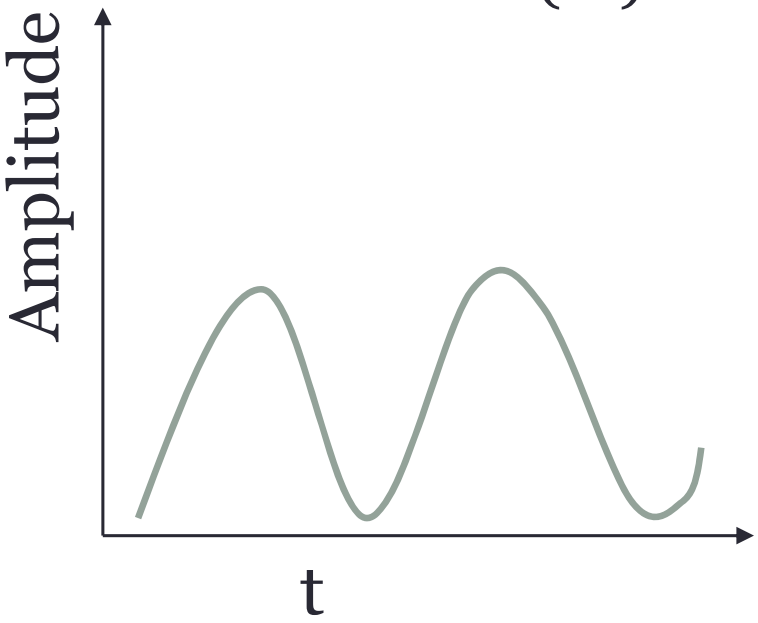
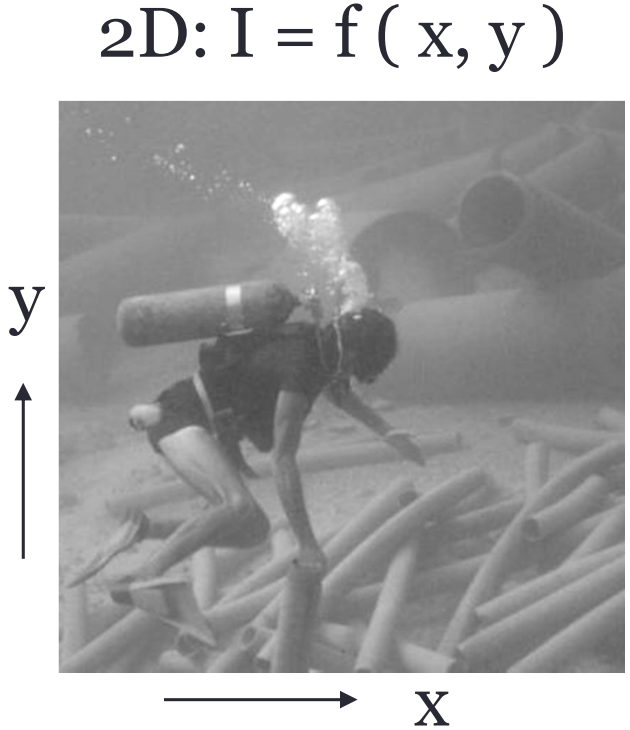
What is a signal?

- Any function dependent on a single or multiple variables

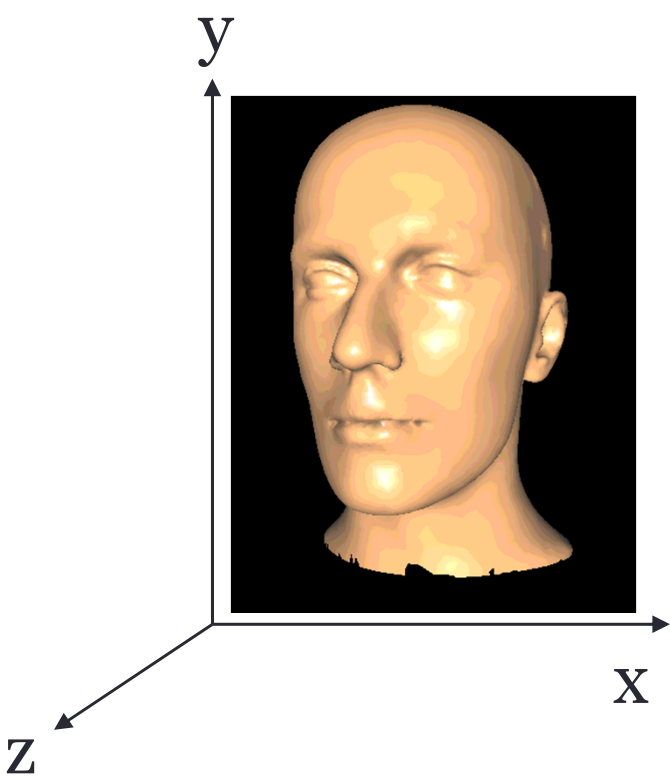
1D: A = f (t)



2D: I = f (x, y)



3D: M = f (x, y, z)



Origin of Signals

- Real life applications
  - Medical Images
  - Seismic Vibrations
  - Audio and Video
  - Radar and Sonar

Signal Processing

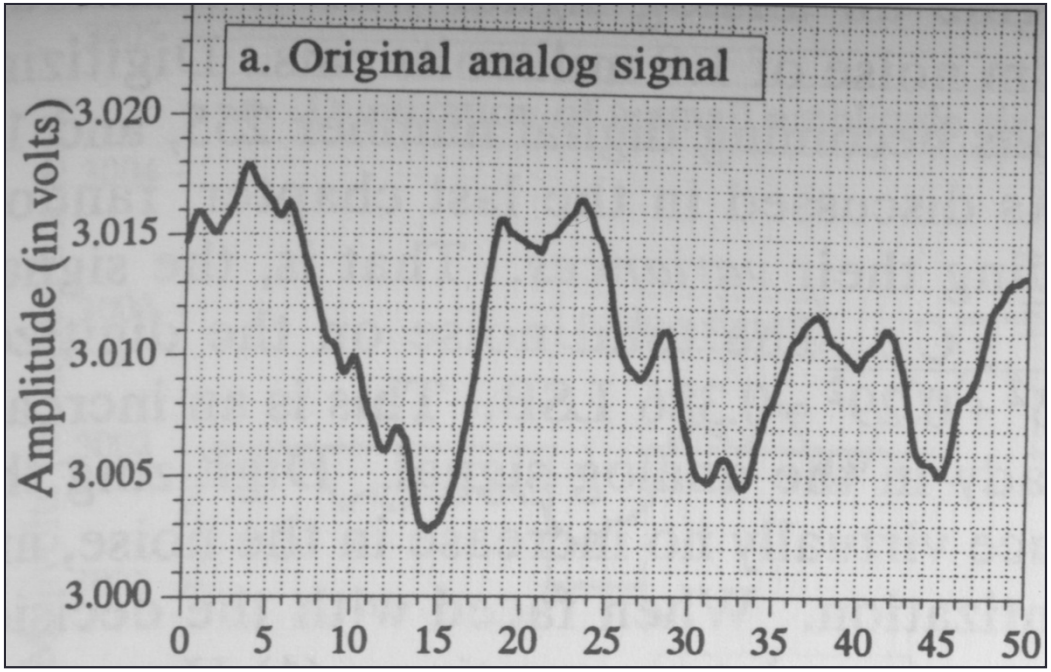
- Science of processing signals
  - Data analysis
  - Data compression
  - Data Storage
  - Data Retrieval
  - Data Communication
  - Special Effects

