



University of British Columbia  
Electrical and Computer Engineering  
ELEC291/ELEC292

## Project 1 – Reflow Oven Controller

Dr. Jesús Calviño-Fraga P.Eng.  
Department of Electrical and Computer Engineering, UBC  
Office: KAIS 3024  
E-mail: [jesusc@ece.ubc.ca](mailto:jesusc@ece.ubc.ca)  
Phone: (604)-827-5387

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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.

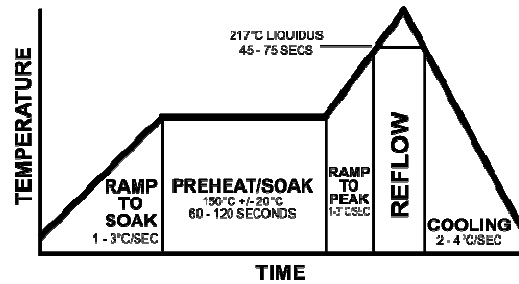
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# Reflow Soldering Profile

[http://en.wikipedia.org/wiki/Reflow\\_soldering](http://en.wikipedia.org/wiki/Reflow_soldering)

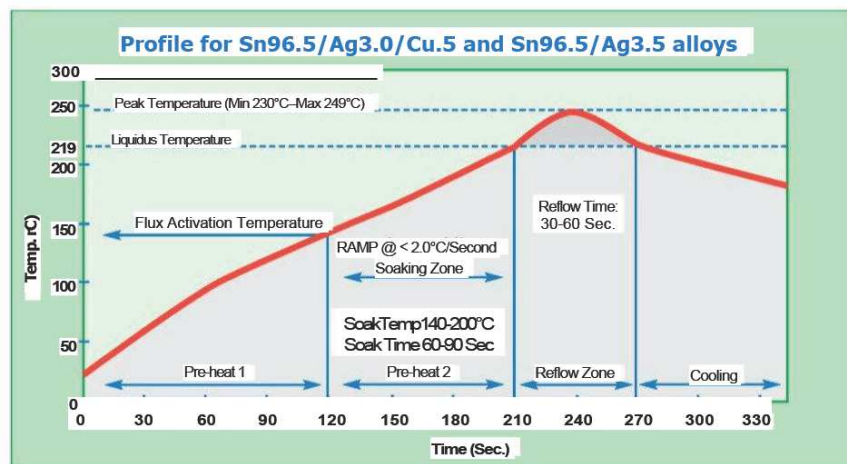


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# Solder Paste Profile (SAC305)



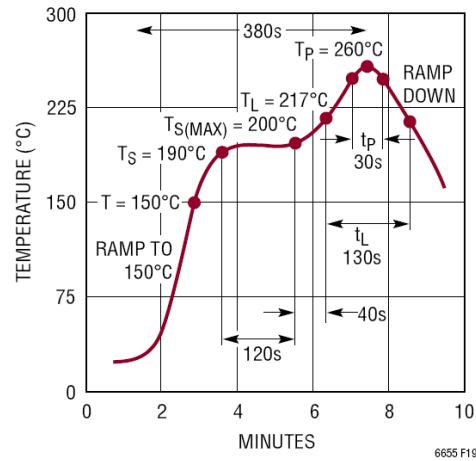
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## SMT Component Thermal Profile

Figure is from LTC6655 datasheet

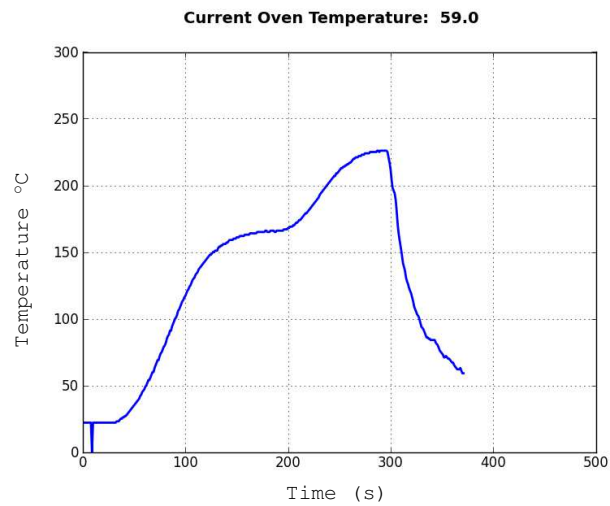


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## My tests thermal profile



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## Warnings:

