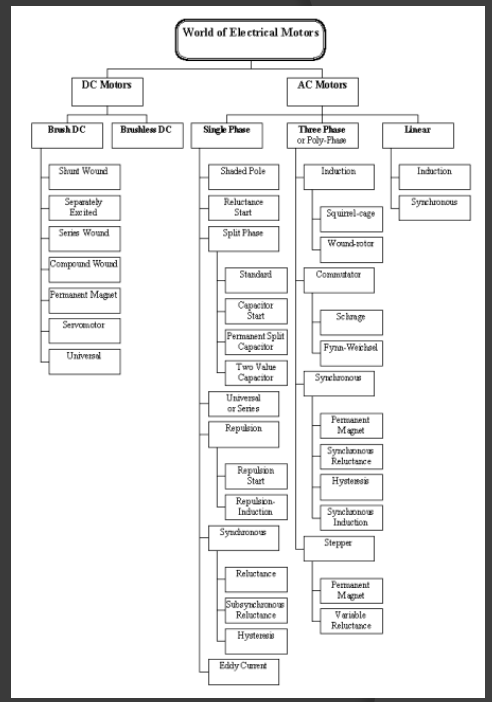
MOTORS

Electrical motors typology

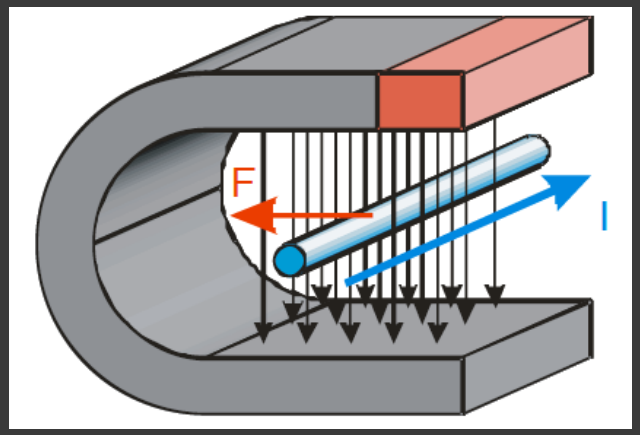
- DC
  - brushed
  - brushless
- AC
  - synchronous
  - asynchronous (induction)
- piezoelectric, ultrasonic,…

- (pneumatic motors, hydraulic motors …)

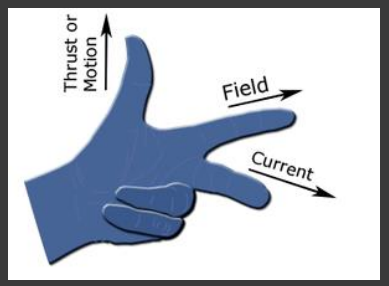


Core principle of DC motors

- Electro-mechanical device
- magnetic field + electrical current ⇨ force



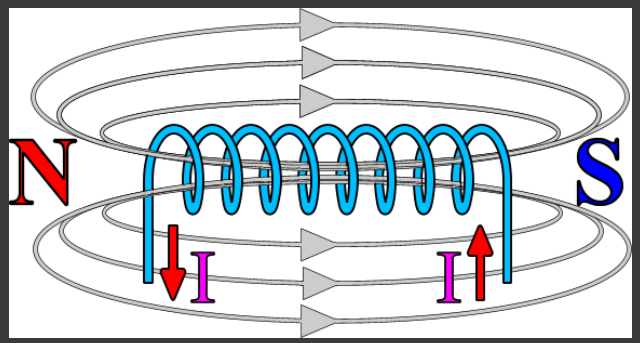
Lorentz force $F = Il \times B$ (or $F = I\int dl \times B$ for bent wire)

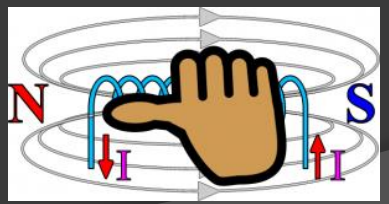


Fleming left hand rule

N → S

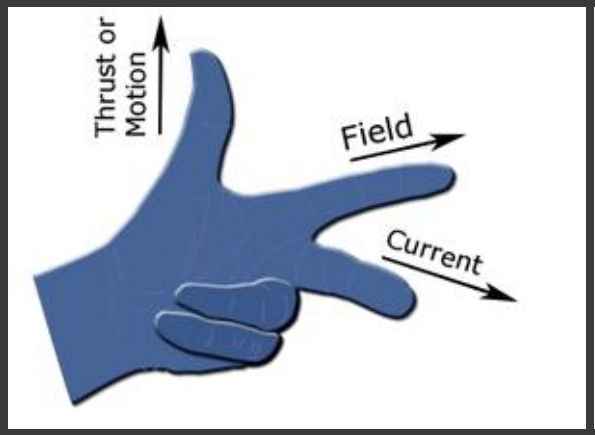
\+ → -

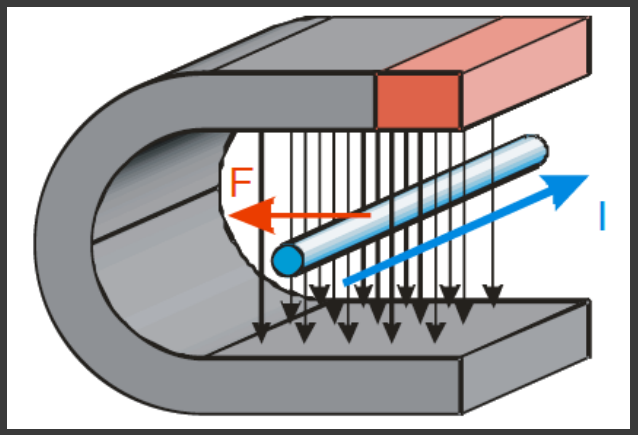




Ampère right hand rule

The idea is simple





Fleming left hand rule

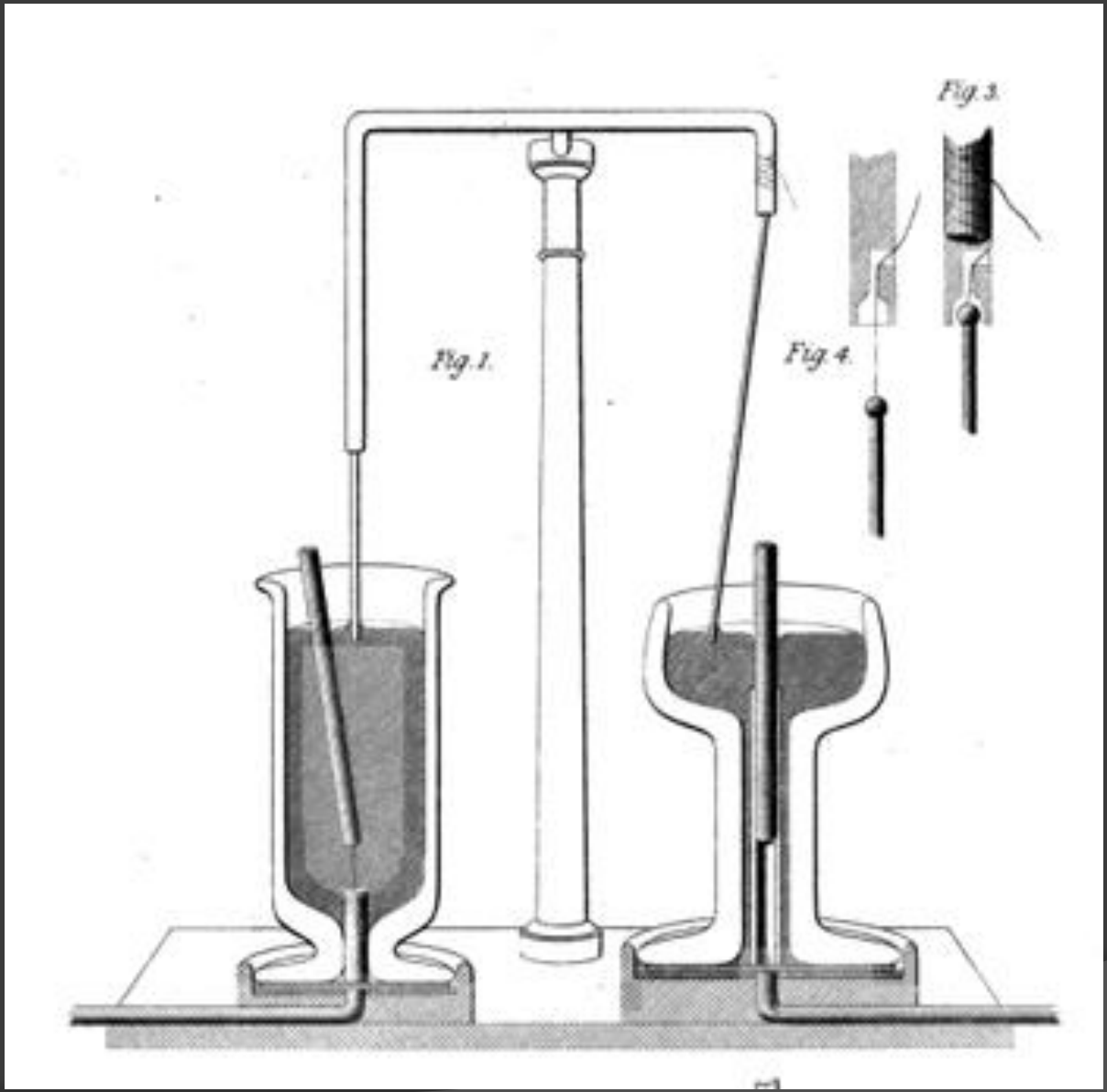
N → S

\+ → -

http://www.youtube.com/watch?v=CoXboA8Ax7Q

… but … *(to be continued)*

Principle example



THE

EDINBURGH

PHILOSOPHICAL JOURNAL,

EXHIBITING A VIEW OF

THE PROGRESS OF DISCOVERY IN NATURAL PHILOSOPHY, CHEMISTRY, NATURAL HISTORY, PRACTICAL MECHANICS, GEOGRAPHY, NAVIGATION, STATISTICS, AND THE FINE AND USEFUL ARTS,

FROM

OCTOBER 1. 1821, TO APRIL 1. 1822.

CONDUCTED BY

DR BREWSTER AND PROFESSOR JAMESON.

TO BE CONTINUED QUARTERLY.

VOL. VI.

