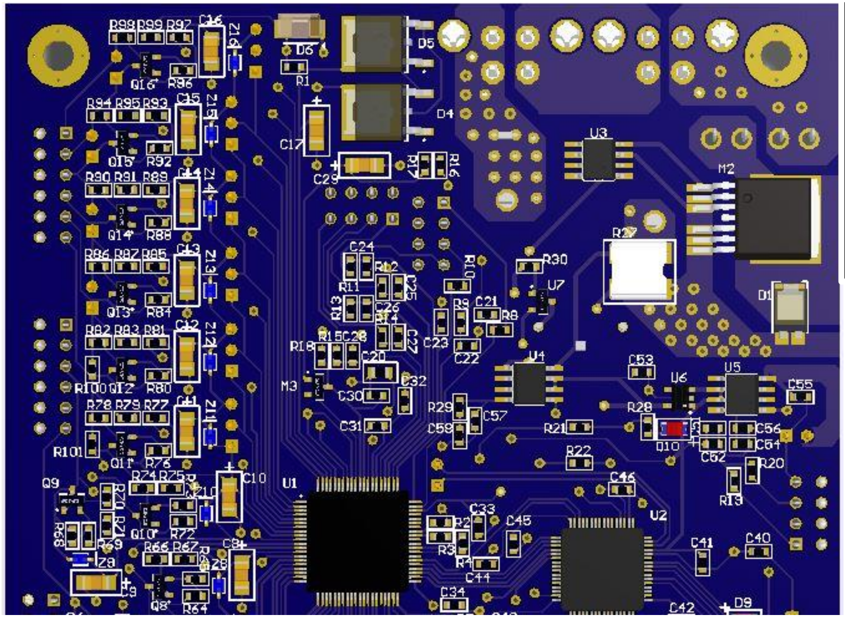
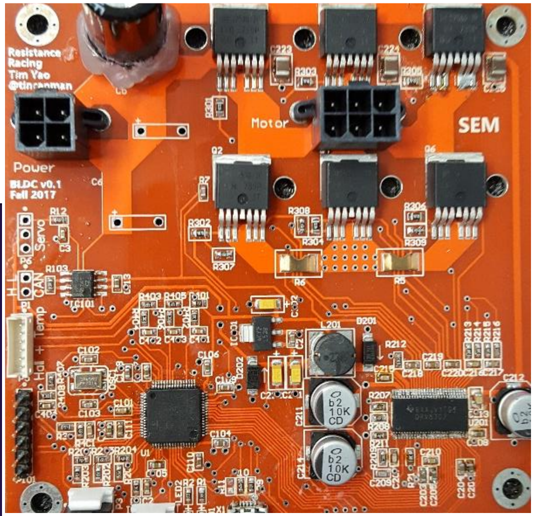
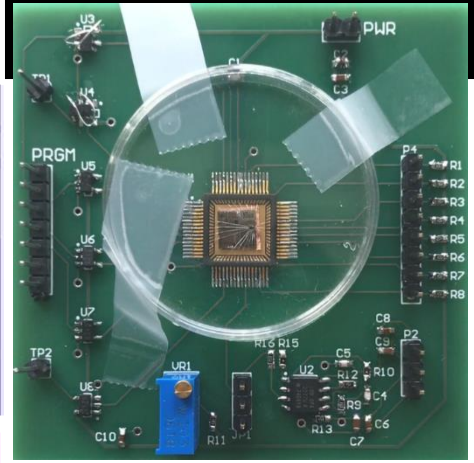
Printed Circuit Board Design

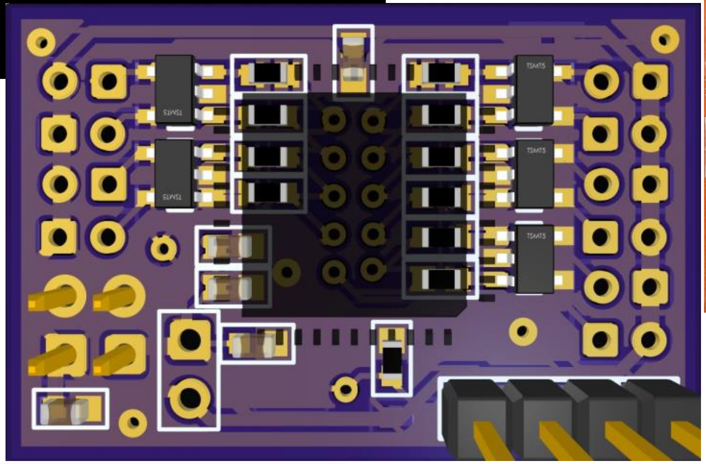


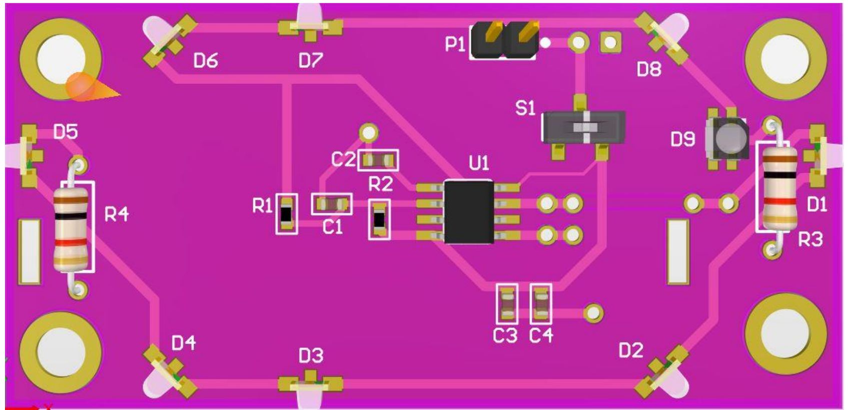
ECE 3400

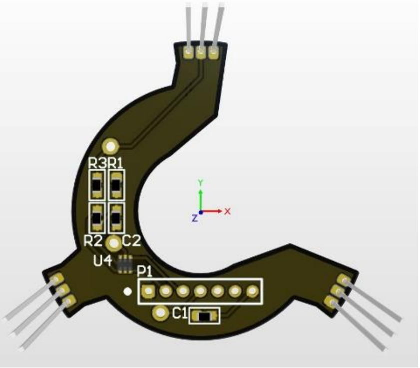
Lhh48@cornell.edu

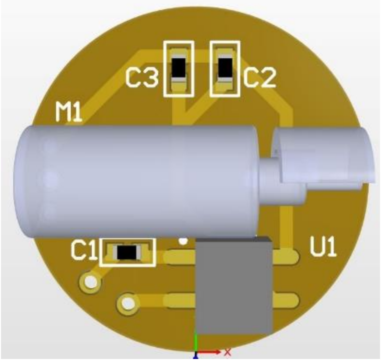


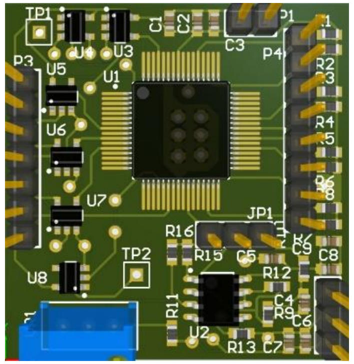


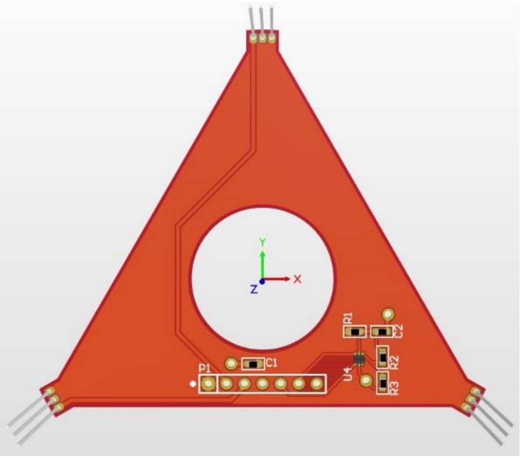










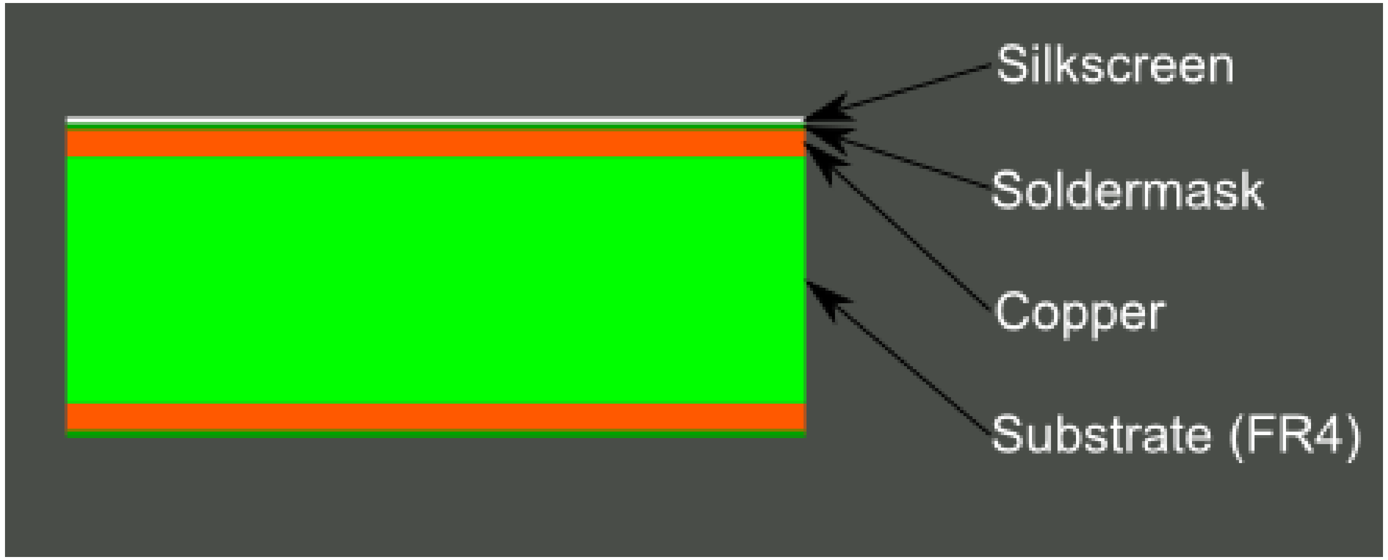


Agenda

- What is a PCB? Should I use a PCB?
- Design example
  - Component selection
  - Schematic design
  - Layout basics
- Layout Considerations
  - Trace Width, Pours, Thermals
  - Grounding
  - Decoupling
  - High-Frequency considerations
  - 3D Modelling
  - Testing
  - Mistakes
  - Other
- Eagle demo if time

What is a PCB?

- Interleaved layers of copper and insulator
- Number of layers = number of copper layers



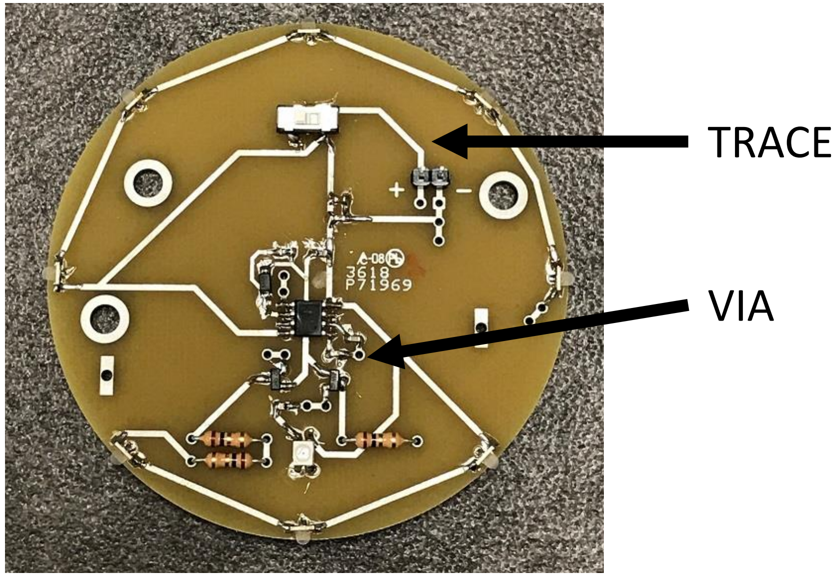
Useful Terms

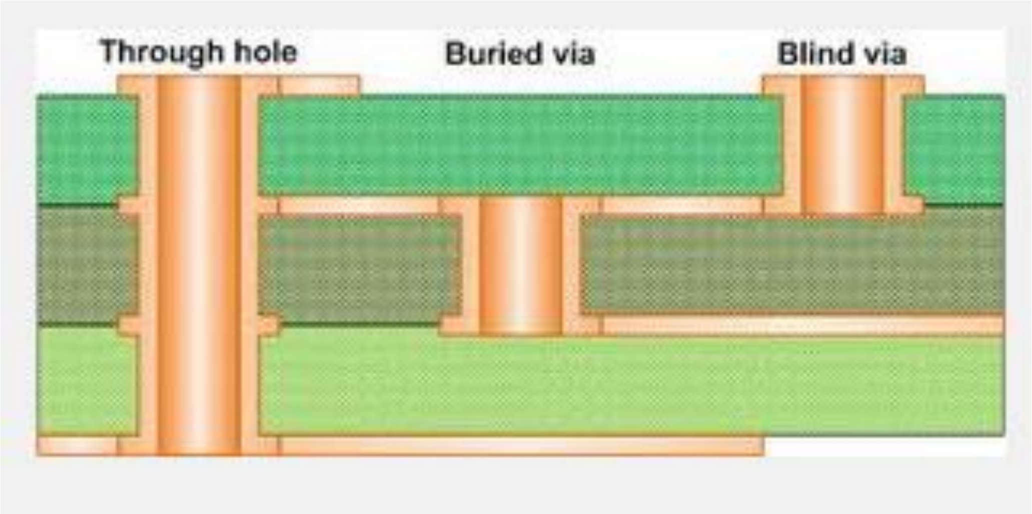
<u>Trace</u>

Copper path (equivalent of wire)

<u>Via</u>

Hole in board with connection between layers





Useful Terms

<u>Pad</u>

Exposed copper for component placement

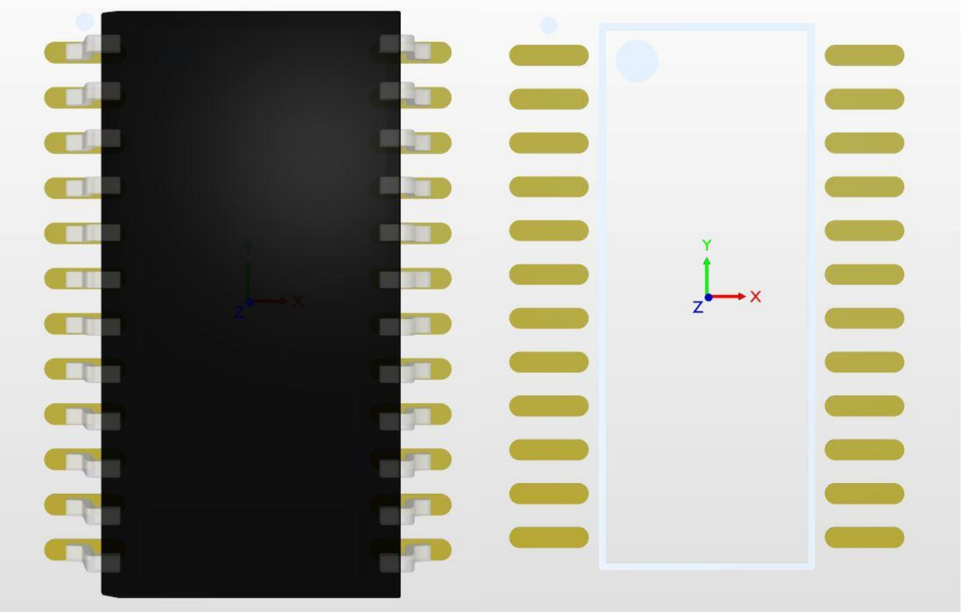
<u>Package</u>

Casing for a component with metal leads coming out.

