ECED3901 Design Methods II

LECTURE #5: THERMAL CONSIDERATIONS & LAB #1

Colin O’Flynn

What are we covering?

- Cooling Electronics
  - Mpemba Effect (not really related but interesting)
  - Heat Transfer basics
  - Thermal resistance
  - Calculating heat rise
  - Selecting heat sinks
- Lab #1 Additional Details

(Not this sort of cool)

Cooling Electronics

Everything you know about cooling is wrong.

Question: You are making ice cubes for a summer party, and need them to freeze ASAP. What is fastest way to do this?

Option #1) Cold water from your tap

Option #2) Hot water from your tap

Mpemba effect

- In 1963, a student (Mpemba) was making ice cream at school, which used boiling milk
- In a rush he put his in the freezer warm (instead of waiting for it to cool first)
- His froze earlier than others – asked his physics teacher, who told him he was wrong.
- Mpemba continues to ask, but is told “All I can say is that is Mpemba's physics and not the universal physics”
- Mpemba asks a visiting professor Dr. Osborne, who agrees to try the experiment… the technicians who try it say the hot water froze first, “But we'll keep on repeating the experiment until we get the right result.”
- Becomes clear hot water did freeze first – Dr. Osborne & Mpemba later write up results

Source/Additional Details:
http://math.ucr.edu/home/baez/physics/General/hot_water.html

Mpemba effect

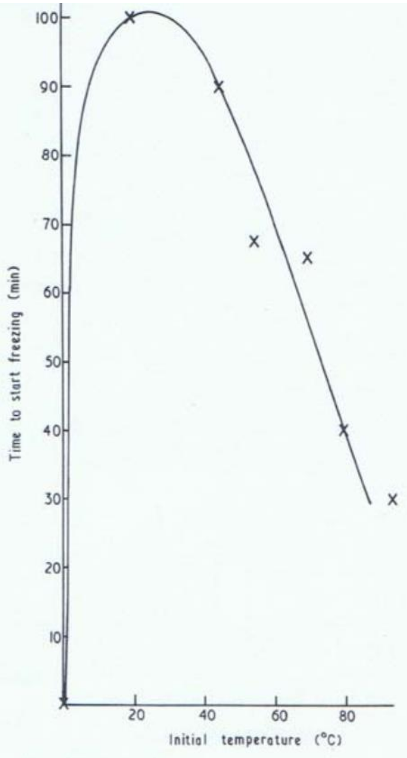


Figure 1 A graph of the time for water to start freezing against the initial temperature of water.

Lesson: **Proof-of-Concept > Assumptions**

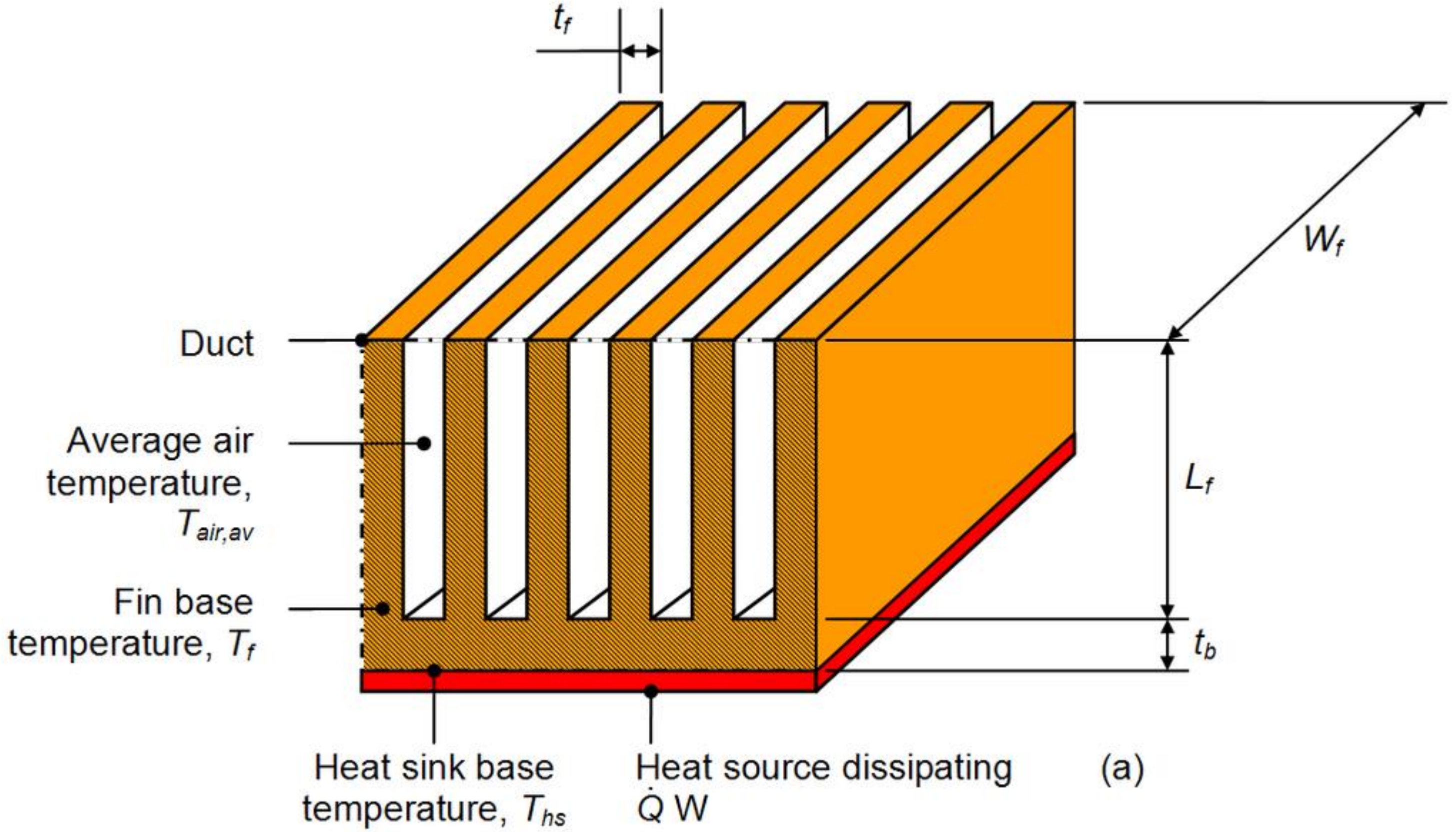
Heat Transfer Basics

Heat flows from HOT to COLD

Types of Heat Transfer

- Conduction
- Convection
  - Natural
  - Forced-Air
- Radiation

Example of Heat Transfer Flow



Source: http://en.wikipedia.org/wiki/Heat_sink#/media/File:Heat_sink_thermal_resistances.png

Conductive Heat Transfer

$$Q = \frac{kA}{t}\Delta T$$

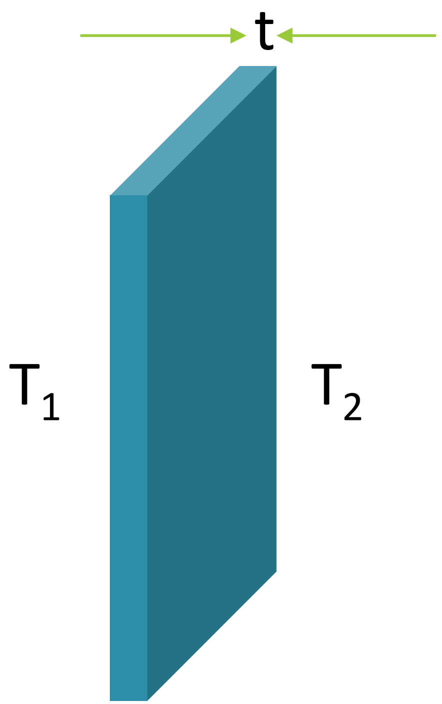
Q = amount of heat (Watts)

k = Thermal conductivity (W m^{-1} K^{-1})

