Internet of Things

Senior Design Project Course

Signals and Systems

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Signals And Systems

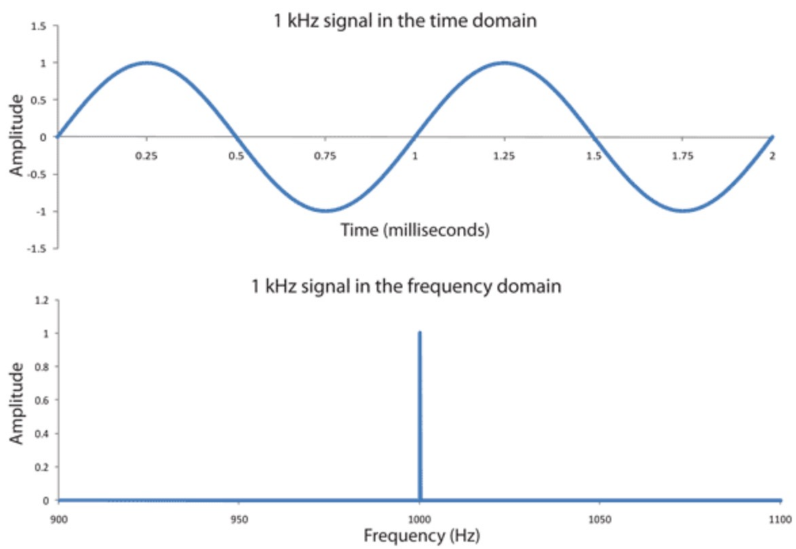
Signals and Systems

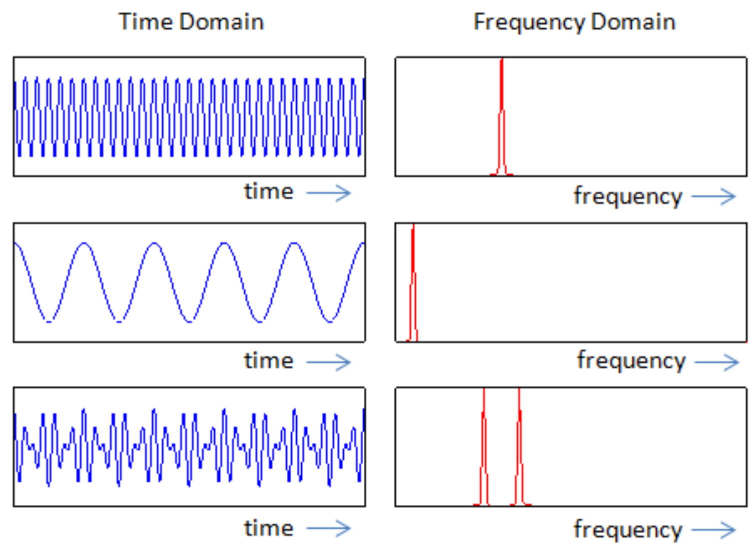
- In this part of lecture, we learn the following
  - Spectrum
  - Analog vs Digital
  - Time sampling
  - Quantization
  - Pulse Width Modulation

- How is it related to IoT?
  - Physical world events are continuous, while MCU operate on digital signals.
  - For reading and interpreting continuous input data from sensors
  - For generating continuous output data for actuators

What Is a Signal

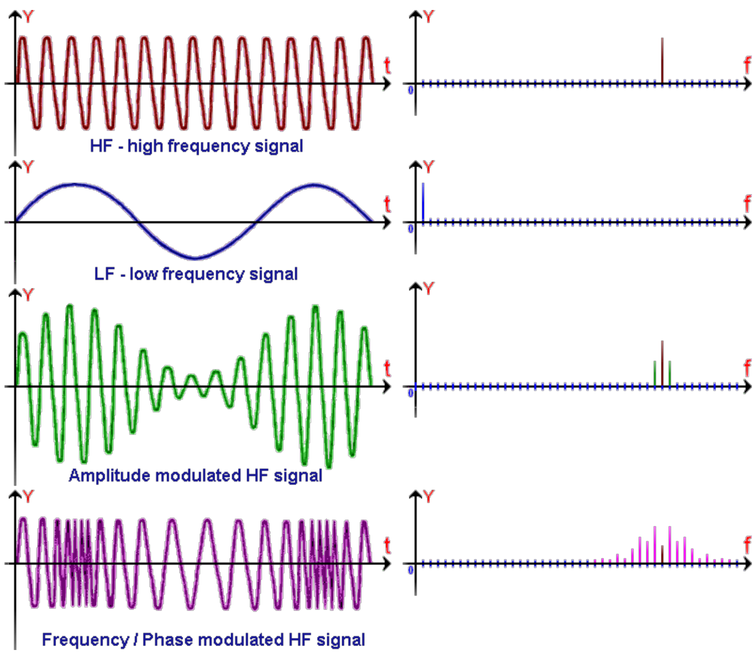
- A function that carries information in **Time** and **Frequency**

