Analog to Digital Conversions

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Introduction

Perception

- Humans perceive the world in analog/continuous proportions

Analog Signals

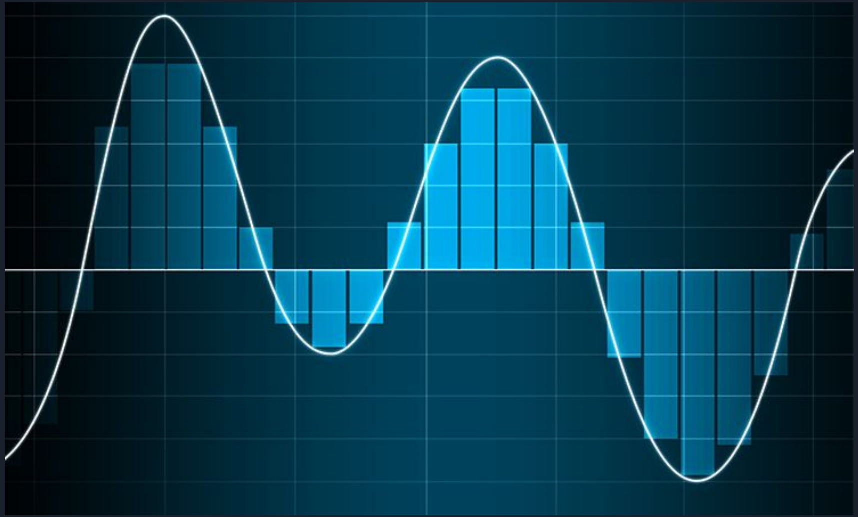
- Voltage, current, or physical quantities that vary with time

Digital Signals

- Represents data as a sequence of discrete values

ADC

- Converts our analog world into a form countable by computers (digital)



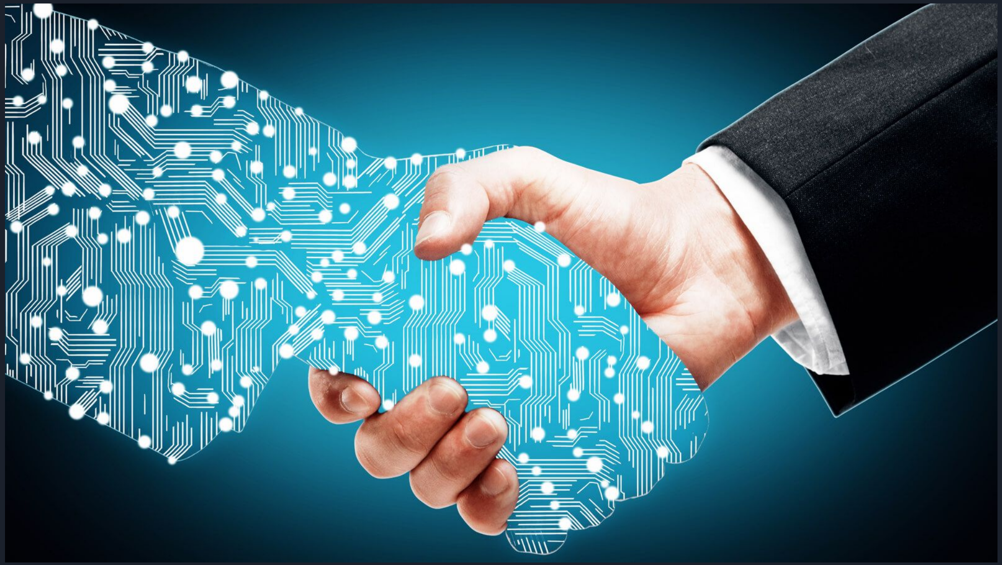
Digitization

ADC Digitization

- Ratio of an input and reference value expressed in a digital value

Digitization Process

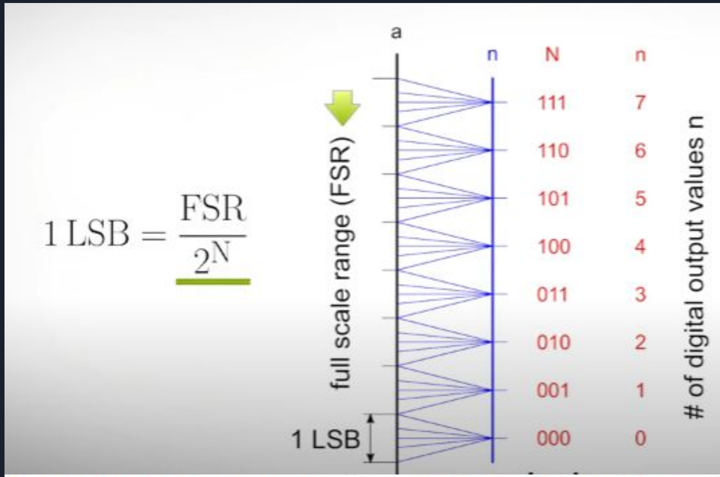
- Quantization:
  - Input signal is subdivided into n intervals
- Encoding
  - Each interval assigned to a certain value



Digitization cont...

