**ECE 4160/5160**
**MAE 4910/5910**

Prof. Kirstin Hagelskjær Petersen
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# Fast Robots
# EMI and routing

Suggested seating…

| Tuesday lab (seats 1-4) | Wednesday lab (seats 5-8) | Thursday lab (seats 9-12) |
|---|---|---|

# Logistics – Bluetooth!

- Please fill out the survey for “Bluetooth Connection issues”
  - *Whether or not you have issues*
  - https://docs.google.com/forms/d/e/1FAIpQLSe1sHQBRMJE_zK7o9oRLefktpf3c5SqVNkMKxHo2lAeumfOAw/viewform?usp=sf_link

- Potential Bluetooth Solution (least complex -> most complex)
  - Verify matching MAC addresses and UUIDs.
  - Verify MAC addresses are left padded. Eg:
    - c0:7:94:96:ab:44 -> Invalid MAC address
    - c0:07:94:96:ab:44 -> Valid MAC address
    - (words need leading zero if they are only one digit)

# Logistics – Bluetooth!

- Please fill out the survey for “Bluetooth Connection issues”
  - *Whether or not you have issues*
  - https://docs.google.com/forms/d/e/1FAIpQLSe1sHQBRMJE_zK7o9oRLefktpf3c5SqVNkMKxHo2lAeumfOAw/viewform?usp=sf_link

- Potential Bluetooth Solution (least complex -> most complex)
  - Verify matching MAC addresses and UUIDs.
  - Verify MAC addresses are left padded.
  - Enable/Disable use of UUID
    - Use of UUID helps deconflict cases on multiple boards with the same MAC address
    - Does not work for all operating systems
    - Defined in line 13 & 16 of base_ble.py
    - Use in line 53 of base_ble.py

# Logistics – Bluetooth!

- Please fill out the survey for “Bluetooth Connection issues”
  - *Whether or not you have issues*
  - https://docs.google.com/forms/d/e/1FAIpQLSe1sHQBRMJE_zK7o9oRLefktpf3c5SqVNkMKxHo2lAeumfOAw/viewform?usp=sf_link

- Potential Bluetooth Solution (least complex -> most complex)
  - Verify matching MAC addresses and UUIDs.
  - Verify MAC addresses are left padded.
  - Enable/Disable use of UUID
  - Windows Subsystem for Linux (Ed post #39, Olive Faber)
    - Requires recompiling the WSL kernel for Bluetooth support
  - Running from within VS Code (Ed post #43, Rafael Fortuna)
- We are still working on a more reliable solution on the lab computers…

# Logistics – Teams!

- Form Teams!
  - How to use your teammate(s)
    - Work/strategize together
    - Do the pre-lab together
    - Do electronics/mechanics/software *on your own*!
    - Debug jointly if things don't work
    - Compare results, but *write your own report*
    - If your system fails, borrow your teammate's
    - *Always* credit collaborators and references

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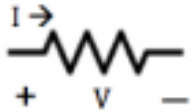
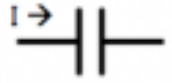
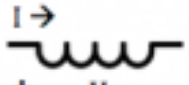
# Fast Robots
# EMI and routing

# Topics this week…

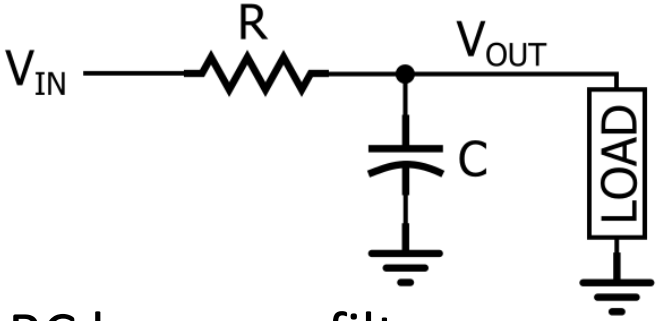
- Tuesday
  - RCL recap
  - Electro Magnetic Interference
  - Electrostatic Discharge
  - Wiring and Routing
  - Lab 3 pre-lab discussion
- Thursday
  - Batteries
  - Actuators
  - Motor drivers
  - Oscilloscope

# Basics

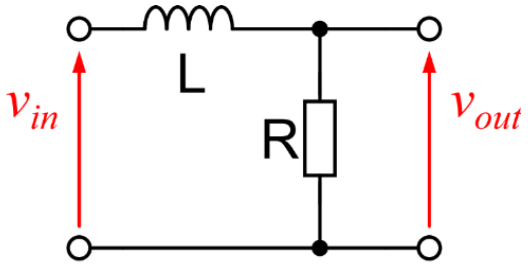
*Hyperphysics.com*

| Circuit Element | Symbol | Current-Voltage Relationship in Time | Impedance |
|---|---|---|---|
| Resistor |  | | $R$ |
| Capacitor |  | | $\frac{1}{j\omega C}$ |
| Inductor |  | | $j\omega L$ |

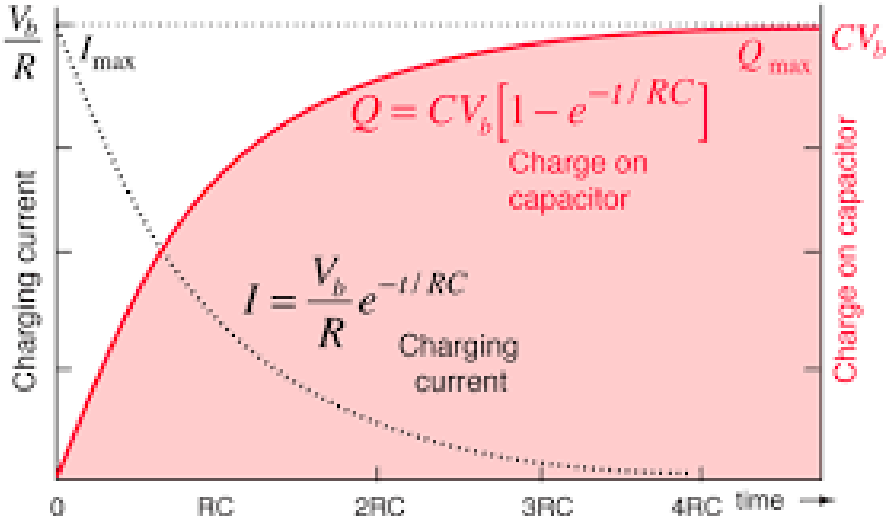
- What characterizes R / C / L?
- What is the impedance R/ C / L at high/low frequencies?

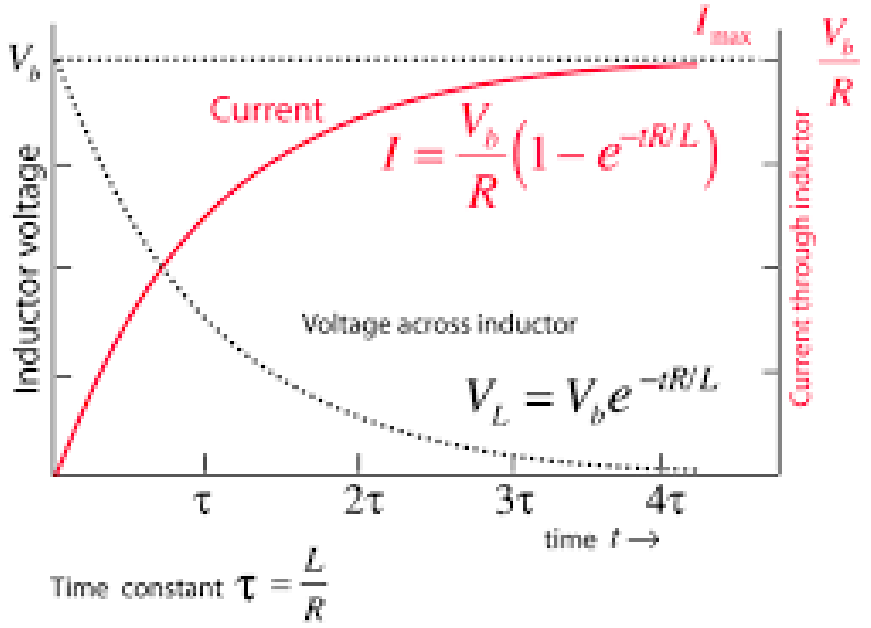



RC low pass filter




RL low pass filter



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# Electro-Magnetic Interference


https://www.emcstandards.co.uk/emi-stories


Ray-Ban


0ms
0:05.0
0:10.0
0:15.0
0:20.0
0:25.0
0:30.0
0:35.0
0:40.0
0:45.0
0:50.0
0:55.0
1:00.0
1:05.0
1:10.0
1:15.0
1:20.0
1:25.0
1:30.0
1:35.0
1:40.0
1:45.0
1:50.0
1:55.0


TELEPHONE


Ray-Ban


https://www.emcstandards.co.uk/emi-stories

# EMC Directive

- The ability of the system to operate without interfering with other systems
- The ability of the system to operate despite interference from other systems
  - Under *typical* conditions (domestic, commercial, industrial)

