E7020e

HARDWARE #2

SWITCHING

MECHANICAL

Push-button
Toggle switch
Rotary switch
Rotary encoder
Relay
…

ELECTRONIC

Transistor (BJT, MOSFET, …)
Solid State Relay (SSR)
Optocoupler
H-Bridge
…

MECHANICAL SWITCHES

Momentary ("on" only while you press it)

Latching ("stateful")

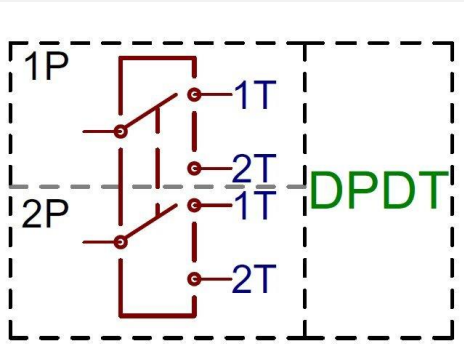
Pole (P) = number of circuits / "inputs"

Throw (T) = number of positions / "outputs" per circuit

SPST (Single pole, single throw) = Single circuit with single output (on/off)
SPDT (Single pole, double throw) = Single circuit with two outputs (on1/on2)
DPDT (Double pole, double throw) = Two circuits with two outputs (on1a-on1b/on2a-on2b)

Rated for max voltage, current, number of operations

Debouncing



DEBOUNCING

Two pieces of metal slamming together → contact bounce

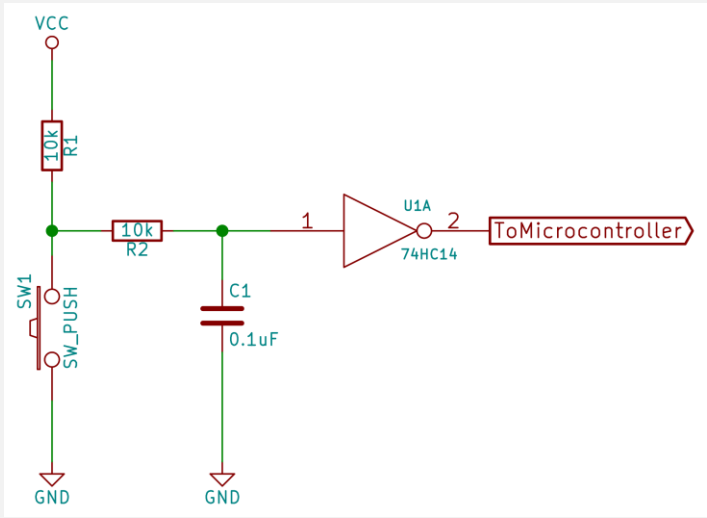
Single press → multiple fast presses / releases, lasting several milliseconds

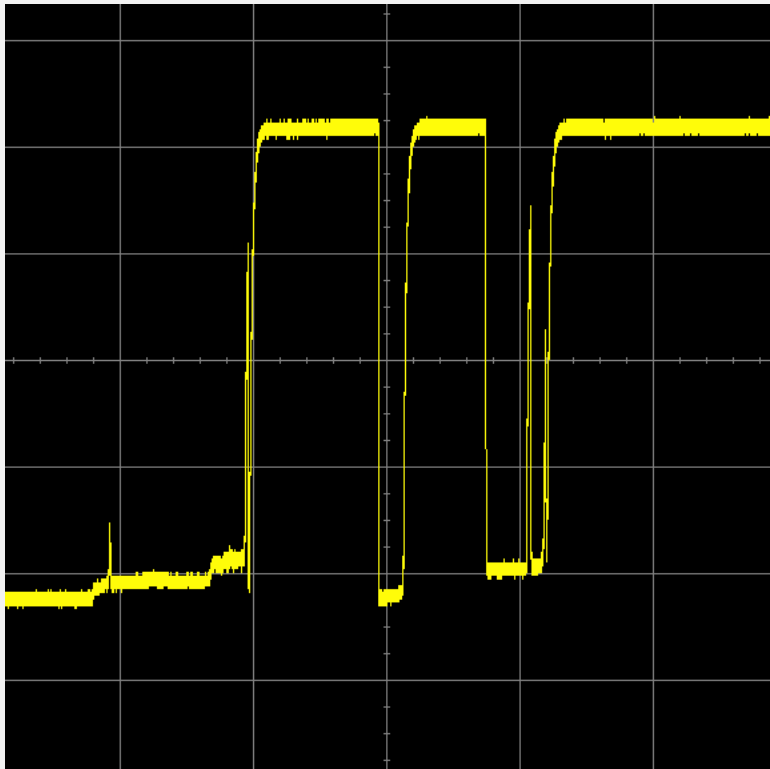
Problem for MCU (interrupts)

Multiple events from single press

Hardware (RC, IC)

Software (timer/counter)





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ELECTRONIC SWITCHING

LOW SIDE SWITCHING

Turn on/off the return path

NMOS

MCU can sink more current than it can source

Most common

Load has high potential even when switched off (potential safety issue)

HI SIDE SWITCHING

Turn on/off the power source

PMOS

PMOS has higher channel resistance than NMOS → higher power loss

NMOS possible using "gate driver"