Digitization

- 2^(N) = n
  - If n = 8 then N = 3. ADC will represent those 8 quantization levels with 3 bits
- Resolution (LSB)
  - LSB:
    - Smallest change in input signal the ADC can measure
    - If starting in middle of 1 quantization level, you must change input signal by ½ LSB to enter the next level
  - In terms of voltage
    - Each Input voltage inside a resolution range will be converted to a specific binary #
    - Resolution = Voltage Range / 2^(n)
      - 20 mV / 2^(16) = .305 x 10^(-6)



Input Voltage (mV) (Real Value)	Binary (Base 2) Value
-10 000 to -9 999.695	0000000000000000
...	...
...	1111111111111110
0.0 to +0.305	1000000000000000
...	1000000000000001
...	...
+9 999.695 to +10 000	1111111111111111

Transfer Function of an ADC

Unipolar ADCs:

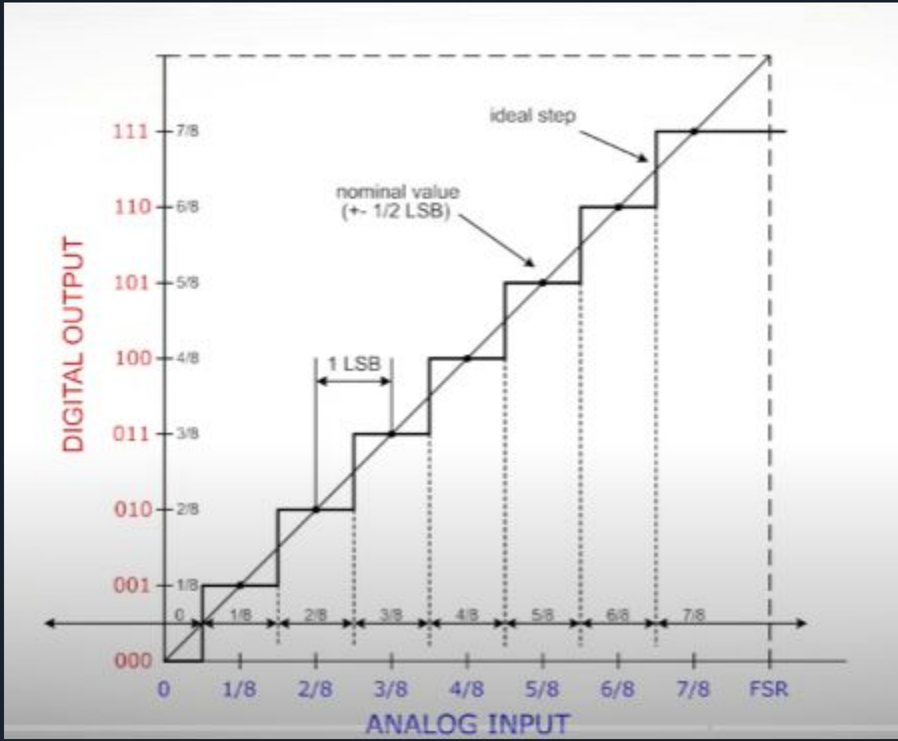
- ADCs that only handle positive inputs

Bipolar ADCs:

- ADCs that can handle negative and positive

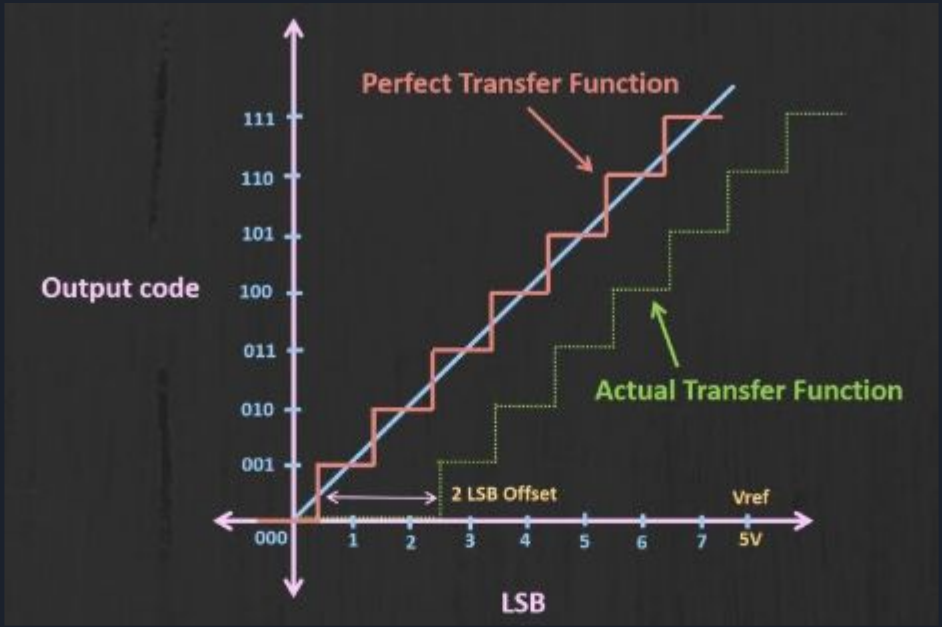
Ideal Transfer Function

- Does not take into account errors
- Most considered errors
    - Offset Error
    - Gain Error
    - Non-Linearity Error



Offset Error

- Difference between the measured and ideal function
  - Starting at 0 point on the x-axis
- Constant error at each point in curve. Can be corrected easily
  - ADCs offer adjustment and calibration settings for offset



Gain Error

Gain Error

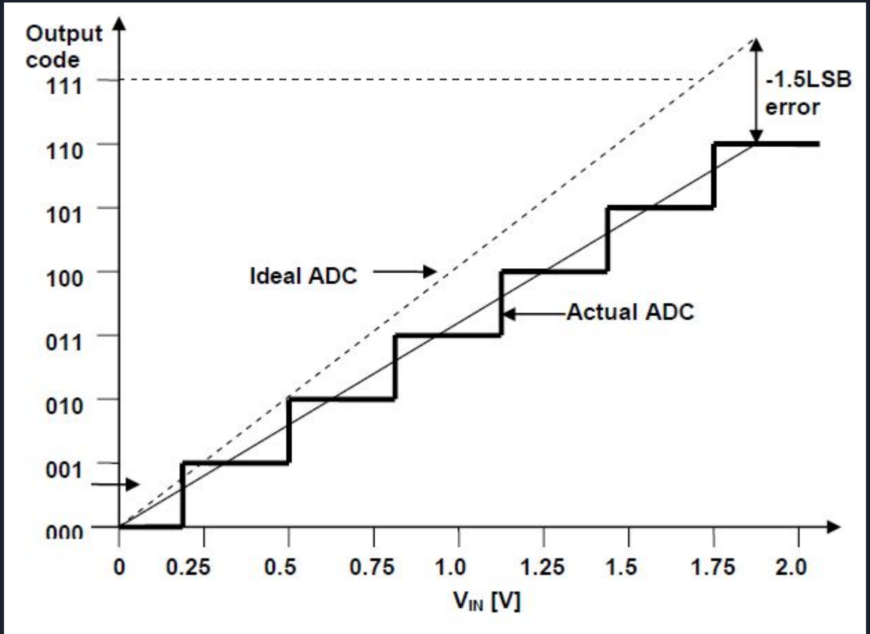
- Difference between midpoint of the final step of the ideal function from the midpoint of the actual function
  - Offset error is accounted for first

