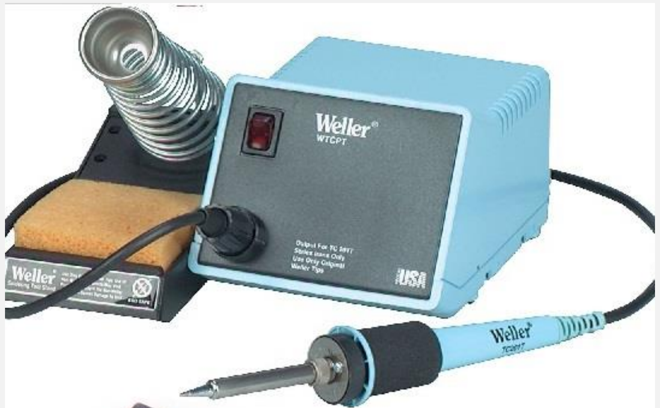

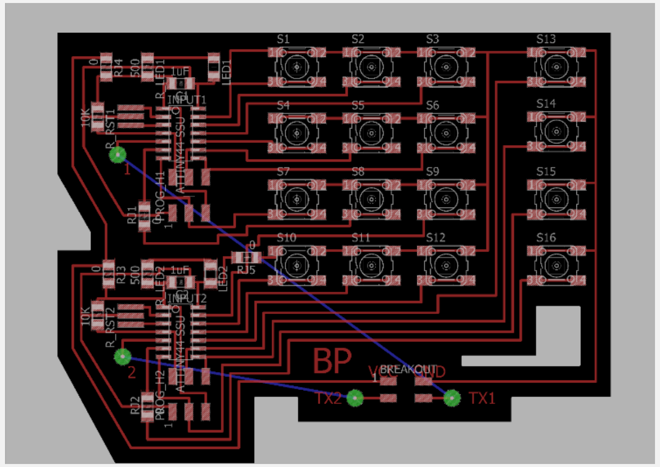

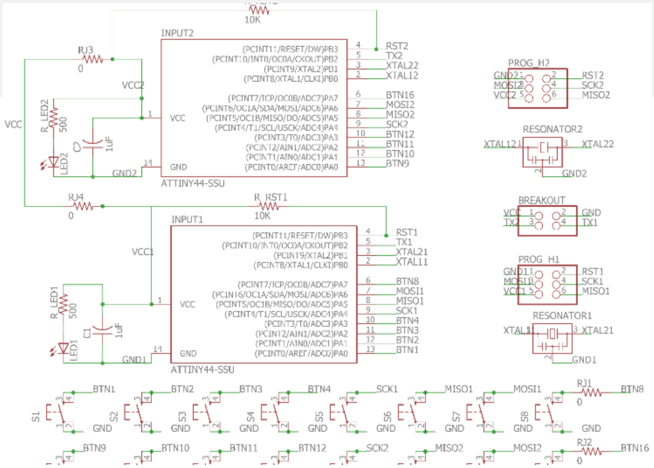

Electronics Production and Design

Slides: brian_plancher@g.harvard.edu, Fall 2021
Recitation: Jake Read, Fall 2022

The road ahead

This week

Electronics Production

- Mill and stuff a circuit board

The road ahead

This week	2 weeks from now
Electronics Production	**Electronics Design**
• Mill and stuff a circuit board	• Design your own circuit board • Mill and stuff it

The road ahead

This week	2 weeks from now	4 weeks from now
Electronics Production	**Electronics Design**	**Embedded Programming**
• Mill and stuff a circuit board	• Design your own circuit board • Mill and stuff it	• Design your own circuit board • Mill and stuff it • Program it

The next few weeks have a simple task!

1. Learn (or recall) basic electrical engineering

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2. Use it to design a custom circuit board in a new software program

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2. Use it to design a custom circuit board in a new software program
3. Mill it and solder on all the parts properly

The next few weeks have a simple task!

1. Learn (or recall) basic electrical engineering
2. Use it to design a custom circuit board in a new software program
3. Mill it and solder on all the parts properly
4. Learn (or recall) some programming: “Arduino” i.e. C++

The next few weeks have a simple task!

1. Learn (or recall) basic electrical engineering
2. Use it to design a custom circuit board in a new software program
3. Mill it and solder on all the parts properly
4. Learn (or recall) some programming
5. Write a new program to test your custom board

The next few weeks have a simple task!

1. Learn (or recall) basic electrical engineering
2. Use it to … a new software…
3. Mill it an…
4. Learn (or recall) some programming
5. Write a custom program to test your board

Seems like a lot !

The road ahead

Today's Focus

This week	2 weeks from now	4 weeks from now
Electronics Production	**Electronics Design**	**Embedded Programming**
• Mill and stuff a circuit board	• Design your own circuit board • Mill and stuff it	• Design your own circuit board • Mill and stuff it • Program it

Why do I even need to know anything about electrical engineering?

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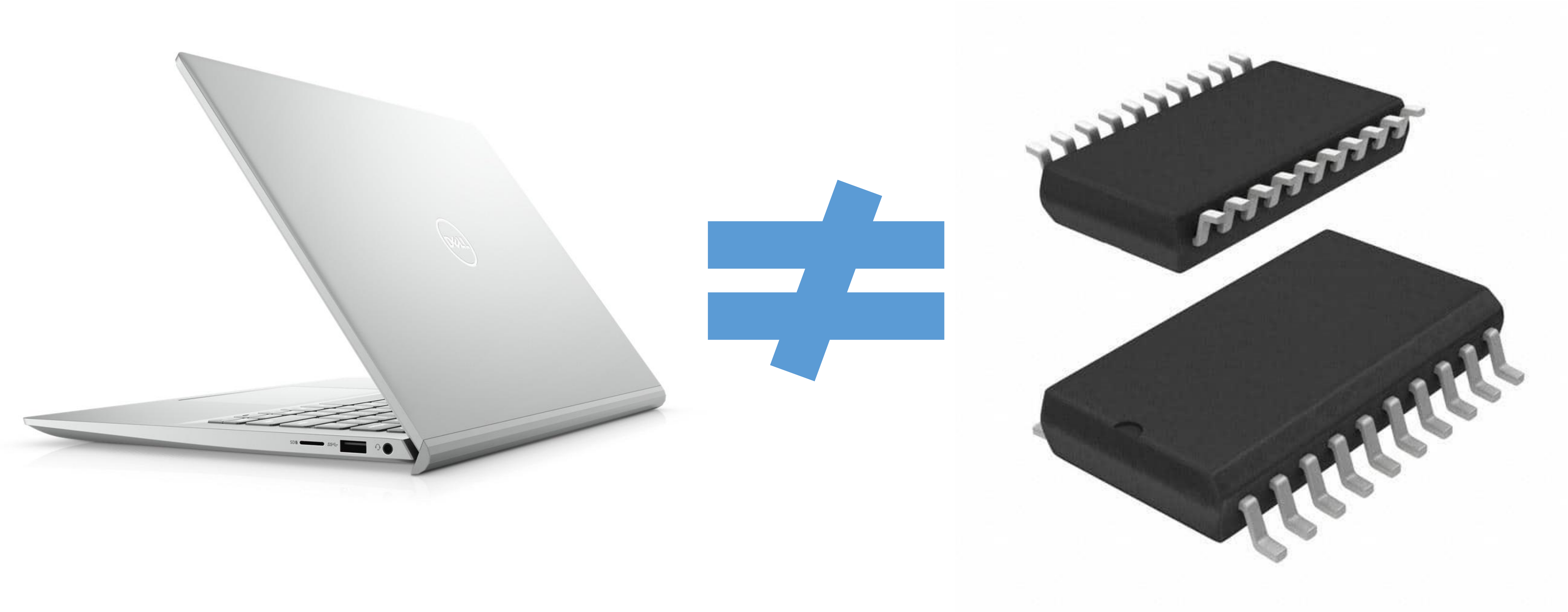
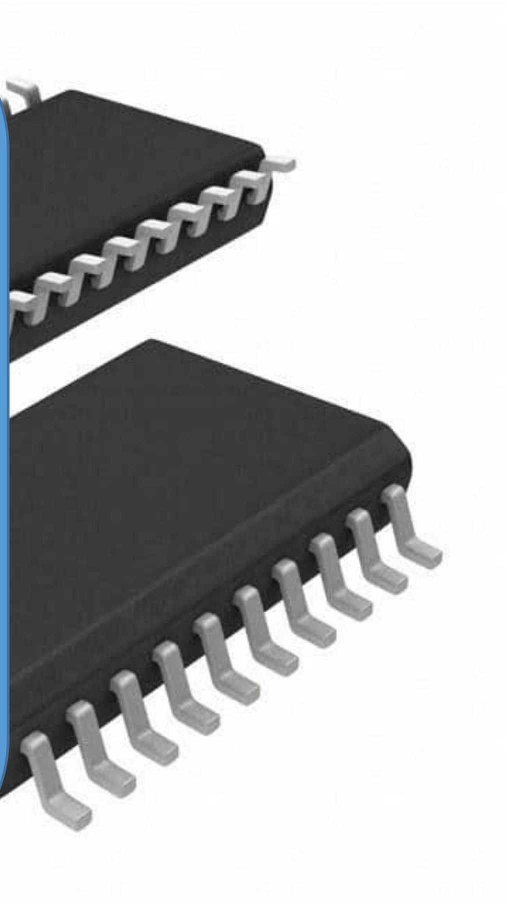


Why do I even need to know anything about electrical engineering?

We are going to learn how to make our own custom circuit boards that connect inputs and outputs to our own microcontrollers!



Ohm's Law:

$$V = I * R$$

Voltage (measure in volts)

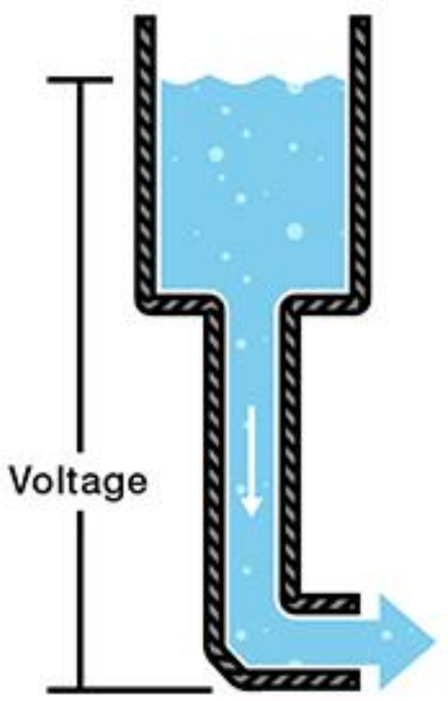
I: Current (measure in amps)

Resistance (measured in ohms)

https://learn.sparkfun.com/tutorials/voltage-current-resistance-and-ohms-law/all

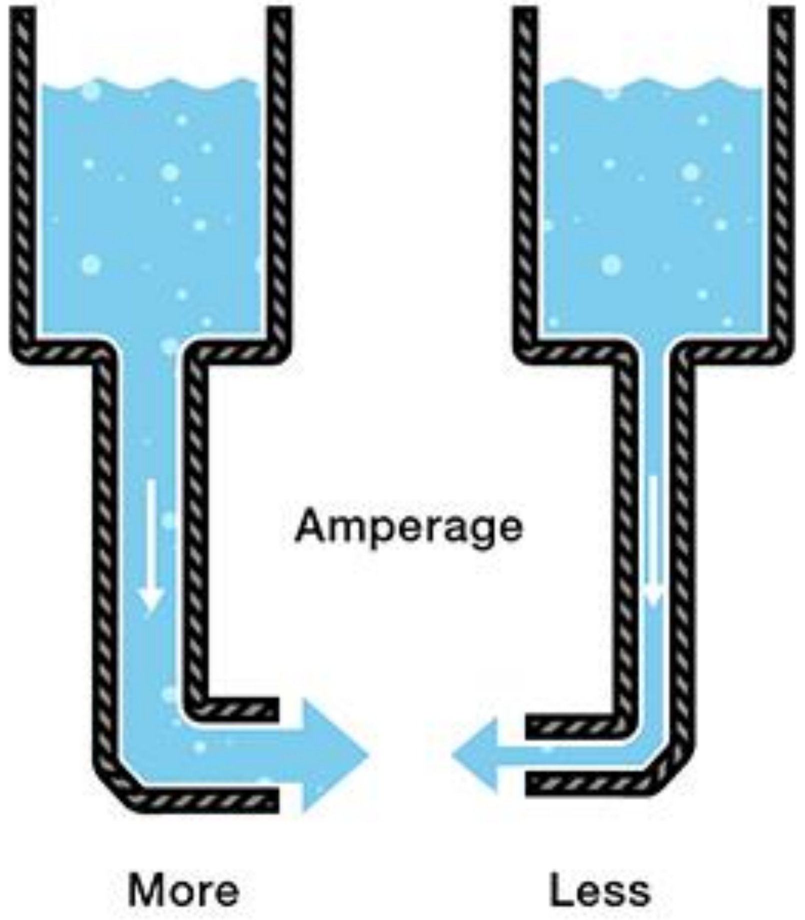
Voltage

Measures the **difference in electrical potential** between two points – often an input voltage (vcc) and ground (gnd)



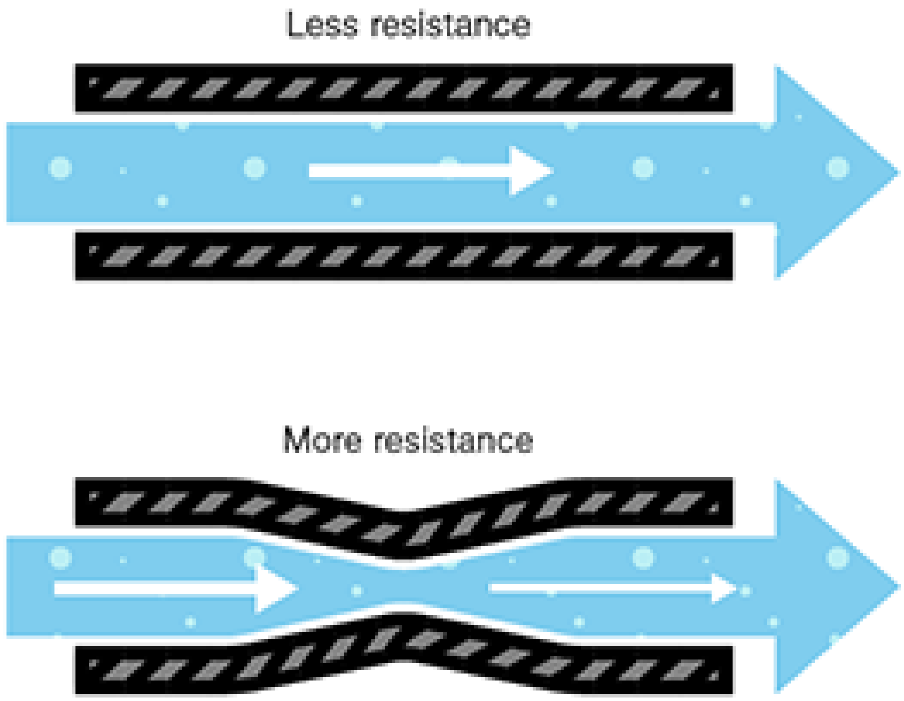
Current

Measures the **rate of flow of electrons** in a circuit



Resistance

Measures **how hard it is for electrons to move** through a circuit



Triplets

- Voltage: potential to do work (electron pressure)
- Current: work (electron flow)
- Resistance: … friction (electron resistance)

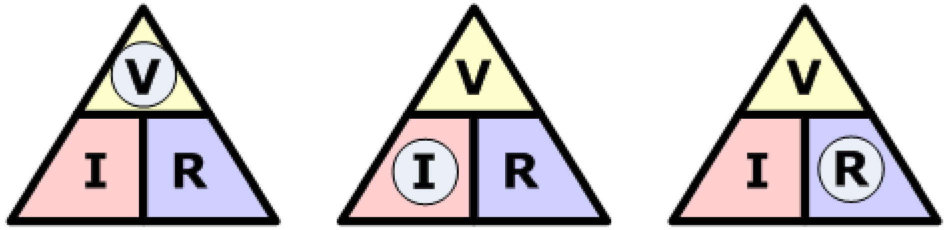
Ohm's Law:

$$V = I * R$$

Voltage (measure in volts)

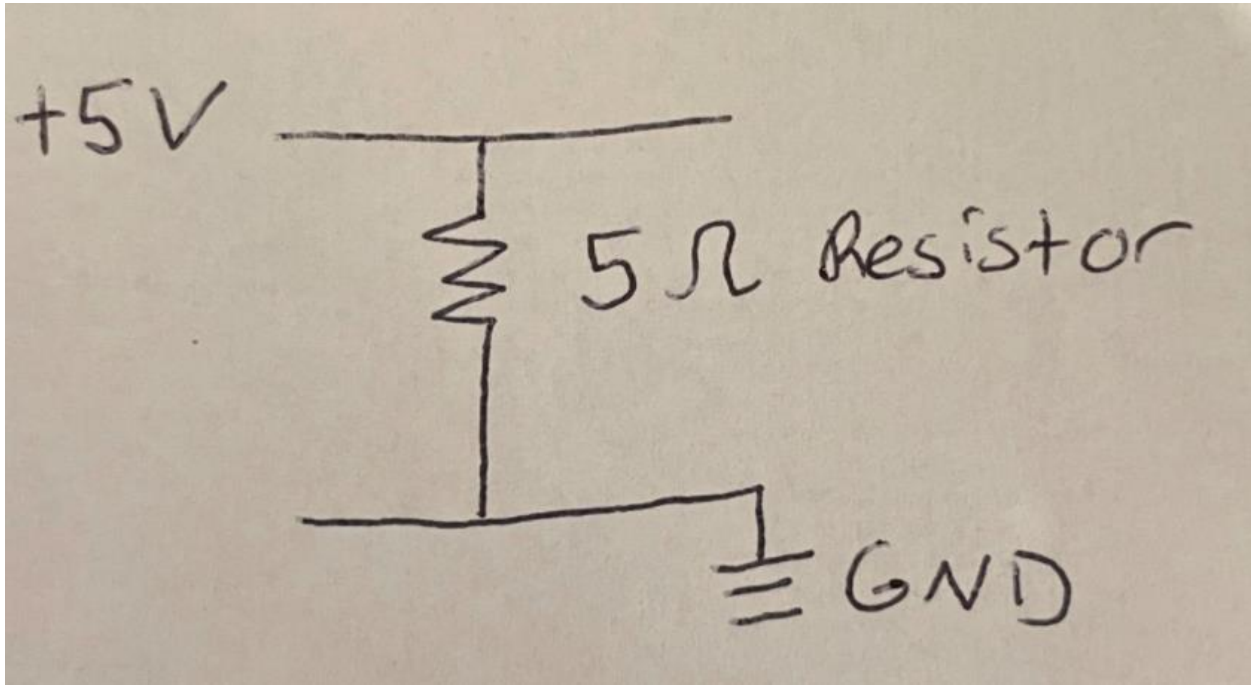
I: Current (measure in amps)

Resistance (measured in ohms)



$V = I \times R$ $\qquad$ $I = \frac{V}{R}$ $\qquad$ $R = \frac{V}{I}$

How much current goes through this resistor?



