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Lecture 7

Actuators and Motion Control: Servo and Stepper Motors

Mechatronics

MMME3085

Module Convenor – Abdelkhalick Mohammad

Lecture Objectives

- To understand the different types of servomotor
- To understand the main characteristics of servo motors
- To understand how servomotors may be interfaced to a computer
- How Stepper motor works
- How they can be interfaced to a controller

A typical Mechatronics System

Computer or micro-processor

2,3,10

1,4,10

Program e.g., in C

Buses in computer

Digital output inter-face; timer

Digital input inter-face; counters

Digital signal

DAC

Analogue signal

Digital signal

5,6

Digital signal

ADC

Analogue signal

Digital signal

7,8,9

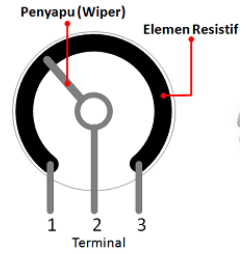
Electronic hardware

Actuators

Mechanical system

Sensors

Electronic hardware

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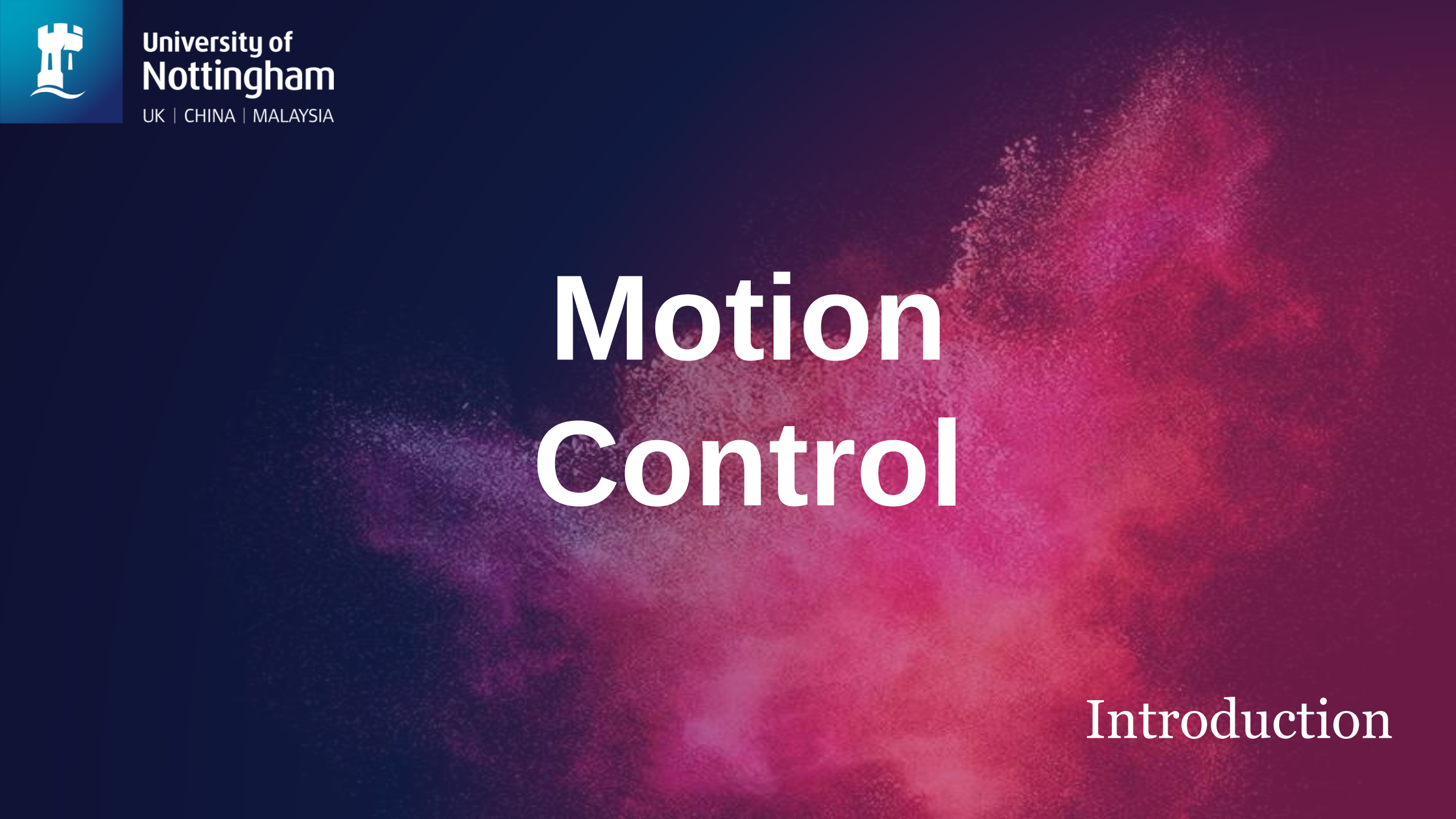
Recap

From last lectures

So far, we learned …

- How to deal with digital signals including train of pulses
  - Generate digital signal
  - Read digital signal
- Timer/Counters as a hardware solution
- Registers in µp
- State Tables
- Finite State Machines
- Interrupt
- DAC and ADC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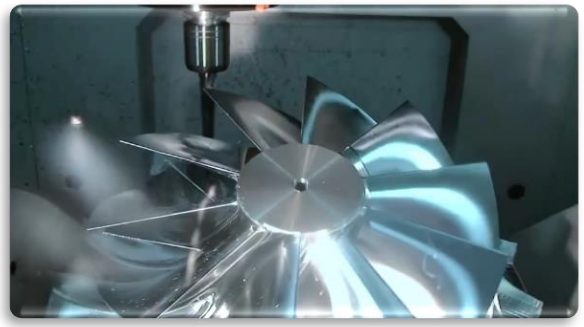
Motion
Control
Introduction

Actuators

- So far we have considered how we can:
  - Measure what is going on in our equipment using a variety of sensors, transducers etc.
  - Interface the signals from these to our computer, microprocessor etc.
  - Avoid some of the pitfalls (noise, aliasing etc.)
- Now we need to consider:
  - How we make things happen under an electrical signal using actuators
  - How we can interface these to a computer or similar device

Motion control

- Widely used in:
  - Machine tools, robotics etc. (e.g. Motion control system for CNC applications)
  - Laboratory equipment (e.g. within optical experiments or equipment)



CNC machine

Robotic

http://www.directmotion.com

Two approaches to motion control

- Servo motors
  - Work in closed loop mode
- Stepper motors
  - Work in open loop mode (usually)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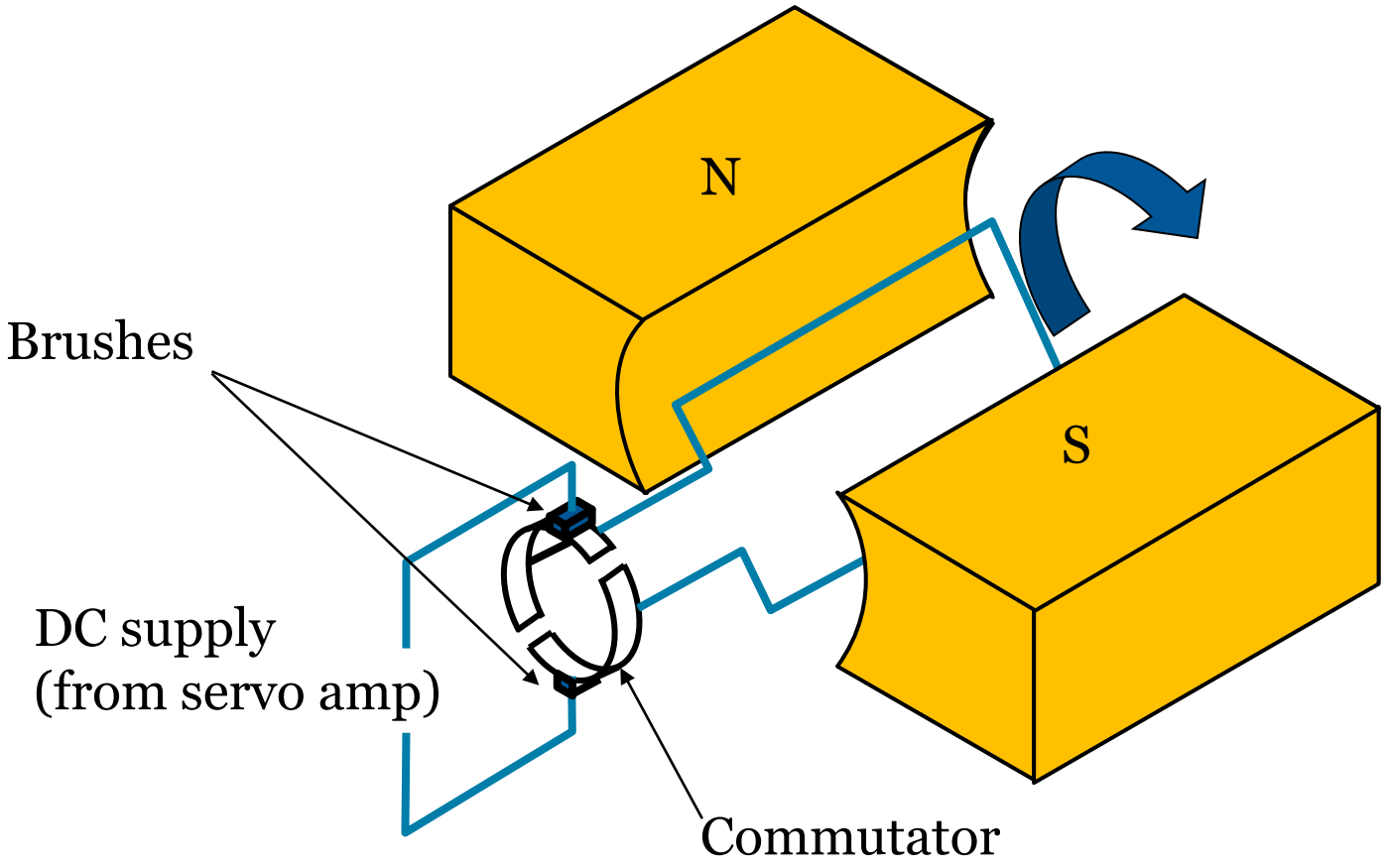
Servo Motors
Introduction

What is a servomotor?

- In principle: any motor used in closed-loop control of torque, speed or position.
- Rapid response and precise positioning are required.
- Requirements of a servomotor are therefore:
  - high ratio of torque to inertia
  - torque must be smooth and ripple-free
  - need to be able to handle high currents

How does a servomotor work?



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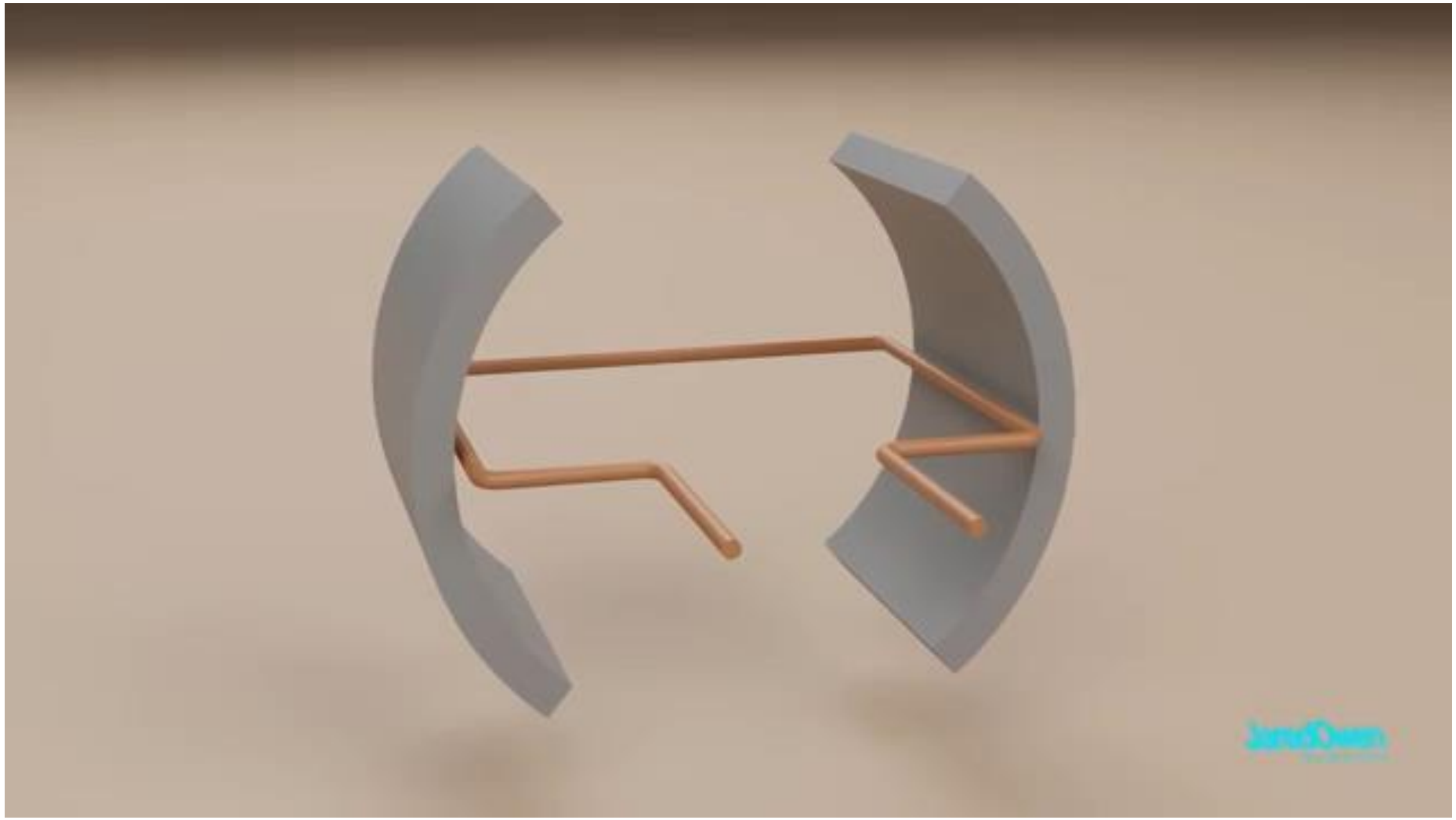
How does a servomotor work?



www.youtube.com/watch?v=CWulQ1ZSE3c

What types of servomotor exist?

- Conventional DC (Iron core motor)
- Ironless DC servomotors (printed armature, pancake, basket type etc.)
- Brushless servomotors: sometimes classed as DC, sometimes as AC

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Servo Motors

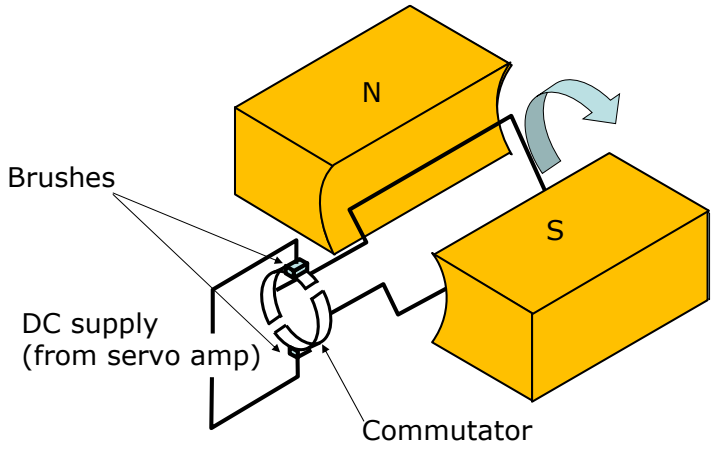
Characteristics

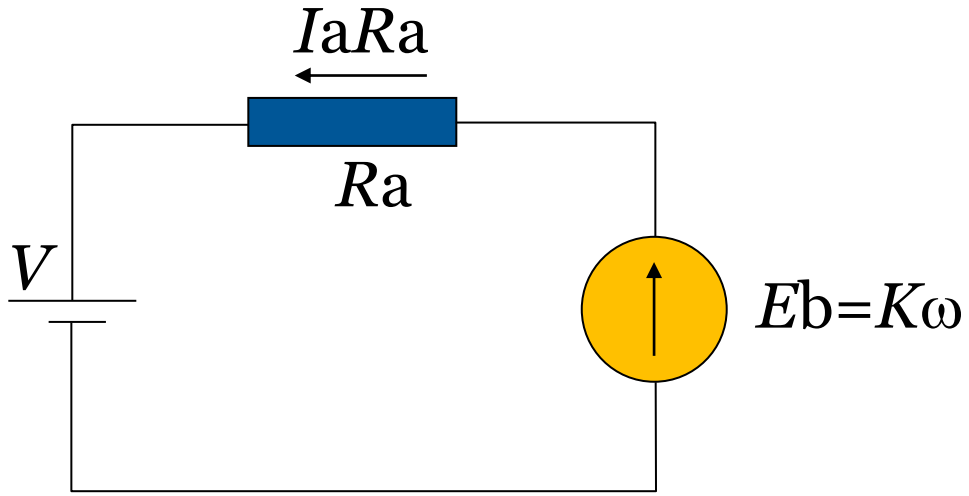
What are the characteristics of servomotors?

- Provided the magnetic field is constant, then:
  - Torque ∝ current, i.e. $T = K I a$
  - Supply voltage ∝ no-load speed
  - (more accurately: back-EMF ∝ angular velocity i.e. $Eb = K \omega$, *the motor acts as a generator and generates an back-EMF*)

What are the characteristics of servomotors?