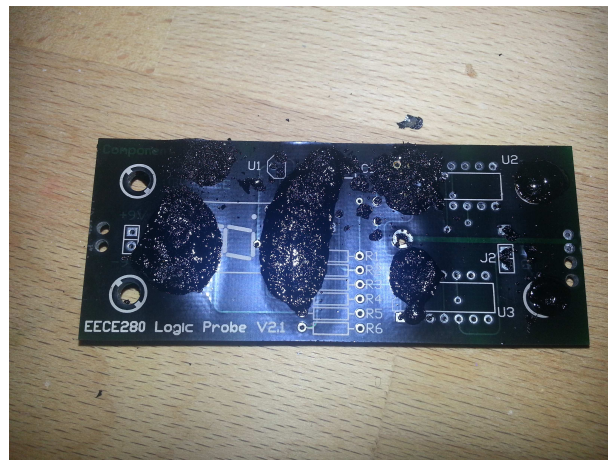
- Don't let your reflow time be more than 45s or the silk screen may darken.
- Don't let your reflow max temperature climb over 240 °C or your PCB may burn: lots of smelly smoke!

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## PCB Burnt in Reflow Oven



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## 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.

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## 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_Slow.mp4)  
[http://courses.ece.ubc.ca/281/2017/Paste\\_and\\_Components\\_Fast.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](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](http://courses.ece.ubc.ca/281/2017/Thru_hole.mp4)

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

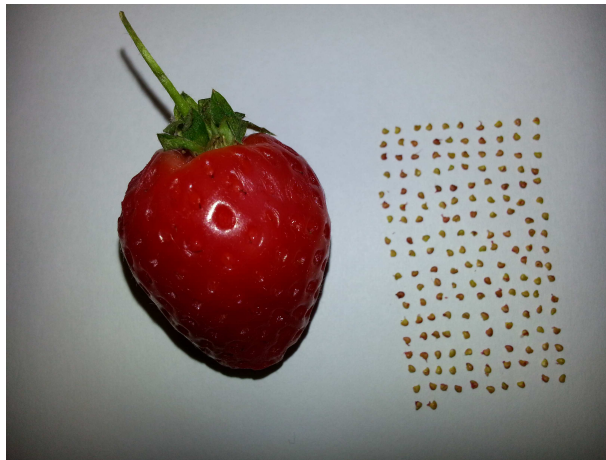


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## Mastering the Tweezers and Loupe, Step 2: remove seeds!



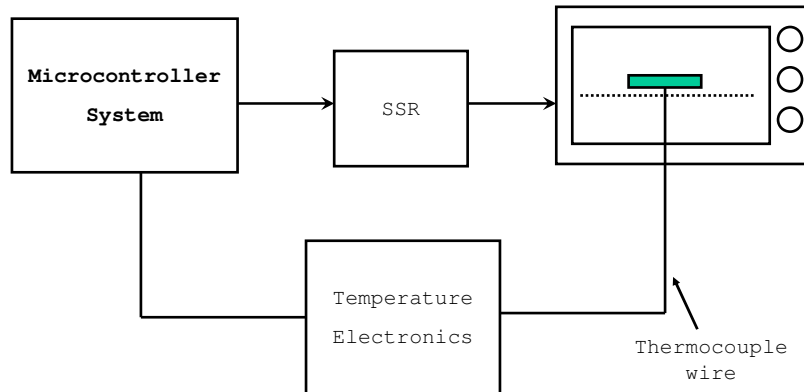
172 seeds!

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## Oven Controller Typical Block Diagram



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## 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.
- Temperature measurement validation data from 25 °C to 240°C. Max error  $\pm 3^{\circ}\text{C}$ .