Safety

ELECTRONIC SWITCHING

MOSFET

Low “on” resistance

Body diode - only be used in one direction, the other way it acts like a diode

AC - Use two back-to-back

Cheap

OPTO COUPLER

Light controlled transistor

Isolates logic and load circuits

SOLID-STATE RELAY

Use MOSFETS inside

Configured as an "ideal" switch

Isolates logic and load circuits

AC & DC

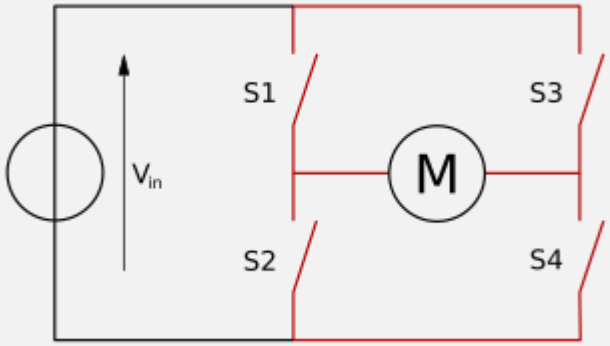
ELECTRONIC SWITCHING

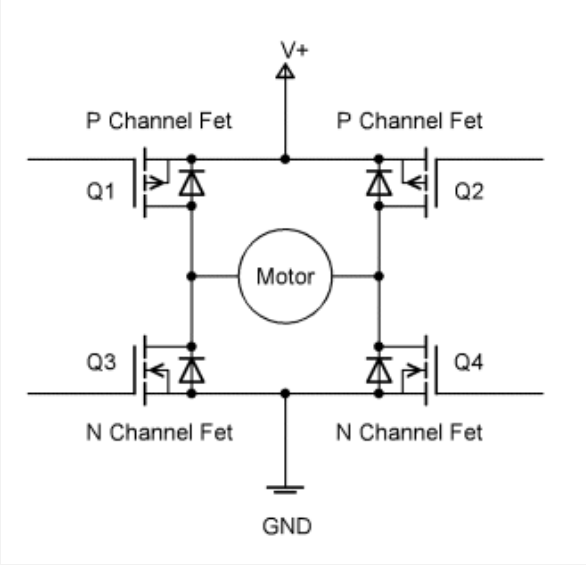
H-BRIDGE

DC motors

Switch direction

Available as IC





SWITCHING

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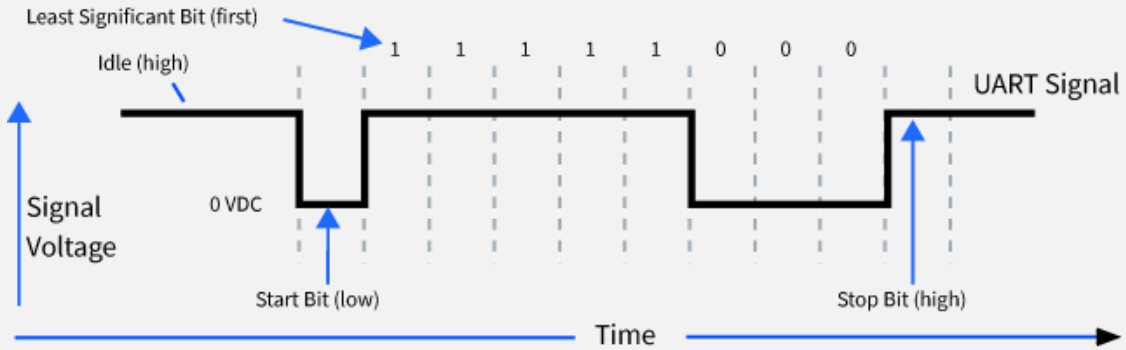
SERIAL COMMUNICATION

"One bit at a time"

Baudrate



SYNCHRONOUS

Clock + Data lines

SPI

ASYNCHRONOUS

No clock line

Agreed upon Baudrate

UART

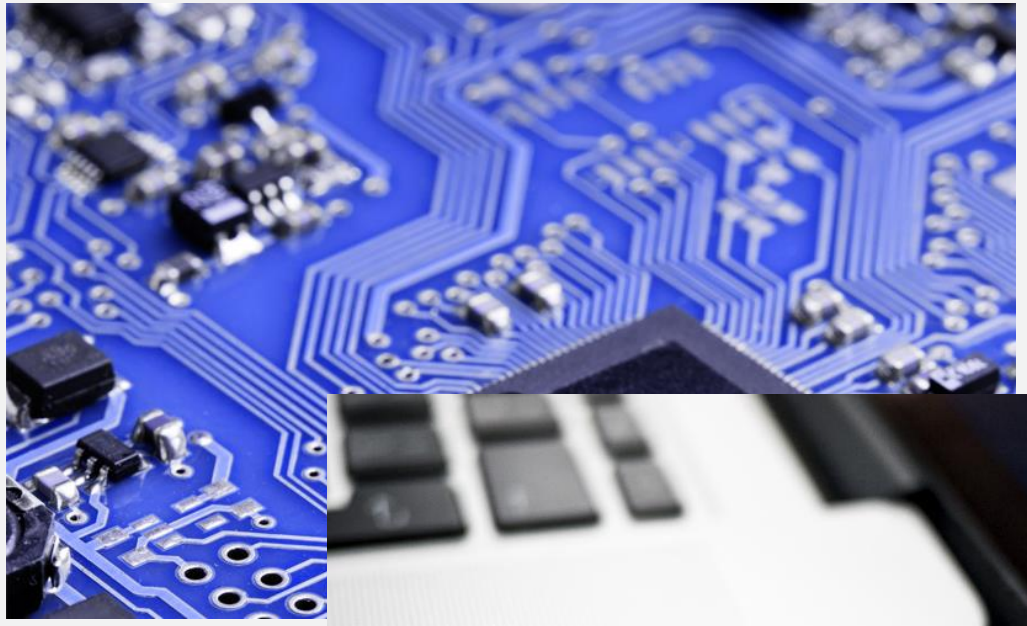
SERIAL COMMUNICATION

CHIP-TO-CHIP

- SPI
- I²C
- UART
- …

BOARD-TO-BOARD

- USB
- ETHERNET
- RS-232
- …



SPI Serial Peripheral Interface

Synchronous

4 wires (SCLK, MOSI, MISO, NCS)