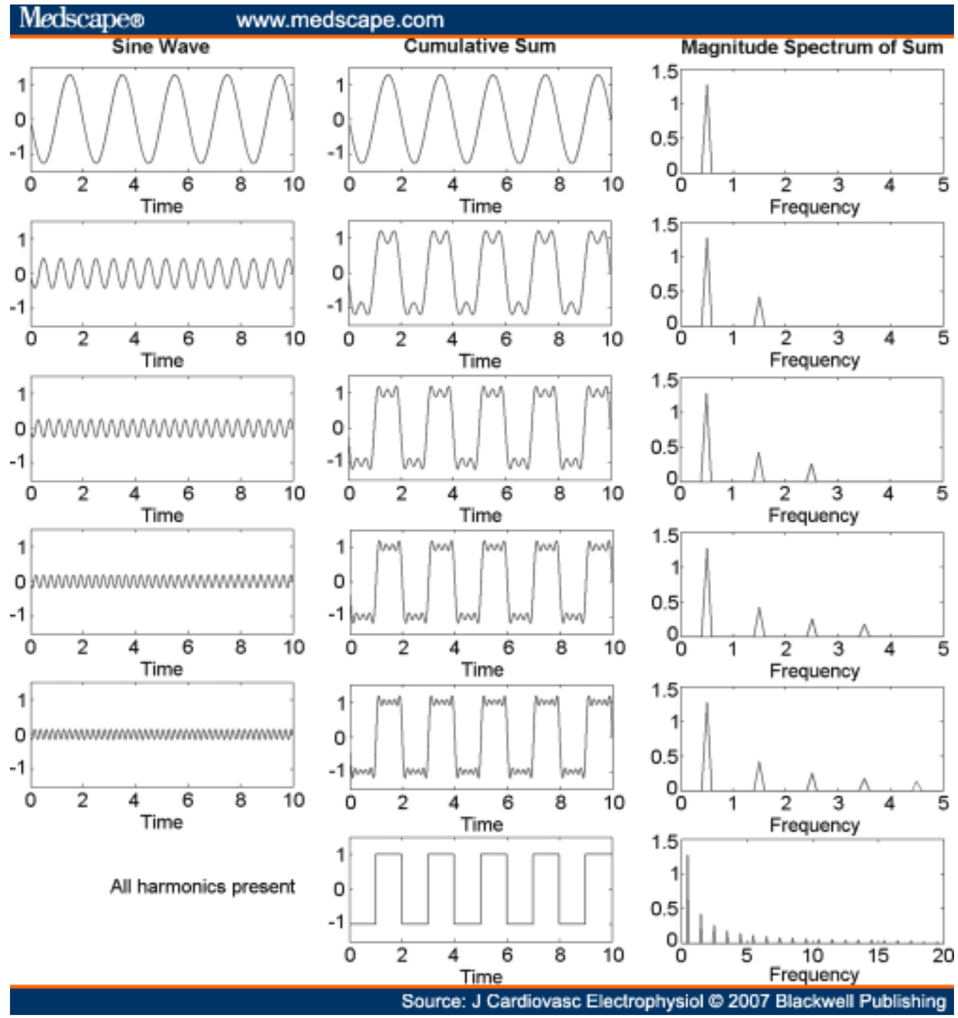




What Is a Spectrum?

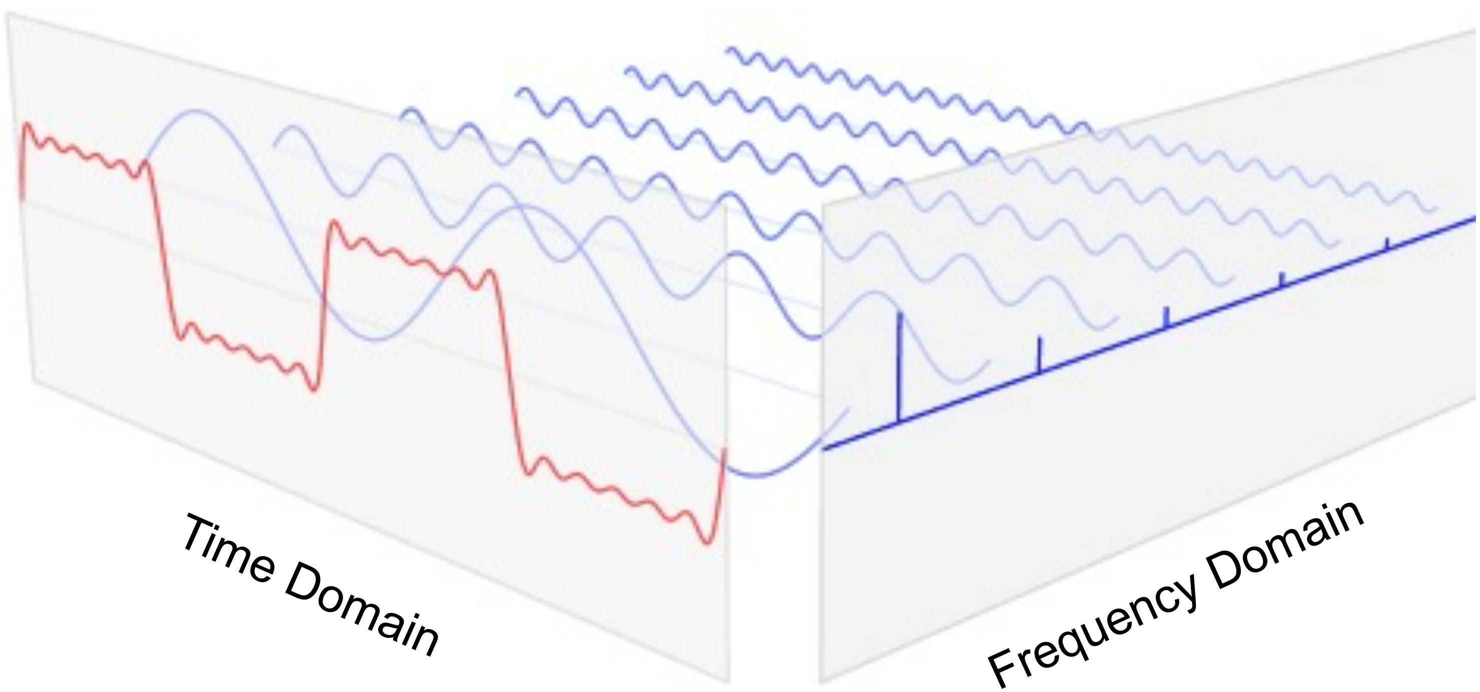
- Spectrum is the **representation of a signal in frequency domain**.





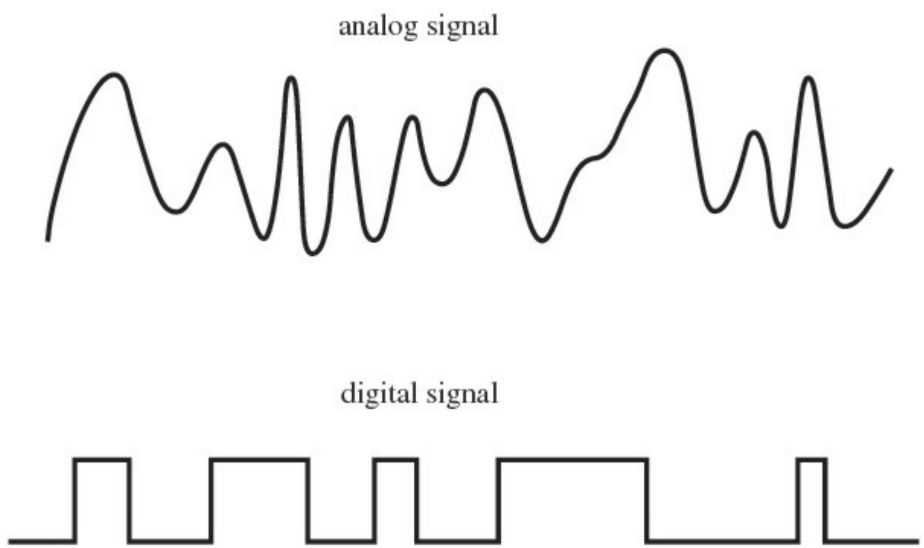
Visualizing The Spectrum!

- Visualizing the relationship between time and frequency domain.