Don't learn diagram or derivation, for background only





$$V = Eb + IaRa = K\omega + T\,Ra/K$$

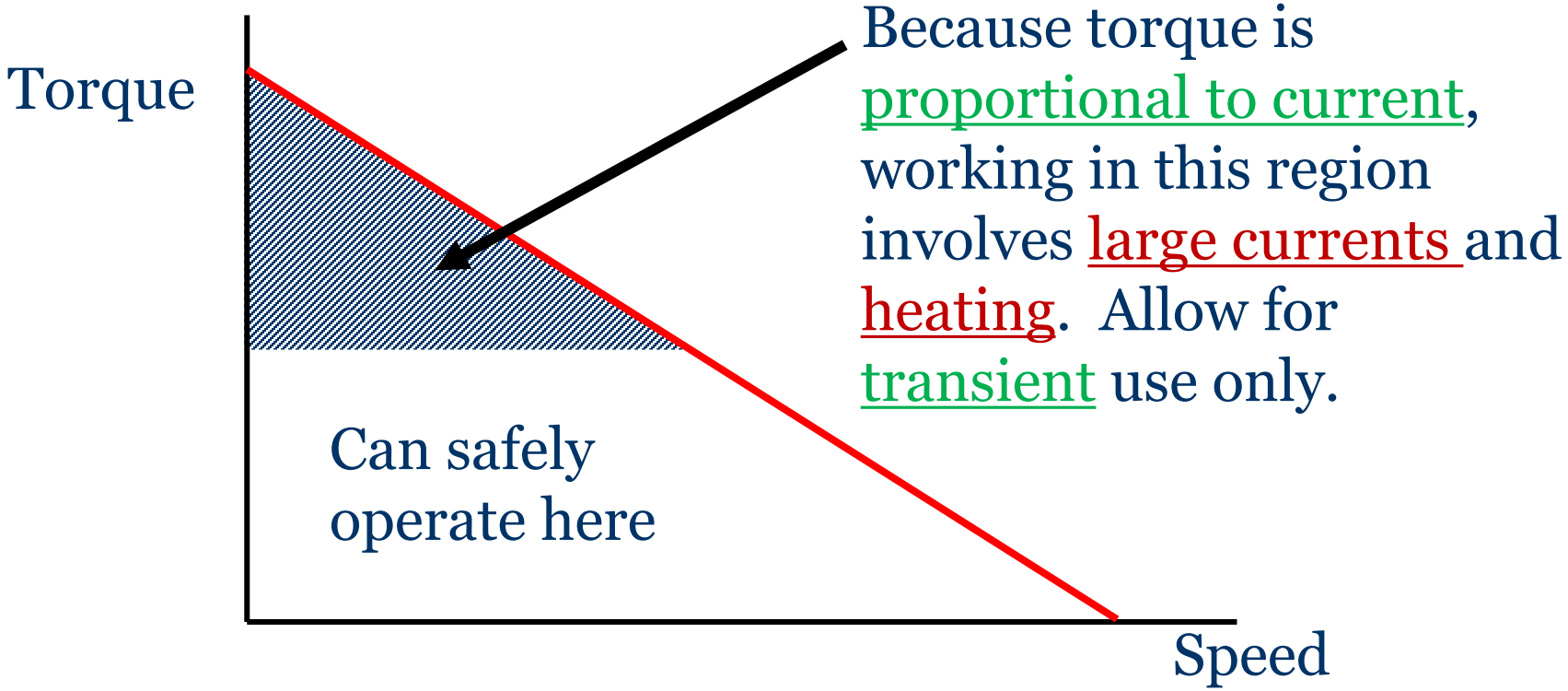
$T = K\,Ia$

$Ia = T/K$

$$T = VK/Ra - K^2\omega/Ra$$

What are the characteristics of servomotors?

$$T = VK/Ra - K^2\omega/Ra$$

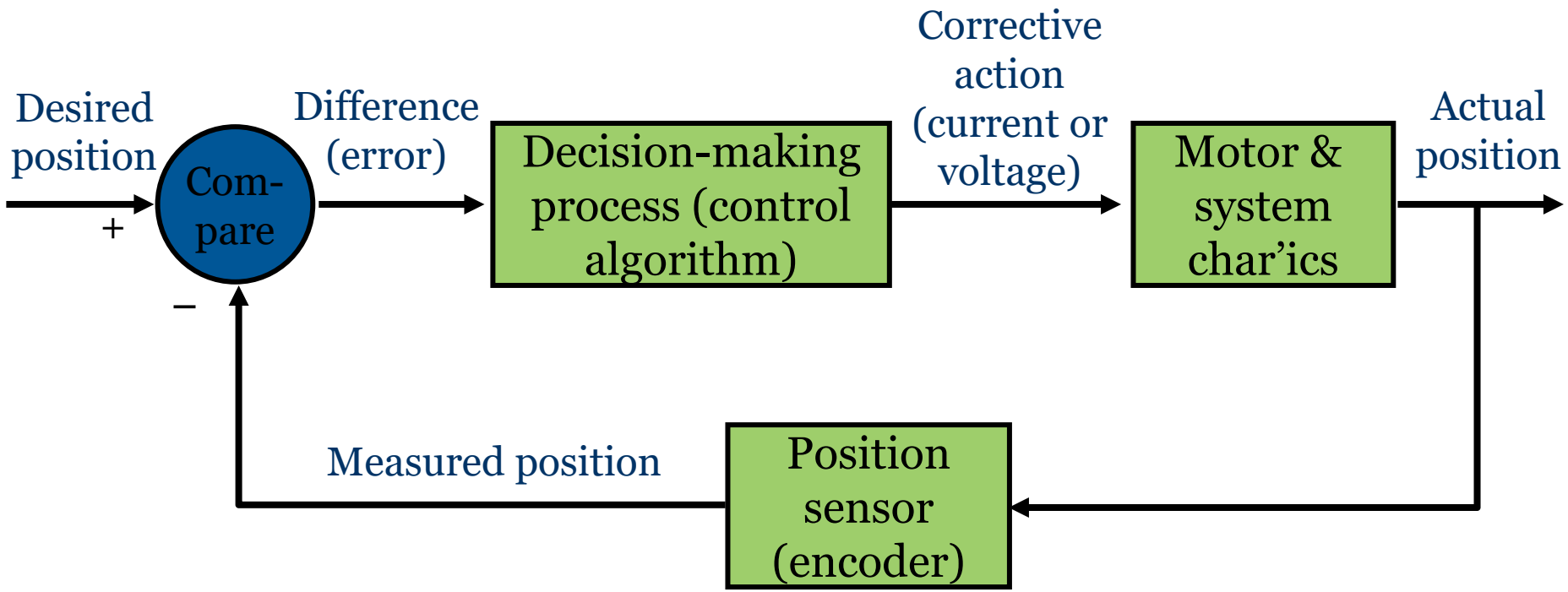


Because torque is proportional to current, working in this region involves large currents and heating. Allow for transient use only.

Control implications of motor characteristics

- Speed is highly dependent upon load, position is indeterminate
- Consider as a “torque source”
- To obtain accurate position or speed, must use feedback (closed loop control)
- These days, nearly always use optical encoder:
  - Usually incremental
  - Sometimes absolute

Control loop for a servo motor

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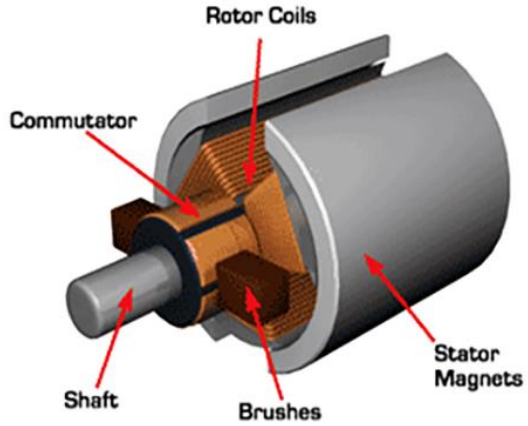
Servo Motors
Types

Types of Servomotors

1. Conventional (iron core) type

- Permanent magnets are on the stator and armature rotates in this magnetic field
- Armature is made of iron and copper and hence its moment of inertia is large.

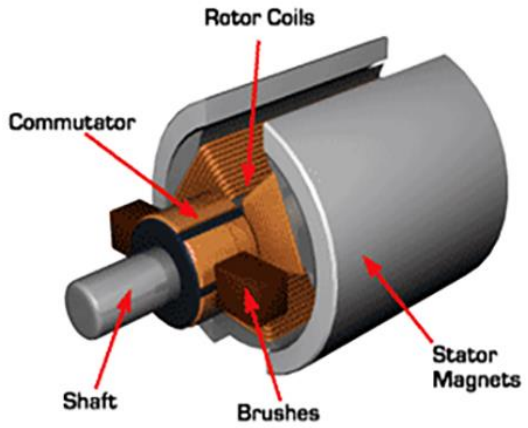


https://holmeshobbies.com

Adapted from https://www.active-robots.com/gear-motor-encoder.html

Types of Servomotors

- **Conventional (iron core) type**
  - But attraction of armature poles to magnets makes for "torque ripple" and "cogging" (unwanted detent torque)



https://holmeshobbies.com

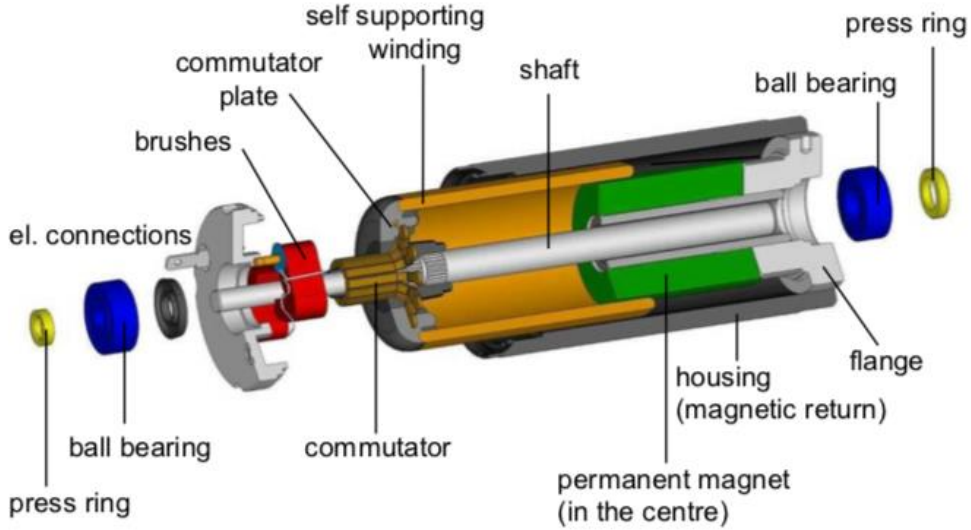
Adapted from https://www.active-robots.com/gear-motor-encoder.html

Types of Servomotors

2. Ironless type:

- Armature windings are made into a self-supporting structure (disc-shaped or cup-shaped)

https://www.maxonmotor.in/

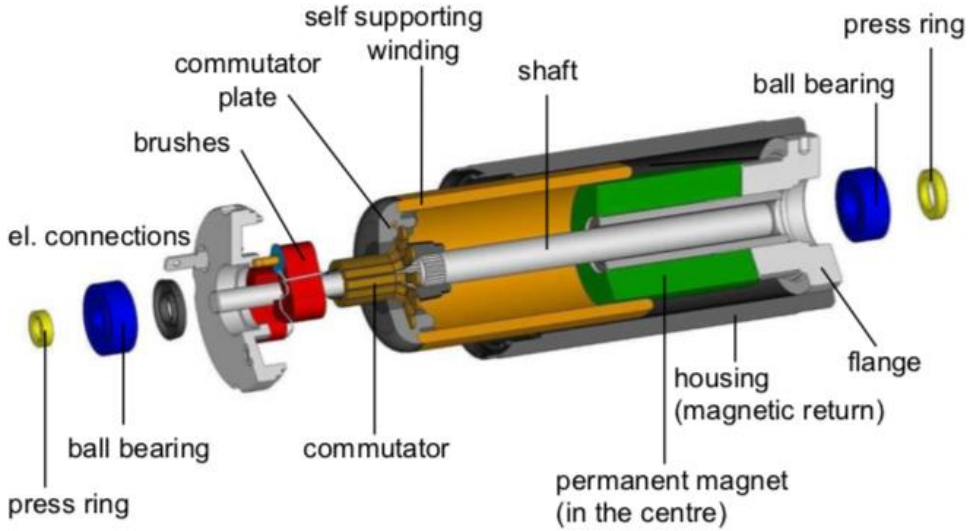


http://www.solarnavigator.net/maxon_swiss_motor.htm

Types of Servomotors

2. Ironless type:

- The magnetically-conducting core is then made stationary, and the armature disc or cup runs in a narrow gap in the circuit



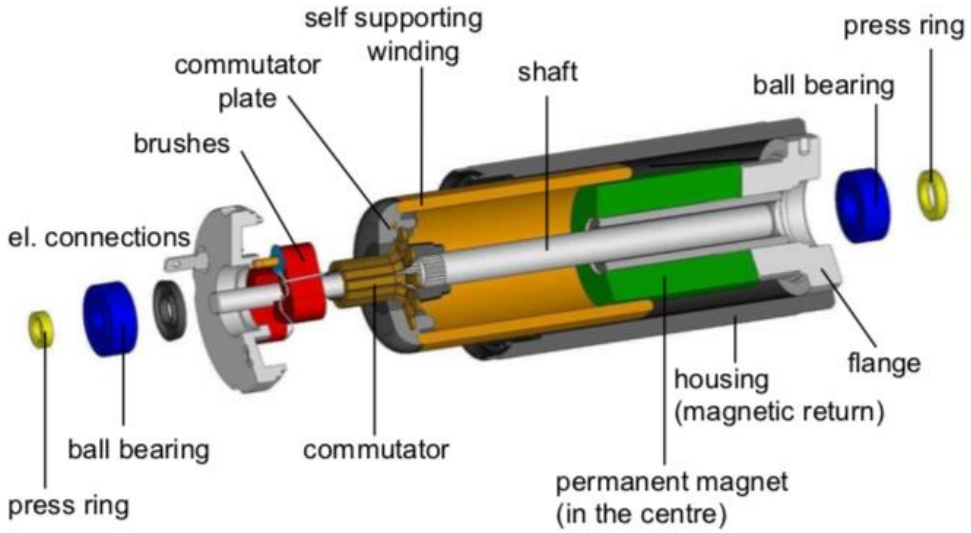
https://www.maxonmotor.in/

http://www.solarnavigator.net/maxon_swiss_motor.htm

Types of Servomotors

2. Ironless type:

- Inertia is thus kept very low
- No "cogging", much reduced torque ripple



https://www.maxonmotor.in/

http://www.solarnavigator.net/maxon_swiss_motor.htm

Types of Servomotors

3. Brushless type

- In effect, this is a DC permanent magnet motor turned inside-out
- Rotor is a permanent magnet
- "Armature" windings are placed on stator, hence no need for brushes
- Commutation is carried out using solid-state switches rather than mechanical commutator

Types of Servomotors

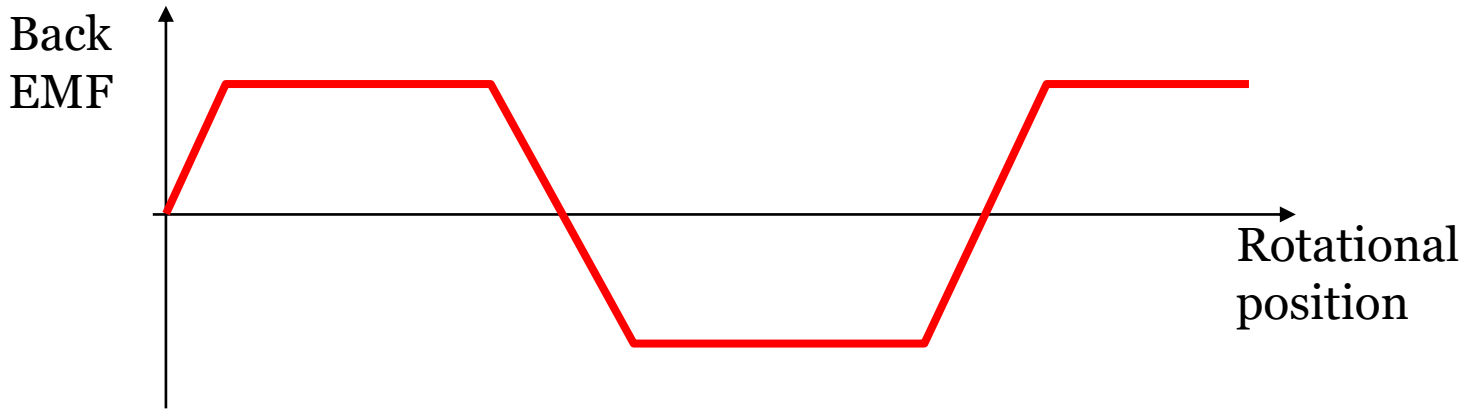
3. Brushless type

Commutation of Brushless Motors

- Commutation needs knowledge of rotor position
- Brushless servomotor incorporates an angular position sensor used to trigger the solid-state switches
- How we treat them differs slightly for:
  - DC – straightforward switching of windings, otherwise still treat as DC motor
  - AC – windings are fed with sinusoidally-varying voltage

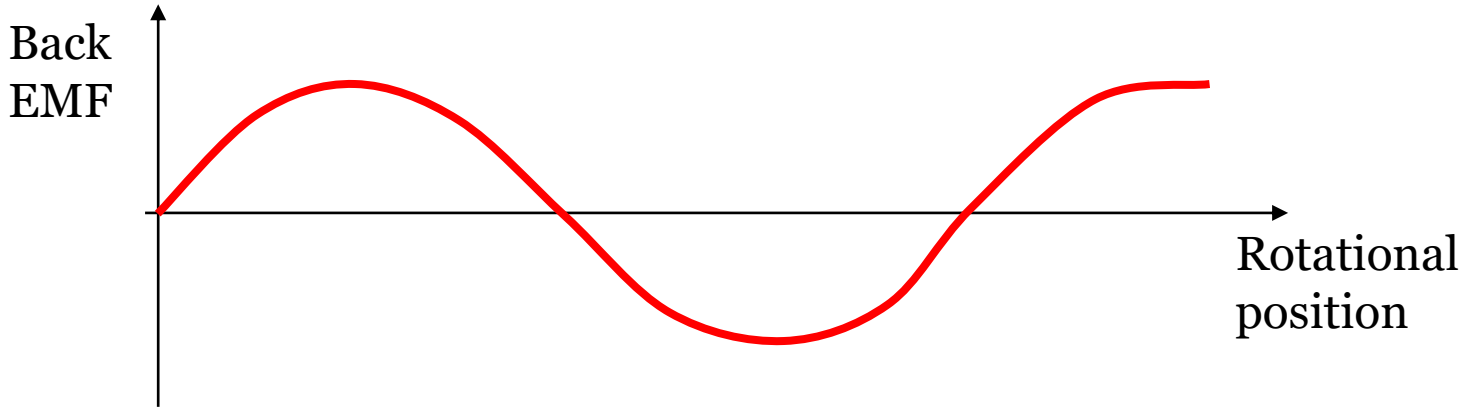
"DC" brushless motors

- Fed with voltage ∝ desired speed
- Switched to each winding in turn using solid-state commutation
- Back EMF is constant while winding connected



"AC" brushless motors

- Fed with a sinusoidally-varying supply to each winding via suitable circuitry
- Constructed so that back-EMF is sinusoidal.