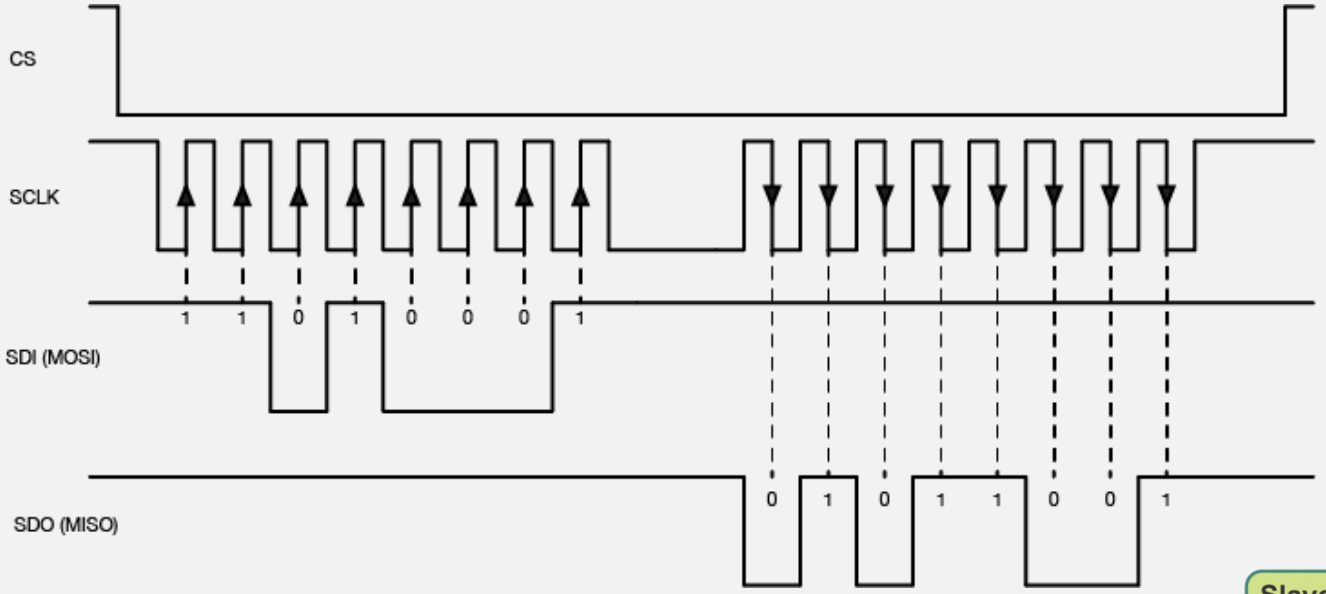
Chip-to-chip communication

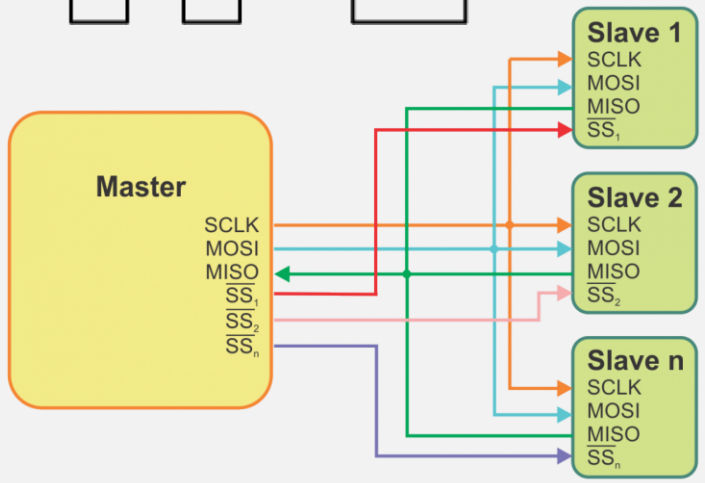
One master (aka “controller”)
Multiple slaves (aka “peripherals”)

Shared clock and data lines
Chip select pin

High speed (push-pull drivers, usually Mbits)

Full duplex (can read and write simultaneously)
Only master can drive the communication