Usually black plastic.

<u>Surface Mount</u> (SMT/SMD)

Components that can be soldered onto pads, not through-holes



SMD Package Pads

Thru-Hole

PCB Tradeoffs

Pros

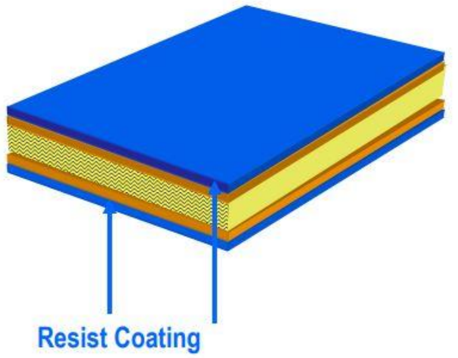
- Permanence/Reliability
- **Space-Savings**
- **Simple to Manufacture**
- Immune to movement
- Better grounding

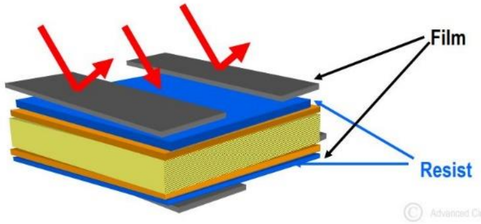
Cons

- **Permanence**
- Lead-Time
- Isolation
- High-Frequency Effects
- Testability
- Thermal Management

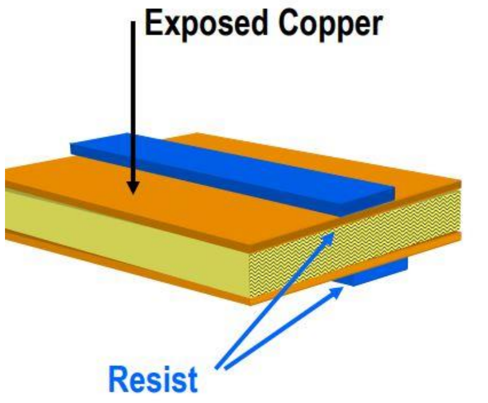
PCB Manufacturing

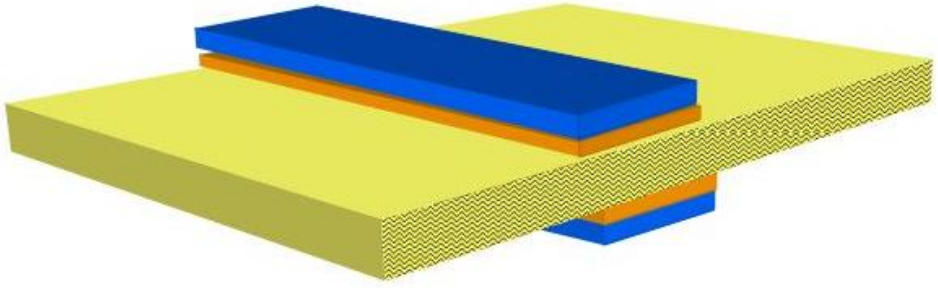
- Etching – Primarily used in industry, best tolerances





- **Milling** – Drill/Cut undesired copper
- Printing – Specialized conductive nano-inks
- Direct Plating
- Direct Cutting

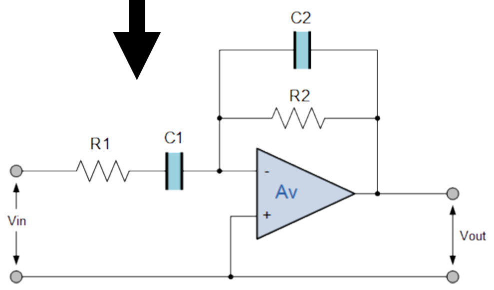


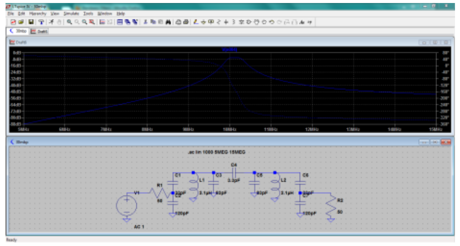


Design Process

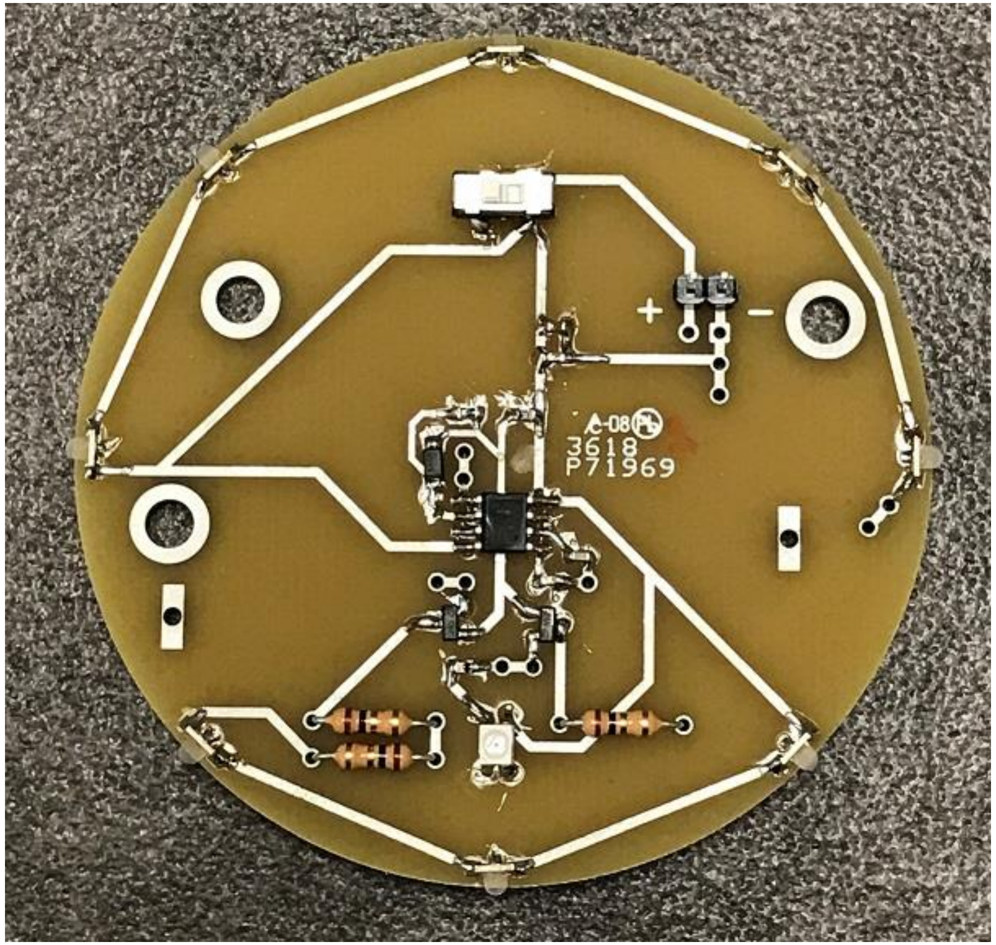
1) Specifications
2) Topology & Component Selection
3) Schematic
4) Simulation
5) Layout
6) Print 1:1 on paper and check
7) Export Gerbers and Order
8) Solder
9) Testing/Verification
10) Use

- 2 points: Working amplifier (or active filter) circuit for audio





Design Example – IR Hat



1) Specifications

<u>What should it do? How well? In what conditions?</u>

Given: Make a PCB which emits IR at ~10kHz

- Powered by 9V
- Mounts to robot chassis
- Should be detectable from 2 feet away without amplification
- Cheap

Open:

- Board dimensions
- Frequency accuracy
- Consistency between boards
- Harmonic content
- Protection mechanisms
- Everything else…

2) Topology Selection

<u>At a high level, what will I use to meet the specifications?</u>

- Microcontroller-Based? FPGA-Based? Timer-Based? Oscillator-Based?
- Waveform filtering? Duty cycle?
- Protection?
  - Fuses
  - Diode protection (Real diodes or ideal diode?)

2) Component Selection

Look on Digikey, Mouser, Ebay, Alibaba, etc.

Compare Parts		Image	Digi-Key Part Number	Manufacturer Part Number	Manufacturer	Description	Quantity Available	Unit Price USD	Minimum Quantity	Packaging	Series	Part Status	Type	Count	Frequency	Voltage - Supply	Current - Supply	Operating Temperature	Package / Case	Supplier Device Package	Mounting Type
			296-6501-2-ND	NE555DR	Texas Instruments	IC OSC SGL TIMER 100KHZ 8-SOIC	67,500 - Immediate	$0.10440	2,500	Tape & Reel (TR) Alternate Packaging	-	Active	555 Type, Timer/Oscillator (Single)	-	100kHz	4.5 V ~ 16 V	10mA	0°C ~ 70°C	8-SOIC (0.154", 3.90mm Width)	8-SOIC	Surface Mount
			296-6501-1-ND	NE555DR	Texas Instruments	IC OSC SGL TIMER 100KHZ 8-SOIC	71,360 - Immediate	$0.48000	1	Cut Tape (CT) Alternate Packaging	-	Active	555 Type, Timer/Oscillator (Single)	-	100kHz	4.5 V ~ 16 V	10mA	0°C ~ 70°C	8-SOIC (0.154", 3.90mm Width)	8-SOIC	Surface Mount
			296-6501-6-ND	NE555DR	Texas Instruments	IC OSC SGL TIMER 100KHZ 8-SOIC	71,360 - Immediate	Digi-Reel®	1	Digi-Reel® Alternate Packaging	-	Active	555 Type, Timer/Oscillator (Single)	-	100kHz	4.5 V ~ 16 V	10mA	0°C ~ 70°C	8-SOIC (0.154", 3.90mm Width)	8-SOIC	Surface Mount
			296-21752-2-ND	NA555DR	Texas Instruments	IC OSC SGL TIMER 100KHZ 8-SOIC	50,000 - Immediate	$0.10440	2,500	Tape & Reel (TR) Alternate Packaging	-	Active	555 Type, Timer/Oscillator (Single)	-	100kHz	4.5 V ~ 16 V	10mA	-40°C ~ 105°C	8-SOIC (0.154", 3.90mm Width)	8-SOIC	Surface Mount
			296-21752-1-ND	NA555DR	Texas Instruments	IC OSC SGL TIMER 100KHZ 8-SOIC	52,346 - Immediate	$0.48000	1	Cut Tape (CT) Alternate Packaging	-	Active	555 Type, Timer/Oscillator (Single)	-	100kHz	4.5 V ~ 16 V	10mA	-40°C ~ 105°C	8-SOIC (0.154", 3.90mm Width)	8-SOIC	Surface Mount
			296-21752-6-ND	NA555DR	Texas Instruments	IC OSC SGL TIMER 100KHZ 8-SOIC	52,346 - Immediate	Digi-Reel®	1	Digi-Reel® Alternate Packaging	-	Active	555 Type, Timer/Oscillator (Single)	-	100kHz	4.5 V ~ 16 V	10mA	-40°C ~ 105°C	8-SOIC (0.154", 3.90mm Width)	8-SOIC	Surface Mount
			296-39169-2-ND	SE555DR	Texas Instruments	IC OSC SGL TIMER 100KHZ 8-SOIC	52,500 - Immediate	$0.12705	2,500	Tape & Reel (TR) Alternate Packaging	-	Active	555 Type, Timer/Oscillator (Single)	-	100kHz	4.5 V ~ 18 V	10mA	-55°C ~ 125°C	8-SOIC (0.154", 3.90mm Width)	8-SOIC	Surface Mount
			296-39169-1-ND	SE555DR	Texas Instruments	IC OSC SGL TIMER 100KHZ 8-SOIC	55,634 - Immediate	$0.46000	1	Cut Tape (CT) Alternate Packaging	-	Active	555 Type, Timer/Oscillator (Single)	-	100kHz	4.5 V ~ 18 V	10mA	-55°C ~ 125°C	8-SOIC (0.154", 3.90mm Width)	8-SOIC	Surface Mount
										Digi-Reel®			555 Type								

2) Component Selection

Always make a bill of materials (BOM)