Full Scale Error

- Sum of offset and gain error

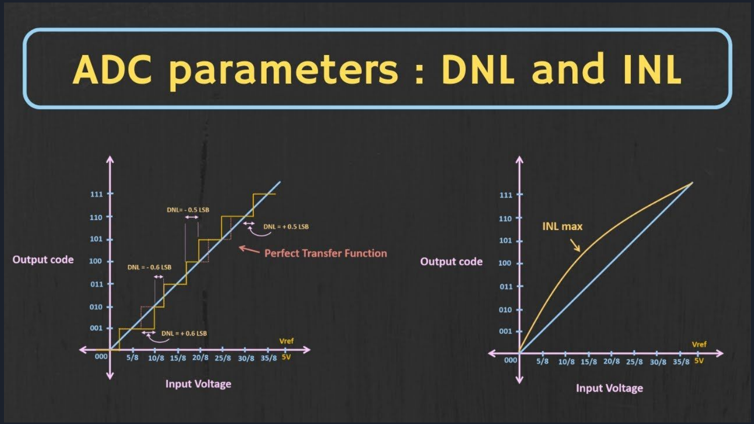
Correction

- Both errors can be eliminated by ADC calibration settings



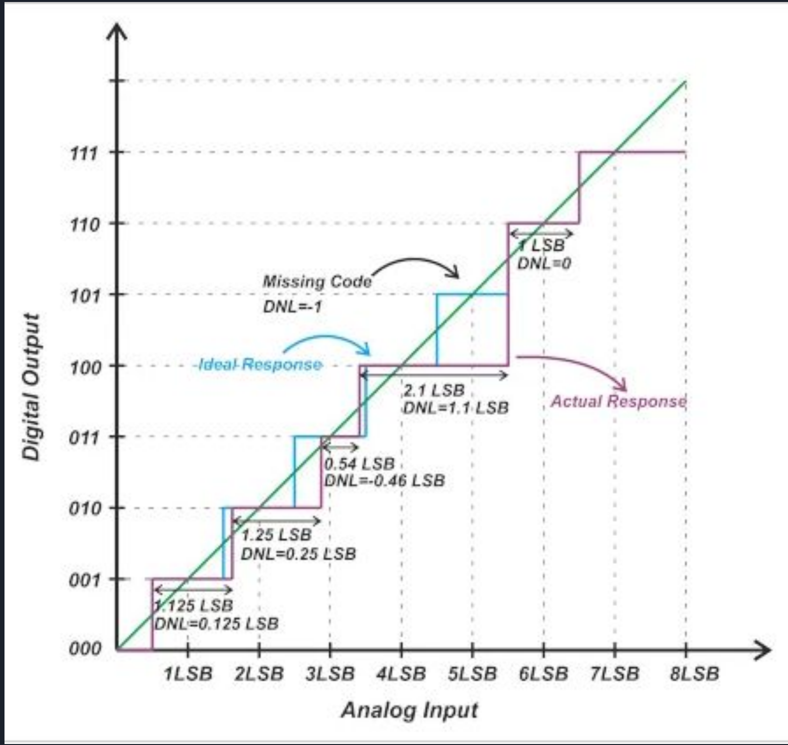
Non-Linearity Errors

- Error Causation
  - Appear when endpoints of real and ideal curves match due to gain and offset calibration
  - Represented with curvatures in the transfer function lines
- Types of Nonlinearity Error
  - Differential (DNL)
  - Integral (INL)



DNL

- DNL = (W(k) - Wideal) / Wideal
  - deviation from the ideal output step size for a given input range
  - Not defined by 1st and last transitions
    - Due to offset and gain errors being calibrated out
  - W(k) = width of current binary numbers level
  - Wideal = ideal width of the binary level
- DNL Example
  - DNL (001) = (W(001) - 1) / 1 = .125
  - Code 1 or 001 is .125 LSB larger than the ideal step size
- Negative DNL
  - Represents a missing code. No input value produces the code. Step size = 0
  - Non-Ideal code transitions
- Ideal Code Widths
  - DNL = 0



