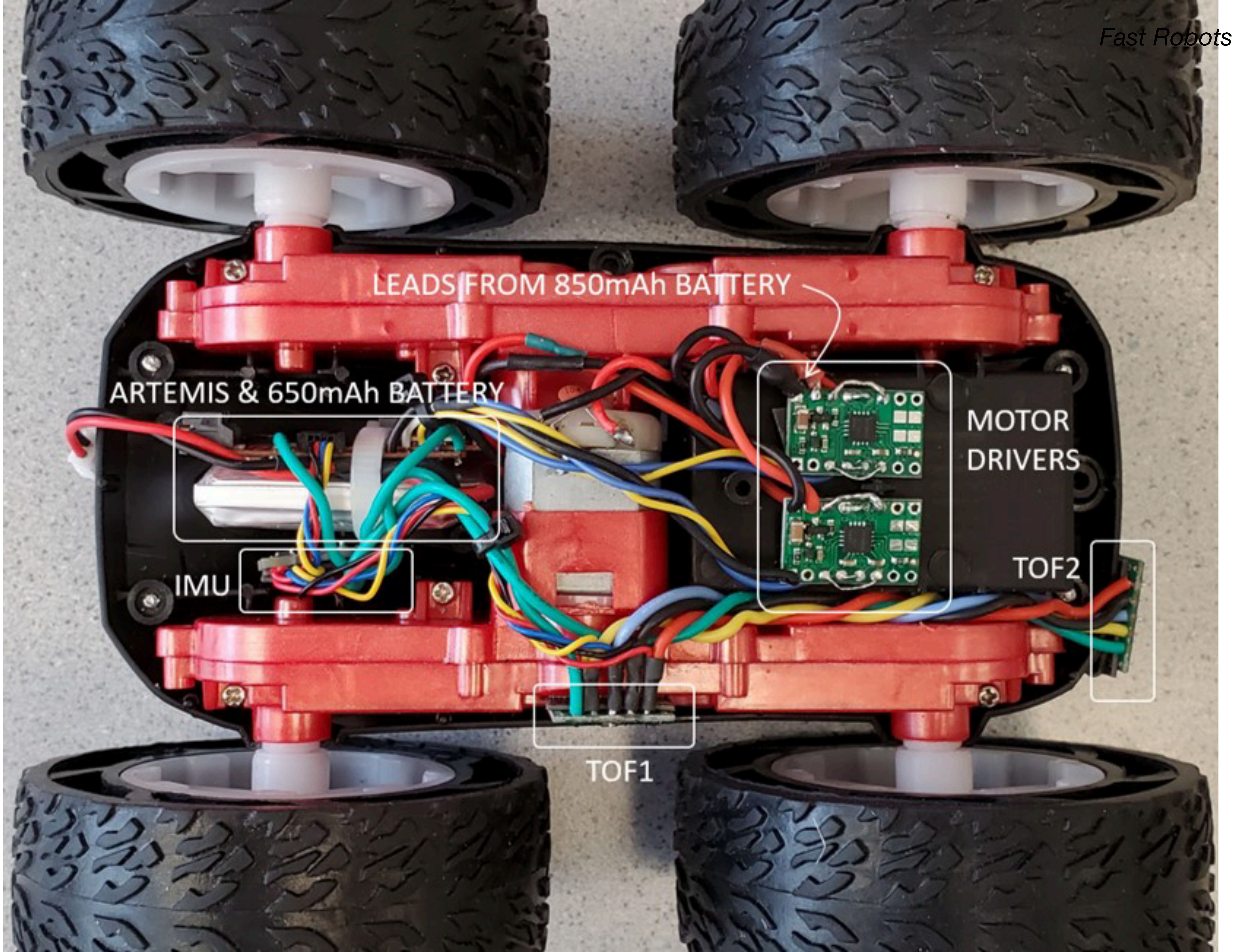
EMI and Wiring

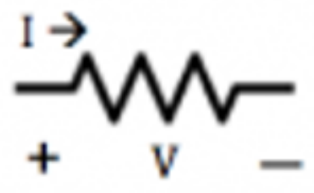
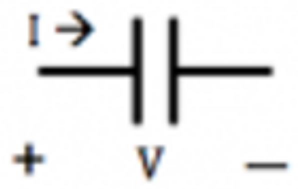
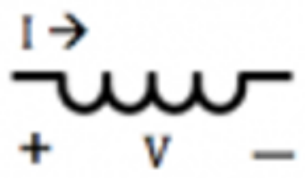
Fast Robots, ECE4160/5160, MAE 4190/5190

E. Farrell Helbling, 2/3/26
Slides adapted from Prof. Kirstin Petersen

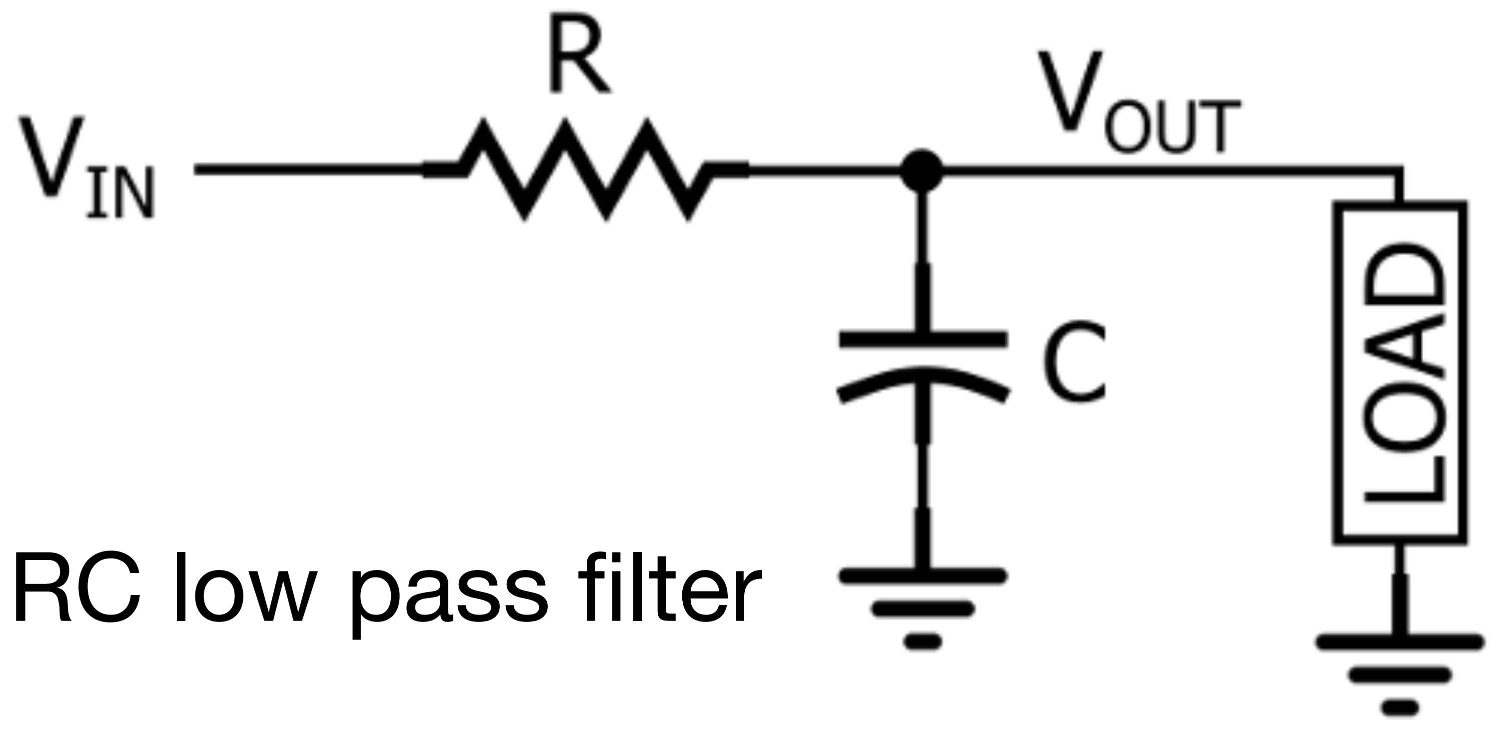

LEADS FROM 850mAh BATTERY
ARTEMIS & 650mAh BATTERY
MOTOR
DRIVERS
IMU
TOF2
TOF1

RLC Recap (very brief)

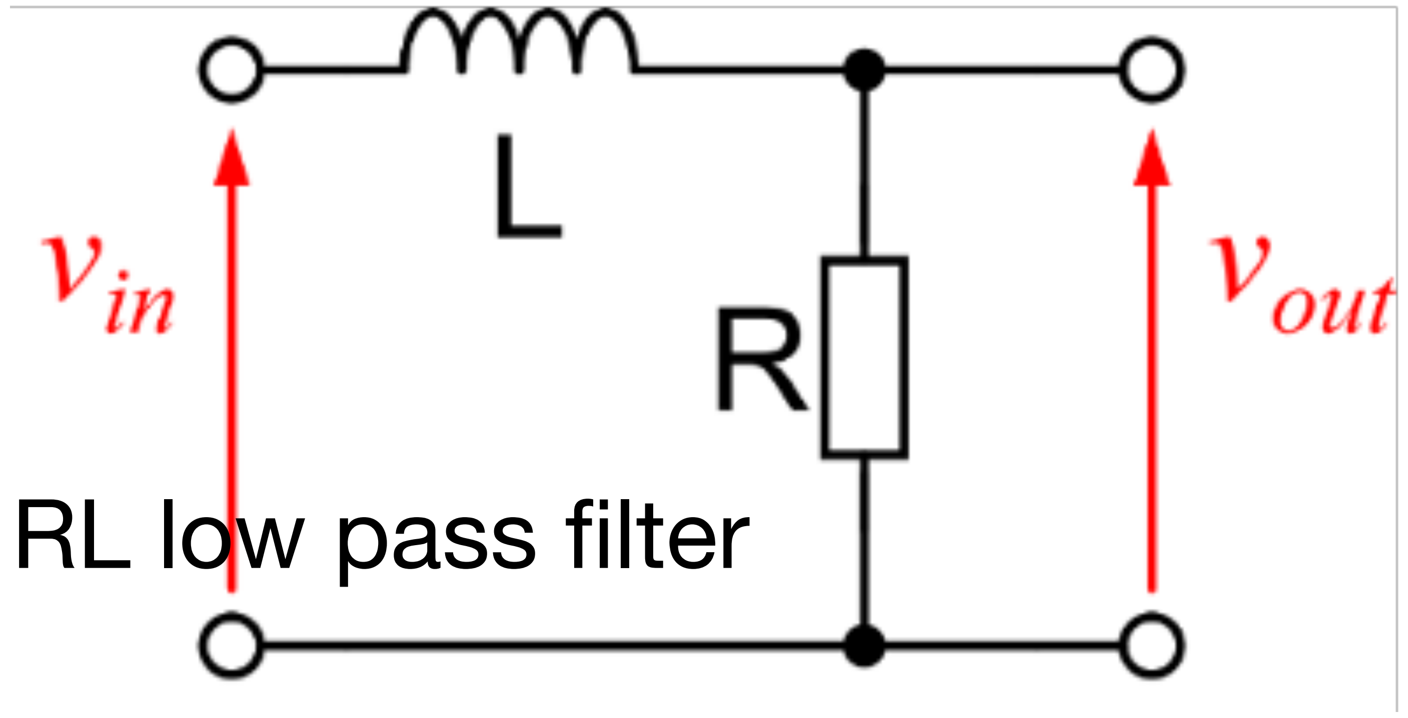
Basics

Circuit Element	Symbol	Current-Voltage Relationship in Time	Impedance
Resistor			
Capacitor			
Inductor			

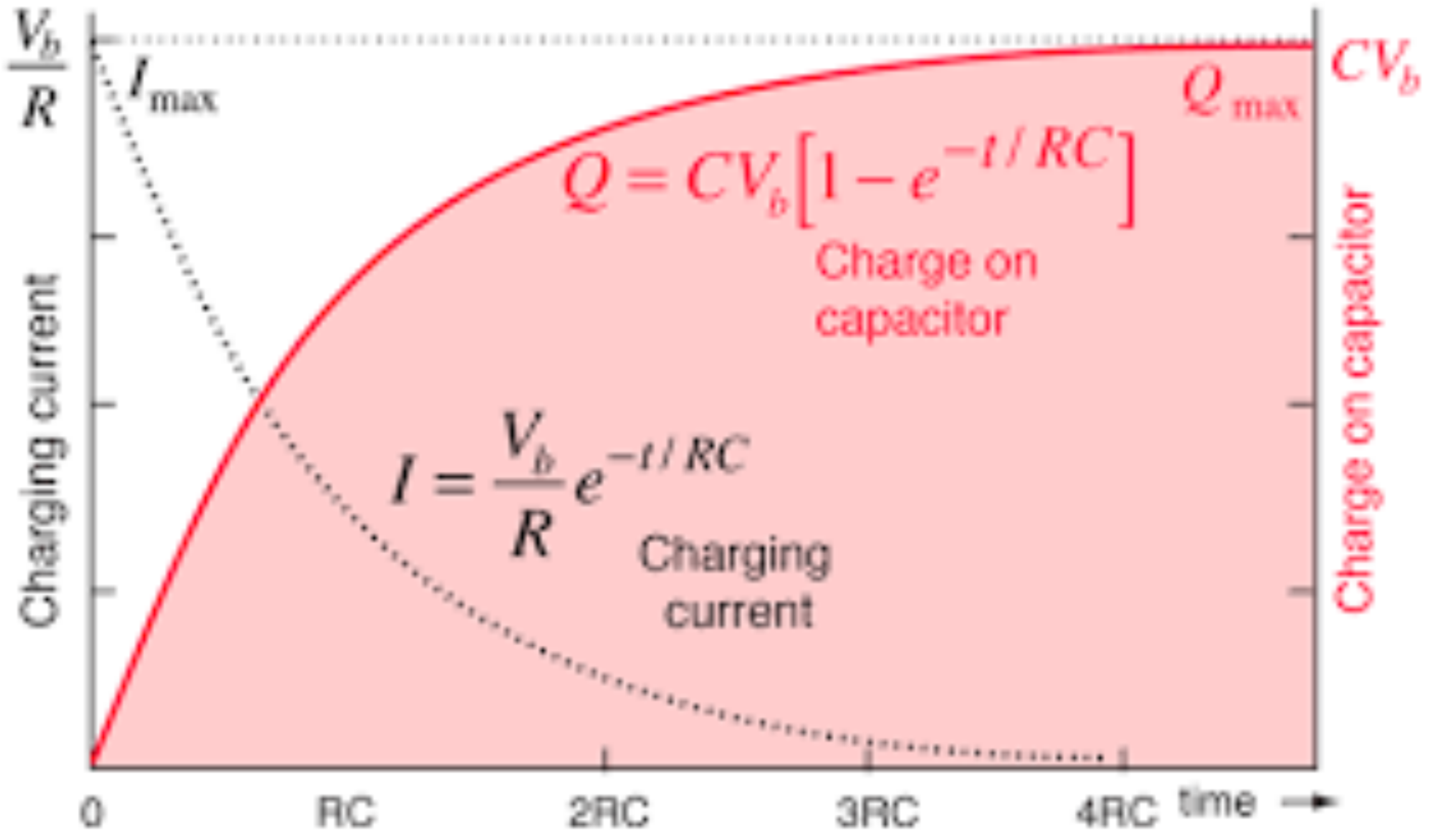
- What are some characteristics of R/C/L?
- What is the impedance of R/C/L at low/ high frequencies?