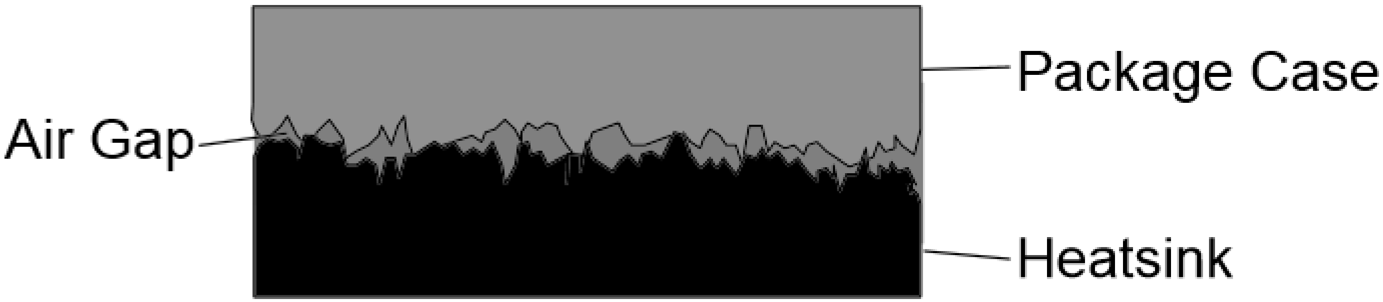
A = Area (m^2)

t = thickness (m)

ΔT = Change in temperature (Celsius)



Thermal Compound



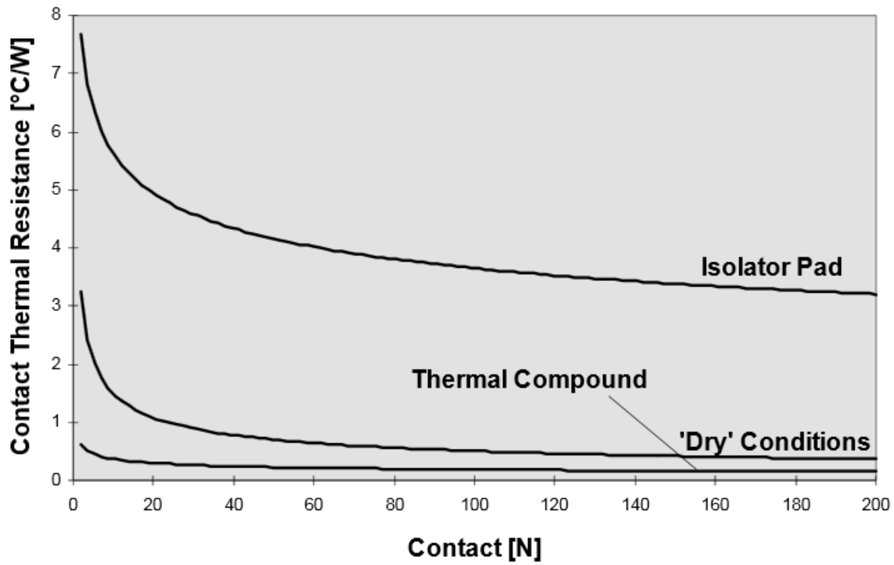


Figure 1.6 - Contact Thermal Resistance Plotted Against Contact Force

Example: Very Expensive Thermal Compound

Normal Compound = $

Compound made with ground horn from virgin unicorns = $$$

Example: Very Expensive Thermal Compound

Compound	Thermal conductivity (ca. 300 K) ($W\ m^{-1}\ K^{-1}$)
Diamond	20 – 2000
Silver	418
Aluminum nitride	100 – 170
β-Boron nitride	100
Zinc oxide	25.2

Source: http://en.wikipedia.org/wiki/Thermal_grease

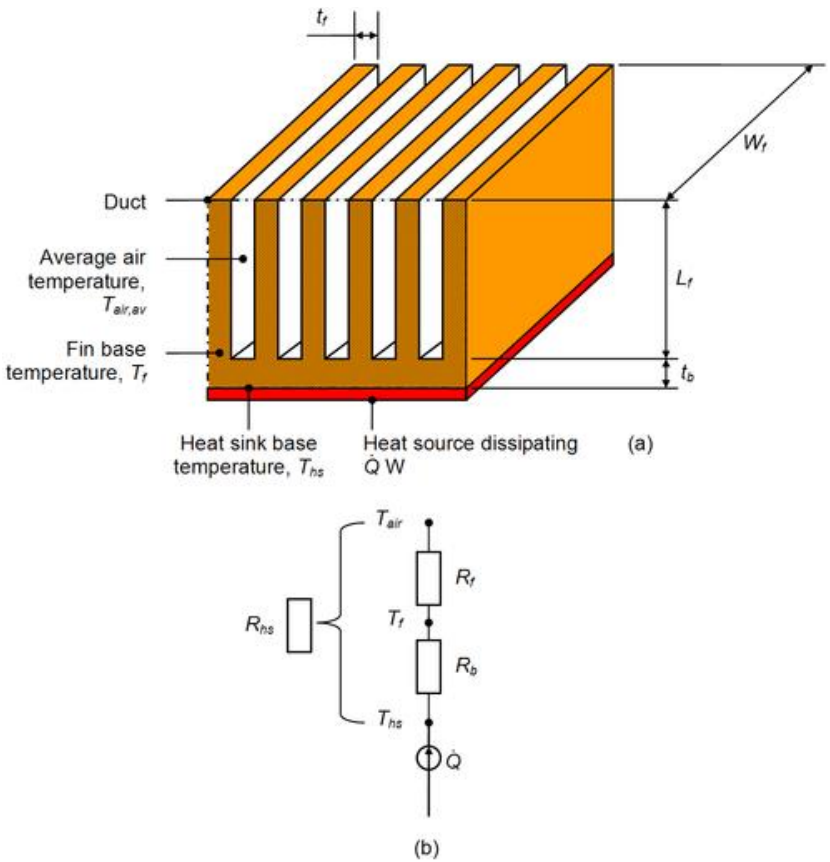
$Q = 50W$

Source: http://en.wikipedia.org/wiki/List_of_CPU_power_dissipation_figures#Intel_Core_i7_2

Delta-T for Zinc-Oxide vs. Others

$$\Delta T = \frac{Qt}{kA} = \frac{50 * 0.2E-3}{25.2 * (0.03 * 0.03)} = 0.4C$$

How to Calculate a System?



