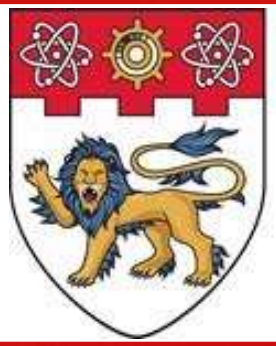


NANYANG TECHNOLOGICAL UNIVERSITY
SINGAPORE

MA2012 INTRODUCTION TO MECHATRONICS SYSTEMS DESIGN

Lecture 4

Prof Ang Wei Tech

College of Engineering
School of Mechanical and Aerospace Engineering

RECAP

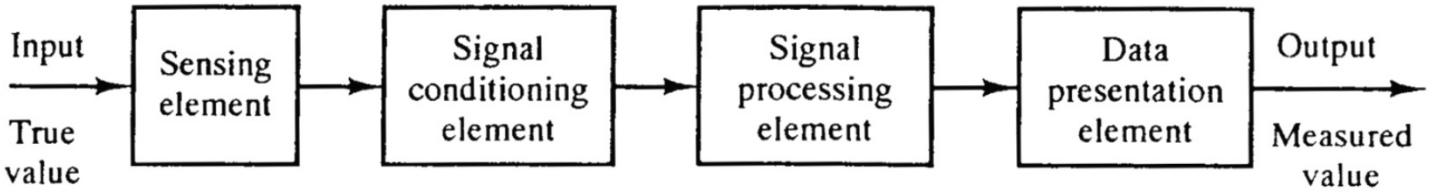
DIGITAL SENSORS

- Switches, Incremental Encoder
- Interfacing with Digital Sensors

ANALOG SENSORS

- Analog Output (e.g. Potentiometer), Digital and Analog Outputs (e.g. accelerometer)

ACQUISITION PROCESS AND ELEMENTS



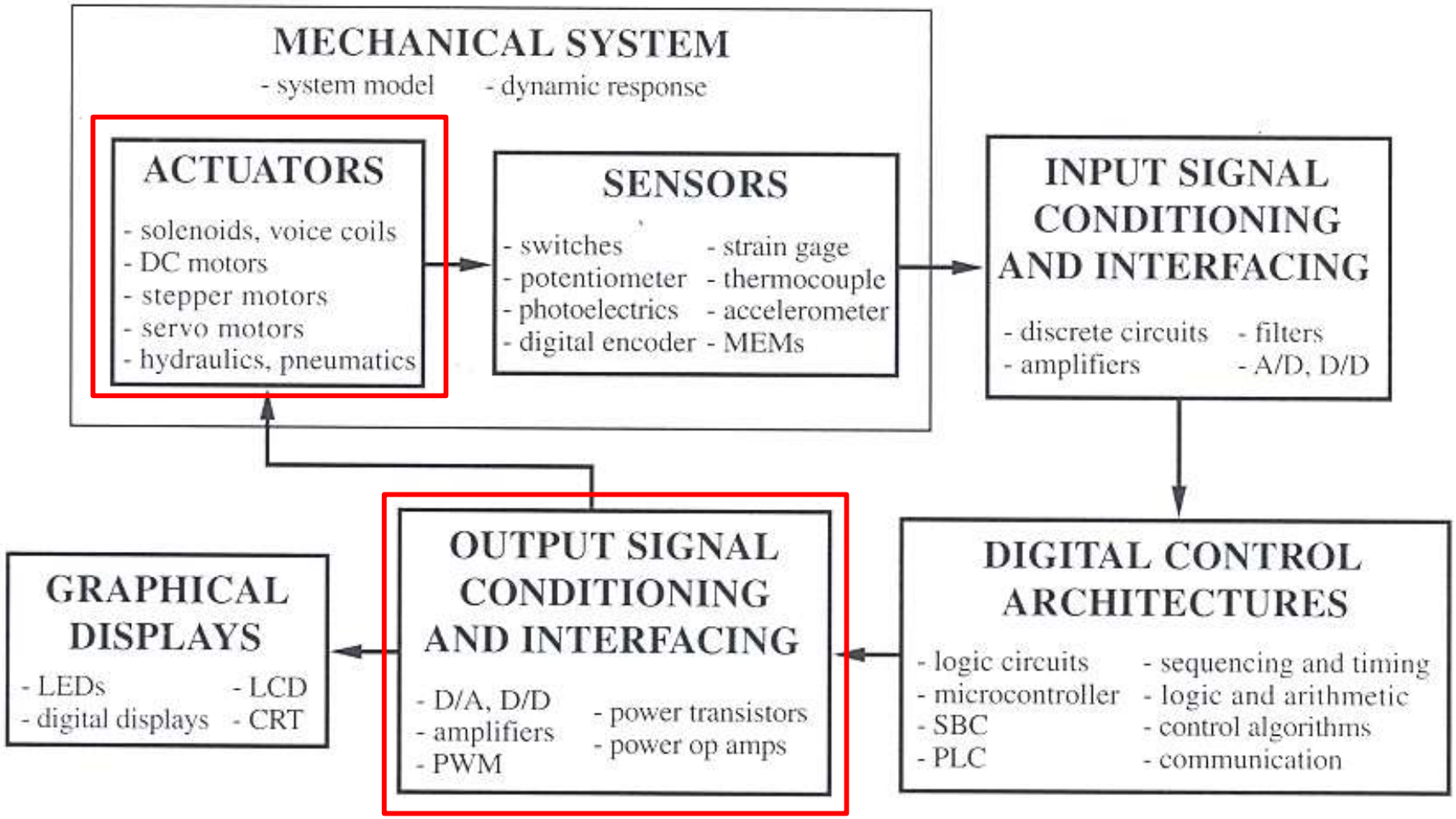
DIGITIZATION OF ANALOG SIGNAL

- Shannon sampling theorem, Nyquisit frequency, Aliasing

A/D CONVERSION, ADC

- Successive Approximation
- Flash Converter

MECHATRONIC SYSTEM COMPONENTS



TYPES OF ACTUATORS

MA2012 COVERS

- DC Motor
- Stepper Motor
- Servo
- Solenoid

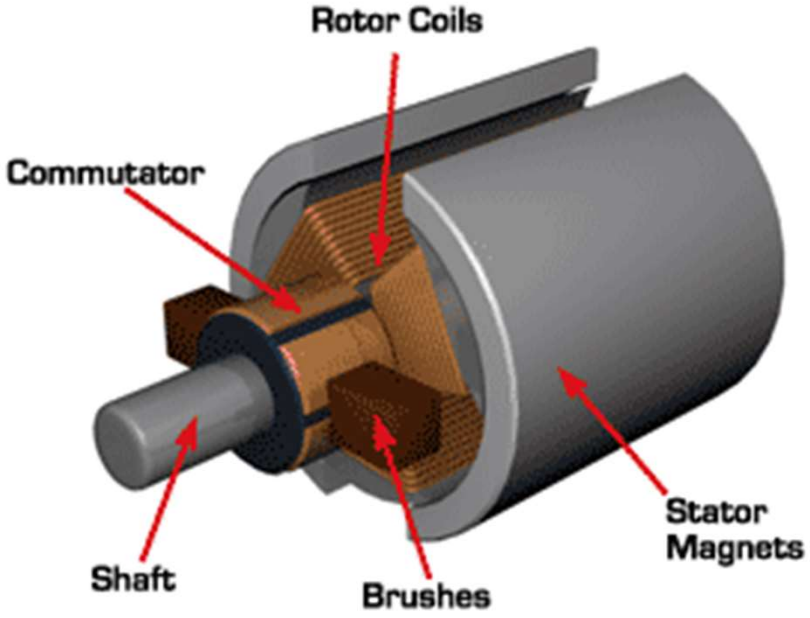
TYPES NOT COVERED

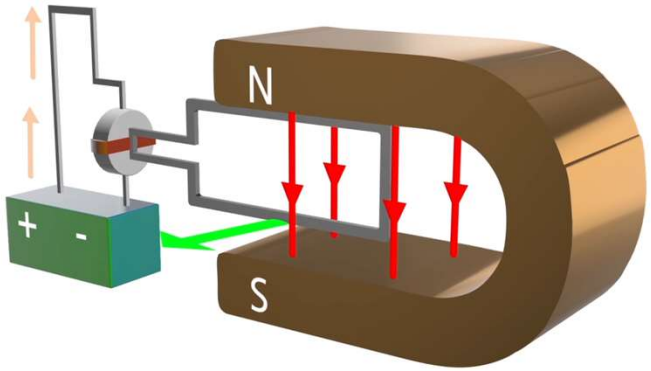
- AC Motor
- Hydraulic Actuator
- Pneumatic Actuator
- Piezoelectric Actuator
- Shape Memory Alloy

DIRECT CURRENT MOTOR

PERMANENT MAGNET OR BRUSHED DC MOTORS

- Stator: external, fixed
- Rotor: internal, rotates



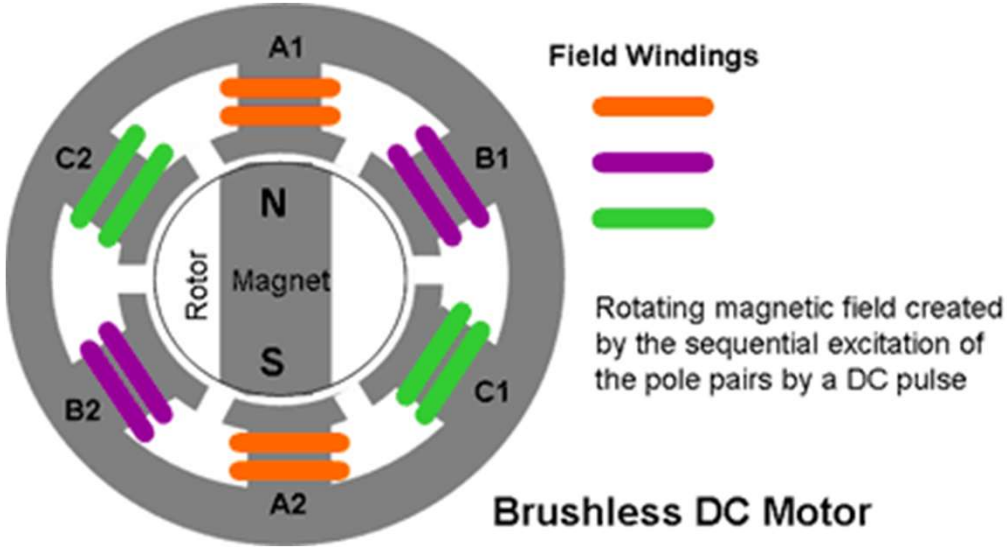


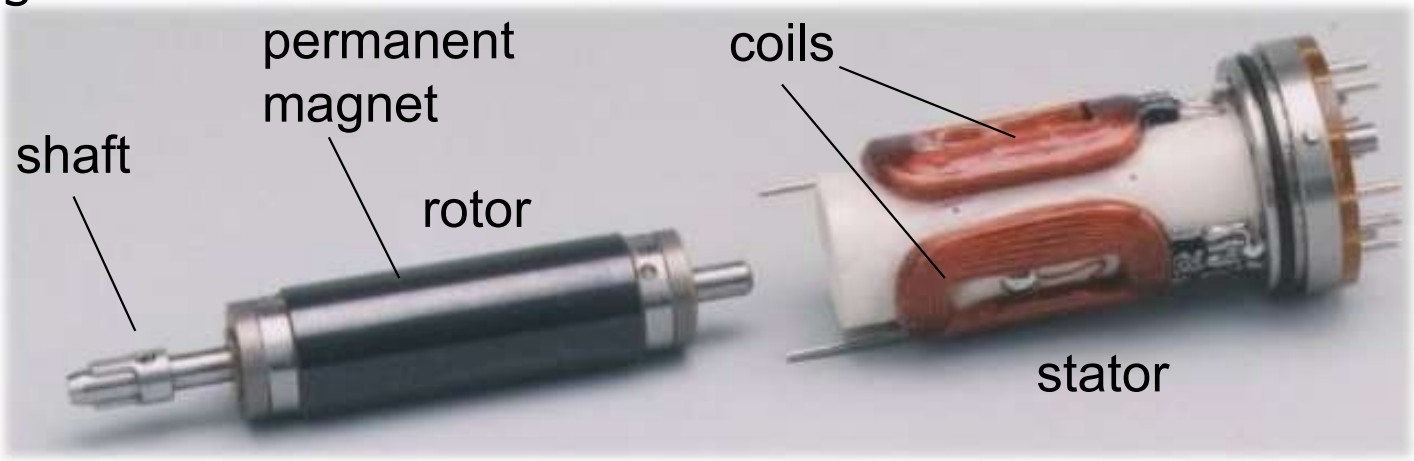
Click animation to play

DIRECT CURRENT MOTOR

BRUSHLESS DC MOTOR

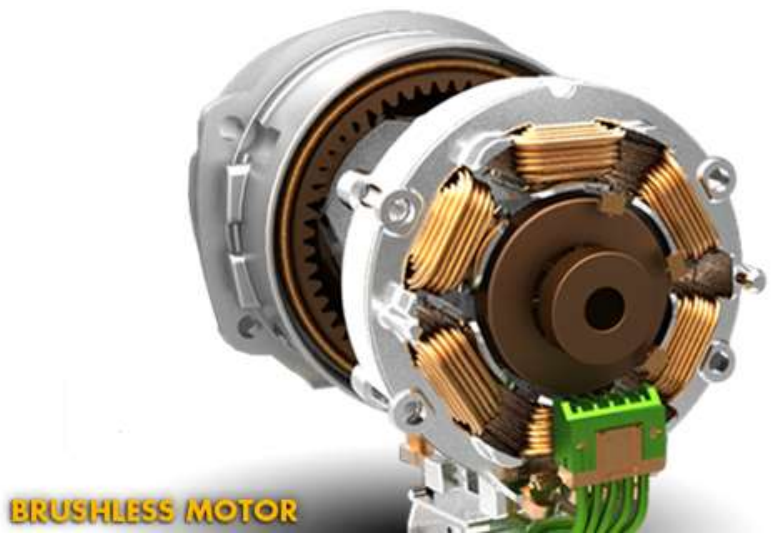
- Brushed motor inside-out
  - Permanent magnet rotor
  - Stator with rotating magnetic field
- Need to know exact angular position of the rotor so as to excite the correct coils
  - Typically with Hall effect sensors





