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Computer Systems / Rekenaarstelsels 245

Lecture 29

Actuation: Switches and Motors/
Aksies: Skakelaars en Motors

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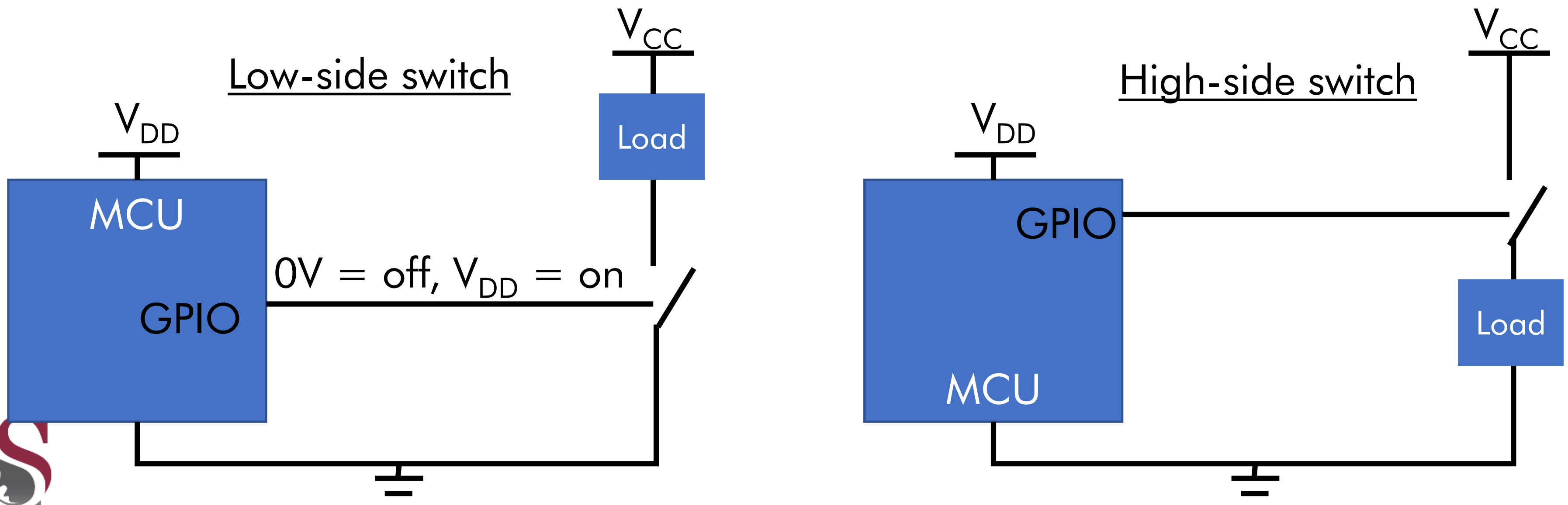
Microcontroller Actuation
Mikrobeheerder Aksies

- Microcontroller systems usually have to make things change in the real world
  - Move a robot arm
  - Switch on a fan or heater element
  - Speed control of the quad-copter motors (than turn the propellers)
  - Switch on/off an electromagnet to open or close a lock
- (Actuation usually also involves feedback of some sort – position or speed sensor, temperature, etc.)
- Actuation usually involves high current – and microcontrollers are low current devices
- As a result, there will be some other electronic components involved
  - Power switch
  - Motor driver
  - H-bridge
- Most of the time, the microcontroller simply outputs GPIO signals (on/off), or PWM

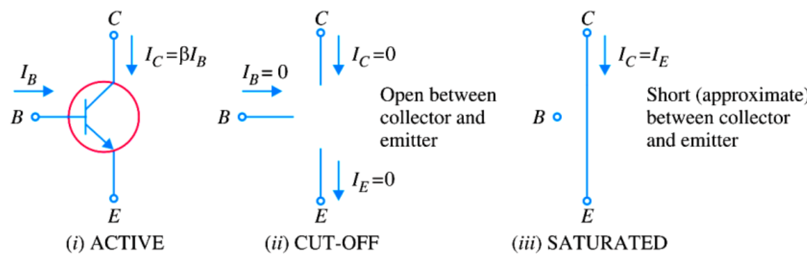
Switches
Skakelaars

- In general, we need a microcontroller-enabled switch to switch power to a load on or off, where the load
  - Requires higher current than the MCU can provide
  - Requires a higher supply voltage than what the MCU uses
  - (usually both of those)
- Low-side switch: switch occurs between ground and the load
- High-side switch: switch occurs between VCC and the load

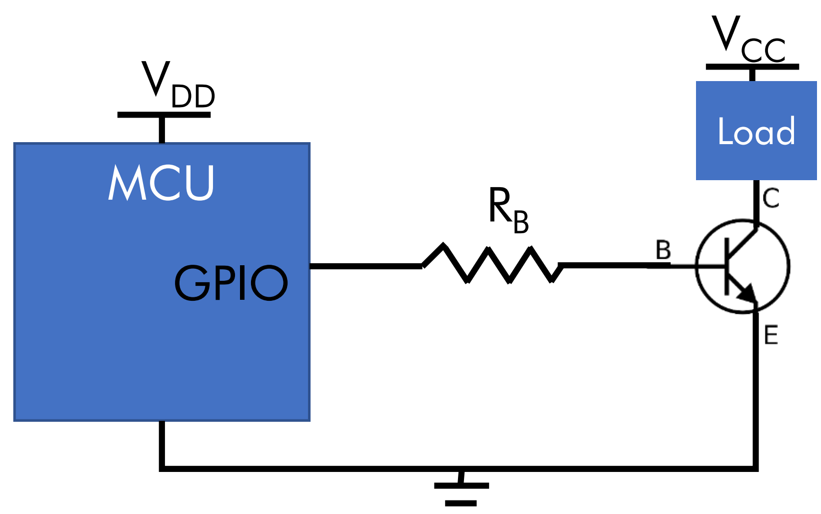


Switches – BJT
Skakelaars

- Switches are easily implemented using transistors
- Using BJTs (Binary Junction Transistor):
  - Operated in cut-off (OFF) and saturation (ON) regions



