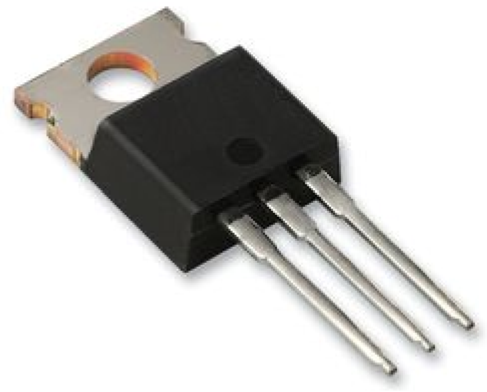
CC2511 Week 6 Lecture 2

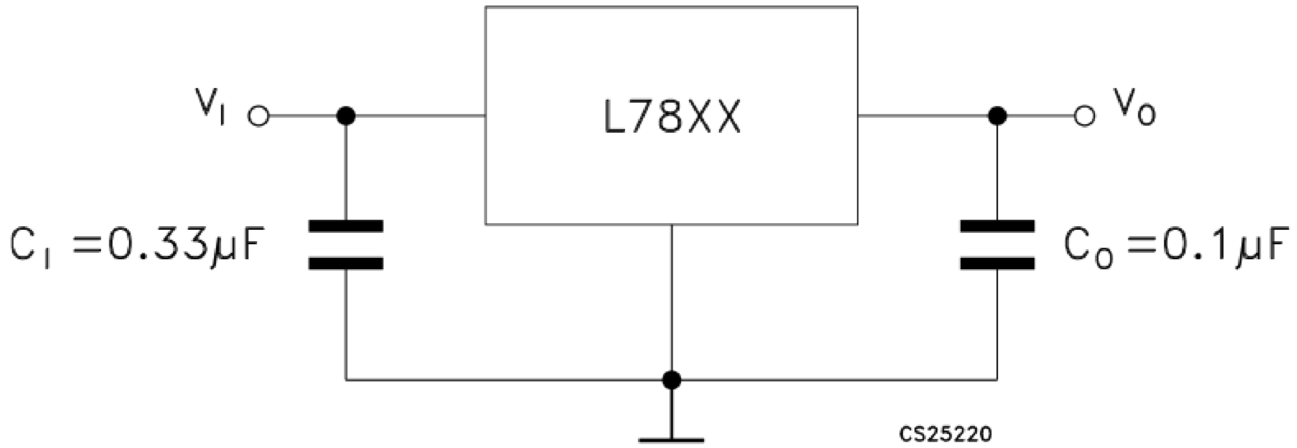
Part 1: Voltage regulation and practical PCB considerations

Part 2: Servo and stepper motors

Voltage regulation

- A **voltage regulator** generates a precise output voltage from a variable input voltage.
- Example: **L7805ABP** input voltage 10 V to 35 V, output voltage 5.0 V.





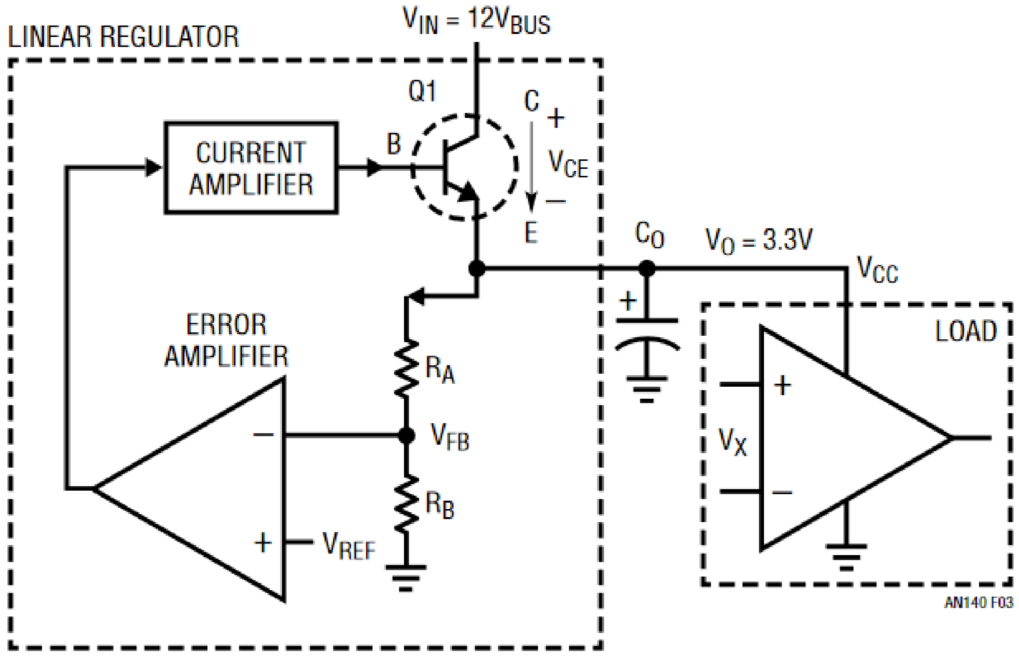
Drop-out voltage

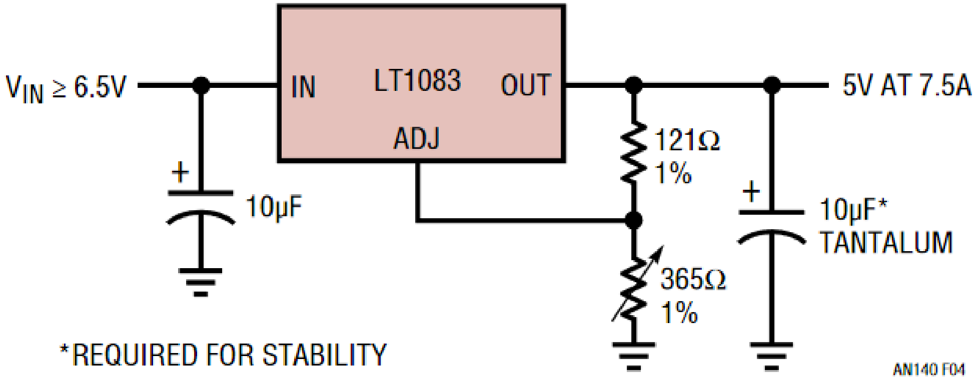
- The **drop-out** voltage is the smallest possible difference between input voltage and output voltage.
- Example: output = 5 V, dropout = 2 V, minimum input = 7 V.
- A **low-dropout** (**LDO**) regulator has a small drop-out voltage (e.g. hundreds of millivolts)

Types of regulators

Linear regulators:

- Use a transistor as a variable resistance to dissipate the excess voltage as heat ($P = V_{drop} I_{load}$).
- Cheap and simple.
- Inefficient for high current loads.
- Produces a clean, stable output voltage with minimal ripple.
- Good for low dropout applications and powering sensitive electronics.





Images from Linear Technology Application Note AN140.

Types of regulators

Switching regulators:

- Use rapid switching to connect and disconnect the source.
- Switching noise is smoothed using a lowpass filter.
- More expensive and complex.
- Higher efficiency, especially for high current applications.
- Some switching noise is always present in the output.

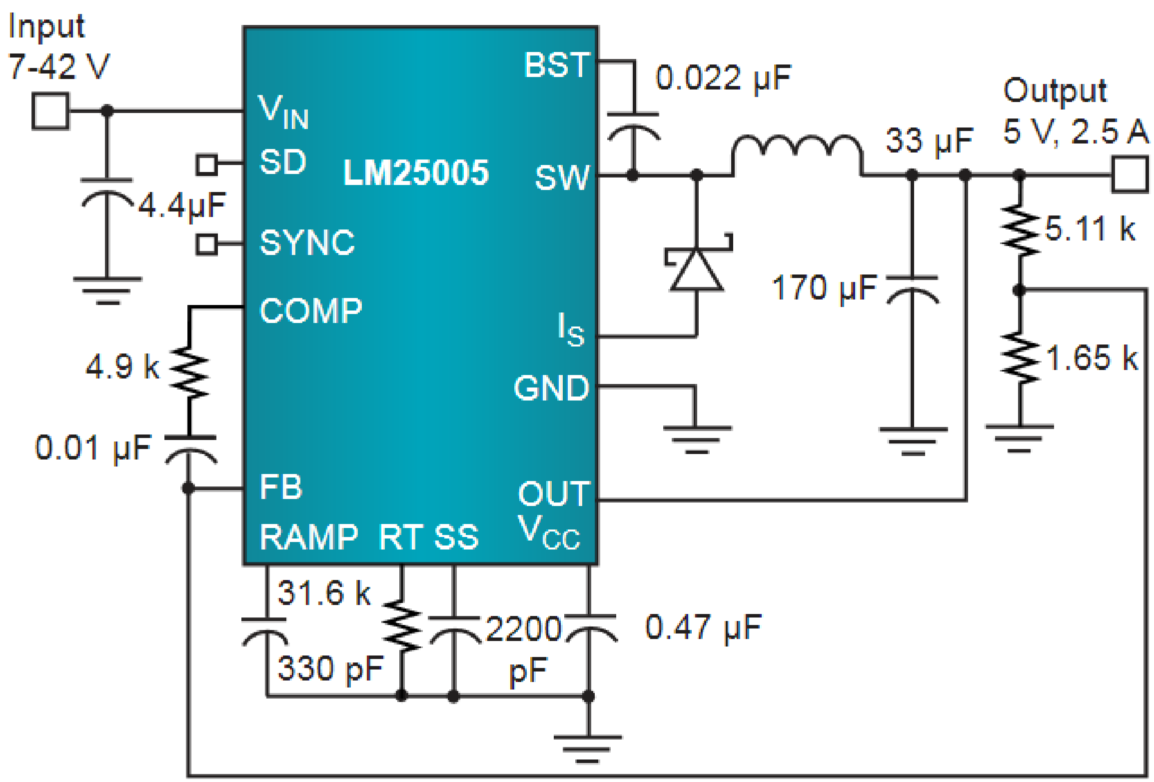


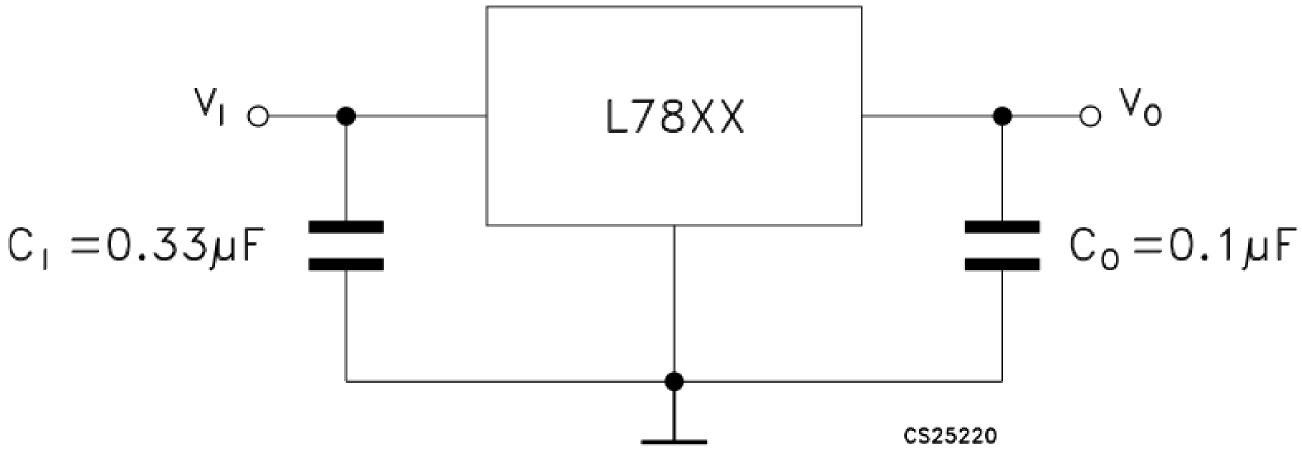
Image by Bob Bell and David Pace, Texas Instruments, Buck regulator topologies for wide input/output voltage differentials, 2016.

Types of switching regulators

- **Buck converters** step down in voltage.
- **Boost converters** step up in voltage.
- **A buck/boost converter** can achieve both (depending upon the input voltage).

Application circuit

- The regulator datasheet will show the application circuit.
- Pay close attention to the component selection and layout guides recommended by the manufacturer, especially for switching regulators.