DIRECT CURRENT MOTOR

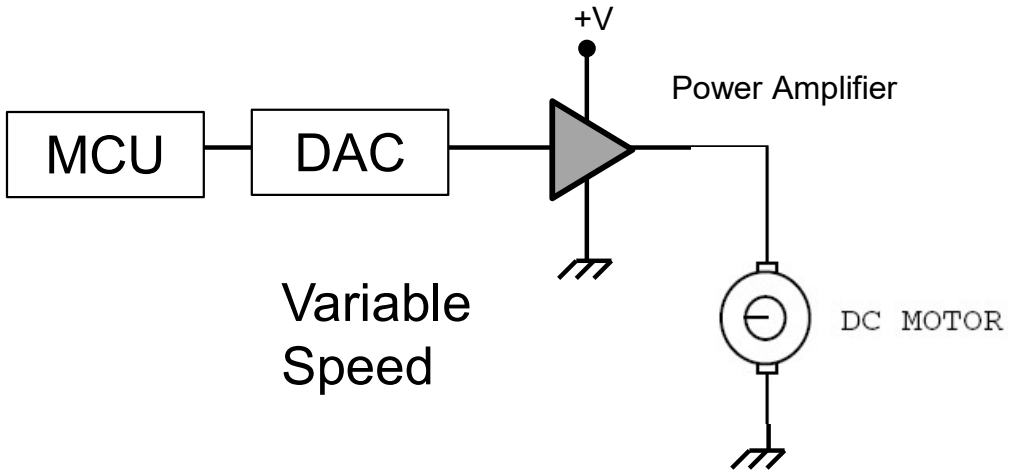
Brushless	Brushed
Simple maintenance	Low cost: simple construction & control, only two wires needed
High efficiency: No drop in voltage across brush, low electrical noise	More robust in harsh environment, because no electronic components
Higher speed range	
Reduced size	

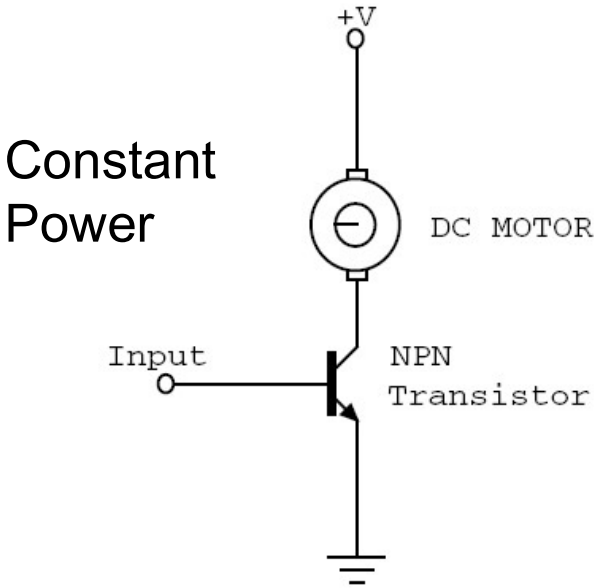


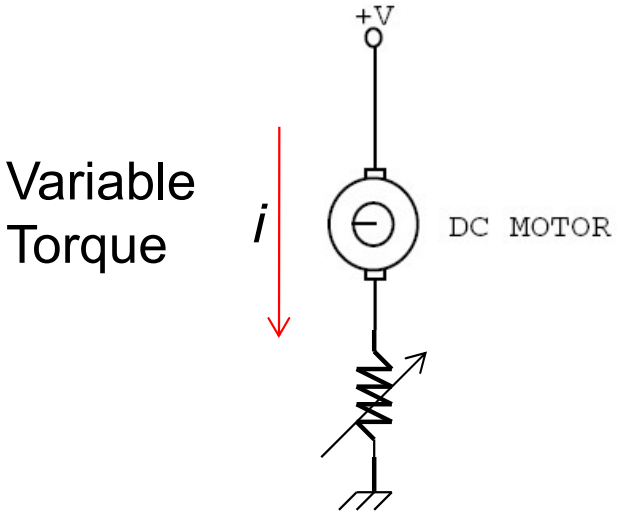
CONTROLLING DC MOTORS

- Motion Control Fundamentals
  - Power = VI = $\tau\omega$
  - DC motor control
    - Voltage controls velocity: $V \propto \omega$
    - Current controls torque: $I \propto \tau$
- Using power amplifiers is possible but is typically avoided
  - Large power dissipation, over-heating of the amplifier
- Digital-to-Analog Converter (DAC) is expensive
  - Most MCUs are not equipped with a DAC
- Solution:
  - Pulse Width Modulation (PWM)

CONTROLLING DC MOTORS





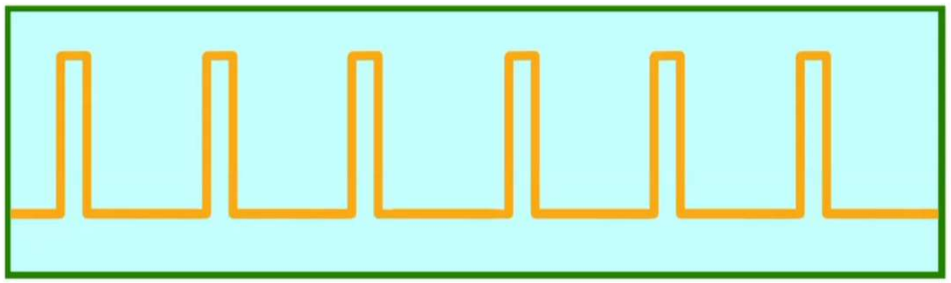


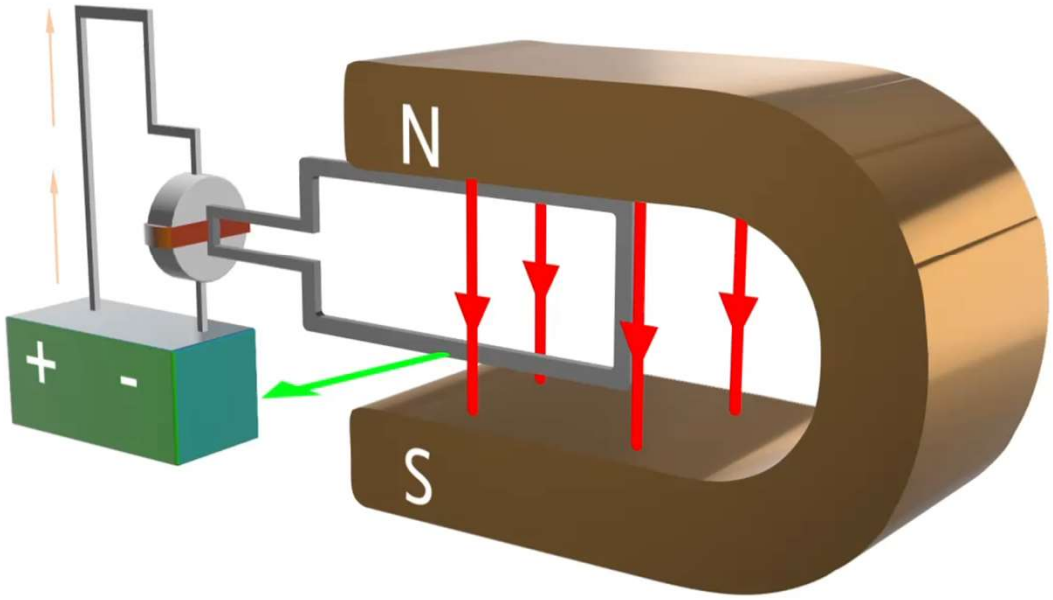
PULSE WIDTH MODULATION

- If switch is always on, lamp receives 9V and light up to the rated brightness
- If switch is 50% on and 50% off very quickly (1 – 200 kHz), lamp receives an equivalent of 4.5 V, thus only 50% of rated brightness

PULSE WIDTH MODULATION

Duty Cycle = 10%





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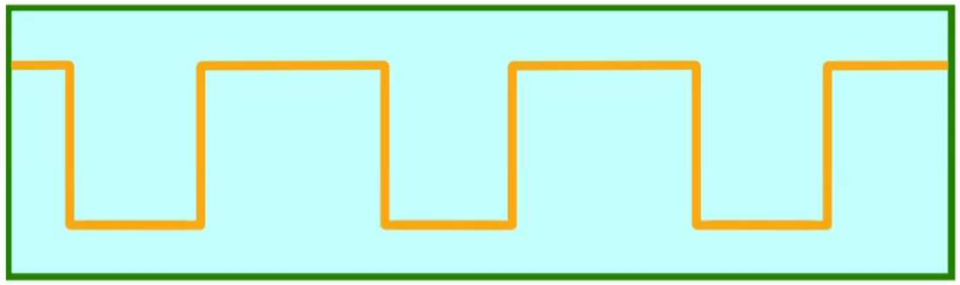
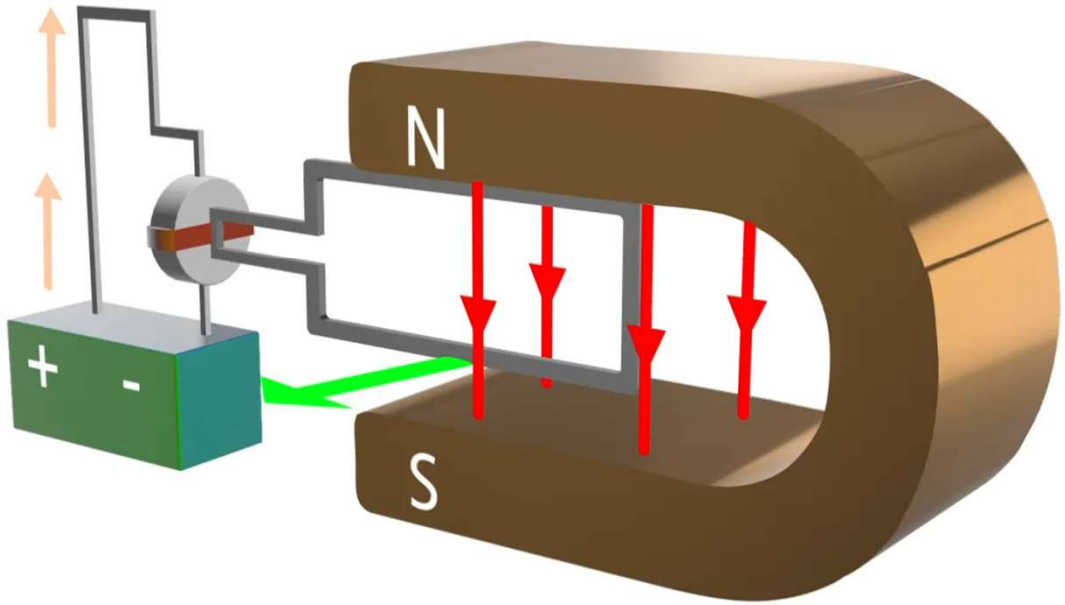
PULSE WIDTH MODULATION

