I2C Thermocouple Circuit For Microcontrollers

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Introduction

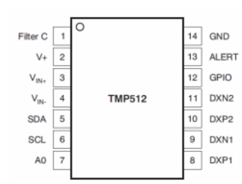
Thermocouples are popular temperature measurement sensors that cover a temperature range from well below zero °C to over a thousand °C. They have good accuracy, are available in many configurations and are inexpensive. This is not to say that they are easy to use! Thermocouple are a measurement challenge:

- *Output levels are less than 50 mV and may be positive or negative*
- *The "cold junction" temperature must be compensated*
- *The output response is non-linear*

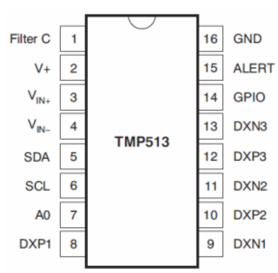
Historically, measurement solutions to meet these challenges have been complex requiring several ICs and many discrete components. A few dedicated single chip solutions exist but all have shortcomings, including cost and availability.

I2C Single-Chip Solution

The TI TMP512/TMP513 Temperature and Power Supply System Monitor provides an ideal single-chip solution for thermocouple measurement. The chip features a 12-bit ADC with an input range of 40 mV that can handle bi-polar signals, and an accurate on-chip temperature sensor for reference junction compensation. Where maximum measurement accuracy is required, external PN temperature sensors may be used to measure temperature at the junction point.



SO-14 Package



SO-16 Package

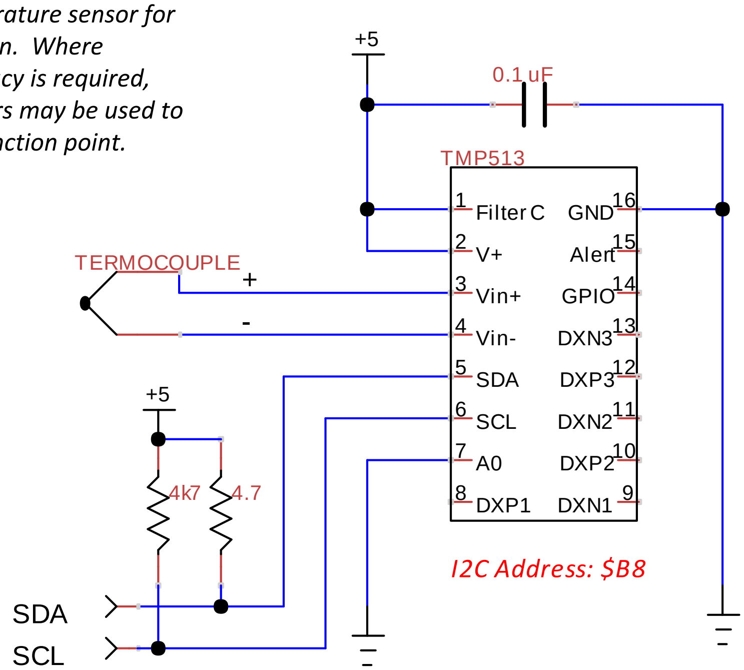
The Circuit

The thermocouple measurement circuit is shown below. Either the TMP512 or TMP513 may be used in the circuit.

The thermocouple is connected between V_{IN}+ and V_{IN}-. The connection between the thermocouple wires and PCB traces or the connection of the thermocouple connector and PCB traces form the reference junction. This should be as close to the TMP51x as possible and away from any heat sources so that the temperature measured by the chip's sensor is a true representation of the reference junction temperature.

If this connection must be made some distance from the chip or the maximum possible accuracy is desired, an external transistor may be used. Some thermocouple connectors even have a clip so that a TO-92-package can be placed right on the terminals.

The simplest circuit implementation is shown below. Input filtering may be added at the thermocouple input – consult the TMP512/ TMP513 data sheet for information on this and on remote temperature sensors.



Software

Only a few features of the TMP512/TMP513 are used by this application so only a few of the registers are accessed. Most options are left in the default state.

Step 1 – Reset the TMP512/TMP513

Do this on program initialization to ensure known state.

Configuration Register 1 ***$00***

Bit #	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Bit Name	RST	ONE-SHOT	BRNG	PG1	PG0	BADC4	BADC3	BADC2	BADC1	SADC4	SADC3	SADC2	SADC1	Mode3	Mode2	Mode1
Value	1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Step 2 – Initialize the TMP512/TMP513

Set the TMP512/TMP513 for thermocouple readings. The default settings for the integral temperature sensor are satisfactory.