Source: http://en.wikipedia.org/wiki/Heat_sink#/media/File:Heat_sink_thermal_resistances.png

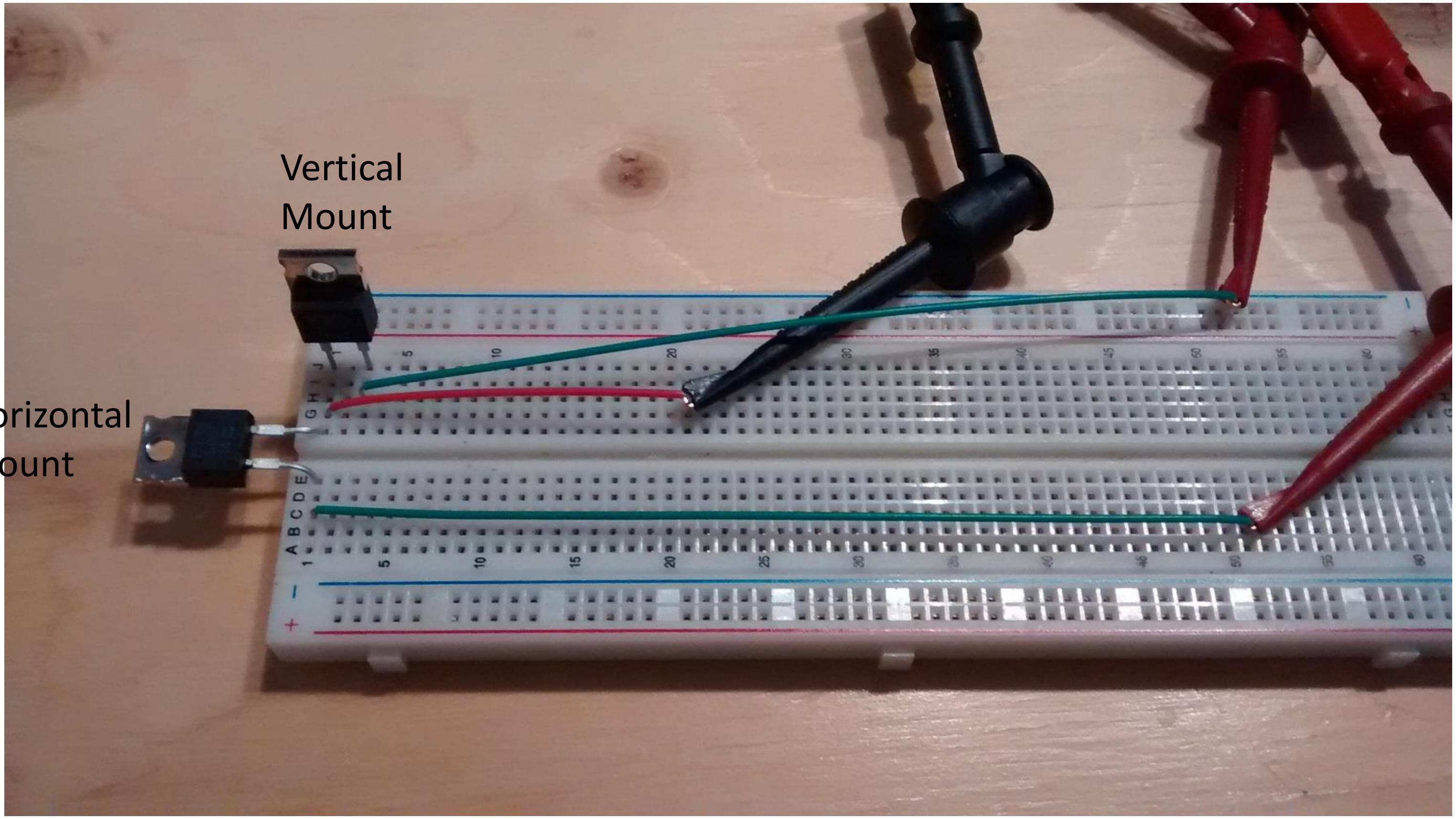
Caveats to Always Remember

1. Everything is about *heat difference*
2. Given values will be valid for the specific environment

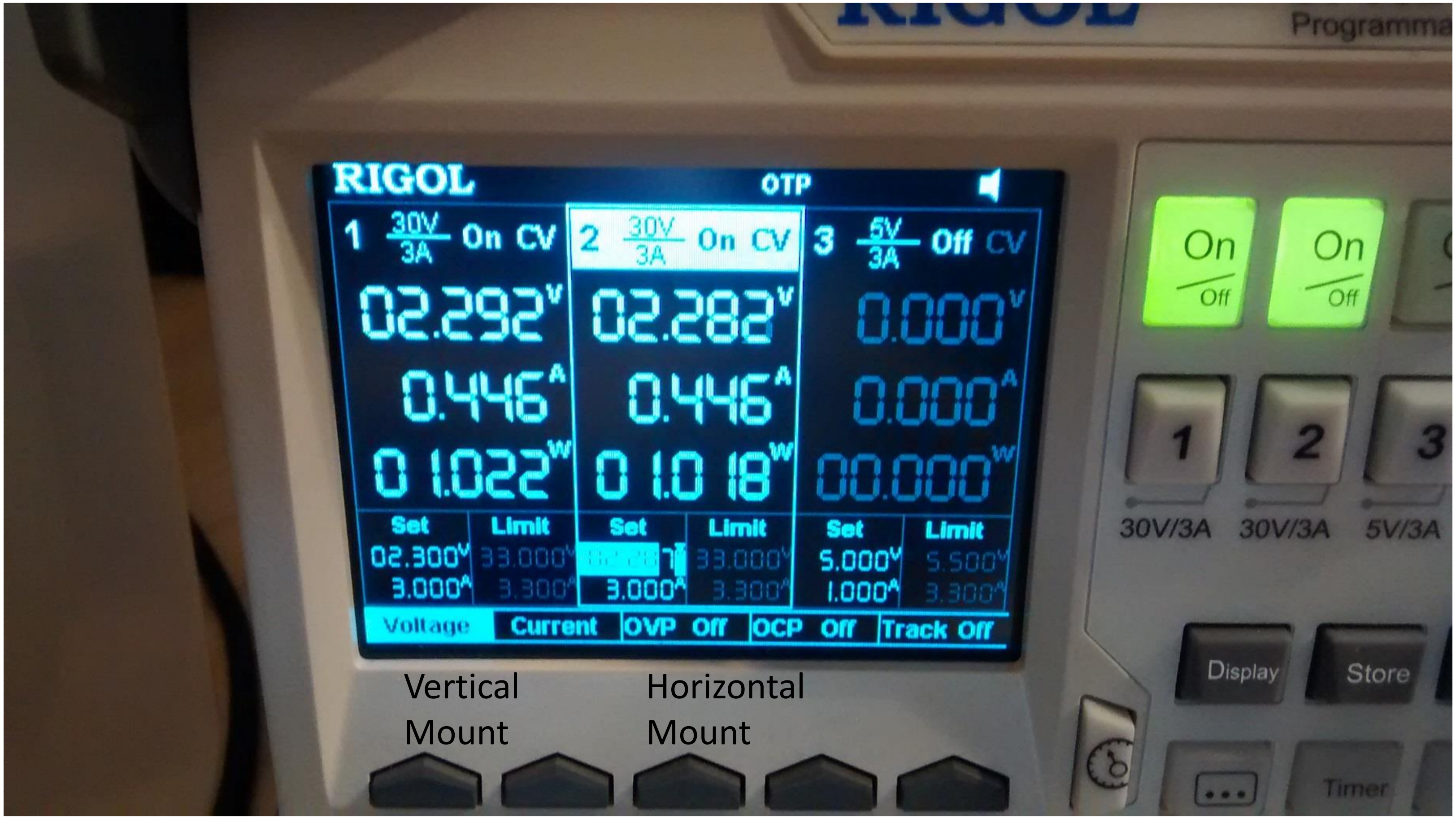
Thermal Characteristics

Symbol	Parameter	FQP27P06	Unit
$R_{\theta JC}$	Thermal Resistance, Junction-to-Case, Max.	1.25	°C/W
$R_{\theta CS}$	Thermal Resistance, Case-to-Sink, Typ.	0.5	°C/W
$R_{\theta JA}$	Thermal Resistance, Junction-to-Ambient, Max.	62.5	°C/W