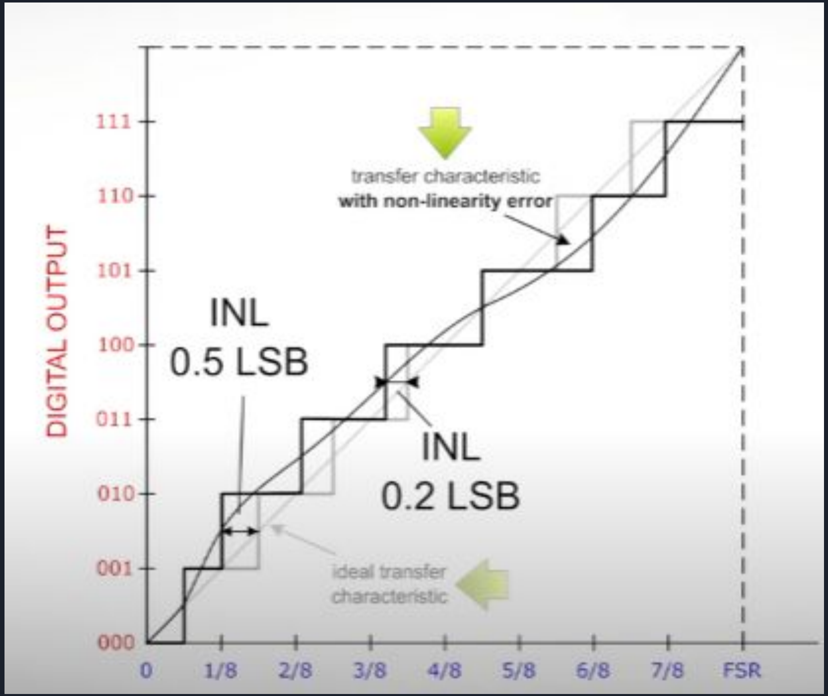
INL

INL

- Difference between actual straight line transfer curve and the measured curve
  - Measured in the middle of a step
- Also defined as cumulative effect of DNL errors

Why is it Important

- Digital value must be consistently and accurately hit for certain ADC applications
  - Audio applications



$$INL[m] = \sum_{i=1}^{m-1} DNL[i]$$

$$INL(3) = DNL(1) + DNL(2) = +0.125\ LSB + 0.25\ LSB = +0.375\ LSB$$

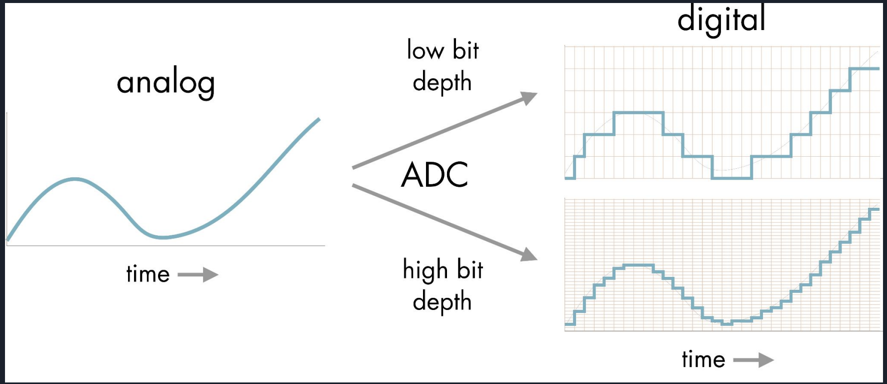
Other Types of Error

- reference-voltage noise
  - noise on analog reference can cause inaccurate digital conversions
- analog-input signal noise
  - high-frequency signal variations affect the signal source
- analog-signal source resistance
  - Impedance/resistance between the pin and signal source may cause a voltage drop
- temperature influence
  - Offset error drift and gain error drift

Sampling Depth

Sampling/bit depth and resolution

- Sampling Depth: Number of quantization intervals (n)
- Resolution: # of bits needed to create the number of quantization intervals
    - If n =8 and 2^(N) = n
    - ADC has a 3 bit resolution



Quantization Error

Quantization

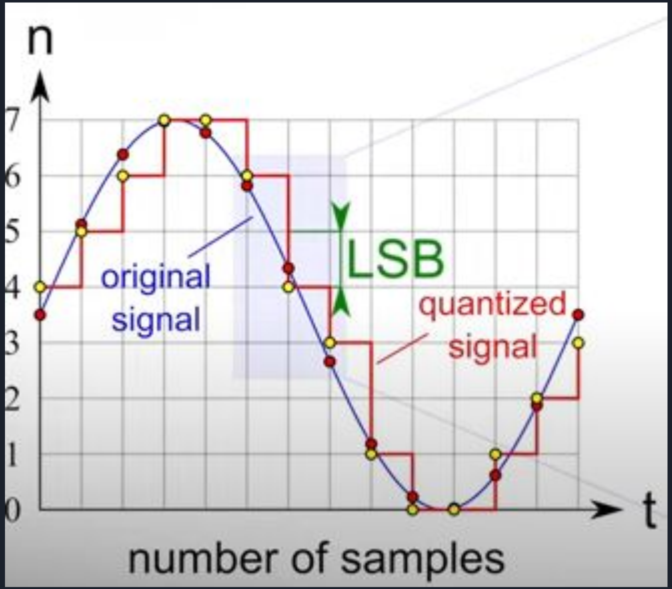
- Process of mapping infinite amount of values to a finite amount of values

Quantization Error

- Difference between analog signal & closest digital value at each sampling instant