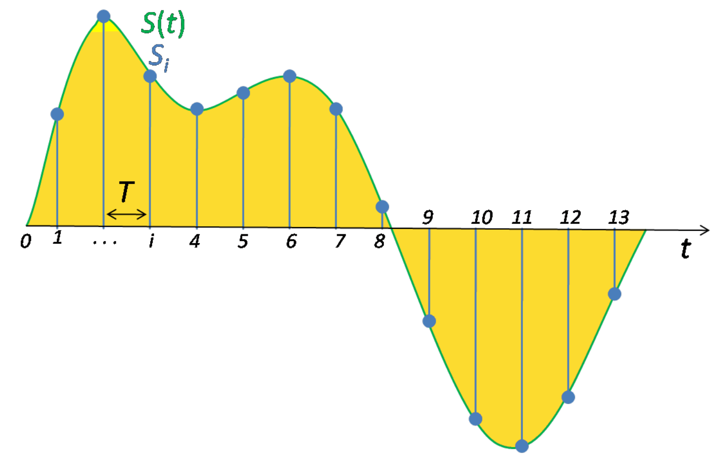
Analog vs Digital Signals

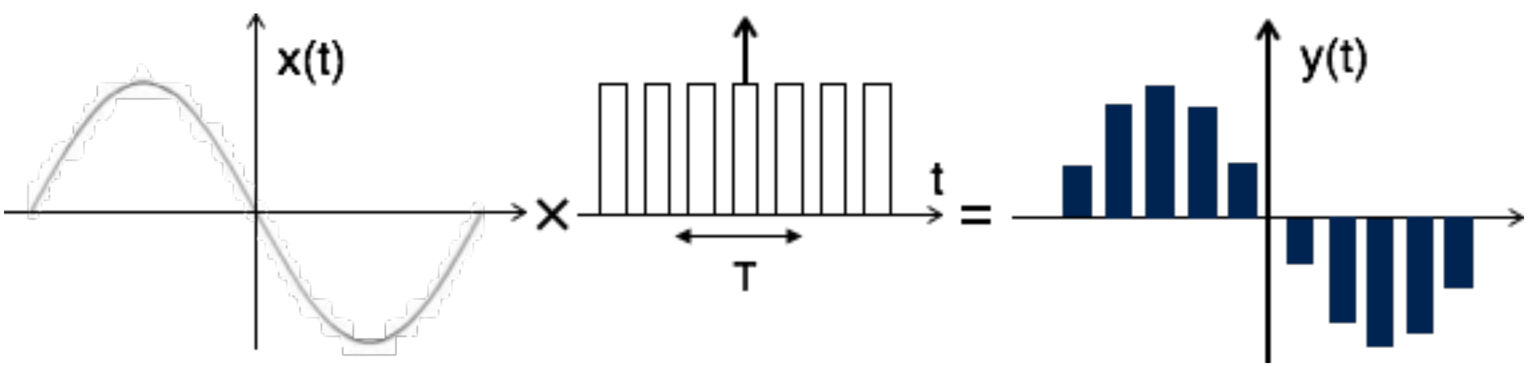
- Analog
  - Continuous
  - Usually output of sensors
  - ADC → analog to digital converter
- Digital
  - Discrete/sampled
  - Ones and zeros
  - What we process
  - DAC → digital to analog converter



Time Sampling (discrete-time signals)

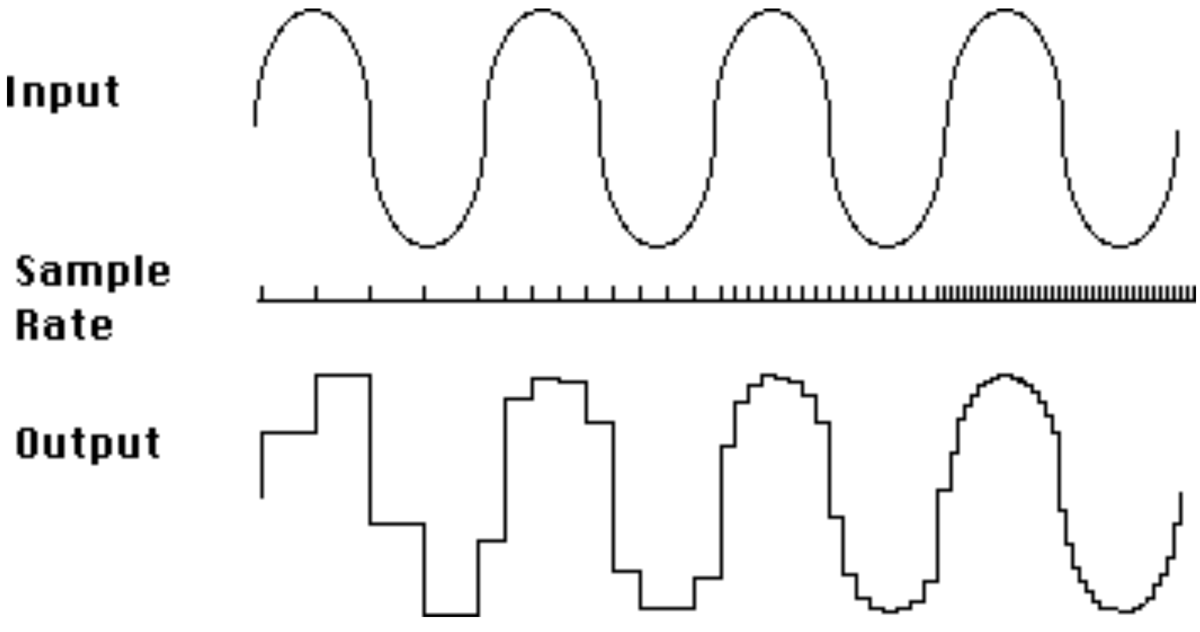
- F = frequency of sampling
- T = sampling period
- F = 1/T





