# Lecture 04
# Prototyping & Digital Circuits

CE346 – Microcontroller System Design

Branden Ghena – Spring 2025

Some slides borrowed from:
Josiah Hester (Northwestern), Prabal Dutta (UC Berkeley)

# Administrivia

- Labs
  - See schedule of Lab hours available on Canvas for checkoffs
    - Due by end-of-day Thursday (but last office hours ends at 6pm)

- Quiz
  - Today at end of class! (tell your friends who aren't here)
  - Someone remind me at ~4:30 if I don't stop

# Project Proposals

- It is time to start forming teams and working on Proposals
  - Due next week Friday! (04/25)

  - Project and proposal details will be posted to Piazza later today
    - 1-2 pages, with some specific items you MUST include

- Project teams are 2-3 students (4 under rare occasions)
  - You may NOT work alone
  - There is a partnership survey if you want us to match you with someone
    - Due by end-of-day Sunday

# Today's Goals

- Explore another peripheral interaction pattern: DMA

- Understand the basics of digital circuitry
  - Enough to be able to interact with the Microbit

- Discuss prototyping methods and basic circuits components

# Outline

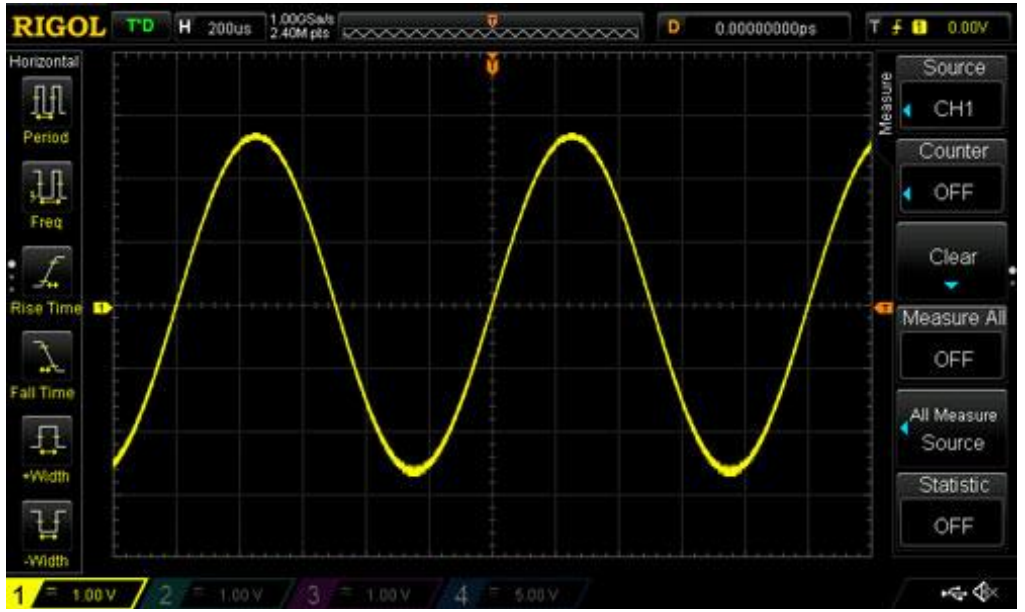
- **Digital Circuits**
- Prototyping
- Components

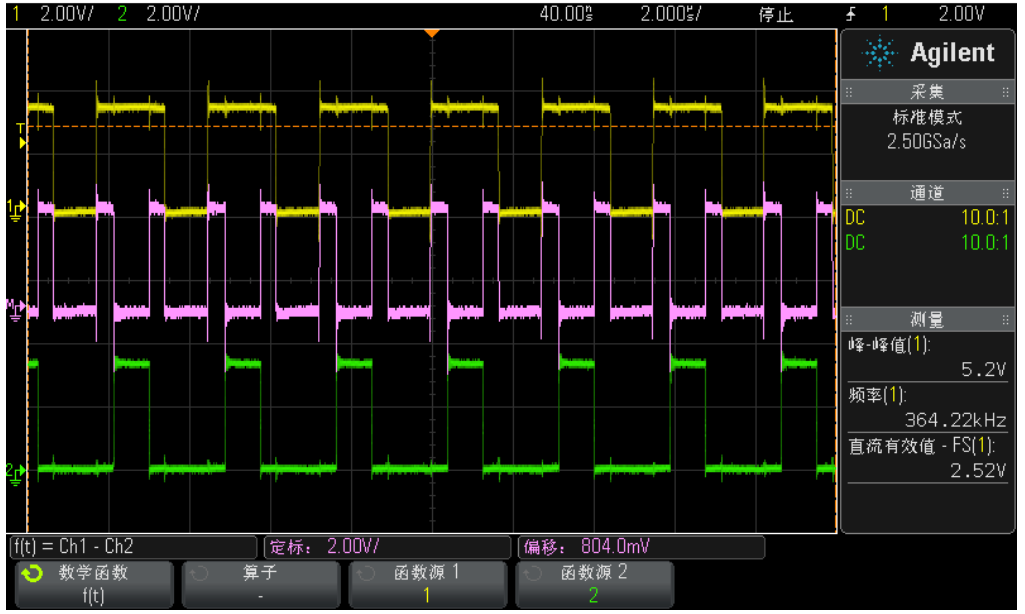
# Digital signals

- Exist in two states:
  - High (a.k.a. Set, a.k.a. 1)
  - Low (a.k.a. Clear, a.k.a. 0)

- Simpler to interact with
  - Constrained to two voltages
  - With quick transitions between the two

  - No math for voltage level
    - Either high or low



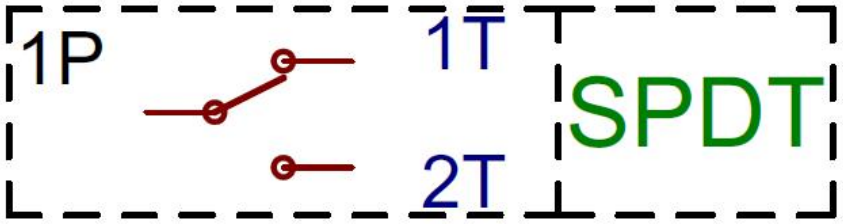



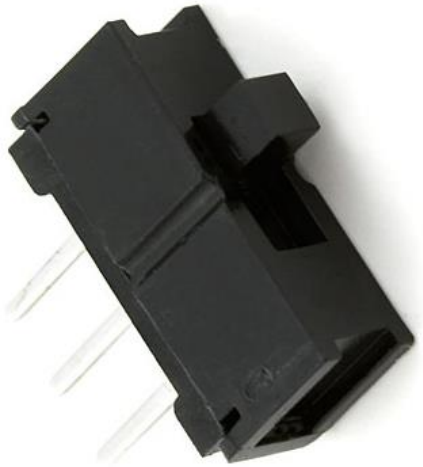
# Digital circuits

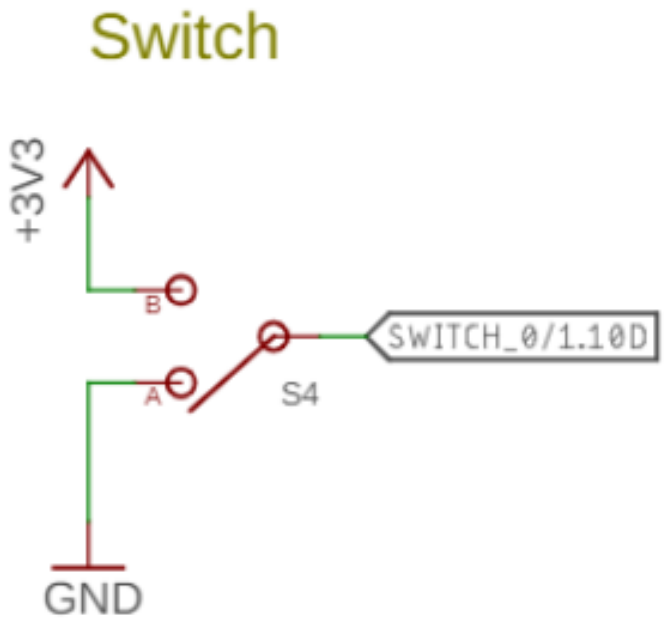
- Connecting components together with digital signals
  - Mostly ICs
  - Also buttons/switches and LEDs
- Way simpler than analog circuits
  - Mostly connecting boxes with wires
  - Plus a few resistors here and there
- An abstraction
  - Not sufficient for fully understanding electronics behavior, but close

# Switches

- Single Pole, Double Throw switch
  - Middle pin (Pole) connects to one of two outer pins (Throws)



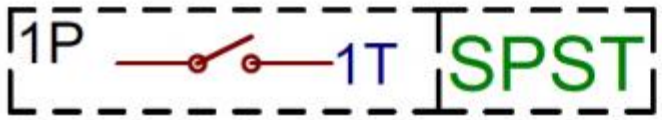



- For controlling microcontrollers
  - Often connect outer pins to VCC and Ground respectively
  - Input then goes High or Low depending on switch state

https://learn.sparkfun.com/tutorials/button-and-switch-basics/

# Buttons

- Single Pole, Single Throw switch
  - Pole pin either connects to Throw pin or is disconnected
  - Come in normally-closed (connected) and normally-open (disconnected)





# Disconnected circuits


- When button is pushed, input signal is low
- **What is the value of the input when the button is unpressed?**

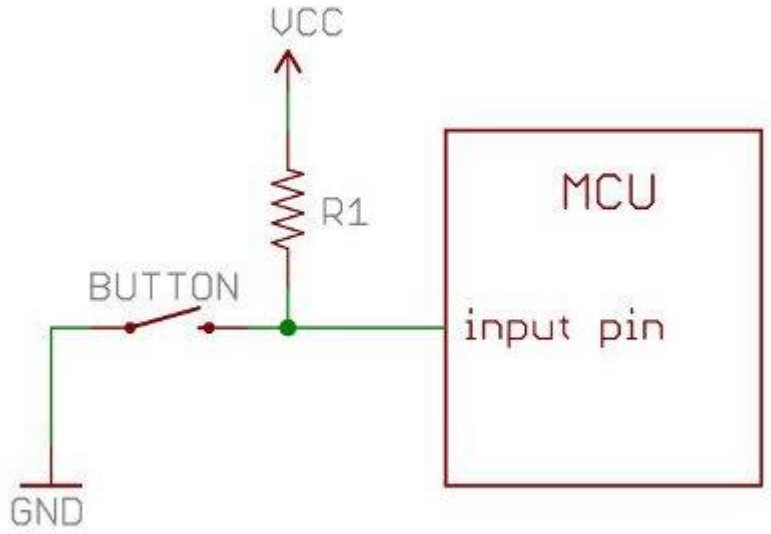
# Disconnected circuits


- When button is pushed, input signal is low
- **What is the value of the input when the button is unpressed?**
  - Floating! Could be any voltage
  - Solution: need to connect weakly to either high or low voltage