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Servo Motors

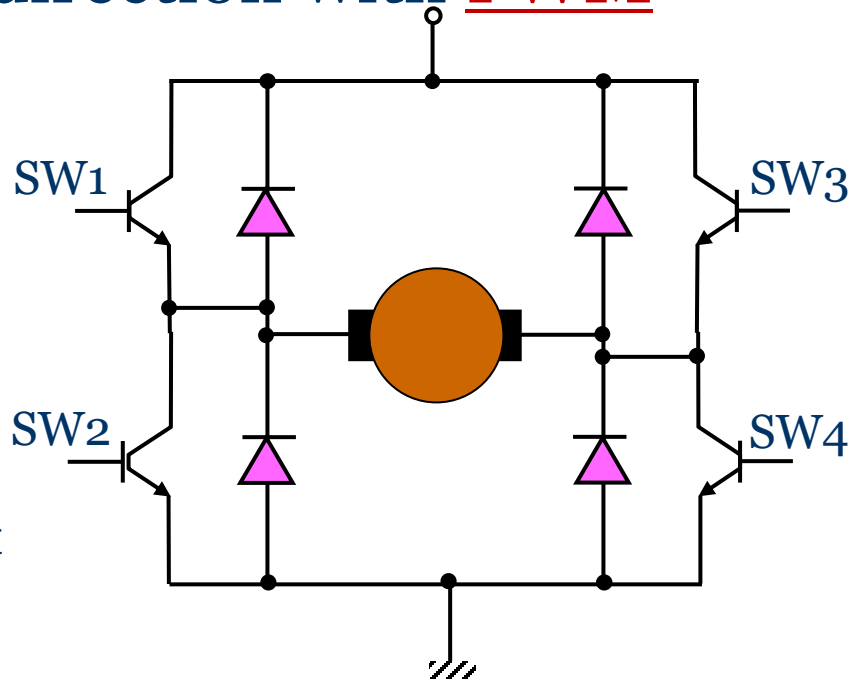
Interfacing of Servomotors

Interfacing of Servomotors

- Concentrate on brushed and brushless **DC** servomotors for present time
- Recall that we need:
  - Means of creating varying voltage supply
  - Feedback of position
  - Controller

H bridge driver using PWM

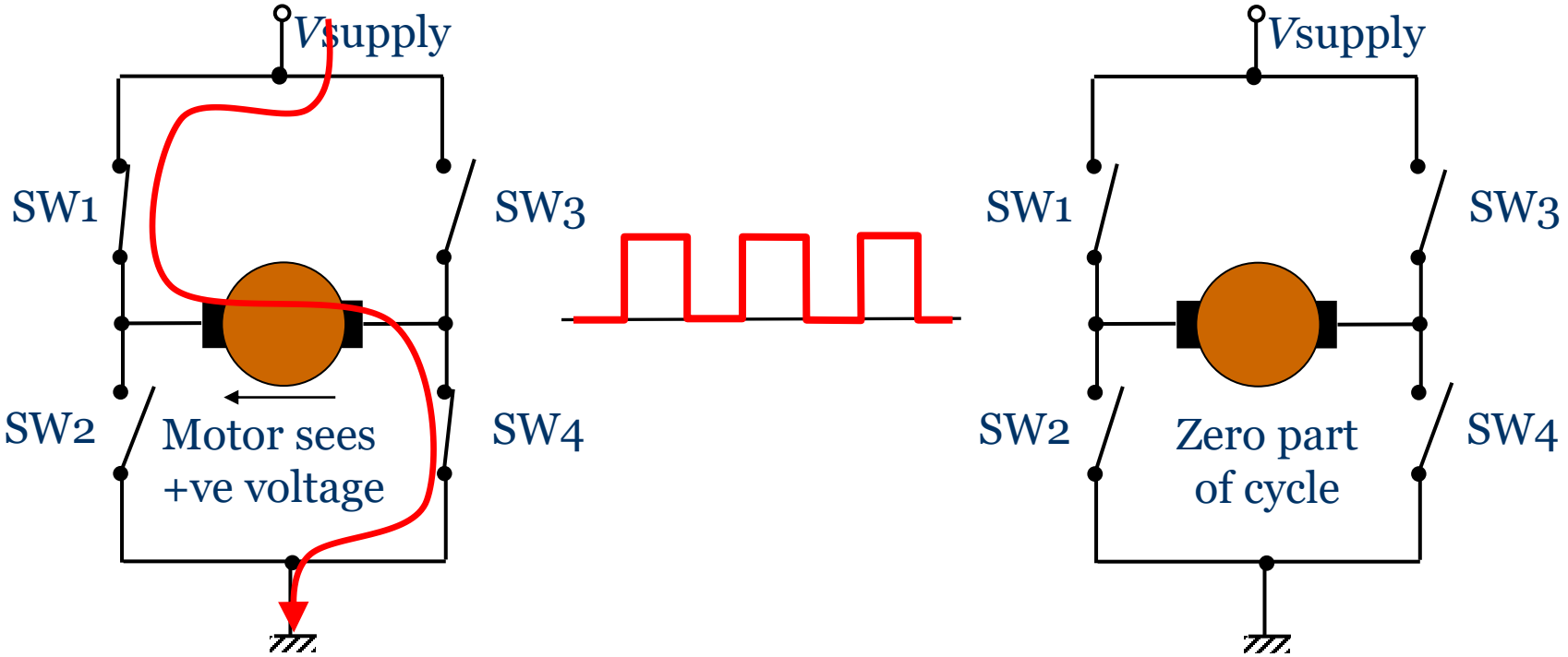
- We don't genuinely drive with variable voltage
- Use H-bridge to switch motor on and off in forward and reverse direction with PWM



Don't learn circuit but learn how it works on following slides…

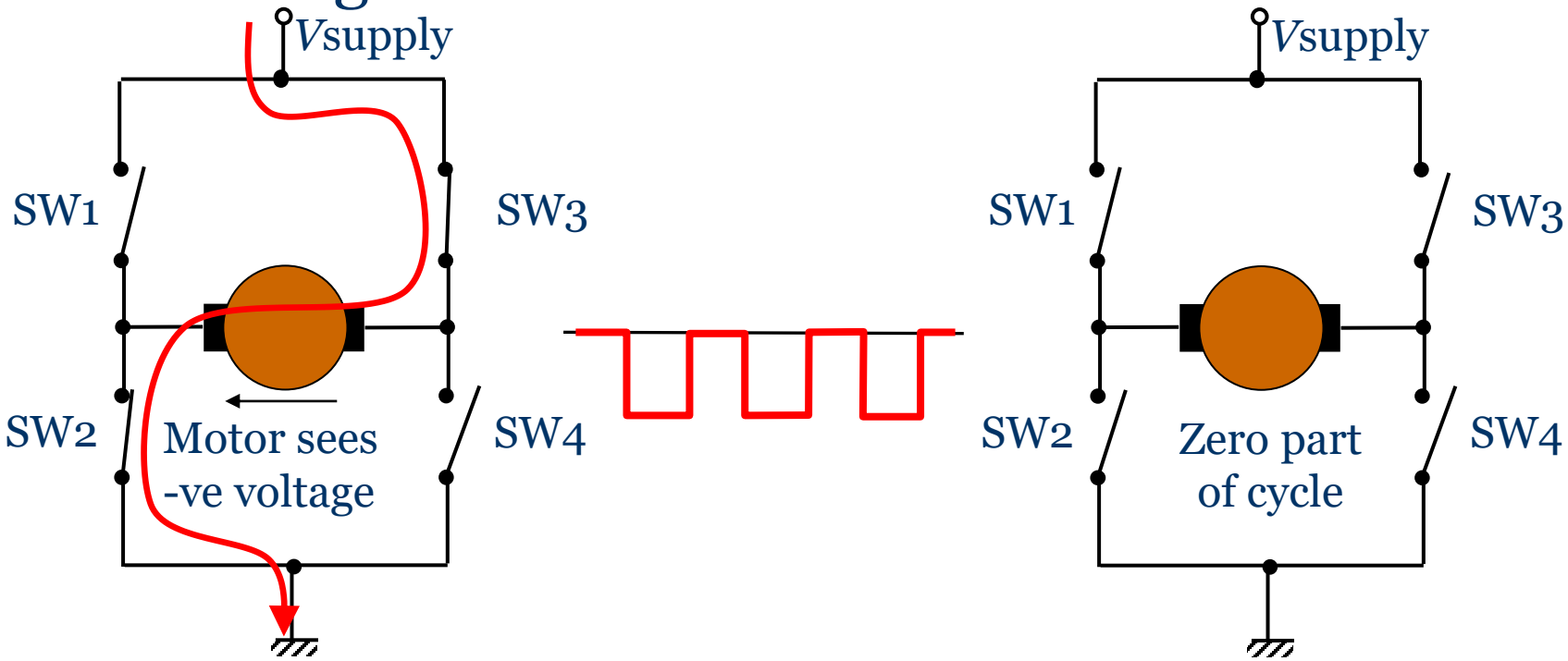
H bridge driver using PWM

- Vary amount of time switches are closed to achieve PWM e.g. SW1 & SW4 for forward



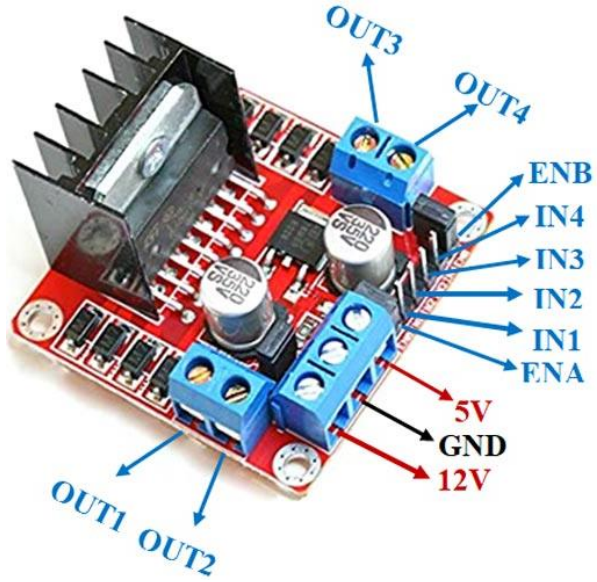
H bridge driver using PWM

- Or SW2 and SW3 for reverse
- Note: motor only interested in potential difference across bridge

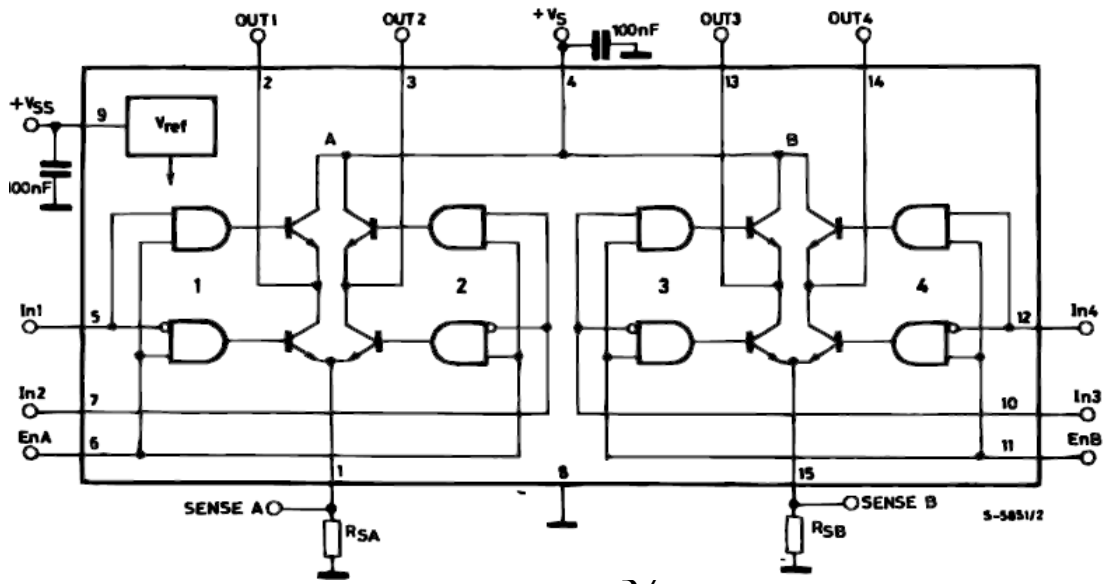


H bridge driver using PWM

- We use one half of the L298N H-bridge integrated circuit (don't learn circuit!) with additional freewheeling diodes on board



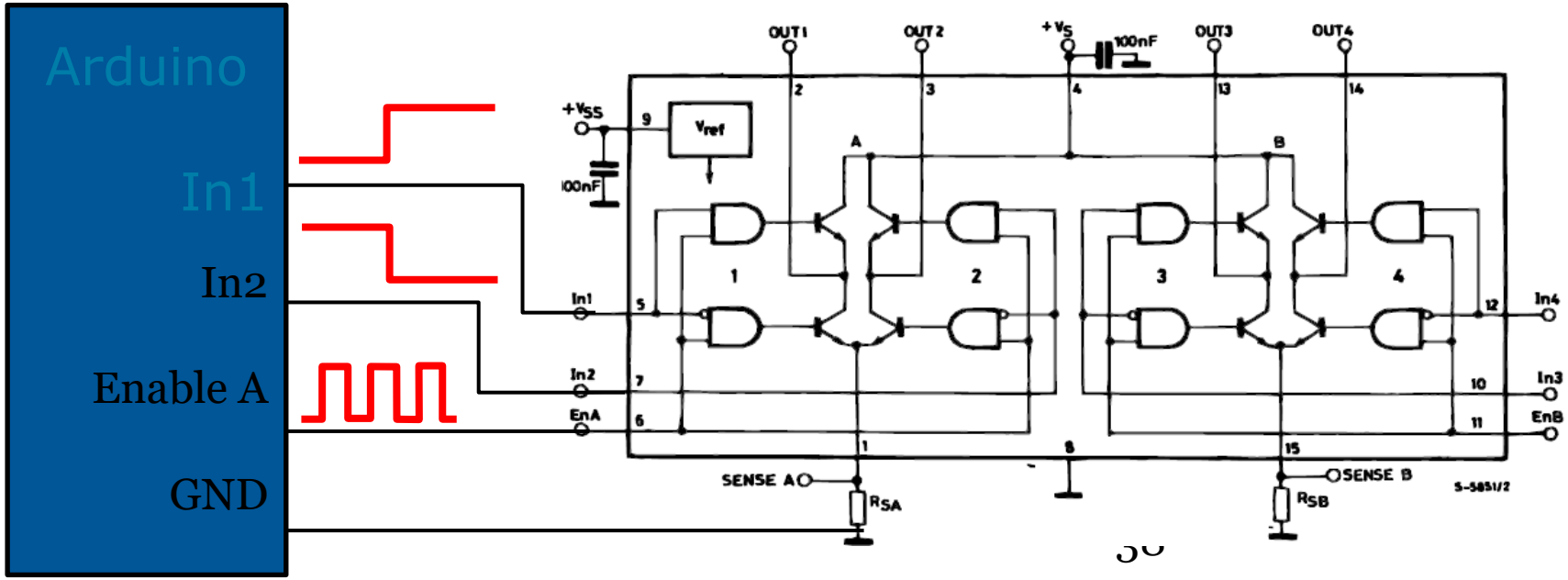
https://www.amazon.co.uk



From L298 data sheet

H bridge driver using PWM

- Drive one half of L298N H-bridge IC from Arduino (**try to understand but don't learn circuit!**) lines for forward, reverse and enable



From L298 data sheet

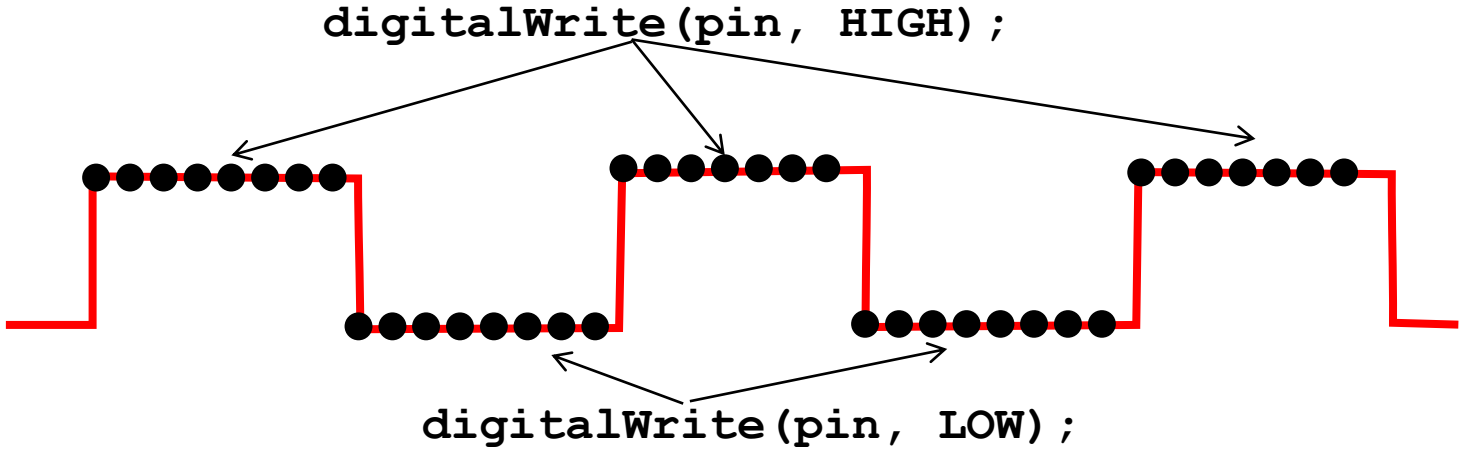
How is PWM generated in practice?

