MASSEY UNIVERSITY

278.478: Mechatronics

Lecture 3 – Stepper Motors

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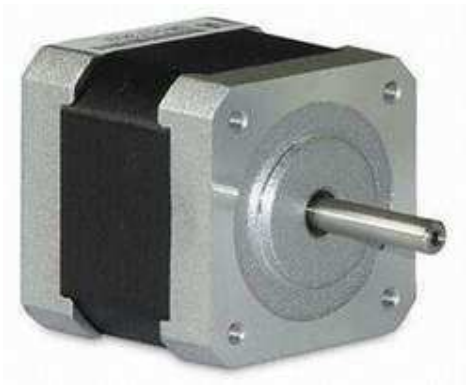
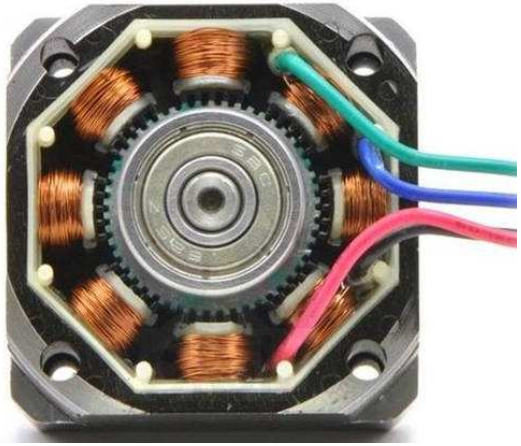
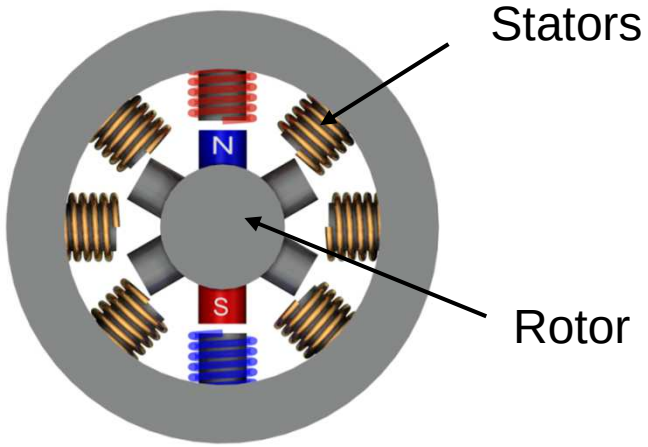
Contents

Stepper motor (*Cleverness with magnets and coils*)

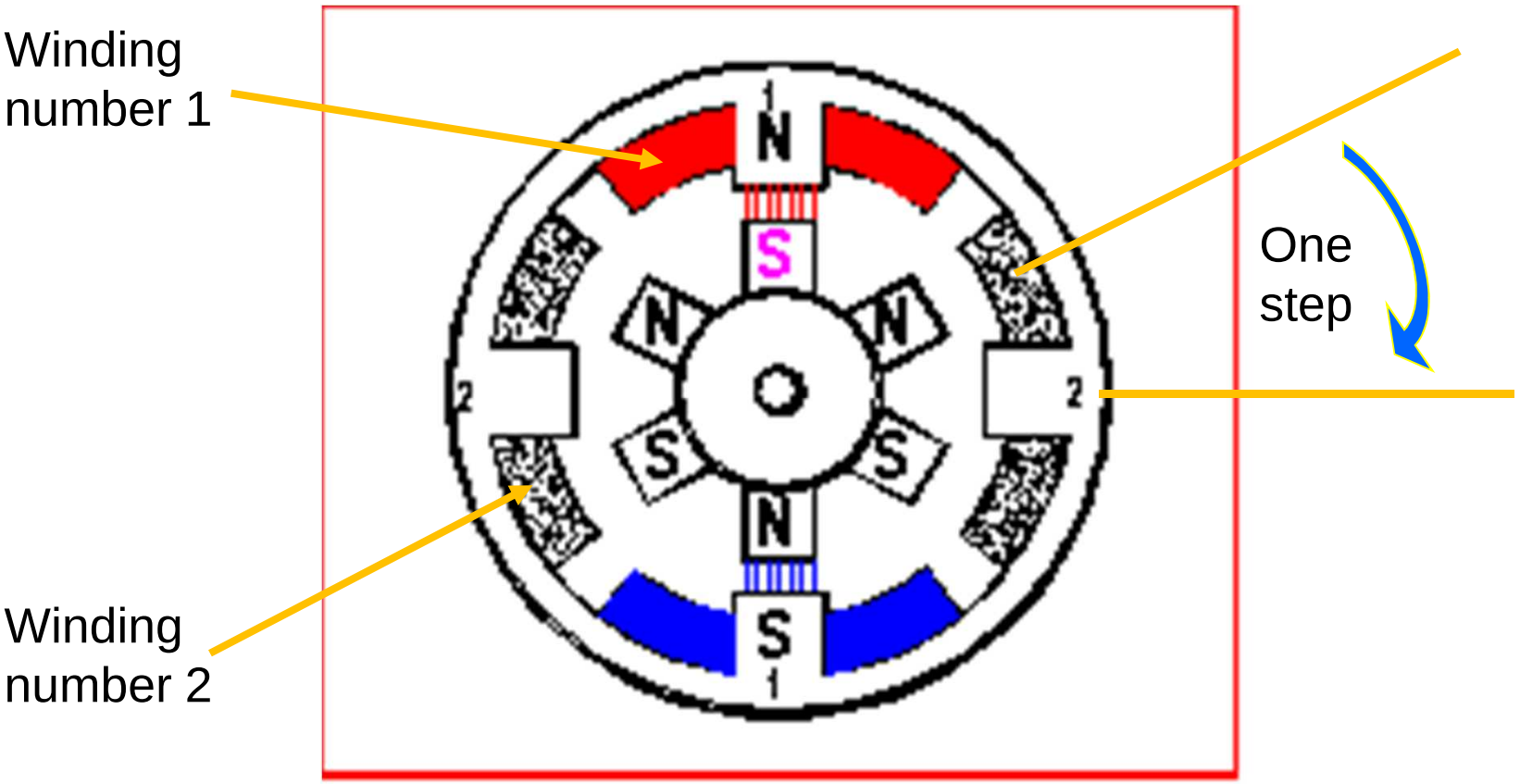
- Stepping motors convert switched excitation changes to precise increments of rotation
- This property allows stepping motors to be used in positioning systems without the need for feedback
- Rotor positioning is achieved by magnetic alignment of rotor and stator poles





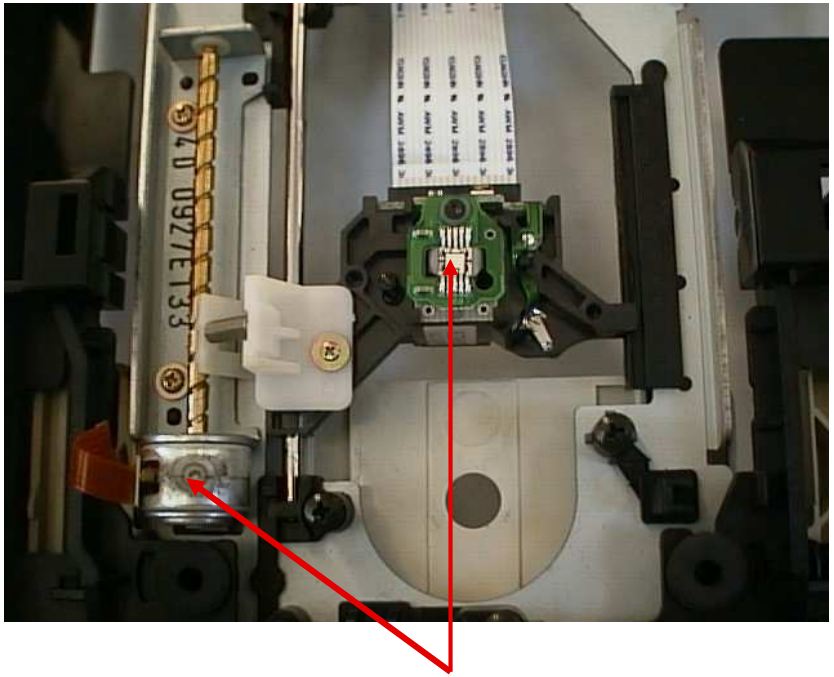


Stepper motor (*Six pole rotor, two electromagnets*)

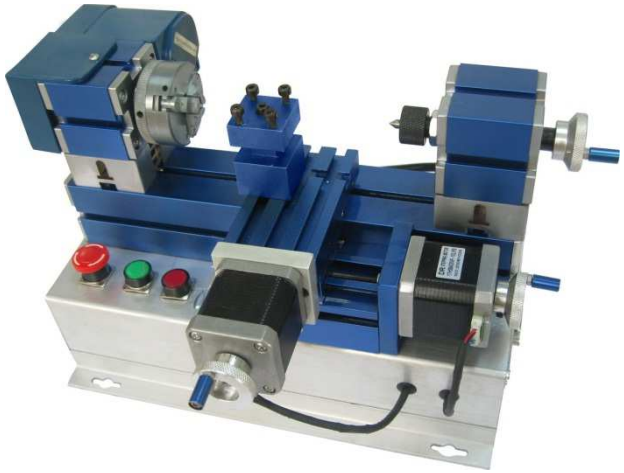


How many steps are required for one complete revolution?

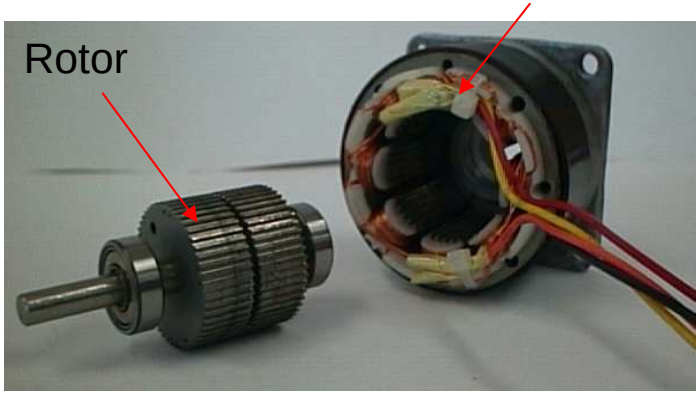
Stepper motor applications



Stepping Motor to move read-write head



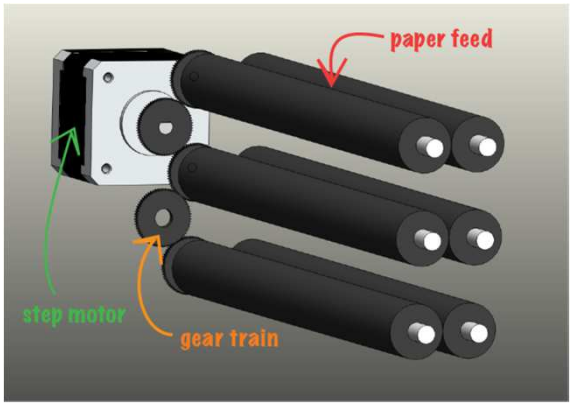
CNC lathes

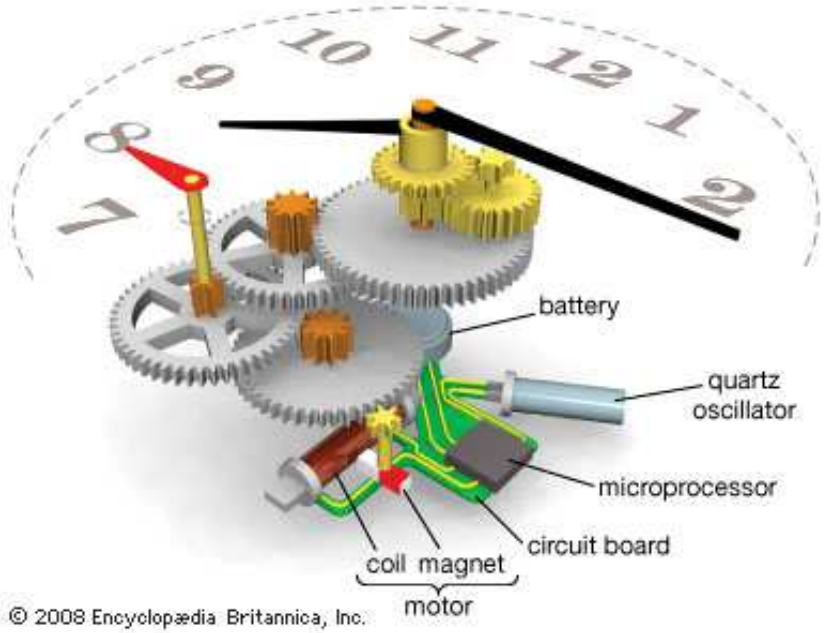


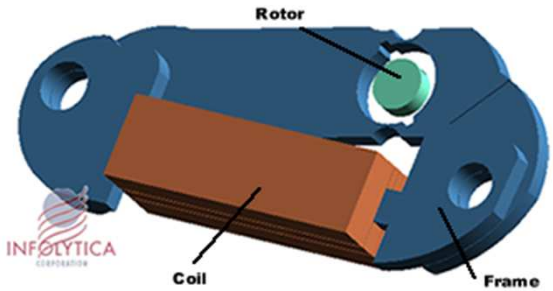
CNC Stepping Motor

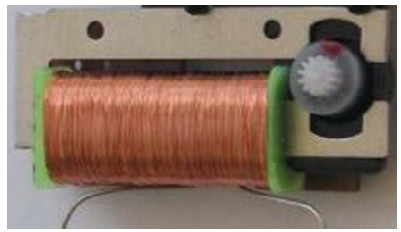
Stepper motor applications

Paper feeder on printers







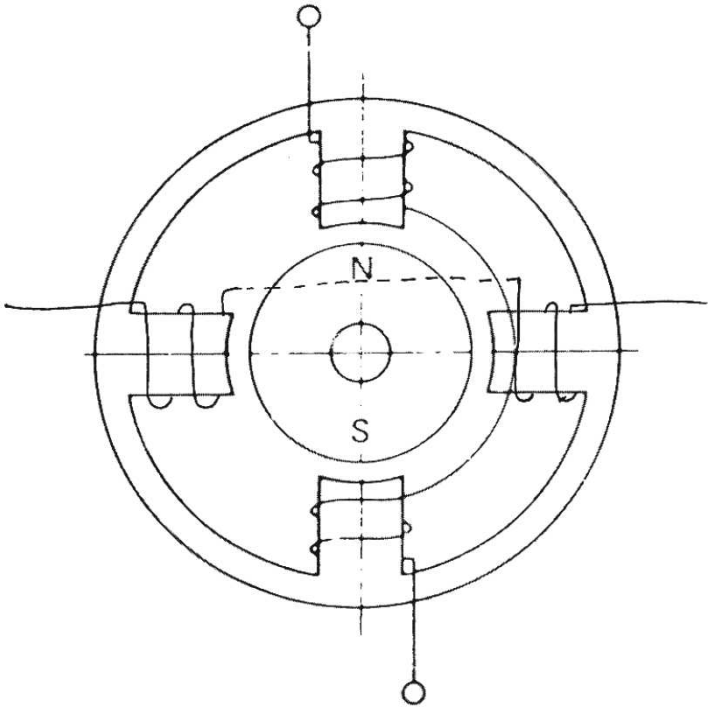


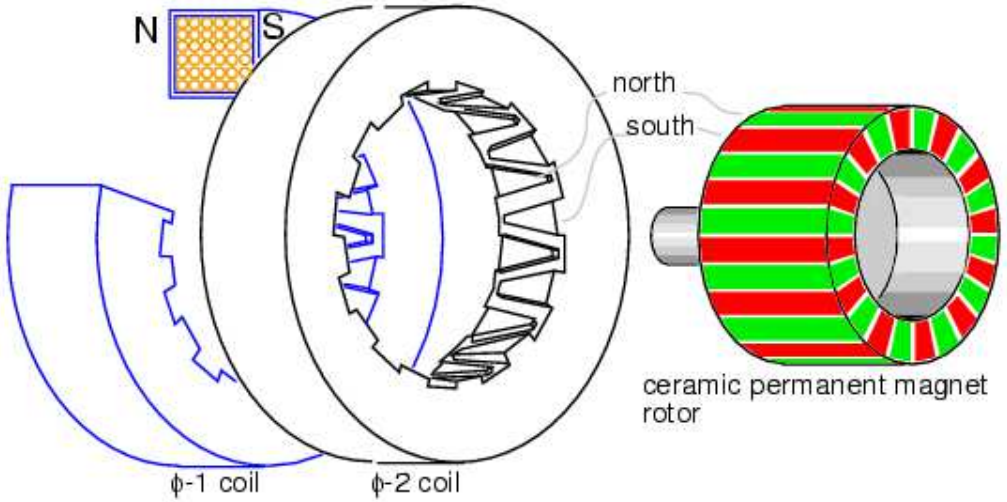
Lavet stepper motor used in clocks

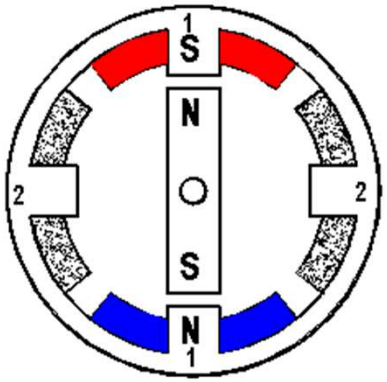
Types of stepper motors

- Permanent magnet stepper motor
- Variable reluctance stepper motor
- Hybrid stepper motor
- Lavet type stepper motor