  - Low-side BJT uses NPN transistor. (High-side BJT switch uses PNP)
  - Selection of R_B and transistor (β):
  - To turn on in saturation,
    - I_C has to equal $I_{LOAD} = V_{CC}/R_{LOAD}$
    - I_B has to equal (at least) I_{LOAD}/β
    - And since $I_B = V_{DD}/R_B$ (when on)
    - R_B has to be smaller than $V_{DD} \cdot \beta / I_{LOAD}$

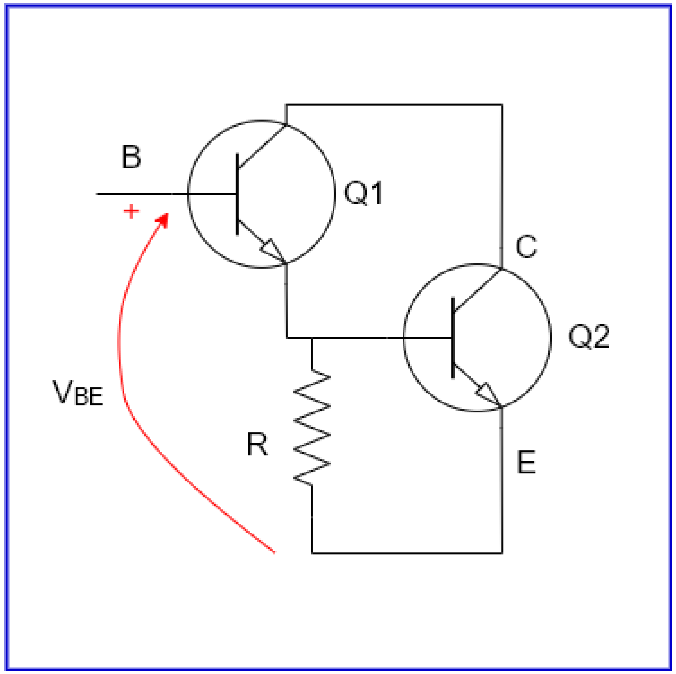


Switches – BJT
Skakelaars

- Example: I_{LOAD} = 1A (V_{CC} = 10V, R_{LOAD} = 10 ohm), β = 100
- I_B has to be at least 10mA, and for VDD = 3.3V, R_B has to be less than 330 ohm

- BJTs dissipate power (voltage across collector and emitter in saturation mode)

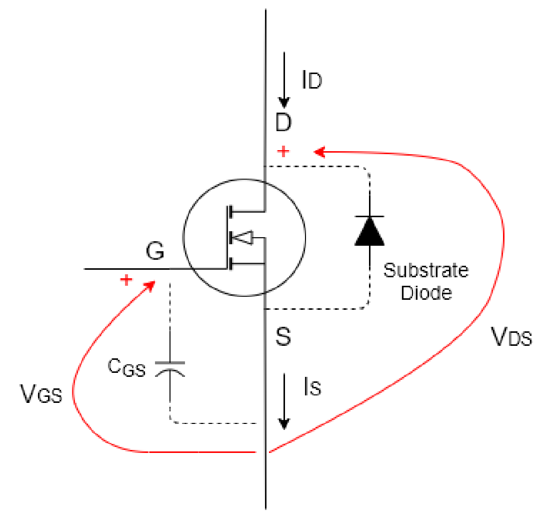
- BJT power transistors usually don't have β larger than 50
- If GPIO max current (I_B) is max 20mA, the largest load current that it can switch is ~1A
- Use "Darlington pair" configuration when higher current has to be switched



https://predictabledesigns.com/how-to-switch-large-loads-with-a-microcontroller-using-transistors/

Switches – MOSFET
Skakelaars

- MOSFETs switch based on gate-source voltage V_{GS} (not switched by current current)
- Almost no current flows from GPIO pin to keep switch on – much higher current can be switched on using a MOSFET
- Low-side switch uses N-Channel, high-side uses P-Channel
- MOSFETs don't have a drain-to-source saturation voltage drop (like BJTs). Instead they have a drain-to-source resistance (R_{DS}) which is a function of V_{GS}
- Power MOSFETs have much lower power dissipation