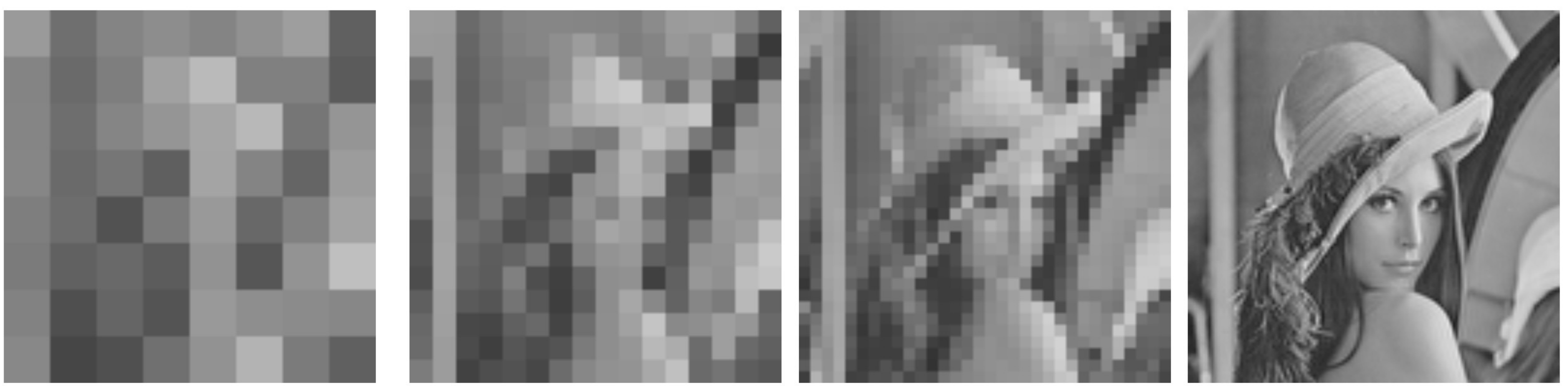
Discrete Time Signals

- Higher sampling rate
  - (+) Higher accuracy
  - (-) Higher power consumption



Sampling Two Dimensional Signals

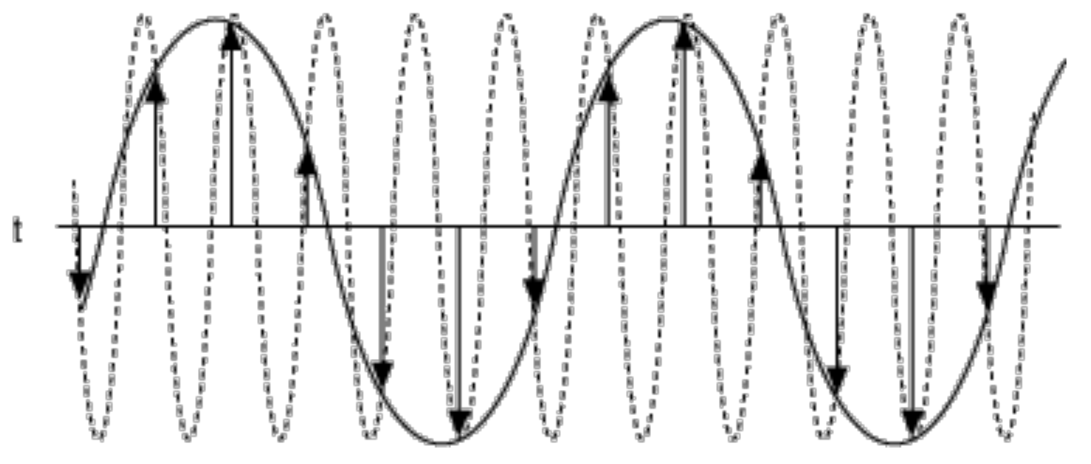
- Pictures are two-dimensional spatial signals
- Videos are three-dimensional spatio-temporal signals
- Below sampling of picture Lena with different spatial sampling rates
  - 8×8, 16×16, 32×32, and 128×128 samples (from left to right)
  - Each sample is represented with $n = 8$ bits
    Each square represents average of luminance values it covers



Source: http://iphome.hhi.de/schwarz/assets/pdfs/00_Introduction.pdf

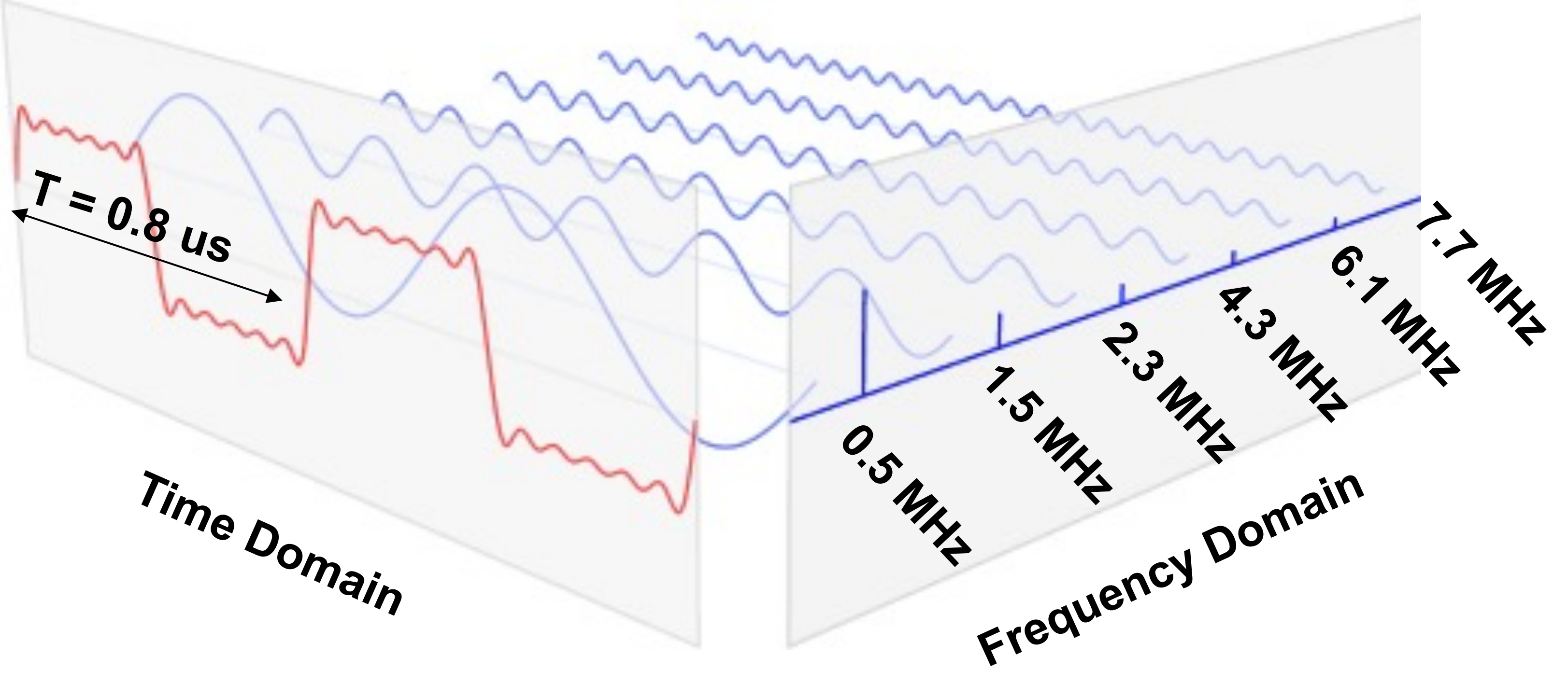
Nyquist-Shannon Theorem

- If a function x(t) contains no frequencies higher than *B Hertz,* it is completely determined by giving its ordinates at a series of points spaced 1/(2*B*) seconds apart.
- If the sampling frequency is less than 1/(2B) a wrong wave form could be sampled (An example is shown below)
- **Rule:**
  - The sampling frequency F_S should be equal or grater than 2B
  - **F_S>=2B**