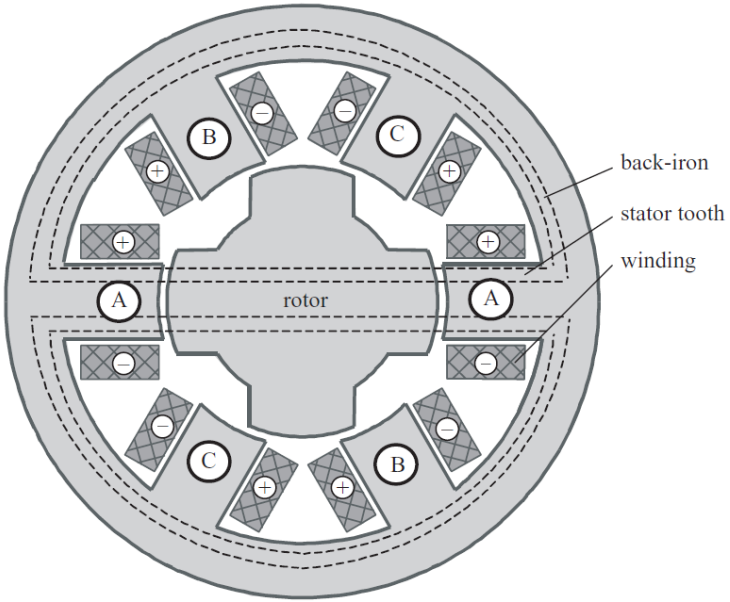
Permanent magnet (PM) stepper motor

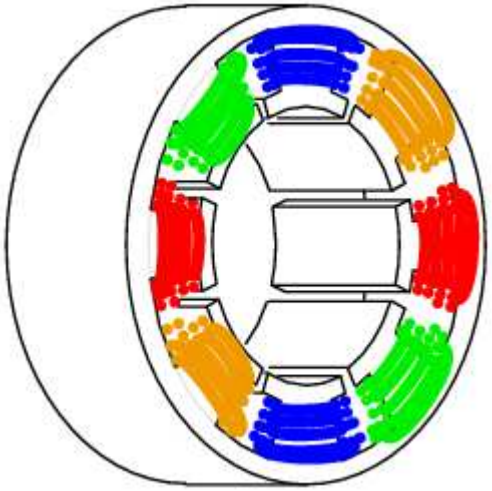




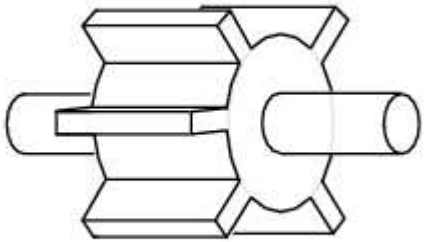


Variable reluctance (VR) stepper motor





Stator

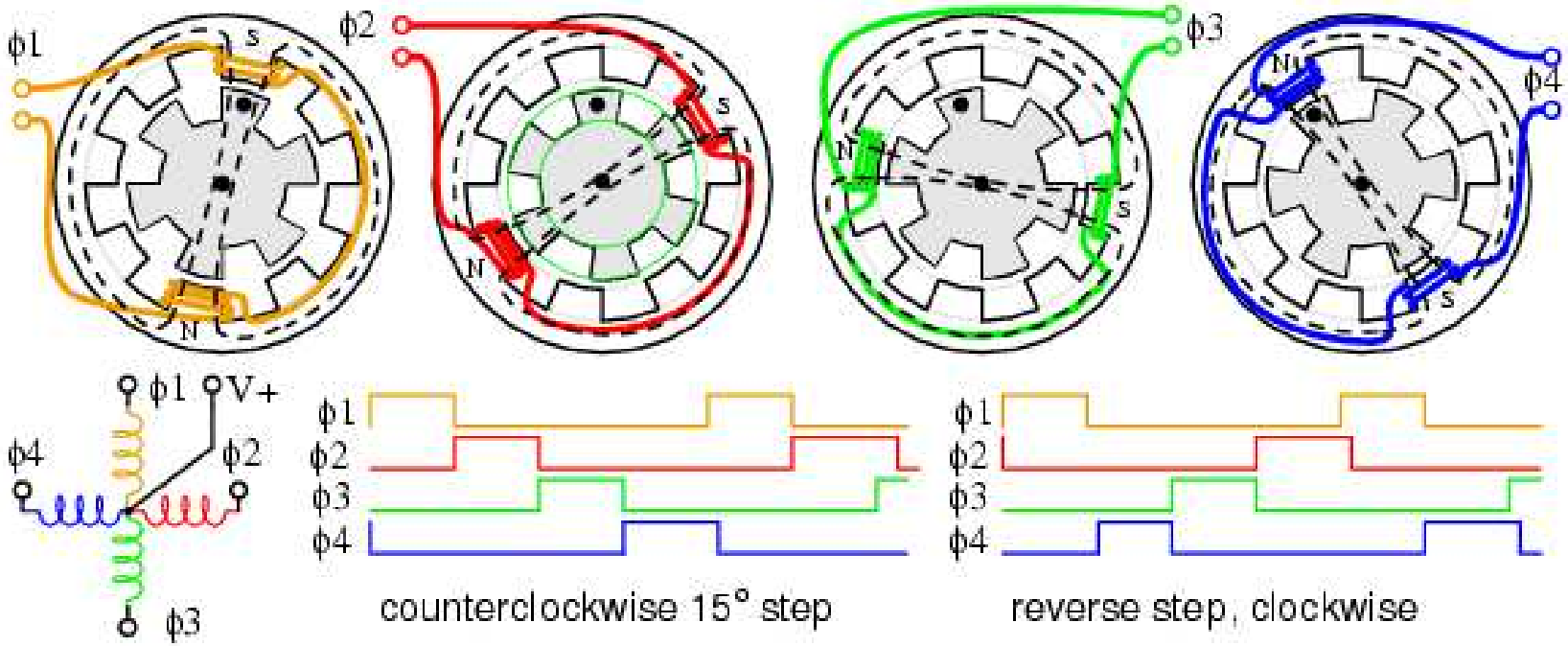


Rotor

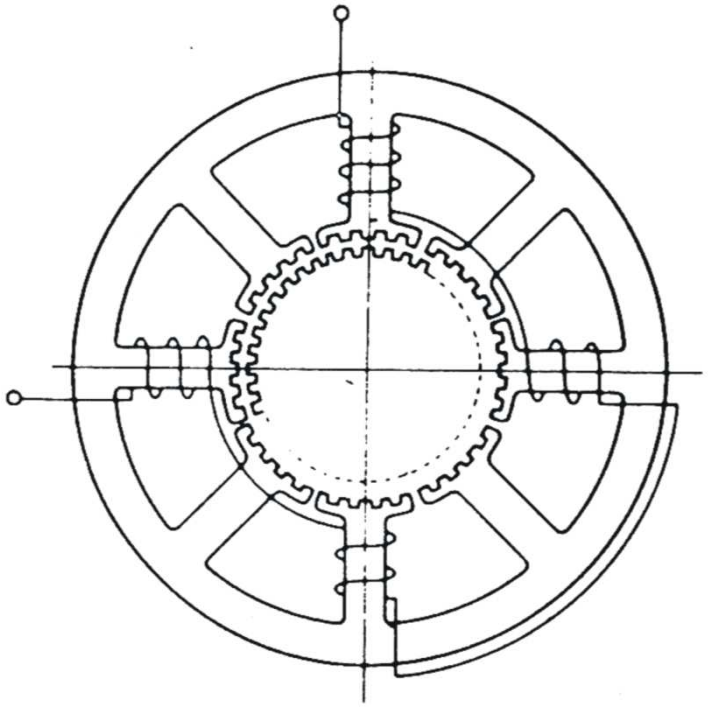
VR stepper motor relies upon magnetic flux seeking the lowest reluctance path through a magnetic circuit.

- The rotor is a soft iron cylinder with salient (protruding) poles.
- This is the least complex, most inexpensive stepper motor.
- The only type of stepper with no detent torque in hand rotation of a de-energized motor shaft.
- Large step angle

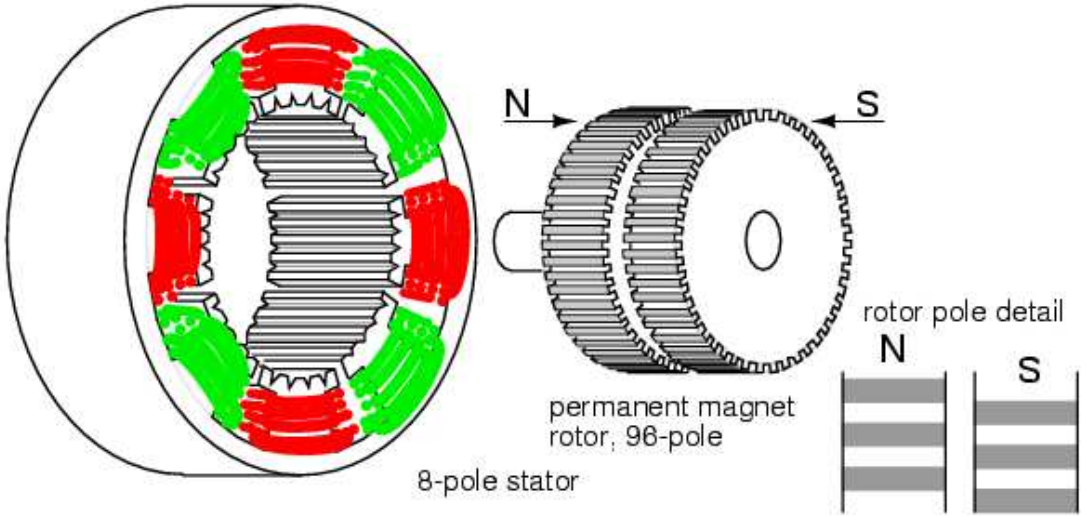
VR stepper motor – stepping sequence

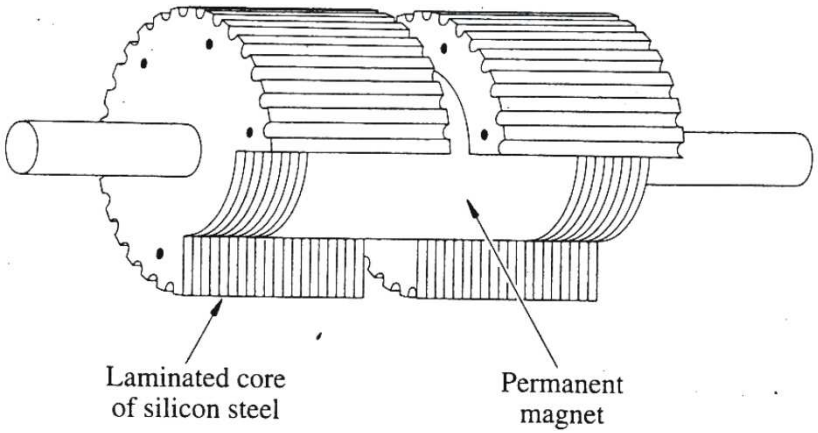


Hybrid stepper motor



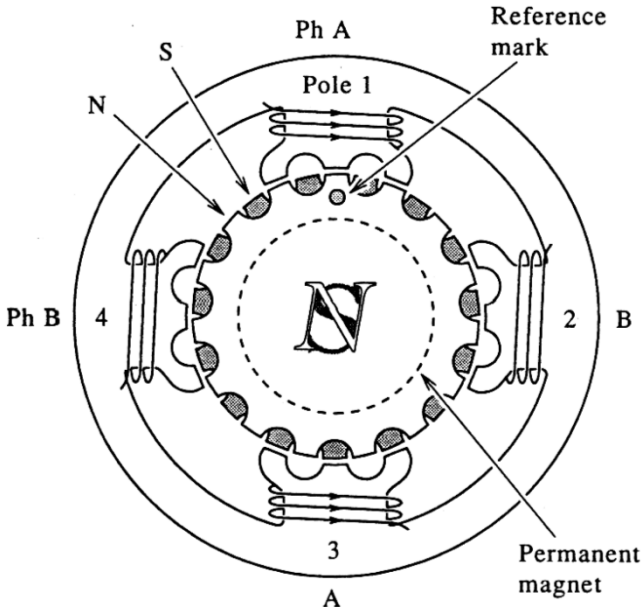
Combines features of both PM and VR stepper motor