EDINBURGH:

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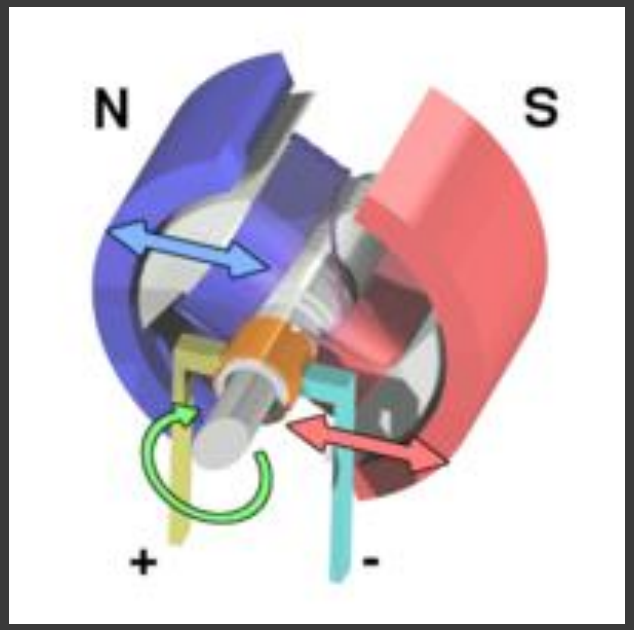
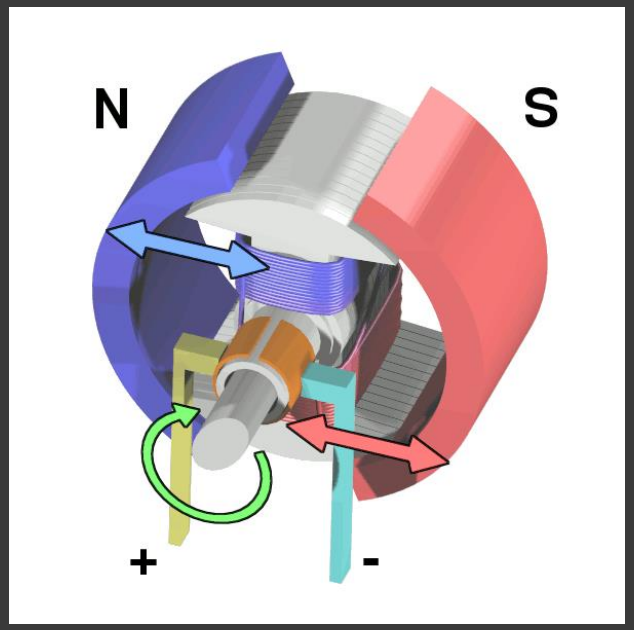
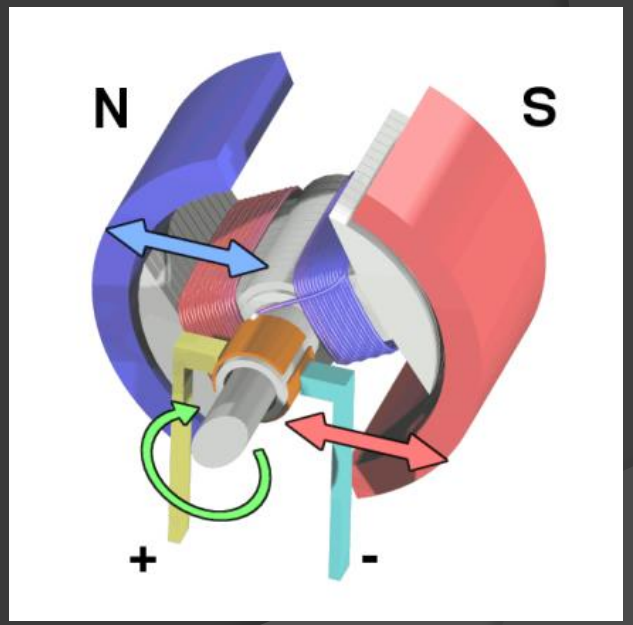
1822.

DC brushed motors

- The simplest form:
  - stator / rotor (armature) / brushes / commutator



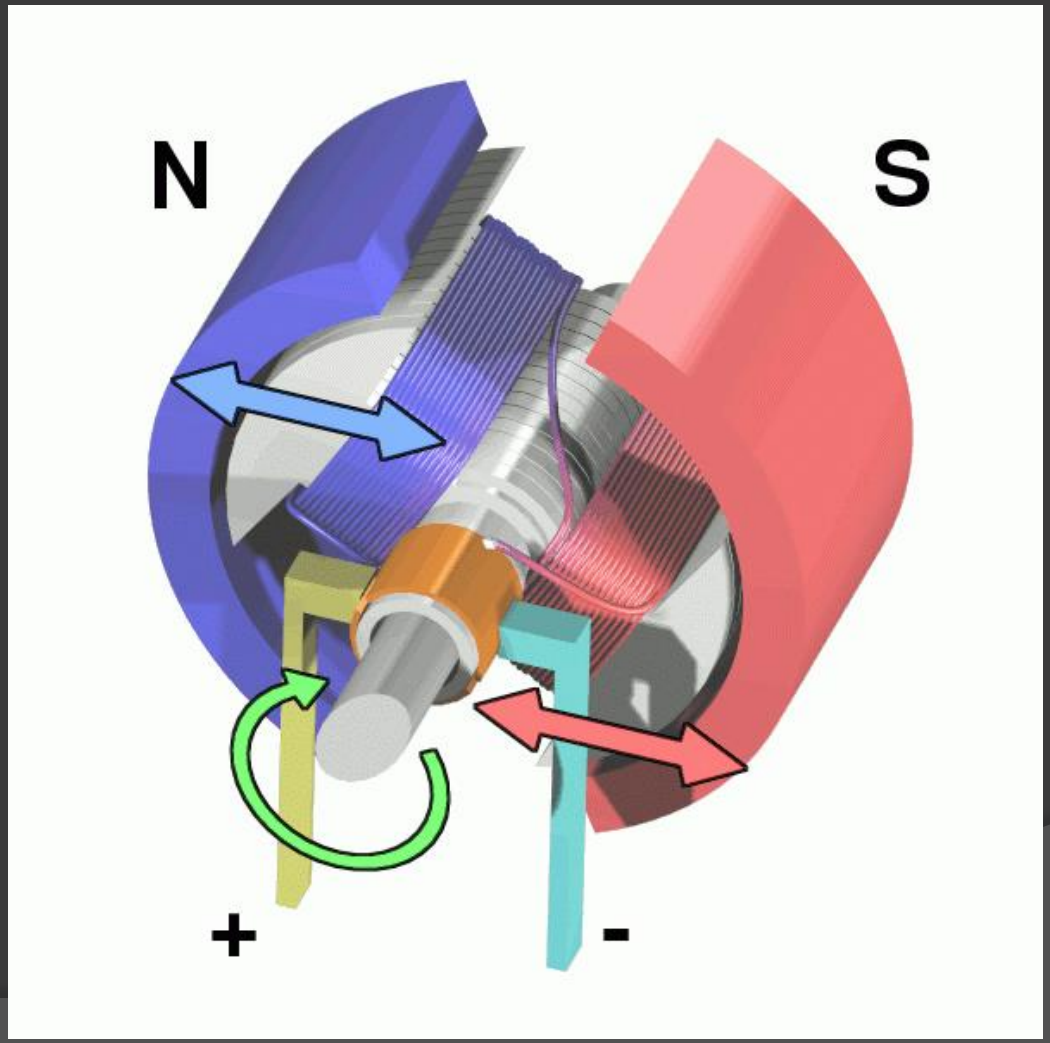




stejnosměrné, kartáčové, komutátorové

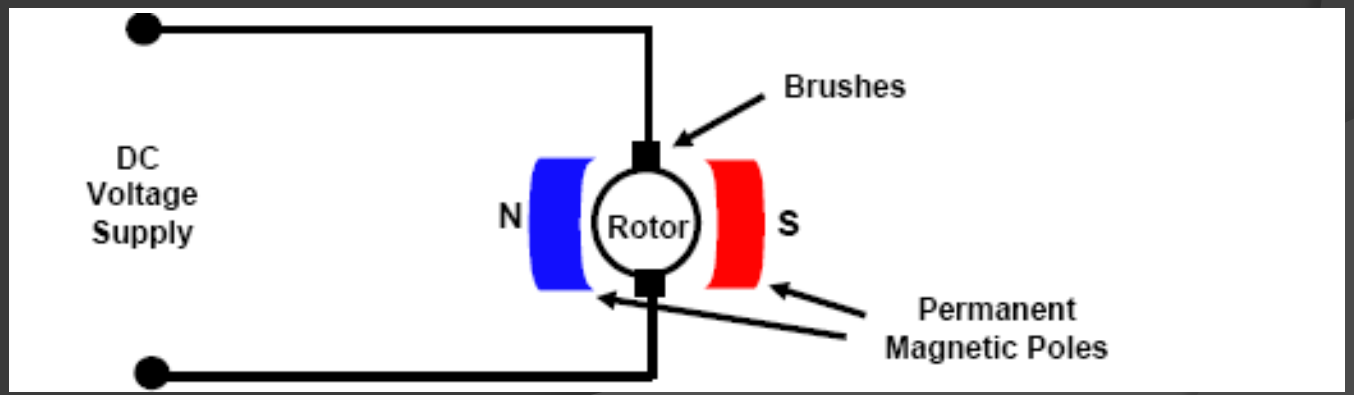
DC brushed motors

- The simplest form:



Types of DC brushed motors

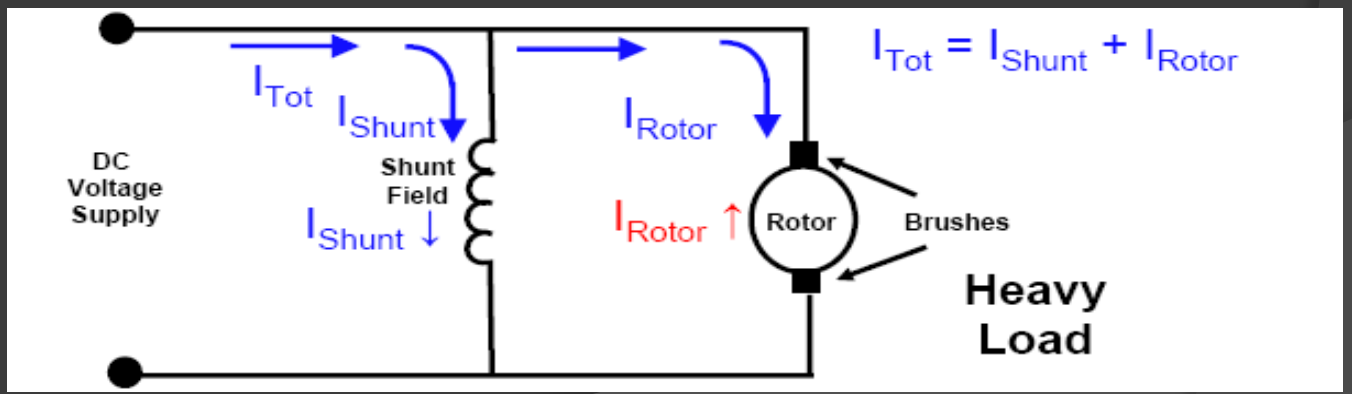
- Permanent magnet



pictures courtesy of John Mouton, Microchip

Types of DC brushed motors

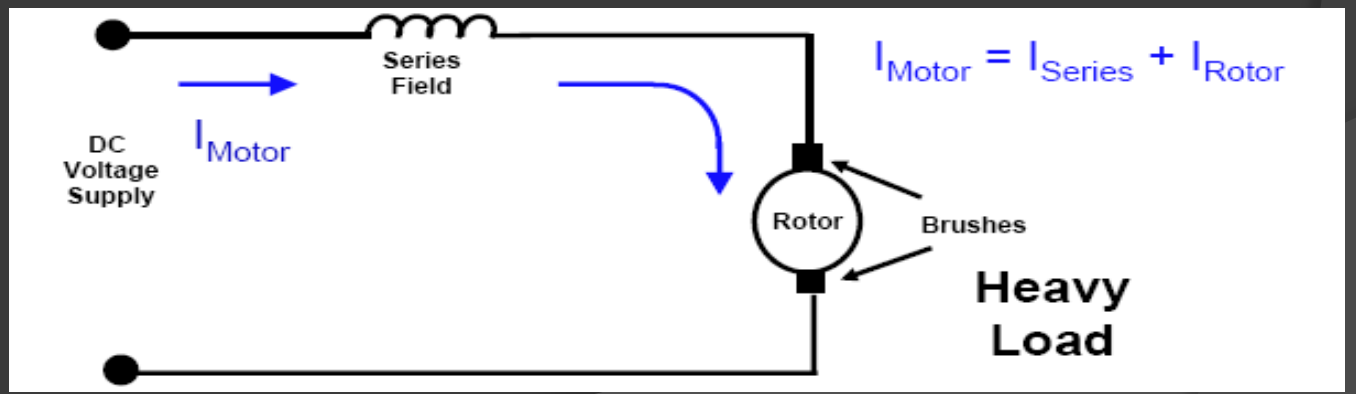
- Permanent magnet
- Wound stator
  - shunt wound



pictures courtesy of John Mouton, Microchip

Types of DC brushed motors

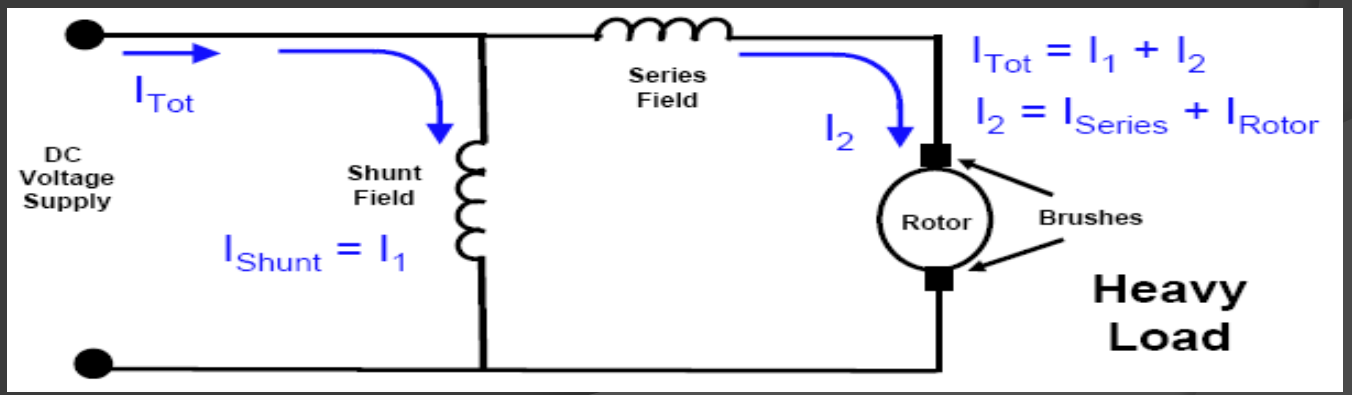
- Permanent magnet
- Wound stator
  - shunt wound
  - series wound



pictures courtesy of John Mouton, Microchip

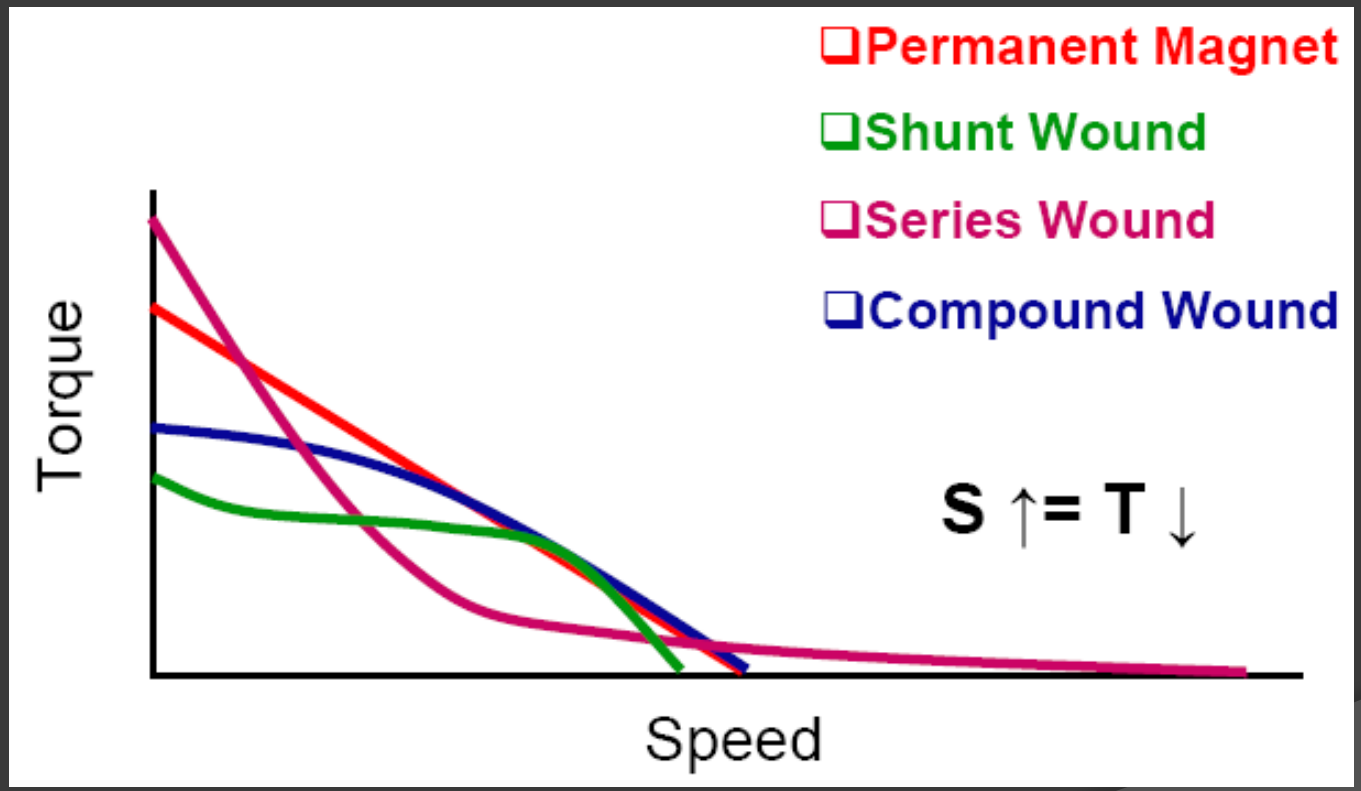
Types of DC brushed motors

- Permanent magnet
- Wound stator
  - shunt wound
  - series wound
  - compound wound



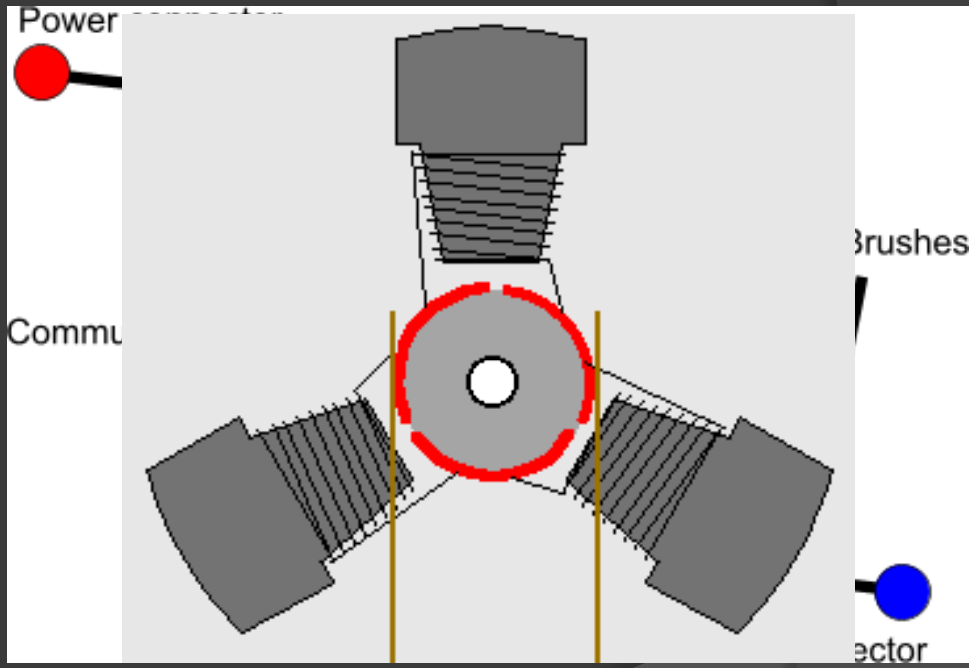
pictures courtesy of John Mouton, Microchip

Brushed motors performance



Brushed motor problem

- Brushes aligned across the gap
  - zero torque
  - short circuit
- Solution
  - wider gap?
  - more poles



pictures courtesy of Giorgos Lazaridis, Eric Seale

(DC motor) Speed control

- Voltage level regulation
  - Fixed voltage + fast on-off switching
    - ⇨ PWM
- Frequency regulation
  - for AC or ECM