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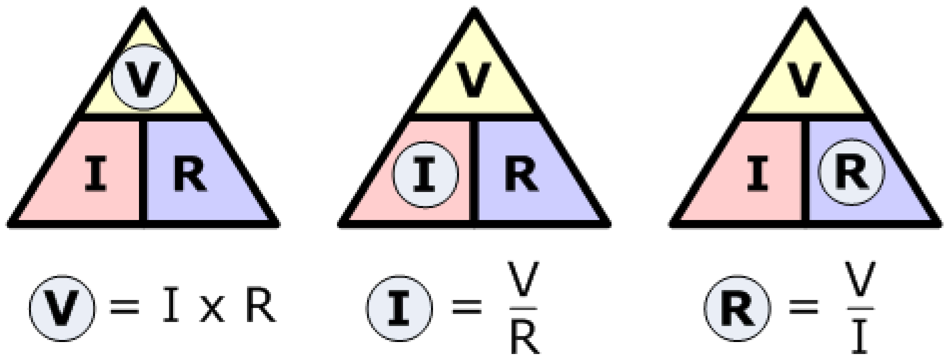

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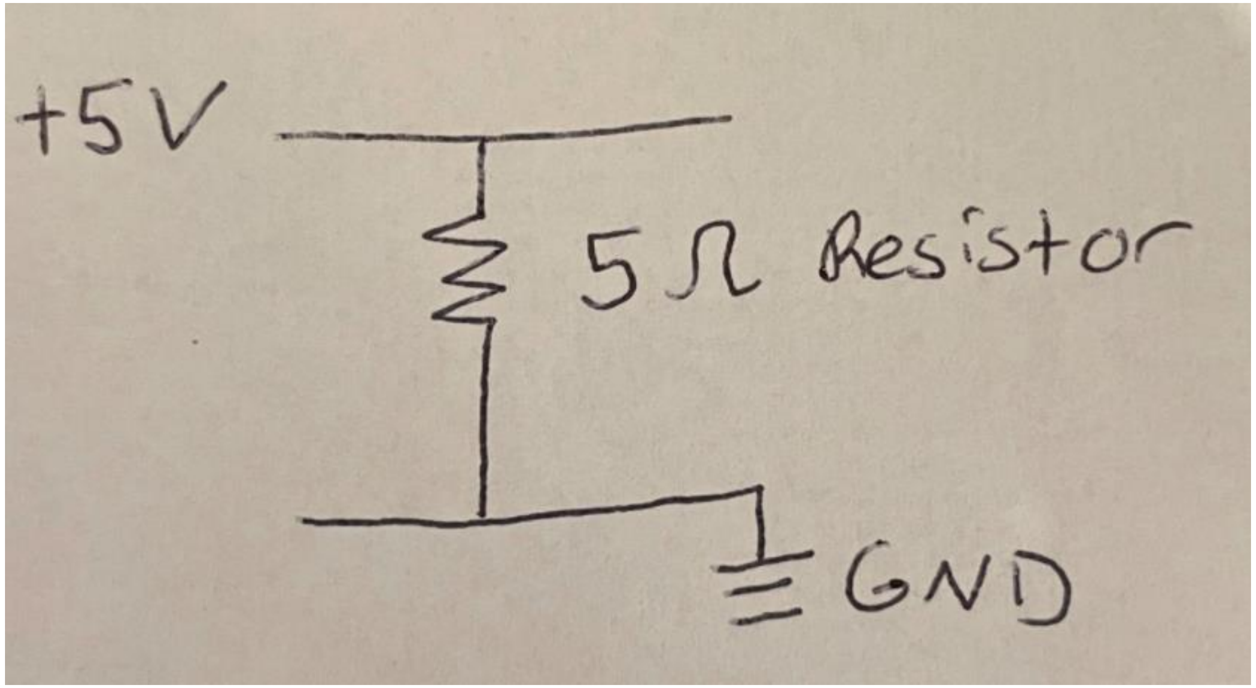

1A

Ohm's Law:

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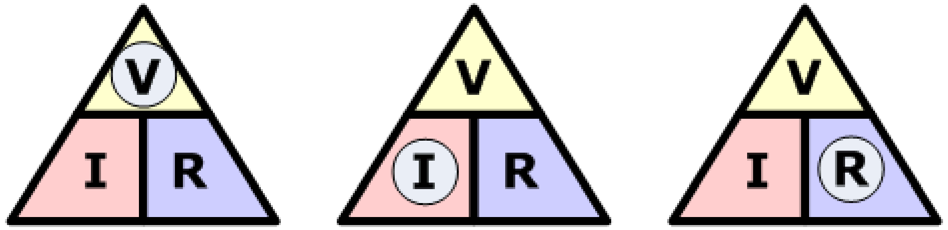

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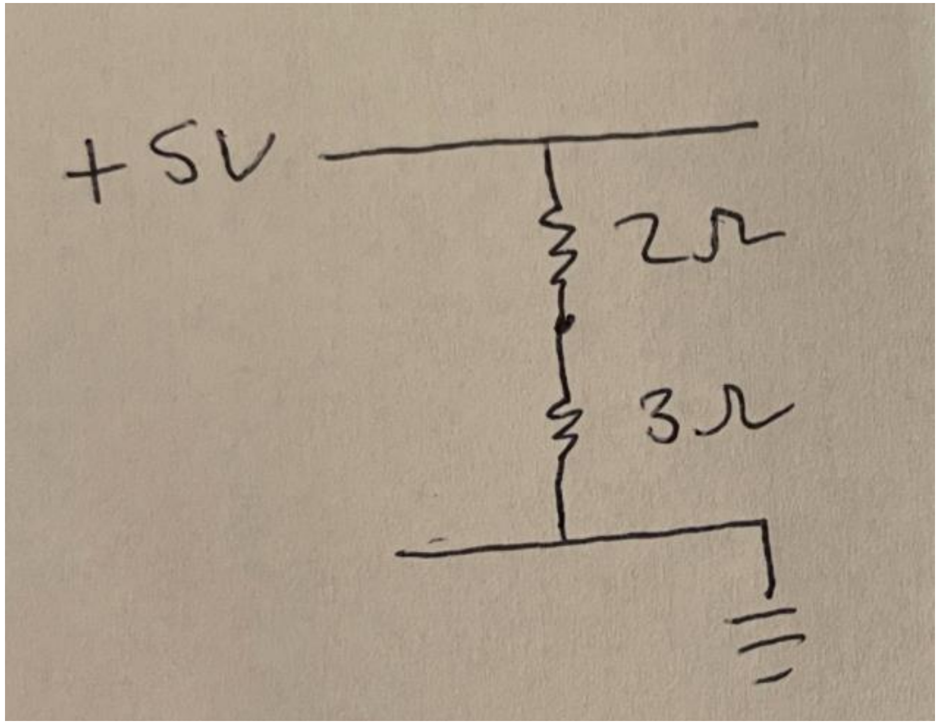

Ohm’s Law:

- Resistance in series adds
- To learn more about series and parallel check out this link: https://en.wikipedia.org/wiki/Series_and_parallel_circuits

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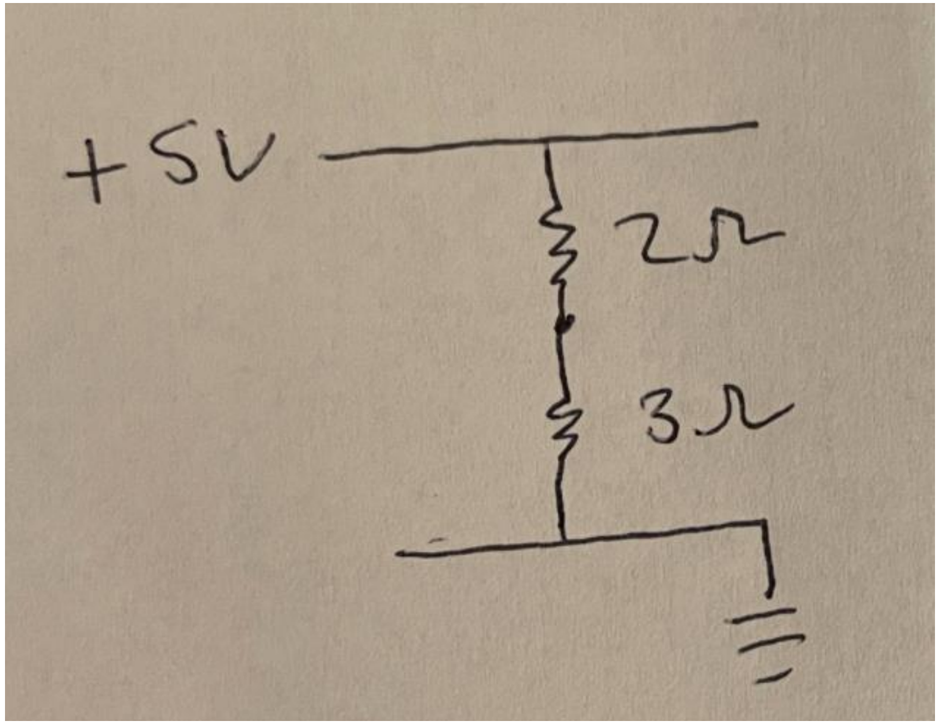

1A

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- To learn more about series and parallel check out t https://en.wikipedia.org/wiki/Series_and_parallel_circuits

+3V here!

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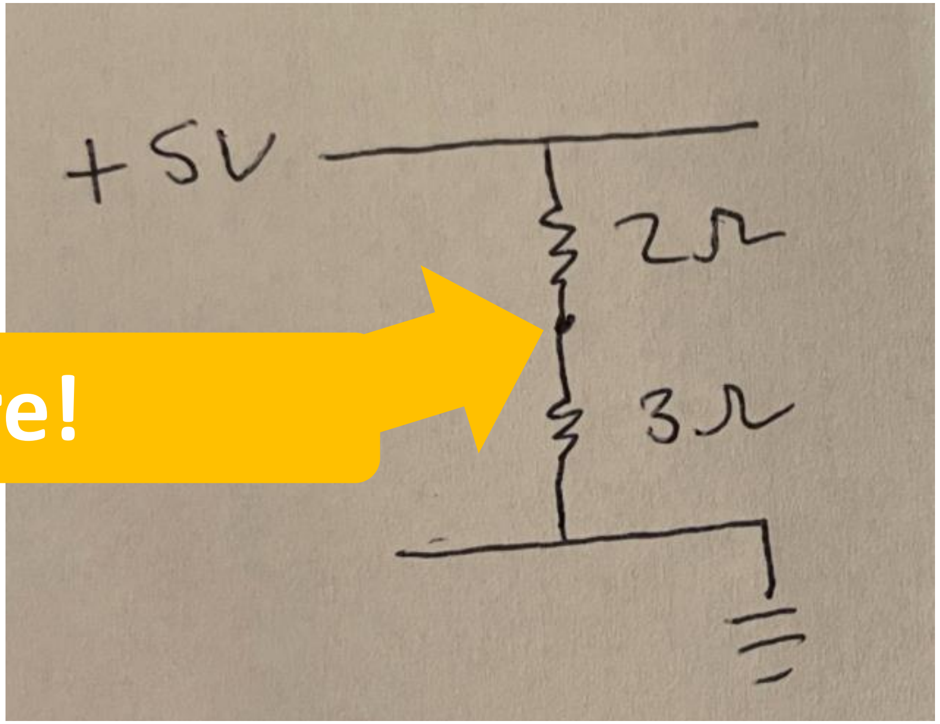

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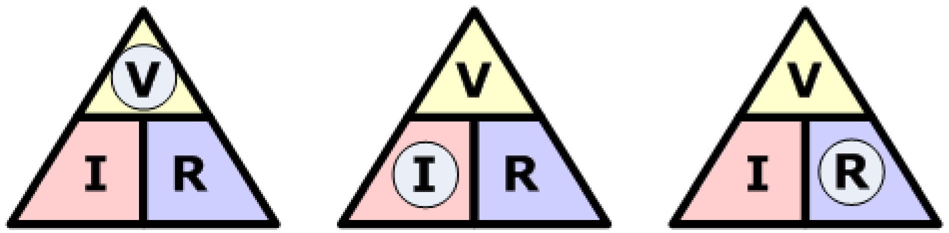

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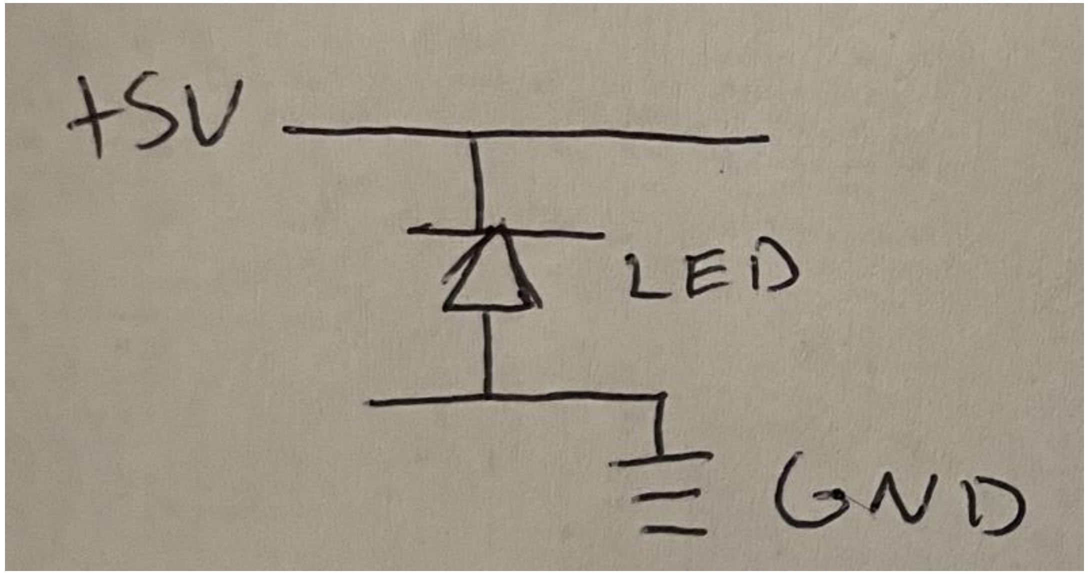

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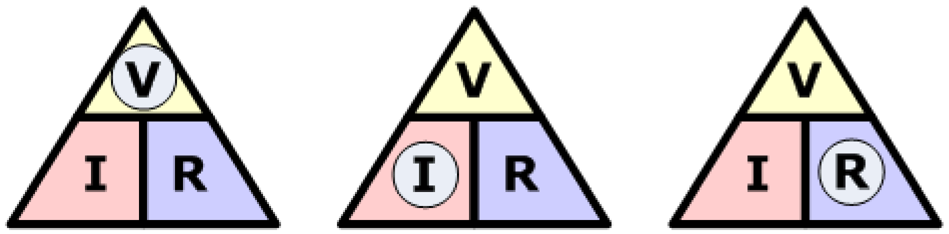

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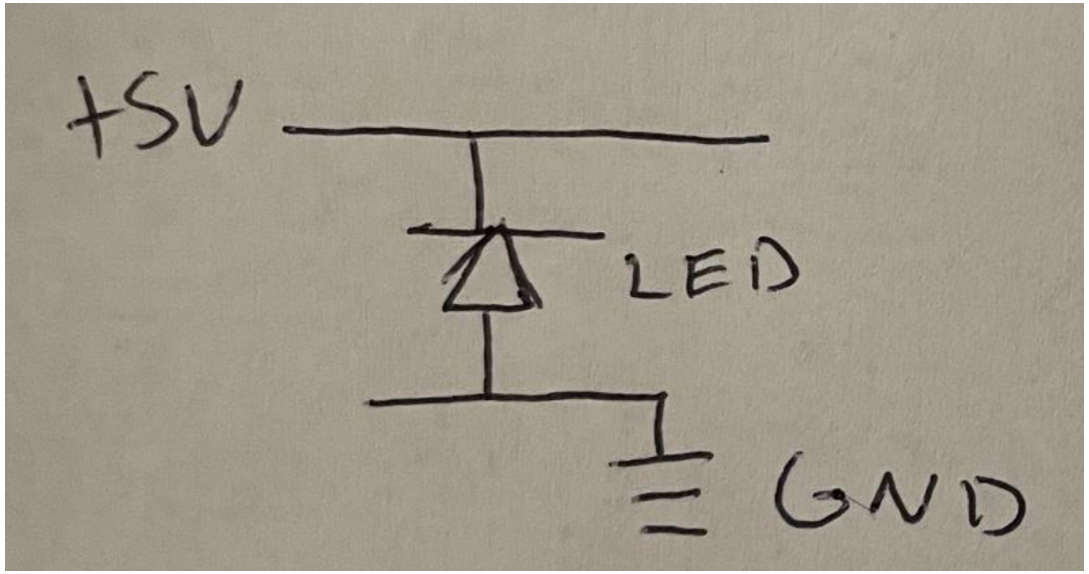


Trick Question – 0A

All diodes are one way!

Ohm's Law:

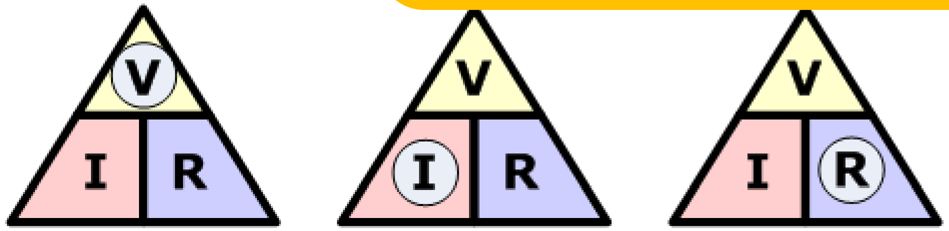
$$V = I * R$$

Voltage (measure in volts)

I: Curre

Resistan

Green line on surface mount parts!