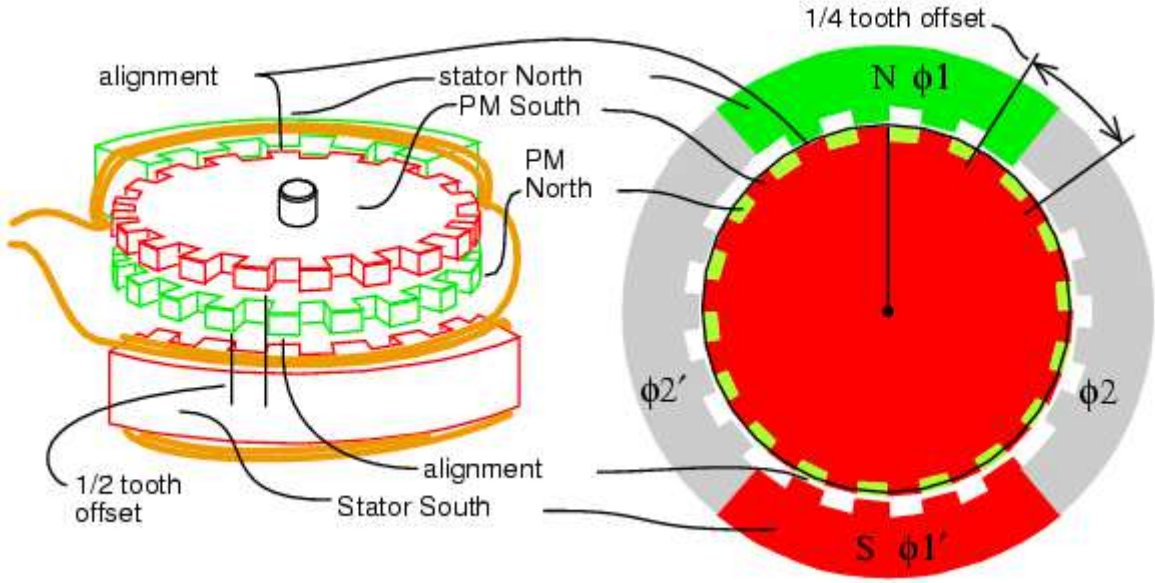


The hybrid motor rotor

Hybrid stepper motor

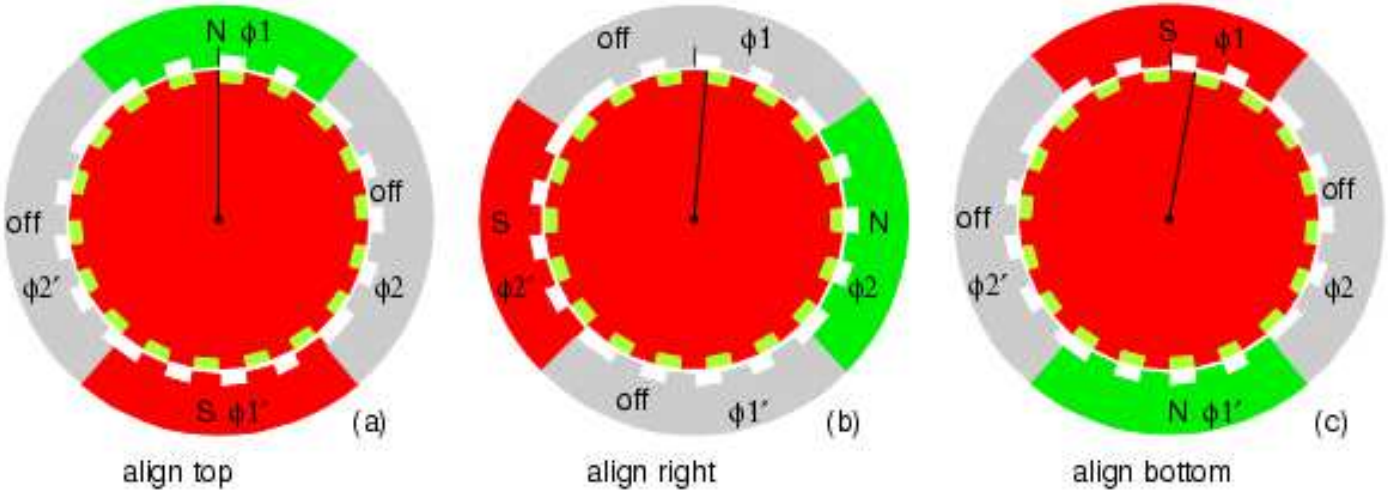


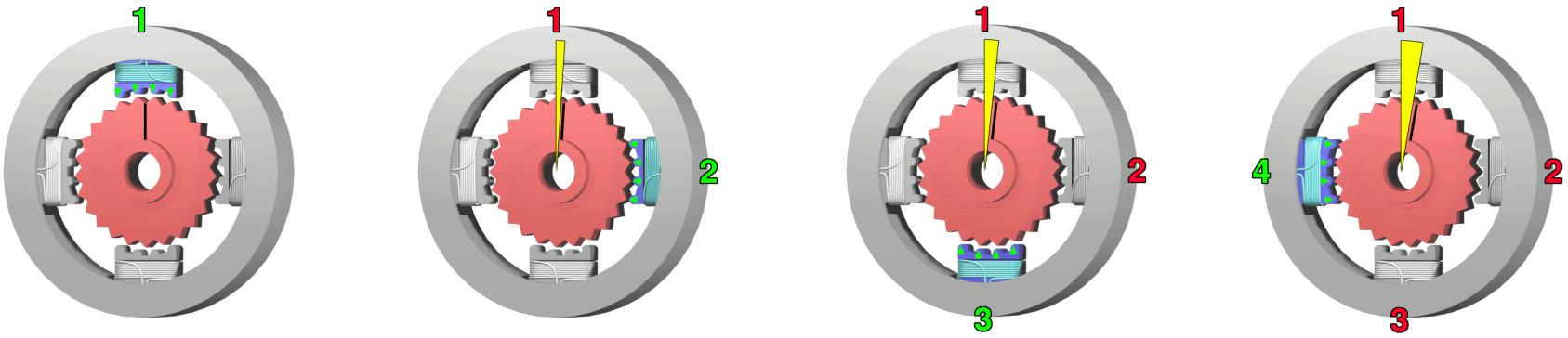
Offset teeth in hybrid rotor



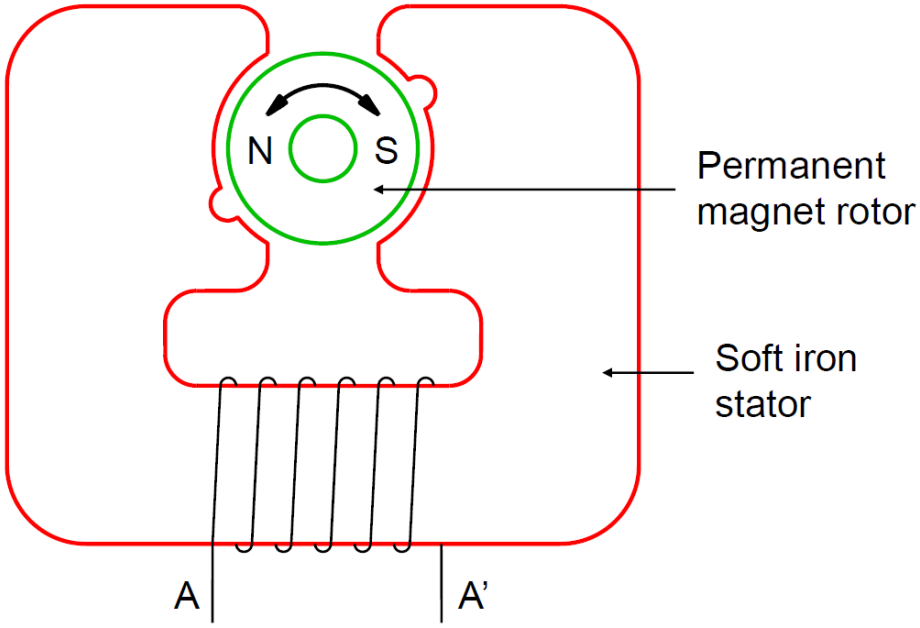
Schematic diagram

Hybrid stepper motor – stepping sequence



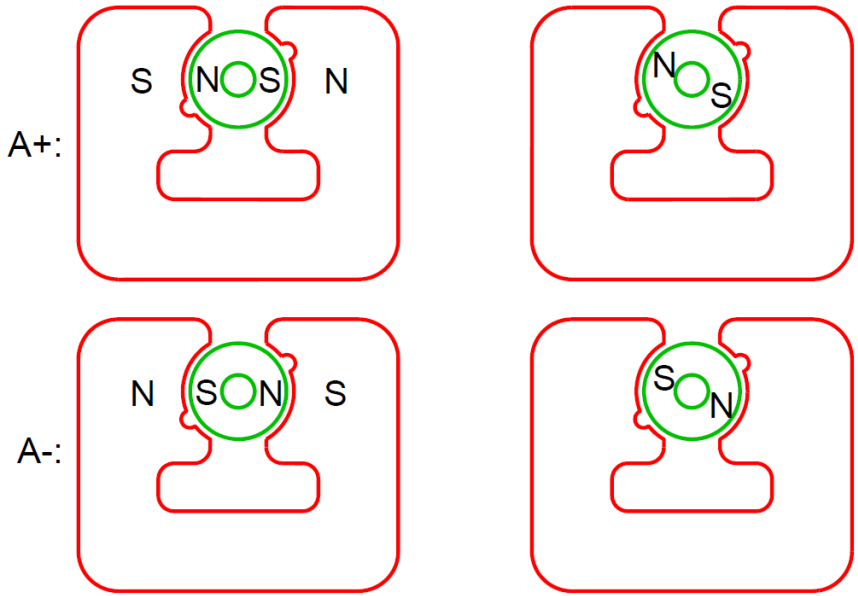


Lavet type stepper motor



Single-phase stepping motor

Stepping sequence

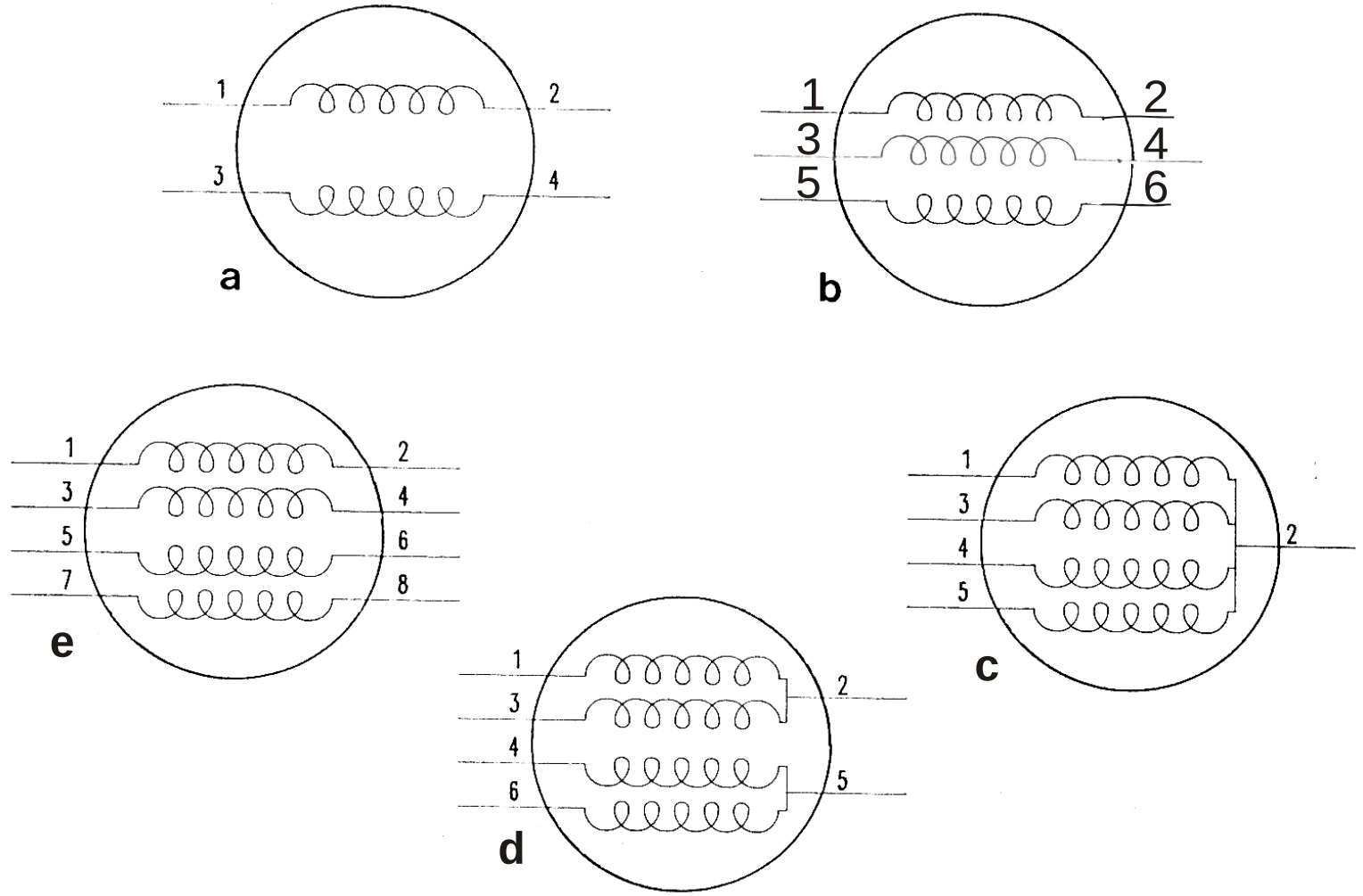


Comparison of motor types

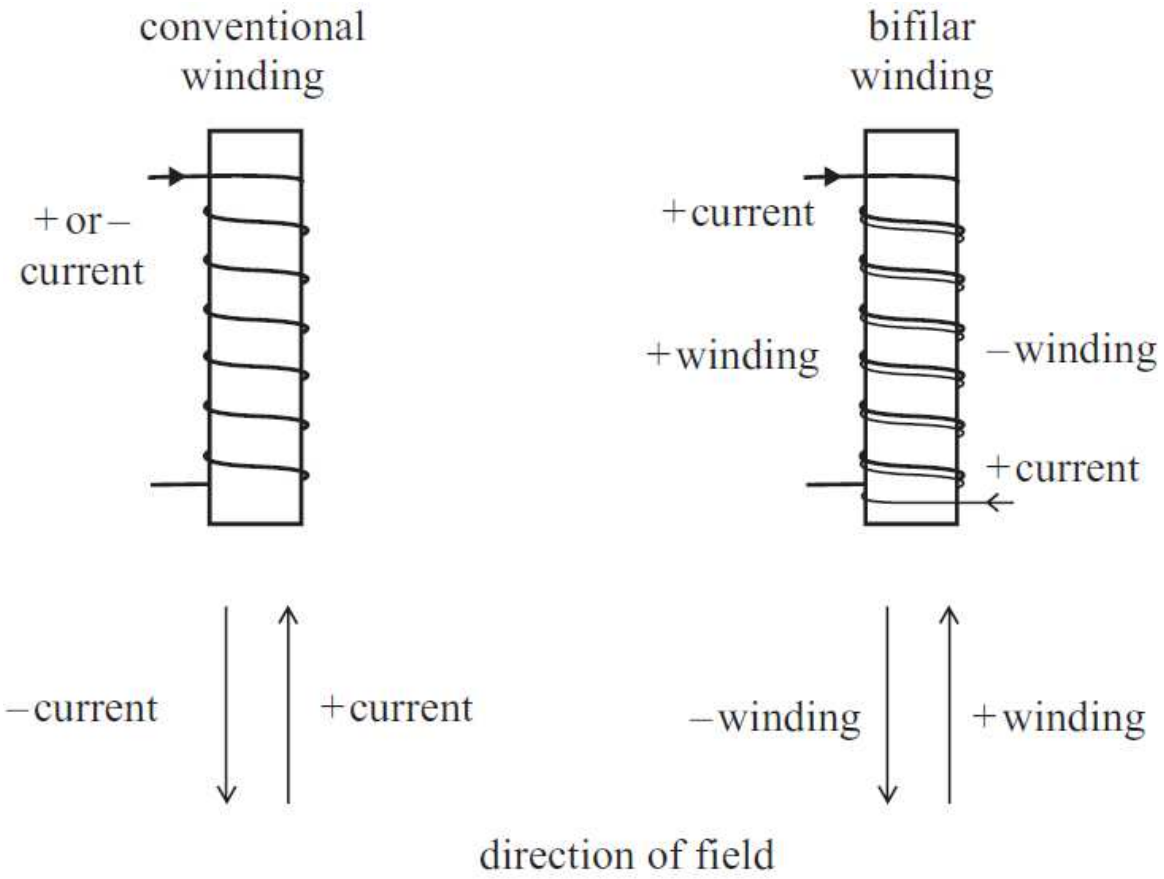
- Permanent-magnet stepping motors are inferior in performance to hybrid motors, and are only used in specialised applications
- Hybrid motors have a smaller step size and a higher torque than a similar VR motor
- Hybrid motors also have a detent torque
- Hybrid motors have 2, rather than 3/4, windings
- VR motors have a lower rotor inertia than hybrid motors

Stepper motor wiring

Winding direction is important



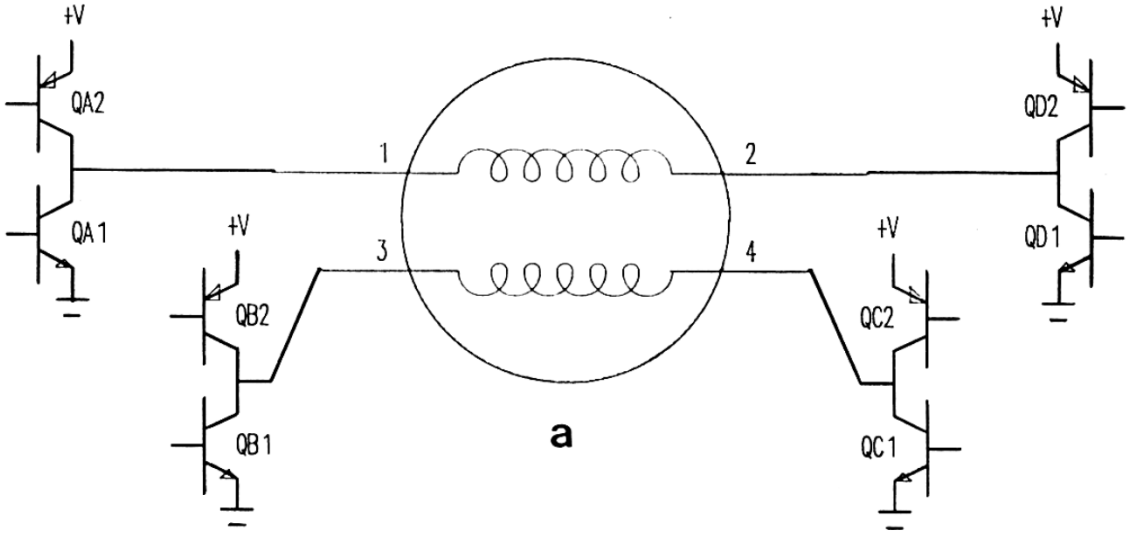
Stepper motor wiring – bifilar windings



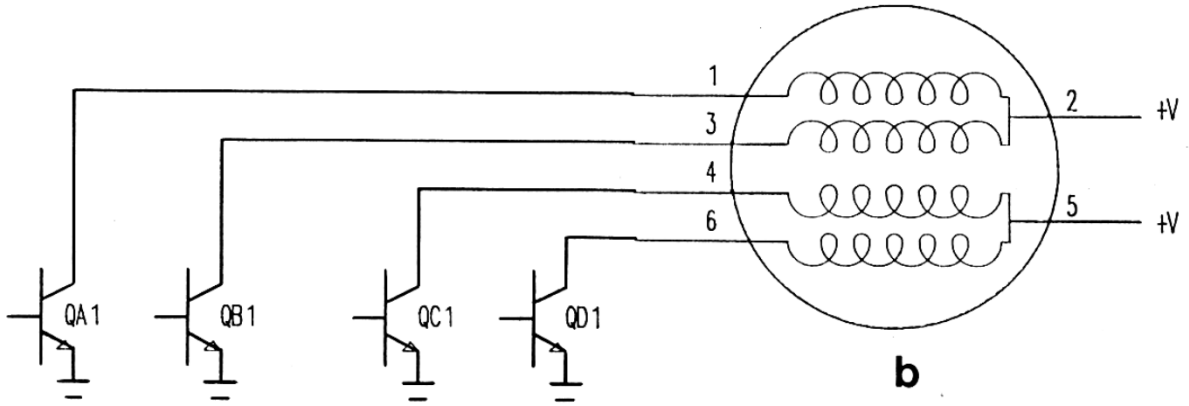
Comparison of conventional and bifilar windings