Pulse-Width Modulation

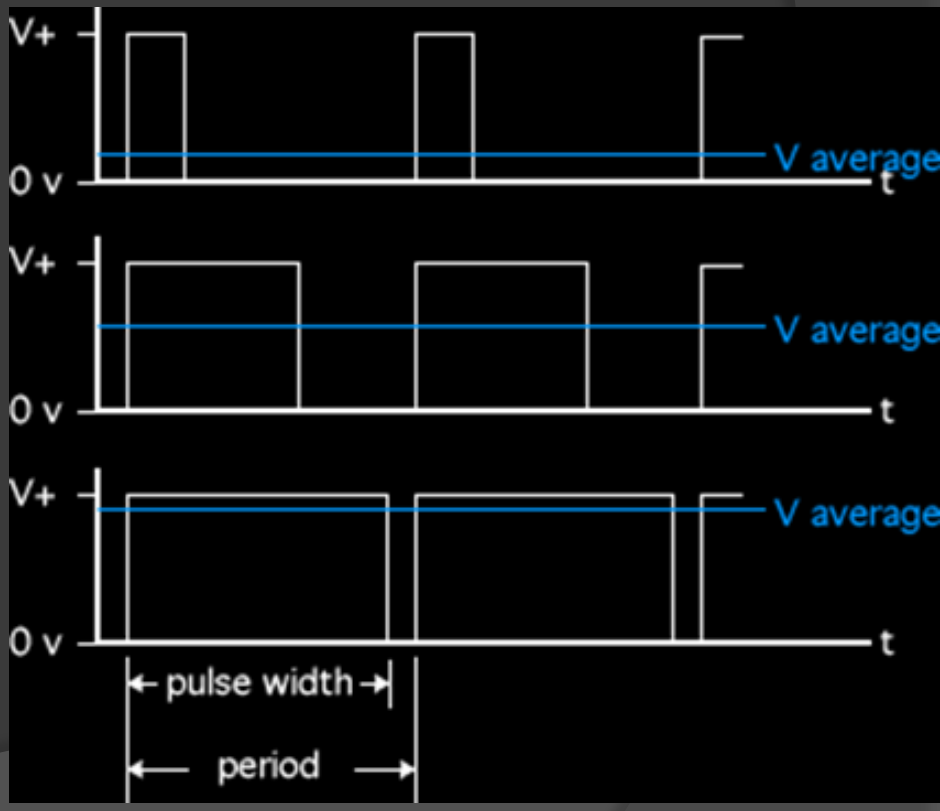
- pulse-duration modulation,
  pulsně-šířková modulace

$$\bar{y} = \frac{1}{T}\int_0^T f(t)dt$$

$$= \frac{1}{T}\left(\int_0^{DT} y_{max}dt + \int_{DT}^{T} y_{min}dt\right)$$

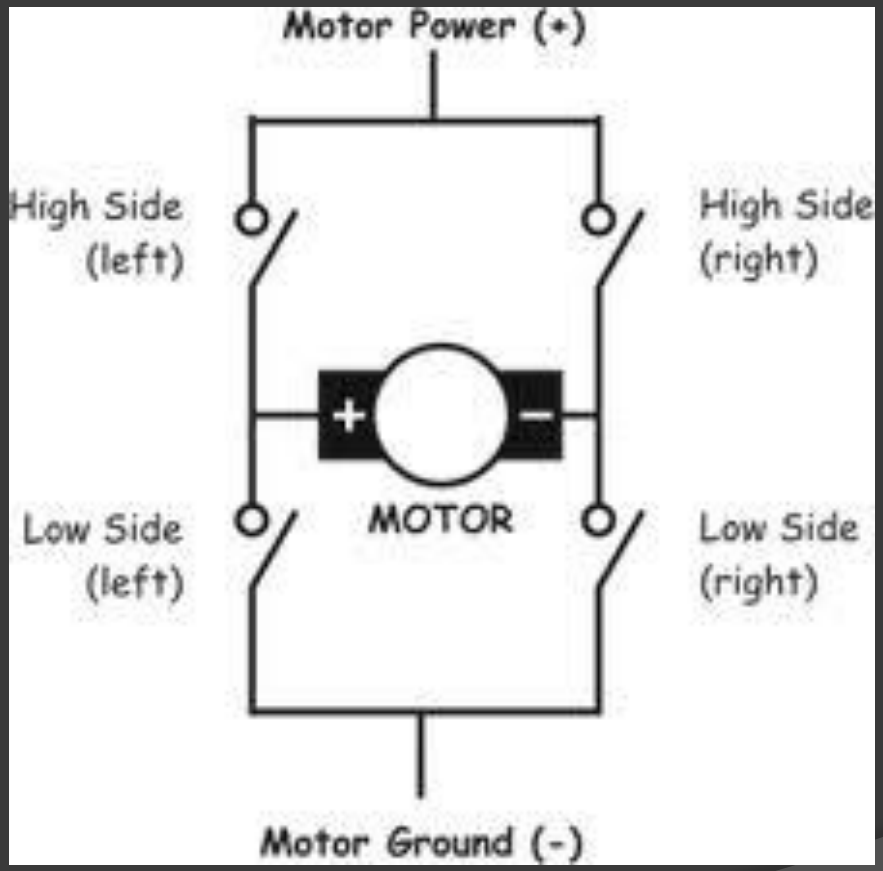
$$= \frac{D*T*y_{max}+(1-D)*T*y_{min}}{T}$$

