Robot Design Lab Electronics

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Robotics research group

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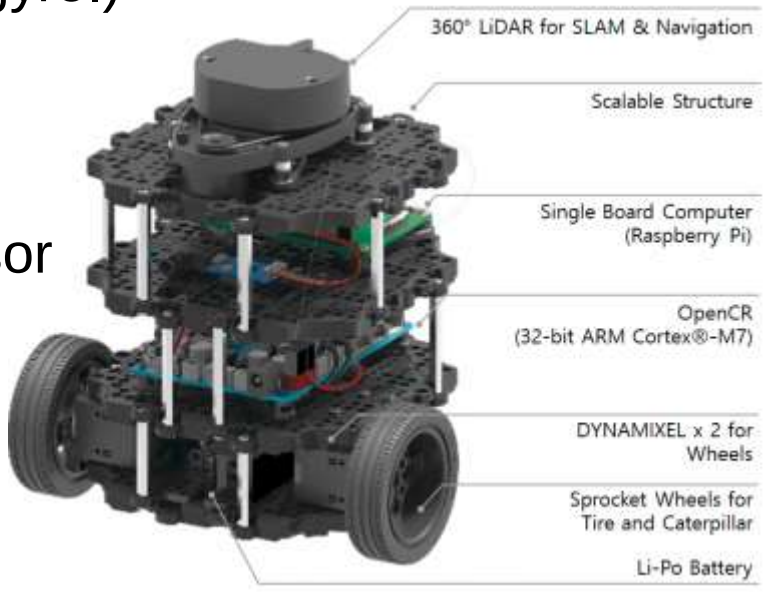
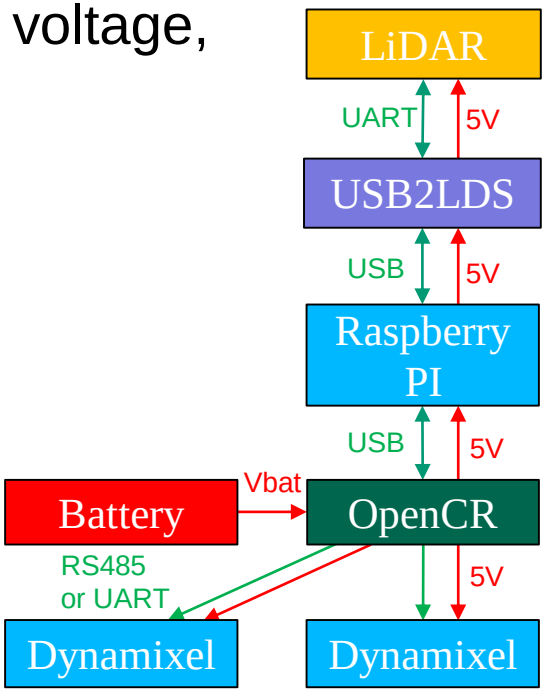
Overview

- Indroduction, TurtleBot 3
- Passive/active Electronic components
  - Resistors, capacitors, inductors
  - Diodes, transistors, voltage converter
- Signals
  - Analog/digital, logic levels, pulse width modulation, differential signals
- Interfaces
    - SPI, I2C, UART
- Integrated circuits
- H-Bridge to drive a Motor
- Battery technologies

1. Robotic System

- Combination of mechanics, electronics and software to interact with „outside“ world
- TurtleBot: mobile robot with own power supply (3s LiPo)
- HW-Interface by OpenCR to actuators, battery voltage, IMU (accel.+ gyro.)
- Control from Raspberry Pi
- Complex sensor LiDAR

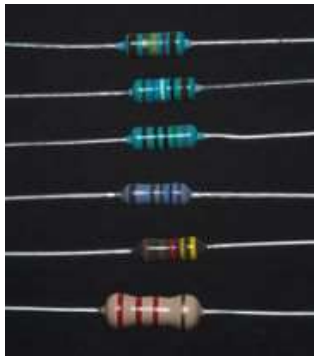




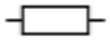
2. Resistor

- The current at a given voltage can be controlled with a resistor
  R = U/I
  I = U/R
- If two resistors are connected in series, the voltage is divided between the resistors
  $u_1+u_2= u_q$
  $I_q=I_1=I_2 \rightarrow u_1/R_1=u_2/R_2$
- When connected in parallel, the current is shared
  $I_1+I_2= I_q$
  $u_q=u_1=u_2 \rightarrow R_1 \cdot I_1=R_2 \cdot I_2$

SMD Resistor

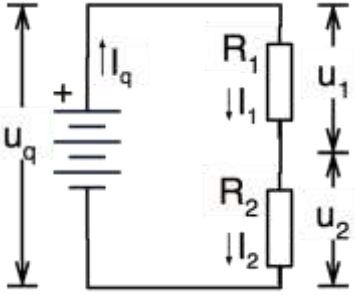


THT Resistor

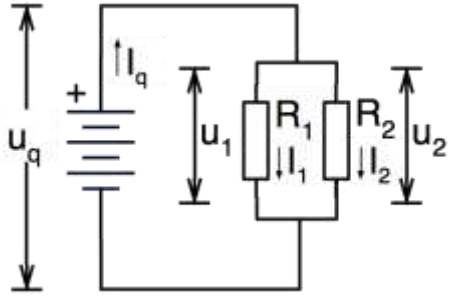


DIN Symbol

ANSI Symbol



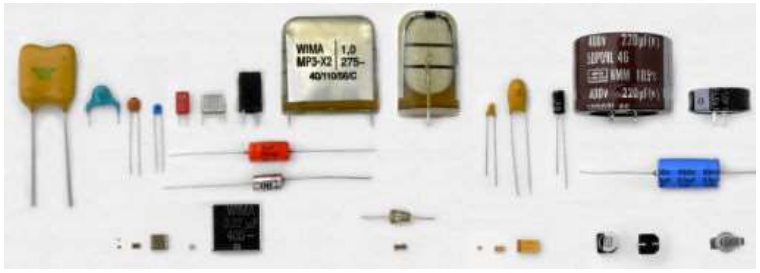
Voltage divider



Current divider

2.1 Capacitor/Inductor

- Capacitors store electrical charge in electric field
- Farad unit (mostly in the nano or micro range) → 1 F = 1 As/V
- Coils store energy in a magnetic field
- Unit Henry → 1 H = 1 Vs/A



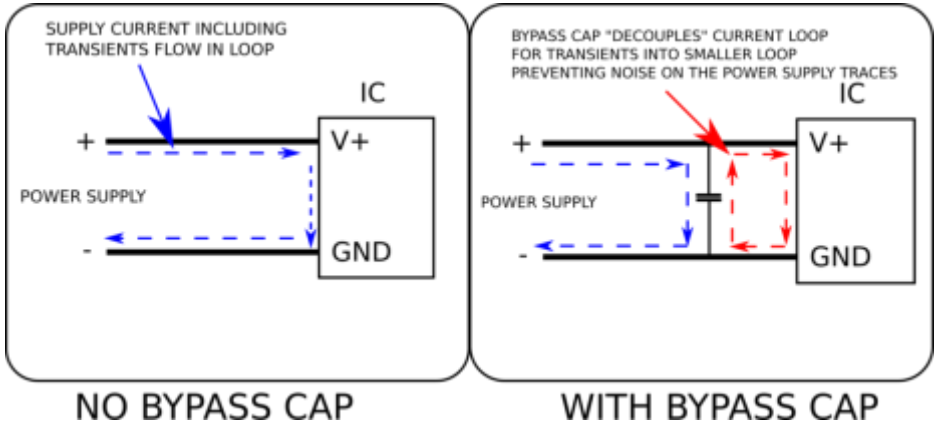
Unipolar Capacitor | Bipolar Capacitor | (alternative symbol)