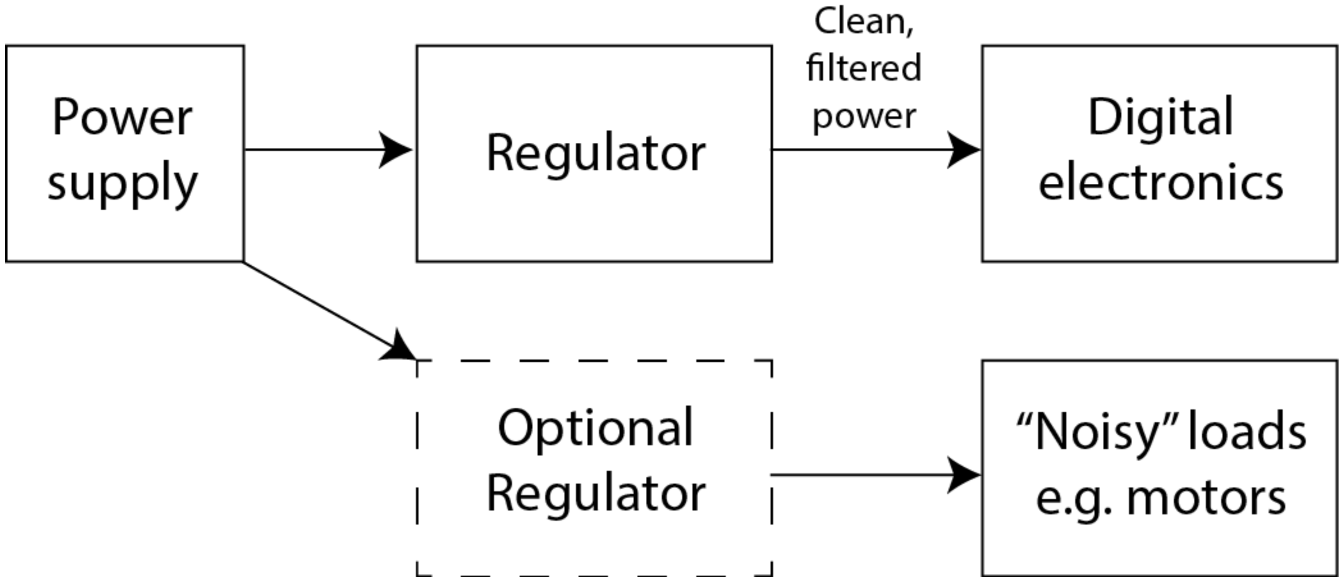
Power supply terminology

Name	Meaning
Vaa	Analog supply (the supply for the analog part of a circuit). Not very common terminology.
Vcc	Power supply
Vdd	Power supply
Vss	Ground [This terminology is rarely used]
Vee	Ground [This terminology is rarely used]

- The terminology:
  - Vcc is adapted from “voltage on the collector” (for BJTs)
  - Vdd is adapted from “voltage on the drain” (for FETs)
  - Vss is adapted from “voltage on the source” (for BJTs)
  - Vee is adapted from “voltage on the emitter” (for FETs)
- Generally Vcc and Vdd are used interchangeably (but choose one and be consistent within a single design)

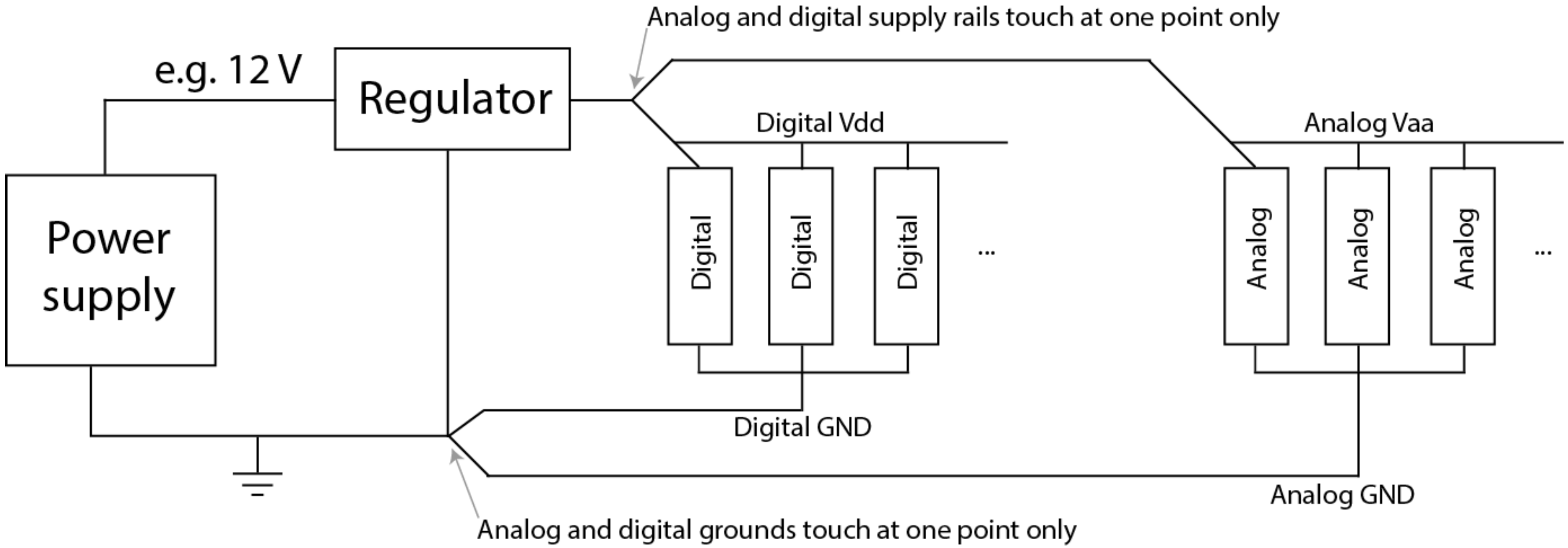
The importance of clean power

- Digital electronics can be sensitive to fluctuations/noise in the power supply.
- Place all the digital electronics behind a dedicated voltage regulator.



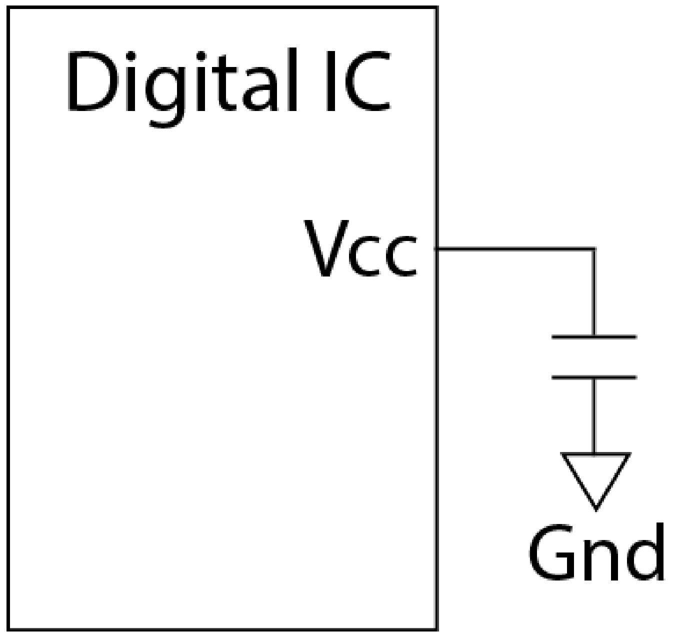
The importance of clean power

- Digital components generate high frequency switching noise, which is detrimental to analog components.
- Keep analog electronics separate.



Decoupling capacitors

- Place capacitors between Vcc and ground as near as possible to the IC.
- The capacitor provides a reservoir of charge to handle variations in power consumption.
- It shorts out high frequency signals and stabilities Vcc.
- Often a microprocessor data sheet will make recommendations about external capacitors.
- Values ~ 0.1 µF are common.



Realistic capacitors

- Real capacitors have an equivalent series resistance (ESR) and inductance (ESL).
- Different types of capacitors have different tradeoffs.

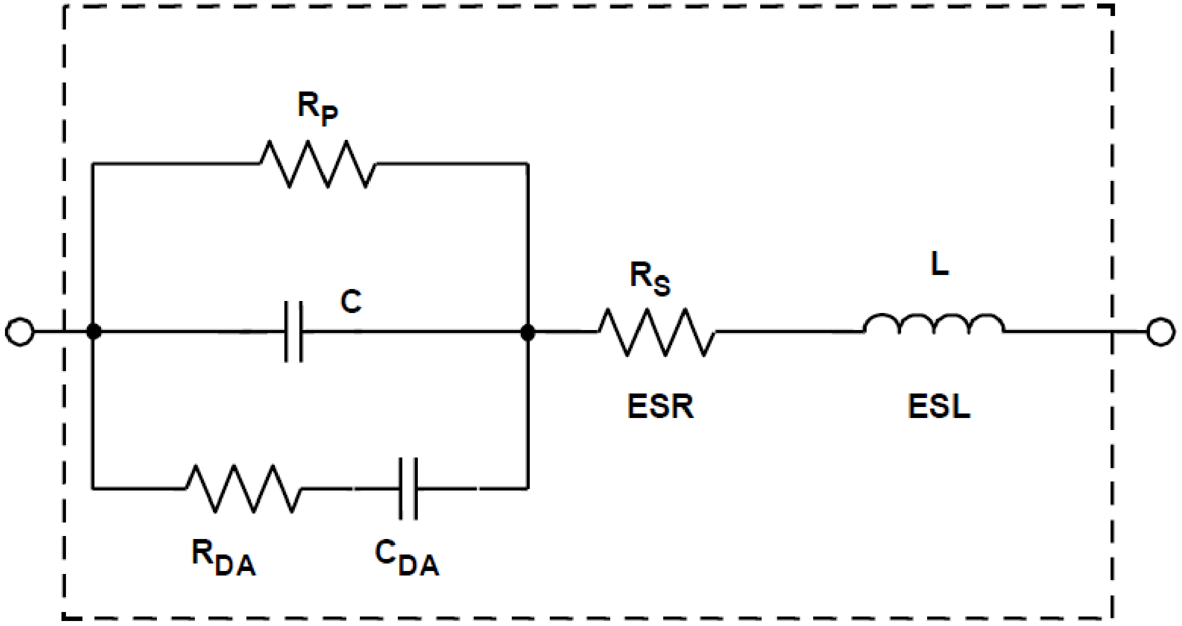


Image from Analog Devices MT-101

Common types of capacitors (1/2)

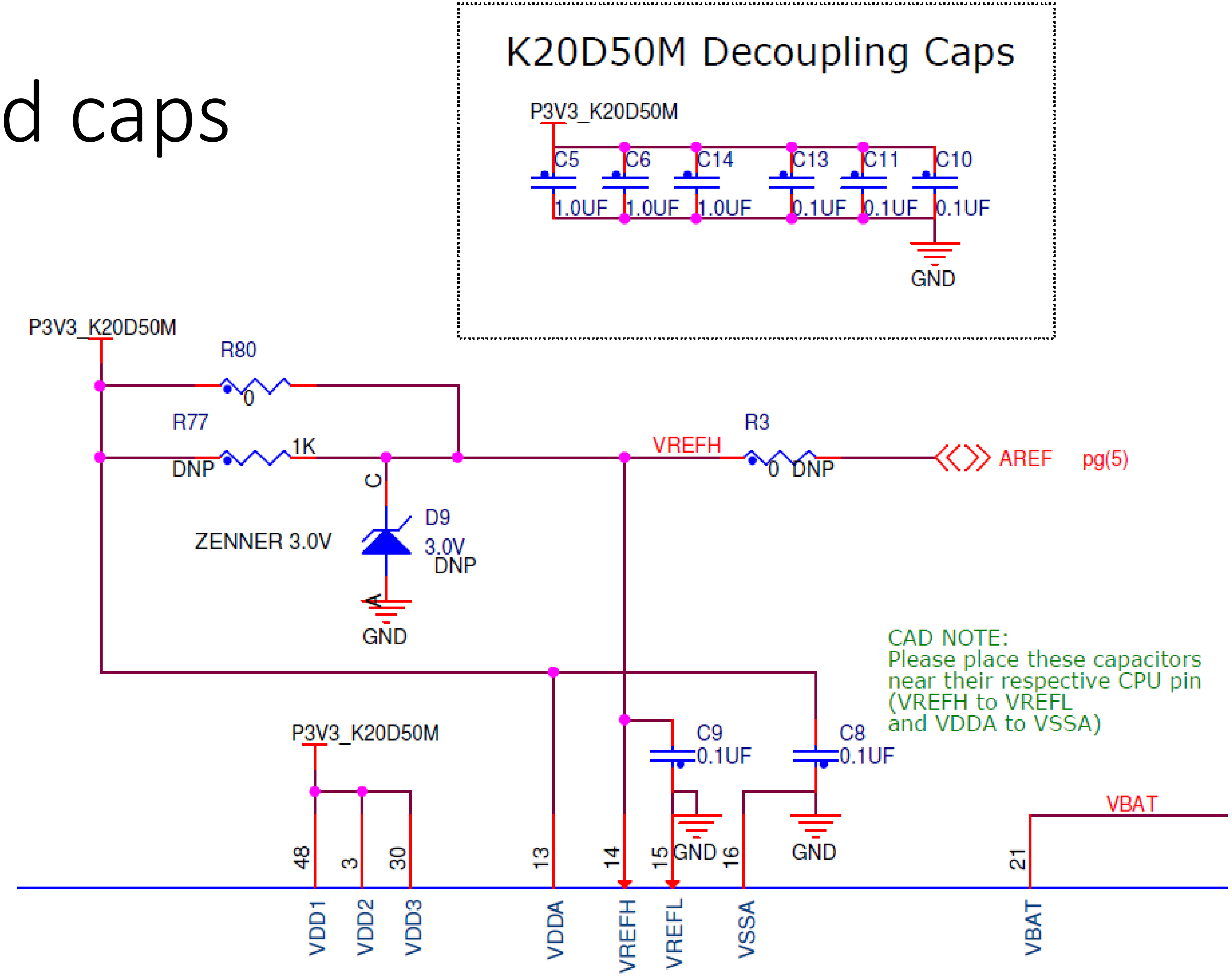
Type of capacitor	Advantages	Disadvantages
Aluminium electrolytic 	• Large capacitances • Low cost	• Polarised • High equivalent series resistance (ESR) • Not suitable for high frequency applications
Ceramic  	• Excellent high frequency performance • Lowest ESR, ESL • Unpolarised	• Small capacitance-voltage product • C decreases with increasing voltage

