University of British Columbia
Electrical and Computer Engineering
ELEC291/ELEC292

Project 1 – Reflow Oven Controller

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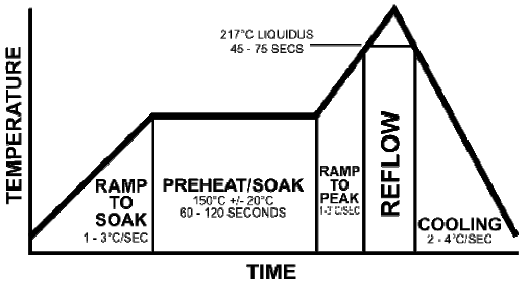
Objectives

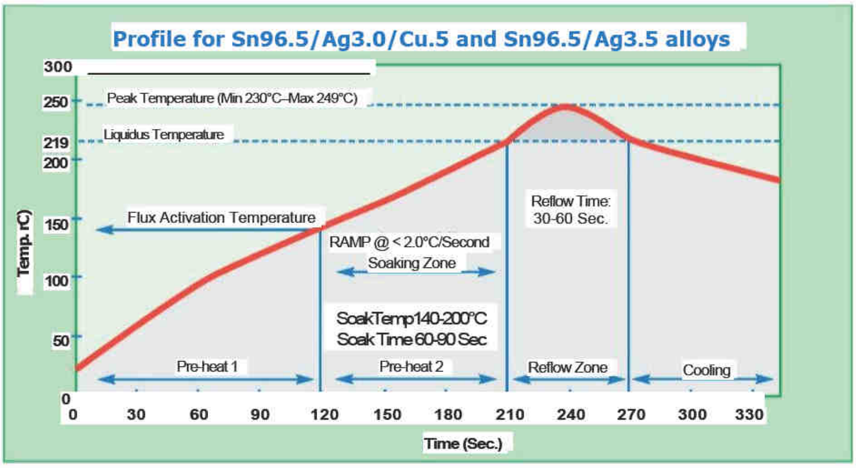
- Learn about reflow soldering thermal profiles.
- Understand the steps used in the assembling of PCBs with SMT components.
- Understand the components of a reflow oven controller.
- Measure temperature using a thermocouple.
- Control and AC load using a Solid State Relay.

Reflow Soldering Profile

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

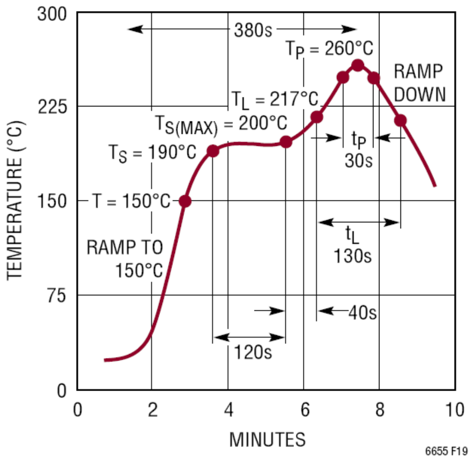


Solder Paste Profile (SAC305)



SMT Component Thermal Profile

Figure is from LTC6655 datasheet



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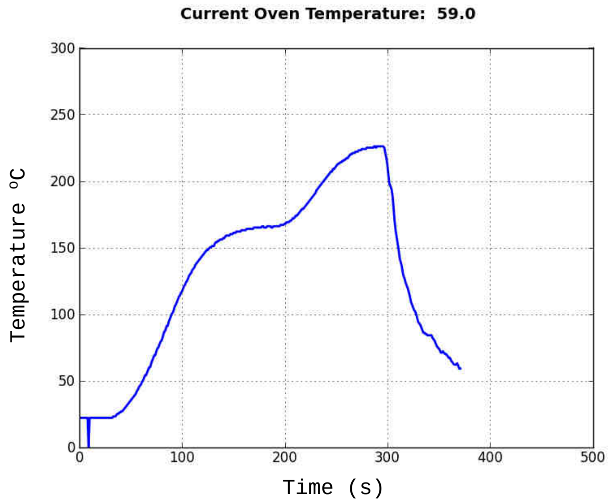
My tests thermal profile