DIN symbol | ANSI symbol

- power supply
- filters
- Signal conditioning

2.2 Bypass Capacitors

- Bypass/Decoupling Capacitor
- Mostly [1...100]nF
- Used on all components to remove interference to/from the power supply
- Connected in parallel and as close as possible to the component



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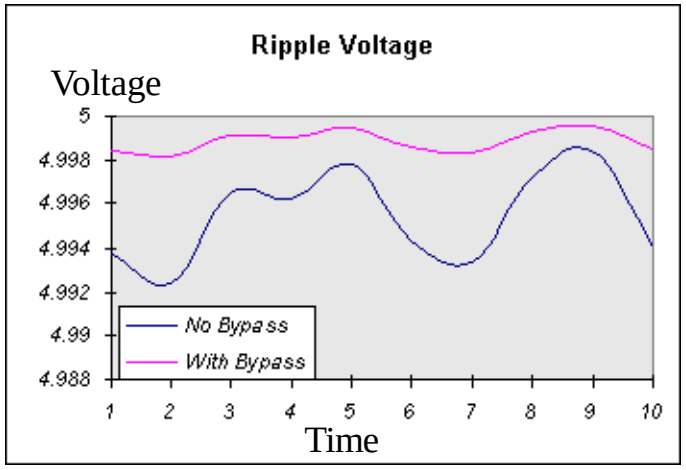
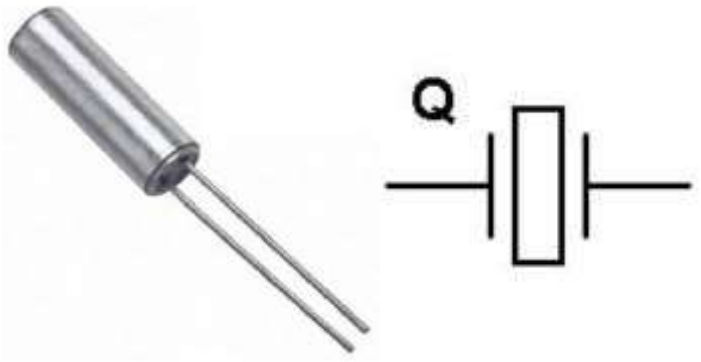


Kevin Ross
www.seattlerobotics.org

2.3 Crystal

- Uses the reverse piezoelectric effect
- Has a very well-defined resonance frequency (often ±20ppm and better)
- Oscillates when the output signal is amplified and returned to the crystal
- Common range 20 kHz … 100 MHz
- Crystal for RTC: 32,768 kHz (2^{15} Hz)
- Mostly used to generate the clock signal which coordinates actions of digital circuits
- Used as time reference within timers

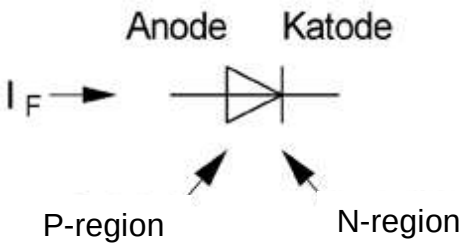


darcy.rsgc.on.ca

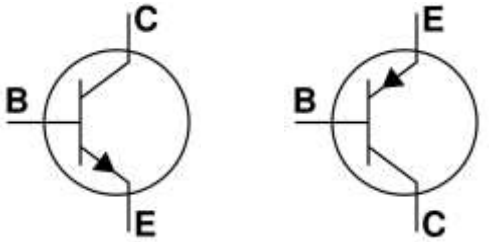
2.4 Diodes/Transistors

- Diode passes current in one direction
  - Forward voltage drop ~0.7V
- Bipolar Junction Transistor (BJT)
  - switch when current flows B-E
  - amplified current through C-E
  - current controlled amplification
- MOS-Field-Effect-Transistor (MOSFET)
  - switch when voltage between G-S
  - amplified current through D-S
  - voltage controlled amplification
- Transistors form the basis for digital logic (1947 invented by John Bardeen & Walter Brattain at AT&T‘s Bell lab.)

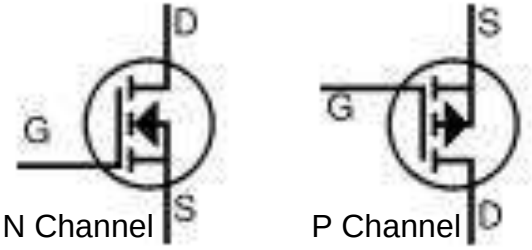
Diode



BJT Transistor

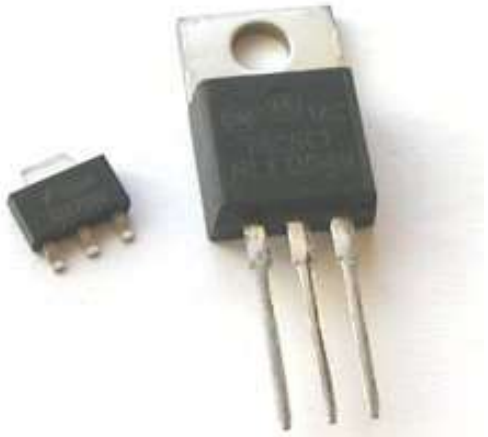


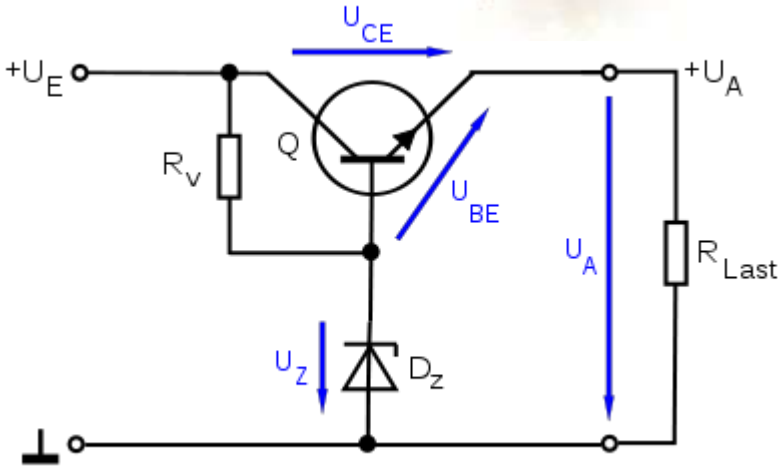
MOSFET Transistor



2.5 Linear voltage regulator

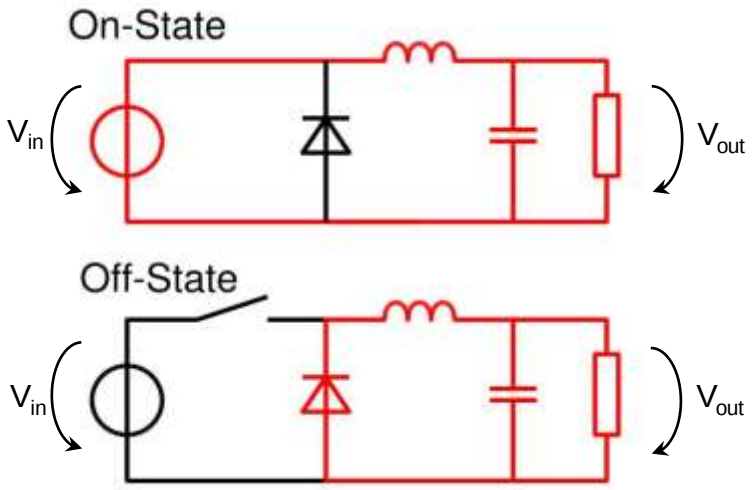
- Based on voltage divider
- Operates with BJT or MOSFET
- Excess energy is converted into heat
  - Not efficient when $V_{in} >> V_{out}$
- Drop-Out Voltage
  - LDO Regulator ($V_{in} – V_{out} < 1$ V)
- Efficiency example 12V to 5V @1A
  - 5W output power | 5V * 1A
  - 7W heat | (12V - 5V) * 1A
- Easy to use with stable output