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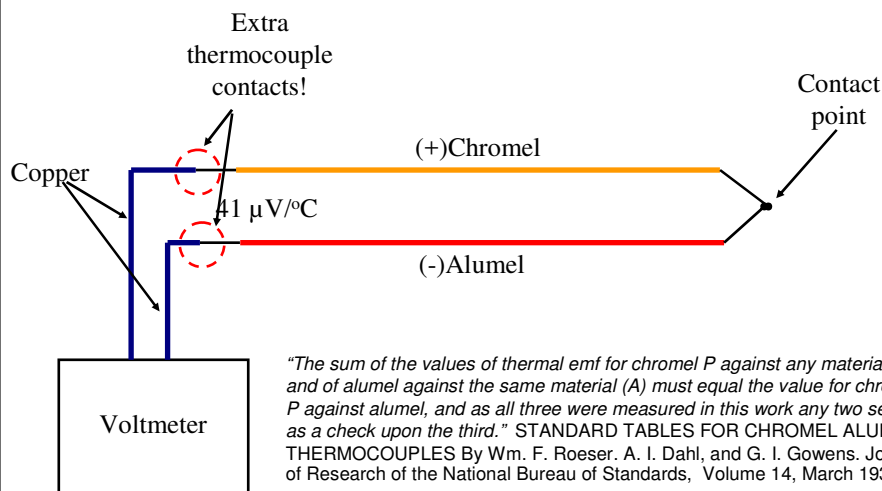
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## K-Type Thermocouple

- Has two wires: Yellow (+) and Red (-).
- About  $41 \mu\text{V}/^\circ\text{C}$ . You'll need an amplifier!
- Very accurate conversion table provided by the National Institute of Standards and Technology (USA):

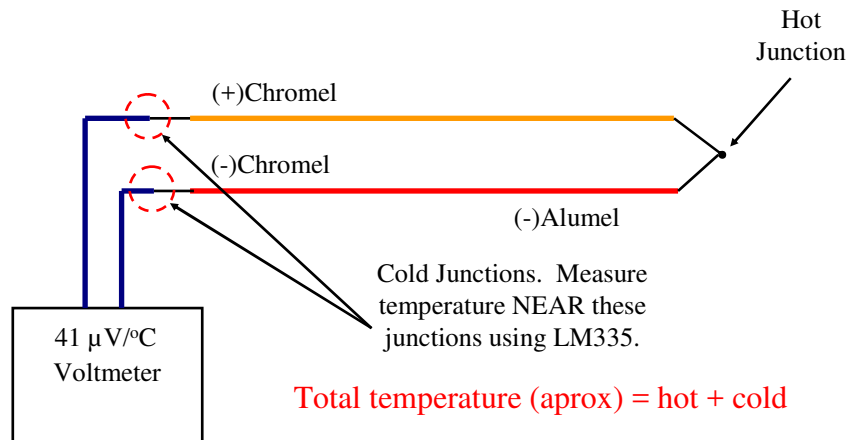
[http://srdata.nist.gov/its90/download/type\\_k.tab](http://srdata.nist.gov/its90/download/type_k.tab)

## Using a K-type Thermocouple





## Using a K-type Thermocouple



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

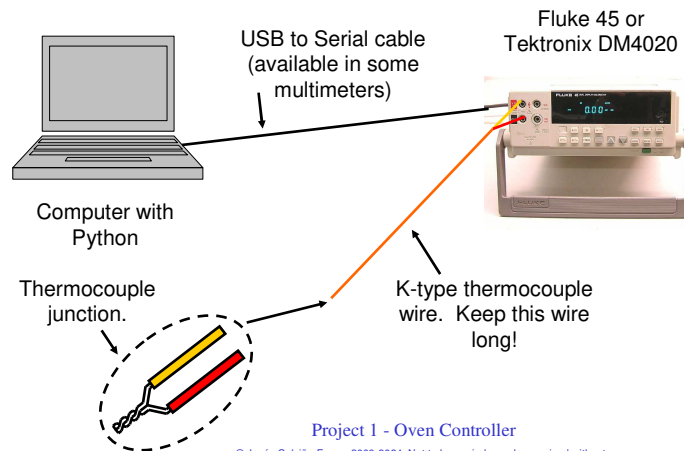
- Thermocouple wire: included in project kit.
- Voltmeter with micro-volt resolution: Fluke 45 or Tektronix DM4020.
- Ambient temperature in the lab. Most of the time between 20°C and 24°C. If not measured, use 22°C. Or use your LM335!
- USB to serial adapter attached to the multimeter to connect a computer.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

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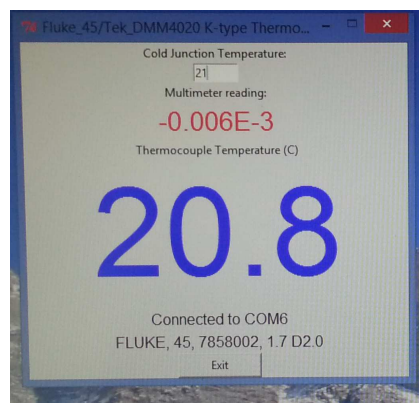
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## Testing a K-Type Thermocouple in the Laboratory: Setup



