constantan	-200 to 1000
J	Iron / Constantan	-210 to 1200
K	Chromel / Alumel	-200 to 1372
N	Nicrosil / Nisil	-200 to 1300
R	Platinum / Rhodium	-50 to 1768
S	Platinum / Rhodium	-50 to 1768
T	Copper / Constantan	-200 to 400

Before electronic correction was available, thermocouple measurements were done based on a 0°C reference temperature for the connection point (the open end of the thermocouple). The connection point was typically placed in an ice bath to ensure the temperature was kept near 0°C, and is still referred to as the cold junction. Electronic correction is now used. The temperature of the cold junction is measured and the Seebeck voltage is adjusted to compensate for the difference between the cold junction temperature and 0°C. Figure 2 shows a typical thermocouple connection. An instrumentation amplifier is used to amplify the small Seebeck voltage before applying the value to an analog-to-digital converter.

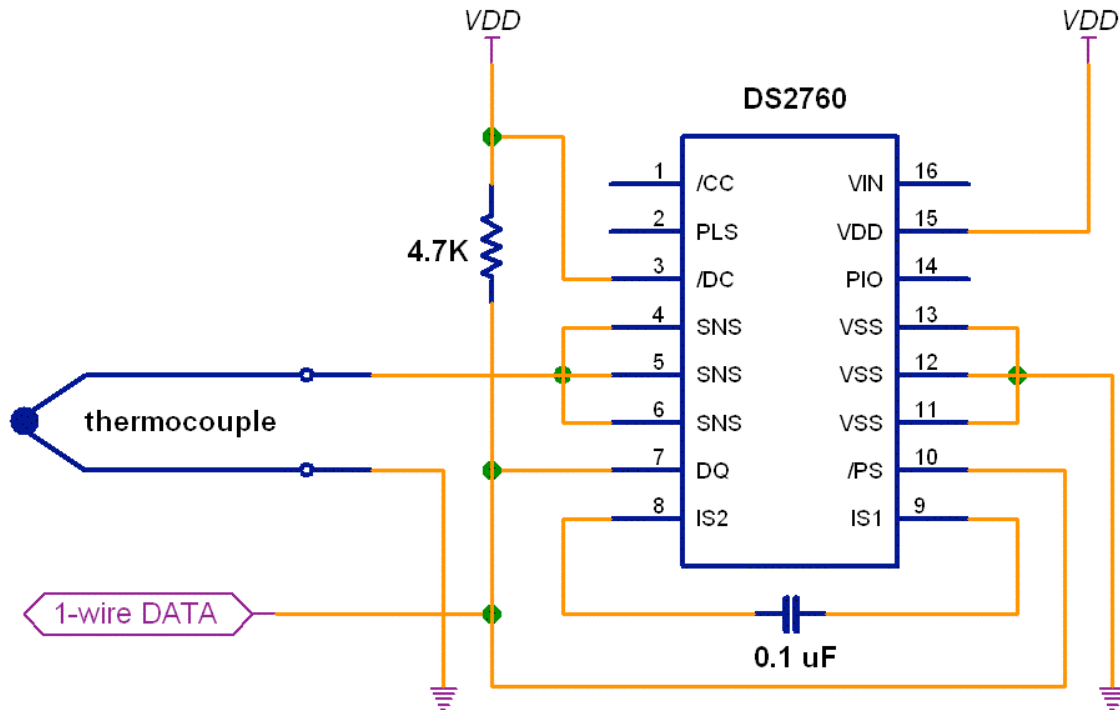
**Figure 2 – Thermocouple Connection (Type J)**



## Thermocouple Example

The Maxim/Dallas DS2760 1-wire High Precision Li+ Battery Monitor chip can be used very effectively as an interface for standard thermocouples as shown in Figure 3. Parallax has produced a thermocouple kit using this chip that provides a convenient circuit board and sample thermocouples.

Figure 3 – DS2760 Thermocouple Connection



The DS2760 provides the instrumentation amplifier for measuring the Seebeck voltage and an integrated temperature sensor for measuring the temperature of the cold junction.

## Calculating Thermocouple Temperatures

Converting the Seebeck voltage to a temperature requires an  $n^{\text{th}}$  order polynomial calculation, but fortunately this is easy to do with the uM-FPU (see *uM-FPU Application Note 5 – Calculating Polynomials*). The National Institute of Standards and Technology (NIST) publishes coefficient tables for the polynomial calculations for all standard thermocouples. The standard tables for converting Seebeck voltage to temperature assume that the cold junction is at  $0^{\circ}\text{C}$ , which is not the case for most modern thermocouple interfaces. To compensate for this, the cold junction temperature is measured to determine the temperature difference from  $0^{\circ}\text{C}$ , and the Seebeck voltage that would be generated by this temperature difference is calculated. This voltage is the compensating voltage, and it is added to the Seebeck voltage to get the adjusted Seebeck voltage. The temperature is then calculated using the adjusted Seebeck voltage.

The steps required to calculate thermocouple temperatures are as follows:

- Step 1 Read the cold junction temperature
- Step 2 Calculate compensating voltage
- Step 3 Read the Seebeck voltage
- Step 4 Add the compensating voltage to the Seebeck voltage
- Step 5 Calculate the temperature for the adjusted Seebeck voltage

The calculations in steps 2 and 4 both involve  $n^{\text{th}}$  order polynomial calculations. The NIST thermocouple database provides coefficient tables for converting from temperature to voltage (used in Step 2) and from

voltage to temperature (used in Step 4). These coefficients are used with the uM-FPU polynomial calculation routine or with the POLY instruction.