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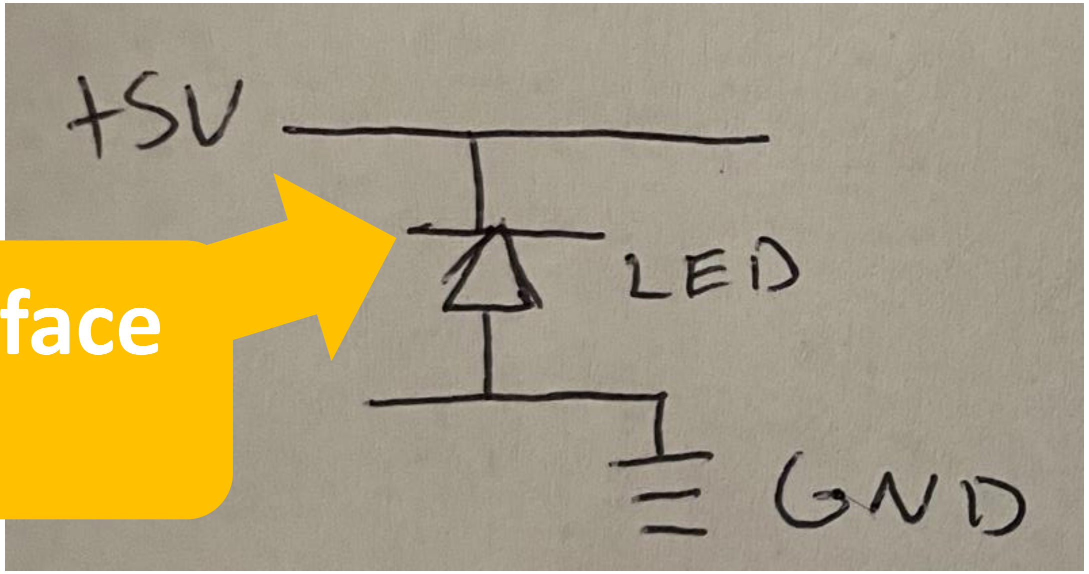

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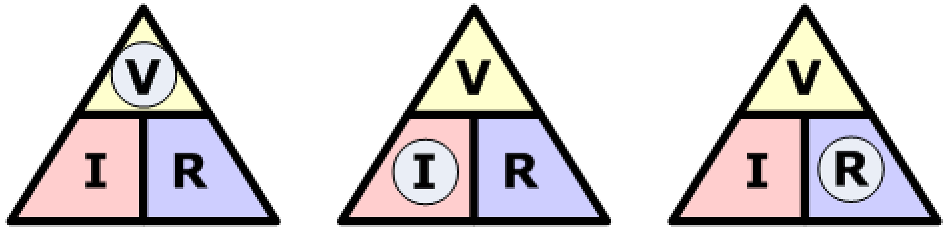

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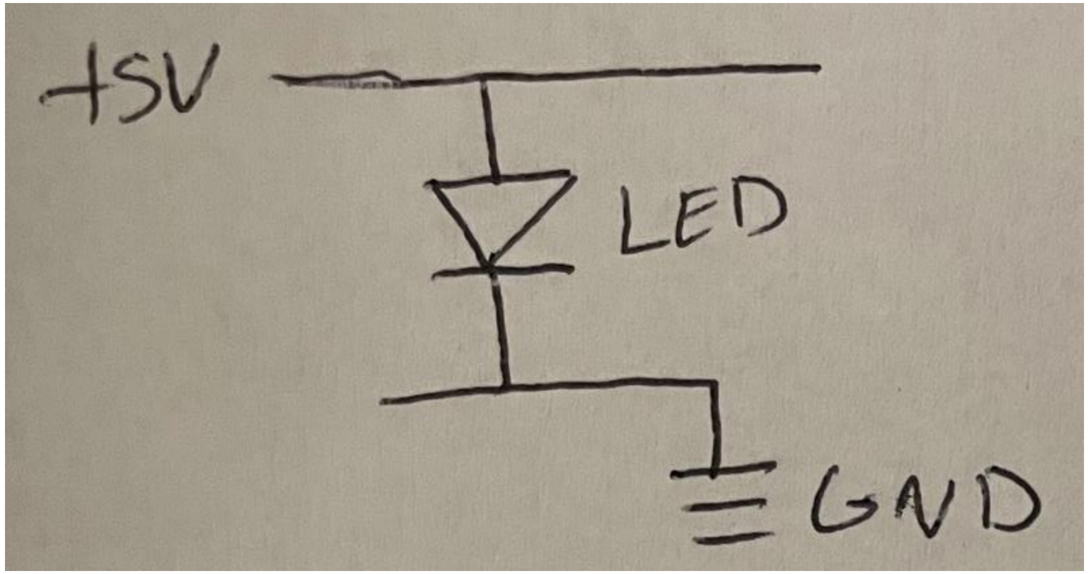
Ok so what about this (correct direction) LED?



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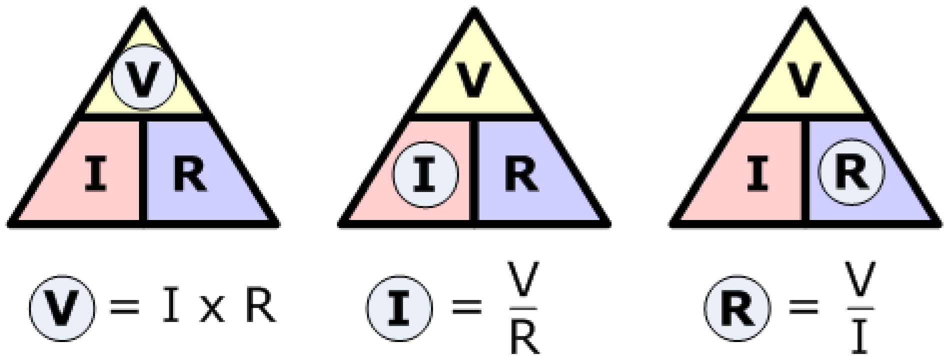
I: Current (measure in amps)

Resistance (measured in ohms)



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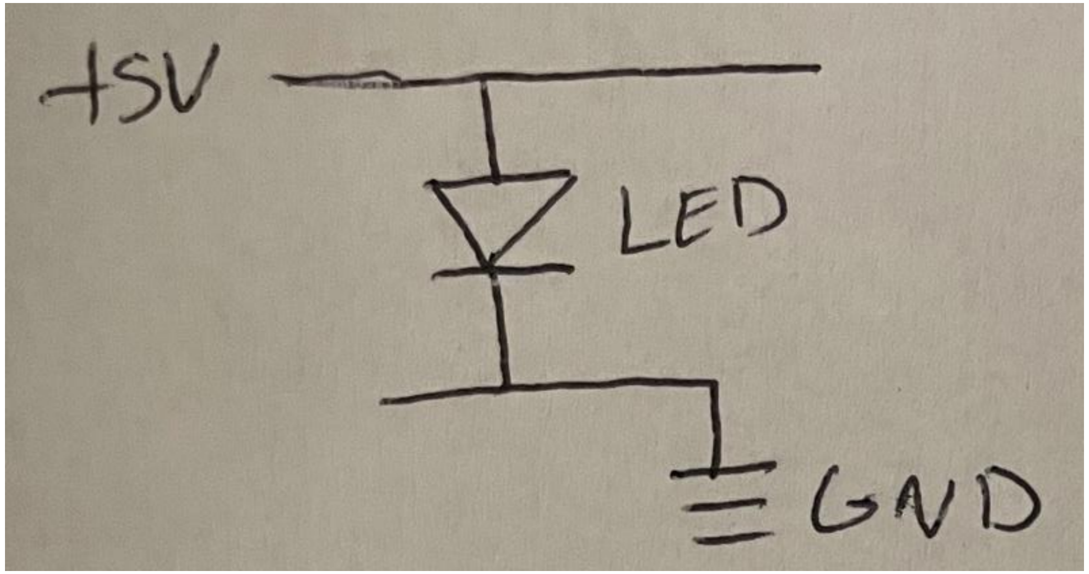


Trick Question Again – ∞A
Diodes have 0 resistance!

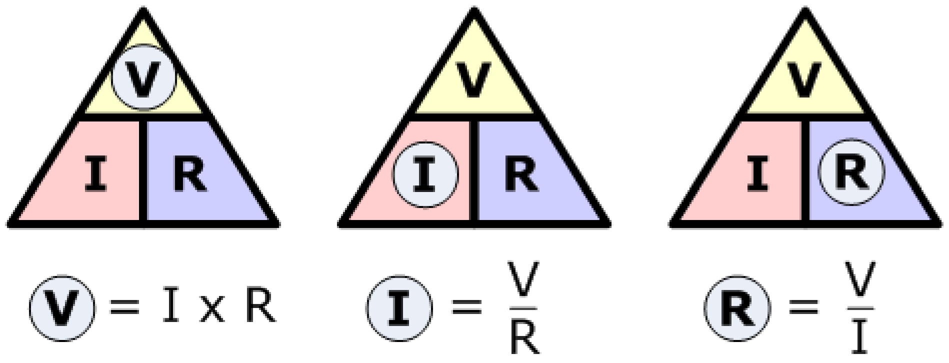
Ohm's Law:

$V =$

Voltage (r

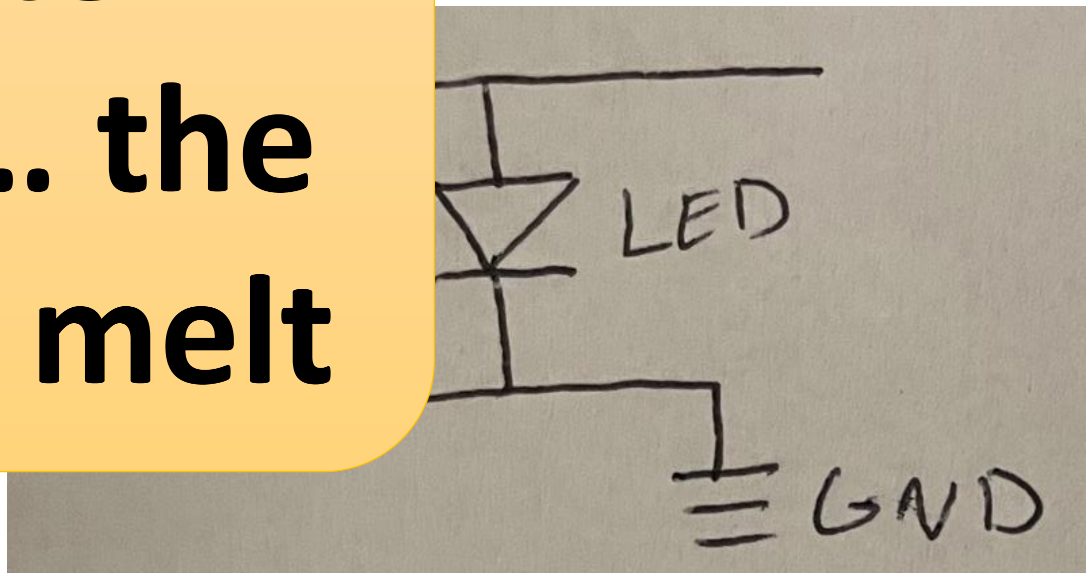
I: Current

Resistance (



Ok so what about this
t direction) LED?

Infinite current… the part will melt



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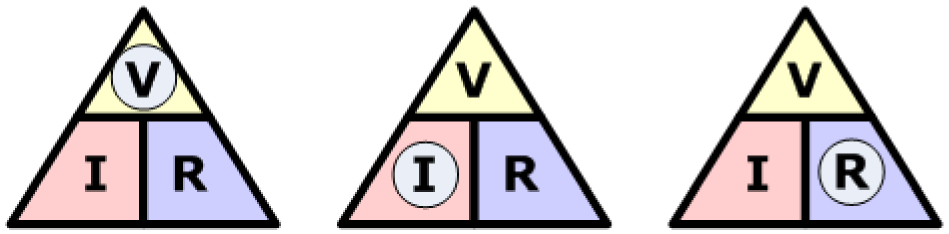

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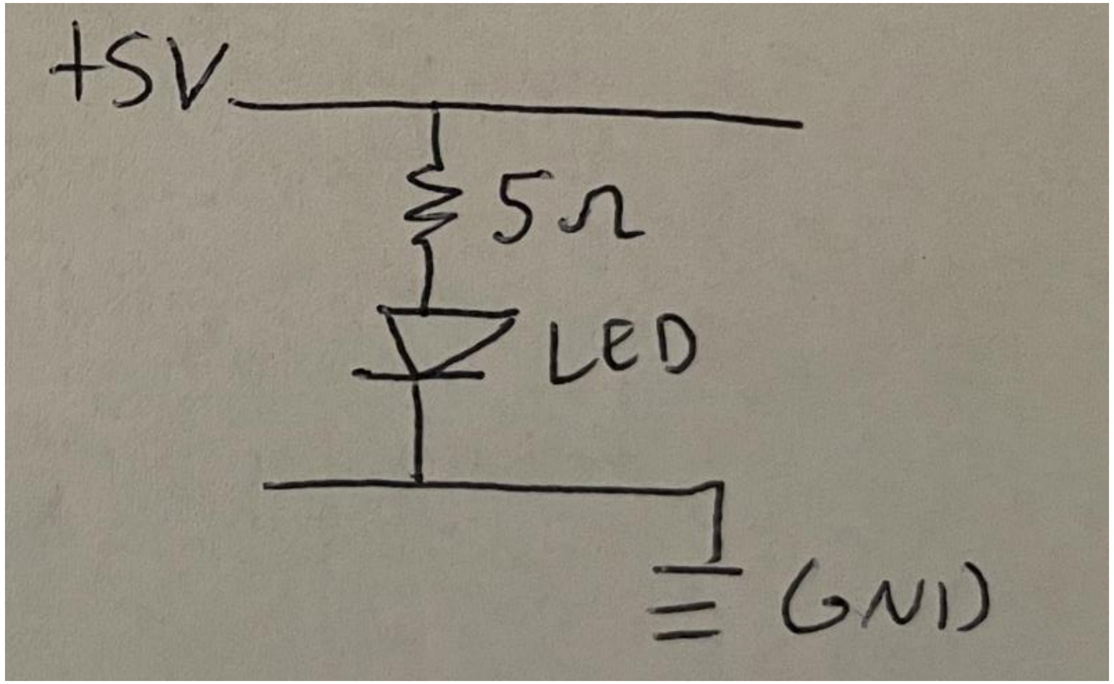
Ok so what about this (correct direction) LED with a **current limiting resistor!**



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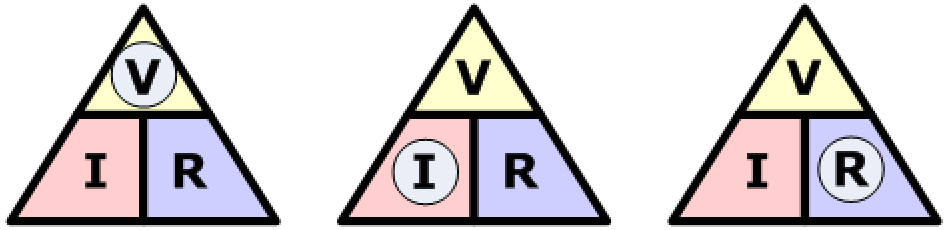

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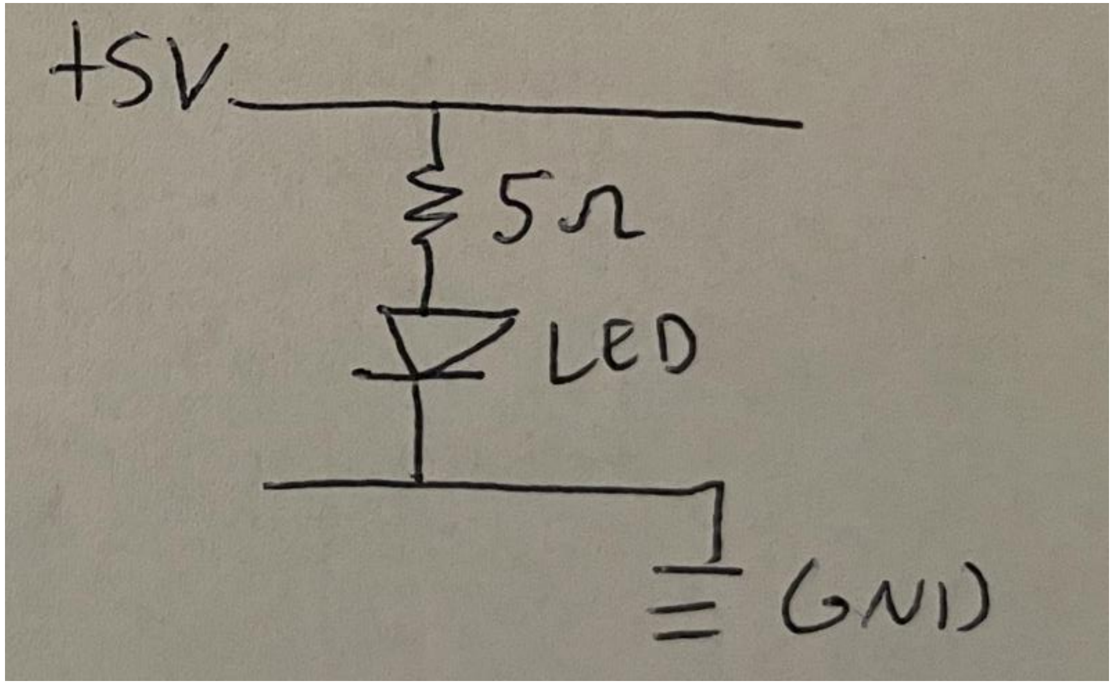
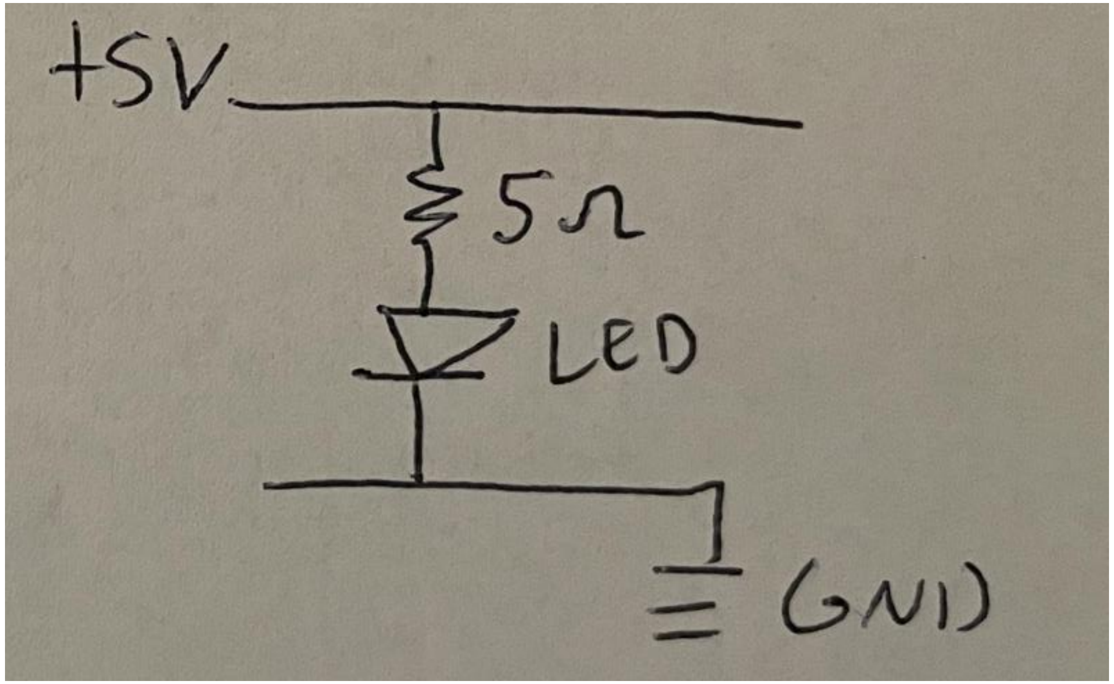


1A

Ohm's Law:

- 500 to 1K ohm resistors work well (for me)
- The order of the resistor and LED does NOT matter

Ok so what about this (correct direction) LED with a **current limiting resistor!**



1A

Our second equation - Capacitance

$$C = I * dv/dt$$

Capacitance (measured in farads) (also a charge measurement, charge = CV)