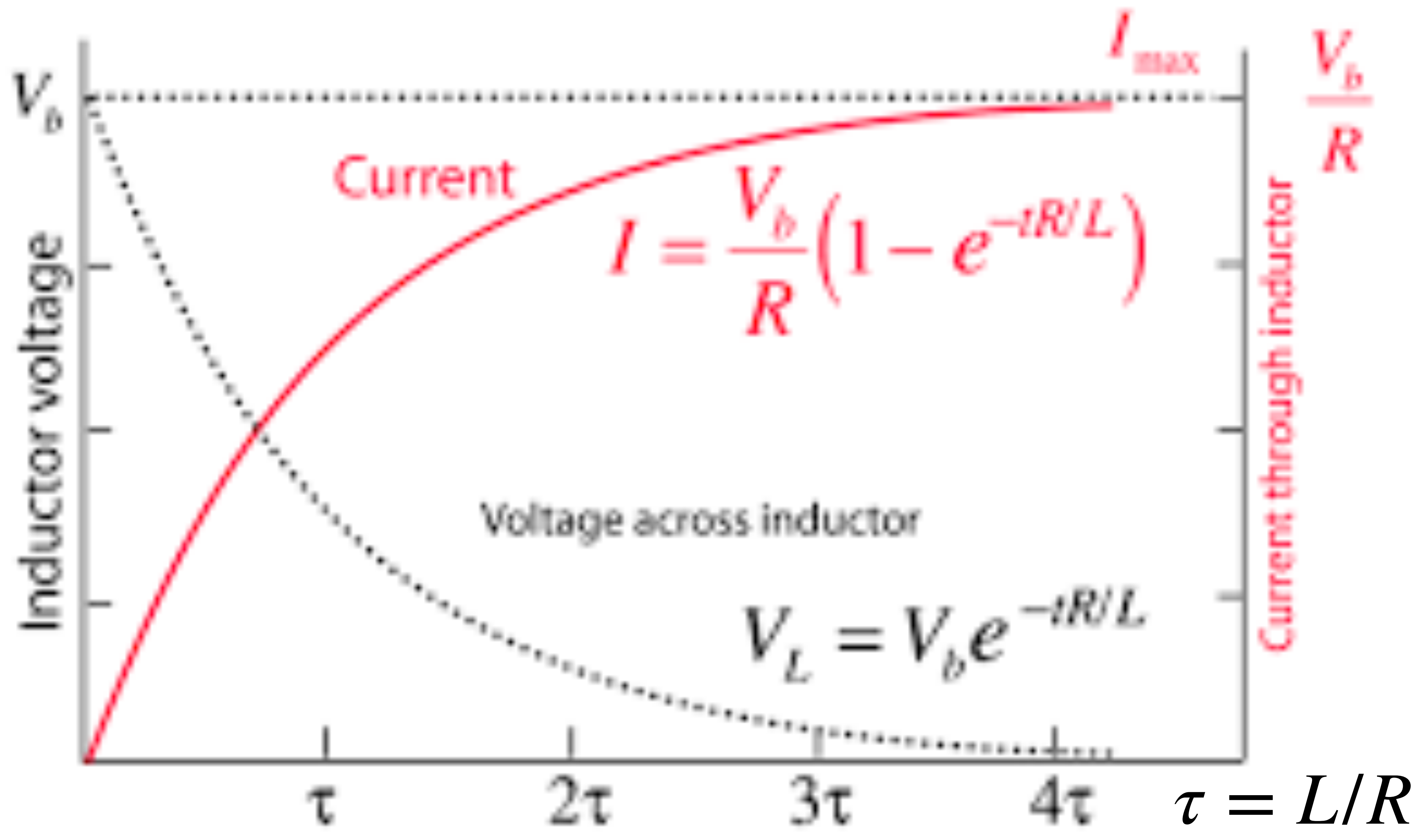


RC low pass filter



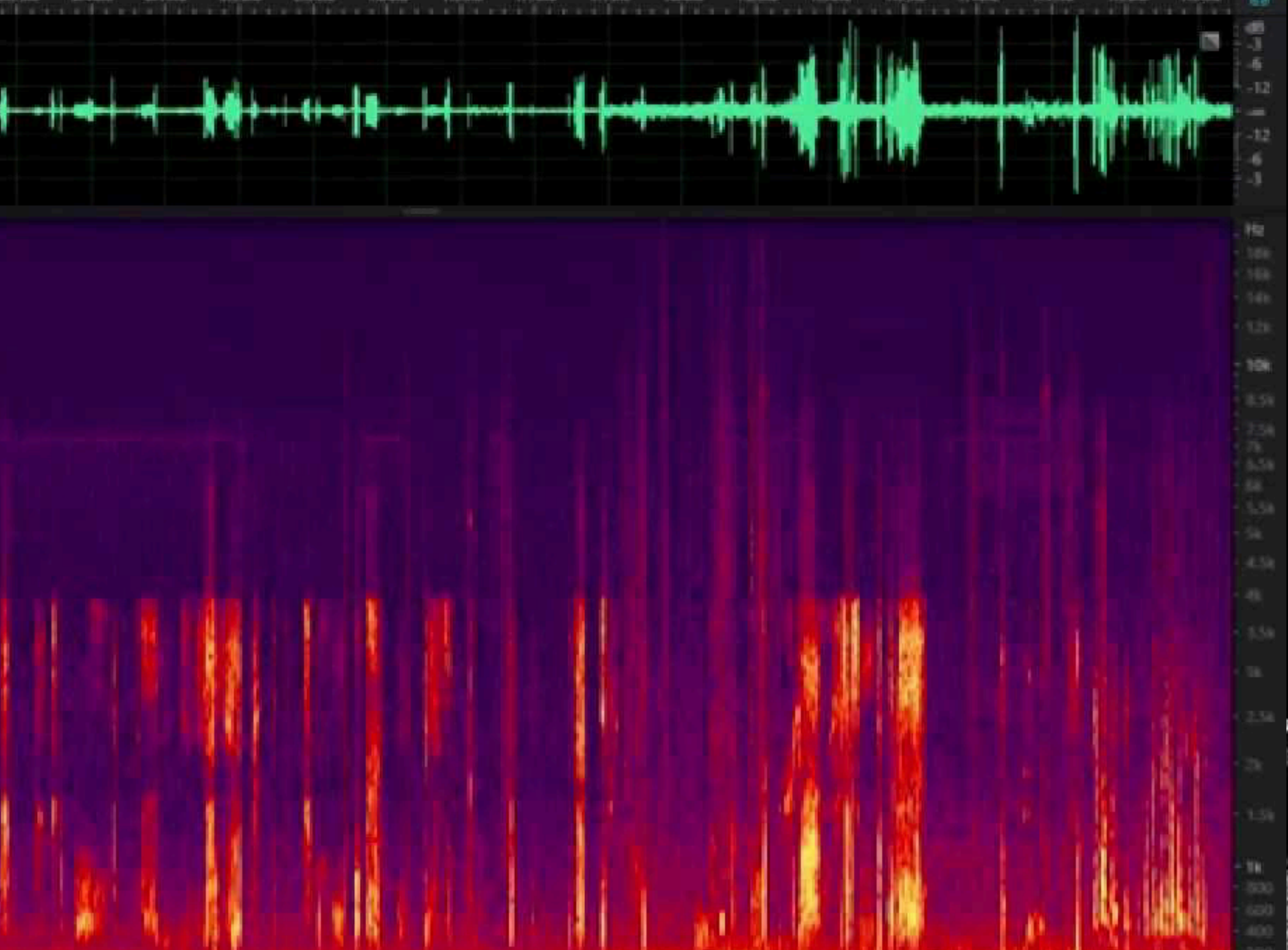
RL low pass filter



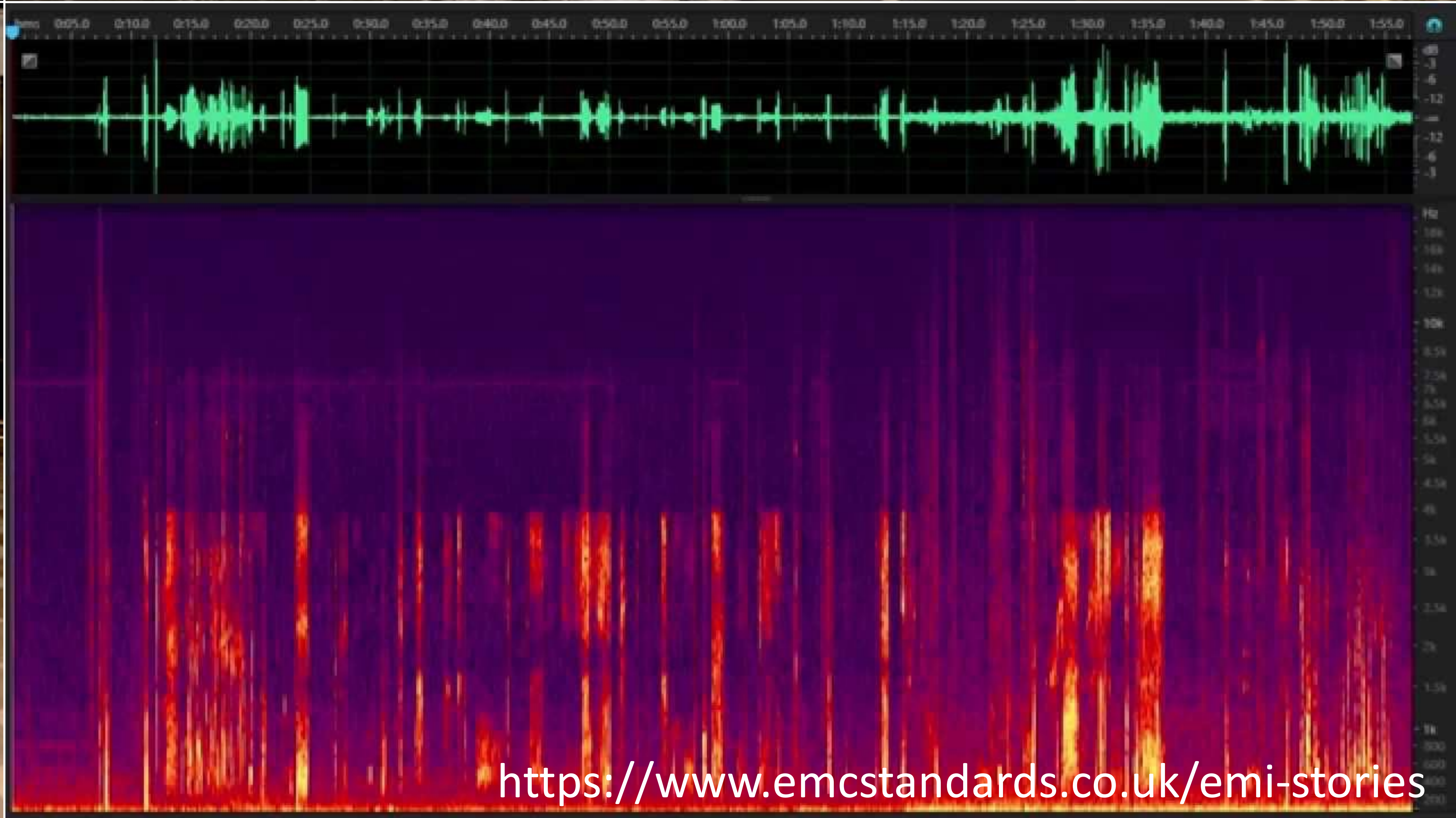


Electromagnetic Interference


Ray-Ban



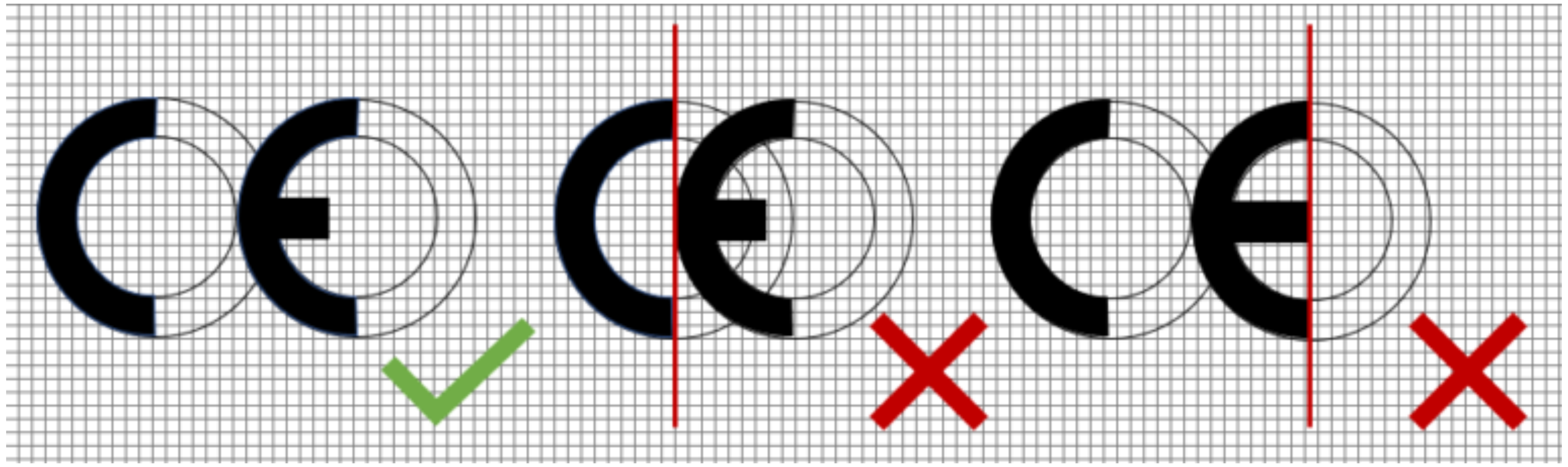

TELEPHONE



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

EMC Directive

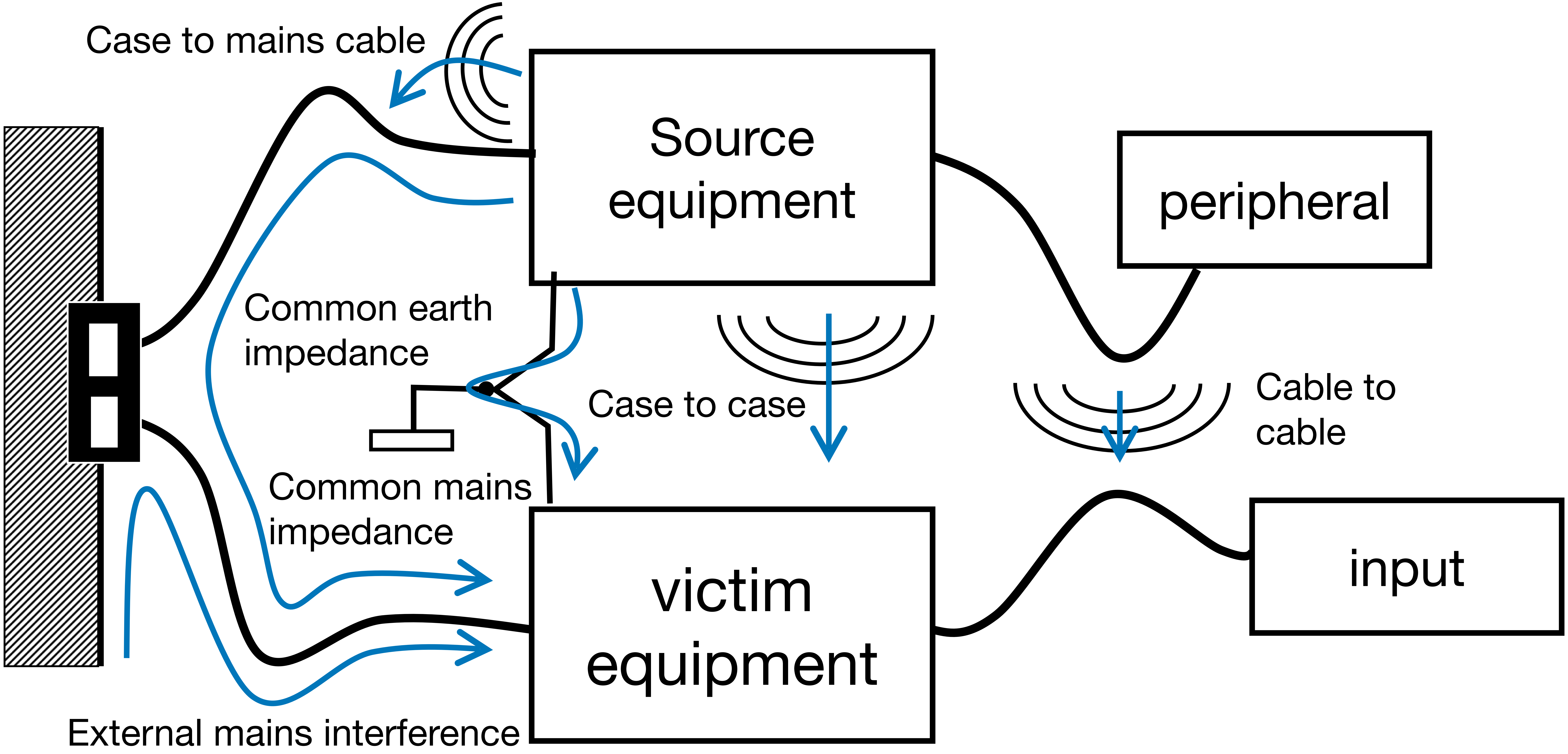
- The ability of the system to operate without interfering with other systems
- The ability of the system to operate despite interference from other systems
    - Under *typical conditions* (domestic, commercial, industrial)



Electromagnetic Interference

What are sources of EMI in your system?