# Current flows through the "path of least resistance"

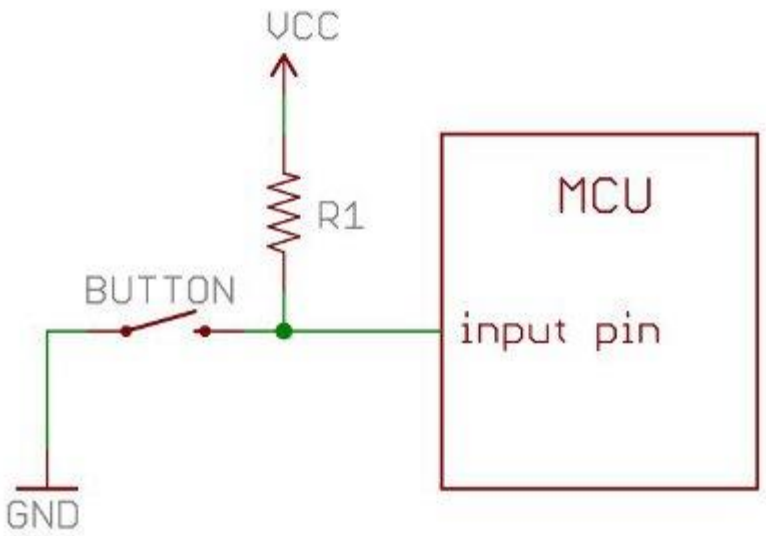
- Simplification
  - Works well for the types of circuits we use

- Pull-up resistor
  - When button is open (disconnected), the only path is through the resistor
  - When button is closed (connected) the least resistance path is through the button to Ground



# Pull-up resistors and pull-down resistors

- Resistor sets the "default" value of a wire
  - Pull-up connects to VCC
  - Pull-down connects to Ground
  - Usually 10-100 kΩ

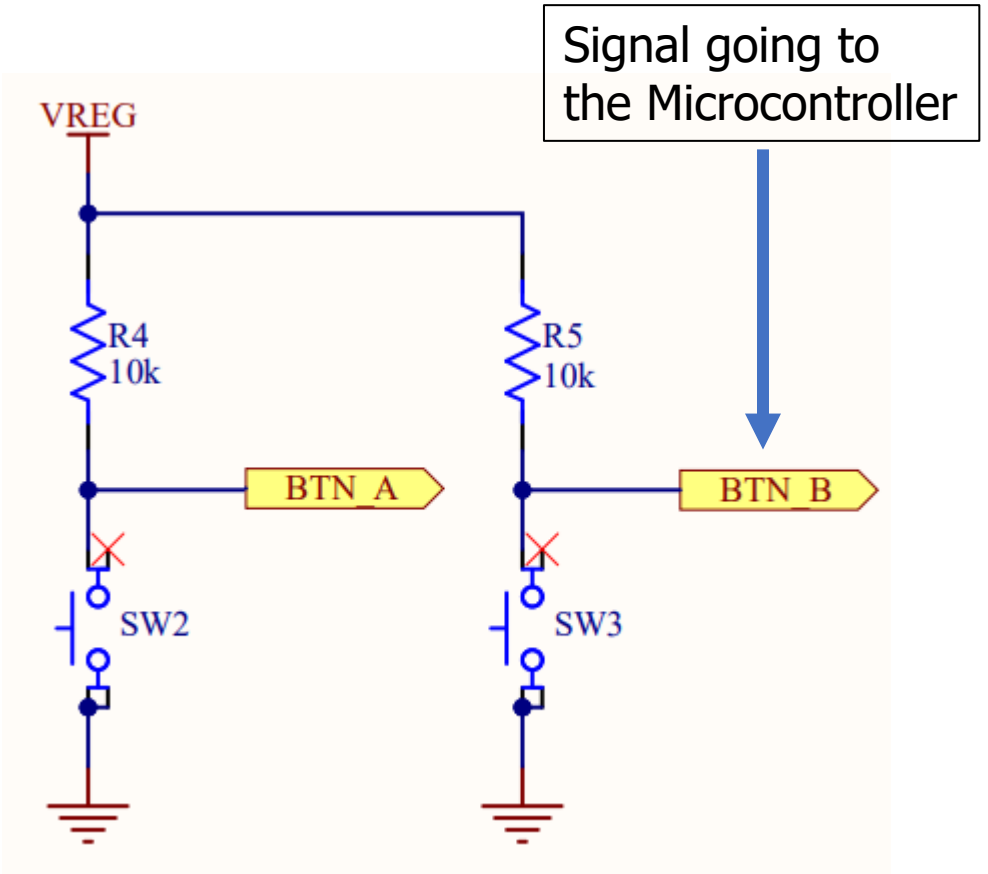



- When button is open (disconnected)
  - Connection through the resistor sets signal

- When button is closed (connected)
  - Signal is directly connected to a voltage source
  - Much lower resistance means that signal dominates

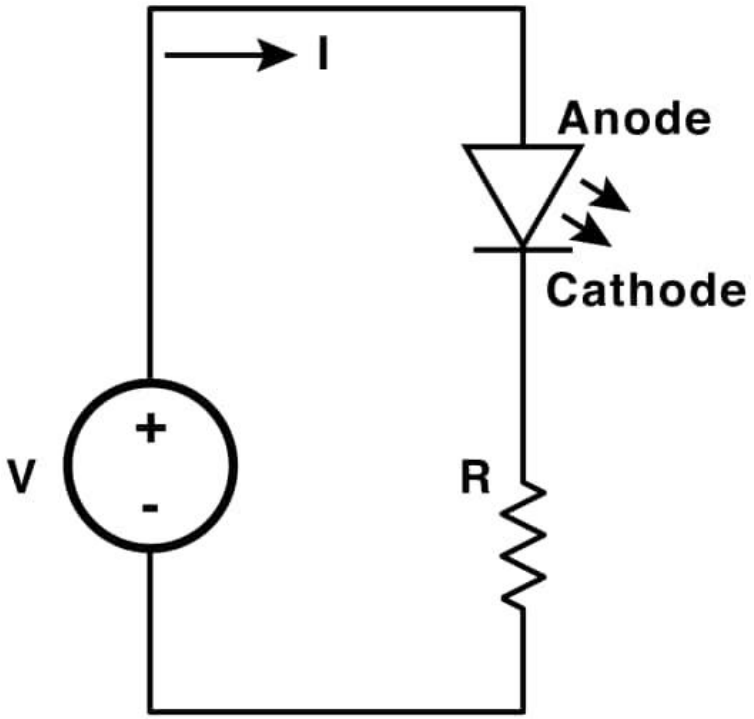
# Buttons on the Microbit

- Normally open buttons
  - Disconnected by default
- Active low signal
  - Activating (pushing) button creates a low signal
- Pull-up resistors
  - Set button signal high by default



# LEDs

- Light Emitting Diodes
  - Generate light as current passes through them
  - Various colors available
- Diodes
  - Only allow current to go through one way
  - Not particularly relevant for LEDs
    - Treat as a digital component

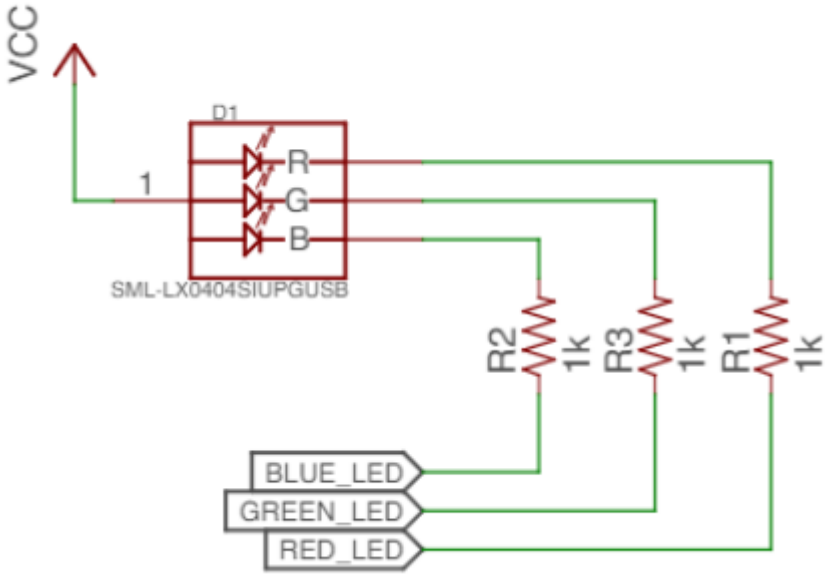


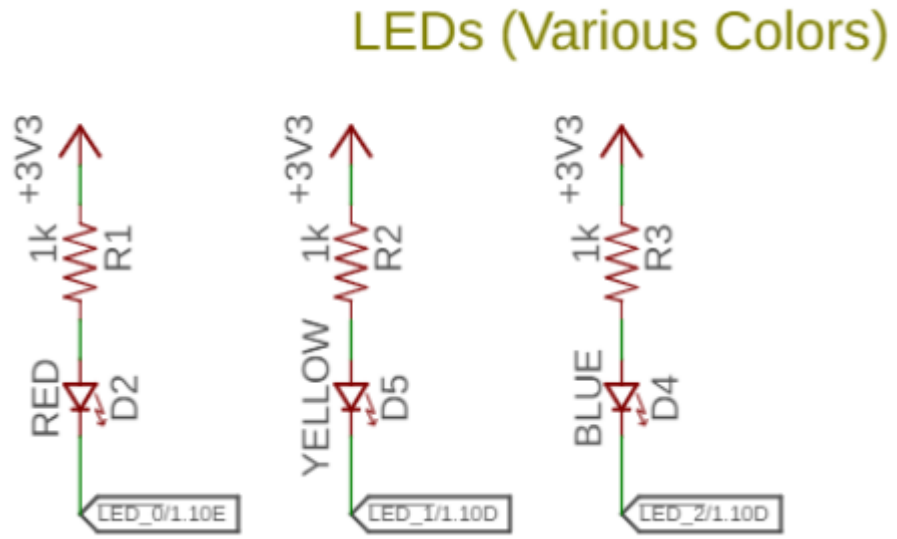

- Connect anode to high voltage and cathode to ground
  - Plus a resistor to limit the total amount of current

