IoT End Devices

Karel Slavicek
Vaclav Oujezsky

2024

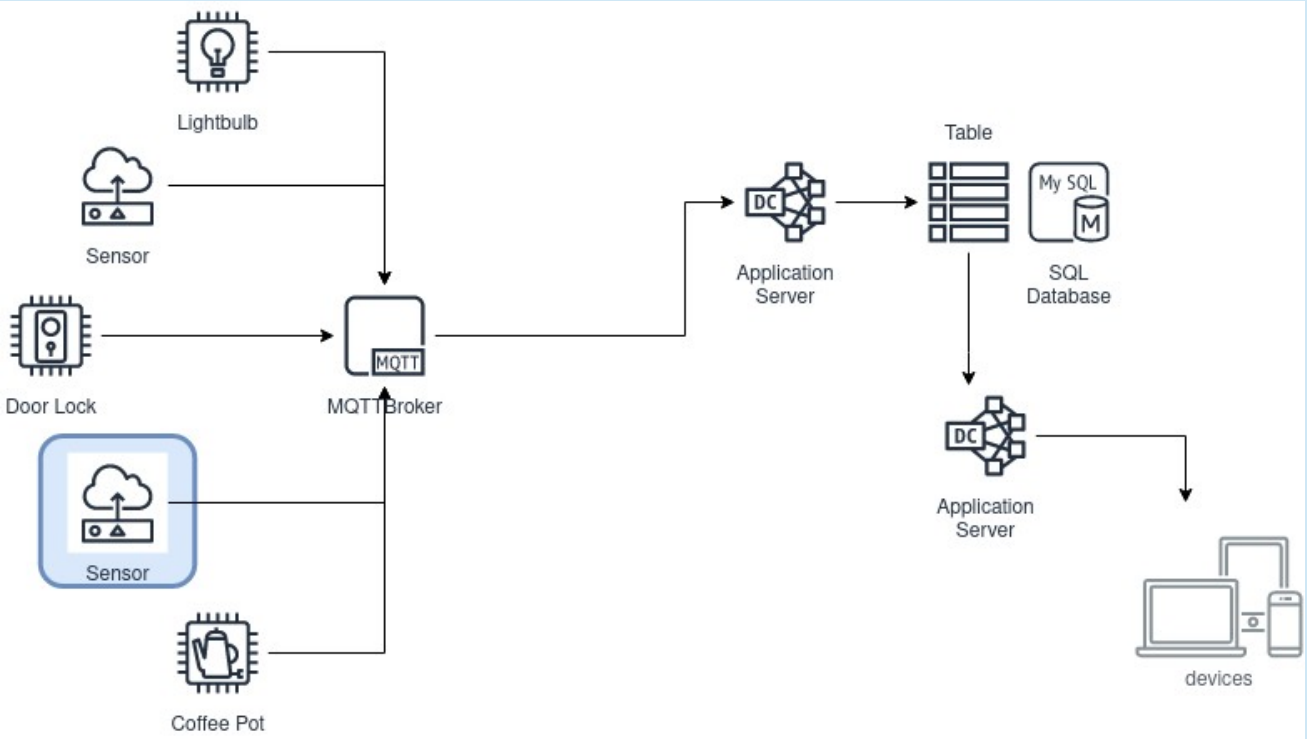
Schedule update

- Next week, 8th of October, the lecture at 10:00 is canceled.
- Lab exercises take place according to schedule.

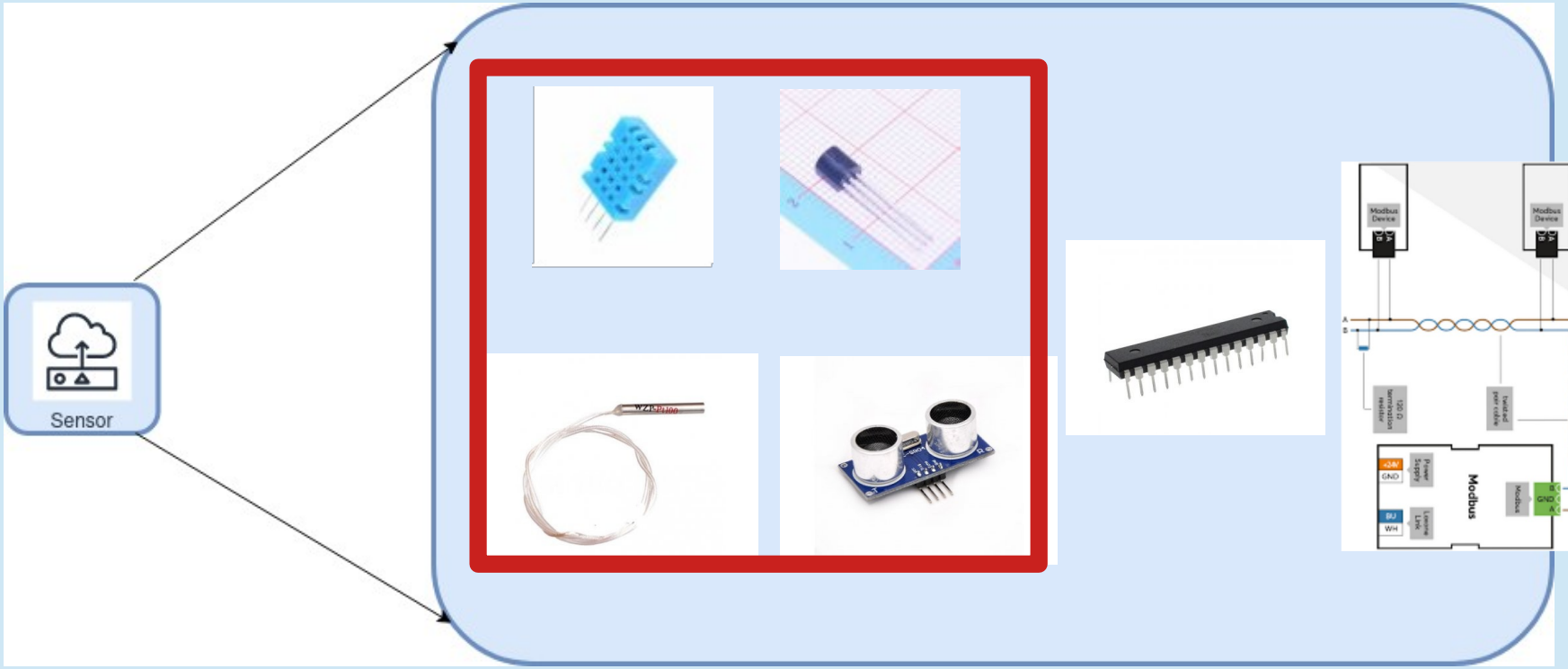
Global remarks

- Overview of available components
- Don’t try to memorize it all
- Key reprezetatives available in the lab
- More components on demand
- Very very brief excursion into electronic design

Structure of an IoT System



Structure of an IoT System



Overview

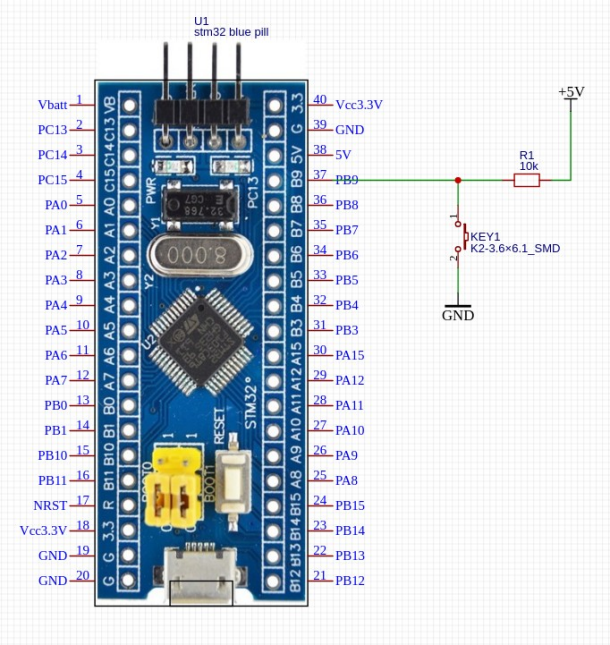
- HMI
  - Input devices
  - Displays
- Environmental sensors
- Proximity, positioning and inertial measurements
- Biometric
- Data storage and supportive devices

HMI Input Devices

- Pushbuttons and switches
- Capacitive / Inductive touch sensors
- Keyboard
- Rotary encoder

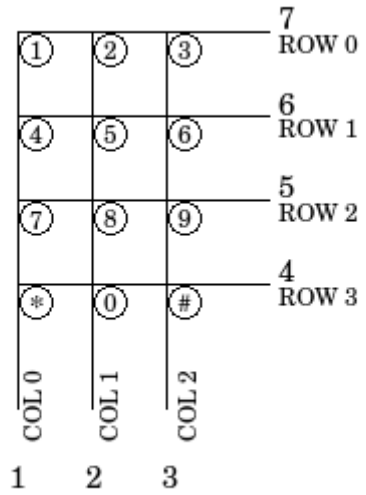
Pushbuttons and switches

- Frequently with „negative“ logic:
- Possible utilization of internal pull-up resistors of MCU



Keyboard

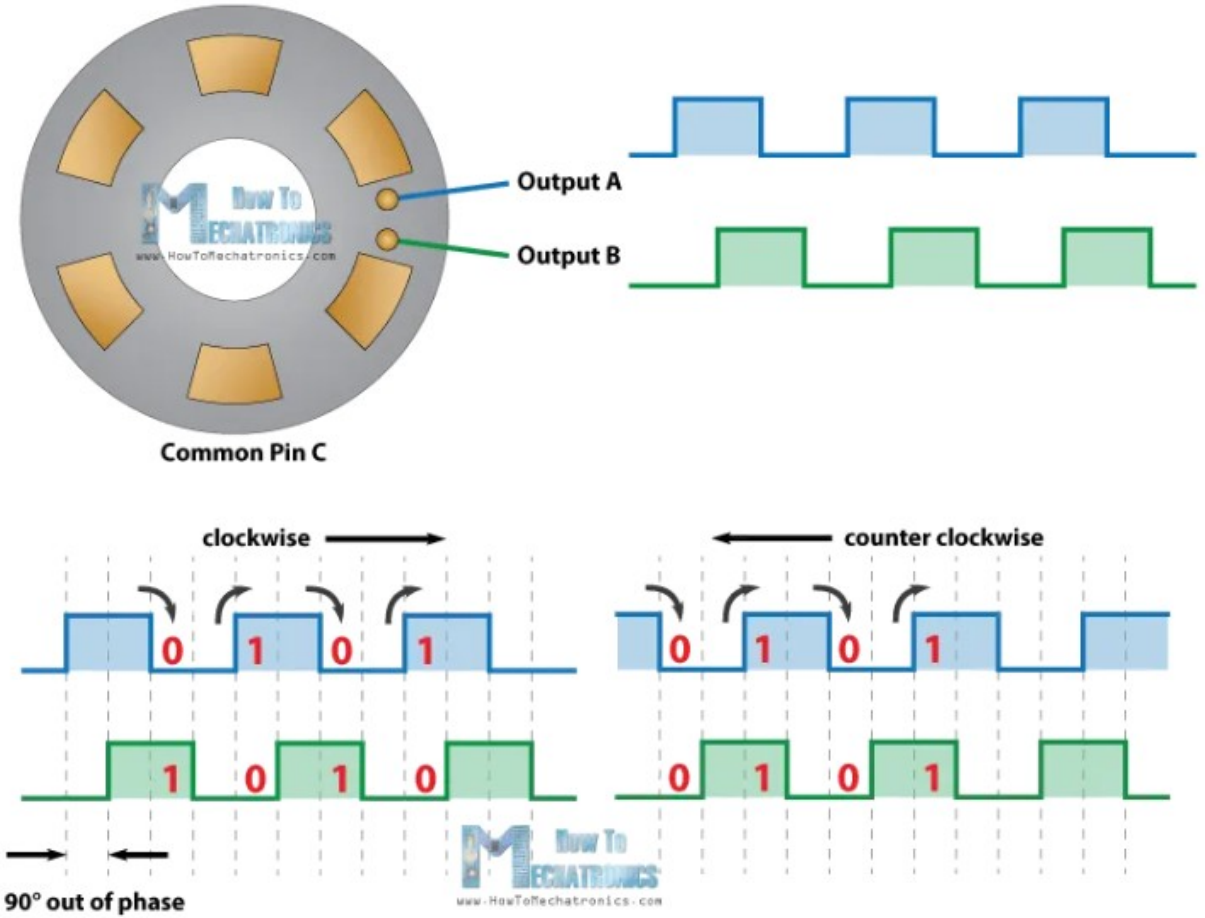
- Rows and columns
- Set all row pins as Input_Pullup
- Go column by column
- Set column pin output LOW
- Read all row pins