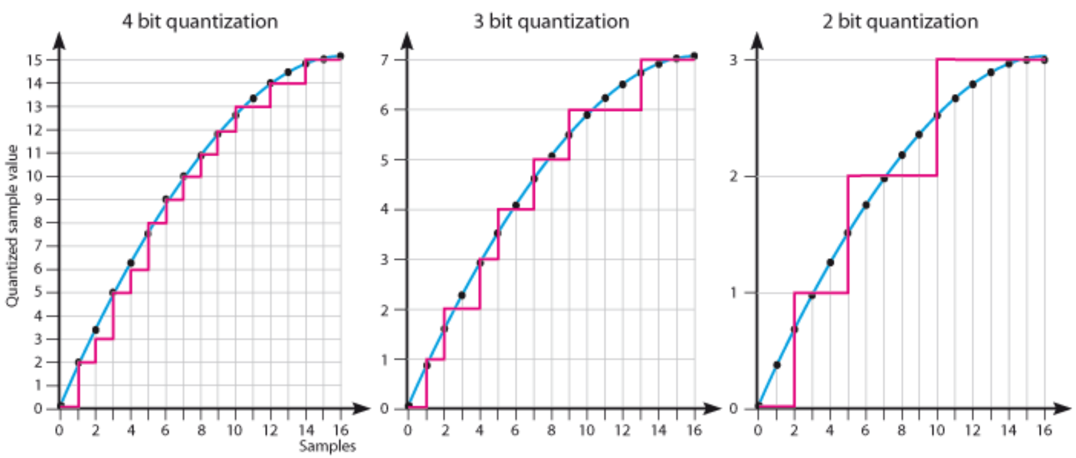
Quiz:

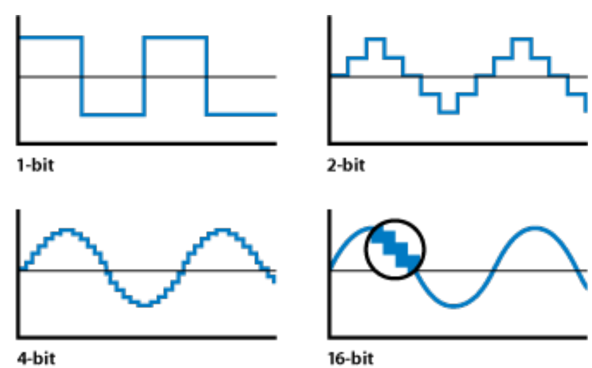
- What should our sampling Period (T) be?



Signal Quantization

- **Quantization** is the process of constraining an input from a continuous or otherwise-large set of values (such as the real numbers) to a discrete set.
- Number of quantization bits defines the accuracy of signal estimation.
  - More quantization bits → (+) higher accuracy → (-) but more data to process and communicate
  - Less quantization bits → (-) less accuracy → (-) but less data to process and communicate
  - E.g. representing a gray color with 8 bit → 256 shades of gray (high quality image)
    representing a gray color with 4 bits → 16 shades of gray (low quality image)





Two Dimensional Signal Quantization

- Below quantization of picture Lena with different bits/sample
  - k = 1, 2, 4, and 8 bits/sample (from left to right)
  - The spatial sampling rate is fixed to 128×128

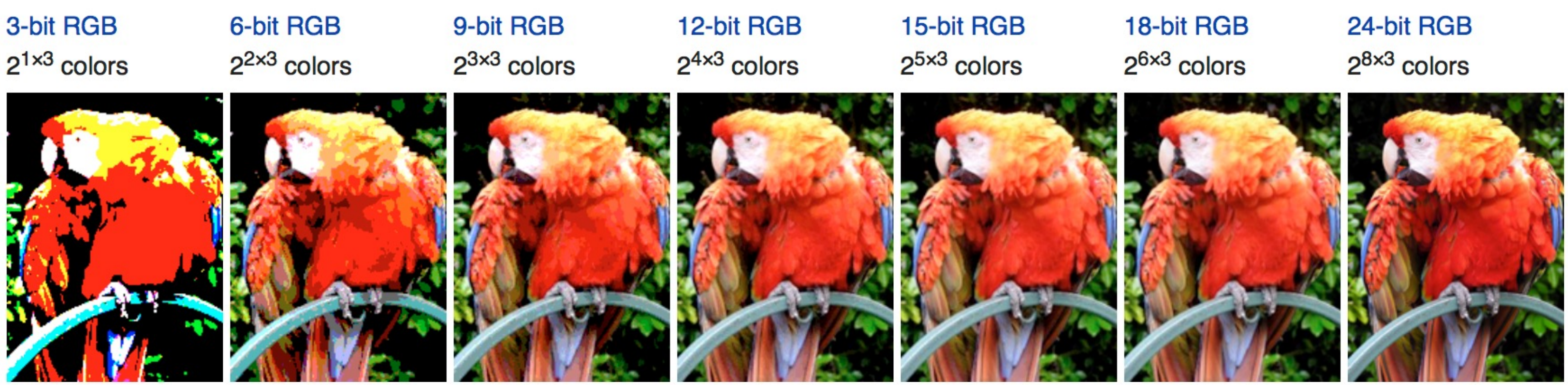
Source: http://iphome.hhi.de/schwarz/assets/pdfs/00_Introduction.pdf

Signal Quantization

- A parrot image quantized
  - **W** = width of image in pixels (lets consider
  - **H** = height of image in pixels
  - **3** channels of Red, Green and Blue (RGB) are needed.
  - Lets consider WxH = 544x372 (WebTV image size)
- Size of image
  - 3-bit RGB = WxHx3x1 = 544x372x3x1 = 607104 =~ 75.8KBytes
  - 6-bit RGB = WxHx3x2 = 544x372x3x2 = 1214208 =~ 151.8 KBytes
  - 24bit RGB = WxHx3x8 = 544x372x3x8 = 4856832 =~ 607.1 Kbytes