Reference: Analog Devices MT-101

Common types of capacitors (2/2)

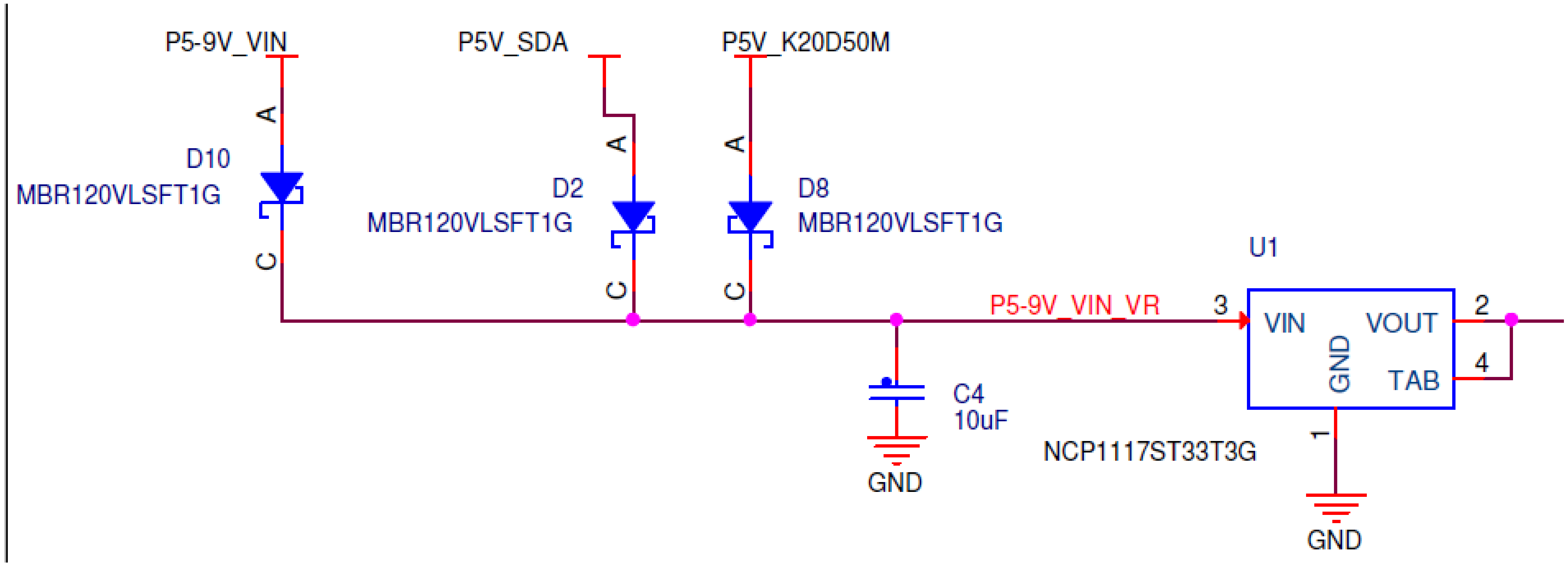
Type of capacitor	Advantages	Disadvantages
Film 	• Commonly used for high voltage applications. • Unpolarised	• Expensive
Tantalum electrolytic  	• High CV product • Stable at cold temperatures	• Polarised: fire hazard if reversed • Higher cost than aluminium electrolytic

FRDM board caps

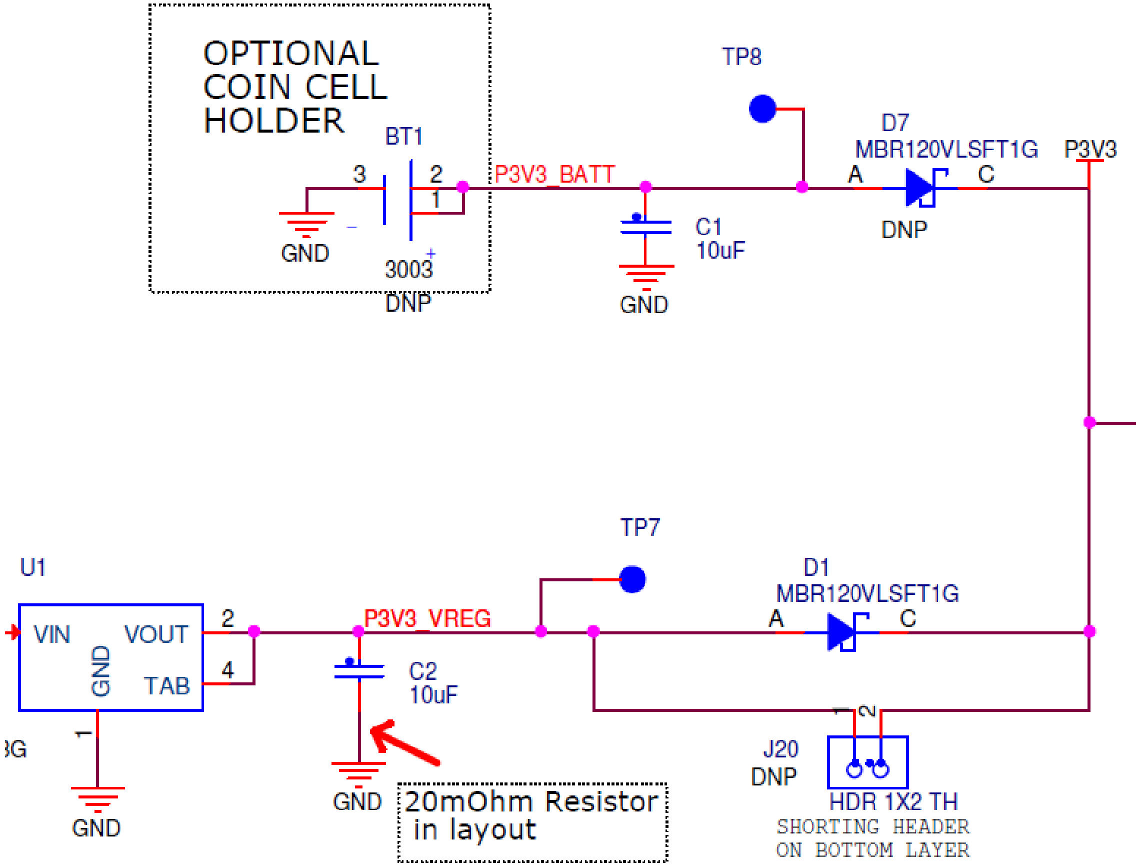


Power supply protection

- If multiple power supplies are present, diodes **must be used** to guarantee the direction of current flow



Power supply protection



Reverse polarity power

- Diodes will also protect against the power supply being connected in the reverse polarity
- Check the reverse breakdown voltage of your diode to make sure it will withstand the necessary voltage

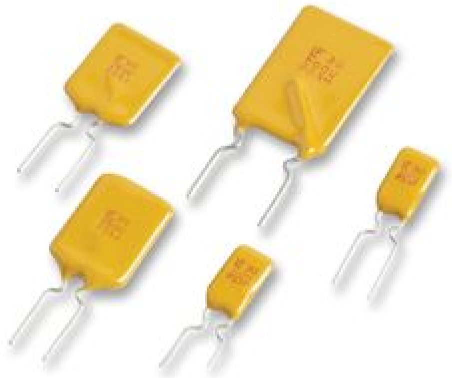
Protection

- **Over-current** events occur when the current exceeds a predetermined threshold.
- Usually this indicates a short-circuit.

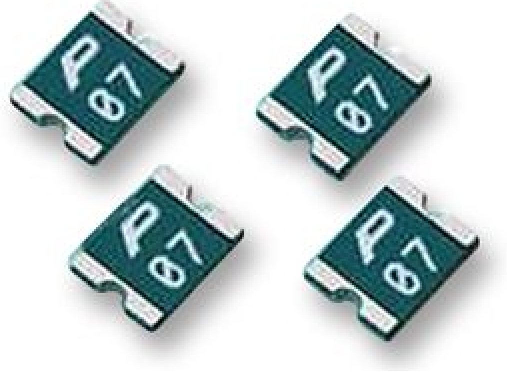
- A **fuse** is a piece of material that burns out if the current exceeds its rated threshold.
- The fuse must be replaced once it has blown.

Positive Temperature Coefficient (PTC) Resettable Fuses

- Resettable fuses automatically return to normal after the short circuit condition is removed.
- Also called **polyfuses** or **polyswitches**, but these are trademarks belonging to specific manufacturers.



- Resettable fuses provide the protection of a fuse without the hassle of replacing blown units.



Operational principle of a PTC fuse

1. High current flows.
2. Temperature rises.
3. Resistance rises.
4. Temperature rises further ($P = I^2R$).
5. Resistance increases further.
6. Temperature rises further.
7. Fuse trips.

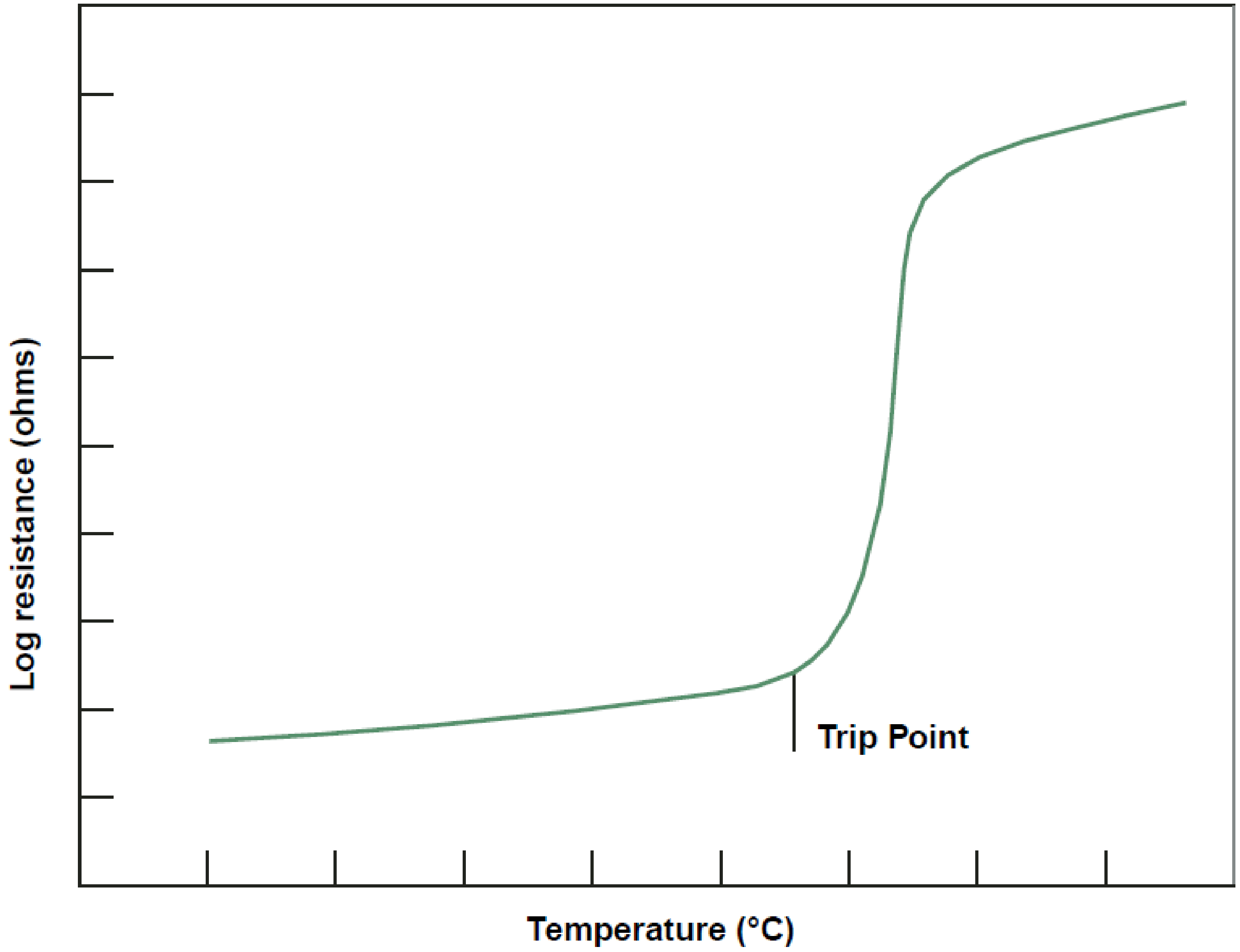


Image from Littelfuse Polyfuse PTC Selection Guide

PTC fuse: recovery

- The resistance drops once cooled (over several seconds).
- It may take hours or days for the resistance to fully recover.

- Conventional fuses have a lower resistance and are more suitable if the voltage drop across the fuse is an issue.

Resettable fuse specifications

- The “holding current” is the maximum current that can be carried without tripping, across the whole rated ambient temperature range.
- The “tripping current” is the minimum current that is guaranteed to trip the fuse.

Example device

- For this device, the typical time to trip is 0.05 seconds.
- Initial resistance: 0.25 Ω
- 1 hour after tripping: 0.9 Ω.

LITTELFUSE 1210L050YR POLYFUSE, PTC, 1210, 0.5A

Add to Favourites

Click to zoom

Image is for illustrative purposes only. Please refer to product description.