https://learn.sparkfun.com/tutorials/light-emitting-diodes-leds

# Active state for LEDs

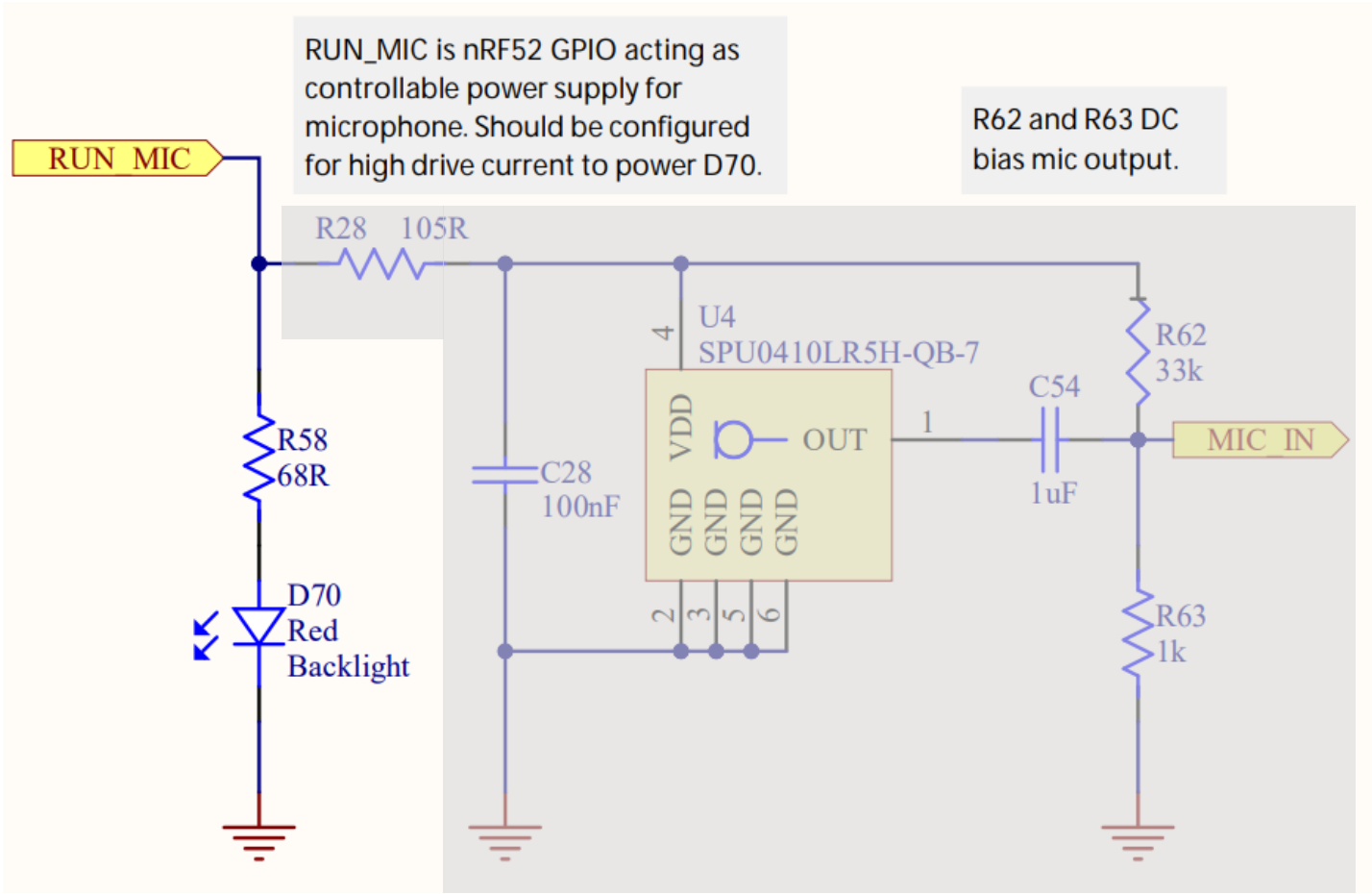
- LEDs can be active high or active low depending on configuration
  - Active high is how people assume they work
  - Active low is often used instead
    - GPIO pins can usually sink more current than they can source



# LEDs on the Microbit

- Microphone LED
  - Active high
- Simple to use, just set the GPIO high to enable it

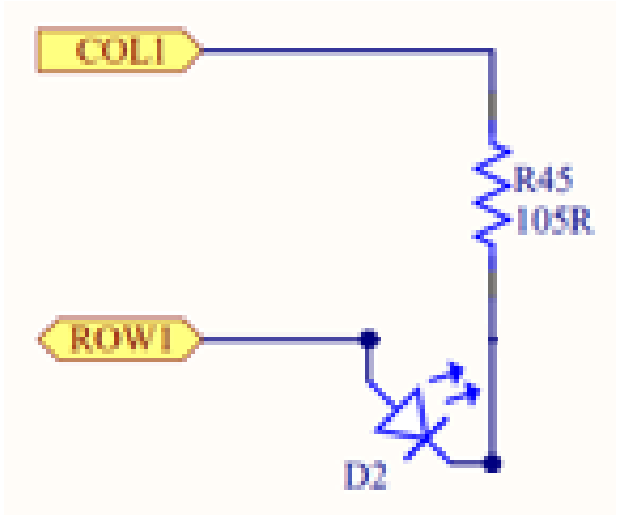


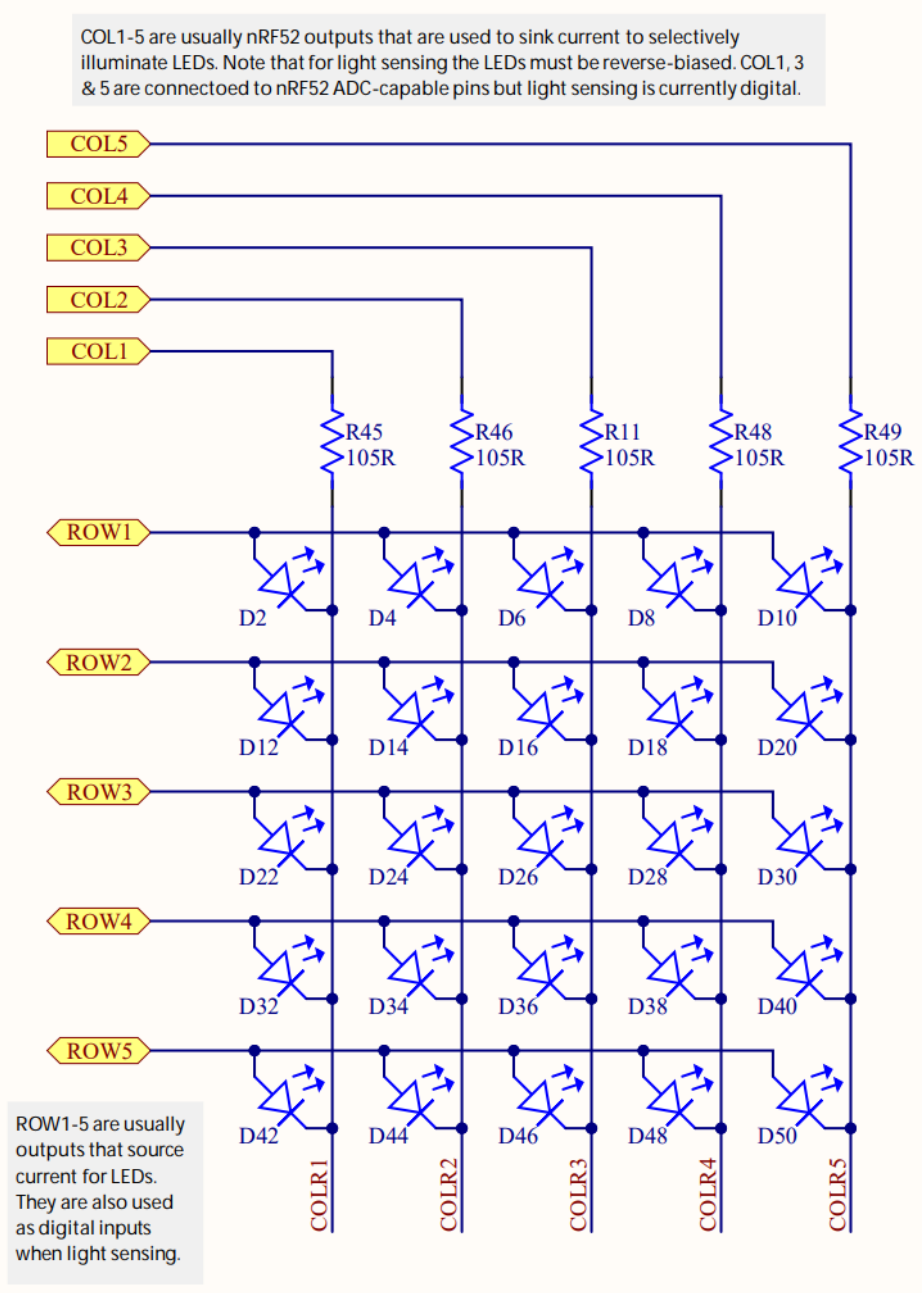

Ignore this other part for now

# LEDs on the Microbit

- Use two GPIO pins to control each LED
  - Row high as VDD
  - Column low as Ground

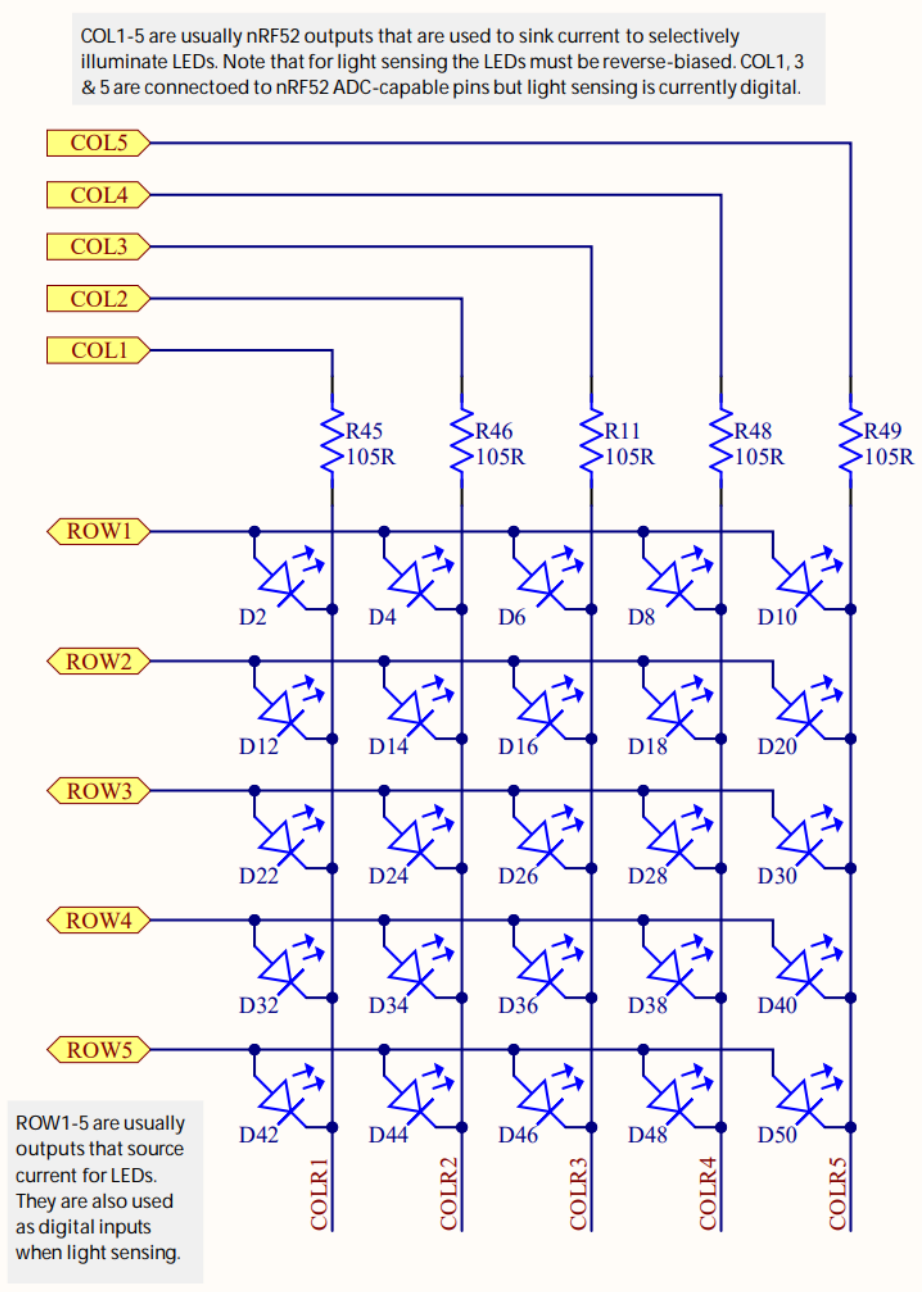
- Connections on circuit schematics only exist where there are dots



