University of British Columbia
Electrical and Computer Engineering
ELEC291/ELEC292

Project 1 – Reflow Oven Controller

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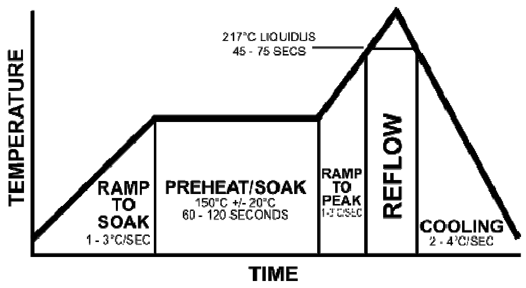
Objectives

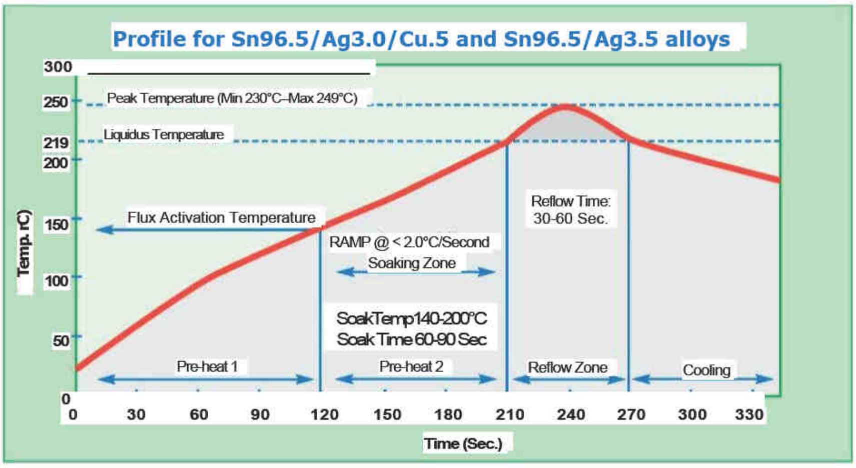
- Learn about reflow soldering thermal profiles.
- Understand the steps used in the assembling of PCBs with SMT components.
- Understand the components of a reflow oven controller.
- Measure temperature using a thermocouple.
- Control and AC load using a Solid State Relay.

Reflow Soldering Profile

http://en.wikipedia.org/wiki/Reflow_soldering

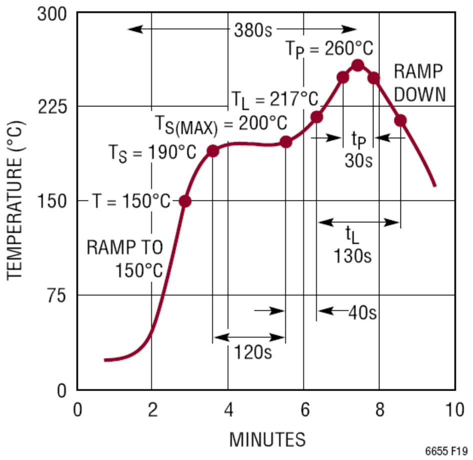


Solder Paste Profile (SAC305)



SMT Component Thermal Profile

Figure is from LTC6655 datasheet



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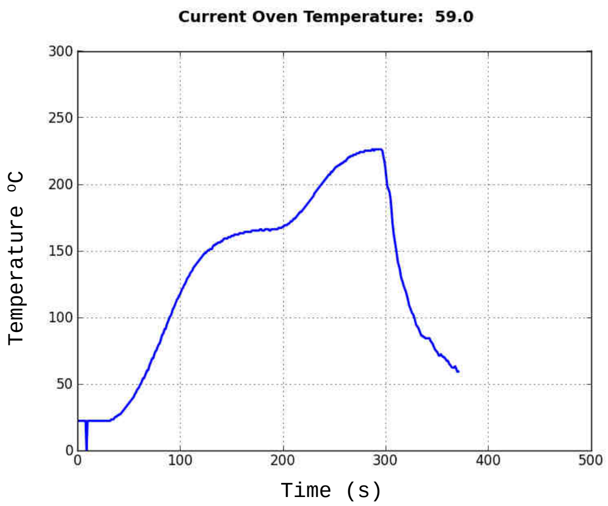
My tests thermal profile