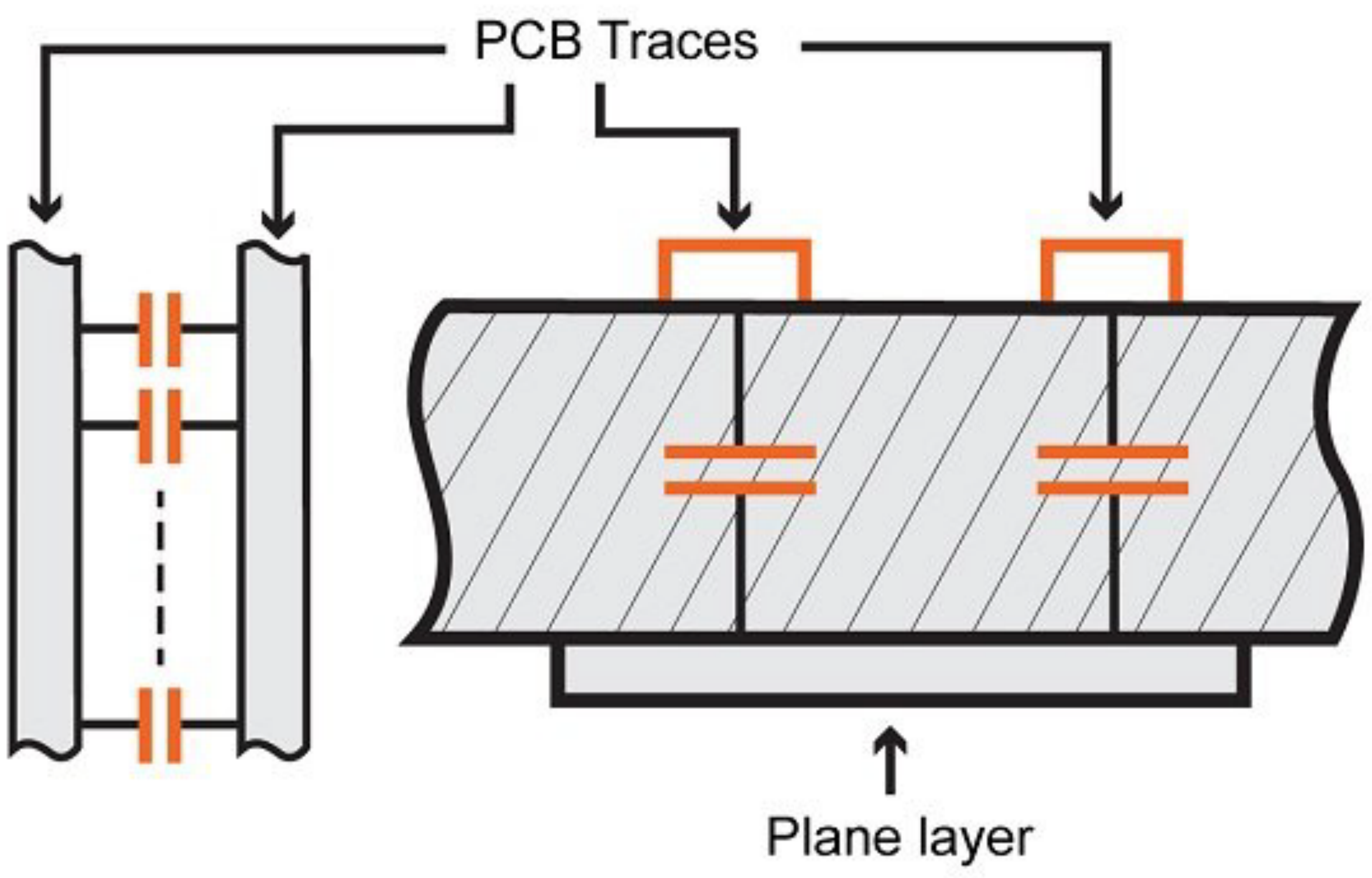
Electromagnetic Interference



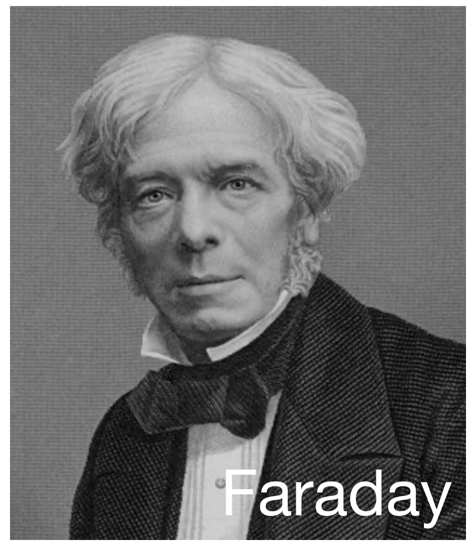
Two modes of interference: Conducted EMI , Radiated EMI

Conducted EMI

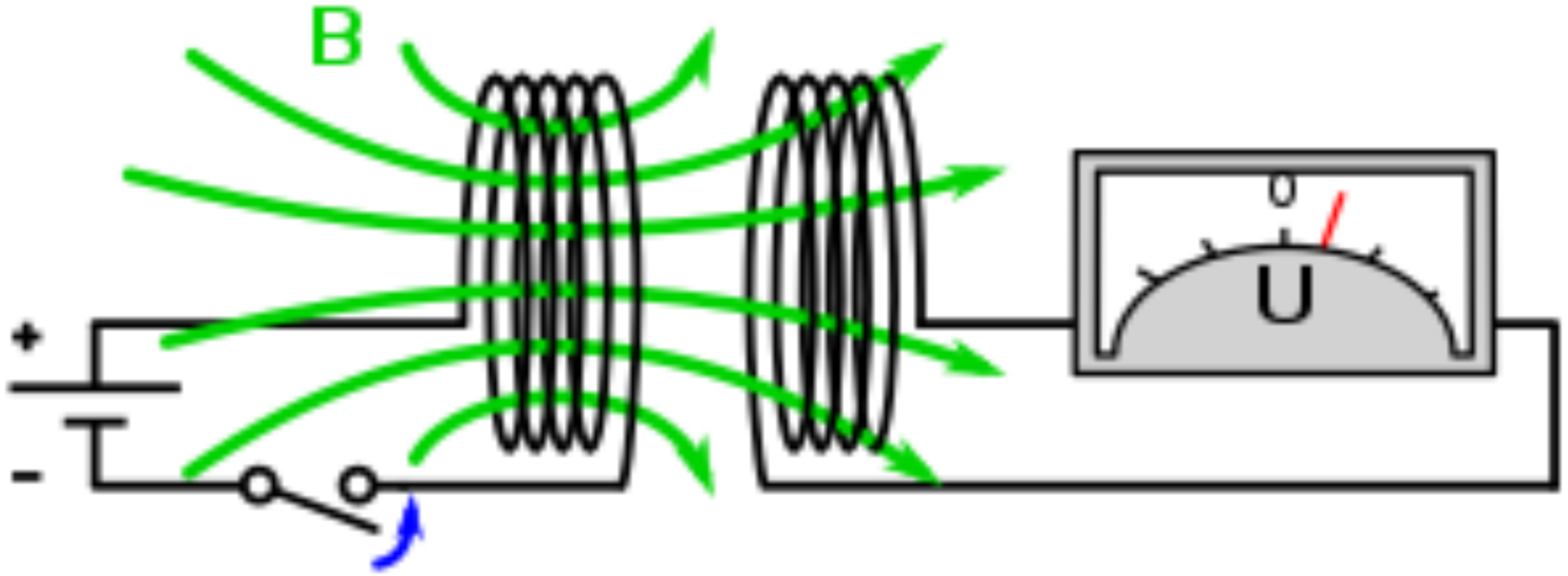
- Shared current paths in resistive wires
  - Ohm's law: $V = IR$
  - Longer shared paths, higher coupling
- Parasitic capacitance
  - Electric field over short distances
  - Higher frequency, higher coupling

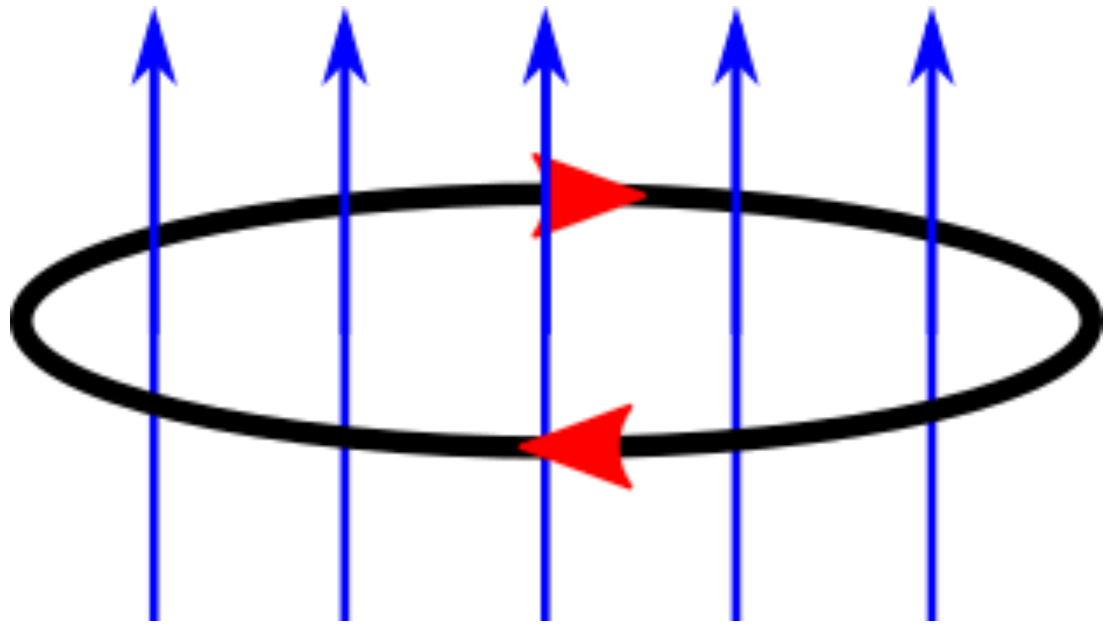


Radiated EMI



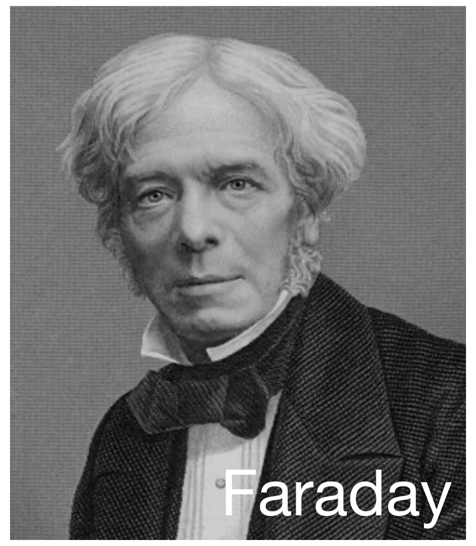
- Faraday's Law
  - Electromotive "force" [V]
  - $EMF = -N\frac{\Delta\Phi}{t}$, where $\Phi = BA$
- Lenz's Law
  - EMF produces a current with a magnetic field that opposes the source
  - Radiated EMI increases with…
    - magnetic field strength
    - loop area
    - signal frequency

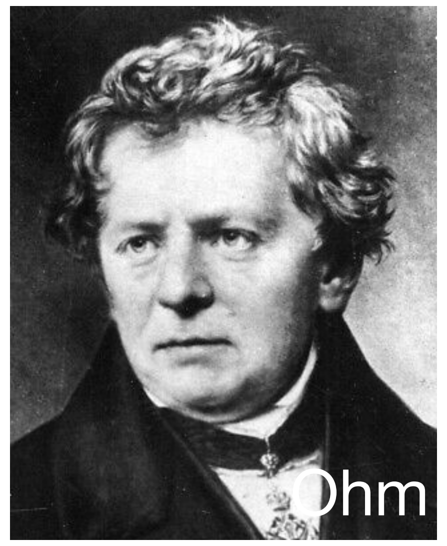




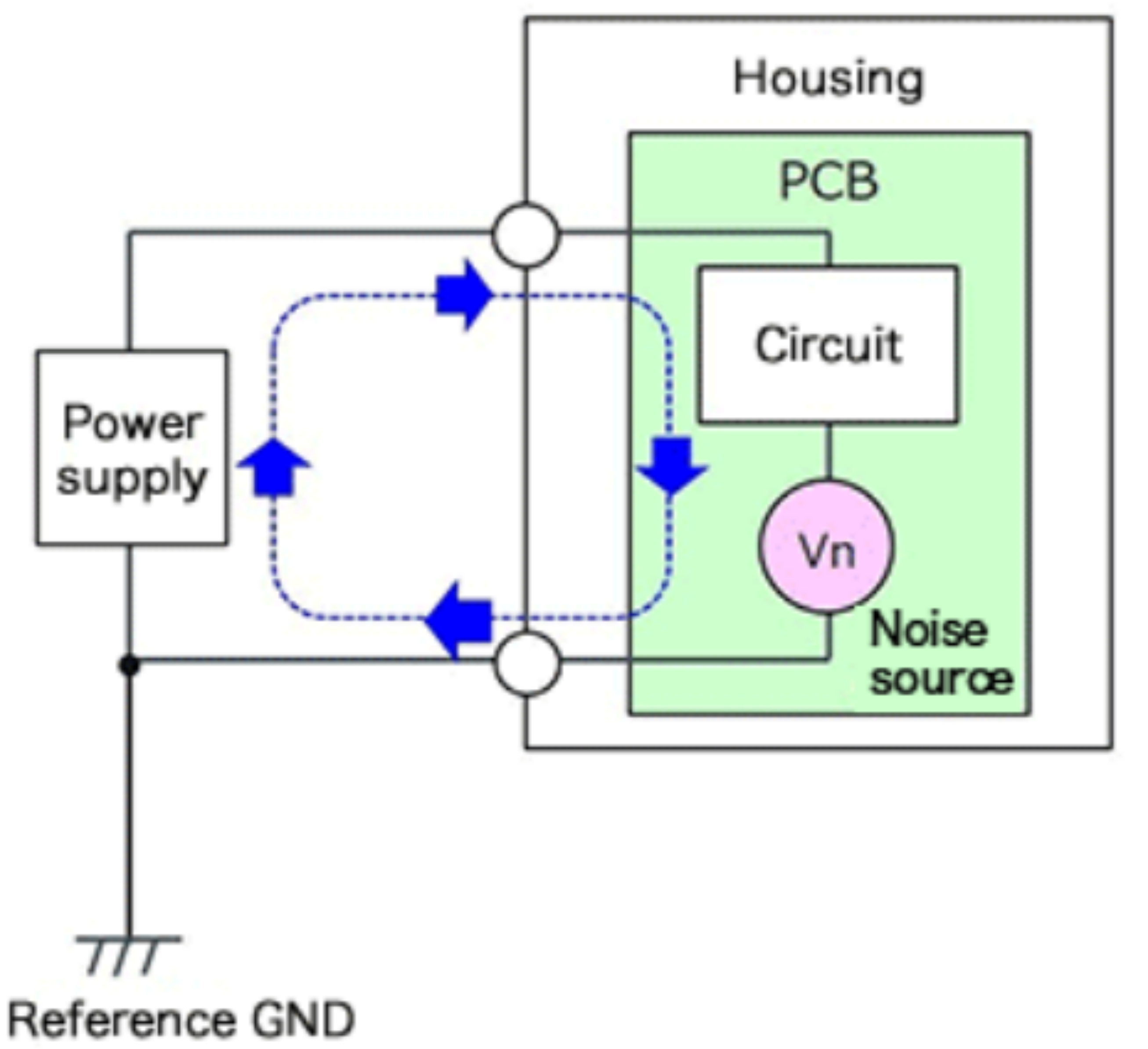
(Flemings right hand rule)