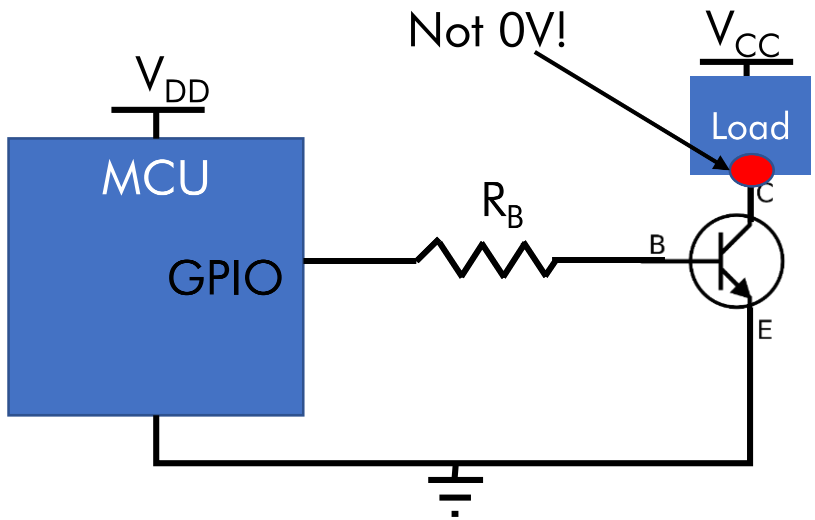


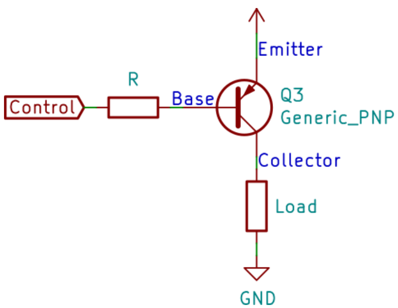
N-Ch enhancement-type MOSFET

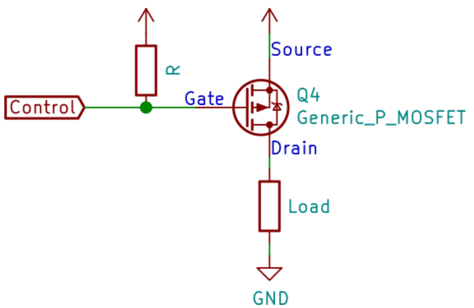
- Possible issue with power MOSFET is the gate-to-source capacitance – the microcontroller GPIO current is low, so it might take a while for the gate capacitance to charge up → switching time is lower than with BJT.
- This might be an issue with fast PWM.

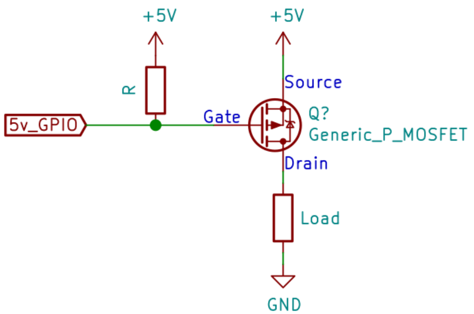
Switches – Low-side vs. High-side
Skakelaars

- Low-side transistor switches are easiest to implement
- But because there is a voltage across collector-emitter ($V_{CE\text{-}sat}$) or drain-source (V_{DS}) the load low voltage will not be at 0V
- For some loads this is OK, but if it matters you need a high-side switch
  - PNP BJT
  - P-channel MOSFET
- Logic is inverted for high-side MOSFET switch
- Load supply voltage cannot be higher than input (GPIO) voltage, otherwise the switch will never turn off – in such a case you need additional driver



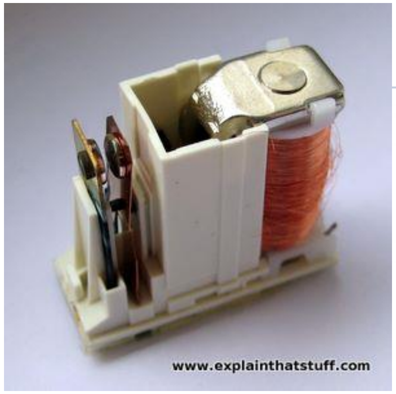


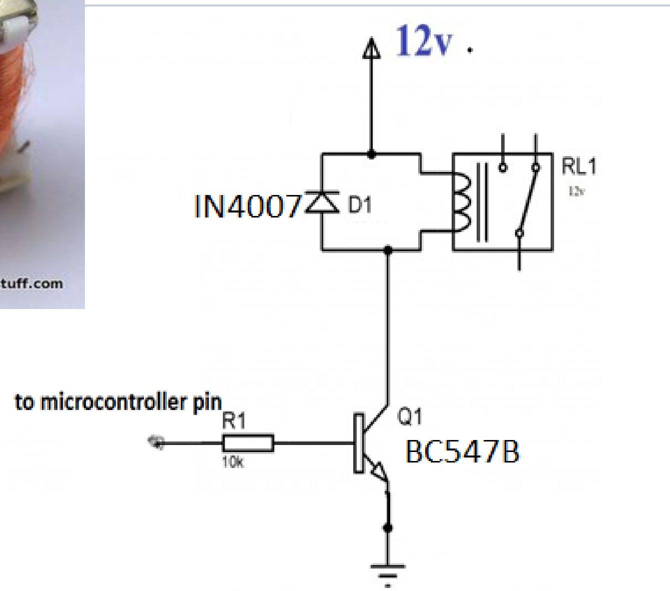




Switches – Relays
Skakelaars

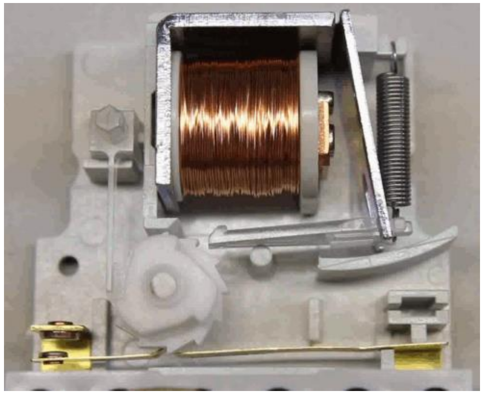
- Relays can switch arbitrary high current and voltage
- Relays have physical contacts that open/close using electromagnet actuator. From the microcontroller side, we control the electromagnet
- Typical configuration used to switch 220V AC signals using a microcontroller





