Electronics Essentials for 2.017

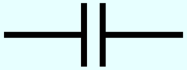
Reviewing Basics

- *Kirchoff's Voltage rule*: voltages V at a node are the same.
- *Kirchoff's Current rule*: sum of currents i flowing into and out of a node is zero.
- Analogy: Voltage is like fluid pressure, current is like fluid volumetric flow rate. The wire is like a pipe.

- Resistor R: V = IR,
  - Dissipation: Resistive Power $P = I^2R = V^2/R$
  - Analogy: viscous losses in pipe flow

Ohms, Ω

- Capacitor C: i = C dV/dt
  - Analogy: a hydraulic accumulator



farads, f

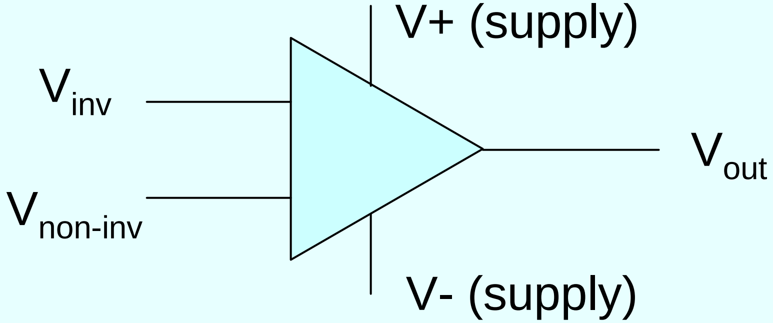
- Inductor H: V = L di/dt
  - Analogy: inertia of water in a pipe

henries, h

The Op-Amp

Two inputs (called inverting and non-inverting); one output.

The output voltage is a HUGE gain multiplied by the difference between the inputs.



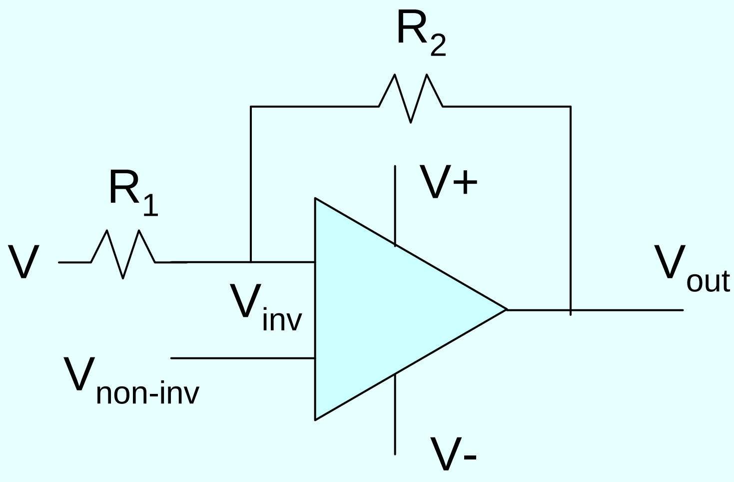
Horiwitz's & Hill's golden rules:

a. The op-amp enforces (in proper use)

$$V_{inv} = V_{non\text{-}inv}$$

b. No current flows into the device at either input

Example Op-Amp: Adding a Voltage Bias



$(V-V_{inv})/R_1 = (V_{inv}-V_{out})/R_2$ and
$V_{inv} = V_{non\text{-}inv}$ →

$VR_2 = V_{inv}(R_1+R_2) – V_{out}R_1$ →

$V_{out} = V_{non\text{-}inv} (R_1 + R_2)/R_1 – VR_2/R_1$

Letting R1 = R2, then

$V_{out} = 2V_{non\text{-}inv} – V$

The circuit inverts the input V and adds on $2V_{non\text{-}inv}$

IF V_{non_inv} is ground, then V_{out} is just –V. This is just an ***inverting amplifier.***