- Could use hardware: counter-timer (e.g. on Arduino; also on PC e.g. 8254) as in Lab 1
- Simply use **`analogWrite(pin, value)`**

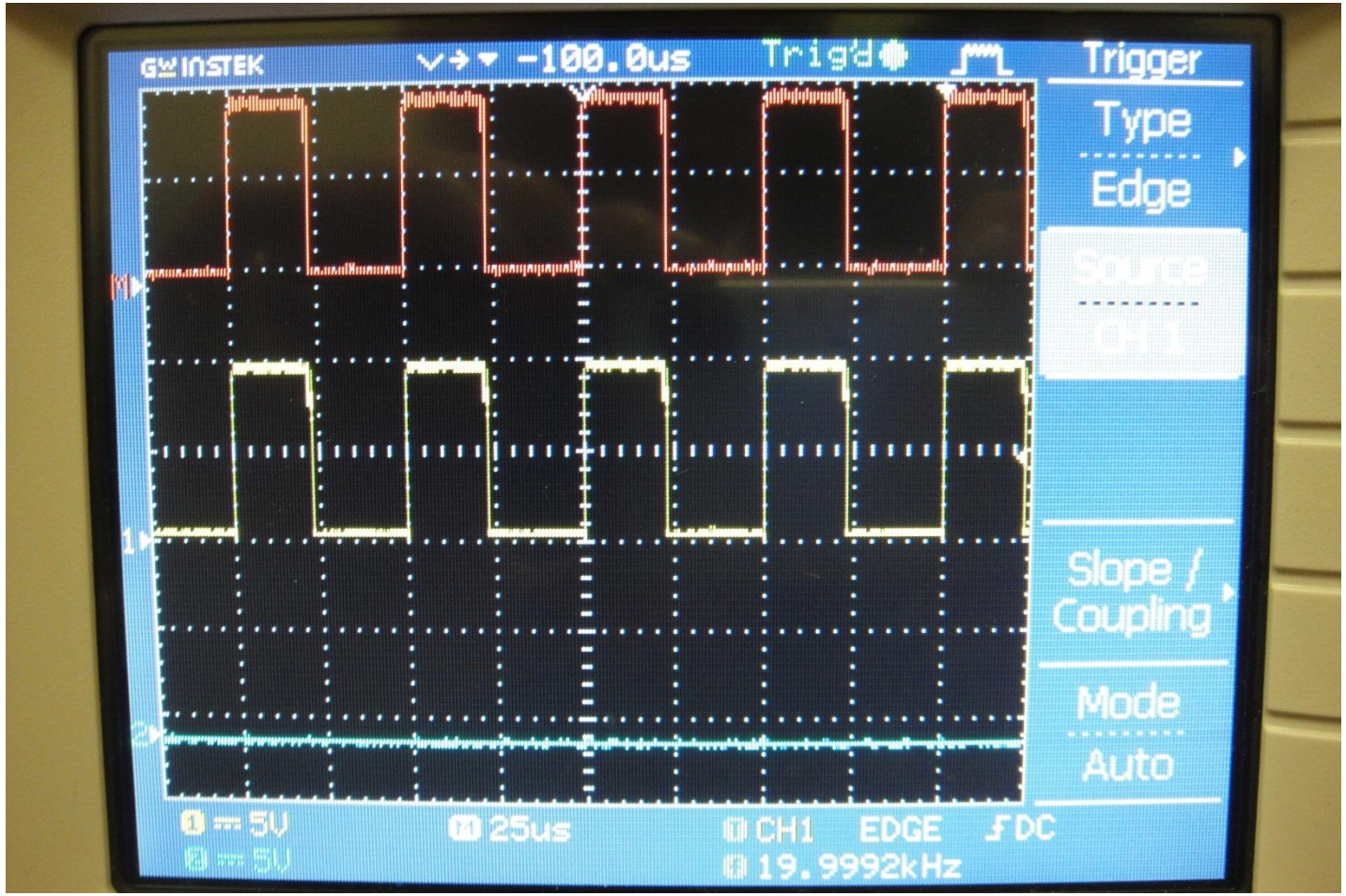
```
void driveMotorPercent(double percentDutyCycle)
/* Output PWM and H bridge signals based on positive
   or negative duty cycle % */
{
      percentSpeed = constrain(percentSpeed, -100, 100);
      int regVal = map(percentSpeed, -100, 100, -255, 255);
      analogWrite(enA, (int)abs(regVal));
      digitalWrite(in1, regVal>0);
      digitalWrite(in2, !(regVal>0));
}
```

How is PWM generated in practice?

- Alternatively use a "bit-banging" approach:
  - Have a loop which repeats very rapidly
  - Write a "high" output for some passes through loop within a given cycle
  - Write a "low" output for remaining passes



H bridge driver using PWM (ideal)



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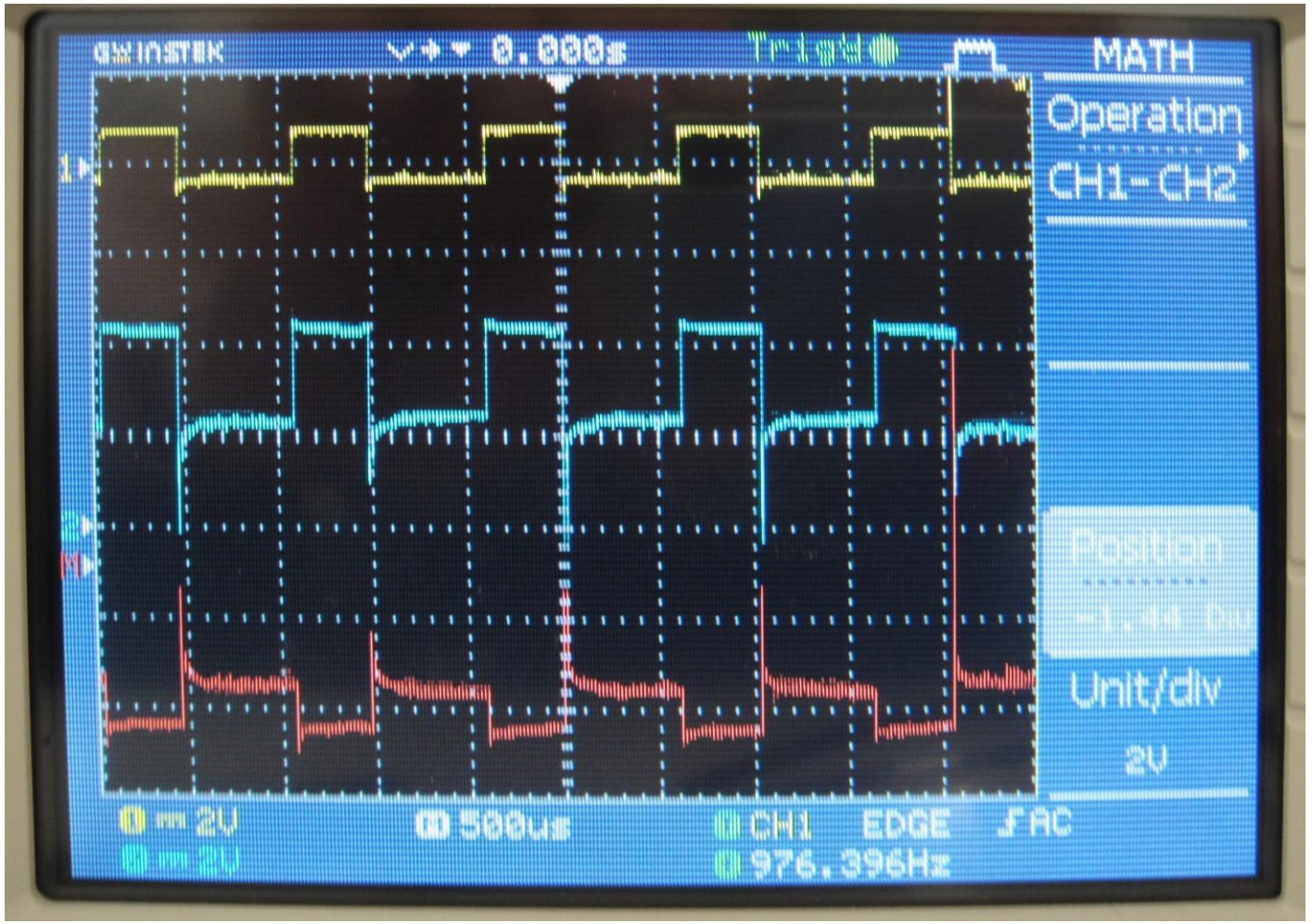
H bridge driver using PWM (L298N, coasting between cycles)



Summary up to now

- Concept of servomotor introduced
- Characteristics of servo motor are introduced
- Main types of servomotor described
- Emphasis on PWM:
  - Generated in hardware e.g. counter-timer
  - Using **`analogWrite`** function
  - Generated by “bit-banging” in software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Stepper
Motors
Introduction

Motion control - continued

- So far we have considered:
  - How we can achieve accurate positioning using servomotors
  - How closed-loop control and position sensors are essential to the use of servo motors

- Now we need to consider:
  - How stepper motors achieve roughly the same objective using open-loop control

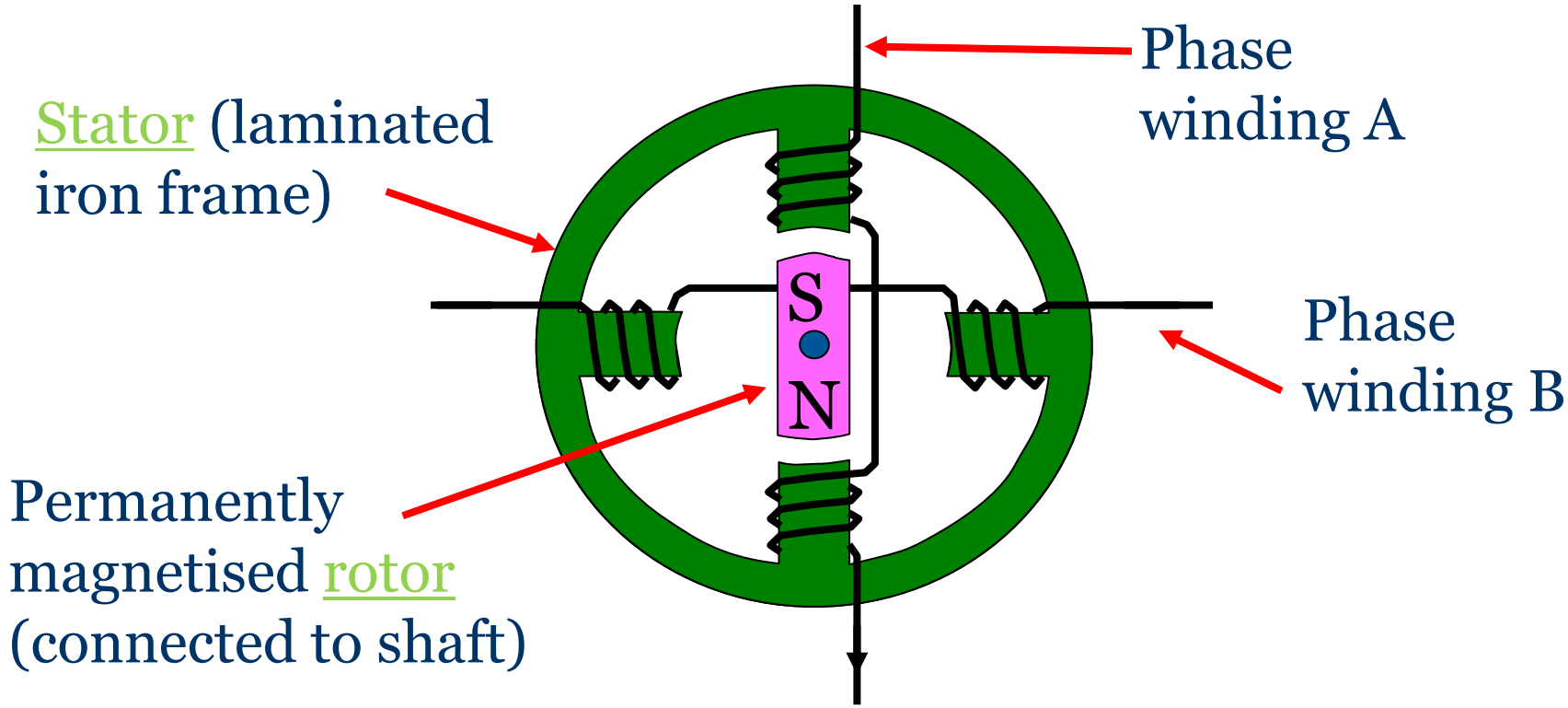
Learning outcomes

- To understand finer details of how a stepper motor is used
- To understand how to interface a stepper motor to a computer
- To appreciate the issues associated with generating the movements for a stepper motor

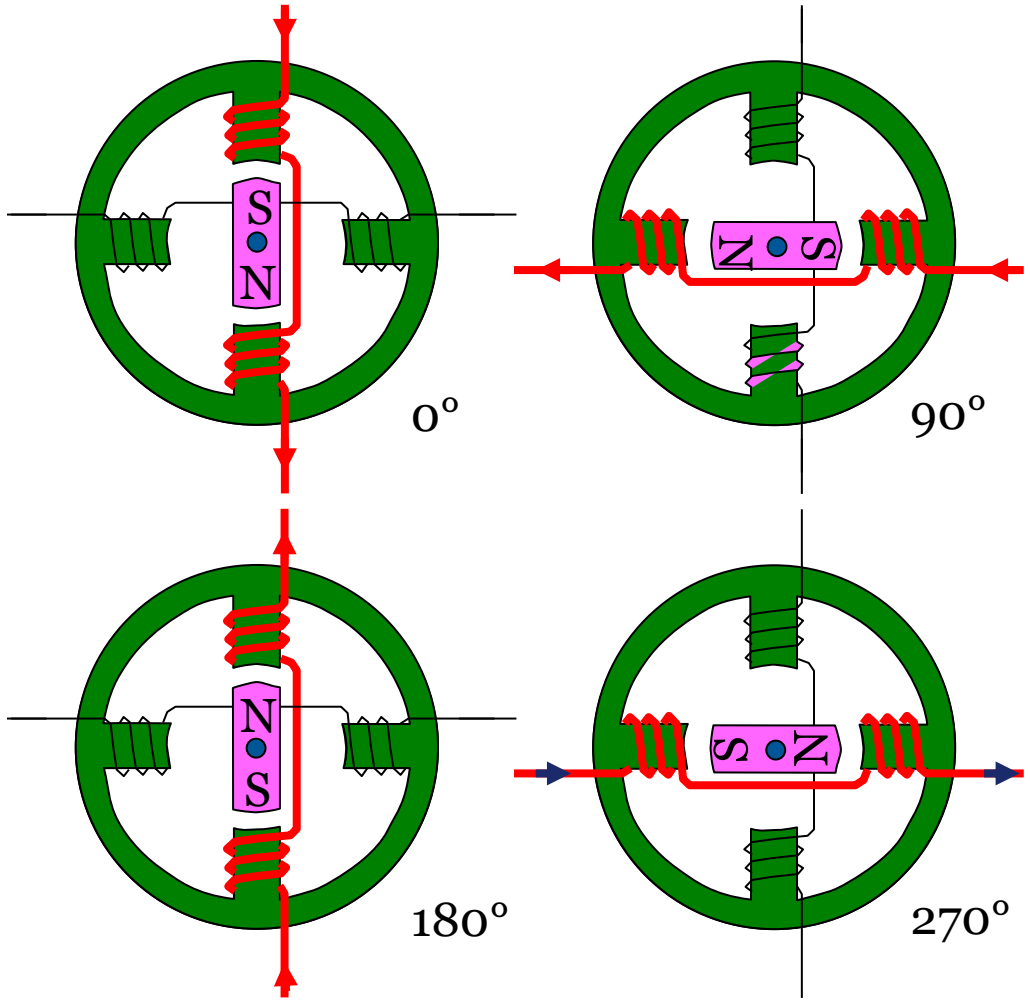
Stepper motors – brief revision

- Simple and convenient way of providing precise movement
- Normally open loop mode, no feedback
- They are used in a wide variety of applications including:
  - 3D printers and hobby CNC machines
  - Computer peripherals
  - Laboratory equipment
  - Student projects