Rotary encoder

- Counting pulses
- Clockwise
- Counterclockwise

- Navigation in a list
- Zooming in / out



Displays

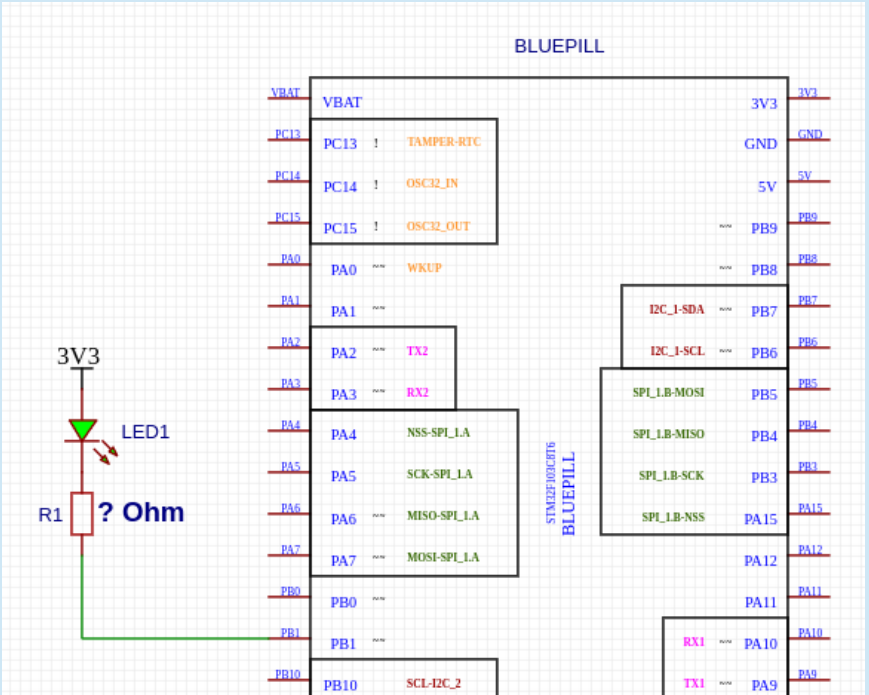
- LED, RGB LED, LED matrix
- 7-Segment LED
- LCD
- TFT
- OLED
- E-Paper

LED, RBG LED

- Current limited by resistor
- Light intensity regulated by PWM (Pulse-Width Modulation)
- Resistor value computation:

Ohms law

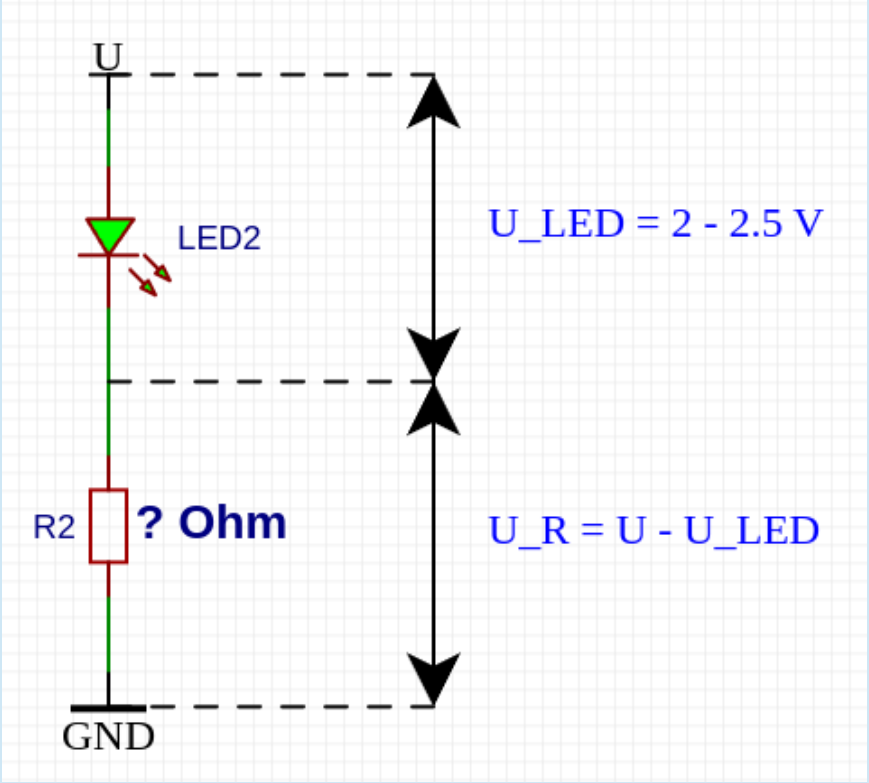
U = R x **I**



LED, RGB LED – Ohms law

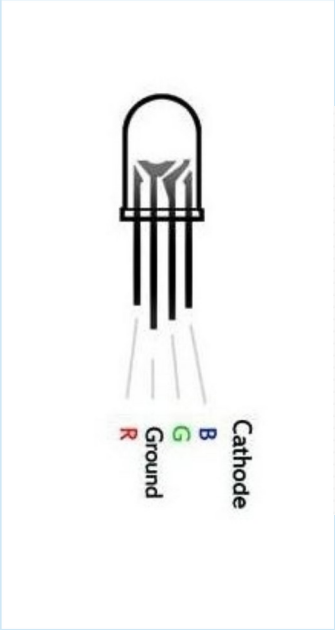
- Commonly, the LED can survive up to 20 mA
- 1 – 2 mA should be enough
- R = (U – 2V) / 2mA

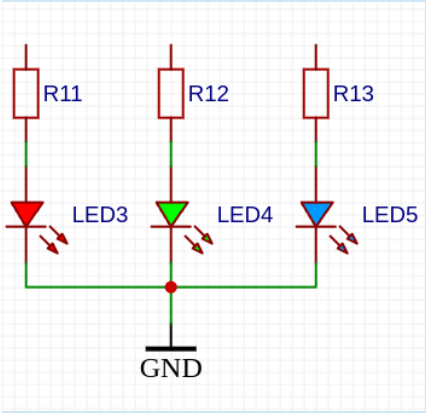
  R = (3.3V – 2V) / 2mA = 650 Ω
- Nearest common value 680 Ω
- Required precision of current set: low

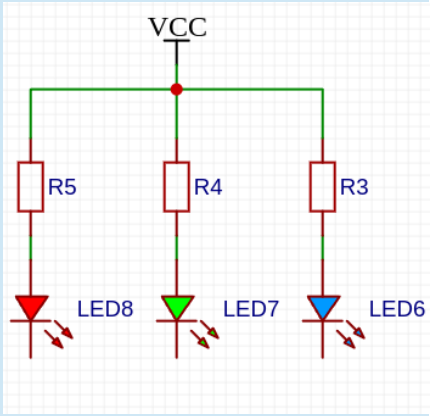


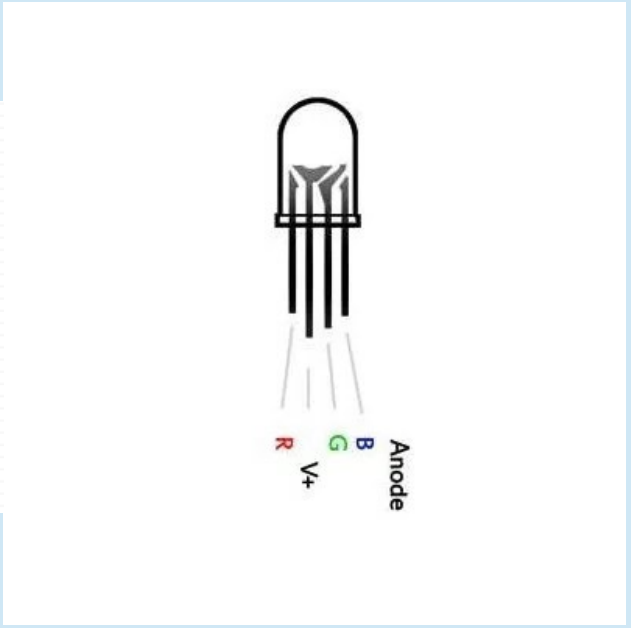
RGB LED

- Three LED diodes in one package
- Both common cathode and common anode



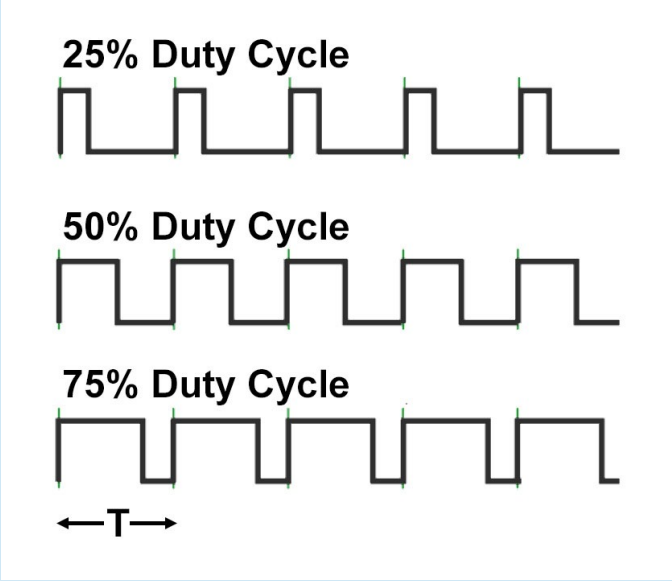






LED, RBG LED

- Current limited by resistor
- Light intensity regulated by PWM (Pulse-Width Modulation)
- PWM frequency at least 50Hz
- Recommended at least 100Hz
- PWM can be generated in software
- Hardware generated PWM is expected
- Depends on hardware architecture