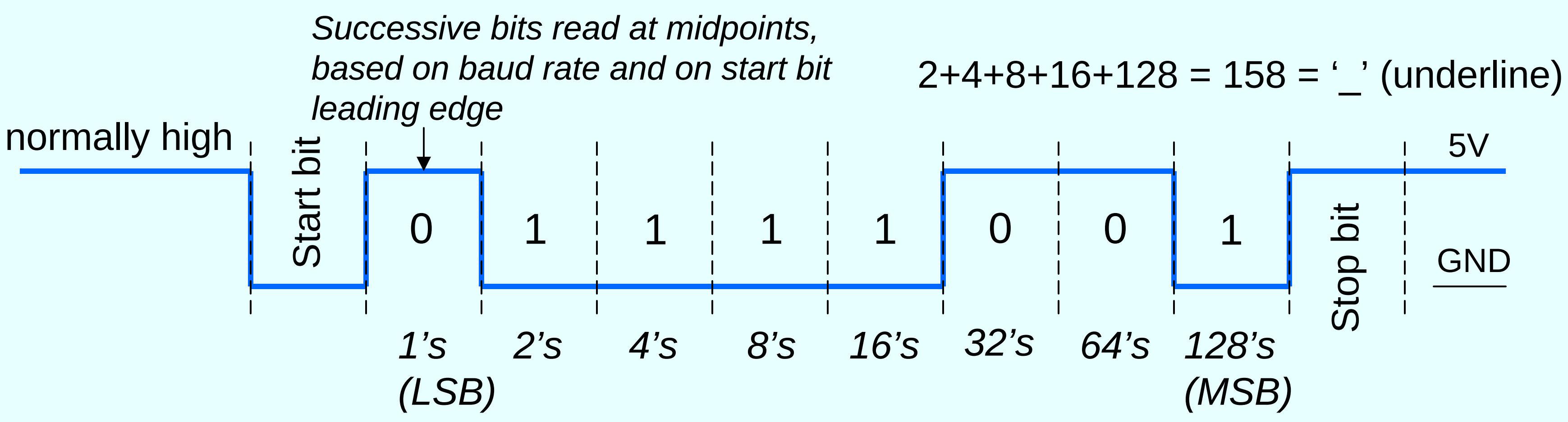
Voltage bias useful for bringing signal levels into the range of sensors.

The op-amp is discussed in detail by Horowitz and Hill, covering integrators, filters, etc.

Serial Communications

- *How to transmit digital information fast and reliably over a few wires?*
- Examples: RS-232, RS-485, etc. refer to pins & wires
- A minimal case of RS-232 (DB25 connector is full case):
  - Asynchronous operation; both sides agree on BAUD rate
  - Three wires: send (TX), receive (RX), ground
  - No error checking! No flow control!

EXAMPLE using CMOS components:



EXAMPLE: A GPS String

- Garmin GPS25 series – Smart embedded device!
- Similar to TT8's interface with you – I/O strings are passed through a serial port
- Reconfigurable through special commands
- Output at 1Hz
- String maintains <u>exactly</u> the same syntax: e.g.,

$GPRMC,hhmmss,V,
ddmm.mmmm,N,dddmm.mmmm,E,
000.0,000.0,ddmmyy,000.0,E,N,*XX<CR><LF>

➔ *73 chars appear as one line:*

$GPRMC,hhmmss,V,ddmm.mmmm,N,dddmm.mmmm,E,000.0,000.0,ddmmyy,000.0,E,N,*XX

Serial devices communicate using <u>characters</u> encoded into <u>bits</u>. This includes upper- and lowercase letters, carriage returns and linefeeds, punctuation, etc.

Characters are not numbers! E.g.,

char c = ‘7’ ;

char d[2] = ‘92’ ;

int n ;

The numerical value of **c** is [00110111] (binary) or 55 (decimal).

But because the ASCII characters ‘0’,’1’,’2’,’3’,’4’,’5’,’6’,’7’,’8’, and ’9’ occur in order, making simple conversions is easy:

n = c – ‘0’ ;

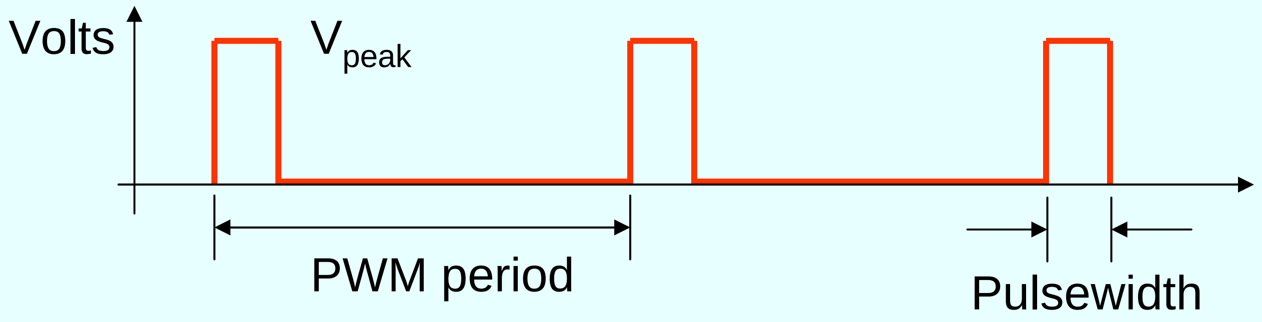
assigns to **n** the actual number 7. The ASCII character that goes with 7 is known as BEL – on many machines this will ring a bell if it is sent to the screen as a character! – **printf(“%c”,n)** ;