$$= D * y_{max} + (1-D) * y_{min}$$

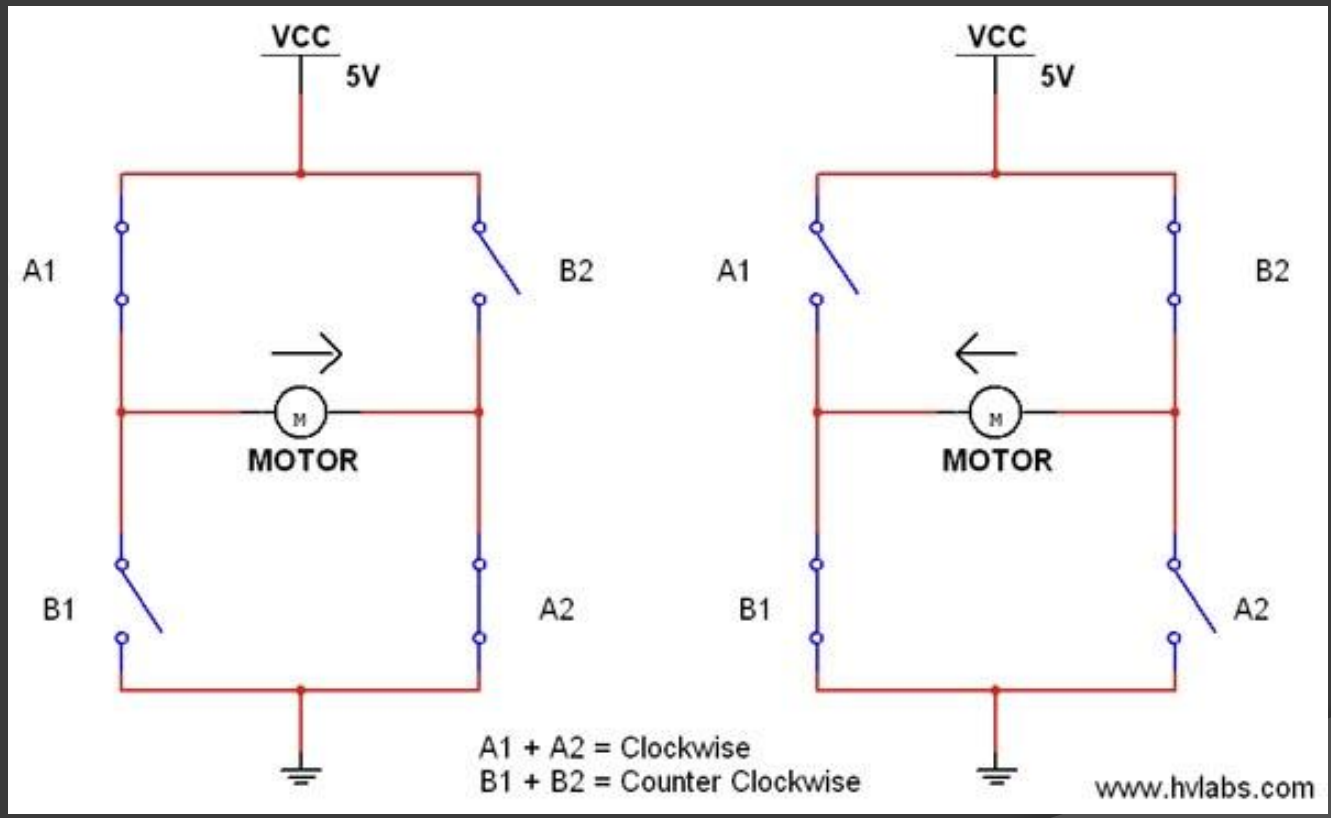


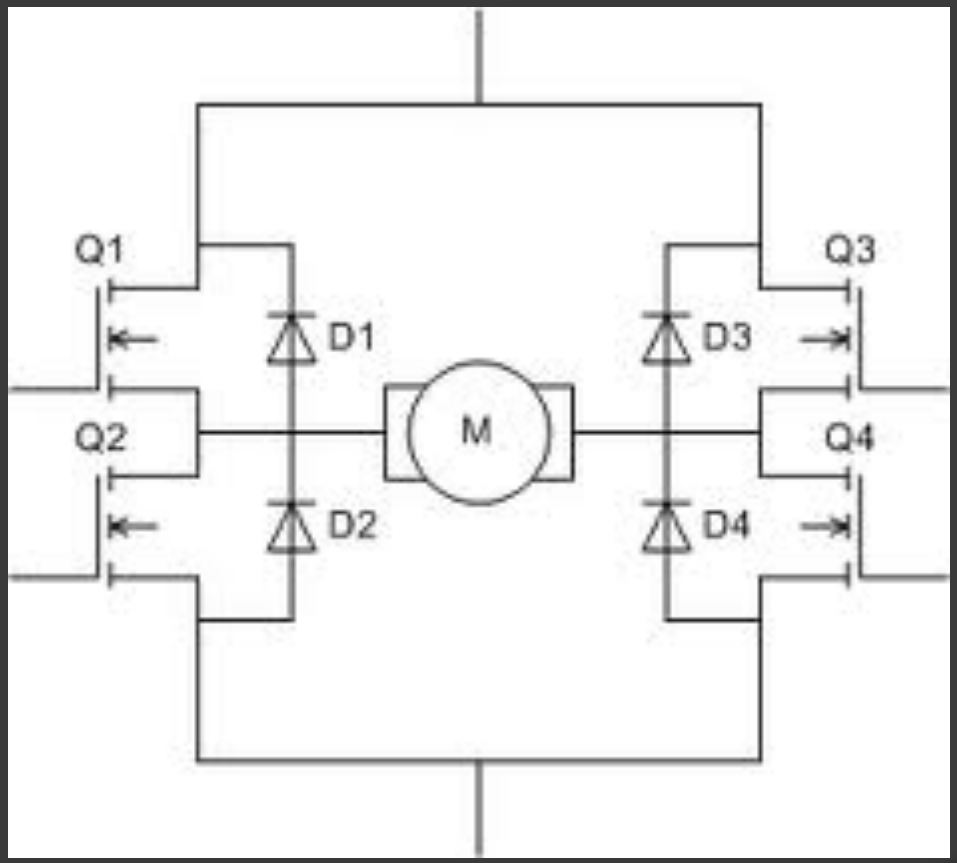
PWM in real life

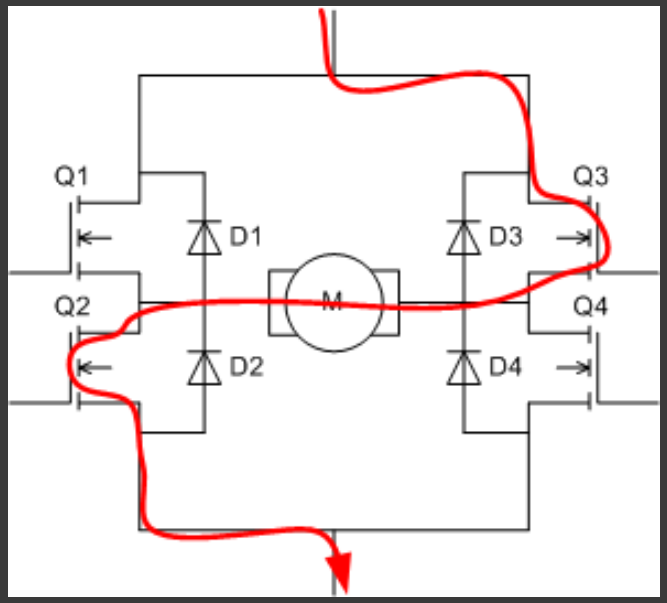
Direction control

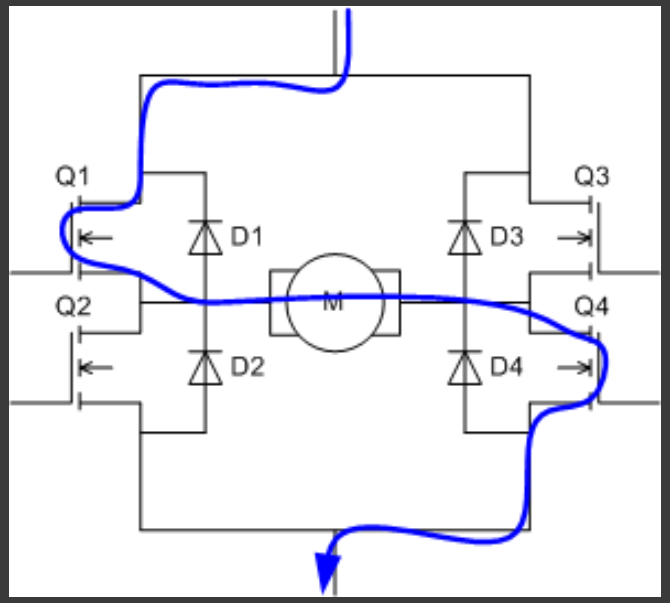


H-bridge principle



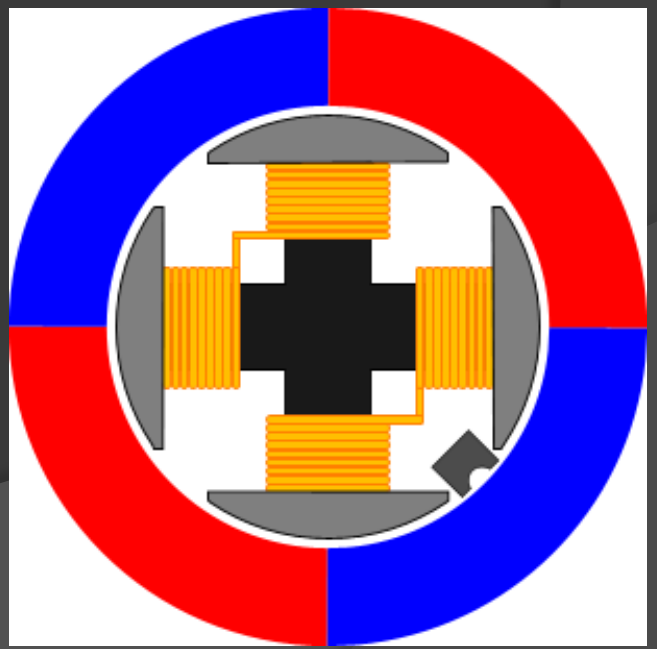

Q1
Q3
D1
D3
Q2
M
Q4
D2
D4


Q1
Q3
D1
D3
Q2
M
Q4
D2
D4


Q1
Q3
D1
D3
Q2
M
Q4
D2
D4

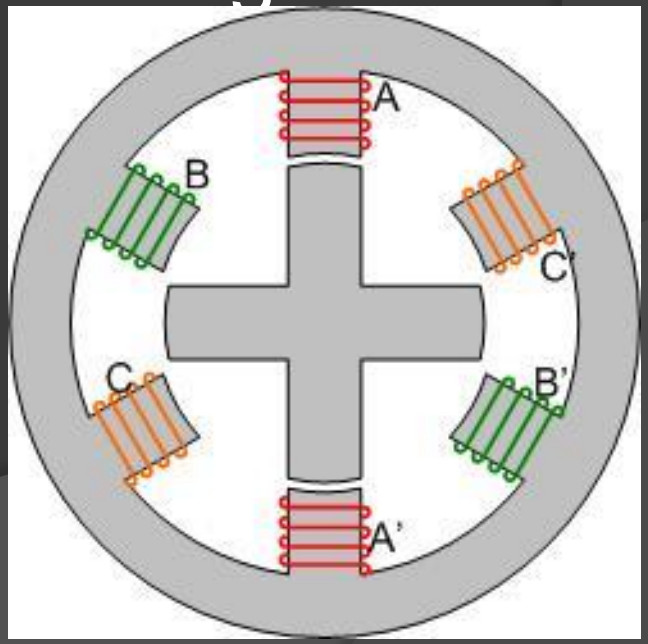
DC brushless motors (BLDC, ECM, ECDC)

- Stator made of coils,
  rotor made of permanent magnet
- External commutation – coil switching
  - need of knowing shaft position

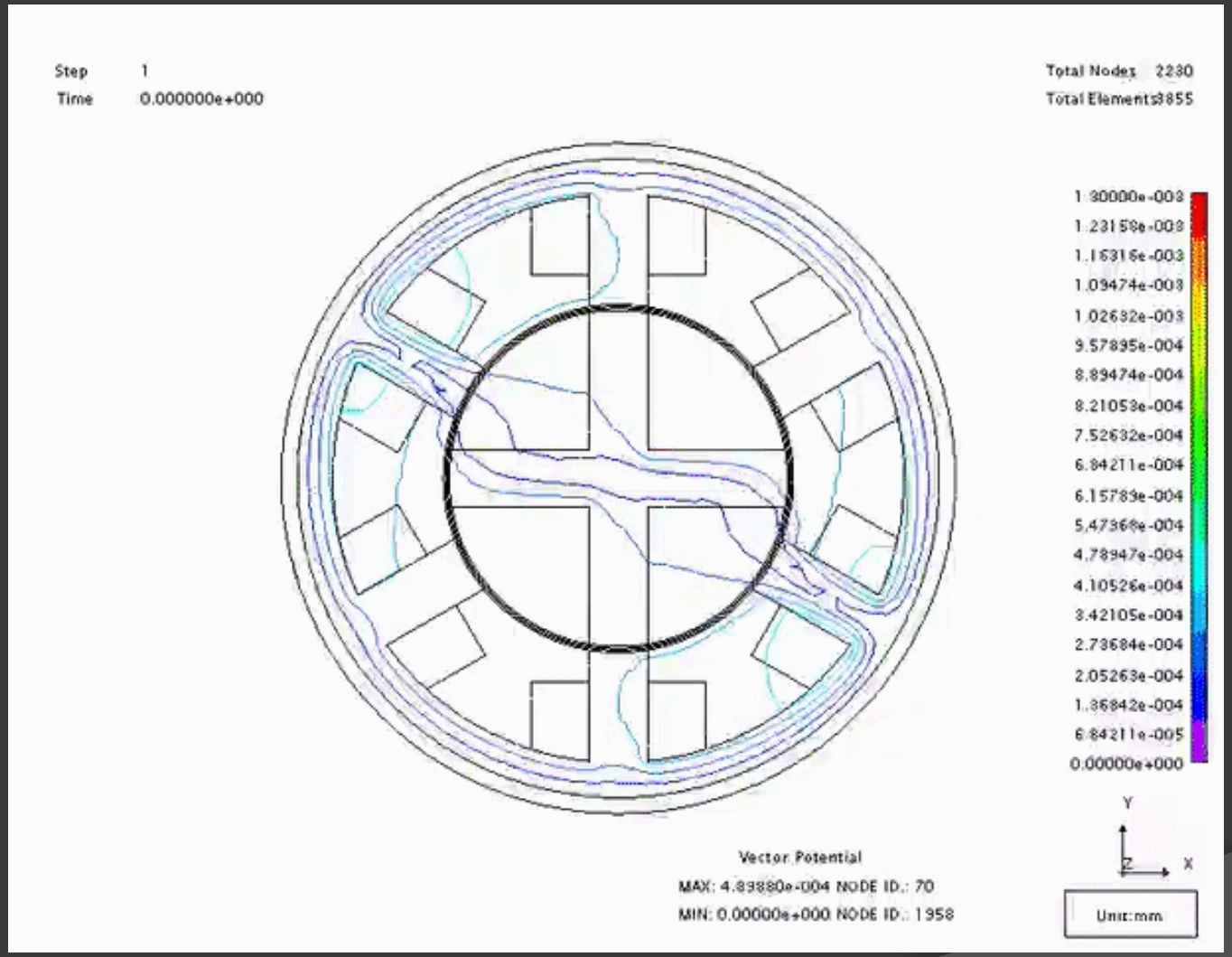


DC brushless motors (BLDC, ECM, ECDC)

- Stator made of coils,
  rotor made of permanent magnet
  - or SRM - switched reluctance motor
    (rotor made of magnetically weak material)
- External commutation – coil switching
  - need of knowing shaft position
    (Hall sensors or BEMF)



Switched Reluctance Motor



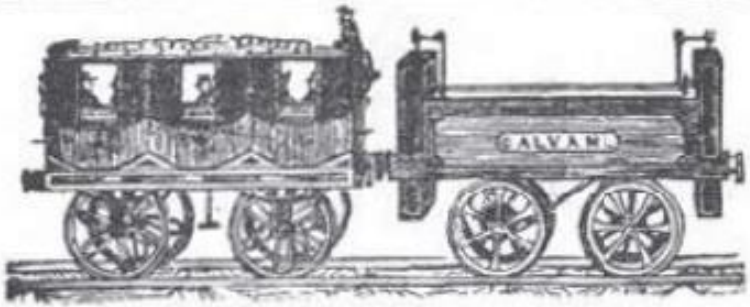
courtesy of Andy Knight, University of Calgary

ELECTRO-MAGNETIC

EXHIBITION,

UNDER THE PATRONAGE OF THE

Royal Scottish Society of Arts.