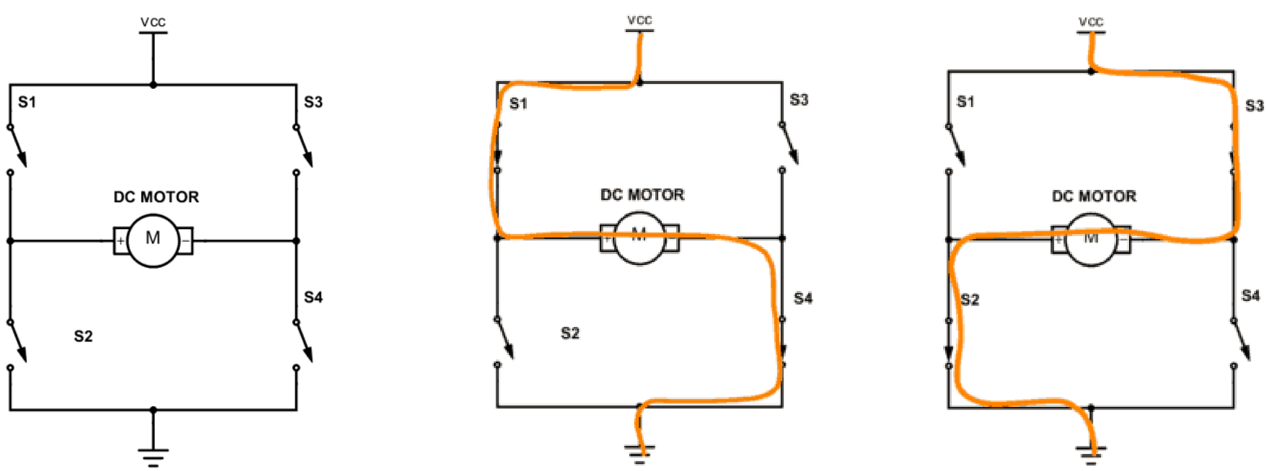
- You still can't drive the electromagnet directly from the microcontroller GPIO – use a transistor switch
- You also need to have a "flyback diode" – switching off the coil causes voltage spike due to inductor current – may cause arc or EM noise. The flyback diode allows current in coil to dissipate

- Some relays are "latching" – they only need current to switch, but not to keep the switch closed
- They are mechanical components – they wear out after a while. Cannot use with PWM



Switches – H-bridge
Skakelaars

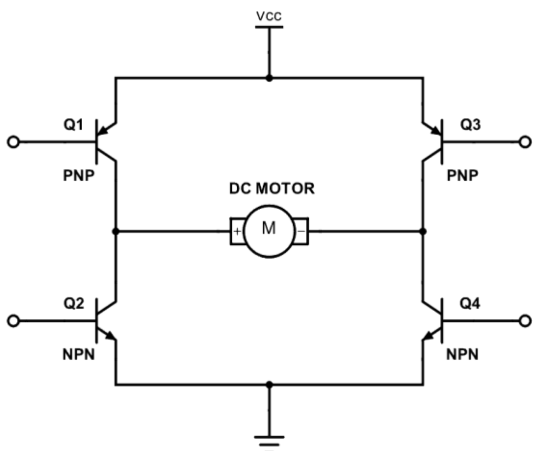
- H-Bridge: Arrangement of 4 switches to allow current to flow through a load in both directions
- Quite useful (and necessary) for motor control
- Closing appropriate switch combinations result in positive and negative current through the load

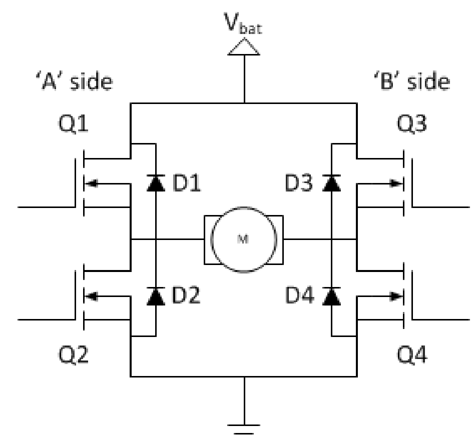


- Close S1 and S4 → Current flows in one direction
- Close S2 and S3 → Current flows in the other direction
- Close S1 and S3 at the same time, or (S3 and S4) → Smoke comes out!

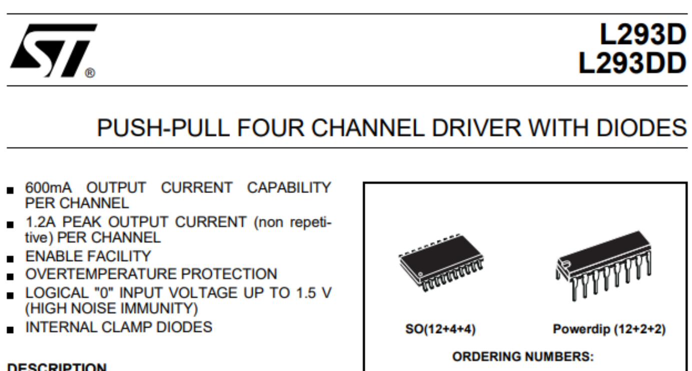
Switches – H-bridge
Skakelaars

- H-Bridges are implemented using BJT or MOSFET transistors
- (combination of NPN+PNP, or P-Channel and N-Channel)





- Available in packages (ICs)
- Sometimes only the H-bridge transistors (and diodes)
- Sometimes includes other wheel control electronics – wheel driver IC