Common/ Differential Mode Noise



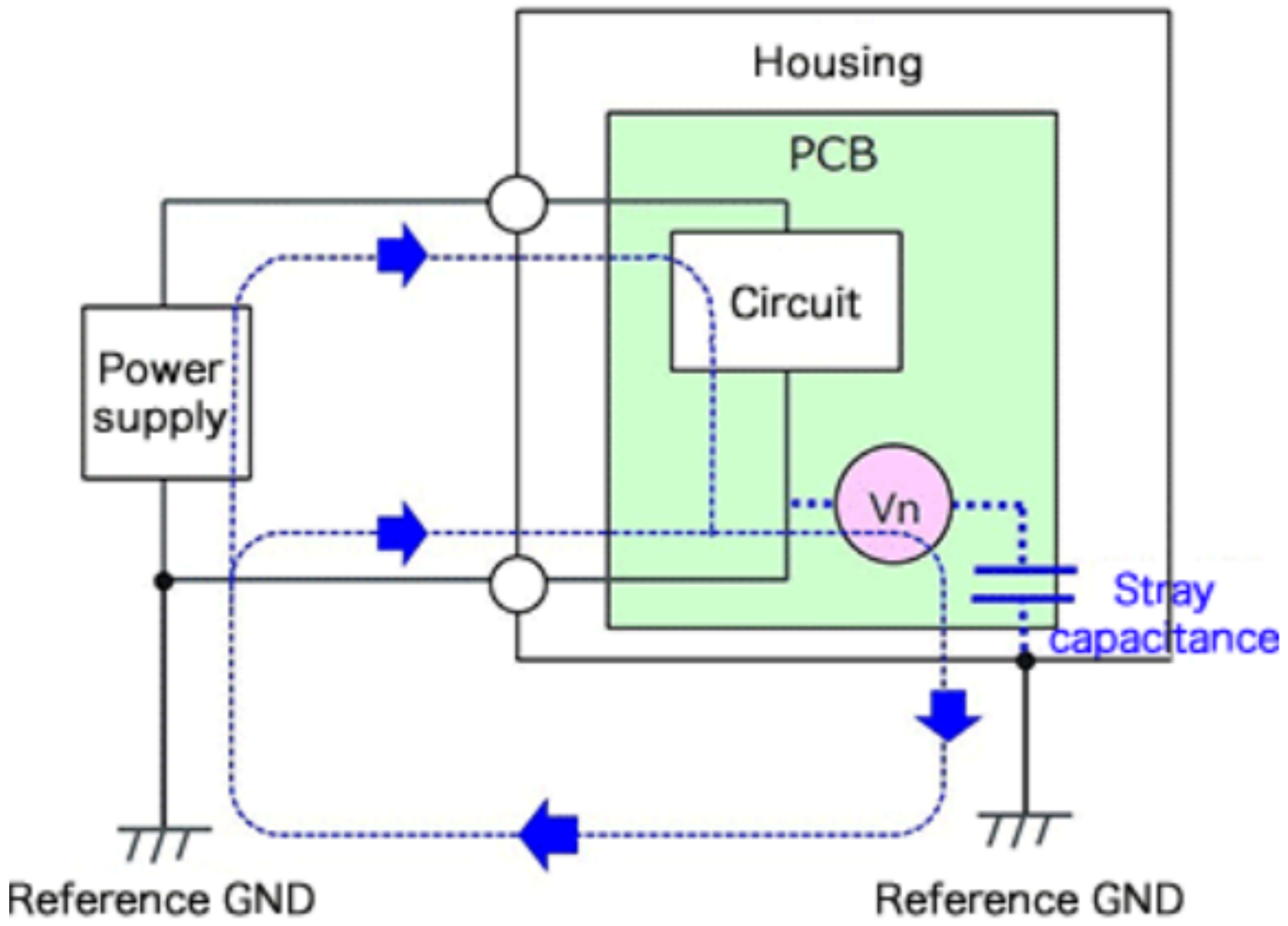


Differential (normal) mode noise



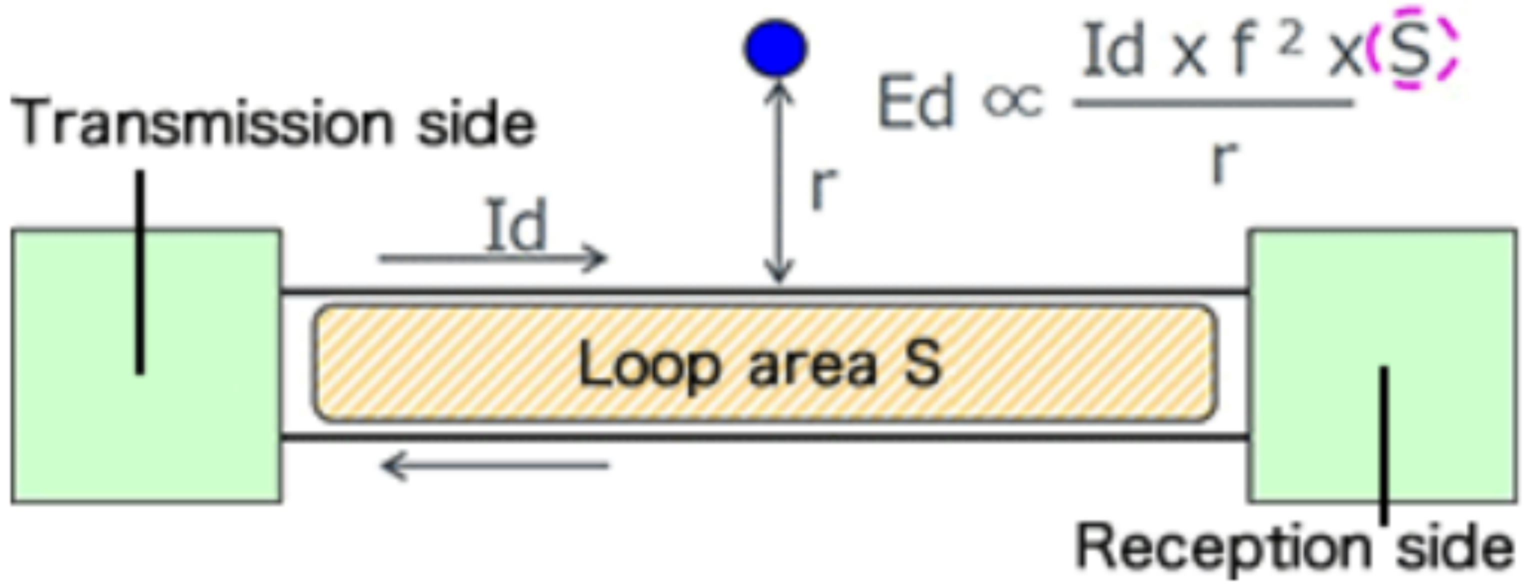
- A mode in which a noise current flows on the same path as the power supply current
- Noise voltage occurs across power supply lines

Common mode noise

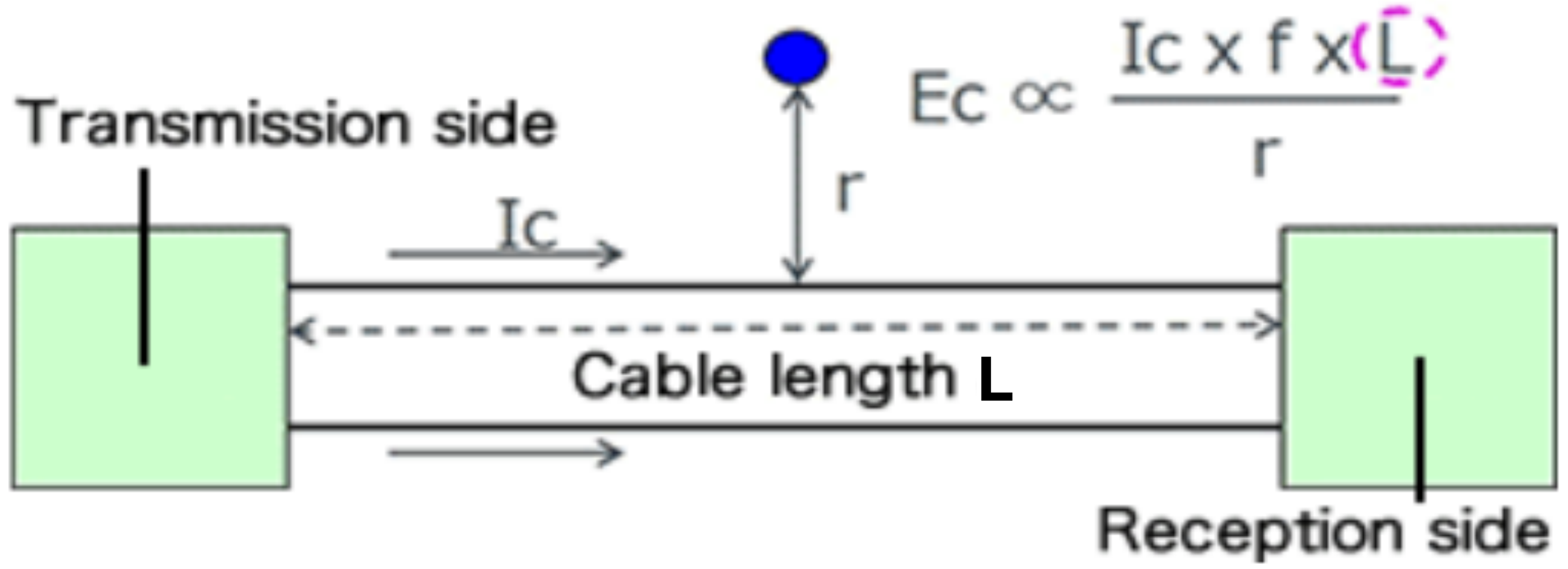


- Noise voltage does not occur across power supply lines
- Noise voltage occurs across power supply line and reference GND
- Noise currents flow in the same direction on the power supply positive and negative sides