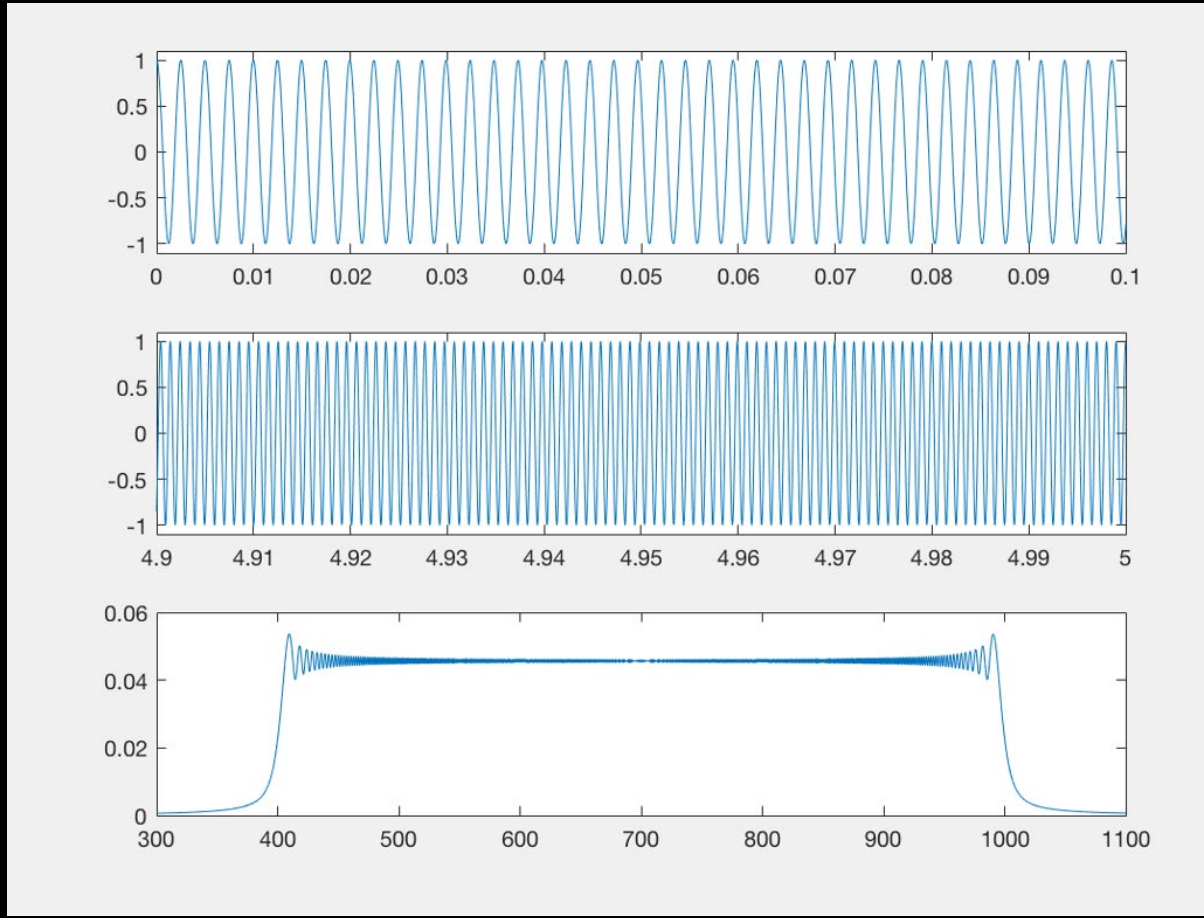

(not to be confused with…)


02 . 01
AFP

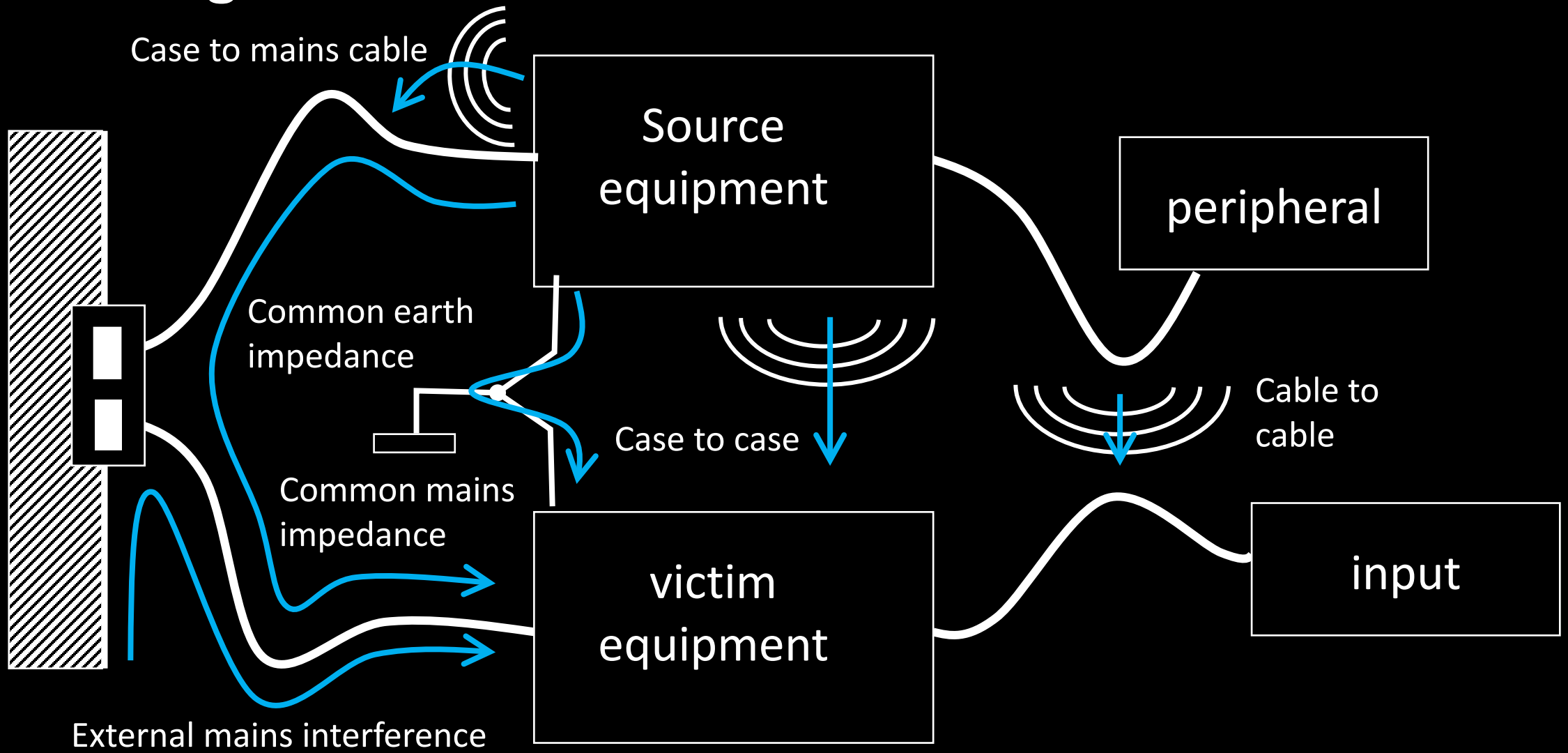
# Electromagnetic Interference

*What sources of EMI are in your system?*

- DC motors
- Switching circuitry (motor drivers)
- Digital signals (I2C, USB)
- Shared power supply (batteries)
- Etc.