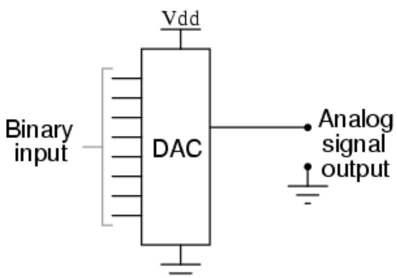
Signal Quantization

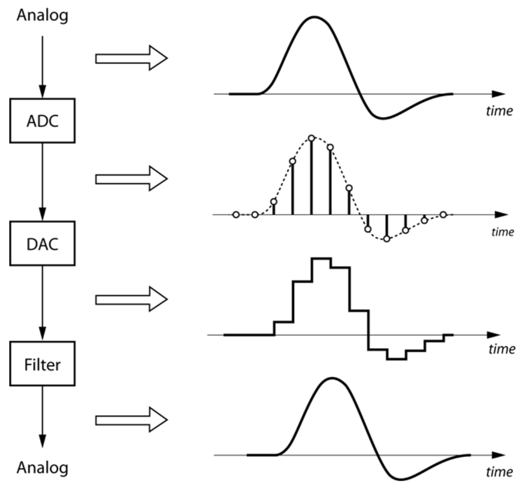
- Lets consider we can communicated 1MByte/S and for each MByte/S we consume 1mW.
  - 3-bit RGB → =~ 75.8ms to transfer, 75.8uW to communicate → consume low power.
  - 6-bit RGB → =~ 151.8ms to transfer, 151.8uW to communicate → consume twice the power.
  - 24bit RGB → =~ 607.1ms to transfer, 607.1uW to communicate → consume 8 times the power.

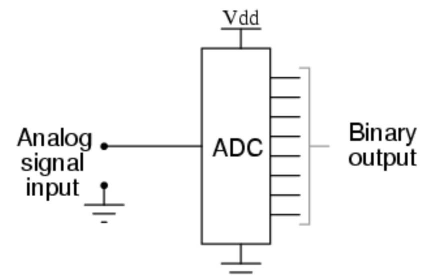


Signal Conversation

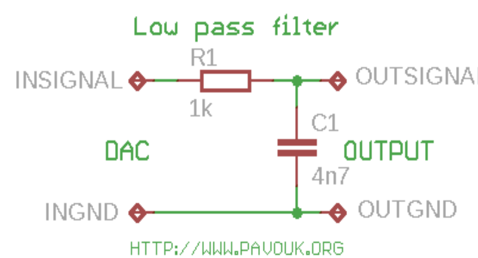
- Digital to Analog converter
  - **DAC**, **D/A**, **D–A**, **D2A**, or **D-to-A**
  - A device that converts a digital signal into an analog signal
- Analog to Digital converter
  - **ADC**, **A/D**, **A–D**, **A2D**, or **A-to-D**
  - A device that converts an analog signal into a digital signal







Generating an analog signal from a discrete signal require a reconstruction *filter* to **smooth** the discrete steps.



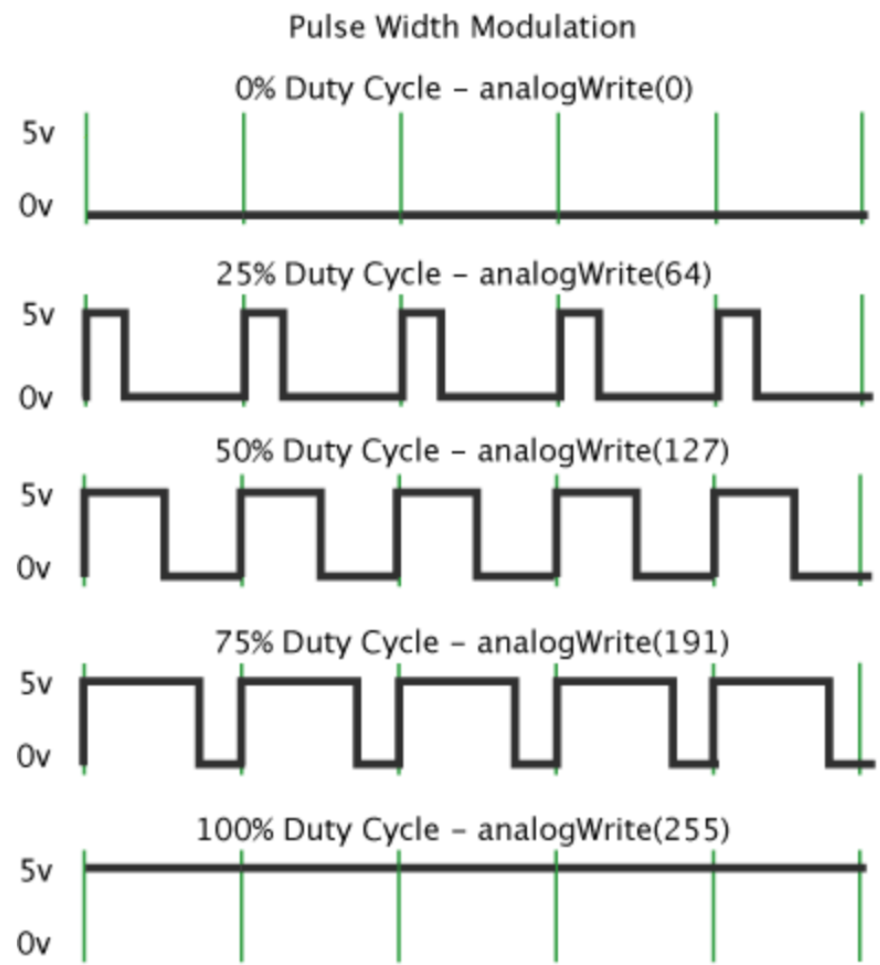
Your Assignment for the next class

- **Can we sample a signal by lower sampling frequency as determined by Nyquist-Shannon Theorem?**
  - Hint: Maybe by using compress sensing?

- **Your assignment:** Research, Read online articles, and write a 1-page report on how compress sensing is works and what are its limitations!
  - **Due date: Nov 11th (upload to canvas)!**