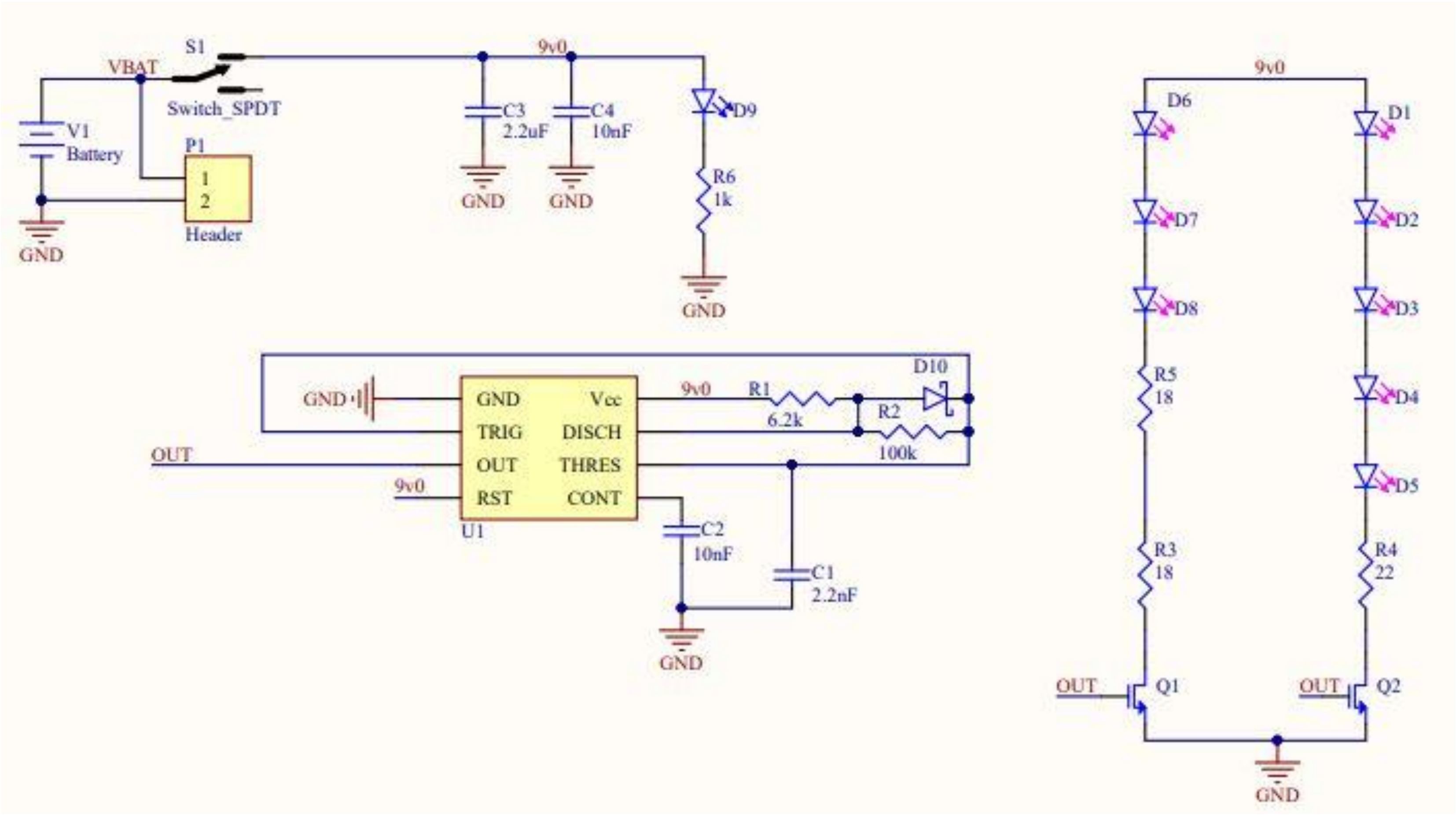
Item #	Ref Des	Qty	Qty Owned	Qty to Order	Manufacturer	Part #	Distributor	Description	Package/ Type	Unit Cost	Notes	Ordered	Placed	Website
1	U1	1	0	15	TI	296-21752-1-ND	Digikey	555 Timer	SOIC-8	0.364		NO	NO	https://www.digikey.c
2	D1-D8	8	0	25	SunLED	1497-1205-1-ND	Digikey	IR LED 880nm	SMD	0.319	Side View, 880nm	NO	NO	https://www.digikey.c
3	D9	1	0	0	LED	CLM4B-RKW-CWBXBAA3CT-ND	Digikey	Red LED	4-PLCC	0.205	70mA Imax	NO	NO	https://www.digikey.c
4	S1	1	0	0	Nidec-Copal	563-1318-1-ND	Digikey	Slide Switch	SMT	1.0152	200mA,12V	NO	NO	https://www.digikey.c
5	D10	1	0	10	ON Semi	NRVTS260ESFT1	Digikey	Schottky	SMD	0.273		NO	NO	https://www.digikey.c
6	R1	1	0	0	Panasonic	P6.2KDBCT-ND	Digikey	Res	_0603	0.3	6.2k	NO	NO	https://www.digikey.c
7		1	0	10	Vishay	MCT0603-5.60K-	Digikey	Res	_0603	0.152	5.6k	NO	NO	https://www.digikey.c
8	R2	1	0	0	Panasonic	P100KDBCT-ND	Digikey	Res	_0603	0.3	100k	NO	NO	https://www.digikey.c
9	R3	1	0	0			Digikey	Res	_0603			NO	NO	
10	R4	1	0	0			Digikey	Res	_0603			NO	NO	
11	R5	1	0	0			Digikey	Res	_0603			NO	NO	
12	R6	1	0	0	Rohm	RHM1.0KDCT-NI	Digikey	Res	_0603	0.087	1k	NO	NO	https://www.digikey.c
13	C1	1	0	10	Murata	490-4931-1-ND	Digikey	Cap	_0603	0.057	2.2nF	NO	NO	https://www.digikey.c
14		1	0	0	Samsung	490-4777-1-ND	Digikey	Cap	_0603	0.0254	1nF	NO	NO	https://www.digikey.c
15	C2,C4	2	0	0	AVX	478-1227-1-ND	Digikey	Cap	_0603	0.0334	10nF	NO	NO	https://www.digikey.c
16	C3	1	0	0	Samsung	1276-1045-1-ND	Digikey	Cap	_0603	0.0306	2.2uF	NO	NO	https://www.digikey.c

Total Cost	~$20

For Ordering

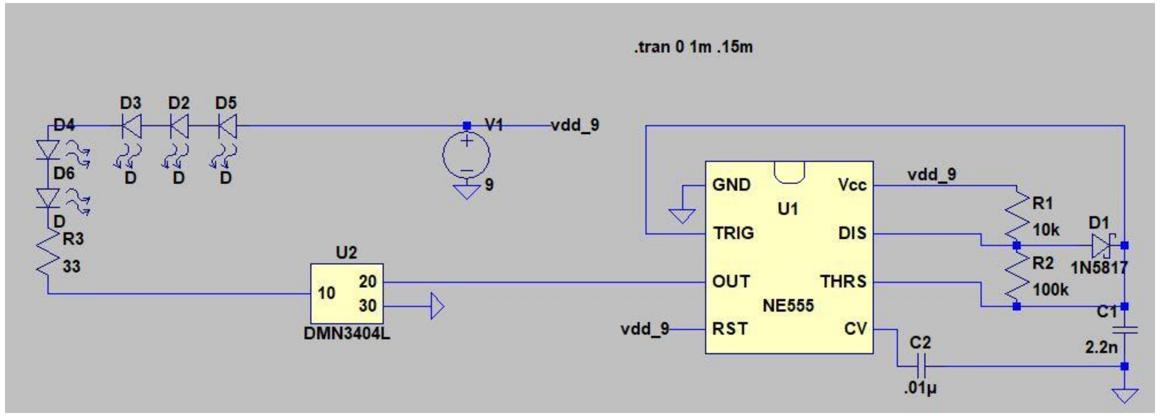
Digikey Part Number	Quantity
296-21752-1-ND	15
1497-1205-1-ND	25
NRVTS260ESFT1GOSCT-ND	10
MCT0603-5.60K-CFCT-ND	10
490-4931-1-ND	10

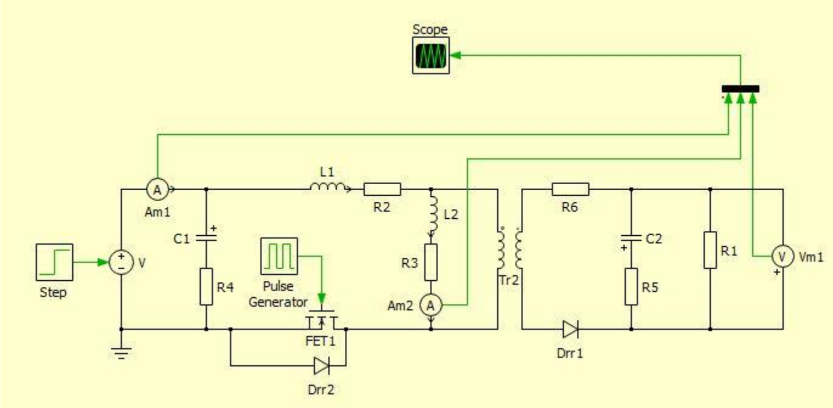
3) Schematic Design



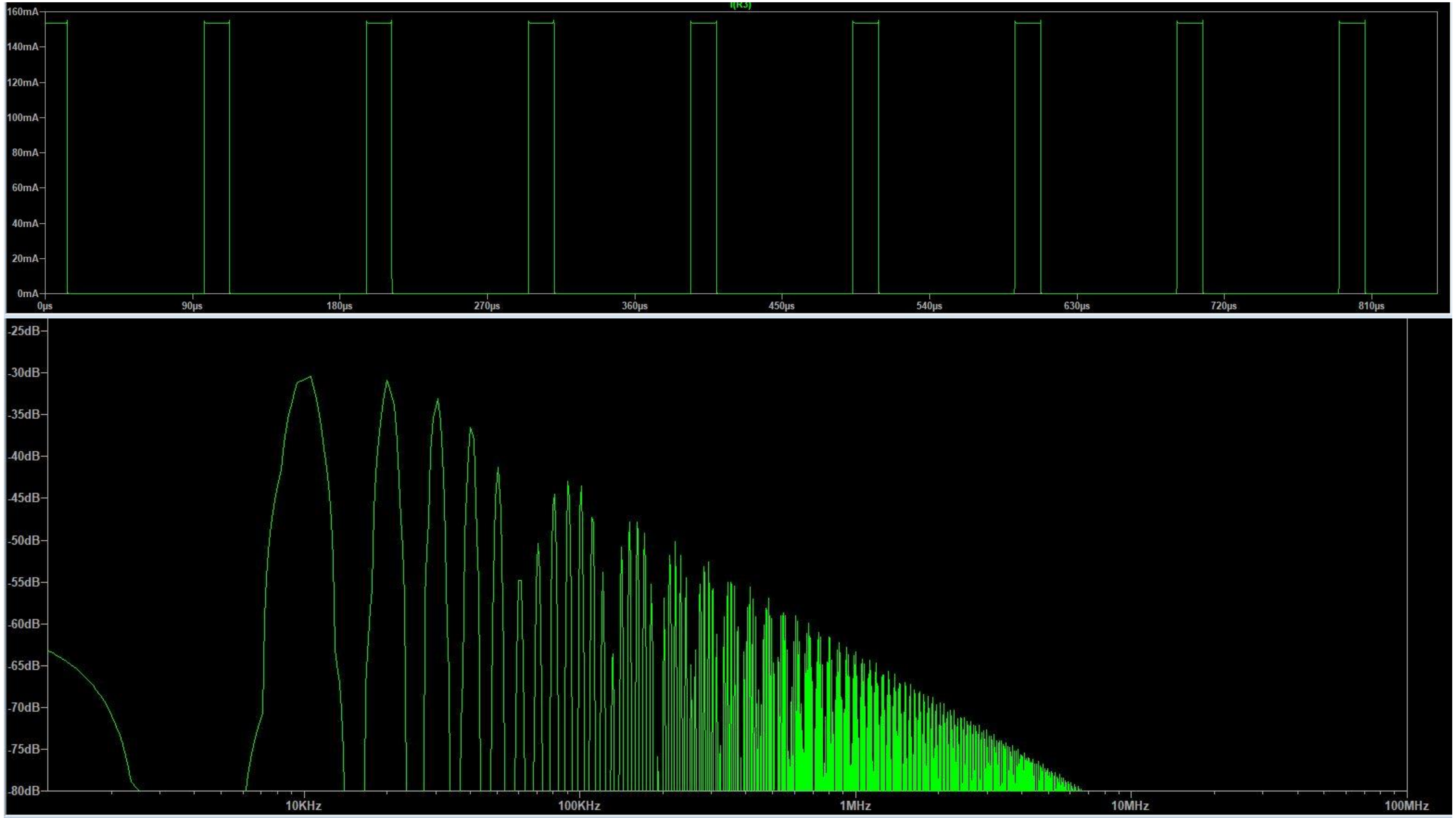
4) Simulation

- Can verify analog functionality and simple digital
- Recommend LTSpice due to real component models but many options… (Pspice, PartSim, PLECCS, EasyEDA, Autodesk Circuits, etc.)