Duty Cycle = 50%



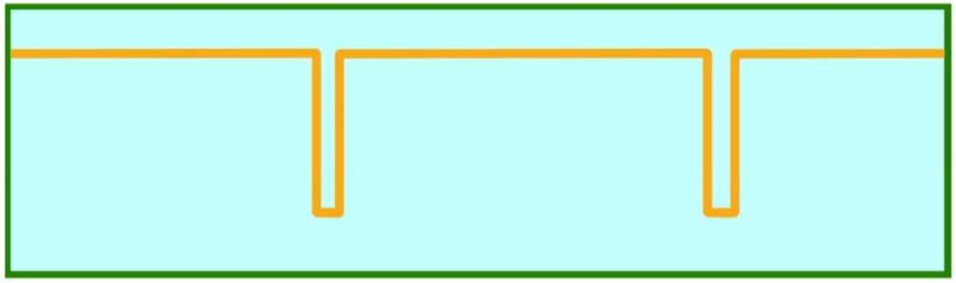


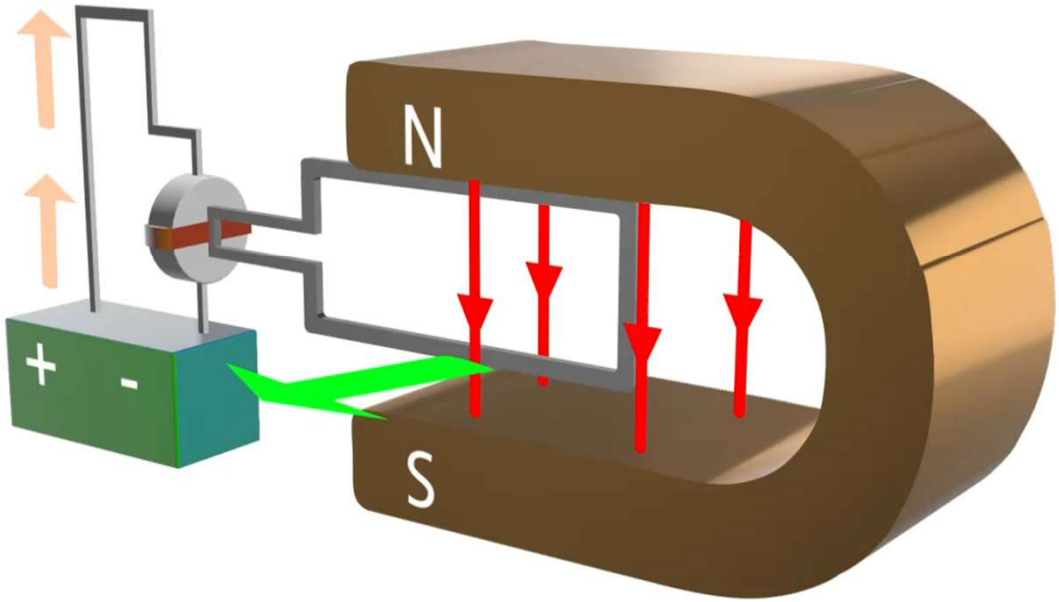
Click animation to play

CONTROLLING DC MOTORS

PULSE WIDTH MODULATION

Duty Cycle = 90%

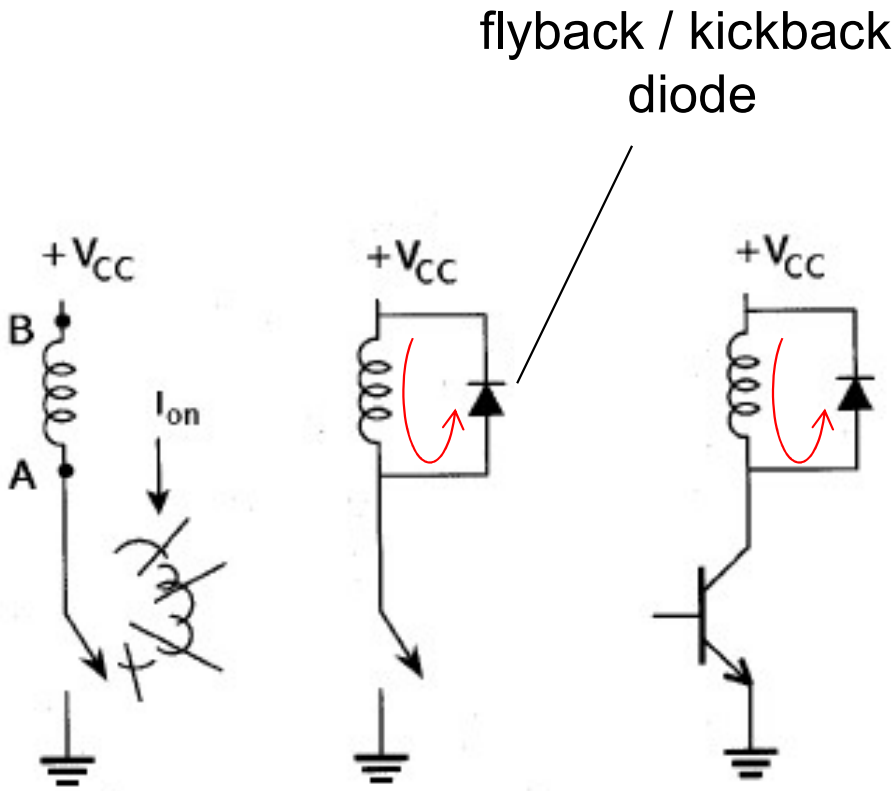




Click animation to play

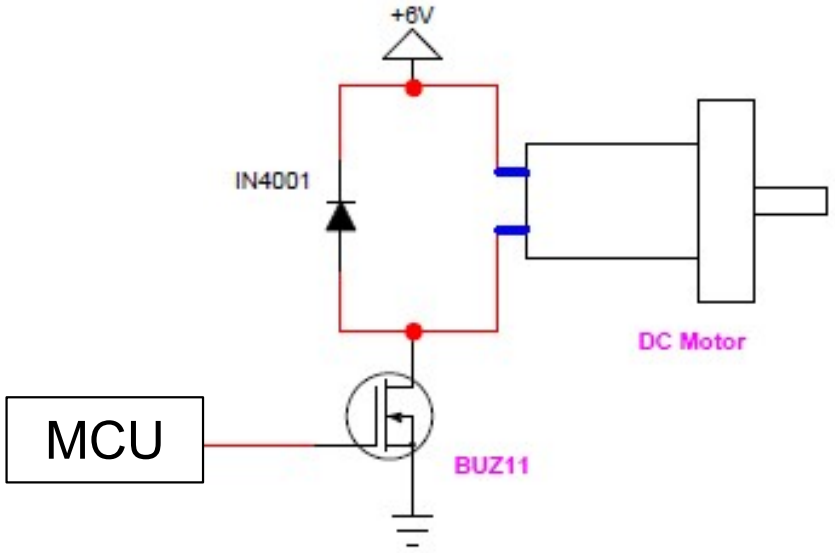
INDUCTIVE KICKBACK

- The steady-state current though an inductor, I_{on}, cannot immediately go to zero when the switch is opened. The changing current induces a voltage across the inductor, making the potential A greater than B, causing the switch to 'blow up'
- Kickback or flyback diode protects the switch (physical or transistor) from blowing up

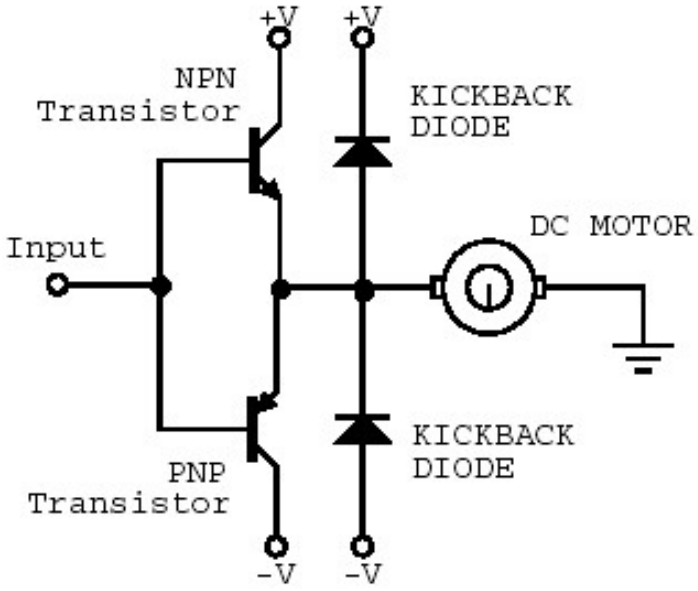


CONTROLLING DC MOTORS

- PWM (Uni-direction)



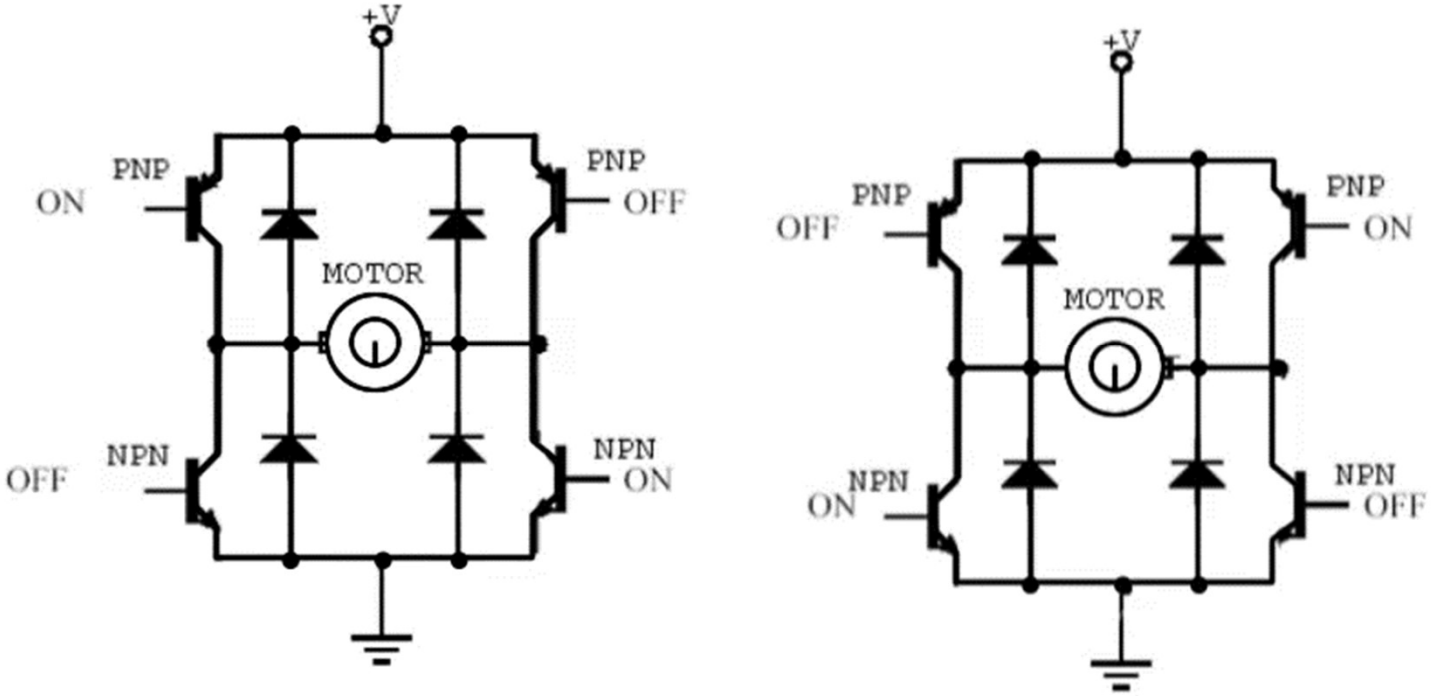
- PWM (Bi-direction)



Bi-directional DC motor control using a dual power supply

DCM DRIVING: GENERAL PWM

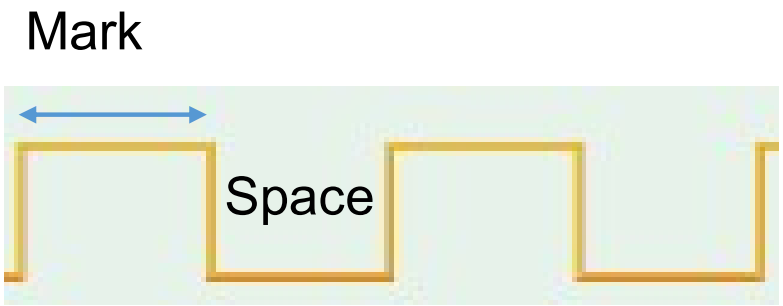
- PWM bi-directional control with H-bridge circuit



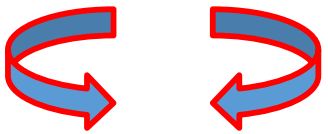
Click animation to play

SERVO MOTOR

- The drive flange can rotate ½ revolution
- It is driven by width of high pulse (Logic 1) called 'Mark' length