Littelfuse

Manufacturer: LITTELFUSE
Order Code: 1822208RL
Manufacturer Part No 1210L050YR

Technical Data Sheet (161.99KB) EN
Re-reeling Services

Availability

Availability: 1,099

110 in stock for next day delivery

185 deliver in 6-7 days from our SG warehouse
804 deliver in 6-7 days from our UK warehouse

see cut-off times

Check stock and lead times

Price for: Cut Tape 1
Minimum order quantity: 150
Order multiple quantity: 10

Price: $0.985

Quantity 150 Buy

Product Information

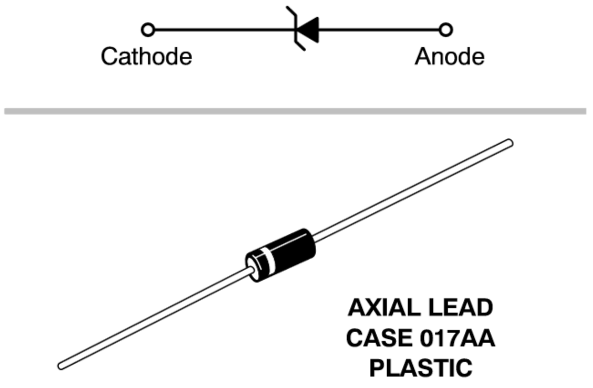
- **Carrying Current Max:** 100A
- **Holding Current:** 500mA
- **Initial Resistance Max:** 0.9ohm
- **Operating Voltage:** 13.2V
- **PTC Fuse Case Style:** 1210 [3225 Metric]
- **SVHC:** No SVHC (17-Dec-2014)
- **Tripping Current:** 1A

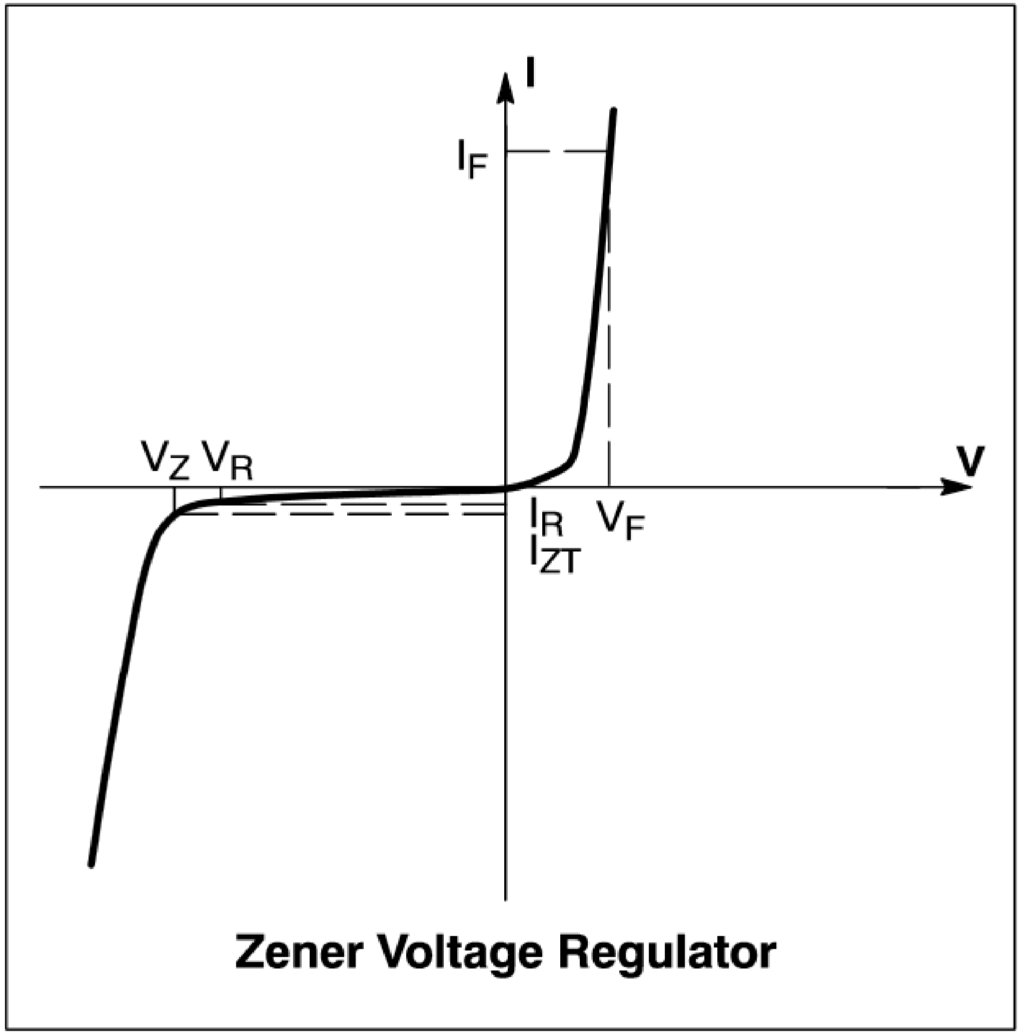
Price

Quantity	List Price
100 - 249	$0.985
250 - 499	$0.907
500 - 999	$0.83
1000+	$0.69

Zener diodes

- A Zener diode is a diode with a well-defined reverse breakdown voltage.

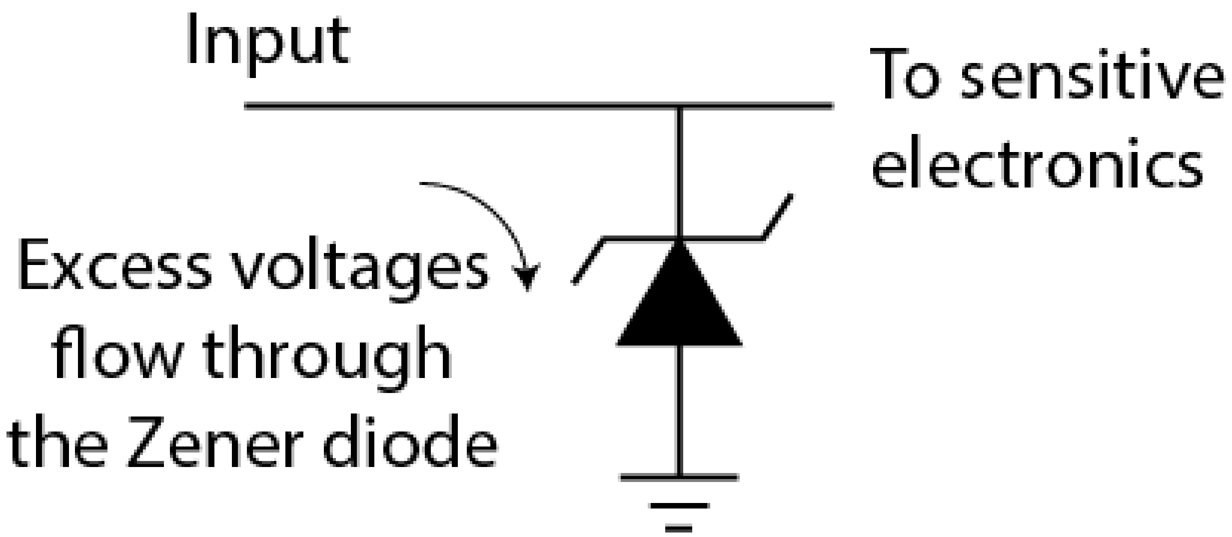




Images from ON Semiconductor datasheet 1N5333B

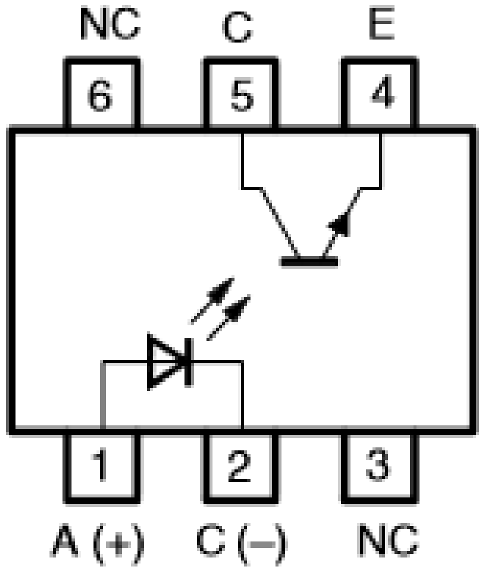
Usage of a Zener diode

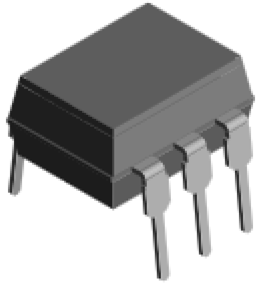
- A Zener diode will clip a voltage to a particular level, e.g. 3.3 V.



Optocouplers

- The ultimate way to isolate sensitive components is to use an optocoupler.
- There is an **optical** (not electrical) link between each side of the circuit.
- Typical design: A LED activates a phototransistor.
- Suitable for isolating mains electricity from consumer electronics.





Power supply and protection overview

- Use voltage regulators to produce stable voltages or to change the voltage to suit the application.
- Decoupling capacitors must be placed between Vcc and GND near sensitive ICs.
- Useful protective devices include fuses, resettable fuses, zener diodes, and optocouplers.

Part 2: Servo and stepper motors

We previously looked at controlling DC motors with H bridge circuits.

Other types of motors:

- Servo motors, with built-in control electronics.
- Stepper motors, for precise control of position.

