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ECE 4160/5160
MAE 4910/5910

Fast Robots
Batteries & Actuators

ECE 4160/5160
MAE 4910/5910

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(Rechargeable) Batteries

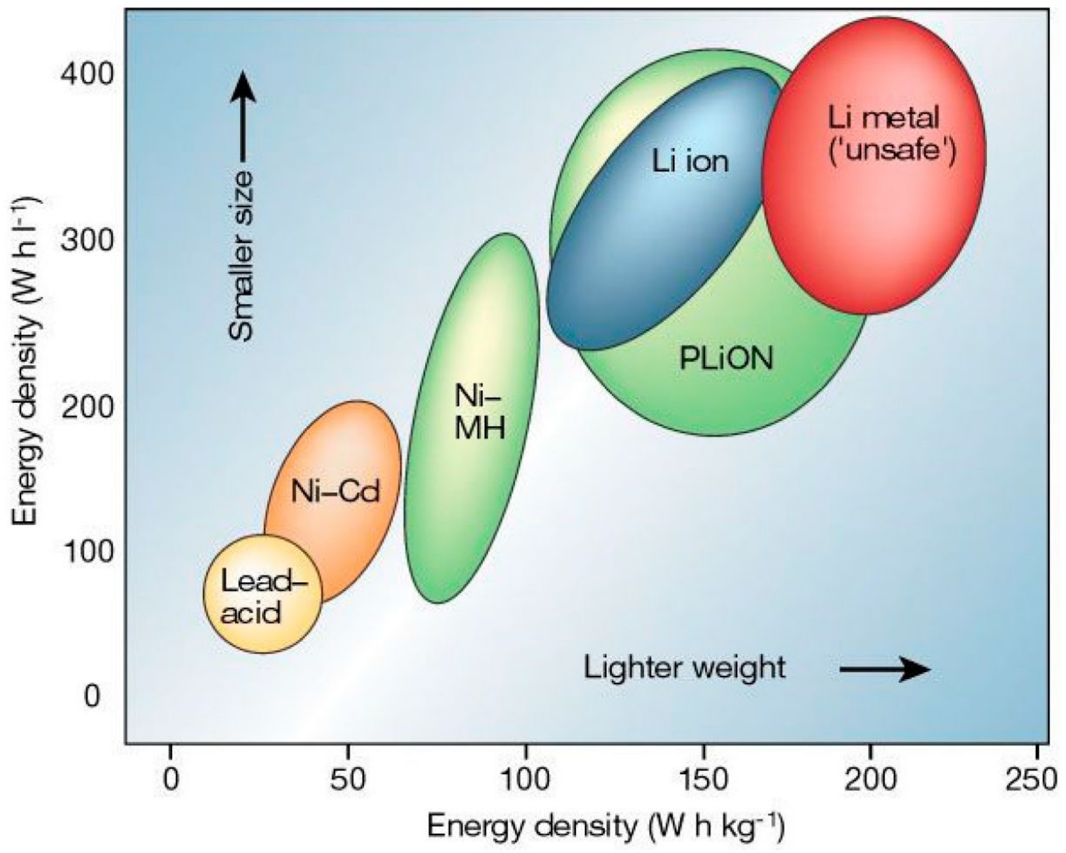
https://batteryuniversity.com/article/whats-the-best-battery

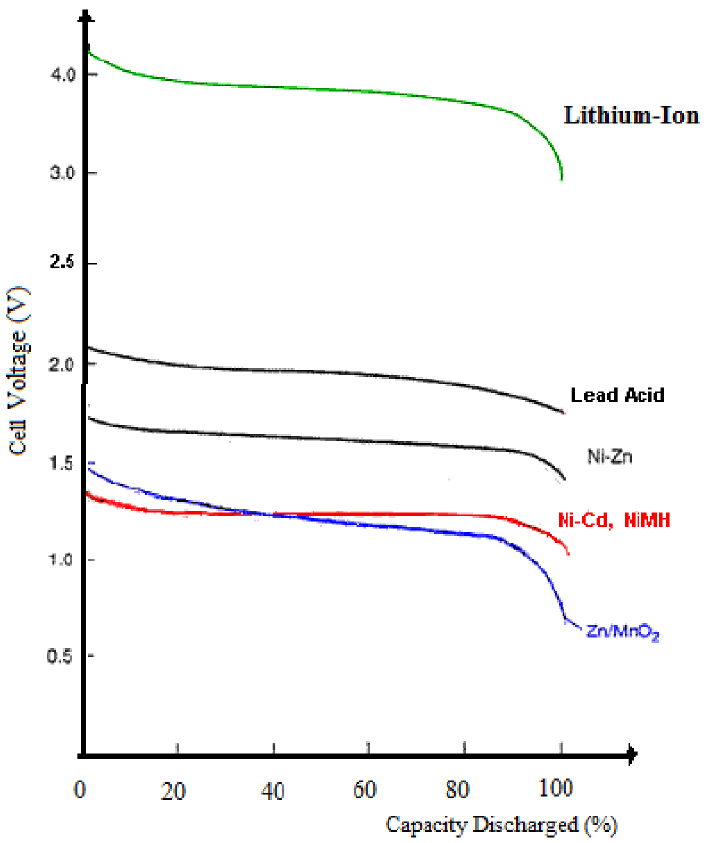
Important properties

What do you look for when choosing a battery?

- Battery capacity
- Cell voltage
- Discharge curve
- Discharge rate (C)
- Charge rate
- Cycle times
- Aging / "shelf life"
- Safety
- Environmental concerns
- Form factor/weight
- Cost

MDPI, Energies

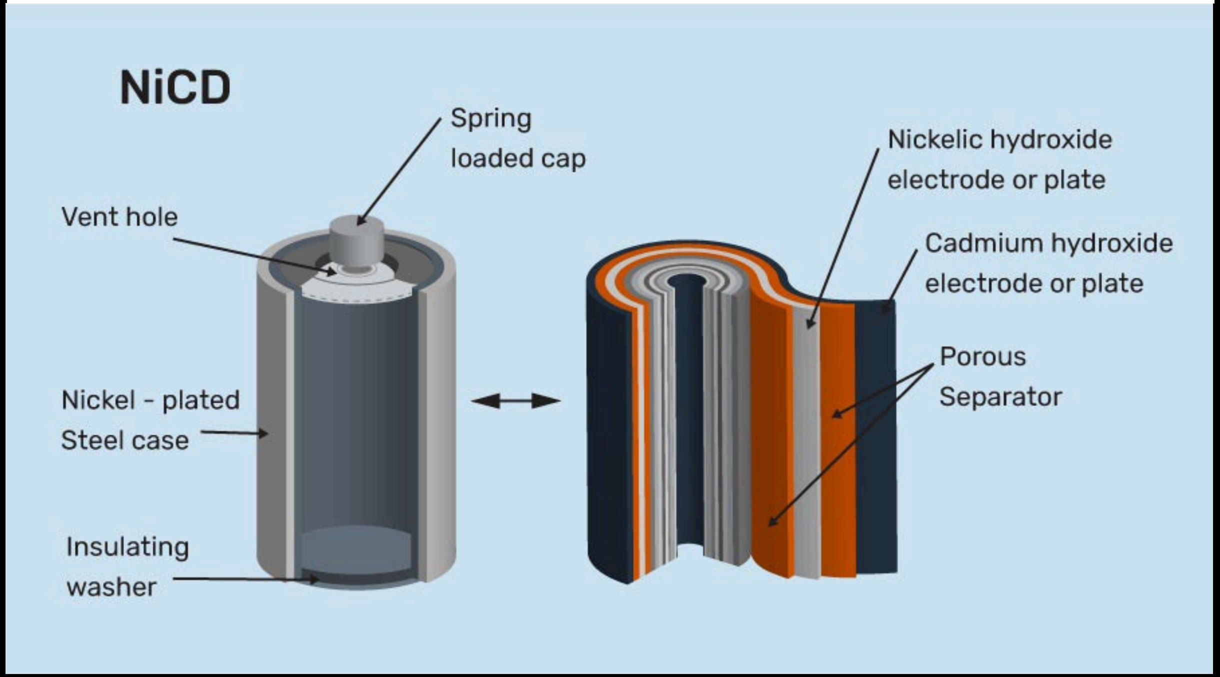




https://batteryuniversity.com/article/whats-the-best-battery

Rechargeable Batteries

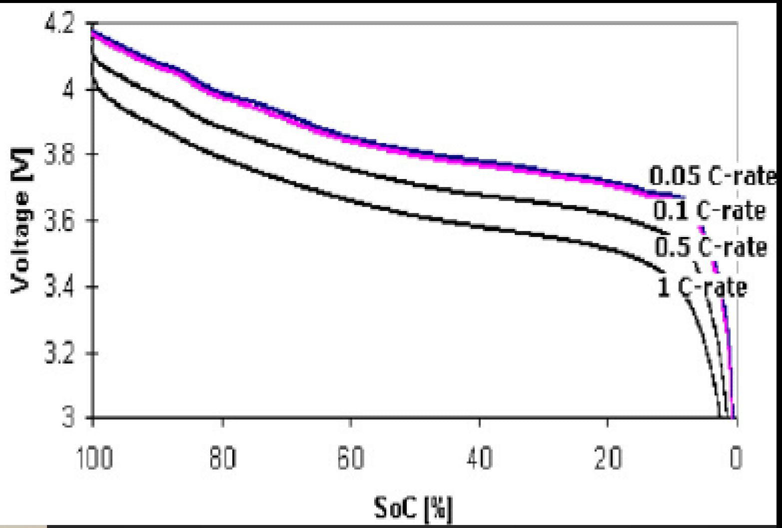
- Lead Acid (SLA)
  - Cheap
  - Large power applications
  - Low energy density
- Nickel Cadmium (NiCd)
  - Mature tech, affordable
  - Fairly low in energy density
  - High discharge rate
  - Long cycle life
  - Better in rigorous working conditions
  - Periodic full discharge/charge is critical
  - Contains toxic metals
- Nickel-Metal Hydride (NiMH)
  - Higher capacity/energy density than NiCd
  - Medium discharge rate
  - More robust
    - Reduced cycle life
      - No toxic metals
      - More expensive than NiCd



https://batteryuniversity.com/article/whats-the-best-battery

Rechargeable Batteries

- Lithium Ion (Li-Ion)
  - High energy density
  - Light weight
  - Low maintenance battery
  - Low self-discharge
  - Max discharge rate: 1-2C ?
  - High cell voltage (single cell batteries)
  - Form factor: Prismatic and cylindrical
  - Protection circuits for charge/discharge
  - Aging, Safety concerns
- Lithium Polymer (Li-Po)
  - Light weight
  - Free form-factor
  - Less safety concerns (dry/gel electrode)
  - Max discharge rate: 3-60C
  - Lower energy density than Li-Ion
  - Cost more than Li-Ion