Configuration Register 1 ***$00***

Bit #	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Bit Name	RST	ONE-SHOT	BRNG	PG1	PG0	BADC4	BADC3	BADC2	BADC1	SADC4	SADC3	SADC2	SADC1	Mode3	Mode2	Mode1
Value	0	0	0	0	0	0	0	1	1	1	1	0	0	1	0	1

D14: Continuous Measurements
D12, D11: PGA = 1 for T/C Measurement (40 mV range)
D6 – D3: 12-bit Measurement for T/C, 16 averages
D2 – D0: Mode – Shunt Voltage (T/C) only, continuous

Step 3 – Read the Thermocouple Voltage

The thermocouple voltage will be negative if the thermocouple temperature is below the reference junction temperature. A negative value is indicated when the sign bits = 1.

Shunt Voltage Register ***$04***

Bit #	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Bit Name	Sign	Sign	Sign	Sign	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Value																

If the value is negative, the two's complement must be calculated – see the following page.

The value contained in D11:D0 x 10 is the thermocouple voltage in µV if it is positive.

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Calculating the Two's Complement
When the sign bits are negative, the thermocouple temperature is negative with respect to the reference junction. The two's complement must be calculated to determine the negative voltage.

*Invert each bit. The easiest way is to use the **NOT** function:*

```
TCValue = NOT(TCValue)
```

Add 1 to the value:

```
TCValue = TCValue + 1
```

Multiply the result times -10 to obtain the thermocouple voltage in µV; remember to use a variable type that can handle a negative number.

Step 4 – Read the Reference Junction Temperature
D15:D3 contain the local (reference junction) temperature. Read register 4, shift the data right 3 bits (or divide by 8) and multiply the result by 0.0625 to obtain the temperature in °C.

Local Temperature Result Register ***$08***

Bit #	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Bit Name	*T12*	*T11*	*T10*	*T9*	*T8*	*T7*	*T6*	*T5*	*T4*	*T3*	*T2*	*T1*	*T0*	---	*/PVLD*	---
Value																

Calculating the Thermocouple Temperature
The output voltage of the thermocouple is non-linear. The easiest way to calculate the temperature on a microcontroller is using a lookup table. Tables are available on-line for all types of thermocouples. An effective way to achieve good accuracy is to use a table that lists voltages in one degree increments (use a Celsius table for the readings shown here) and interpolate between the values for higher resolution. This keeps the table size reasonable while keeping the accuracy high.

To calculate the actual thermocouple temperature:
- *1. Determine the temperature for the measured thermocouple voltage.*
- *2. Add the reference junction temperature to this value to obtain the actual temperature at the thermocouple junction.*

Sample Code
Sample code in Swordfish Basic for Microchip PIC18F-series microcontrollers and a Type K thermocouple table is available at
Digital-DIY.com, a site devoted to PIC programming and applications..

Alternative Measurement Solutions

MAX6675 - Cold-Junction-Compensated K-Thermocouple-to-Digital Converter (0°C to +1024°C)
MAX6674 - Cold-Junction-Compensated K-Thermocouple-to-Digital Converter (0°C to +128°C)
These Dallas-Maxim use an SPI interface. They are limited to Type-K thermocouples, expensive (~US$15 in single unit pricing) and are difficult to obtain.

AD595: Type K Thermocouple Amplifier with Cold Junction Compensation
AD594: Type J Thermocouple Amplifier with Cold Junction Compensation
The Analog Devices parts have an analog output of 10 mV/°C. The measurement range is limited when using a 0 – 5 volt supply.

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Prototype Build

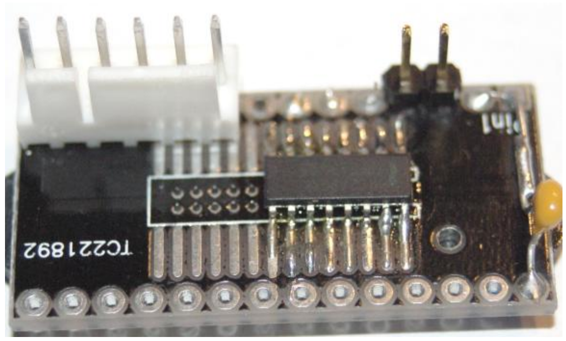
The TMP512/TMP513 circuit is extremely simple. The prototype was built on an SOIC-28 adapter board, which allowed space to add a six-pin connector for use with the TAP-28 PIC application board.