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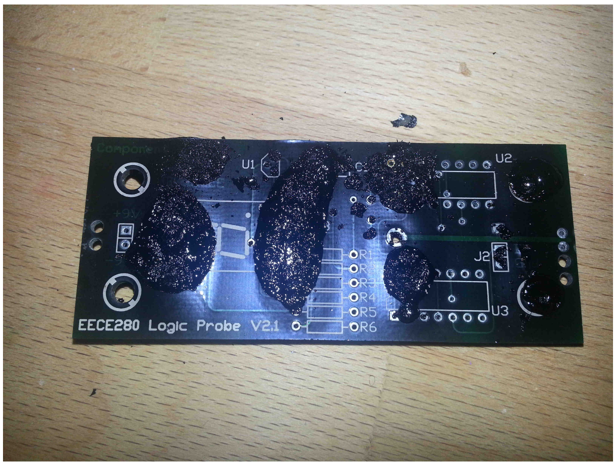
Warnings:

- Don’t let your reflow time be more than 45s or the silk screen may darken.
- Don’t let your reflow max temperature climb over 235 ^{o}C or your PCB may burn: lots of smelly smoke!

PCB Burnt in Reflow Oven



Steps Assembling a PCB with SMT components.

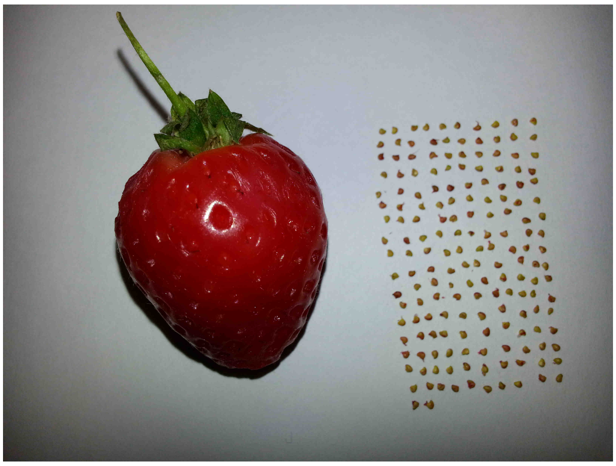
- Step 1: Apply solder paste to the PCB. You will use a Mylar stencil. (I personally believe this is the most critical step in the whole process!)
- Step 2: Place the SMT components into the PCB.
- Step 3: Reflow soldering. You will be using a toaster oven with a controller of your own design.
- Step 4: Hand soldering of TH (thru hole) components.

Steps Assembling a PCB with SMT components.

- Video 1 shows how I applied solder paste.
  http://courses.ece.ubc.ca/281/2015/Step1-Solder_Paste.mp4
- Video 2 shows how I placed the components by hand using tweezers.
  http://courses.ece.ubc.ca/281/2015/Step2-Placing_Components.mp4
- Video 3 shows how I reflow soldered the SMT components using a toaster oven.
  http://courses.ece.ubc.ca/281/2015/Step3-Reflow_soldering.mp4
- Video 4 shows how I soldered the TH components.
  http://courses.ece.ubc.ca/281/2015/Step4-Soldering_Connectors.mp4

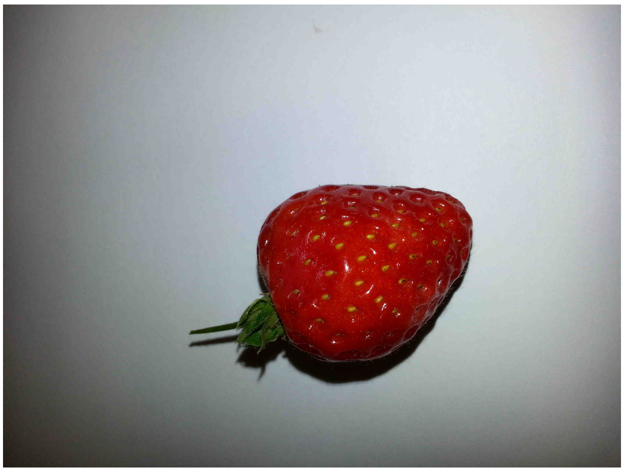
Mastering the Tweezers and Loupe, Step 1: find tools and materials

Mastering the Tweezers and Loupe, Step 2: remove seeds!