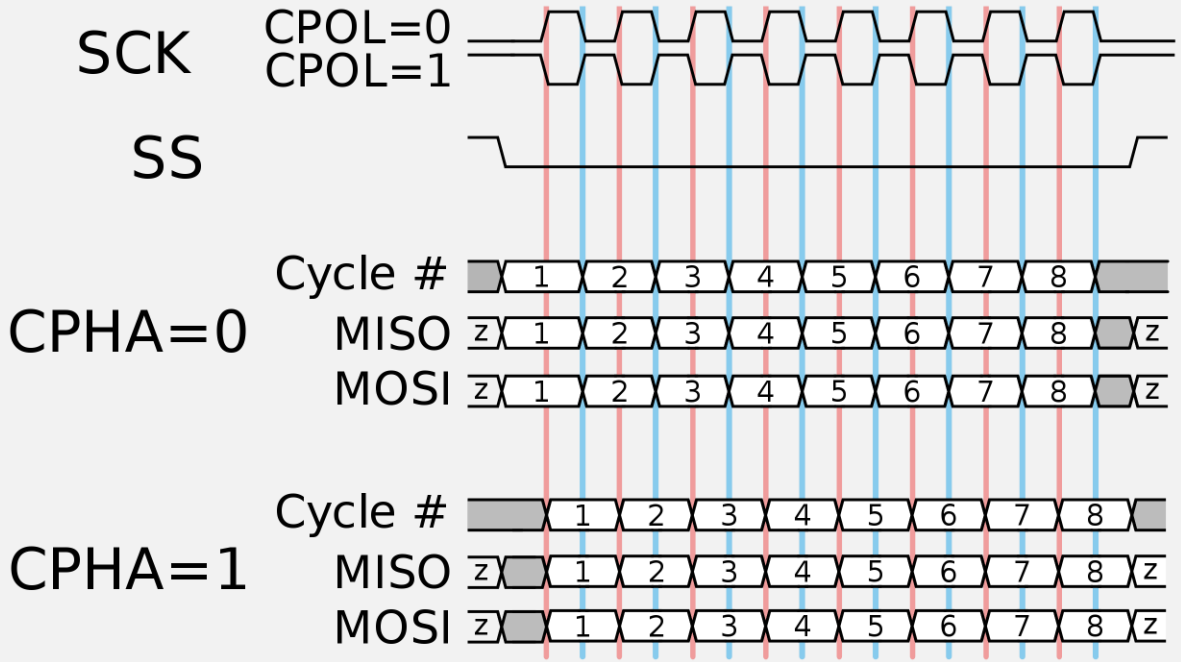
SPI Serial Peripheral Interface

MODE

CPOL = Clock polarity

CPHA = Clock phase

Mode	CPOL	CPHA
0	0	0
1	0	1
2	1	0
3	1	1



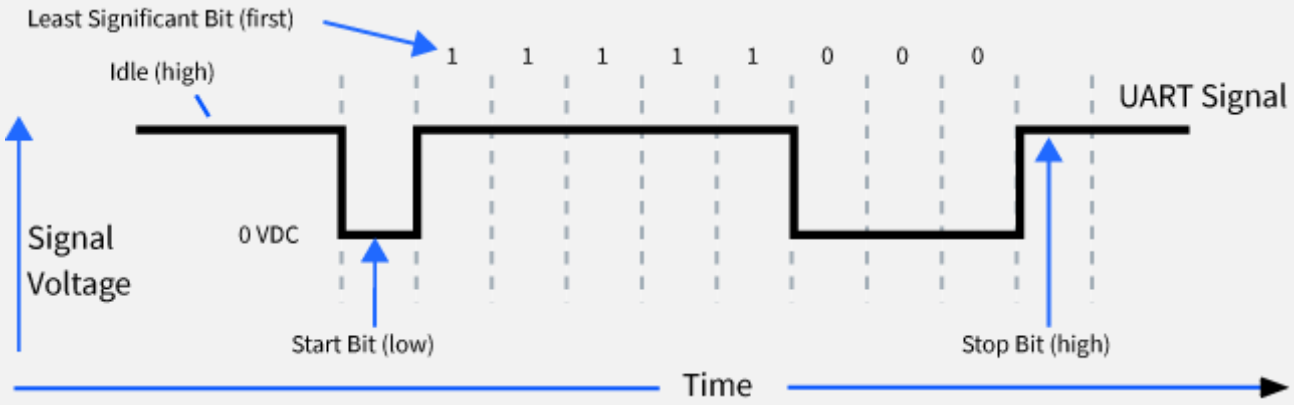
UART Universal Asynchronous Receiver/Transmitter

Asynchronous (no clock line)

Agreed upon protocol, for example:

9600 8N1

9600 baud, 8 data bits, no parity, 1 stop bit



2 wires – RX & TX

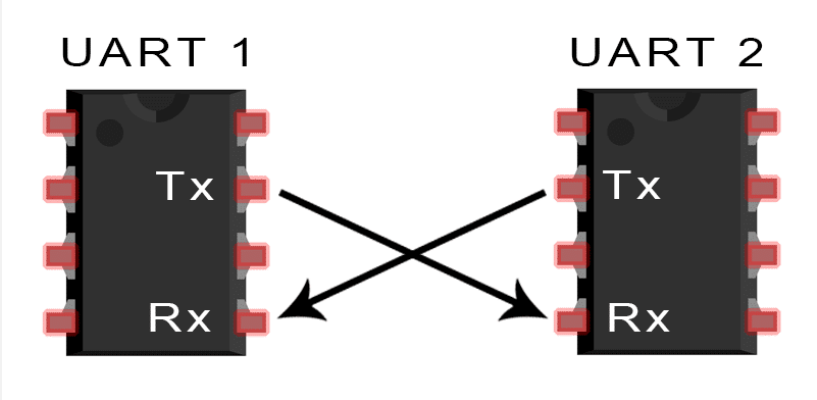
+ (optional) flow control (RTS, CTS)

Point-to-point

Full duplex (can read and write simultaneously)

Both ends can initiate communication

Lower speed (no clock → sampling @ 16x rate)