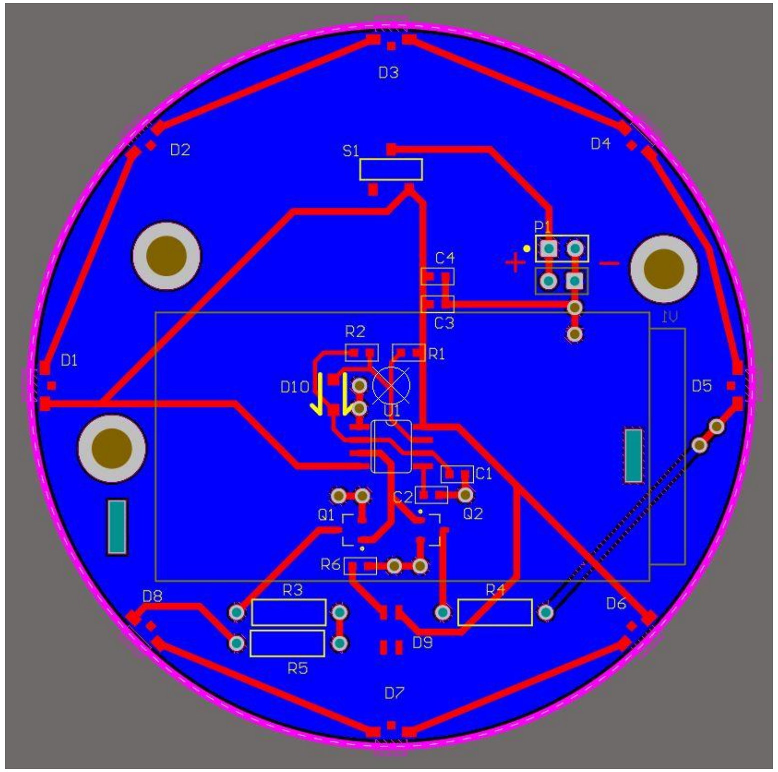


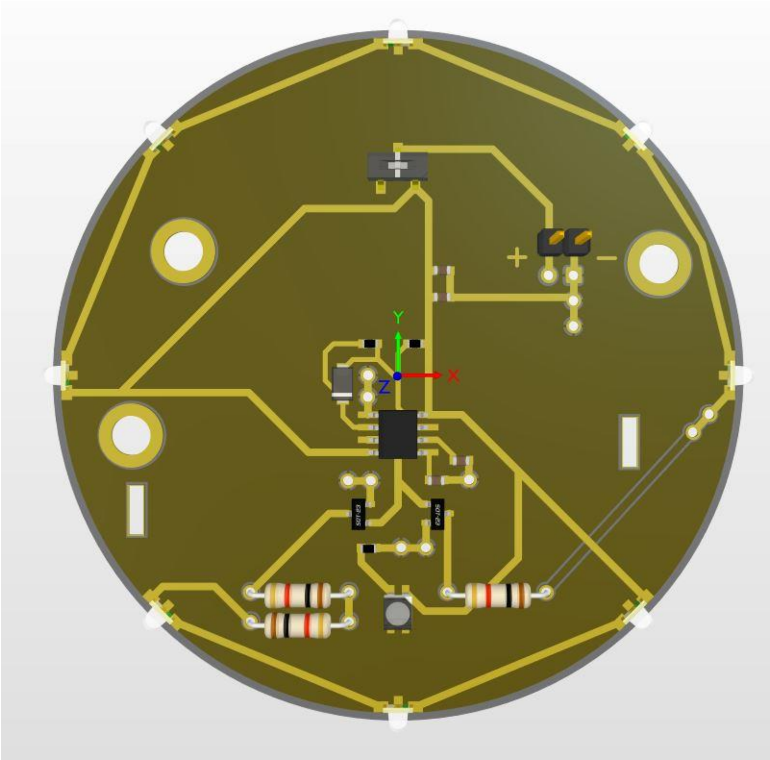
4) Simulation



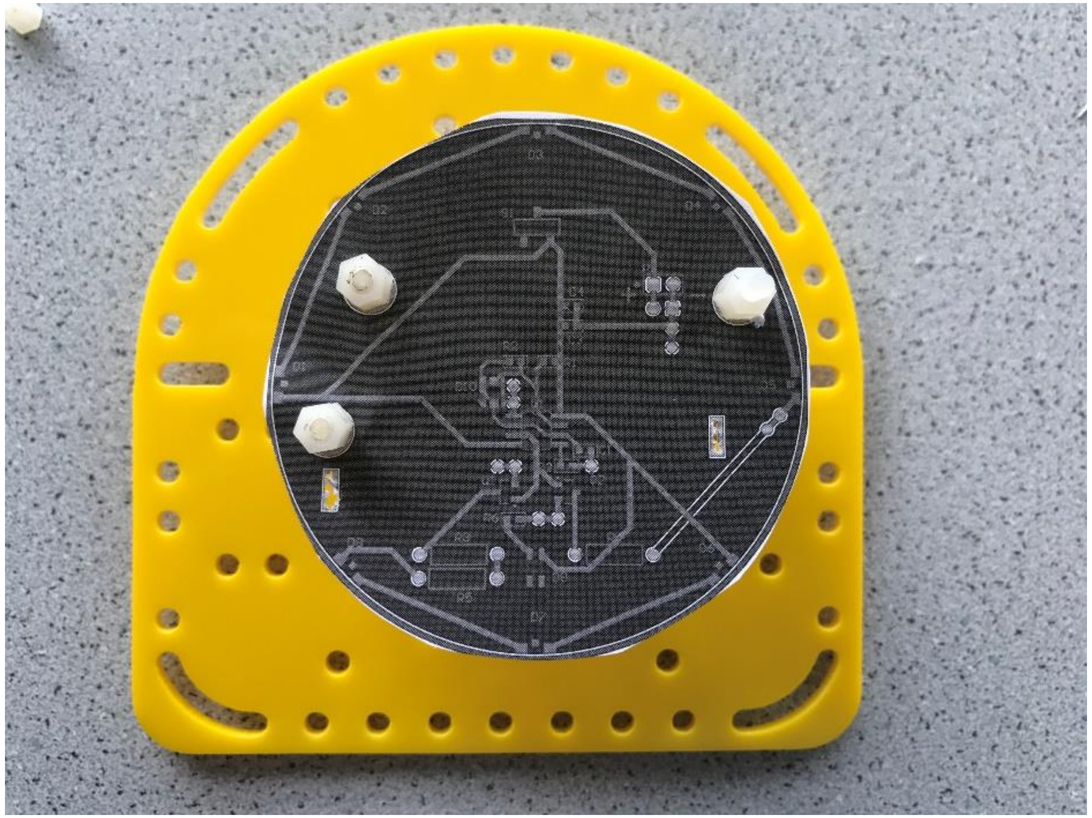
5) Layout

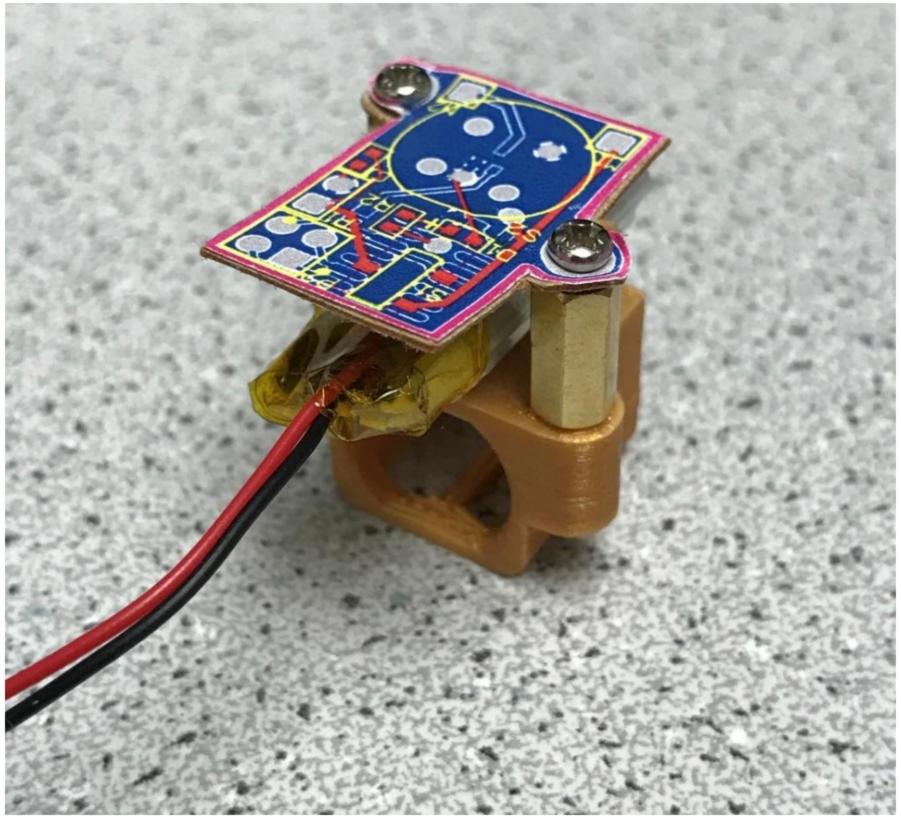
<u>How do I want to physically place my components?</u>





6) Print and Check





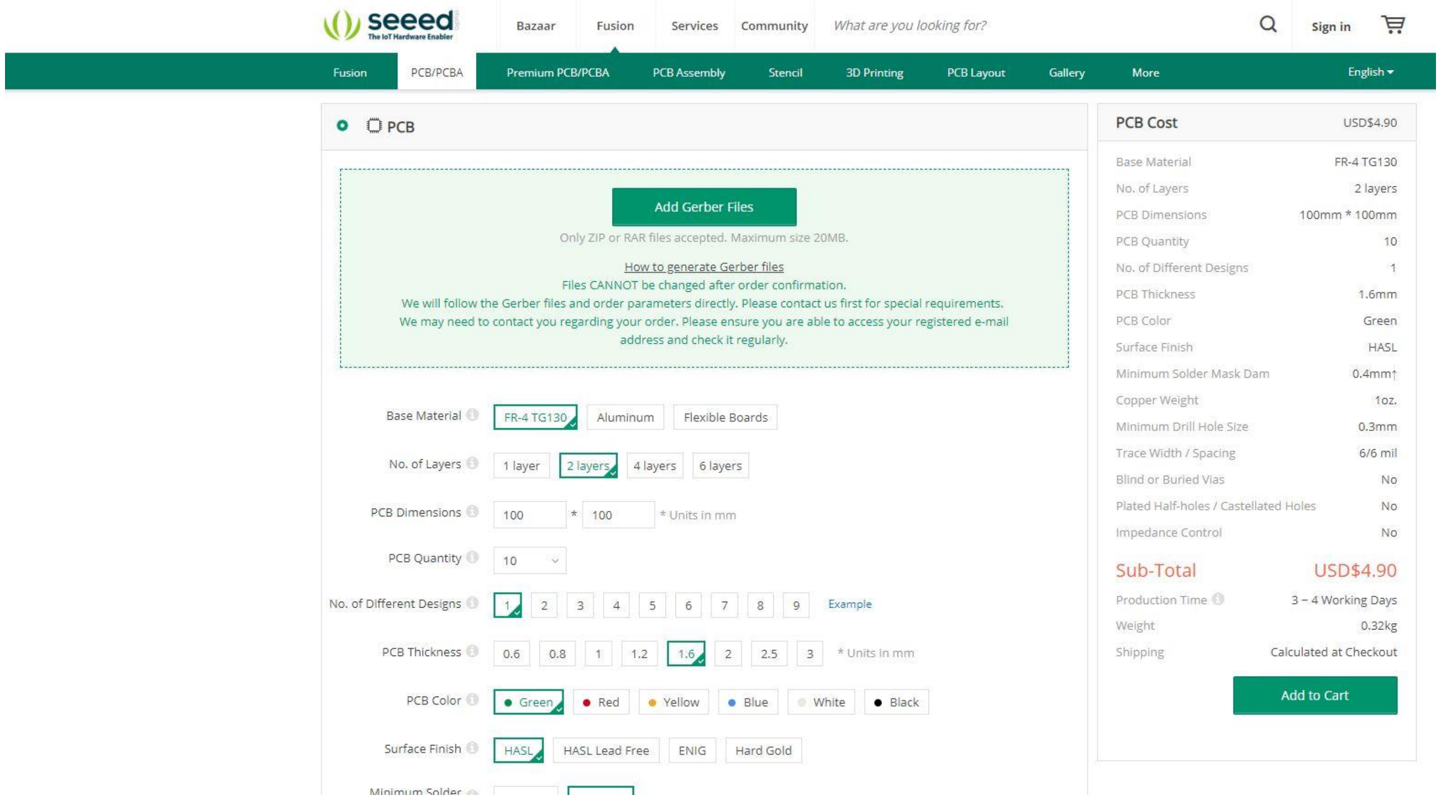
7) Export Gerbers

Gerber files are what the fabrication house uses to make the board.

- Generate Gerbers
- Create zipped folder
- Check that they are correct (http://www.gerber-viewer.com/)
- Upload to website

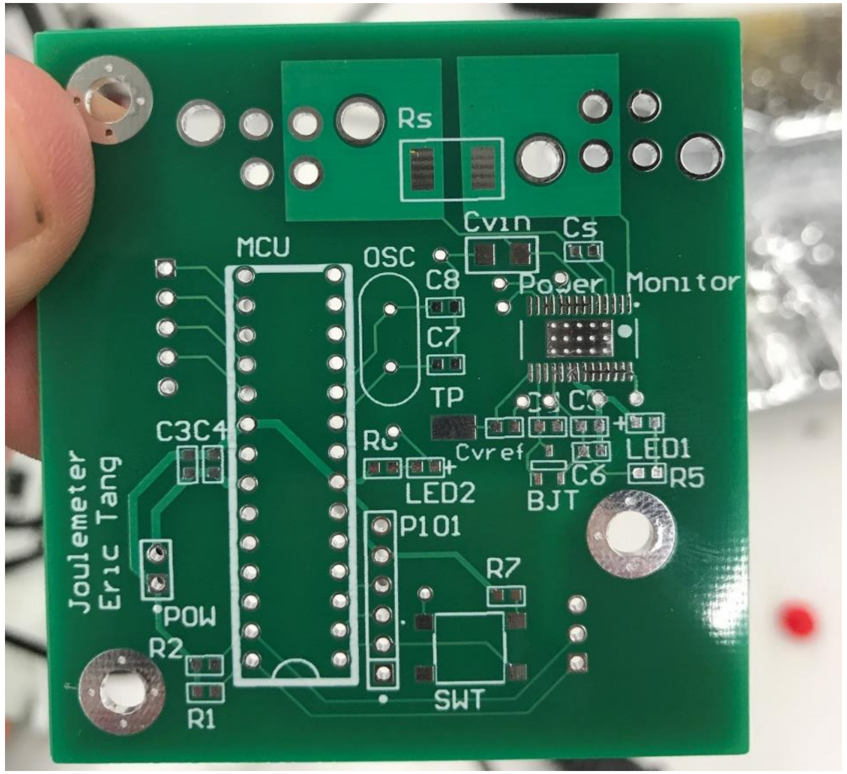
7) Order

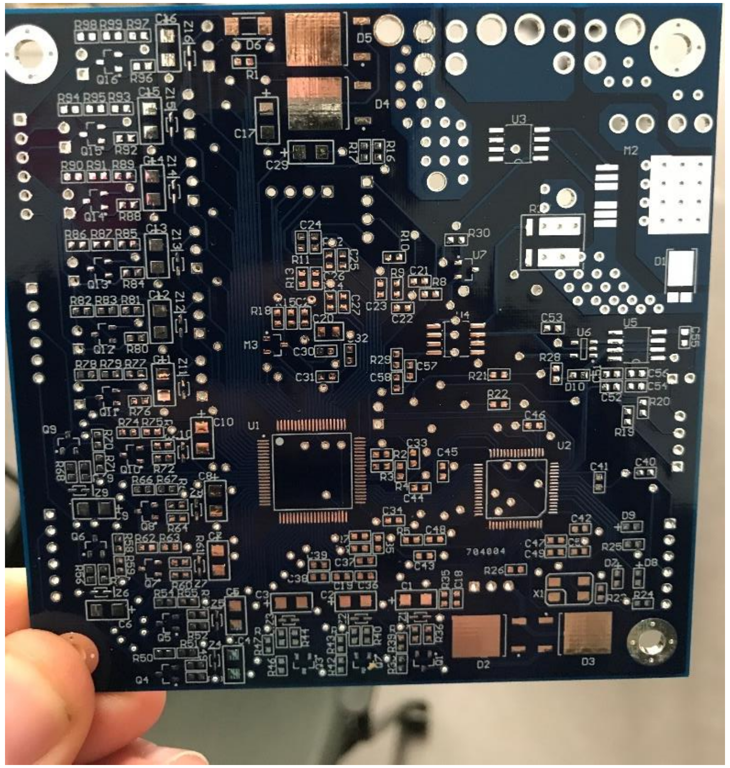
Advanced Circuits, Seeedstudio, Oshpark, PCB Minions, ……



8) Solder

Your board looks like this when you get it back

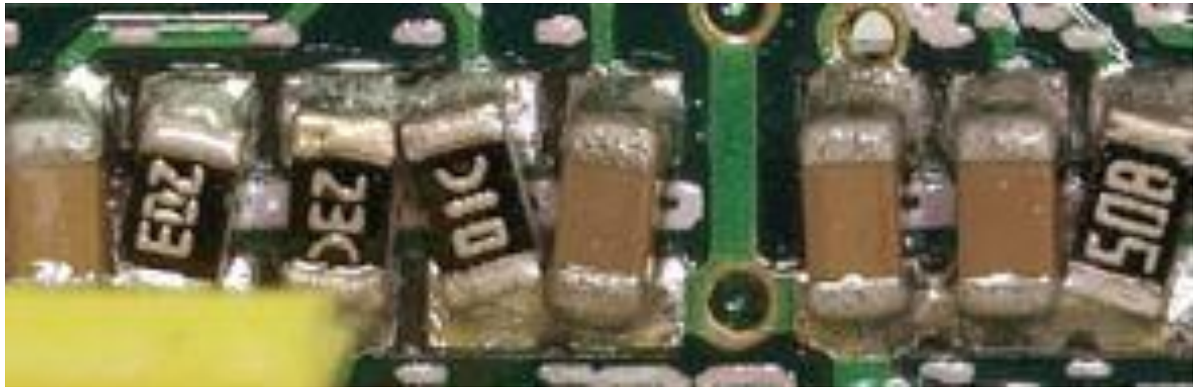




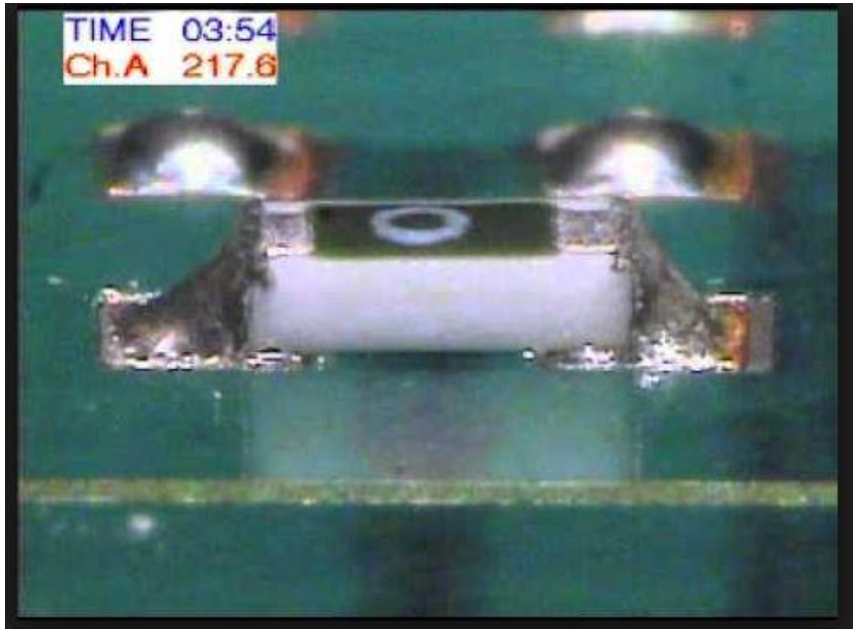
8) Solder

- Always do SMD components first!
- Usually smaller → bigger, IC's first then resistors/caps
- Once finished with SMD, shortest → tallest thru-hole components
- Can solder and test incrementally
- Need to see a proper fillet!