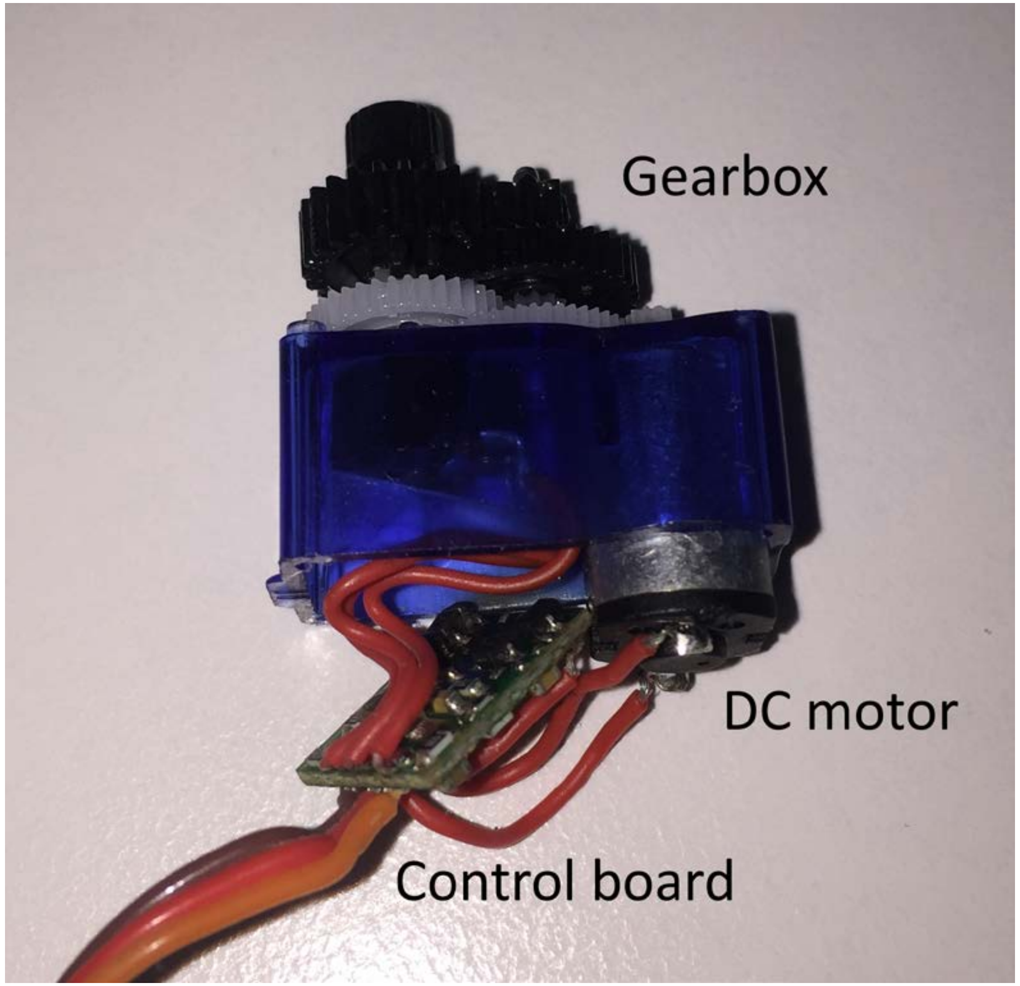
Servo motors

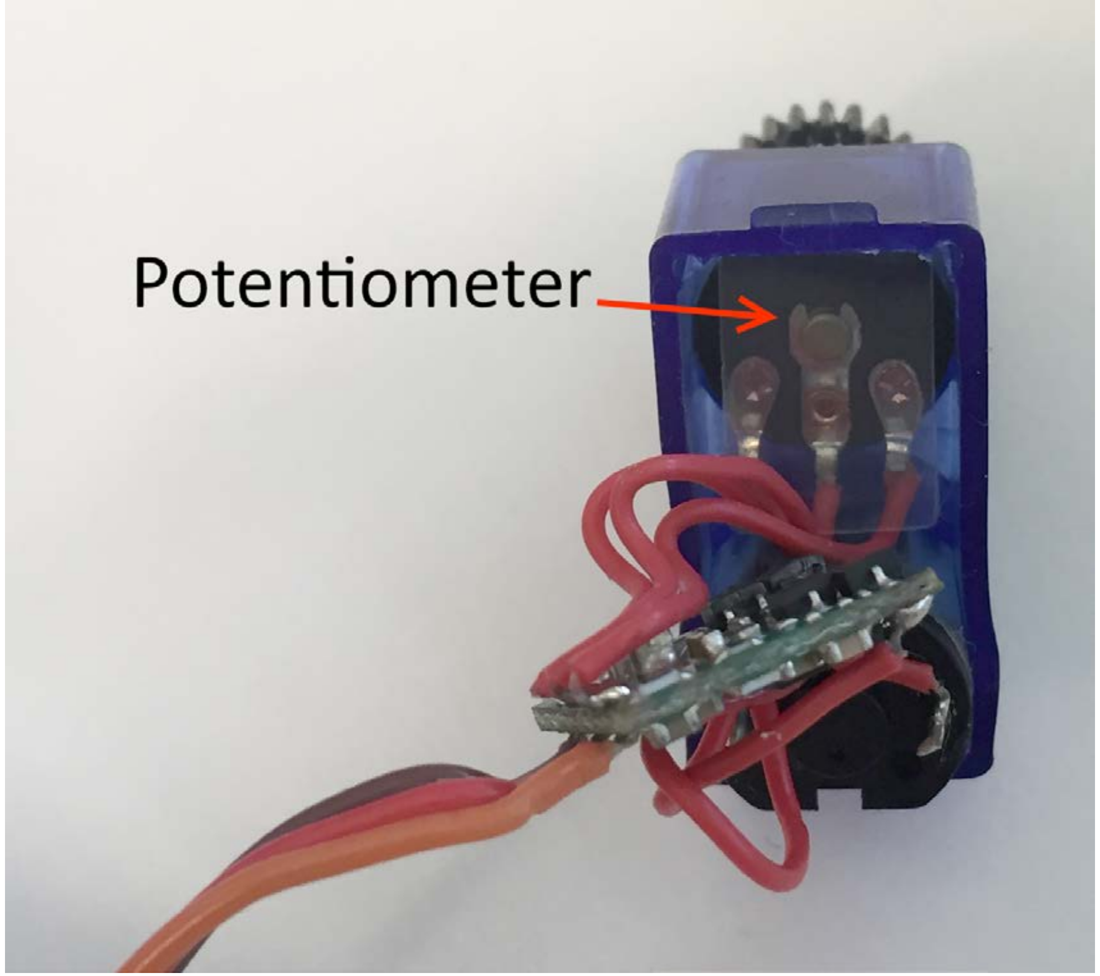
- A servo motor contains:
  - An electric motor
  - Gearbox
  - H bridge or equivalent
  - Control system to drive the H bridge
- Small DC servos (top picture) are called "RC servos".
- There also exist industrial-sized servos that may be driven by DC or AC.

Two types of servos

- Servos have a built-in control system.
- **Regular servo motors** hold a specified **position**.
  - Normal RC servos can rotate only approximately 180°.
  - There are mechanical stops in the gearbox that prevent rotation beyond 180°.
  - These may be called “180° servos”, “positional servos”, or just “servos”.
- **Continuous rotation** servo motors hold a specified **speed**.

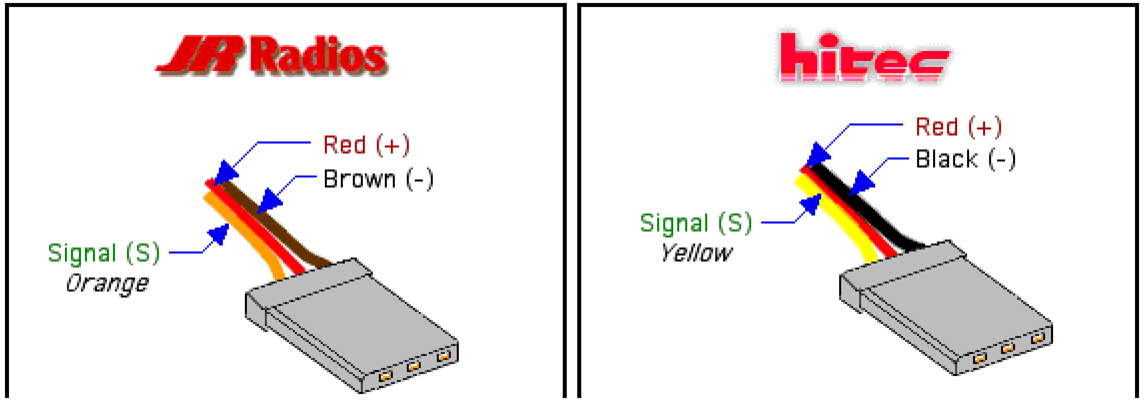
Inside a small positional servo

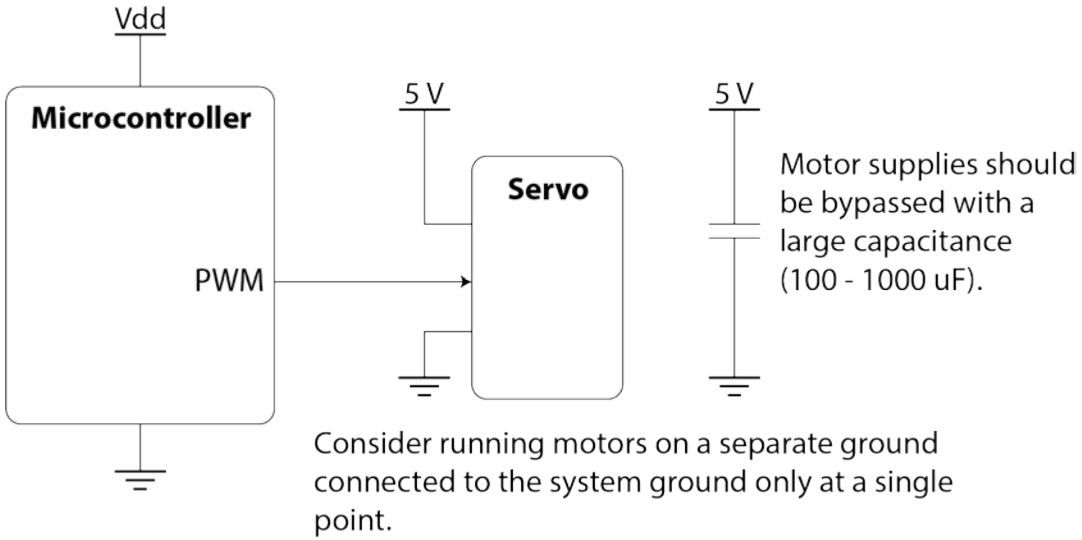




Operation of a servo motor

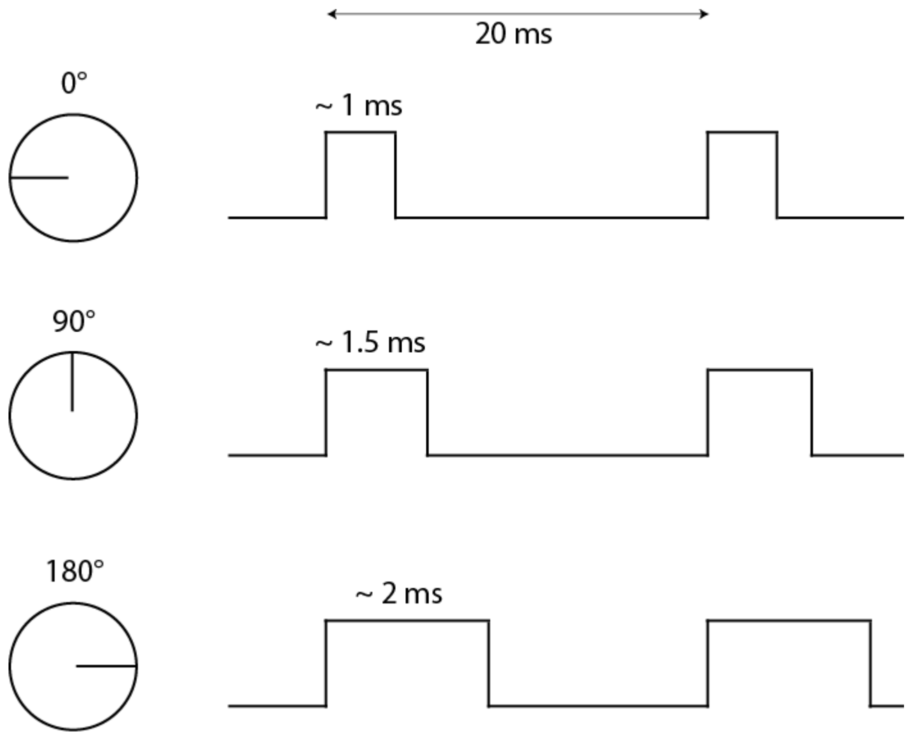
- RC servos have 3 pins:
    - Supply, typically +5V
    - Ground
    - Control signal
- The control signal is pulse width modulation (PWM).
- Electronics inside the servo read the control signal and drive the motor accordingly.





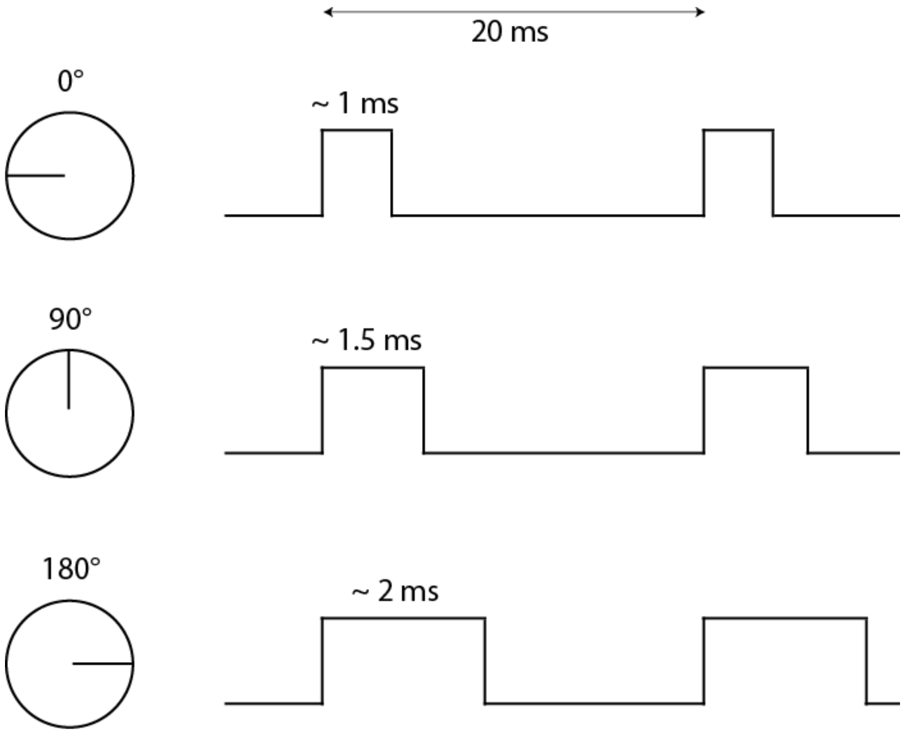
Servo control signals

- The servo reads the **duty time**.
- Typically use 20 ms PWM period, but many servos will accept other periods.
- May need to experiment with PWM duty times to find the precise limits for a particular servo.