I^2C INTER-INTEGRATED CIRCUIT

Synchronous

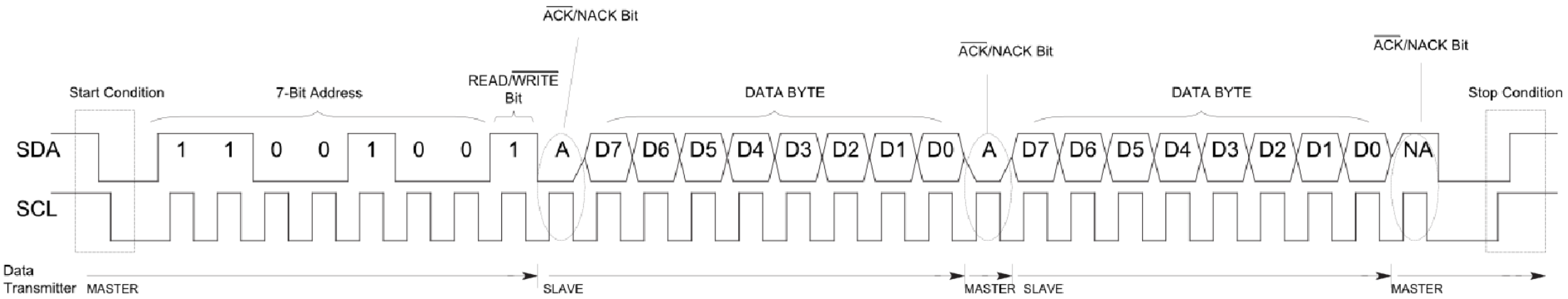
2 wires – SCL & SDA

Open drain (needs pull-up resistors)

One master, multiple slaves

Addressing scheme (7 bit, 10 bit)

Only master can initiate communication



ANALOG SIGNALS

ANALOG

Continuous signal

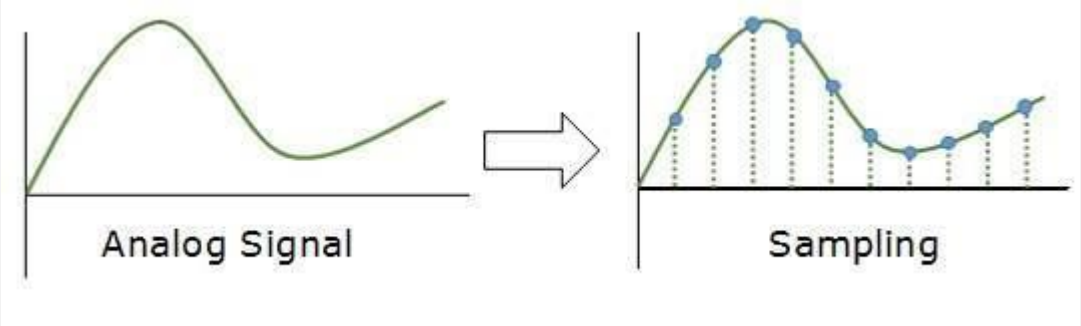
DIGITAL

Discrete time

Discrete value

ADC ANALOG-TO-DIGITAL CONVERTER

Samples the analog voltage
Sample rate
Bit depth



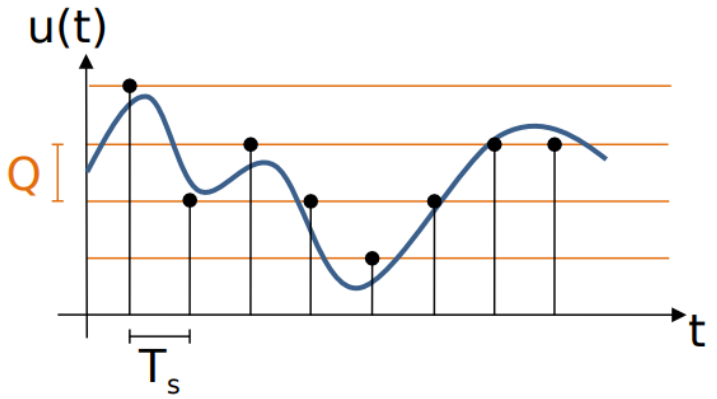
Successive approximation converter
Sigma-delta ADC
…

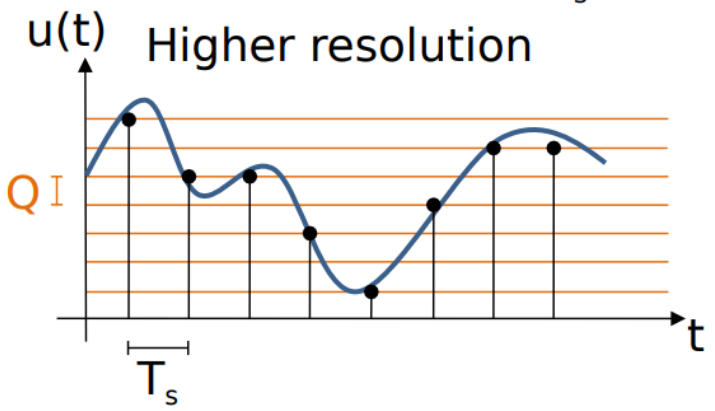
CONSIDER

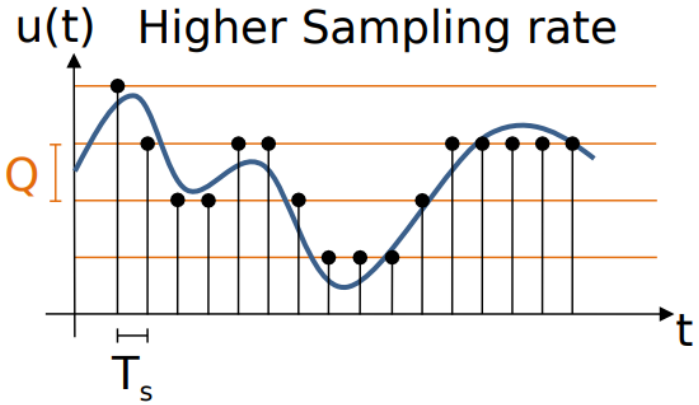
Resolution
Speed
Precision
Power
Cost

ADC ANALOG-TO-DIGITAL CONVERTER

ACCURACY







ADC ANALOG-TO-DIGITAL CONVERTER

NYQUIST/SHANNON SAMPLING THEOREM

Minimum sampling frequency should be at least
twice as high as max significant frequency
$f_s > 2 \times f_{max}$