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## Run 'Multimeter\_Temp.pyw'

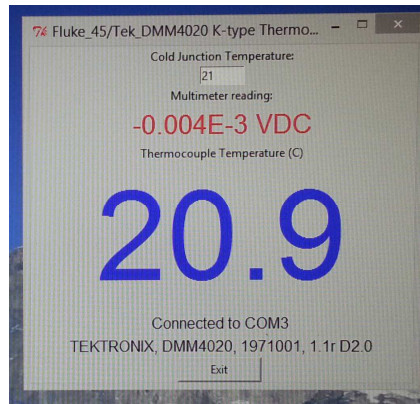


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## Run 'Multimeter\_Temp.pyw'

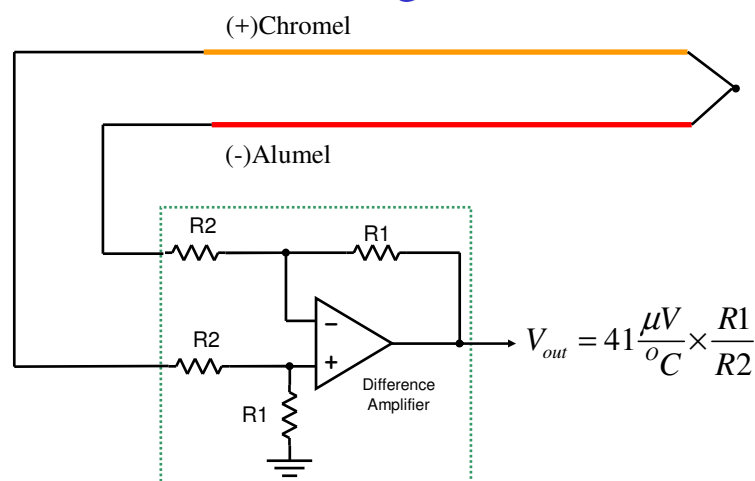


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## Amplifying the Thermocouple Voltage

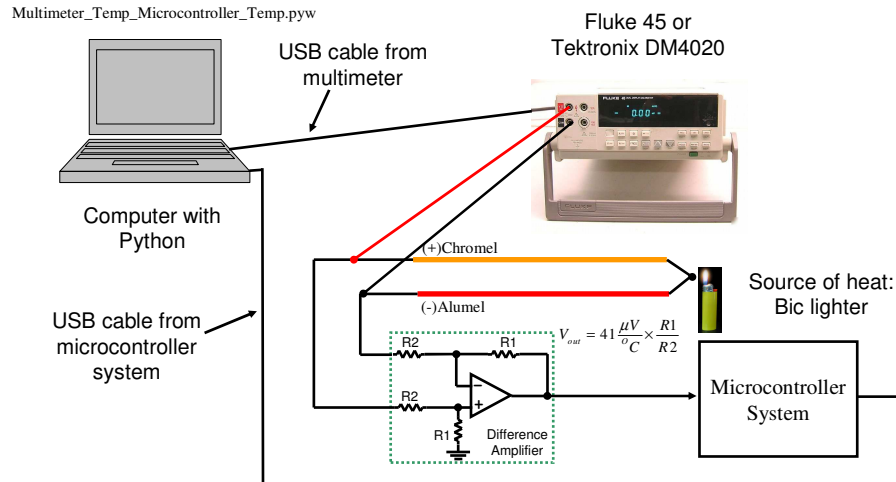


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## Setup to verify correct temperature measurement.



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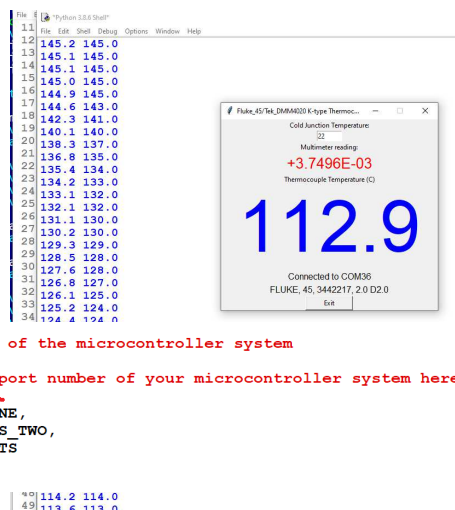
## Setup to verify correct temperature measurement.