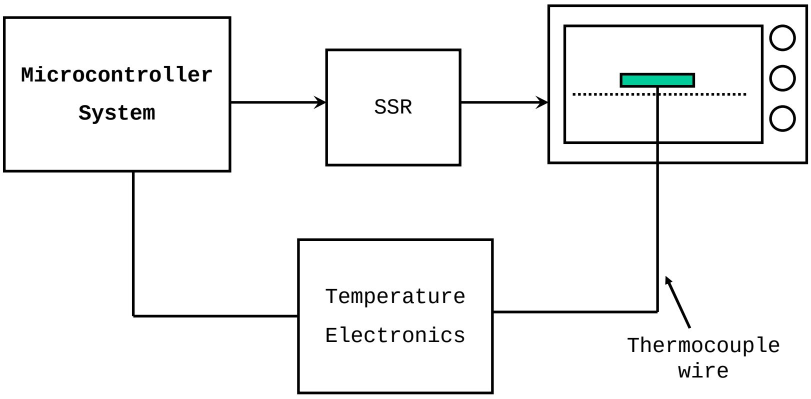


172 seeds!

Tweezers Wizard level: Put the seeds back!



Oven Controller Typical Block Diagram

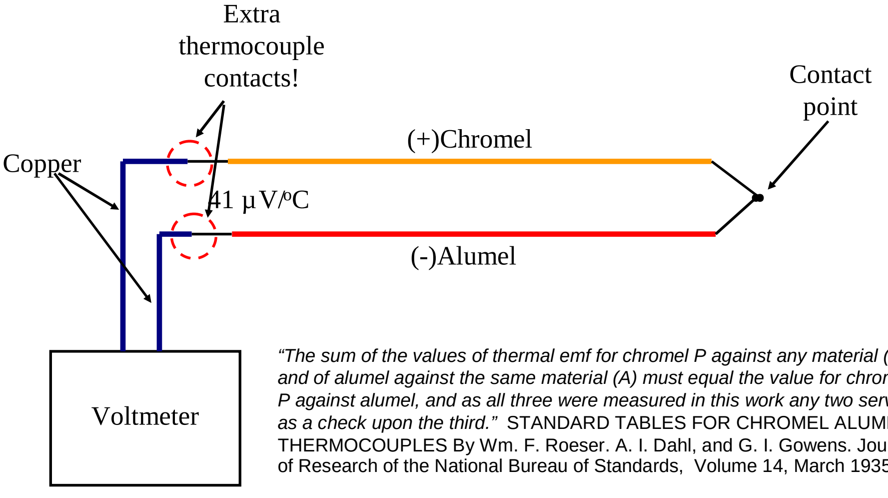


K-Type Thermocouple

- Has two wires: Yellow (+) and Red (-).
- About 41 μV/ºC. You'll need and amplifier!
- Very accurate conversion table provide by the National Institute of Standards and Technology (USA):

  http://srdata.nist.gov/its90/download/type_k.tab

Using a K-type Thermocouple



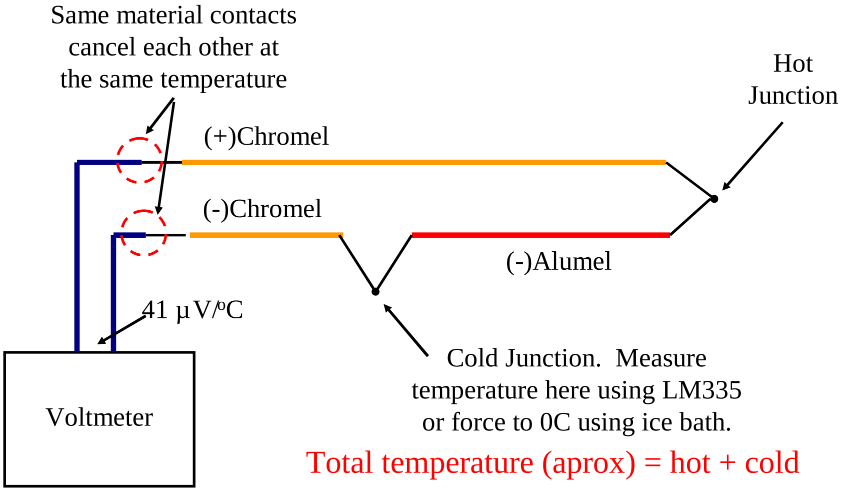
"The sum of the values of thermal emf for chromel P against any material (A) and of alumel against the same material (A) must equal the value for chromel P against alumel, and as all three were measured in this work any two serve as a check upon the third." STANDARD TABLES FOR CHROMEL ALUMEL THERMOCOUPLES By Wm. F. Roeser. A. I. Dahl, and G. I. Gowens. Journal of Research of the National Bureau of Standards, Volume 14, March 1935