### Step 1 Read the cold junction temperature

The cold junction temperature is read from the DS2760 temperature register as a 16-bit value. The lower five bits of the temperature value are undefined, so the value is divided by 32 to shift the value right by five bits. The resolution is 0.125 degrees Celsius, so the value is divided by 8 to convert to temperature in degrees Celsius. These two operations can be combined, so after loading the value and converting it to floating point, the value is simply divided by 256 (32\* 8) to get the cold junction temperature value in degrees Celsius.

```

read 16-bit cold junction temperature to dataHigh, dataLow

SELECTA+X                ; select X as A register
LOADWORD,dataHigh, dataLow ; load DS2760 value to register 0
                          ; convert to floating point
FSET                     ; X = DS2760 value
WRITEB, $43, $80, $00, $00 ; load 256.0 to register 0
FDIV                     ; X = X / 256.0

```

### Step 2 Calculate compensating voltage

To calculate the compensating voltage for the cold junction temperature, a polynomial calculation is done to convert from temperature to mV. A routine is called that calculates the polynomial based on a table of coefficients stored in EEPROM. The first entry in the table is the order of the polynomial (the highest exponent). The next entries are the 32-bit floating point values for the coefficients of the polynomial, from the highest term to the lowest term. An example of the EEPROM data for the polynomial calculation is shown below. For more information on calculating polynomials, see *uM-FPU Application Note 5 – Calculating Polynomials*.

```

DATA      8                ; Type J, Temp to mV, 8th order
DATA      $19, $97, $2E, $47 ; 0.156317256970E-22
DATA      $A0, $14, $06, $FA ; -0.125383953360E-18
DATA      $25, $71, $83, $DA ; 0.209480906970E-15
DATA      $AA, $3F, $FF, $CE ; -0.170529583370E-12
DATA      $2F, $11, $72, $0F ; 0.132281952950E-09
DATA      $B3, $B7, $FF, $AA ; -0.856810657200E-07
DATA      $37, $FF, $A6, $5D ; 0.304758369300E-04
DATA      $3D, $4E, $5C, $81 ; 0.503811878150E-01
DATA      $00, $00, $00, $00 ; 0.000000000000E+00

```

The Type K thermocouple requires an additional exponential term defined as:

$$a_0 \cdot e^{a_1 \cdot (t - a_2)^2}$$

Where  $t$  is the cold junction temperature, and  $a_0$ ,  $a_1$ , and  $a_2$  are defined constants. This is easily calculated using the uM-FPU as follows:

```

SELECTA+X                ; select X as the A register
FSUB+A2                  ; X = X - A2
FMUL+X                   ; X = X * X
FMUL+A1                   ; X = X * A1
EXP                       ; X = exp(X)
FMUL+A0                   ; X = X * A0
SELECTA+Y                ; select Y as the A register
FADD+X                   ; Y = Y + X

```

**Step 3 Read the Seebeck voltage**

The Seebeck voltage is read from the DS2760 current register as a 16-bit value. The lower three bits are undefined, so the value is divided by 8 to shift the value right by three bits. The resolution is 15.625  $\mu\text{V}$ , so the value is multiplied by 0.015625 to get the value in mV. These two operations can be combined, so after loading the value and converting it to floating point, the value is simply multiplied by 0.001953125 (0.015625 / 8) to get the Seebeck voltage in mV.

```

read 16-bit Seebeck voltage to dataHigh, dataLow

SELECTA+X                ; select X as A register
LOADWORD,dataHigh, dataLow ; load DS2760 value to register 0
                          ; convert to floating point
FSET                     ; X = DS2760 value
WRITEB, $3B, $00, $00, $00 ; load 0.001953125 to register 0
FMUL                     ; X = X * 0.001953125

```

**Step 4 Add the compensating voltage to the Seebeck voltage**

The compensating voltage is added to the Seebeck voltage as follows:

```

SELECTA+X                ; select X as the A register
FADD+Y                   ; X = X + Y

```

**Step 5 Calculate the temperature for the adjusted Seebeck voltage**

To calculate the thermocouple temperature a polynomial calculation is done to convert from the adjusted Seebeck voltage to the temperature in degrees Celsius. An example of the EEPROM data for the polynomial calculation is shown below.

```

DATA    7                ; Type J, mV to Temp, 7th order
DATA    $30, $0C, $2F, $49 ; 5.099890E-10
DATA    $B3, $65, $89, $09 ; -5.344285E-08
DATA    $36, $70, $98, $76 ; 3.585153E-06
DATA    $B9, $85, $AD, $52 ; -2.549687E-04
DATA    $3C, $29, $E5, $A2 ; 1.036969E-02
DATA    $BE, $4C, $EC, $5D ; -2.001204E-01
DATA    $41, $9E, $46, $25 ; 1.978425E+01
DATA    $00, $00, $00, $00 ; 0.000000E+00

```

The polynomial calculation to use for a thermocouple changes depending on the temperature range. For each different type of thermocouple there is a polynomial calculation defined for each of two or three temperature ranges. If a thermocouple will be used across a temperature range, the Seebeck voltage can be checked before the temperature conversion, to determine which polynomial calculation to perform. The sample code provides an example of this. See the NIST ITS-90 Thermocouple Database for a full description of the temperature ranges and polynomial coefficients.

**Further Information**

Sample uM-FPU programs that measure temperature using a DS2760 interface and the uM-FPU floating point coprocessor are available for various microcontrollers.

Check the Micromega website at [www.micromegacorp.com](http://www.micromegacorp.com) for up-to-date information.

NIST ITS-90 Thermocouple Database located at <http://srdata.nist.gov/its90/main/>

Parallax DS2760 Thermocouple Kit located at <http://www.parallax.com/>