Driving stepper motors

Bipolar drive



Unipolar drive



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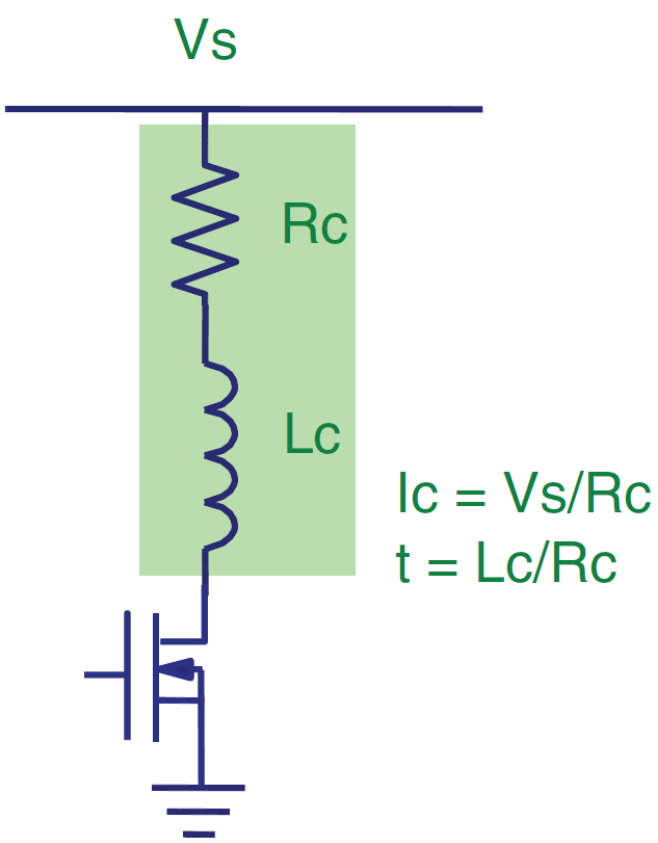
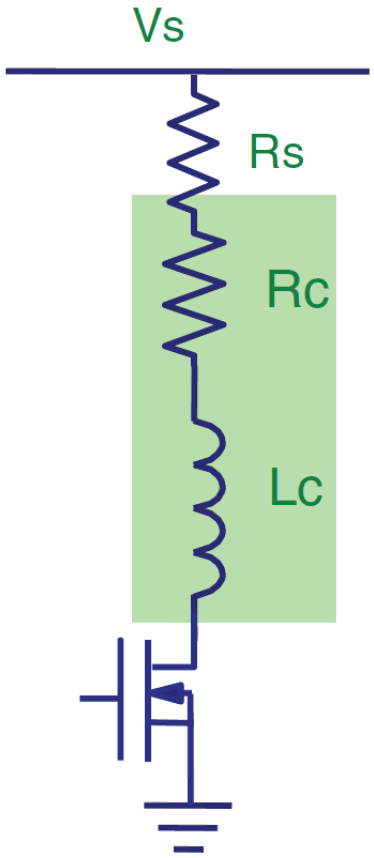
Stepper drive circuits – L/R & L/nR drive

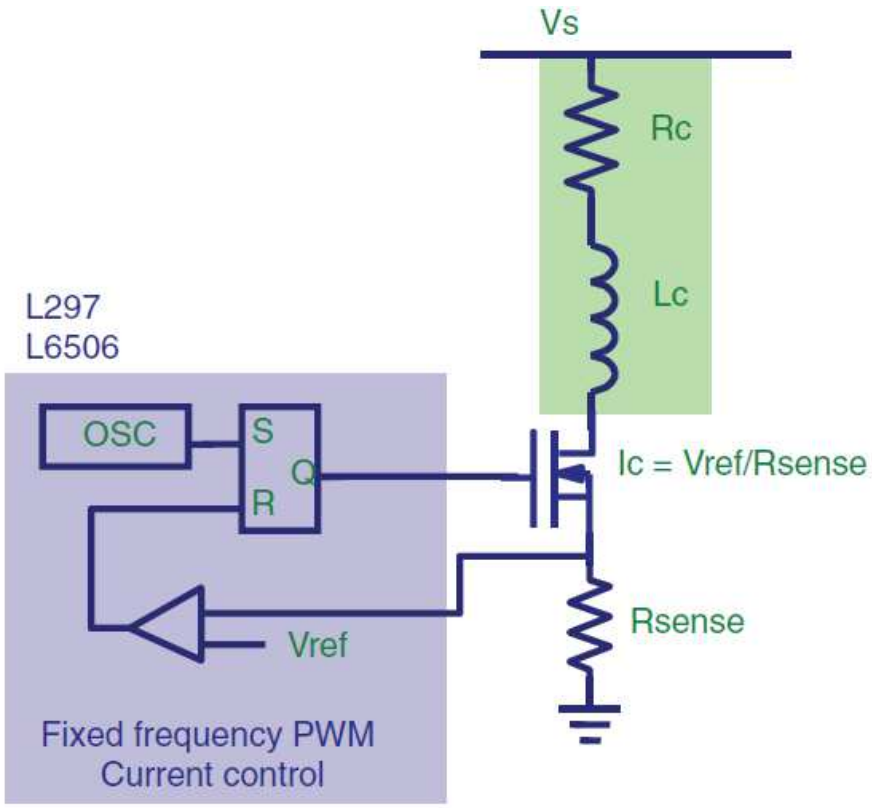


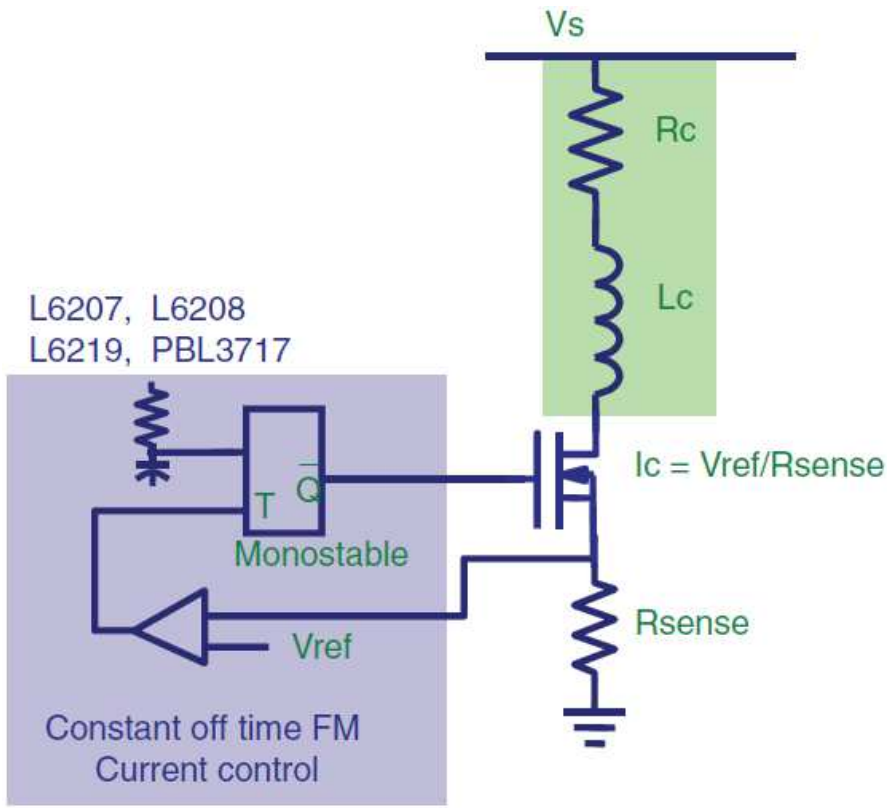
Ic = Vs/Rc
t = Lc/Rc



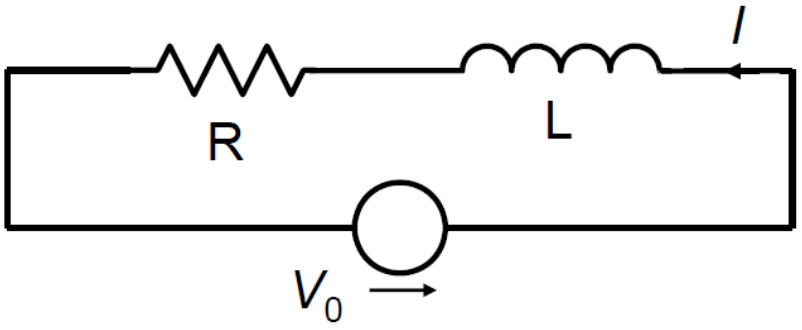
Ic = Vs/(Rc+Rs)
t = L/(Rc+Rs)

Stepper drive circuits – Chopper drive





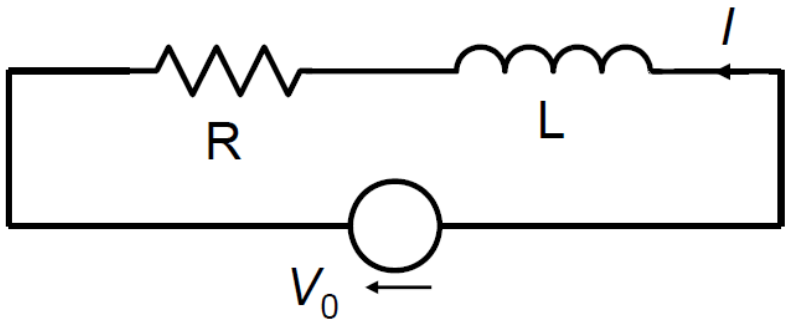
L/R drive - Stator winding excitation and de-excitation



Stator winding excitation

$$R.I + L.\frac{dI}{dt} = V_0$$

$$I = I_0.\left\{1 - \exp\frac{-t}{T_0}\right\} \quad \text{where:} \quad I_0 = \frac{V_0}{R} \quad T_0 = \frac{L}{R}$$



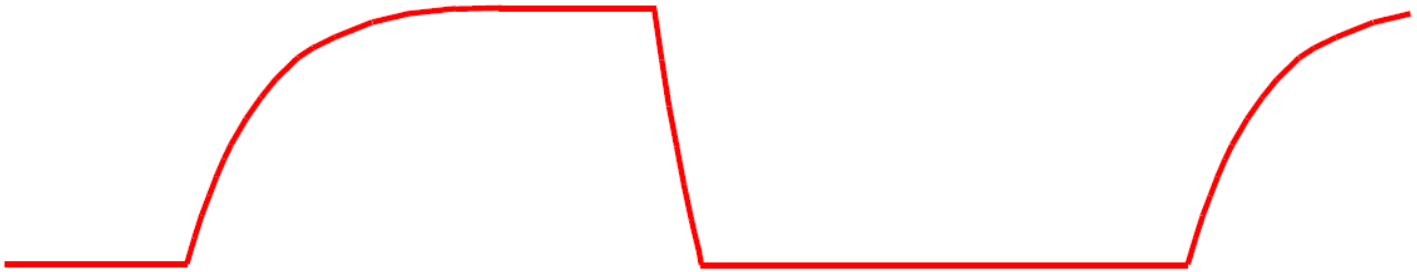
Stator winding de-excitation

$$R.I + L.\frac{dI}{dt} = -V_0$$

$$I = I_0.\left\{2\exp\frac{-t}{T_0} - 1\right\} \quad \text{where:} \quad I_0 = \frac{V_0}{R} \quad T_0 = \frac{L}{R}$$

L/R drive - Current waveforms

Low stepping rate:

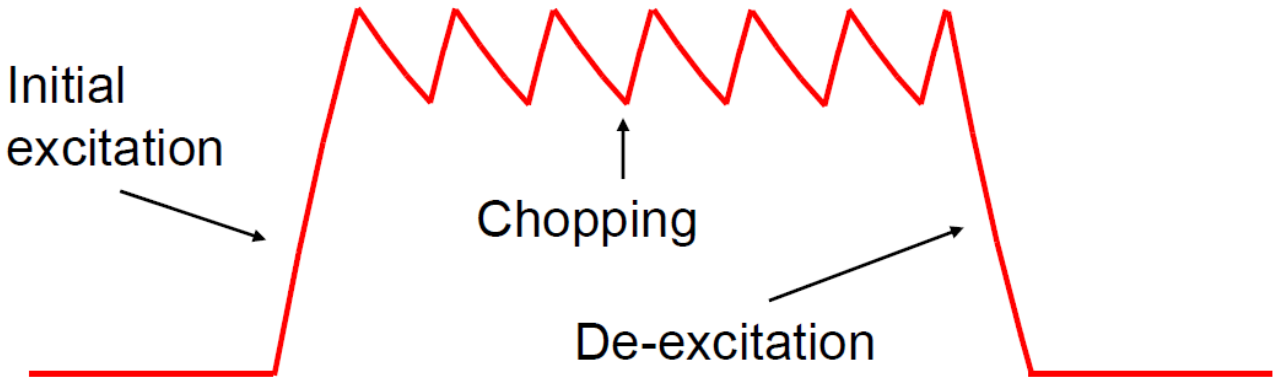


High stepping rate:

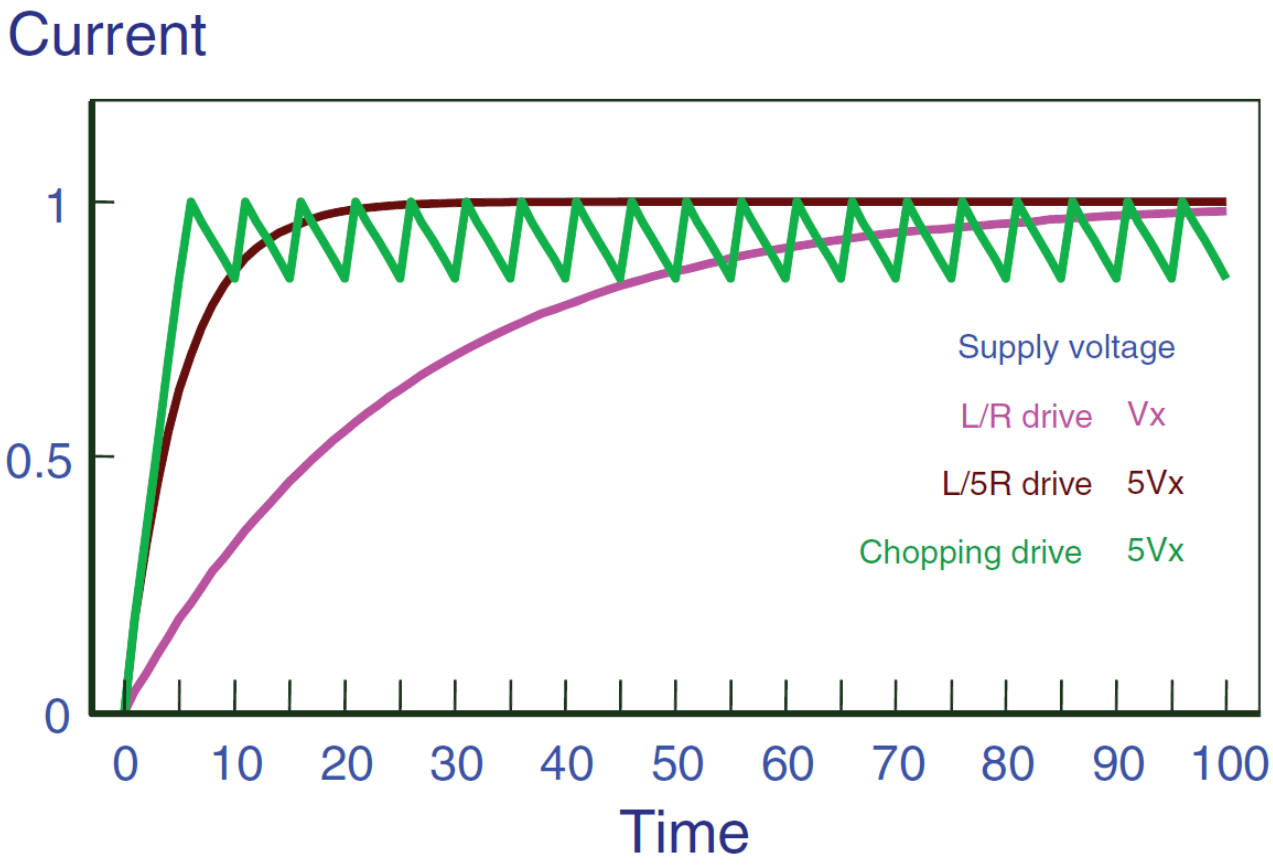
Chopper drive - Current waveform

When stator current reaches nominal current the chopper drives goes into freewheel mode

$$T_0 \approx \frac{I_0.L}{V_0} \longrightarrow T_0 = \frac{L}{R}$$

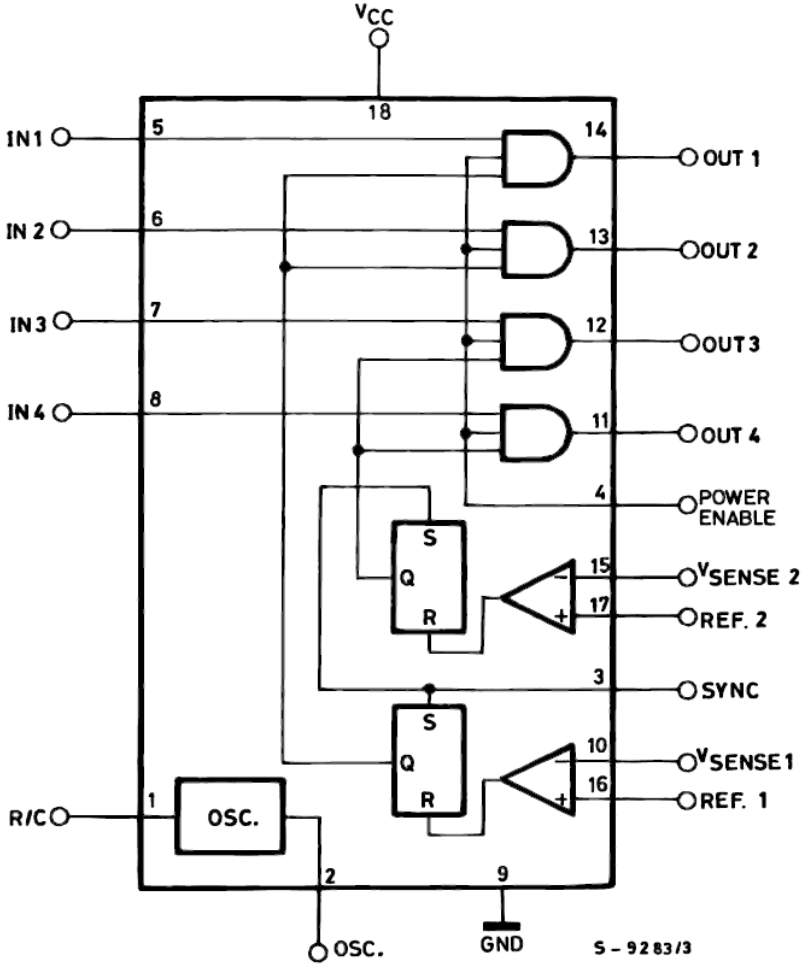


Current waveforms for L/R, L/nR and switch mode drive

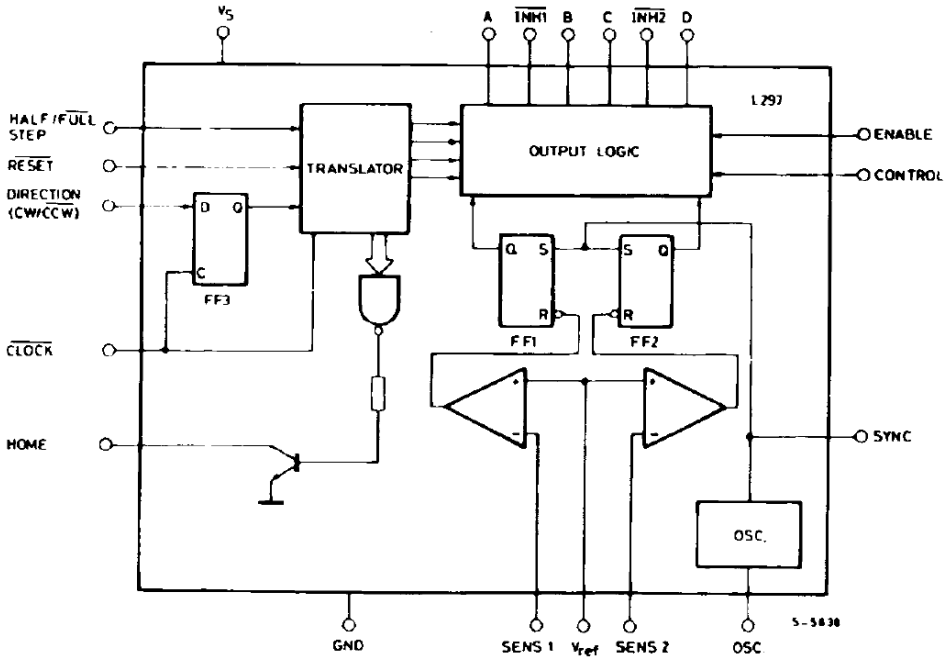


Example (current controller for stepping motors)

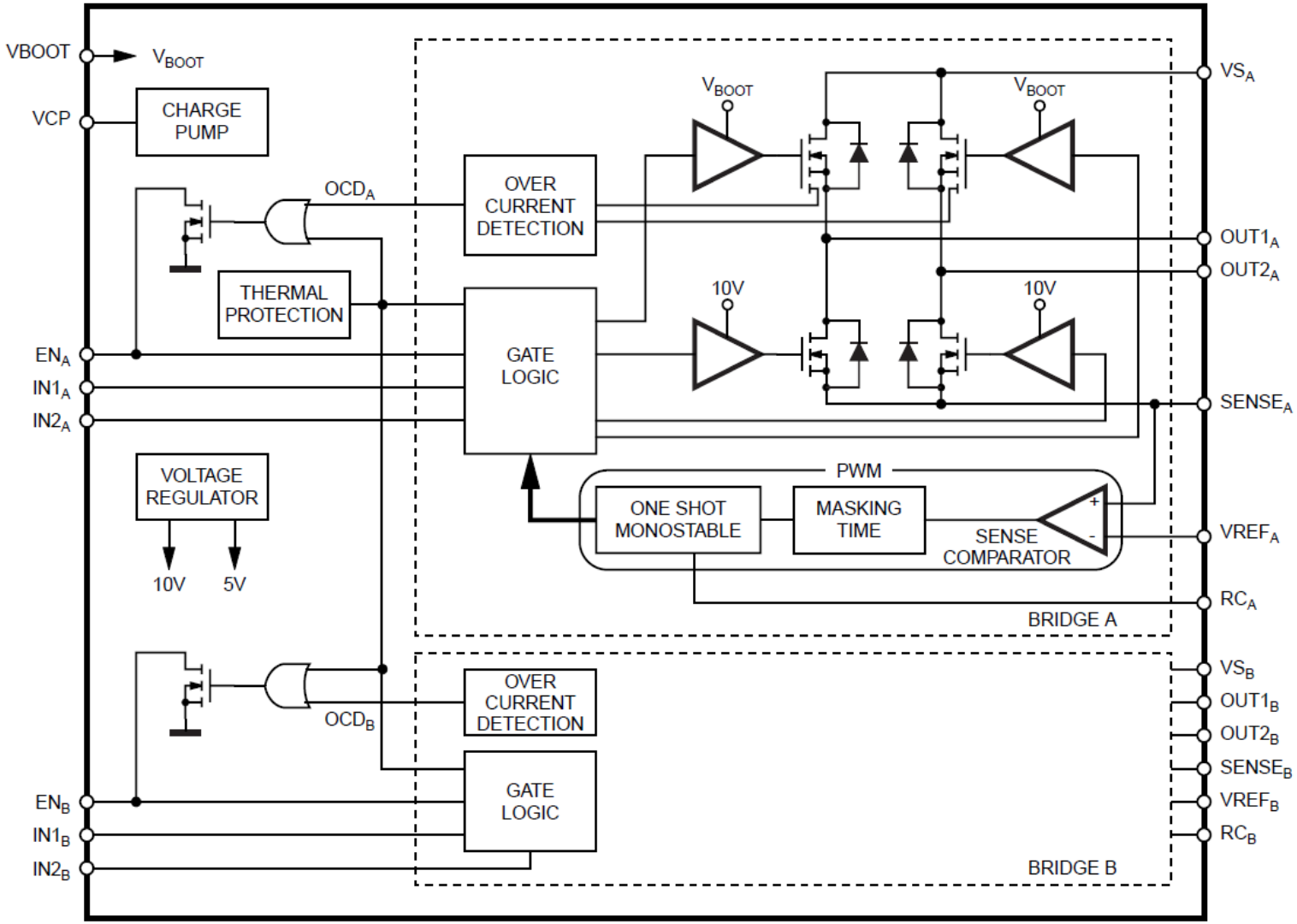
L6506



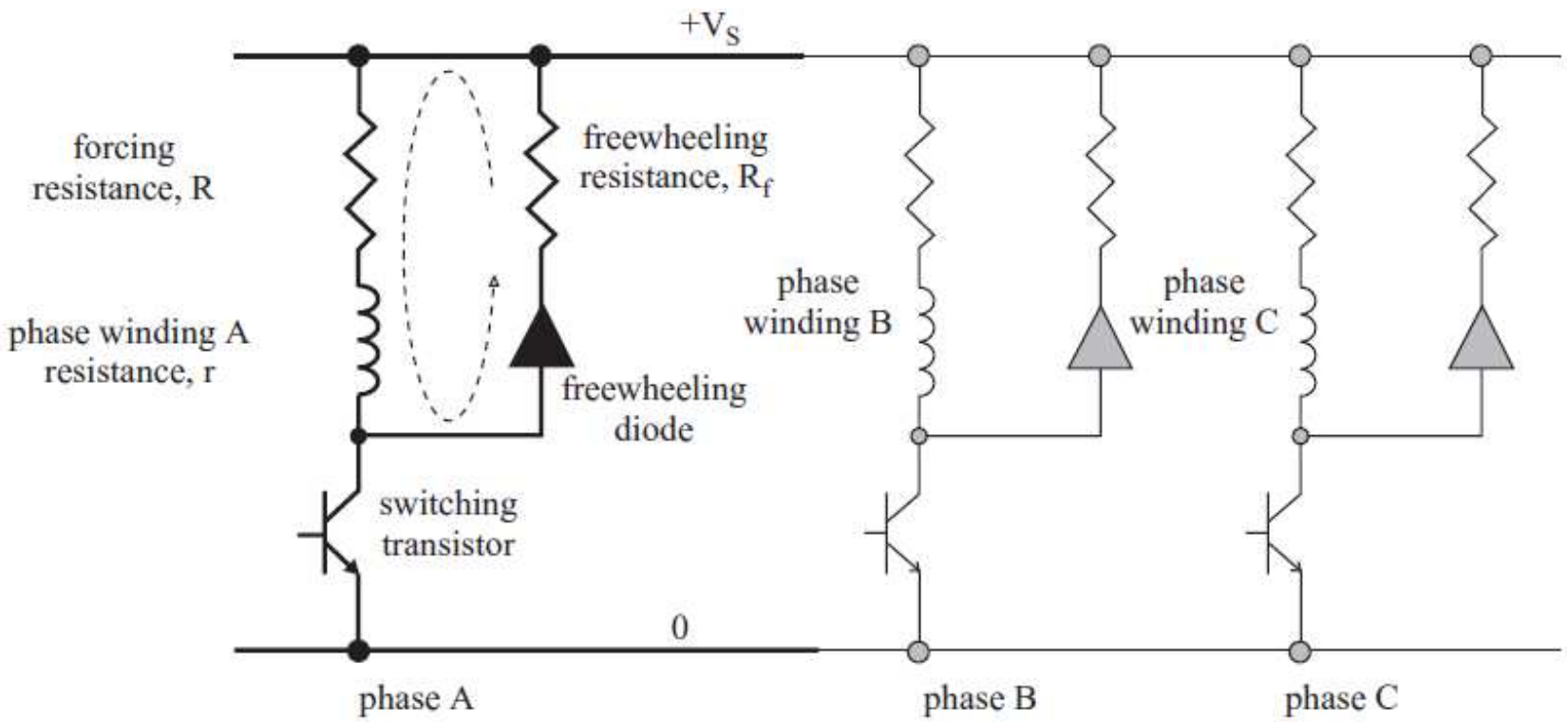
L297



Example (L6207: dual full bridge driver with PWM current controller)