Using a K-type Thermocouple

Temp (C)	Chromel-Platinum (mv)	Alumel-Platinum (mv)	Difference	Chromel-Alumel (mv) Table
0.00	0.00	0.00	0.00	0.00
50.00	1.35	-0.67	2.02	2.02
100.00	2.81	-1.29	4.10	4.10
150.00	4.35	-1.78	6.13	6.13
200.00	5.96	-2.17	8.13	8.13
250.00	7.62	-2.53	10.15	10.15
300.00	9.32	-2.89	12.21	12.21
350.00	11.03	-3.26	14.29	14.29
400.00	12.75	-3.64	16.39	16.39
450.00	14.47	-4.03	18.50	18.50
500.00	16.21	-4.43	20.64	20.64

Tables 3 and 5 of: http://nvlpubs.nist.gov/nistpubs/jres/14/jresv14n3p239_A1b.pdf
STANDARD TABLES FOR CHROMEL ALUMEL THERMOCOUPLES By Wm. F. Roeser. A. I. Dahl, and G. I. Gowens. Journal of Research of the National Bureau of Standards, Volume 14, March 1935

Using a K-type Thermocouple

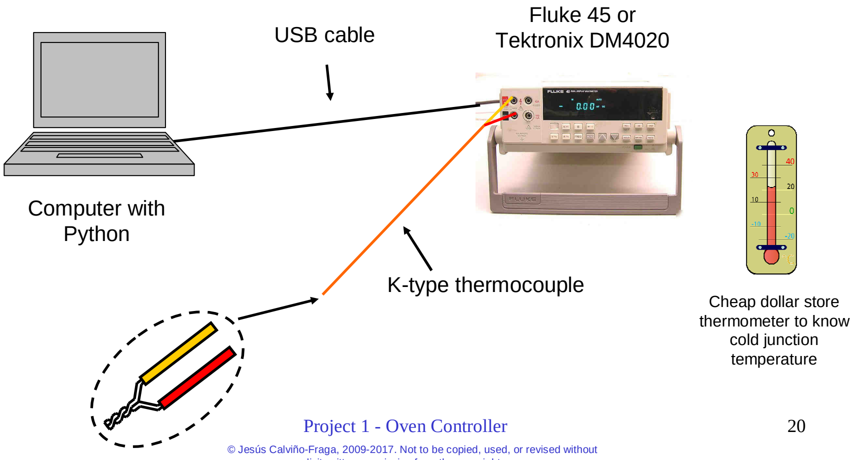


Total temperature (aprox) = hot + cold

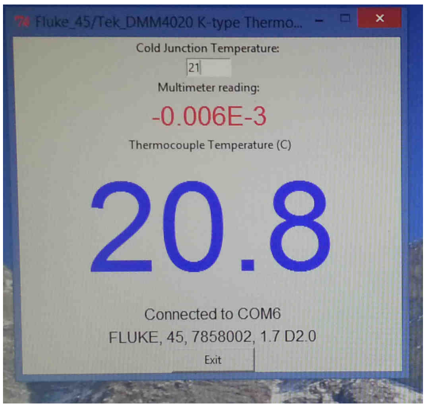
Testing a K-Type Thermocouple in the Laboratory. You'll need:

- Thermocouple wire: included in project kit.
- Voltmeter with micro-volt resolution: Fluke 45 or Tektronix DM4020.
- Ambient temperature in the lab. Most of the time between 20C and 24C. If not measured, use 22C. Or use your LM335!
- USB to serial adapter attached to the multimeter to connect a computer.
- Python 3.4.x and 'kconvert.py' and 'Multimeter_Temp.pyw'