Quantization Noise

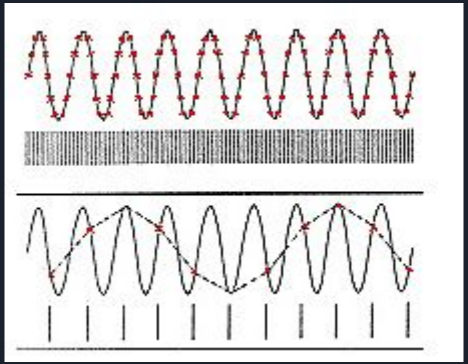
- Noise introduced by quantization error (distortion)
- Higher resolutions yield less noise
- SNR = 6.02N + 1.77 for sinusoidal signals
  - N = 12, SNR = 74.01 dB
  - N = 16, SNR = 98.09 dB



Sampling Rate

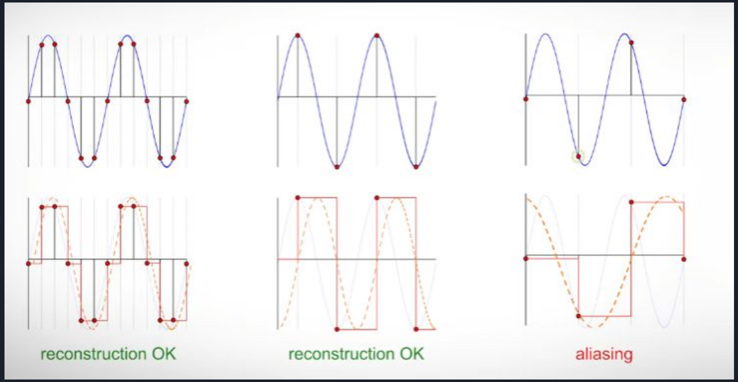
Sample Rate

- How often we sample the input signal



Aliasing or Sampling Error

- Nyquist: Sample at least twice as fast as the highest frequency
    - Goal: Sample at least twice in each cycle or signal distorts at lower frequencies.
- If not met, digital signal will be not resemble original signal (aliasing)
- Aliased signals can not be corrected through filtering



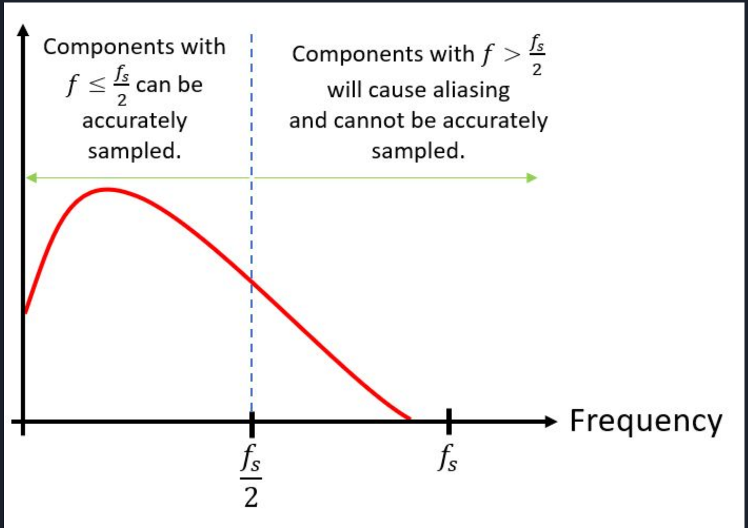
Sampled 6 times per period

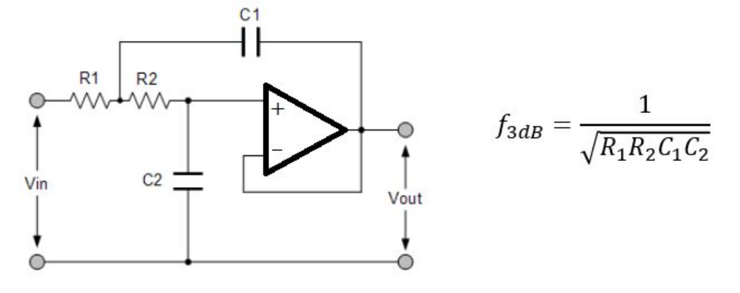
Sampled 2 times per period

Not sampled enough

Anti-Aliasing Filters

- Anti Aliasing Filters
  - low pass filter with the cutoff frequency set to Nyquist frequency
- Purpose:
  - Remove all frequency content greater than Nyquist frequency that would be aliased
- Calculating Values
  - Set 3 dB cutoff to correspond to smallest Nyquist frequency in your system





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