Nytimes.com

Societal Perspective on Lithium and Cobalt…

- Lithium prices are up 280% since Jan 2021
  - Green transport / EV, phones, etc.
  - 80% is mined in Australia, Chile, and China
  - China controls ~50% of Lithium processing and refining
  - US mines and processes 1%
  - Environmental concerns…
- Cobalt is used for the electrolytes
  - Congo sits on ~50% of the Cobalt
  - 2016-2020: China Molybdenum took ownership of two of the largest US-owned Cobalt mines in Congo

Lithium production in Chile

Cobalt electrolytic and 1cm3 cube

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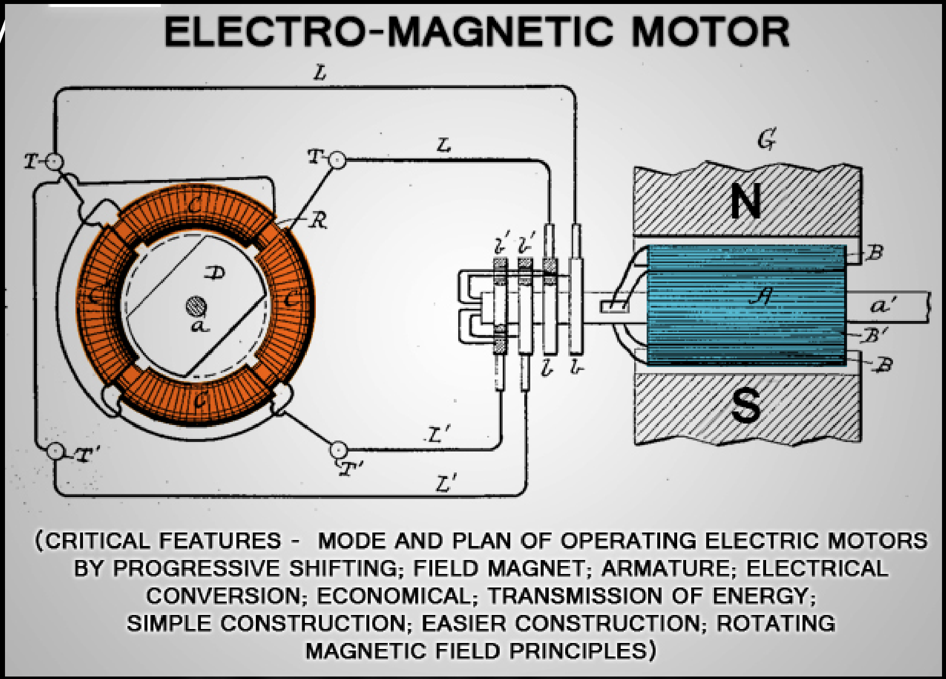
Electric Motors

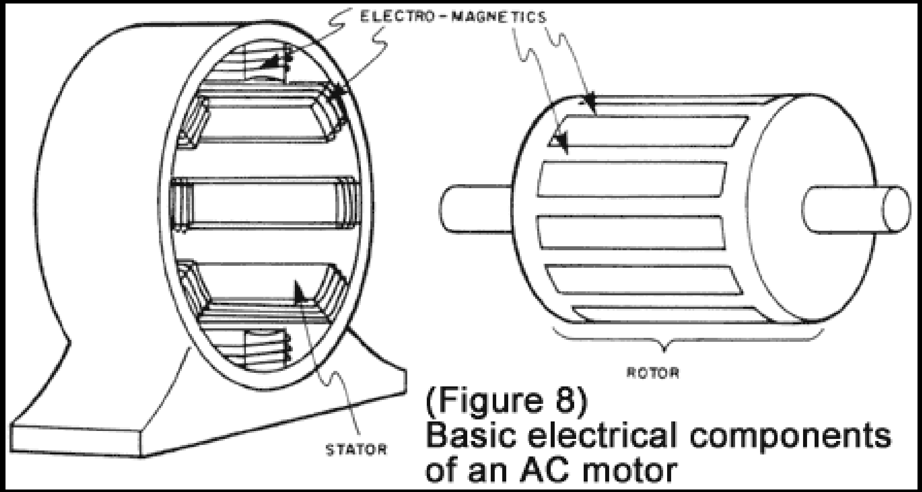
AC Motors

https://www.explainthatstuff.com/induction-motors.html

- High power/torque
- Access to a mains/wall outlet
- Synchronous AC motors
    - Rotor turns as fast as the magnetic field fluctuates
- Asynchronous AC motors / Induction motors
    - Rotor turns slower than the field
    - Coil, frequency, and load dependent
- Simple, low cost, long lasting
- You'll need a variable frequency drive to change their speed



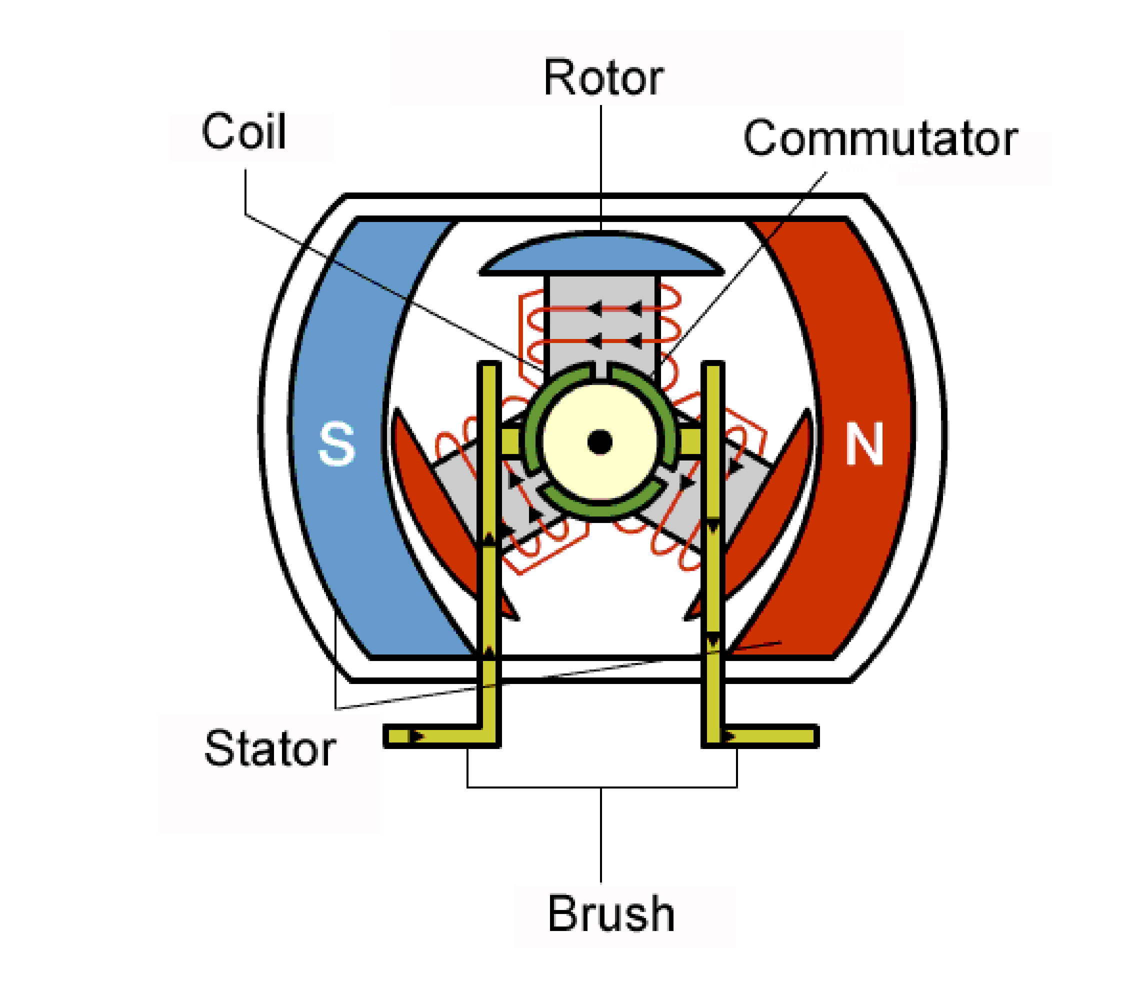
#8 TESLA PATENT US 381968 A



(Figure 8)
Basic electrical components of an AC motor

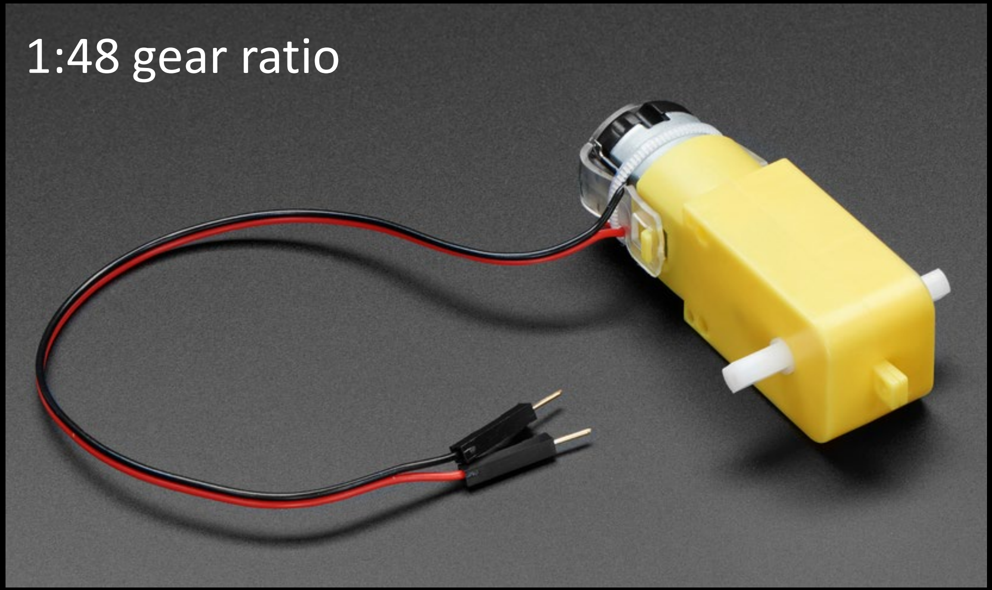
Brushed DC motor

- Brushes conduct current from source to armature
- Most commonly Permanent Magnet DC motors (PMDC)
- Pros
  - Inexpensive
  - Easy speed control (DC voltage)
  - Light weight
  - Reasonably efficient
  - Great for low power, low form factor applications
- Cons
  - Mechanical wear
  - Electrical noise
  - Gearing is often needed