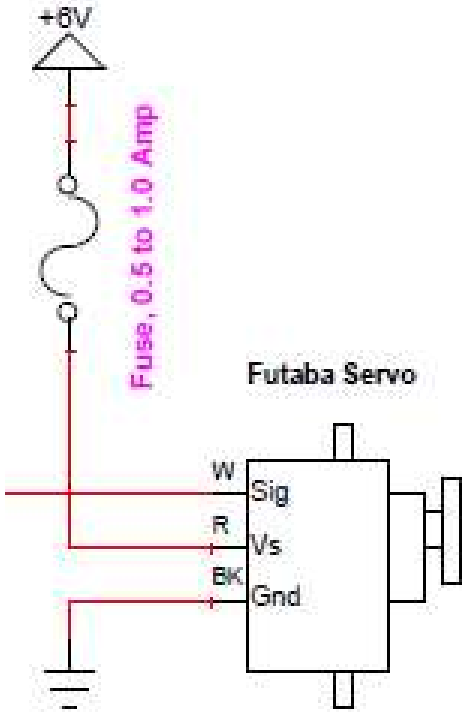
0° to 180°

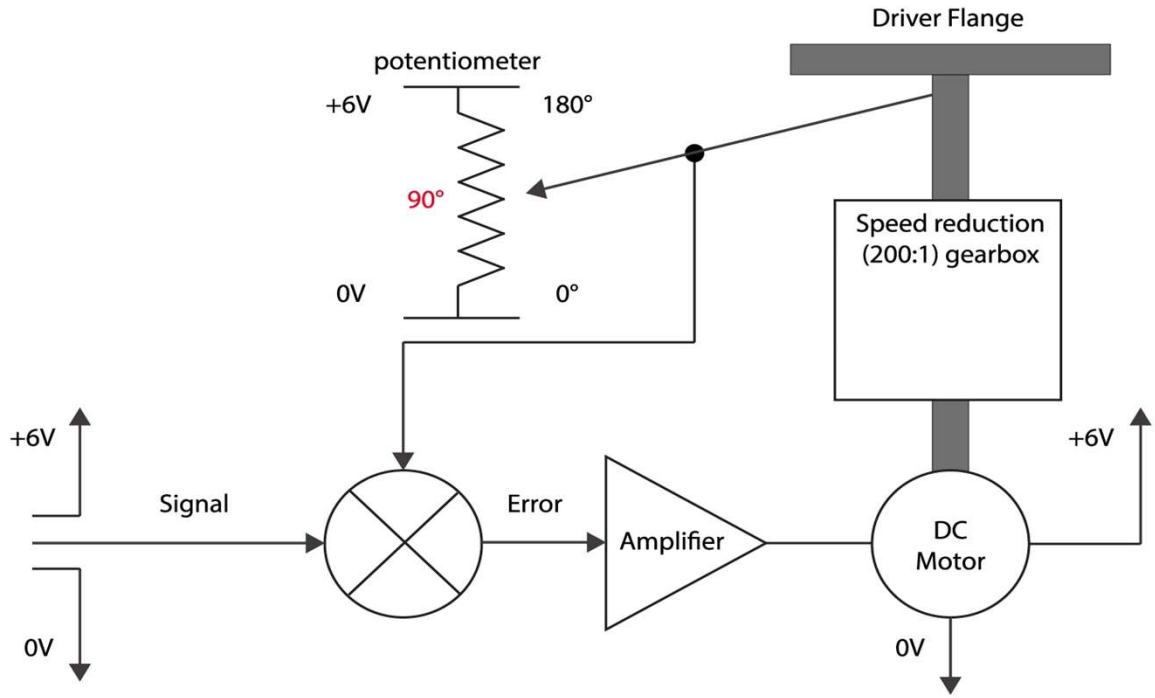


Click video to play

SERVO MOTOR

- Working Principle

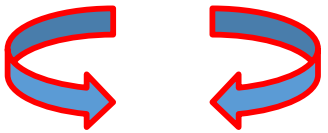


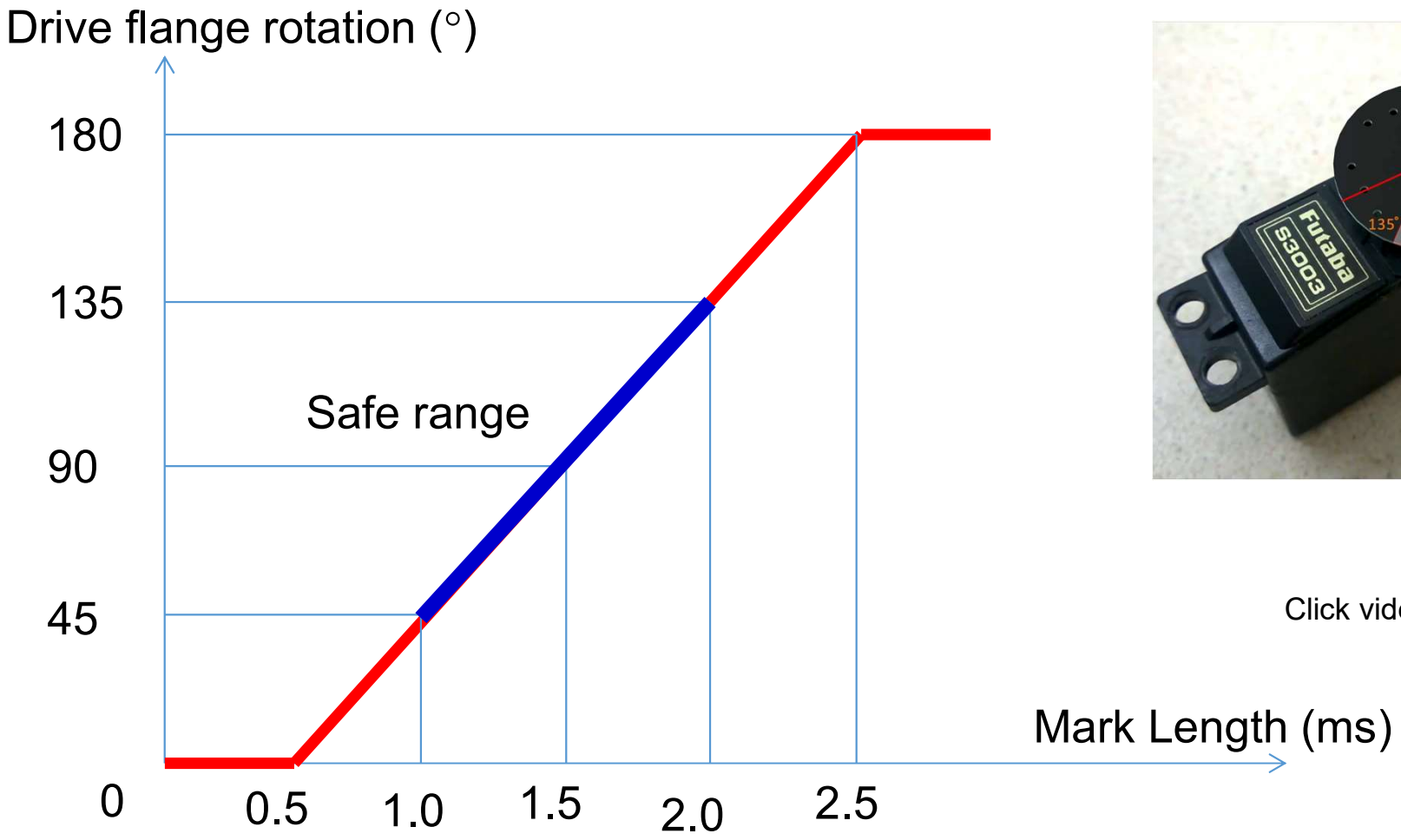


Click animation to play

DRIVING A SERVO MOTOR

45° to 135°

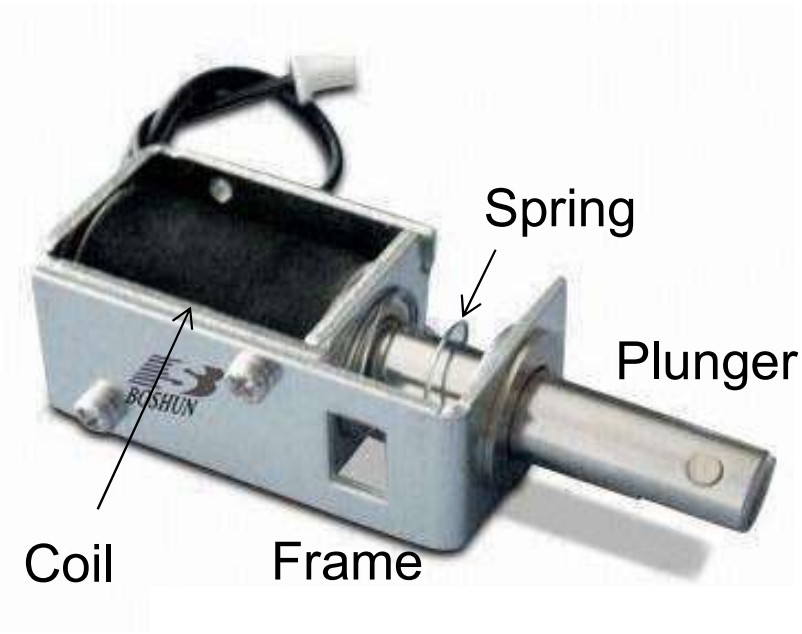


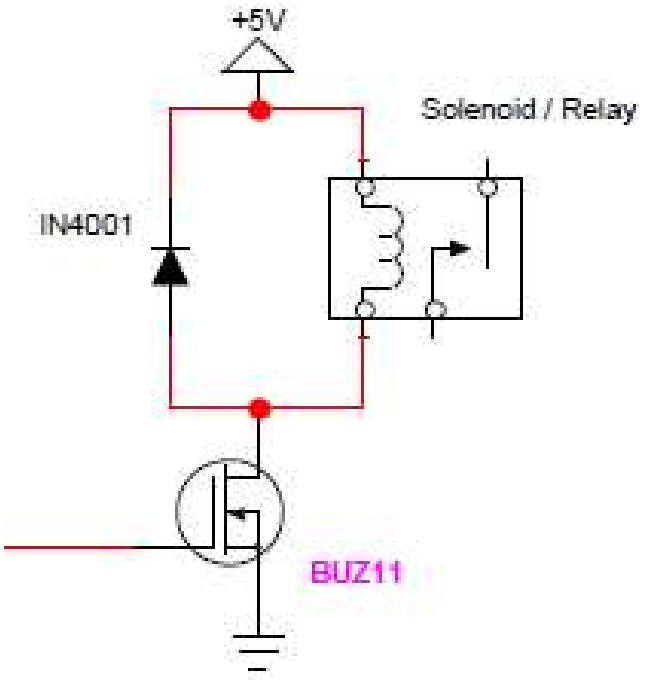


Click video to play

Solenoid

- Construction
  - Stationary iron frame (stator)
  - Coil (solenoid)
  - Ferromagnetic plunger (armature)
- Types
  - Push or pull
- Control
  - A pulse to turn on or off



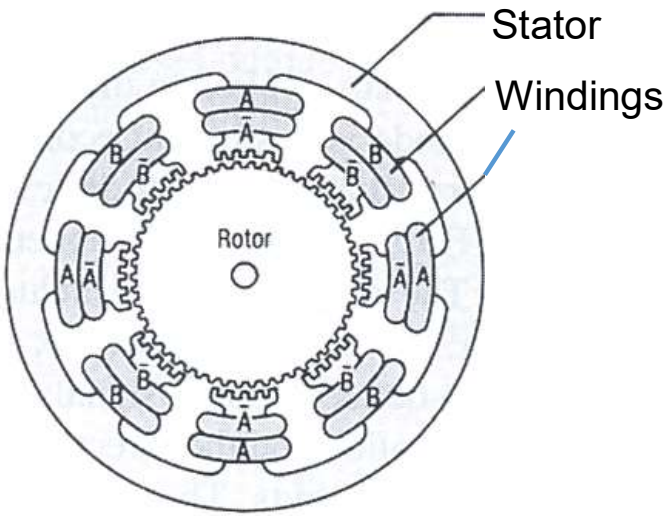


STEPPER MOTOR WORKING PRINCIPLE

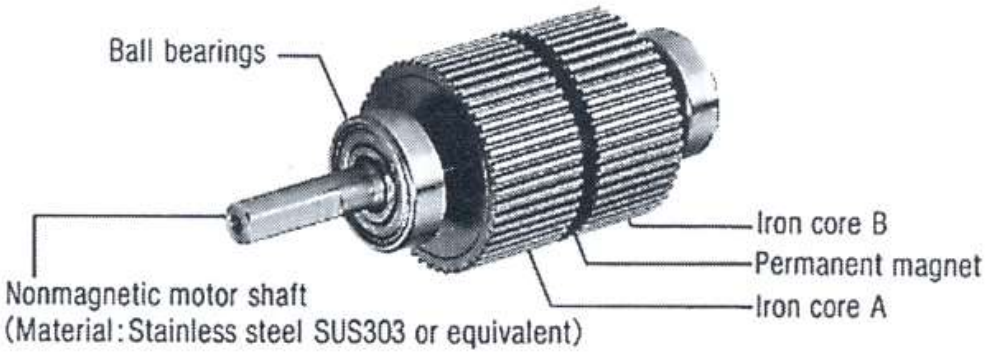
Construction

- Permanent magnet rotor
- Stator with rotating magnetic field

if just one winding of the motor is energized, the rotor will snap (rotate) to a fixed angle and then hold that angle until the torque exceeds the holding torque of the motor.

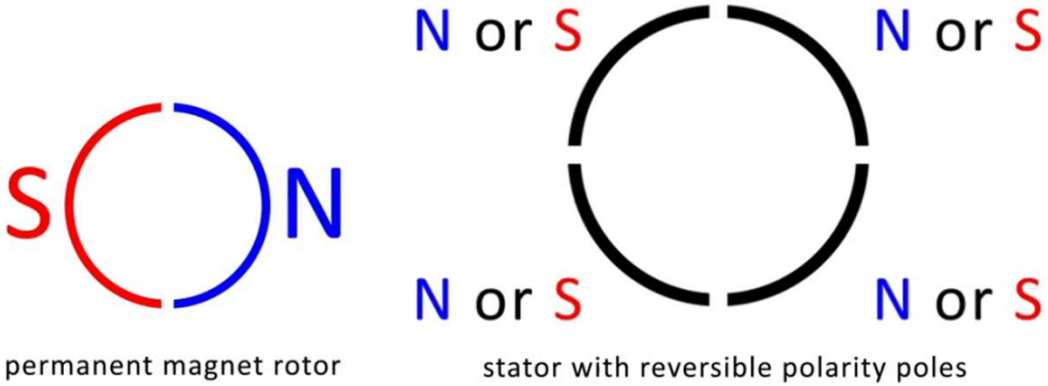


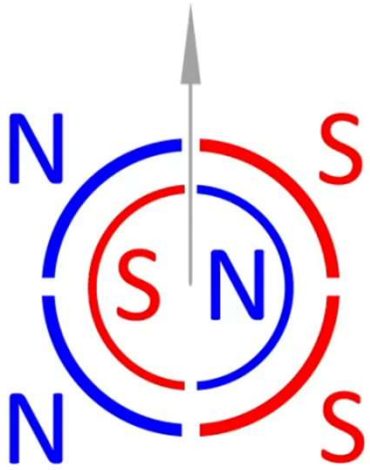
Rotor & Stator Configuration



Stepper Motor Construction

STEPPER MOTOR WORKING PRINCIPLE





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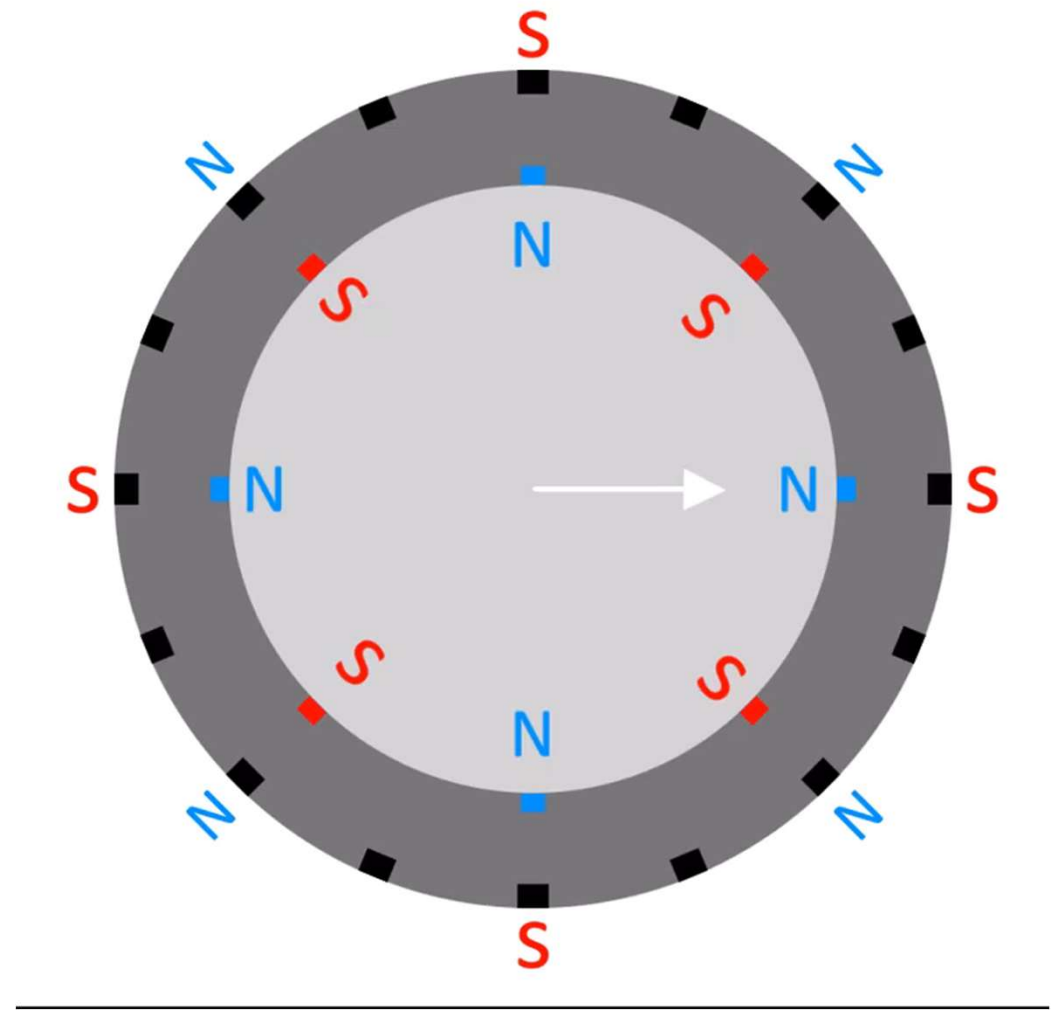
STEP SEQUENCE – HIGHER RESOLUTION

- Double the number of poles will half the step size



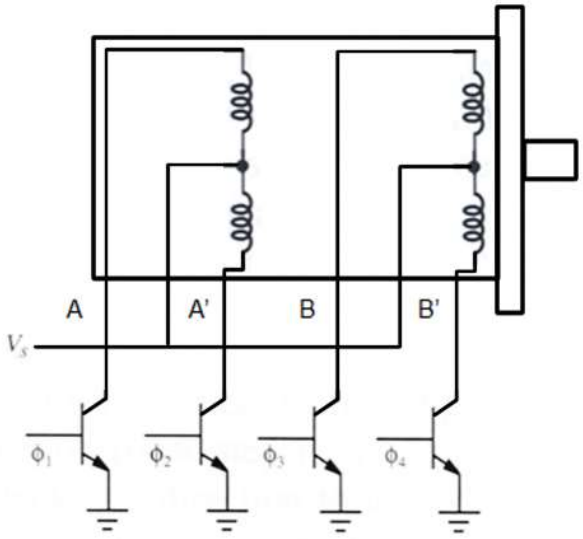
Click animation to play

MICRO-STEPPING

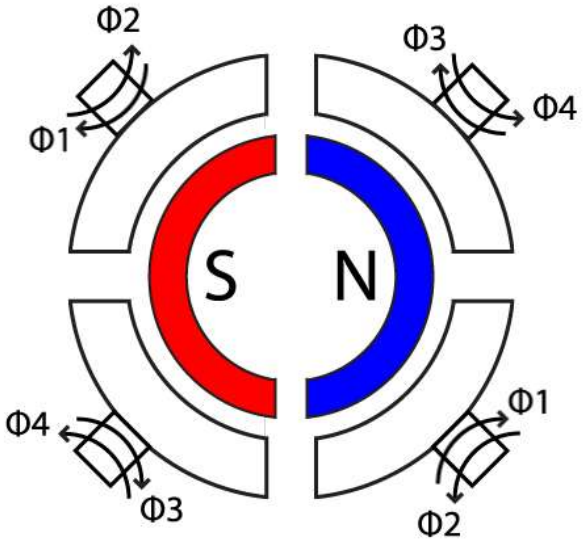
- Higher resolution can be achieved by controlling the fractions of current flowing into poles A & B individually
- See URL