L293D
L293DD

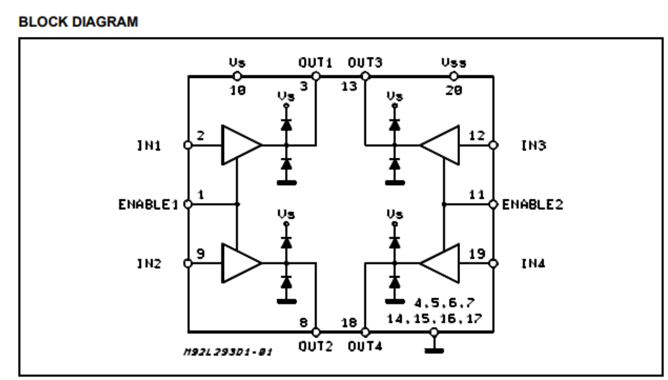
PUSH-PULL FOUR CHANNEL DRIVER WITH DIODES

- 600mA OUTPUT CURRENT CAPABILITY PER CHANNEL
- 1.2A PEAK OUTPUT CURRENT (non repetitive) PER CHANNEL
- ENABLE FACILITY
- OVERTEMPERATURE PROTECTION
- LOGICAL "0" INPUT VOLTAGE UP TO 1.5 V (HIGH NOISE IMMUNITY)
- INTERNAL CLAMP DIODES

SO(12+4+4) Powerdip (12+2+2)

ORDERING NUMBERS:

DESCRIPTION



Motor Control
Motor Beheer

General

- Motors require high currents – usually microcontroller signals are used as input to driving electronics
- Motor and microcontroller needs separate supplies, so that motor glitches, noise, back EMF, does not interfere with microcontroller power supply
- (Also, motors need higher supply voltage, and MCUs operate from lower supply to conserve power)
- Usually used in conjunction with some feedback – motor speed control, or motor position control – microcontroller needs measurement of speed or position.

Motor Control
Motor Beheer

DC Motors

- Brushed DC motor
- Brushless DC motors (BLDC motor)
- Stepper motors
- Servos

Brushed DC Motors
GS Motors met Borsels

Brushed DC Motors

- Permanent magnets in housing – called the stator
- Rotor/armature connects to shaft, and rotates inside housing
- Terminal wires connect to "brushes". This is a stationary part, and the brushes that touches "commutator" (rotates with the armature)
- DC voltage applied to the terminals causes rotor windings to induce a magnetic field – rotor rotates to align with the field from permanent magnets
- At some point, the commutator would have rotated enough so that brushes will connect with other winding – reversed magnetic field, and rotor keeps on spinning
- Voltage applied to terminals determine rotation speed or torque
- Rotation direction is reversed by applying voltage in the opposite direction

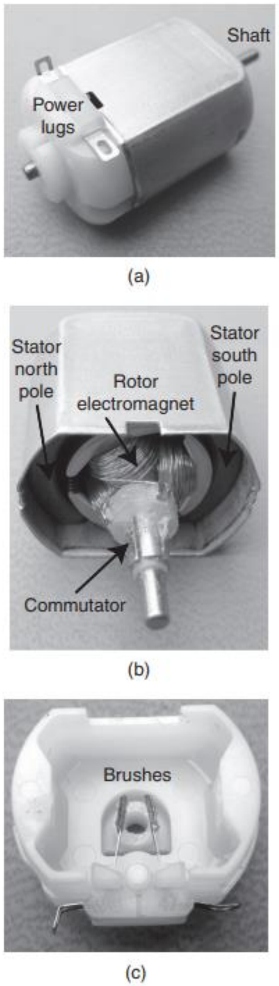
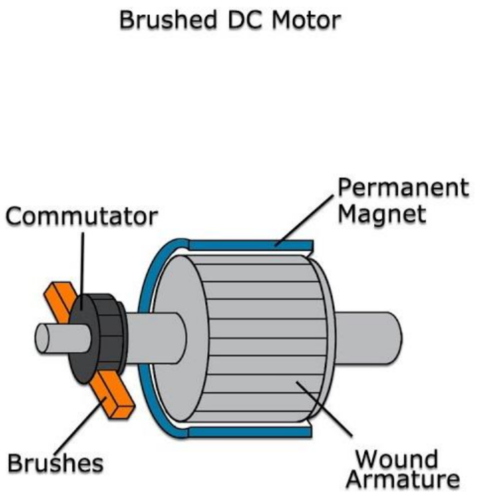
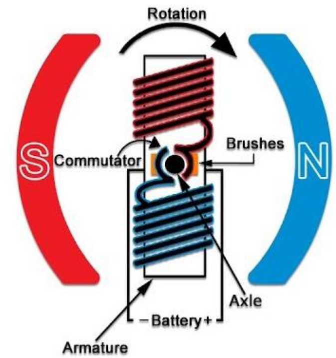


Figure e9.33 DC motor





Motor Control – Brushed DC motors
Motor Beheer – GS Motors met Borsels

- Brushed DC motors are controlled through microcontroller and H-bridge

A	B	C	D	
Closed	Open	Open	Closed	Spin in one direction
Open	Closed	Closed	Open	Spin in opposite direction
Open	Open	Open	Open	Rotor "coasts"
Closed	Open	Closed	Closed	Actively break
Open	Closed	Open	Closed	Actively break