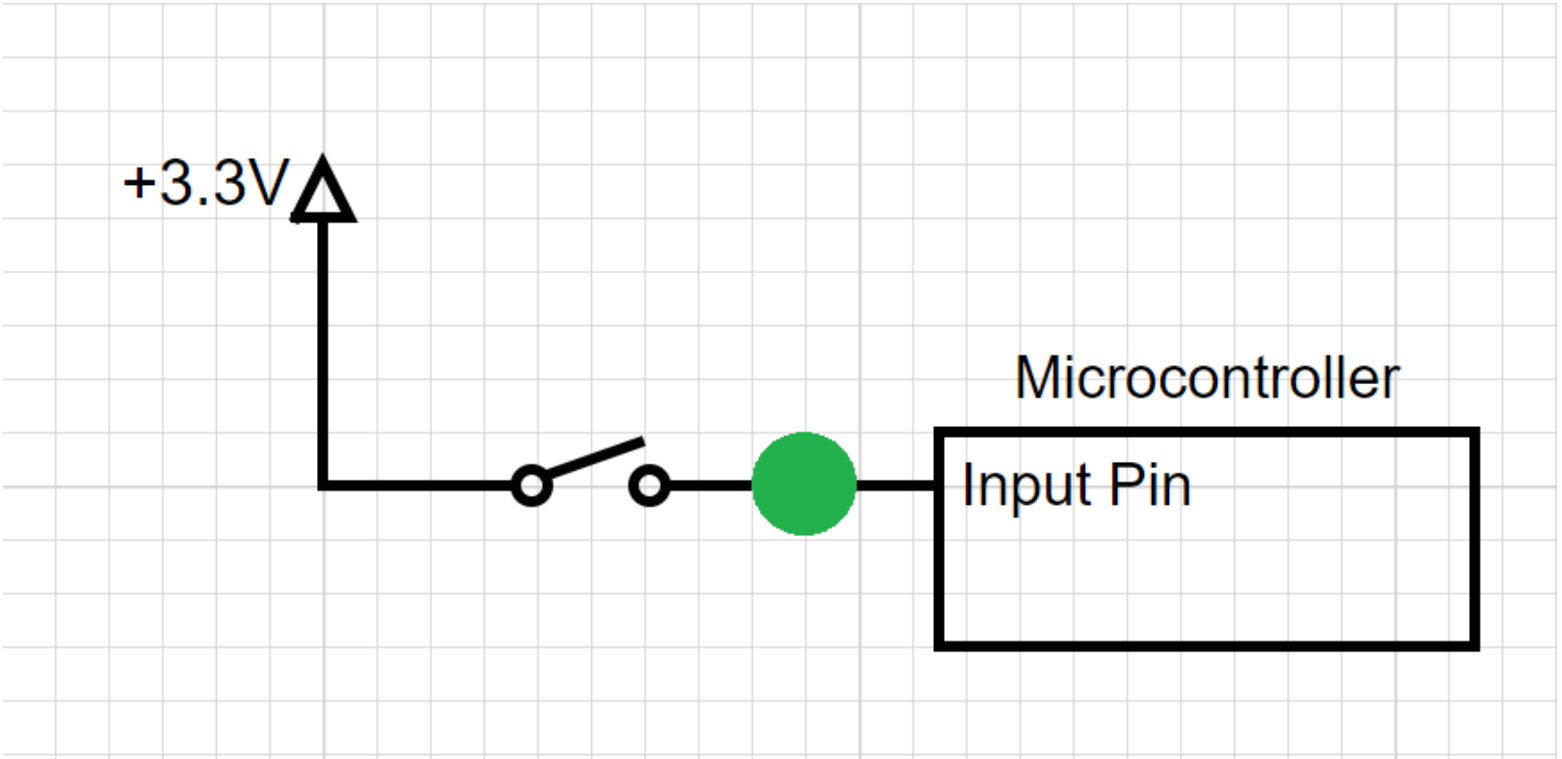
# Controlling the LED matrix

- Cannot individually control all LEDs simultaneously
  - Need to light one row at a time
  - Iterate rows quickly to make them appear on all the time
- We'll have a lab on these later
  - Combines GPIO and timers



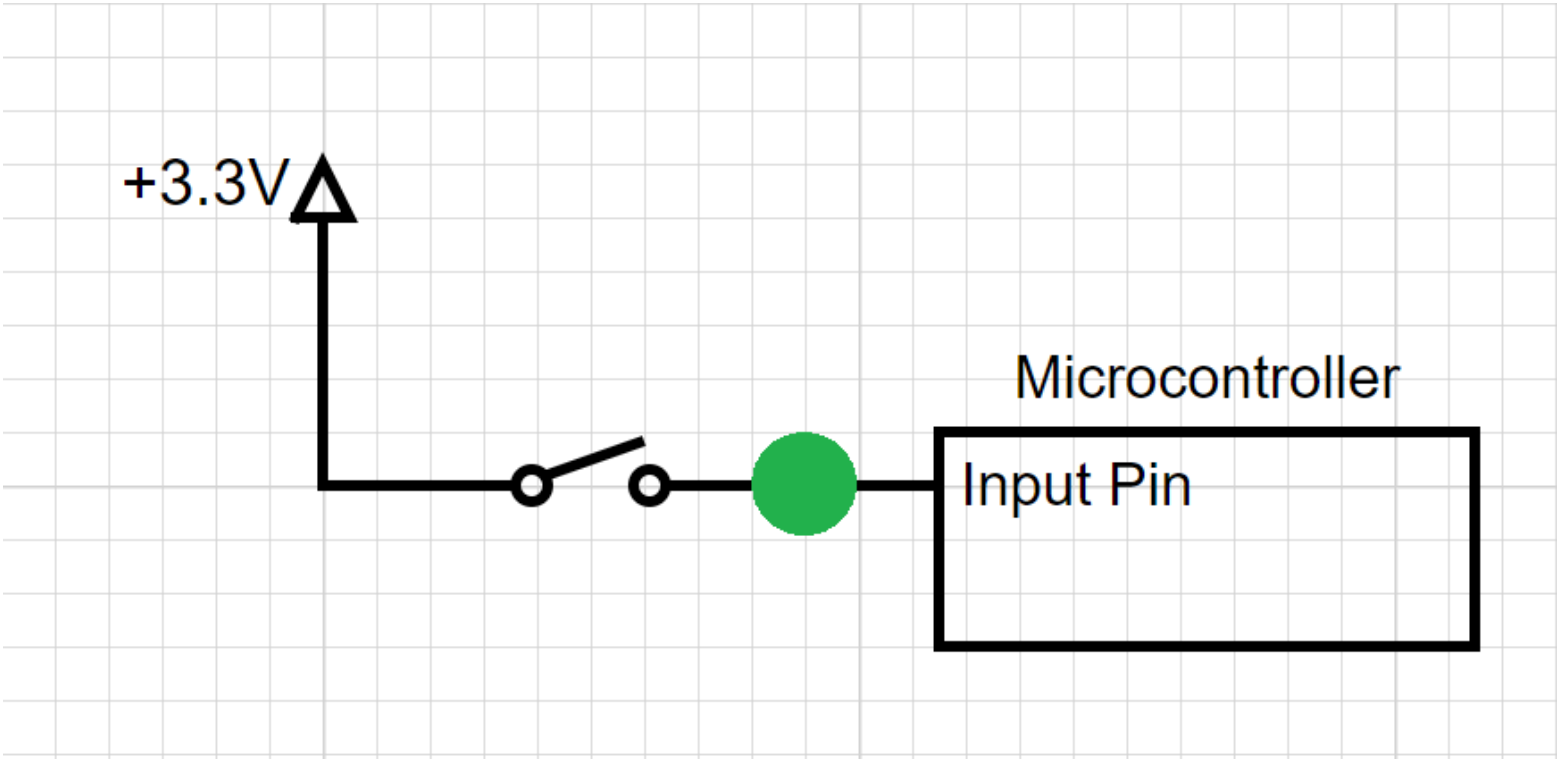
# Break + Question

- Should the spot in green have?
  A. Pull-up Resistor
  B. Pull-down Resistor
  C. Either
  D. Neither



# Break + Question

- Should the spot in green have?
  A. Pull-up Resistor
  **B. Pull-down Resistor** (needs to pull input low by default)
  C. Either
  D. Neither



# Outline

- Digital Circuits
- **Prototyping**
- Components

# Prototyping goals

- Does this thing work at all?
  - Particular IC
  - Circuit layout
  - Software design
  - etc.

- Sometimes before doing something more serious with it
  - Design a PCB, Make a product, etc.