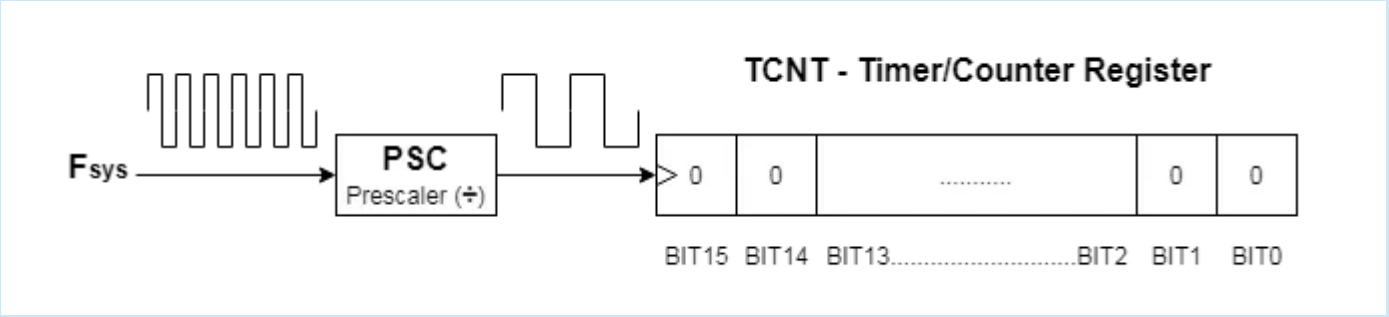


PWM on STM32F103

- 4 timers
- Each has 4 channels
- Channels of one timer have the same period and phase
- Channels are connected to GPIO PINs
- Timer can use internal or external clock source
- System clock is 8 - 72 MHz

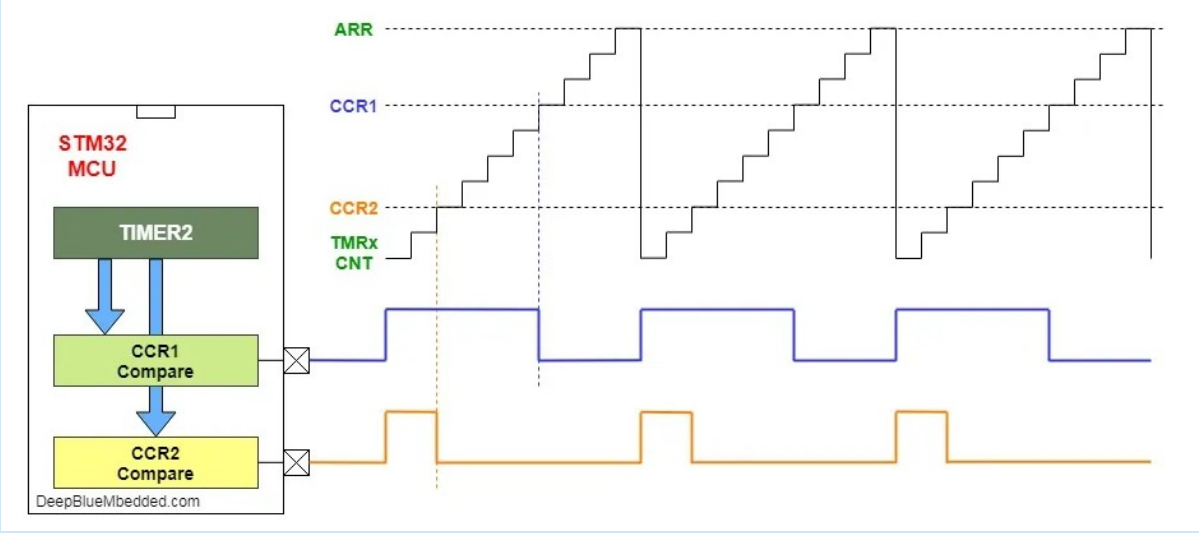
PWM on STM32F103

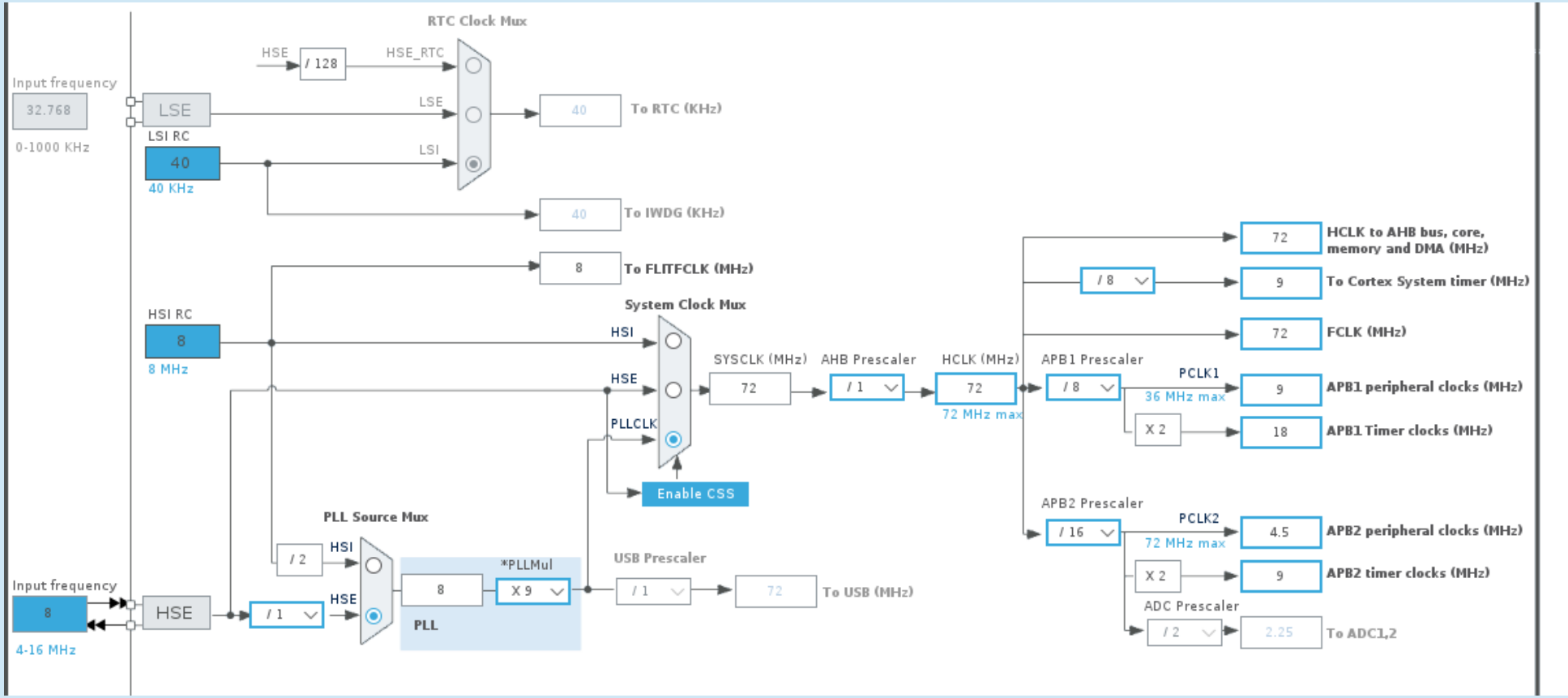
- Timer has 16-bit counter register and a Prescale register
- One of possible modes of operation is PWM

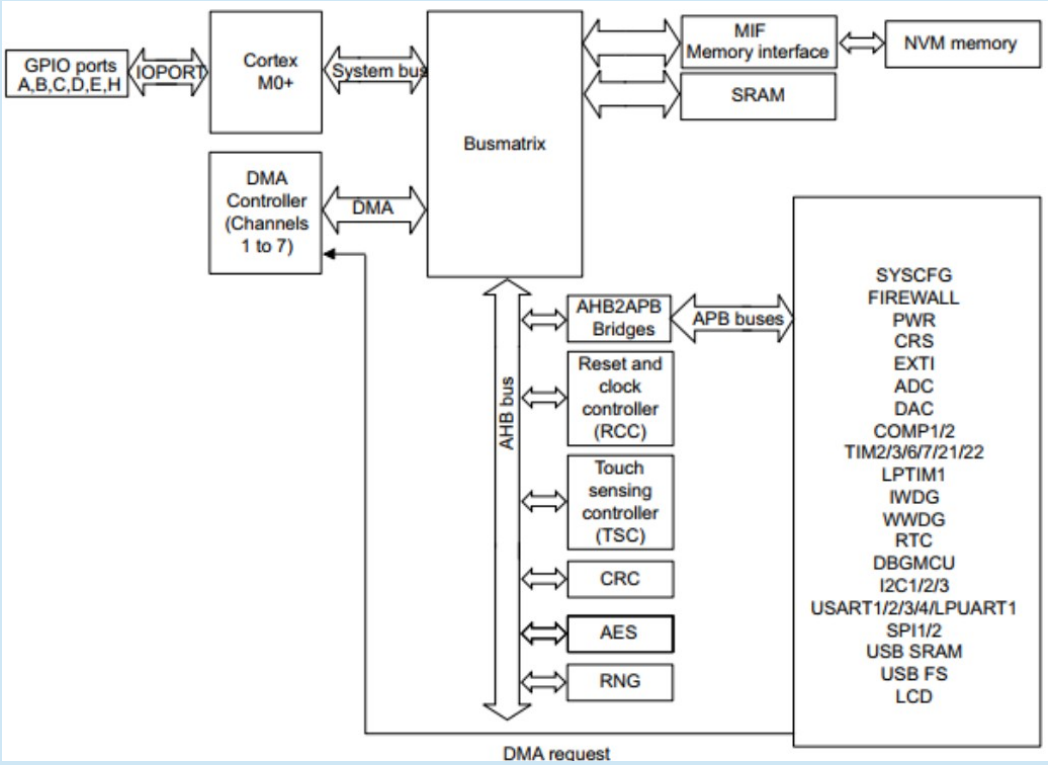


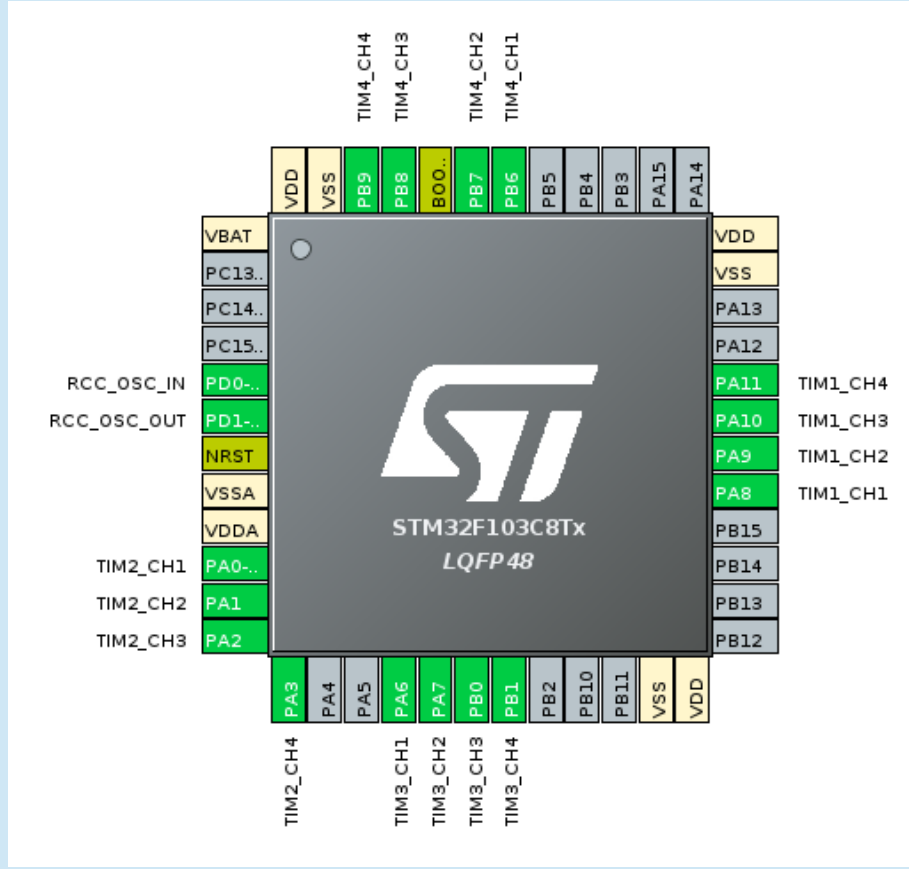
PWM on STM32F103

- Auto-Reload Register (ARR) determines period of PWM
- Capture Compare Register (CCR) determines the duty cycle