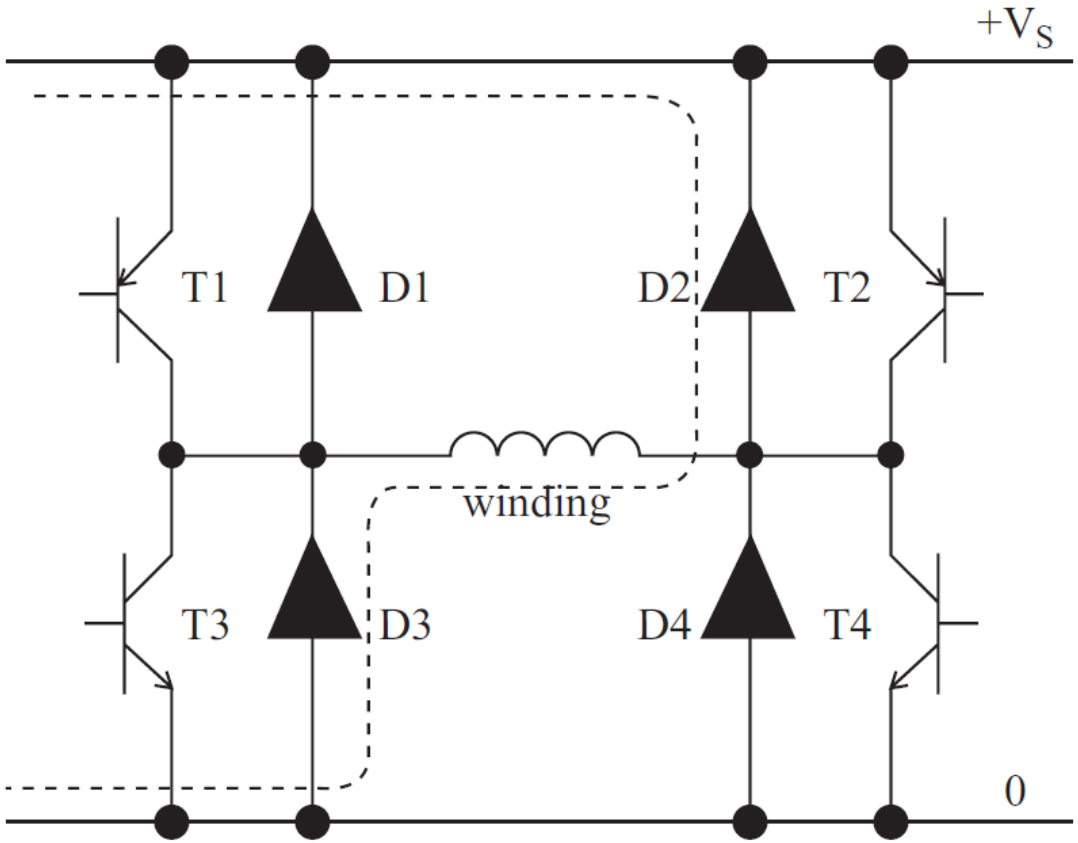


Unipolar drive circuit



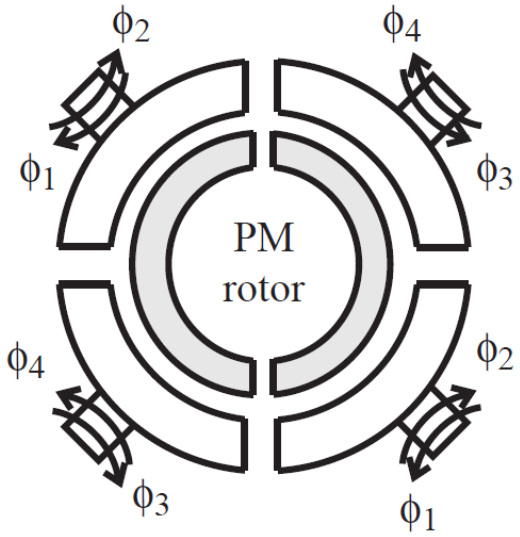
- - - freewheeling/flyback current path

Bipolar drive circuit

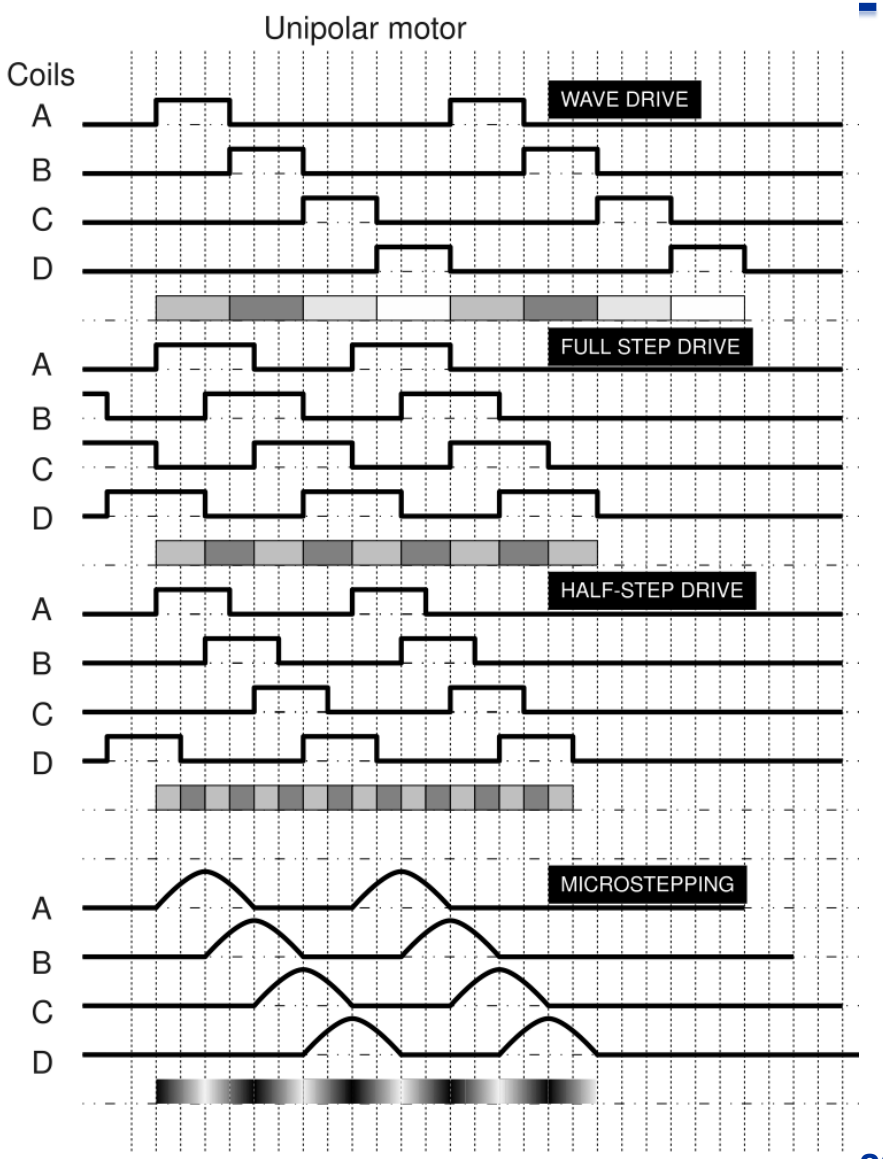


One phase of a transistor bridge bipolar drive circuit
- - - freewheeling/flyback current path after T1 and T4 turn off

Phase current waveforms (or drive sequences)



A	ϕ_1
B	ϕ_2
C	ϕ_3
D	ϕ_4



1. Wave drive
2. Full step drive
3. Half step drive
4. Micro-stepping

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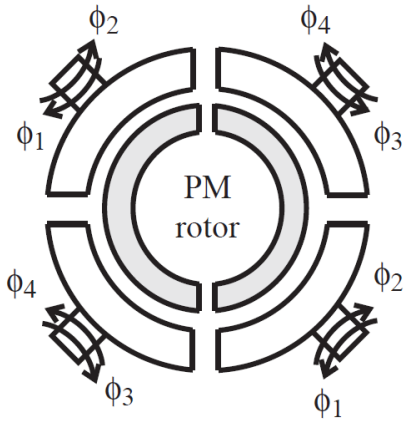
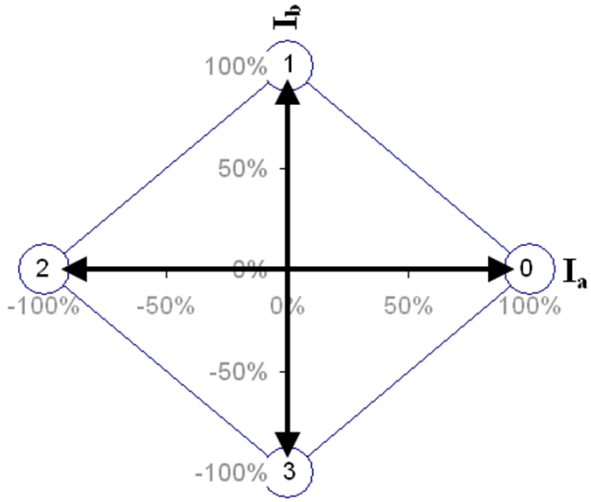
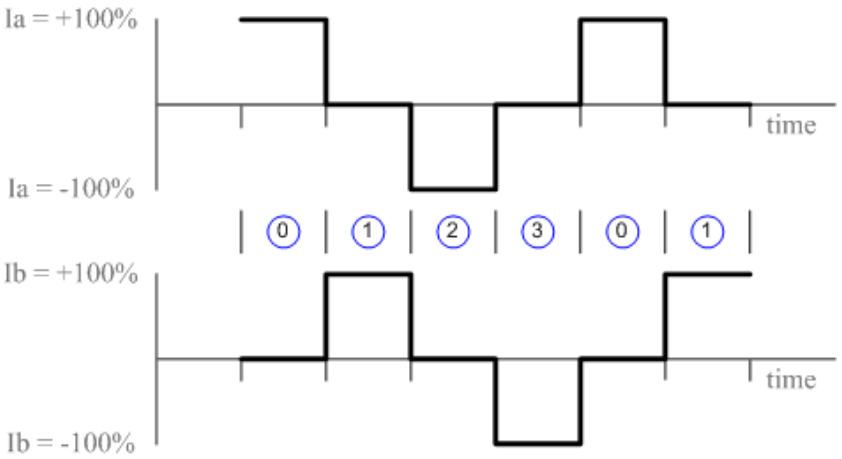
Wave drive



Step	ϕ_1	ϕ_2	ϕ_3	ϕ_4
1	ON	OFF	OFF	OFF
2	OFF	ON	OFF	OFF
3	OFF	OFF	ON	OFF
4	OFF	OFF	OFF	ON

This sequence repeats after 4 steps





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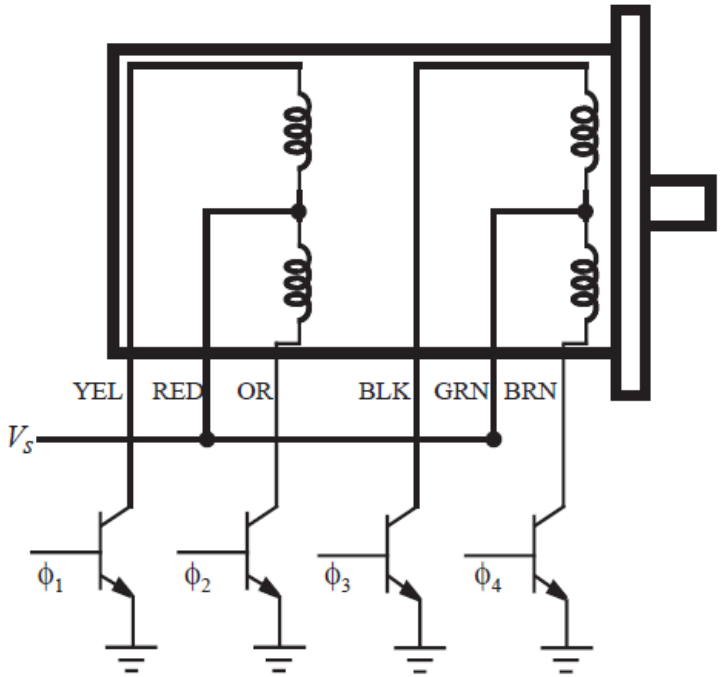
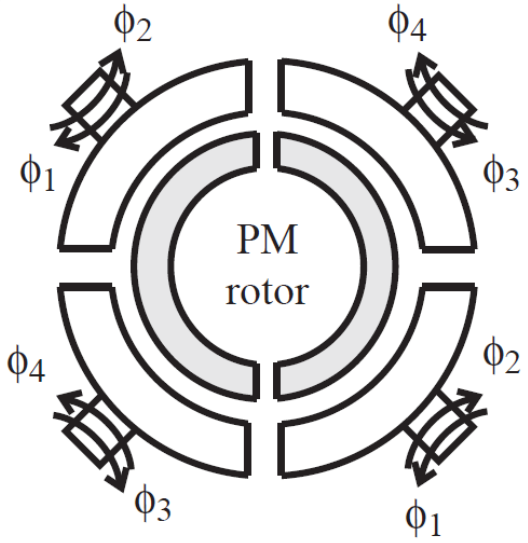
Unipolar full-step phase sequence



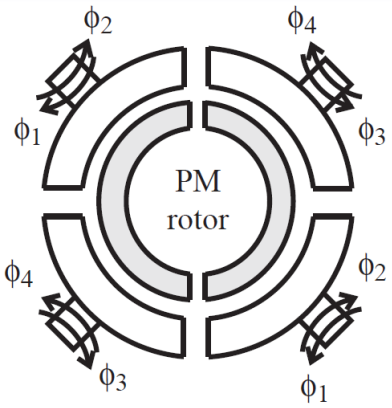
Standard unipolar stepper motor field coil schematic



Unipolar full-step phase sequence

	Step	ϕ_1	ϕ_2	ϕ_3	ϕ_4
CW	1	ON	OFF	ON	OFF
↓	2	ON	OFF	OFF	ON
CCW	3	OFF	ON	OFF	ON
↑	4	OFF	ON	ON	OFF

Unipolar half-step phase sequence



CW
↓

step 1
(ϕ_1, ϕ_3 : ON)

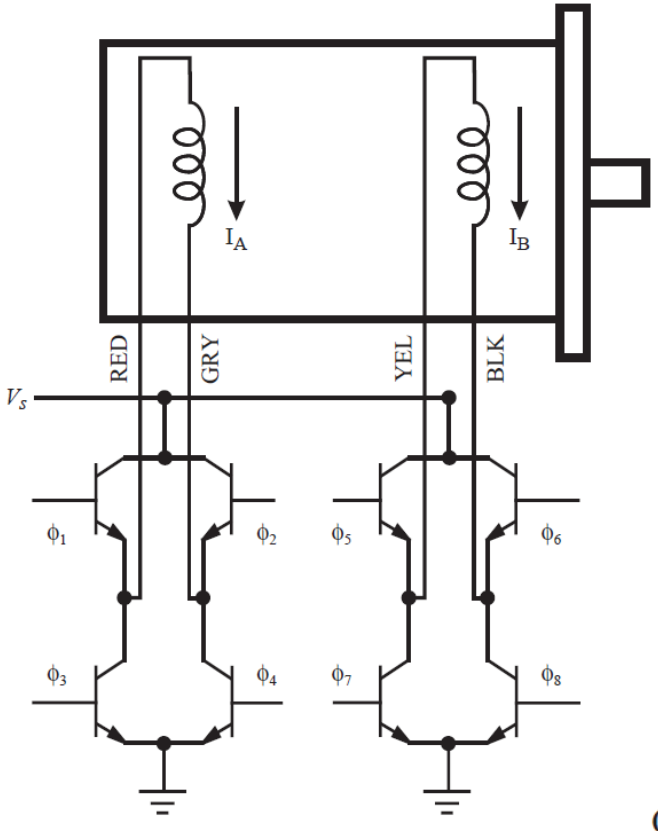
CCW
↑

step 1.5
(ϕ_1: ON)

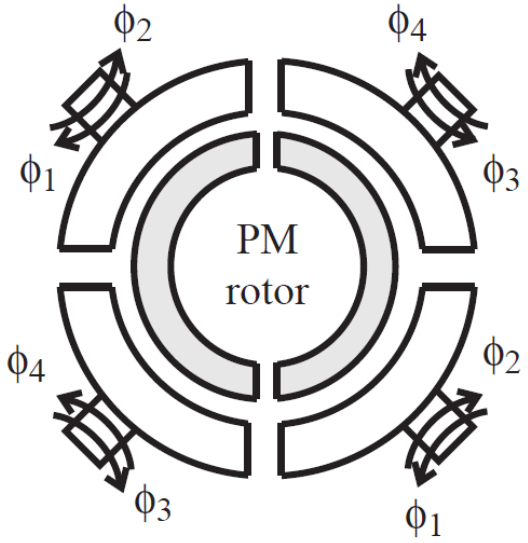
step 2
(ϕ_1, ϕ_4 : ON)

Step	ϕ_1	ϕ_2	ϕ_3	ϕ_4
1	ON	OFF	ON	OFF
1.5	ON	OFF	OFF	OFF
2	ON	OFF	OFF	ON
2.5	OFF	OFF	OFF	ON
3	OFF	ON	OFF	ON
3.5	OFF	ON	OFF	OFF
4	OFF	ON	ON	OFF
4.5	OFF	OFF	ON	OFF

Bipolar full-step phase sequence



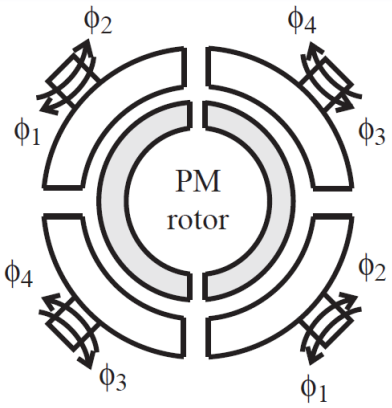
Standard bipolar stepper motor field coil schematic

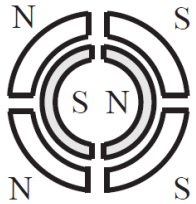


Bipolar full-step phase sequence

	Step	ϕ_1 and ϕ_4	ϕ_2 and ϕ_3	ϕ_5 and ϕ_8	ϕ_6 and ϕ_7
CW	1	ON	OFF	ON	OFF
↓	2	ON	OFF	OFF	ON
CCW	3	OFF	ON	OFF	ON
↑	4	OFF	ON	ON	OFF

Bipolar half-step phase sequence





step 1
(ϕ_1, ϕ_3 : ON)

step 1.5
(ϕ_1: ON)