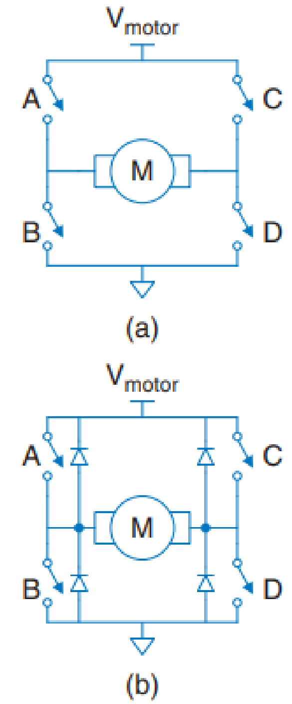


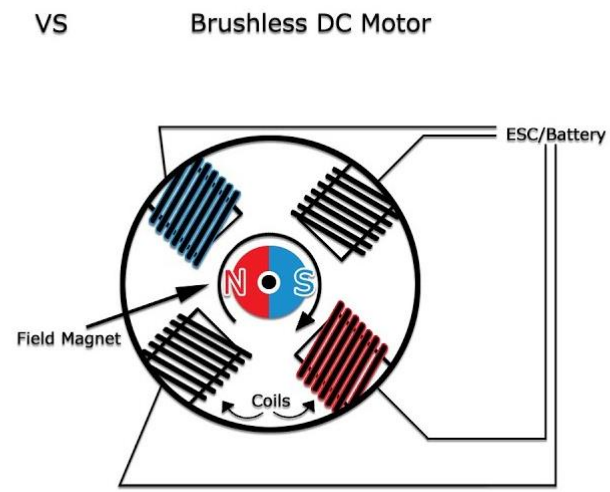
Figure e9.34 H-bridge

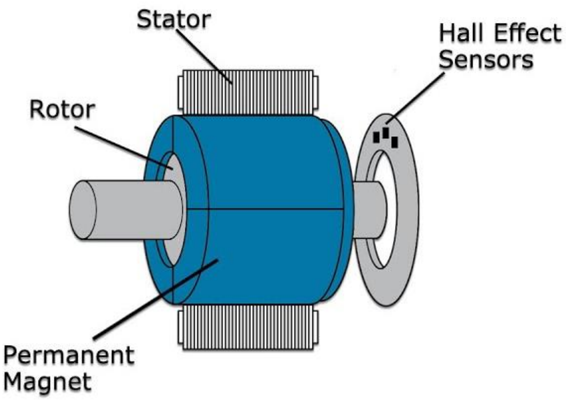
- Protection diodes serve the same purpose as "flyback diode" – prevent voltage spikes when current is switched off or reversed
- Microcontroller controls switches A, B, C and D directly through GPIO, or PWM (or using motor driver IC)
- PWM is used for variable acceleration/speed/torque control. Motor coils are inductors, and will smooth voltage pulses

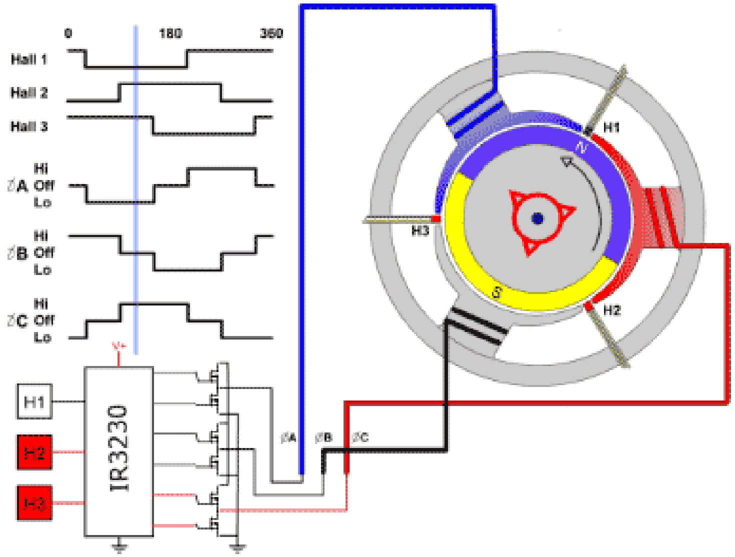
Brushless DC Motors
Borsellose GS Motors

Brushless DC Motors

- Permanent magnets on rotor
- Magnetic field is manipulated by selectively powering coils fixed to stator/housing
- Commutation (flipping of magnetic field) thus happens electronically
- Microcontroller or the device driving the motor has to know how far the rotor has rotated, so that it can know when to power the other coil
- Hall effect sensors in stator senses the rotated position of the rotor
- More efficient but also more complicated to drive/control