How to turn d[2] into a number?

n = 10*(d[0] - ’0’) + (d[1] - ’0’) ;

Pulse Width Modulation

- A Regular Waveform



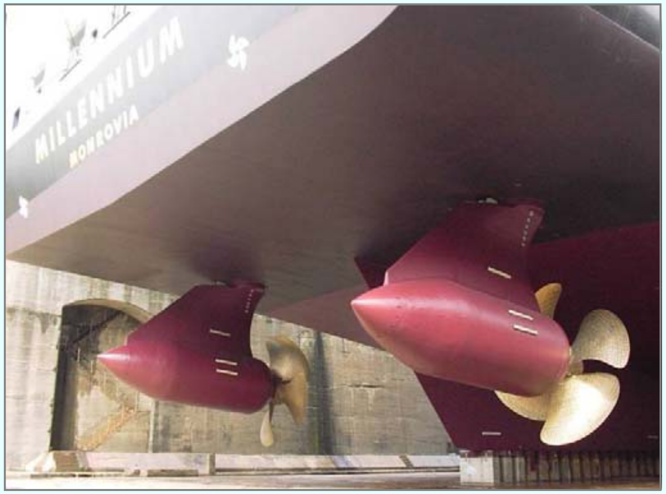
- PWM frequency (Hz) = 1 / PWM period
- Duty cycle = Pulsewidth / PWM period
- PWM frequencies typically range from 100Hz into MHz
- Duty cycles can be used from 0 – 100%, although some systems use much smaller ranges, e.g. 5-10% for hobby remote servos.
- The waveform has two pieces of information: Period and Pulsewidth, although they are usually not changed simultaneously.

Some PWM Uses

- The Allure: very fast, cheap switches and clocks to approximate continuous processes. Also, two-state signal resists noise corruption.
- <u>Sensors</u>: PWM period is naturally related to *rotation or update rate*: Hall effect, anemometers, incremental encoders, tachometers, etc.
- <u>Communication</u>: PWM duty cycle is *continuously variable* → like an D/A and an A/D.
- <u>Actuation</u>: At very high frequencies, physical systems filter out all but the mean; i.e.,

$$V_{effective} = duty\_cycle * V_{peak}$$

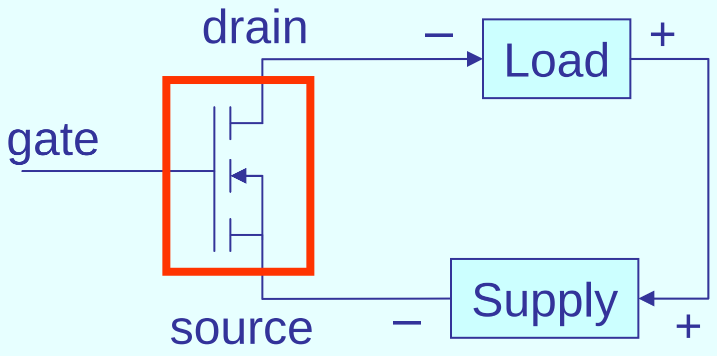
High frequency switching is the dominant mode for powering large motors!



Field Effect Transistor (FET)

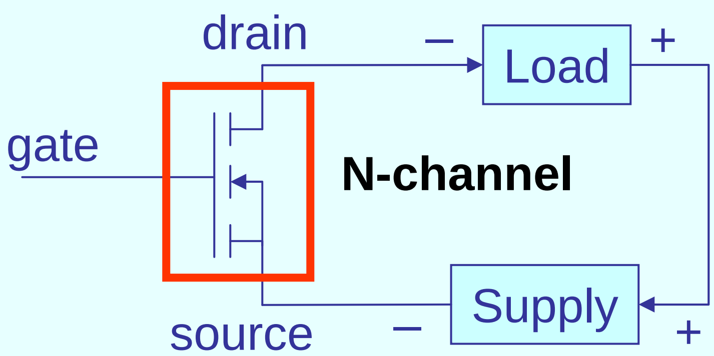
- Like a “valve”, that is very easy to open or close. When FET is open, resistance is low (milli-Ohms); when FET is closed, resistance is high (mega-Ohms or higher)