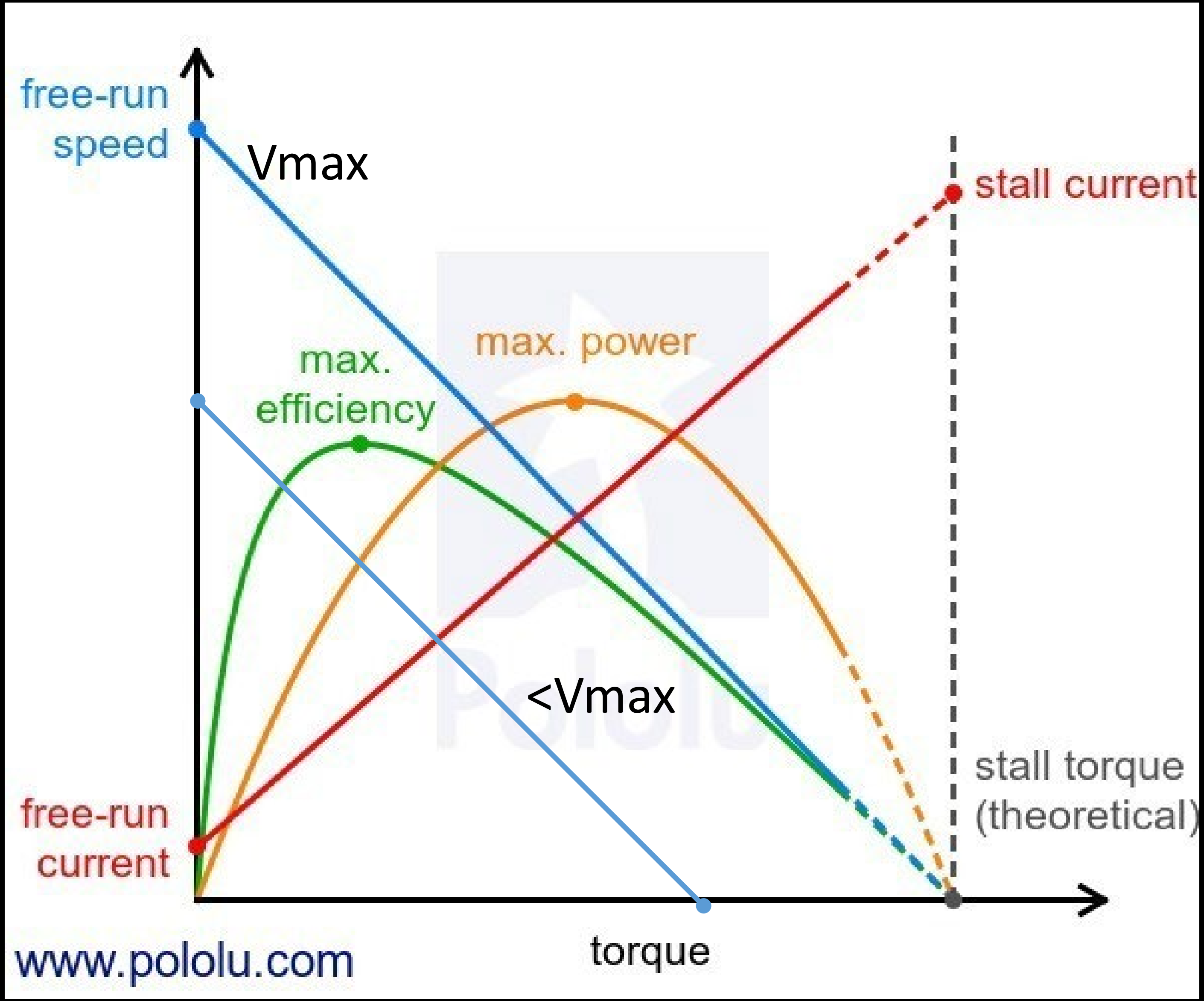


Brushed DC motor

Power = Torque x speed

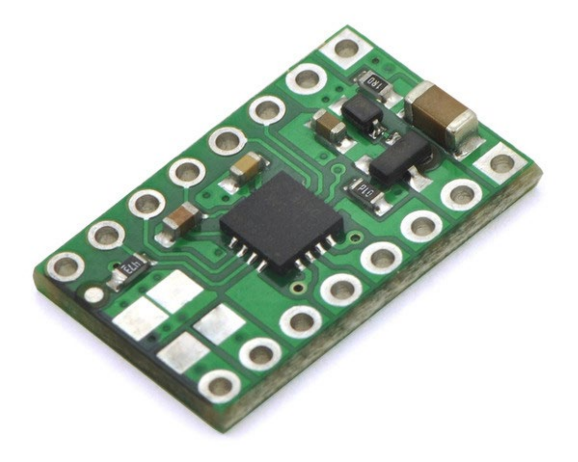


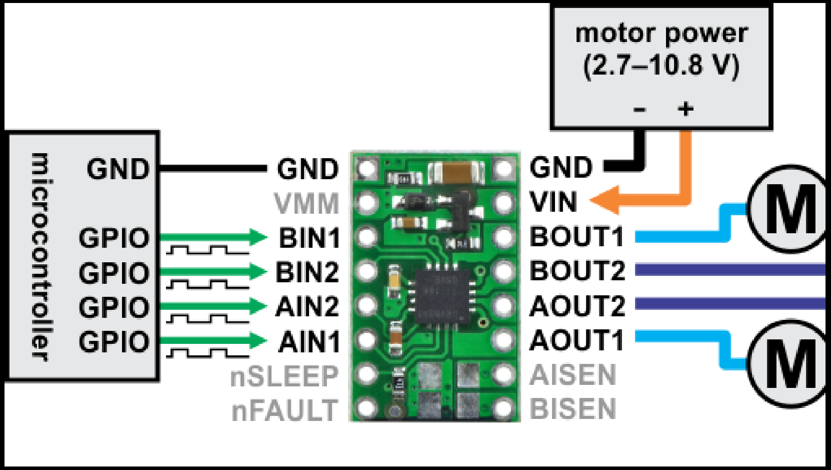
3VDC	0kgcm	150mA	120RPM
3VDC	0.4kgcm	1.1A	0RPM
6VDC	0kgcm	160mA	250RPM
6VDC	0.8kgcm	1.5A	0RPM



Brushed DC motor Controllers

DRV8833 Dual Motor Driver Carrier





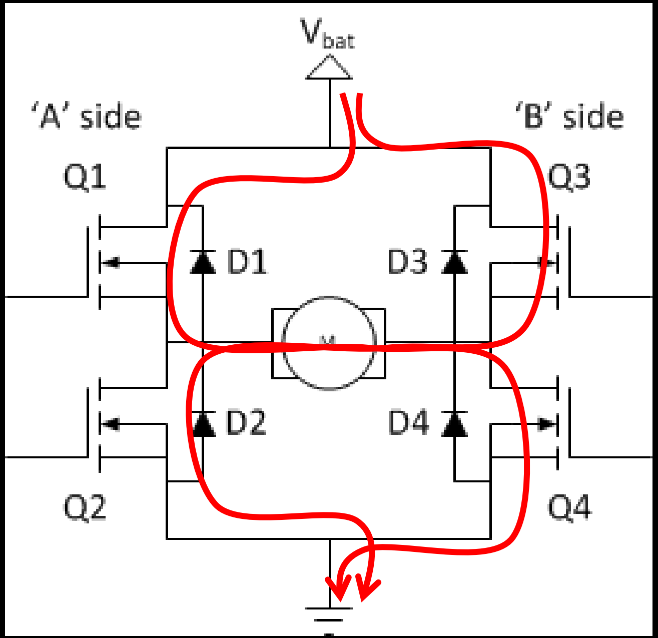


Table 1. H-Bridge Logic

xIN1	xIN2	xOUT1	xOUT2	FUNCTION
0	0	Z	Z	Coast/fast decay
0	1	L	H	Reverse
1	0	H	L	Forward
1	1	L	L	Brake/slow decay

https://www.pololu.com/product-info-merged/2130

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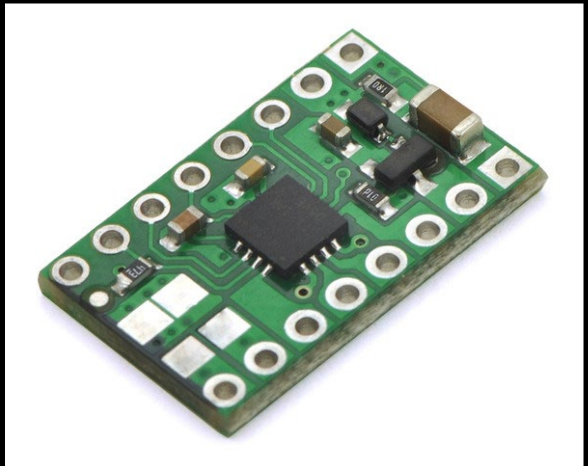

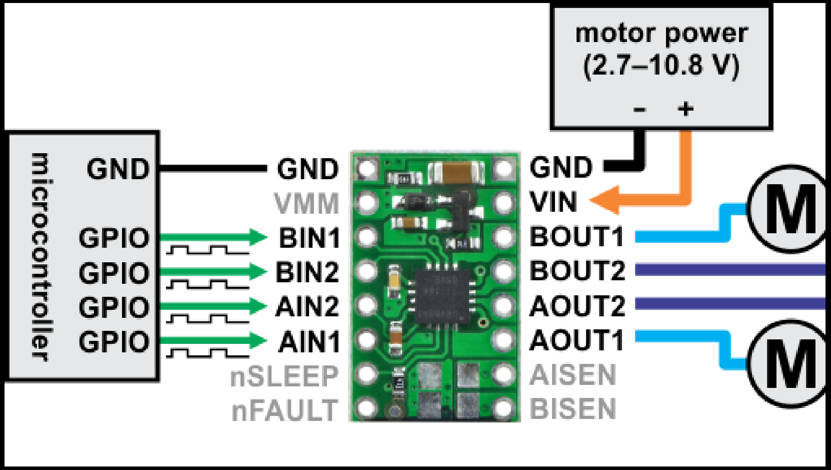

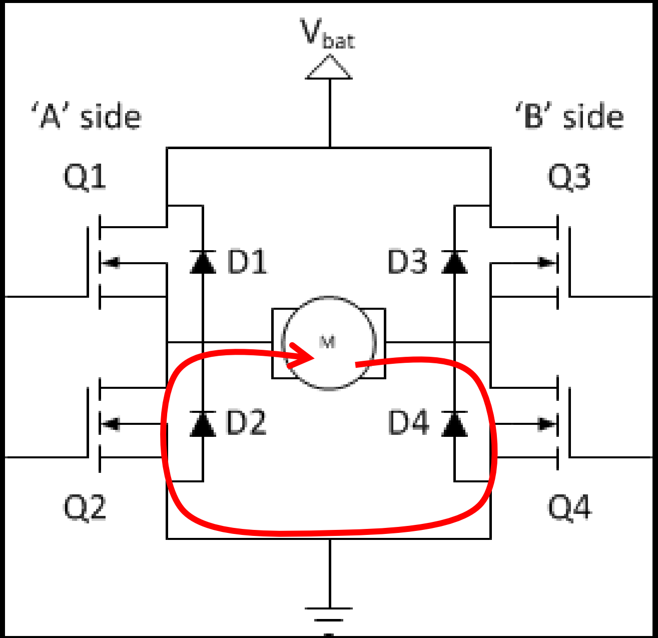

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Brushed DC motor Controllers