  - Not uncommon that the prototype is as far as you'll get

# Isolating tests

- The goal when prototyping is to isolate the question at hand

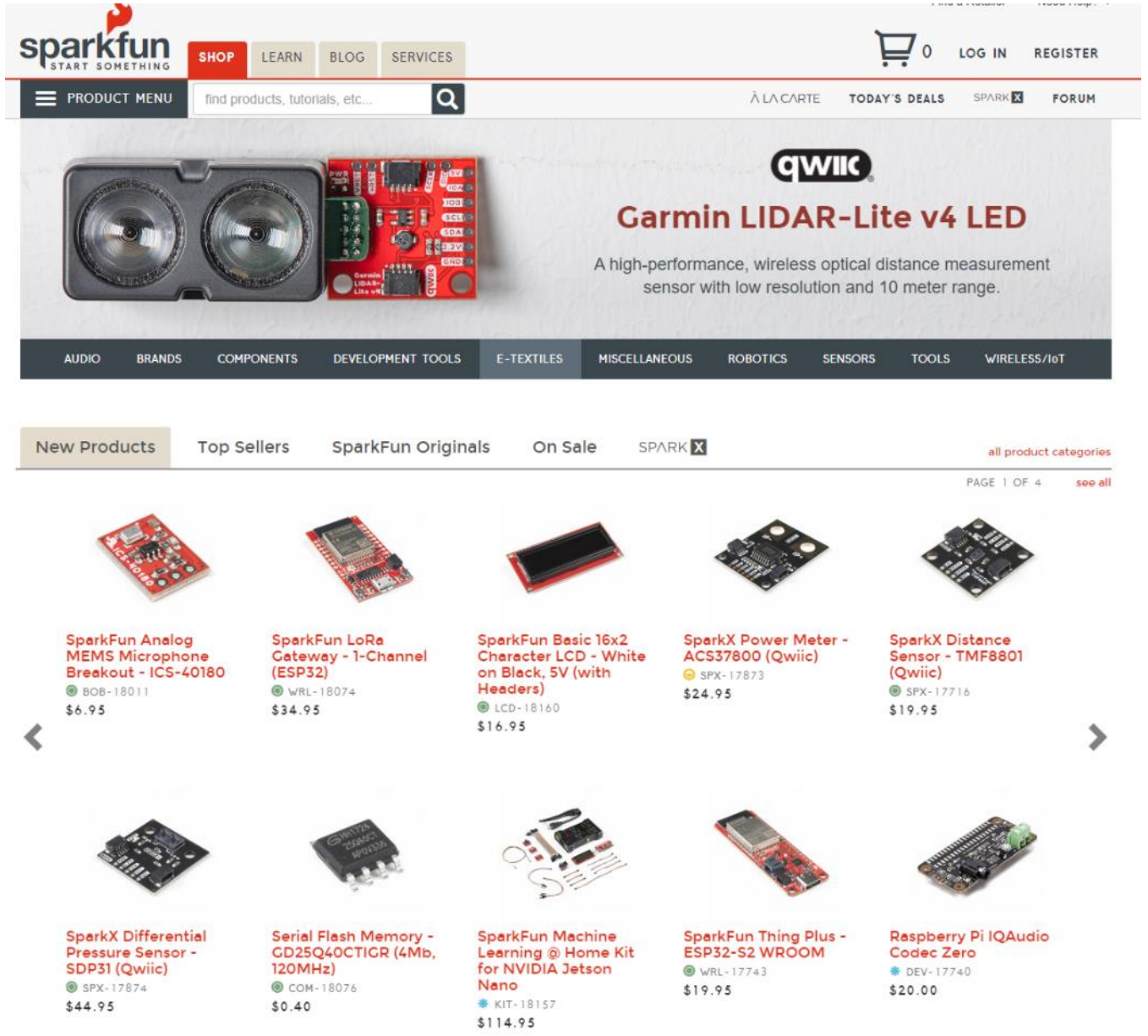
- Do consider
  - New sensor/IC/component/whatever

- Do not consider
  - Power
  - Interference
  - Enclosure
  - Stable microcontroller
  - Soldering skills

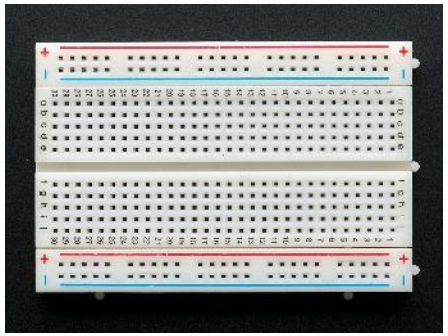
# Buying Parts

- Prototyping vendors
  - Where you look for cool stuff to buy
  - Sparkfun
  - Adafruit
  - NOT Amazon for prototyping parts

- Electronics vendors
  - Where you buy parts when you know what you need
  - Digikey
  - Mouser



# Prototyping methods

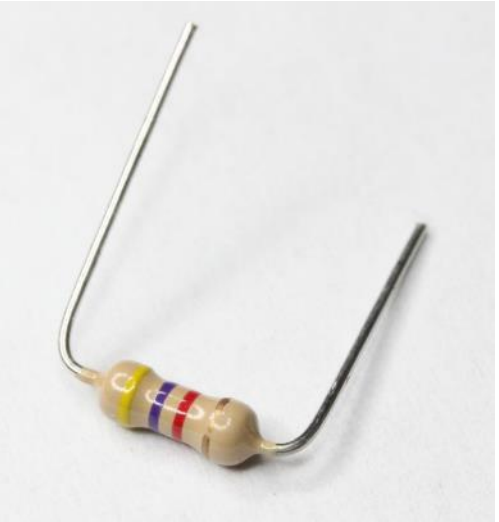


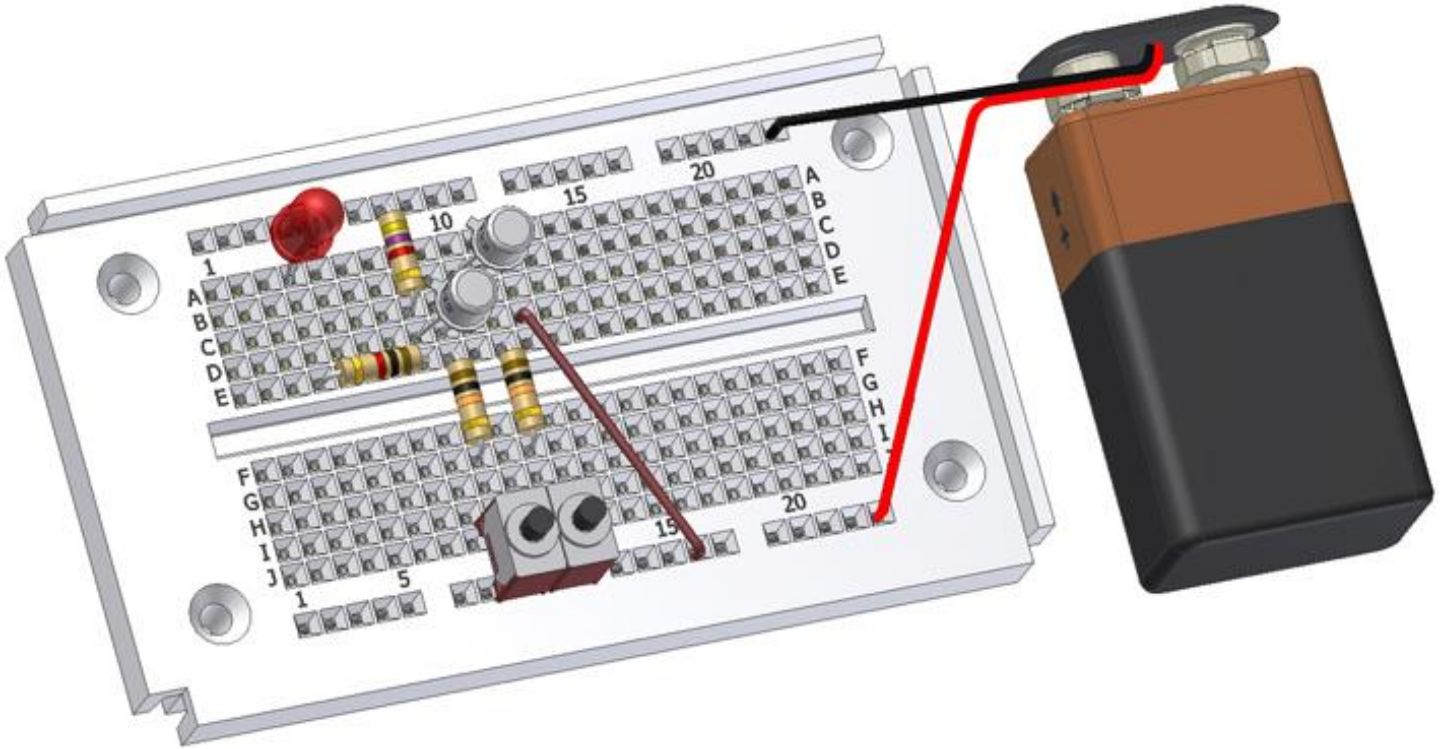

- Breadboarding
  - Plug and connect components as needed
  - Build up arbitrarily complex designs from nothing
- Development kits
  - Pre-fabricated systems design for testing components
- Small-scale test PCBs
  - Design a PCB that demonstrates the thing you're interested in
    - Making a PCB is less hard than some might think (Eagle, Fritzing, etc.)
    - $20-30 for small, low-speed PCBs from batch services like OSHPark

# Breadboards for prototyping

- Reusable platform for temporary circuits

- Plug in jumper wires and through-hold components

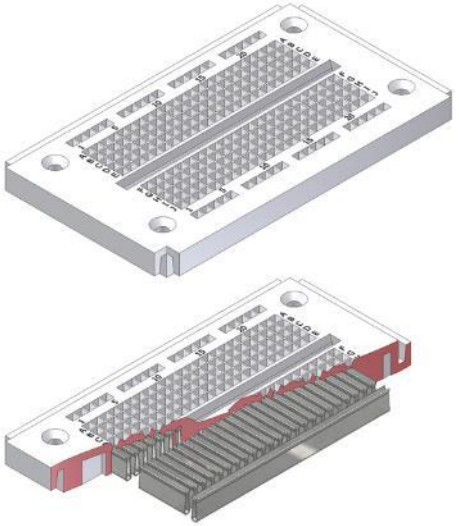


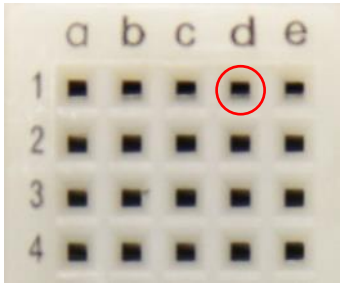


# How a breadboard works

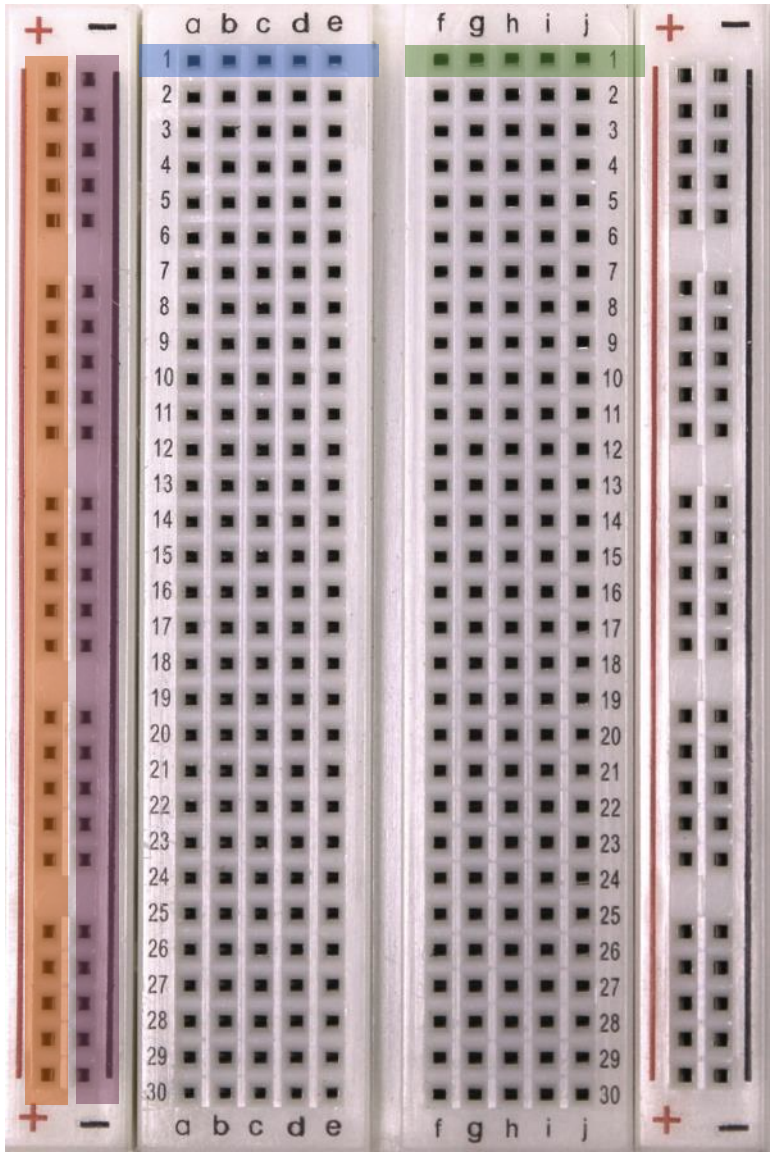
- Component leads and wires are inserted into holes in the breadboard