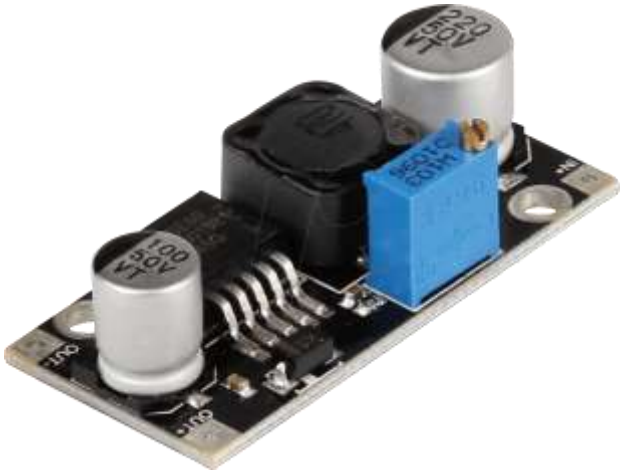




2.6 Switched voltage regulator

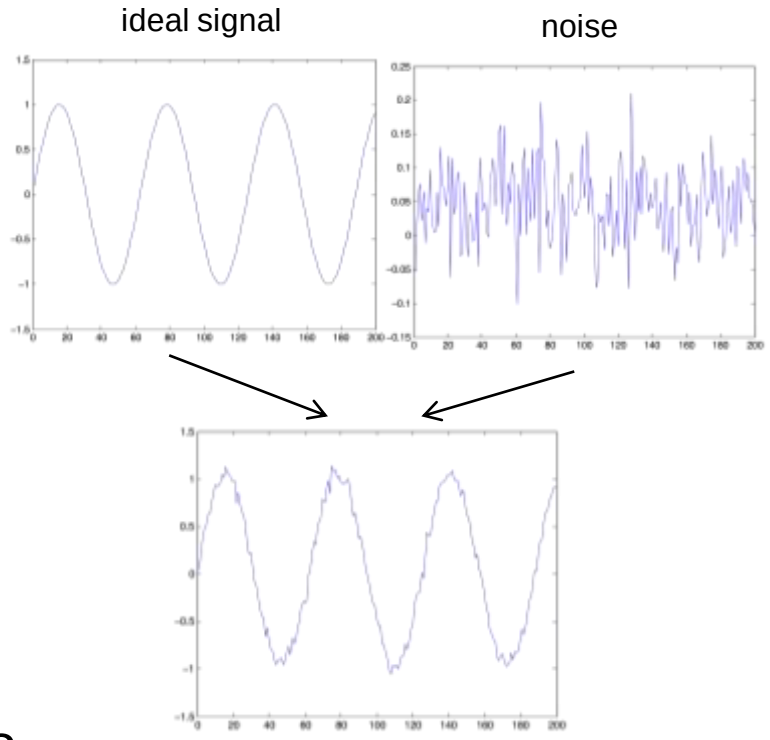
- Uses PWM Signal to generate V_{out}
- The coil limits the current in the on-phase and supplies current in the off-phase
- High efficiency
- Generates interference fields (alternating magnetic fields)
- More complex than linear voltage regulators
- Voltage converter with $V_{out} > V_{in}$ and negative V_{out} possible



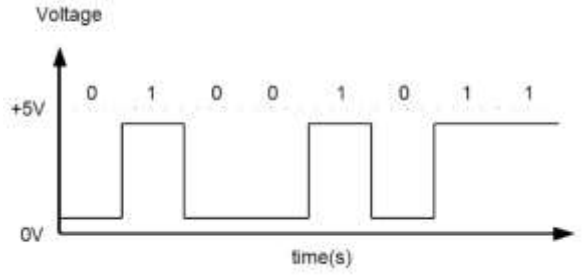


3. Signal

- Electric representation of information
- Mostly voltage at a point in relation to a reference potential (ground)
- Analog signals encode information directly (e.g. audio signal on HiFi)
  - pro: simple interpretation
  - con: signal noise

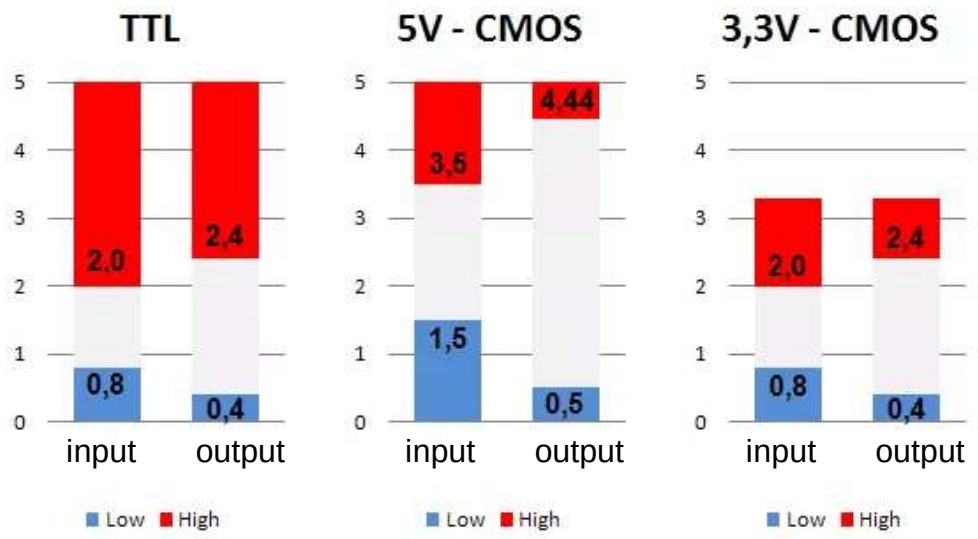


- Digital signals use dedicated voltages to encode 0 (low) and 1 (high)
  - pro: clear information
  - con: discrete, requires complex interpretation



3.1 Digital logic level

- Different voltage levels through different technologies
- Common reference potential (ground)

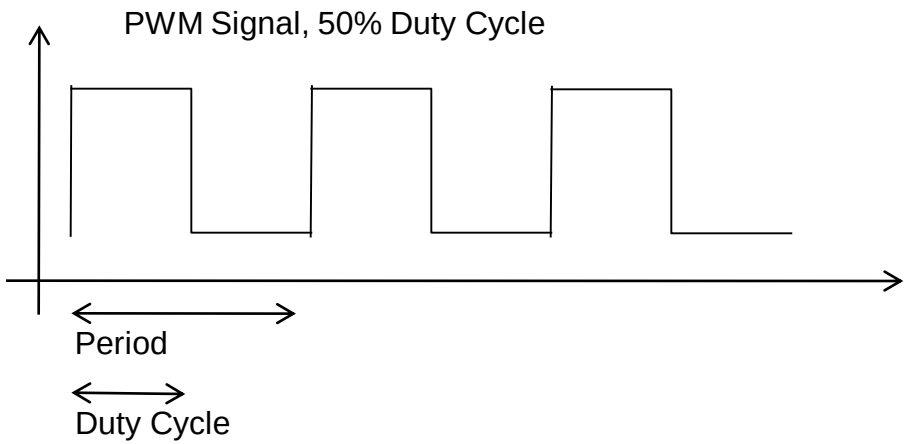


ne555.at

- CMOS: Complementary Metal-Oxide-Semiconductor
  - Describes technology embedding MOSFETs (meatl-oxide-semiconductor field effect transistor)
- TTL: Transistor-Transistor-Logic
  - Based on BJTs (bipolar junction transistors)