Example: Resistor Heat Rise



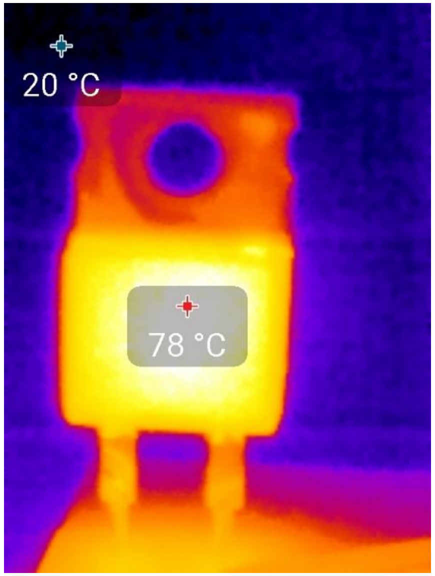
Example: Resistor Heat Rise



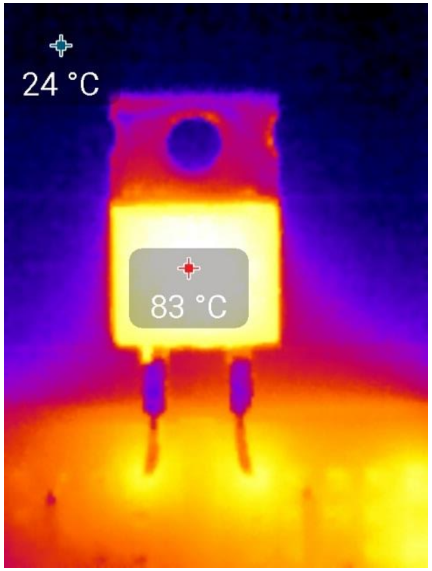
Vertical Mount

Horizontal Mount

Example: Resistor Heat Rise



Vertical Mount



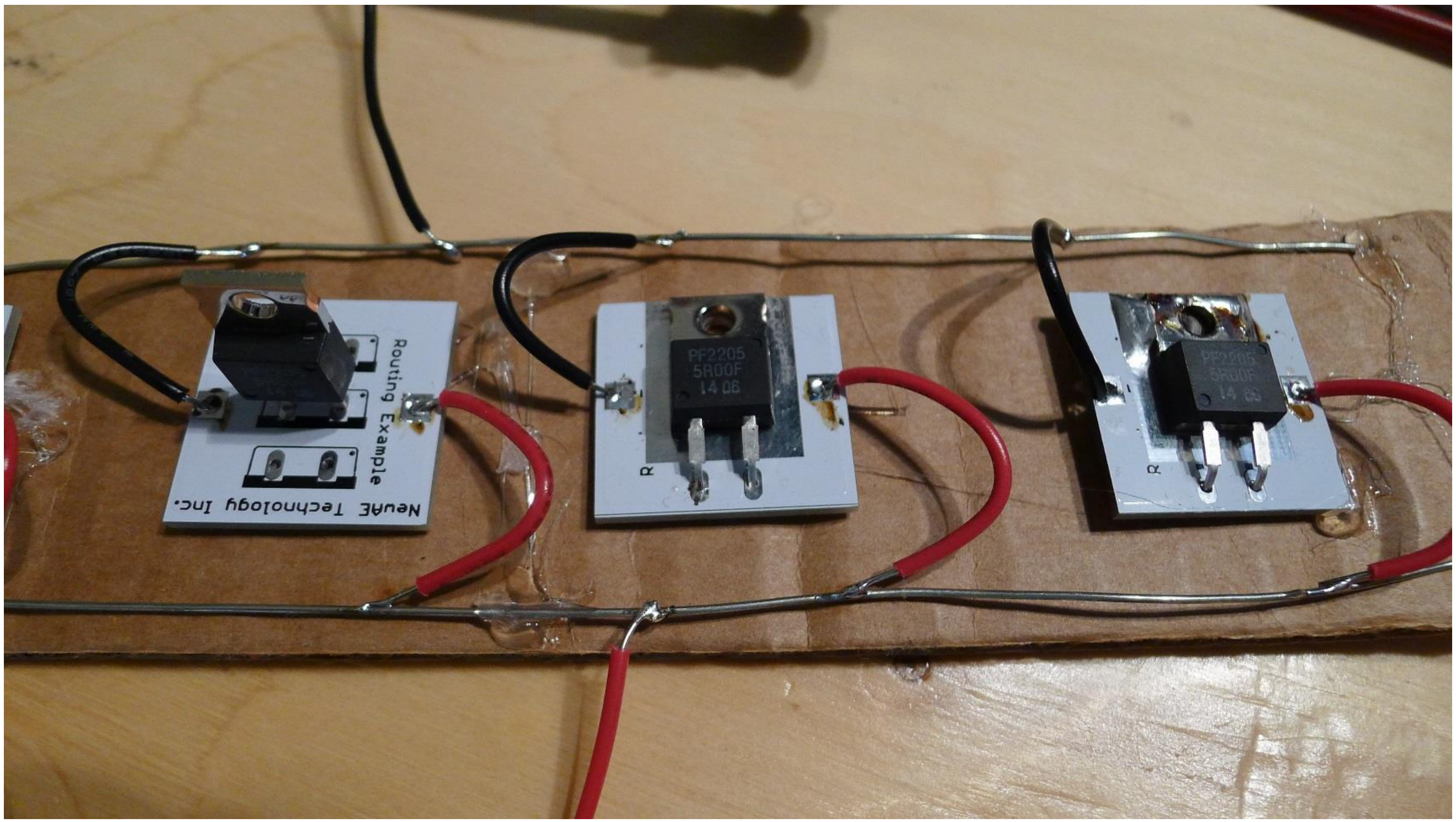
Horizontal Mount

Note: metal tab has low thermal emissivity, and this thermal camera is not accurately capturing the temperature