I: Current (measure in amps)

dV/dt: Change in Voltage over time (measure in volts/second)

https://learn.sparkfun.com/tutorials/capacitors/

Capacitance

$$C = I * dv/dt$$

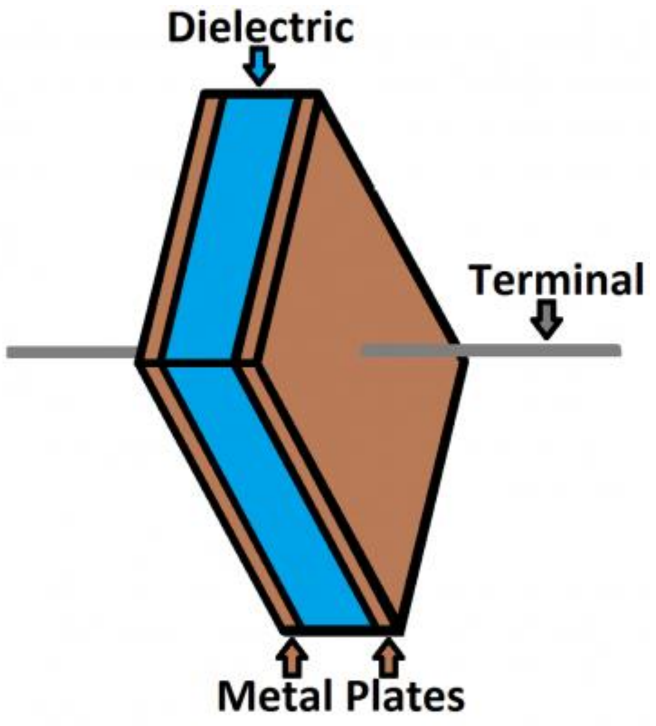
Capacitance (measured in farads)

I: Current (measure in amps)

dV/dt: Change in Voltage over time

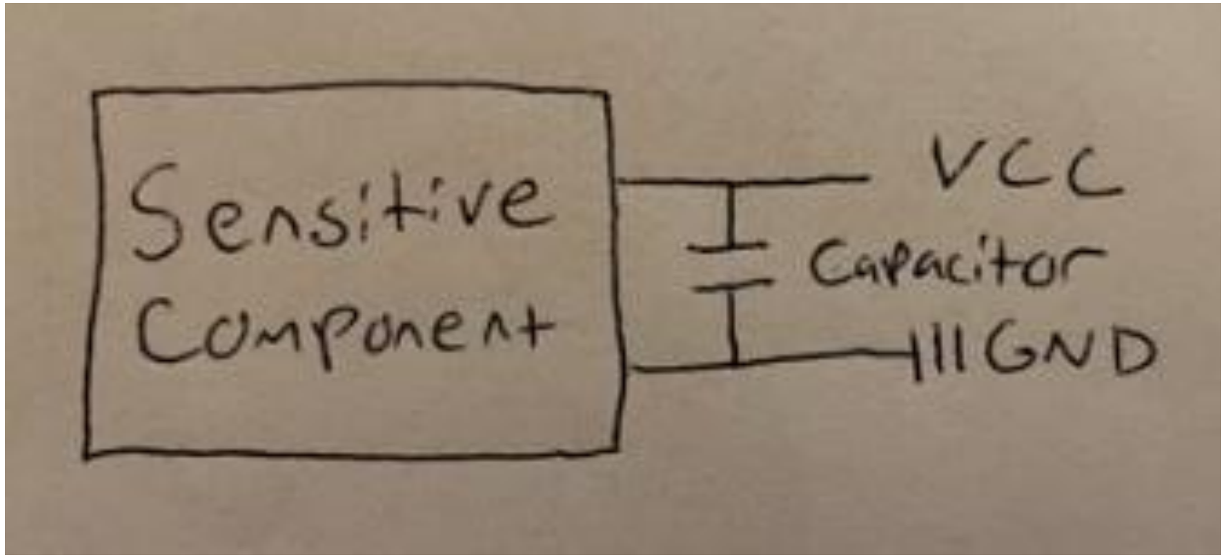
(measure in volts/second)

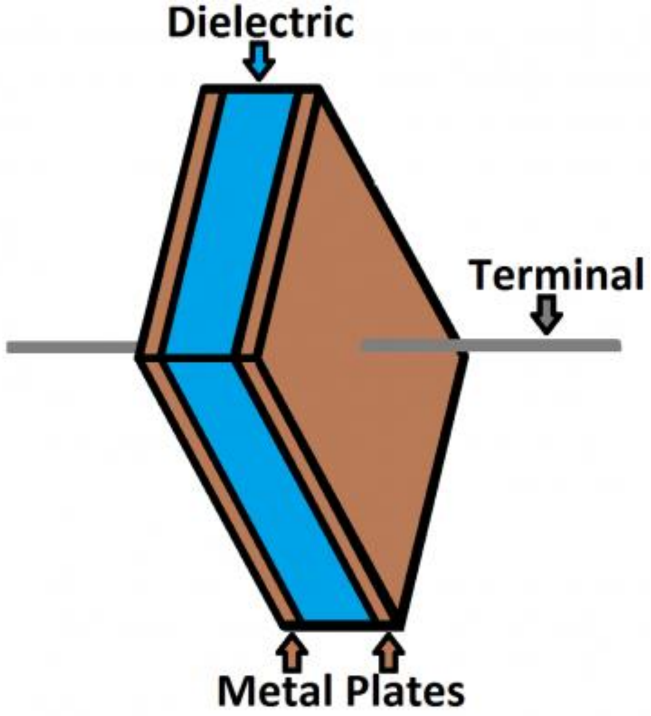
Energy is stored in an *electric* field



Capacitance

The science here can get a little complicated but/and I like to think of a capacitor as a **filter** for changes in voltage





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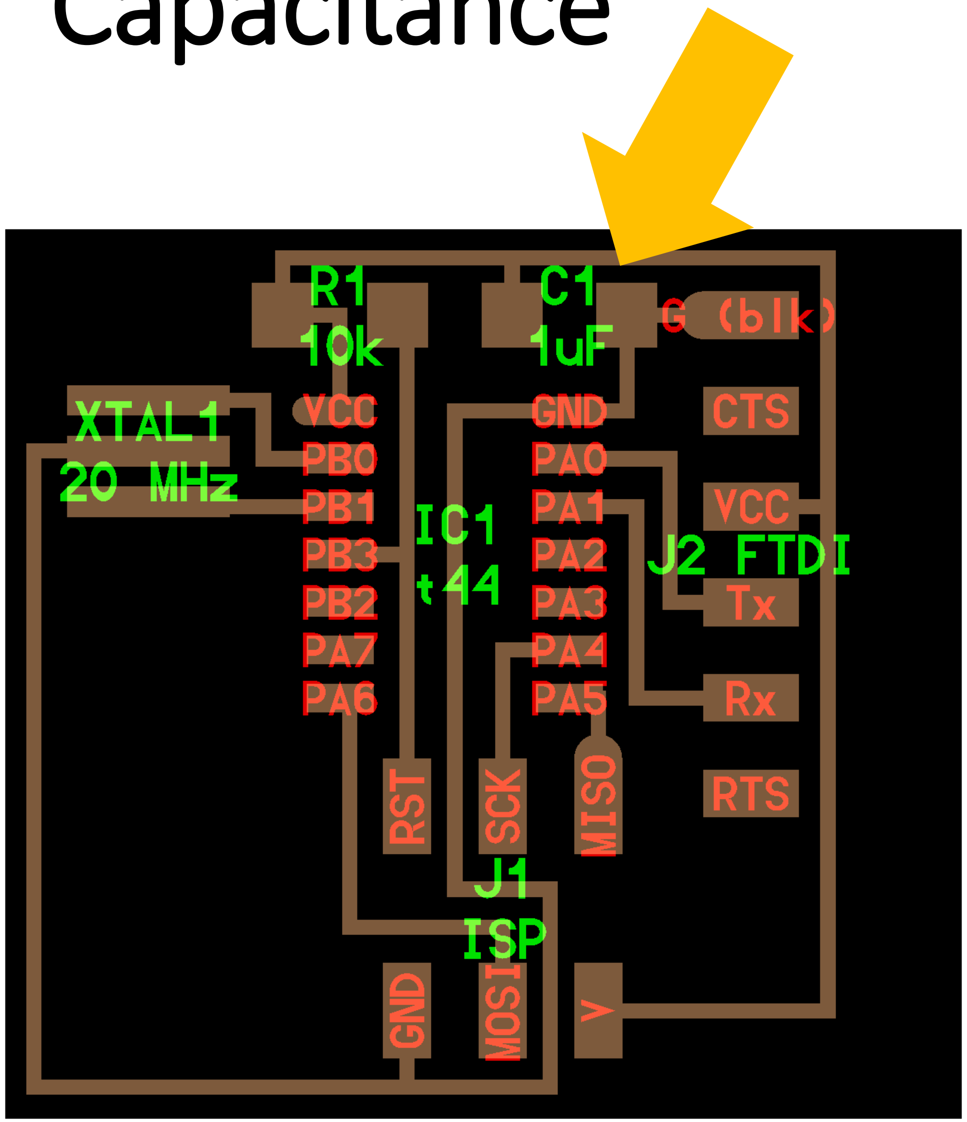
Capacitance



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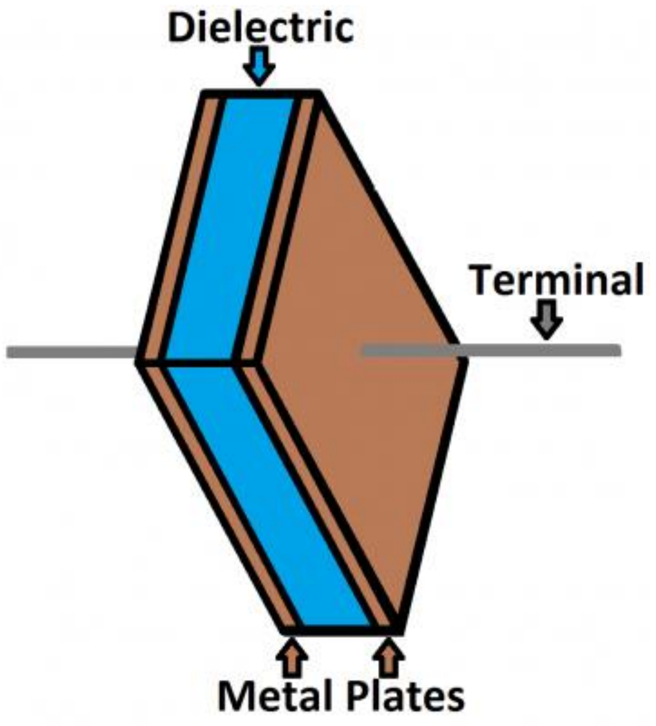

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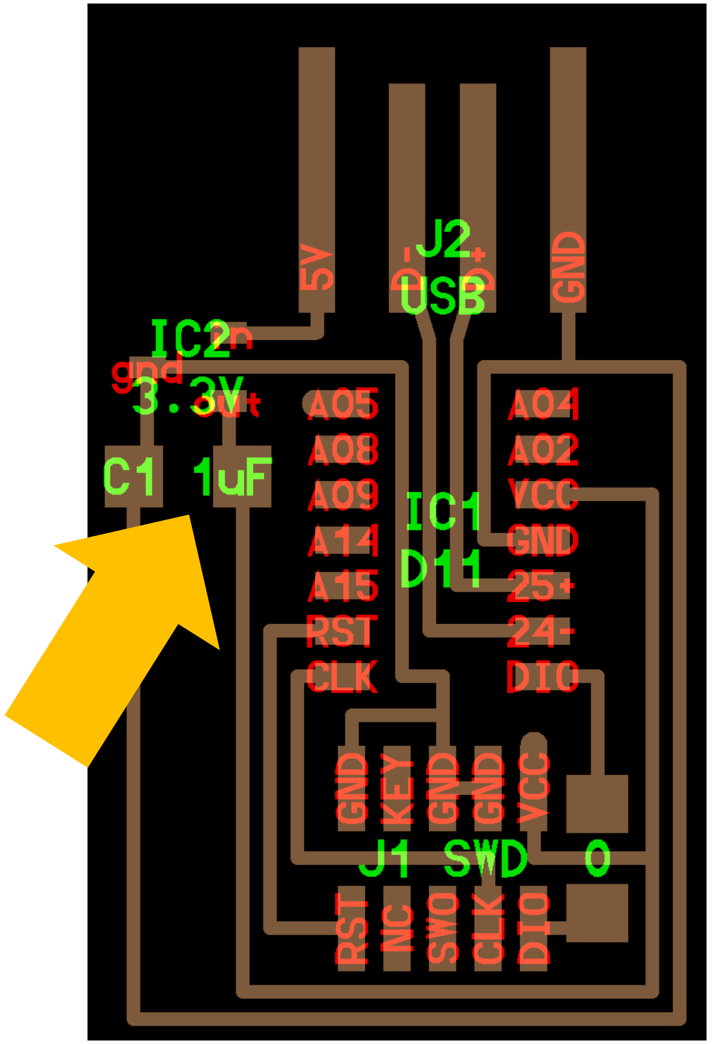

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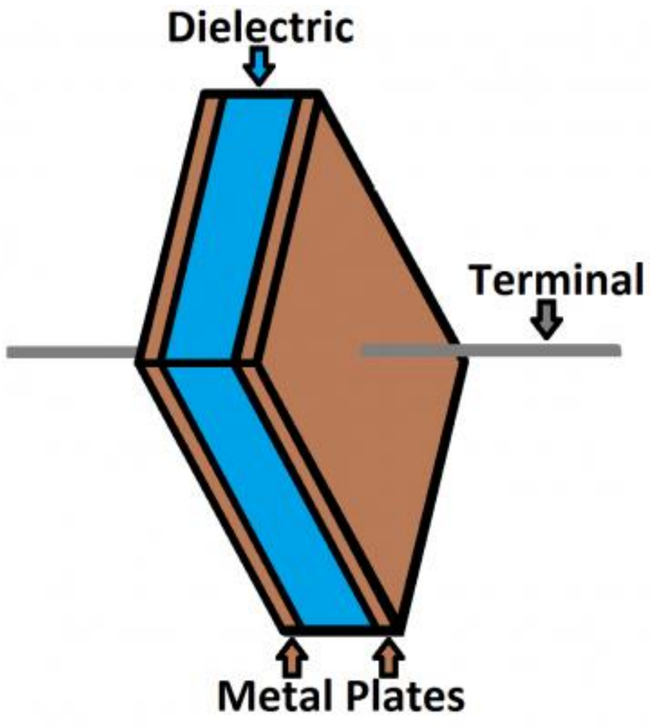


https://learn.sparkfun.com/tutorials/capacitors/application-examples

Inductance

$$v(t) = L\frac{di}{dt}$$

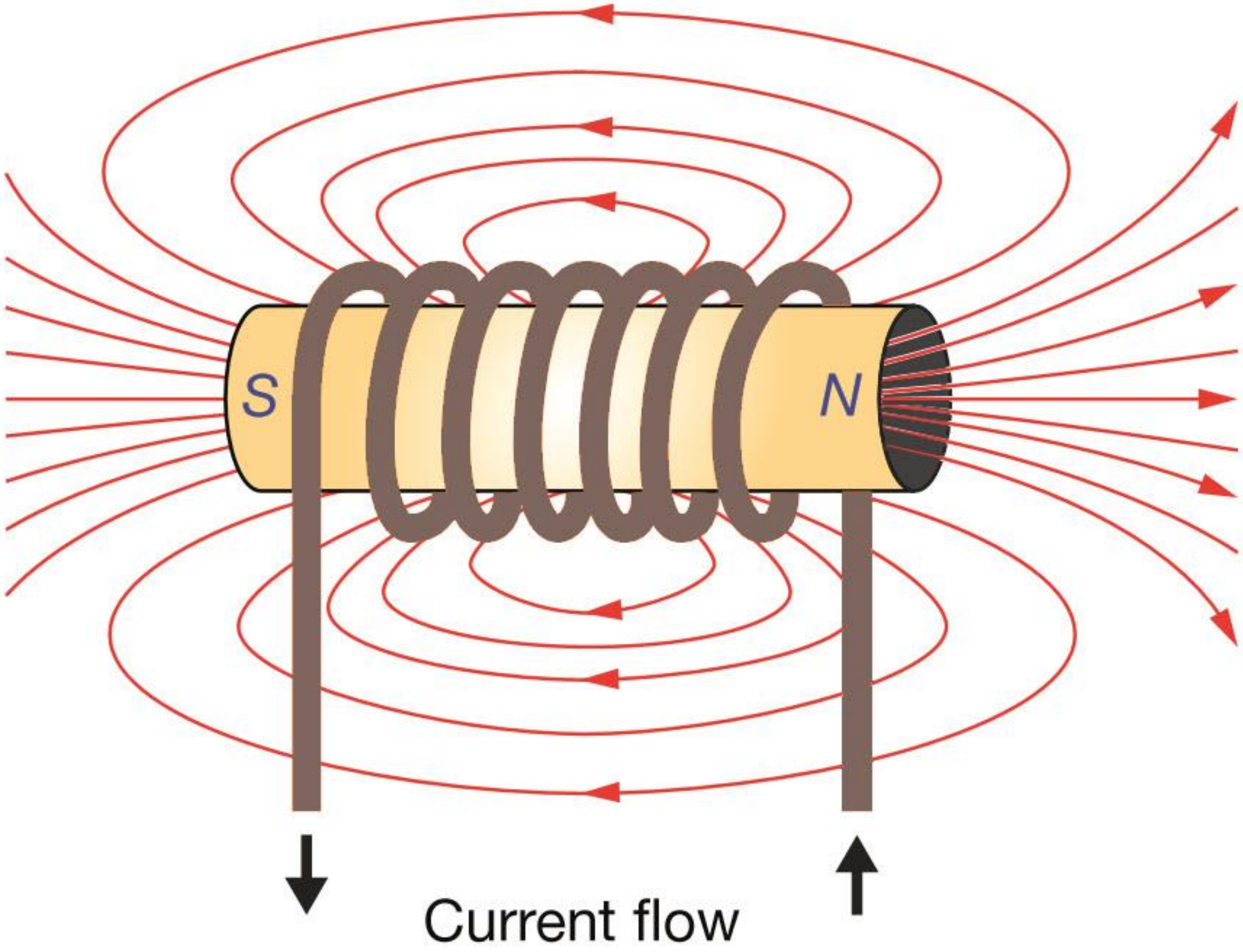
Inductance (measured in "henry"s)

v(t): voltage induced by inductor at this instant

di/dt: Change in Current over time (measure in volts/second)

Inductance

Energy is stored in a magnetic field (!)