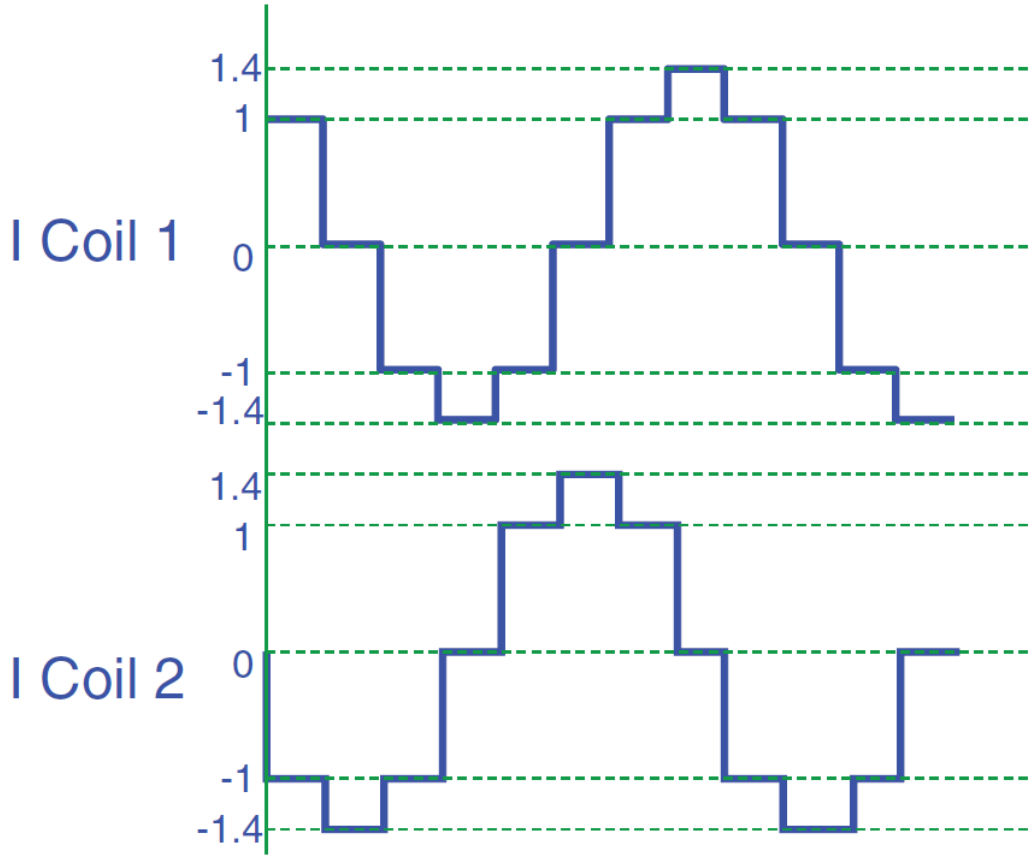
step 2
(ϕ_1, ϕ_4 : ON)

CW
↓

CCW
↑

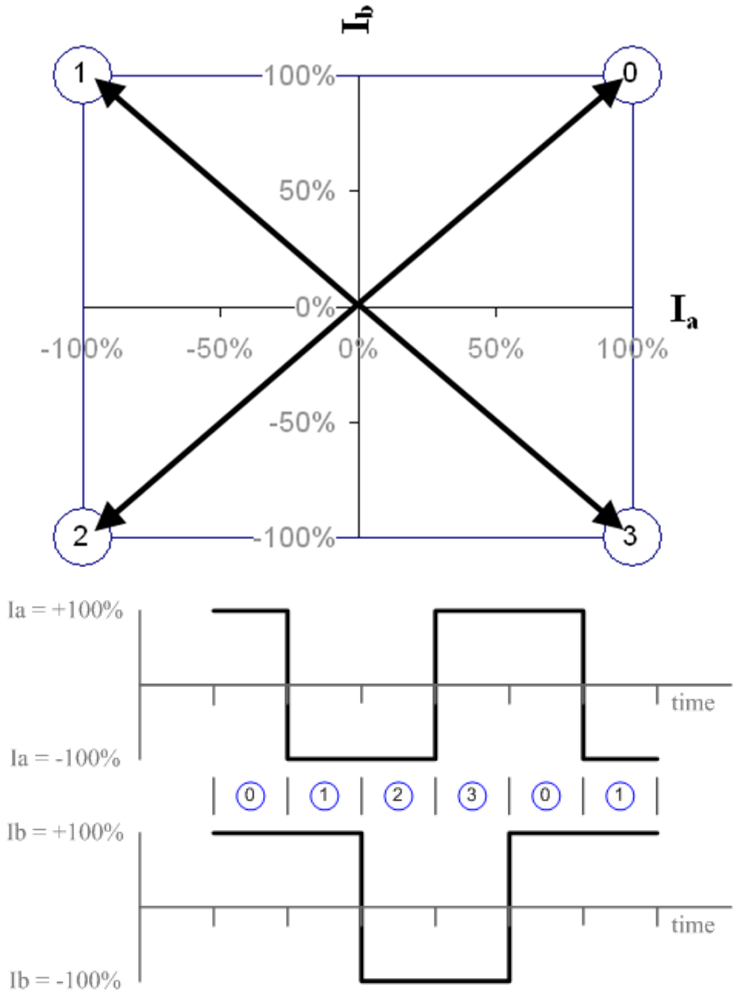
Step	ϕ_1 and ϕ_4	ϕ_2 and ϕ_3	ϕ_5 and ϕ_8	ϕ_6 and ϕ_7
1	ON	OFF	ON	OFF
1.5	ON	OFF	OFF	OFF
2	ON	OFF	OFF	ON
2.5	OFF	OFF	OFF	ON
3	OFF	ON	OFF	OFF
3.5	OFF	ON	OFF	OFF
4	OFF	ON	ON	OFF
4.5	OFF	OFF	ON	OFF

Current waveform to reduce half-step torque ripple

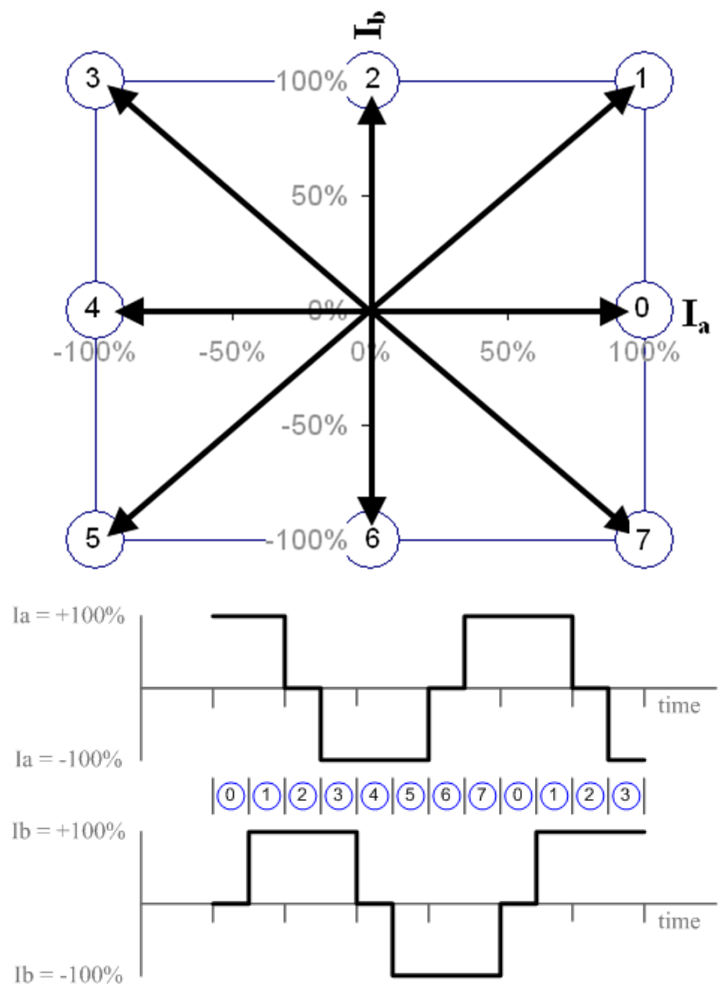


Full and half stepping (re-visit)

Full-step sequence



Half-step sequence



Micro-stepping

- Micro-stepping involves interpolating between full or half-step positions
- This is achieved by linear control of the stator winding drive currents
- Micro-stepping provides greater precision and smoother operation at low speeds, and eliminates resonance
- Micro-stepping requires complex linear drives together with DACs to set the winding currents

Micro-stepping

- In sine-cosine micro-stepping the currents in the A and B stator windings are given by:

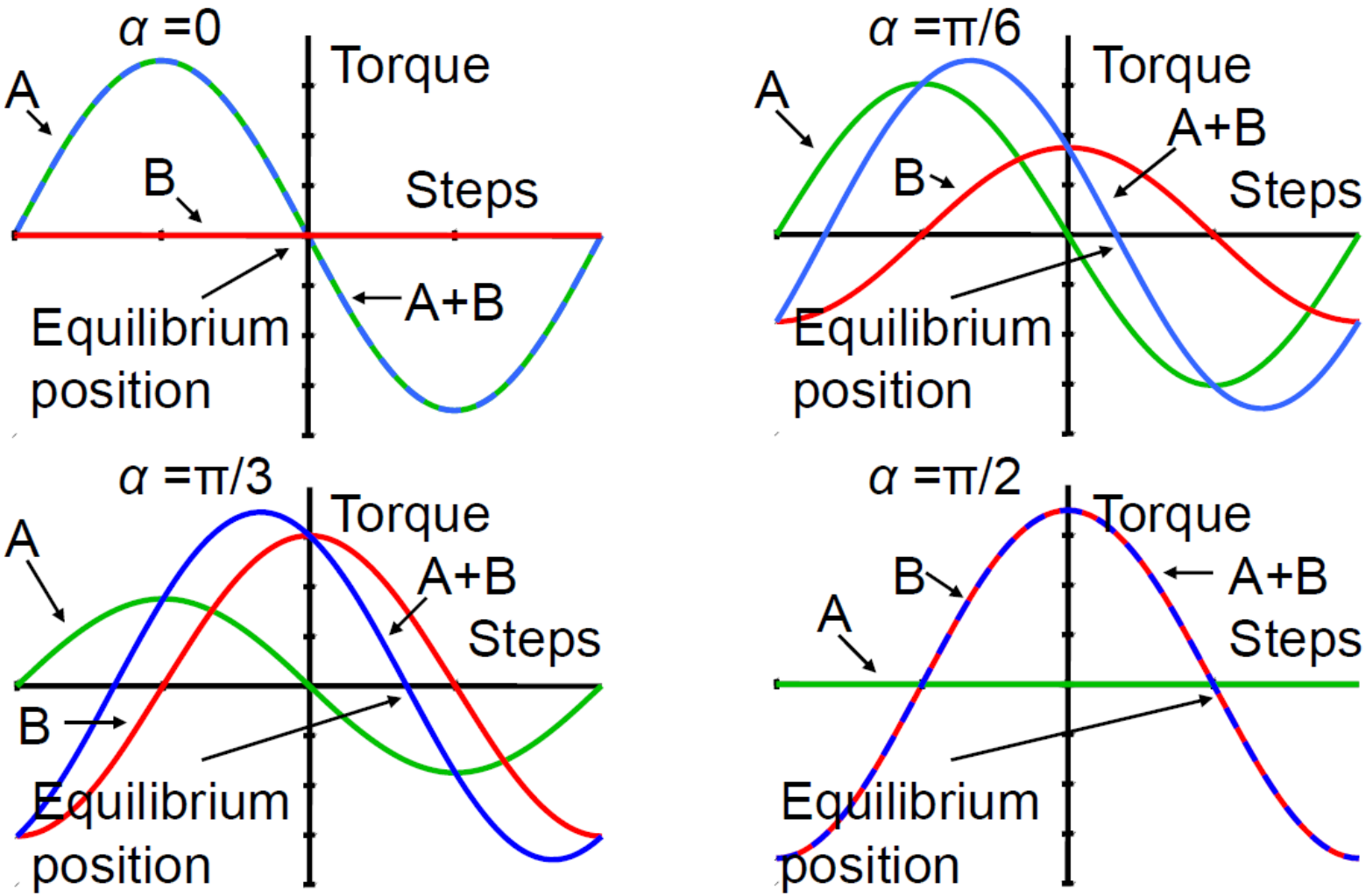
$$i_a = i_0 \sin \alpha$$

$$i_b = i_0 \cos \alpha$$

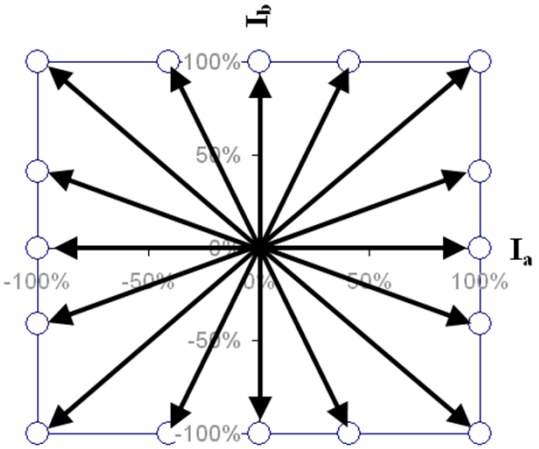
where varying α from 0 to π/2 moves the rotor position by one full step

- In principle there is no limit to the number to the number of micro-step precision
- In practice there is little point in using more than 256 micro-steps between full steps