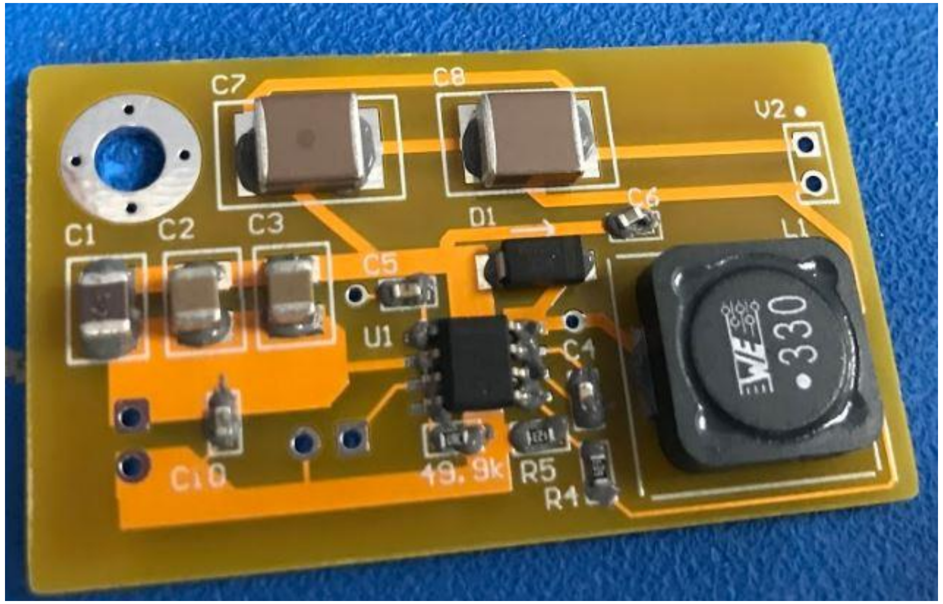
BAD



GOOD



8) Solder



Methods

Soldering Iron

- Melt solder onto pad
- Add flux (optional)
- Pick component with tweezers and hold lead against pad
- Re-melt solder so that it joins lead and pad

(Multiple other techniques)

Solder Paste

- Place paste on all pads (can use stencil)
- Place components onto paste
- Cook

9) Testing & Verification

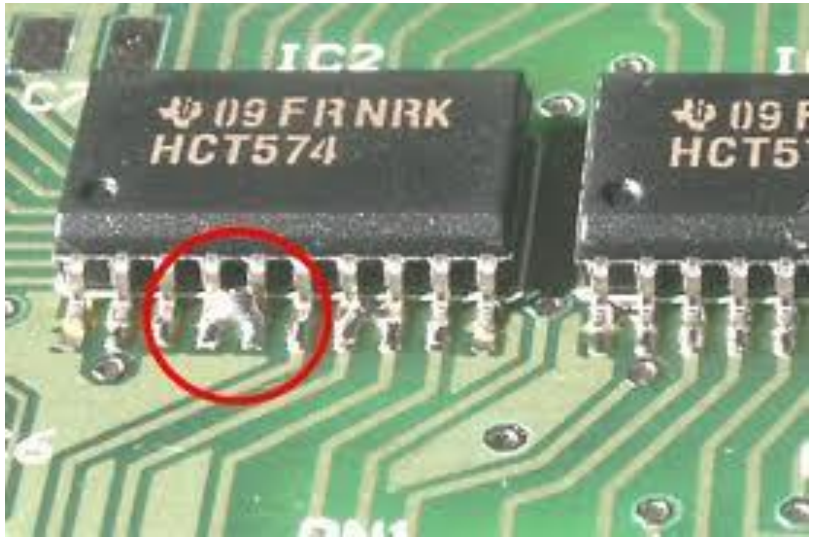
1) Using your eyes and a multimeter you should:

- Visually inspect all solder joints
- Check continuity between each lead and pad (Should be <1ohm)
- Check discontinuity between adjacent leads (Should be infinite resistance)

2) Do an initial power-on test

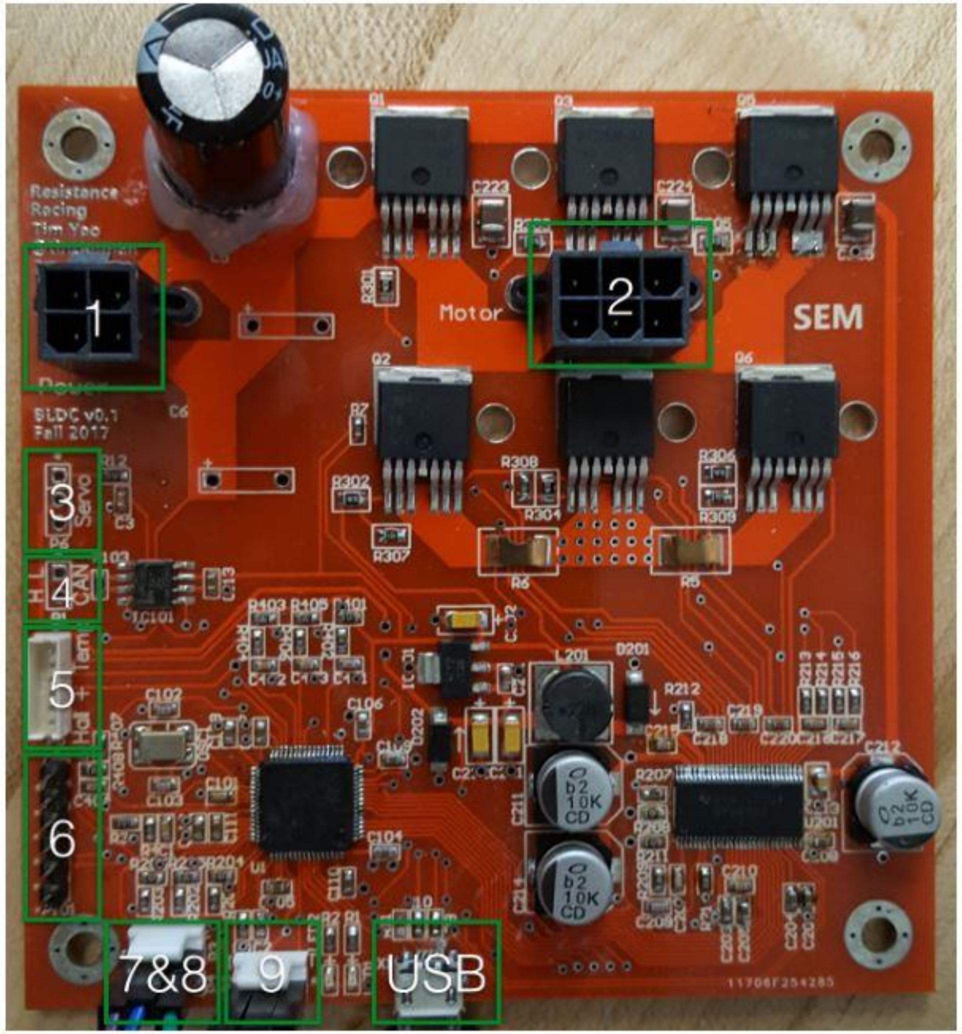
- Use a regulated voltage source!
- If voltage varies or current is high, turn it off!
- Check voltage of test-points and rails

3) Test functionality incrementally



10) Use

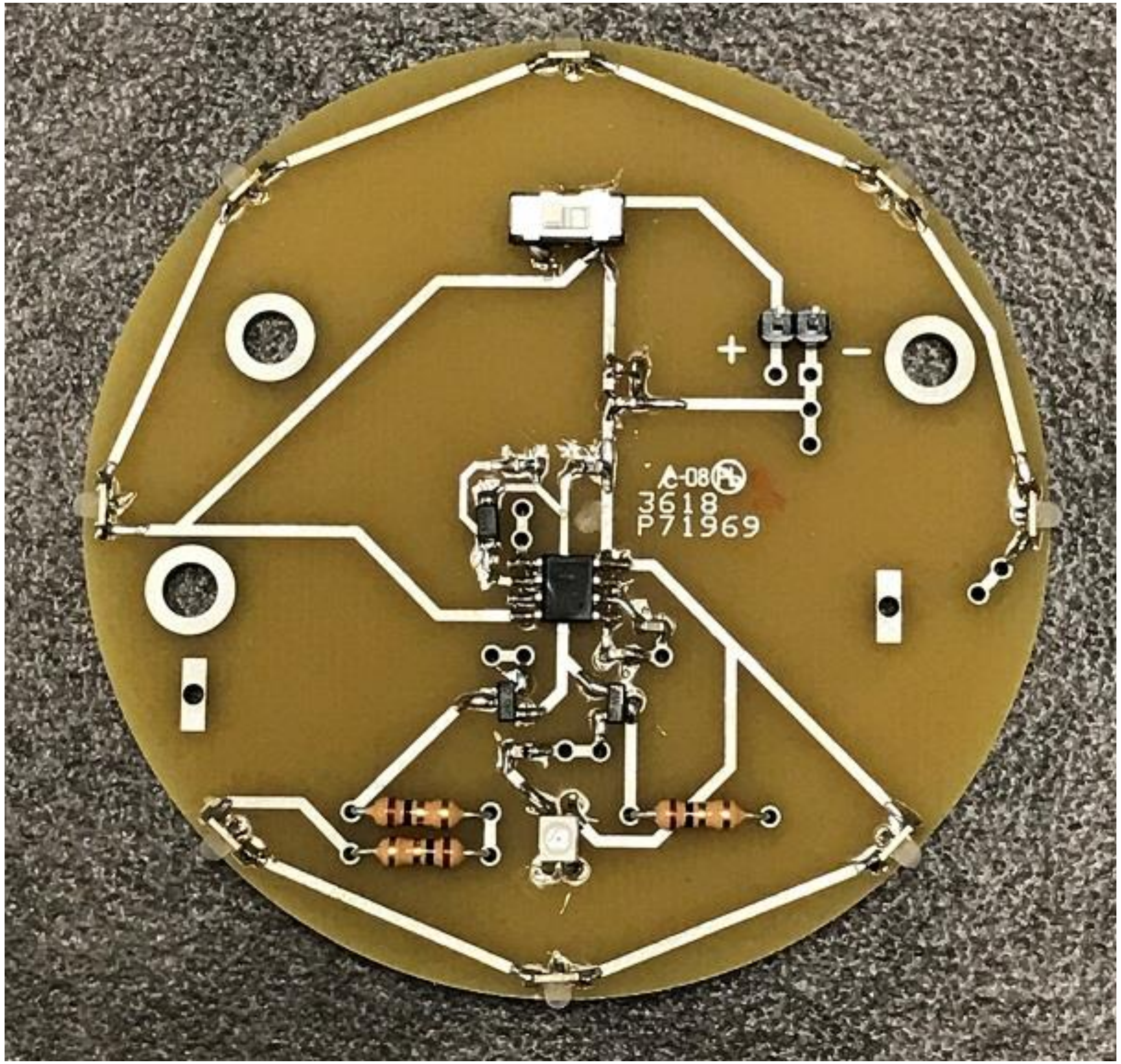
- Diagram your board for ease of use
- Follow ESD guidelines
- Use plastic mounting screws
- Avoid bending board



11) Reflect

Problems with design…

- No protection
- Inaccurate frequency
- Harmonic content
- Fab house mistake
- What else?

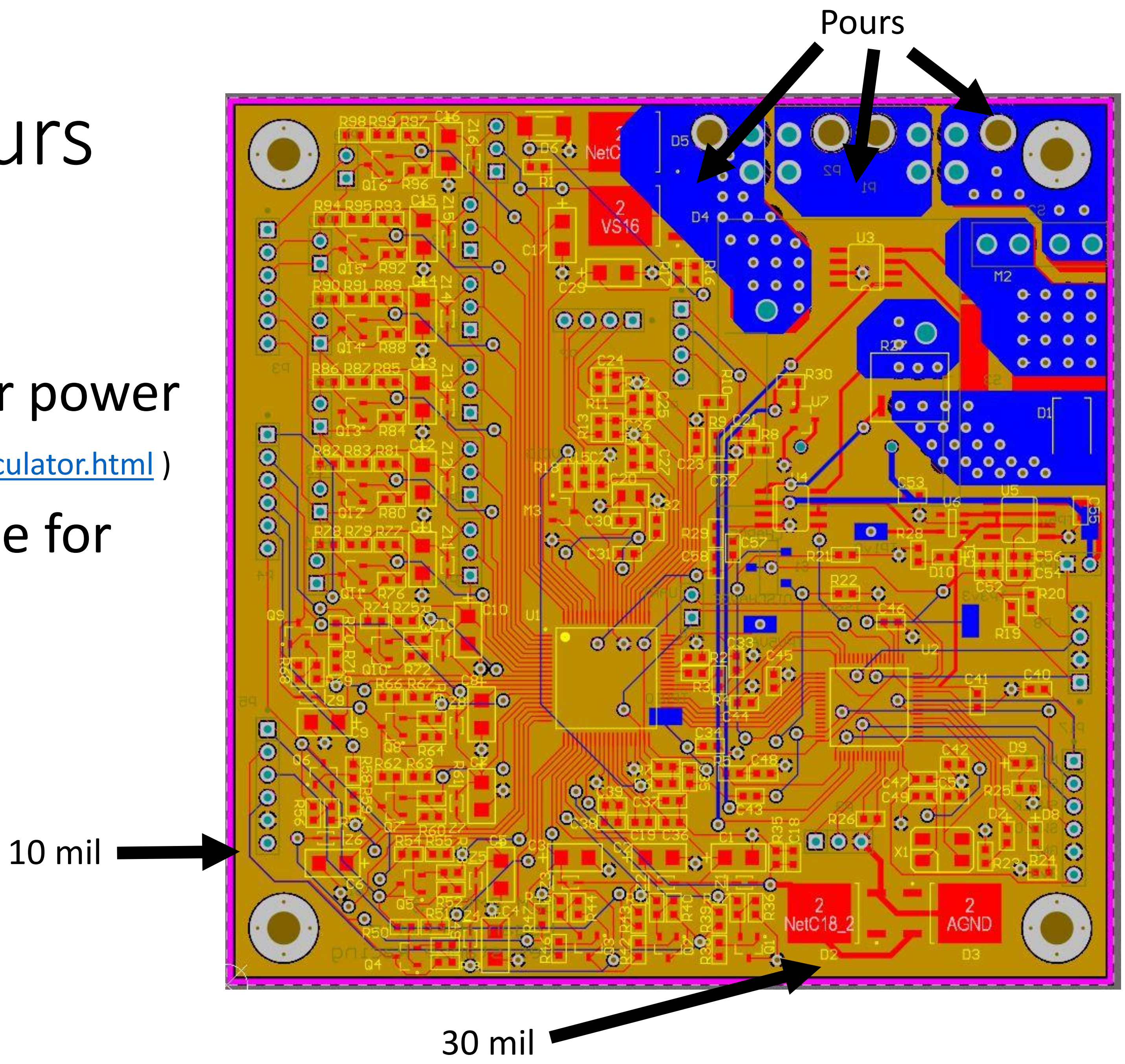


Layout Considerations

- Trace Width, Pours, Thermals
- Grounding
- Digital vs. Analog
- Decoupling
- High-Frequency considerations
- 3D Modelling
- Mistakes
- Other

Trace Width, Pours

- Usually start at 10mil
- Thicker traces for higher power
  (https://www.4pcb.com/trace-width-calculator.html)
- Use pours when possible for greater than ~500mA



Thermals - Simple

FET has on-resistance of 1ohm. Average current is 1A. → Power dissipation is 1W

Too much power? Check Datasheet:

● **Absolute maximum ratings** (Ta = 25°C)