- Half-rows of five holes are connected
- Vertical columns are connected for power/ground



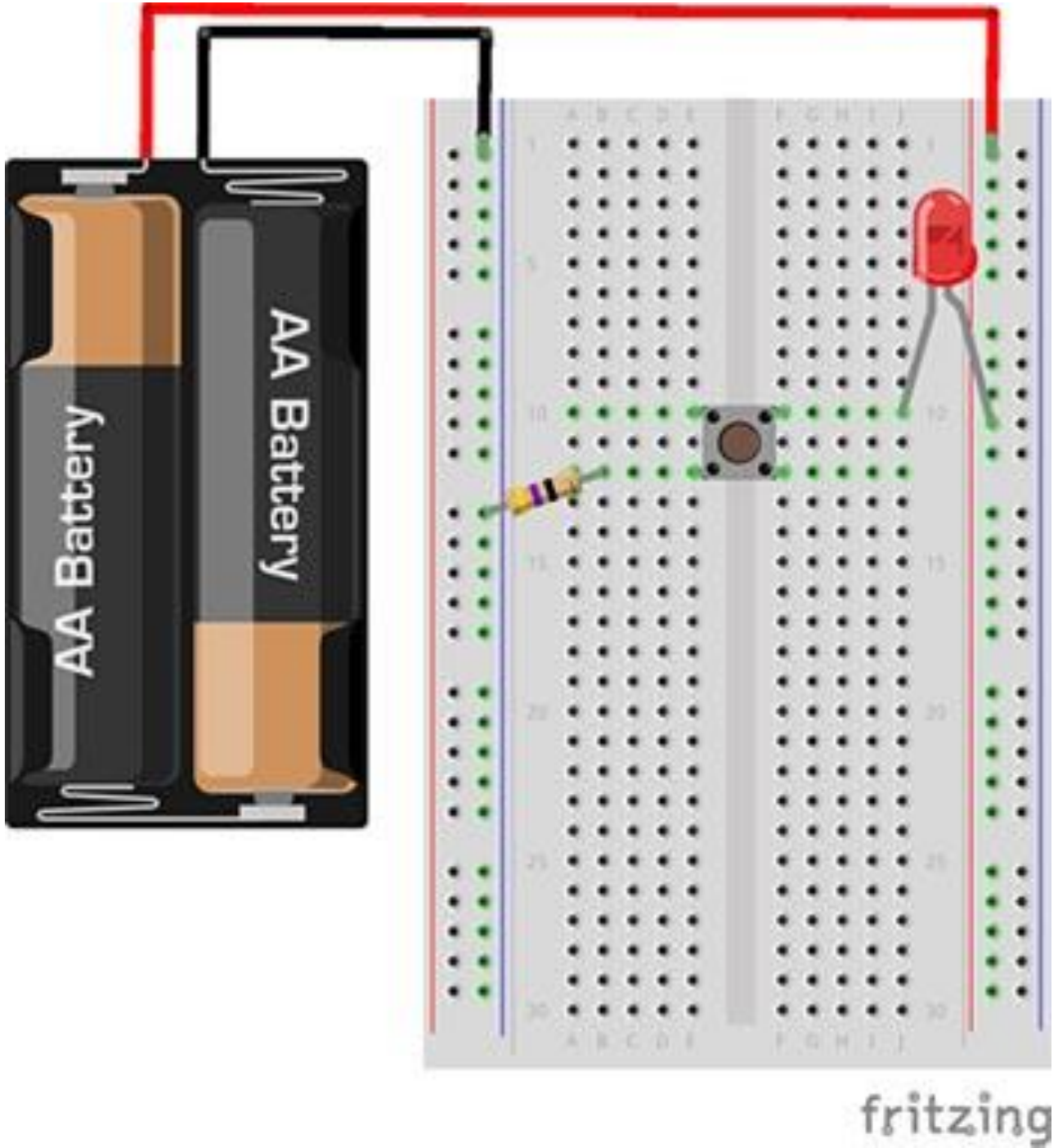



Holes to insert wires



# Breadboard LED example

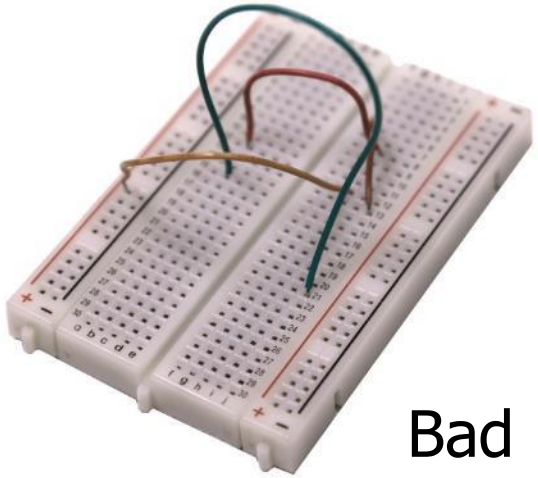
- Uses button to control LED



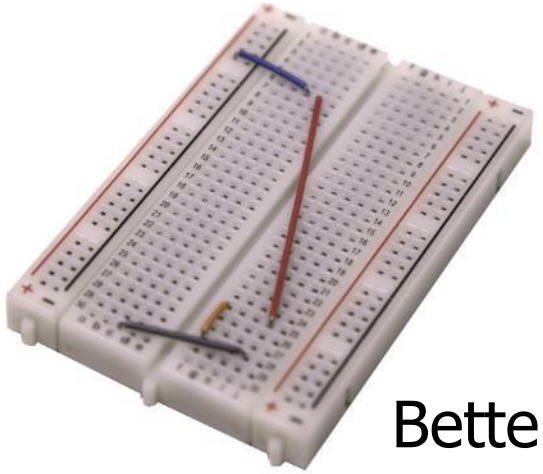
# Breadboard guidelines

- Long wires in large bird nests makes debugging very difficult
  - Shorter, constrained wires are easier to understand
  - In this class, we'll only have large jumper wires though…

- Use the minimum jumpers necessary, mostly use breadboard for connections



Bad

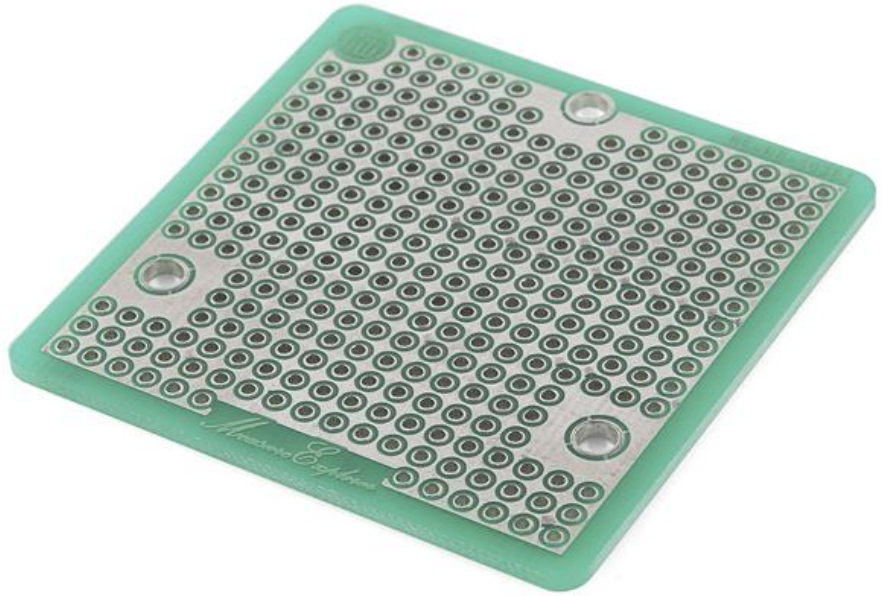


Better

# More permanent breadboards

- Breadboards are also known as “Solderless Breadboards”

- Protoboard allows configurable circuits
  - Solder jumper wires between locations
  - Solder adjacent pads to form connection



- Usually not worth it (just make a PCB)
  - Does solve core problem of breadboards: things getting unintentionally unplugged
  - Might be useful for some projects!

# When to not use breadboards

- Breadboards work great for digital circuits and simple analog!

- High voltage/current are bad for breadboards
  - Honestly, anything above 12 volts DC shouldn’t be in a breadboard
  - Also avoid high-power applications above a few Watts
  - Never put AC in a breadboard!

- Sensitive analog circuits
  - Particularly anything sensitive to capacitance may not work right
  - Sets of metal holes with strips connecting them function as capacitors

- Anything in long term use

# Outline

- Digital Circuits
- Prototyping
- **Components**

# Prototyping components

- We've talked through the theoretical notions of many parts
  - Buttons, Switches, Resistors, LEDs

- Now let's look at the real-world practicalities of working with them
  - Again, some of you will have already learned this
  - But many of you might not have used these things before

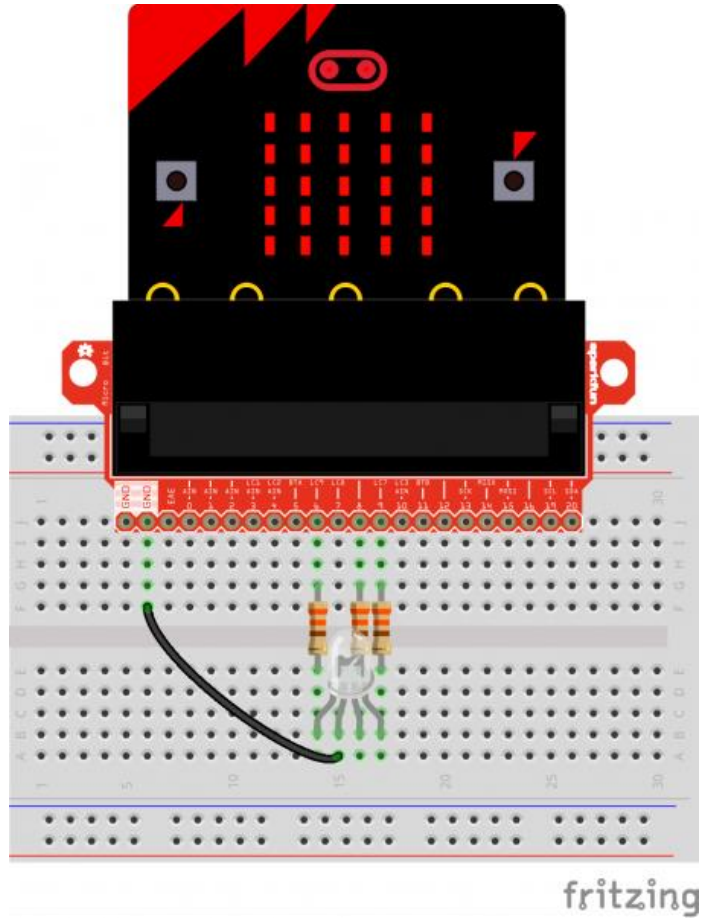
# Microbit breakout

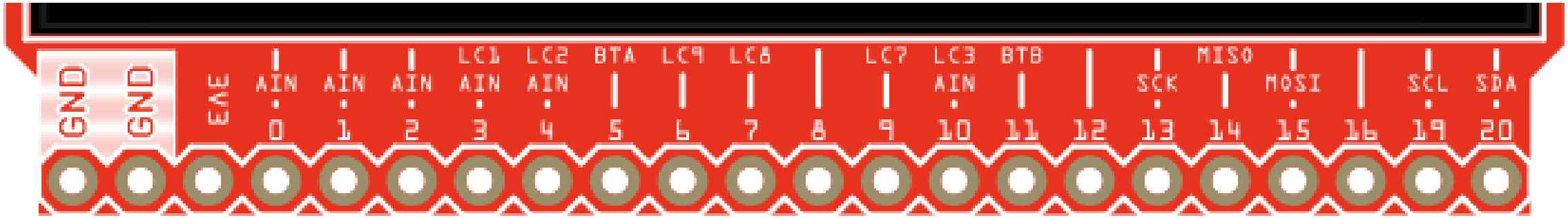
- **Always connect LED matrix side up**

- Breaks out various pins from board
  - Need to consult table to know which pins
  - https://tech.microbit.org/hardware/schematic/