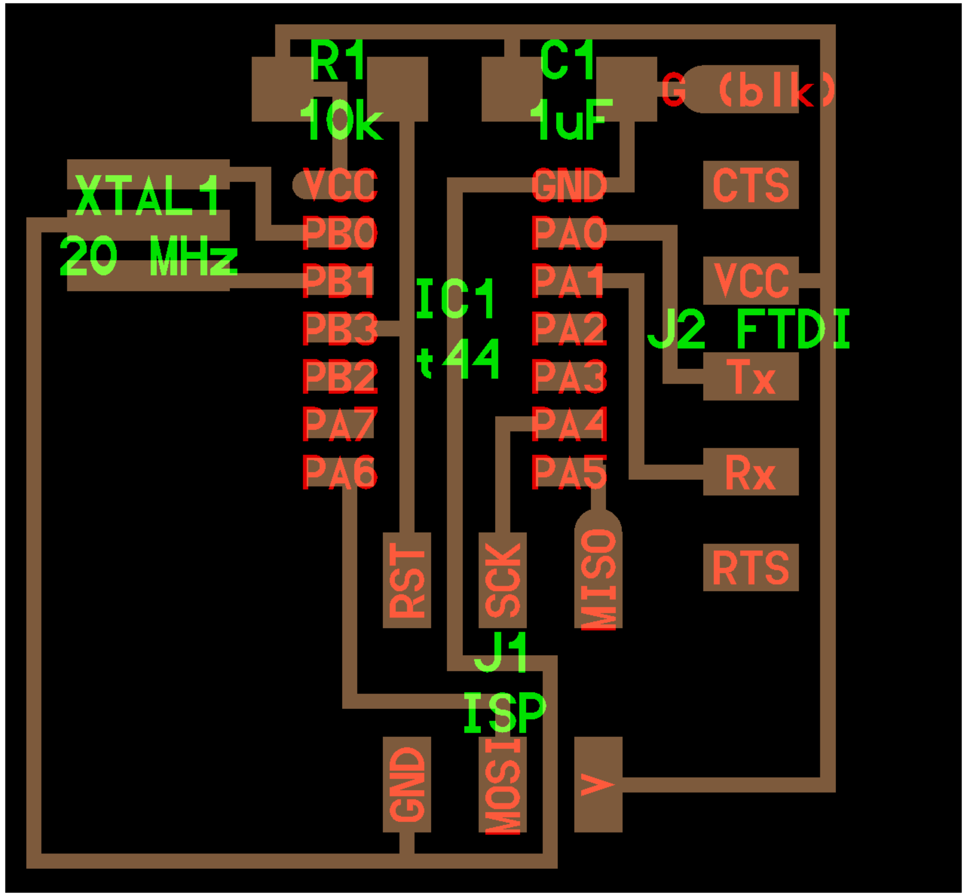


Triplets

- Resistance / Resistors: resists voltage, “does work”
- Capacitance / Capacitors: resists change in voltage
- Inductance / Inductors: resists change in current

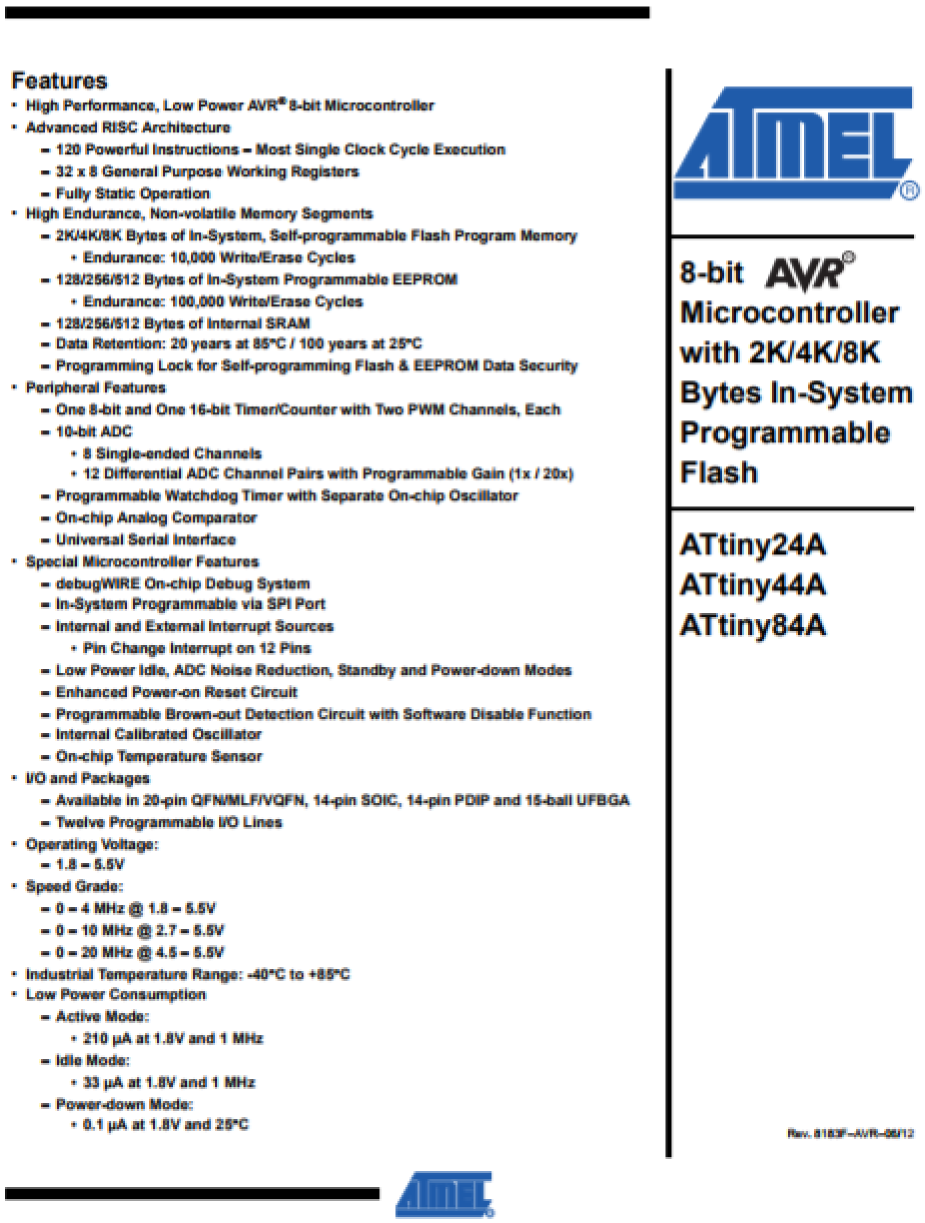
Triplets

- *everything* has *some* resistance, inductance, and capacitance; resistors are inductors, capacitors are resistors, inductors are capacitors, etc…
- we can largely ignore this inconvenience until we hit high powers, high frequencies, and high precision



But how will I know if my component needs a capacitor? And how big of a capacitor will I need? **(and what are all of those labels?)**

http://academy.cba.mit.edu/classes/embedded_programming/doc8183.pdf



Features

- High Performance, Low Power AVR® 8-bit Microcontroller
- Advanced RISC Architecture
  - 120 Powerful Instructions – Most Single Clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
- High Endurance, Non-volatile Memory Segments
  - 2K/4K/8K Bytes of In-System, Self-programmable Flash Program Memory
    - Endurance: 10,000 Write/Erase Cycles
  - 128/256/512 Bytes of In-System Programmable EEPROM
    - Endurance: 100,000 Write/Erase Cycles
  - 128/256/512 Bytes of Internal SRAM
  - Data Retention: 20 years at 85°C / 100 years at 25°C
  - Programming Lock for Self-programming Flash & EEPROM Data Security
- Peripheral Features
  - One 8-bit and One 16-bit Timer/Counter with Two PWM Channels, Each
  - 10-bit ADC
    - 8 Single-ended Channels
    - 12 Differential ADC Channel Pairs with Programmable Gain (1x / 20x)
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
  - Universal Serial Interface
- Special Microcontroller Features
  - debugWIRE On-chip Debug System
  - In-System Programmable via SPI Port
  - Internal and External Interrupt Sources
    - Pin Change Interrupt on 12 Pins
  - Low Power Idle, ADC Noise Reduction, Standby and Power-down Modes
  - Enhanced Power-on Reset Circuit
  - Programmable Brown-out Detection Circuit with Software Disable Function
  - Internal Calibrated Oscillator
  - On-chip Temperature Sensor
- I/O and Packages
  - Available in 20-pin QFN/MLF/VQFN, 14-pin SOIC, 14-pin PDIP and 15-ball UFBGA
  - Twelve Programmable I/O Lines
- Operating Voltage:
  - 1.8 – 5.5V
- Speed Grade:
  - 0 – 4 MHz @ 1.8 – 5.5V
  - 0 – 10 MHz @ 2.7 – 5.5V
  - 0 – 20 MHz @ 4.5 – 5.5V
- Industrial Temperature Range: -40°C to +85°C
- Low Power Consumption
  - Active Mode:
    - 210 µA at 1.8V and 1 MHz
  - Idle Mode:
    - 33 µA at 1.8V and 1 MHz
  - Power-down Mode:
    - 0.1 µA at 1.8V and 25°C

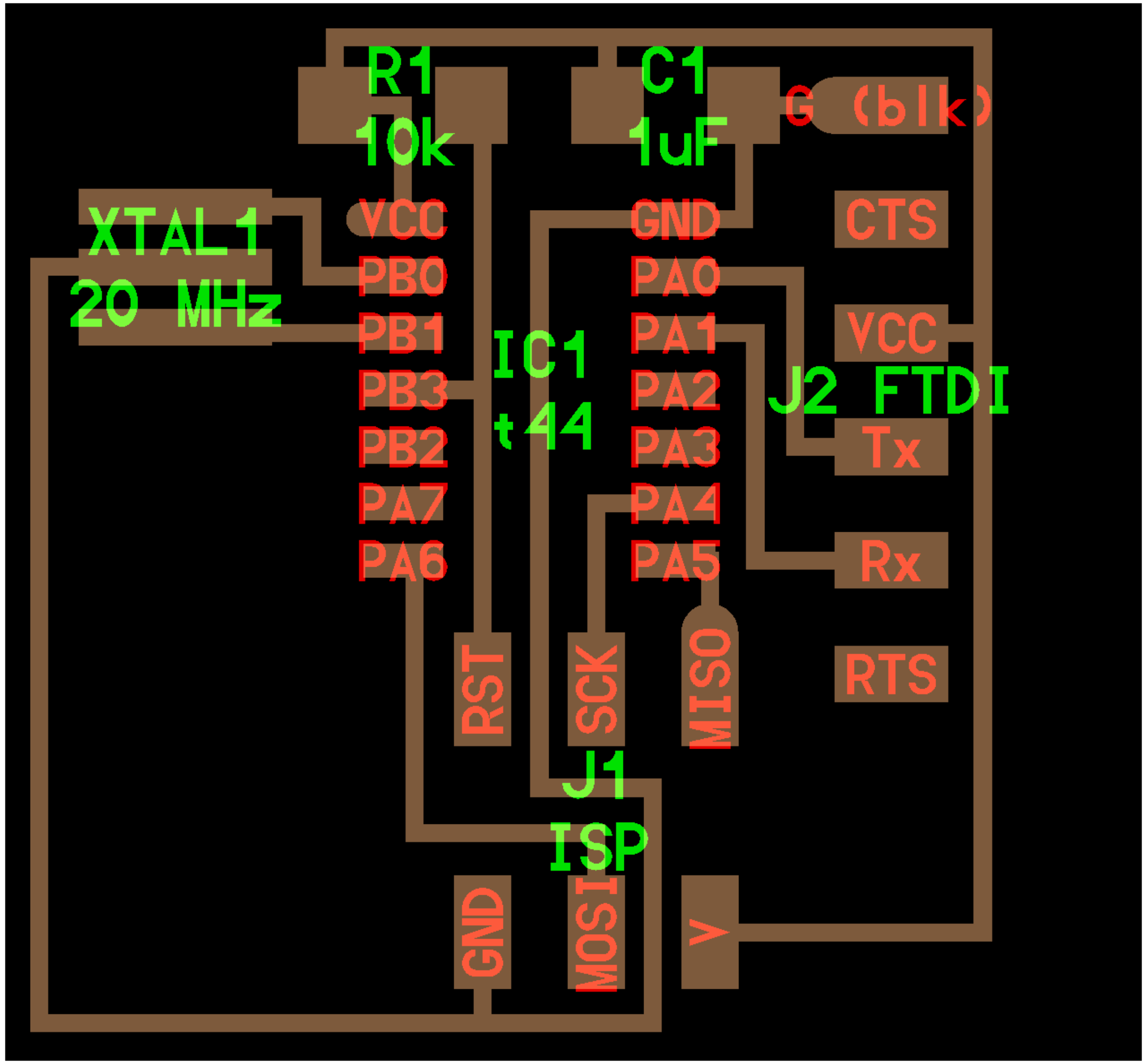
8-bit AVR® Microcontroller with 2K/4K/8K Bytes In-System Programmable Flash

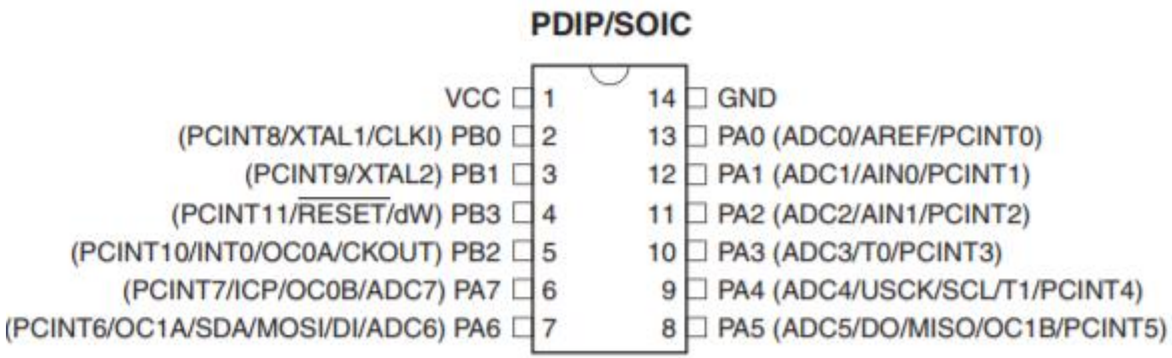
ATtiny24A
ATtiny44A
ATtiny84A

Rev. 8183F–AVR–06/12

Sometimes: read the datasheet

Often: follow design patterns





Oh hey look at Neil's hello world board – it looks like the programming 6 pin header has all of it's named things connected to the ports on the Attiny with those names!

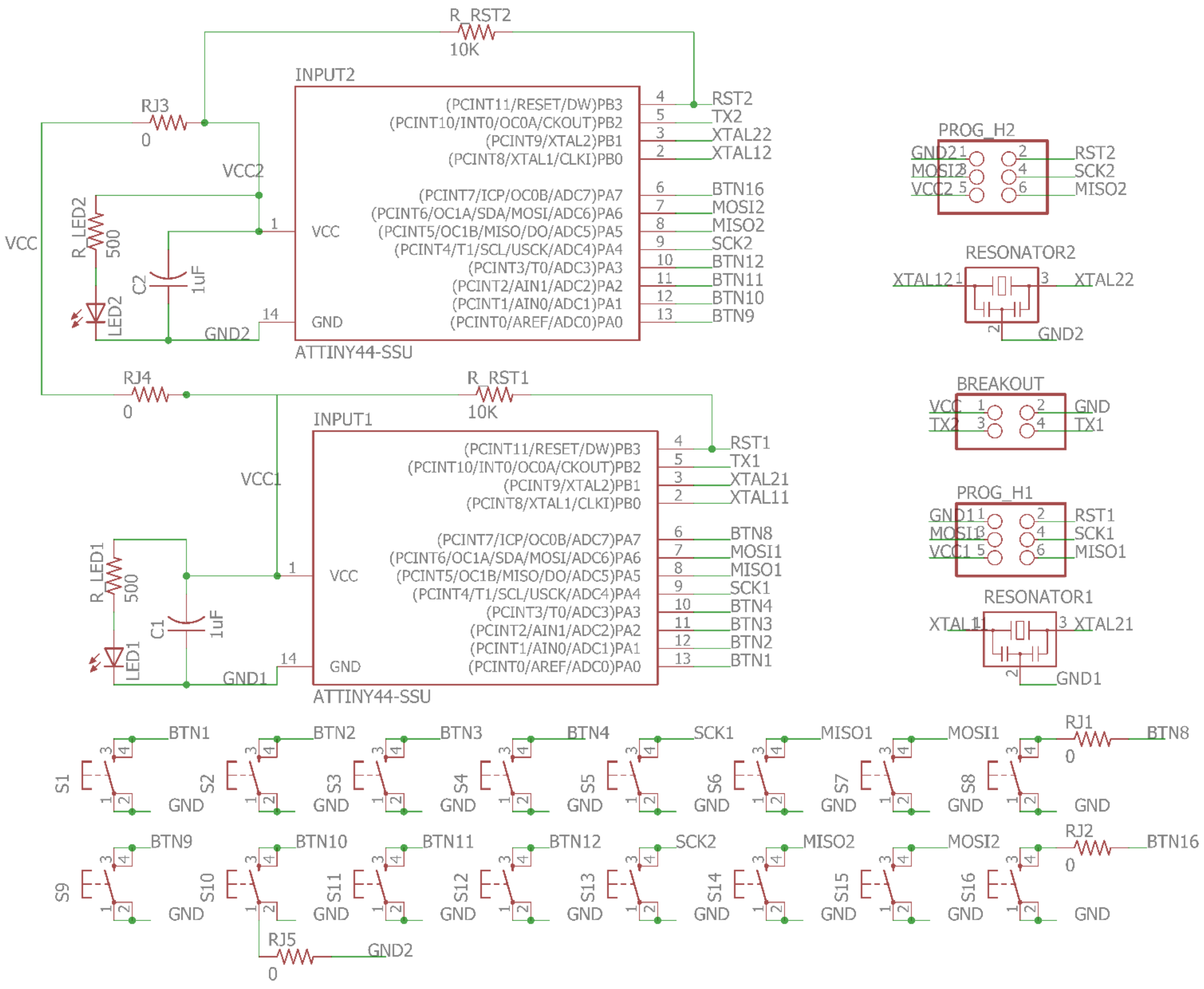
Oh and the clock too (XTAL)!