Applications

- Space
  - Photo Enhancement, Segmentation
- Medical
  - Diagnostic image analysis
- Media
  - Audio and video compression, Quality Control
- Military
  - Radar and sonar data analysis
- Scientific
  - Emergency monitoring and analysis

Analog Signals

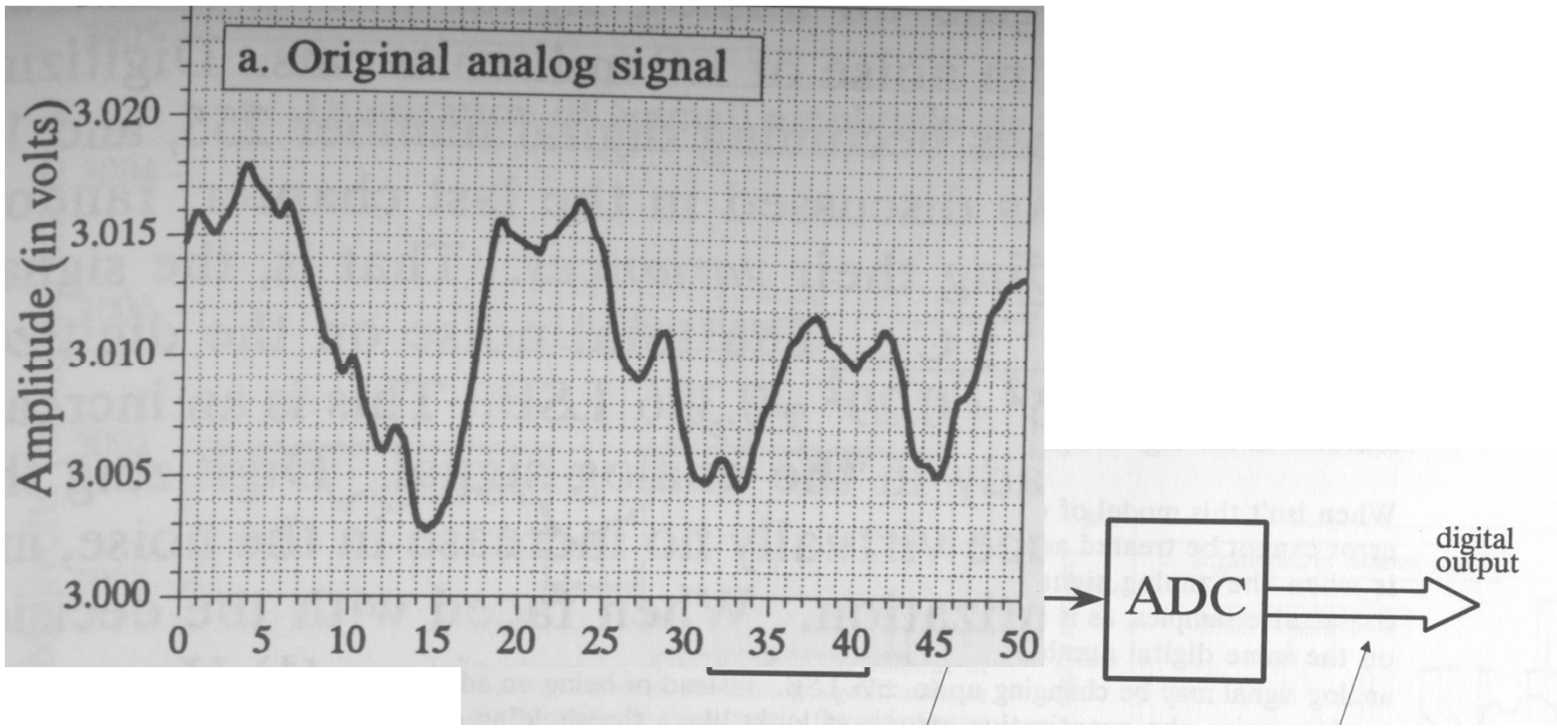
- Both independent and dependent variables can assume a continuous range of values
- Exists in nature