RTC Clock Mux
HSE
/ 128
HSE_RTC
Input frequency
32.768
0-1000 KHz
LSE
LSE
40
To RTC (KHz)
LSI RC
40
40 KHz
LSI
40
To IWDG (KHz)
8
To FLITFCLK (MHz)
System Clock Mux
HSI RC
8
8 MHz
HSI
HSE
PLLCLK
SYSCLK (MHz)
72
AHB Prescaler
/ 1
HCLK (MHz)
72
72 MHz max
APB1 Prescaler
/ 8
PCLK1
36 MHz max
X 2
72
HCLK to AHB bus, core, memory and DMA (MHz)
/ 8
9
To Cortex System timer (MHz)
72
FCLK (MHz)
9
APB1 peripheral clocks (MHz)
18
APB1 Timer clocks (MHz)
Enable CSS
APB2 Prescaler
/ 16
PCLK2
72 MHz max
4.5
APB2 peripheral clocks (MHz)
X 2
9
APB2 timer clocks (MHz)
ADC Prescaler
/ 2
2.25
To ADC1,2
PLL Source Mux
/ 2
HSI
HSE
Input frequency
8
4-16 MHz
HSE
/ 1
8
*PLLMul
X 9
PLL
USB Prescaler
/ 1
72
To USB (MHz)

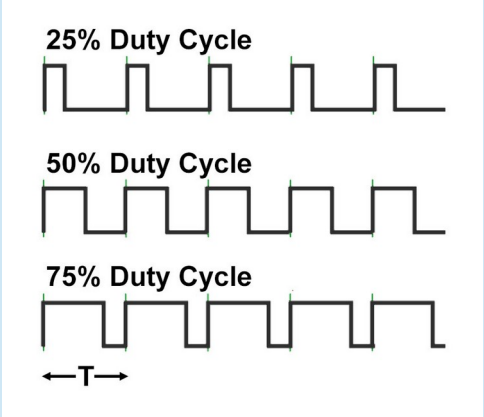

GPIO ports A,B,C,D,E,H
IOPORT
Cortex M0+
System bus
Busmatrix
MIF Memory interface
NVM memory
SRAM
DMA Controller (Channels 1 to 7)
DMA
AHB2APB Bridges
APB buses
AHB bus
Reset and clock controller (RCC)
Touch sensing controller (TSC)
CRC
AES
RNG
SYSCFG
FIREWALL
PWR
CRS
EXTI
ADC
DAC
COMP1/2
TIM2/3/6/7/21/22
LPTIM1
IWDG
WWDG
RTC
DBGMCU
I2C1/2/3
USART1/2/3/4/LPUART1
SPI1/2
USB SRAM
USB FS
LCD
DMA request


TIM4_CH4
TIM4_CH3
TIM4_CH2
TIM4_CH1
VDD
VSS
PB9
PB8
BOO..
PB7
PB6
PB5
PB4
PB3
PA15
PA14
VBAT
PC13..
PC14..
PC15..
RCC_OSC_IN
PD0-..
RCC_OSC_OUT
PD1-..
NRST
VSSA
VDDA
TIM2_CH1
PA0-..
TIM2_CH2
PA1
TIM2_CH3
PA2
VDD
VSS
PA13
PA12
PA11
TIM1_CH4
PA10
TIM1_CH3
PA9
TIM1_CH2
PA8
TIM1_CH1
PB15
PB14
PB13
PB12
STM32F103C8Tx
LQFP48
PA3
PA4
PA5
PA6
PA7
PB0
PB1
PB2
PB10
PB11
VSS
VDD
TIM2_CH4
TIM3_CH1
TIM3_CH2
TIM3_CH3
TIM3_CH4

PWM on STM32F103

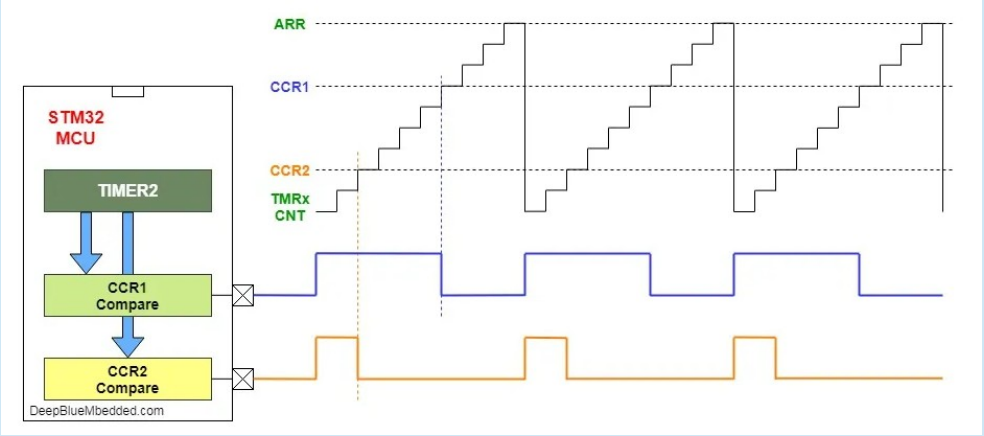
- PWM Frequency

$$F_{PWM} = \frac{F_{CLK}}{(ARR + 1) \times (PSC + 1)}$$



- PWM Duty Cycle (%)

$$DutyCycle_{PWM}[\%] = \frac{CCRx}{ARRx}[\%]$$

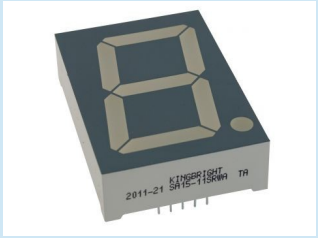


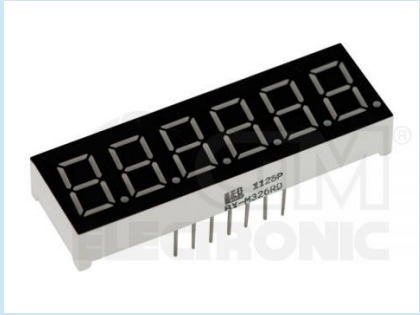
LED Matrix

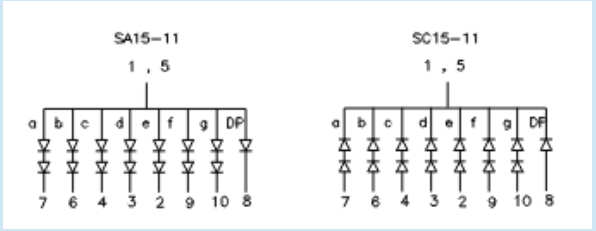
- Matrix of 8x8 LED diodes
- Stackable modules
- Driver MAX7219
  - Acts as a shift register

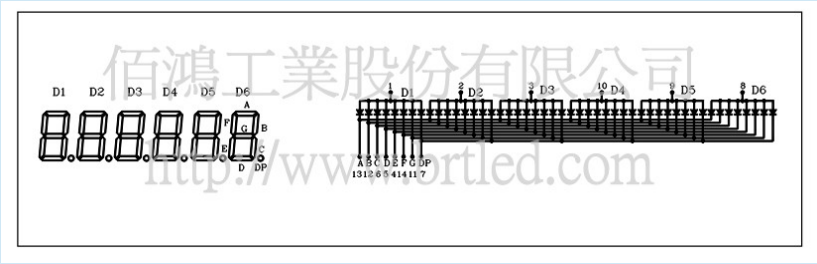
7-segment LED display

- 8 LEDS in one package
- Many sizes
- Beware of maximum current
- Both variants – common cathode and common anode
- Limit number of pins → shift register