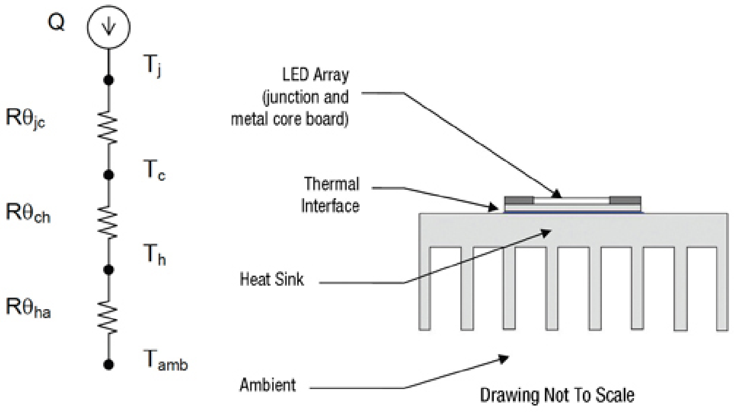
<It is the same ratings for the Tr.1 and Tr.2>

Parameter		Symbol	Limits	Unit
Collector-base voltage		V_{CBO}	30	V
Collector-emitter voltage		V_{CEO}	30	V
Emitter-base voltage		V_{EBO}	6	V
Collector current	DC	I_C	3	A
	Pulsed	I_{CP} *1	6	A
Power dissipation		P_D *2	0.5	W/Total
		P_D *3	1.25	W/Total
		P_D *3	0.9	W/Element
Junction temperature		T_j	150	°C
Range of storage temperature		T_{stg}	-55 to 150	°C

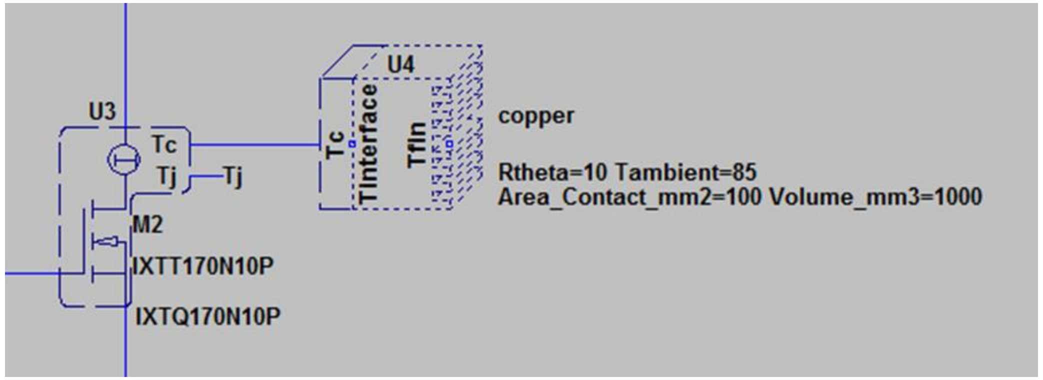
Yes. Add heat-sink.

Thermals - Detailed

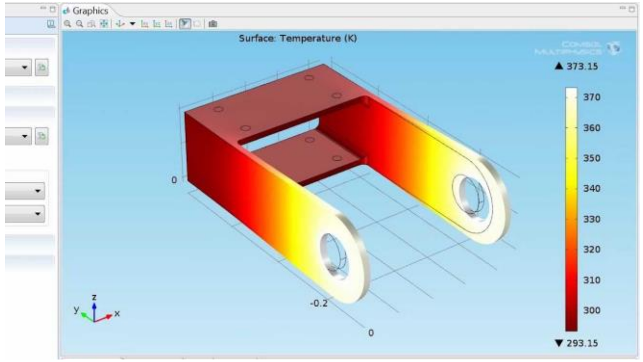
Hand Calculations:



LTSpice Thermals:



FEA Models:

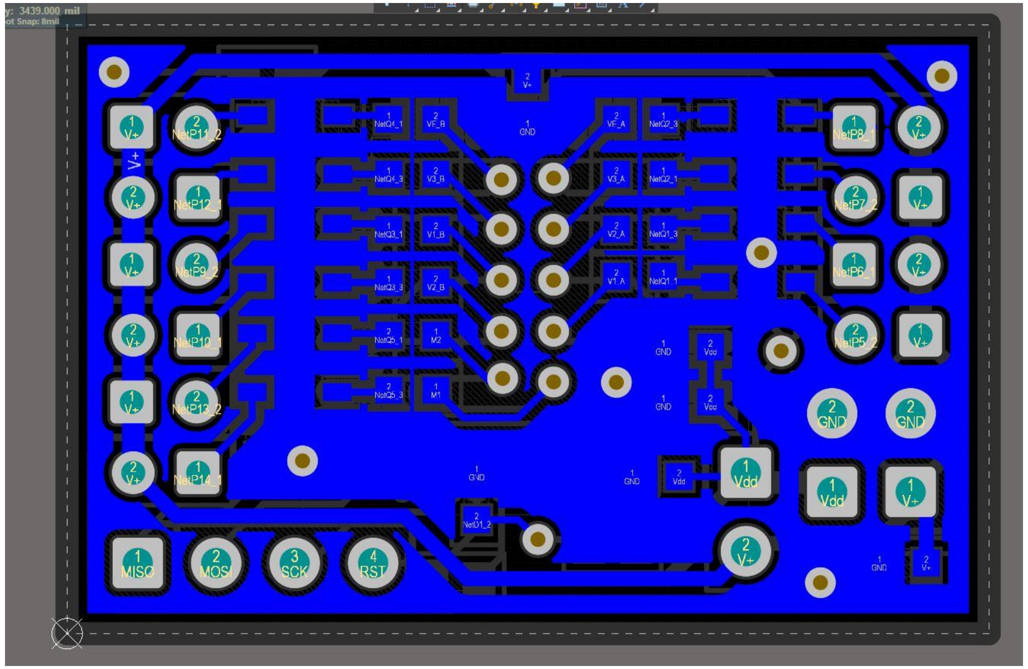


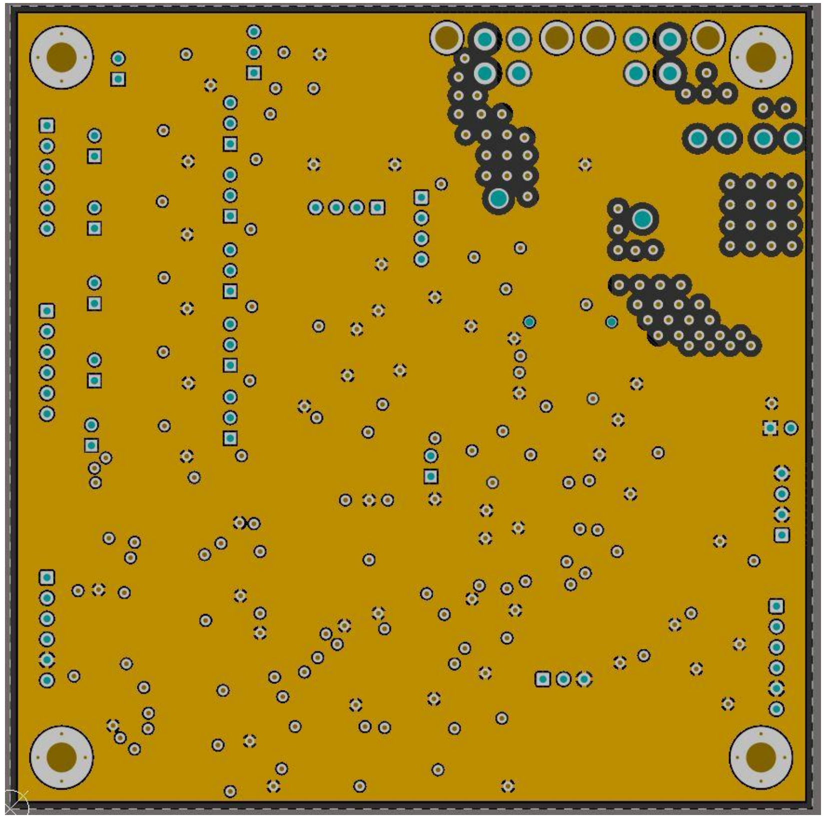
Increasing Accuracy & Complexity

Grounding

Make one layer a complete ground plane if possible!

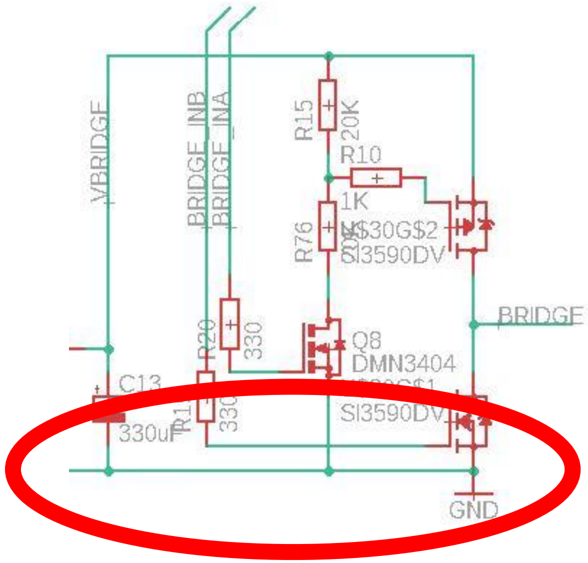
Otherwise be very careful with connections