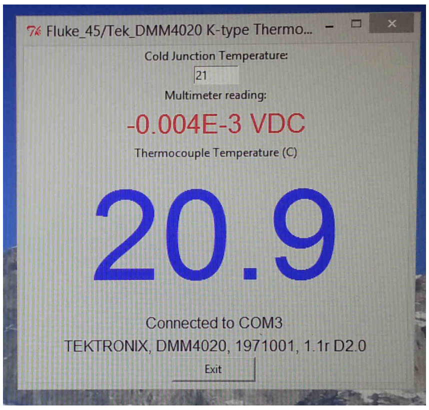
Testing a K-Type Thermocouple in the Laboratory: Setup



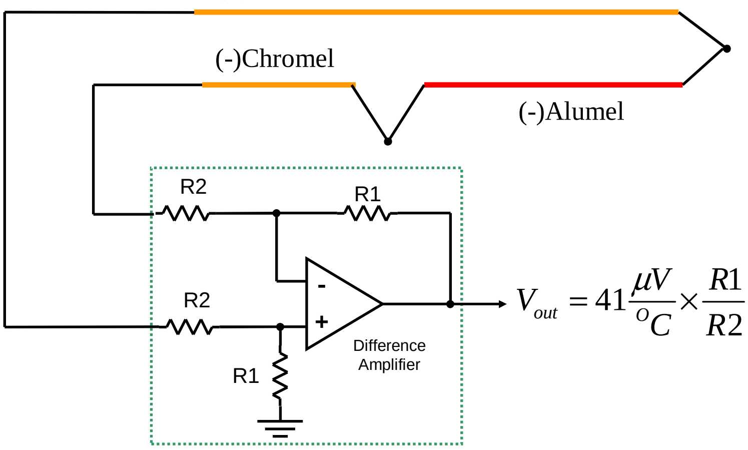
Run ‘Multimeter_Temp.pyw’



Run ‘Multimeter_Temp.pyw’

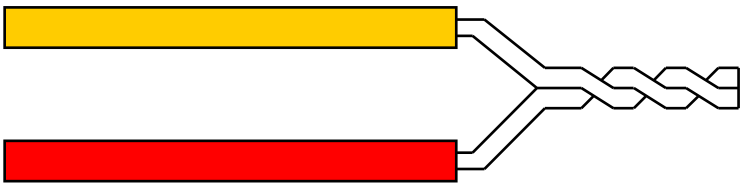


Amplifying the Thermocouple Voltage



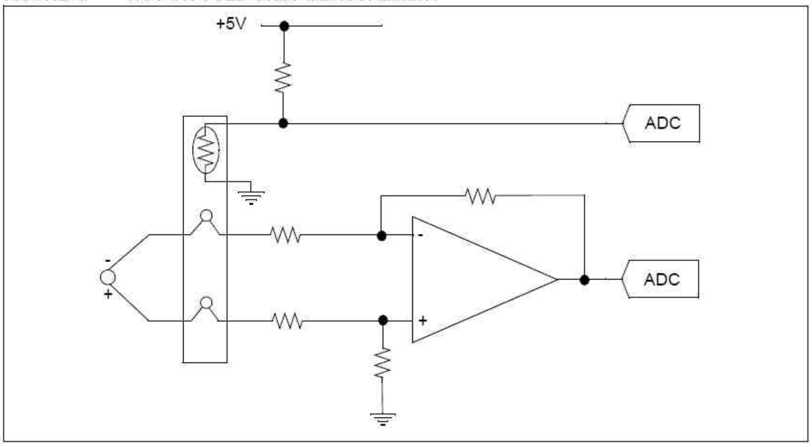
$$V_{out} = 41\frac{\mu V}{^{o}C}\times\frac{R1}{R2}$$

Making the Junctions



Good Reference: Microchip AN844

FIGURE 4: HOT OR COLD ONLY MEASUREMENT



Opamp

- Must have very small input offset voltage, or offset null circuit.
- The OP07 provided in the kit has a typical offset voltage of 50µV. Sometimes is 200 µV! The offset can be null using a potentiometer.
- The OP07 needs dual power supplies, for example +5V and -5V. ICL7660 (or equivalent, included in kits) can be used to produce -5V from +5V.
- Choose the gain carefully! The OP07 will saturate at a voltage below +V.

Temperature Validation Data

- Use the lab multimeter to validate your controller temperature measurements.
- Max acceptable error ±3°C for the range 25°C to 235°C.
- You must include the procedure and the data in the project report. Have it handy for the project demonstration!

