ECE 215 Spring 2025

Objective 2.5: Analog-to-Digital Conversion I

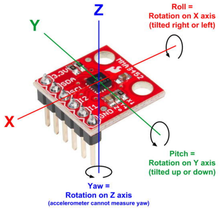
UNITED STATES AIR FORCE ACADEMY

Objective 2.6

I can calculate the ADC sampling rate, voltage resolution, and digital output based on a given input voltage and the ADC's operational parameters.

TRANSDUCERS

- In order to use a computer to do anything with a signal, it needs to be digitized
- Transducers translate between the digital and physical world
- **Input Transducer** = Translates physical to electrical signals
- **Output Transducer** = Translates electrical to physical signals
- **Our focus**: connect input transducer to an ADC / output transducer to a Digital-to-Analog Converter (DAC)



Analog vs. Digital

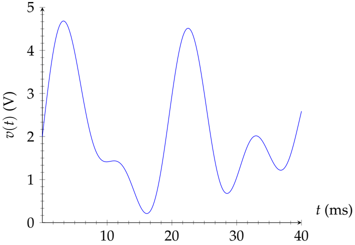
Analog

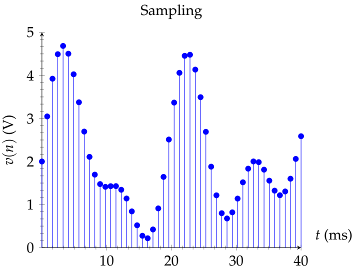
- Continuous stream of information
- No discontinuities in time or amplitude
- Large amounts of data

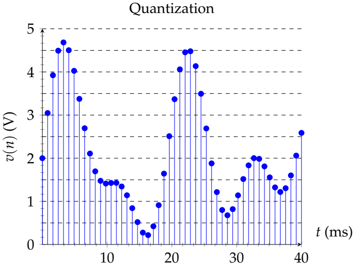
Digital

- Information is **discretized**
- Time axis is **sampled**
- Amplitude information is **quantized**
- Noise resistant
- Easy to store and recover data
- Efficient use of bandwidth
- Lost data
- Sampling errors may exist (aliasing)
- Quantization errors

Analog to Digital - Big Picture



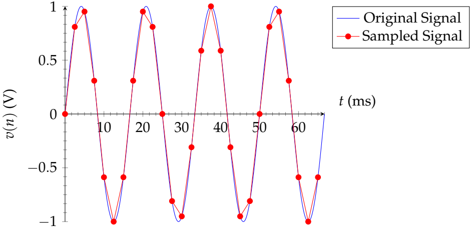




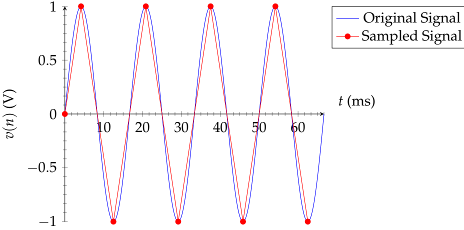
Encoding
=00010100 00011110 00100011 ...

Sampling Rate Matters ($f_0 = 60$Hz)