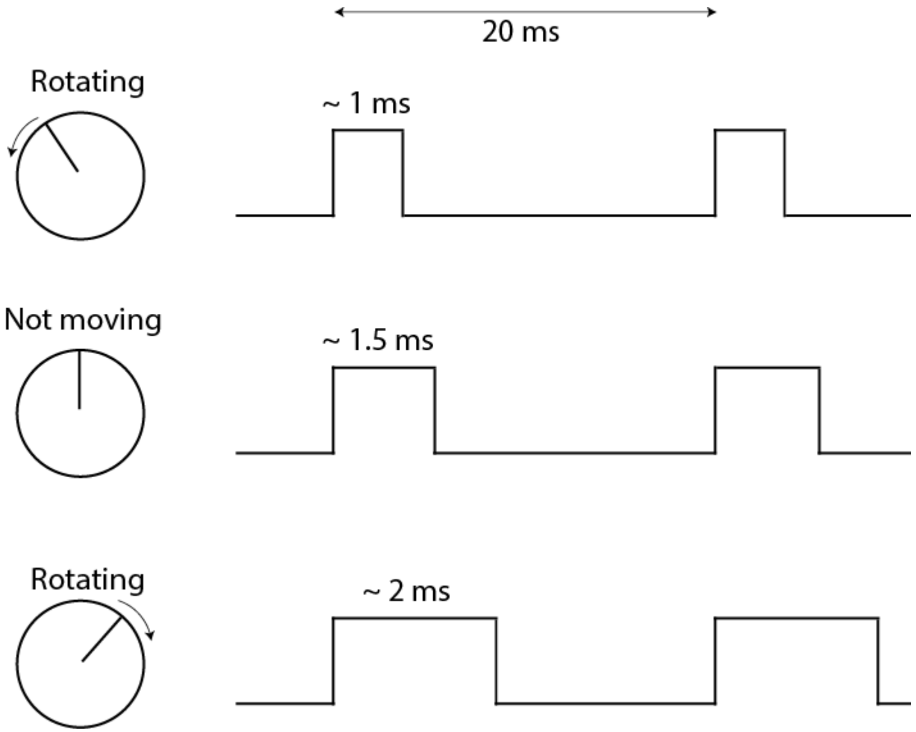


Two types of servo

- Positional servos:

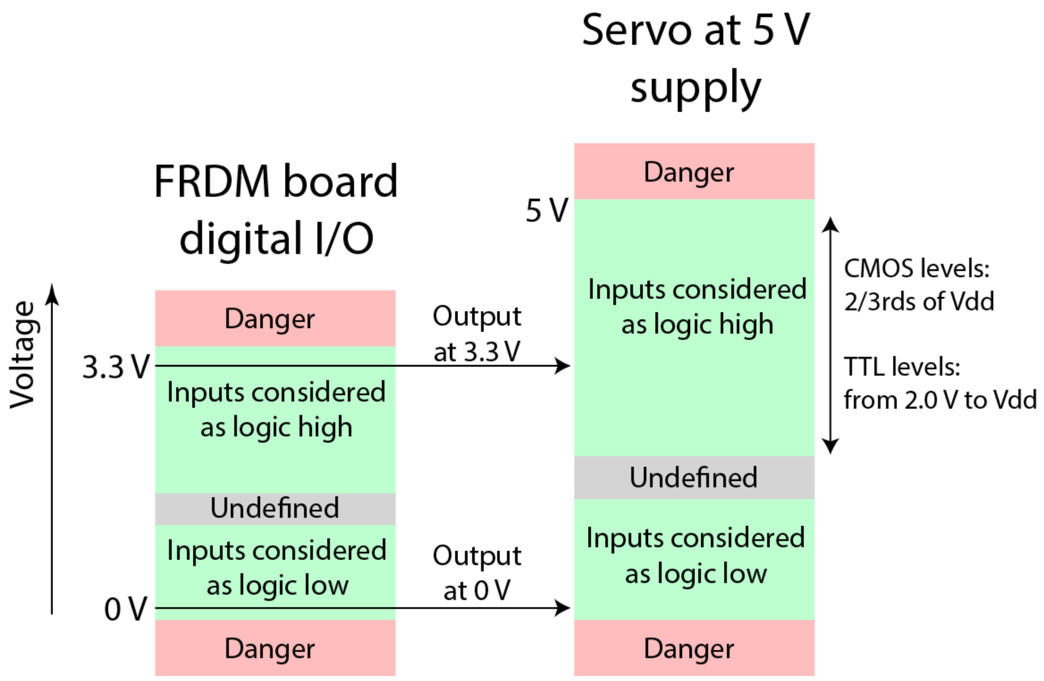


- Continuous rotation servos:



Voltage levels of the PWM

- The PWM signal into the servo is a digital input.
- It will read a range of values as logic 1.
- Can typically run a 3.3 V control signal into a 5 V servo.
  - This depends upon the servomotor control electronics. Check the datasheet!

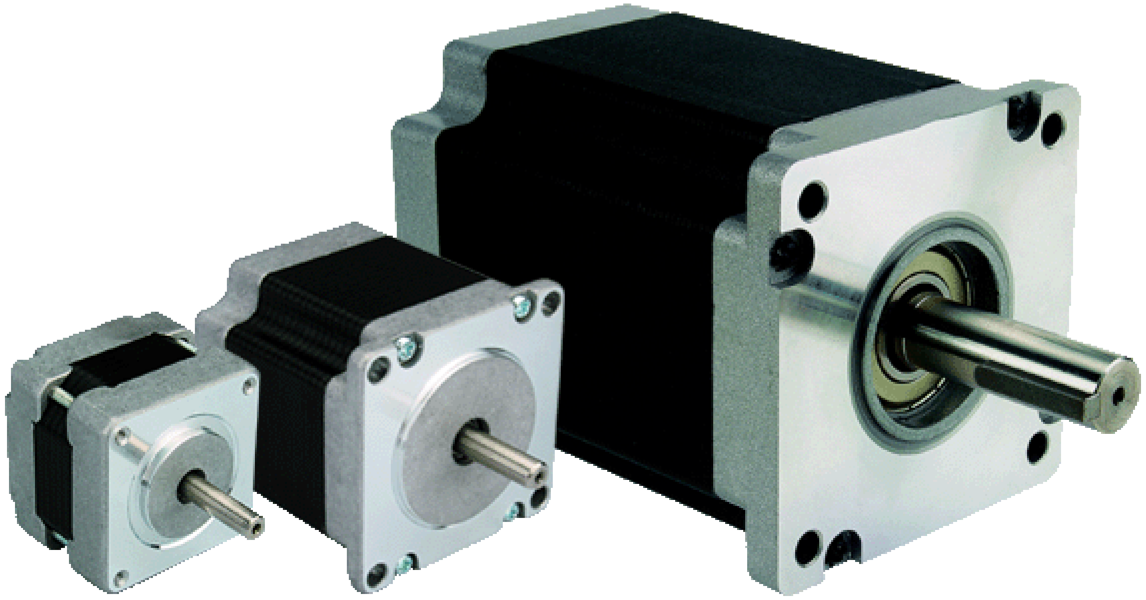


Precision control

- It's difficult to precisely control the position of a DC motor or servo motor.
- **The controller can only respond to perturbations after they occur** (e.g. by monitoring the axle rotation).
- What if you need high precision?
- We would like to have a different type of machine where it would naturally hold the desired position.

Stepper motors

- A stepper motor moves the rotor between discrete “steps”.
- They obtain very good precision (provided the motor has sufficient torque to hold the load).
- Used in industrial machines and equipment.



Cartoon of a stepper motor

- Rotor is magnetised axially (i.e. north-south axis is out of the page).
- Here phase 1 is energised, resulting in an electromagnet running vertically.
- The electromagnet grabs and holds the rotor as shown.
- To turn the motor, turn off phase 1 and turn on phase 2. The motor will "step" to the next position.

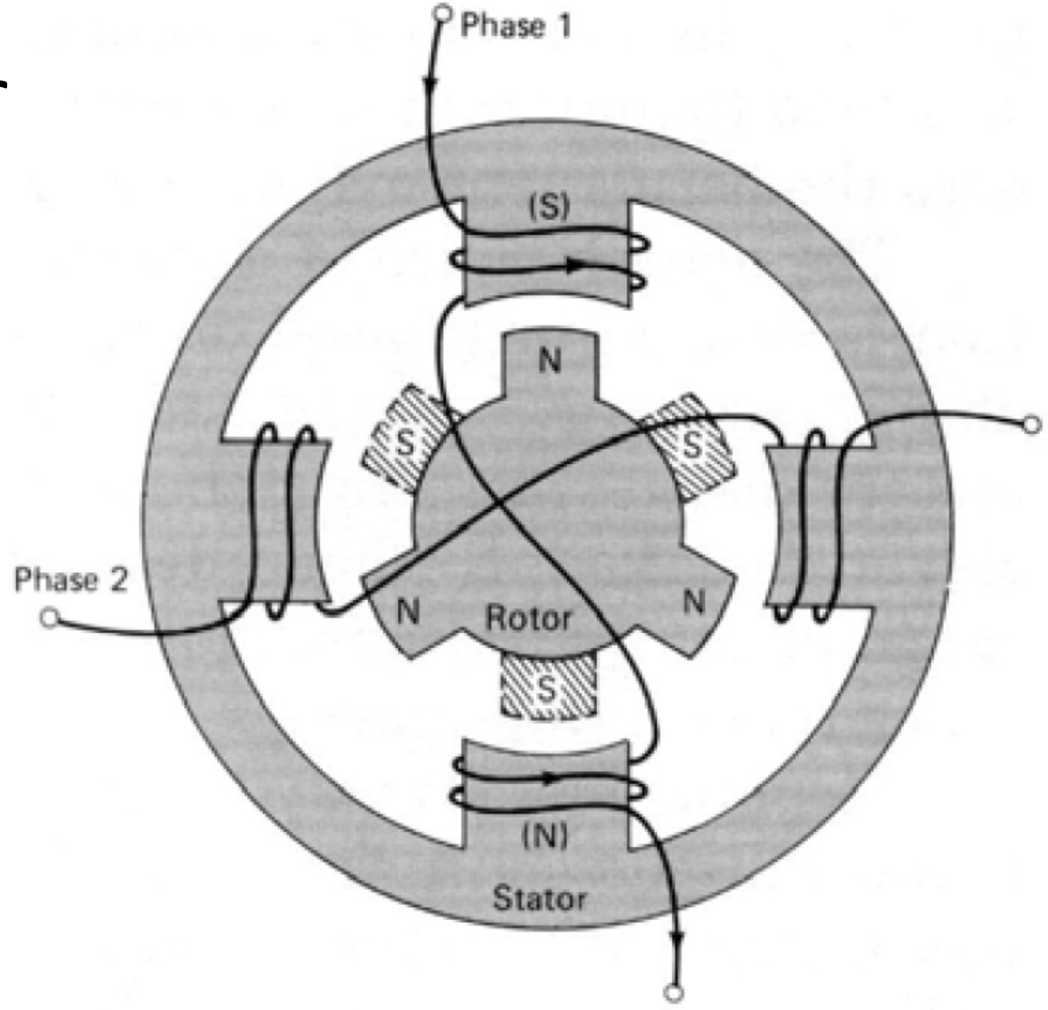


Image by Dave Wilson, Texas Instruments Motor Control Compendium, 2010-2011.

Realistic stepper motor design

Notice the rotational offset between front and back teeth.

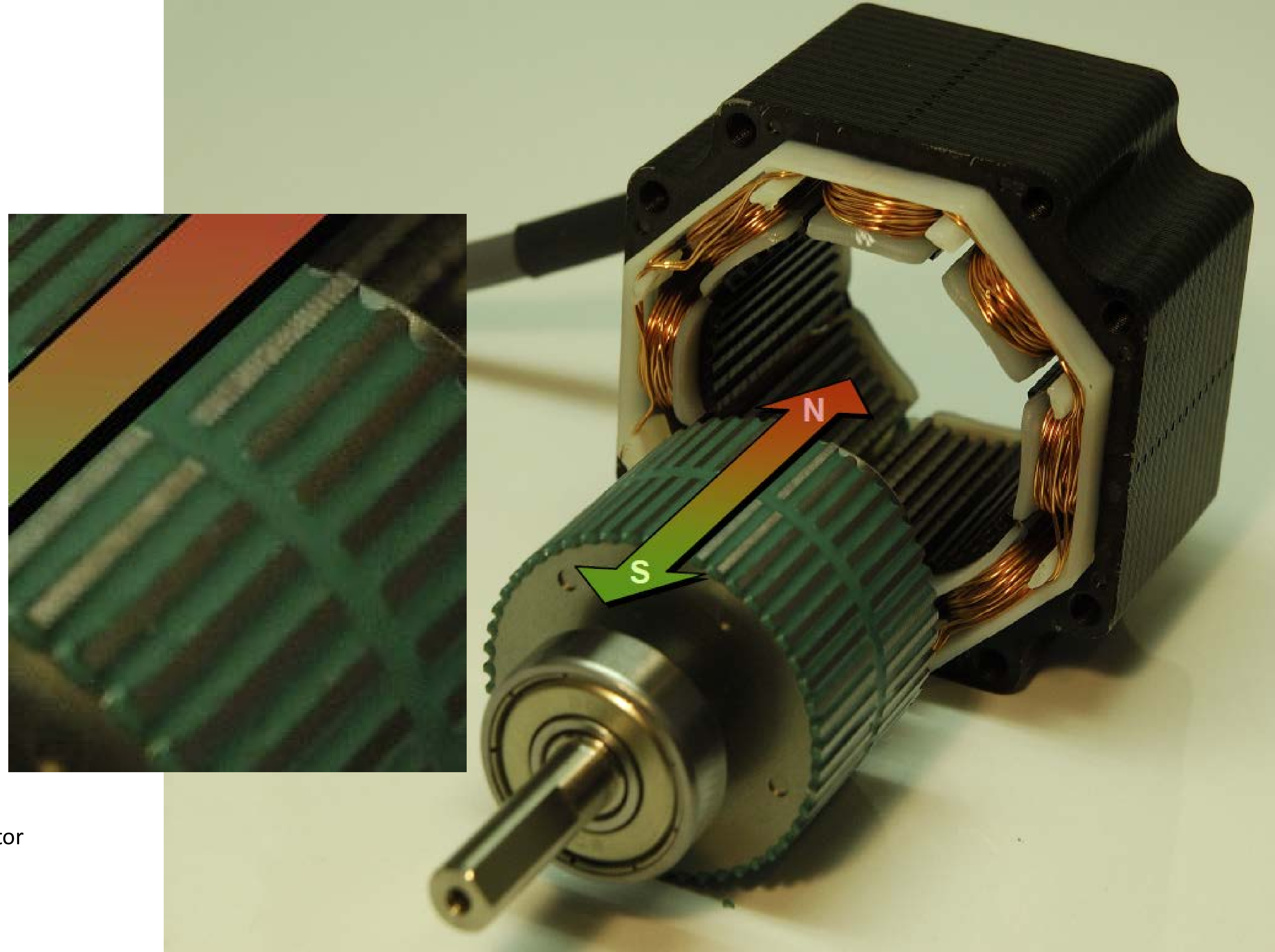


Image from Texas Instruments Motor Control Training

Close-up of stepper motor interior

Rotor teeth aligned with electromagnet.