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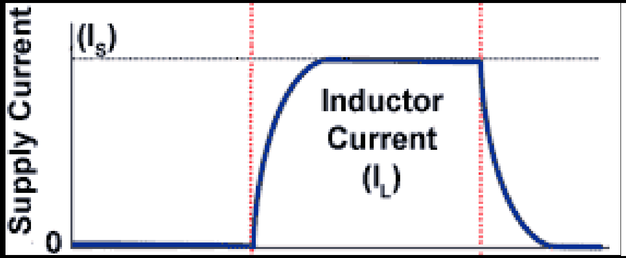
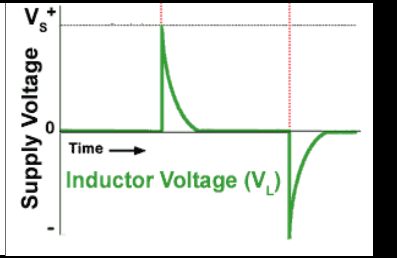
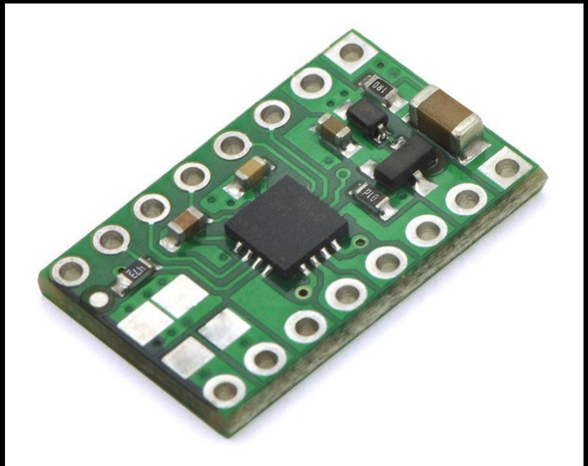
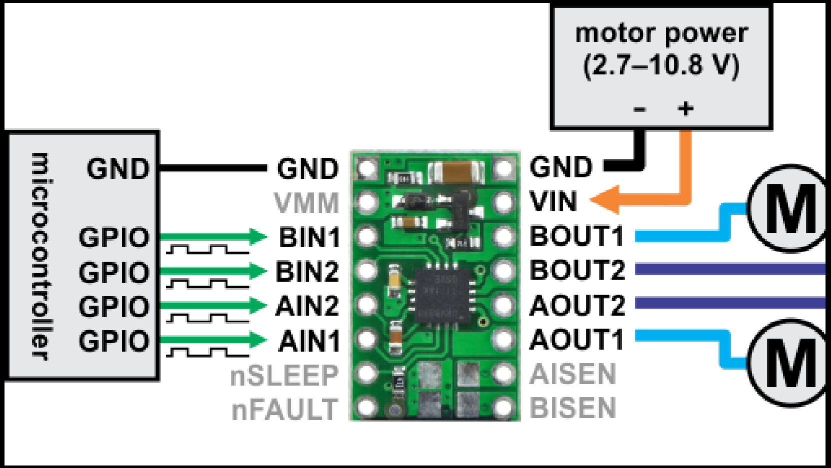
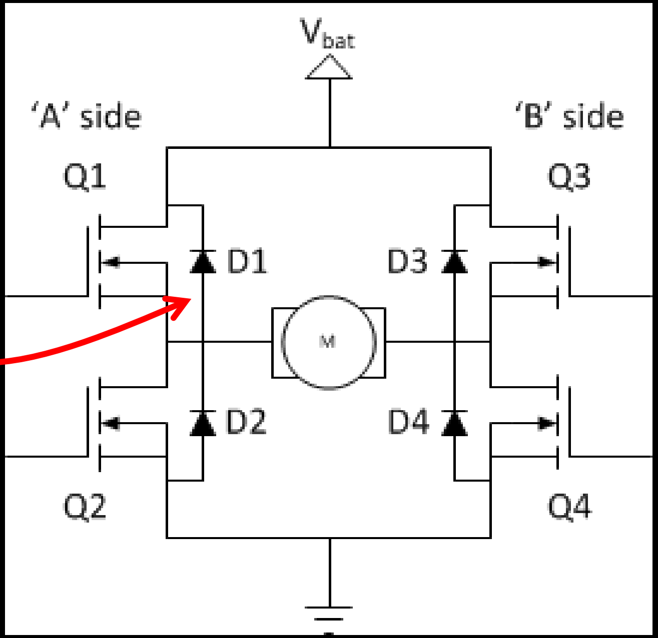








Why "flyback" diodes?



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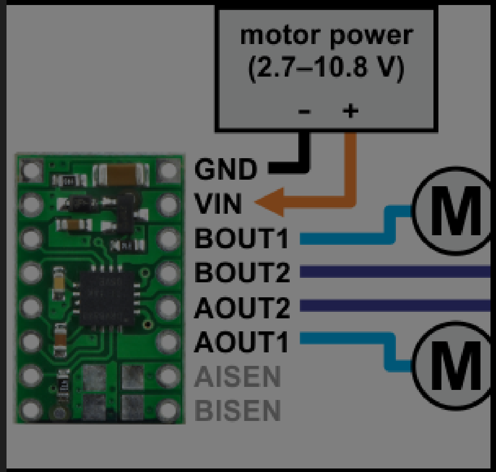
https://www.pololu.com/product-info-merged/2130

Brushed DC motor Controllers

DRV8833 Dual Mo



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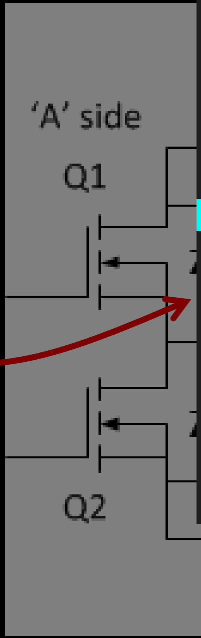
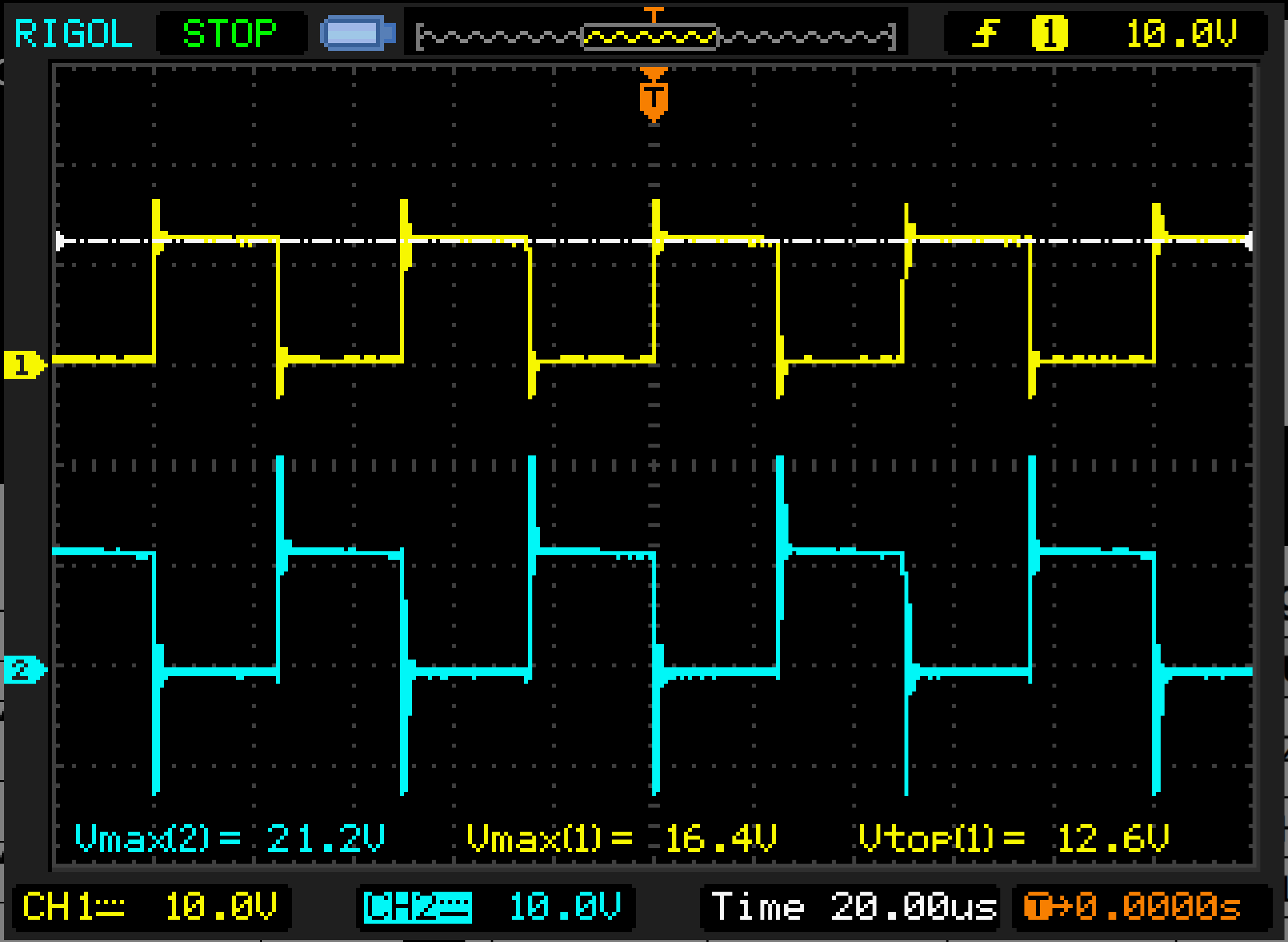
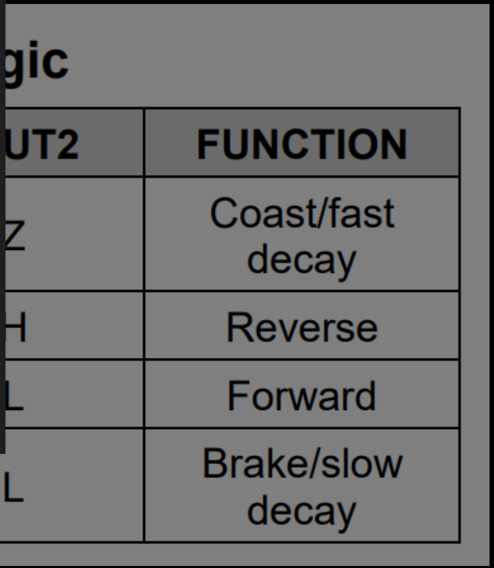