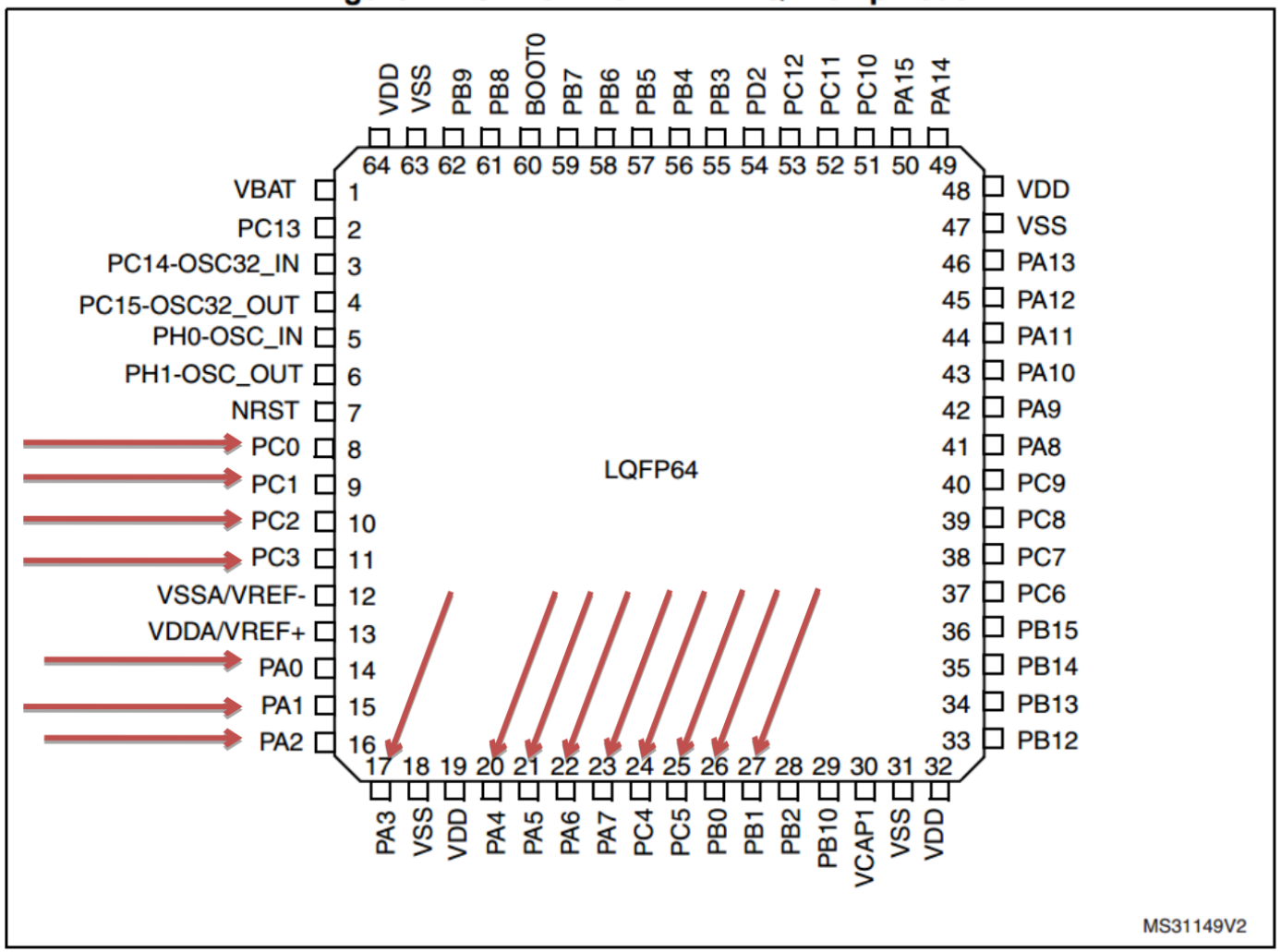
Example: 12-bit converter
Reference Vref = 3.3V
Sampling time Ts= 1ms,
fs = 1kHz

Number of possible values:
$N = 2^{12} = 4096$ Resolution,
$Q = V_{ref}/N \approx 0.8mV$