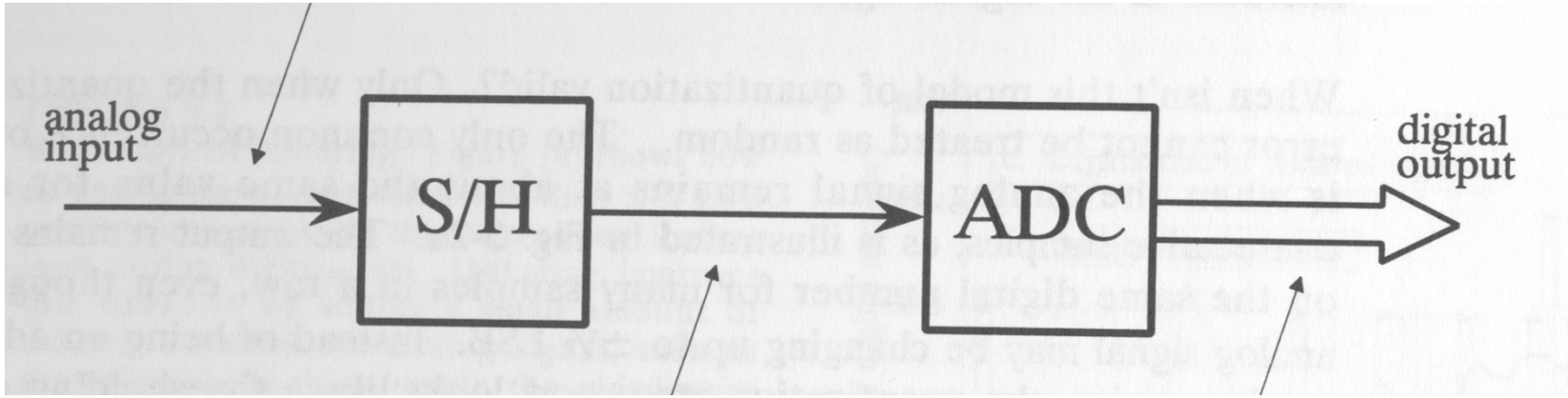
Digital Signals

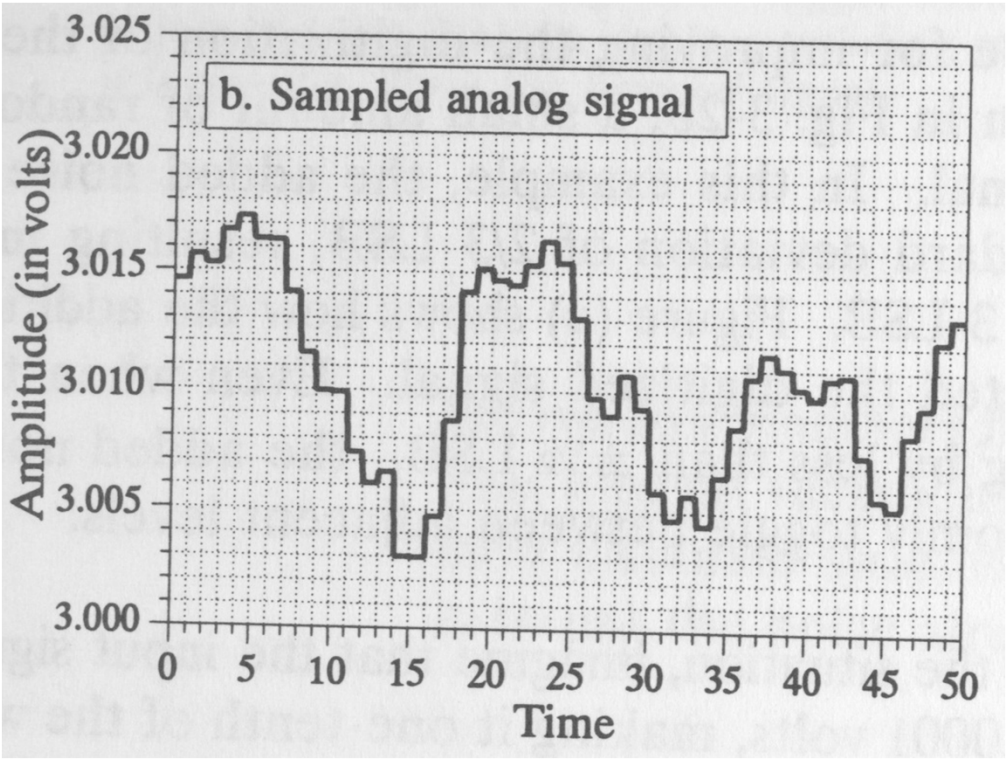
- Both independent and dependent variables are discretized
- Representation in computers
- *Sampling*
  - Discrete independent variable
  - Sample and hold (S/H)
- *Quantization*
  - Discrete dependent variable
  - Analog to Digital Converter (ADC)