If you find this too complicated, just display the measured temperature from the microcontroller on the LCD, and make a video that captures both the temperature measured by the multimeter and the LCD. Then enter the data by hand in Excel.

```

1  ser2.isOpen()
2
3  # configure the serial port of the microcontroller system
4  ser2 = serial.Serial(
5      port='COM7', # Put the port number of your microcontroller system here
6      baudrate=115200,
7      parity=serial.PARITY_NONE,
8      stopbits=serial.STOPBITS_TWO,
9      bytesize=serial.EIGHTBITS
10 )

```

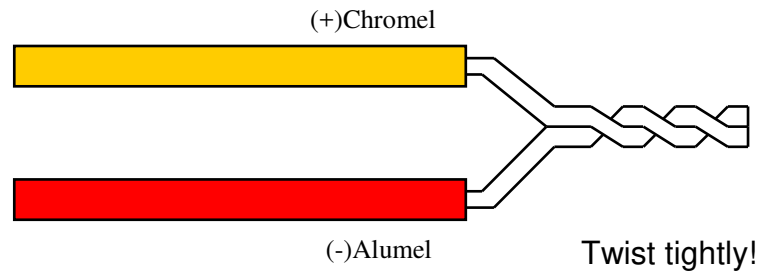


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## Making the hot Junction



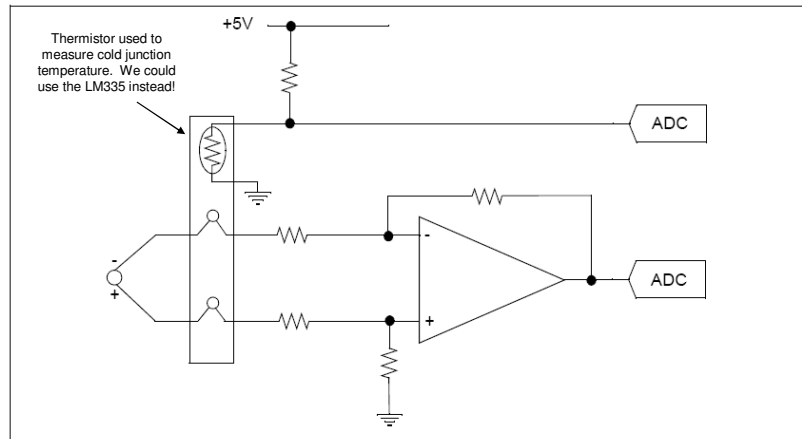
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## Good Reference: Microchip AN844

FIGURE 4: HOT OR COLD ONLY MEASUREMENT



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# 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  $50\mu\text{V}$ . Sometimes is  $200\mu\text{V}$ ! The offset can be null using a potentiometer.
- The OP07 needs dual power supplies, for example  $+5\text{V}$  and  $-5\text{V}$ . LMC7660 (or equivalent, included in the microcontroller kit) can be used to produce  $-5\text{V}$  from  $+5\text{V}$ .
- Choose the gain carefully! The OP07 will saturate at a voltage below  $+V$ . If you use  $+5\text{V}$ , the saturation voltage is around  $3.5\text{V}$ .

# Opamp

## Data Sheet

## OP07

### FEATURES

Low  $V_{os}$ :  $75\mu\text{V}$  maximum  
 Low  $V_{os}$  drift:  $1.3\mu\text{V}/^\circ\text{C}$  maximum  
 Ultrastable vs. time:  $1.5\mu\text{V}$  per month maximum  
 Low noise:  $0.6\mu\text{V p-p}$  maximum  
 Wide input voltage range:  $\pm 14\text{V}$  typical  
 Wide supply voltage range:  $\pm 3\text{V}$  to  $\pm 18\text{V}$   
 $125^\circ\text{C}$  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

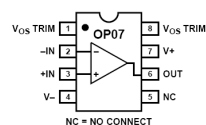


Figure 1.

The wide input voltage range of  $\pm 13\text{V}$  minimum combined with a high CMRR of  $106\text{ dB}$  (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 industry standard for instrumentation applications.