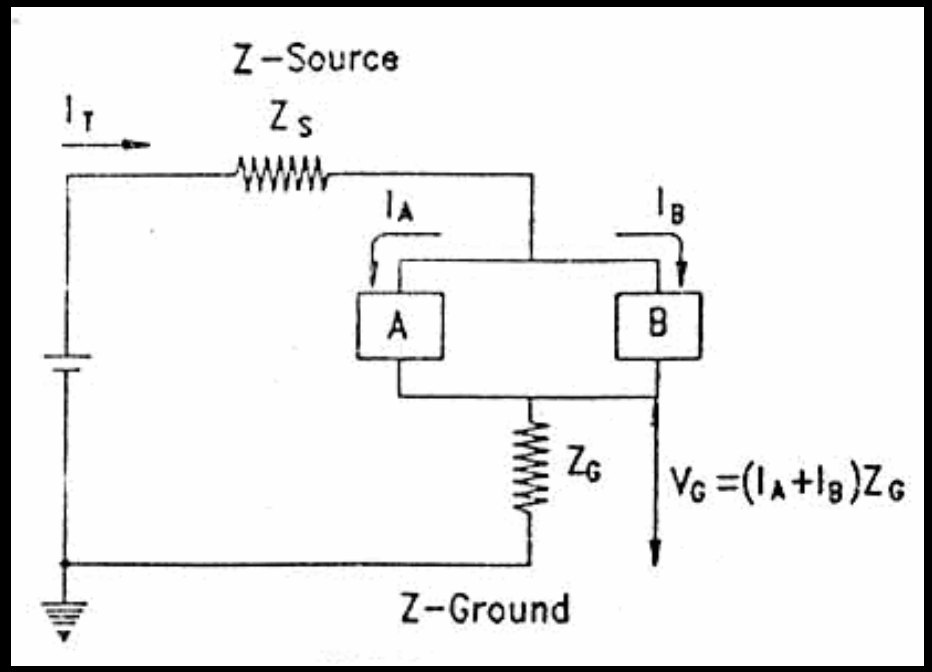
# Electromagnetic Interference

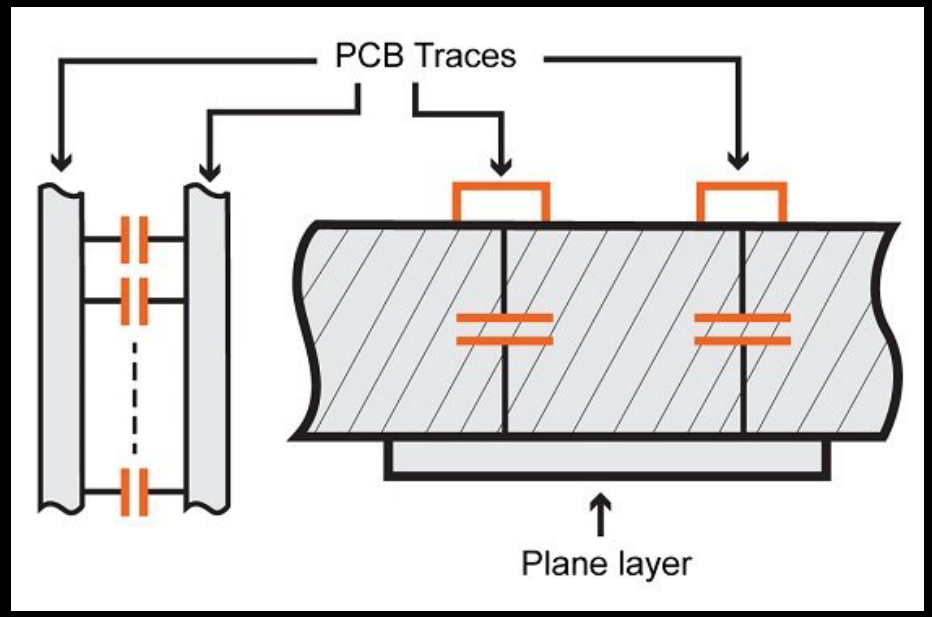



**Two modes of interference: Conducted EMI , Radiated EMI**

# Conducted EMI

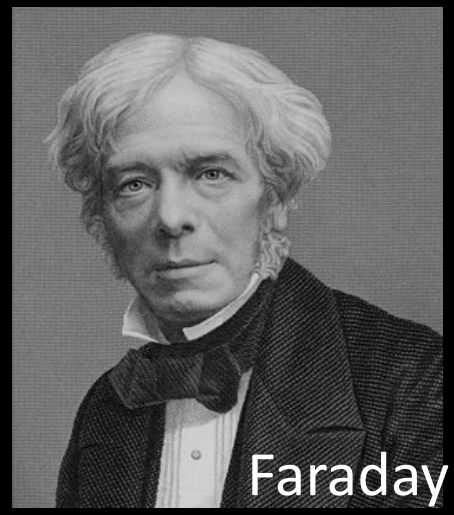
- Shared current paths in resistive wires
  - Ohm's Law
    - U=RI
  - Longer shared paths, higher coupling
- Parasitic Capacitance
  - Electric field over short distances
  - Current in a capacitor
    - I = C dV/dt
  - Higher frequency, higher coupling



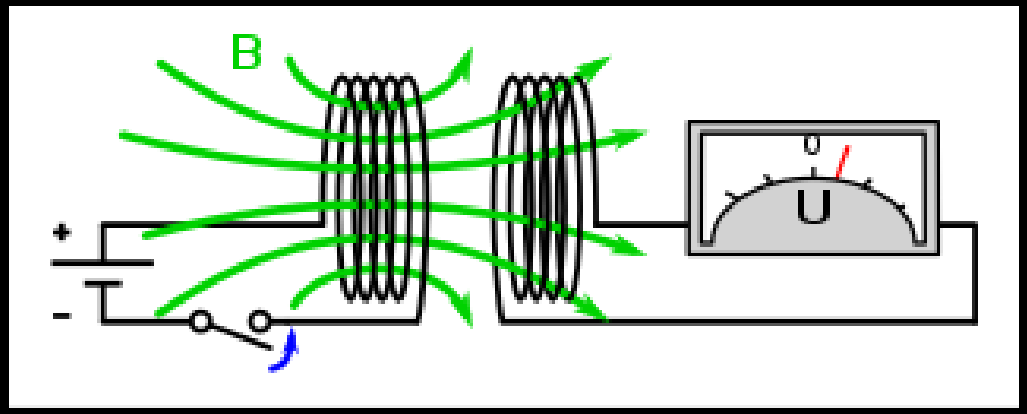



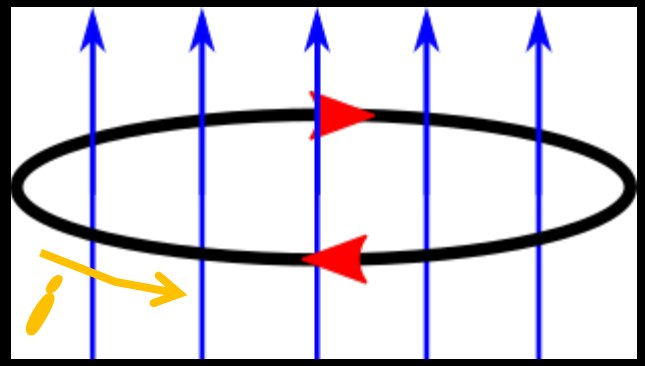
# Radiated EMI

https://resources.pcb.cadence.com/blog/2020-lenz-law-vs-faradays-law-how-do-they-govern-crosstalk-and-emi





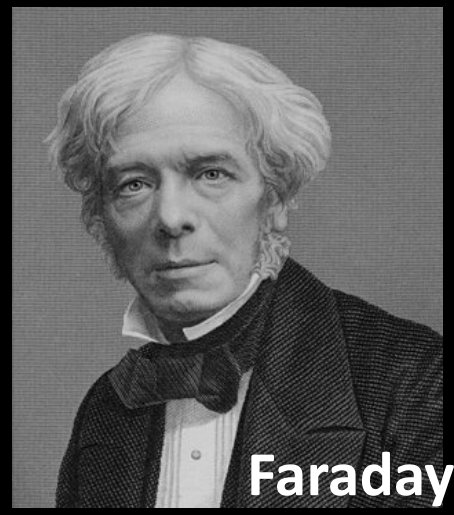


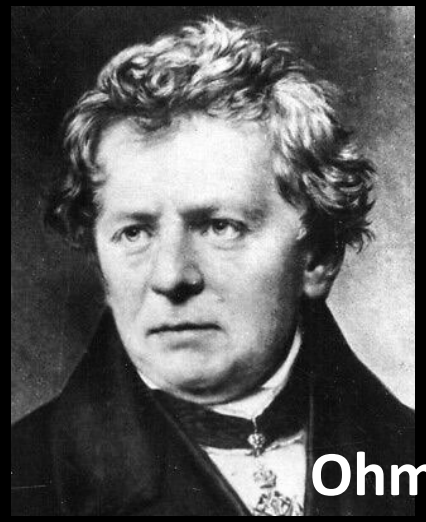
(Fleming's right hand rule)

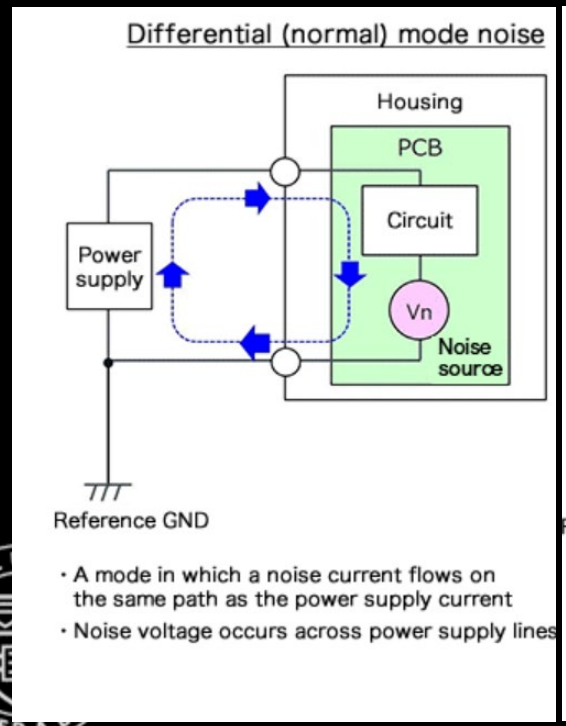
- Faraday's Law
  - Electromotive "force" [V]
  - $EMF = -N\frac{\Delta\Phi}{t}$; where $\Phi = BA$
- Lenz' Law
  - EMF produces a current whos magnetic field that opposes the source
    - The radiated EMI increases with…
      - Magnetic field strength
      - Loop area
      - Signal frequency

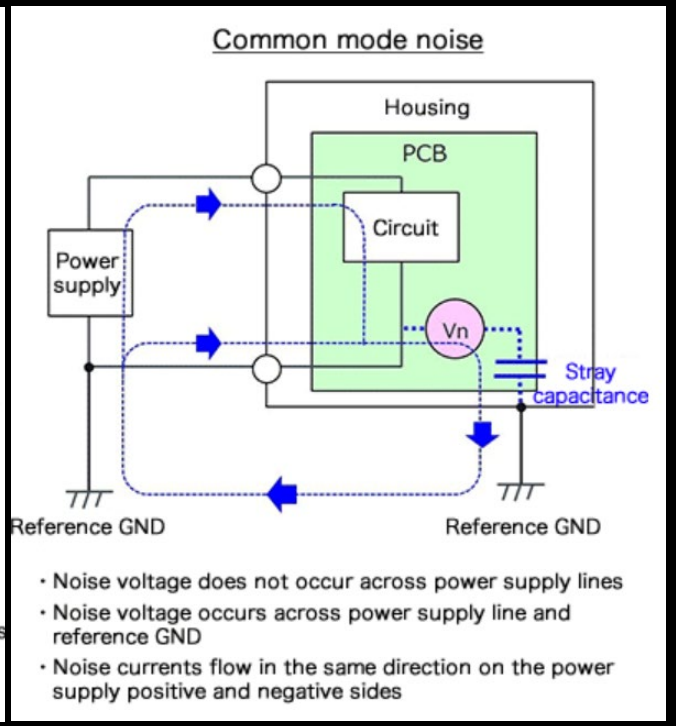
# Common Mode Noise and Differential Mode Noise