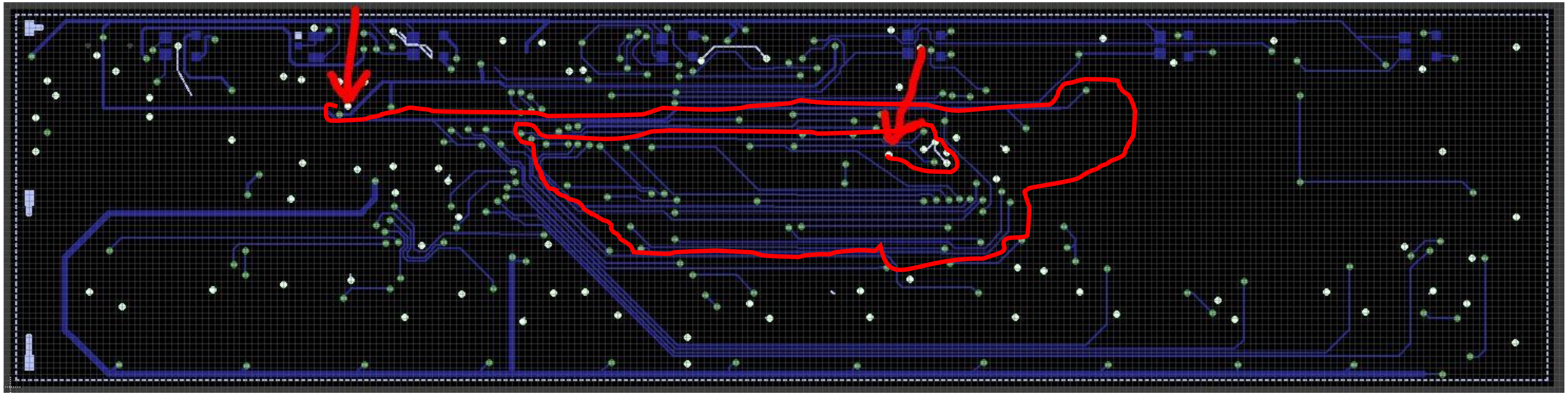




Grounding

Common mistake…

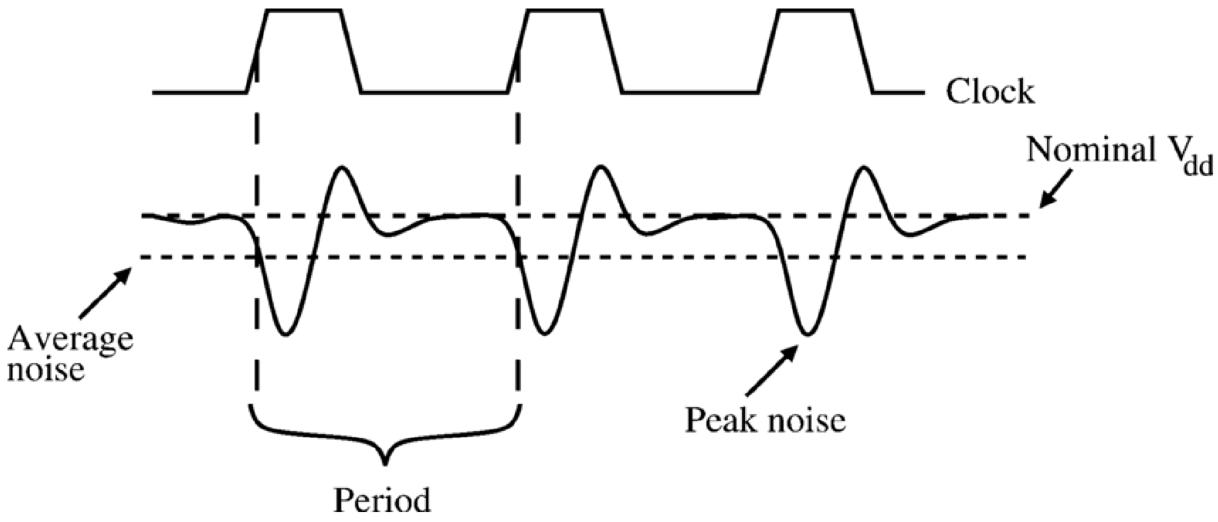


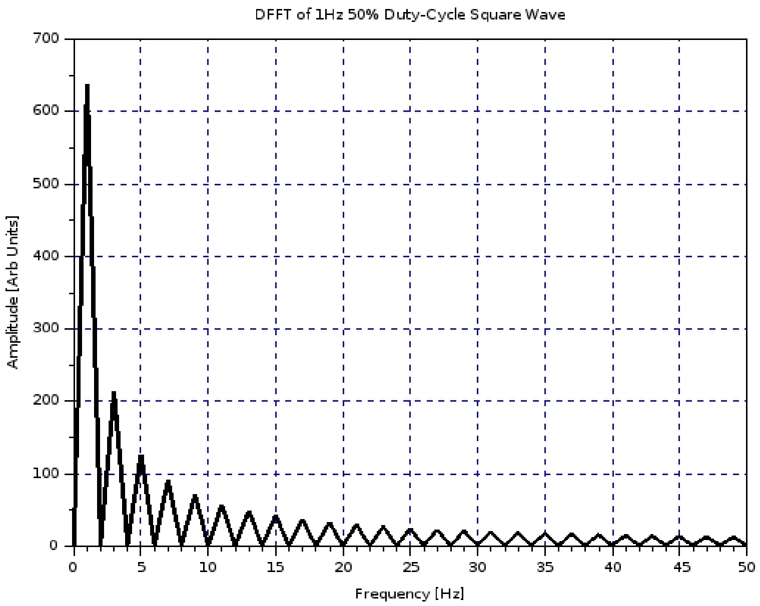


Digital vs. Analog

Digital: High-frequency, high-harmonic-content waveforms

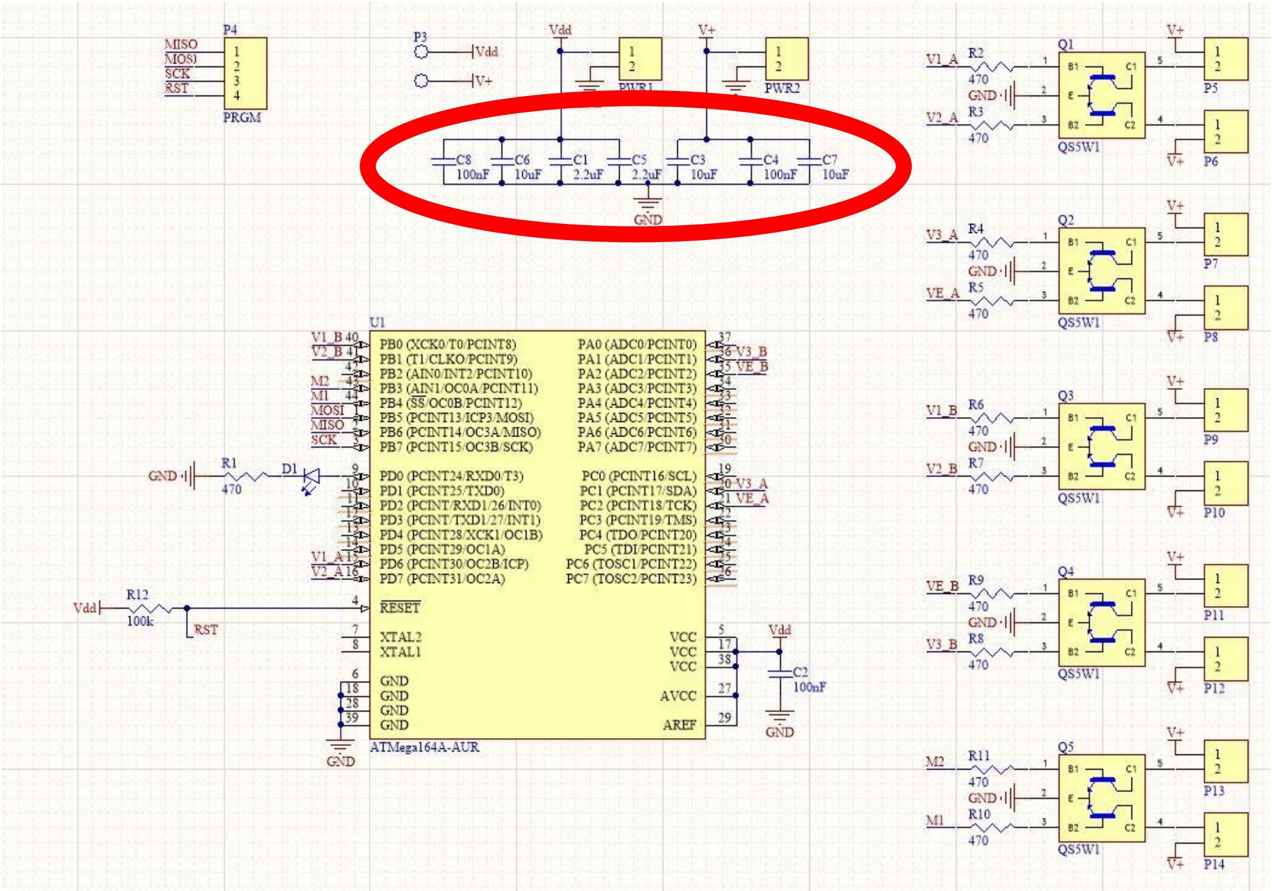
Analog: Sensitive to ground & Vdd references





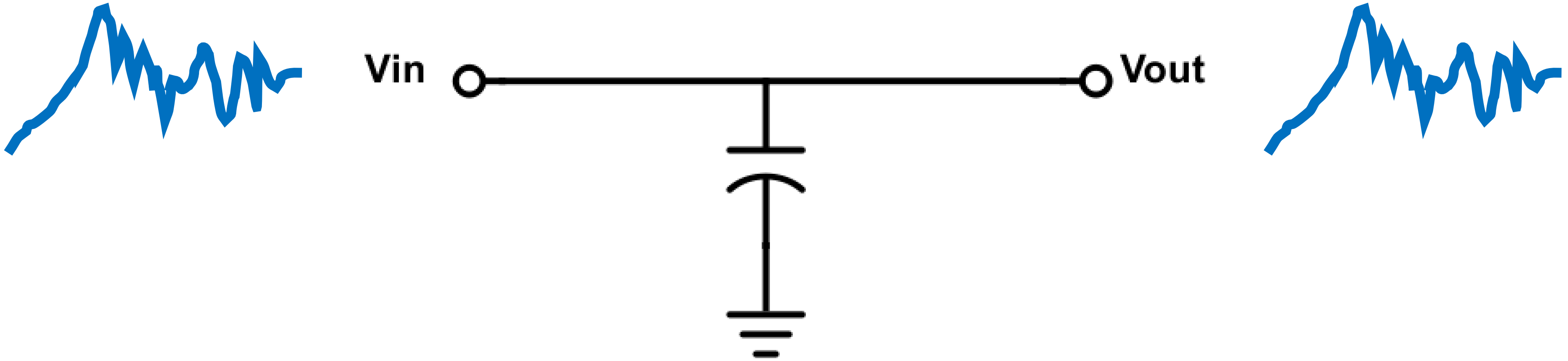
Decoupling

Why does every board have so many caps?



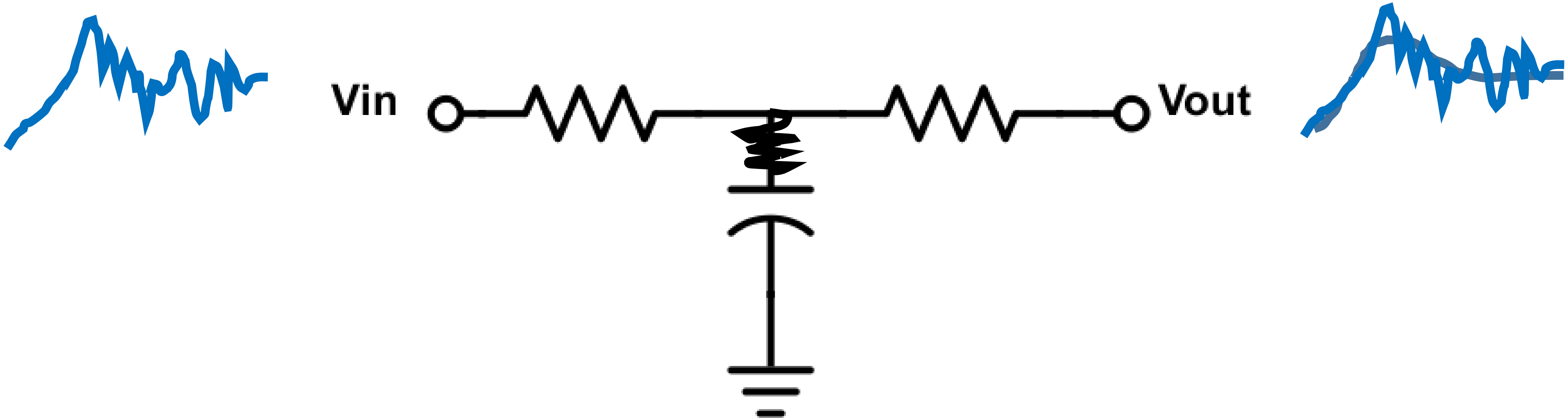
Decoupling

What is the transfer function?



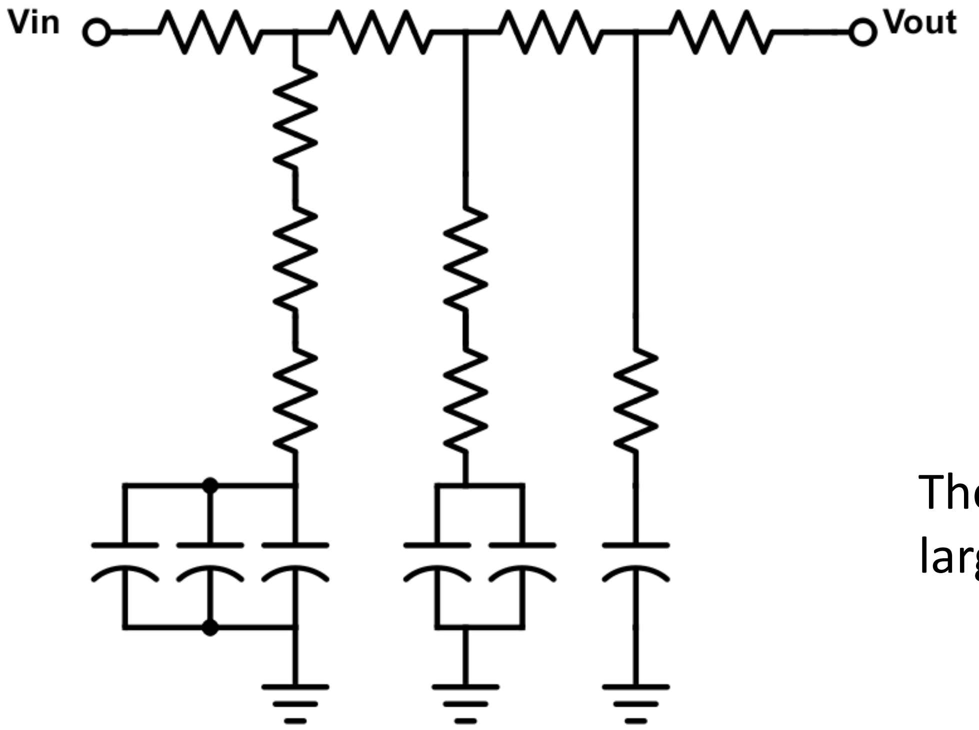
Decoupling

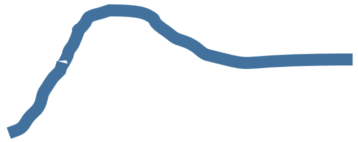
What is the transfer function?



Decoupling

What is the transfer function?





The bigger the capacitor, the larger the time constant.

Decoupling

What is the point of large capacitors?

$$Q = CV$$
$$V = \frac{1}{C}\int i\,dt$$

The bigger the capacitor, the smaller the voltage rise.

Decoupling

In summary:

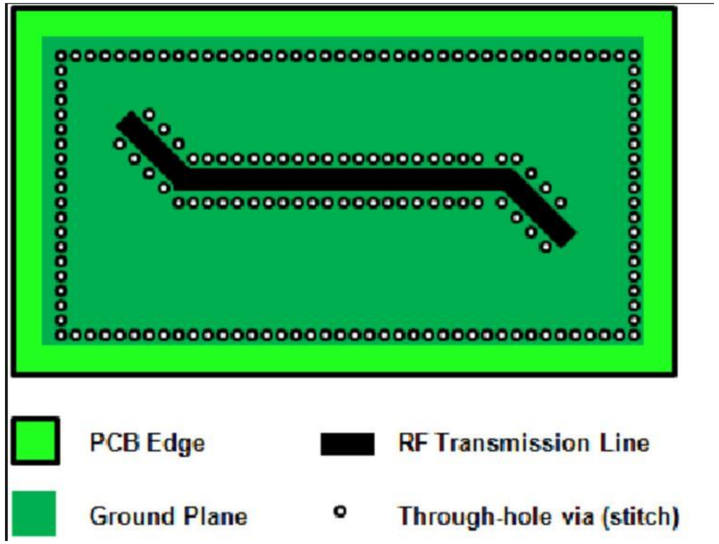
- Place at least one capacitor between every analog voltage and ground
- Place larger capacitors near power input pins
- Place smaller capacitors next to IC
- Good rules of thumb
  - 2.2-10uF next to power input or IC power rail
  - 100nF-1uF along long traces
  - 10nF-100nF next to IC

High-Frequency Considerations

Take ECE 4330 – Intro to Microwave Engineering

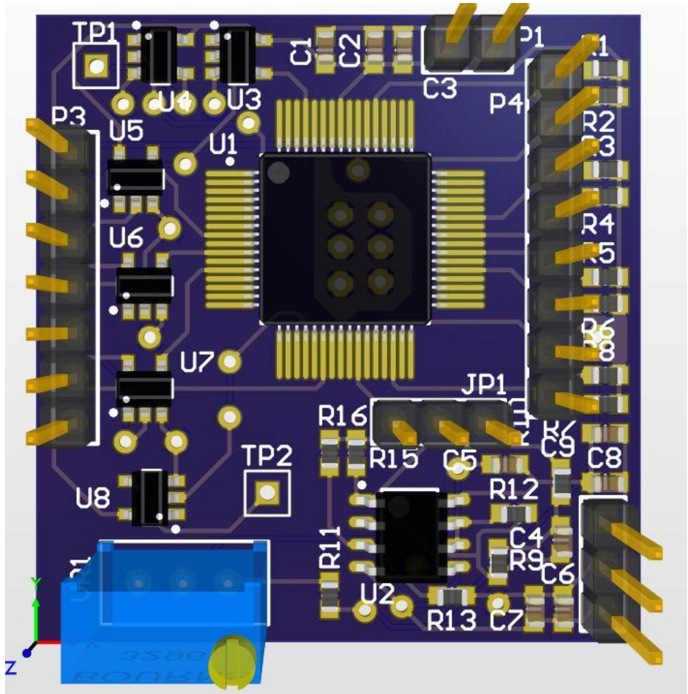
Until then …

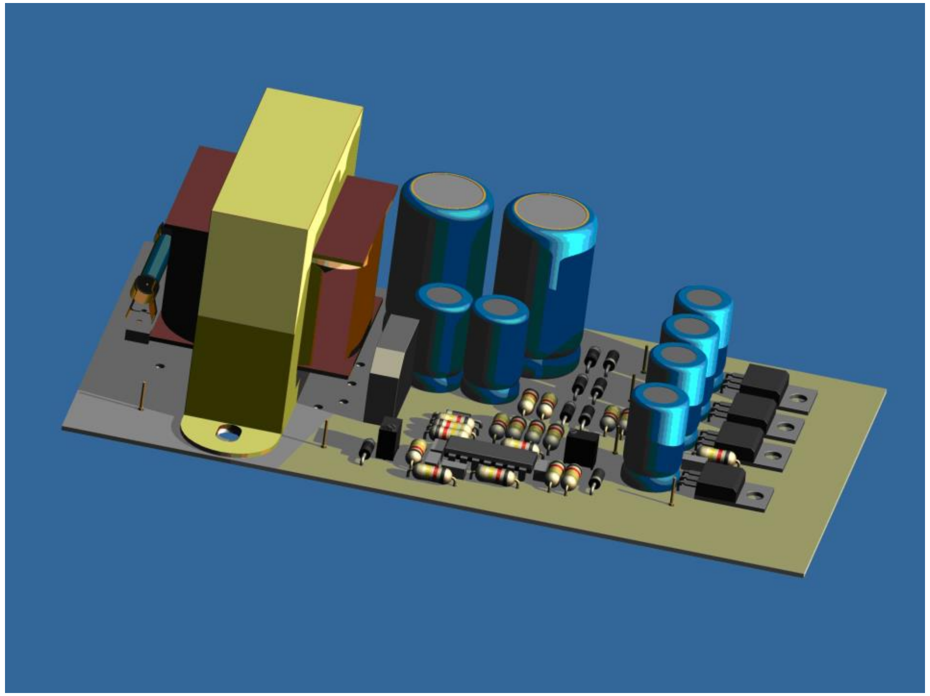
- Keep traces short
- Avoid vias
- Can via-stitch grounds alongside
- Impedance matching is important – sets trace width
- Keep sensitive analog and high-frequency digital apart!