Example of controller temperature differences (compared to Fluke 45)

```
 20C ????, ????, ????, +0.7, +0.8, +1.1, +1.4, +1.4, +1.2, +1.3
 30C +1.3, +1.6, +1.0, +0.0, +0.2, +0.0, +0.3, +0.4, +0.9, +0.4
 40C +0.2, +0.2, +0.2, ????, +0.3, +0.0, +0.1, +0.1, +0.2, +0.1
 50C +0.0, +0.1, +0.0, -0.3, +0.2, +0.5, +0.5, +0.4, +0.6, +0.7
 60C +0.6, +0.9, +0.7, +0.7, +0.7, +0.7, +0.3, +0.7, +0.2, +0.4
 70C +0.3, +0.1, +0.4, +0.2, +0.8, +0.4, +0.6, +0.5, +0.2, +0.4
 80C +0.0, +0.1, +0.1, +0.3, +0.1, +0.2, +0.0, -0.1, -0.2, +0.6
 90C +0.8, +0.3, -0.7, +0.0, +0.4, +0.1, -0.2, +0.0, +0.0, -0.9
100C -0.5, -0.2, -0.1, -0.3, -0.5, +0.1, +0.4, +0.1, +0.6, +0.3
110C ????, +0.4, -0.4, +0.2, +0.9, +0.8, -0.3, -0.2, +0.4, -0.6
120C +0.5, -0.2, +1.7, +0.5, +0.1, +0.3, -0.2, -0.1, -0.1, +0.3
130C +0.2, +0.9, +0.6, +0.3, -0.6, +0.2, +0.6, +0.5, +0.6, +1.3
140C +1.0, +0.6, +1.2, +1.3, +0.5, +0.4, +0.9, +0.3, +0.5, +0.6
150C +0.0, +0.8, +0.4, +0.4, +1.1, +1.2, +1.0, +1.3, +1.2, +1.1
160C +1.0, +1.7, +1.0, +1.2, +0.3, +0.4, +0.4, +0.3, +1.1, +0.6
170C +0.6, +1.1, +1.0, +0.9, +0.8, +0.6, +0.6, +0.8, +0.9, +0.9
180C +0.7, +0.6, +0.6, ????, +0.3, +0.8, +1.5, +1.5, +1.5, +1.2
190C +1.0, +0.5, +1.1, +0.6, +0.5, +0.5, +0.7, +0.6, +0.3, +0.4
200C +0.9, +0.8, +1.4, +0.6, +0.9, +0.8, +0.3, +0.4, +0.3, +0.9
210C +0.4, +1.3, +0.3, +0.7, +0.7, +0.4, +0.5, +0.8, +0.9, +0.5
220C +0.9, +0.6, +0.8, +0.9, ????, +0.4, +0.5, +0.7, +0.5, +0.4
230C +0.7, +0.8, +0.2, +0.4, +0.4, +0.9, +0.9, +0.8, +0.8, ????
```

Sources of Error

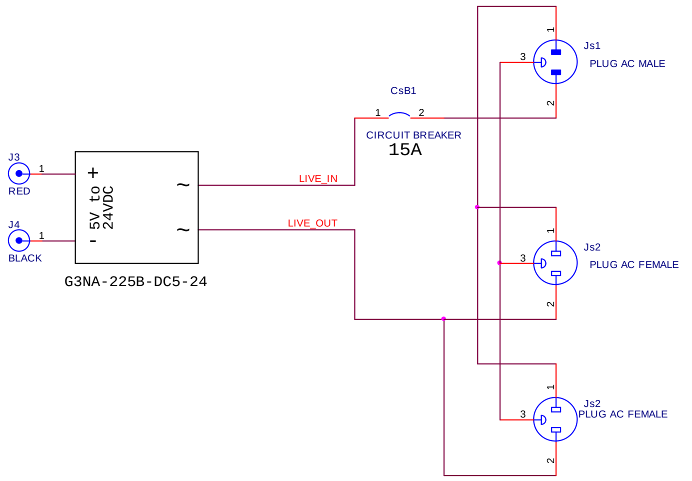
- The amplifier has too much offset. Solution 1: null the offset using a potentiometer. Solution 2: use an ultra low offset op-amp (for example OP177; expensive!)
- Amplifier resistors mismatch resulting in incorrect gain. Solution 1: use the lab multimeter to select resistor that match. Solution 2: buy 1% or 0.1% tolerance resistors (may be expensive!)
- Incorrect cold junction temperature. Solution 1: adjust the output of the LM335 using a potentiometer. You may need an external thermometer or an ice bath to perform a “one point” calibration of the LM335. Solution 2: buy a low error temperature sensor (may be expensive!)
- Conversion from ADC to voltage gives inaccurate values. Solution 1: measure the “Vref” pin of the ADC using the lab multimeter and use that value in your firmware calculations. Solution 2: buy and use a voltage reference IC (expensive!). Solution 3: use LED voltage to calculate VREF.
- The conversion from voltage to temperature introduces unacceptable errors. Solution 1: tune up your calculations. Solution 2: use a look-up table.