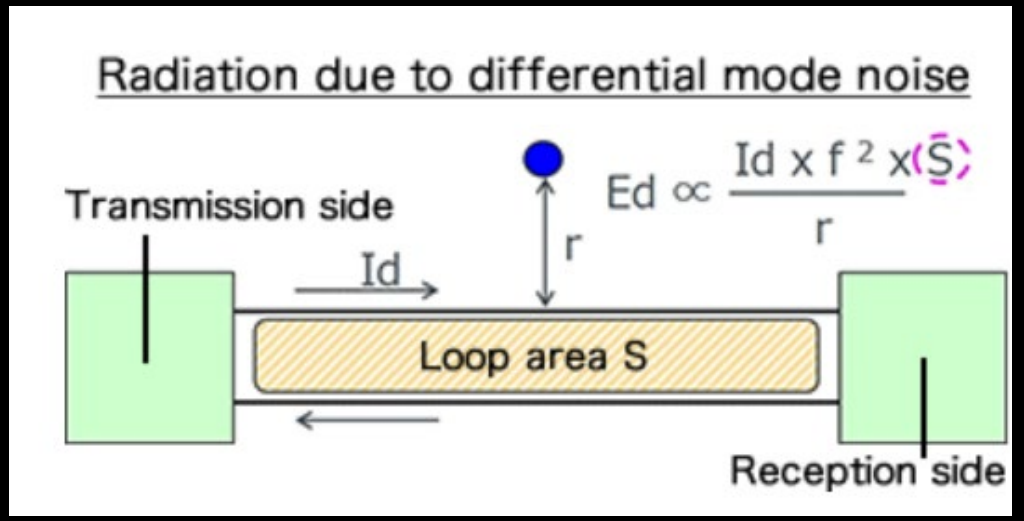


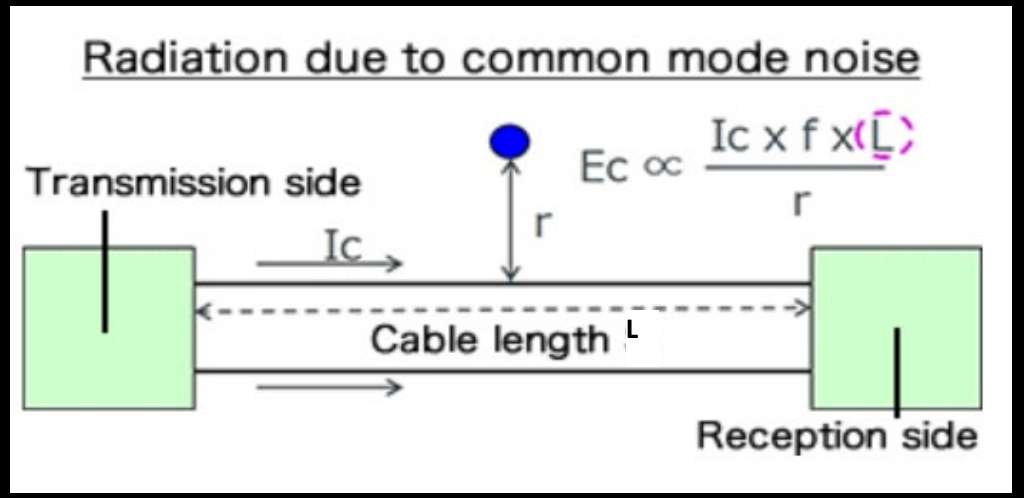




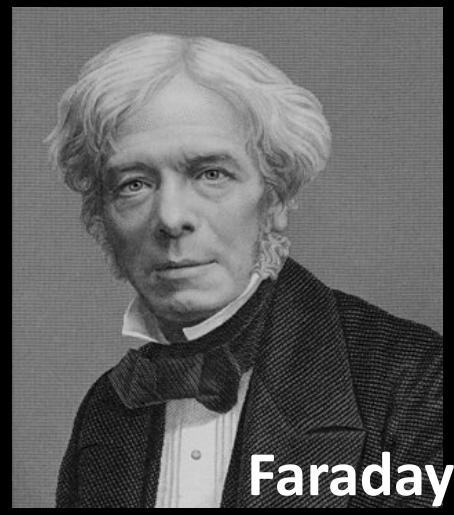



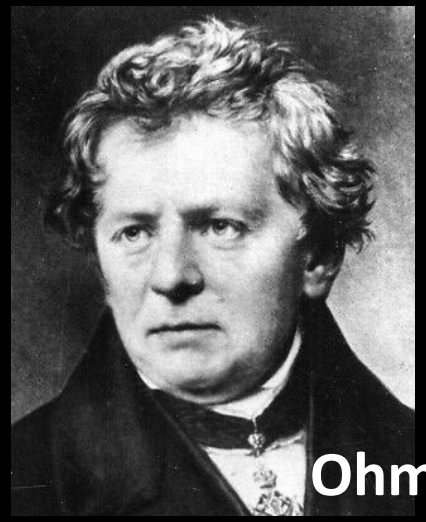




https://techweb.rohm.com/knowledge/emc/s-emc/01-s-emc/6899

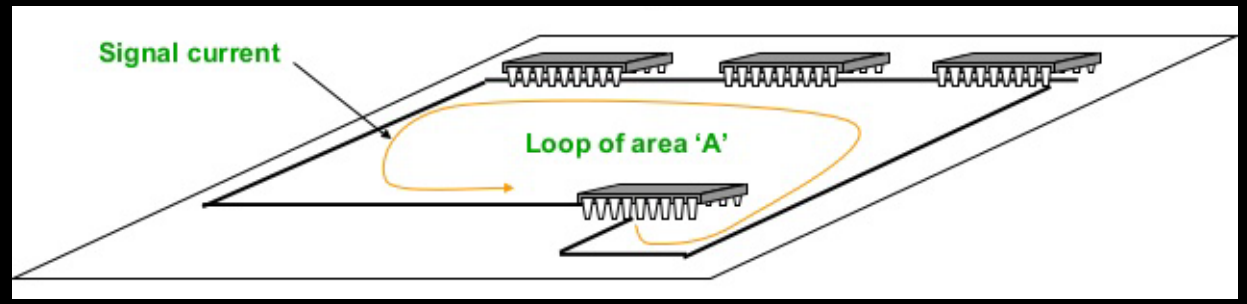
# Common Mode Noise and Differential Mode Noise

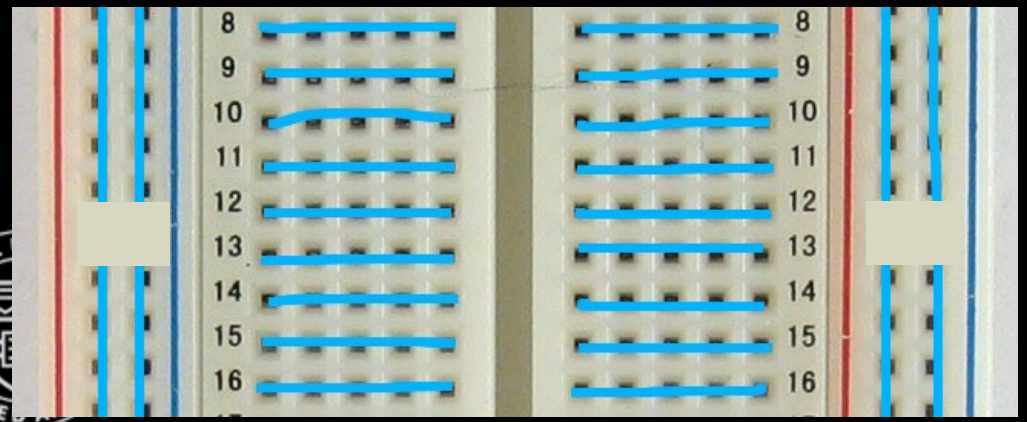

Faraday

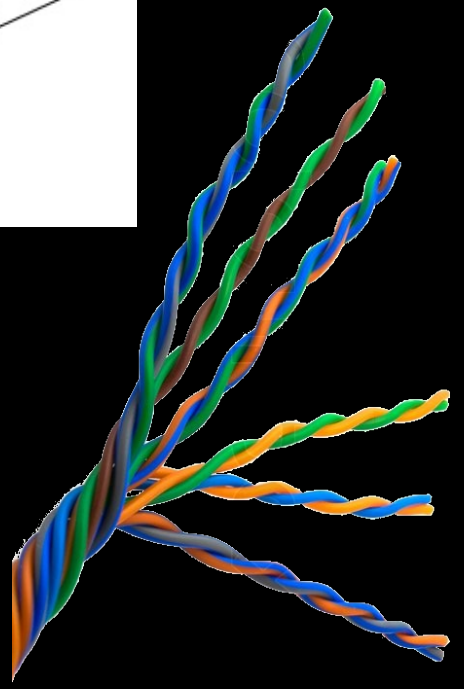

Lenz

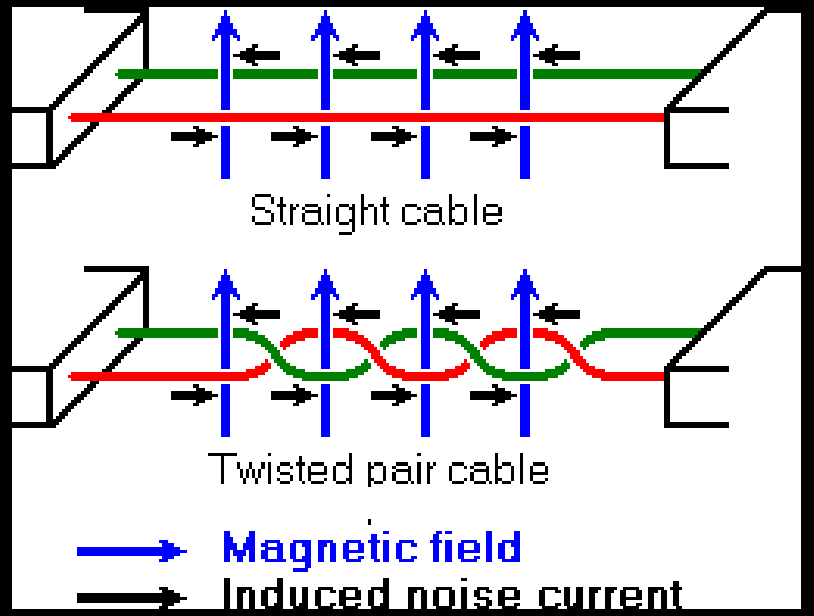

Ohm

- *How to suppress noise?*
  - Use lower frequencies when possible
  - Use shielded cables
  - Minimize common impedances
    - Short, thick wires
  - Lower loop area
  - Twist out/return cables