Analog anti-alias filter:
$f_{lp} \approx 1/(T_s \times 5) = 200Hz$

ADC ANALOG-TO-DIGITAL CONVERTER

Figure 12. STM32F401xD/xE LQFP64 pinout



QUADRATURE DECODER

Rotary encoders

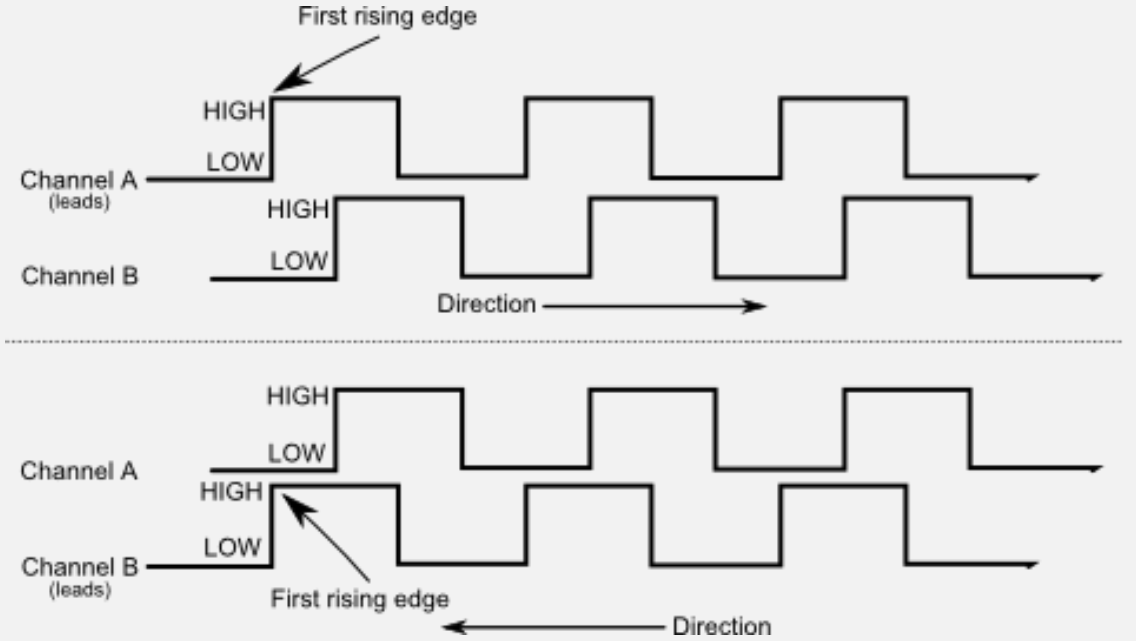
Linear / optical encoders etc

INCREMENTAL

Number of steps

Direction

QEI peripheral in MCU



USE CASES

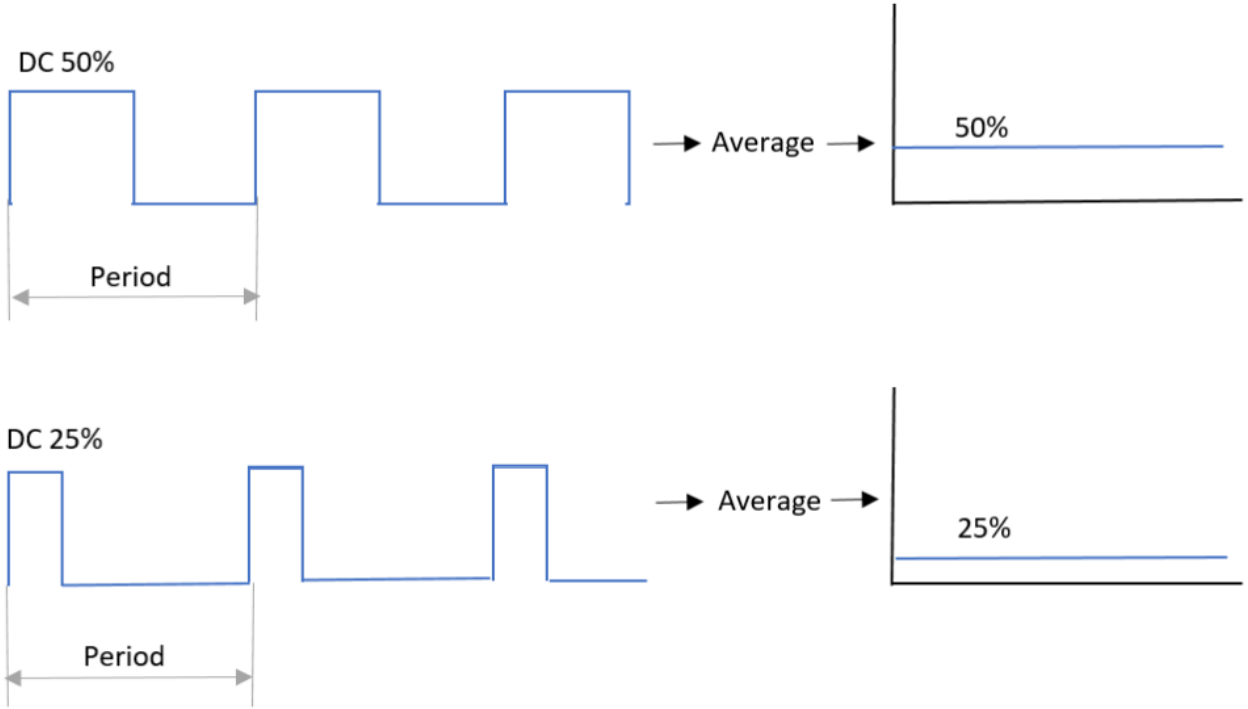
Turn on/off
Adjust on/off time
Control voltage/current
Dim LEDs, Lamps…
Motor torque/speed
Servos
Loudspeakers