Digital Signal

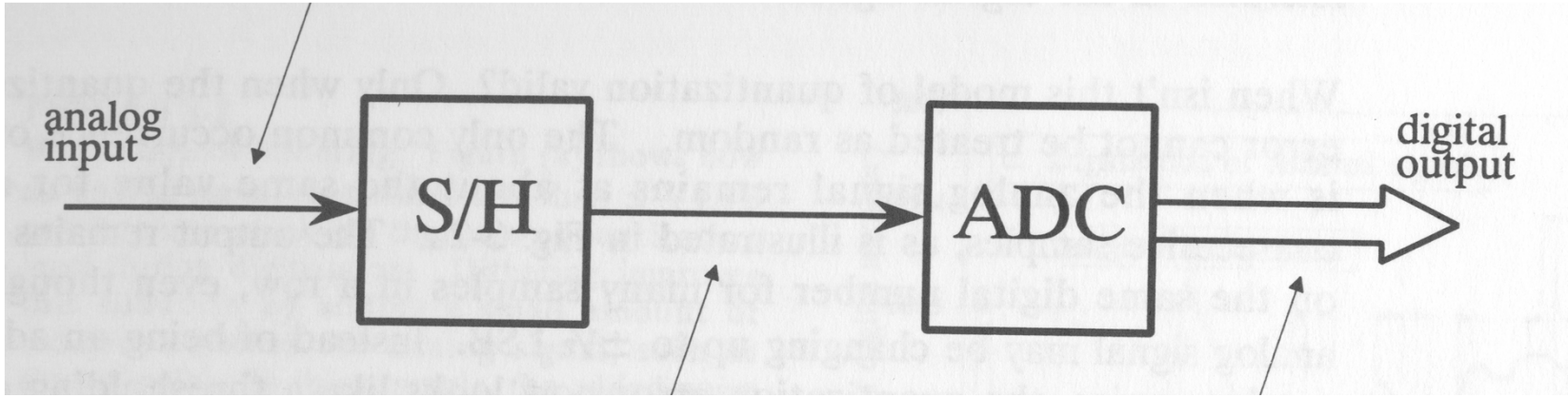


Sampled Signal

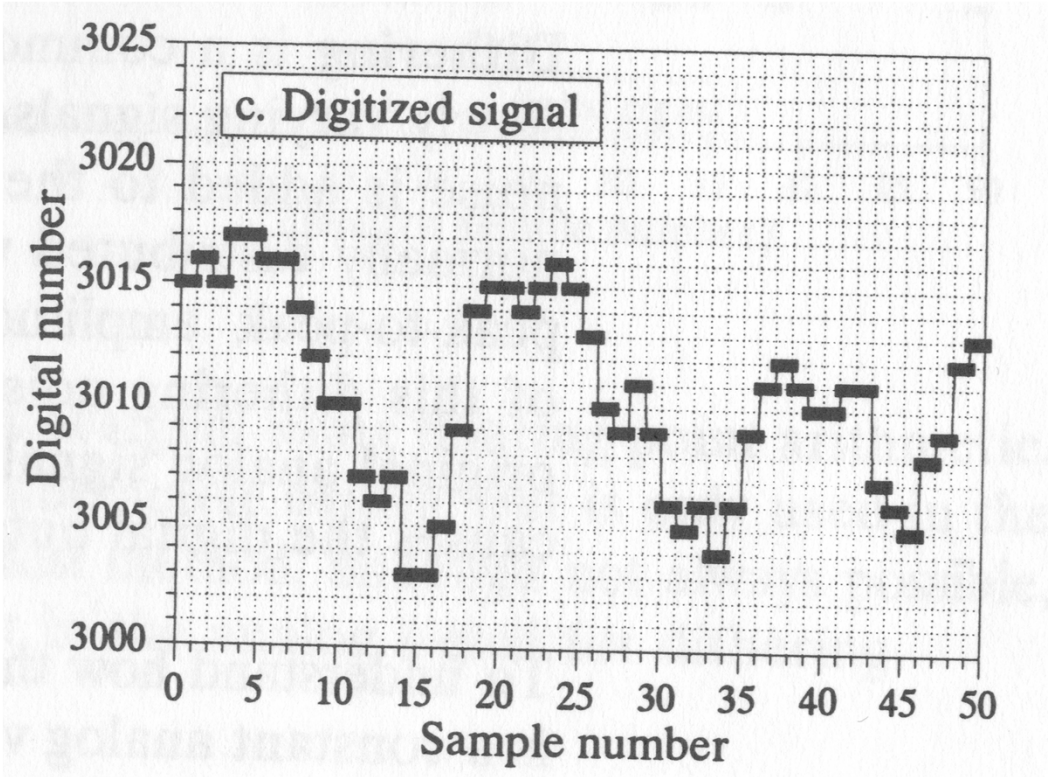




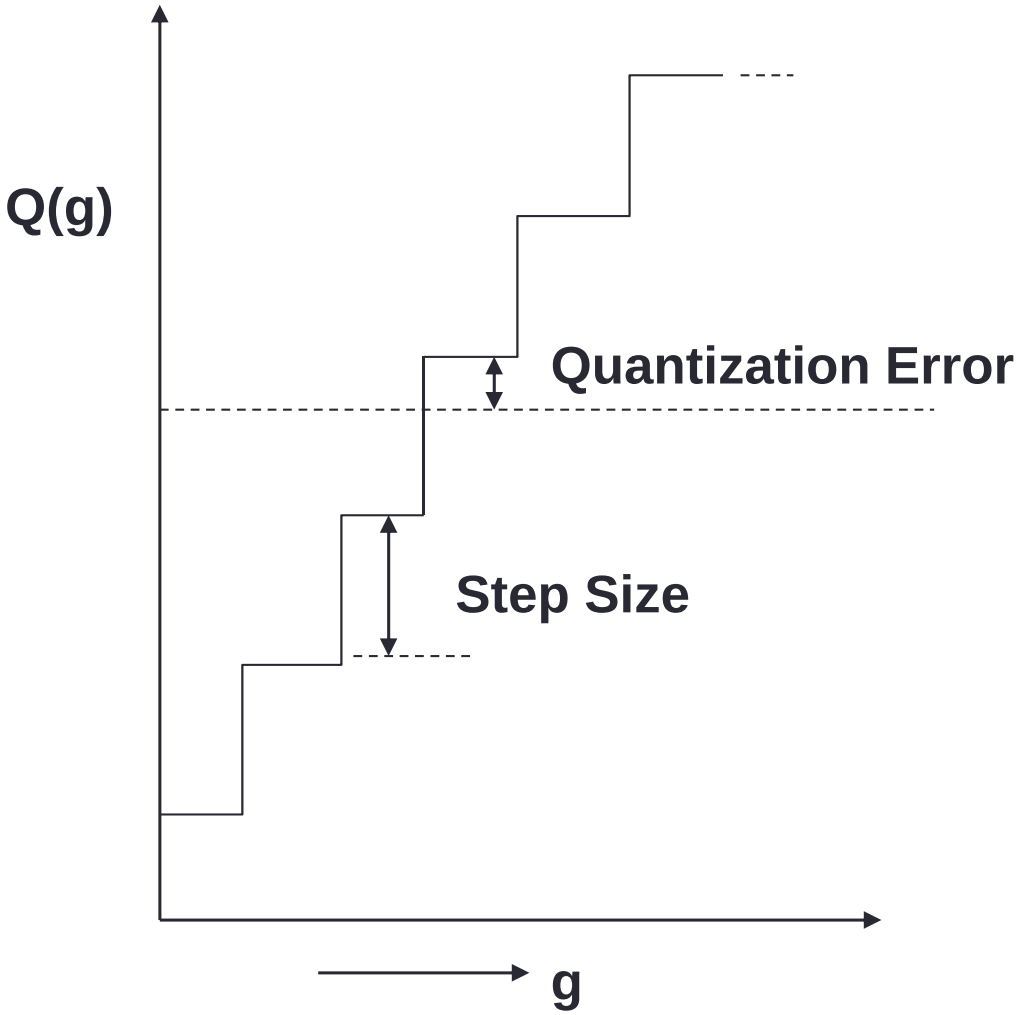
Digitized Signal



- Depends on number of bits
- 12 bits = 4095 levels
- 0.0 ≤ Voltage ≤4.096
- 2.56 and 2.5601 TO 2560
- Each level (LSB) = 0.001
- Error ≤ ±½ LSB
- Called *Quantization Error*