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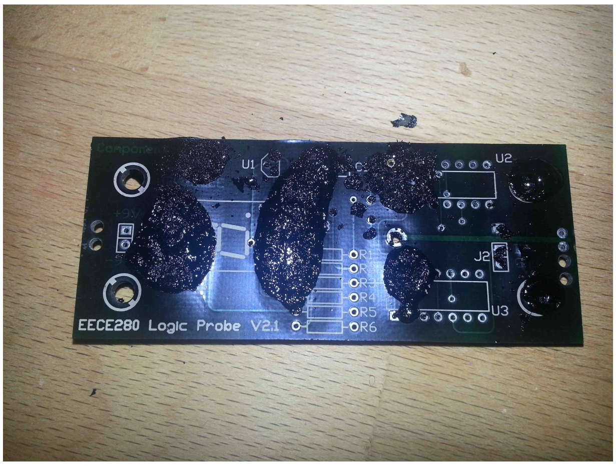
Warnings:

- 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 and placed the components by hand using tweezers.
  http://courses.ece.ubc.ca/281/2017/Paste_and_Components_Slow.mp4
  http://courses.ece.ubc.ca/281/2017/Paste_and_Components_Fast.mp4
- Video 2 Shows how I cleaned the stencil
  http://courses.ece.ubc.ca/281/2017/Cleaning.mp4
- Video 3 shows how I reflow soldered the SMT components using a toaster oven.
  http://courses.ece.ubc.ca/281/2017/Reflow.mp4
- Video 4 shows how to remove a solder bridge
  http://courses.ece.ubc.ca/281/2017/Bridge_removal_horizontal.mp4
- Video 5 shows how I soldered the TH components.
  http://courses.ece.ubc.ca/281/2017/Thru_hole.mp4

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

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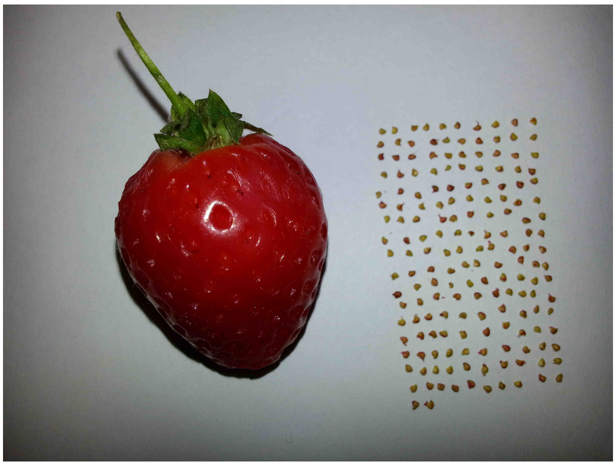
Mastering the Tweezers and Loupe, Step 2: remove seeds!



172 seeds!

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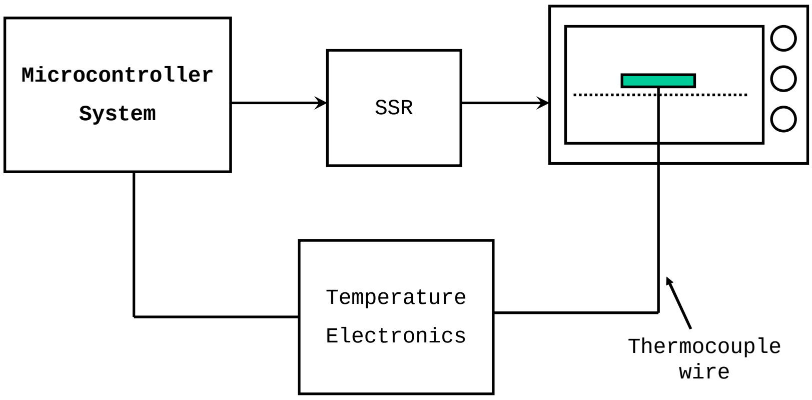
Oven Controller Typical Block Diagram



Microcontroller Requirements

- Must not be an AT89LP51RC2 (or any other member of the AT89LP family from Atmel/Microchip)
- Provided: EECE281 board. Uses the P89LPC9351 microcontroller. 8051 compatible.
- EFM8: Assemble this 8051 microcontroller boards as part of project 1.