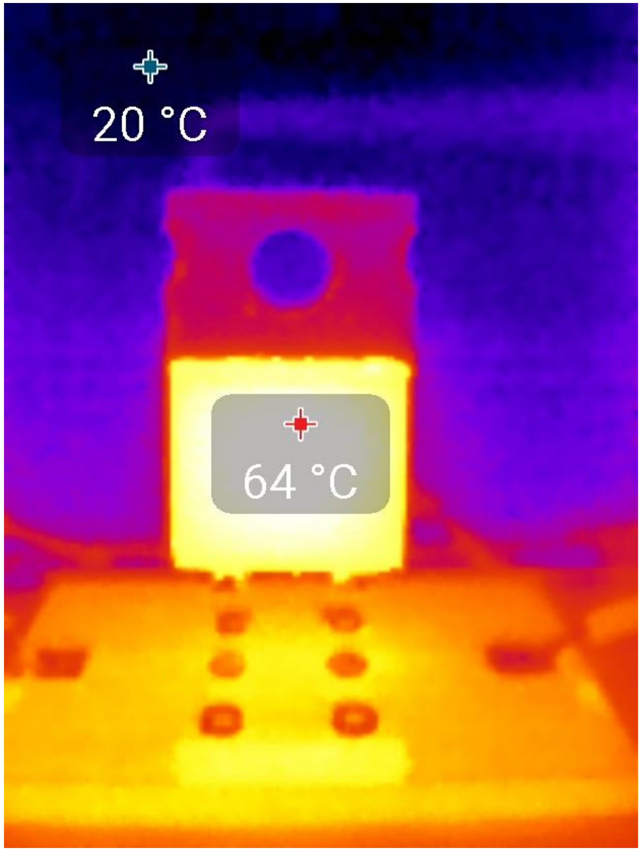
PF2205 Device in TO-220 Package

- Typical for TO-220: Junction-to-Ambient = 62 C/W

Example: Resistor Heat Rise

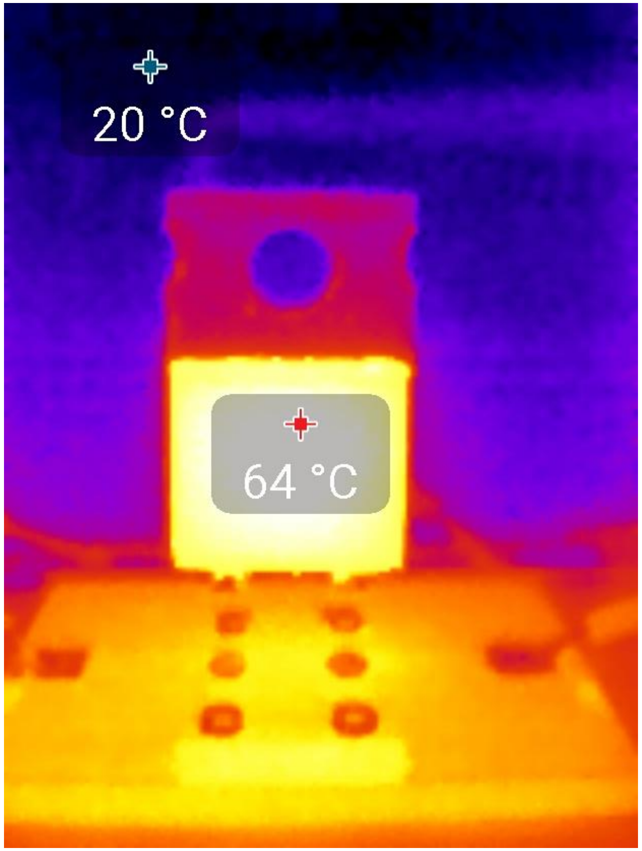


Example: Resistor Heat Rise



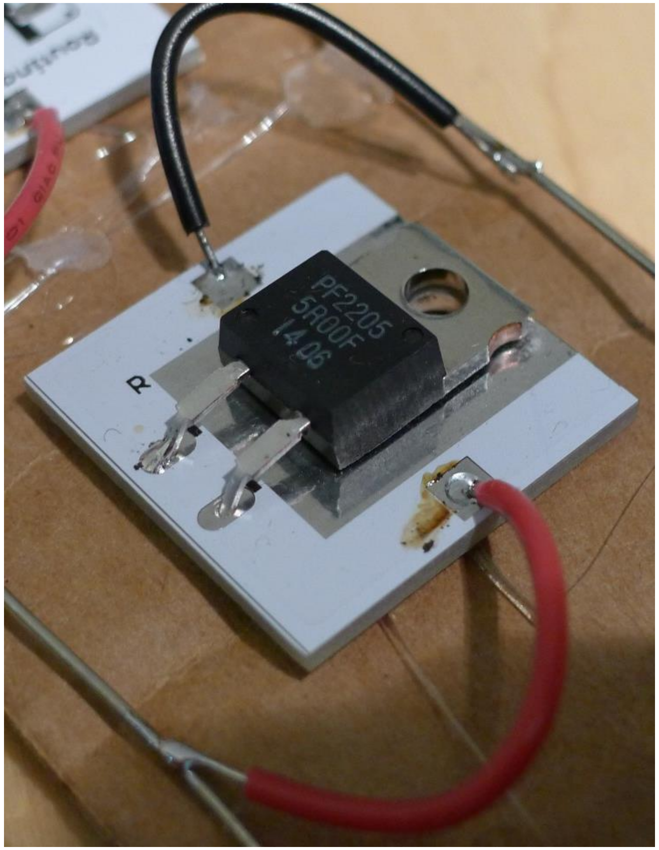
- Vertical mount again
- 1.02W being dissipated
- 14C cooler!

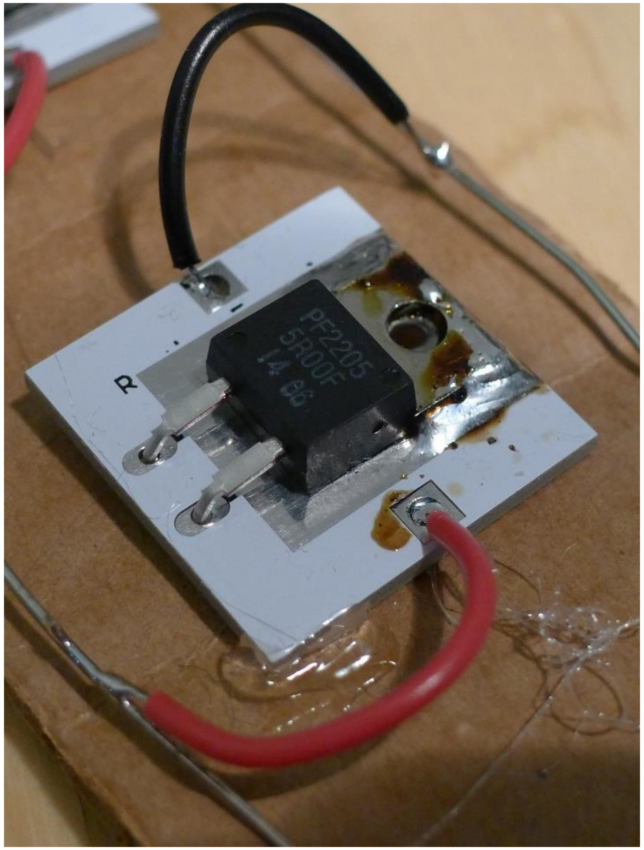
Example: PCB Layout



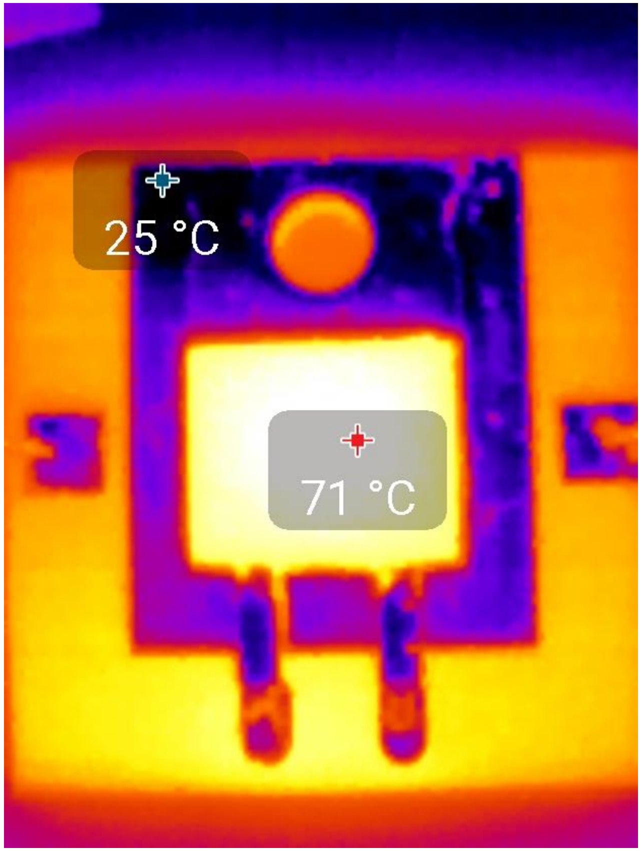
- Full copper pours on top & bottom designed to maximize heat transfer