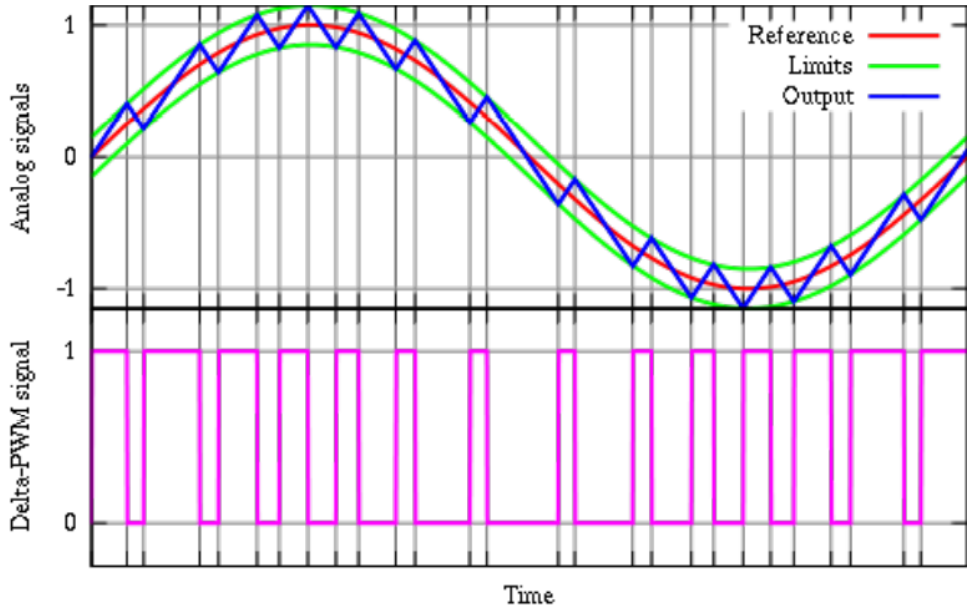
PWM PULSE-WIDTH MODULATION

DUTY CYCLE

ON vs OFF time

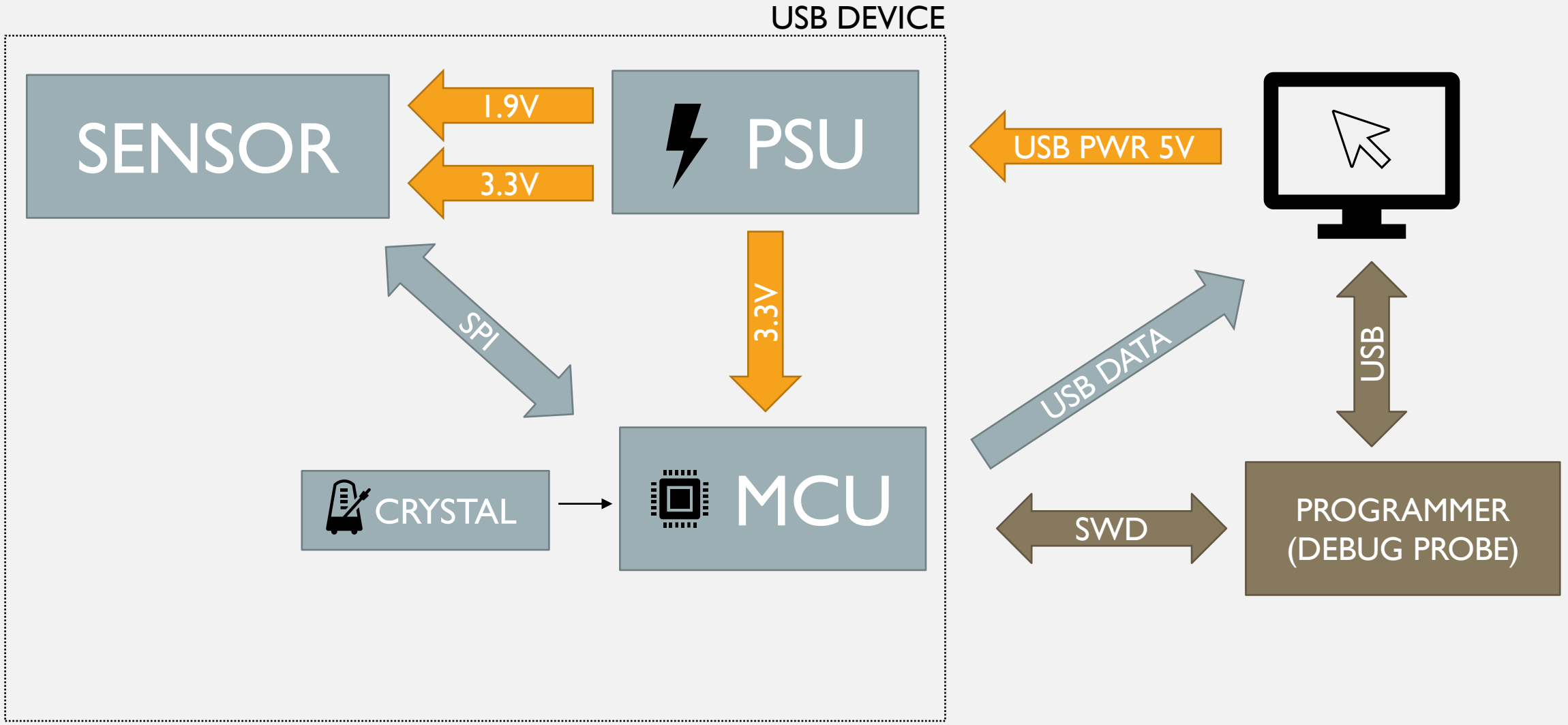
Averaging filter (LPF)





OPTICAL MOUSE EXAMPLE

BLOCK DIAGRAM



LET’S KICAD