3.2 Pulse width modulation

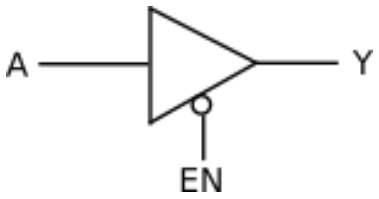
- Coding of analog signal in digital form
- Values of 0% (constant low) and 100% (constant high) possible
- With power stage often used to drive motors or solenoids or to dim LEDs
- Duty expressed in percentage (period/on-time)



Frequency	Period
1Hz	1s
1kHz (1000 Hz)	1ms (1/1000 s)
1MHz (1000 kHz)	1µs (1/1000 ms)
1GHz (1000 MHz)	1ns (1/1000 µs)

3.3 Tristate, Pull-Up/Pull-Down

- Tri-state: High impedance output labelled with ‘Z’
- Outputs can be brought into the tri-state (no signal) state. Important for bus systems
- Pull-ups & pull-downs deliver a defined state as long as no stronger signal is present
- Resistance normally around 10kOhm (depending on the required speed)



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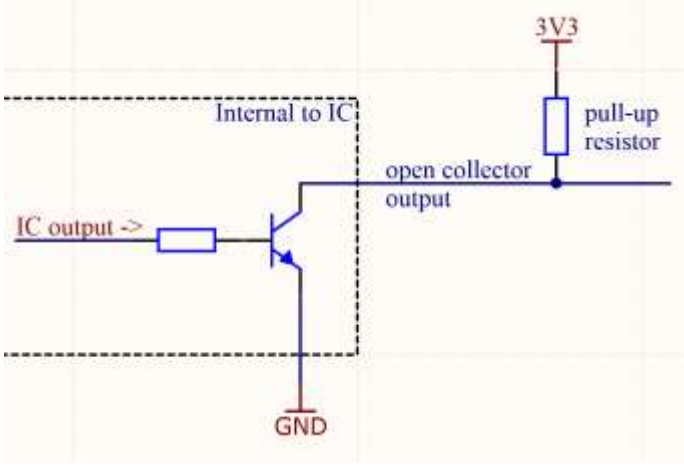
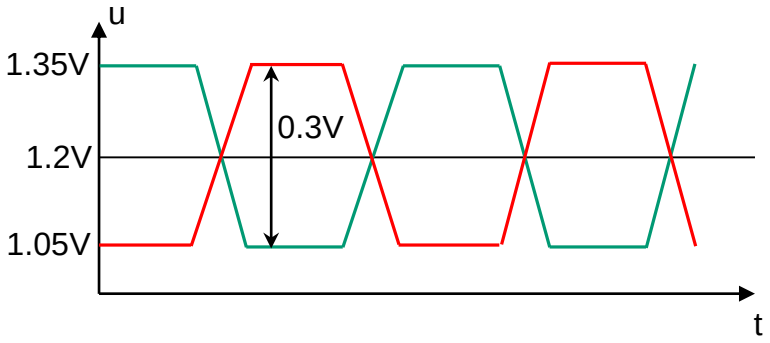
A	EN	Y
0	0	0
1	0	1
0	1	Z
1	1	Z

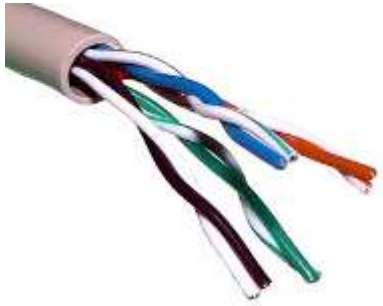


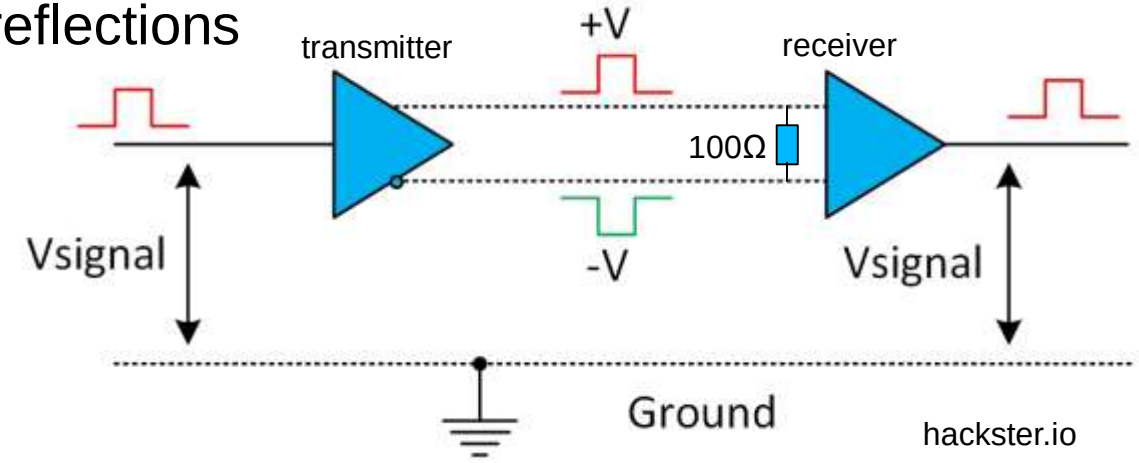
3.4 Differential Signals

Example LVDS

- Offset voltage 1,2 V
- Differential Signal ~300 mV
- Despite differential transmission, ground shift max. 1 V !
- Twisted cable to reduce magnetic coupling
- Terminated to reduce reflections