STEPPING SEQUENCE (WAVE-DRIVE / SINGLE PHASE)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
2				
3				
4				



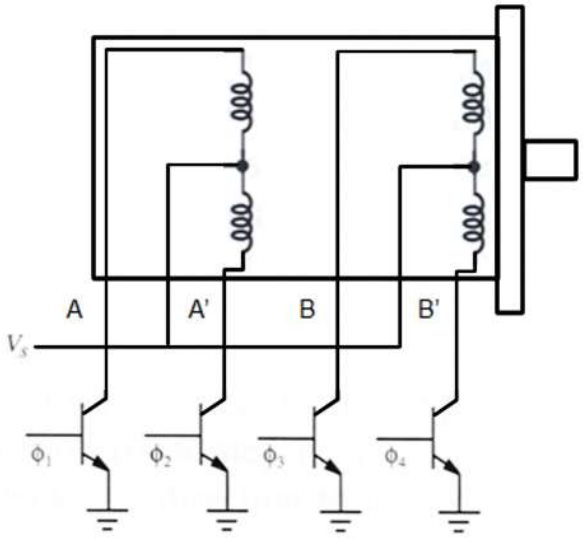
Unipolar stepper motor



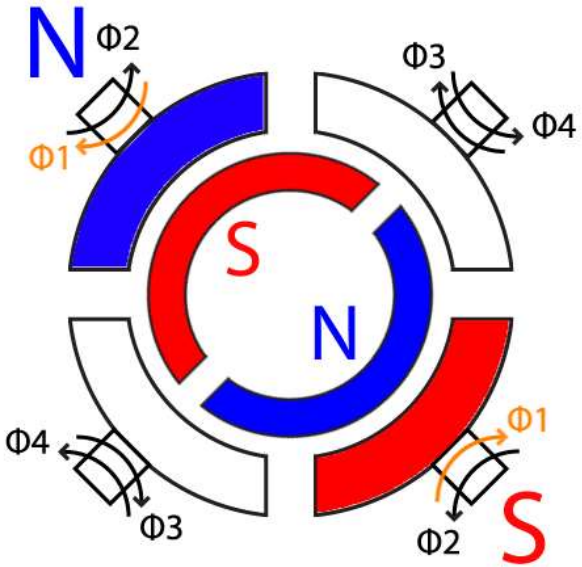
Step 0

STEPPING SEQUENCE (WAVE-DRIVE / SINGLE PHASE)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1	ON			
2				
3				
4				



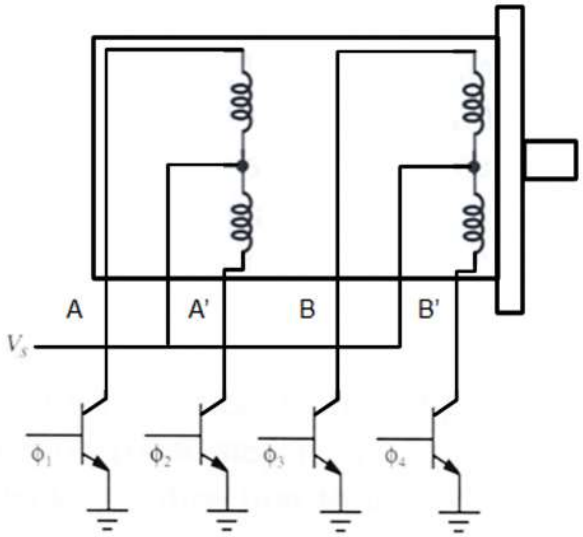
Unipolar stepper motor



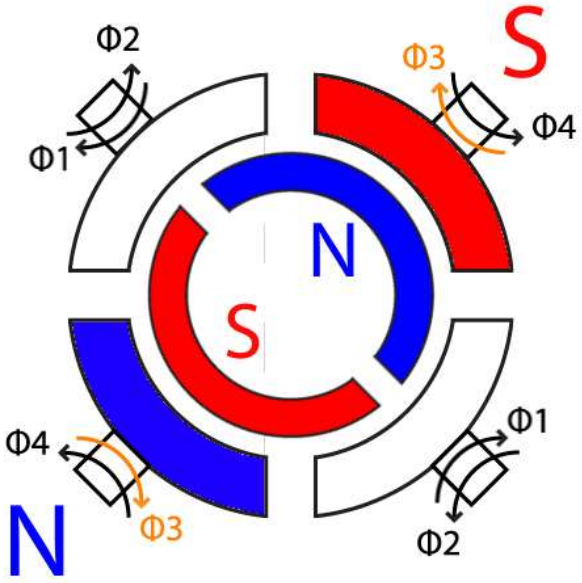
Step 1

STEPPING SEQUENCE (WAVE-DRIVE / SINGLE PHASE)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
2		ON		
3				
4				



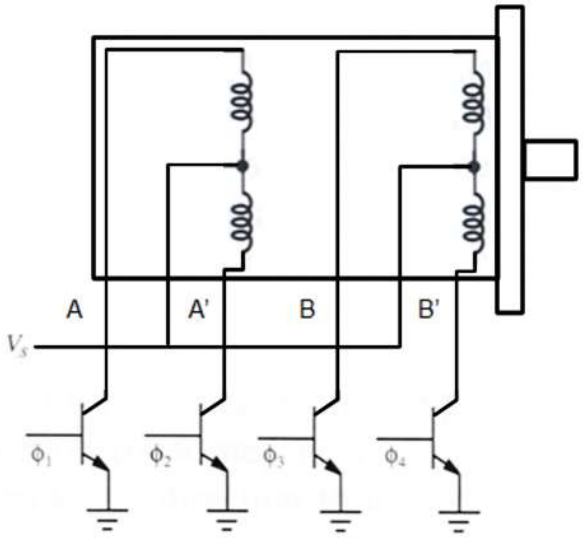
Unipolar stepper motor



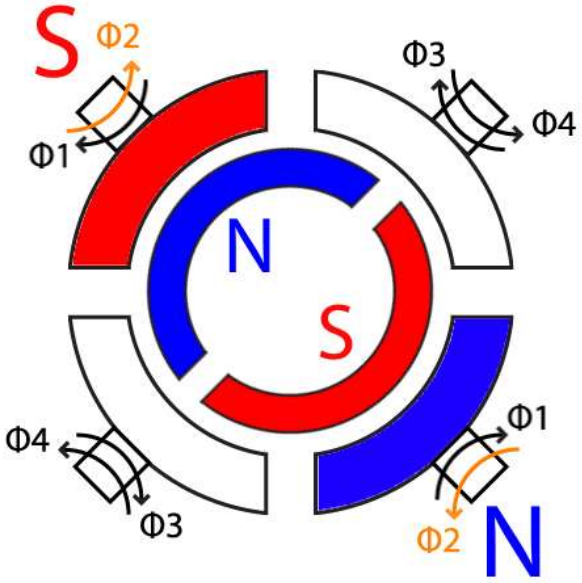
Step 2

STEPPING SEQUENCE (WAVE-DRIVE / SINGLE PHASE)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
2				
3			ON	
4				



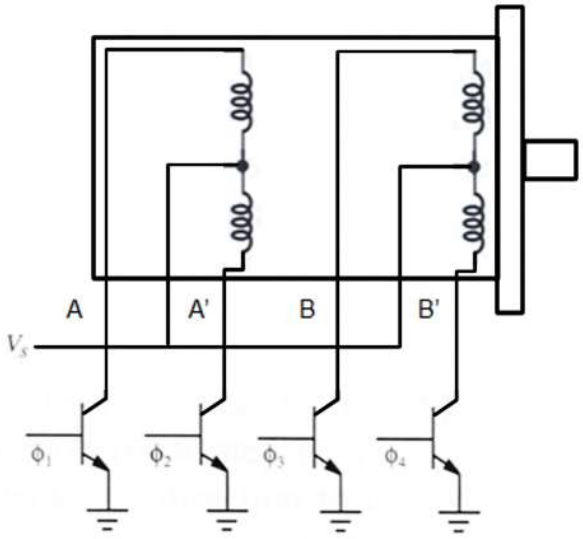
Unipolar stepper motor



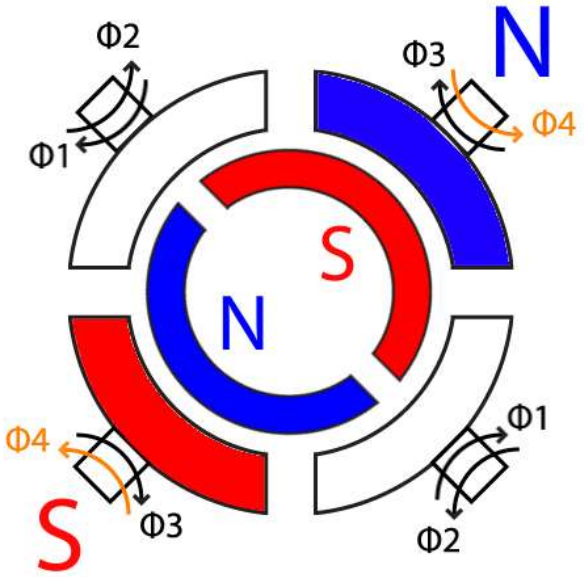
Step 3

STEPPING SEQUENCE (WAVE-DRIVE / SINGLE PHASE)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
2				
3				
4				ON



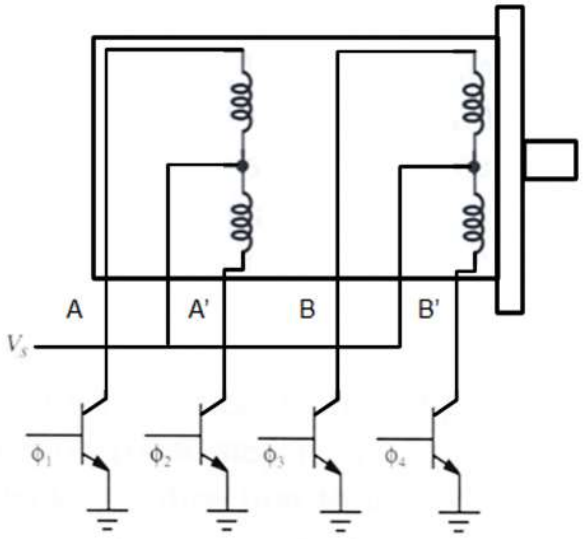
Unipolar stepper motor



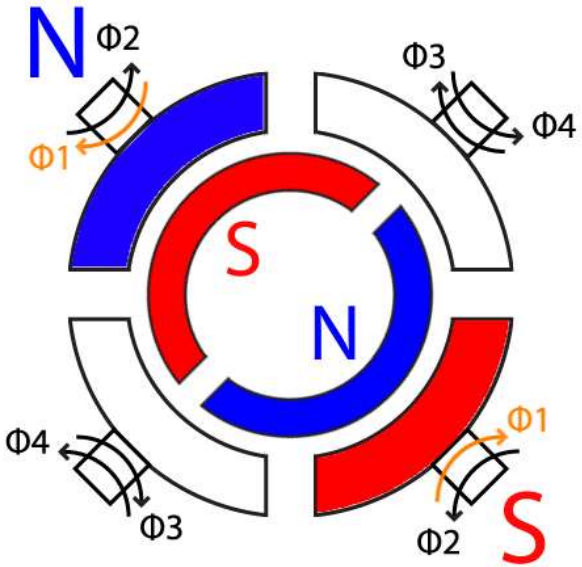
Step 4

STEPPING SEQUENCE (WAVE-DRIVE / SINGLE PHASE)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1	ON			
2				
3				
4				



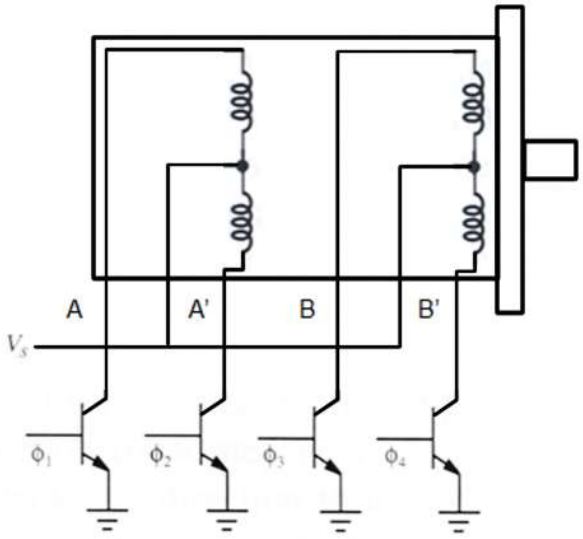
Unipolar stepper motor



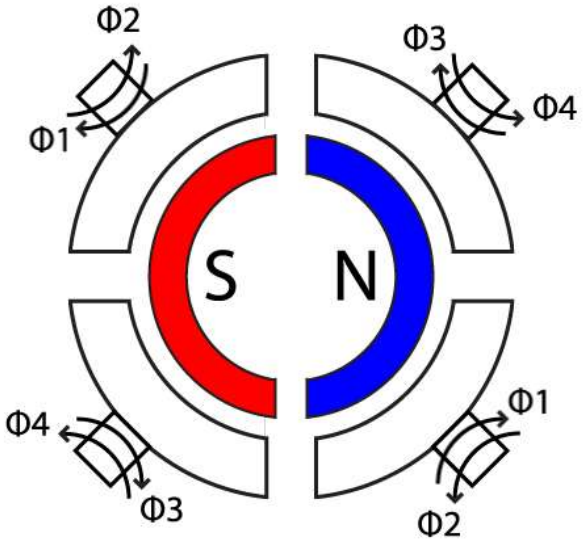
Step 1

STEPPING SEQUENCE (2 PHASE FULL STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
2				
3				
4				



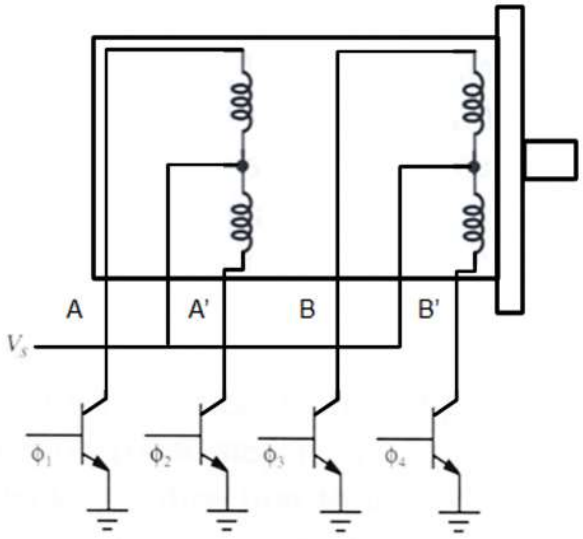
Unipolar stepper motor



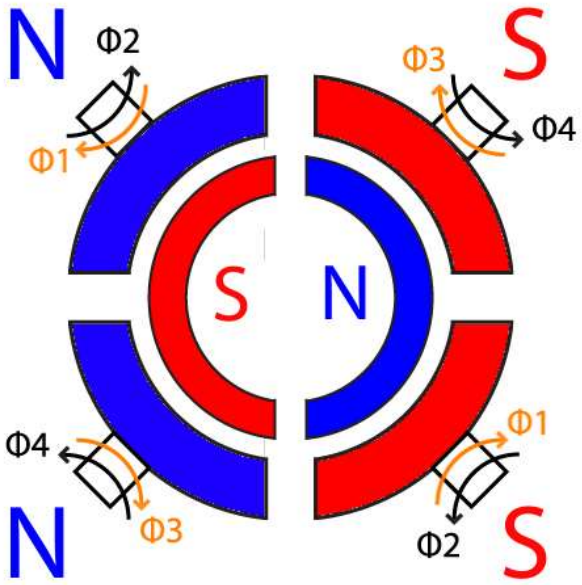
Step 0

STEPPING SEQUENCE (2 PHASE FULL STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1	ON	ON		
2				
3				
4				