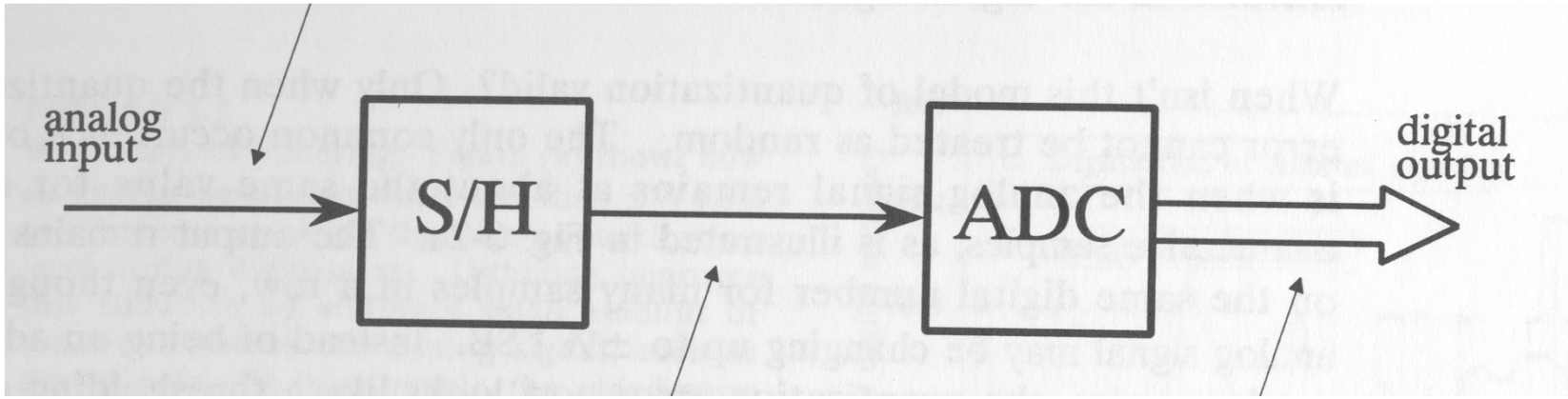
Quantization Error



Uniform Quantization

Maximum Error = ½ Step Size

Digitized Signal



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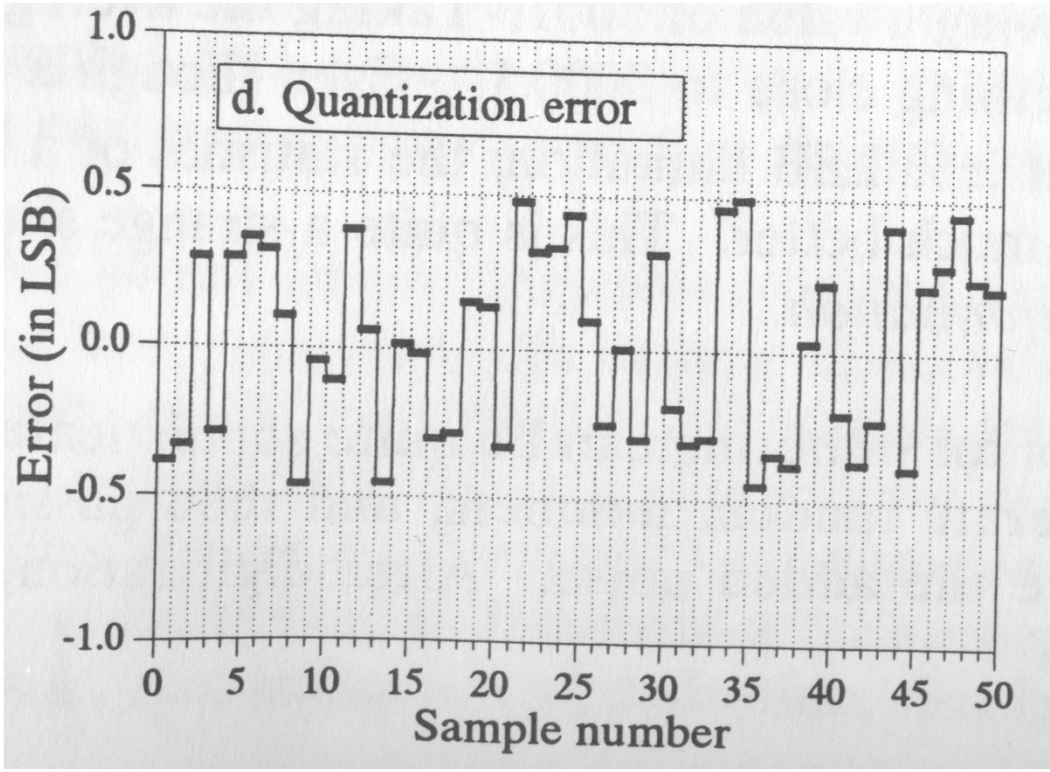
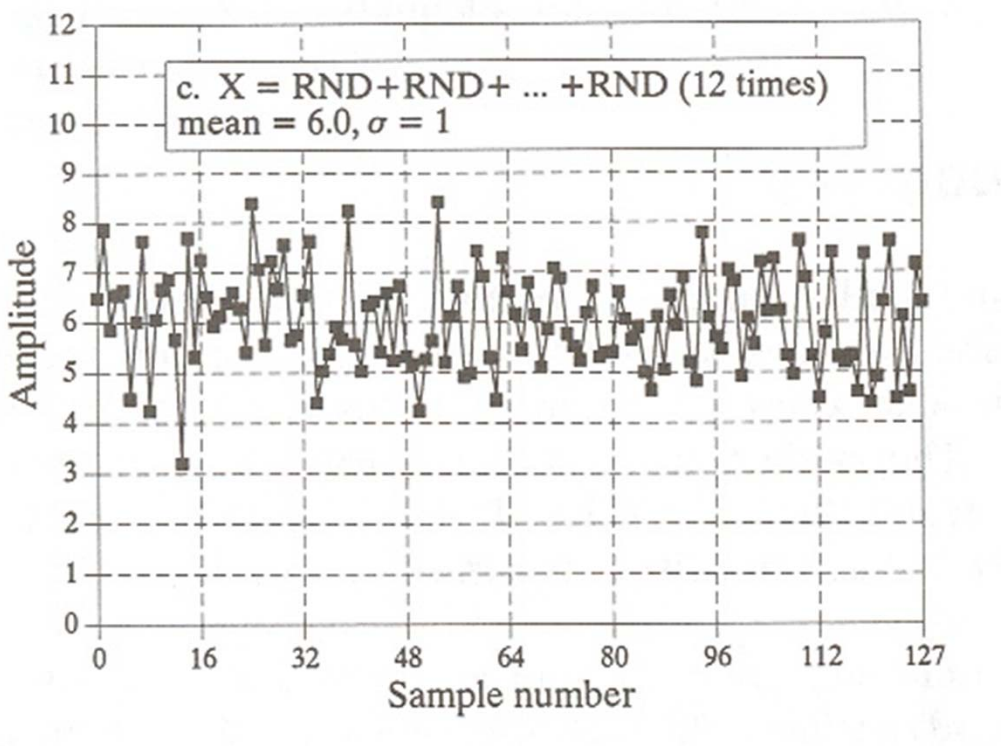


Quantization Error

- Usually like random noise
- Noise is present in most signal acquisition systems
- Random uncorrelated samples added to the original signal