“EDA” Electronic Design Automation
“ECAD” Electronics Computer Aided Design

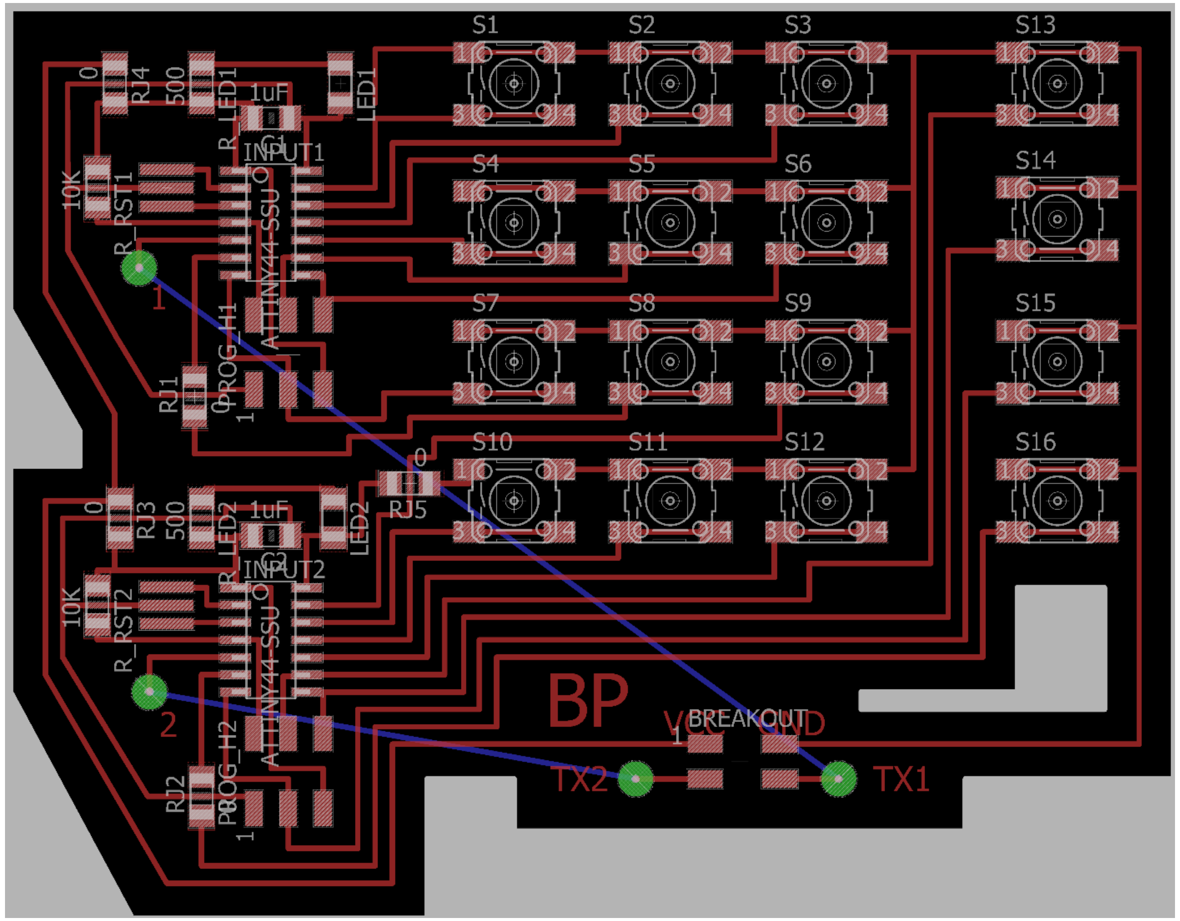
EAGLE

KiCad

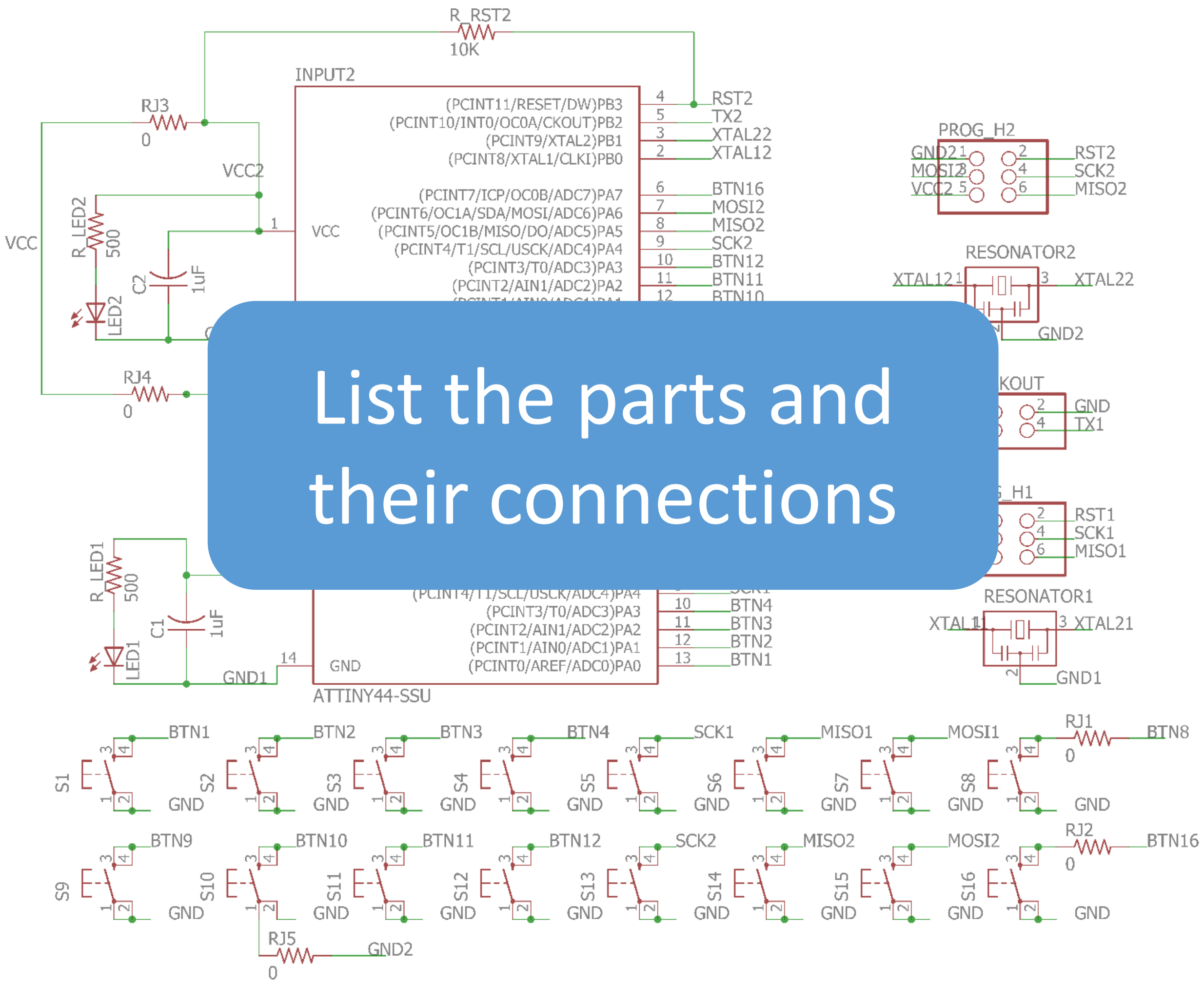
Schematic



Board File

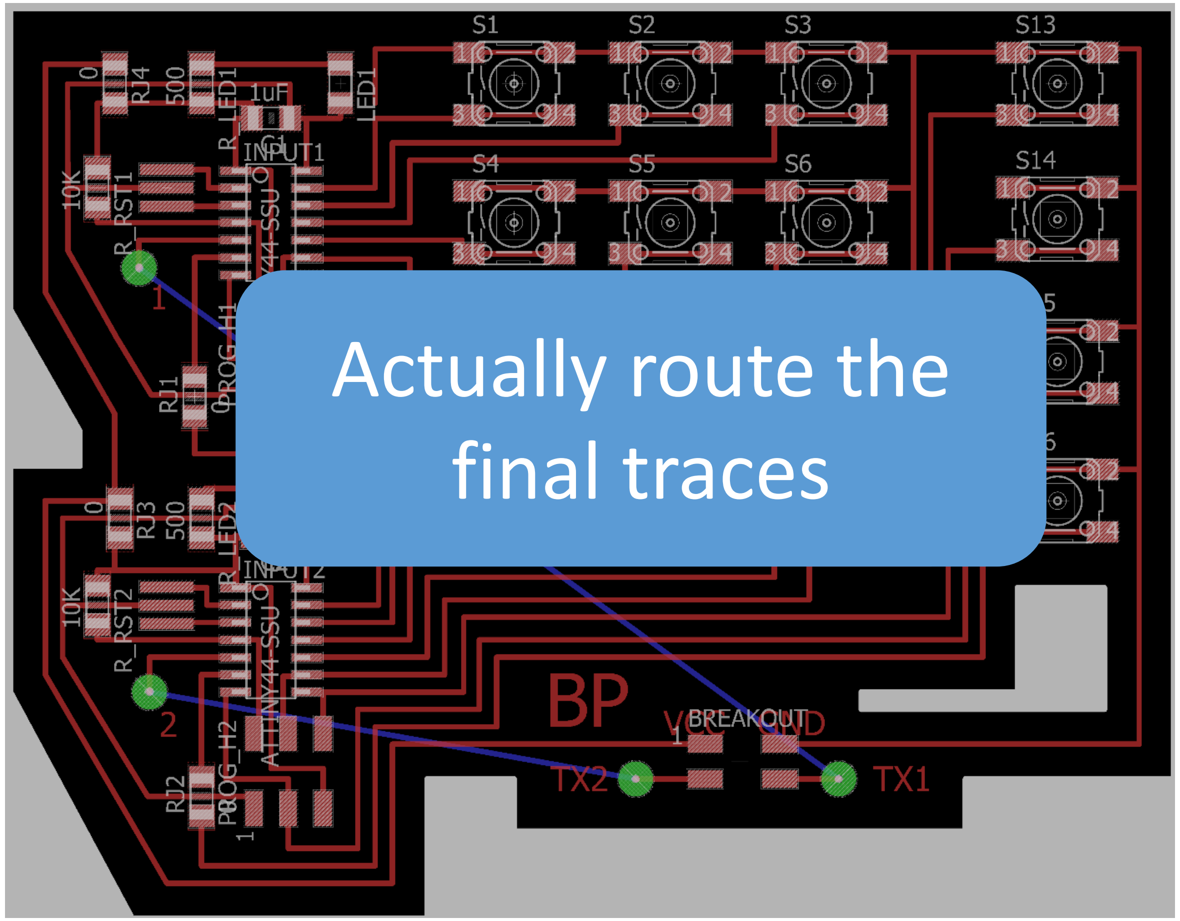


Schematic



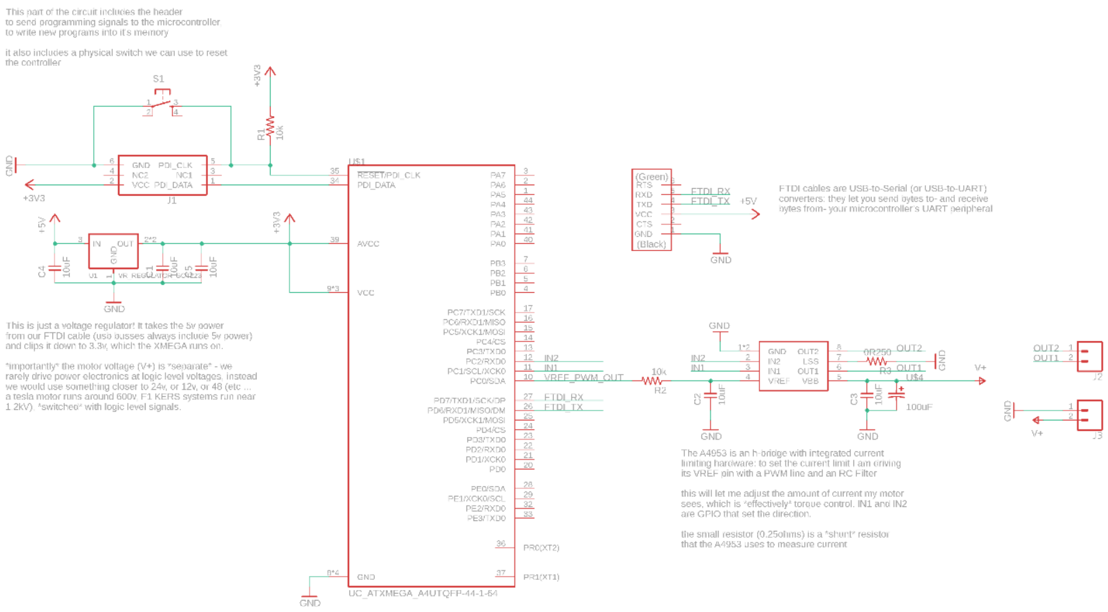
List the parts and their connections

Board File

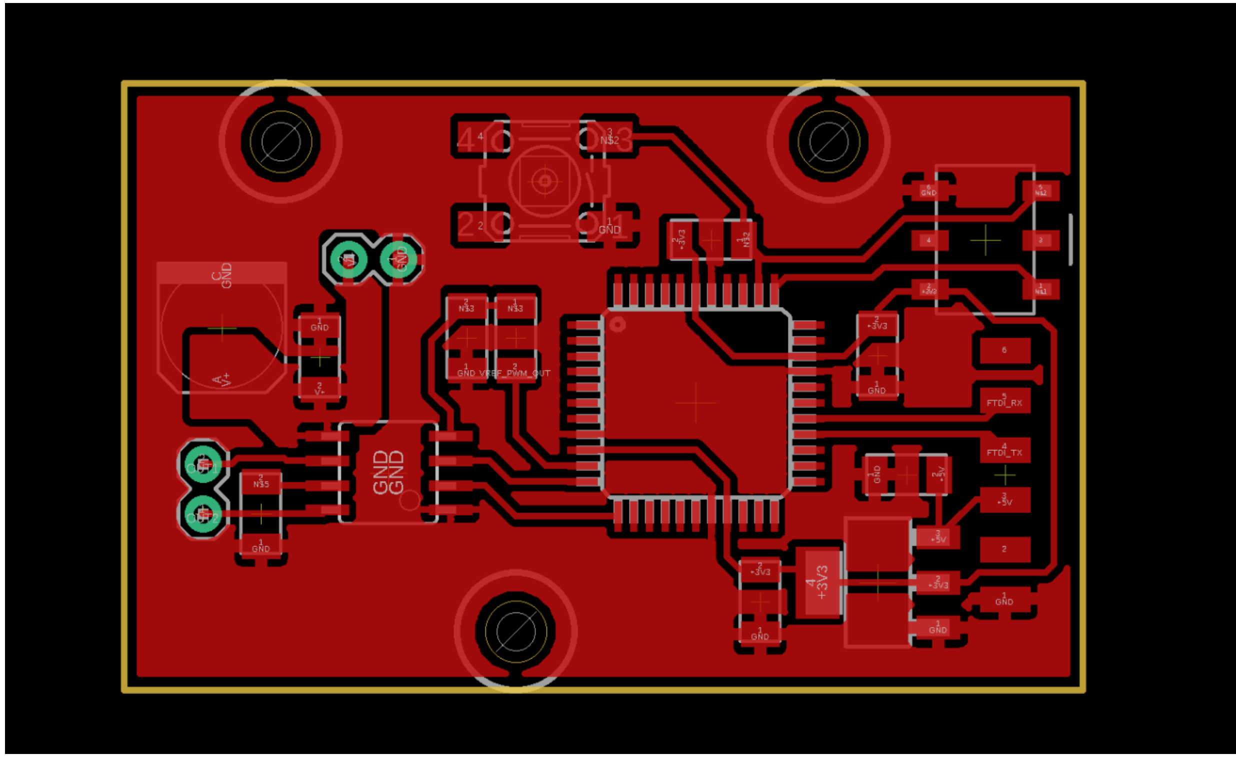


Actually route the final traces

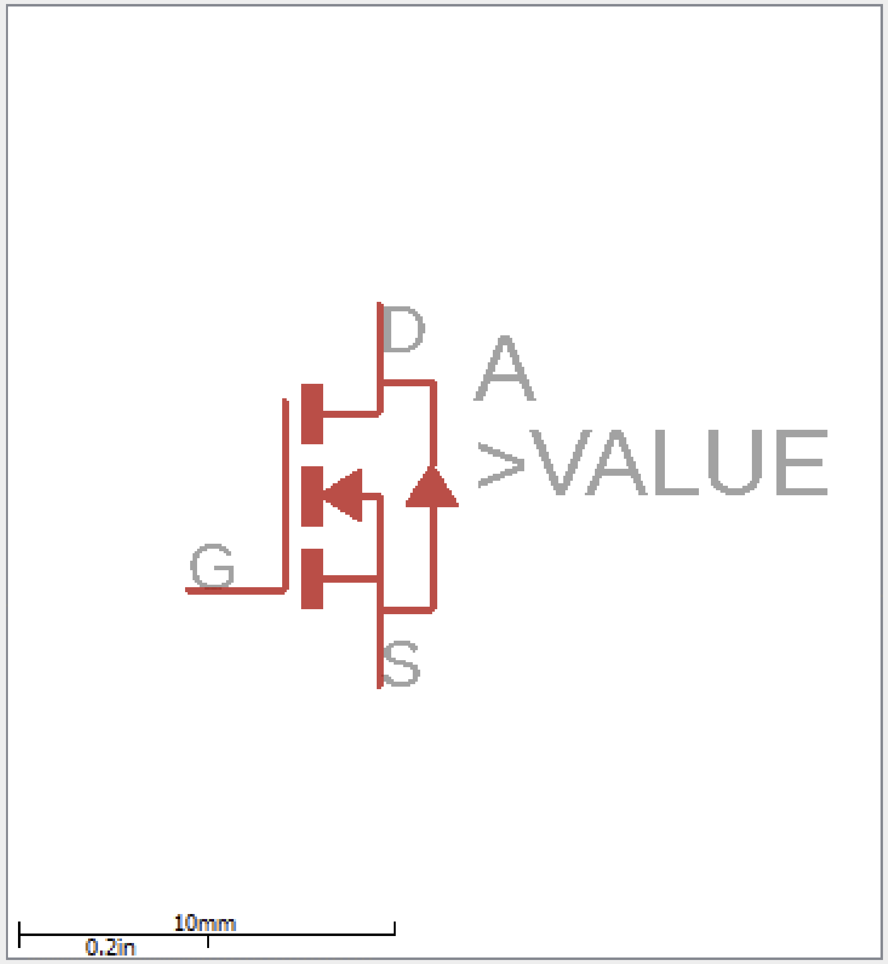
Schematic

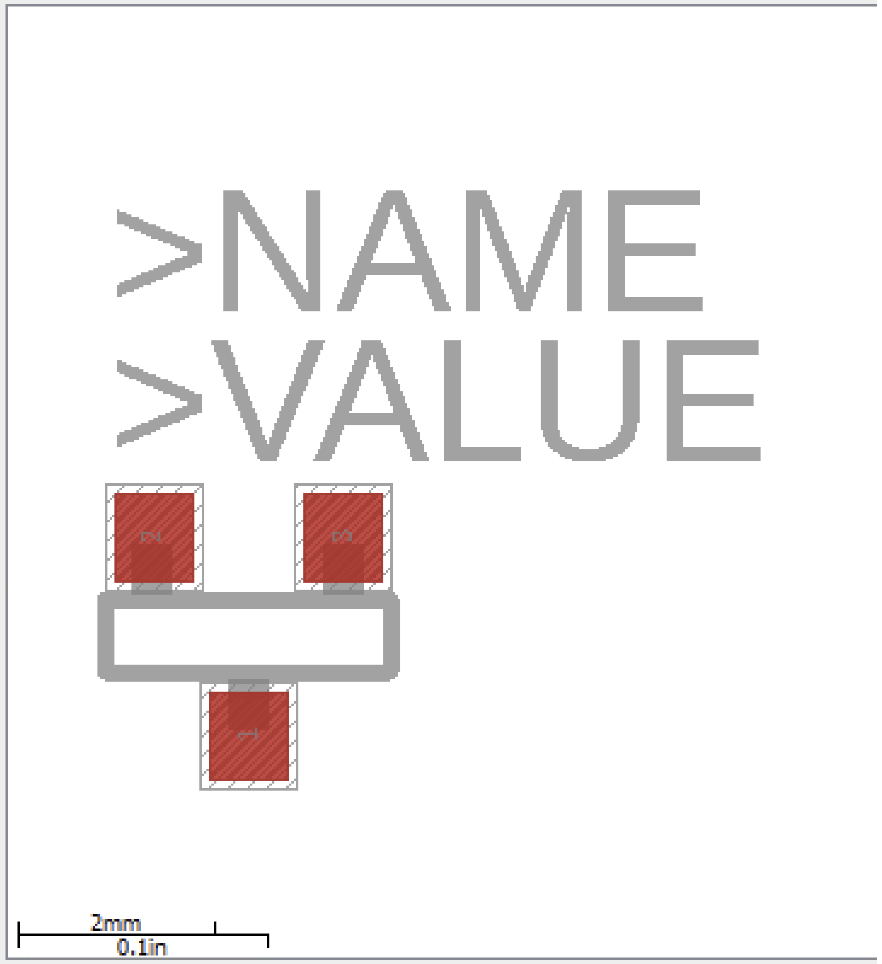


Board File



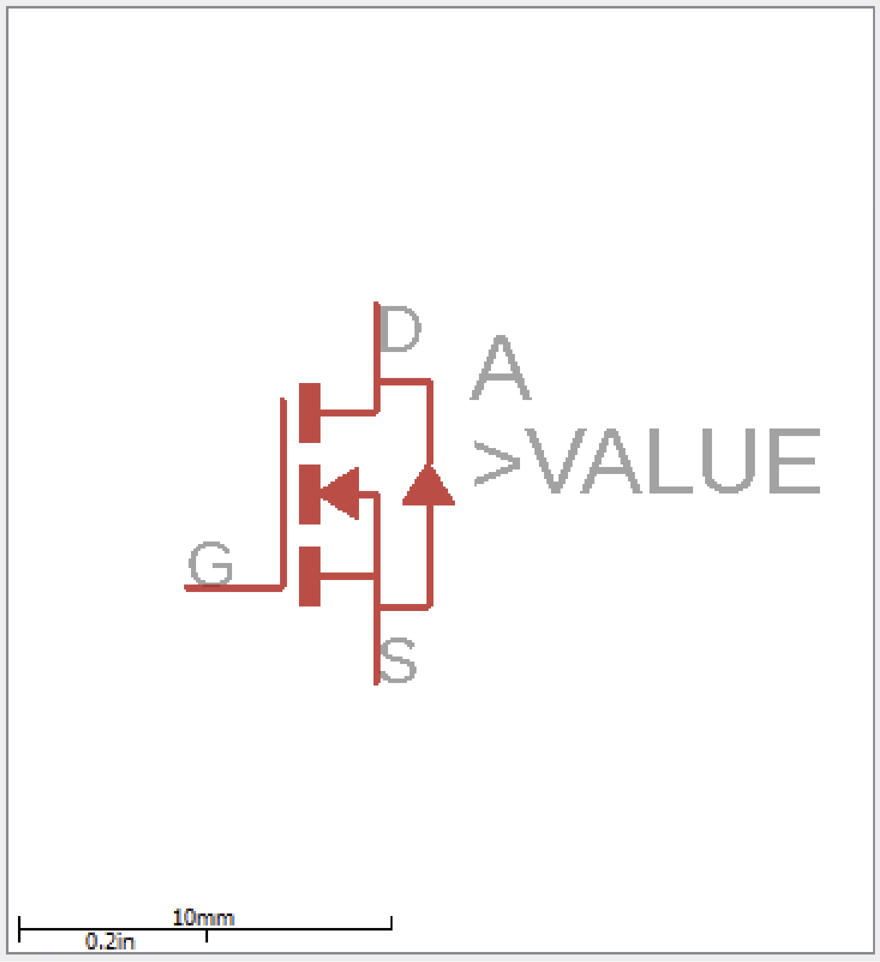
“Symbol” “Footprint”