- Typically three connections:
  - Gate: the signal; low current
  - Source: power in
  - Drain: power out

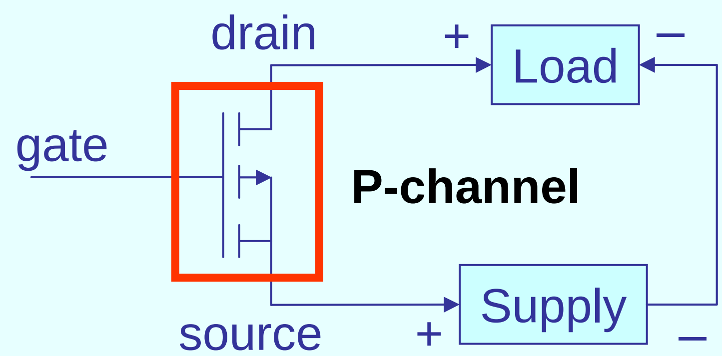


- *N*- and *P*-type junctions are common, and involve the polarity of the device. (*N* is shown)
- Extremely sensitive to static discharge! *Handle with care.*
- MOSFET: modern FET’s capable of handling higher power levels.

Bipolar Control with a MOSFET H-Bridge



MOSFET turns on when $V_{gate} > V_{source}$



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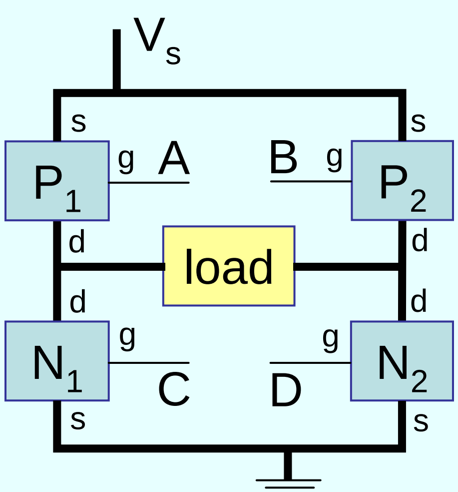
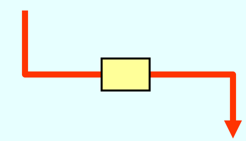
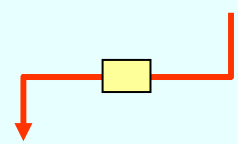


To make flow UL to LR,
set A = GND and D = V_s



To make flow UR to LL,
Set B = GND and C = V_s



Connect A and B to V_s with pull-up resistors;
Connect C and D to GND with pull-down resistors;
Control all four gates explicitly

The Basic DC Brush Motor

Torque τ ←→ (coils)(flux density)(current *i*),
or, in a given motor,

$\boldsymbol{\tau = k_t * i}$ where k_t is the <u>torque constant</u>

But the motion of the coils also induces a voltage in the coil, the <u>back-EMF</u>:

$\boldsymbol{e_b = k_t * \omega}$ *(YES, that's the same k_t!)*

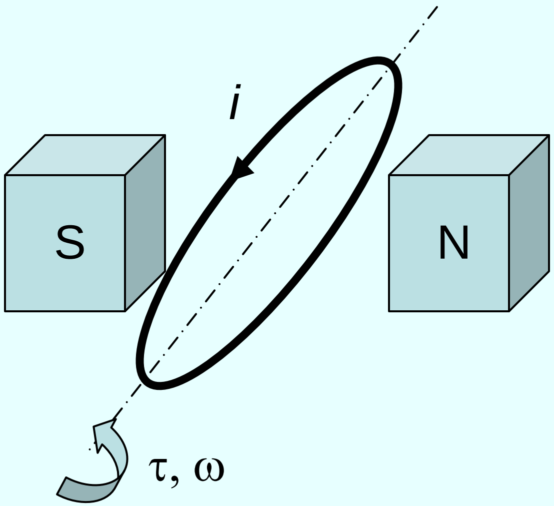
And the windings have a resistance *R*:

$\boldsymbol{e_R = R * i}$

Summing voltages around the loop,

$\boldsymbol{V_{supply} = e_b + e_R}$

Vector relations:
force = current x flux
field = velocity x flux



Properties of the DC Brush Motor

- No-load speed:

  $\tau = 0 \rightarrow i = 0 \rightarrow$ $\boldsymbol{\omega = V / k_t}$

- Zero-speed torque (*BURNS UP MOTOR IF SUSTAINED*):

  $\omega = 0 \rightarrow e_b = 0 \rightarrow i = V / R \rightarrow$ $\boldsymbol{\tau = k_t V / R}$

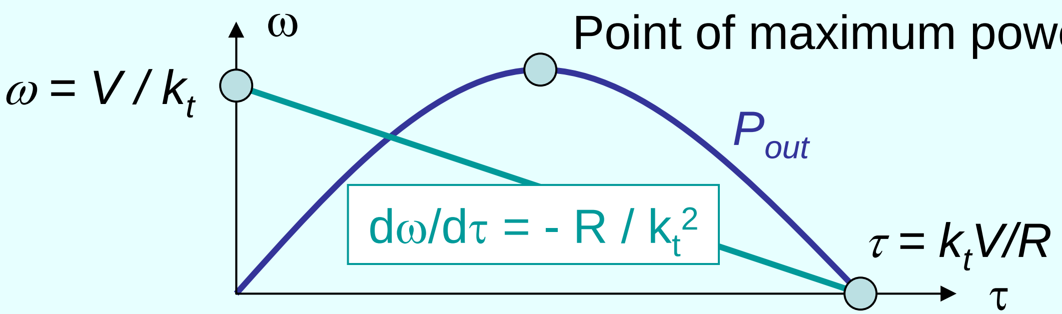
- Power output:

  $P_{out} = \tau \omega = i e_b \rightarrow$ $\boldsymbol{P_{out} = i (V - Ri)}$

- Efficiency:

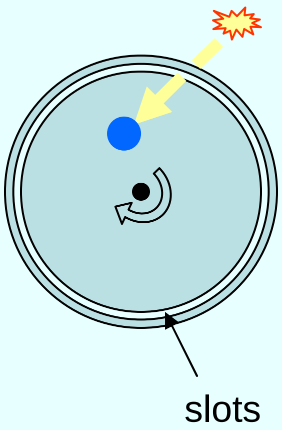
  $\eta = P_{out} / P_{in} = \tau \omega / i V \rightarrow$ $\boldsymbol{\eta = 1 - i R / V}$

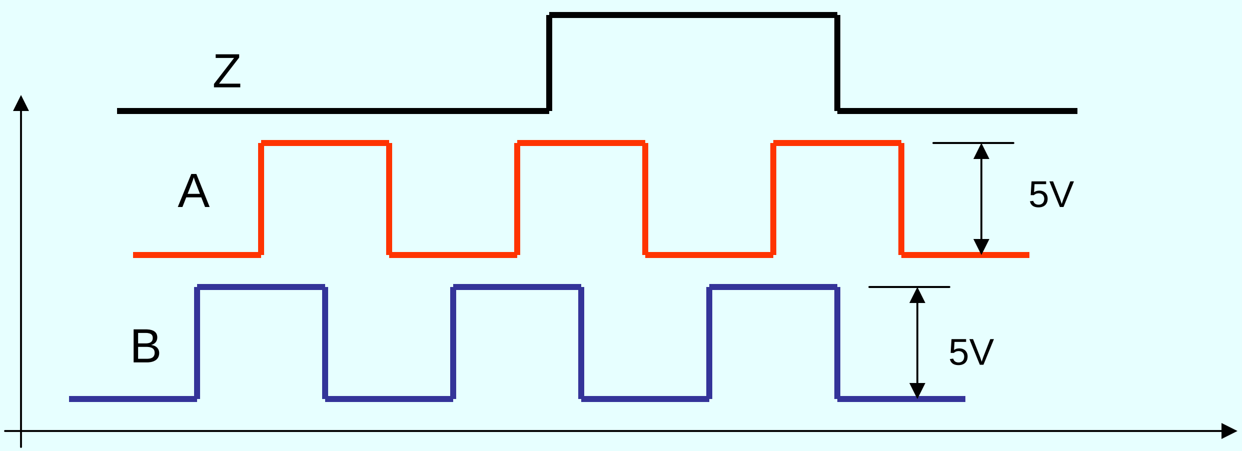
Point of maximum power: $\tau = k_t V / 2 R$