The picture to the right shows a TMP513 mounted to the board along with a 0.1 µF bypass capacitor. The two-pin gold-plated header is for the thermocouple. Point-to-point wiring on the bottom of the board completes the connections.

The six pin header has the I2C SDA and SCL lines along with power and ground.

Initial testing was made using a Type K thermocouple, which provides a measurement range of -269°C to 759°C. The upper end of the range was limited to table values that fit in an integer format (±32767).

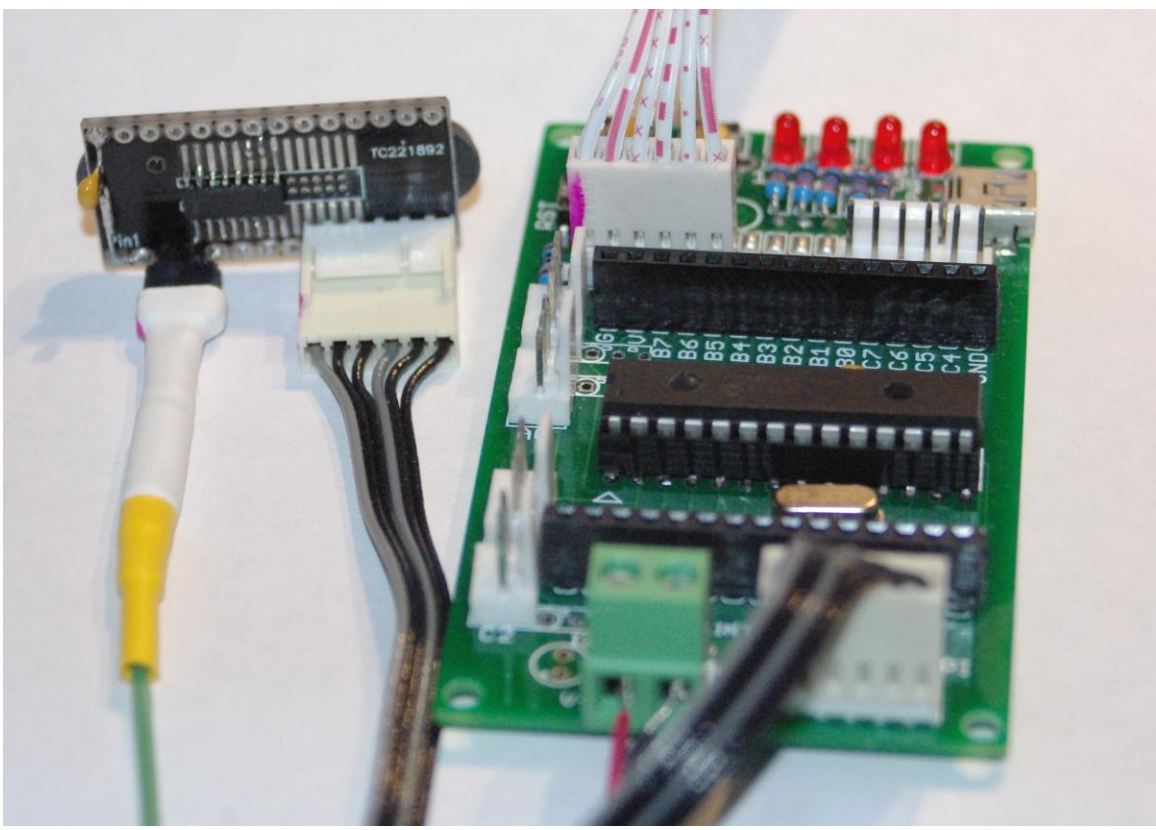
The TAP-28 board used a PIC18F242 with a 20 MHz crystal and hardware I2C although most any type of microcontroller should work fine. The picture below shows the TAP-28 and thermocouple circuit board, connected with a six-conductor cable.



TAP-28 PIC Application Board

The TAP-28 board is designed for low-cost embedded projects and features only the essentials to keep the costs down. Furthermore, all external devices use dedicated connectors for long-term reliability. The TAP-28 supports many PIC18F-series parts in a 28-pin DIP package.

For information about the TAP-28 board, visit www.clever4hire.com/throwawaypic



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