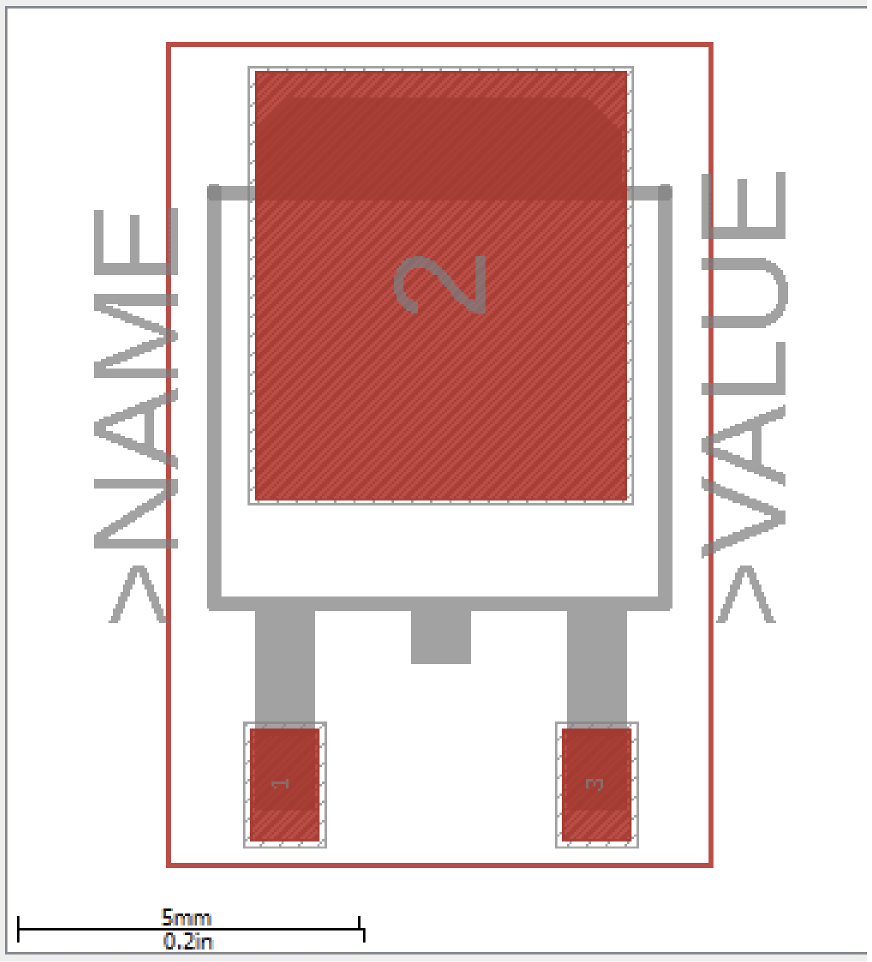


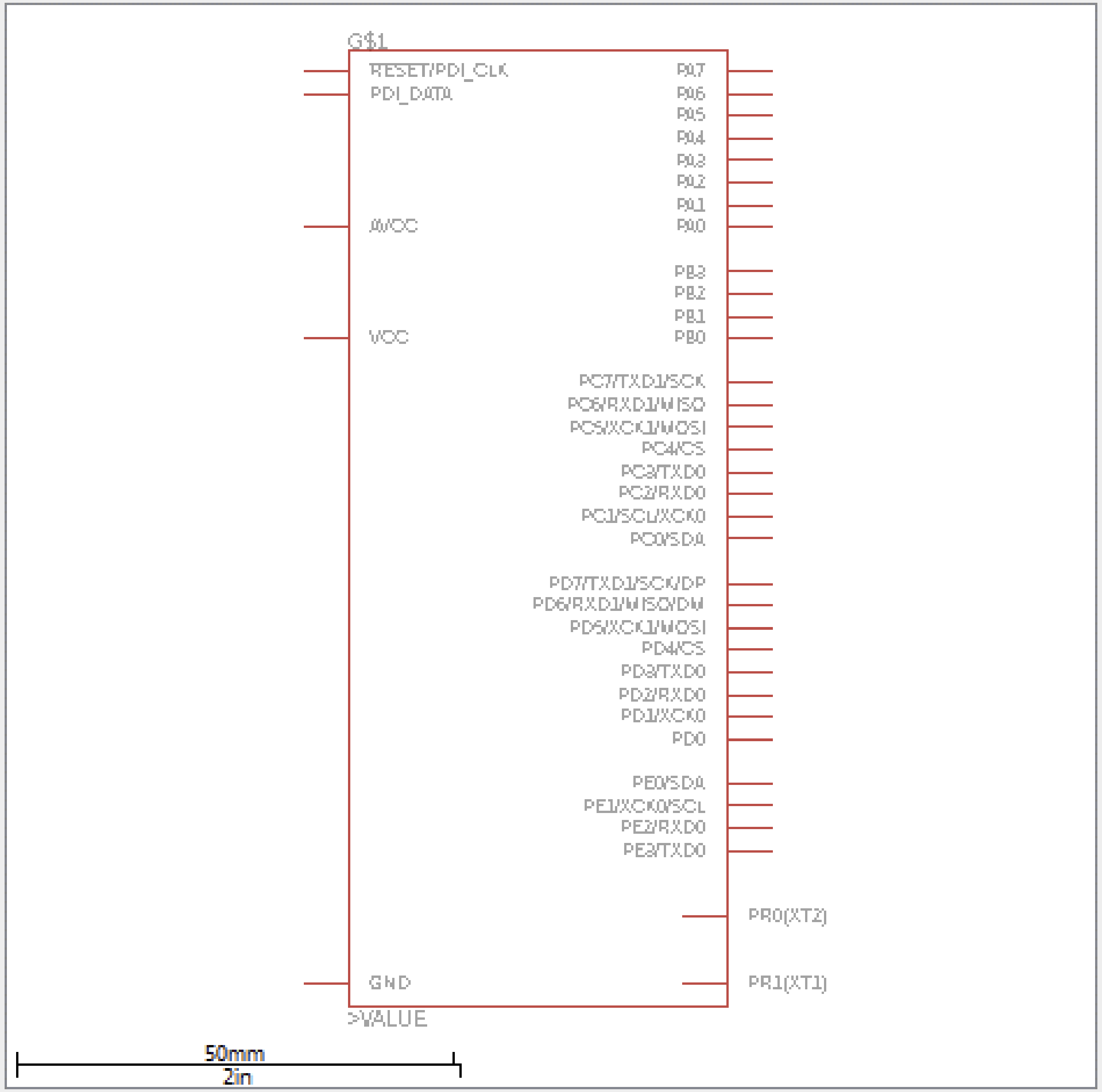
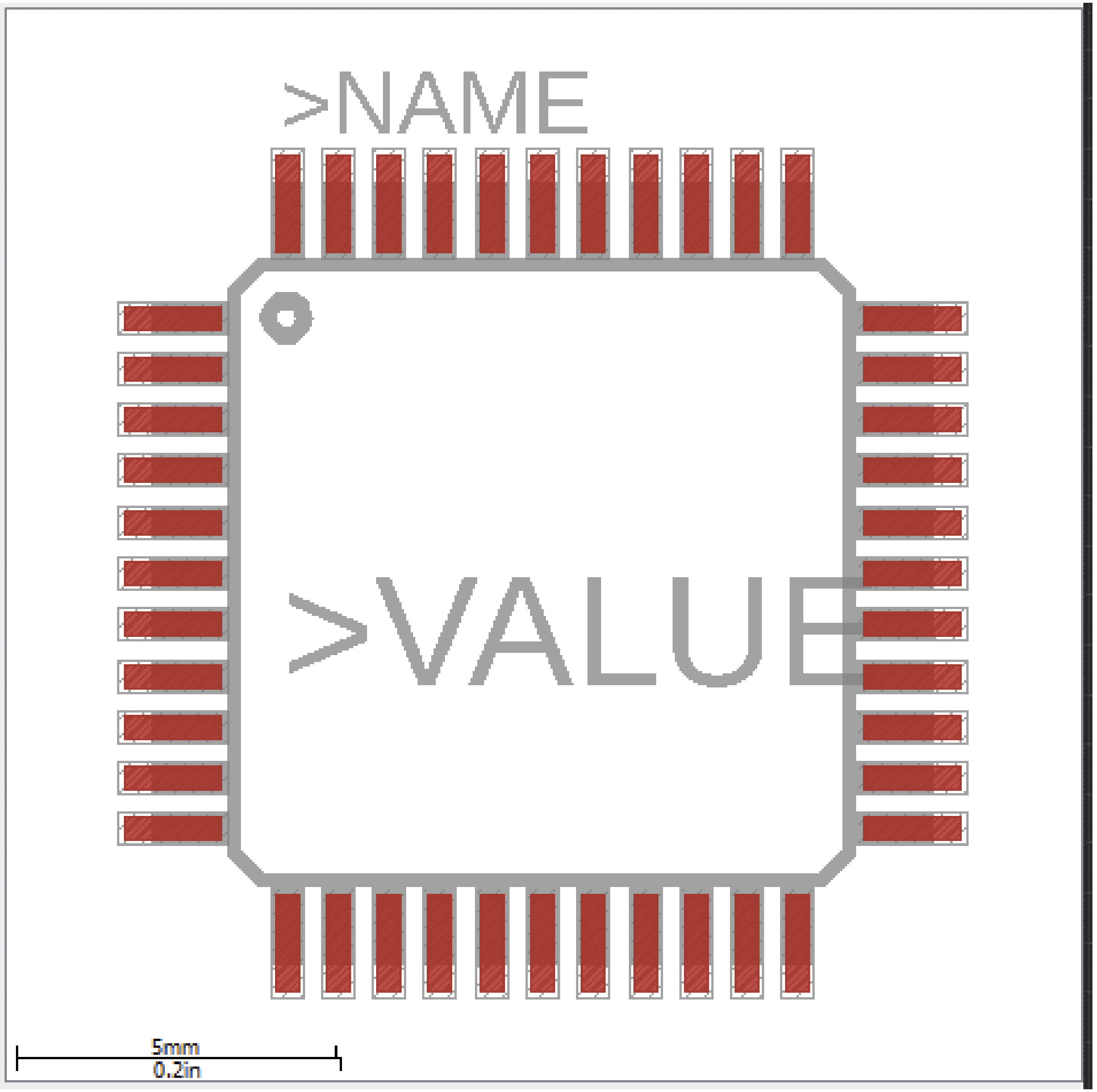


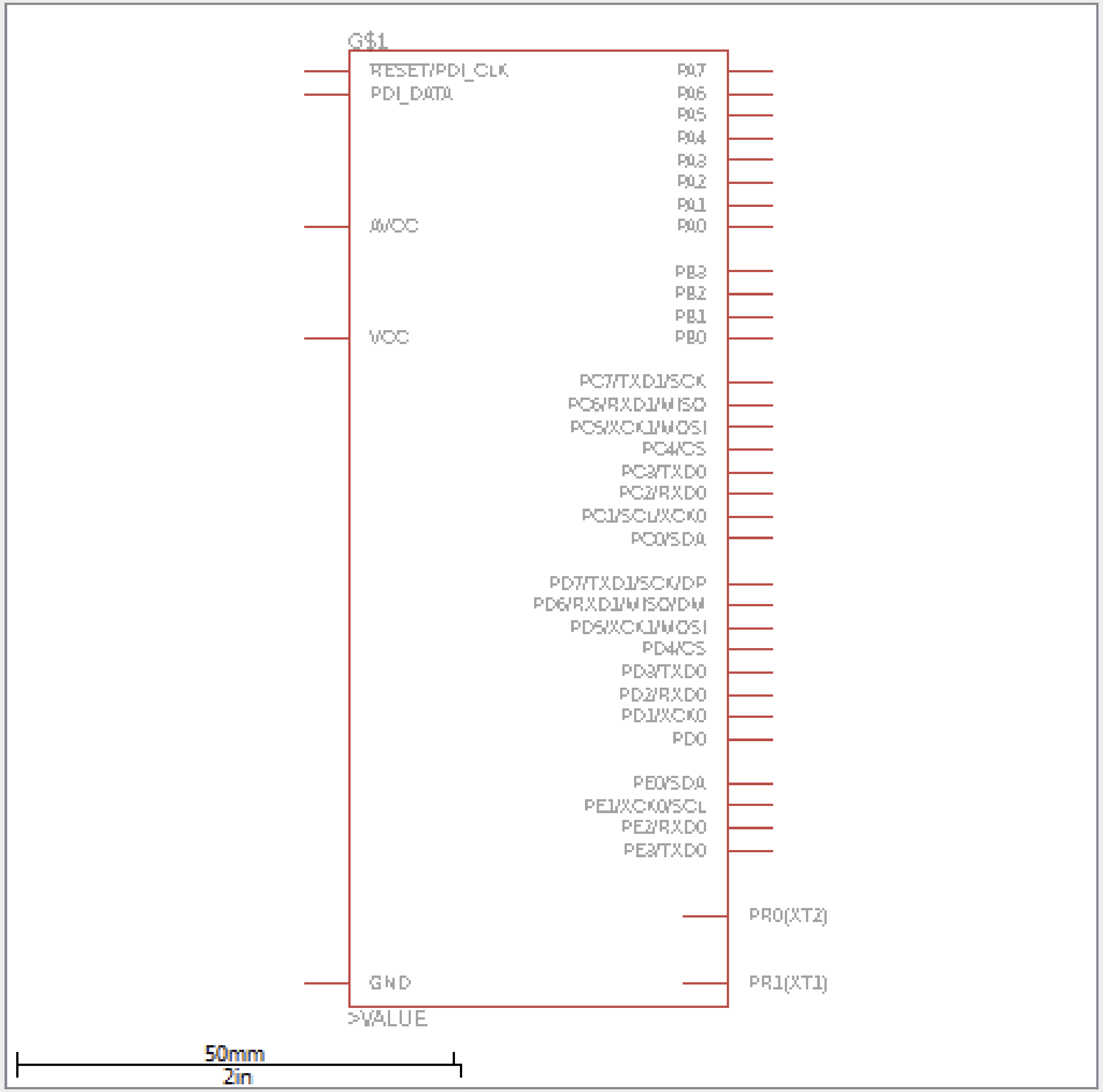
“Symbol”

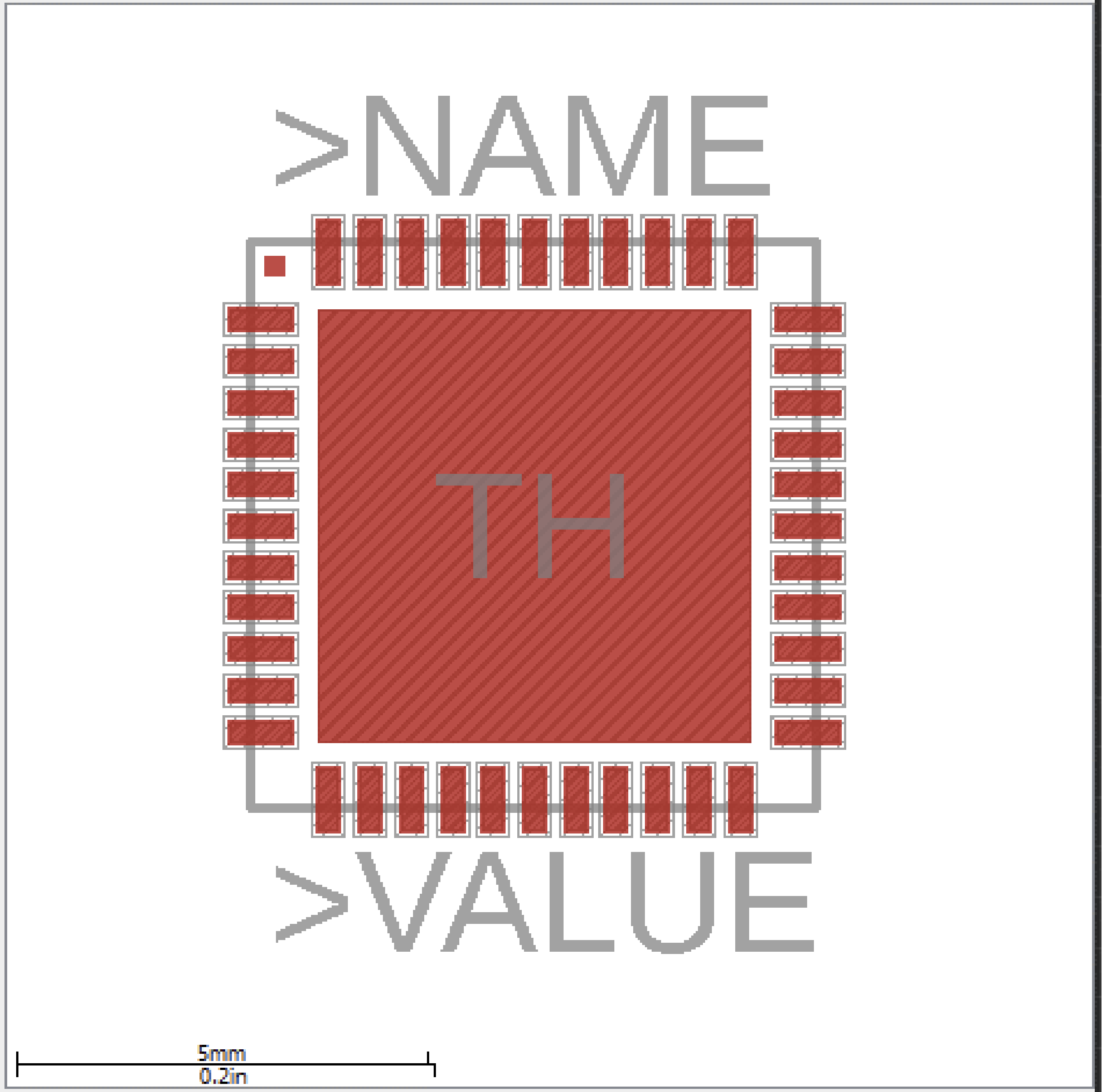
“Footprint”