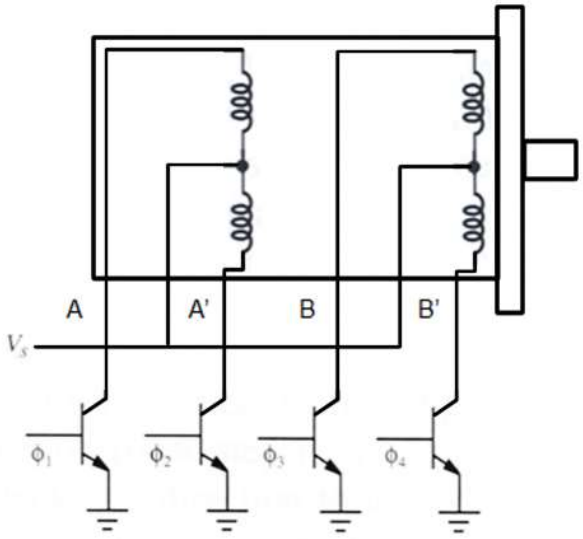
Unipolar stepper motor



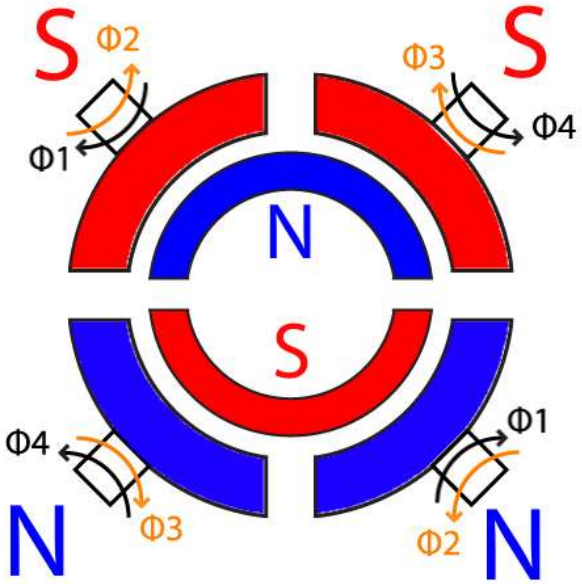
Step 1

STEPPING SEQUENCE (2 PHASE FULL STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
2		ON	ON	
3				
4				



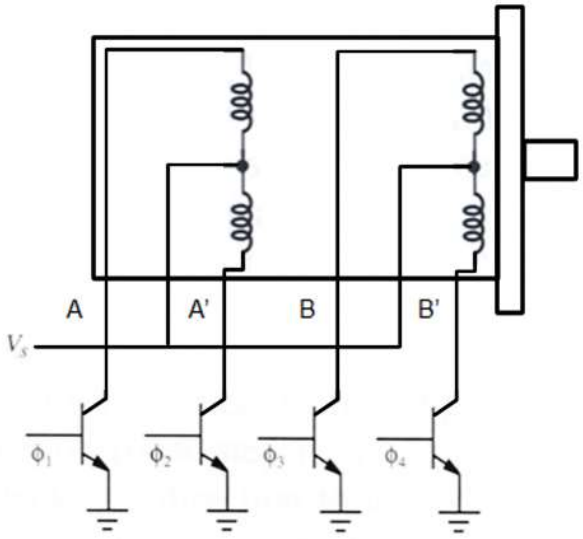
Unipolar stepper motor



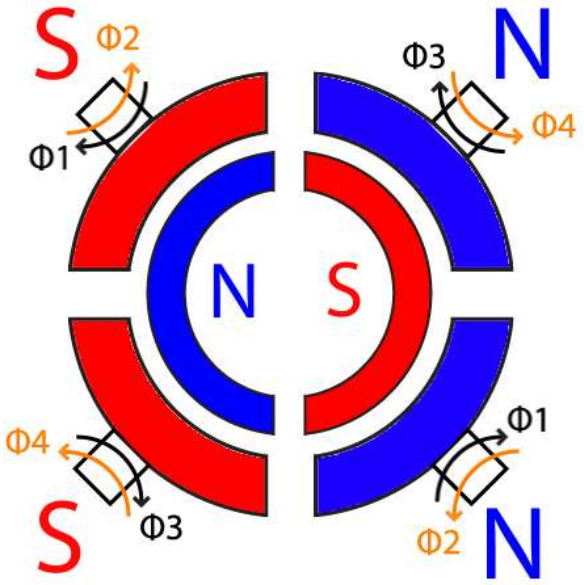
Step 2

STEPPING SEQUENCE (2 PHASE FULL STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
2				
3			ON	ON
4				



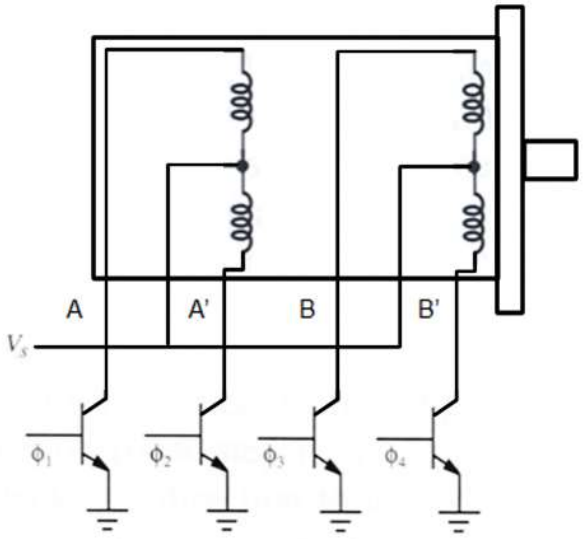
Unipolar stepper motor



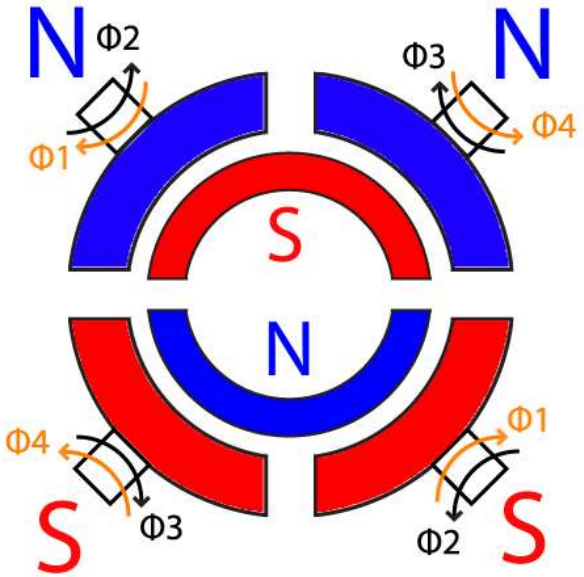
Step 3

STEPPING SEQUENCE (2 PHASE FULL STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
2				
3				
4	ON			ON



Unipolar stepper motor

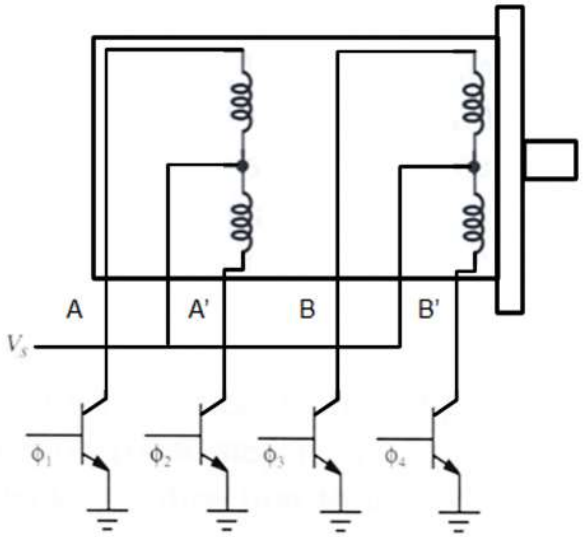


Step 4

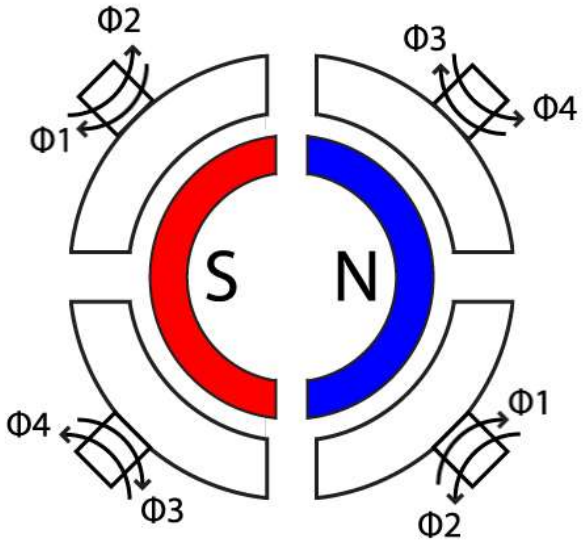
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
1.5				
2				
2.5				
3				
3.5				
4				
4.5				

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor

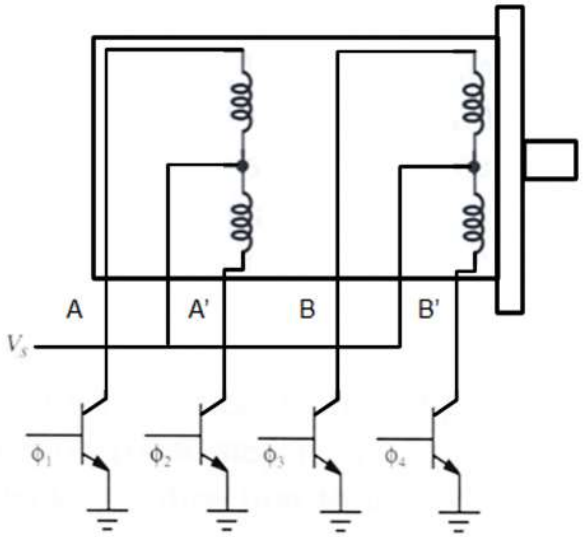


Step 0

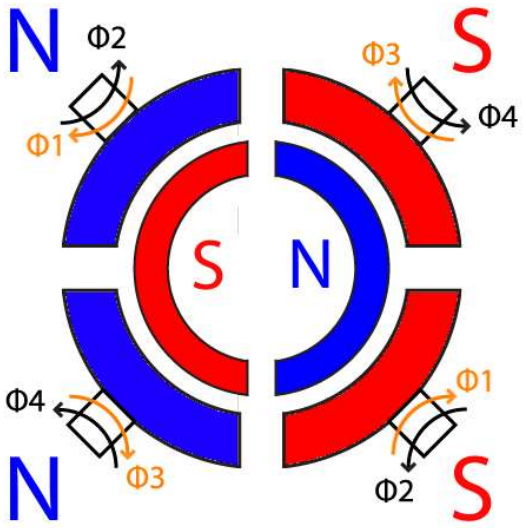
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1	ON	ON		
1.5				
2				
2.5				
3				
3.5				
4				
4.5				

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor

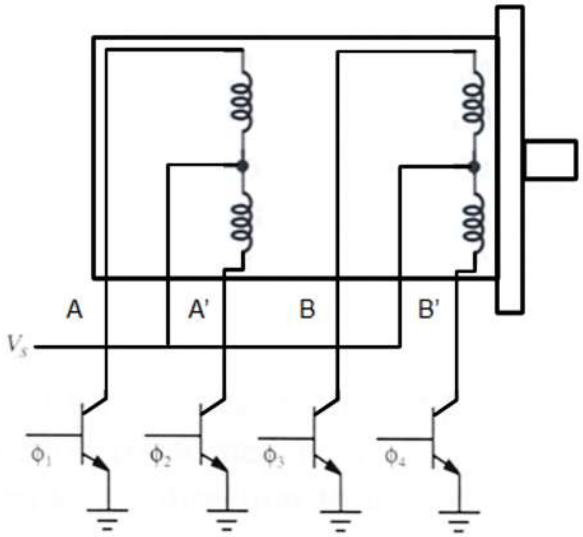


Step 1

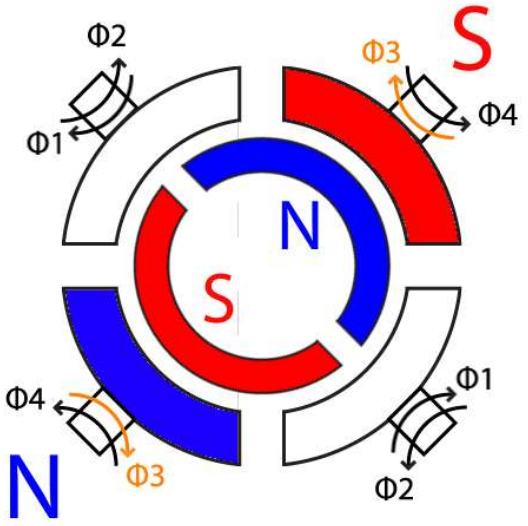
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
1.5		ON		
2				
2.5				
3				
3.5				
4				
4.5				

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor

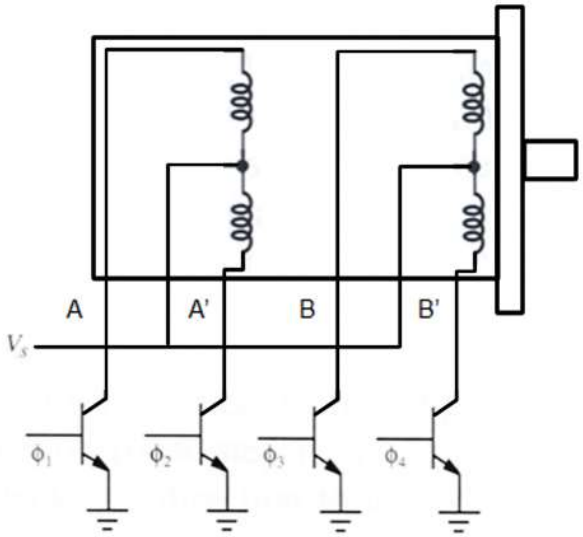


Step 1.5

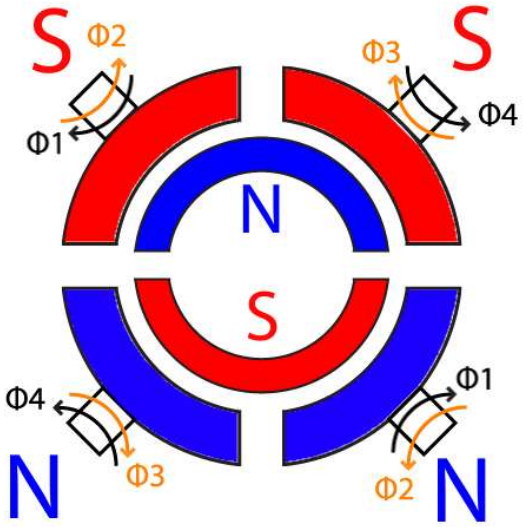
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
1.5				
2		ON	ON	
2.5				
3				
3.5				
4				
4.5				