Next step will rotate axis to align these teeth.

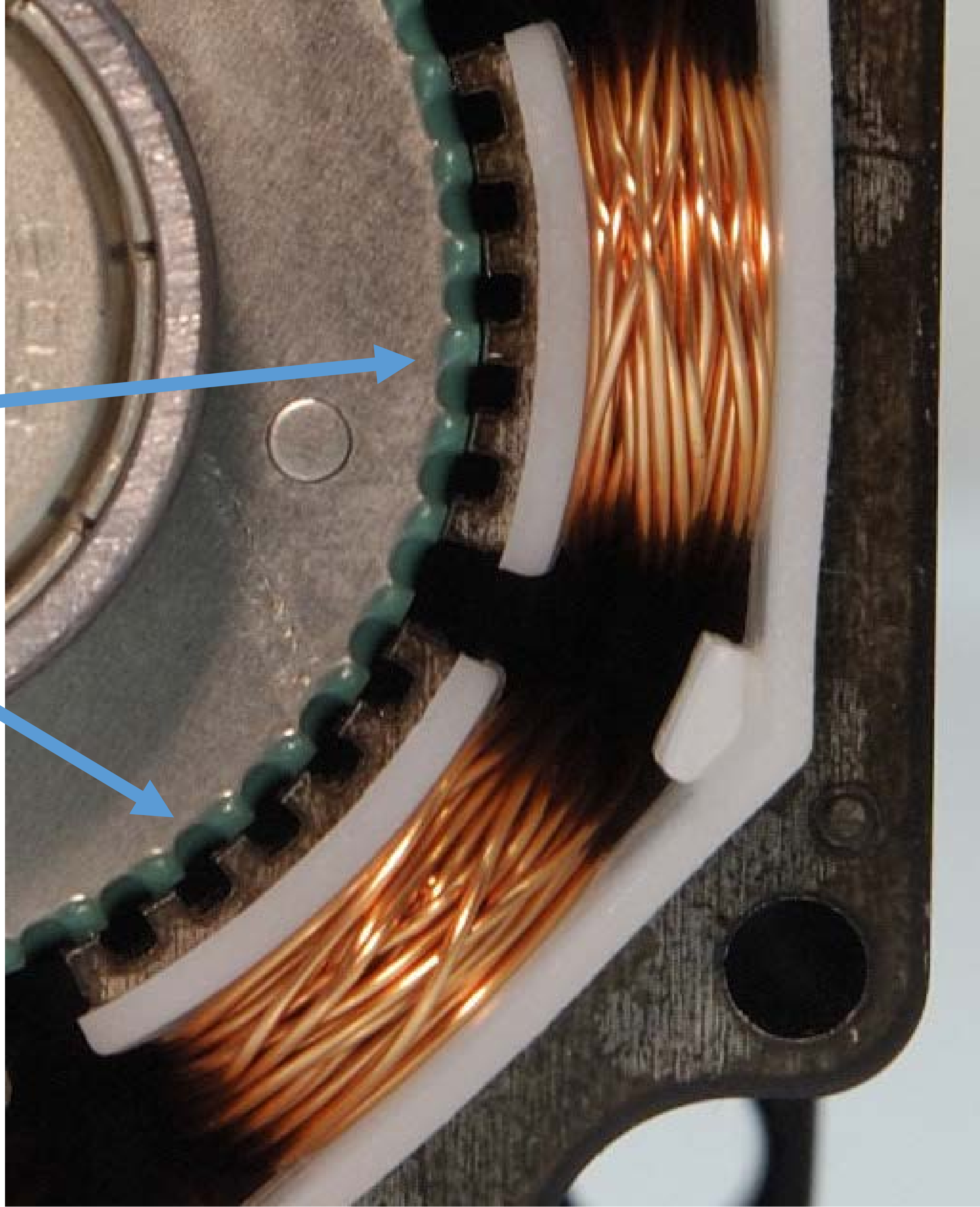


Image from Texas Instruments Motor Control Training

Realistic stepper motor design

48 Stator Teeth

50 Rotor Teeth

North Pole

South Pole

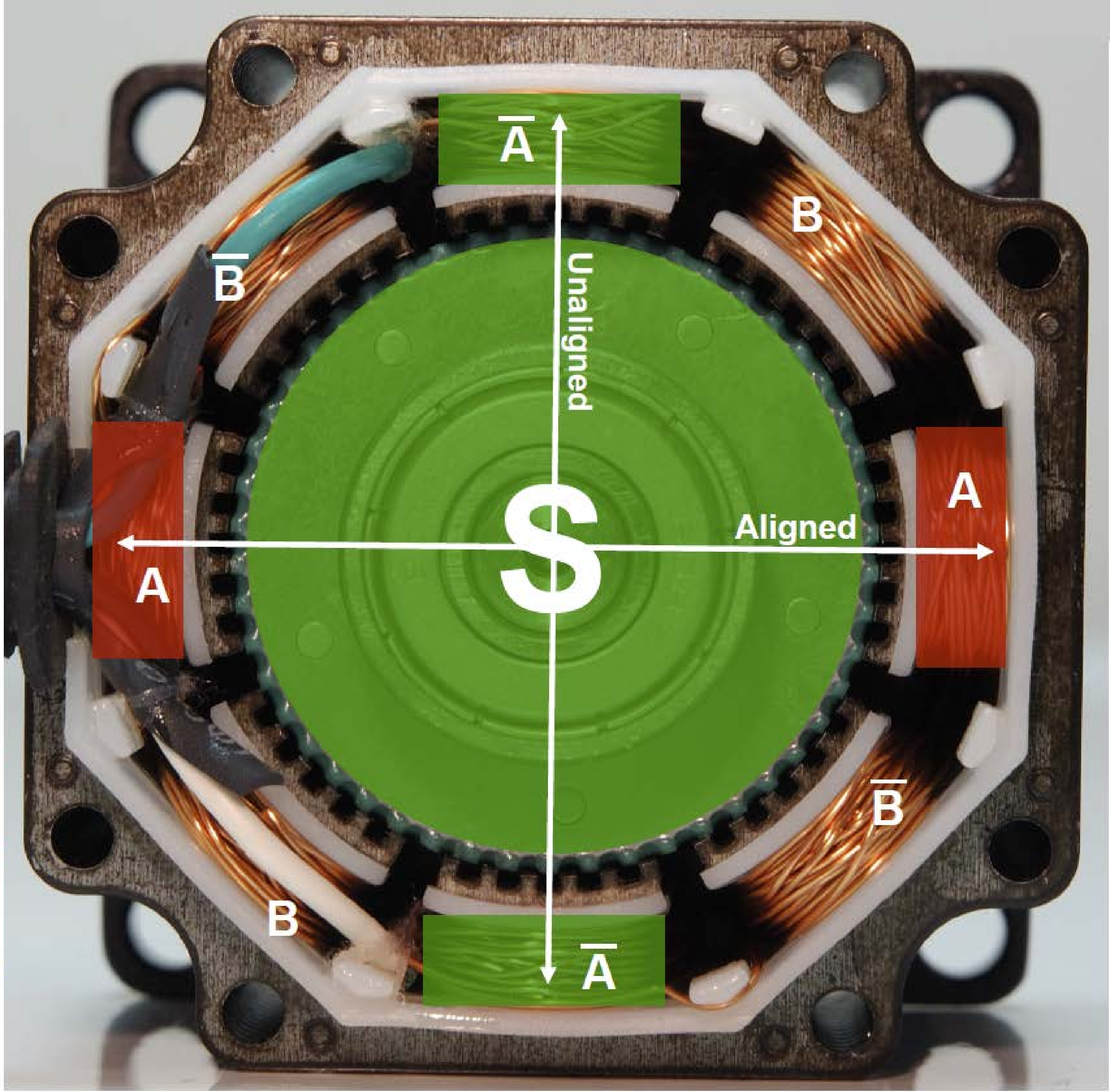
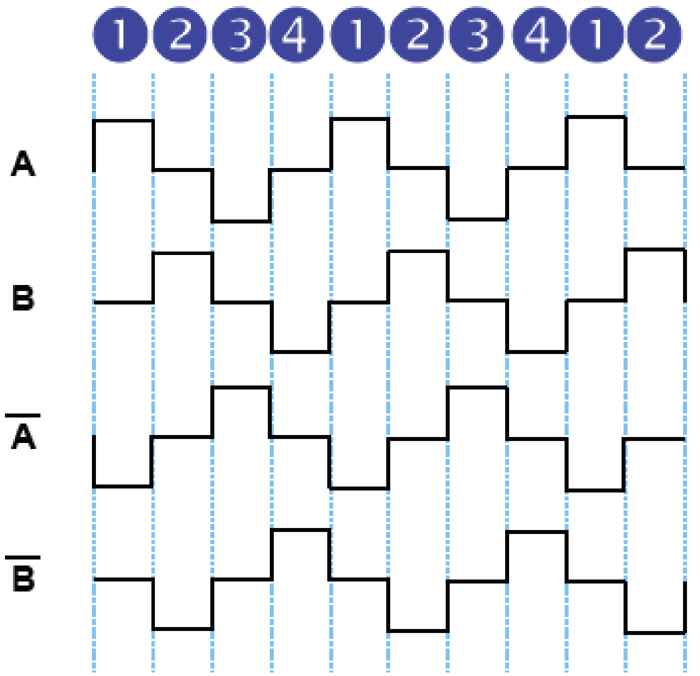


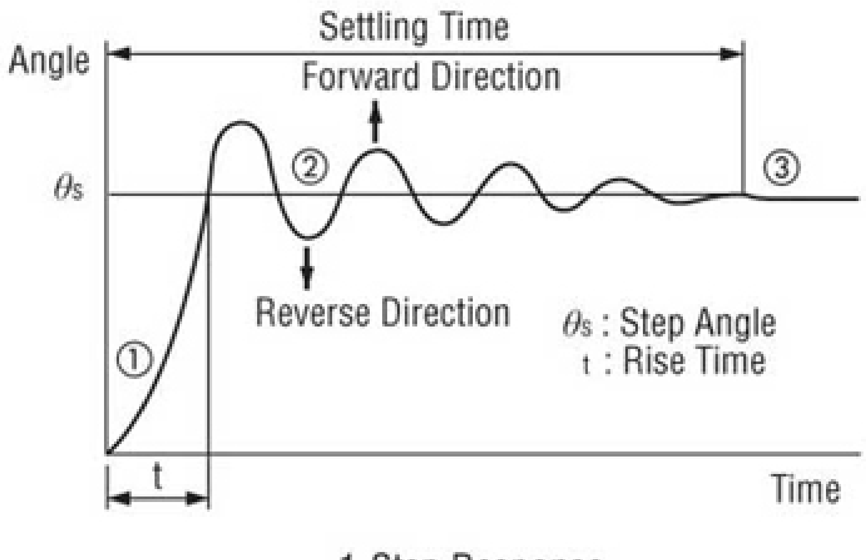
Image from Texas Instruments Motor Control Training

Stepper motor drive voltages

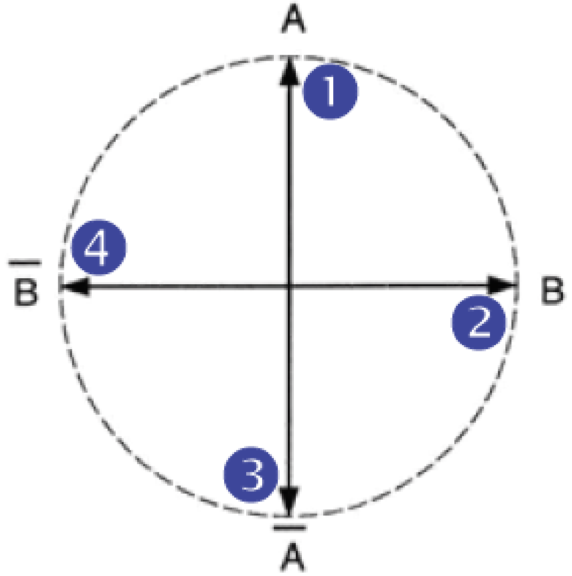
- The simplest way to drive a stepper motor is by energising each phase in turn and alternating the polarity of each phase.
- A problem is that the motor rotation will overshoot on each step.