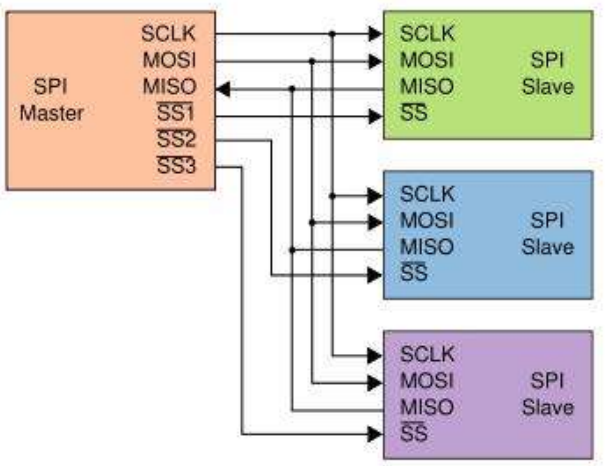


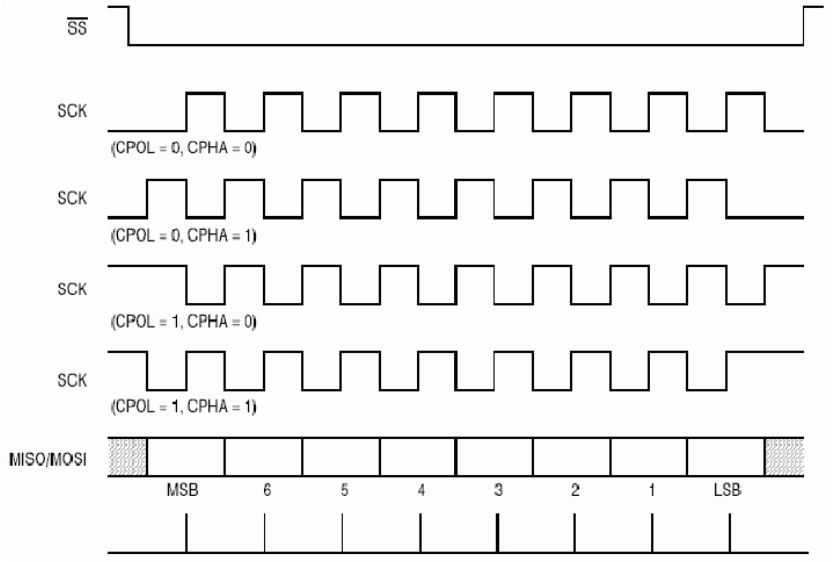
4. Interfaces of ICs

- Serial:
  - one bit, often synchonous to clock, lower bandwidth
  - SPI, I2C, UART, CAN (Controller Area Network)
- Parallel:
  - n bits, synchronous or asynchonous, higher bandwidth
  - memory (RAM, Flash), displays (RGB24), Eth ([R]MII)

4.1 SPI

- Serial Peripheral Interface
- Outputs in tri-state when slave is inactive (/SS high)
- Inputs ignored when slave is inactive (/SS high)
- 4 Signals
  - SCK (Serial Clock)
  - MOSI (Master Out Slave in)
  - MISO (Master In Slave out)
  - SS (Chip Select or CS)
- 4 Modes
  - CPOL (edge)
  - CPHA (phase)

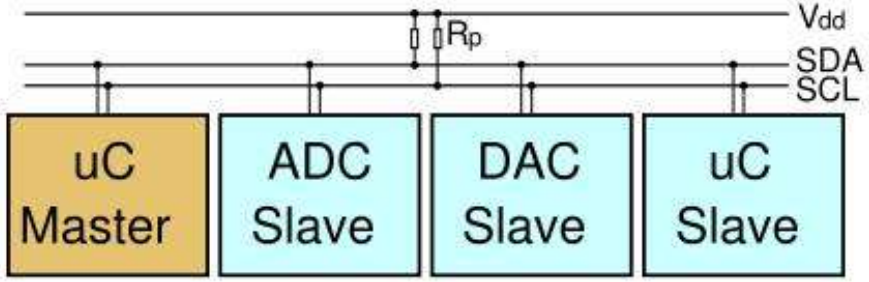


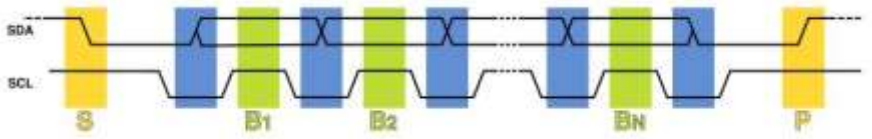


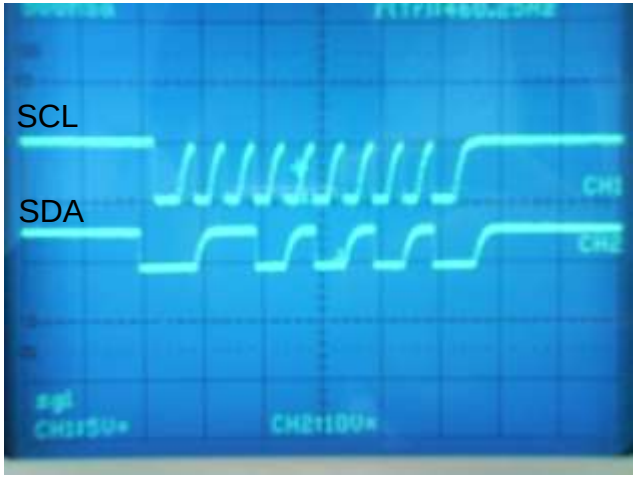
http://www.pyroelectro.com

4.2 I²C/TWI

- Inter-Integrated-Circuit/Two Wire Interface
- Invented by Philips 1982
- Pull-Ups + Open Collector
- Intended for „Onboard“ communication
- Standardized protocol
  - Read/Write Mode in address byte (0: write; 1: read)
  - 7-Bit Slave address
  - Byte wise Transfer
  - Speeds [0.1...3.4] Mbit/s

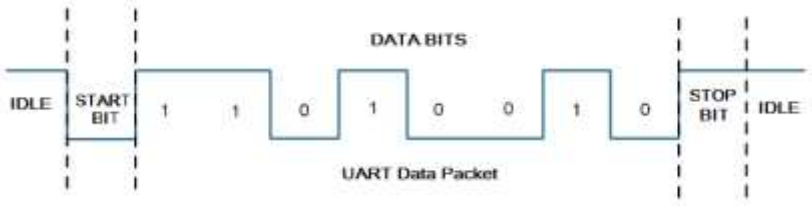






4.3 UART

- **Universal** (A)synchronous Receiver/Transmitter
- Fixed baudrate, receiver and sender need to use same baudrate
- Start bit (indicates start of frame)
- 5-9 Data bits (mostly 8)
- 0-1 Parity bits (optional, mostly 0)
- 1-2 Stop bits (indicates end of frame)
- Standards: 38400, 57600, 115200…
- 115200baud = 115200bit/s -> ~8.7us/bit
- Denotation i.e. 115200/8N1



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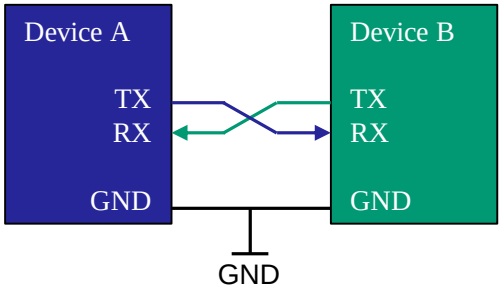
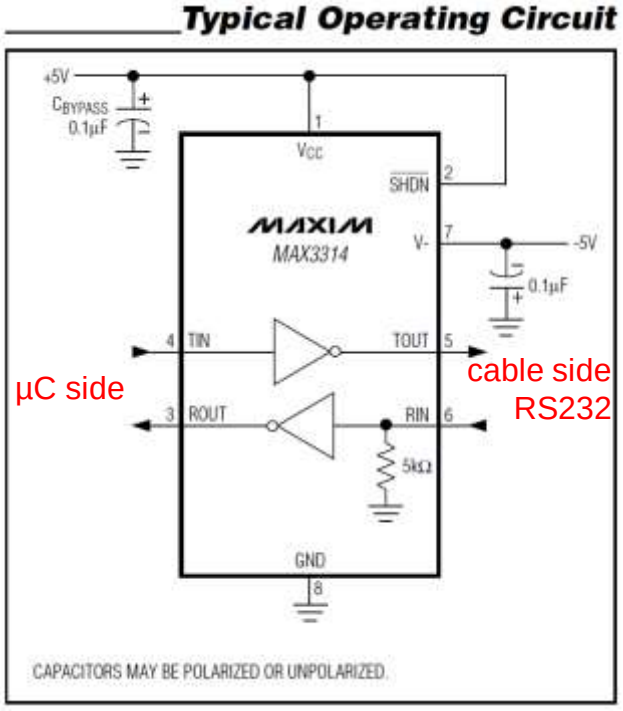