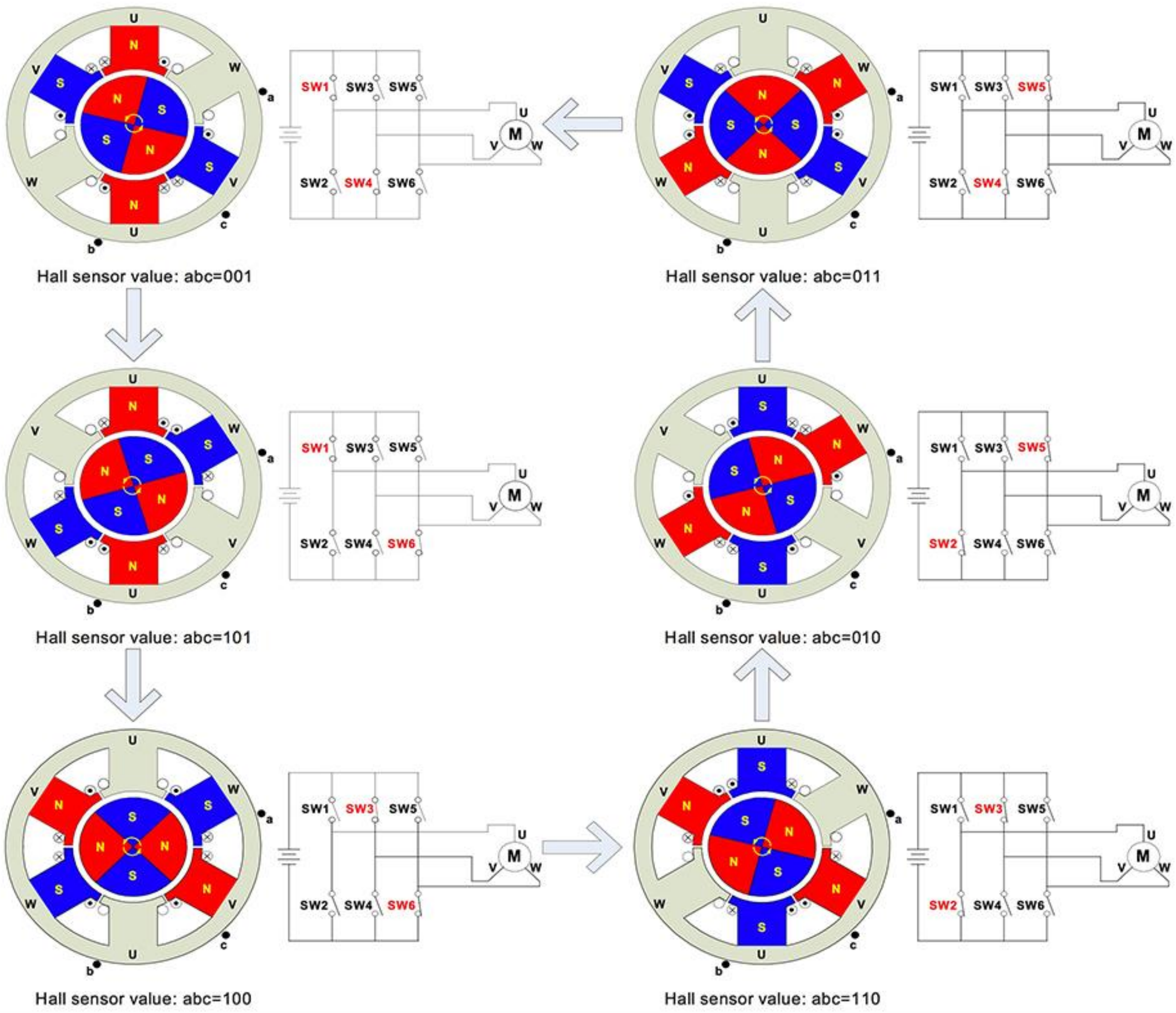




Motor Control – BLDC Motors
Motor Beheer – Borsellose GS Motors

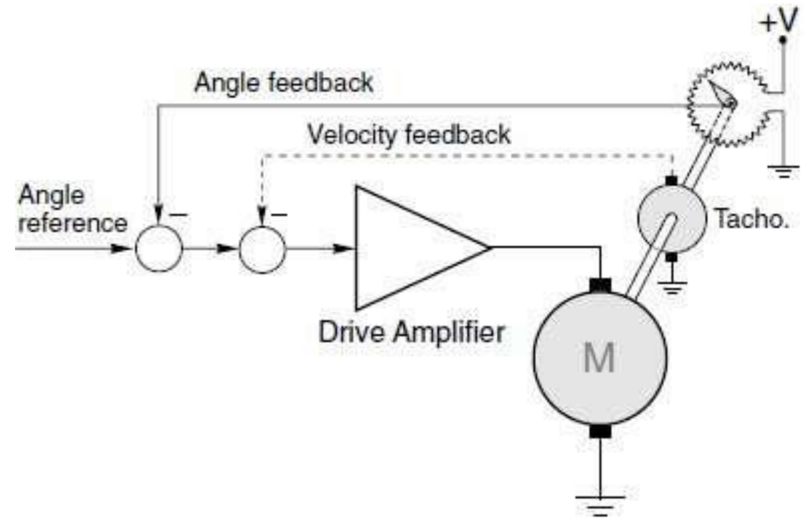
Brushless DC Motors

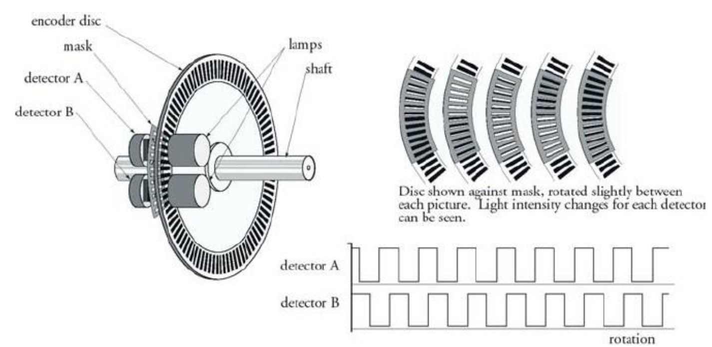
- Use half-H-bridge for each switch pair
- Microcontroller controls the SW1..SW6 switches – through GPIO/PWM
- Microcontroller also needs to sample Hall effect sensors (GPIO Input, possibly with external interrupt)
- Quite timing intensive – most likely a dedicated microcontroller just for this.
- Offload some of the requirements to a dedicated BLDC driver IC with higher-level interface

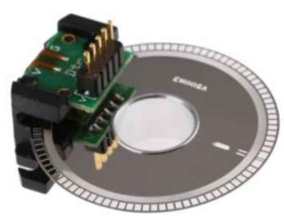


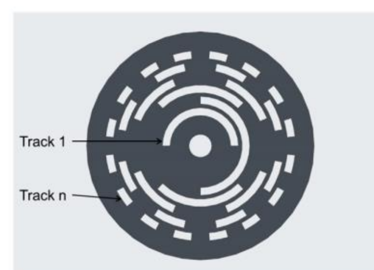
Motor Control – Feedback
Motor Beheer – Terugvoer