Mr. ROBERT DAVIDSON'S
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AS A MOVING POWER,

IS NOW OPEN!

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THE MODELS AND APPARATUS COMPRISE THE FOLLOWING:

A LOCOMOTIVE ENGINE,
Carrying Passengers on a Circular Railway.

A PRINTING MACHINE AND TURNING LATHE.

A SAW MILL.

A MACHINE for COMMUNICATING the ELECTRO-MAGNETIC SHOCK.

AN ELECTRO-MAGNET!
The largest ever made. It weighs upwards of 500 Pounds, and will suspend many Tons.

A GALVANIC TELEGRAPH.

THE COMBUSTION OF METALS,
Attended in each case with Splendid Coruscations, peculiar in color to the Metal operated upon, &c. &c.

MODEL OF THE FLYING MACHINE
In 800 small Wires forced into a Rope)

MODEL OF AN ÆRIAL CARRIAGE,
By Sir GEORGE CAYLEY.

OPEN FROM 12 TILL 6, AND FROM 7 TILL 9.

Admission, ONE SHILLING.

Children under 12 Years of Age, SIXPENCE.

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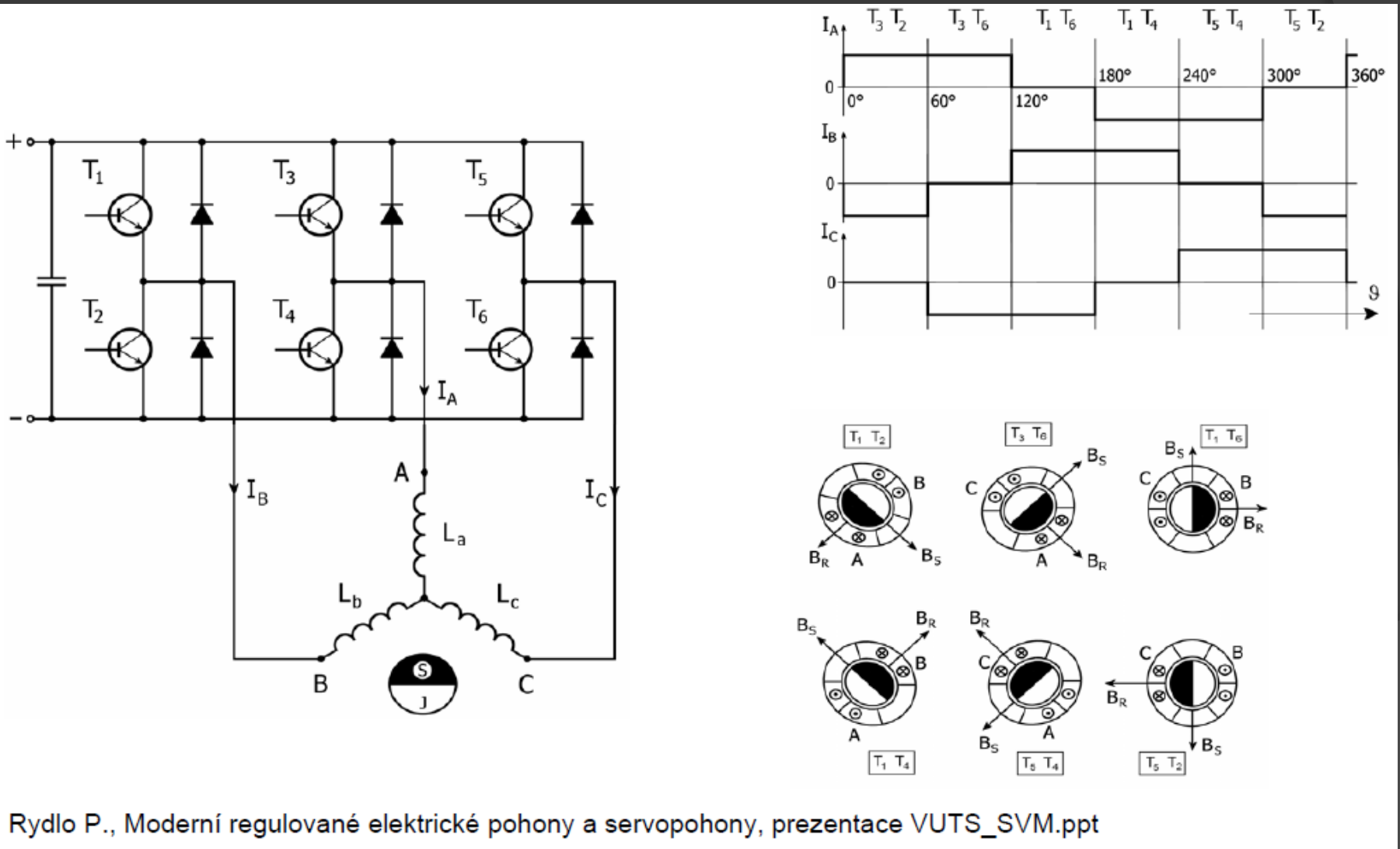
Electronic Commutation



Rydlo P., Moderní regulované elektrické pohony a servopohony, prezentace VUTS_SVM.ppt

DC brushless motors evaluation

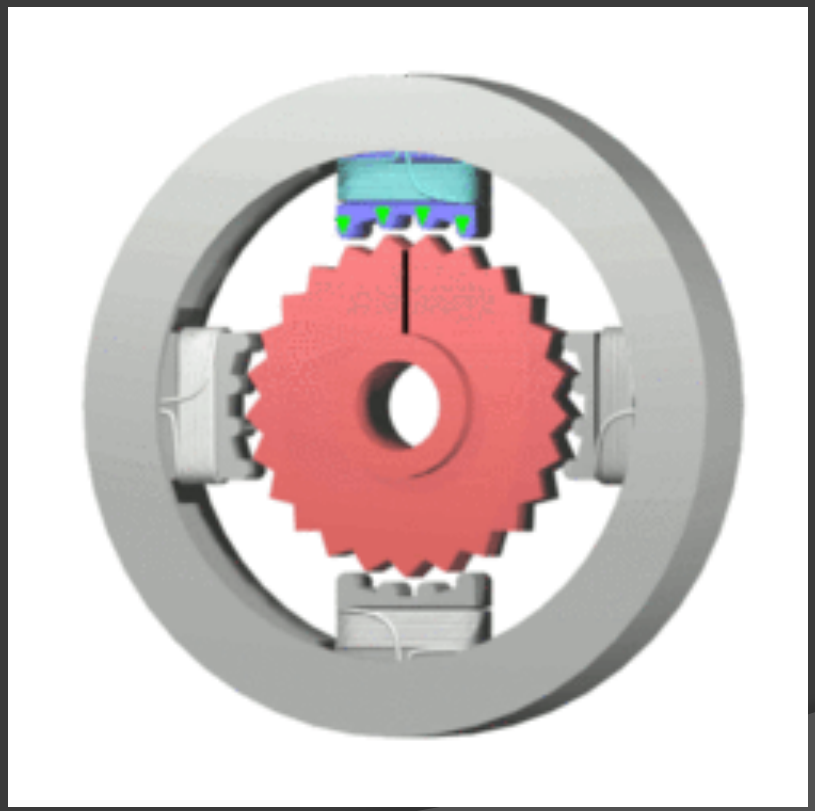
- Advantages:
  - fewer wearable parts, more reliable
  - lighter rotor, better dynamics
  - can operate at high rpm both loaded and unloaded
  - less noise and EMI than brushed
- Issues:
  - stability at low speeds
  - torque ripples

BLDC compared to BDC

- *B*rush*L*ess *DC* - electronic commutation
- Is it better than brushed?
  - linear and good proportion speed : torque
  - good proportion torque : size
  - dynamics (lighter rotor)
  - efficiency
  - speed
  - low noise
  - simpler maintenance

Stepper motors

- Stator made of coils, rotor made of magnet
- Toothed construction

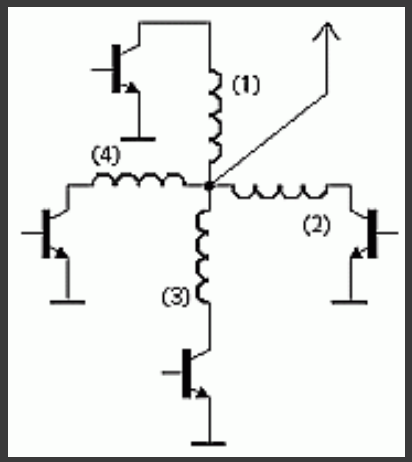


Stepper motors

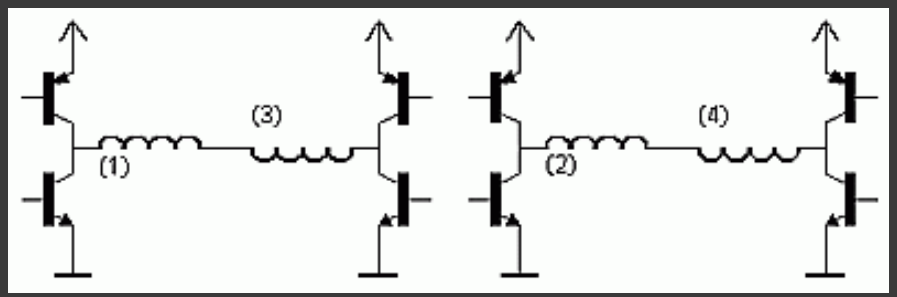
- Stator made of coils, rotor made of magnet
- Toothed construction