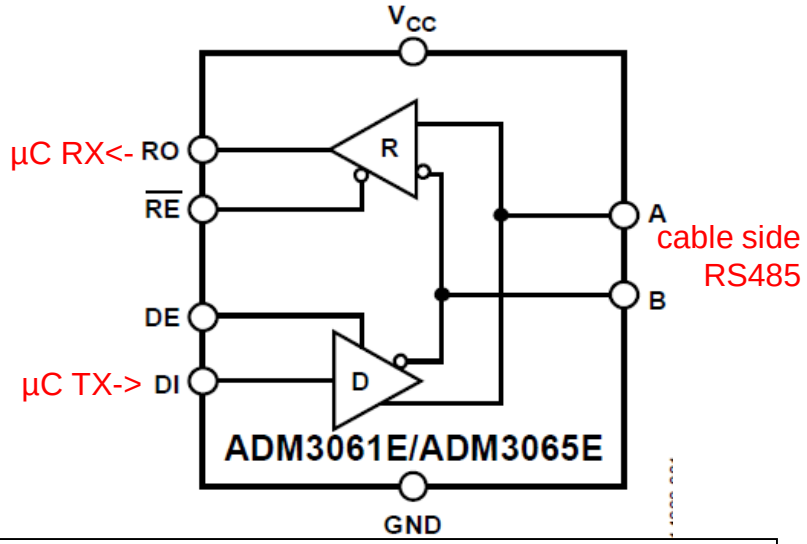
4.4 From UART to RS232

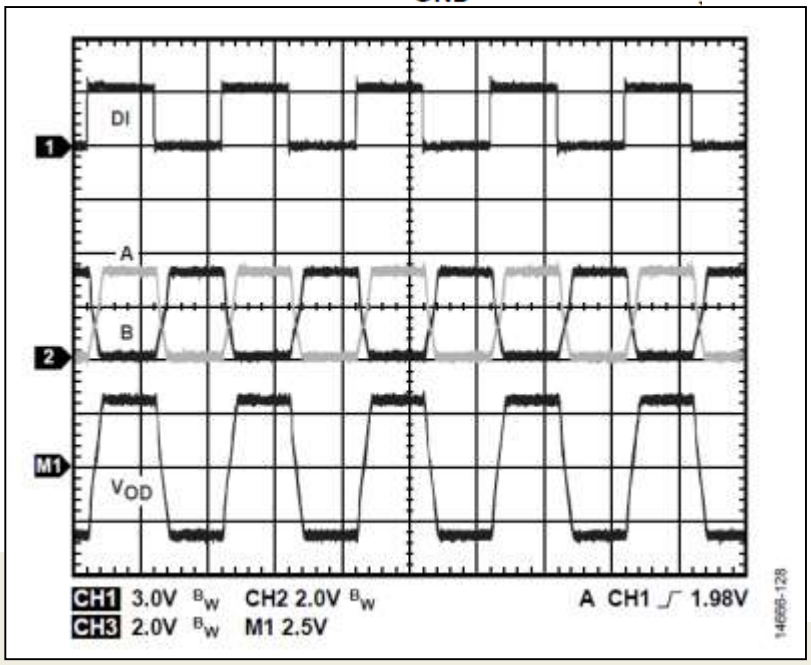
- RS232/RS485/RS422 are Recommended Standards
- RS232: Signal Level inverted
  - 0: 3V ... 15V
  - 1: -3V ... -15V
- Bandwith
  - - very common 115200 bit/s
- Optional Handshaking
- Min. 3 Wires on cable side
  - RX/TX/GND (optional RTS/CTS)
- Line driver i.e. MAX3314 (RS232)
- Non-differential full-duplex



4.5 From UART to RS485

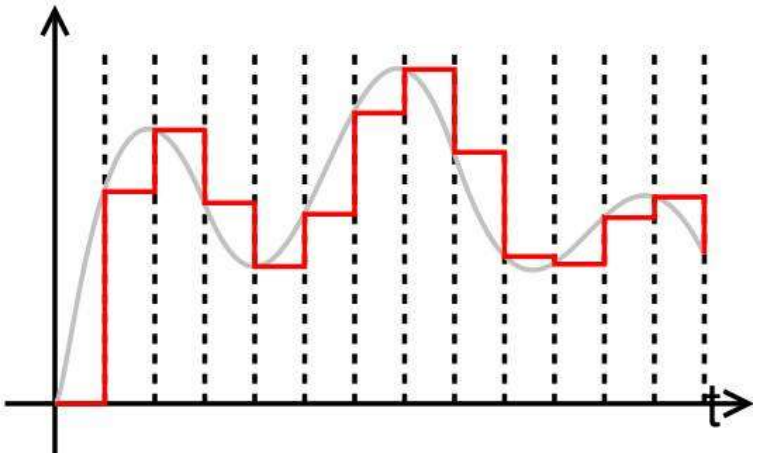
- RS485: Differential Signal A/B
  - 0: -3.5V…-1.5V
  - 1: 1.5V ... 3.5V
- Bandwith
  - - up to several Mbit/s
- 3 Wires on cable side: A/B/GND
- Control signals
  - RE (Read En.) / DE (Driver En.)
- Line driver i.e. ADM3061
- Differential half-duplex

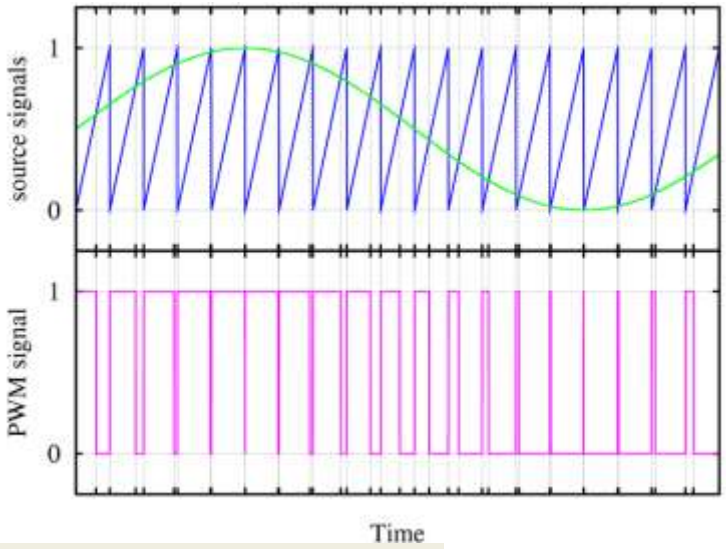




4.6 AD/DA-Converter

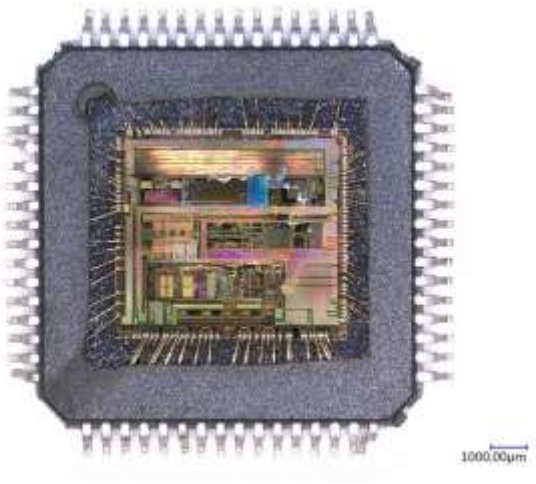
- Sampling frequency i.e. 1MS/s
- Voltage resolution depends on reference voltage and resolution of the device i.e. 12bit @ 3.3V_{ref} : 3.3V/2^12 ~ 0.8mV quantisation
- Analog to Digital (AD)
  - Sample and Hold
  - Multiplexing
  - Successive Approximation
  - Delta Encoded
  - Ramp Compare
- Digital to Analog (DA)
  - Network of resistors
  - Low Pass Filter/PWM





5 Integrated Circuits (ICs)

- Integrate a huge number of components basically MOSFETs in complementary configuration (CMOS)
- i.e. Memory, Processors/Controllers, programmable logic devices, logic etc.