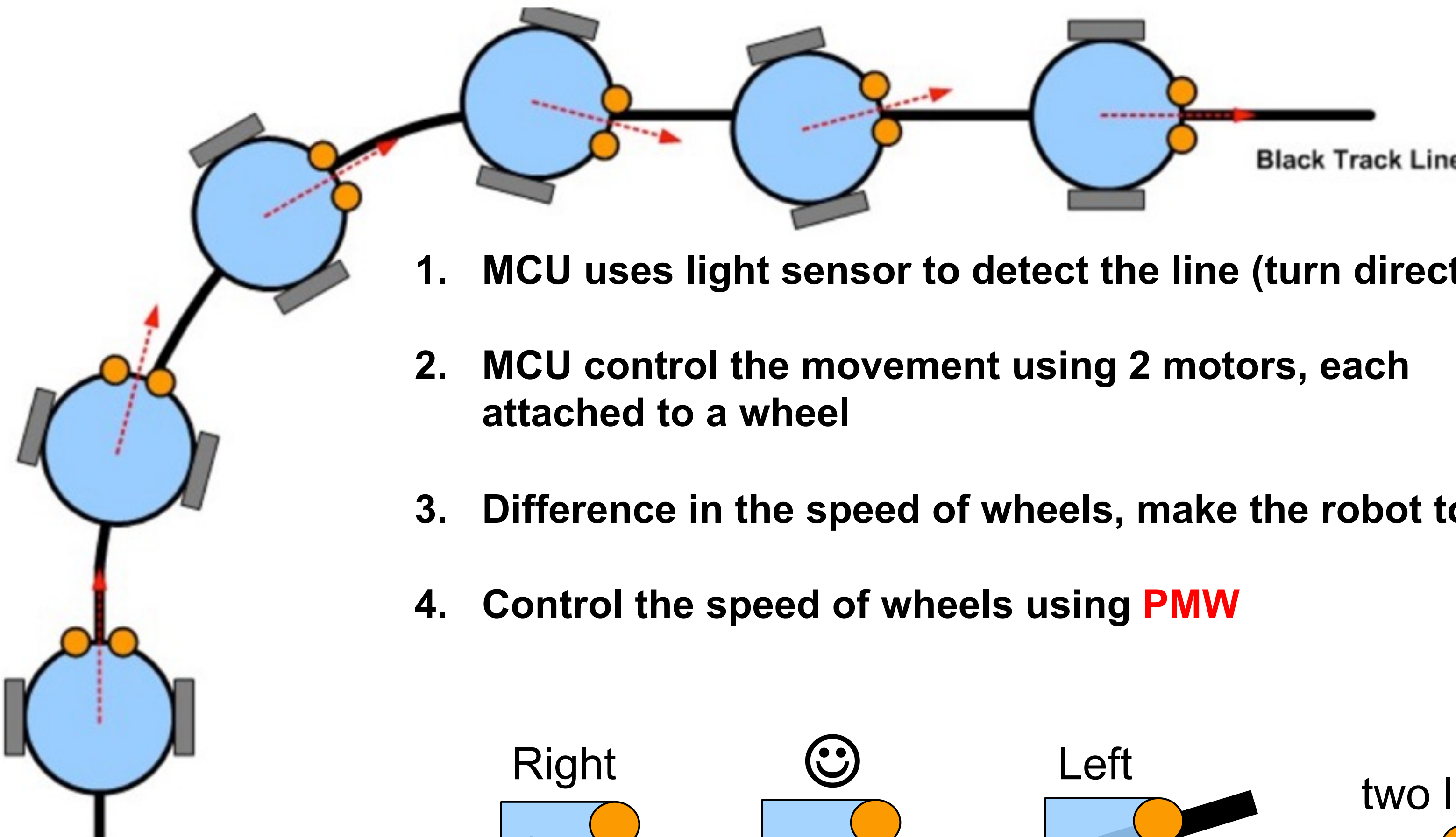
Pulse Width Modulation (PWM)

- A technique for getting analog results with digital means
- **Pulse Width**: The duration of "on time"
- **PWM:** The duration of High (1) and Low (0) Voltage is controlled.
- If you repeat this on-off pattern fast enough the result is as if the signal is a steady voltage between 0 and 5v.
  - With an LED, for example, you can control the brightness of the LED
  - With a motor, you can control the speed of motor.

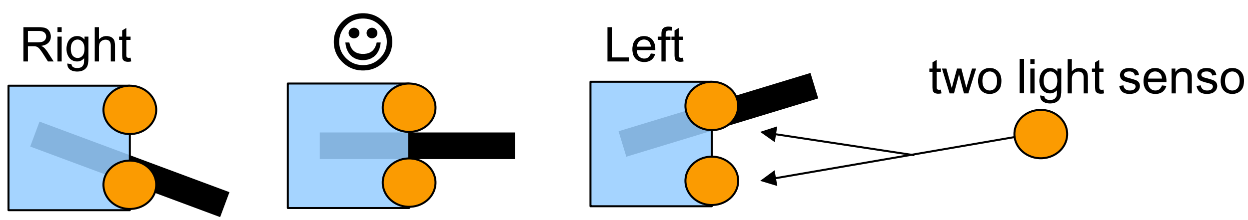


A Cute Example!

Line Tracking Navigation of The Line Follower Robot (LFR)



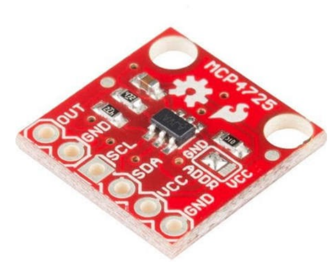
1. **MCU uses light sensor to detect the line (turn directions)**
2. **MCU control the movement using 2 motors, each attached to a wheel**
3. **Difference in the speed of wheels, make the robot to turn**
4. **Control the speed of wheels using PMW**



Example Source: http://www.ermicro.com/blog/?p=1908

What If MCU doesn't have a DAC!!!!!!!

- Use an external DAC!



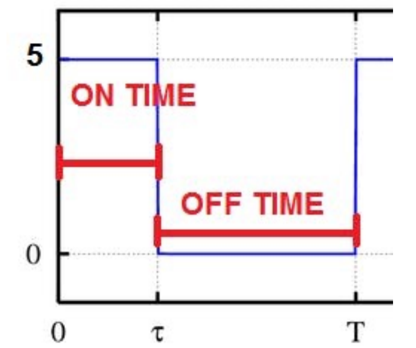
- Can we build a simple one? ☺
- **Our Goal**: To translate numeric values into analog signals using a MCU (Arduino in our case!)
  - have output voltages variable from 0 to 5V by setting only a variable.

- What do you need:
  - Operational Amplifier (you can use almost every operational amplifier, just remember to check that is rail-to-rail).
  - 22uF capacitor
  - 3.3kOhm resistor.

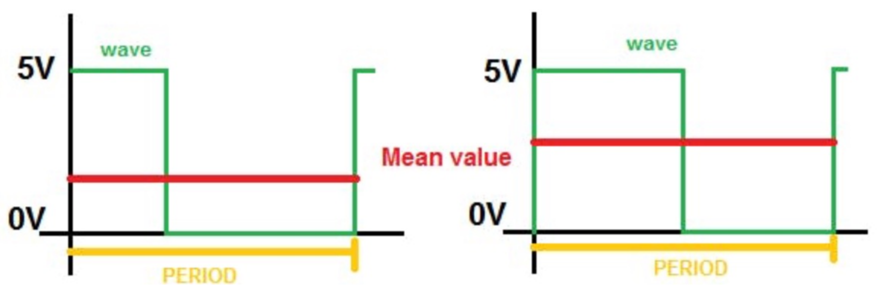
Source: https://create.arduino.cc/projecthub/Arduino_Scuola/build-a-simple-dac-for-your-arduino-4c00bd

Using PWM and Duty Cycle

- **analogWrite()** function allow you to set the output duty cycle
  - vary between 0% and 100% by choosing values with the second parameter you pass to the function (0 - 255)
  - ☺ This means Analog pin has built in PWM
  - analogWrite(pin,127) is 50% duty cycle (default).