https://www.sparkfun.com/products/13989

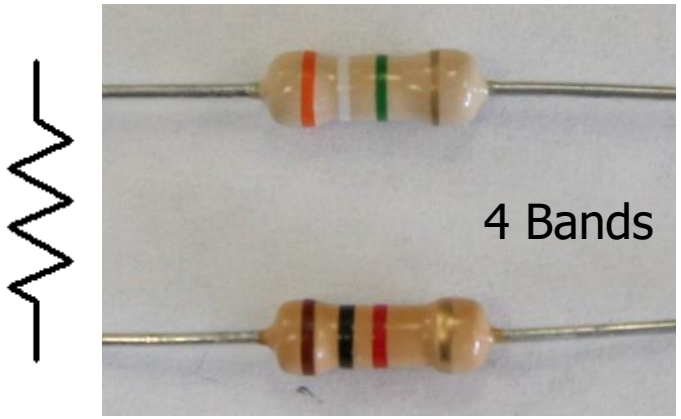
https://learn.sparkfun.com/tutorials/microbit-breakout-board-hookup-guide



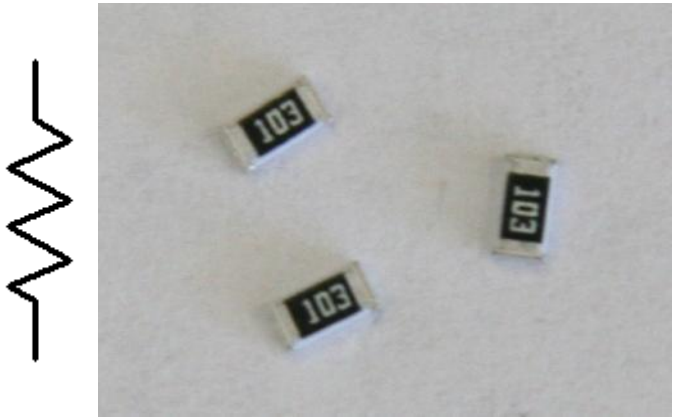



# Resistors

Carbon Film Resistors

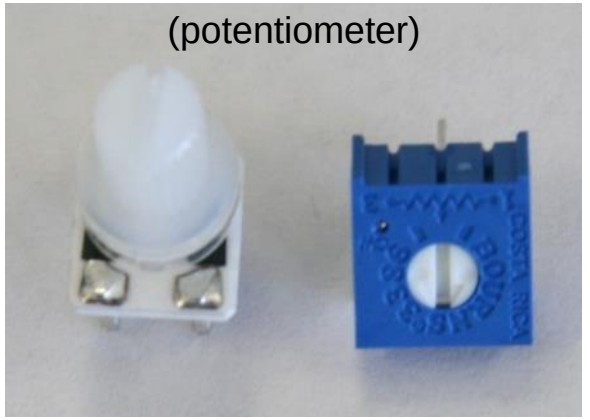



Surface Mount Resistors




Variable Resistors

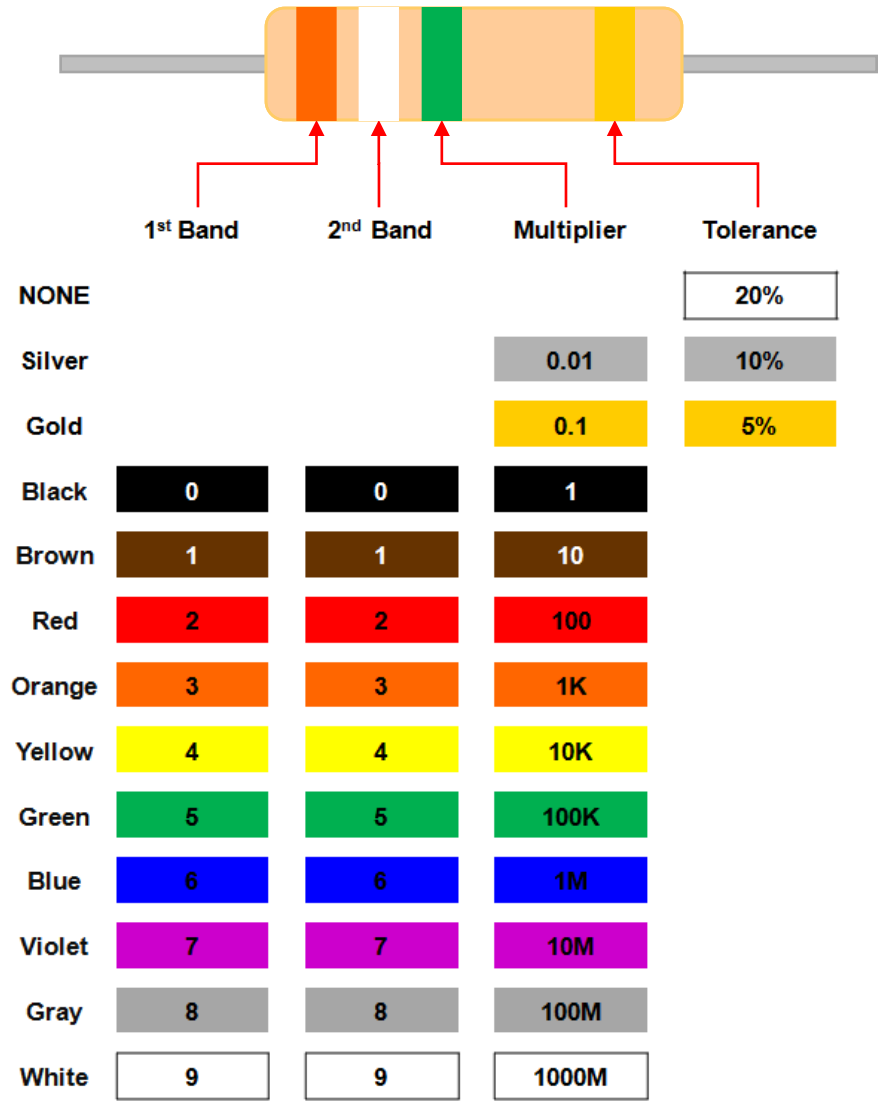
(potentiometer)



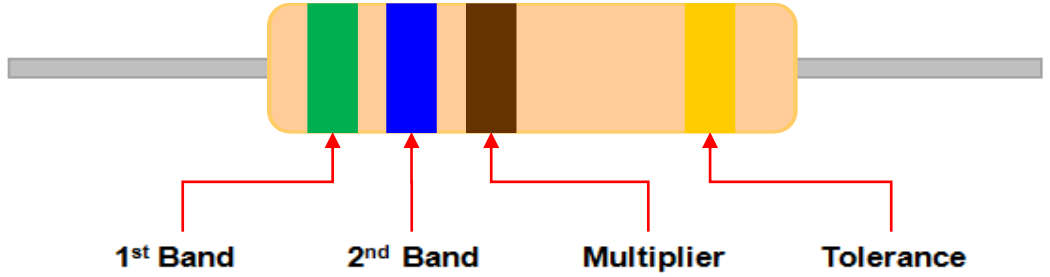
- Resistors are not directional
  - Either orientation is fine and works identically

# Resistor color codes

- Colored bands on resistors label the resistance value of the part
- First and second bands are the digits
- Third band is multiplier
- Fourth band is tolerance
  - Usually gold: +/- 5%