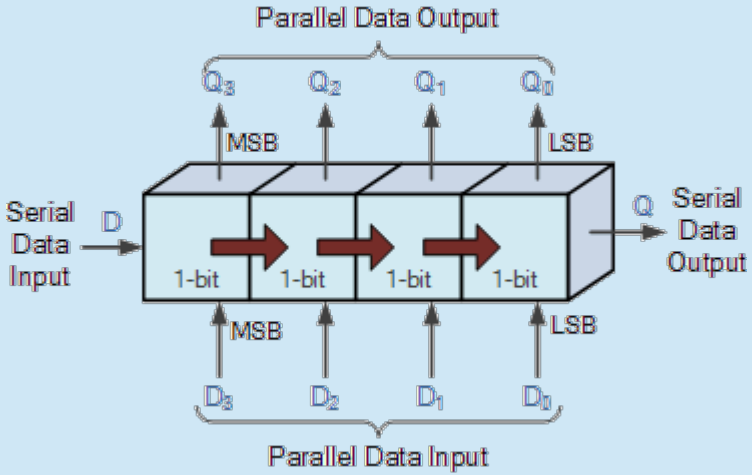


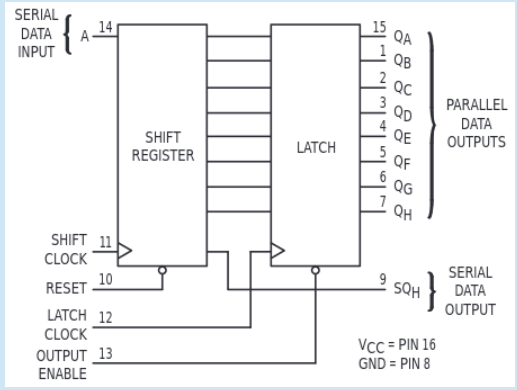


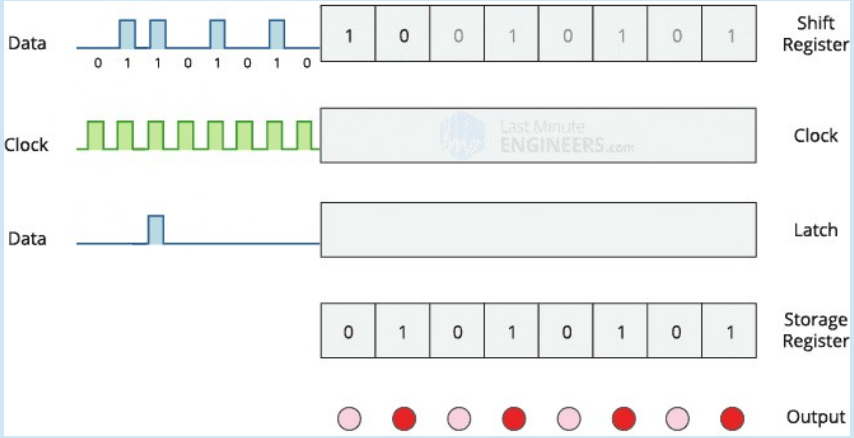


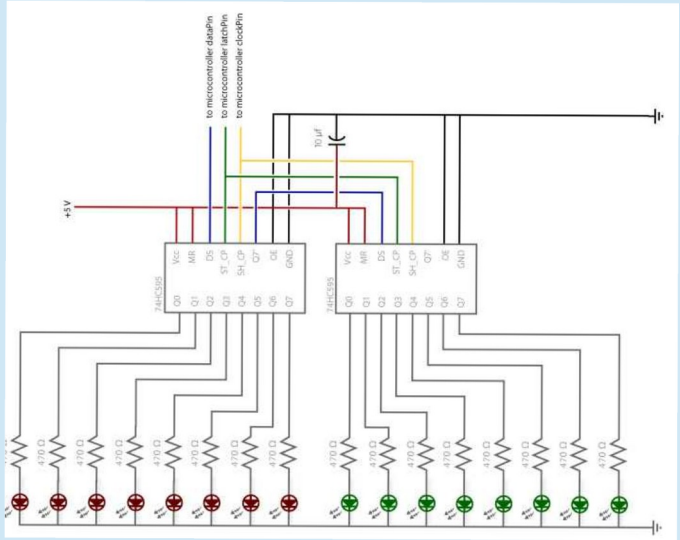


Shift register



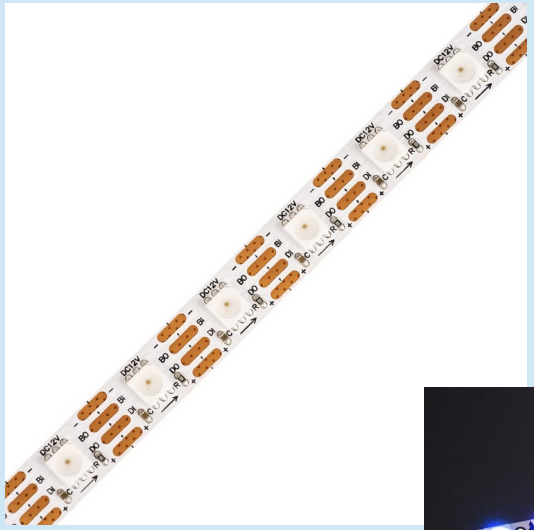






NeoPixel LED

- 3 LED diodes (RGB)
- 3x8 bit
- Simplified shift register (Data_IN, Data_Out)
  Fixed timing



LCD

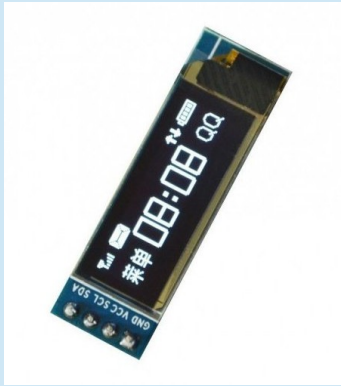
- Traditional, might seem to be a bit old-fashioned
- 2x16 or 4x20 characters
- Based on Hitachi HD44780 chip or clones
- 4 or 8 bits for data + 3 control signals
- Commonly used with I2C converter

TFT

- Matrix of pixels
- Various sizes (in inches and number of points)
- Commonly with SPI interface
- Many modules equipped with touch screen
- Touchscreen has standalone SPI interface
- Example: ILI9341
  - 2.4“ 240x320 pixels

OLED

- Small modules, typically
  - 0.91“ (128x32 pixels)
  - 0.96“, 1.3“ (128x64 pixels)
- Single color, twocolour a bit tricked
- I2C or SPI interface



e-Paper

- E-paper or e-ink
- Can keep the image even if powered off
- Better to blank the screen after couple of days
- Small modules for reasonable price 200x200 points
- Single or dual color
- Suspicious cheap → probably without driver
- SPI interface
- Beware of image size

Environmental sensors

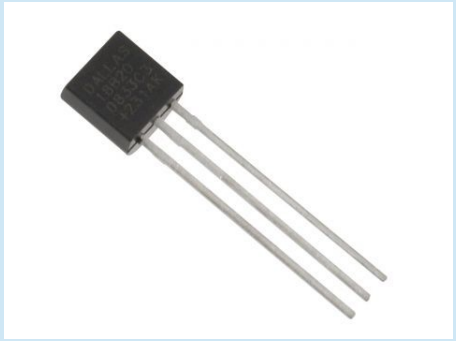
- Temperature
- Relative humidity
- Barometric pressure
- Concentration of gasses
- Concentration of dust particles
- Intensity of light

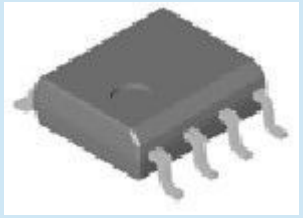
Temperature

- Analog – PT100/PT1000, NTC, ….
- Dallas DS18B20
- NXP LM75
- TI TMP112
- Sensirion SHT30, SHT31, SHT35, SHT45, ….
- Infrared termometers and pyrometers
- Part of humidity and/or barometric pressure measurement

DS18B20

- Interface **1-Wire**
- Unique ID
- Package TO-92, SOIC-8, or hermeticaly sealed





NEXPERIA LM75A

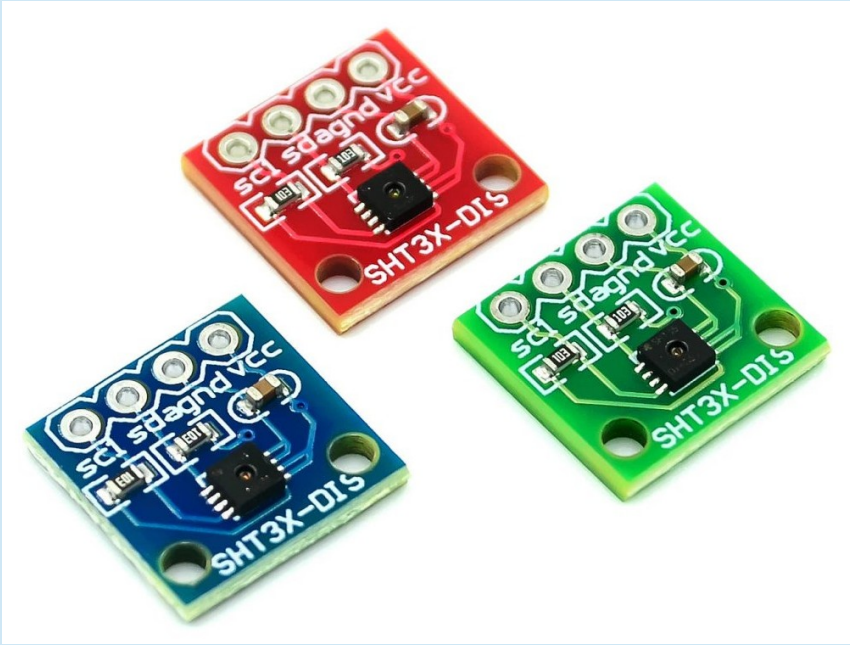
- General purpose chip temperature meters
- Resolution of 0.125 °C
- I2C interface
- Similar devices from TI (LM75A) or Analog Devices (ADT75A)
- SO8 / TSSOP8 / MSOP8 / … package

Texas Instruments TMP112

- Miniature termometers
- SOT563 package (1.2 x 1.6 mm)
- Measurement on PCBs and in electronic devices
- I2C interface
- Alert on treshold (SMBus ALERT function)
- Similar models TMP101, TMP102
- TMP114 in package Picostar (0.76 x 0.76 mm)
- TMP117 in packge WSON / DSBGA package

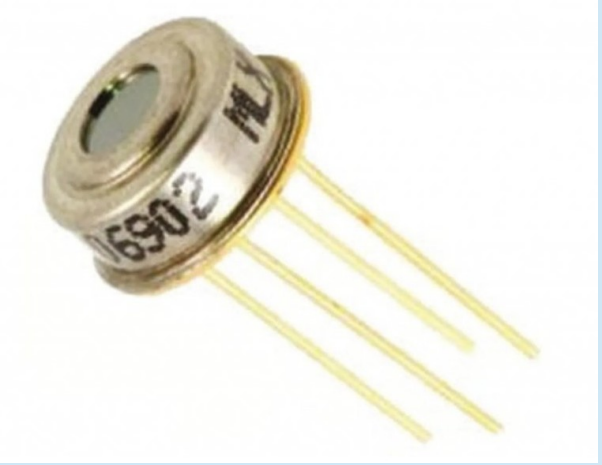
Sensirion

- Swiss manufacturer of sensors
- SHT series includes humidity sensors
- Similar to TI TMP series
- SHT4x about 1.5x1.5mm 0.4uA
- Used mainly on PCBs
- Interface I2C



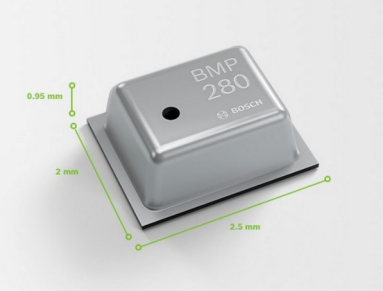
Infrared sensors

- Contactless measurement
- Industrial, building automation, medical
- Many types and modules
- Output analog, I2C, PWM
- Example: Melexis MLX90614, MLX90615



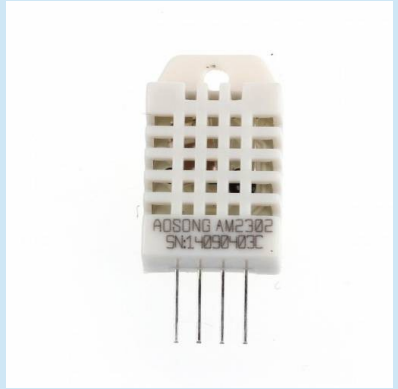
Barometric pressure and combined sensors

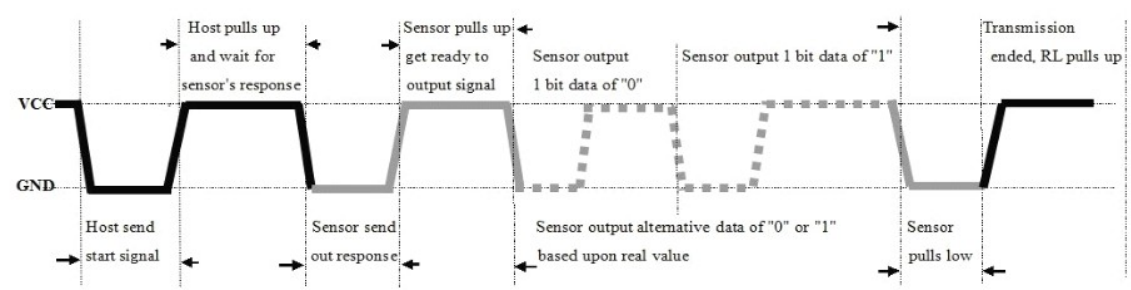
- Robert Bosch GmbH
- One of few chip manufacturers in Europe
- Interface I2C
- BMP180 – just pressure
- BMP280 includes temperature
- BME280 adds humidity

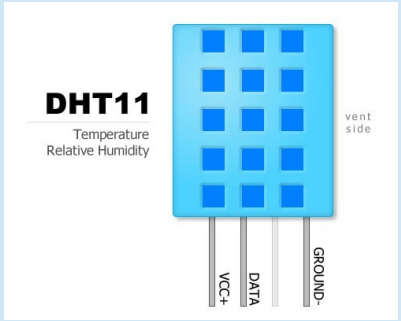


Humidity sensors

- DHT-11 / DHT-22
- Temperature and relative humidity
- Specific serial protocol similar to 1-Wire
- Not compatible with Dallas 1-Wire
- 16 bit relative humidity, 16 bit temperature, 8bit checksum