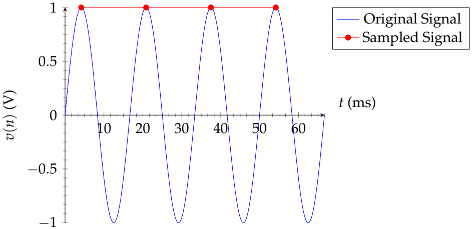
Sampling at $6.67f_0$



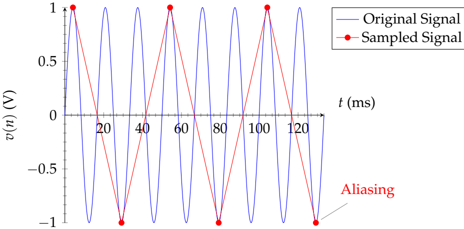
Sampling at $2f_0$



Sampling at f_0

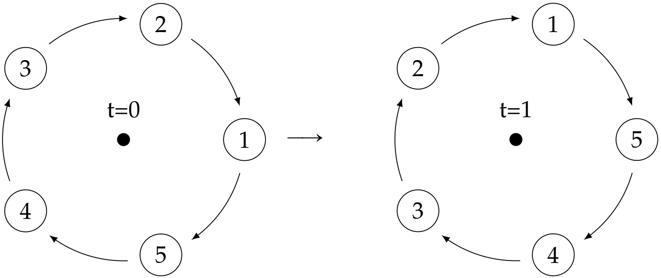


Sampling at $\frac{2f_0}{3}$



Aliasing

- Aliasing is the cardinal sin of ADC
- Once we have introduced aliasing, it can never be fixed
- Avoid aliasing by sampling at $f_s \geqslant 2 * f_{high}$
- Wagon Wheel Effect
- Between $t = 0$ and $t = 1$, the wheel rotates clockwise $4/5$ turn



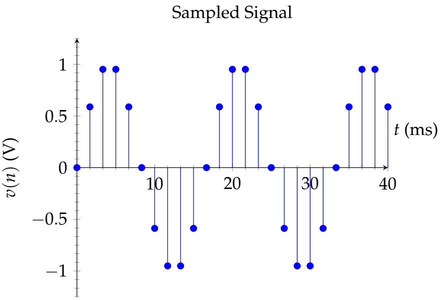
Sampling Rate Example

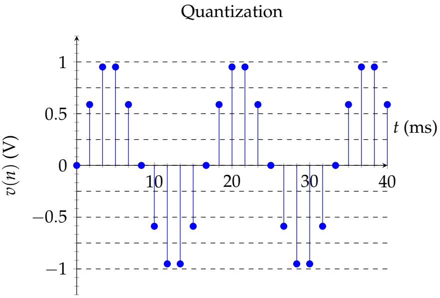
$$\begin{aligned} v(t) = 20 &+ 40\cos 360^\circ * 200 * t + 15\cos 360^\circ * 60 * t \\ &+ 60\cos 360^\circ * 800 * t + 90\cos 360^\circ * 800 * t \\ &+ 30\cos 360^\circ * 40 * t + 20\cos 360^\circ * 600 * t\mathrm{V} \end{aligned}$$

- Given $v(t)$, what sampling frequency should you choose?
- What is the downside of picking too high of a frequency?

Quantization

- Sampling captures data values at specific intervals on x-axis (time)
- Quantization assigns an input to specific "levels" on y-axis (voltage)
- Quantized level converted to binary
- Number of available bits $\longrightarrow$ # levels $\longrightarrow$ resolution (ΔV)





More on Quantization

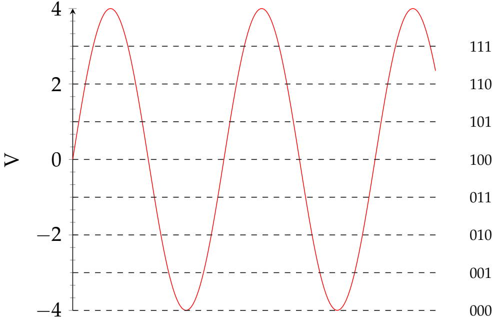
- b: Number of bits for encoding
- Quantization Levels
  - Number of levels: 2^b
  - Lowest level is V_{min}
  - Highest level is V_{max} - ΔV
- Resolution: voltage between levels

$$\Delta V = \frac{V_{max} - V_{min}}{2^b}$$

- Quantized level (QL): The level assigned to a given V_{in}

$$QL = \text{trunc}\left(\frac{V_{in} - V_{min}}{\Delta V}\right)$$

- ADC output: Binary representation of the assigned QL
- Quantization results in data loss
- Clipping happens when ADC and signal voltages are mismatched



For V_{in} = 0.9V, what is the ADC output?

ADC Example

- Given the following signal, create a 5-bit ADC to capture it and calculate the relevant characteristics.
  - f_s, V_{max}, V_{min}, ΔV
- Encode 1.62V from this signal as binary