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor

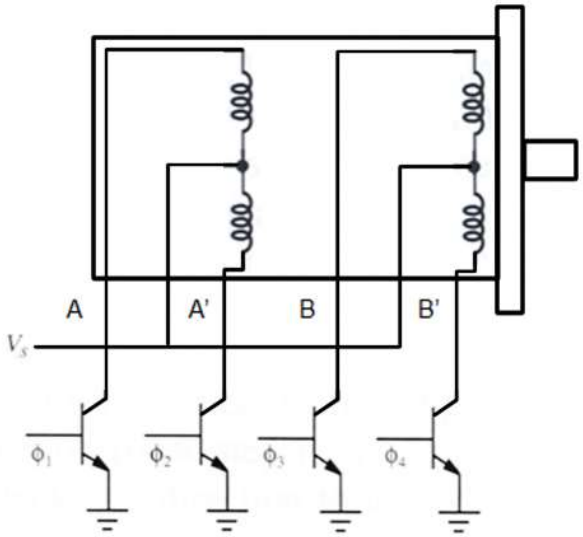


Step 2

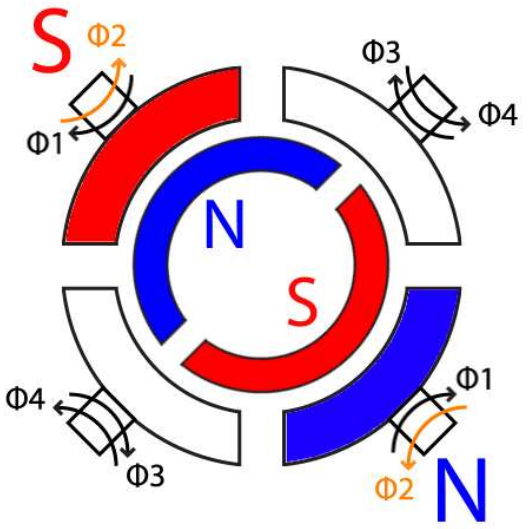
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
1.5				
2				
2.5			ON	
3				
3.5				
4				
4.5				

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor

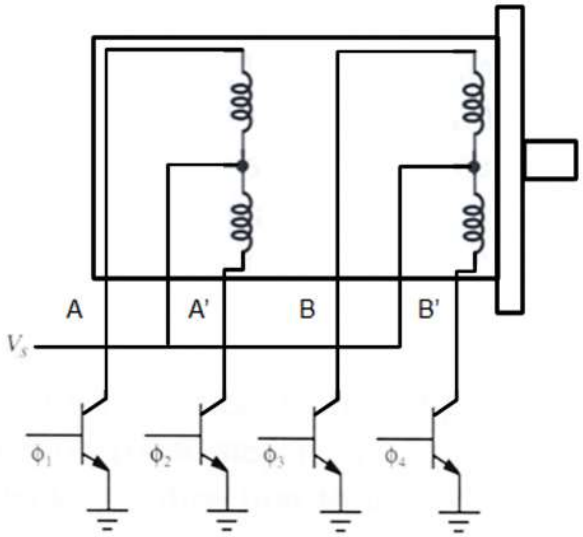


Step 2.5

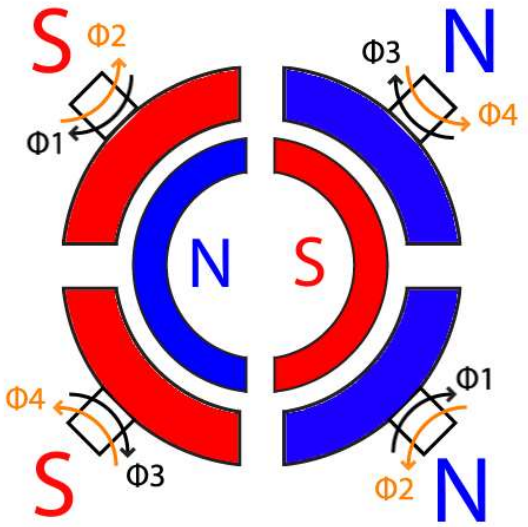
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
1.5				
2				
2.5				
3			ON	ON
3.5				
4				
4.5				

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor

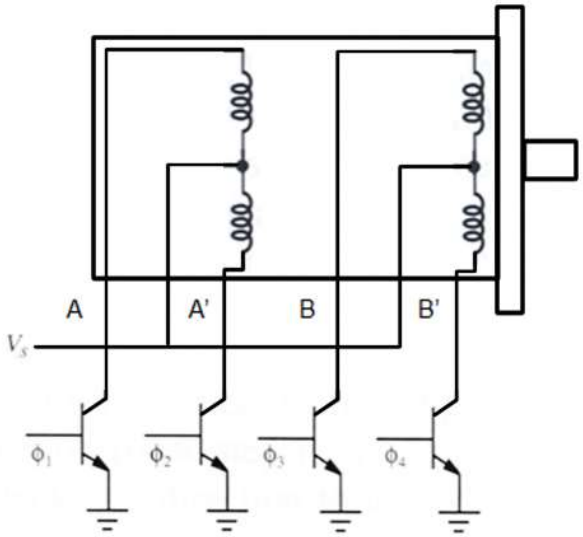


Step 3

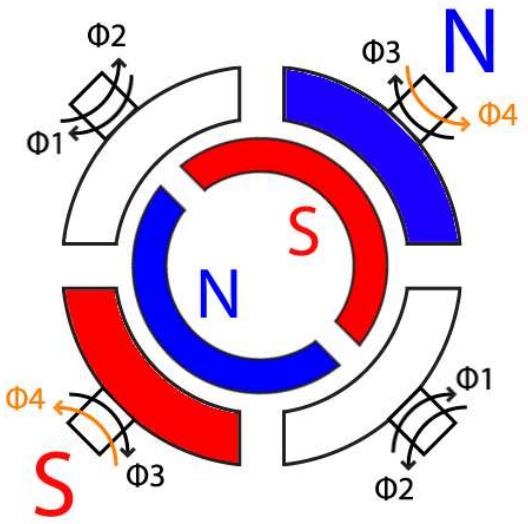
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
1.5				
2				
2.5				
3				
3.5				ON
4				
4.5				

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor

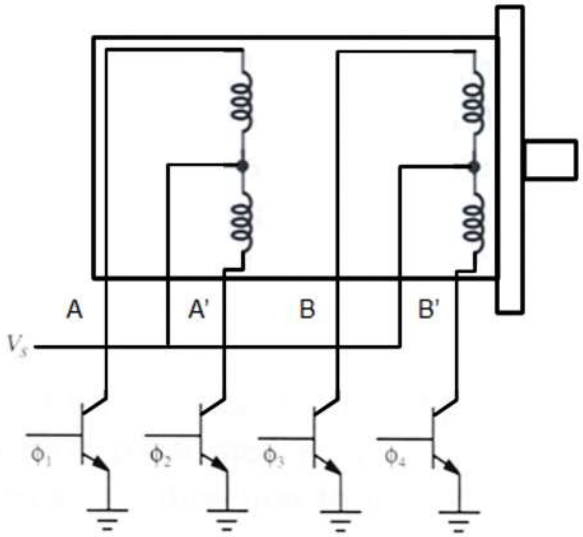


Step 3.5

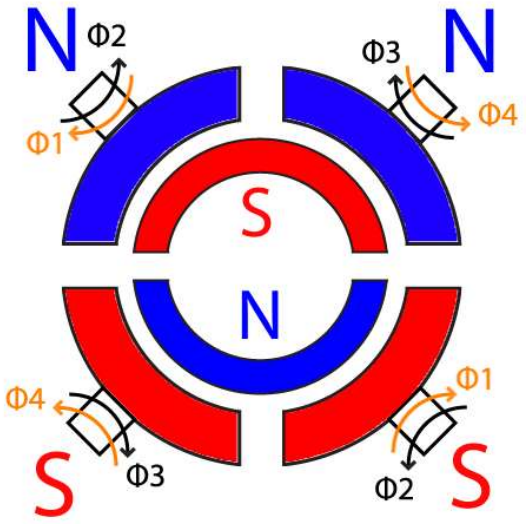
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
1.5				
2				
2.5				
3				
3.5				
4	ON			ON
4.5				

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor

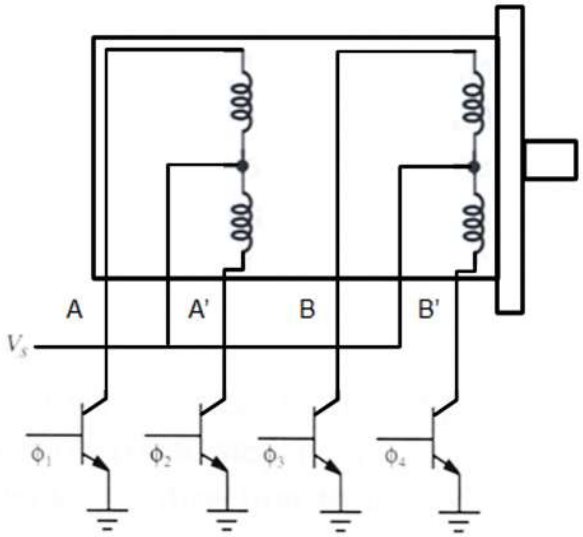


Step 4

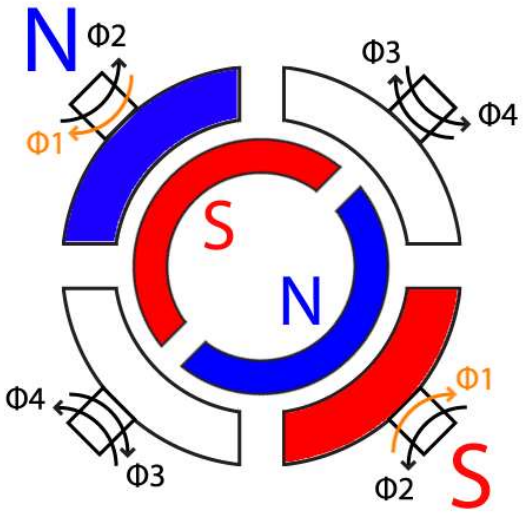
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
1.5				
2				
2.5				
3				
3.5				
4				
4.5	ON			

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor

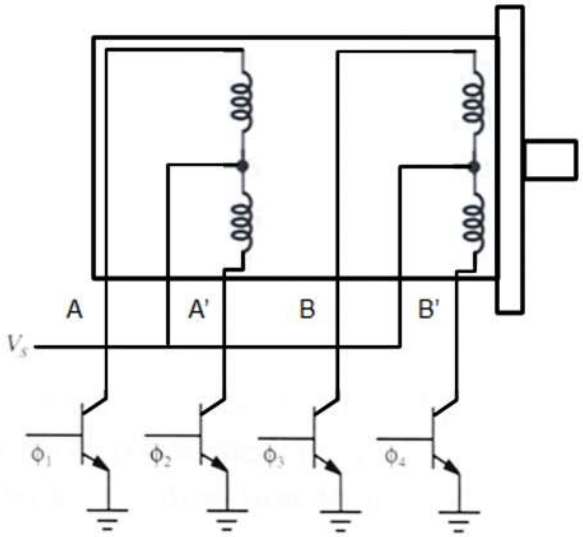


Step 4.5

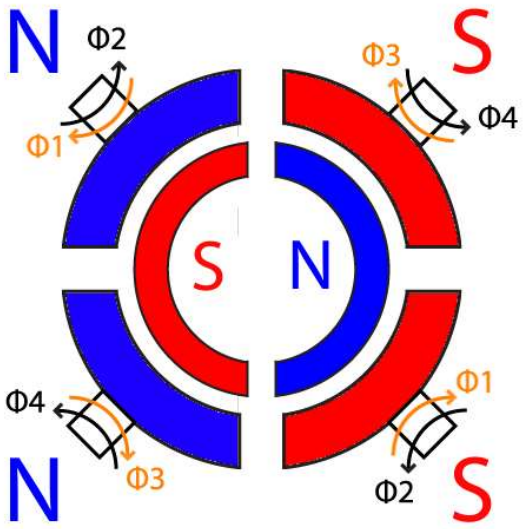
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1	ON	ON		
1.5				
2				
2.5				
3				
3.5				
4				
4.5				

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor

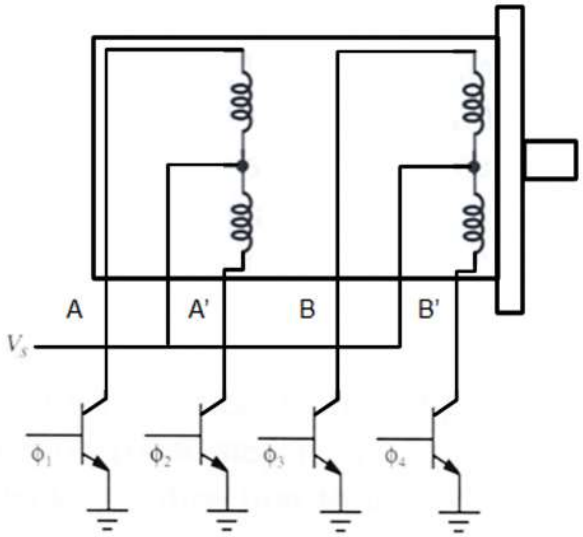


Step 1

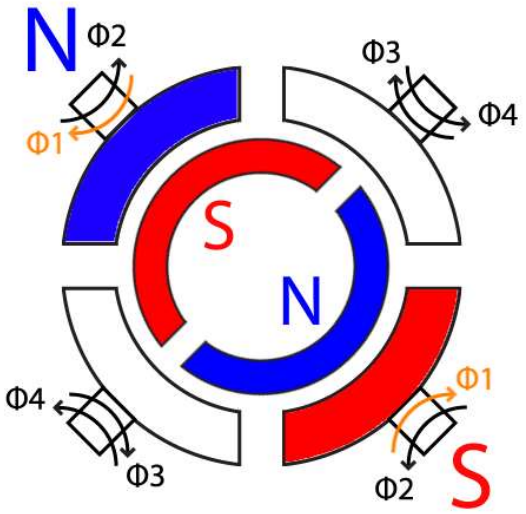
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
1.5				
2				
2.5				
3				
3.5				
4				
4.5	ON			