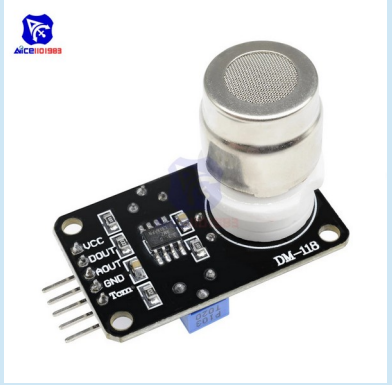


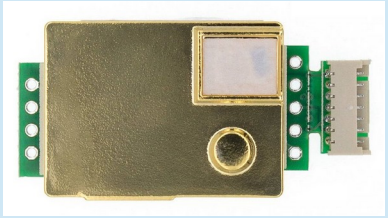
Gas concentration

- Carbon dioxide
- Carbon monoxide
- Combustible gases
- Commonly long pre-heat time
- Frequently analog output

Gas concentration

- MQ-7 – Carbon monoxide
- MQ-2 – Combustible gas
- Carbon dioxide MG811
  - Carbon dioxide NIR based
  - MH-Z19B – UART/PWM
  - SDC30 - UART/I2C/PWM





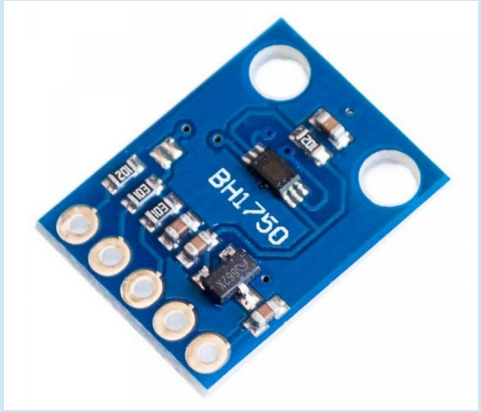
Dust particles

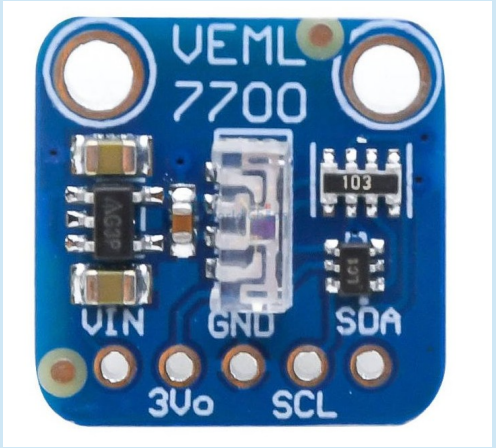
- Sharp GP2Y1010AU0F
- Based on light reflected from dust particle
- Analog output

- Sensirion SEN54-SDN-T
- The same principle
- Interface I2C

Light intensity

- A lot of analog devices
- BH1750
  - I2C
  - 0 - 65535lux
  - Precision and callibration
- VEML7700 (Vishay)
  - I2C
  - 0 - 120000lux



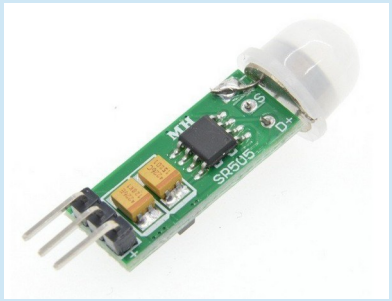


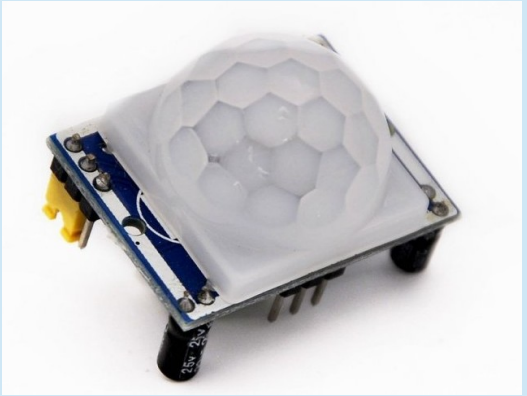
Proximity measurement

- PIR
- Ultrasound
- Lidar

PIR - Pyroelectric (passive) InfraRed

- Motion sensor
- Surveillance
- Binary output
- Some delay
- Various angle and reach
- Many types: HC-SR505, HC-SR501, AM312

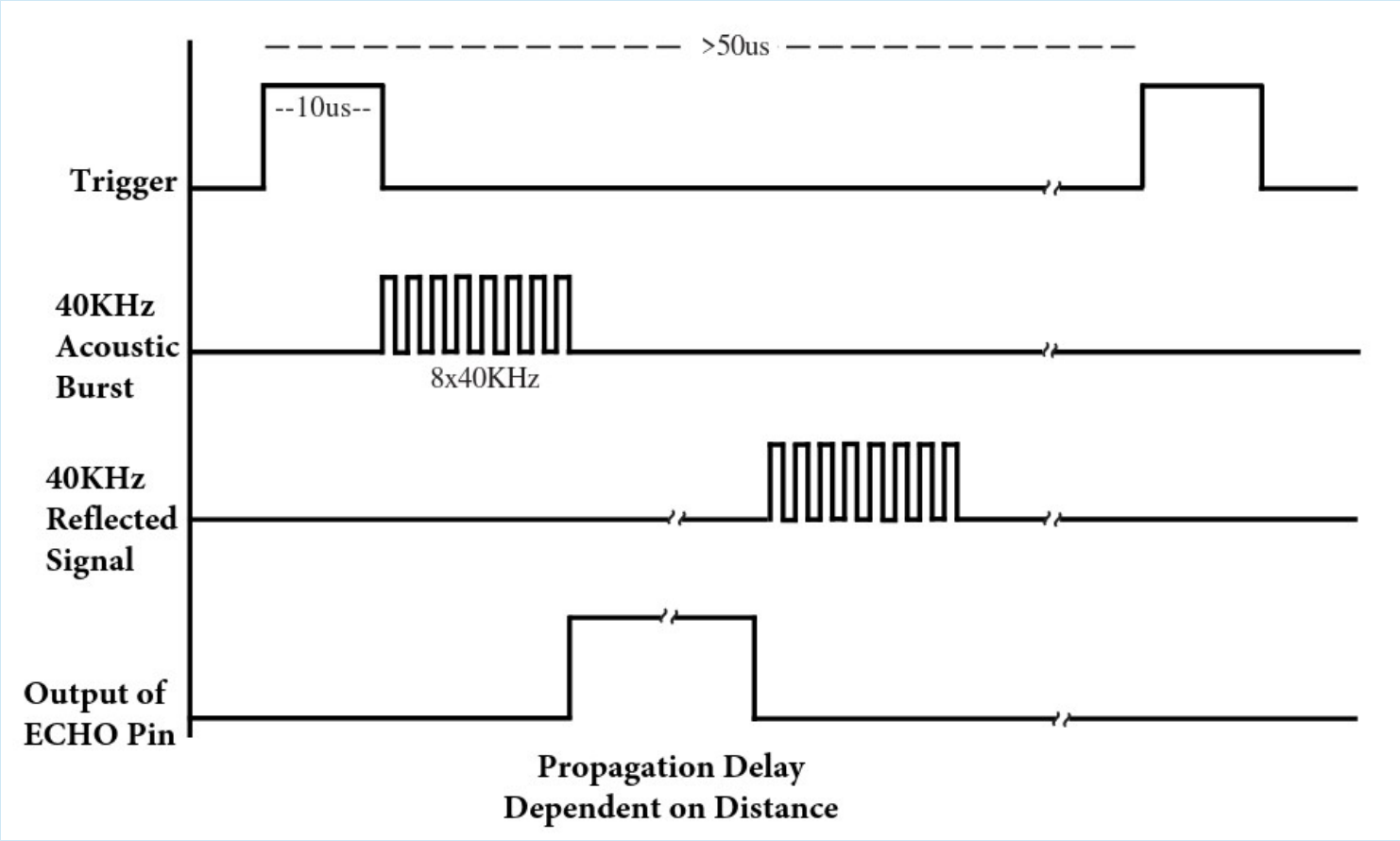




Ultrasound

- Distance measurement
- Originaly parking sensor in cars
- Many new applications
- Reach about 4 m, resolution 0.5 cm
- Trigger pin sends 8 x 40 kHz pulses
- Echo pin receives reflected signal

Ultrasound

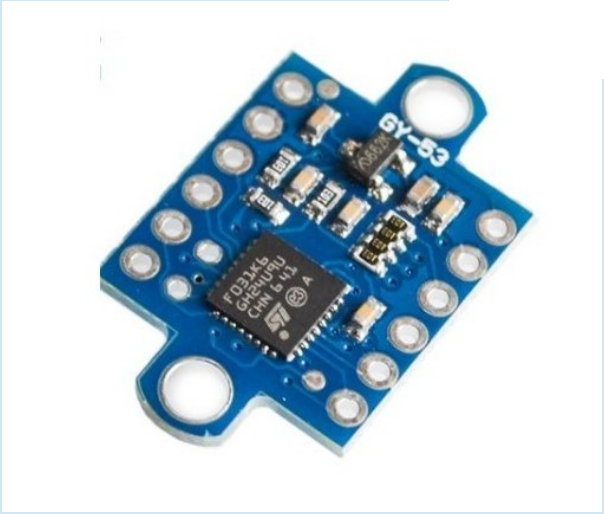

>50us
--10us--
Trigger
40KHz
Acoustic
Burst
8x40KHz
40KHz
Reflected
Signal
Output of
ECHO Pin
Propagation Delay
Dependent on Distance

Ultrasound

- Speed of the sound in air 340m/sec
- Obstacle in distance 1m:
- Time the signal travels from sensor to obstacle = 1/340 s = 2.9 ms
- Signal roundtrip time = 5.8 ms
- Distance in cm = echo pulse width in µs/58

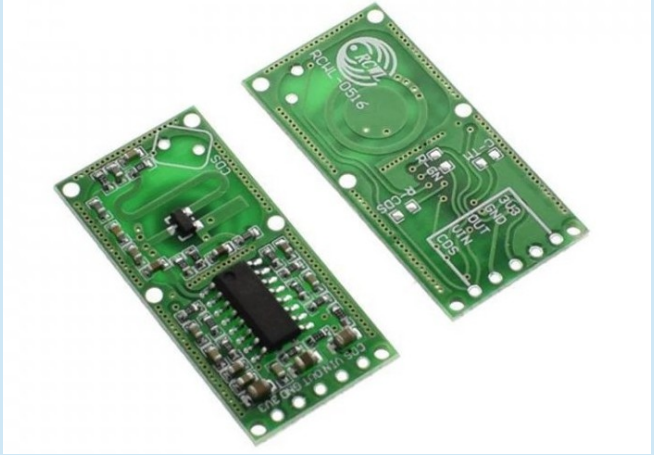
Lidar

- VL53L0X
- I2C interface
- Same principle as ultrasound sensor
- Same reach and precision