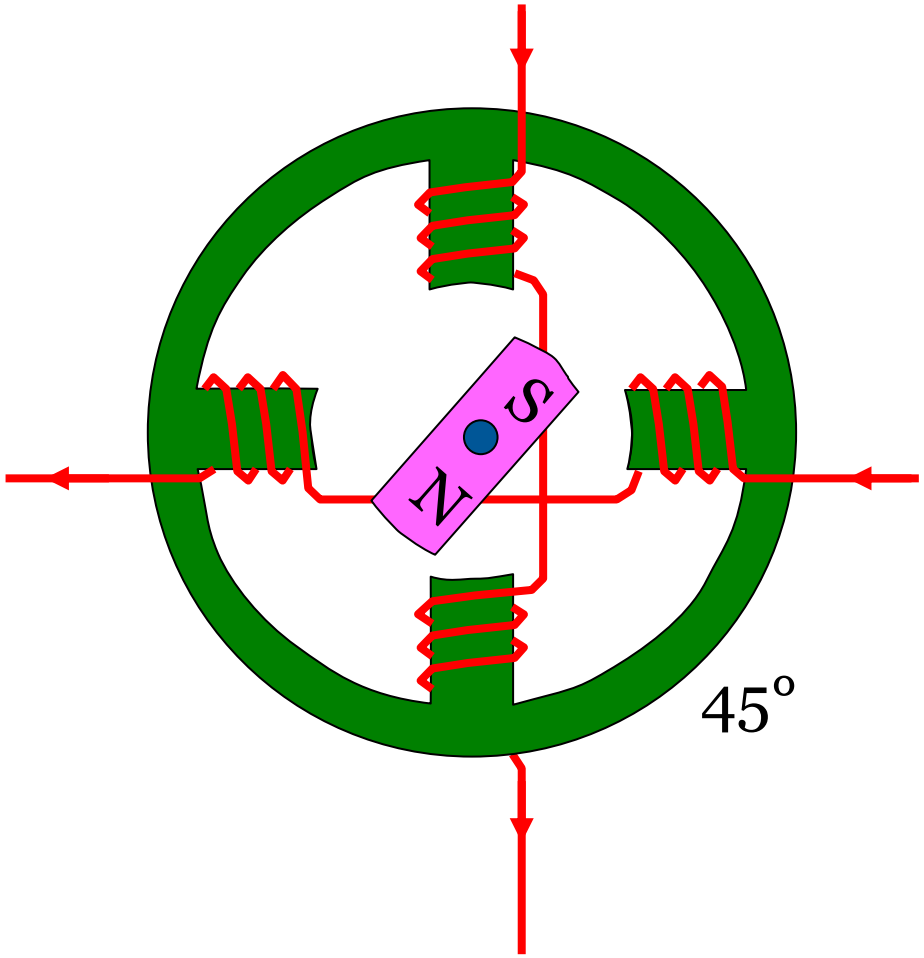
Simplified diagram of a permanent-magnet stepper motor



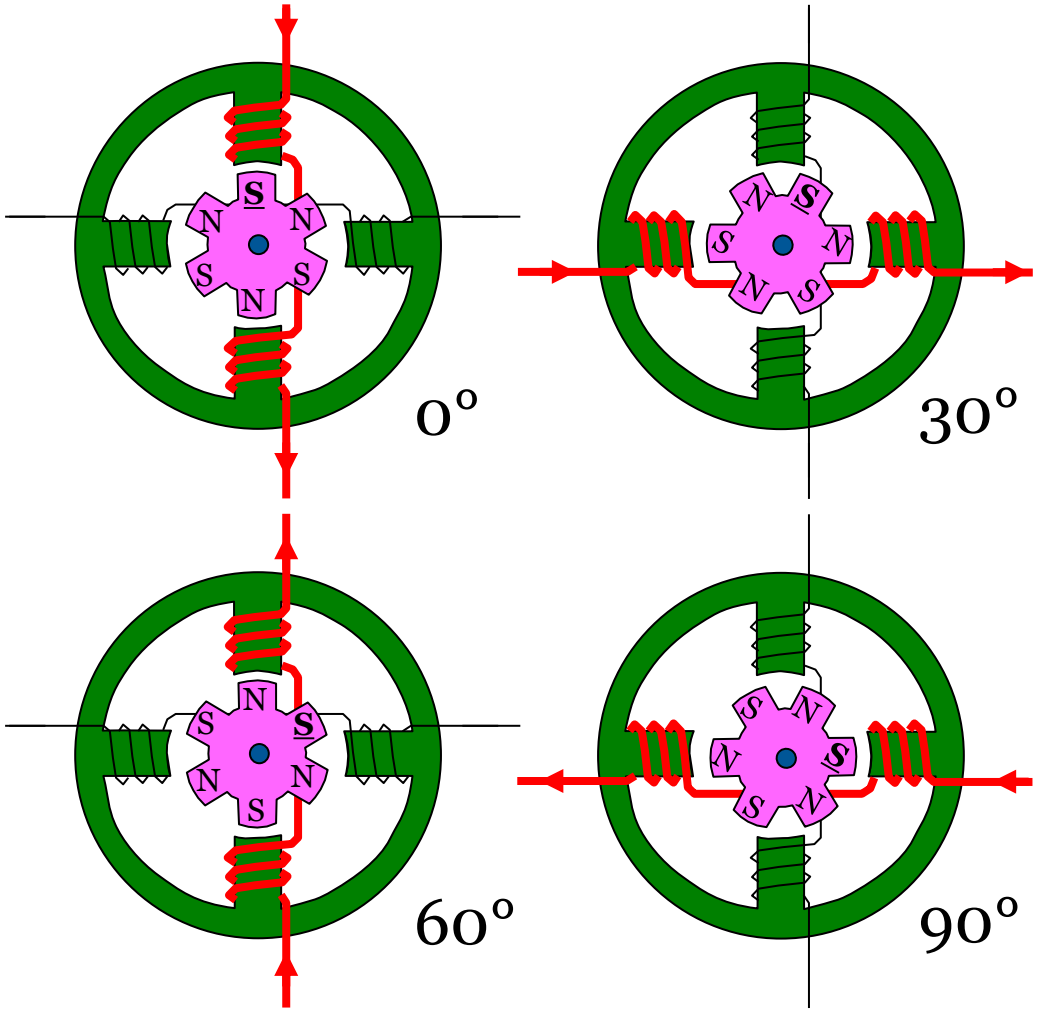
How a stepper motor works



Half stepping (also micro-stepping)



Toothed rotor



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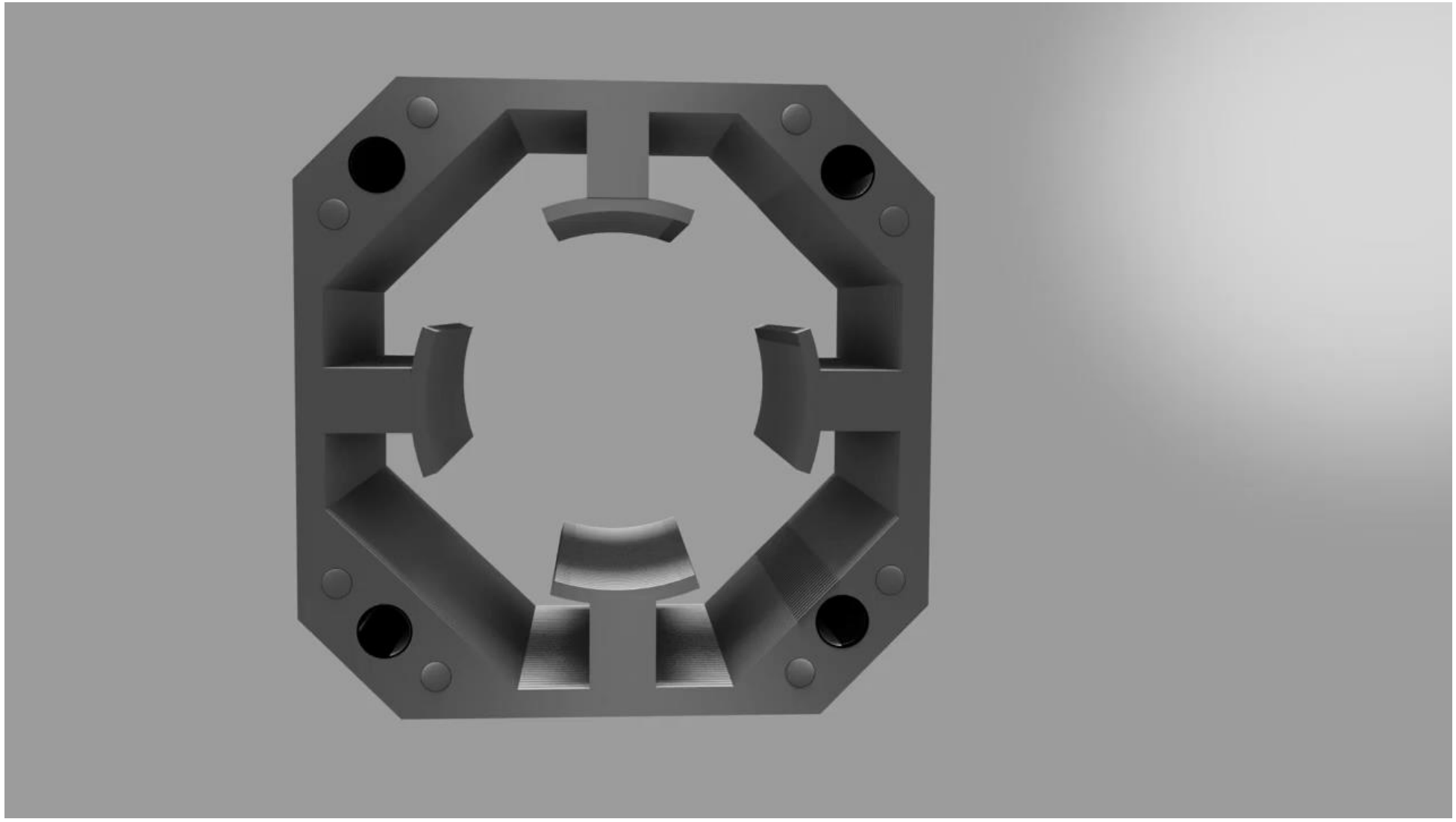
How does stepper motor works?!



https://www.youtube.com/watch?v=VMwv4XFZ2Lo&vl=en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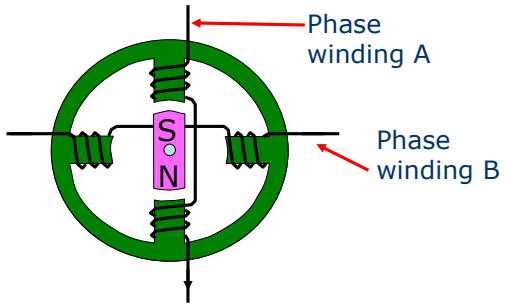
Stepper
Motors
Interfacing to a controller

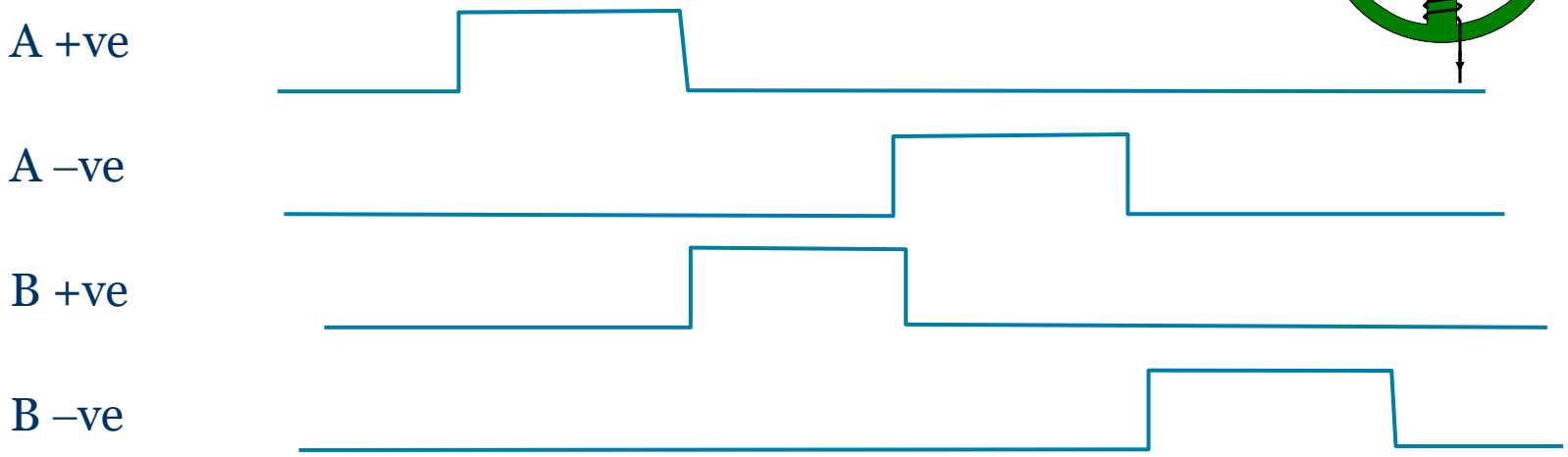
But what provides the sequenced supply to the windings?

- Needs suitable driver circuitry
- Uses logic, along with transistors used as solid state switches, to switch each winding in turn.
- Usually operated on the command of signals from the computer or controller giving “step” and “direction”

What provides the sequenced supply to the windings?

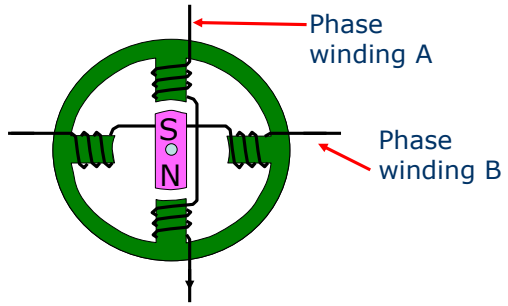
- We need to achieve the following phasing of currents in the windings (for simple full stepping):

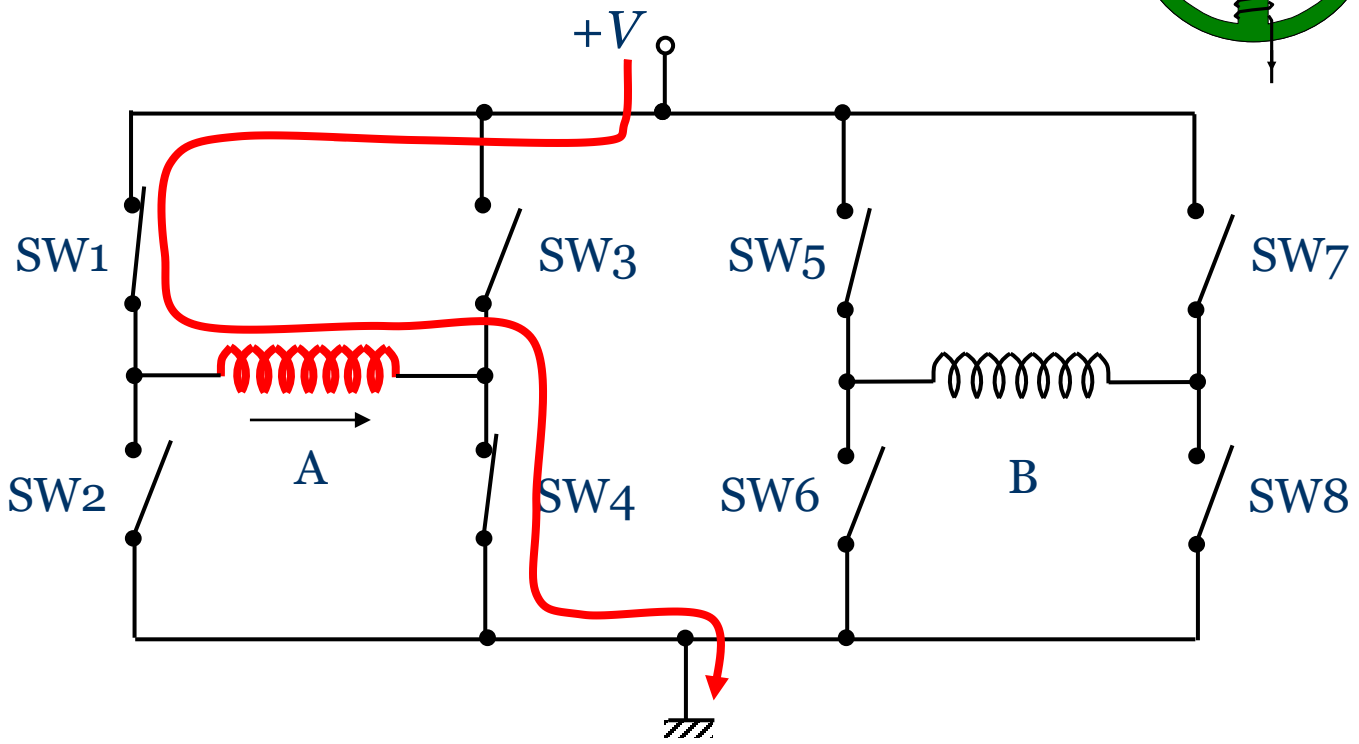




One solution could be!