Proper Sampling

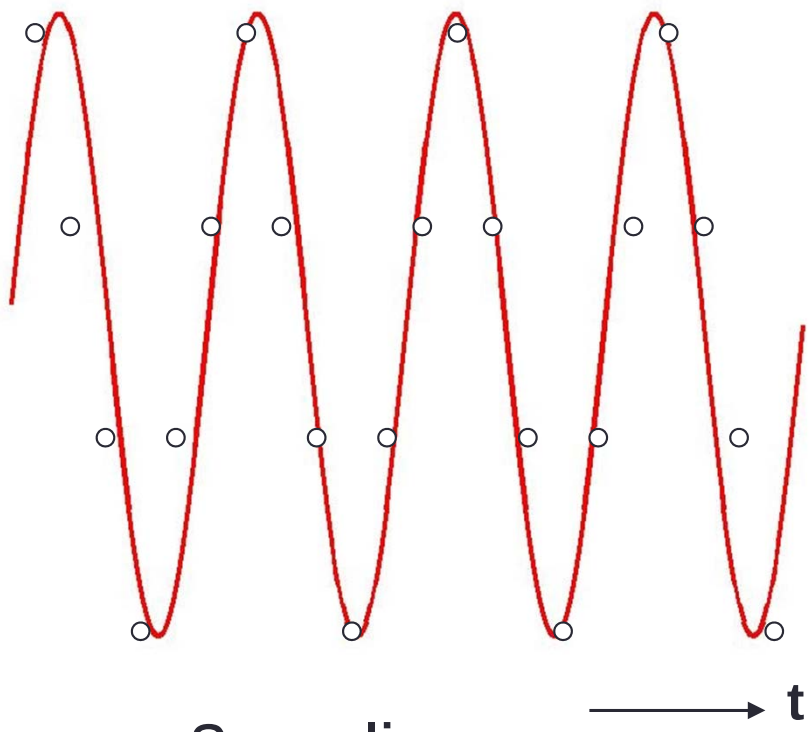
- If the original signal can be reconstructed *unambiguously* from the sampled signal

$$\text{Cycles/ Sample} = \frac{\text{Number of cycles per second}}{\text{Number of samples per second}}$$

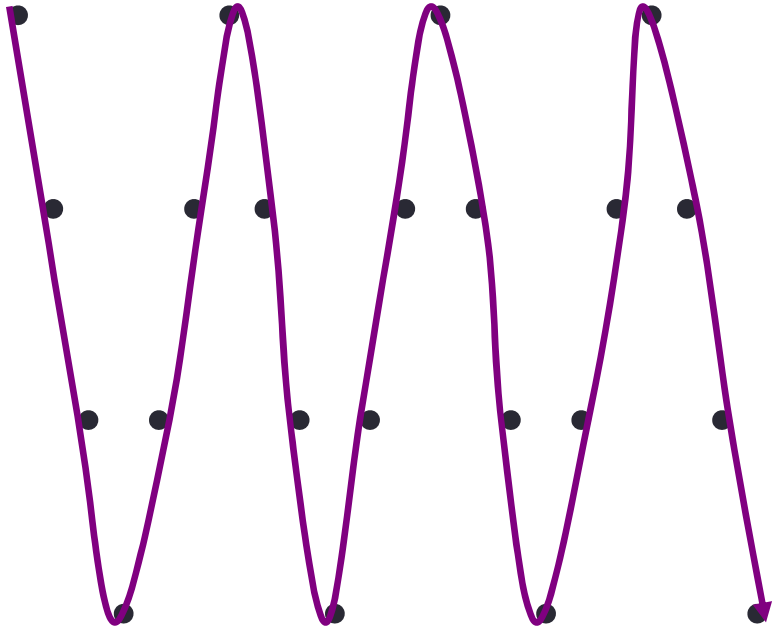
$$= \frac{\text{Analog Frequency}}{\text{Sampling Rate}}$$

Digital Signals

- Defined at only few values of t



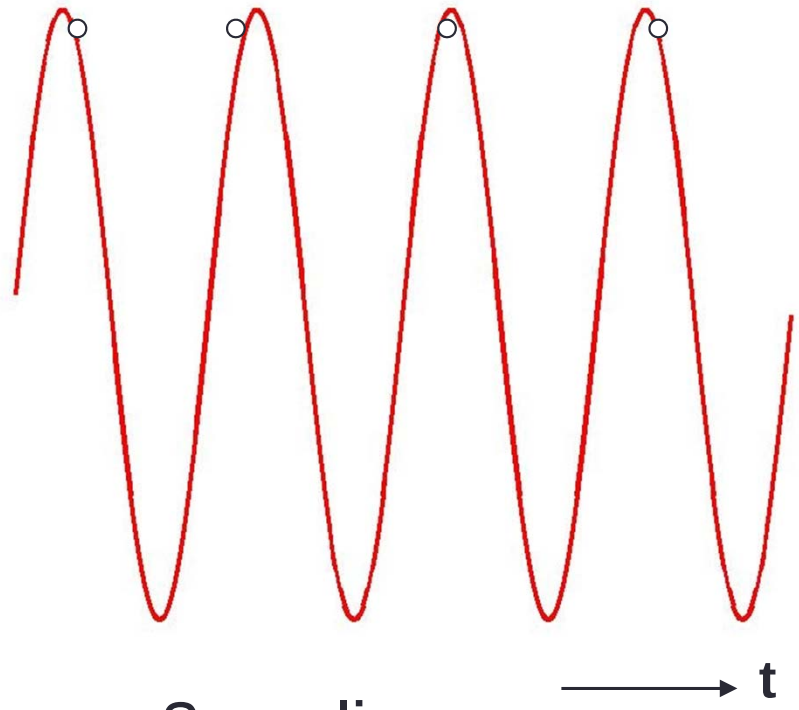
Sampling



Correct Reconstruction

Digital Signals

- Whether you can reconstruct correctly depends on how you sample – sampling rate