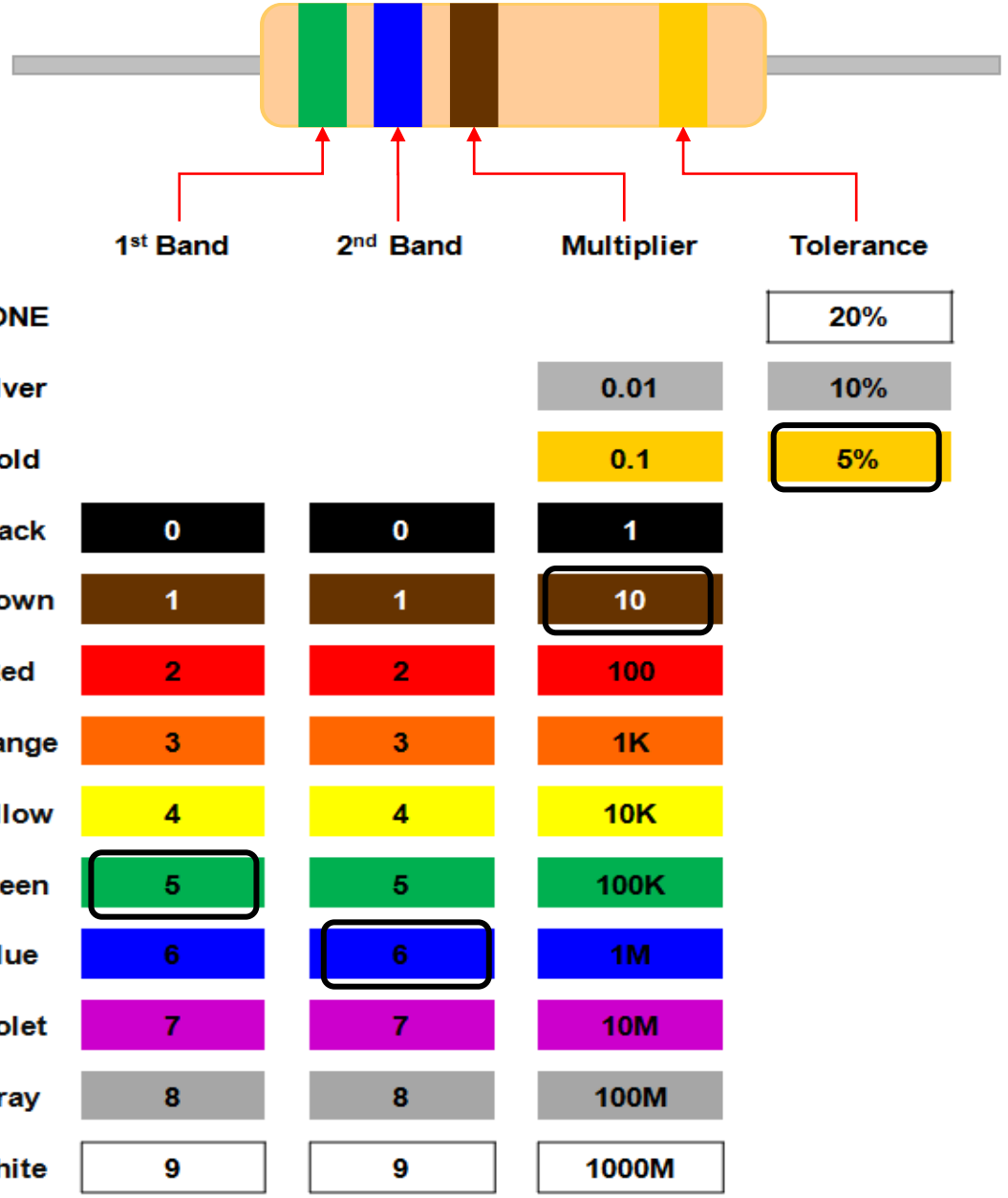
# Example: determine the resistor



| | 1st Band | 2nd Band | Multiplier | Tolerance |
|---|---|---|---|---|
| NONE | | | | 20% |
| Silver | | | 0.01 | 10% |
| Gold | | | 0.1 | 5% |
| Black | 0 | 0 | 1 | |
| Brown | 1 | 1 | 10 | |
| Red | 2 | 2 | 100 | |
| Orange | 3 | 3 | 1K | |
| Yellow | 4 | 4 | 10K | |
| Green | 5 | 5 | 100K | |
| Blue | 6 | 6 | 1M | |
| Violet | 7 | 7 | 10M | |
| Gray | 8 | 8 | 100M | |
| White | 9 | 9 | 1000M | |

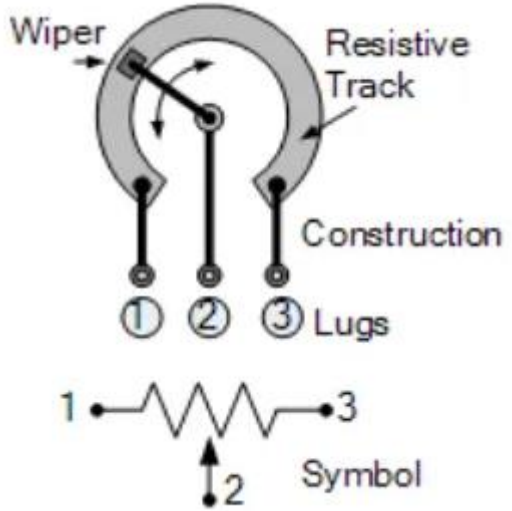
# Example: determine the resistor

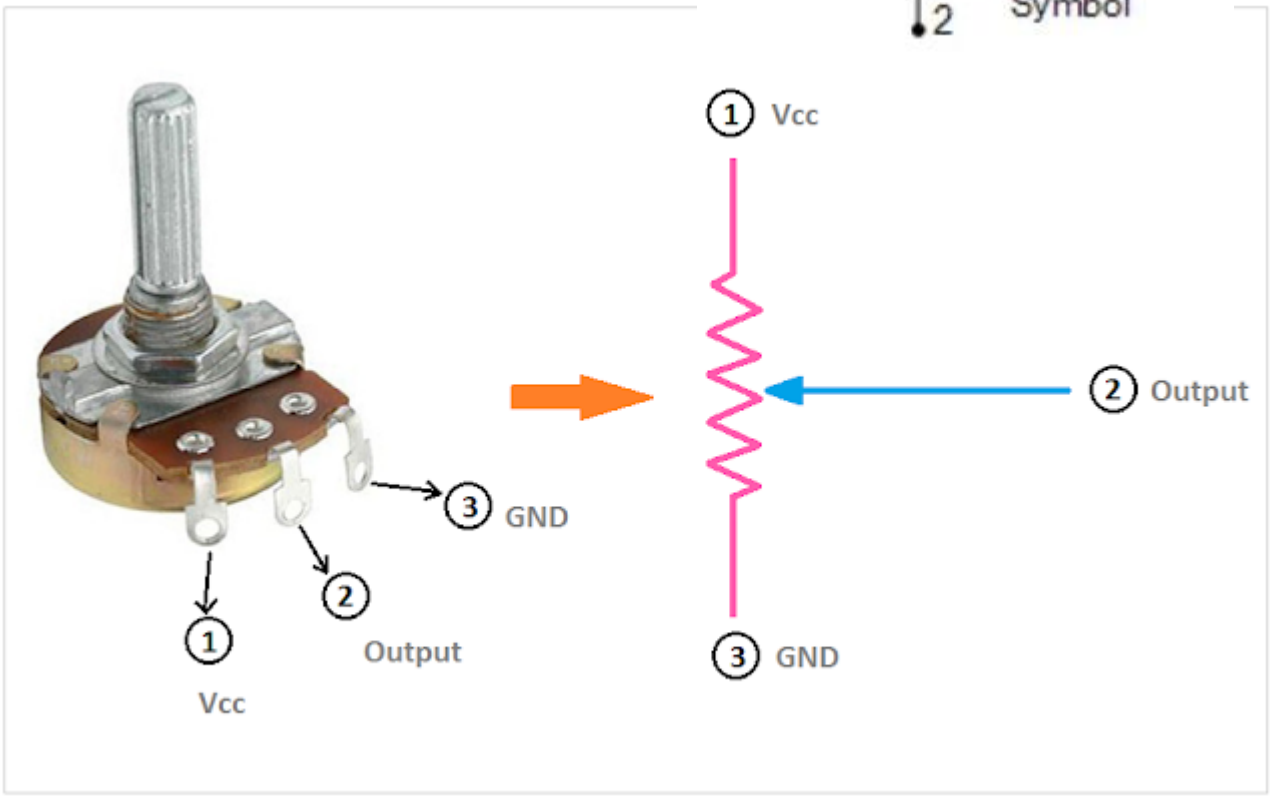
- 56 x 10 Ω = 560 Ω (±5%)



# Potentiometers

- Vary resistance between zero and some maximum
  - 1 kΩ, 10 kΩ, 100 kΩ common
- Connect middle and an edge for just a changeable resistor
- Middle terminal is a movable resistor divider
  - Knob changes middle output if outer pins are VCC and Ground

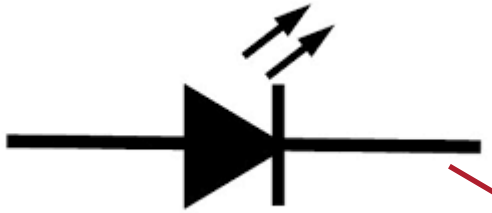


# LEDs

- Directional component: only allows current to flow one way

- Shorter side is the negative one
  - i.e. where current flows to



Schematic Symbol

Negative ( - ) lead

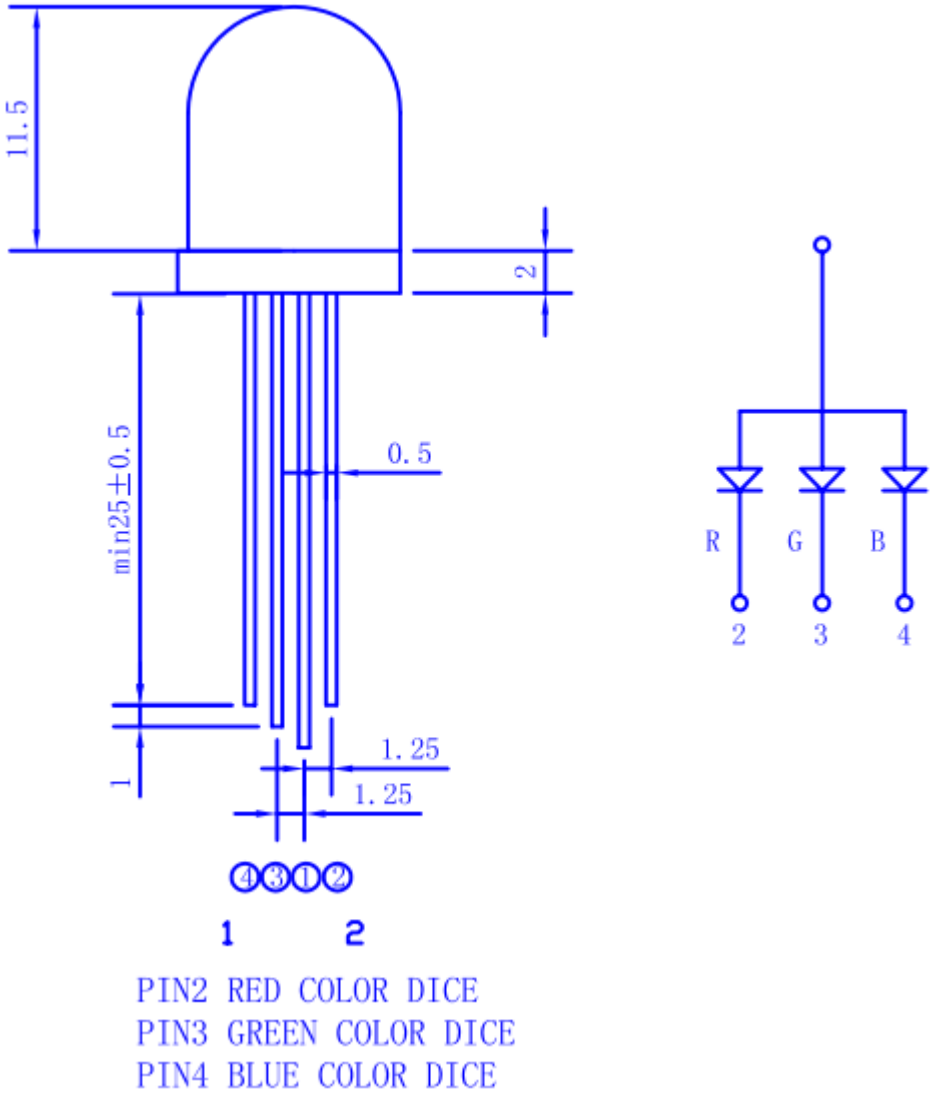
Surface-mount LED

Larger metal component inside of case or case flat spot is cathode or negative (-) lead

Shorter wire is cathode or negative (-) lead

# RGB LED

- Three different colors of LED in a single large diffuser
- Short leads are negative ends
  - One for each color
- Long lead is common power
  - Common anode
- Combinations of LEDs give other colors
  - Cyan, Yellow, Violet, White




https://cdn-shop.adafruit.com/datasheets/FLR-100WAS-RGB.pdf

# Sensors

- Thermistor

- Photoresistor

We'll come back to these in a future lecture

# Outline

- Digital Circuits
- Prototyping
- Components