## Optional Offset Nulling

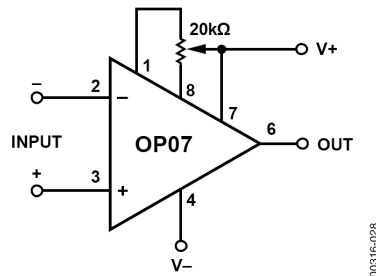


Figure 28. Optional Offset Nulling Circuit

If your OP07 has too much offset, ask me for another one! It may be better.

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## Opamp needs $\pm 5V$

www.ti.com

SNOSEZ9C – 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  $\mu A$  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.

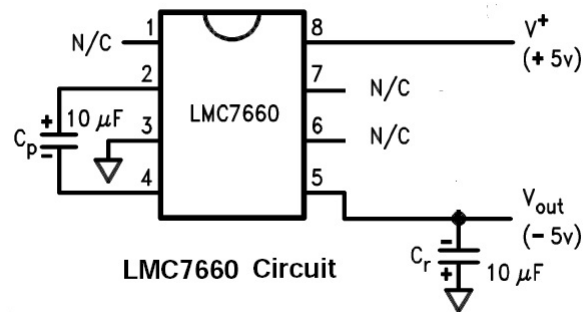
The LMC7660 uses its built-in oscillator to switch 4 power MOS switches and charge two inexpensive electrolytic capacitors.

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## LMC7660



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## Temperature Validation Data

- Use the lab multimeter to validate your controller temperature measurements.
- Max acceptable error  $\pm 3^\circ\text{C}$  for the range  $25^\circ\text{C}$  to  $240^\circ\text{C}$ .
- You must include the procedure and the data in the project report. Have it handy for the project demonstration! **No validation data? Then all your extra features will be ignored and the max demo grade you can get is 65%.**

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## 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	+0.9	+0.9	+0.8	+0.8	????	

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## Sources of Error

- The amplifier has too much offset. Solution: null the offset using a potentiometer. Make sure you are using and ultra low offset operational amplifier like the OP07.
- Amplifier resistors mismatch resulting in incorrect gain. Solution: use the lab multimeter to select resistor with matching resistances and use measured resistance values in your calculations.
- Incorrect cold junction temperature. Solution: adjust the output of the LM335 using a potentiometer or try a different LM335 IC.
- The conversion from voltage to temperature introduces unacceptable errors. Solution 1: tune up your calculations. Solution 2: use a look-up table.

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# Testing Your Controller with Paper!



Paper measures  
7cm x 2cm

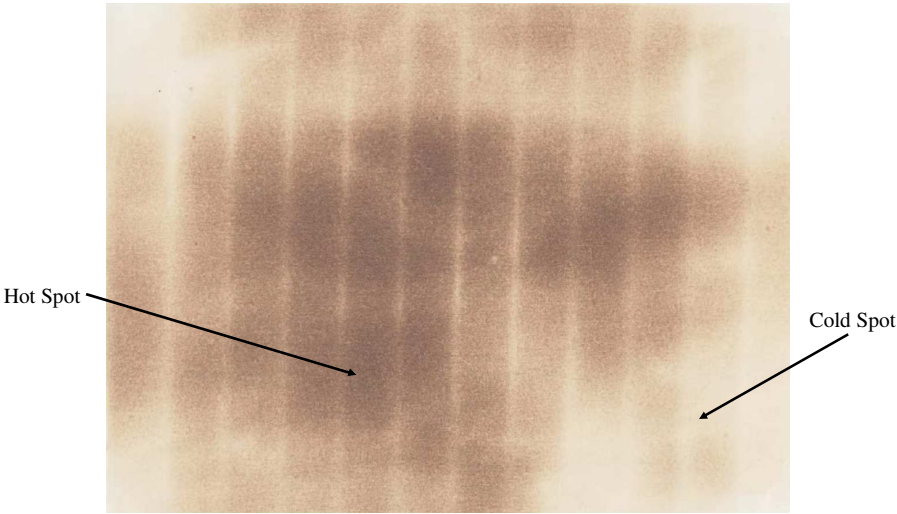
Paper shows reflow  
temperature and  
time

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# Checking Oven Hot/Cold Spots