Other Requirements

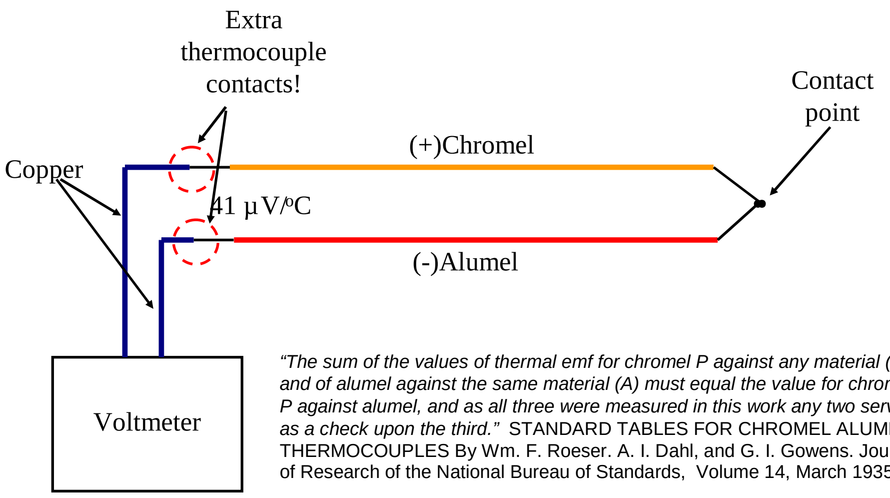
- Selectable reflow profile parameters.
- Display of temperature (s), running time, and reflow process current state using an LCD.
- Talk feedback: temperature, current state, warnings, errors, instructions, etc.
- Start/Stop pushbutton.
- Temperature strip chart plot using the serial port of the system and a personal computer.

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):

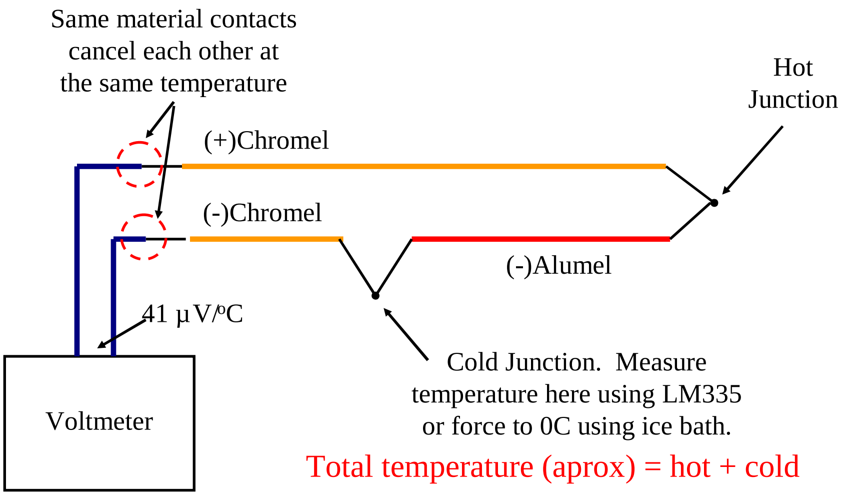
  http://srdata.nist.gov/its90/download/type_k.tab

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

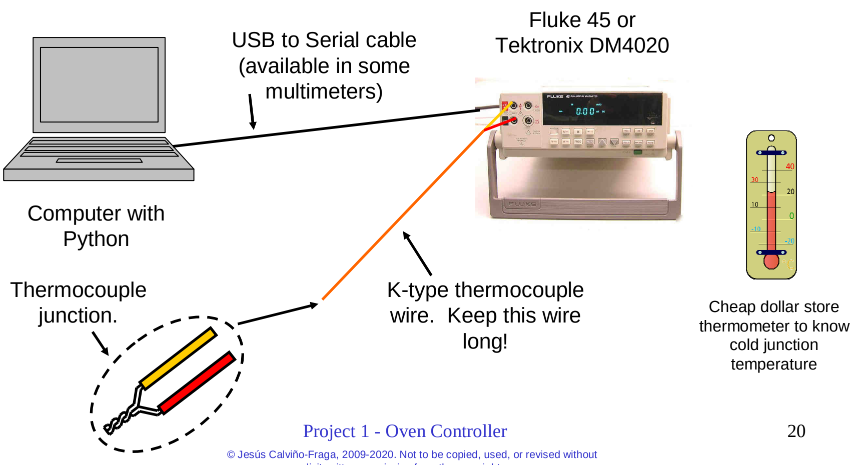


Total temperature (aprox) = hot + cold

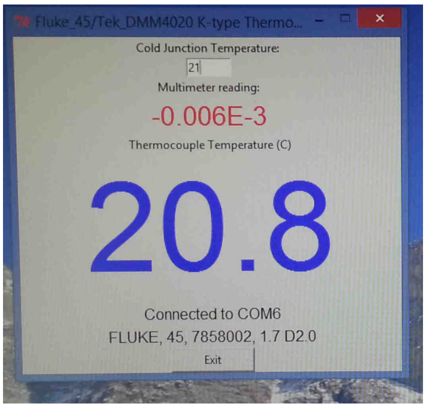
Testing a K-Type Thermocouple in the Laboratory. You'll need:

- 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. Some already connected to the multimeter close to the toaster ovens.
- Python 3.x.x,'kconvert.py', and 'Multimeter_Temp.pyw' (you need both files!)