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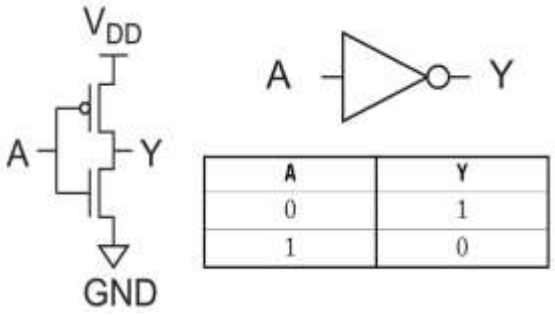

A	Y
0	1
1	0

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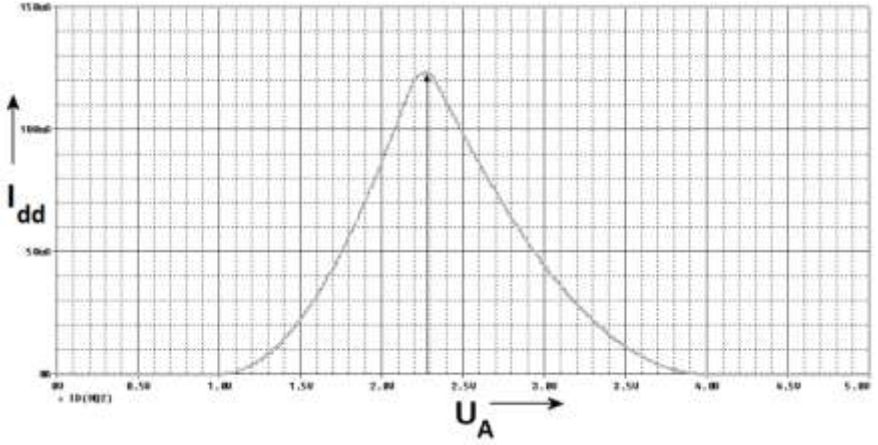


5.1 Memory

Volatile

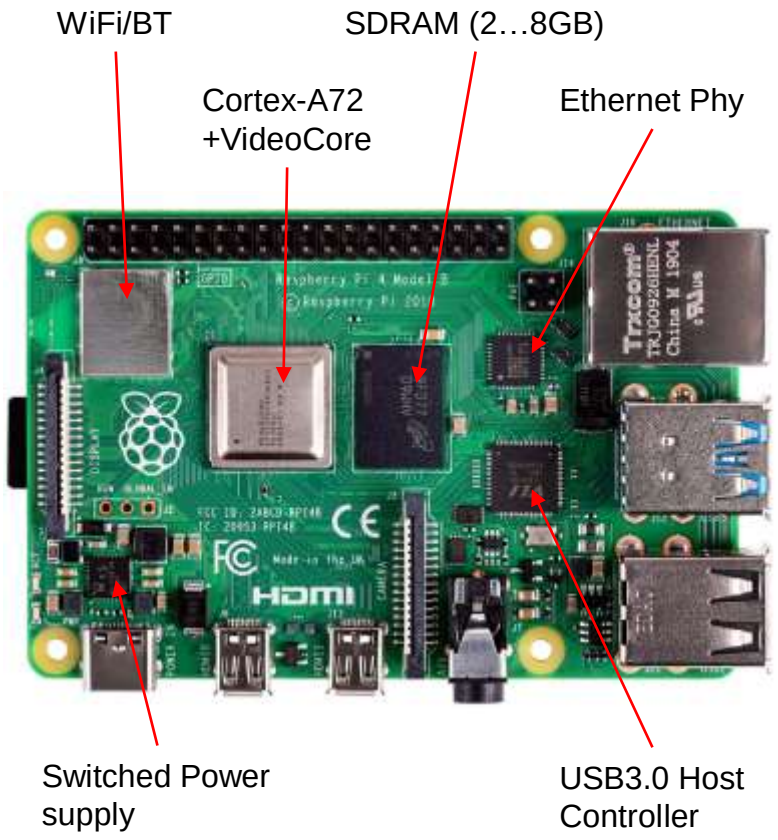
- DRAM (Capacitors)
- SRAM (Transistors)
- Register/Cache (Transistors, very fast and valuable)

Non Volatile

- EEPROM (mostly writable / erasable byte by byte)
- FLASH (can be erased by regions i.e. 4kB)
- ROM
- SRAM with backup battery

5.2 Integrated Circuits (RPi 4)

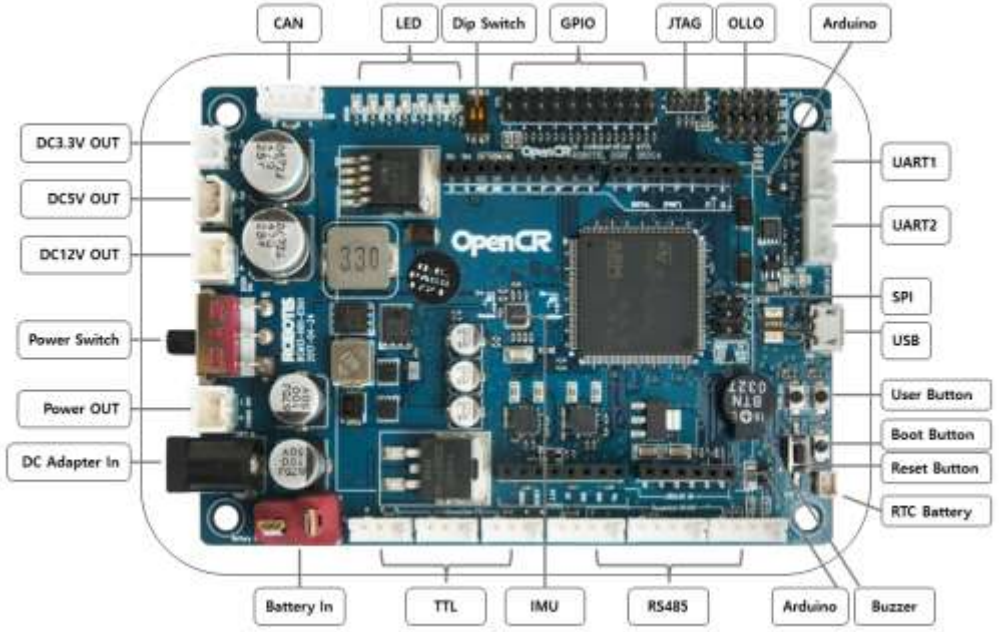
- Microprocessor
  - Program and data storage located externally (microSD card and SDRAM)
  - Much higher power consumption than Microcontroller
- Raspberry Pi 4
  - UARTs, SPIs and I2Cs @ pinheader multiplex with GPIOs