- Two H-bridges
- Connected to windings A and B





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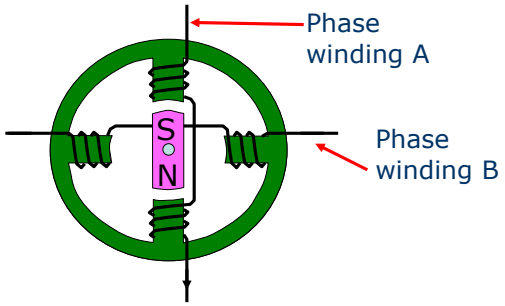

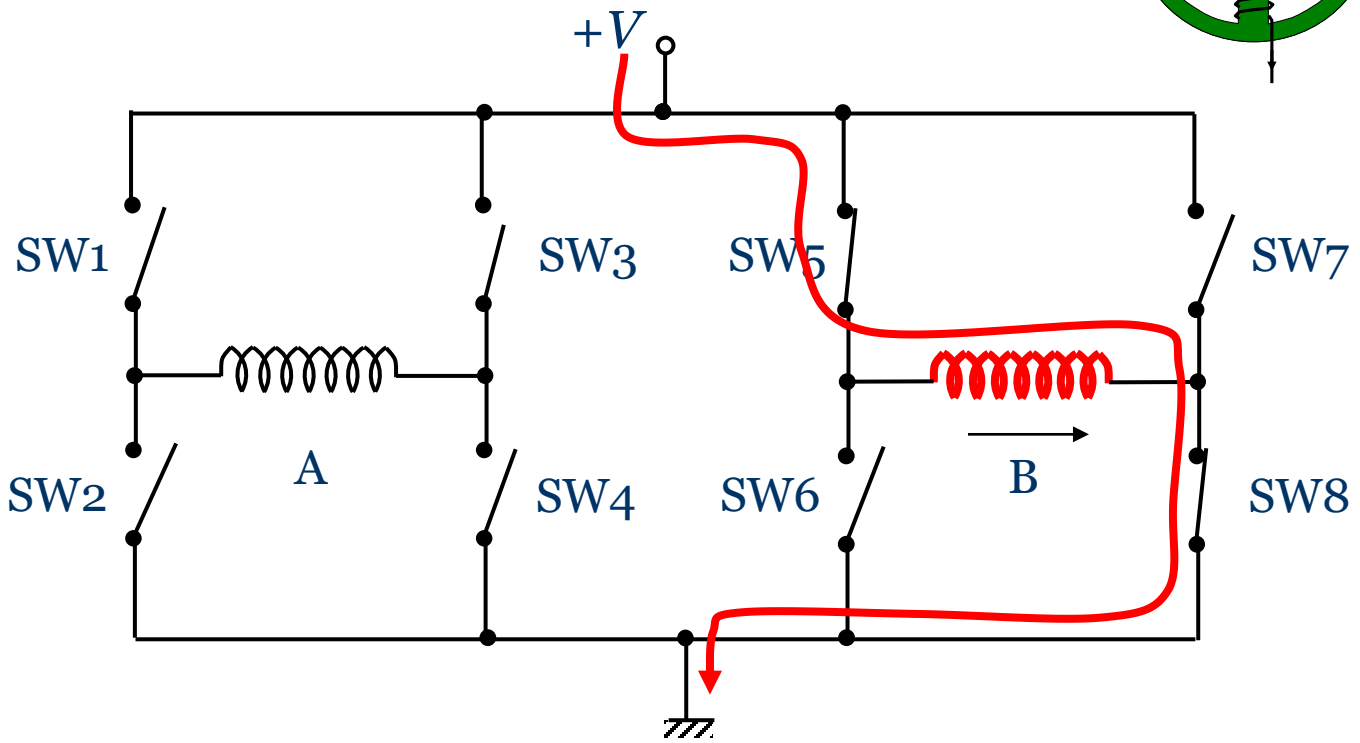

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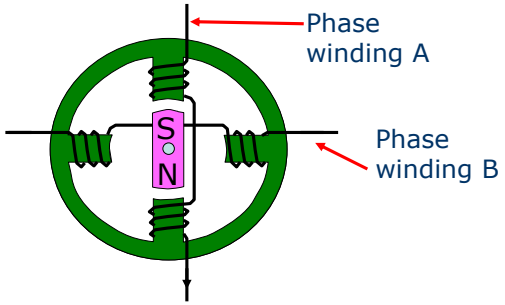

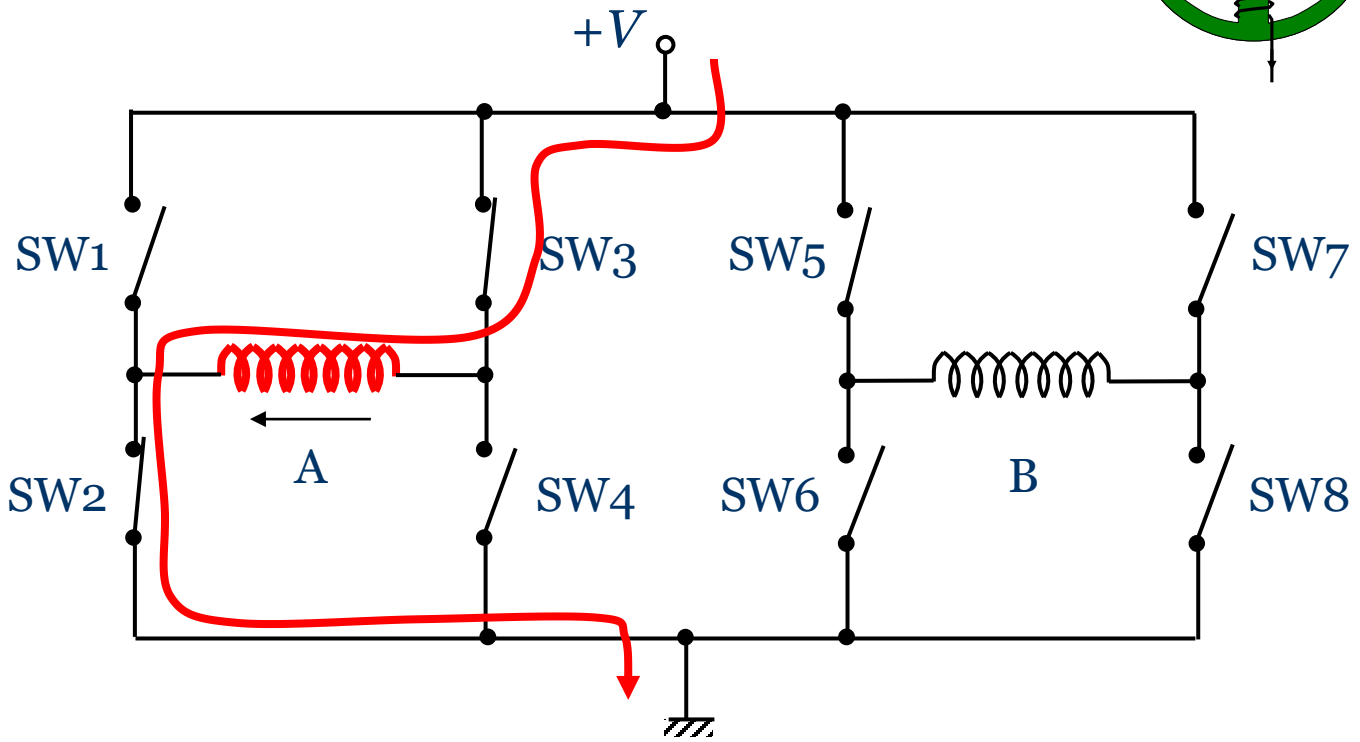

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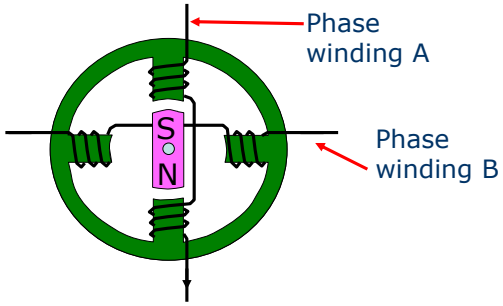
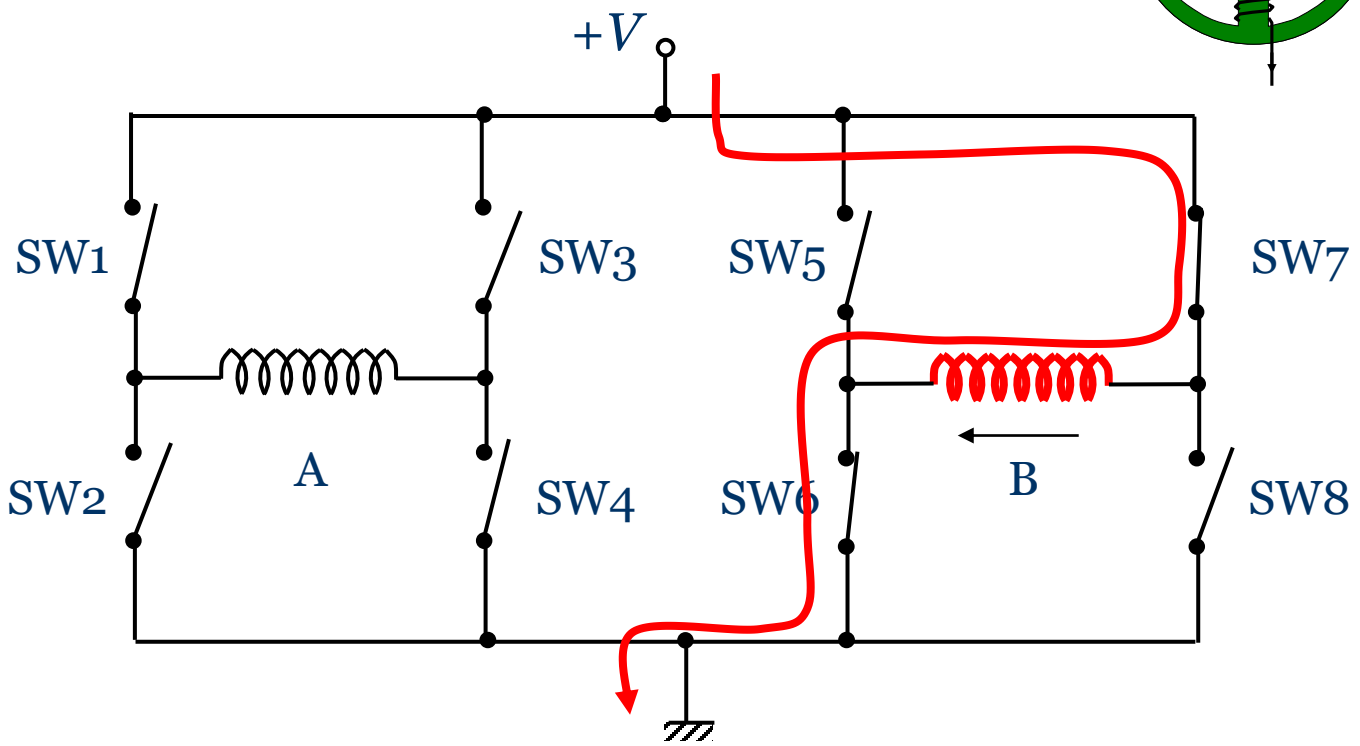
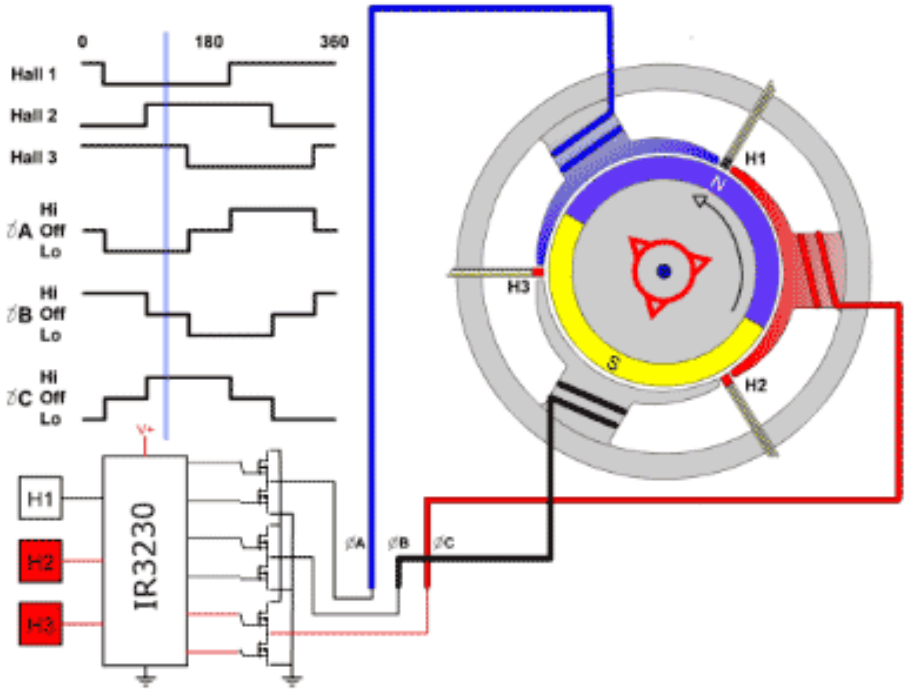
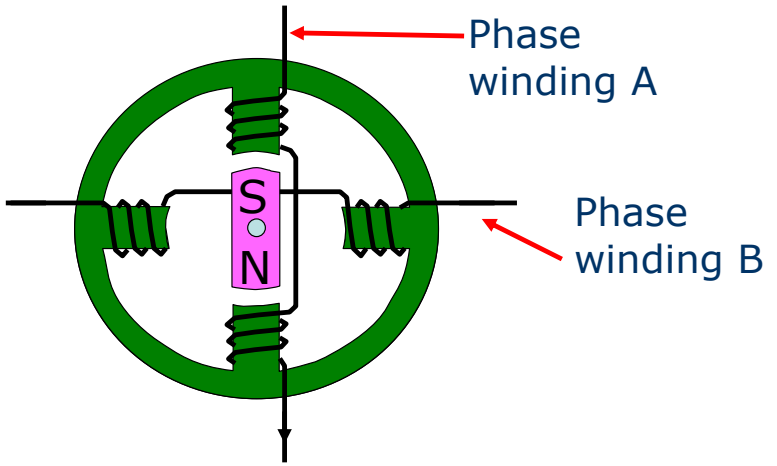
- Two H-bridges
- Connected to windings A and B

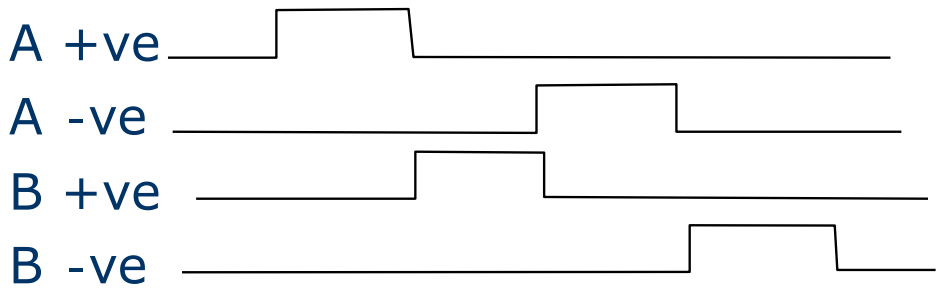




BLDC motor vs Stepper motor







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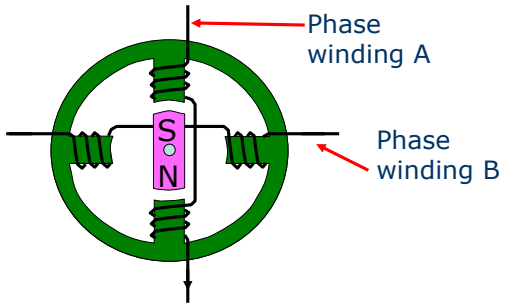
Stepper Motors

Number of Leads

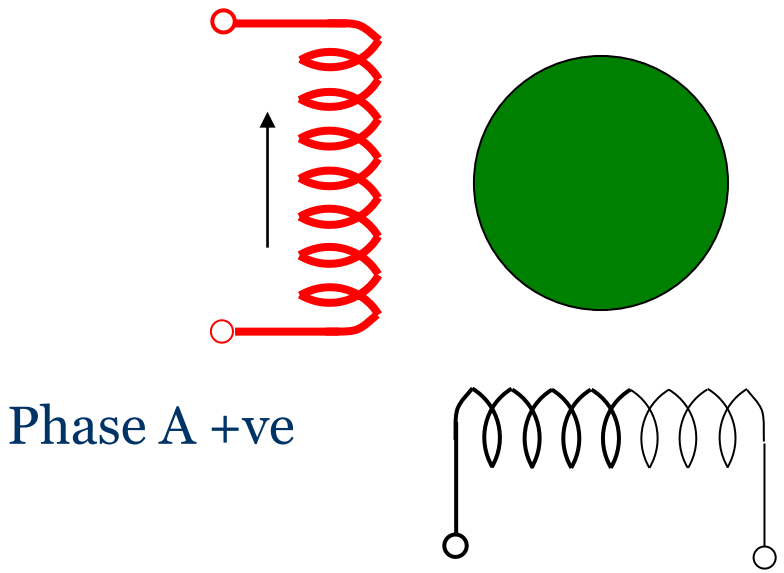
What provides the sequenced supply to the windings?