3D Modelling

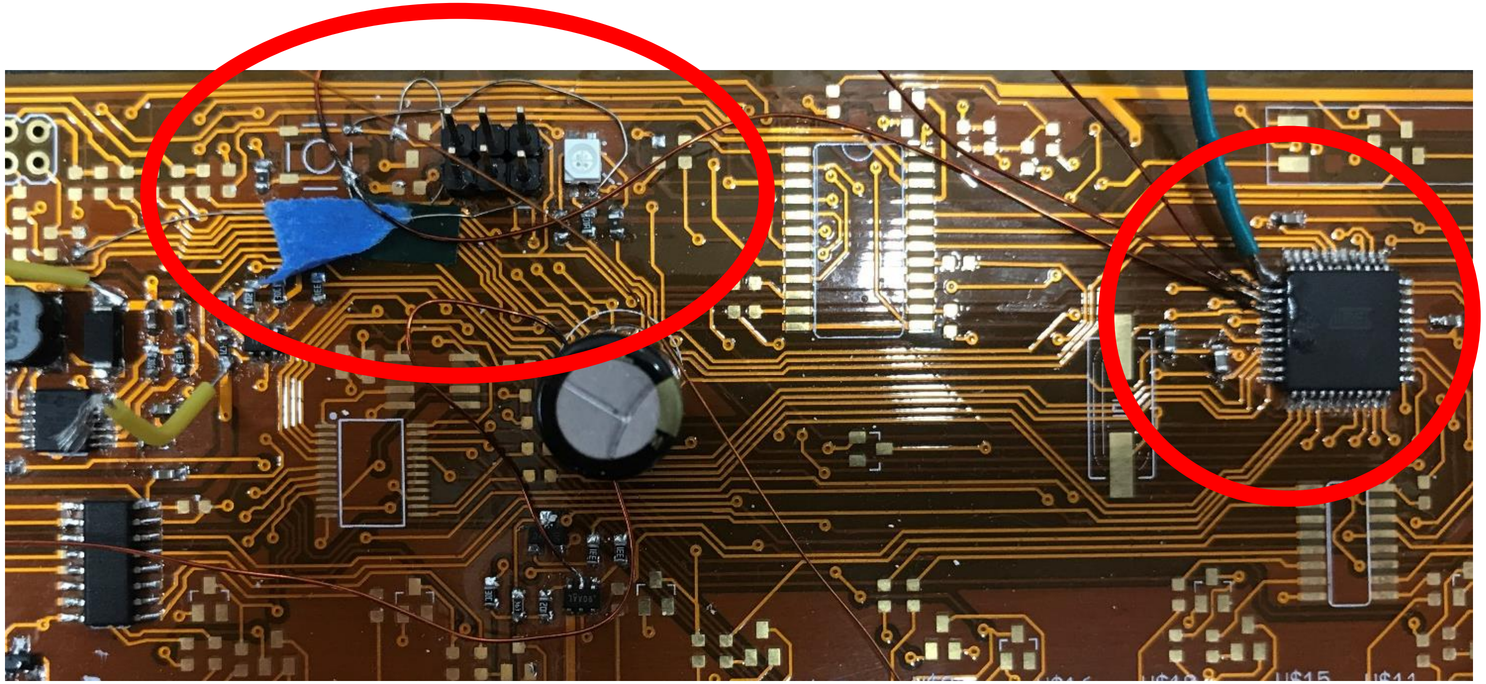
- Can find or make 3D models for every component.
- Can export entire board into solidworks/inventor

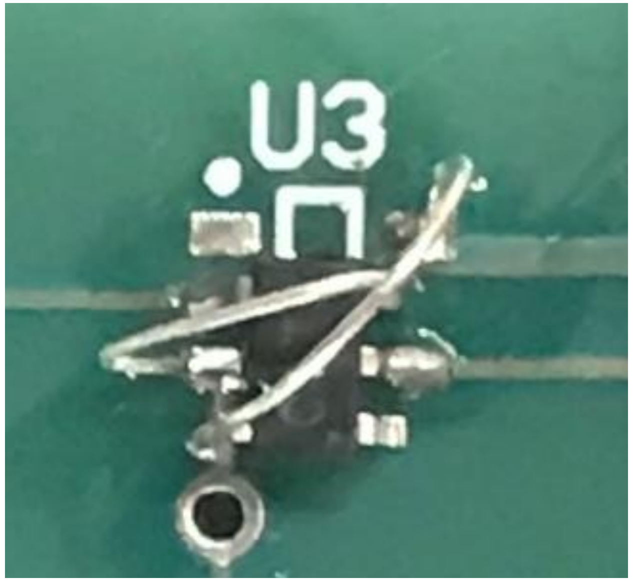




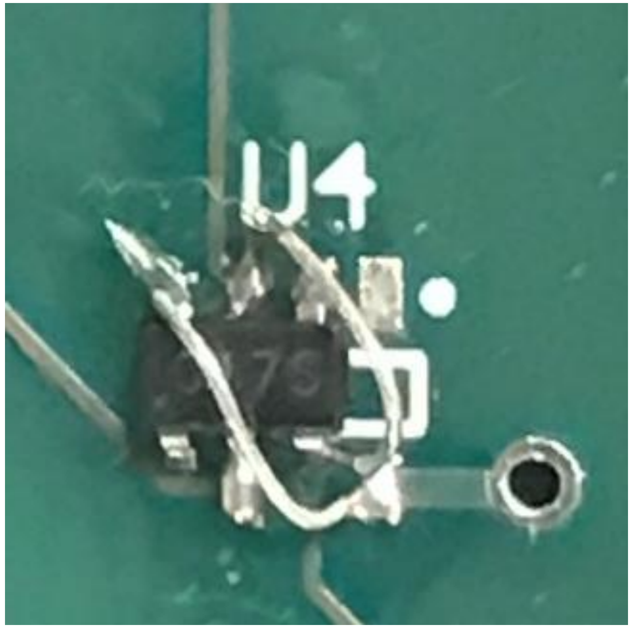
Dealing With Mistakes

- Solder wires onto pins
- "Floating components"
- Cut traces or pins



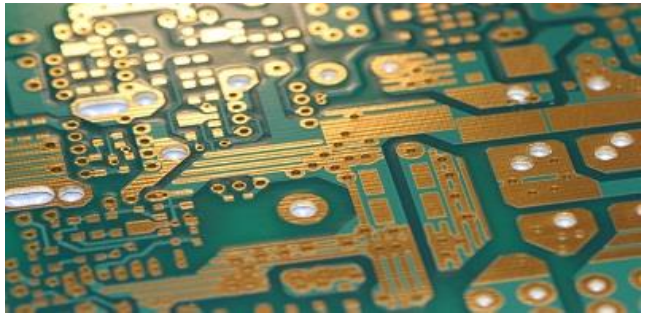


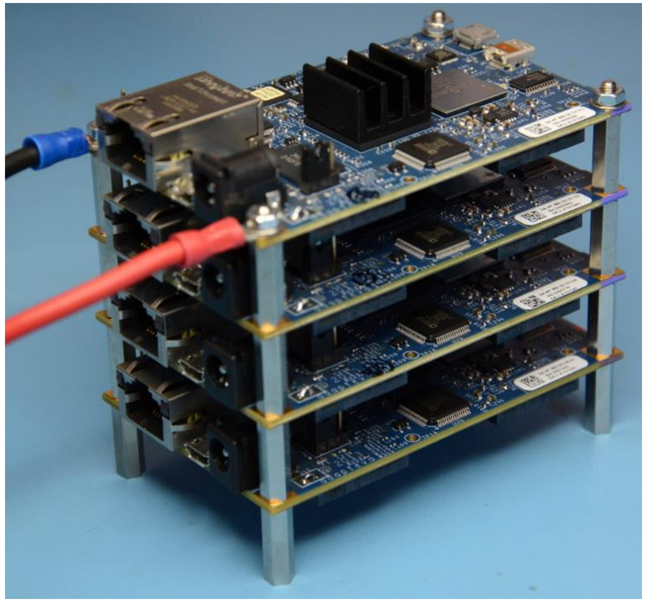
Floating Components

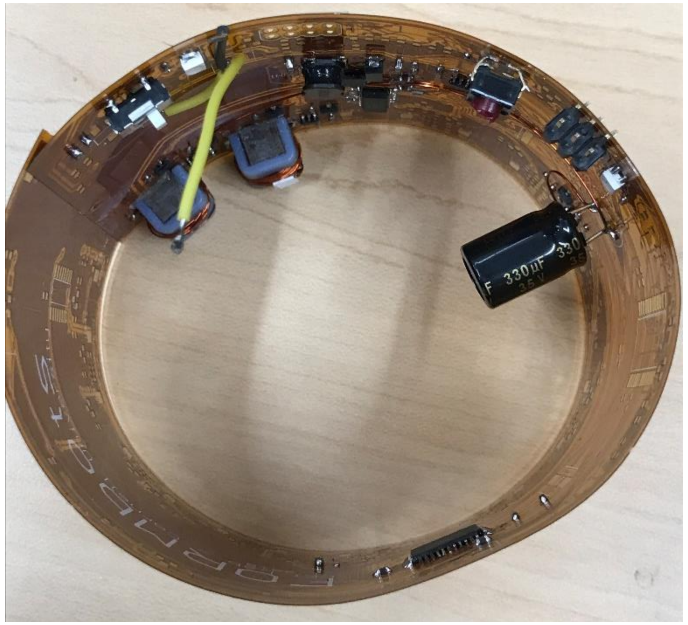


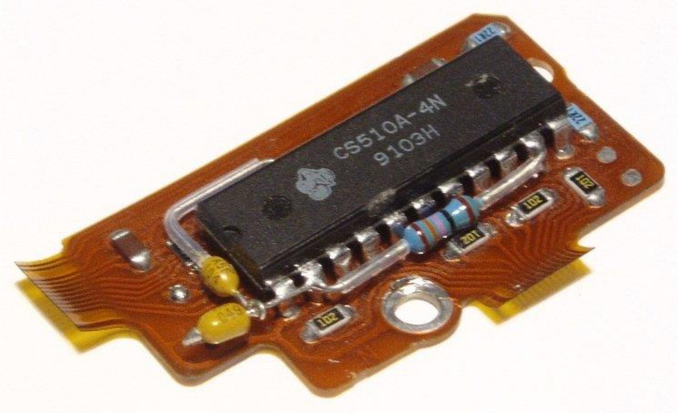
Miscellani

- Gold substrates
- Flexible boards
- Stacked boards
- IC Specifics
- Process Variation
- Many-Layer
- And more…









How can you use a PCB on your robot?

- Amplifier/filter for your microphone circuit
- Amplifier for your treasure circuit
- A tidy base station voltage divider
- The whole thing…?

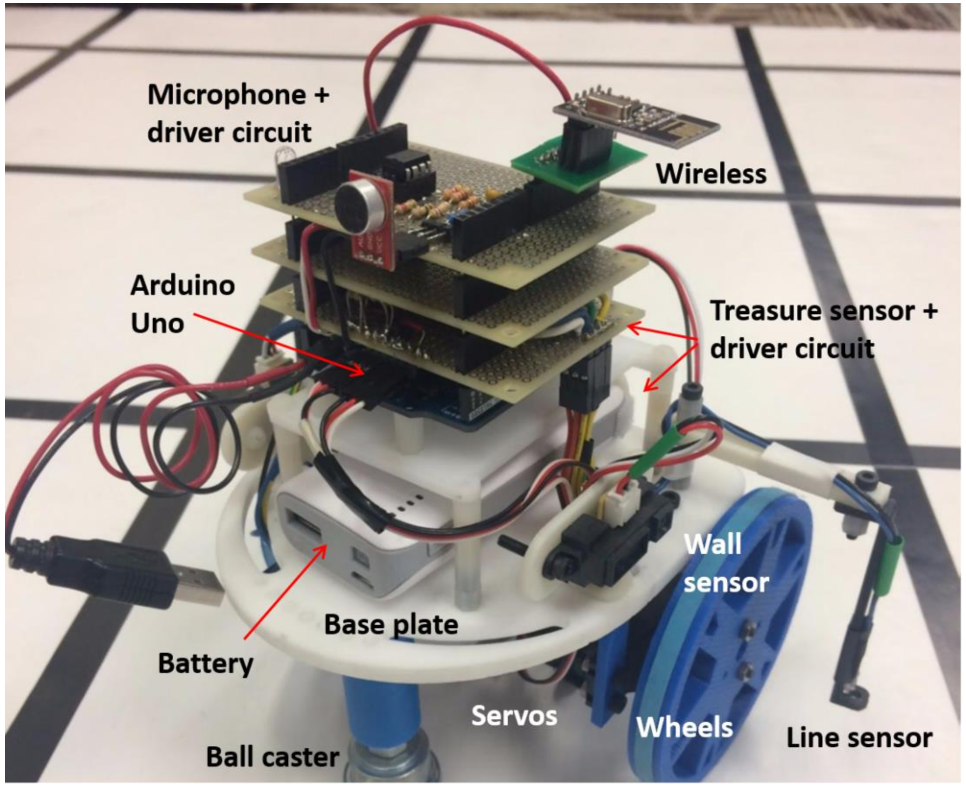
Grading of System Design and Documentation

ECE 3400, Fall 2017

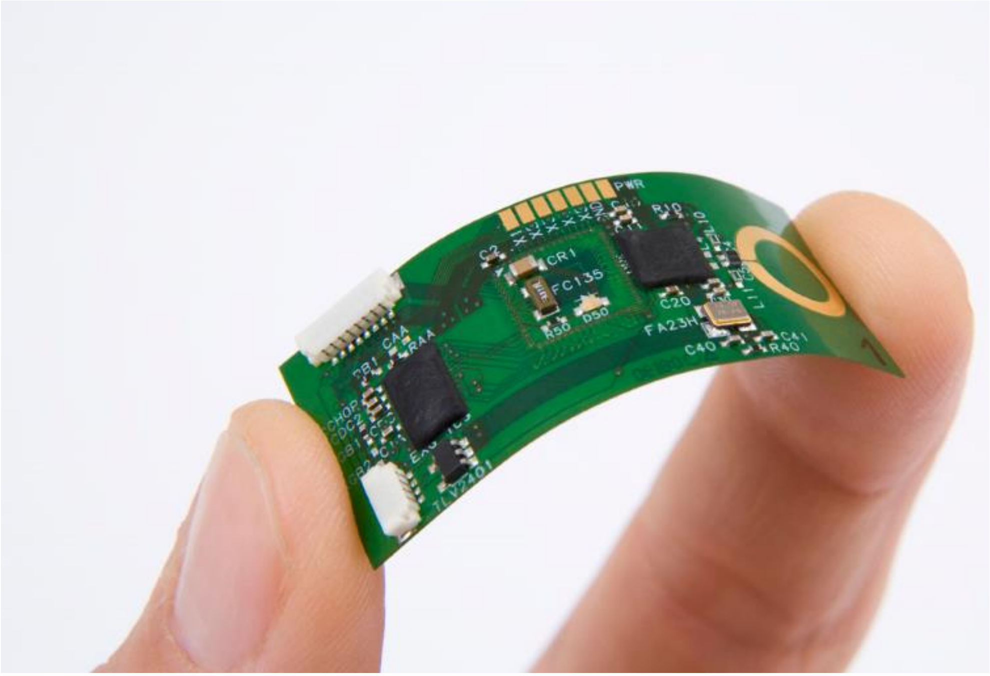
The TA's will award up to 25 points for good system design.

All members on a team will not necessarily be awarded the same number of points.

To earn these points you can for example implement electronic circuits that improve the accuracy of the maze mapping, efficient search strategies, nice FPGA implementation and a great screen display, or new mechanical components to make the robot faster or easier to maintain. If you have tons of spare time, consider using two cooperative robots to map the maze. The sky's the limit!



Happy PCB-ing!



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Board Manufacturing

- https://www.4pcb.com/media/presentation-how-to-build-pcb.pdf

Decoupling

http://www.analog.com/en/analog-dialogue/articles/studentzone-april-2017.html

Soldering

- https://www.build-electronic-circuits.com/smd-soldering/
- https://www.youtube.com/watch?v=3NN7UGWYmBY
- https://www.youtube.com/watch?v=z7Tu8NXu5UA

Class References

Tutorials

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- https://cei-lab.github.io/ece3400-2017/tutorials/Eagle/Eagle_Example.html
- https://cei-lab.github.io/ece3400-2017/tutorials/PCB/

Burn List

- https://cei-lab.github.io/ece3400-2017/tutorials/PCB/burnlist.html