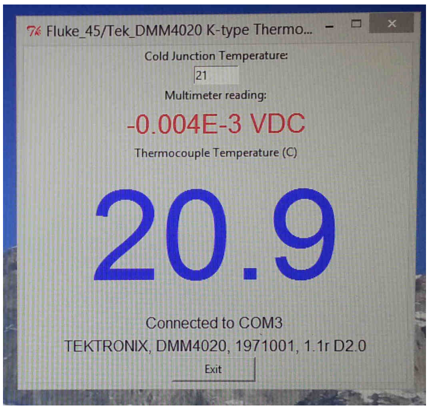
Testing a K-Type Thermocouple in the Laboratory: Setup



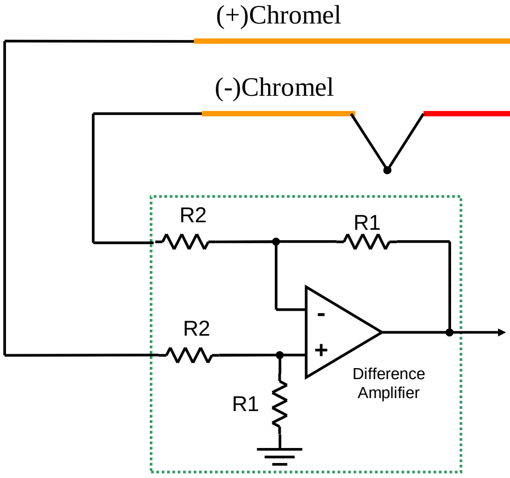
Run ‘Multimeter_Temp.pyw’



Run ‘Multimeter_Temp.pyw’

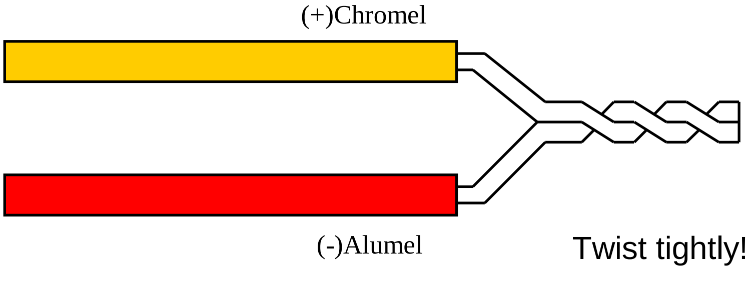


Amplifying the Thermocouple Voltage



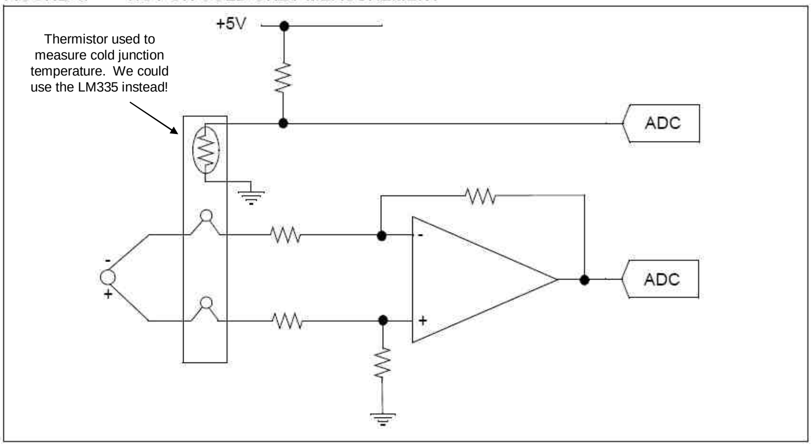
$$V_{out} = 41\frac{\mu V}{^{o}C} \times \frac{R1}{R2}$$

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 microcontroller 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. LMC7660 (or equivalent, included in the microcontroller kit) can be used to produce −5V from +5V.
- Choose the gain carefully! The OP07 will saturate at a voltage below +V.