- Two approaches to obtaining reversible magnetism in motor poles:
  - Energise whole winding in the two possible directions
  - Or:
  - Energise half of each winding in one direction each

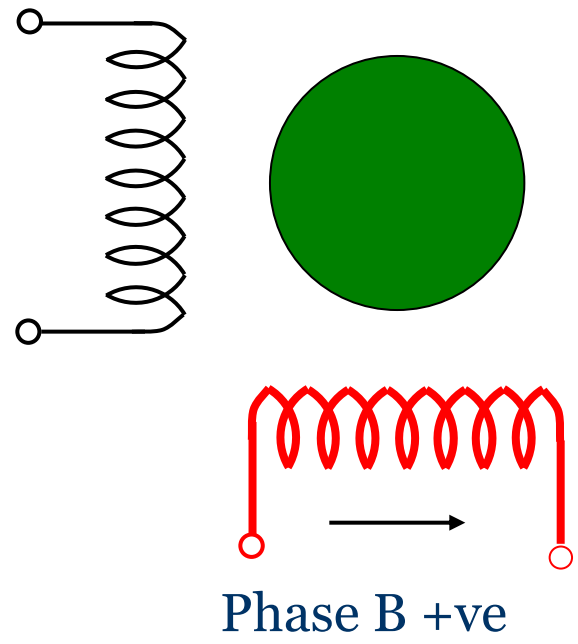


Four lead motor

- Needs a bipolar driver
- Can energise winding in either direction



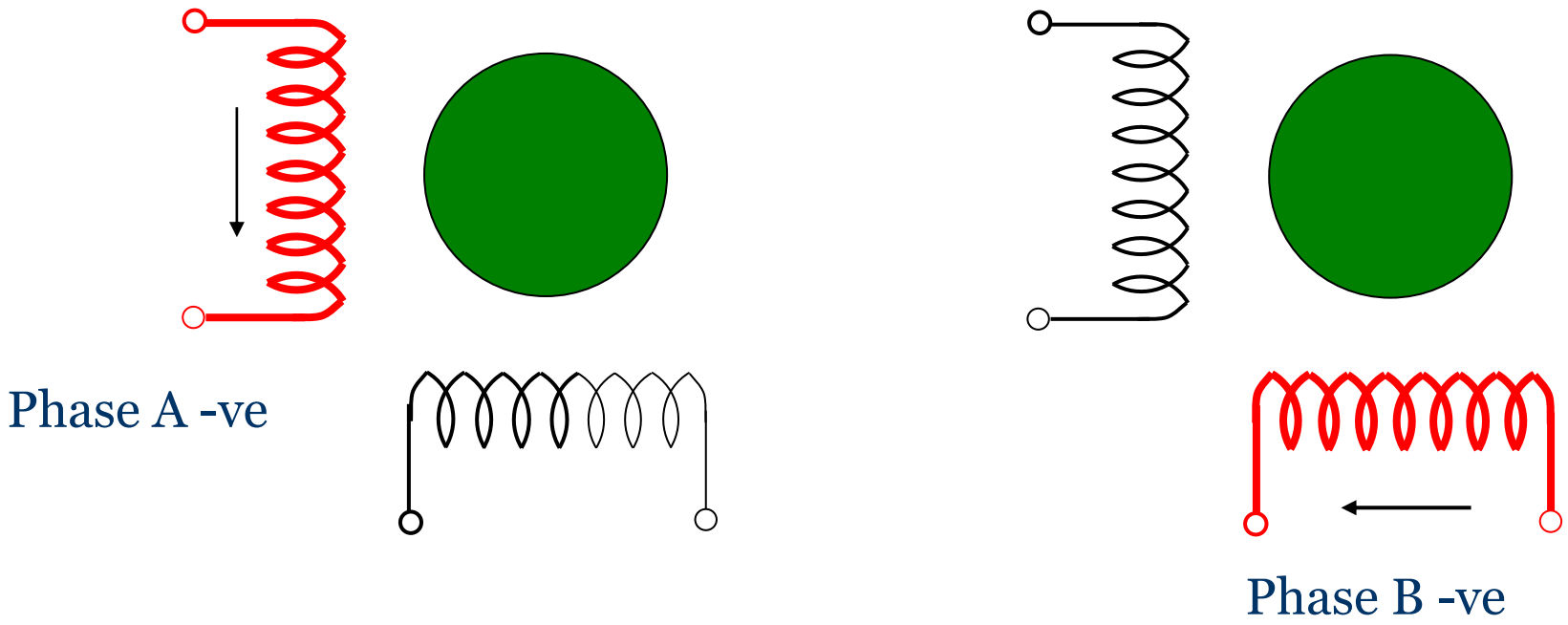
Phase A +ve



Phase B +ve

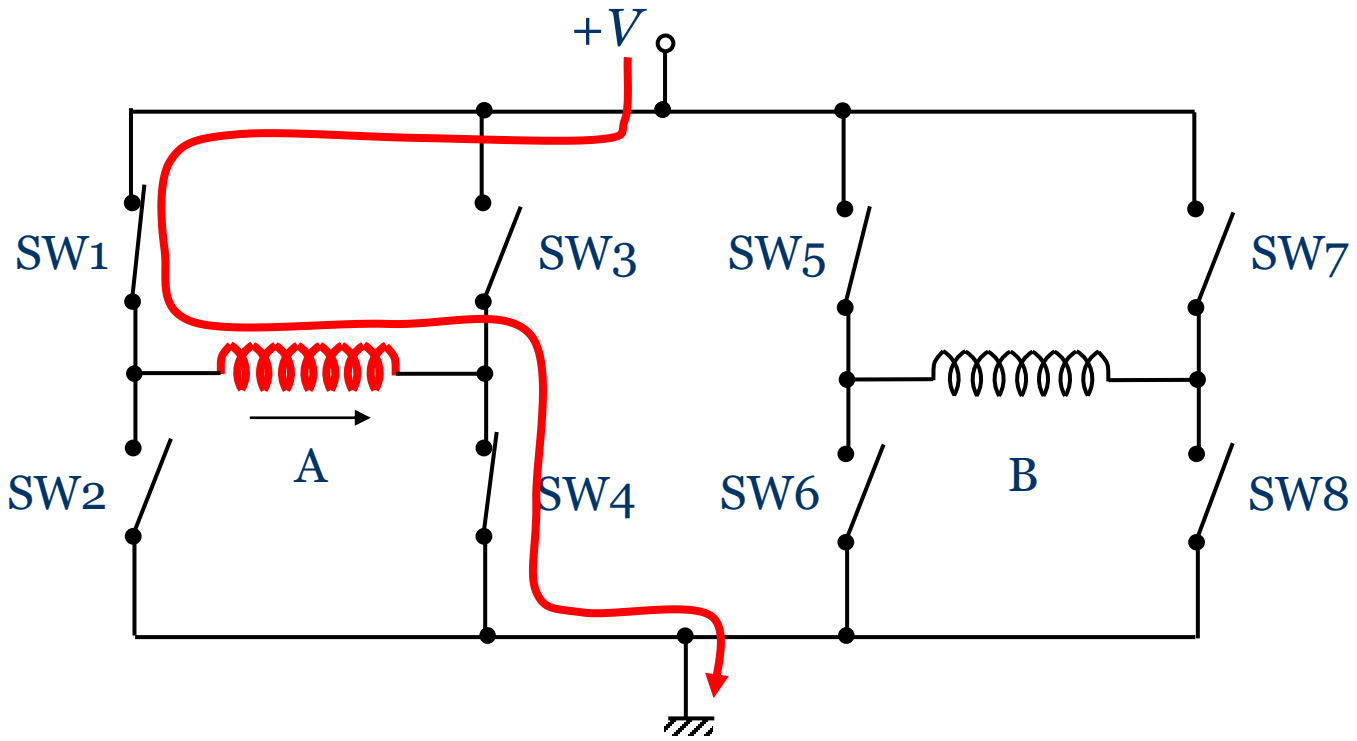
Four lead motor

- Needs a bipolar driver
- Can energise winding in either direction



Bipolar driver

- Two H-bridges
- Connected to windings A and B



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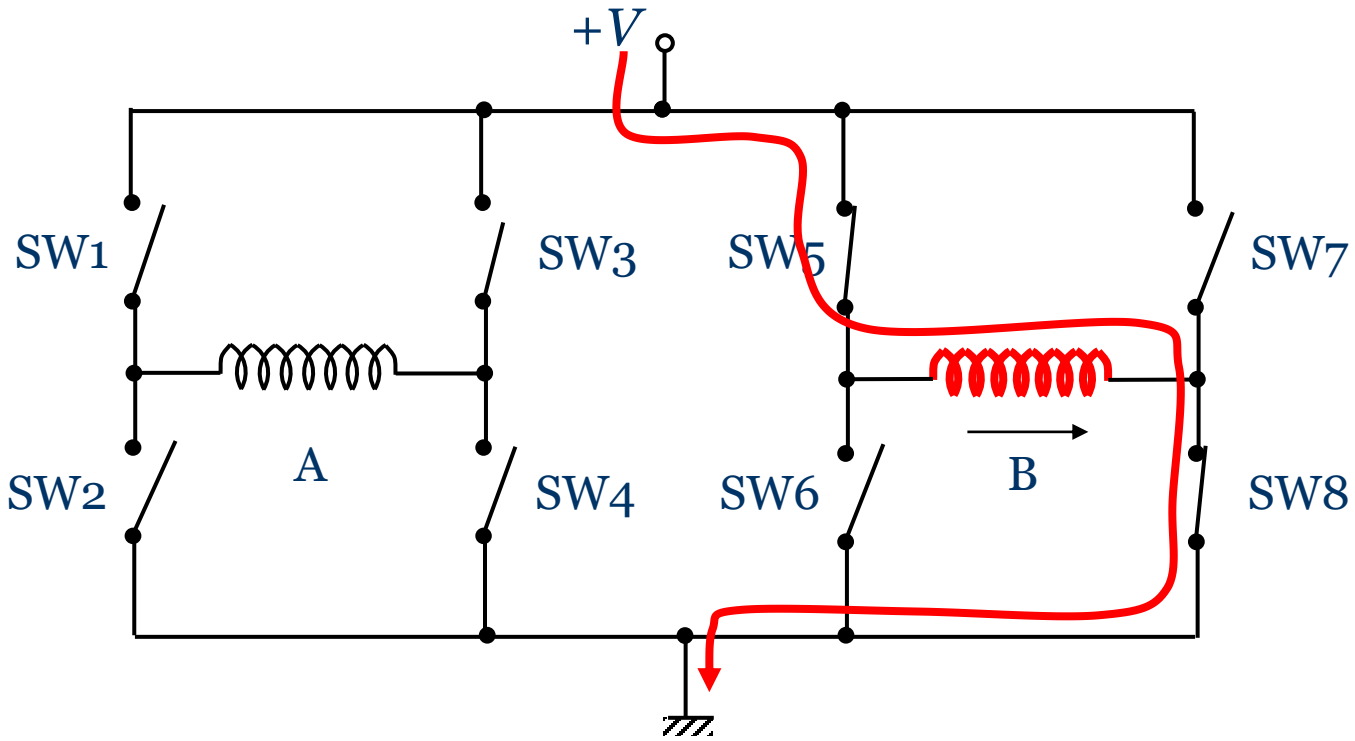

Bipolar driver

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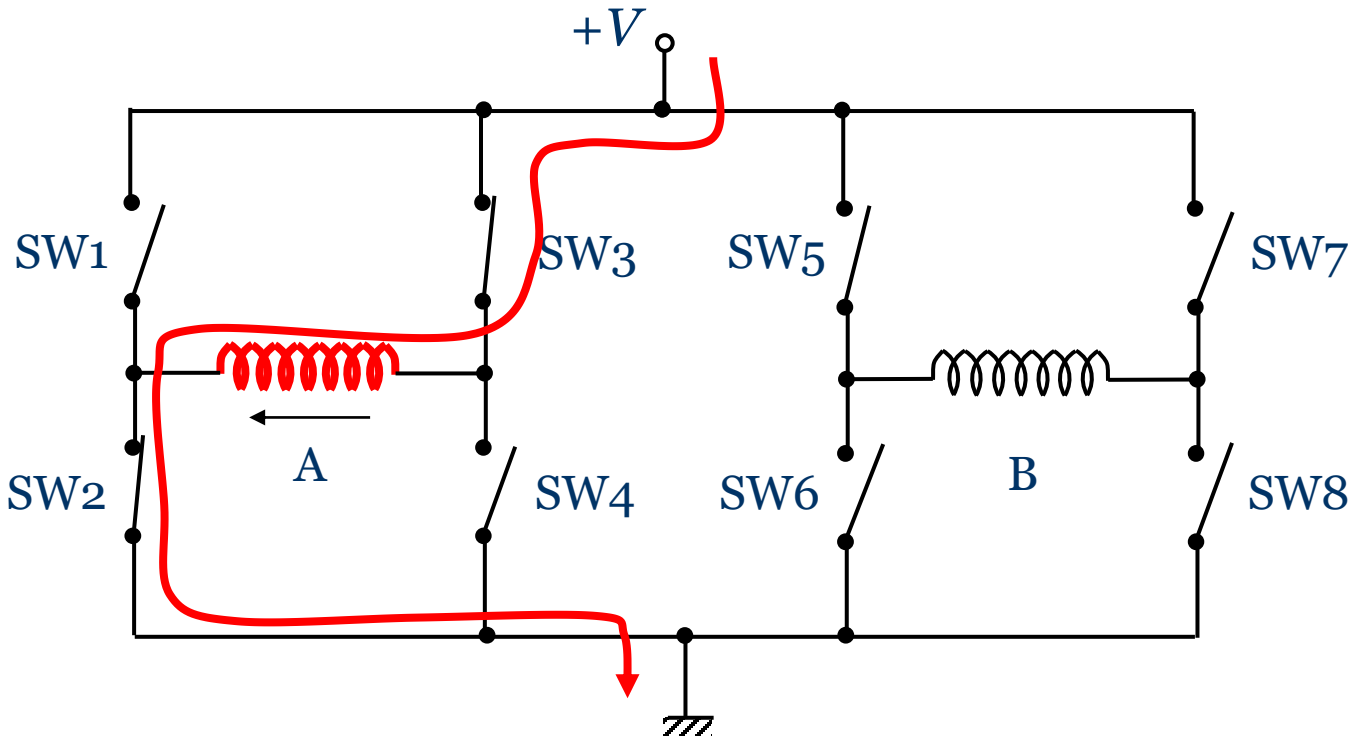