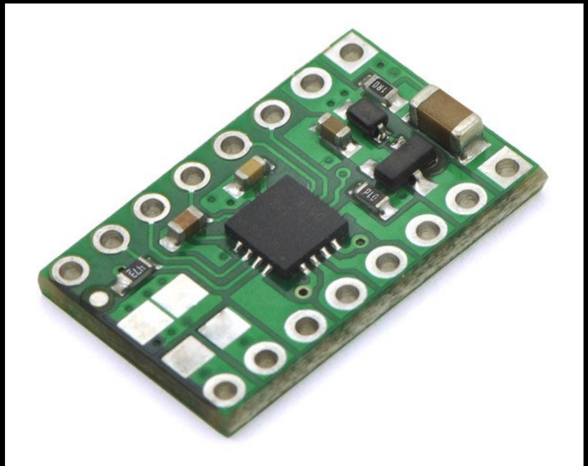


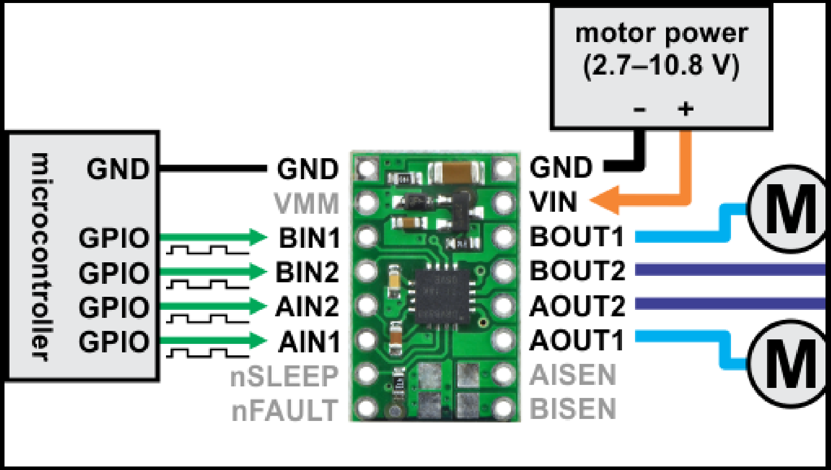


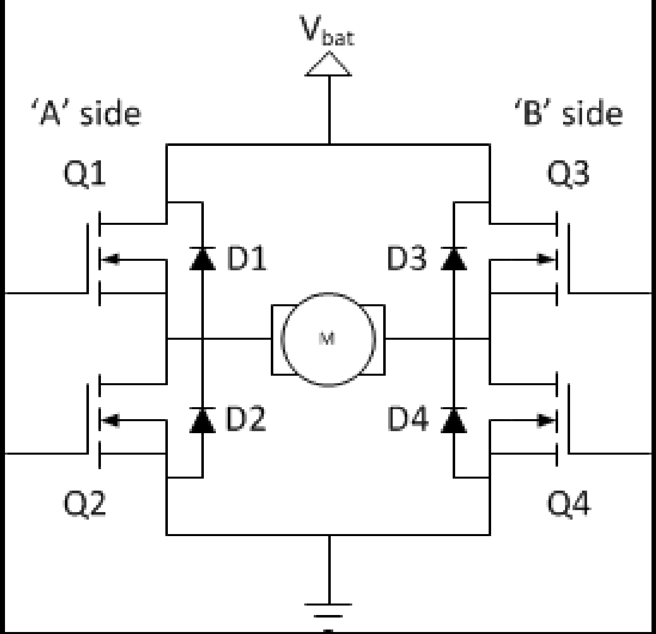
Brushed DC motor Controllers

DRV8833 Dual Motor Driver Carrier

- V_{IN} = 2.7-10.8V
- 3 and 5V compatible inputs
- I_{con} = 1.2A (per channel)
- I_{peak} = 2A (per channel)
- …with active cooling
  - Parallel couple two!







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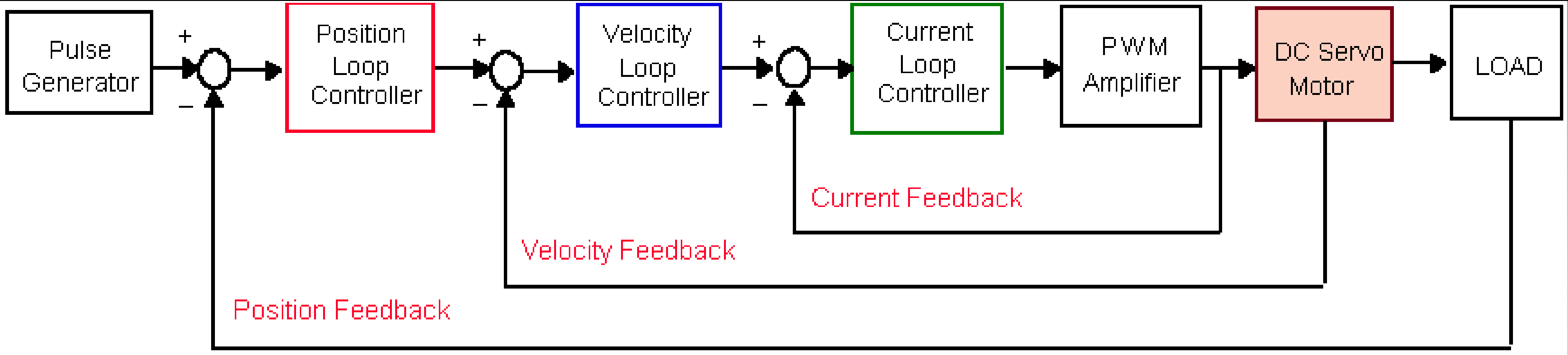
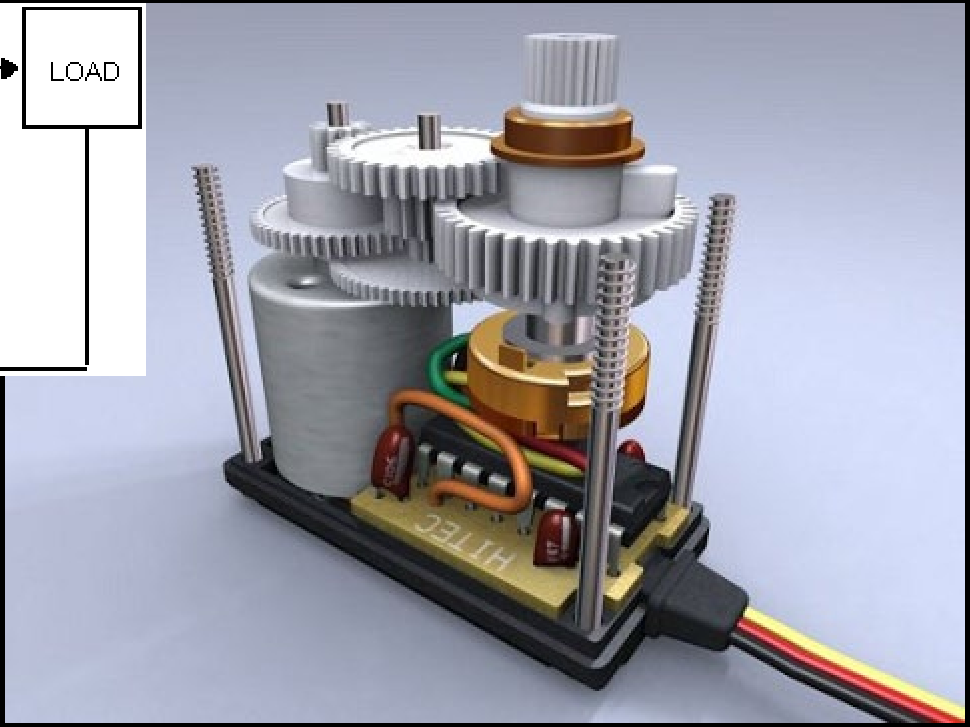
Servo motor

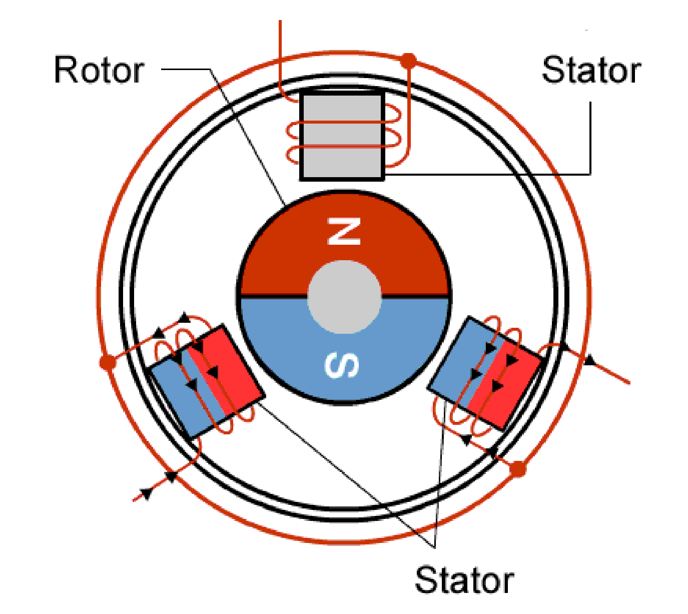
- Hobby-oriented PMDC motor
  - Duty cycle of a 50Hz 0-5V signal
- Continuous rotation servo
- Position controlled servo

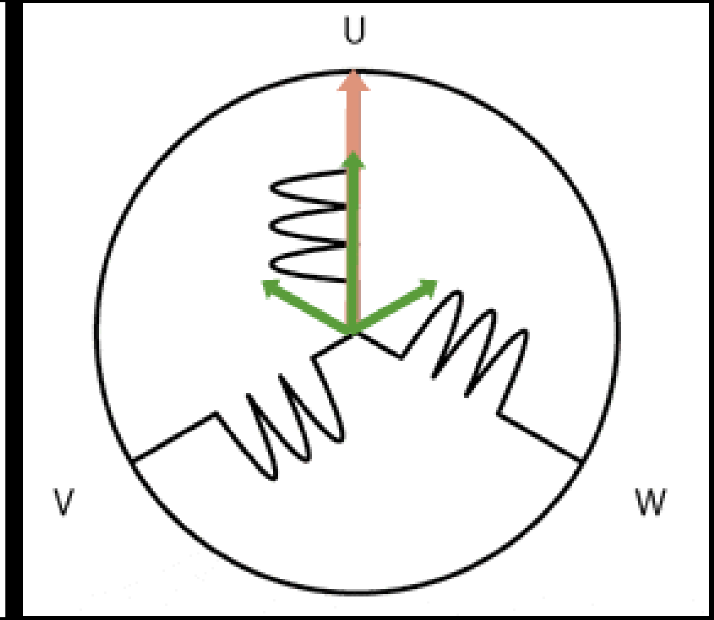




Brushless DC motor (BLDC)