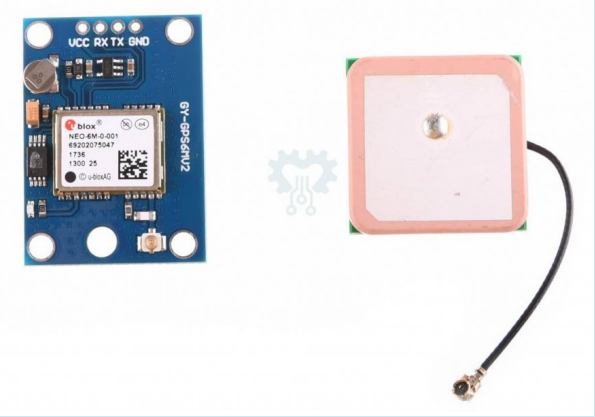
Doppler radar

- RCWL-0516
- Movement detection up to ~ 8m
- Competitor to PIR sensors

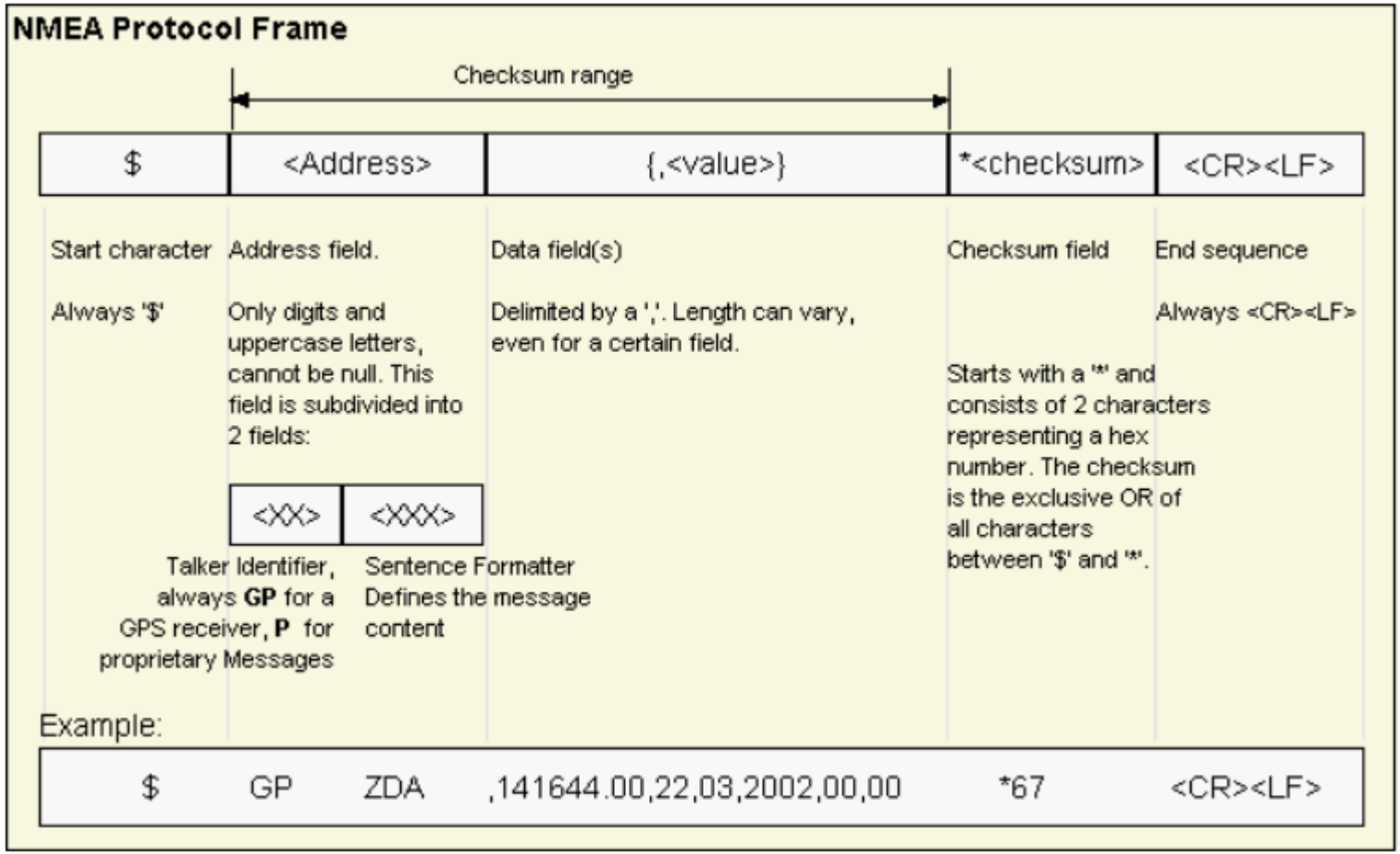


GPS

- Most commonly used module NEO6M / NEO6Mv2
- Antena on uFL connector
- UART and PPS interface
- Serial text based protocol
- NMEA 0183 Standard For Interfacing Marine Electronic Devices, Version 2.30



GPS


NMEA Protocol Frame
Checksum range
$
<Address>
{,<value>}
*<checksum>
<CR><LF>
Start character
Always '$'
Address field.
Only digits and uppercase letters, cannot be null. This field is subdivided into 2 fields:
<XX>
<XXX>
Talker Identifier, always GP for a GPS receiver, P for proprietary Messages
Sentence Formatter Defines the message content
Data field(s)
Delimited by a ','. Length can vary, even for a certain field.
Checksum field
Starts with a '*' and consists of 2 characters representing a hex number. The checksum is the exclusive OR of all characters between '$' and '*'.
End sequence
Always <CR><LF>
Example:
$ GP ZDA ,141644.00,22,03,2002,00,00 *67 <CR><LF>

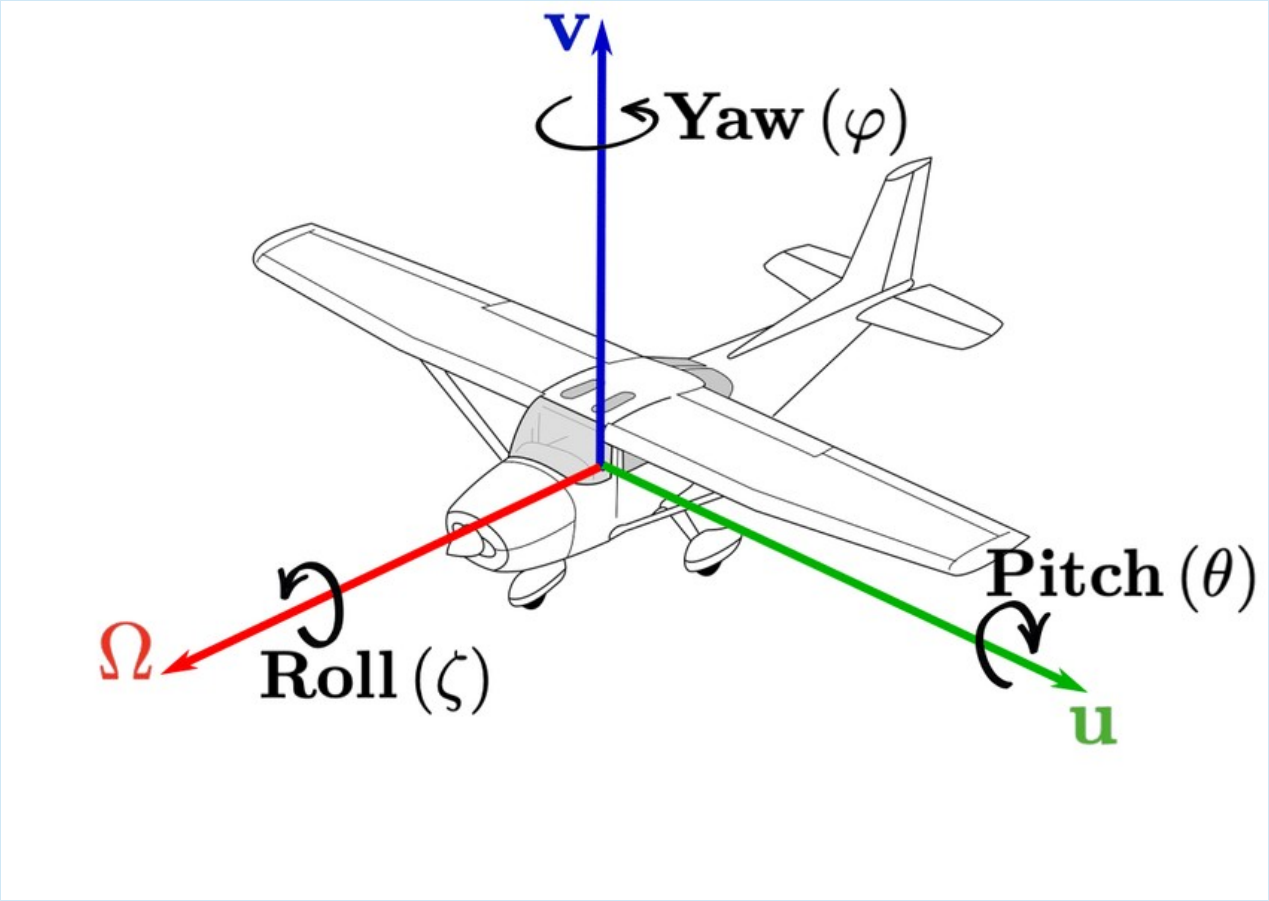
Gyroscope + Accelerometer

- Most popular solutions based on InvenSense MPU6050
- 3-axis gyroscope and accelerometer
- Gyroscope: + 250 500 1000 2000°/s
- Accelerometer: ± 2 ± 4 ± 8 ± 16g
- 16-bit ADC
- Interface I2C
- Alternative MPU6000 – SPI interface

Inertial sensor with magnetometer

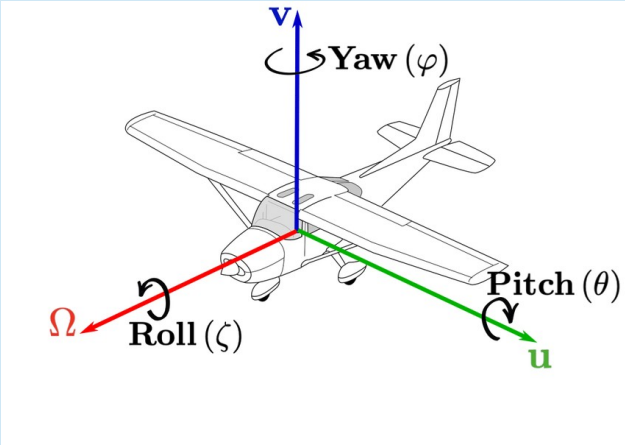
- InvenSense MPU9250
- Similar to MPU6050
- Added magnetometer = electronic compass
- Interface both I2C and SPI
- Position expressed in angle coordinates: yaw, pitch, and roll