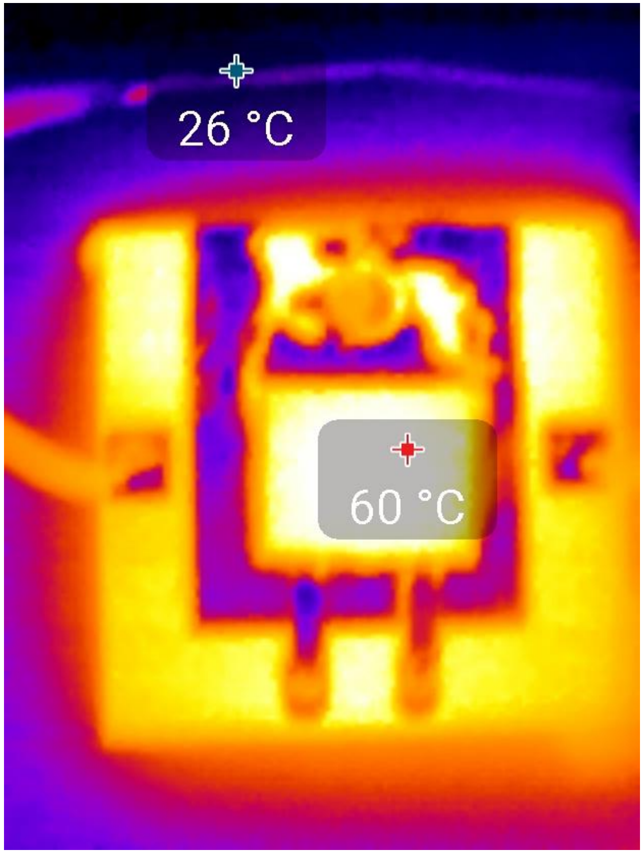
Example: Resistor Heat Rise





Example: Resistor Heat Rise





Example: Heat Rise Calculation

TEXAS INSTRUMENTS

LM7805C, LM7812C, LM7815C

www.ti.com

SNOSBR7D – MAY 2000 – REVISED APRIL 2013

LM78XX Series Voltage Regulators

Check for Samples: LM7805C, LM7812C, LM7815C

FEATURES

- **Output Current in Excess of 1A**
- **Internal Thermal Overload Protection**
- **No External Components Required**
- **Output Transistor Safe Area Protection**
- **Internal Short Circuit Current Limit**
- **Available in the Aluminum TO-3 Package**

DESCRIPTION

The LM78XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM78XX series is available in an aluminum TO-3 package which will allow over 1.0A load current if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Considerable effort was expanded to make the LM78XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

VOLTAGE RANGE

- **LM7805C: 5V**
- **LM7812C: 12V**
- **LM7815C: 15V**

Connection Diagrams

Example: Heat Rise Calculation

ABSOLUTE MAXIMUM RATINGS[(1)(2)]

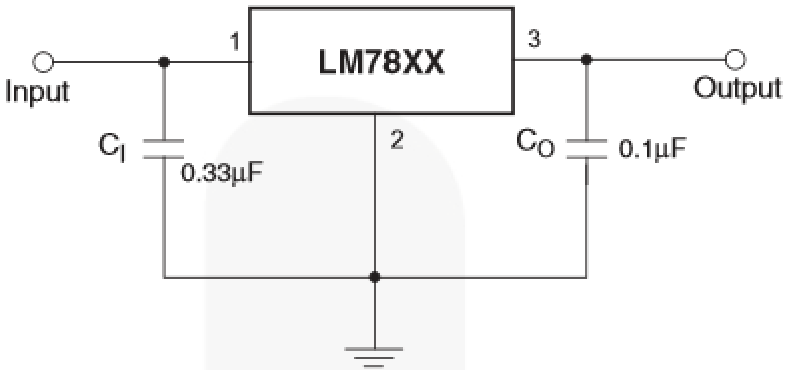
Input Voltage (V_O = 5V, 12V and 15V)		35V
Internal Power Dissipation[(3)]		Internally Limited
Operating Temperature Range (T_A)		0°C to +70°C
Maximum Junction Temperature	(TO-3 Package)	150°C
	(NDE Package)	150°C
Storage Temperature Range		−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	TO-3 Package	300°C
	TO-220 Package NDE	230°C

(1) Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. For ensured specifications and the test conditions, see Electrical Characteristics.
(2) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/Distributors for availability and

LM7805… 12V in, 5V out, 1 amp

Example: Heat Rise Calculation

But what is thermal power dissipated?



Example: Heat Rise Calculation

Thermal power dissipated:

Input = 12V * 1A = 12W

Output = 5V * 1A = 5W

Package dissipates 7W of power

Example: Heat Rise Calculation

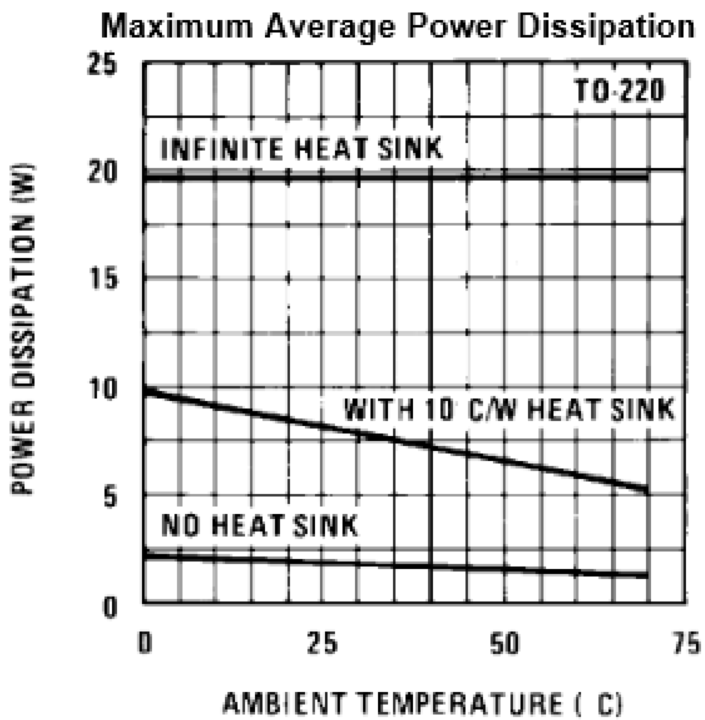
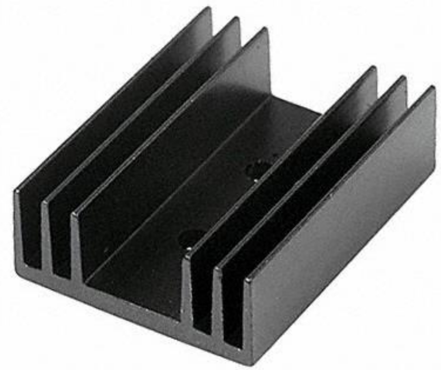


Figure 4.