Typical wiring

- unipolar

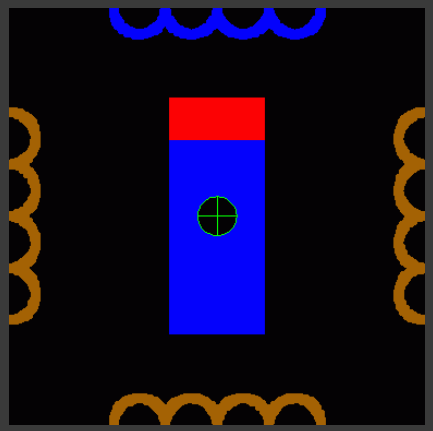


- bipolar

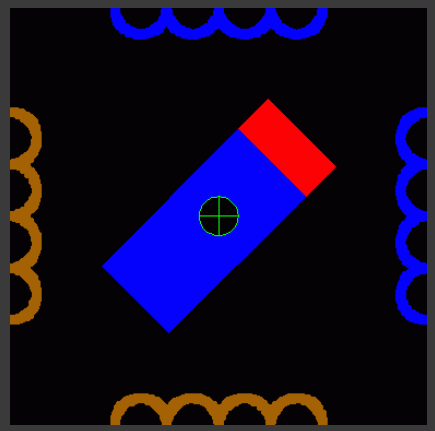


Stepping

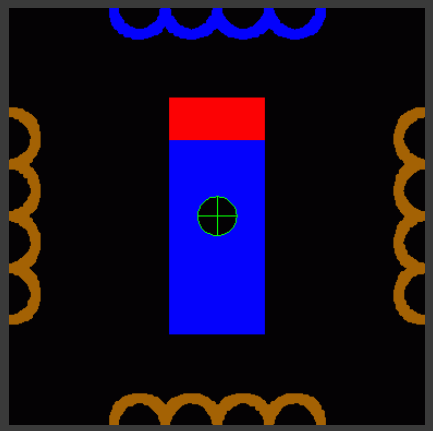
- 1f full



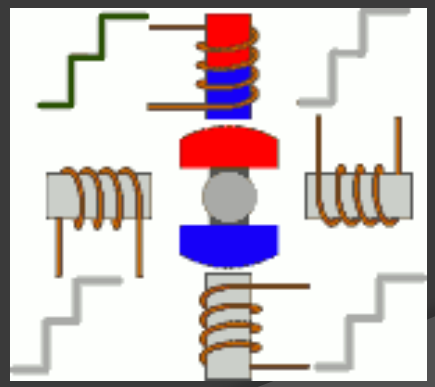
- 2f full



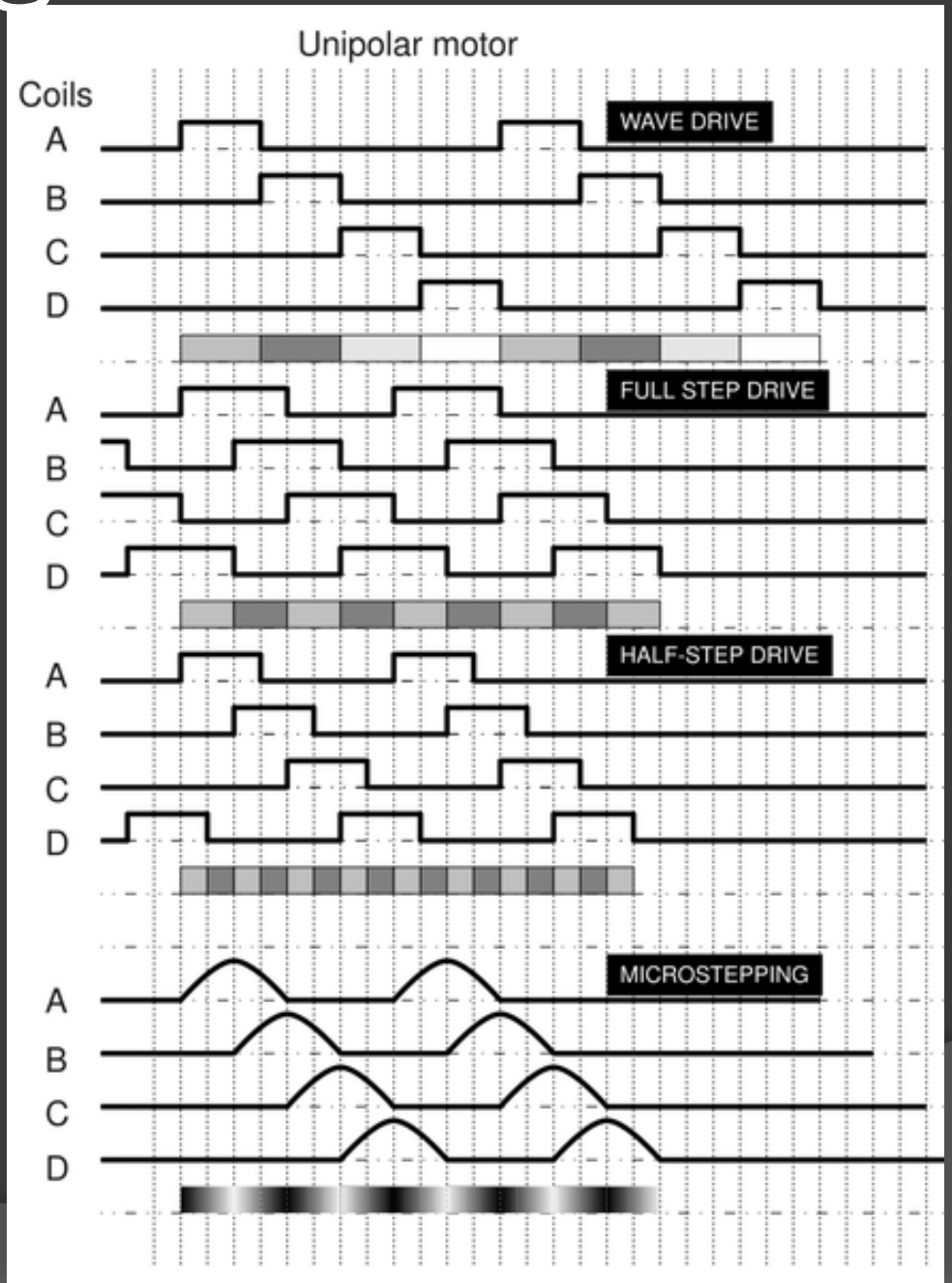
- half



- microstepping



Stepping


Unipolar motor
Coils
WAVE DRIVE
A
B
C
D
FULL STEP DRIVE
A
B
C
D
HALF-STEP DRIVE
A
B
C
D
MICROSTEPPING
A
B
C
D

Stepper motors evaluation

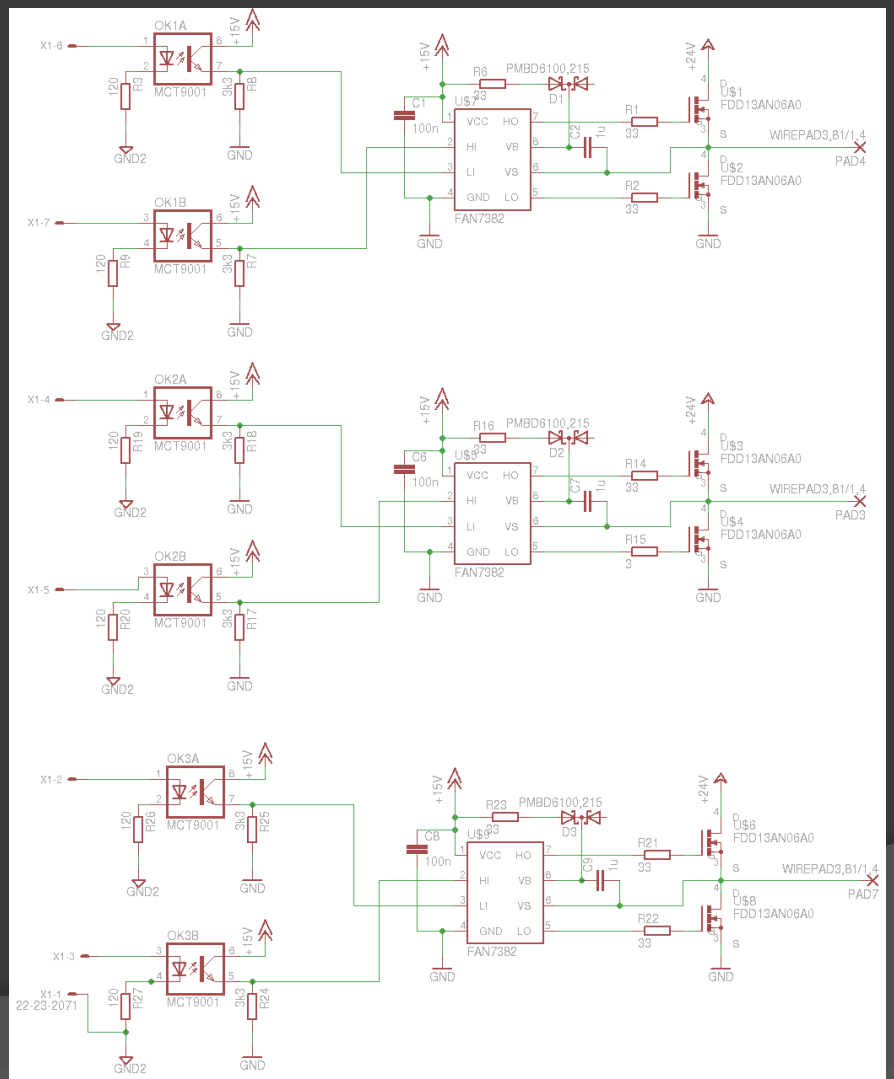
- Advantages
  - well suitable for precise positioning
  - low cost control, simple construction
  - open-loop control possible
- Issues
  - low efficiency
  - low torque at high speeds
  - bad dynamics

BLDC vs Stepper?

- both are brushless
- Typically (but *not* always):
  - BLDC just a few poles (max 8), Stepper more
  - BLDC closed-loop, Stepper open-loop
  - BLDC for higher revolutions, Stepper for lower
  - BLDC for rotation, Stepper for position