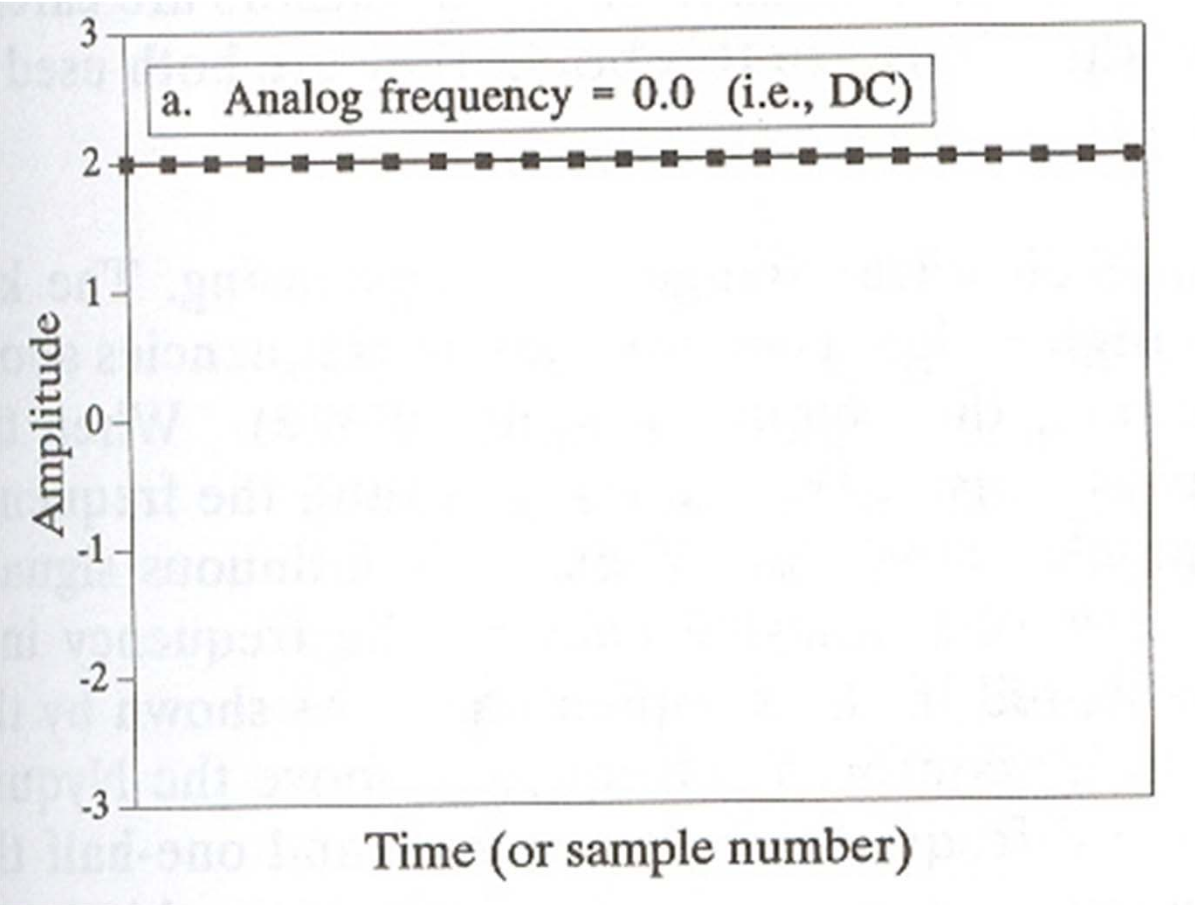


Sampling

Incorrect Reconstruction

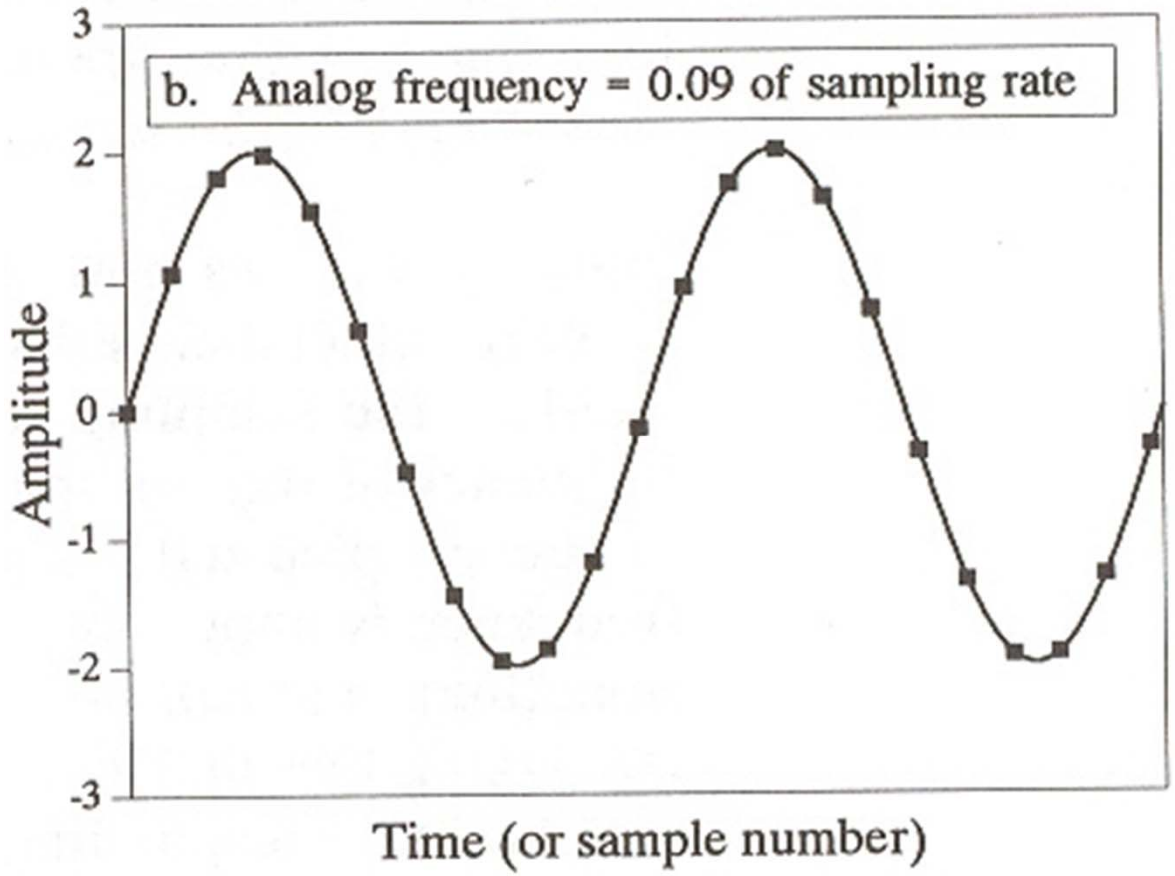
Is it Proper Sampling?