Incremental Encoders for Control

- *What is the position of the motor?*
- Take advantage of cheap, fast counters → make a large number of pulses per revolution, and count them!
- Advantages of the incremental encoder:
  - High resilience to noise because it is a digital signal
  - Counting chip can keep track of multiple motor turns
  - Easy to make – phototransistor, light source, slotted disk
- Two pulse trains required to discern direction: *quadrature*



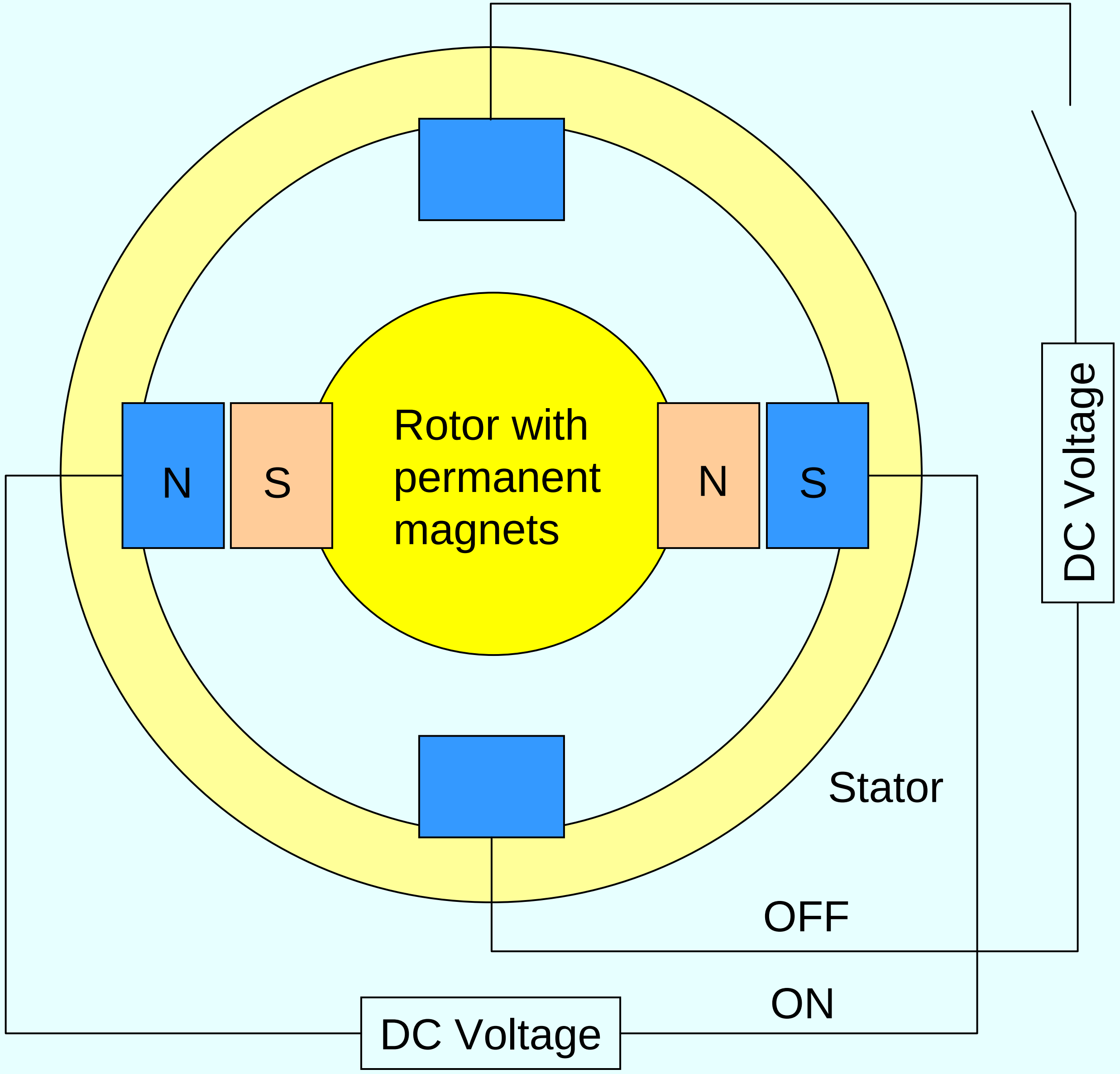


Stepper Motors

Switched coils at fixed positions on the stator attract permanent magnets at fixed positions on the rotor.

Smooth variation of switching leads to half-stepping and micro-stepping

Encoder still recommended!



2.017J Design of Electromechanical Robotic Systems
Fall 2009