Radiation due to differential mode noise



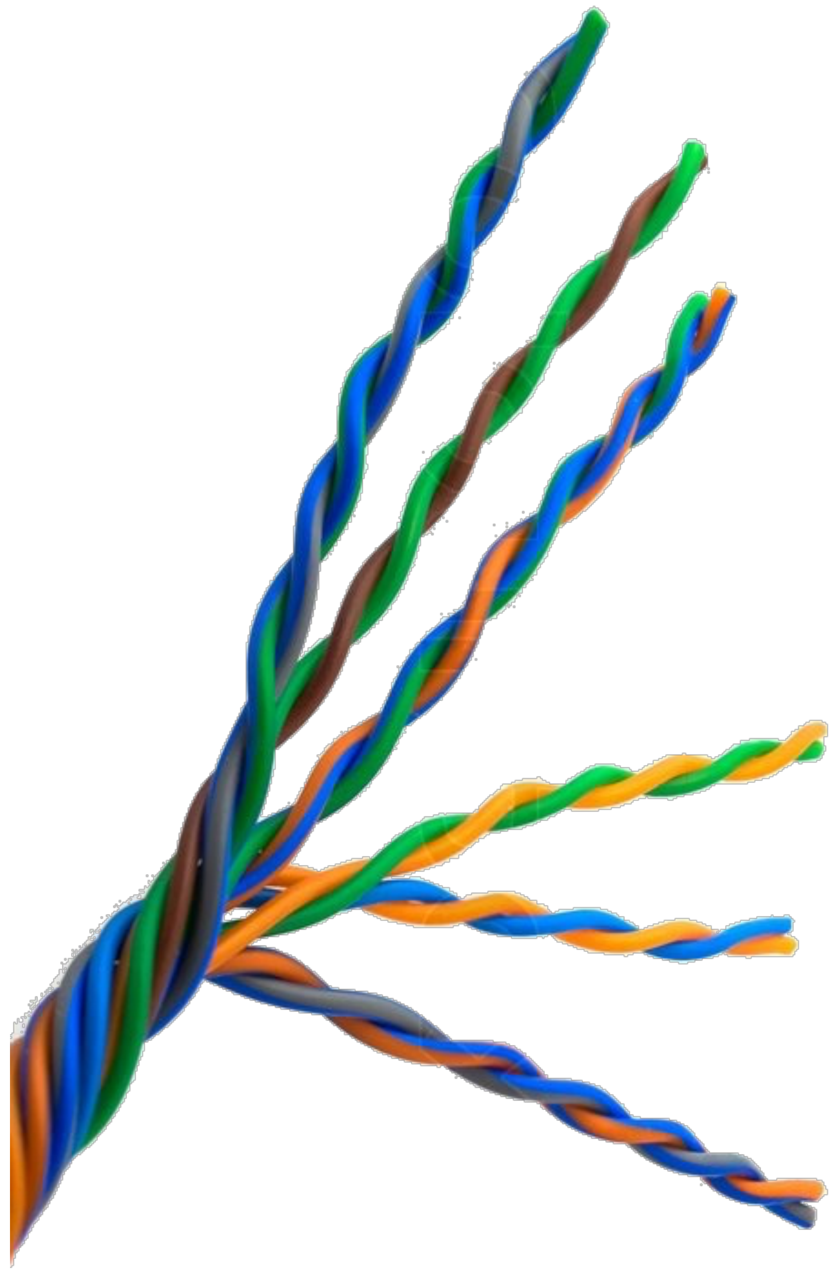
Radiation due to common mode noise

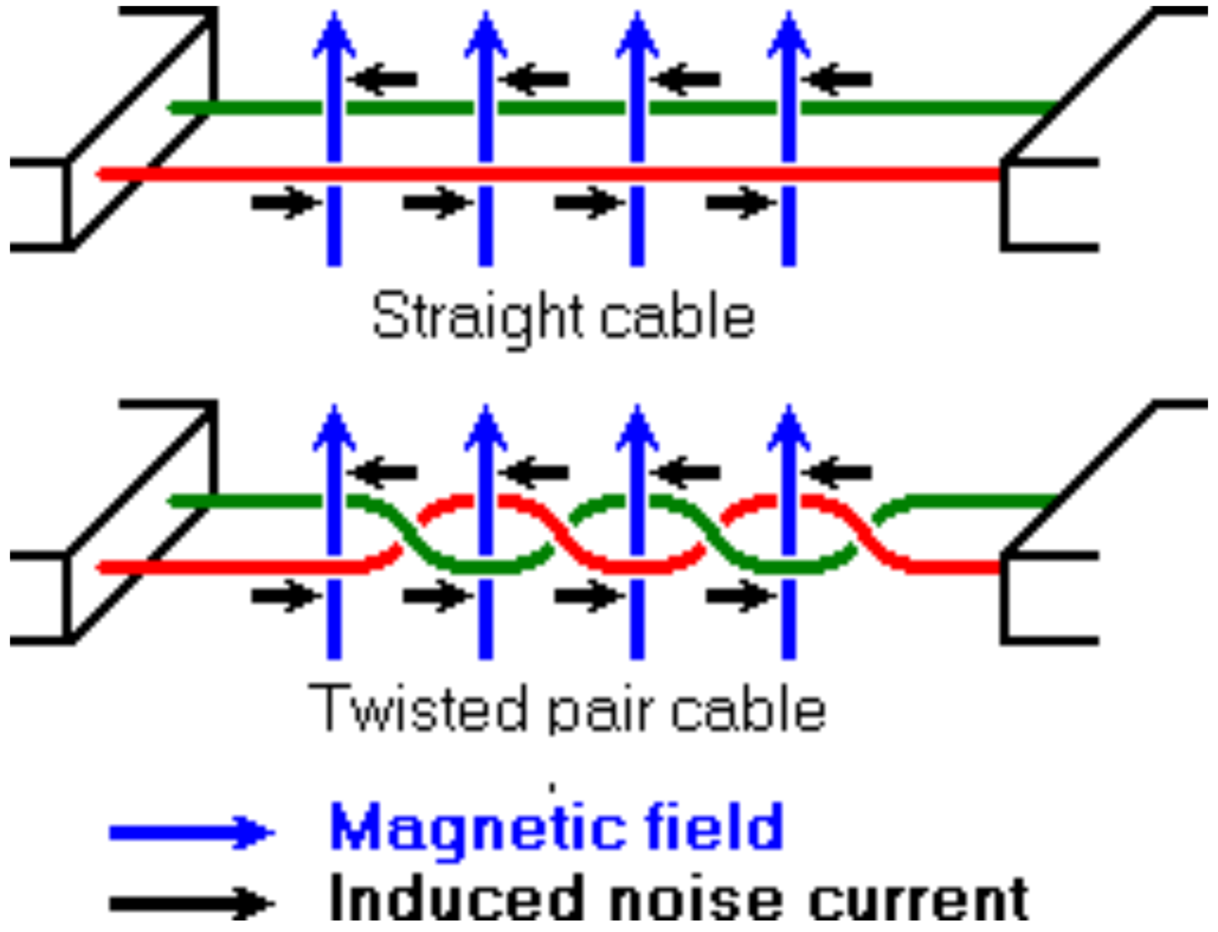


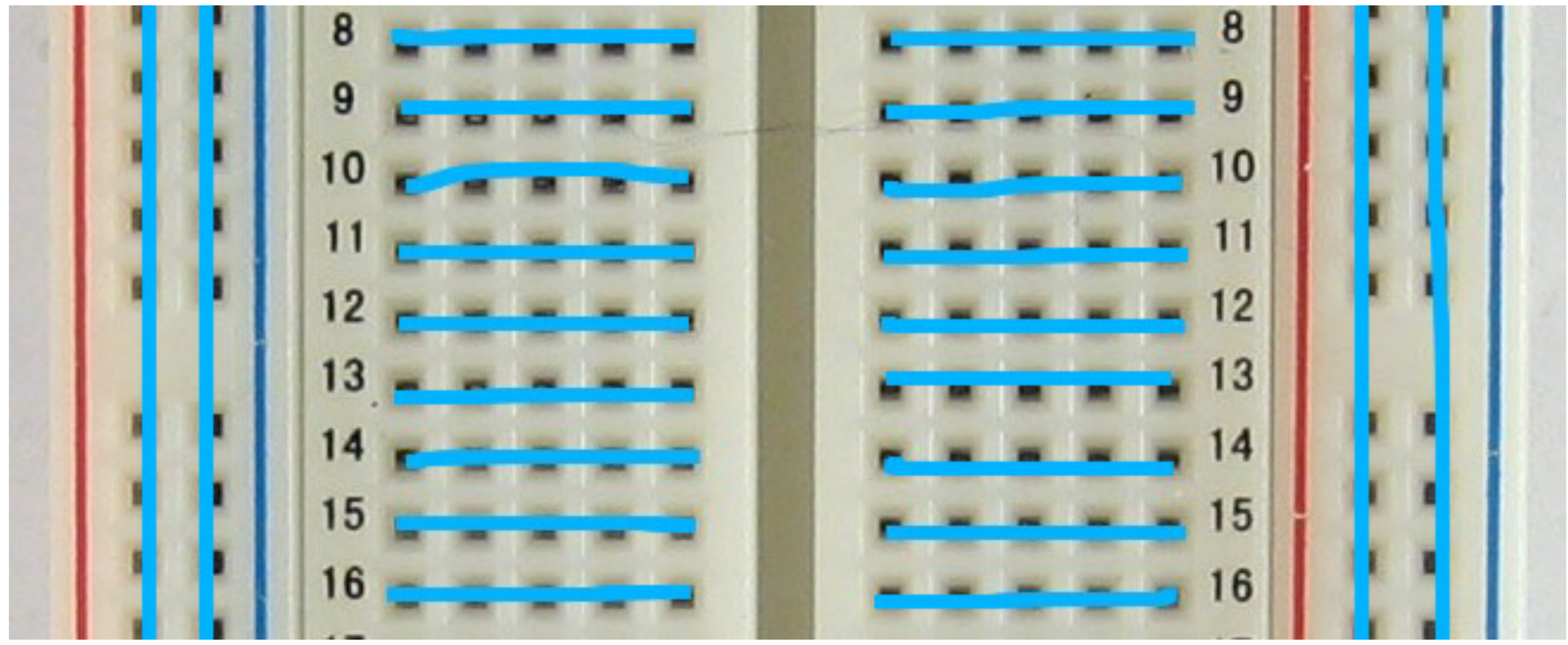
Common/ Differential Mode Noise

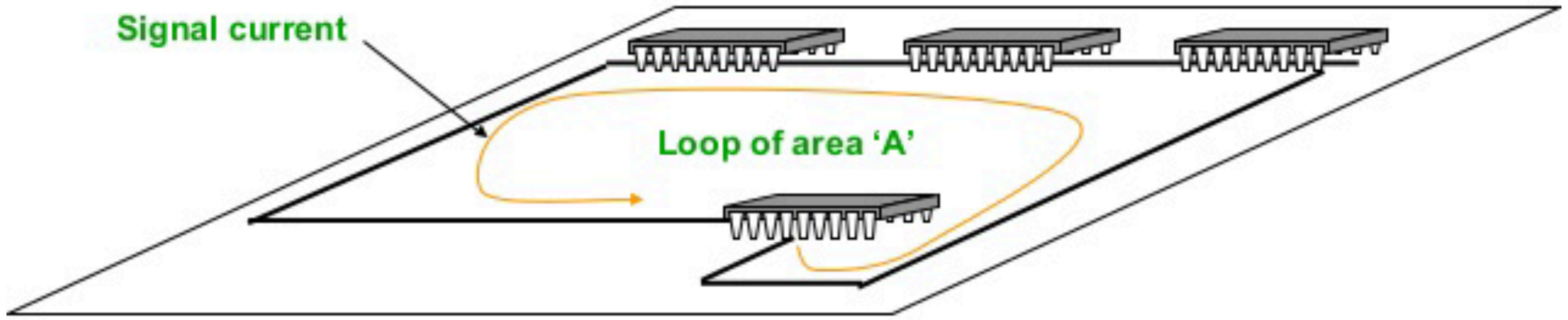
How do we suppress noise?

- Use lower frequencies when possible
- Use shielded cables
- Minimize common impedances
- Lower loop area
- Twist out/return cables