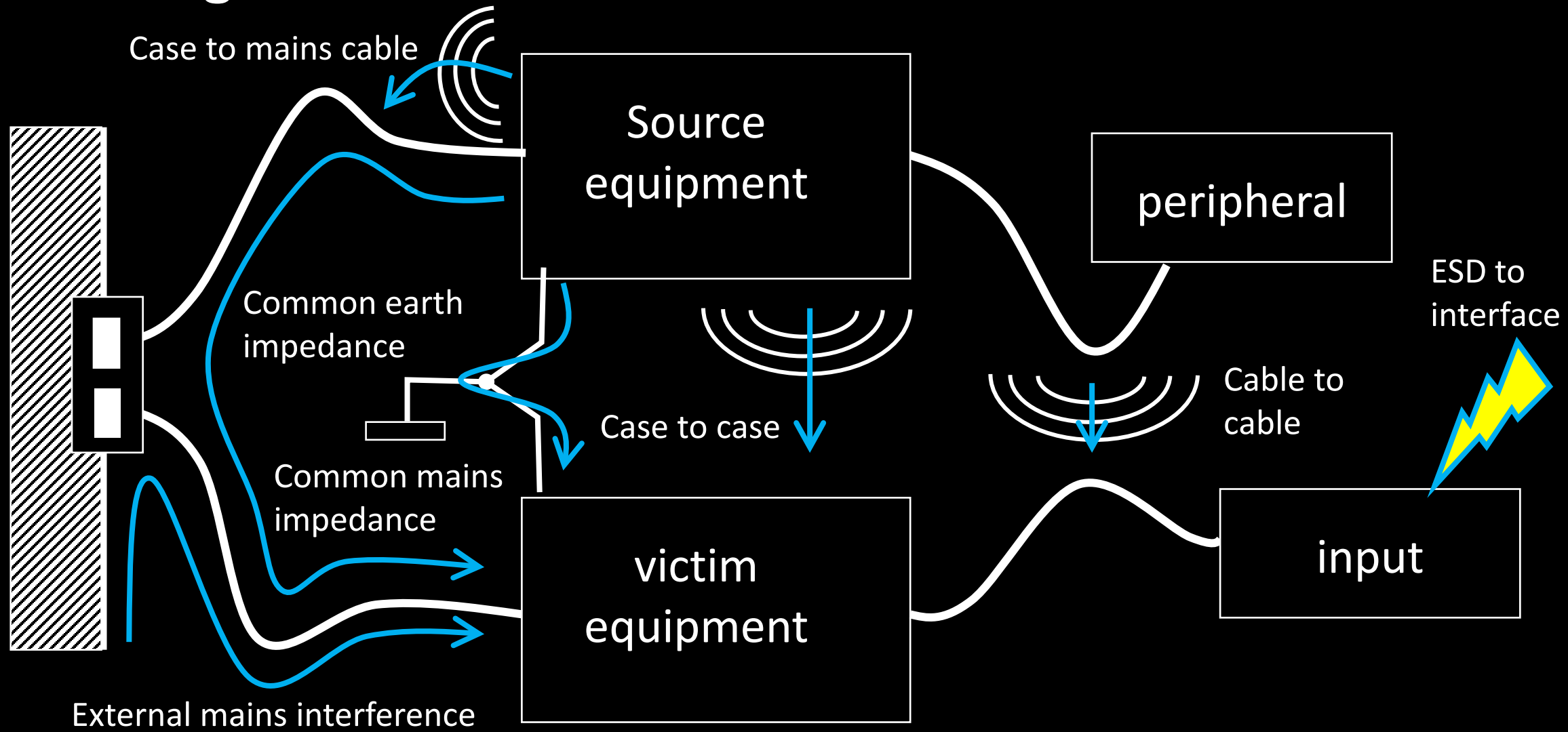


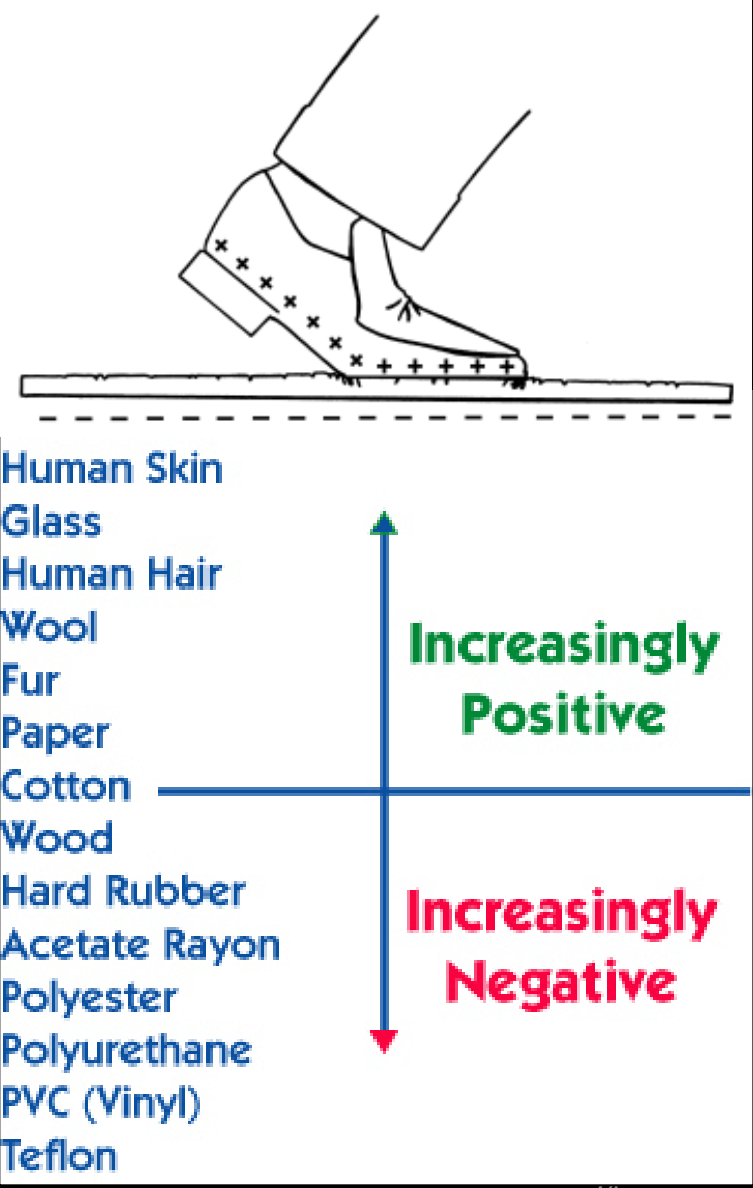


# Electromagnetic Interference

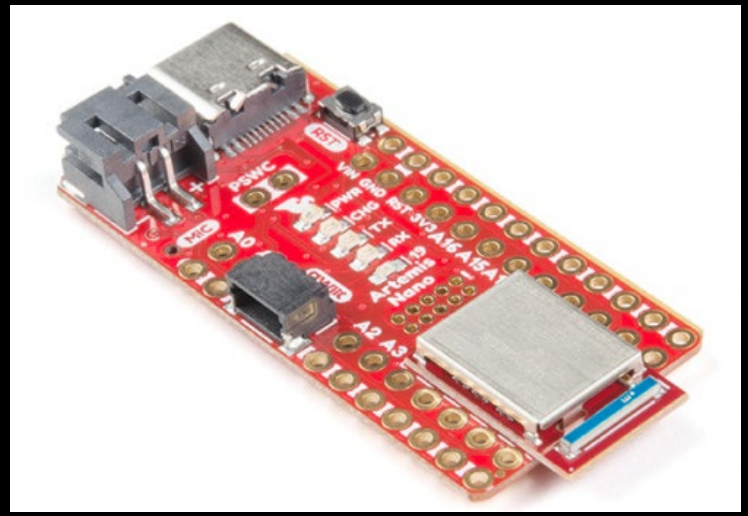


# Electrostatic Discharge

| Static Voltage Generation at different Relative Humidity (RH) levels | | |
|---|---|---|
| Generation Method | 10-25% RH | 60-90% RH |
| Walking across a carpet | 35,000Volts | 1,500Volts |
| Walking across vinyl tiles | 12,000Volts | 250Volts |
| Worker at a workbench | 6,000Volts | 100Volts |
| Poly bag picked up from workbench | 20,000Volts | 1,200Volts |
| Sitting on chair with urethane foam | 18,000Volts | 1,500Volts |