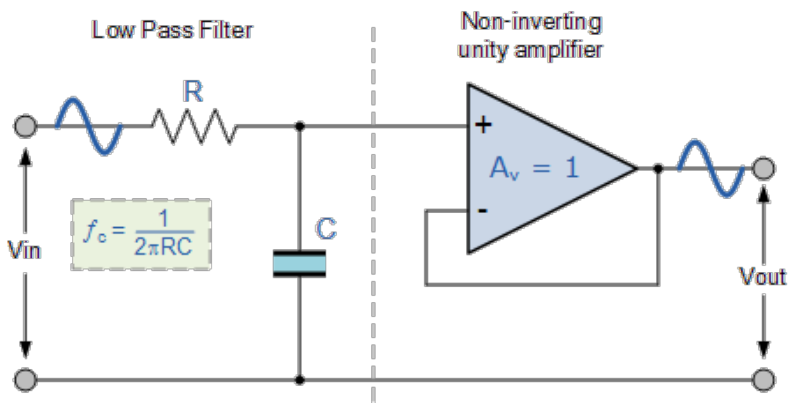


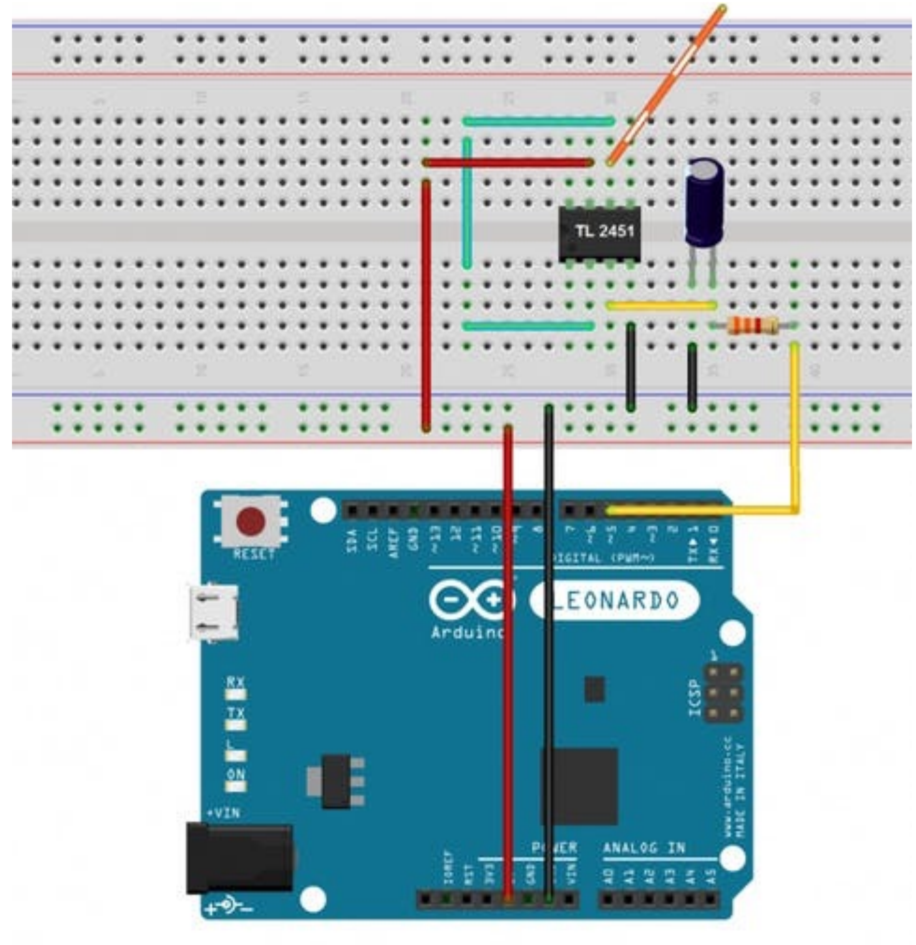
- **Mean or DC** = ON TIME/(OFF TIME + ON TIME)



- You can extract the DC value of the signal by using a **low-pass filter** that allows only the DC signal to pass and blocks nearly all others signals.

Build Your Filter Circuit

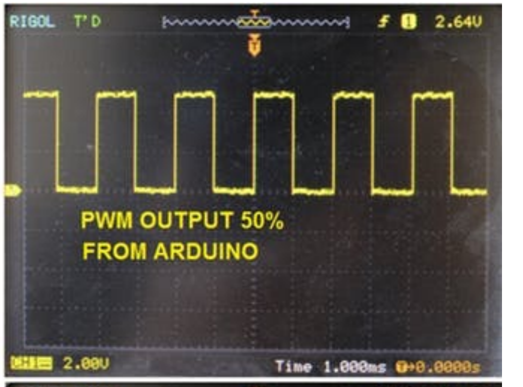




Using the Circuit

- **analogWrite(5,127)** is 50% duty cycle on pin 5.

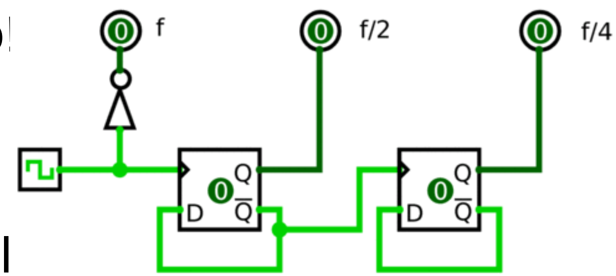
- The DC voltage is then **50%** of supply voltage (5V in this case!) which is 2.5V




```
void setup() {
  // initialize the digital pin as an output.
  pinMode(5, OUTPUT);
}
void loop() {
  analogWrite(5,127);  //Set the PWM at 50 % on digital pin 5
}
```

Know Your MCU DAC and ADC

- The conversion of A2D and D2A takes time.
  - Depending on the type of ADC or DAC converter used, you have a cap on how fast you can convert!
  - Depending on frequency of MCU clock you have a cap!
  - Depending on clock **divider used**, you have a cap!



- Example:
  - If **analogRead()** in Arduino takes 100us for signal conversion → 10,000 samples per second.
    - Can you sample a sound signals 1KHz, 4KHz, 10KHz, 14KHz?

- If you need higher sampling rate in Arduino, there are ways (**out of scope of this class**)
  - Such as playing with clock divider variable (presale)
  - Using ADC free running code which is based on Interrupts
  - If interested to know more click here!