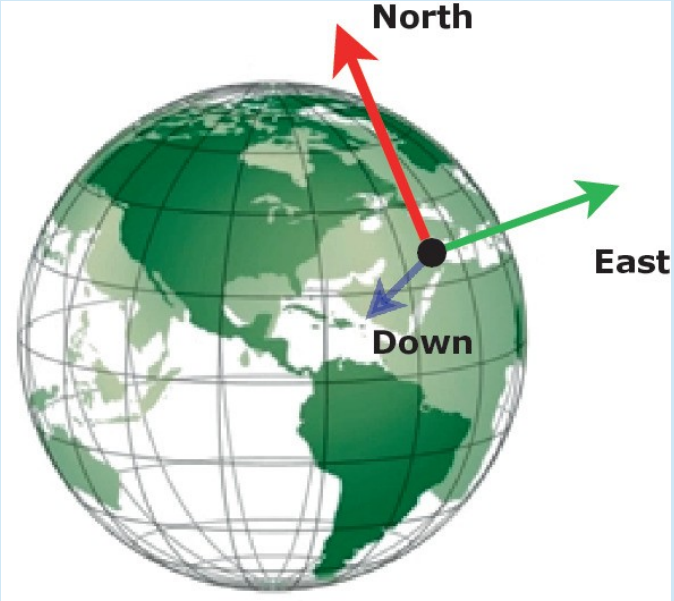
Angle coordinates



Direction cosine method

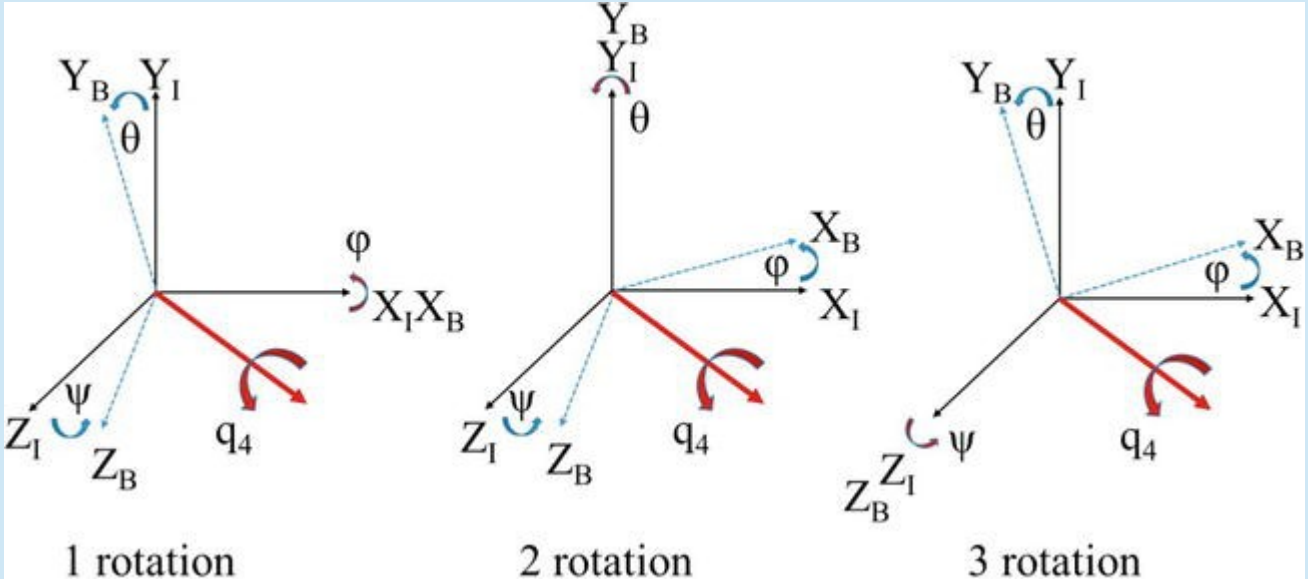
- It is necessary to align output of sensor to the Earth coordinate system and orient it to north pole





Direction cosine matrix

- Offset compensation
- Optionally, Kalman filter for data smoothing
- Euler angles, DCM computation



Biometric sensors

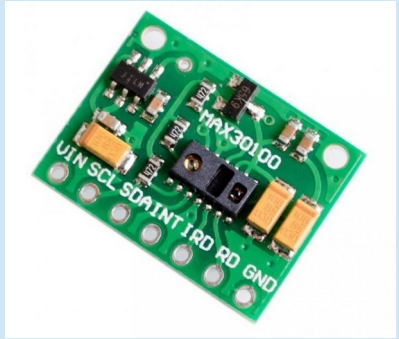
- Fingerprint
- Heart rate
- EKG

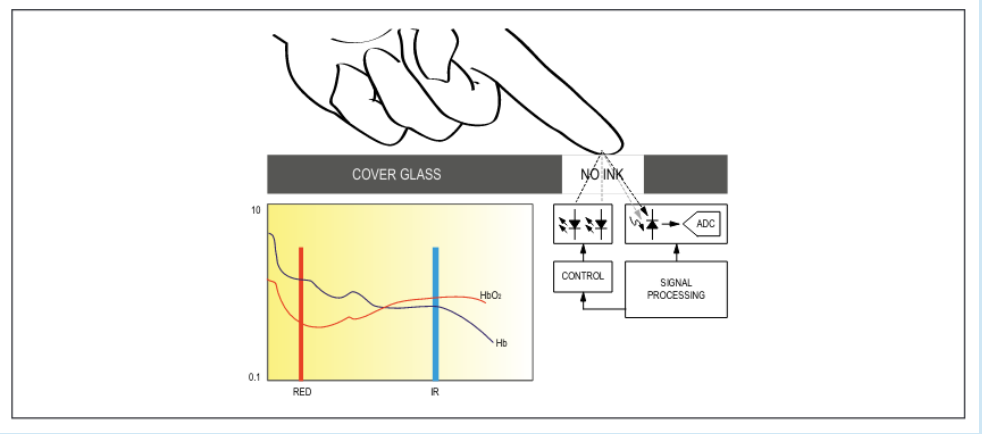
Fingerprint

- Will be part of followup lecture „IoT Security“
- Commonly, UART interface
- Main manufacturer of simple components is Synochip

Heart rate

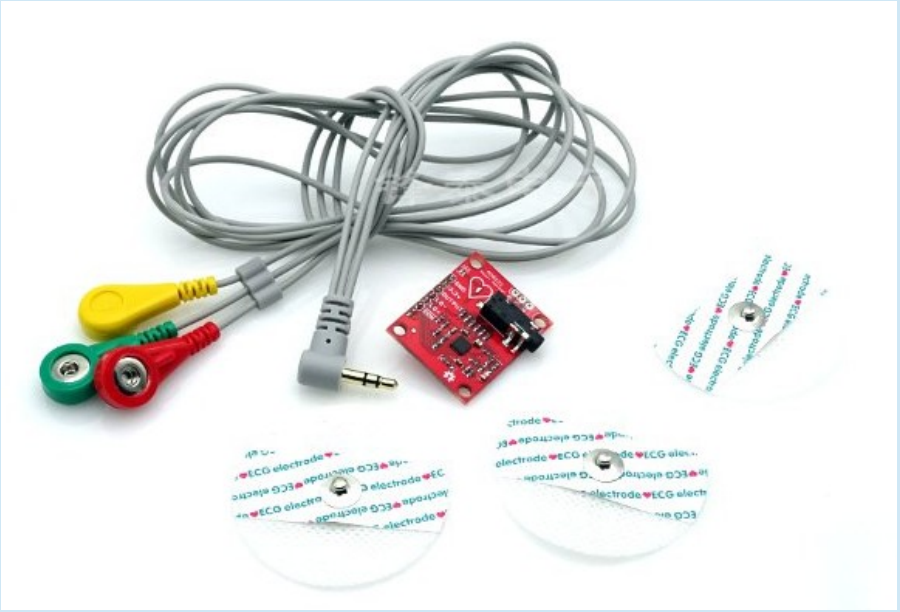
- Chip Maxim Integrated MAX30100
- Includes oxymeter
- IR LED: 880nm
- RED LED: 660nm
- Interface I2C
- Low power consumption





EKG

- Based on Analog Devices AD8232
- Analog output
- Software for Arduino available

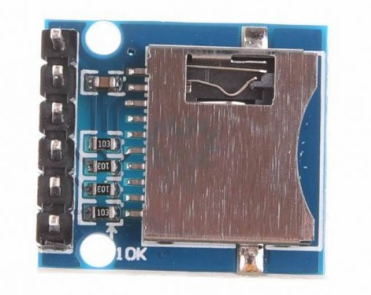


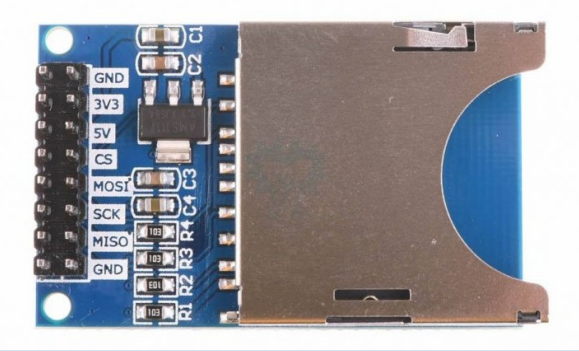
Data Storage

- uSD
- Flash
- EEPROM
- eMMC

uSD card reader

- A lot of simple and cheap modules
- Interface SPI
- Filesystem FAT32
- Software libreries exists, though the FAT is simple enough



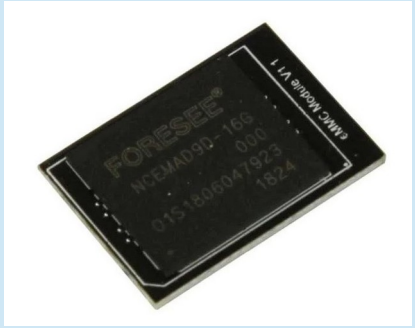


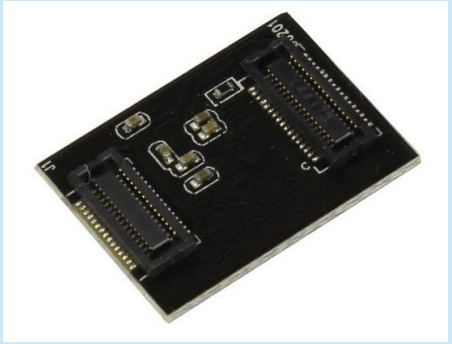
Flash

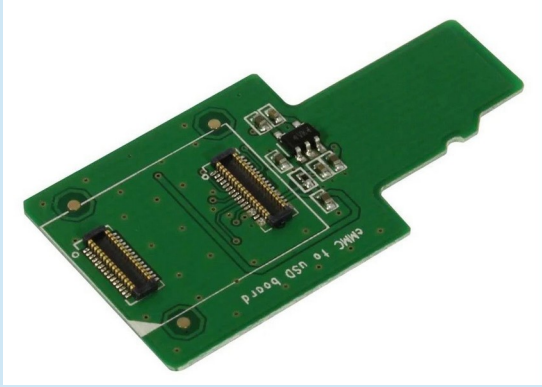
- Block organization, no filesystem
- SPI interface
- Larger capacity than EEPROM and smaller than SD cards
- Popular module W25Q32 – 32MBit = 4MByte

eMMC

- In some sense successor of uSD
- About the same capacity
- More solid mechanical connection
- Used instead of uSD in several Something-Pi
- Reader in uSD format





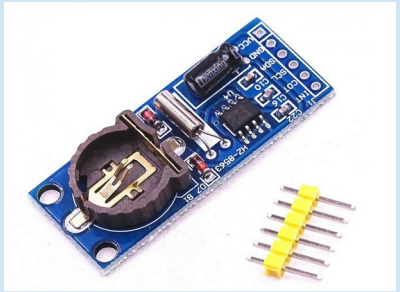


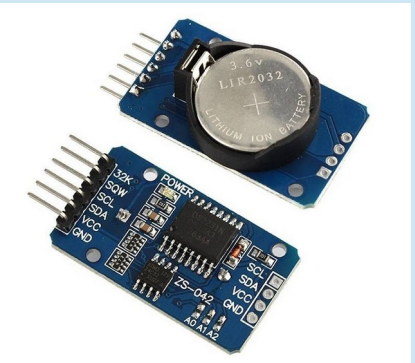
Unsorted

- RTC
- Converters
- Multiplexers
- ADC
- NFC card reader

RTC

- With few exceptions, MCUs used in IoT don’t have real time clock
- Several external RTC exist
- Battery keeping the time
- Interrupt sometimes on exotic voltage level → additional electronics needed to wake-up MCU
- I2C interface
- PCF8563, DS3231





Thank you for your atttention!

Questions and comments?