Bipolar driver

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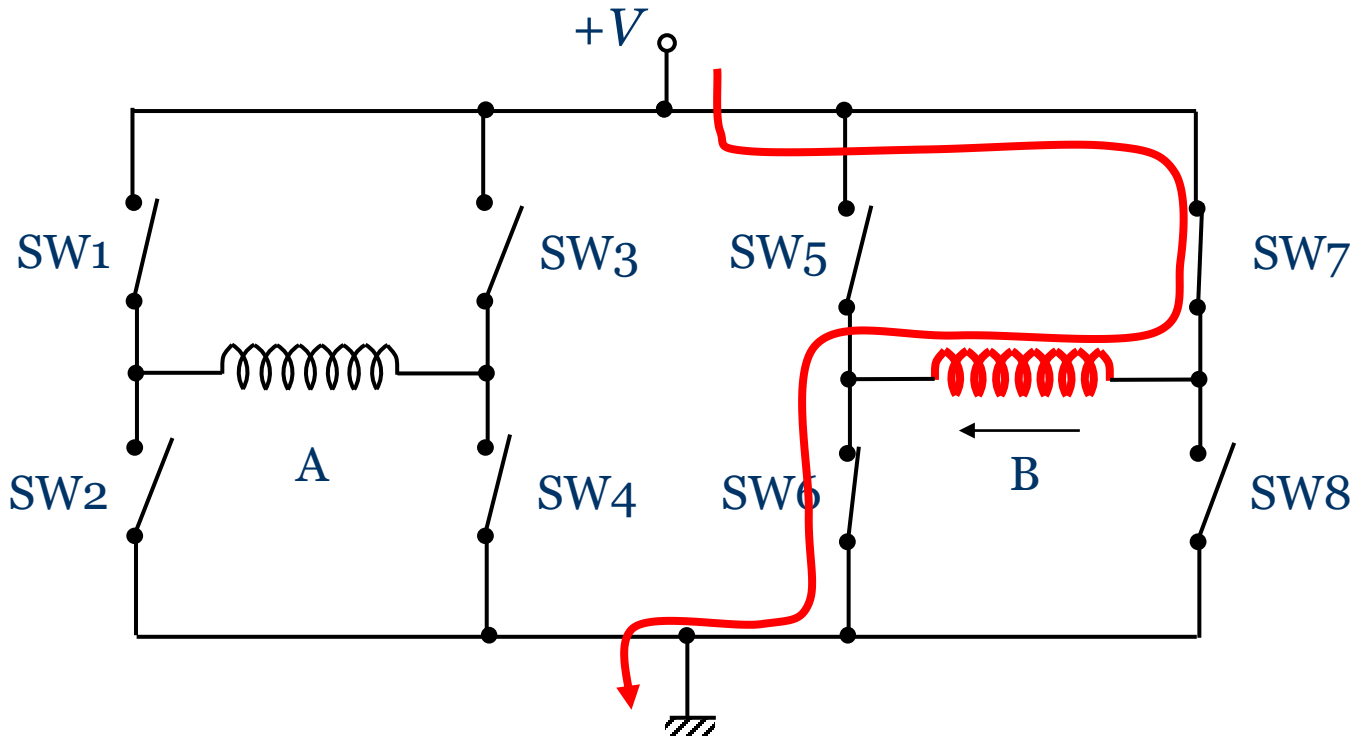
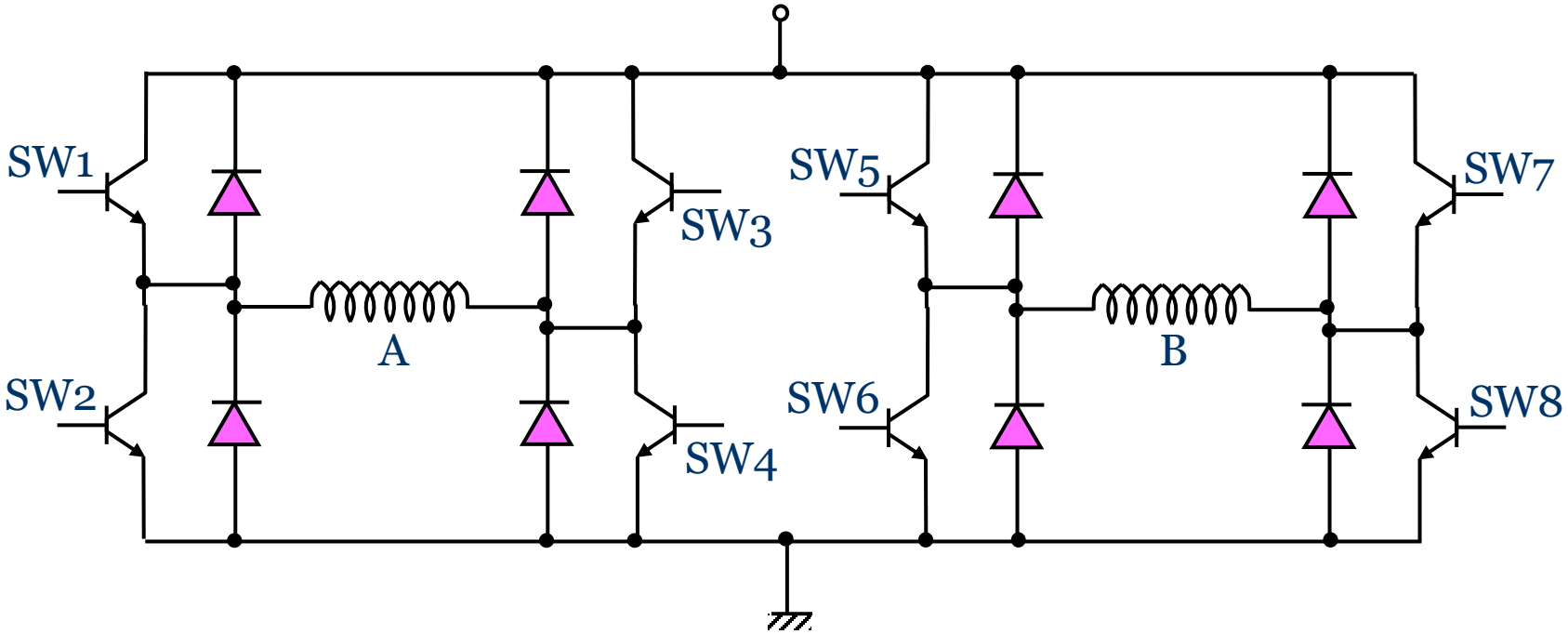
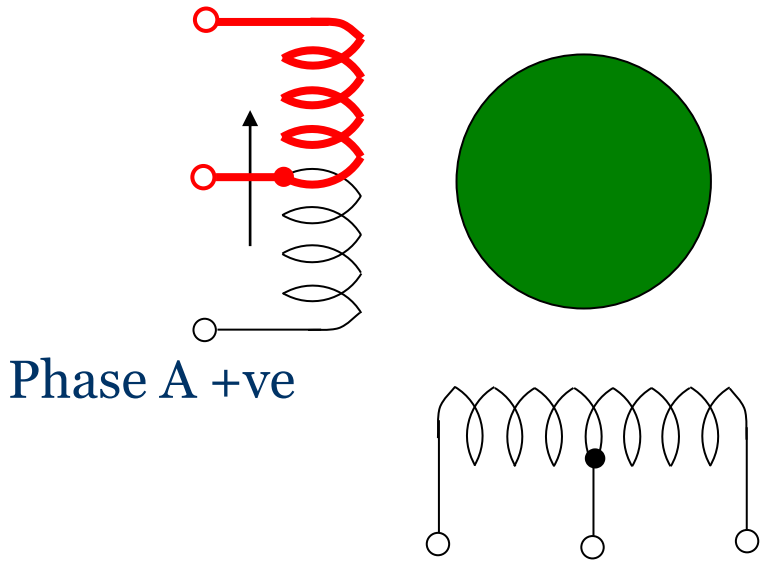


Bipolar driver (more realistic circuit – don't learn)

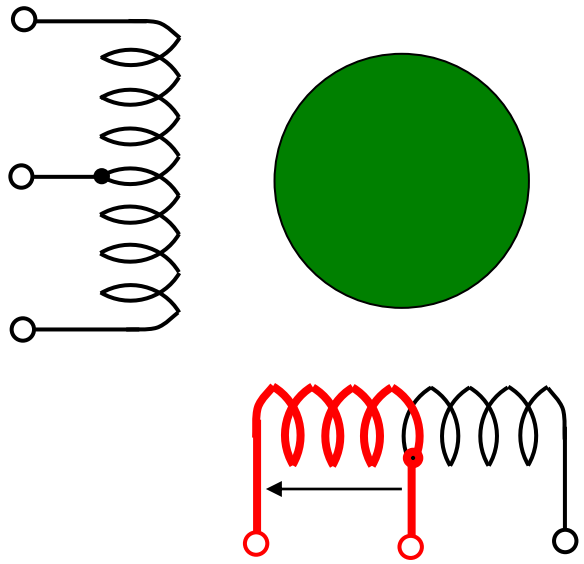


Six lead motor

- Centre tapped windings – unipolar driver, can also use as 4-lead
- Only energise each half in a single direction



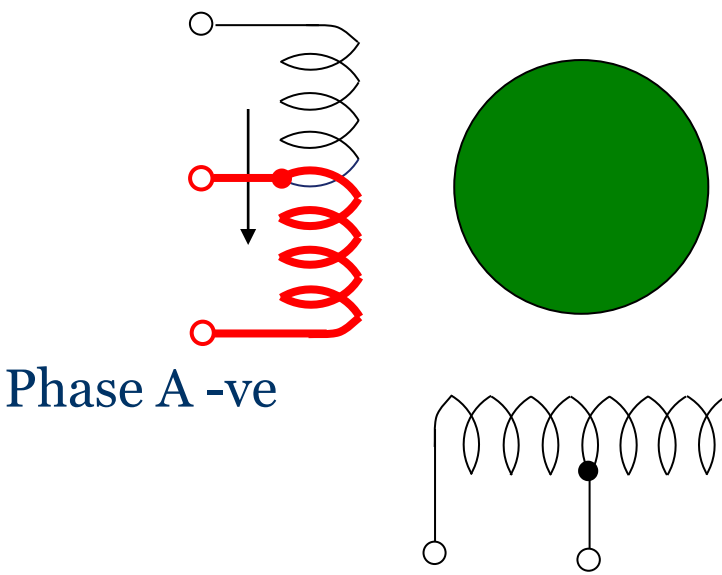
Phase A +ve



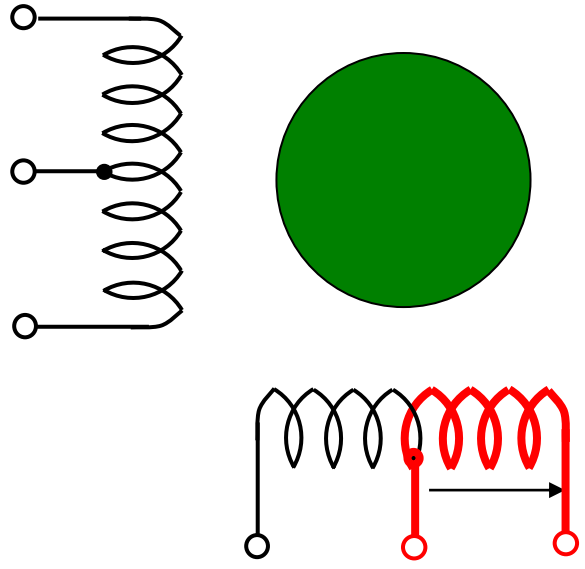
Phase B +ve

Six lead motor

- Centre tapped windings – unipolar driver, can also use as 4-lead
- Only energise each half in a single direction



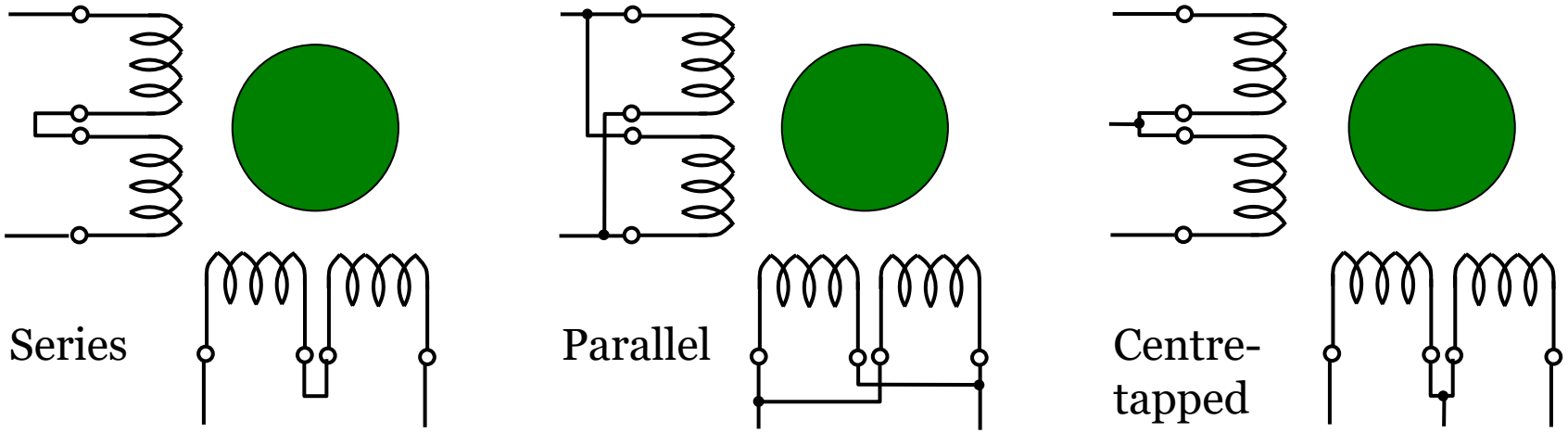
Phase A -ve



Phase B -ve

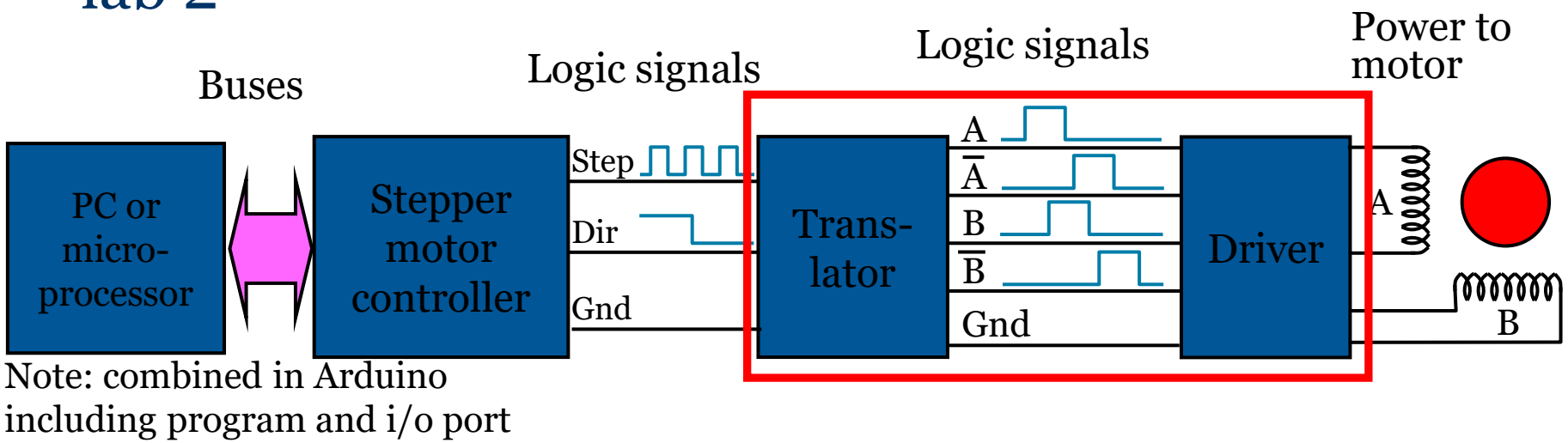
Six lead motor

- Can treat as four or six lead motor



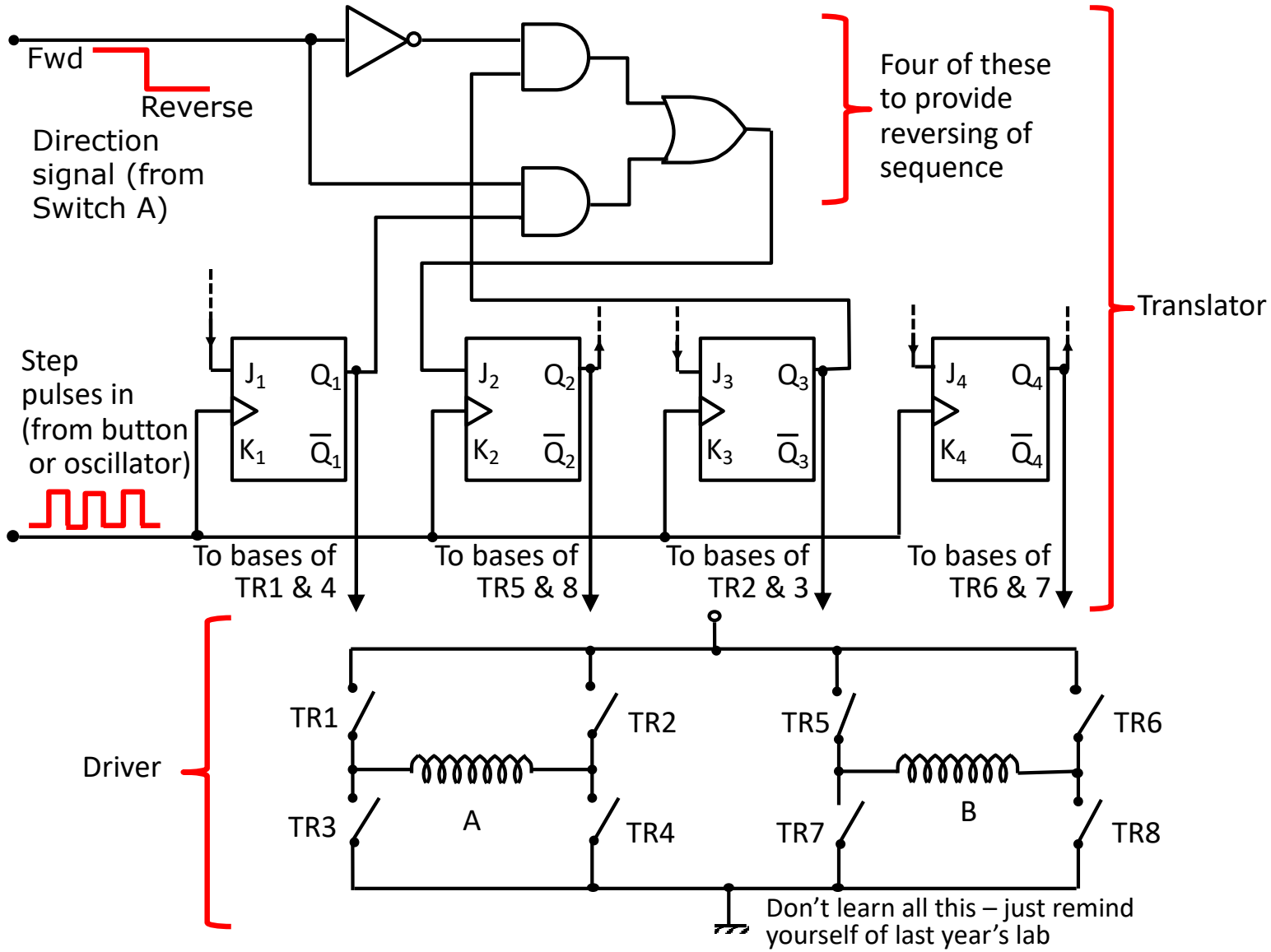
Six lead motor

- Usually we have 2 or more separate circuits:
  - To generate step and direction signals
  - To switch phased currents in windings
- You studied a circuit for exactly this in MM2EMD lab 2



Note: combined in Arduino including program and i/o port

Six lead motor



Six lead motor

Stepper drivers in practice

- Stepper motor driver units:
  - Take in power supply
  - Step and direction signals
  - Power the A and B windings of the stepper motor
  - Both translator & driver
- Separates **control** from **driving** of stepper motor
- Microstepping (like half-stepping but finer grading)

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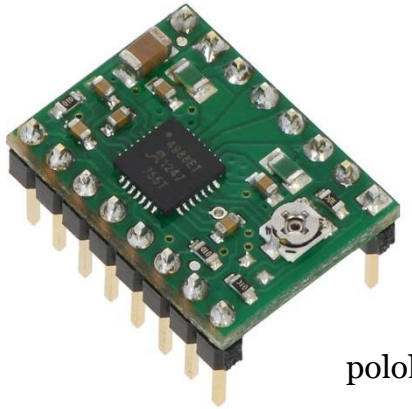

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Summary

- Concept, characteristics and types of servo motor are introduced
- Emphasis on PWM:
  - Generated in hardware e.g. counter-timer
  - Using **`analogWrite`** function
  - Generated by “bit-banging” in software
- How stepper motor works
- Covered the main points of interfacing of stepper motors
- Introduced the reasons for the different numbers of leads on stepper motors