Opamp

Data Sheet **OP07**

FEATURES

- Low V_{OS}: 75 µV maximum
- Low V_{OS} drift: 1.3 µV/°C maximum
- Ultrastable vs. time: 1.5 µV per month maximum
- Low noise: 0.6 µV p-p maximum
- Wide input voltage range: ±14 V typical
- Wide supply voltage range: ±3 V to ±18 V
- 125°C temperature-tested dice

APPLICATIONS

- Wireless base station control circuits
- Optical network control circuits
- Instrumentation
- Sensors and controls
  - Thermocouples
  - Resistor thermal detectors (RTDs)
  - Strain bridges
  - Shunt current measurements
- Precision filters

PIN CONFIGURATION

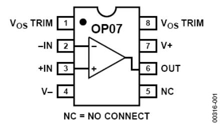


Figure 1.

The wide input voltage range of ±13 V minimum combined with a high CMRR of 106 dB (OP07E) and high input impedance provide high accuracy in the noninverting circuit configuration. Excellent linearity and gain accuracy can be maintained even at high closed-loop gains. Stability of offsets and gain with time or variations in temperature is excellent. The accuracy and stability of the OP07, even at high gain, combined with the freedom from external nulling have made the OP07 an

Optional Offset Nulling

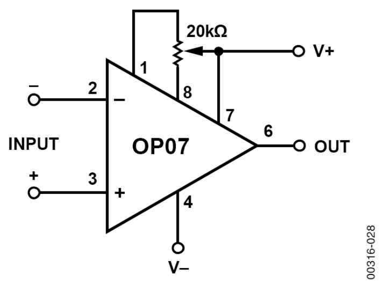


Figure 28. Optional Offset Nulling Circuit

Opamp needs ±5V

www.ti.com SNOSBZ9C – APRIL 1997 – REVISED APRIL 2013

LMC7660 Switched Capacitor Voltage Converter

Check for Samples: LMC7660

FEATURES

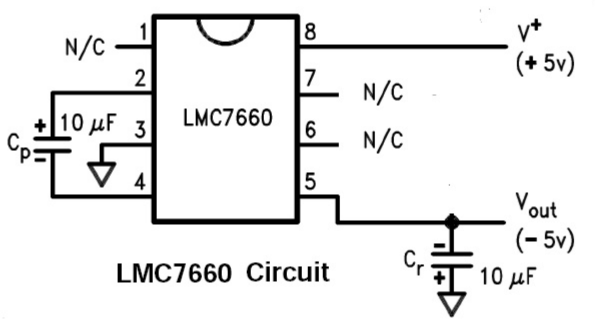
- Operation Over Full Temperature and Voltage Range without an External Diode
- Low Supply Current, 200 µA Max
- Pin-for-pin Replacement for the 7660
- Wide Operating Range 1.5V to 10V
- 97% Voltage Conversion Efficiency
- 95% Power Conversion Efficiency
- Easy to Use, Only 2 External Components
- Extended Temperature Range

DESCRIPTION

The LMC7660 is a CMOS voltage converter capable of converting a positive voltage in the range of +1.5V to +10V to the corresponding negative voltage of −1.5V to −10V. The LMC7660 is a pin-for-pin replacement for the industry-standard 7660. The converter features: operation over full temperature and voltage range without need for an external diode, low quiescent current, and high power efficiency.

The LMC7660 uses its built-in oscillator to switch 4 power MOS switches and charge two inexpensive electrolytic capacitors.

LMC7660



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

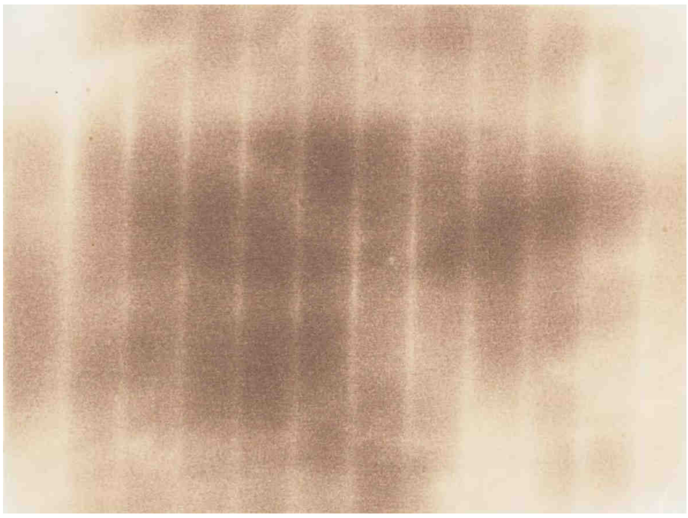
- The amplifier has too much offset. Solution 1: null the offset using a potentiometer. Solution 2: use an ultra low offset op-amp (for example OP177; expensive!)
- Amplifier resistors mismatch resulting in incorrect gain. Solution 1: use the lab multimeter to select resistor that match. Solution 2: 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.