Professionalism

- The first tenant of the code of ethics of professional engineers reads[1]: “*Hold paramount the safety, health and welfare of the public, the protection of the environment and promote health and safety within the workplace*”.
- In the spirit of the above tenant, your reflow oven controller must be designed, built, and tested accordingly.
- Please include in your report any features, designs, procedures, as well as other activities you used to accomplish this requirement.

[1] https://www.apeg.bc.ca/getmedia/e8d858f5-e175-4536-8834-34a383671c13/APEGBC-Code-of-Ethics.pdf.aspx

SSR box block diagram



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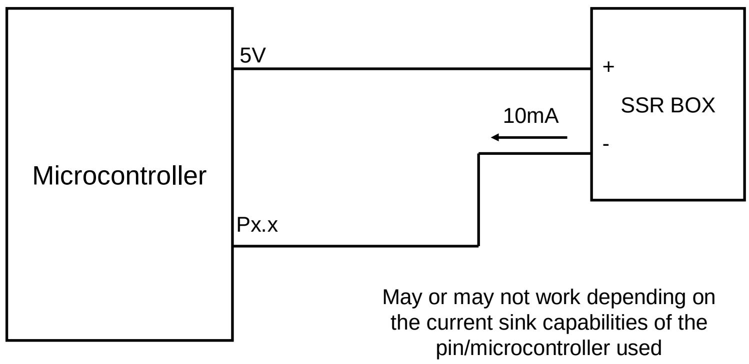
Using a I/O pin to Control SSR Box



May or may not work depending on the current sink capabilities of the pin/microcontroller used

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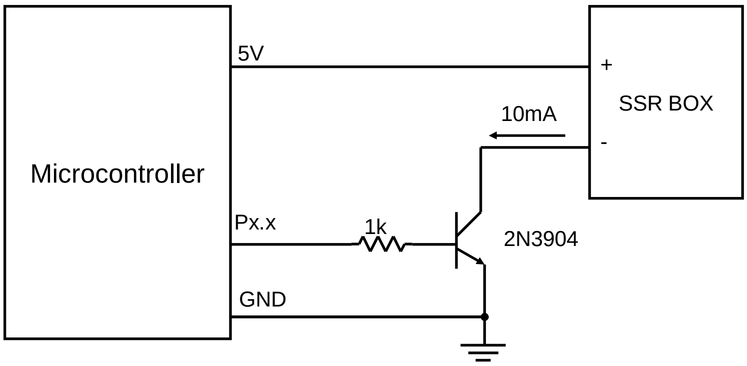
Using a Transistor (more reliable)



Using the SSR box

- Connect a power cord cable to the male AC connector. The power cord cable must be rated for the type of load to be connected. If the SSR box would be used to power a 1500W toaster oven, the power cord cable must be rated for at least 13A.
- Connect the AC load to one of the available AC plugs.
- Apply a DC voltage from 5V to 24V to the control banana plugs.
- We got the SSR box CSA approved!

Using the SSR box

- Do not operate the SSR box for more than 30 minutes at the maximum rated current of 15A.
- The SSR box is designed for resistive loads only. Do not plug inductive loads (such as motors) to the SSR box.
- Do not operate the SSR box if the ambient temperature is above 40^{o}C.
- The SSR box may become warm to the touch after using it for several minutes at maximum rated capacity. If you suspect that the case temperature is over 40^{o}C discontinue using the SSR box immediately.
- Only apply a DC voltage from 5V to 24V to the control pins. Do not apply negative DC voltages of ANY magnitude.
- Do not disassemble the SSR box.
- If the protection breaker is tripped, find and correct the cause of the fault before resetting the breaker to normal operating mode.