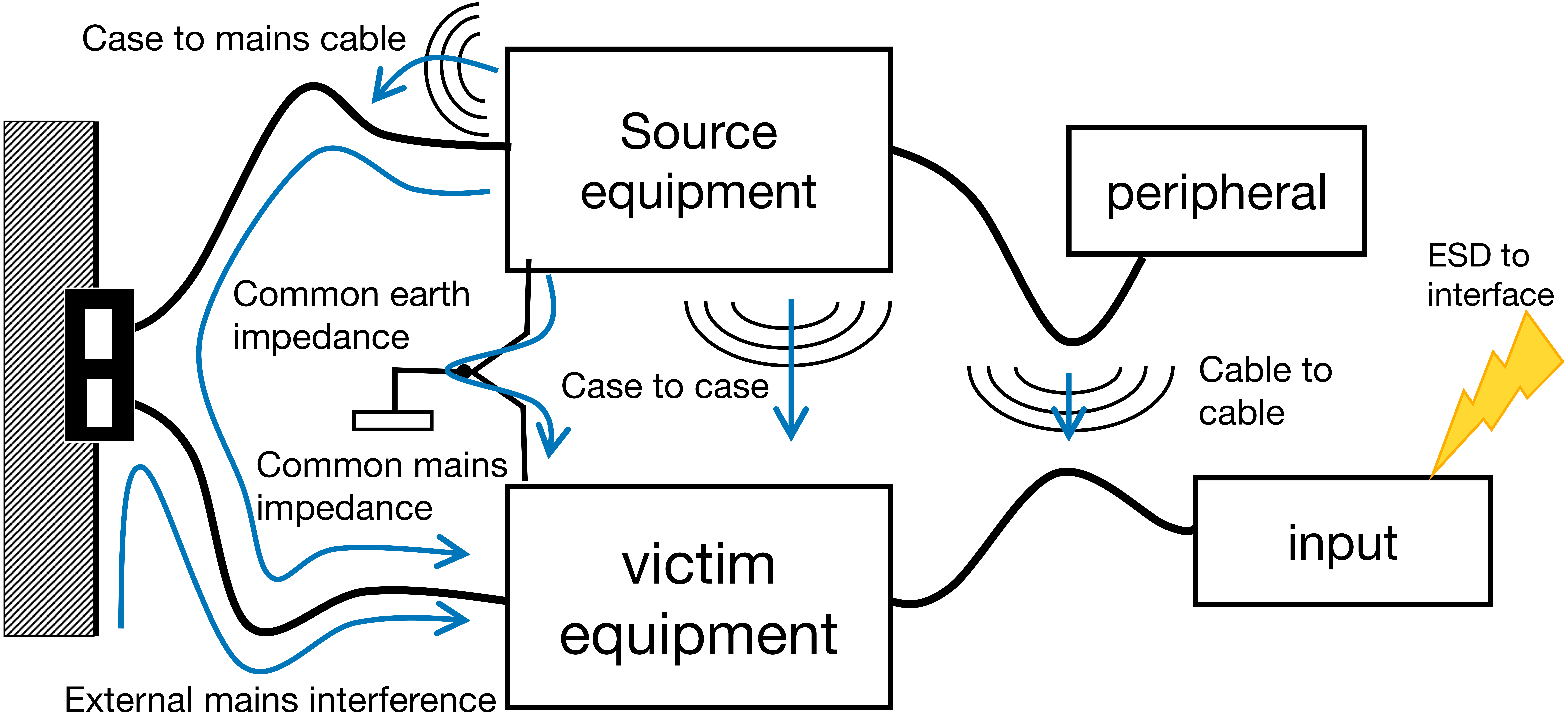






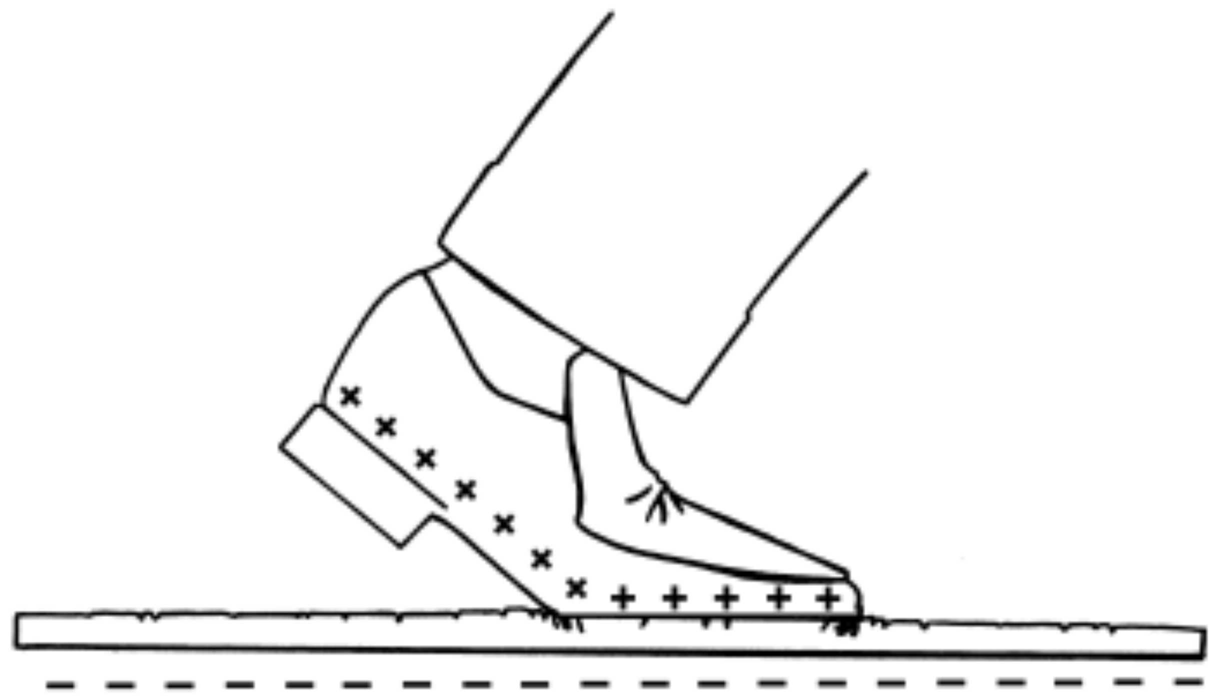


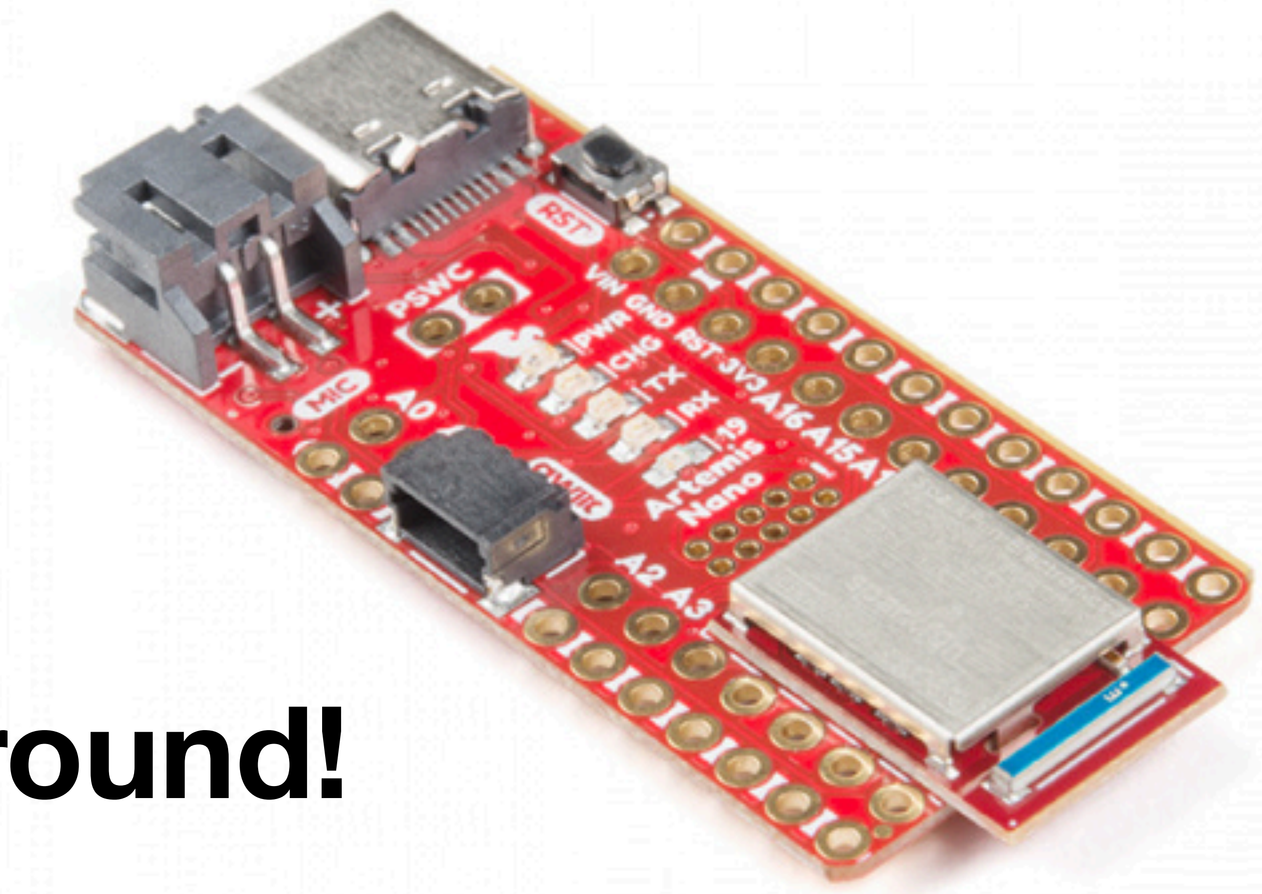
Electromagnetic Interference

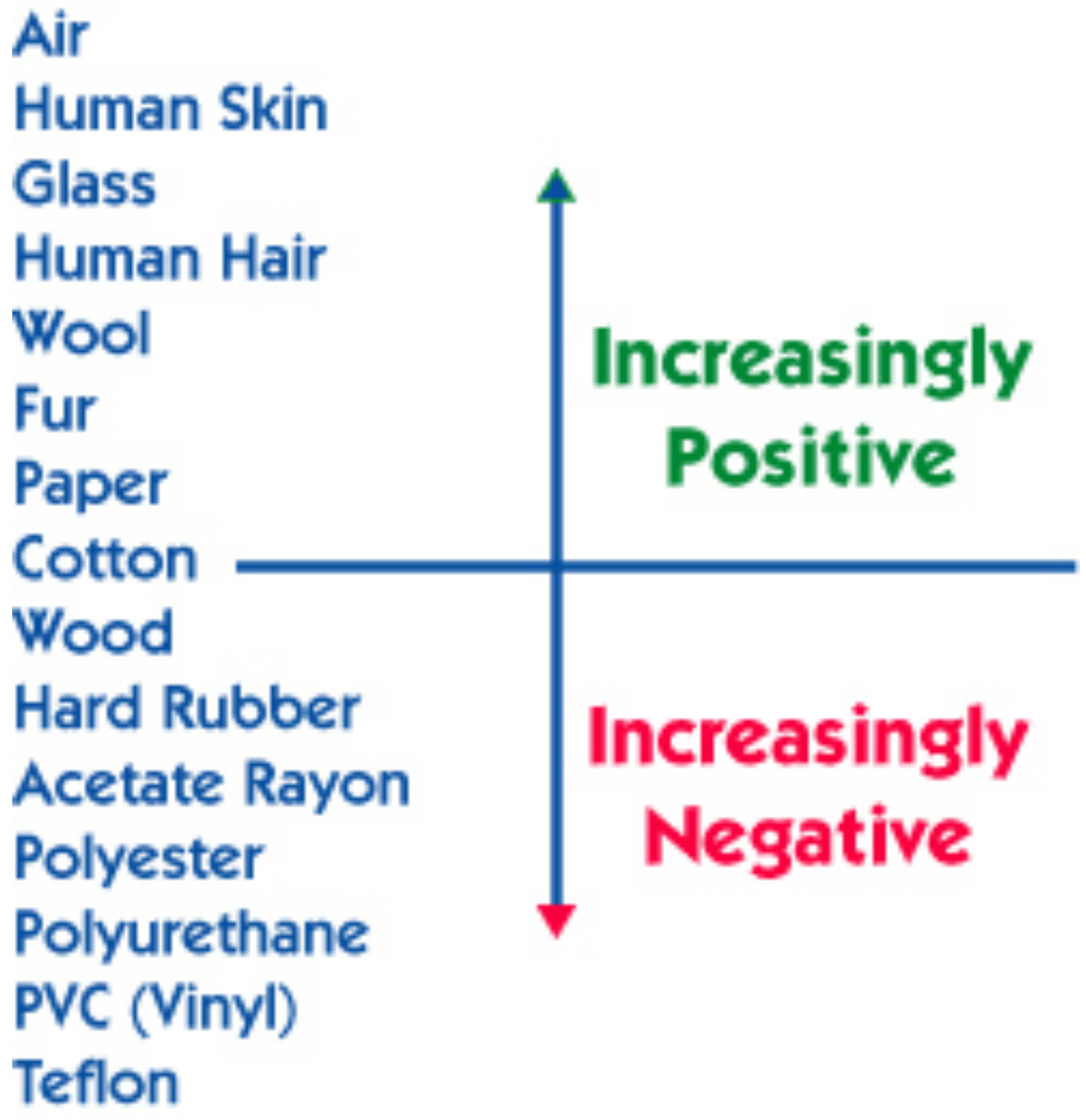


Electrostatic Discharge

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





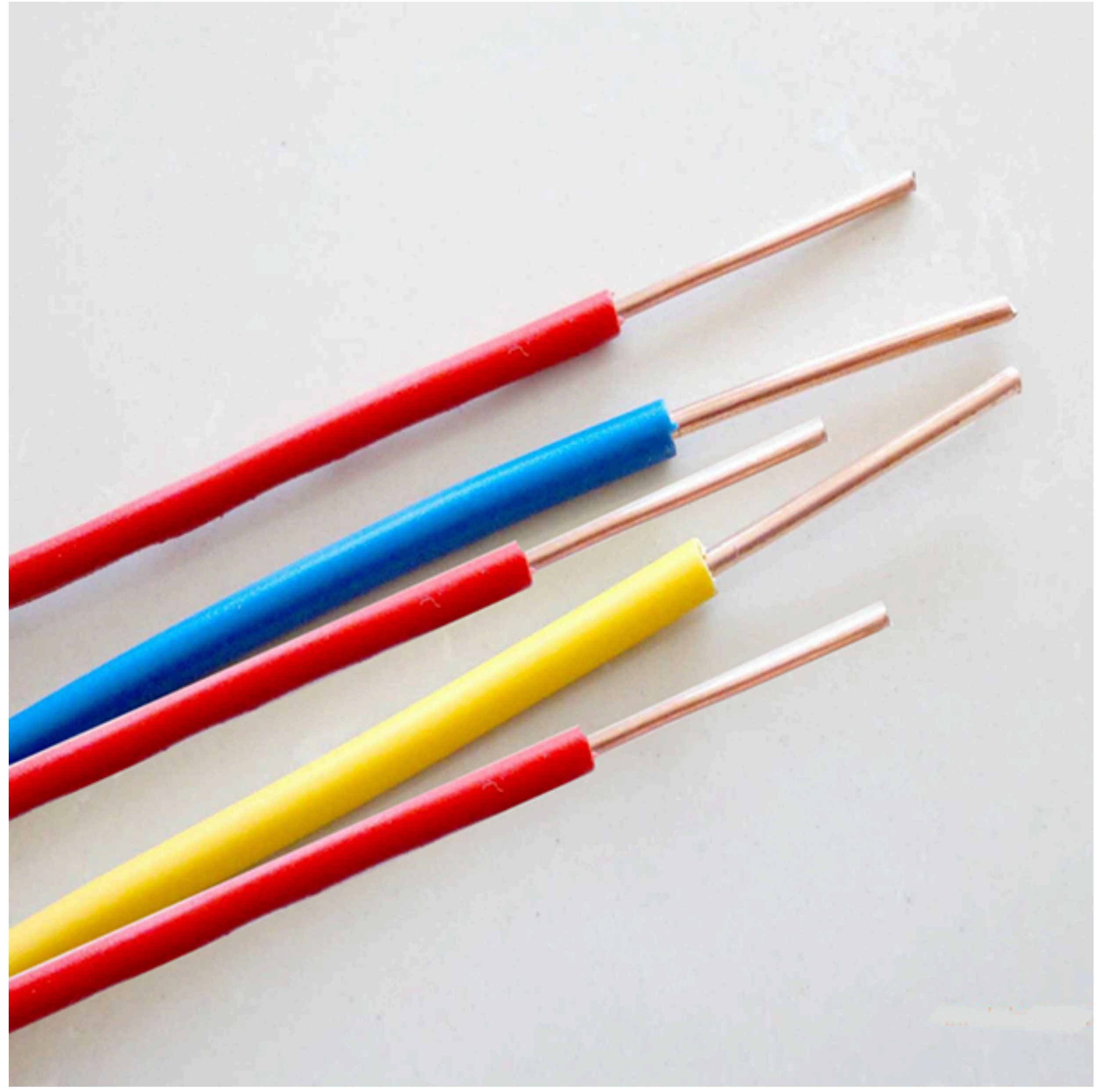


Always discharge through ground!

Wiring and routing

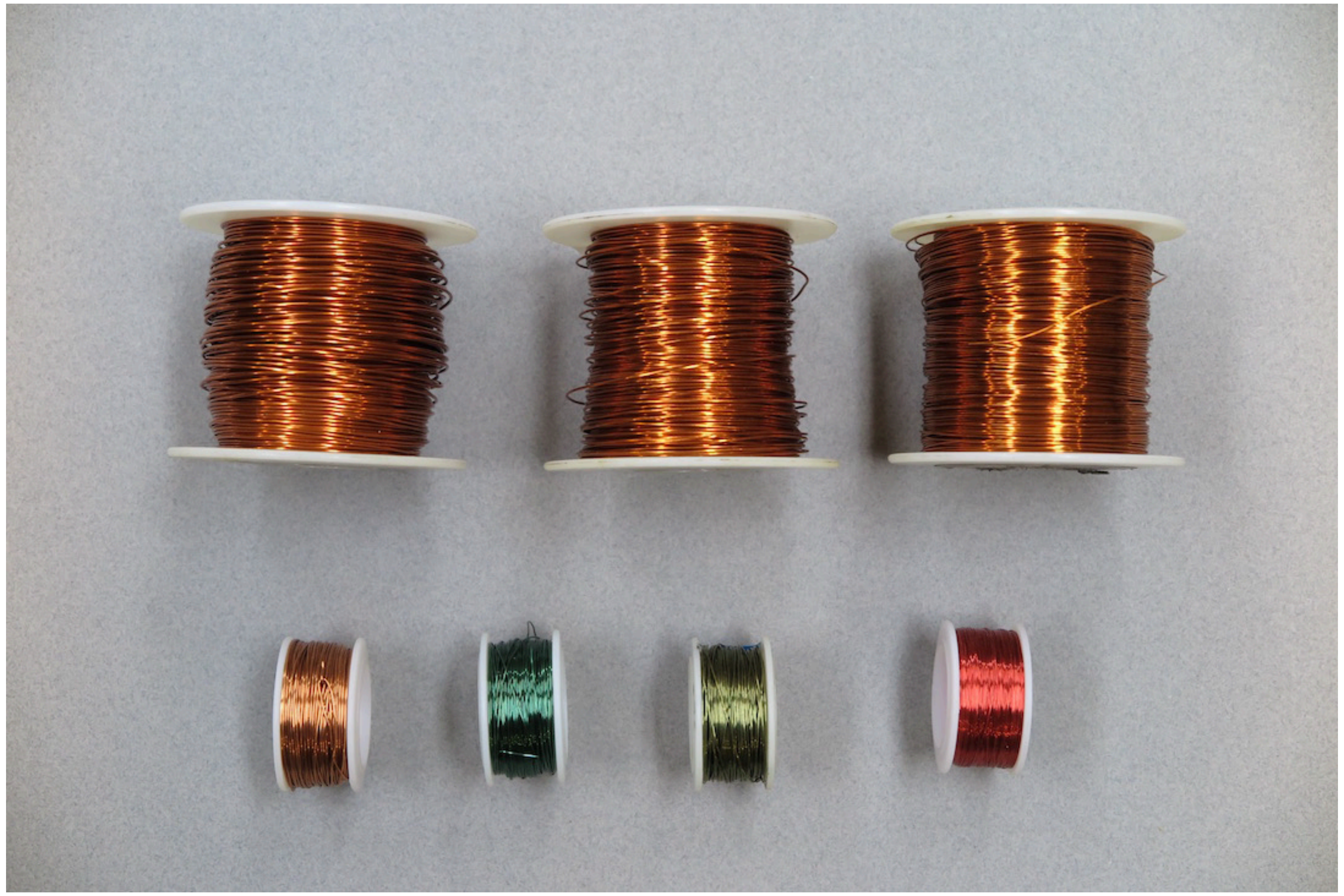
Wire types

- Power and transmission wire: sized according to current
- Signal wires: carry little current, more susceptible to EMI
- Solid core: holds shape, brittle
- Stranded: flexible, use anywhere position is not permanent
- Insulation: Polyvinyl chloride (most common), polyethylene, polyester, rubber, teflon, silicone



Wire types

- Magnet wire
  - Use in motors, transformers
  - Thin, enamel-like, tough coating
    - 100-1000s V and 100s °C
    - Remove with heat, solvent, scraping
  - Cannot tolerate repeated bending



Wire gauge

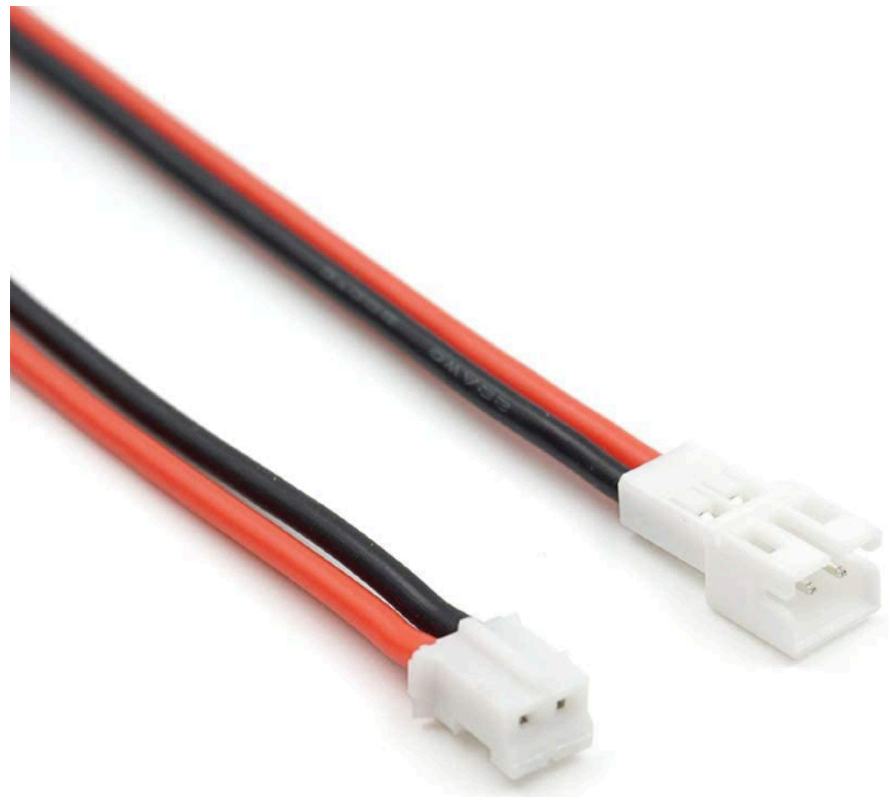
- US standard is American Wire Gauge (AWG)
- Larger the gauge, thinner the wire
  - AWG ≤ 16, power transmission
  - AWG 18-22, low-power motor supplies
  - AWG > 22, signals
- Stranded wire
  - AWG 16 26/30