Sidenote: What is Ambient?

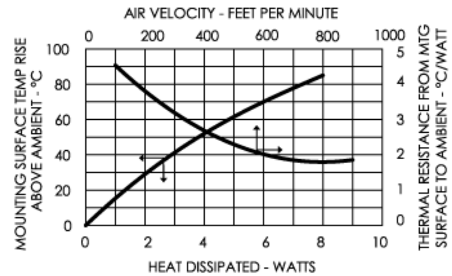
Example Heatsink Options

P/N: V7236A1
$0.313 (Qty 1000)
28 C/W



P/N: 7-340-2PP-BA
$2.82 (Qty 1000)
3.1 C/W

P/N: 7-340-2PP-BA
$1.27 (Qty 1000)
4 C/W @ 500 LFM



Calculating junction temperature

Normally < 125C (7805 may have higher, I'll use 100C to keep margin)

Electrical Characteristics (LM7806)

Refer to the test circuit, -40°C < T_J < 125°C, I_O = 500 mA, V_I = 11 V, C_I = 0.33 µF, C_O = 0.1 µF, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
		T_J = +25°C	5.75	6.00	6.25	

Symbol	Parameter		Value	Unit
V_I	Input Voltage	V_O = 5 V to 18 V	35	V
		V_O = 24 V	40	
$R_{\theta JC}$	Thermal Resistance, Junction-Case (TO-220)		5	°C/W
$R_{\theta JA}$	Thermal Resistance, Junction-Air (TO-220)		65	°C/W
T_{OPR}	Operating Temperature Range	LM78xx	-40 to +125	°C
		LM78xxA	0 to +125	
T_{STG}	Storage Temperature Range		- 65 to +150	°C

Required Case Temperature

Desired T_J = 100C

P = 7W

$T_C = T_J - P * R_{\theta JC}$

$= 100 - 7 * 5$

$= 65$ C

Required Heatsink Temp

Desired T_A = 50C

P = 7W (heatsink is dissipating)

Temp rise of heatsink = 65C – 50C = 15C

15C / 7W = 2.14 C/W

Required Heatsink Temp

Desired T_A = 30C

P = 7W (heatsink is dissipating)

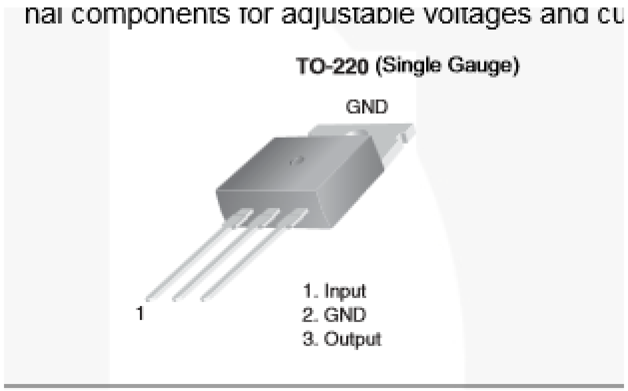
Temp rise of heatsink = 65C – 30C = 35C

35C / 7W = 5 C/W

Lesson Here

- Thermal calculation fairly straightforward for ballpark
- Easy to add too much padding → greatly complicates design

Electrical Isolation



LM7805

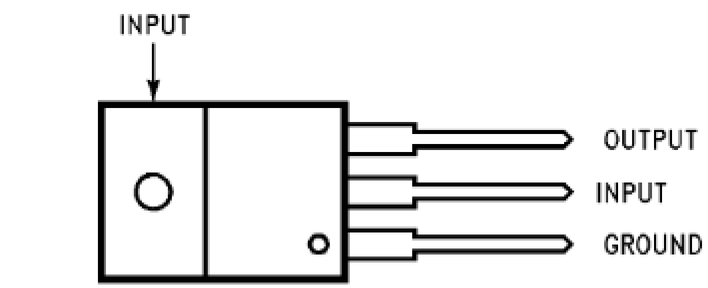
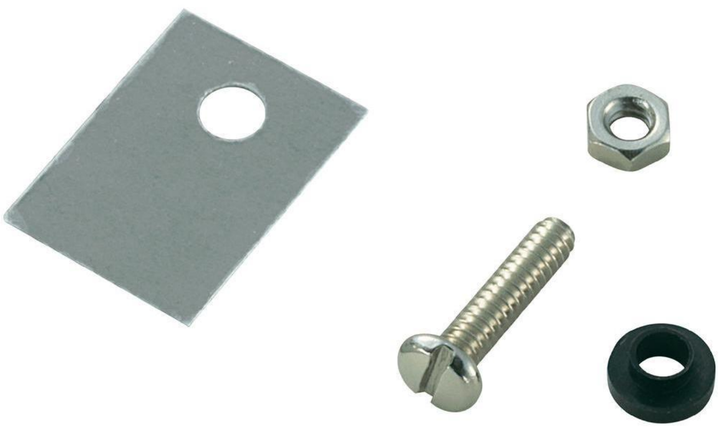
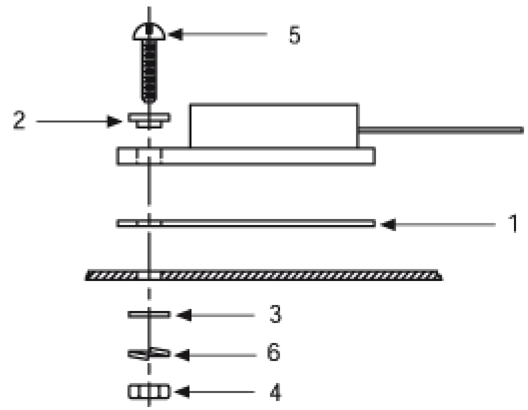


Figure 1. TO-220 Package
Front View

LM7905

Electrical Isolation



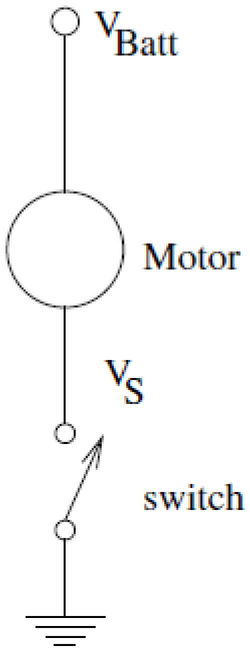


Various Heatsink Notes

- Heatsinks are NOT a good name
  - Doesn’t “sink” anything, just increases your surface area
- Calculations similar to voltage drops across resistors
  - Add thermal resistances in series
  - Can draw ‘schematics’ with thermal resistances even
- Be careful of tab connection → requires electrical isolation

Lab #1 Notes

Driving a motor… easy!



Source: Dr. Gregson’s Design Methods II ECED 3901 Manual, 2005.