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor

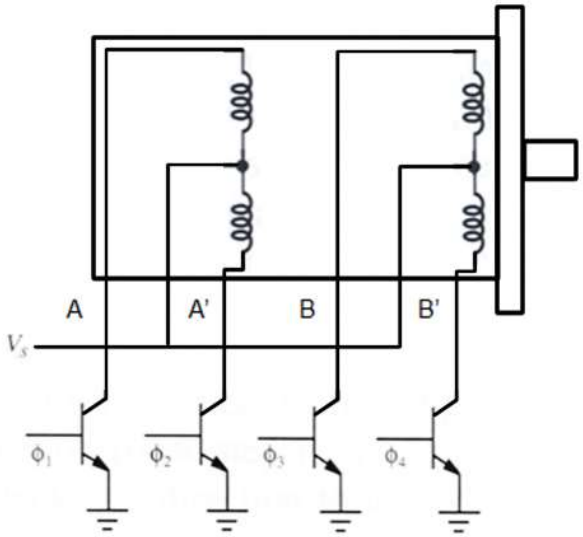


Step 4.5

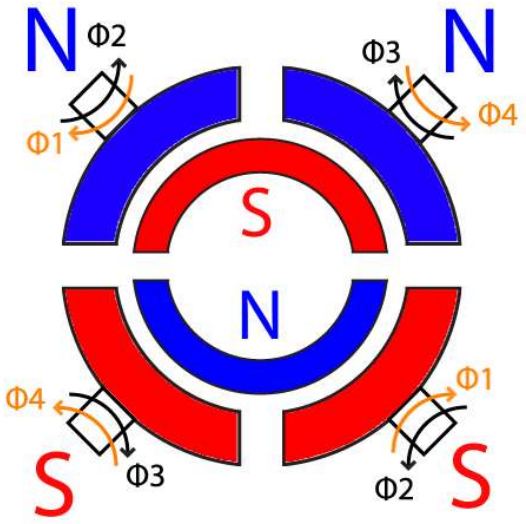
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
1.5				
2				
2.5				
3				
3.5				
4	ON			ON
4.5				

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor

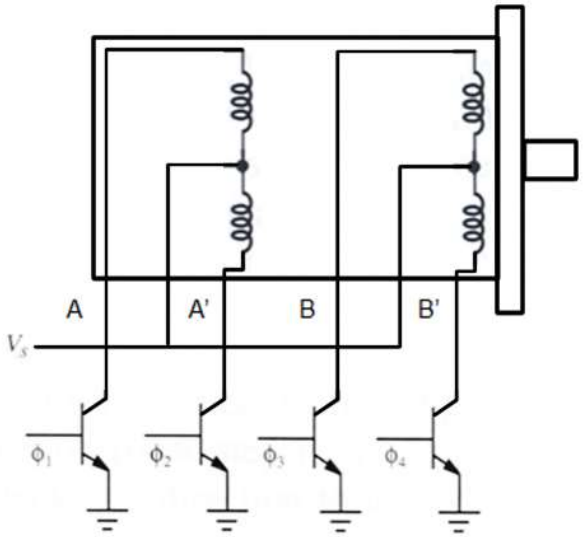


Step 4

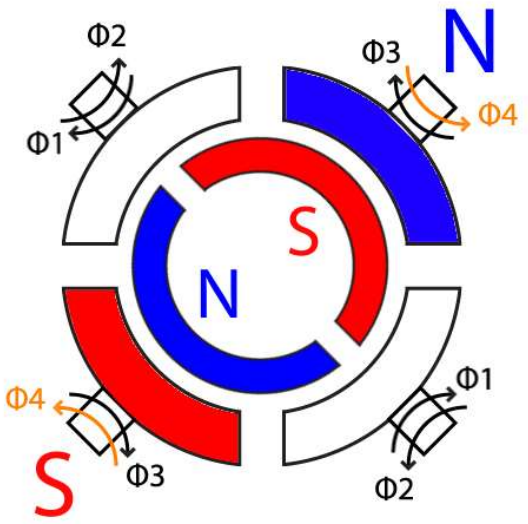
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
1.5				
2				
2.5				
3				
3.5				ON
4				
4.5				

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor

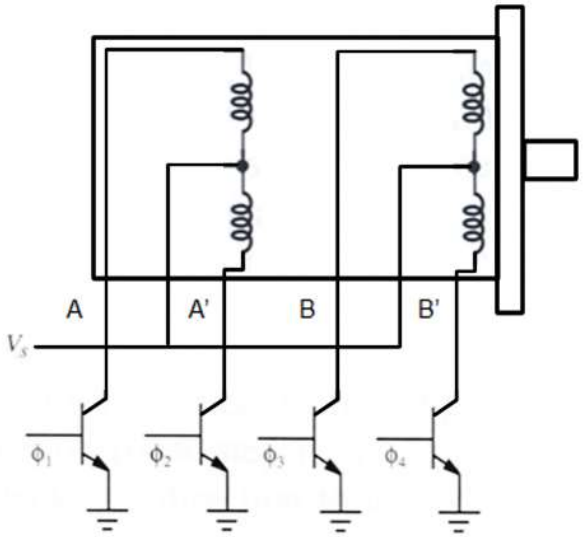


Step 3.5

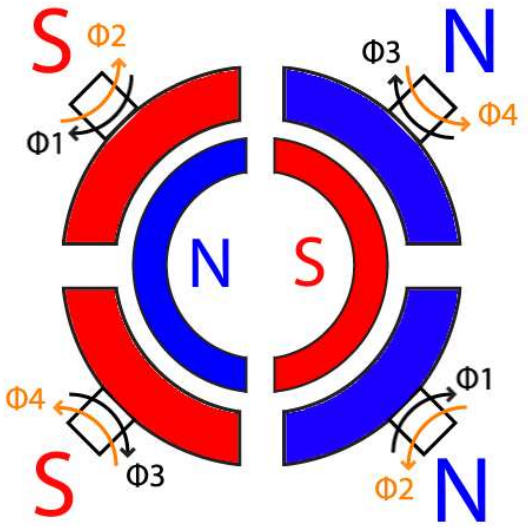
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
1.5				
2				
2.5				
3			ON	ON
3.5				
4				
4.5				

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor

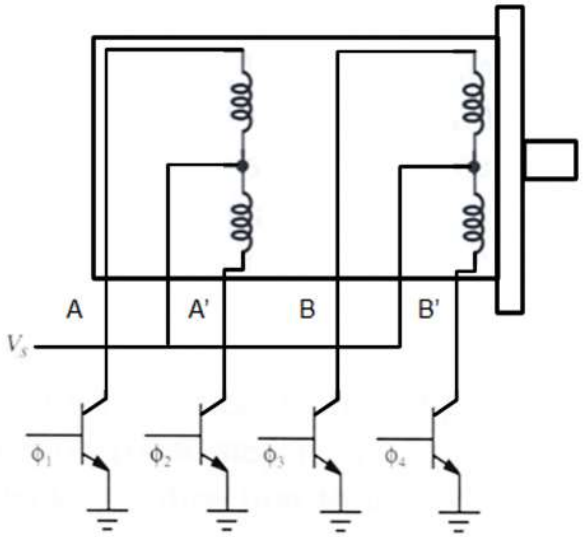


Step 3

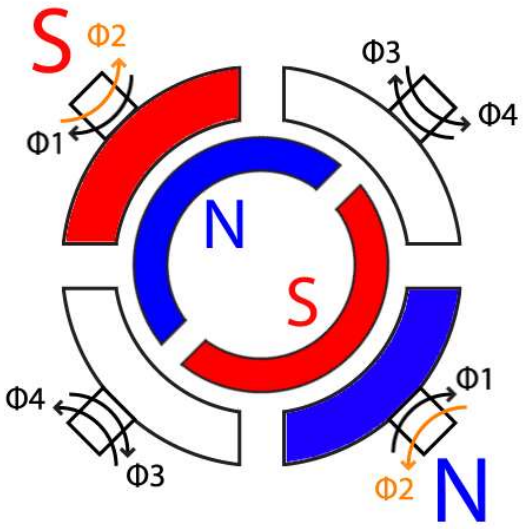
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
1.5				
2				
2.5			ON	
3				
3.5				
4				
4.5				

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor

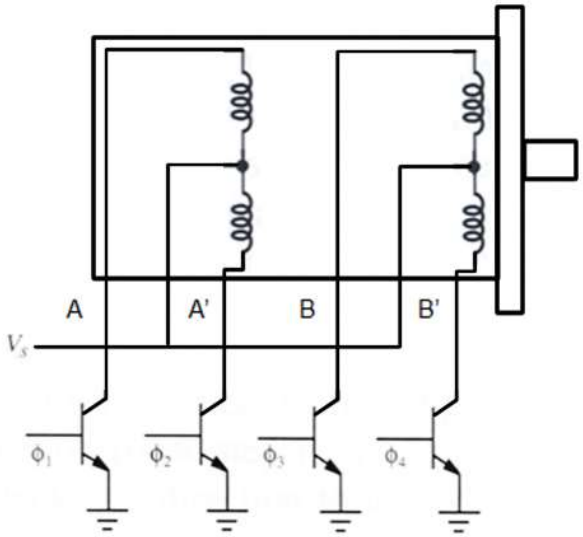


Step 2.5

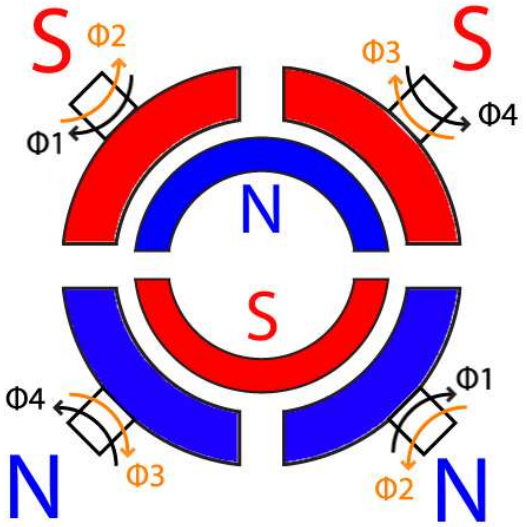
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
1.5				
2		ON	ON	
2.5				
3				
3.5				
4				
4.5				

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor

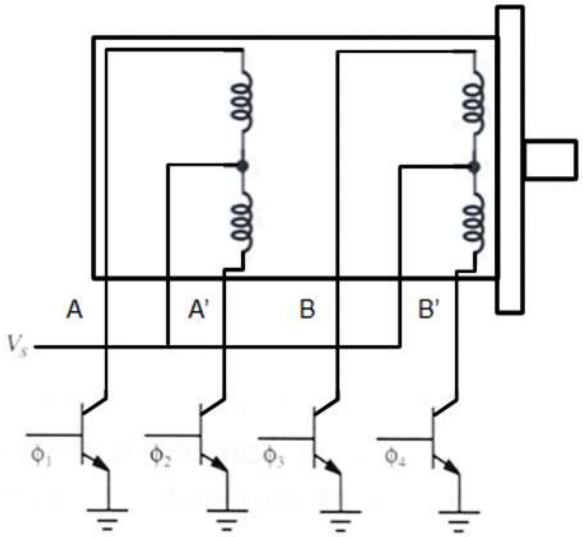


Step 2

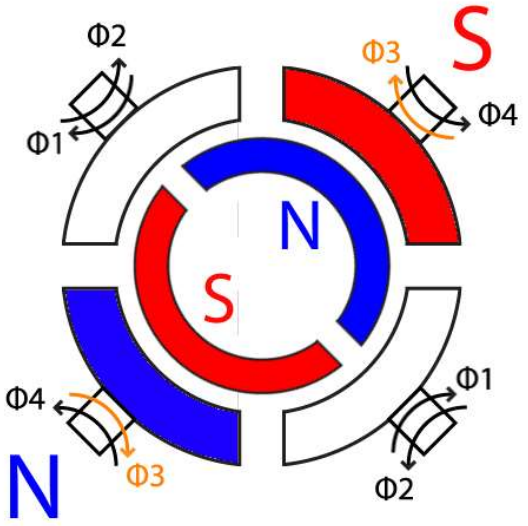
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1				
1.5		ON		
2				
2.5				
3				
3.5				
4				
4.5				

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor

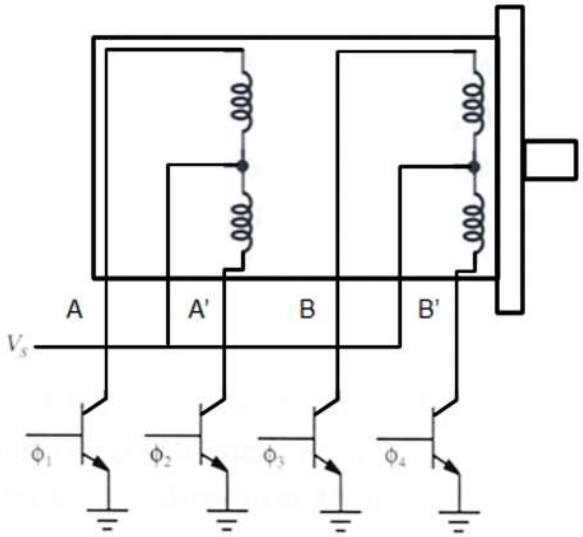


Step 1.5

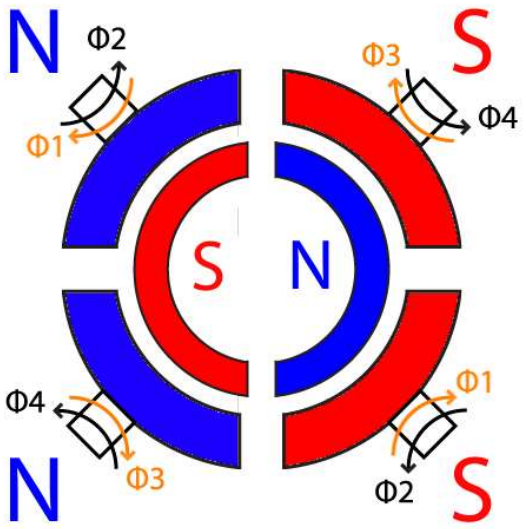
STEPPING SEQUENCE (2 PHASE HALF STEP)

Step	A (ϕ_1)	B (ϕ_3)	A' (ϕ_2)	B' (ϕ_4)
1	ON	ON		
1.5				
2				
2.5				
3				
3.5				
4				
4.5				

CCW: 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 1…
CW: 1, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, 1…



Unipolar stepper motor



Step 1

SUMMARY

DIRECT CURRENT MOTOR

- Construction
  - Brushed vs Brushless
- Control
  - Pulse Width Modulation (PWM)
  - Inductive Kickback & Diode protection

SERVO MOTOR

- Working principle
- Control: Mark length

SUMMARY

SOLENOID

- Construction & Control

STEPPER MOTOR

- Construction & Working Principle
- Control
  - Wave Drive / Single Phase
  - Two Phase Full Step
  - Two Phase Half Step
  - Microstepping