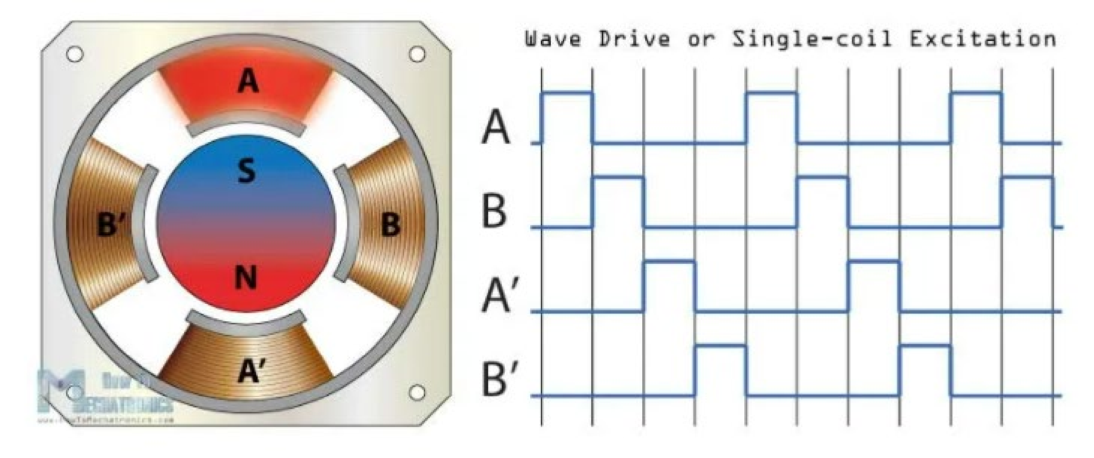
- Inside-out PMDC
- Higher efficiency (85-90% compared to 74-80% brushed motors)
- No wear, easier cooling, low EMI
- Higher power, high starting torque
- Precise control of torque and speed
  - Discrete control (easy, but jerky)
  - Sinusoidal control
- Position sensing
  - Sensors (hall effect, etc.)
  - Sensor less (back-EMF)
    - Lower speeds, worse control
    - Initialization

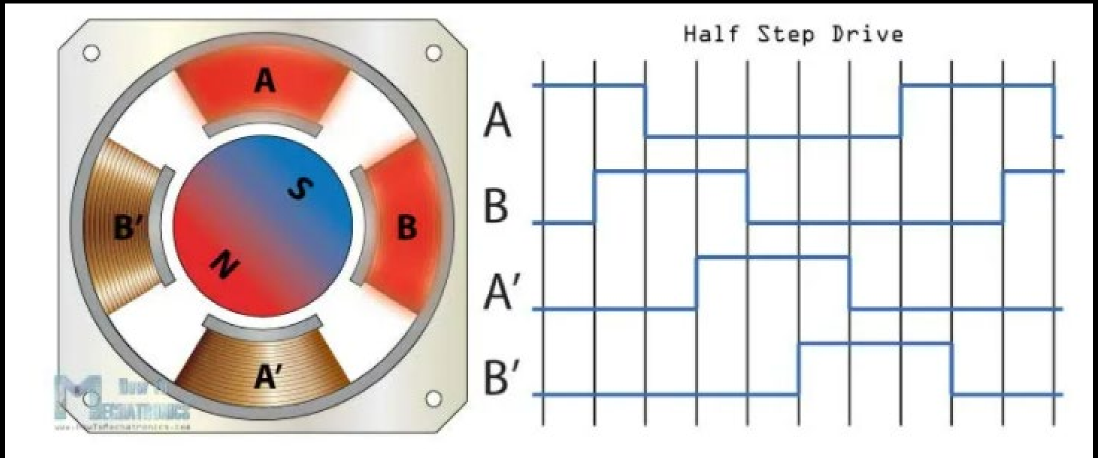


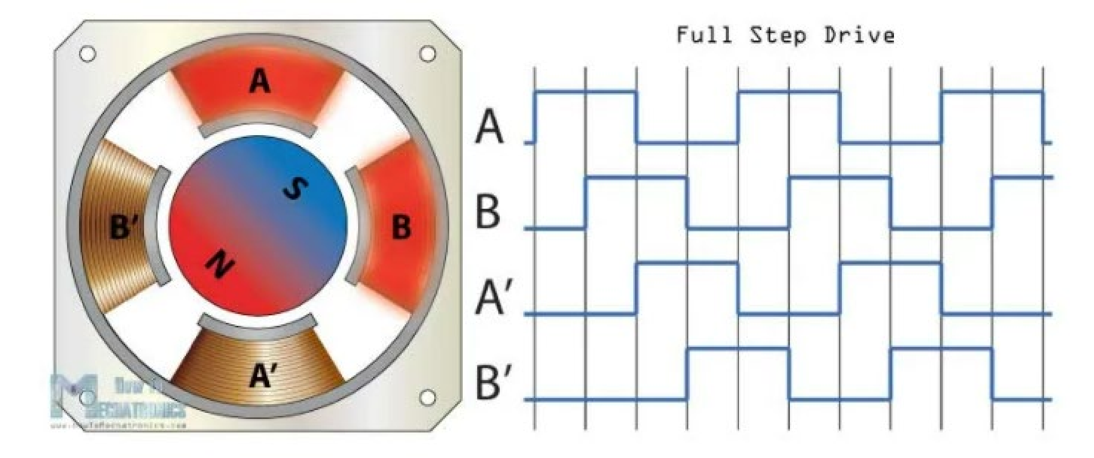


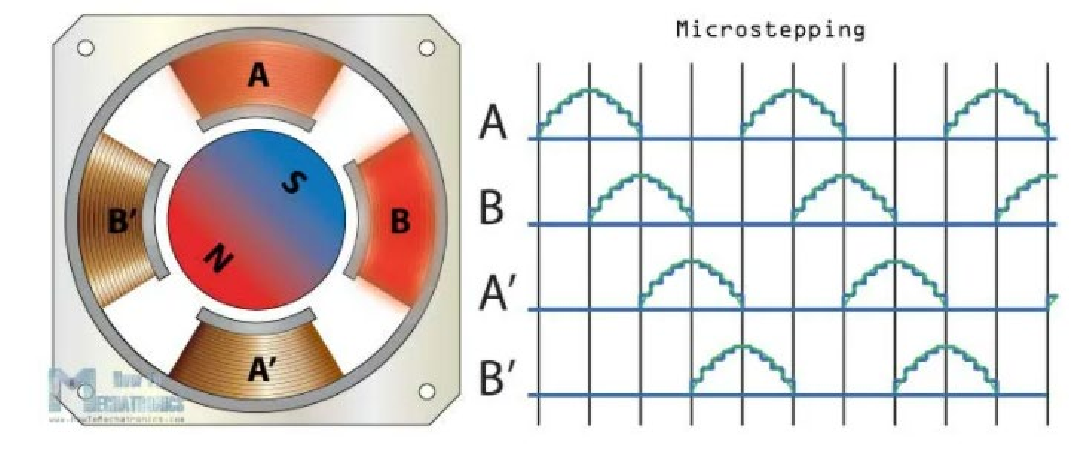
Stepper motor

- Good choice when low speed and high precision is needed
- Advantages: High torque compared to servos, constant holding torque, frictionless
- Disadvantages: Low efficiency, torque declines rapidly with speed, low torque to inertia





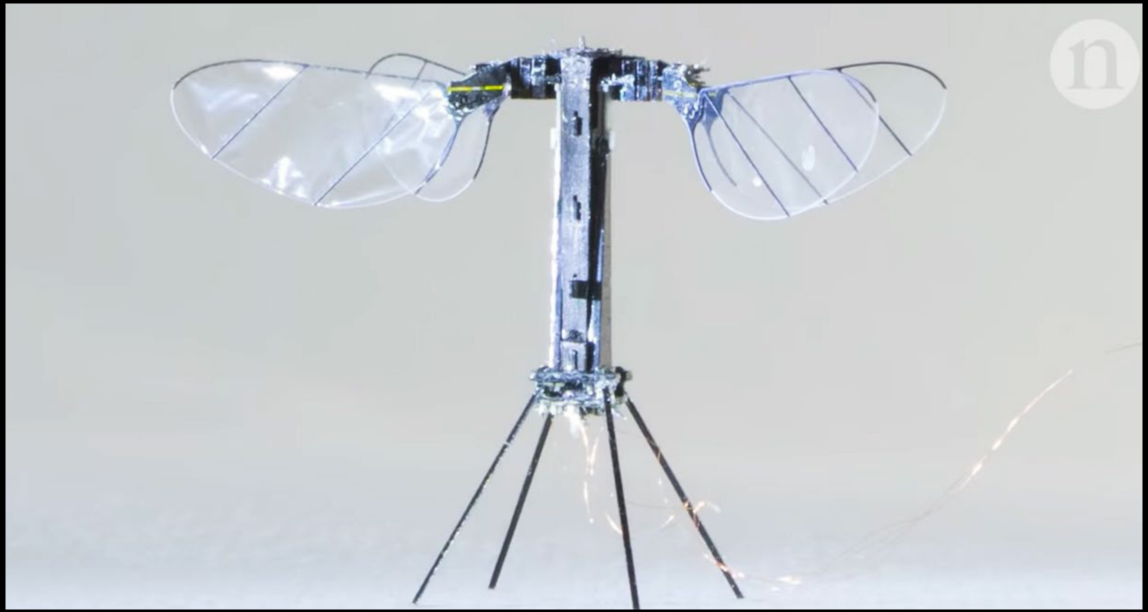




Fast Robots

Actuators…

- A device that converts energy into mechanical motion
  - Electric
  - Magnetic
  - Mechanical
  - Hydraulic
  - Pneumatic
  - Bio-hybrid
  - Light-driven
  - Thermal
  - Etc.