- *Always discharge through ground!*



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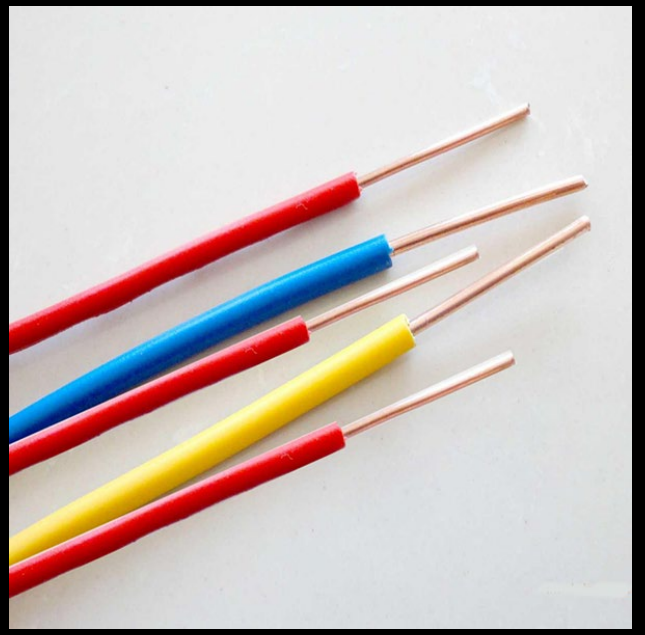
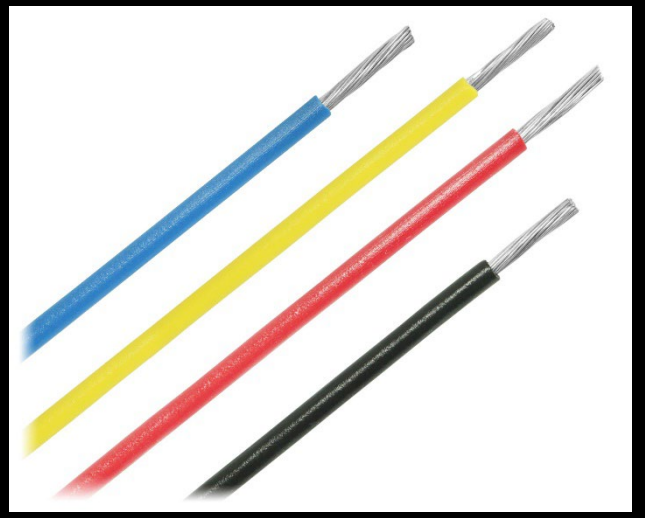
# WIRING AND ROUTING

# Wiring and Routing

- Power transmission wires
  - Sized according to power
- Signal wires
  - Carry little current, but are more susceptible to EMI

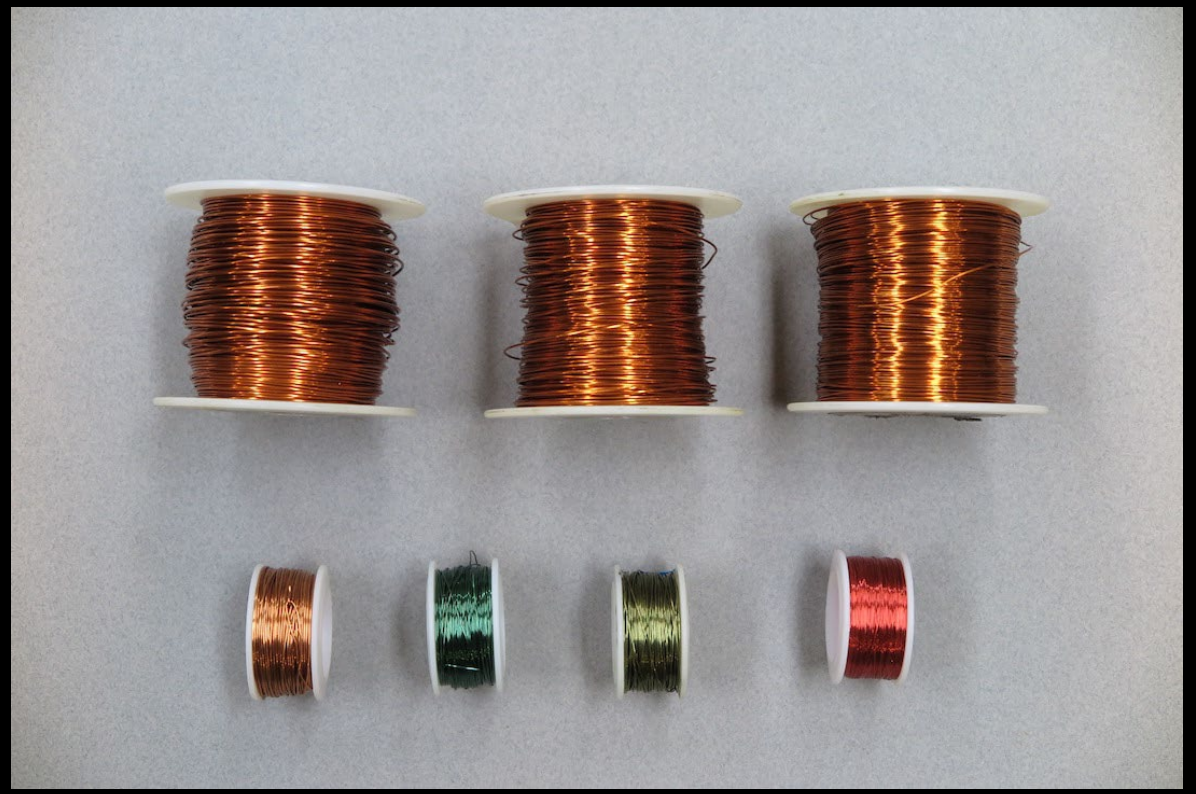
- Solid core
  - Holds shape, but is brittle
- Stranded
  - More strands, more flexible
  - Use anywhere the position is not permanent
    - Insulation
      - Most common: polyviny chloride
      - Polyethylene, polyester, rubber, and Teflon
      - PH427: Silicone





# Wiring and Routing

- Magnet Wire
  - Use in motors, transformers where high density routing is needed
  - Thin enamel-like, tough coating
    - 100-1000s V and 100s of degrees C.
    - Removal with heat or solvent
  - Cannot tolerate repeated bending



# Wiring and Routing

Wire Gauge

- US standard is American Wire Gauge (AWG)
- The larger the gauge, the smaller the wire
  - AWG 16 and lower are for power transmission
  - AWG 18-22 can be used for low-power motor supplies
  - AWG 22 signals
- Stranded wire
  - AWG 16 26/30

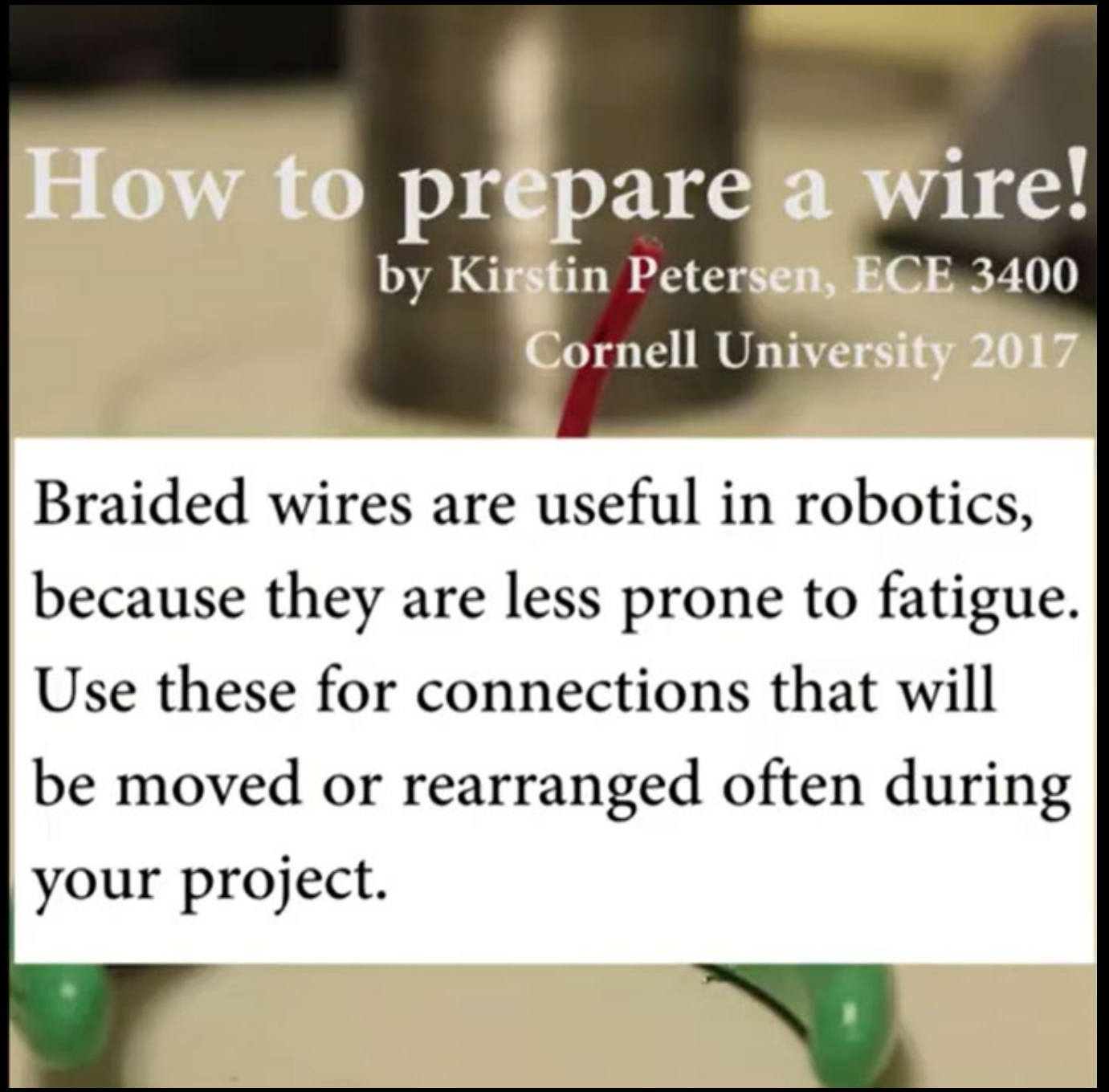
| AWG gauge | Conductor Diameter Inches | Conductor Diameter mm | Conductor cross section in $mm^2$ | Ohms per 1000 ft. | Ohms per km | Maximum amps for chassis wiring | Maximum amps for power transmission |
|---|---|---|---|---|---|---|---|
| 0000 | 0.46 | 11.684 | 107 | 0.049 | 0.16072 | 380 | 302 |
| 000 | 0.4096 | 10.40384 | 84.9 | 0.0618 | 0.202704 | 328 | 239 |
| 00 | 0.3648 | 9.26592 | 67.4 | 0.0779 | 0.255512 | 283 | 190 |
| 0 | 0.3249 | 8.25246 | 53.5 | 0.0983 | 0.322424 | 245 | 150 |
| 1 | 0.2893 | 7.34822 | 42.4 | 0.1239 | 0.406392 | 211 | 119 |
| 2 | 0.2576 | 6.54304 | 33.6 | 0.1563 | 0.512664 | 181 | 94 |
| 3 | 0.2294 | 5.82676 | 26.7 | 0.197 | 0.64616 | 158 | 75 |
| 4 | 0.2043 | 5.18922 | 21.1 | 0.2485 | 0.81508 | 135 | 60 |
| 5 | 0.1819 | 4.62026 | 16.8 | 0.3133 | 1.027624 | 118 | 47 |
| 6 | 0.162 | 4.1148 | 13.3 | 0.3951 | 1.295928 | 101 | 37 |
| 7 | 0.1443 | 3.66522 | 10.6 | 0.4982 | 1.634096 | 89 | 30 |
| 8 | 0.1285 | 3.2639 | 8.37 | 0.6282 | 2.060496 | 73 | 24 |
| 9 | 0.1144 | 2.90576 | 6.63 | 0.7921 | 2.598088 | 64 | 19 |
| 10 | 0.1019 | 2.58826 | 5.26 | 0.9989 | 3.276392 | 55 | 15 |
| 11 | 0.0907 | 2.30378 | 4.17 | 1.26 | 4.1328 | 47 | 12 |
| 12 | 0.0808 | 2.05232 | 3.31 | 1.588 | 5.20864 | 41 | 9.3 |
| 13 | 0.072 | 1.8288 | 2.63 | 2.003 | 6.56984 | 35 | 7.4 |
| 14 | 0.0641 | 1.62814 | 2.08 | 2.525 | 8.282 | 32 | 5.9 |
| 15 | 0.0571 | 1.45034 | 1.65 | 3.184 | 10.44352 | 28 | 4.7 |
| 16 | 0.0508 | 1.29032 | 1.31 | 4.016 | 13.17248 | 22 | 3.7 |
| 17 | 0.0453 | 1.15062 | 1.04 | 5.064 | 16.60992 | 19 | 2.9 |
| 18 | 0.0403 | 1.02362 | 0.823 | 6.385 | 20.9428 | 16 | 2.3 |
| 19 | 0.0359 | 0.91186 | 0.653 | 8.051 | 26.40728 | 14 | 1.8 |
| 20 | 0.032 | 0.8128 | 0.519 | 10.15 | 33.292 | 11 | 1.5 |
| 21 | 0.0285 | 0.7239 | 0.412 | 12.8 | 41.984 | 9 | 1.2 |
| 22 | 0.0253 | 0.64516 | 0.327 | 16.14 | 52.9392 | 7 | 0.92 |