Example Circuit

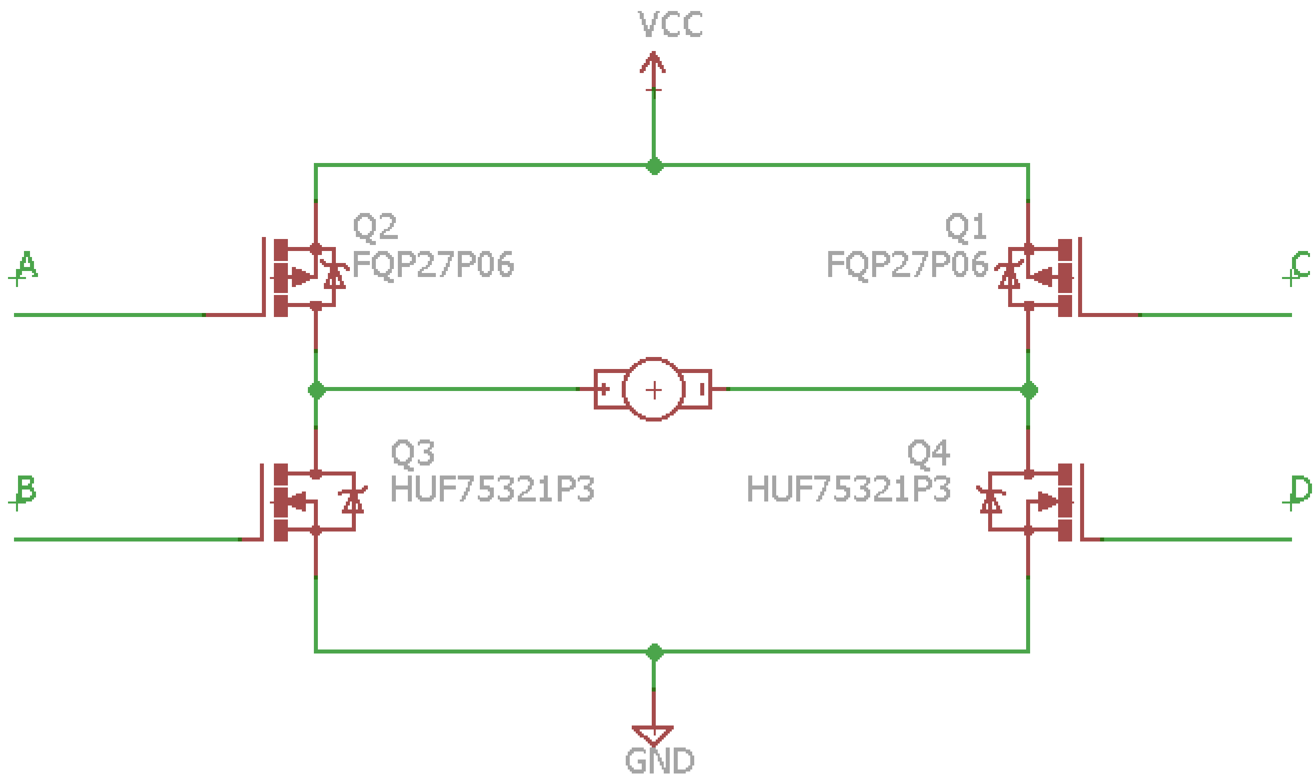

200.0
V
160.0
120.0
80.0
40.0
0.0
-40.0
-80.0
-120.0
-160.0
-200.0
-2.622
-1.622
-0.622
0.378
x1.0
µs

Seeing the Effects

Part #1 of this lab:

1) Look at the inductive spike
2) Add a diode to supress the spike

H-Bridge – Basics (for Lab)



Building an H-Bridge

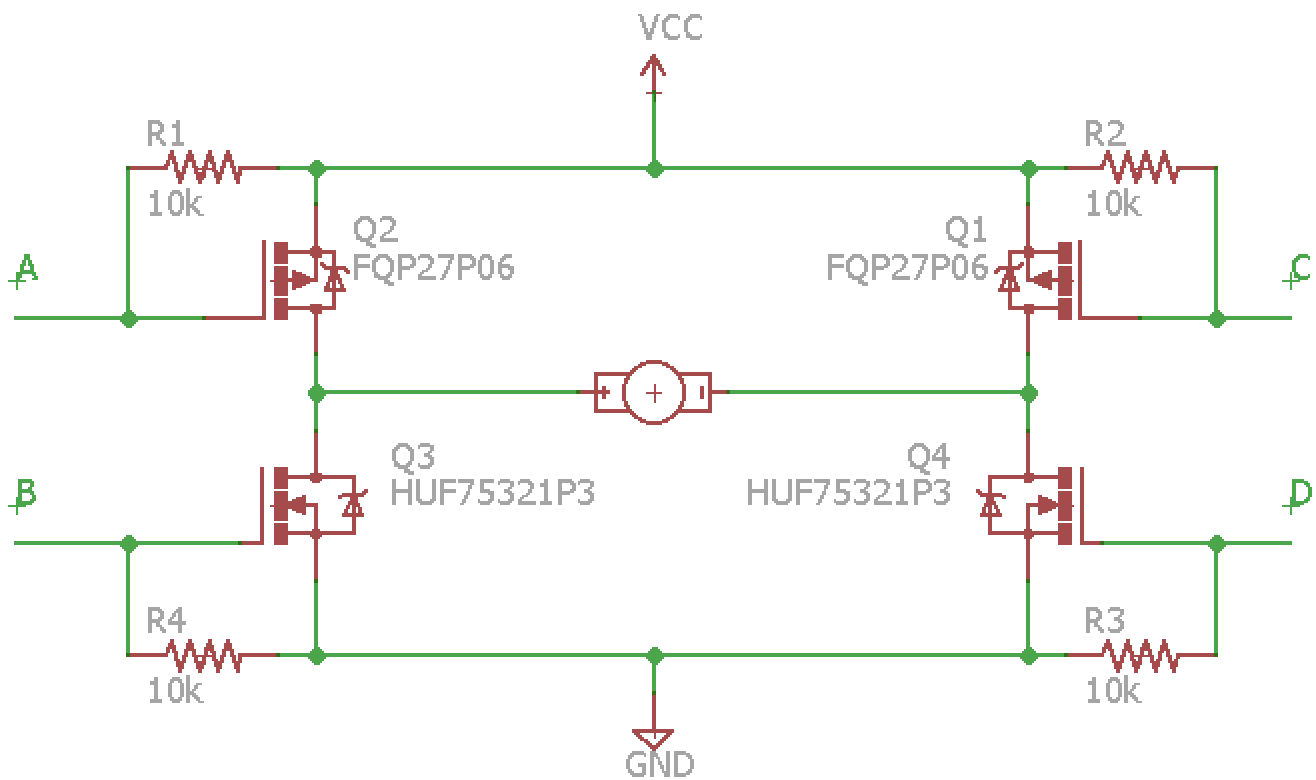
Colin O'Flynn

Help! How do I Solder?

Colin O'Flynn

Testing the H-Bridge

Avoid smoke…


VCC
R1
10k
Q2
FQP27P06
R2
10k
Q1
FQP27P06
A
C
Q3
HUF75321P3
Q4
HUF75321P3
B
D
R4
10k
R3
10k
GND

Learn Drive Signals

Testing PWM?

Let’s Go

- Labs will be done in groups of 2 (same as robot comp)
- Lab report due 1 week after lab day
- One lab report per group