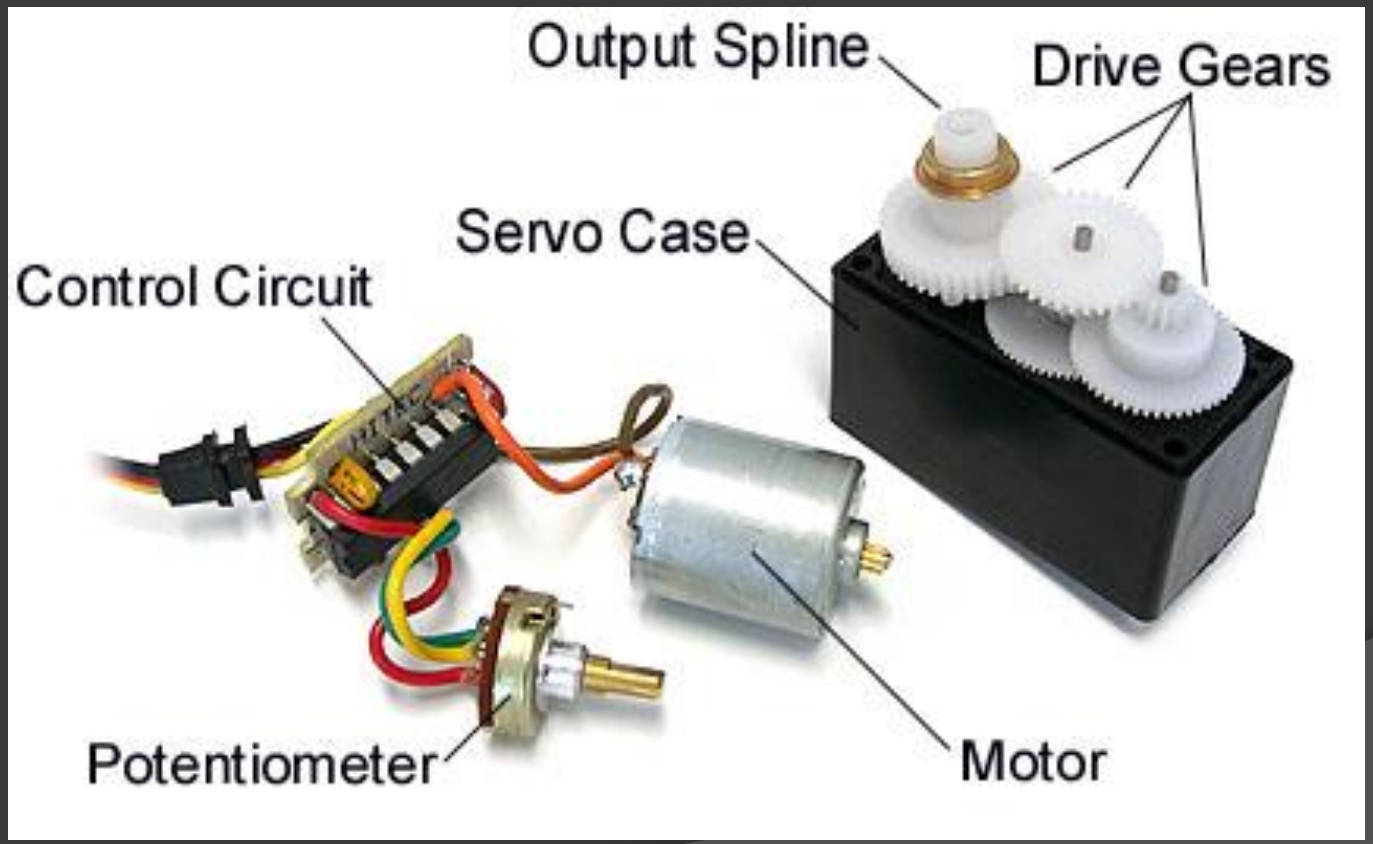
... continued
The idea is simple

- The devil is in the details



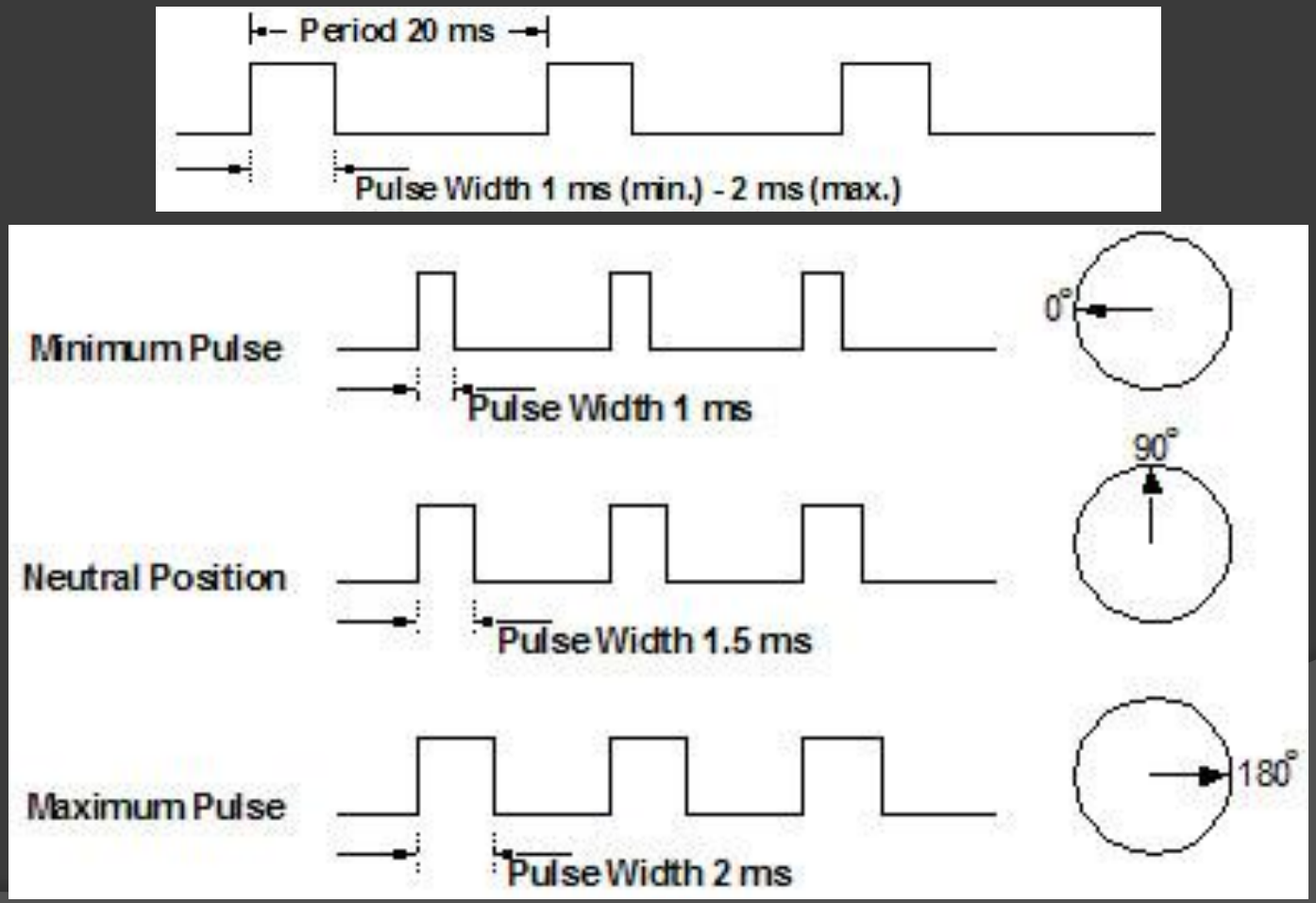
RC Servo

- DC motor + feedback

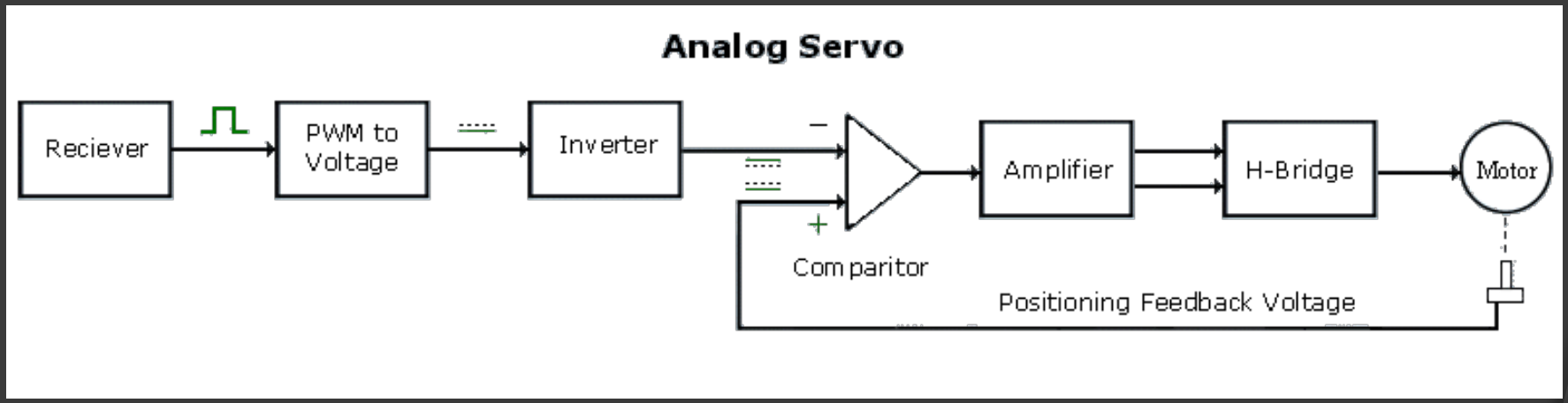


RC servo control signal

- “Standard” control

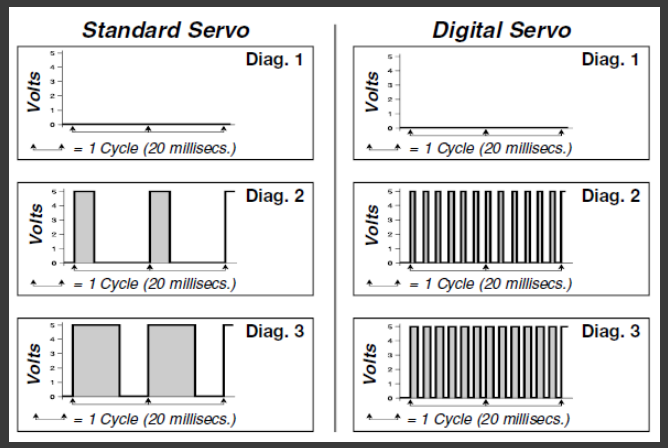


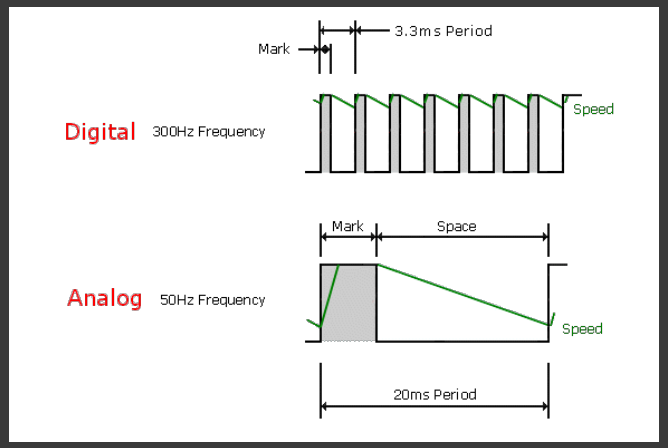
Analogue servo control loop



RC “Digital servo”

a) drop-in replacement of standard servo
   - just the electronics inside is not analogue





b) digital communication with the controller
   - programmable

Servo for continual rotation

- Indicative trimmer replaced by fixed resistors
  - Voltage divider, usually 1:1 (sometimes with adjustment)
  - PWM controls direction and speed:
    - 1.5ms – stop (the position corresponds to the middle)
    - <1.5ms – the measurement indicates the servo is in the middle position and the signal asks for something else ⇨ the servo will try to reach the position in one direction, the more away from 1.5ms, the faster.
    - >1.5ms – similarly in the opposite direction, the servo will try to reach the position, the more away from 1.5ms, the faster.
  - Fluent for “old analogue” servos
    may cause problems for “type a)” digital servos
    unusable for “type b)” digital servos