cnx-software.com

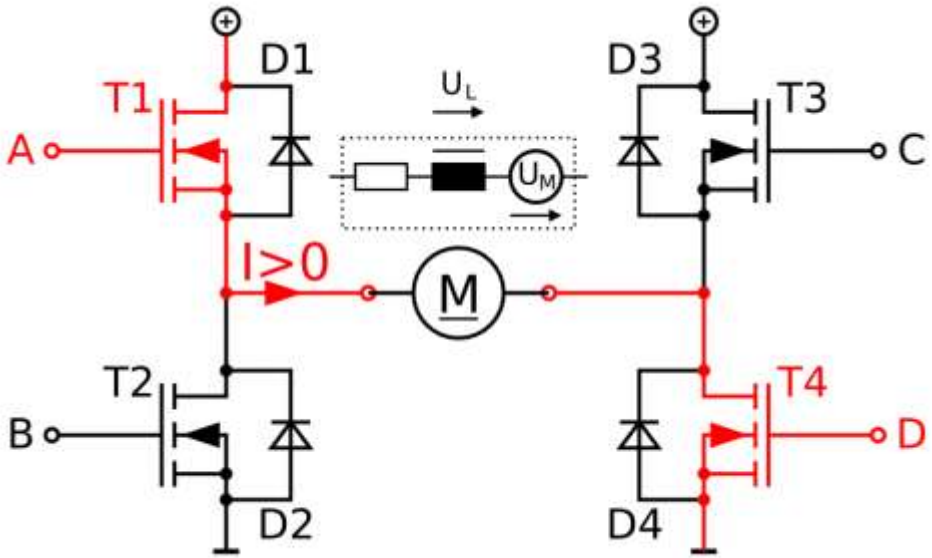
5.3 Integrated Circuits (OpenCR)

- Microcontroller typically integrates
  - Several GPIOs (general purpose In/Out) with independent config for push-pull, opendrain, pull-up/down or multiplex to periphery
  - Peripherals (UARTs, SPIs, I2Cs, analog peripheral…)
  - Flash to store program
  - RAM for data
- µC: STM32F746ZGT6
  - Manufacturer: ST-Microelectronics (st.com)
  - Cortex-M7 @ 216MHz



6 H-Bridge to drive a Motor

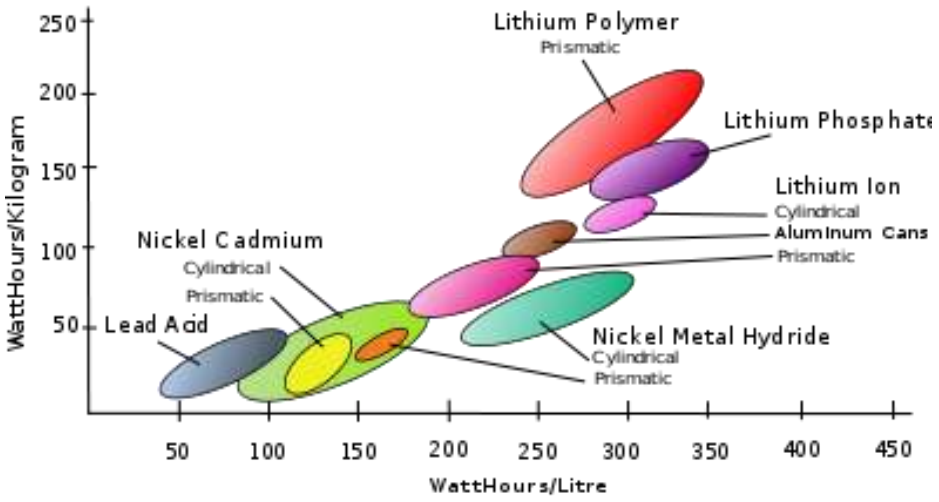
- Four transistors T1…T4 forming the letter ‚H‘ to drive a simple DC-Motor
- H-Bridge is able to switch polarity to a connected load i.e. to drive a Motor in both directions
- Signals A…D usually driven by microcontroller applying PWM to control motor current (->speed/torque)
- Control of motor current is done by switching between T1 and T2 while T4 held on (duty of PWM controls current)
- Other motor direction: switching T3 and T4 while T2 on
- Using free-wheeling diodes D2 (D4) instead of switching T2 (T4) would increase power dissipation

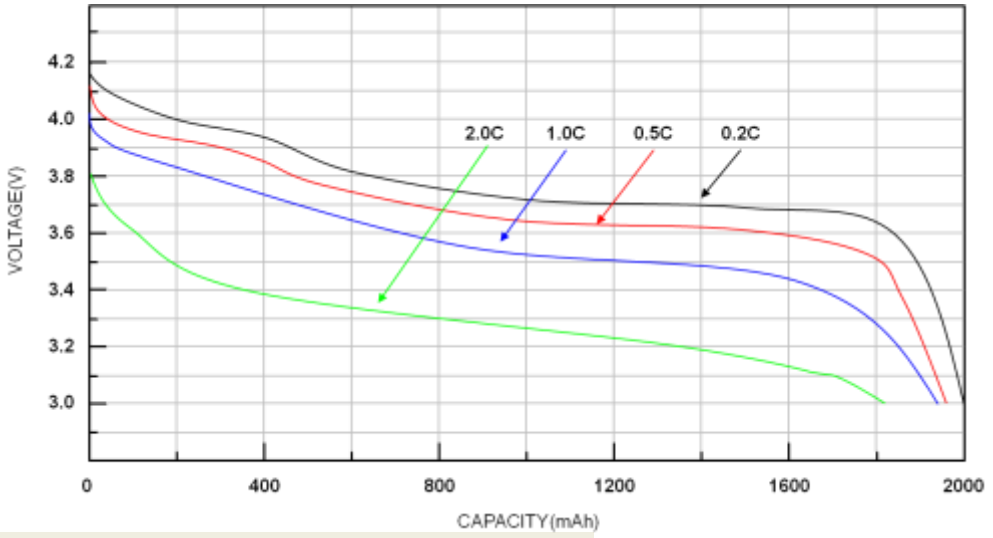


de.wikipedia.org/wiki/Vierquadrantensteller

7 Batteries

- LiPo (Lithium Polymer)
  - Nominal voltage 3.7V
  - Voltage between 2…4.2V (depends on actual model)
  - Charge/discharge rate often expressed as C (capacity)
  - i.e. 3s LiPo: 11.1V 1800mAh -> 2C = 3.6A
  - Huge energy density -> do not over/undercharge -> risk of fire

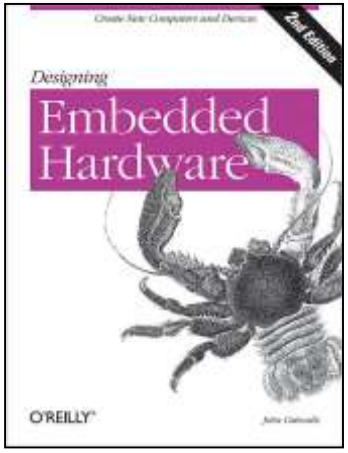




Reference/Links

Description	URL https://...
Documentation of TurtleBot3 and OpenCR	emanual.robotis.com/docs/en/platform/turtlebot3/overview
Manufacturer of STM32	st.com
UART/SPI/I2C	youtube.com/watch?v=IyGwvGzrqp8
Hardware related forum	electronics.stackexchange.com
Robotics related forum	robotics.stackexchange.com

Books
Horowitz, Paul and Hill, Winfield. The Art of Electronics. Second Edition. Cambridge University Press, 1989.
Catsoulis, John. Designing Embedded Hardware. Second Edition. O'Reilly Media, 2005.



Thank you for your attention!

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