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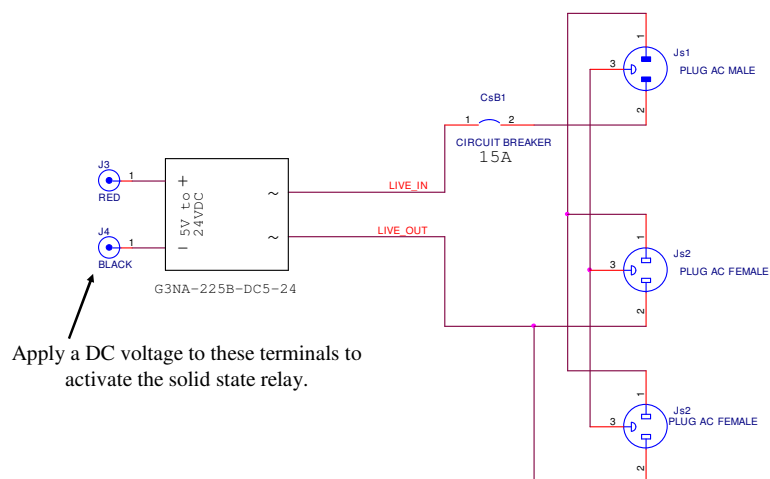
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# Professionalism

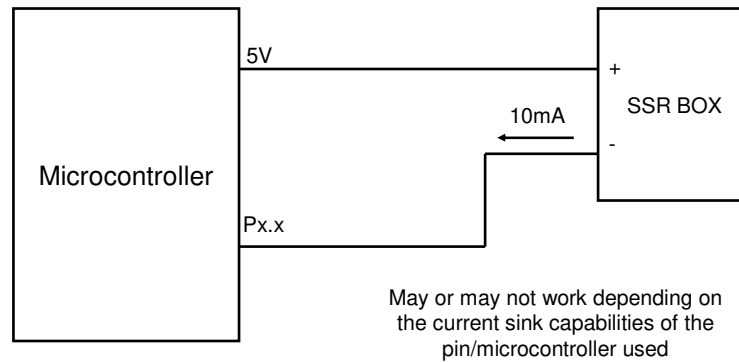
- The first tenant of the code of ethics of professional engineers reads<sup>1</sup>: “*Hold paramount the safety, health and welfare of the public, the protection of the environment and promote health and safety within the workplace*”.
- In the spirit of the above tenant, your reflow oven controller 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.

<sup>1</sup> <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

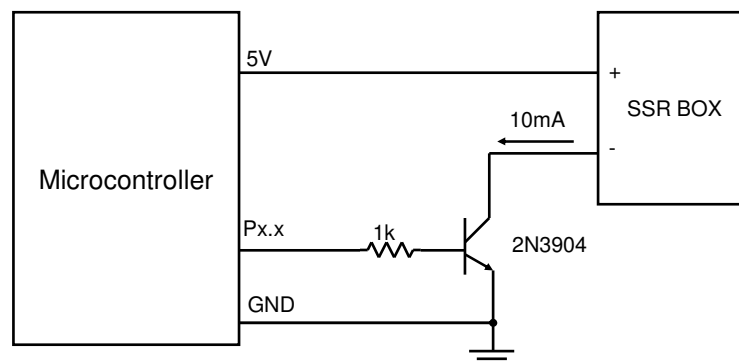


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## Using a Transistor (BJT, more reliable)

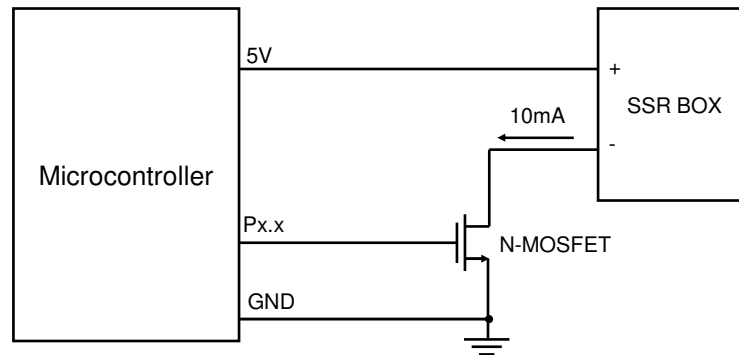


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## Using a Transistor (MOSFET, more reliable, easier)



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## 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!

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## 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°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°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.

Project 1 - Oven Controller

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