- A motor actuation system needs to know
  - What angle did the robot arm rotate through (absolute angle feedback)
  - How fast is the motor rotating (speed feedback)
- Hall-effect sensors can be used for coarse rotation speed measurement
- Rotation speed can be integrated to estimate angle
- For accurate rotation angle, and angular rate feedback, use optical encoder
- Sample through GPIO external interrupt
- (Same applies for linear actuation – also makes use of linear optical encoder strips)









(a)

Servos and Stepper Motors
Servos en Stapper Motors

Servo Motors

- Servo = DC motor + driving electronics + gearbox + shaft encoder
- Usually constrained or limited rotation – motor to control flaps of an RC model airplane or glider, steering on an RC car

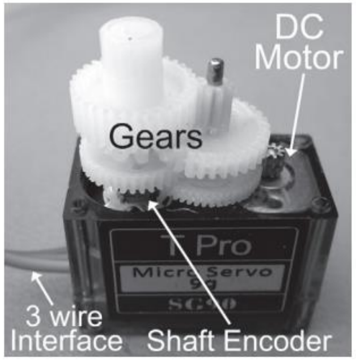
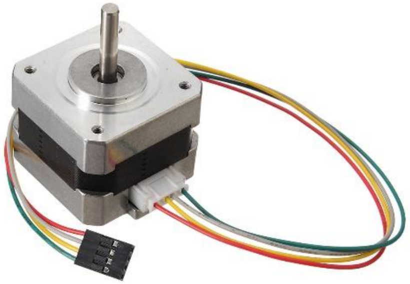


Figure e9.37 SG90 servo motor

Stepper Motors

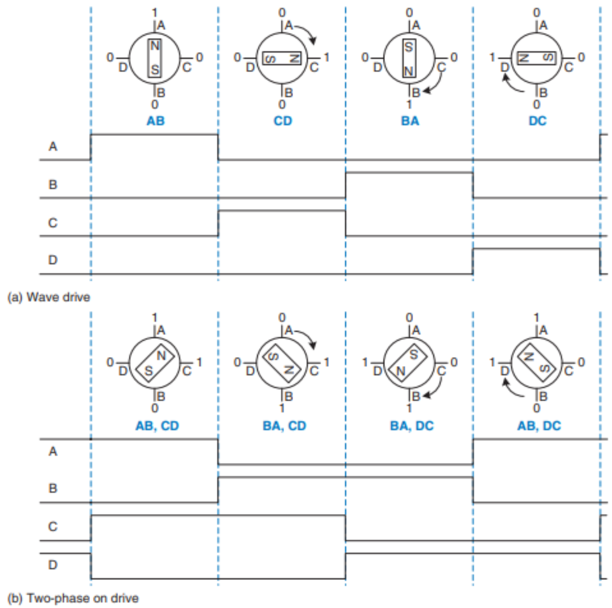
- Advances in discrete steps (not necessarily continuous rotation) as pulses applied to alternate inputs
- Steps in fraction of full rotation – allows for precise position control
- High torque capability
- Also used with gearboxes
  - Increased torque, finer position control
  - Linear position motor



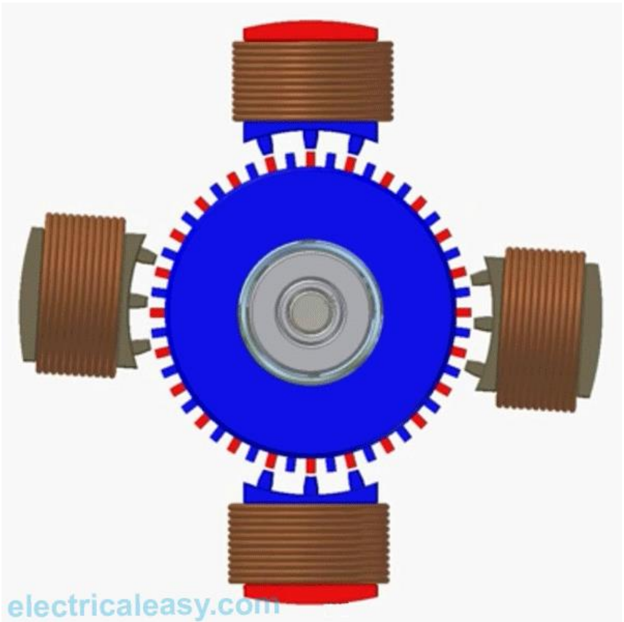
Motor Control – Stepper Motors
Motor Beheer – Stapper Motors

Stepper Motors

- Are also Brushless DC Motors
- There are different ways to drive the coils



- Driving two phases at the same time increases torque
- To control, use the same approach as with BLDC: microcontroller outputs signal to H-bridge. Probably won't use PWM
- Or use dedicated stepper motor controller



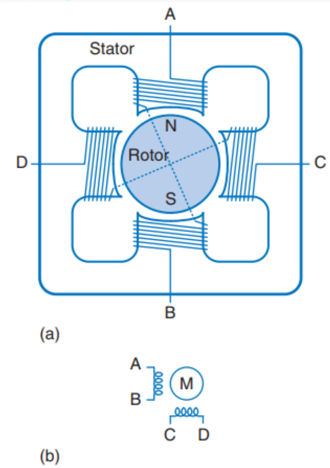


Figure e9.40 Two-phase bipolar motor: (a) simplified diagram, (b) symbol