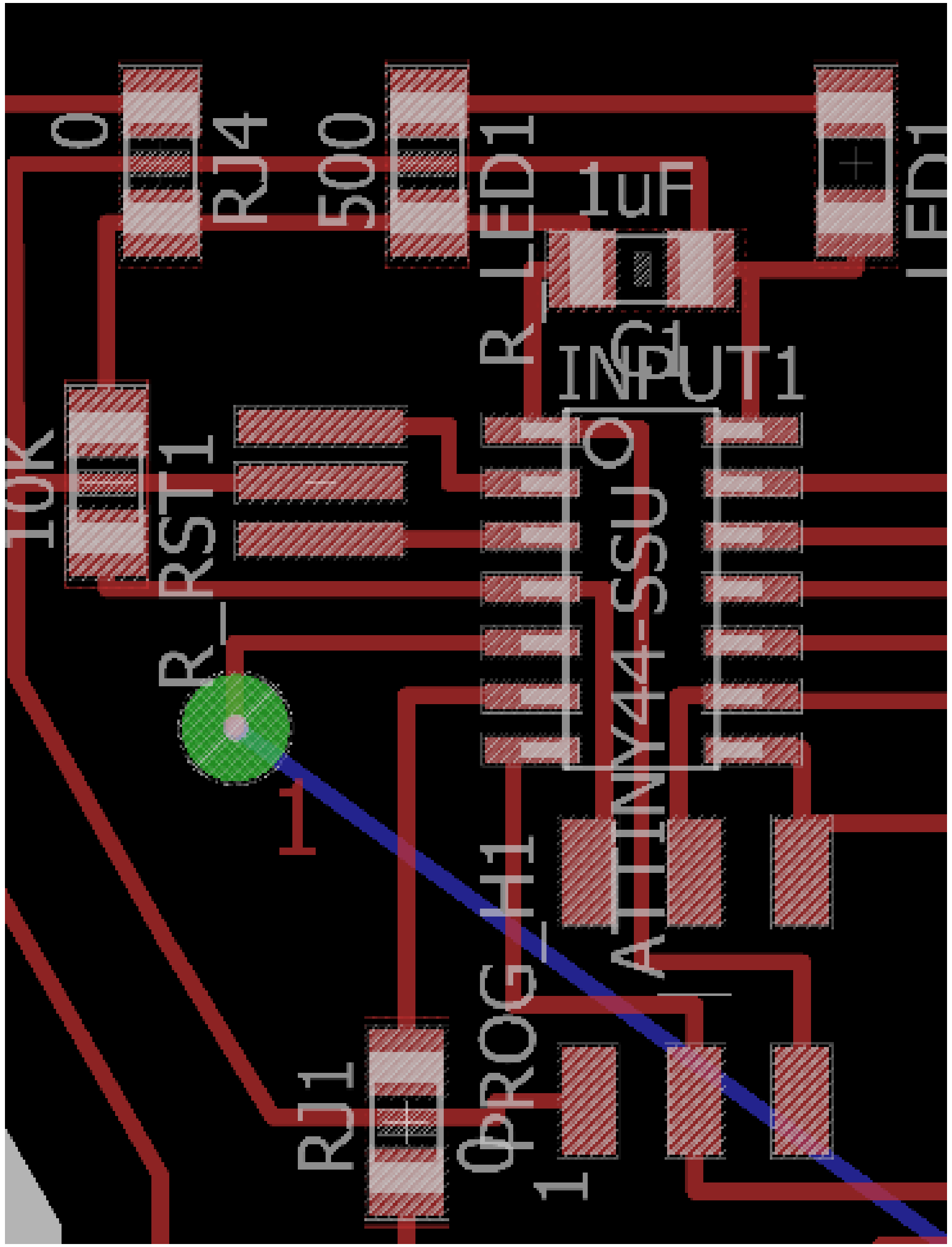


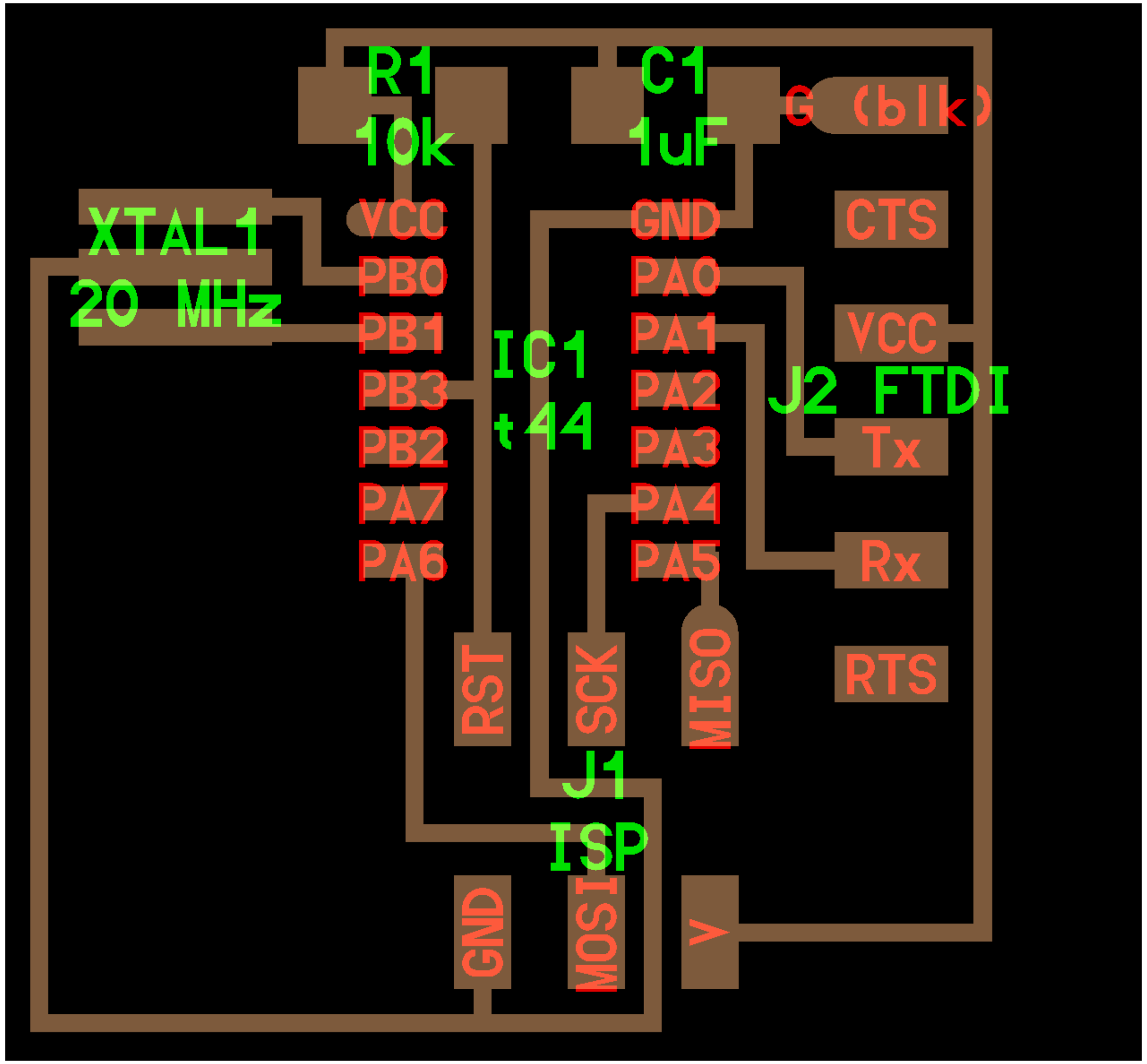



G$1
RESET/PDI_CLK
PDI_DATA
AVCC
VCC
GND
PA7
PA6
PA5
PA4
PA3
PA2
PA1
PA0
PB3
PB2
PB1
PB0
PC7/TXD1/SCK
PC6/RXD1/MISO
PC5/XCK1/MOSI
PC4/CS
PC3/TXD0
PC2/RXD0
PC1/SCL/XCK0
PC0/SDA
PD7/TXD1/SCK/DP
PD6/RXD1/MISO/DM
PD5/XCK1/MOSI
PD4/CS
PD3/TXD0
PD2/RXD0
PD1/XCK0
PD0
PE0/SDA
PE1/XCK0/SCL
PE2/RXD0
PE3/TXD0
PR0(XT2)
PR1(XT1)
>VALUE
50mm
2in

>NAME
>VALUE
5mm
0.2in


G$1
RESET/PDI_CLK
PDI_DATA
AVCC
VCC
GND
>VALUE
PA7
PA6
PA5
PA4
PA3
PA2
PA1
PA0
PB3
PB2
PB1
PB0
PC7/TXD1/SCK
PC6/RXD1/MISO
PC5/XCK1/MOSI
PC4/CS
PC3/TXD0
PC2/RXD0
PC1/SCL/XCK0
PC0/SDA
PD7/TXD1/SCK/DP
PD6/RXD1/MISO/DM
PD5/XCK1/MOSI
PD4/CS
PD3/TXD0
PD2/RXD0
PD1/XCK0
PD0
PE0/SDA
PE1/XCK0/SCL
PE2/RXD0
PE3/TXD0
PR0(XT2)
PR1(XT1)
50mm
2in


>NAME
TH
>VALUE
5mm
0.2in

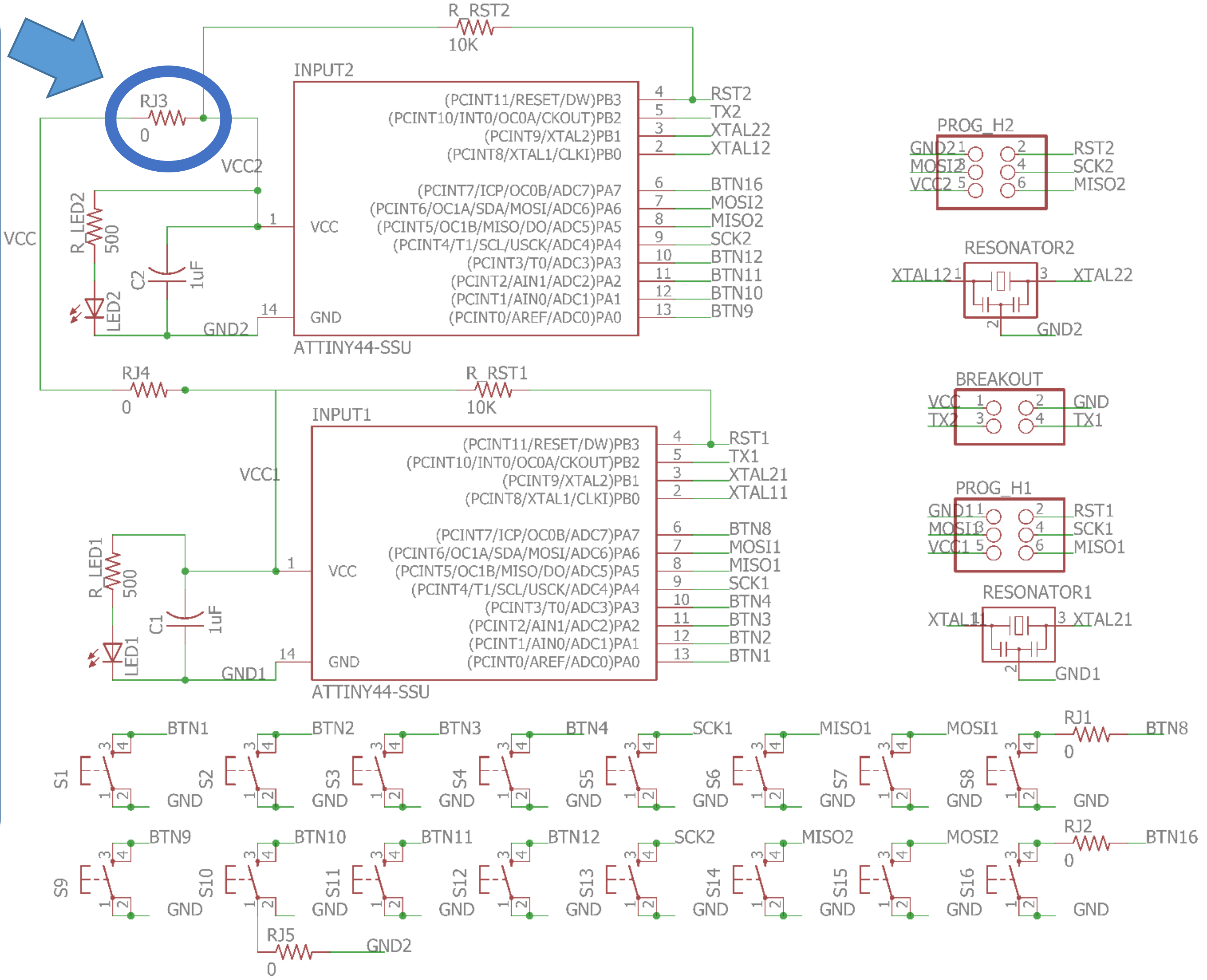

0
RJ4
500
R_LED1
1uF
LED1
C1
INPUT1
10K
R_RST1
ATTINY44-SSU
PROG_H1
RJ1
1

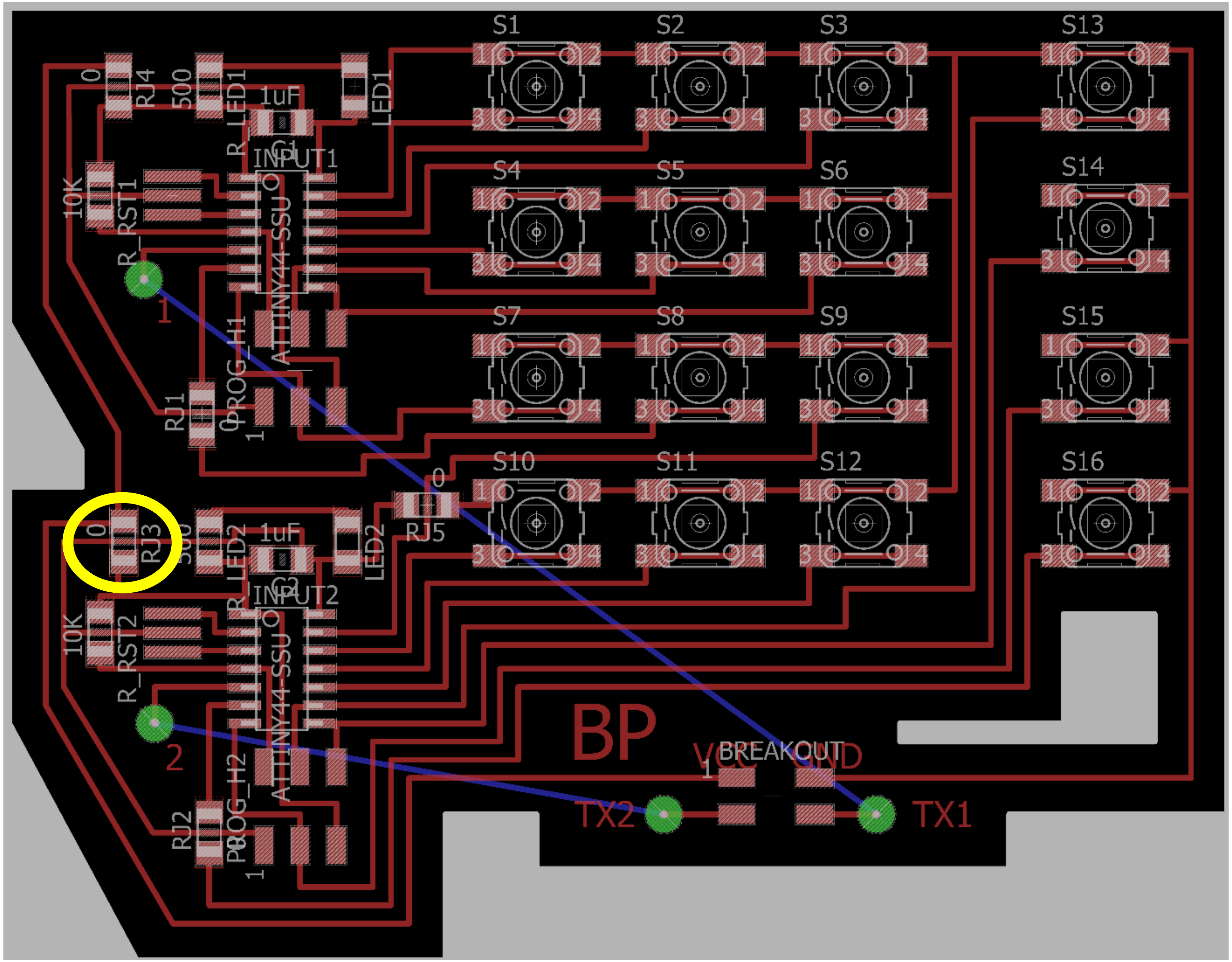

R1
10k
C1
1uF
G (blk)
XTAL1
20 MHz
VCC
PB0
PB1
PB3
PB2
PA7
PA6
GND
PA0
PA1
PA2
PA3
PA4
PA5
IC1
t44
CTS
VCC
J2 FTDI
Tx
Rx
RTS
RST
SCK
MISO
J1
ISP
GND
MOSI
V

Tips for board schematics and routing:

1. **Do the schematic first** (and finish it before moving on to routing) (Neil’s examples lack schematics)
2. **Use lots of names** to keep the schematic clean
3. **Triple check the schematic** before moving onto routing (and have someone else check it)
4. **Copy the routing patterns Neil or others use**
5. **Add 0 ohm resistors** if you get stuck routing

Here's a nice example of a 0 ohm resistor that was added later during routing





S1
S2
S3
S13
S4
S5
S6
S14
S7
S8
S9
S15
S10
S11
S12
S16
RJ4
R_LED1
LED1
1uF
C1
INPUT1
10K
R_RST1
ATTINY44-SSU
PROG_H1
RJ1
RJ5
RJ3
R_LED2
LED2
1uF
C2
INPUT2
10K
R_RST2
ATTINY44-SSU
PROG_H2
RJ2
BP
BREAKOUT
VCC
GND
TX1
TX2

Design Patterns in Practice

- Bypass Capacitors
- Current-Limiting Resistors
- Buttons, Pull-Up Resistors
- Voltage Regulators
- RC Filters
- Low-Side Switches

EDA Basics

- Adding / Finding Components
- Modifying "Net Lists"
- Moving, Routing, etc