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

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

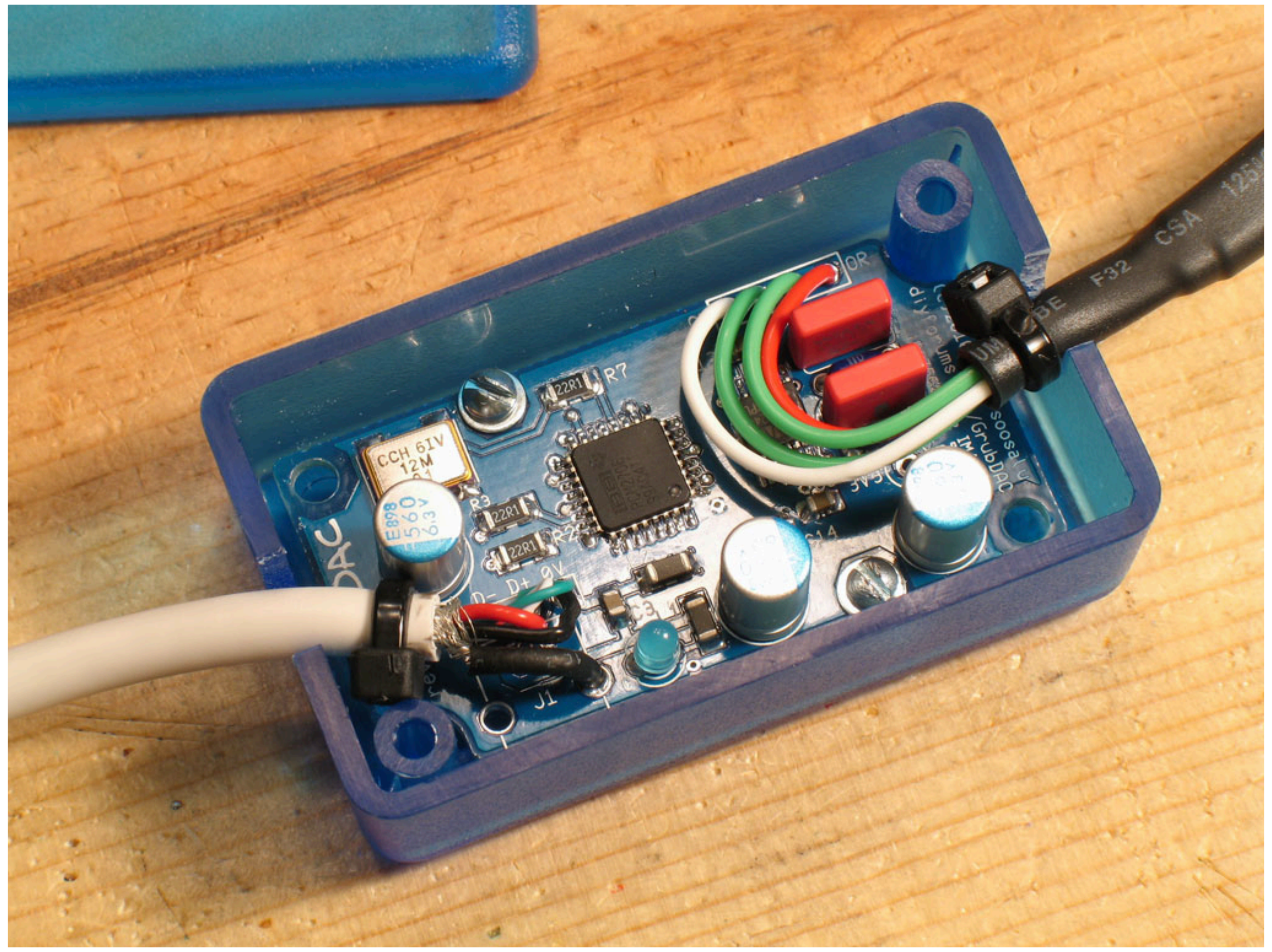
Connection points

- Solder permanent connection points
- Minimize connection points
  - Can use for modularity
- Connectors
  - Signal transfer
  - Power transfer
  - Female: hot side, male: receiver
  - Reversible
  - General
  - Protocol



Good practice

- Use color convention
  - Red/Black: VCC/ GND
  - Purple: battery voltage
  - Green/white/yellow/orange/blue: signal
- Fastening
  - avoid pinch points
  - service loops
  - strain relief
  - hot glue: good for semi-permanent connections (brittle)
- Insulation
  - Hot glue
  - heat shrink
  - tape: ages, leaves residue



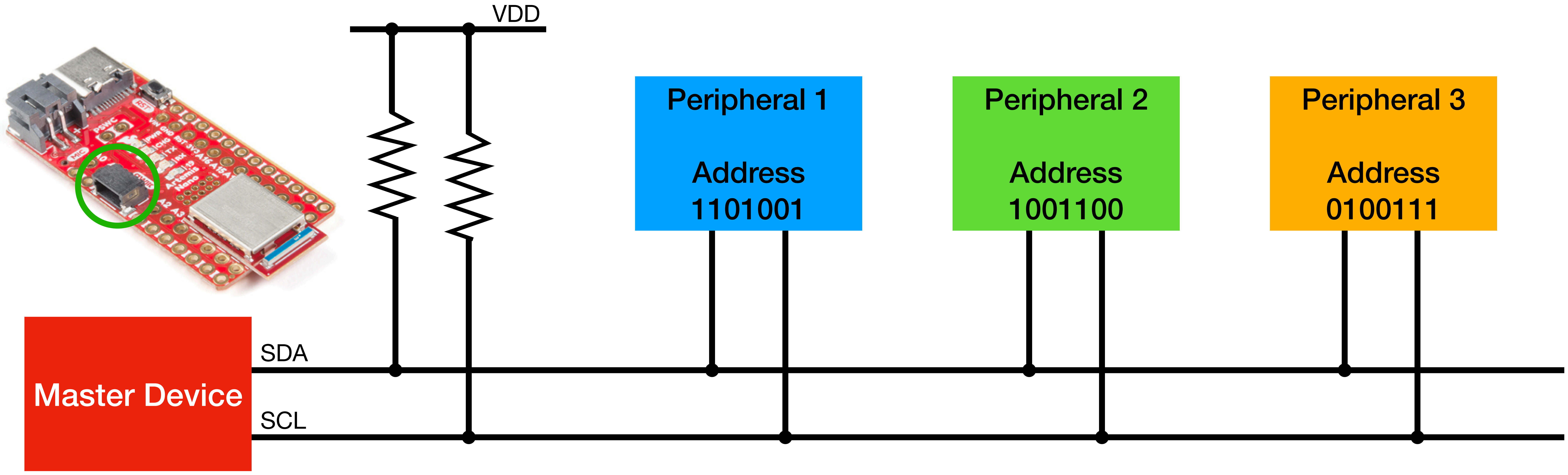
Labs 2-4 Hardware integration

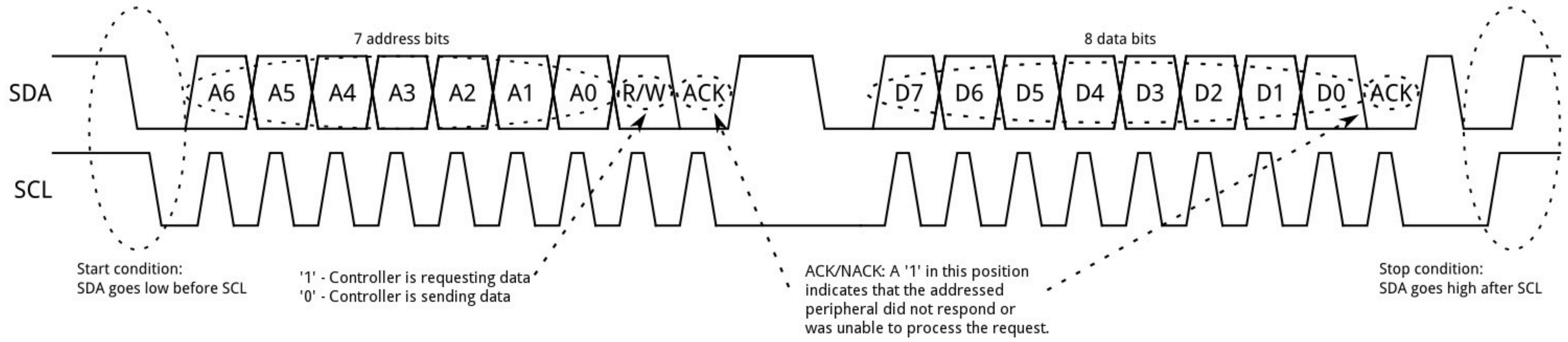
Hardware Labs

- Lab 2: IMU sensor
- Lab 3: ToF sensors and batteries
- Lab 4: Motor drivers and open loop control