https://www.powerstream.com/Wire_Size.htm

## Connection Points

- Solder permanent connection points
- Minimize connection points
  - BUT use for modularity

- Connectors
  - Signal transfer
  - Power transfer

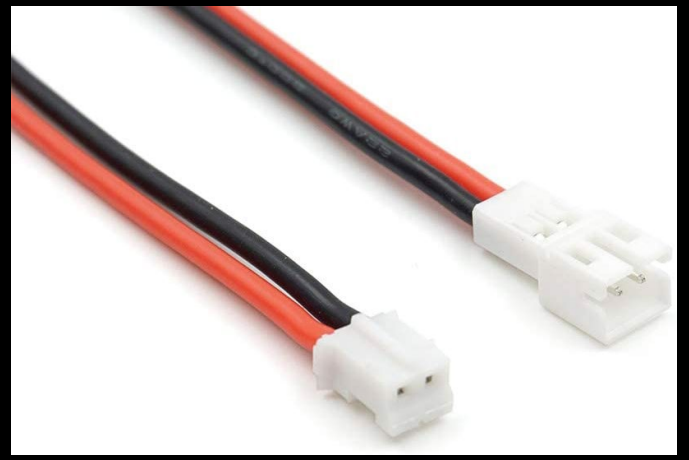


# Connection Points

- Solder permanent connection points
- Minimize connection points
  - BUT use for modularity

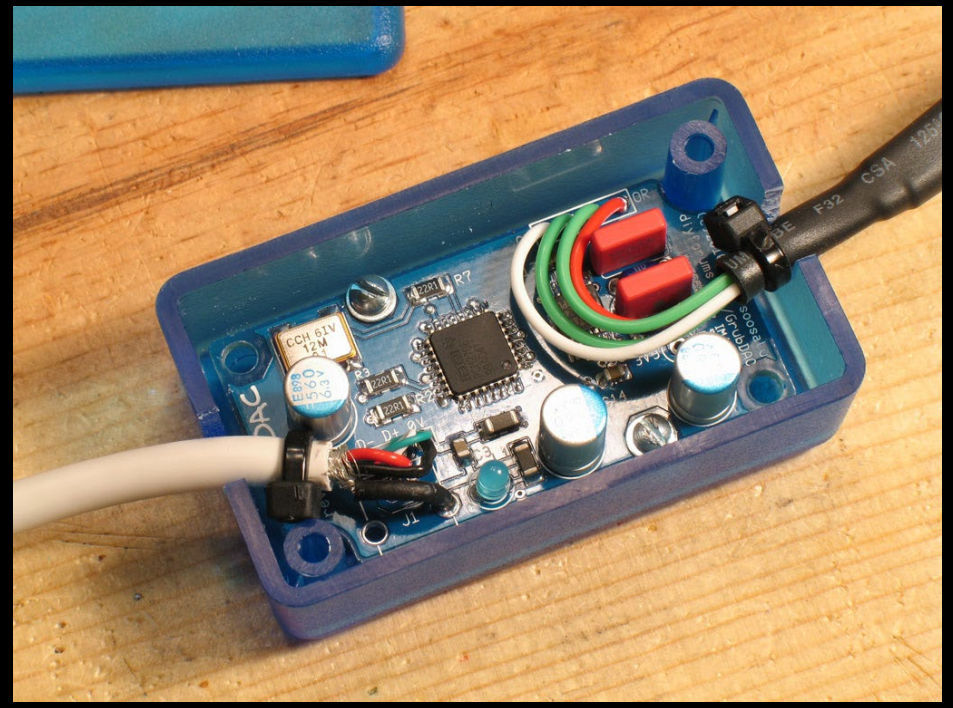
- Connectors
  - Signal transfer
  - Power transfer
  - Female: hot side
  - Male: Receiver
  - Reversible

  - General
  - Protocol




# Good practices

- Use color convention
  - Red/Black: Vcc/Gnd
  - Purple: V+ (raw power or battery voltage)
  - Green/white/yellow/orange: signal wires
- Fastening
  - Avoid pinch points
  - Service loops
  - Strain relief
  - Hot glue
    - Good for semi-permanent connections
    - Becomes brittle over time
- Insulation
  - Hot glue
  - Heat shrink
  - Electrical tape ages and leaves residue



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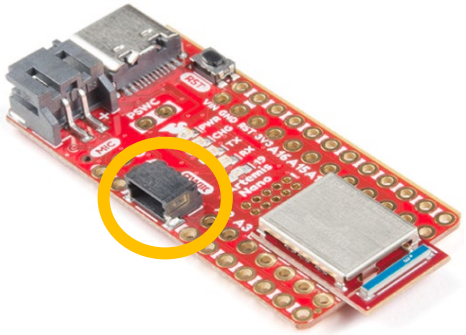
# Lab 3 Pre-lab

# Lab 3-5: Hardware

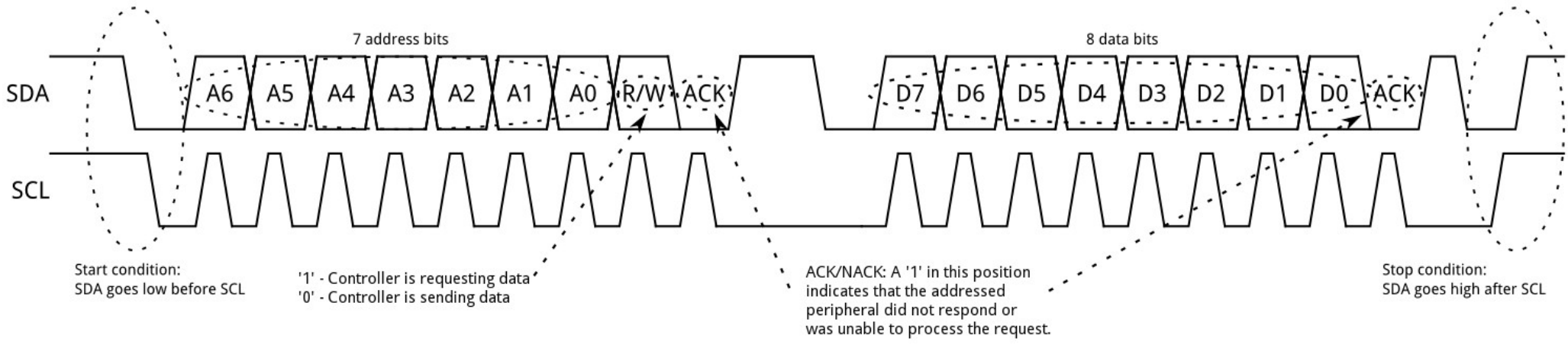
- Lab 3: TOF sensors (https://cei-lab.github.io/FastRobots-2023/Lab3.html )
  - Good example from last year: https://anyafp.github.io/ece4960/
  - But the tasks have changed somewhat…