Prof. Helbling, ECE/Cornell

Movie S8: Navigation through an intricate environment

Prof. Petersen, ECE/Cornell

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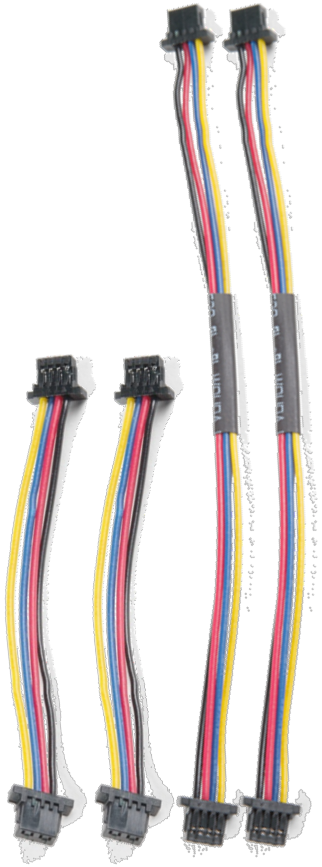
Lab 3-5 pre-lab (continued)

Lab 3-5: Hardware

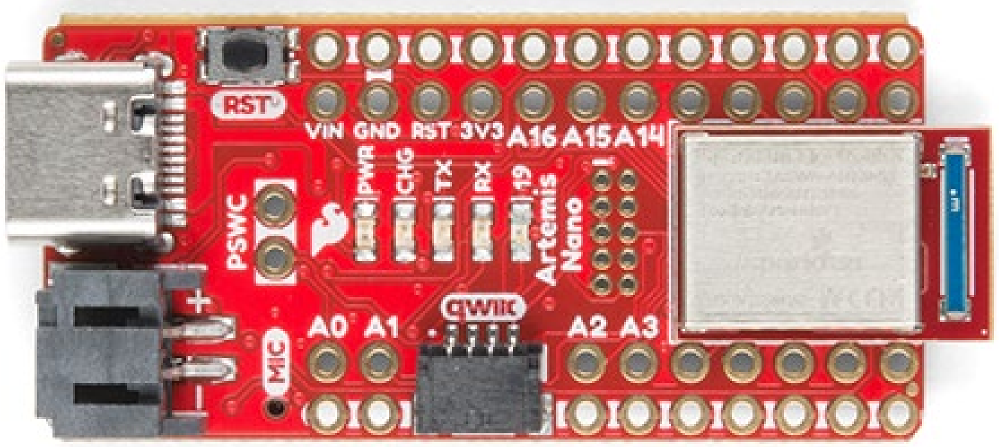
- Lab 3: TOF sensors (https://cei-lab.github.io/FastRobots-2023/Lab3.html)
- Lab 4: IMU sensors and battery
- Lab 5: Motor drivers

- 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!>**

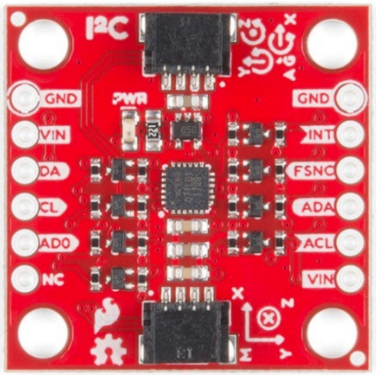
Lab 3-5: Hardware



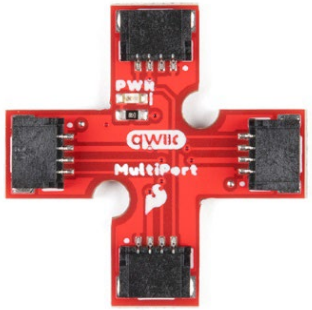
DRV8833 (Pololu)



Artemis Nano (Sparkfun)

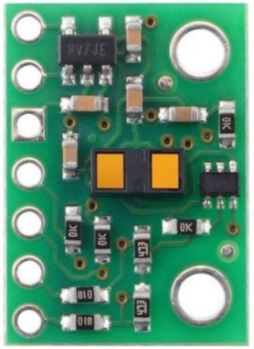


ICM20948 (Sparkfun)



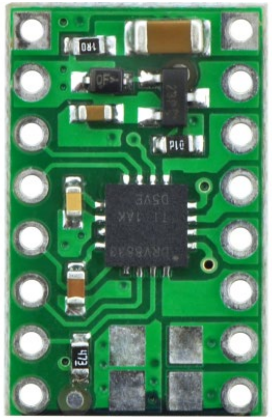
VDD (2.8V out)
VIN (2.6–5.5V)
GND
SDA
SCL
XSHUT
GPIO1

VDD (2.8V out)
VIN (2.6–5.5V)
GND
SDA
SCL
XSHUT
GPIO1



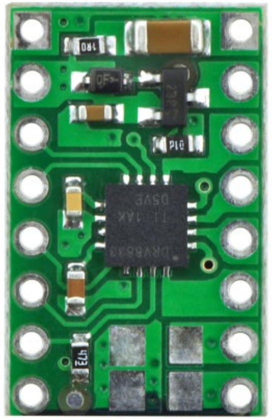
VLX53L1X (Pololu)

GND, VMM, BIN1, BIN2, AIN2, AIN1, nSLEEP, nFAULT



GND, VIN, BOUT1, BOUT2, AOUT2, AOUT1, AISEN, BISEN

GND, VMM, BIN1, BIN2, AIN2, AIN1, nSLEEP, nFAULT



GND, VIN, BOUT1, BOUT2, AOUT2, AOUT1, AISEN, BISEN

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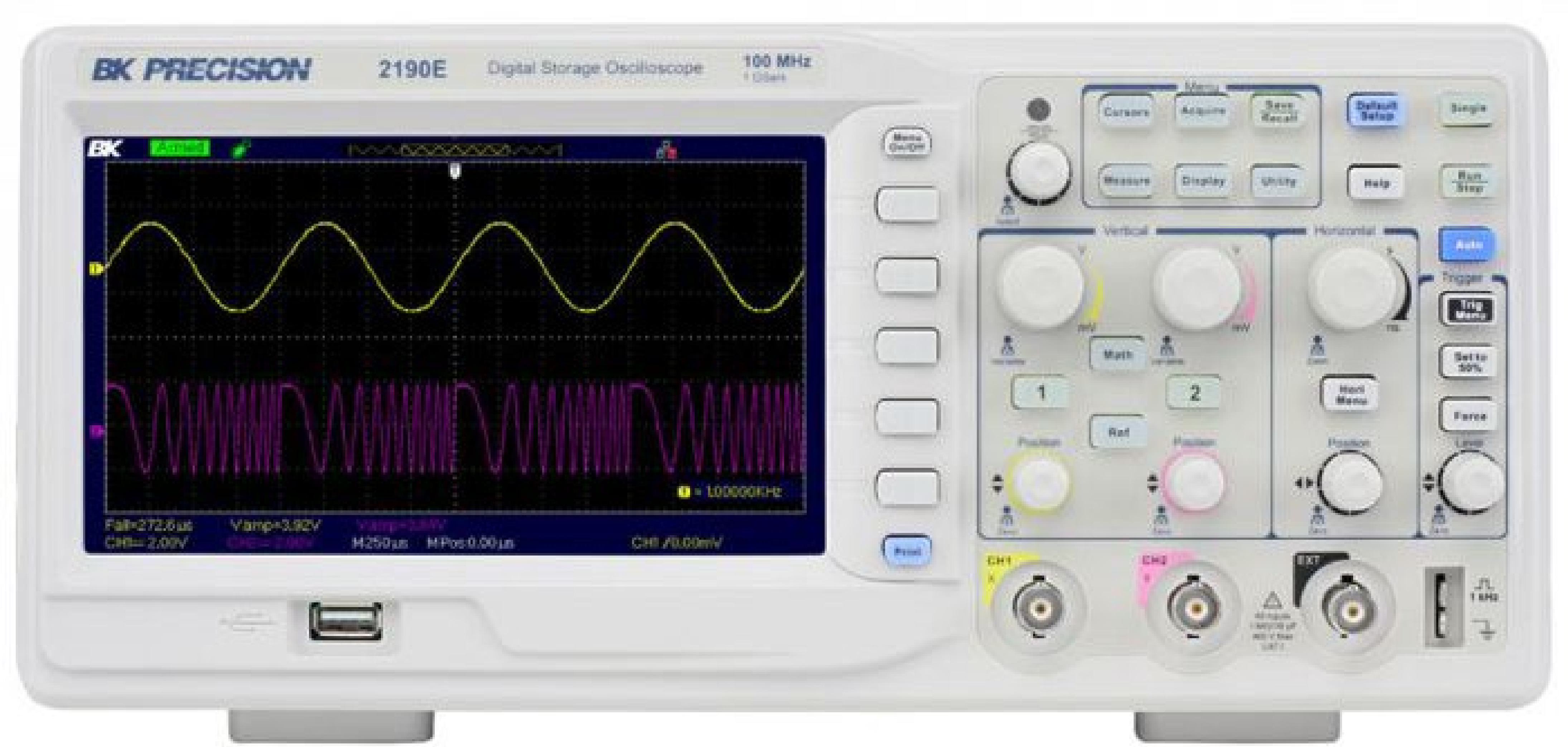
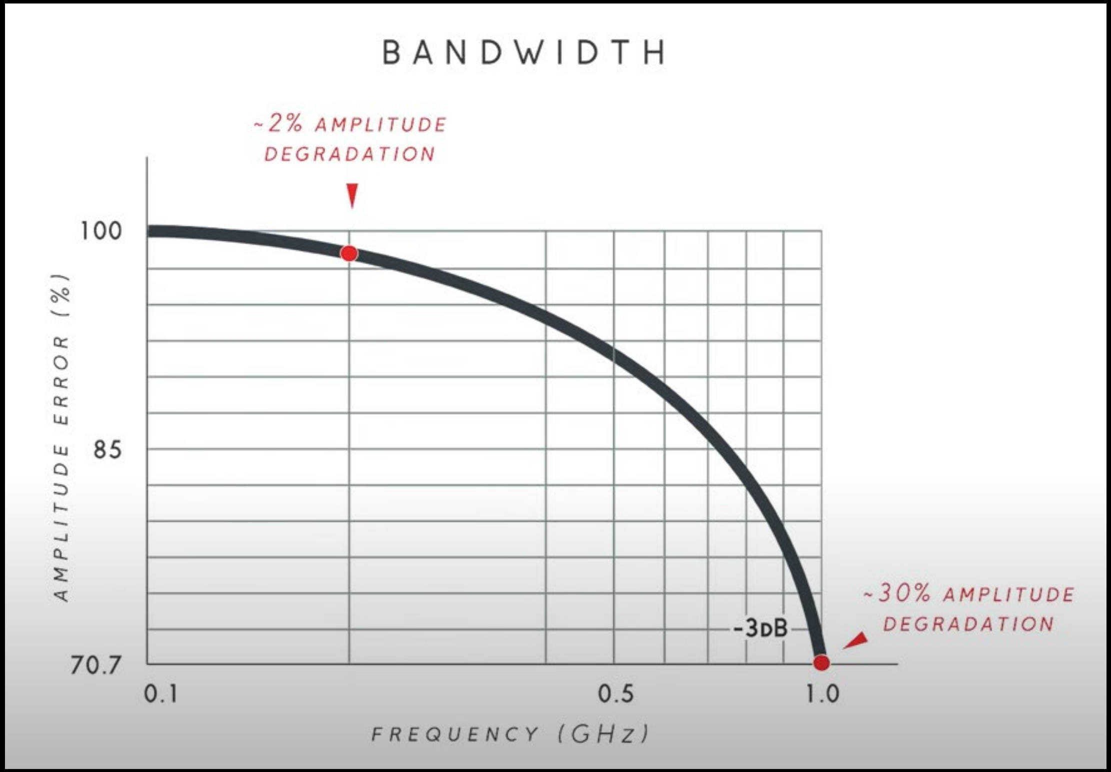
Oscilloscopes