Lab 2-3: Communication with sensors

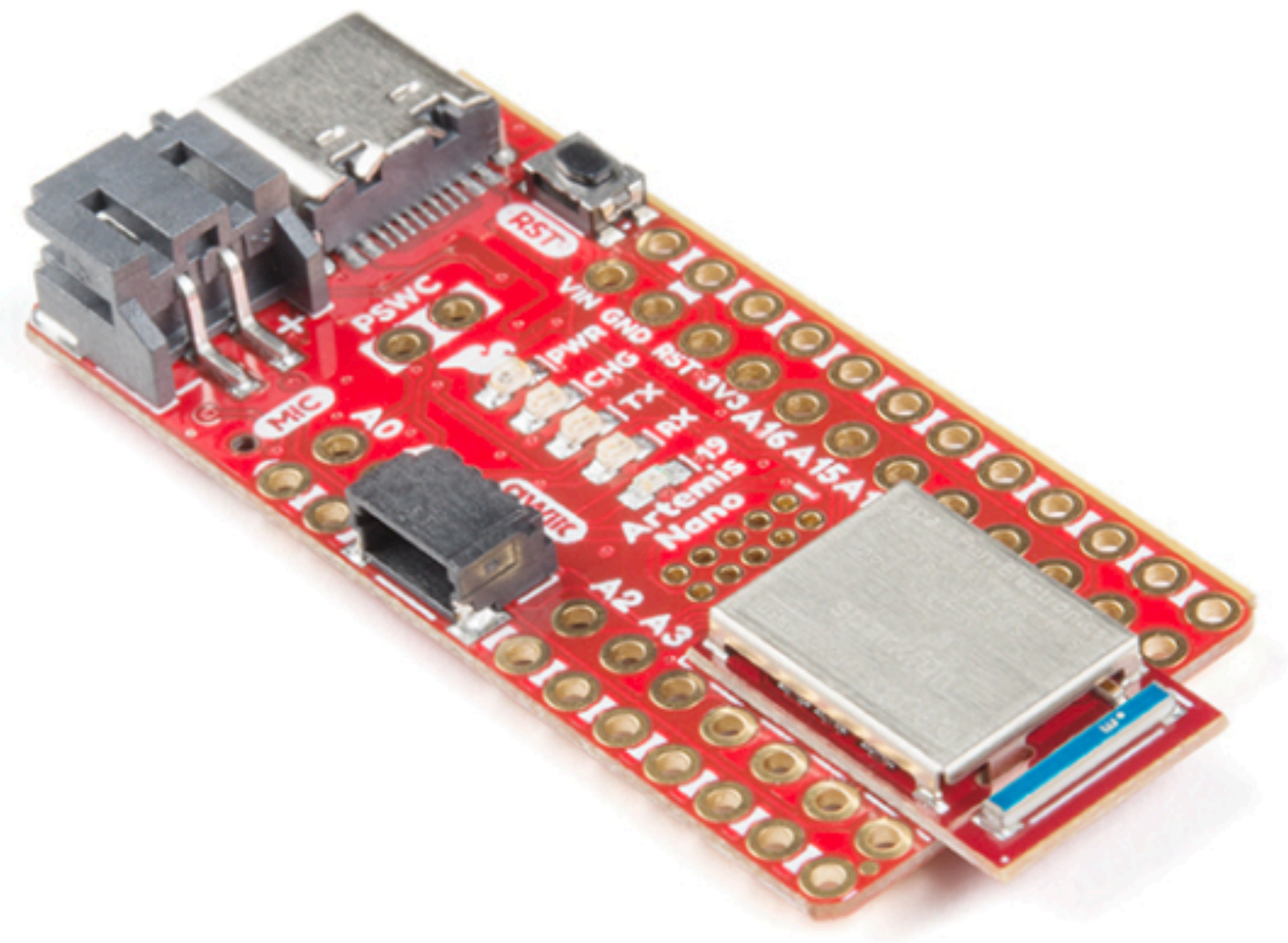
I2C

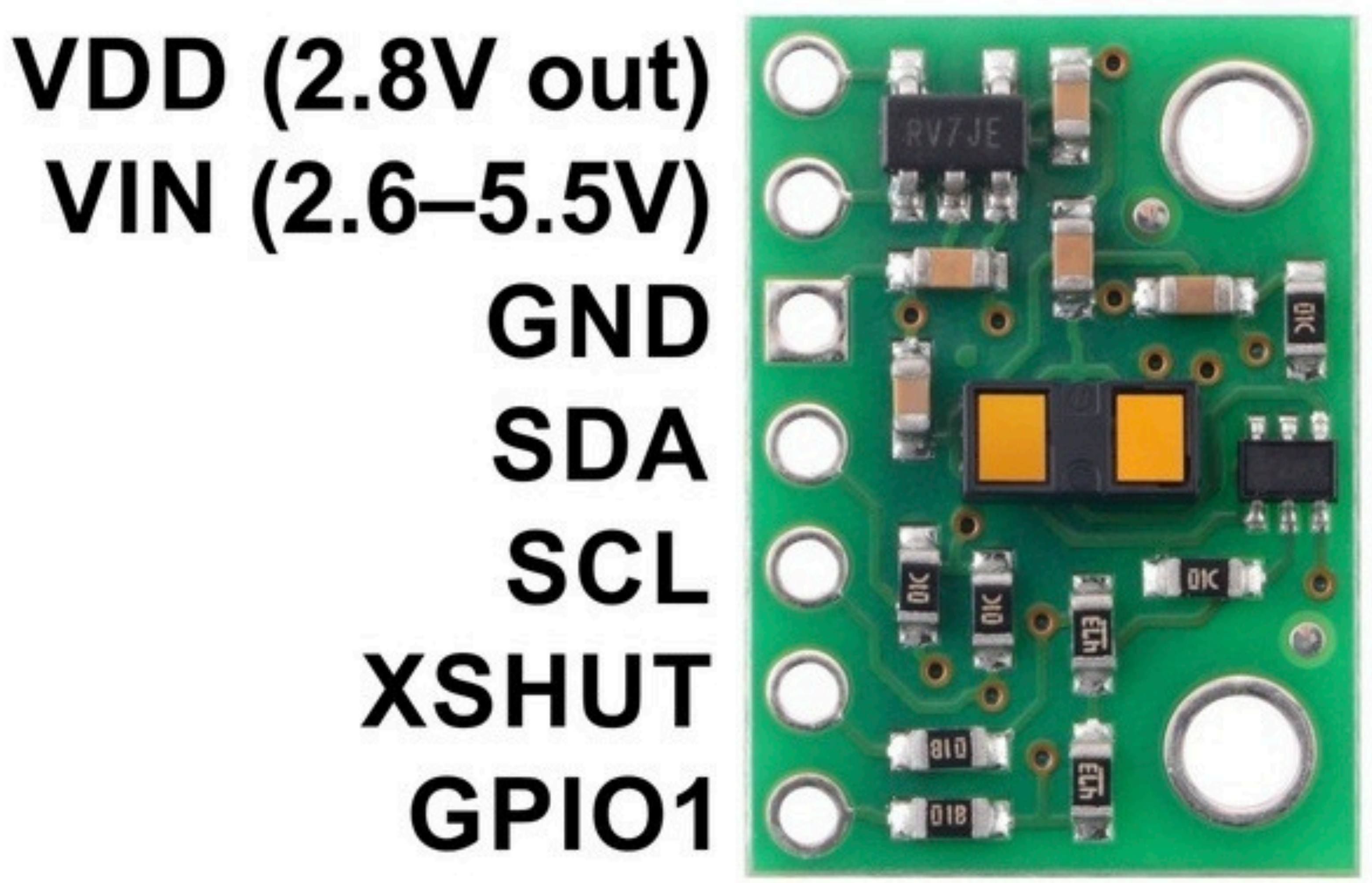


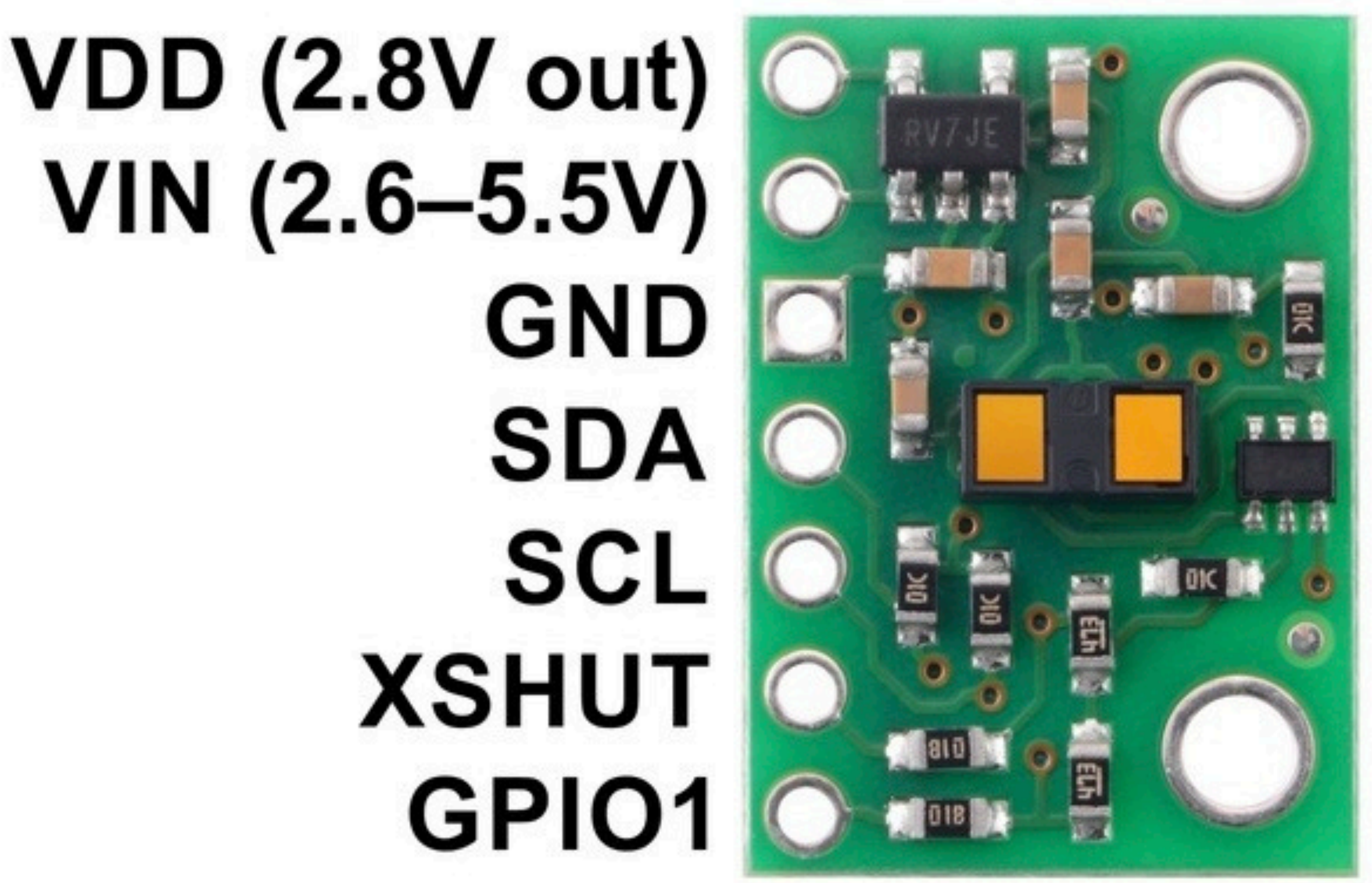


Lab 2-3: Communication with sensors

Lab 3: two sensors have the same default address!





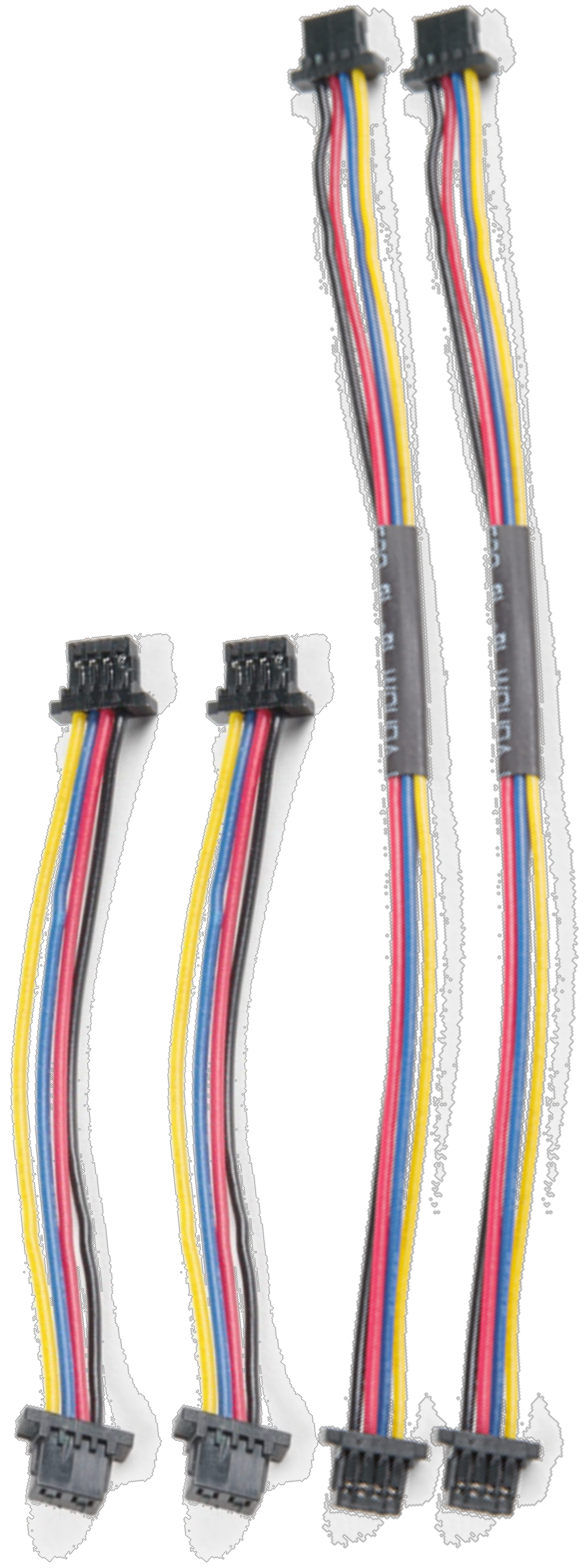


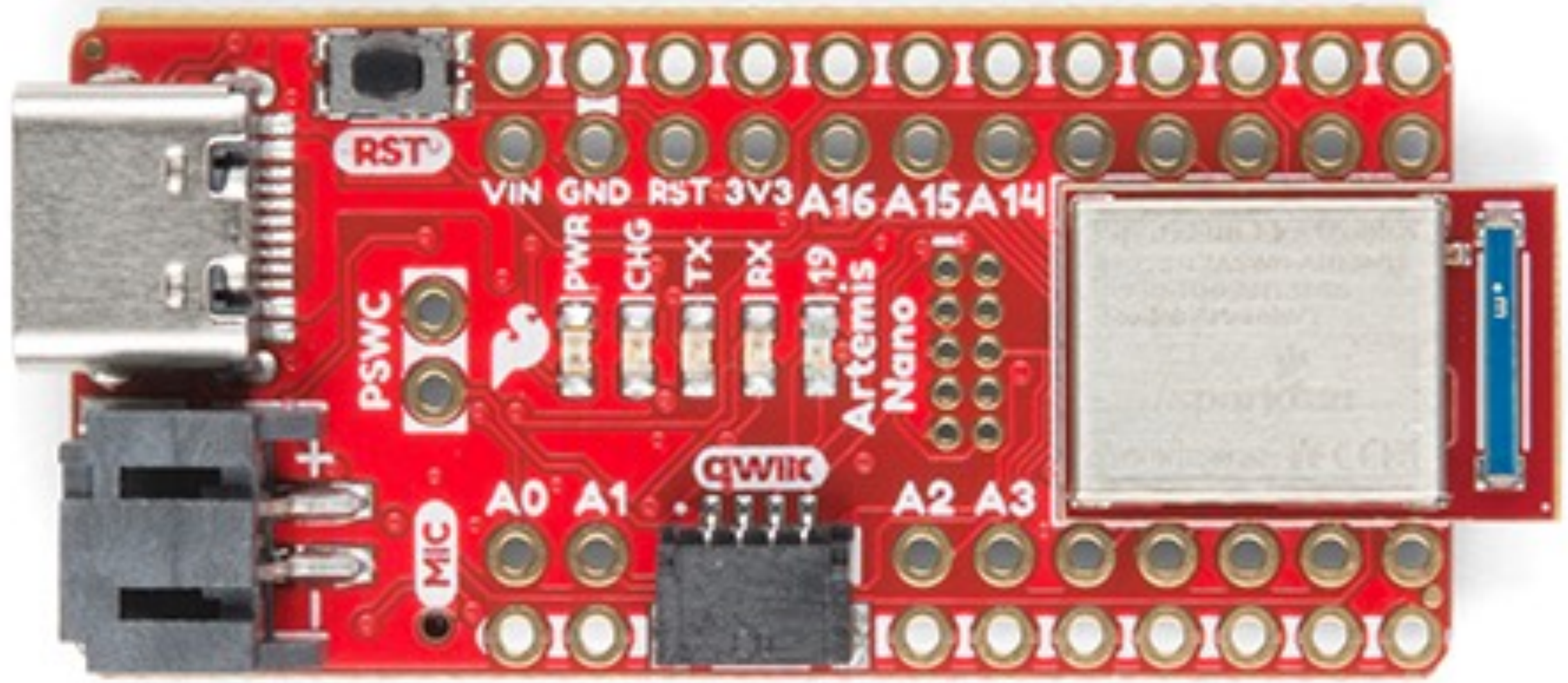
Hardware Labs

Things to consider

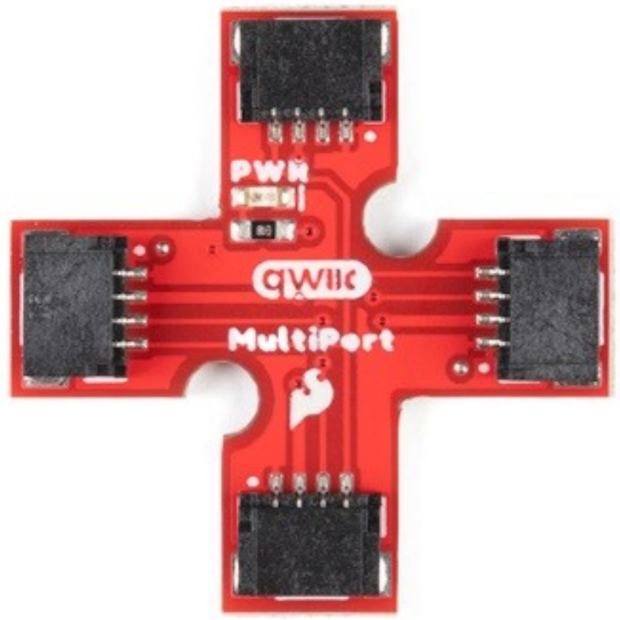
- Where/ how do you place components?
- Routing paths (w/ EMI considerations)
- Color coding
- Permanent solder joints/ detachable connections?
- Single core or braided wires?
- Which side of the breakout boards do you want to solder to?
- What cable will you use where? Which will you cut for the ToF sensors?
- Identify the colors of the signals in the QWIIC cable (GND, VCC, SDA, SCL)
- In lab 3 and 4, focus on getting your soldering done if you don't have access outside of lab!

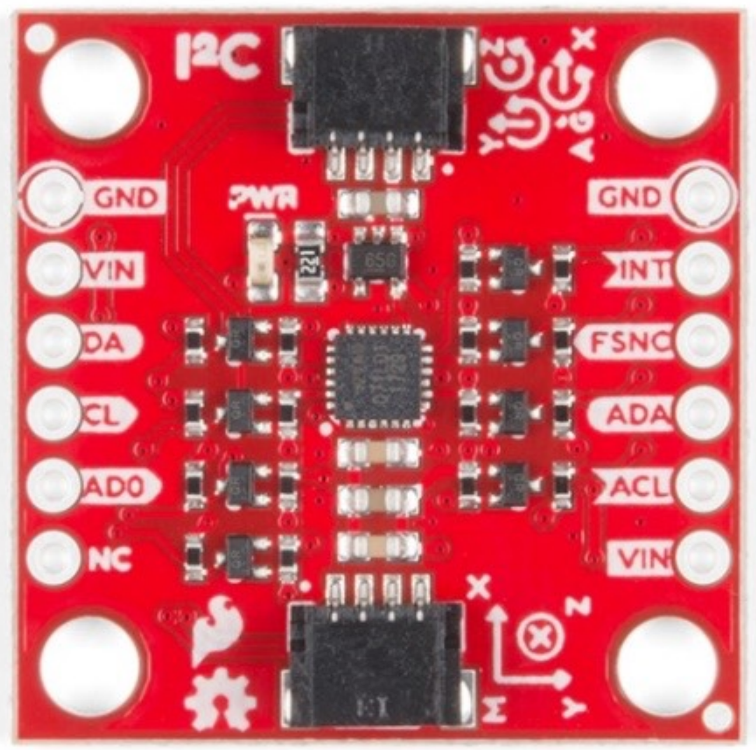
Hardware





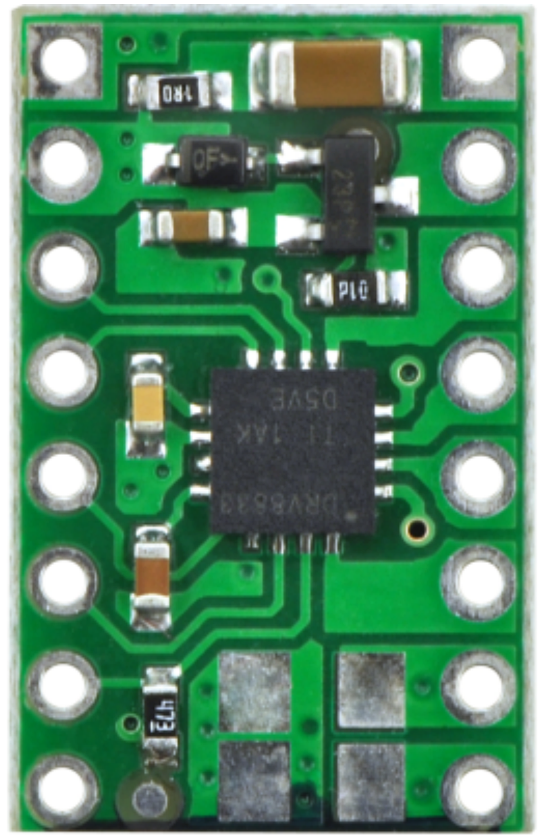
Artemis Nano (Sparkfun)

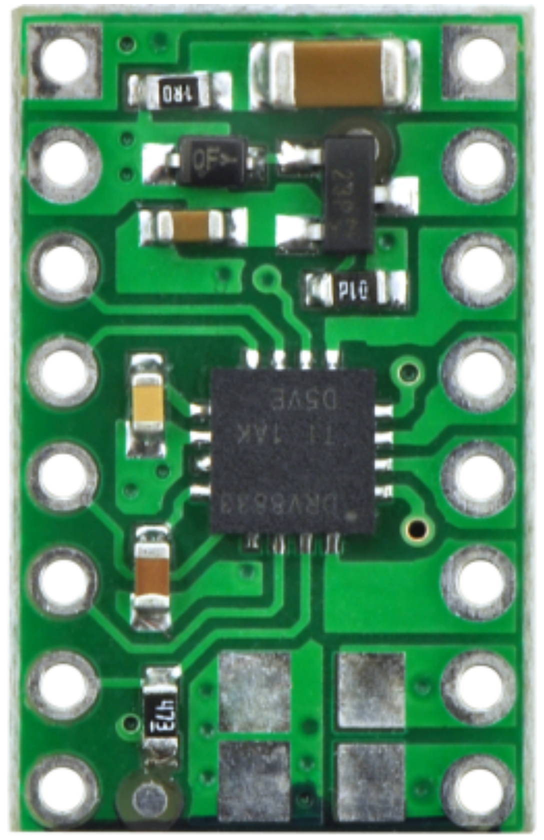




ICM20948 (Sparkfun)

VLX53L1X (Pololu)





DRV8833 (Pololu)

Hardware

Class Action Items

- Lab 2 starts this afternoon, you get your cars! Please do not start ripping it apart, that starts lab 4!
- Please stay up to date on Ed posts, updates to the class website (including the OH calendar), and these lecture slides! Most information can be found in multiple locations.
- A reminder about collaborations!

Collaborations

- We encourage you all to work together! This is meant to be a collaborative class, we want all 60 of your robots to work!
- There are 7 of us on the teaching team, we cannot possibly debug all issues that arise (not that we won't try). Please use each other as a resource!
- Things to do together: work and strategy, prelabs, debugging, compare results, borrow a robot if your hardware fails
- Things you must do alone: electronics, mechanics, software. Write your own reports
- **ALWAYS credit collaborators** (even last years websites).