# Communication with Sensors / Sparkfun “Qwiic” connectors

## I2C



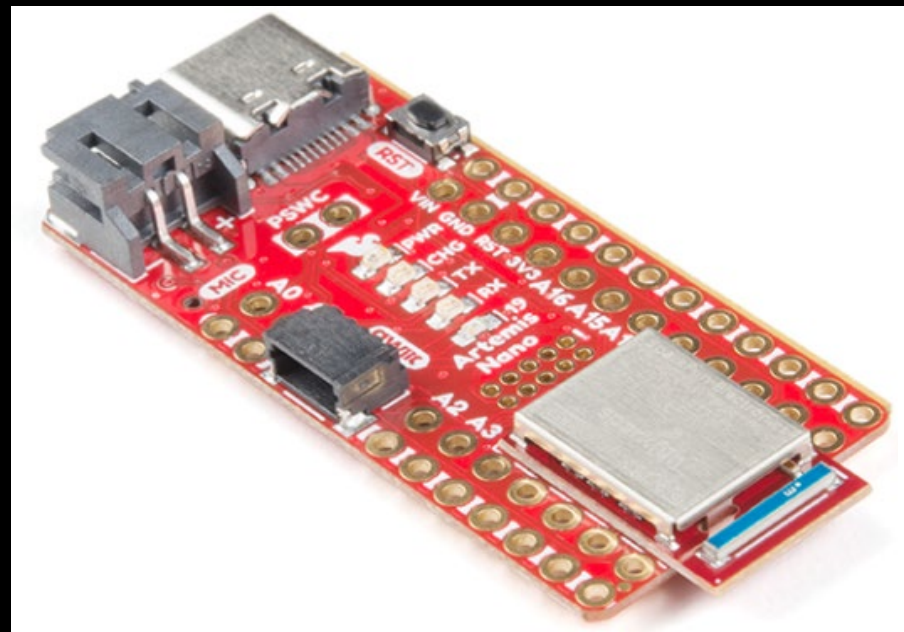


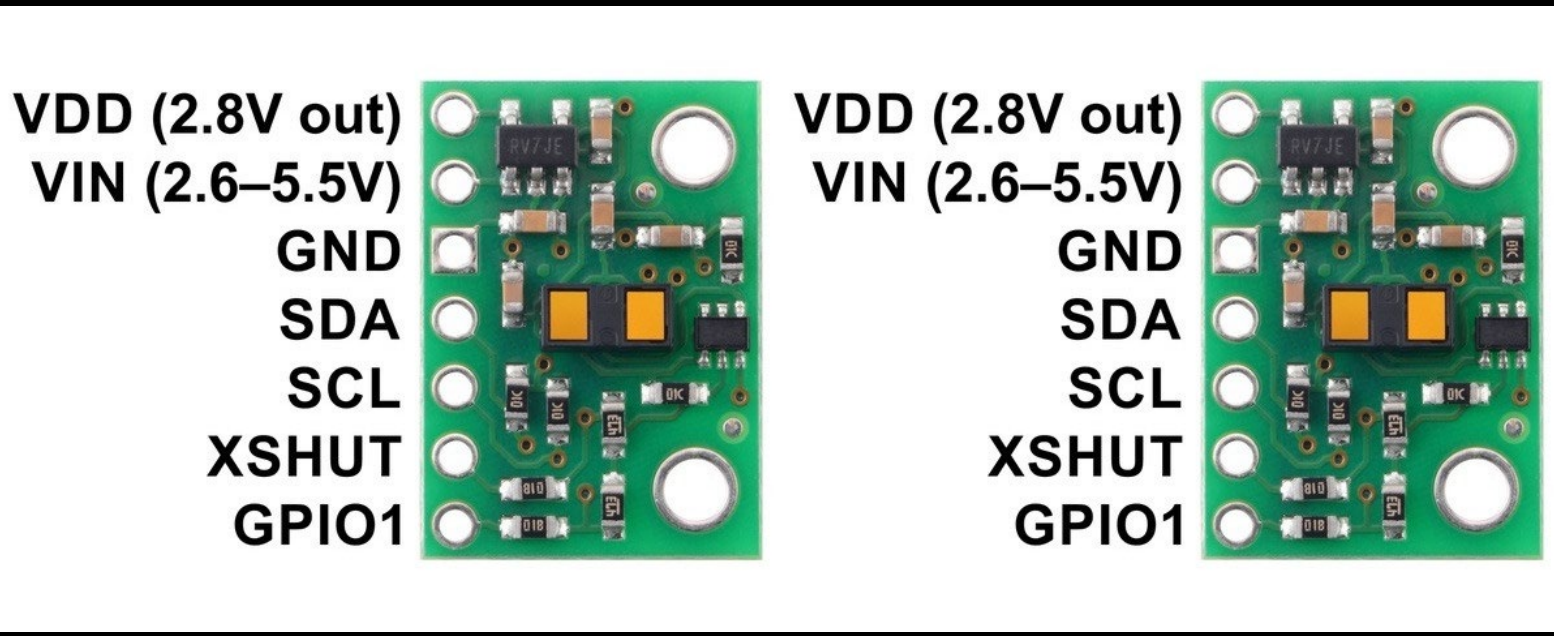




Fast Robots

# Lab 3-5: Hardware

- Lab 3: TOF sensors (https://cei-lab.github.io/FastRobots-2023/Lab3.html )
  - How to deal with two ToF sensors with the same default address?



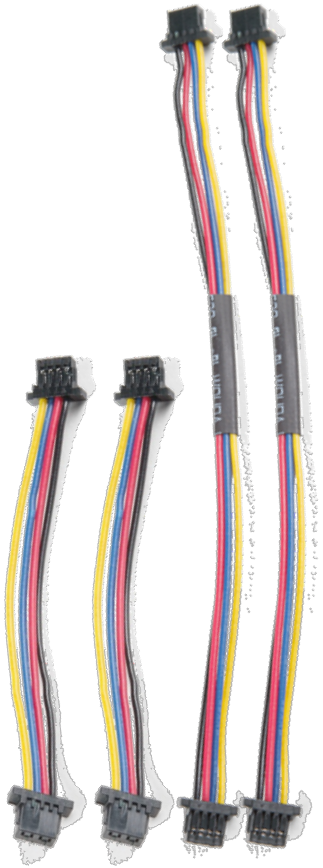


# Lab 3-5: Hardware

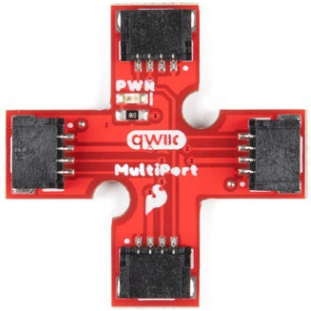
- Lab 3: TOF sensors (https://cei-lab.github.io/FastRobots-2023/Lab3.html )
- Lab 4: IMU sensors and battery
- Lab 5: Motor drivers

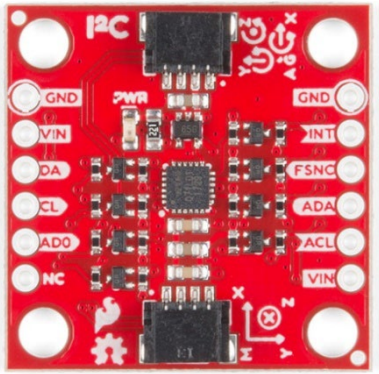
- Things to consider…
  - Where/how do you place components?
  - Routing paths (w. EMI considerations)
  - Color coding
  - Permanent solder joints / Detachable connections?
  - Single core or braided wires?
  - Which side of the breakout boards do you solder to?
  - What cable will you use where? Which will you cut for the ToF sensors?
  - Identify the colors of the signals in the QWIIC cable (GND, VCC, SDA, SCL)
  - **<FOCUS on getting all soldering done during your lab section this week!>**

# Lab 3-5: Hardware

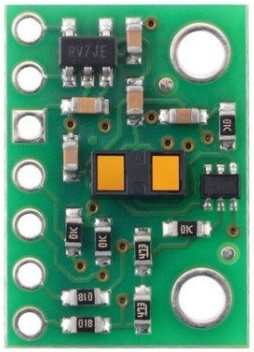


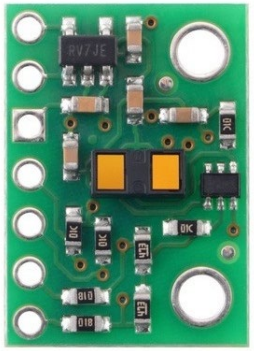

Artemis Nano (Sparkfun)



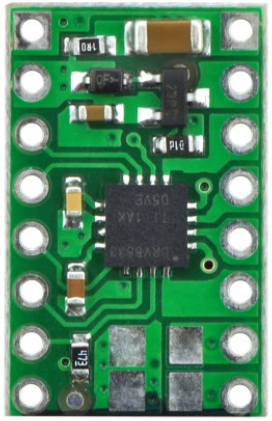



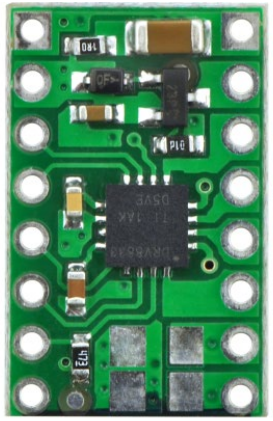

ICM20948 (Sparkfun)




VLX53L1X (Pololu)




DRV8833 (Pololu)

# Lab 3-5: Hardware

- Think about the placement of components and batteries