Testing Your Controller with Paper!

Paper measures 7cm x 2cm

Paper shows reflow temperature and time

Checking Oven Hot/Cold Spots

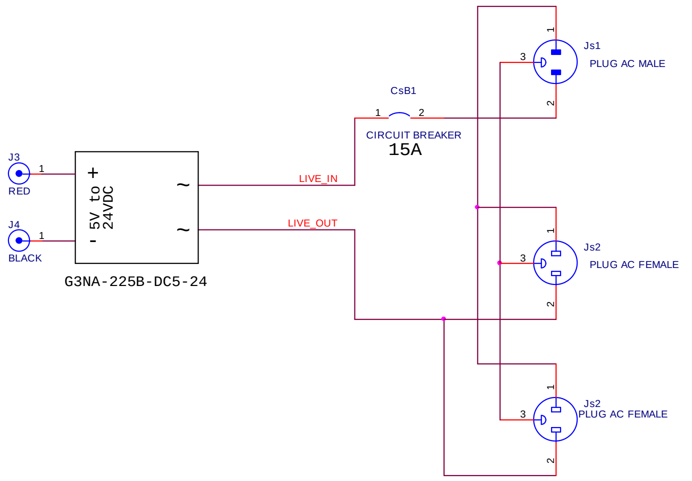


Professionalism

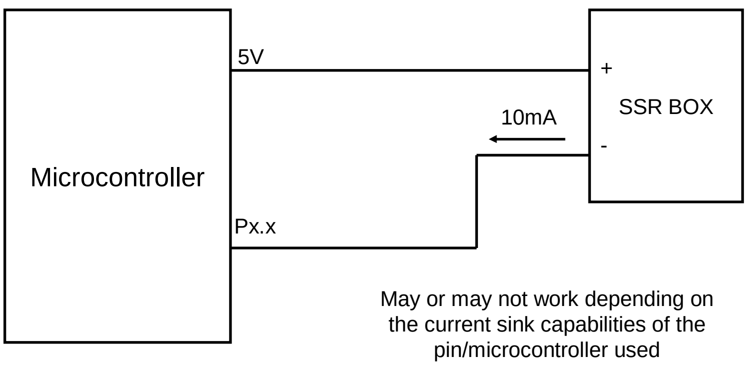
- The first tenant of the code of ethics of professional engineers reads[1]: "*Hold paramount the safety, health and welfare of the public, the protection of the environment and promote health and safety within the workplace*".
- In the spirit of the above tenant, your reflow oven controller must be 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

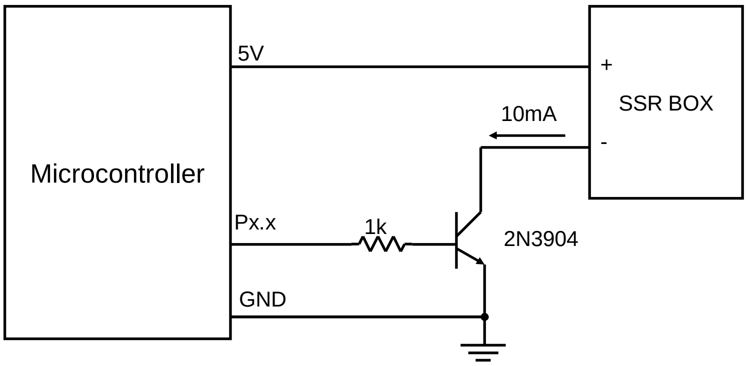


Using a I/O pin to Control SSR Box



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

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 40ºC.
- 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 40ºC 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.

LPCM sound output

- Zip file available on Canvas ('LPCM_Sound_with_P89LPC9351.zip") on how to setup the ICs (25Q32 flash memory, and LM386 audio amplifier) with the P89LPC9351 microcontroller (check for file "Adding Wav Sound to a P89LPC9351.pdf").
- Instruction on how to generate a WAV file.
- Program to run in the computer and P89LPC9351 to store WAV file in 25Q32.
- Playback example for P89LPC9351.