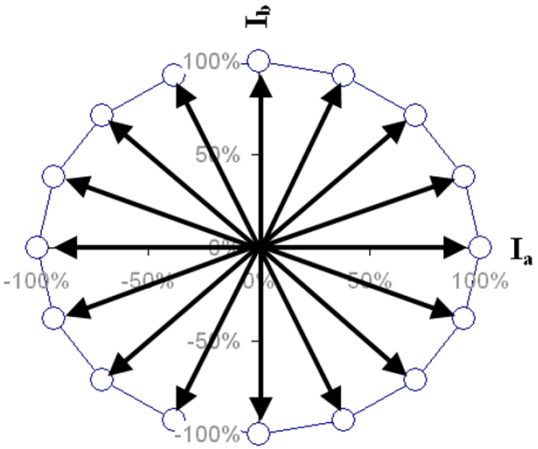
Micro-stepping



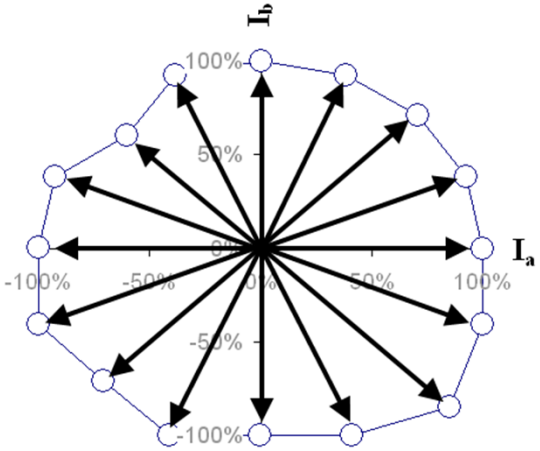
Micro-stepping



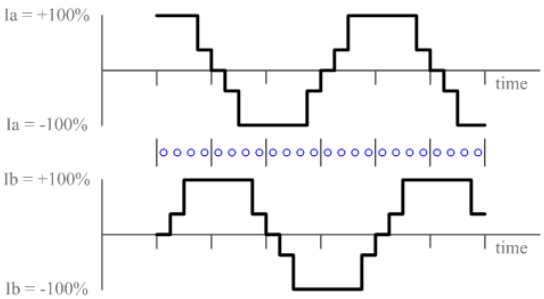
Square path

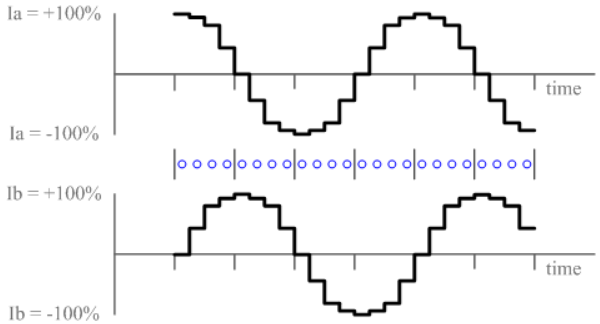


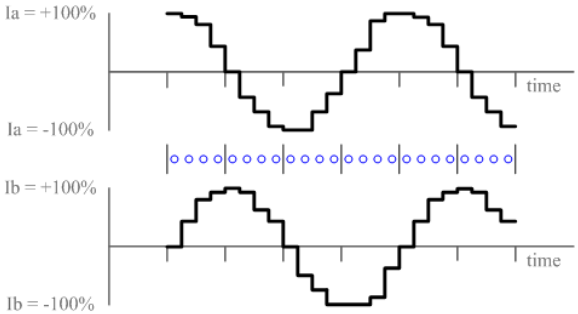
Circular path



Arbitrary path







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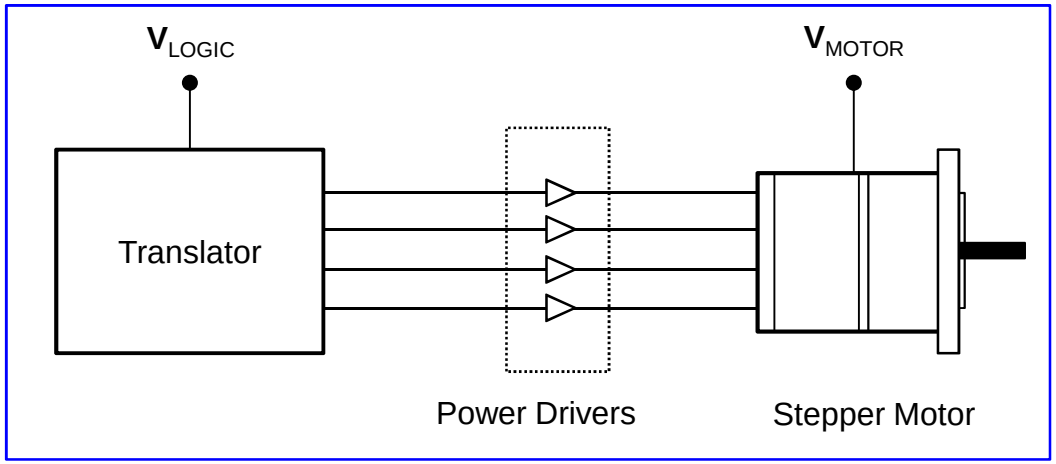
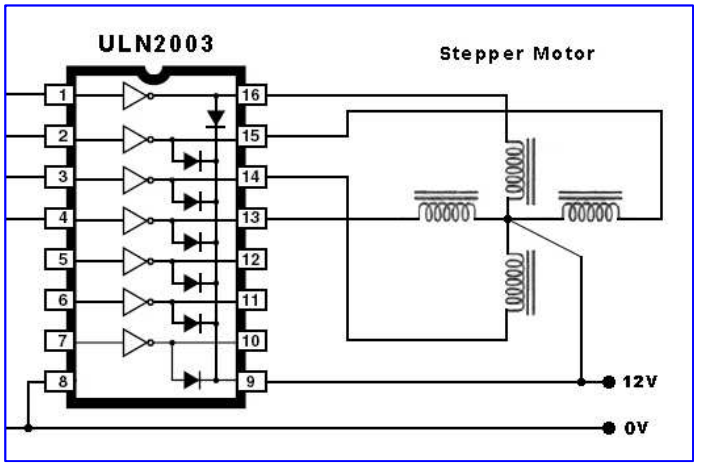
Micro-stepping

- The apparent superior precision of micro-stepping is only realised in practice in the absence of significant coulomb friction and load torque
- The actual shape of the static torque curve is not exactly sinusoidal; this results in the micro steps being non-uniformly spaced
- DAC quantisation will also result in non-uniformly spaced micro steps
- Very high step rates are necessary to achieve normal rotation speeds

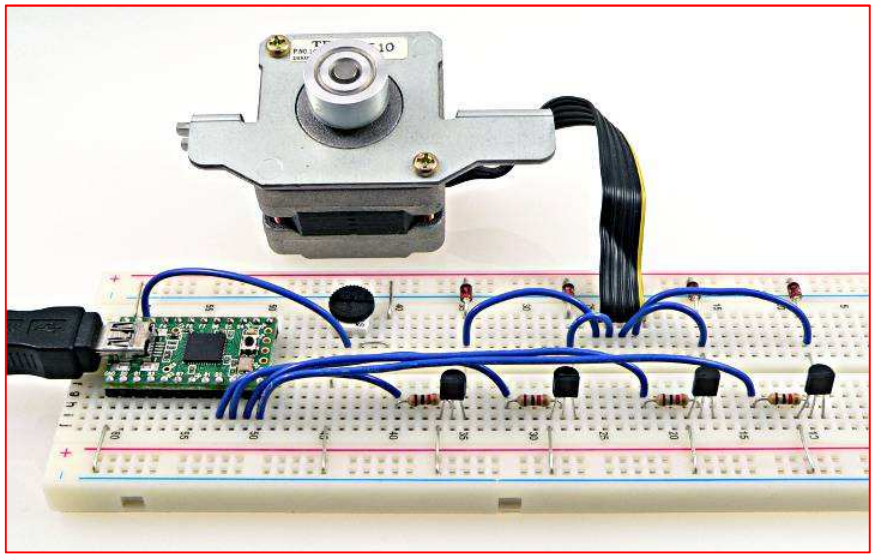
Generating the drive





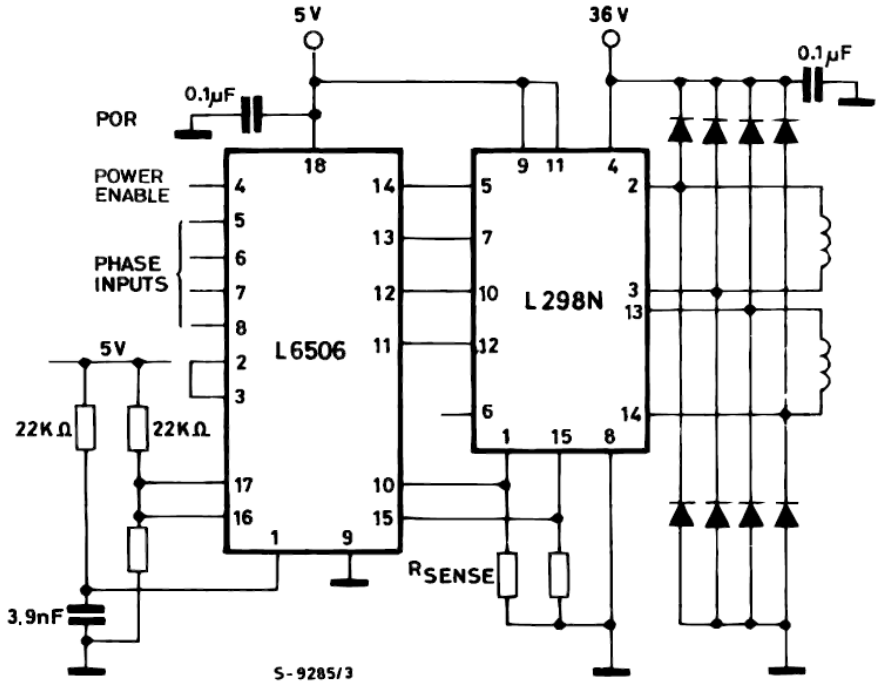
General stepper motor driver architecture

EXAMPLE

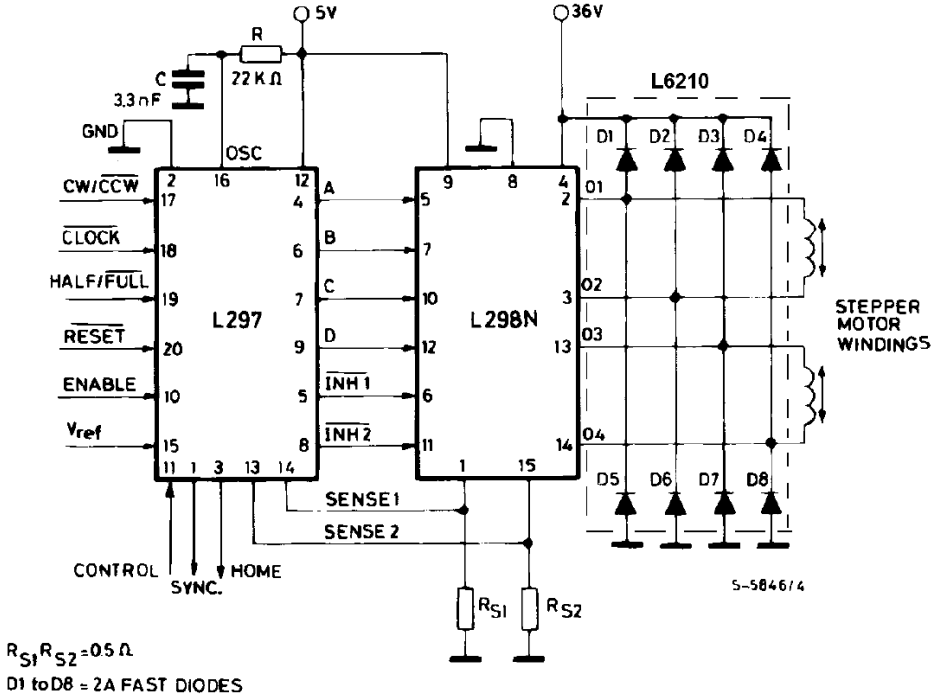


Generating the drive

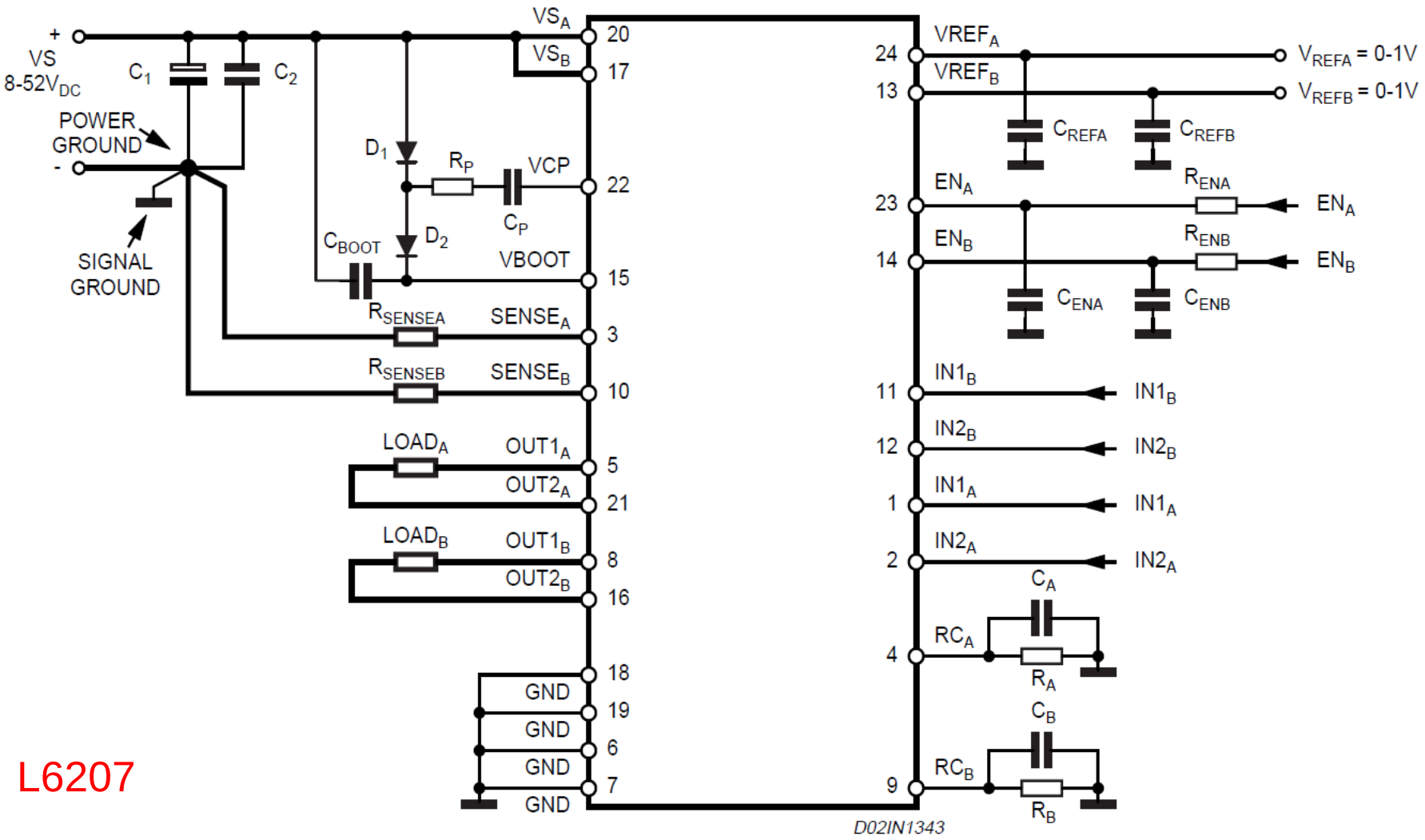
L6506 + L298



L297 + L298

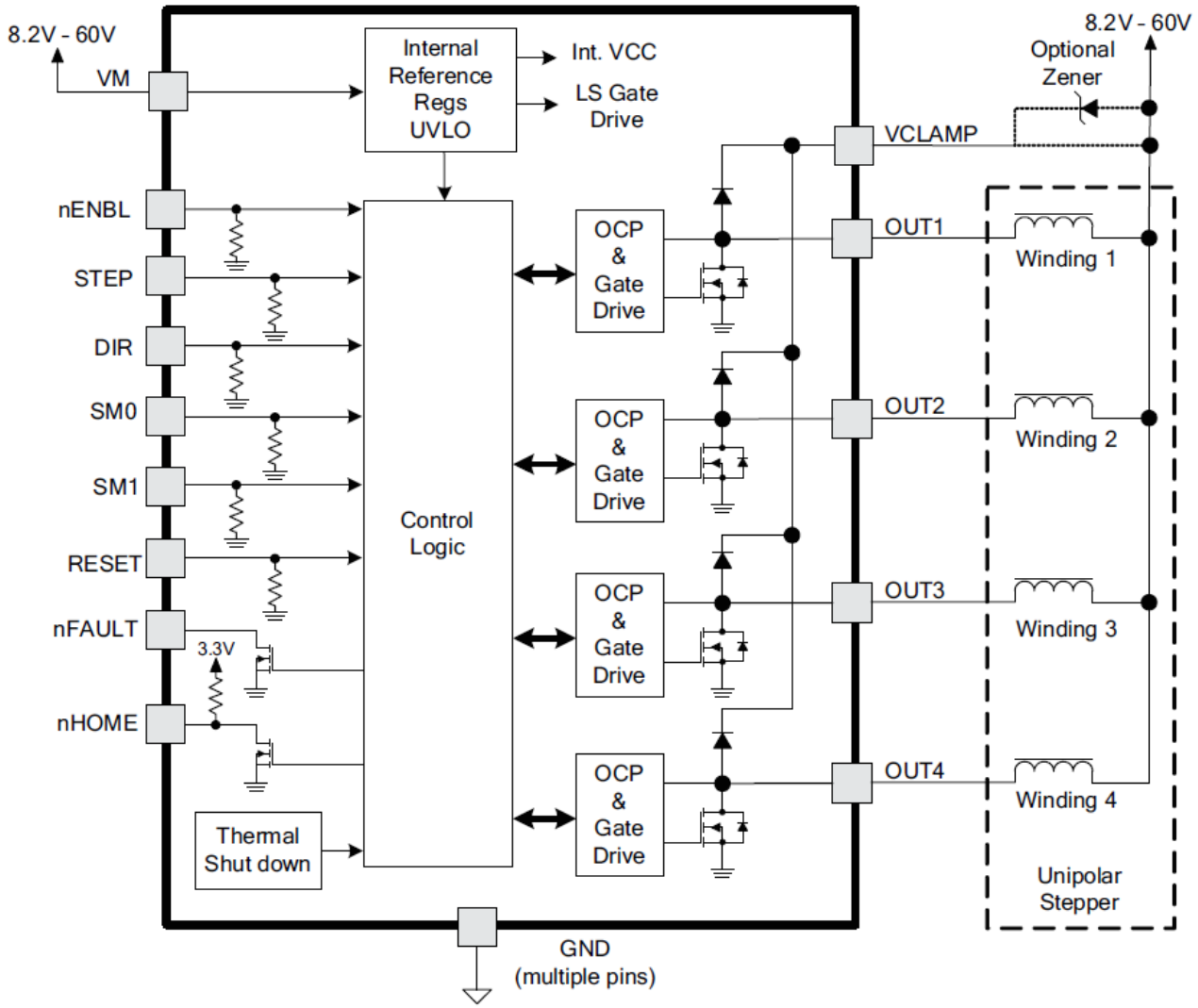


Generating the drive



L6207

Generating the drive



DRV8805

Generating the drive (practical way)

- Numerous stepper motor controllers with serial, USB or PCI interfaces are available.
- Design engineers (including mechatronics engineers) usually only select appropriate controllers for their designs.

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