Aim:

To produce a LabVIEW based application to determine the time constant of a Type K thermocouple in water.

Objective 1: construct a cold junction compensation for the thermocouple and provide sufficient gain for subsequent digitization of the signal by means of a moderate performance ADC device (eg NI-USB 6008)

Objective 2: develop a LabVIEW application to extract the time constant from a measured thermocouple transient response by means of an automated fitting procedure.

Objective 1:

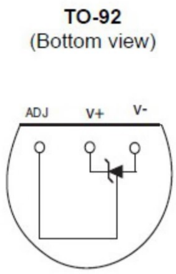
Since we don't have a thermocouple amplifier, we will have to construct a CJC circuit. You have previously characterised an LM335 IC temperature sensor and this is what we will use as our reference compensation device.

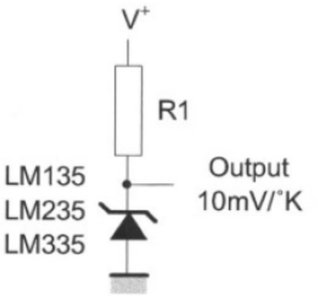
The thermocouple signal is small (sensitivity about 40 μV/degC) and requires significant amplification. An instrumentation amplifier will amplify the raw Tc signal which is proportional to ($Tc-T_{ref}$) but this needs CJC correction. The law of intermediate temperatures gives us:

$$E_{T,0} = E_{T,Tref} + E_{Tref,0}$$

You need to produce signals $E_{T,Tref}$ and $E_{Tref,0}$ which are scaled identically. The LM335 produces 10 mV/K which is a conveniently scaled signal so it makes sense to scale the Tc signal similarly. This can be done in two stages. Most of the work has to be done in hardware via the instrumentation amplifier, giving a signal big enough to present to the ADC, but the final trim will need to be done in software (LabVIEW programme).

You can build the circuit in a modular fashion. One prototyping board can be used for the LM335 (we can recycle one from another module!) and the instrumentation amplifier can be built on a second board.





Basic connection

It makes sense to rationalise the power supply requirements. The INA118 needs ± 12-15 V and the LM335 needs a bias current of 0.5 -5 mA via a resistor and a single ended power supply. If you use +15 V then the resistor has to be chosen to restrict the bias current.

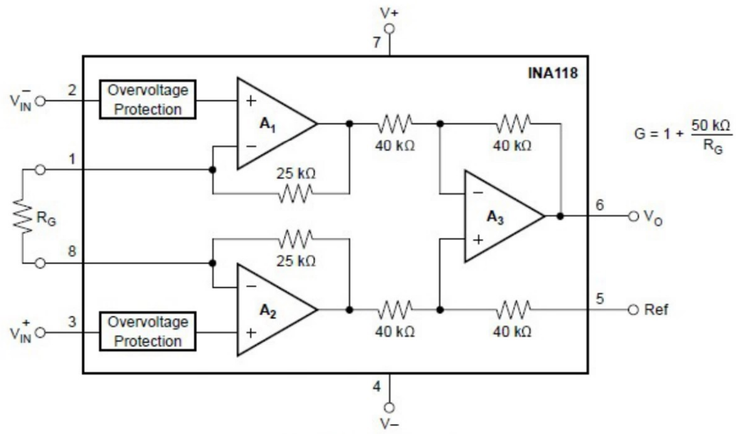
Assuming a sensor output of 3 V (ie 300 K) the resistor value is given by:

15 V = 3V + I_{bias} *R
If you pick I_{bias} = 2 mA then R = (15-3)/0.002 = 6 kΩ

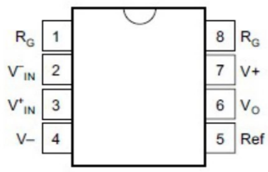
The gain of the instrumentation amplifier INA118 is set by a single external resistor R_G. The gain is:

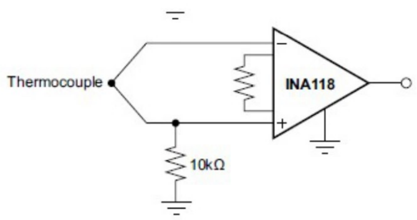
$$G = 1 + \frac{50\ \text{k}\Omega}{R_G}$$

Don't agonise over the exact value of R_G. Just make the Tc signal big enough and use software to trim it exactly.



Simplified Schematic





Objective 2:

A first order temperature sensor, initially at temperature T_o, subject to a positive temperature step change of ΔT, will display the following dynamical temperature response.

$$T(t) = \Delta T[1 - \exp(-t/\tau)] + T_0$$

This function has three fitting parameters, here generalised as *a,b,c*:

$$y(x) = \mathrm{a}[1 - \exp(-x/b)] + c$$

The function is not linear in *b*, so an iterative method must be used to establish the best fit values. (all three parameters have to be fitted at simultaneously, however *a* and *c* are contingent on the experimental parameters (room and water temperature) whereas *b* is a property of the thermocouple).

The fitting routine needs to be presented with a clean transient signal, uncontaminated by the ‘flat’ bit before the step function itself. This would ideally be done using a hardware trigger facility to begin the acquisition on the rising transient. Unfortunately, the USB devices don’t have a hardware trigger. One solution is to capture several (eg 5) seconds of data to include the transient and then use a ‘gate and trigger’ LabVIEW function to isolate the transient.

The iterative non-linear fitting function requires the definition of the function (above) as well as initial values for a,b,c. The initial values generally don’t need to be chosen too carefully. The iterative function will still generally converge.