Waveform period is 4 steps (Full Stepping)



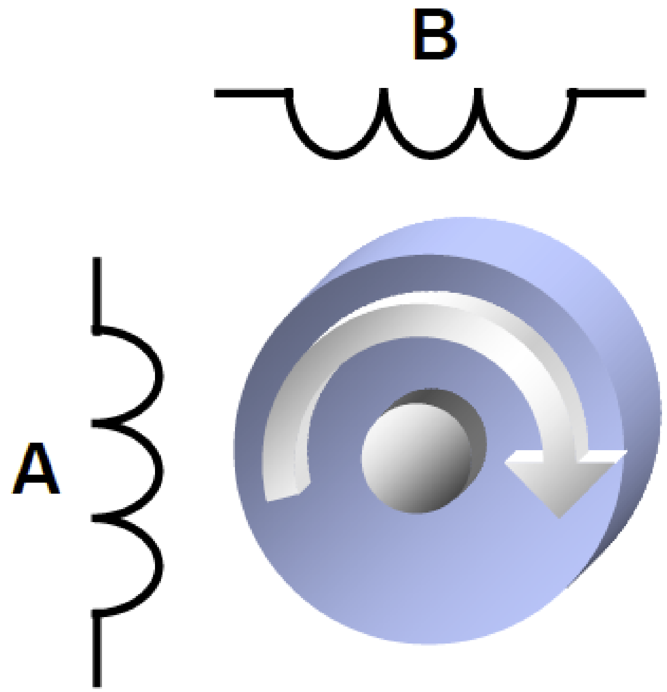
1-Step Response

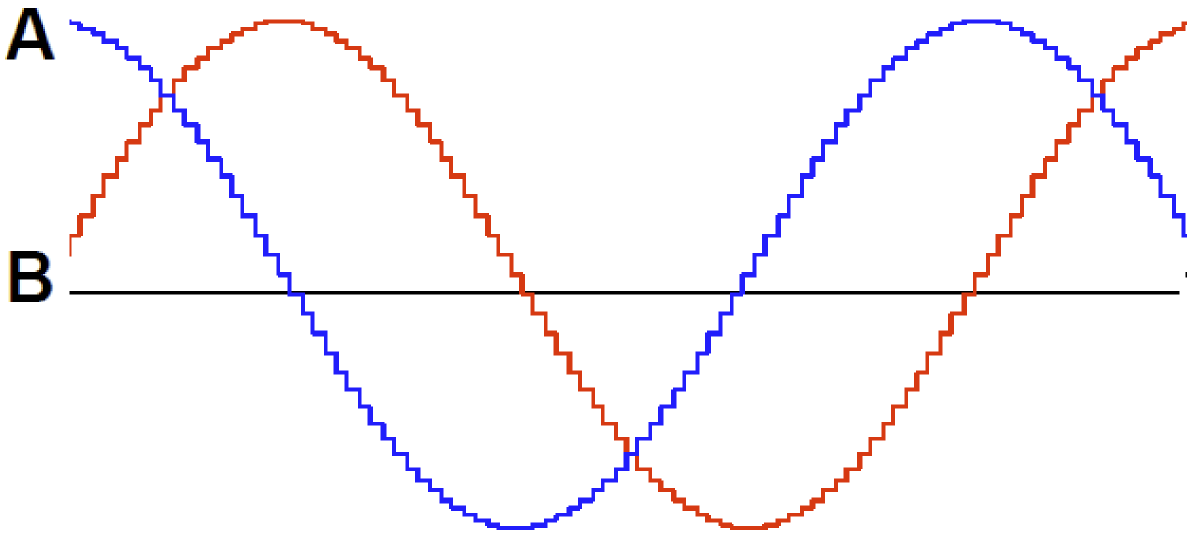


Images from Texas Instruments Motor Control Training and Oriental Motor Stepper Motor Overview

Improving the stepper motor response

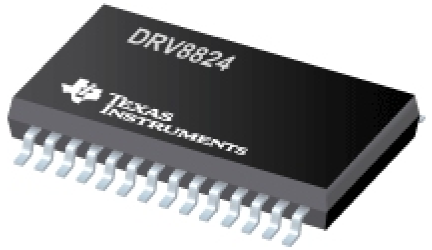
- “Microstepping” (voltage waveform shown) improves response characteristics by easing the rotor between steps.
- Requires more sophisticated driver circuitry to implement.





Stepper motor drivers

- In many applications you would use a specialised stepper motor driver (example device shown).
- This should provide:
  - Microstepping.
  - Current limiting / current sensing.



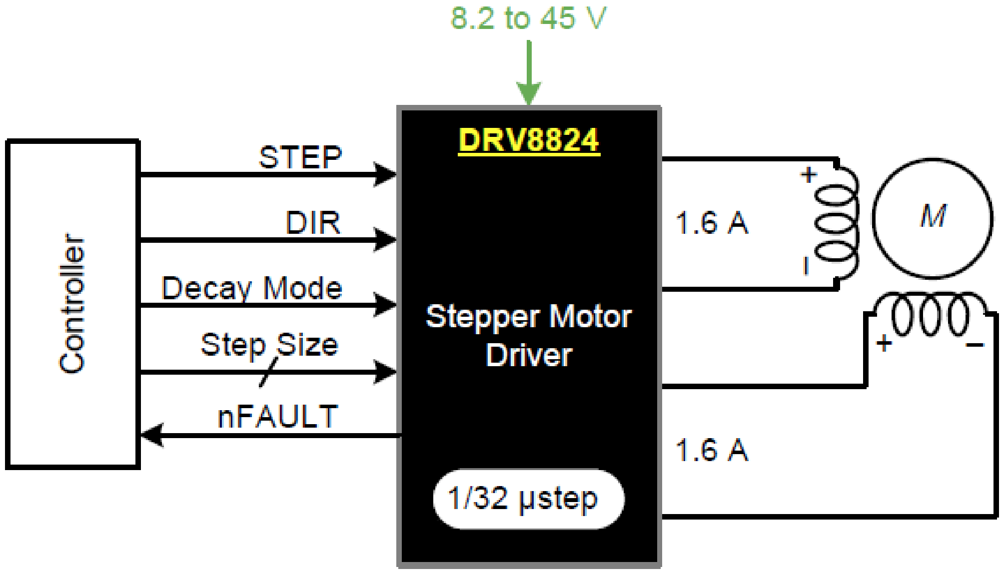


Image from TI DRV8824 datasheet.

Using a stepper motor driver

Typical stepper motor drivers have a digital interface where a rising edge on a “step” pin causes the motor to advance by one microstep.

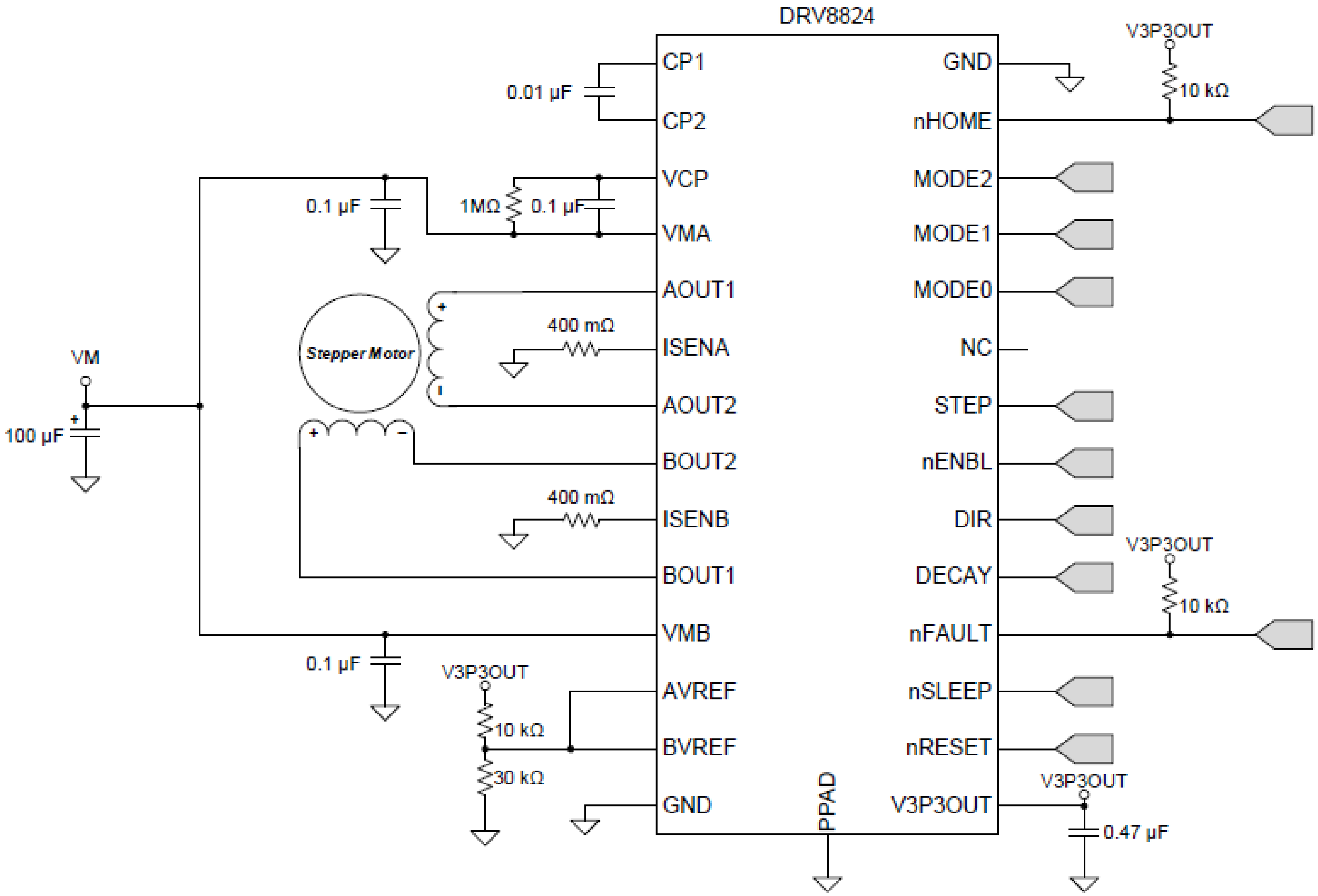
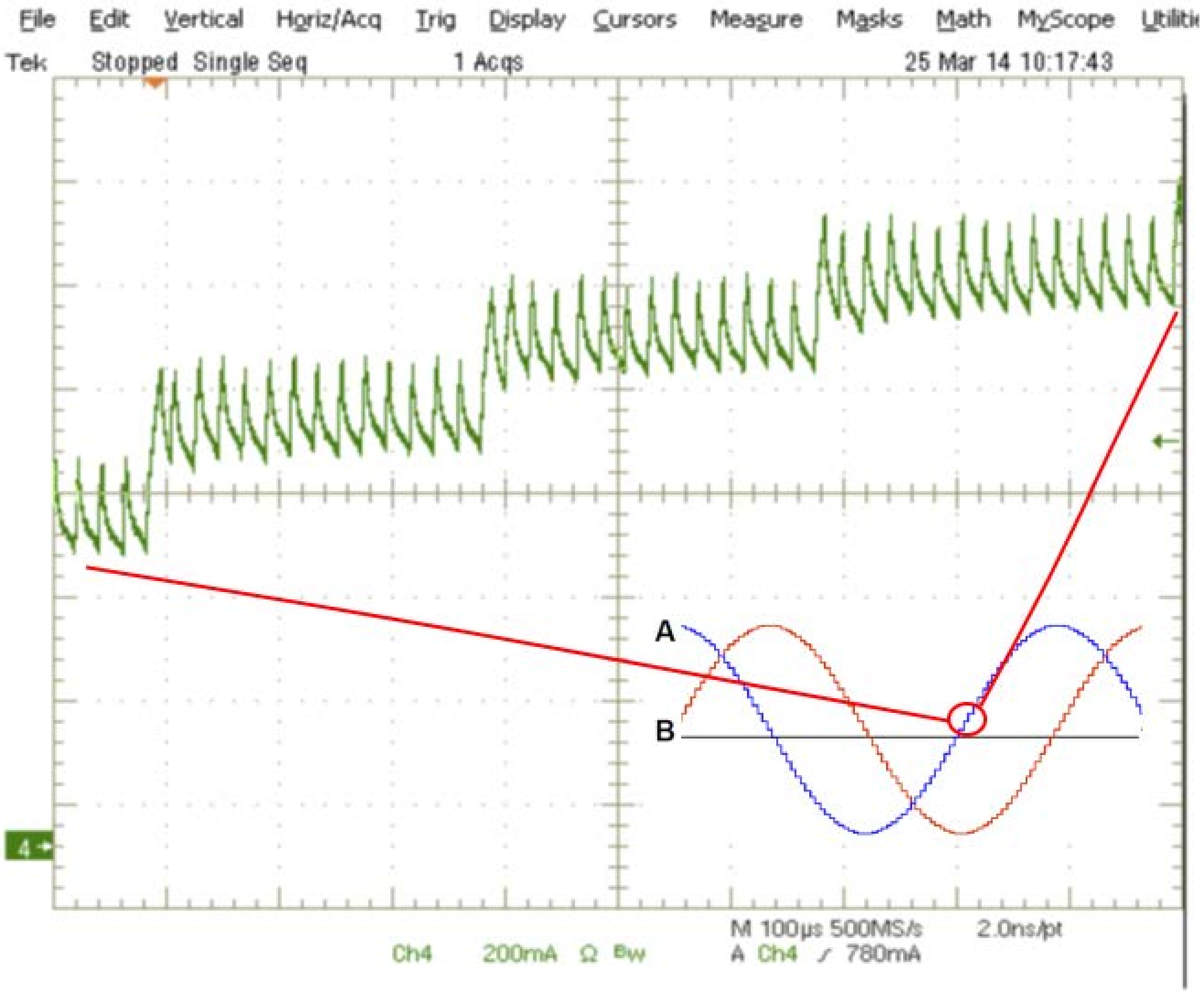


Image from TI DRV8824 datasheet.

Example output from stepper motor driver

- This snapshot shows driving voltage over 4 microsteps.
- Within each microstep, voltage rises until the current limit is reached, then decays until the next PWM period.
- The current limit is adjusted depending upon the microstep counter.



Oscilloscope screenshot from TI DRV8824 datasheet.

Motor summary

- **Servo motors** are motors with a built-in control system that hold the specified position/speed.
- **Stepper motors** enable precise control but require more sophisticated driver circuits.