- DC signal
- Freq = 0.0 x Sampling Rate
- Proper



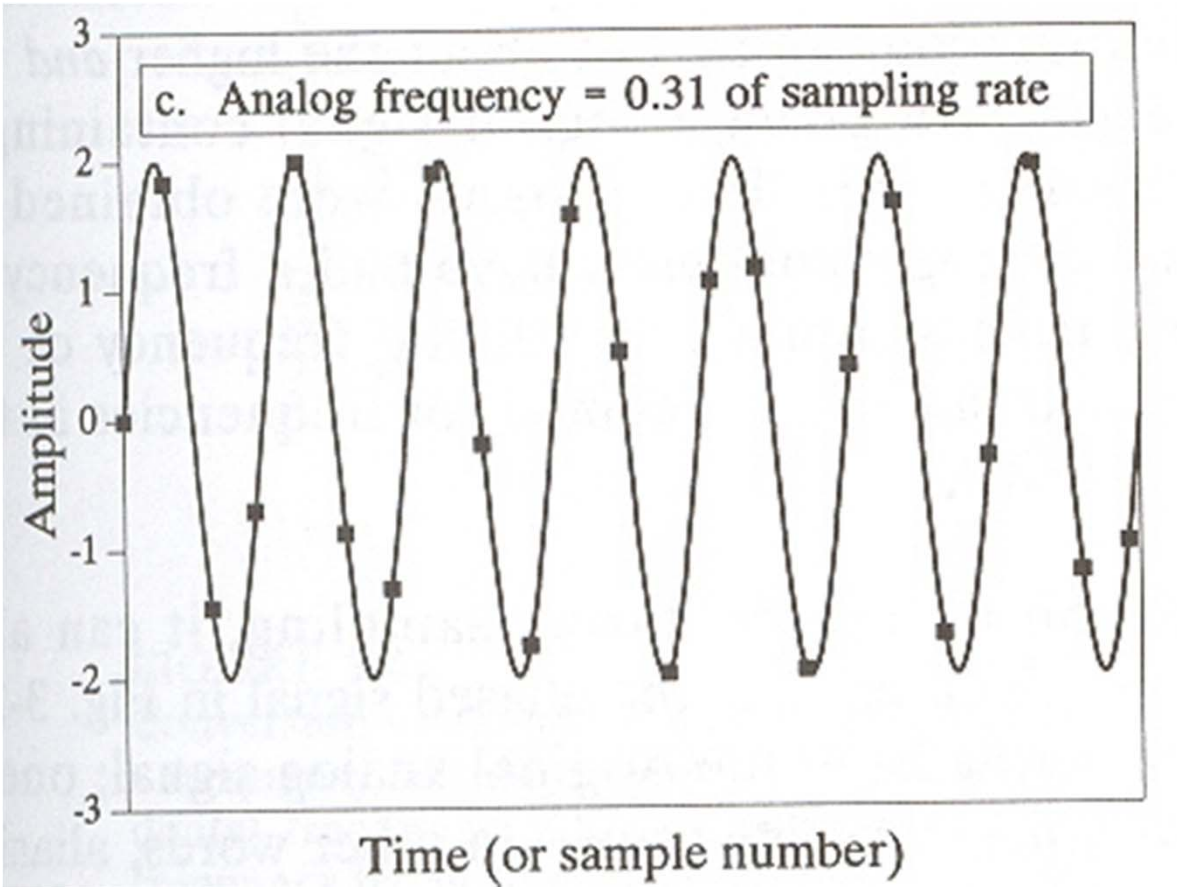
Is it Proper Sampling?

- Freq = 0.09 x Sampling Rate
- Each sample covers 0.09 cycles
- Proper



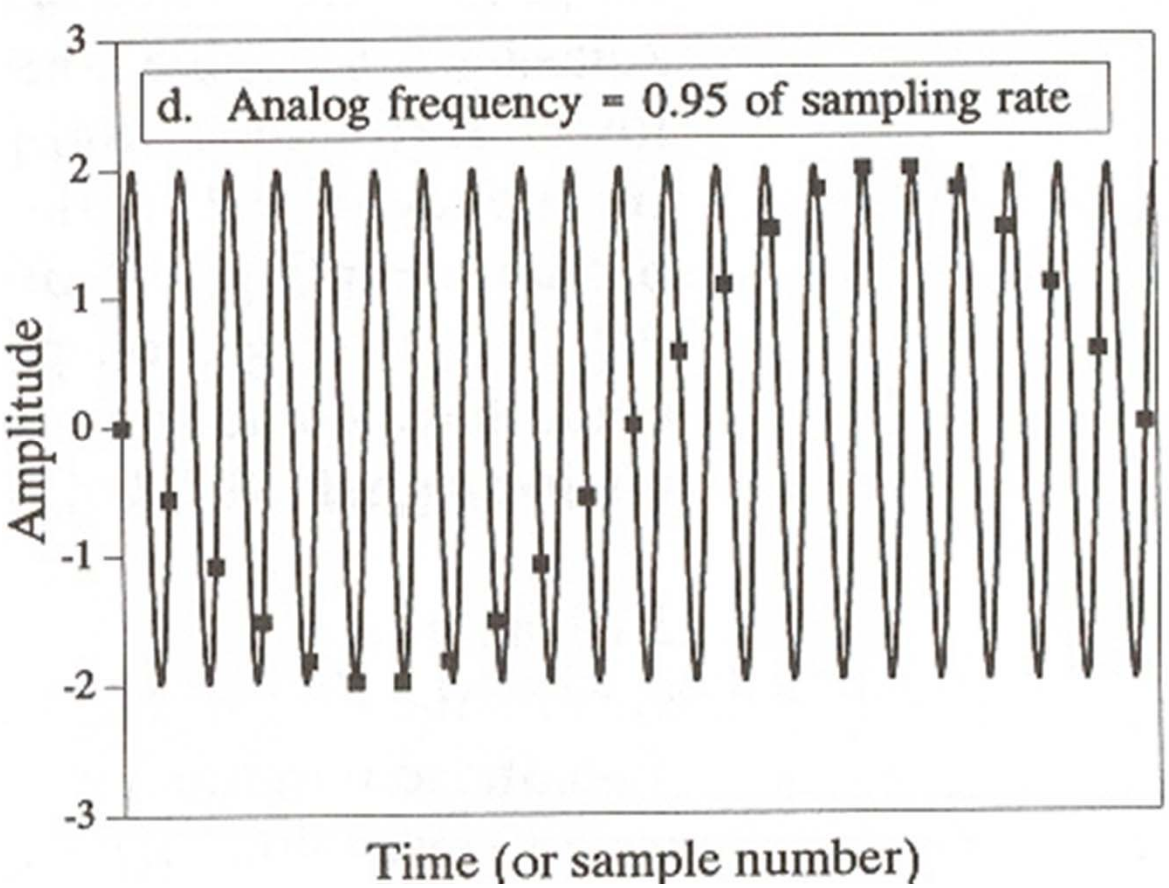
Is it Proper Sampling?

- Freq = 0.31 x Sampling Rate
- Larger fraction of cycles per sample
- Proper



Is it Proper Sampling?

- Freq = 0.95 x Sampling Rate
- Much larger parts of cycles per sample
- Not Proper
- Aliasing
- Changes frequency and phase



Sampling Theorem

- Proper Sampling: At least one sample per half cycle
- Freq ≤ 0.5 x Sampling Rate
- Sampling Rate ≥ 2 x Frequency
- Nyquist Rate