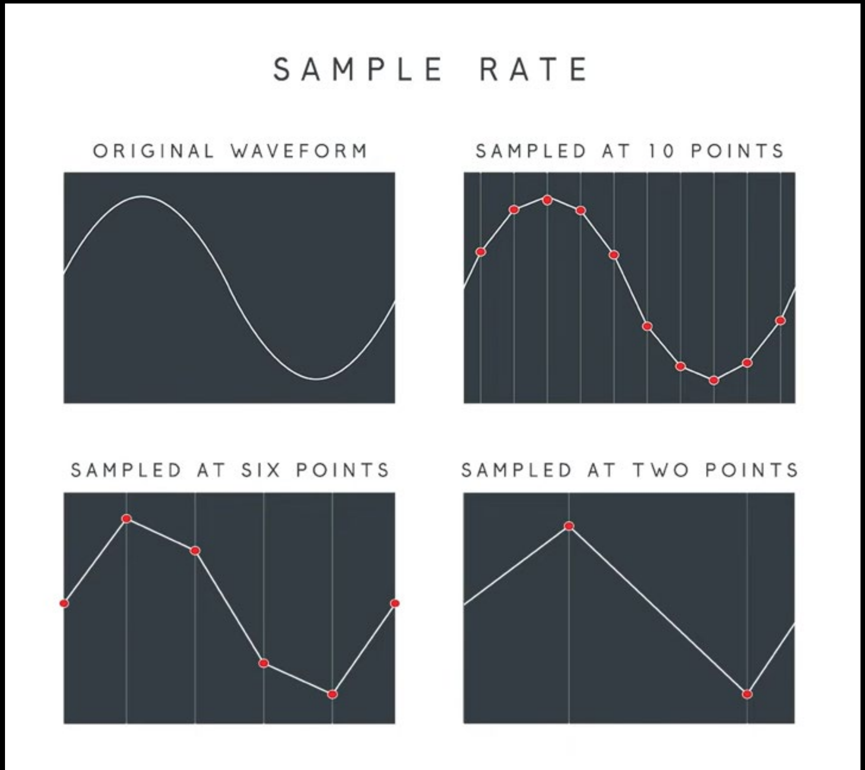
Oscilloscope Setup



Oscilloscope Characteristics

- Bandwidth
- Sample rate
- Resolution

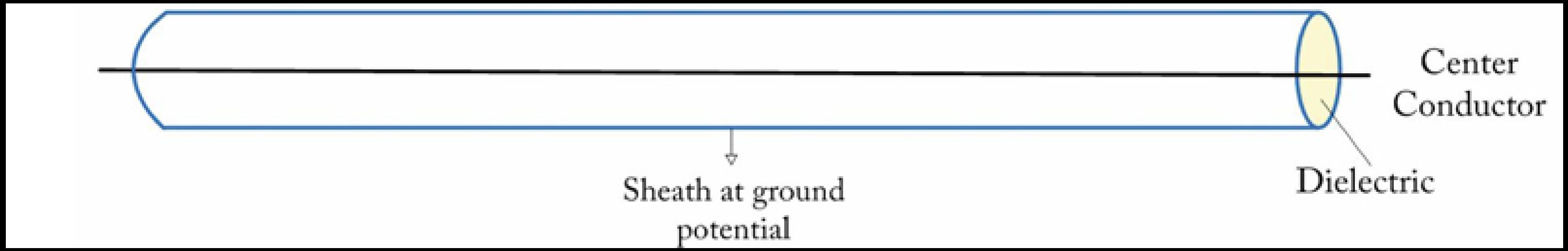




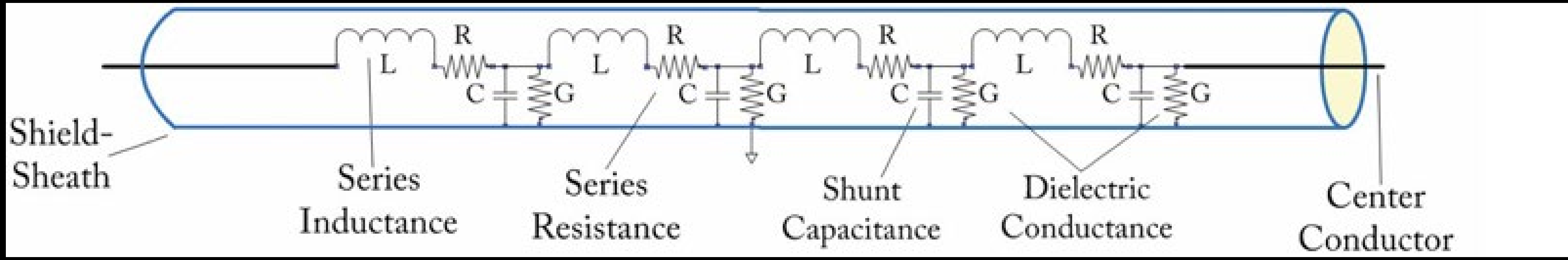
Oscilloscope Probes

- Scope inputs resemble a 16pF capacitor in parallel with a 1MOhm resistor
- At high frequencies the coax cable acts as a low pass filter
- 1x attenuation for low amplitude, low frequency signals
- 10x attenuation for load-sensitive circuits, high frequency- or high amplitude signals

Low frequency coax cable



High frequency equivalent circuit



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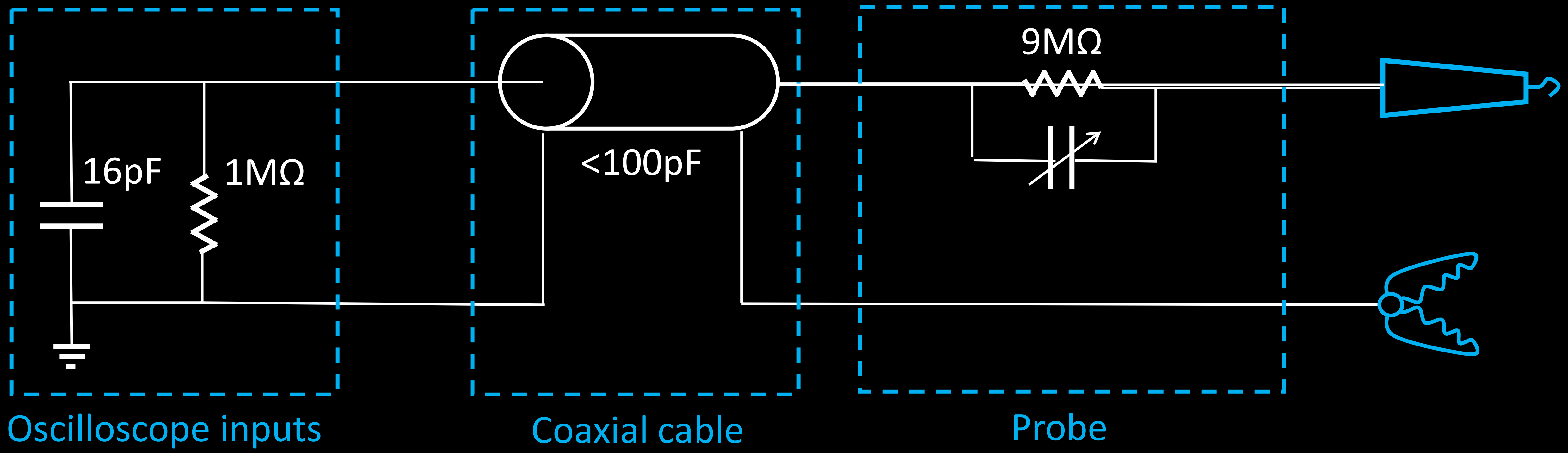
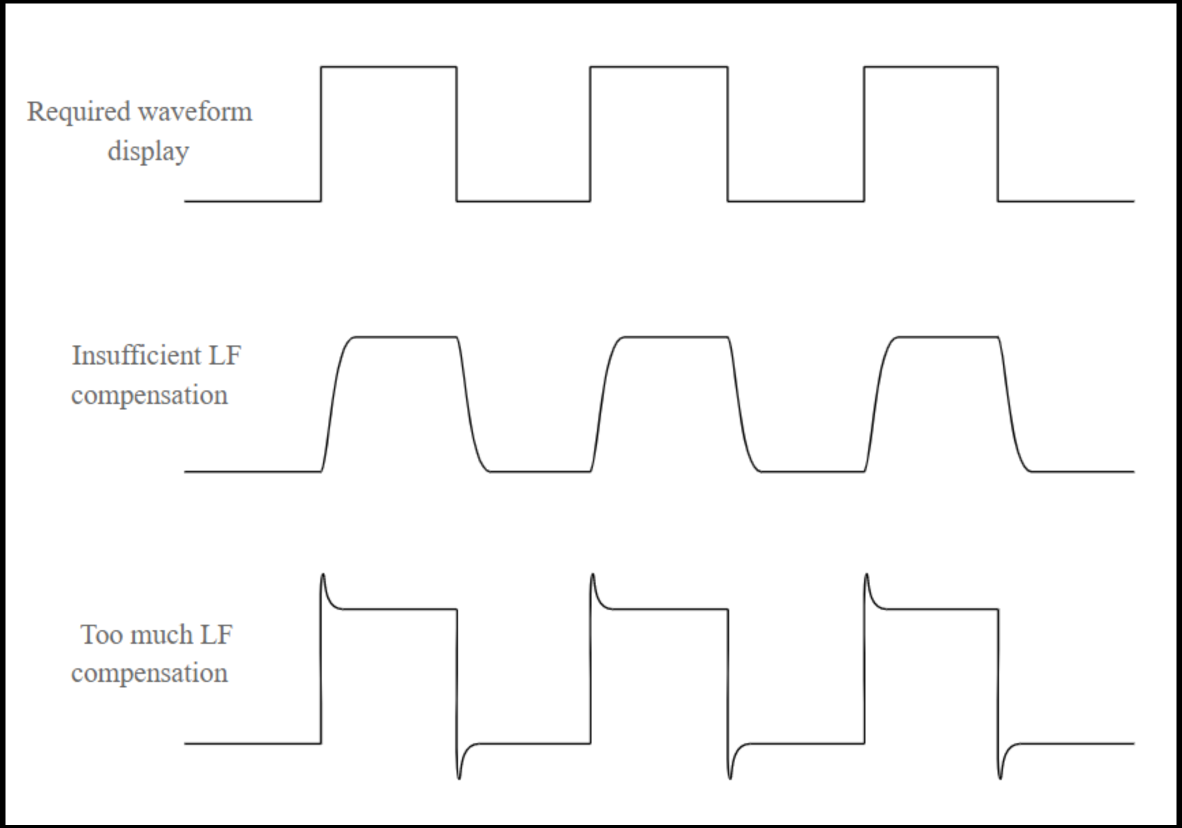


Oscilloscope Probes

- 10x probe calibration
  - Use the built-in square wave generator
  - Adjust capacitor until the square wave looks square!



Oscilloscope Setup