

Sampling

- Discrete sampling
- Binary representations of data
- Aliasing
- Dynamic range

- Reading:

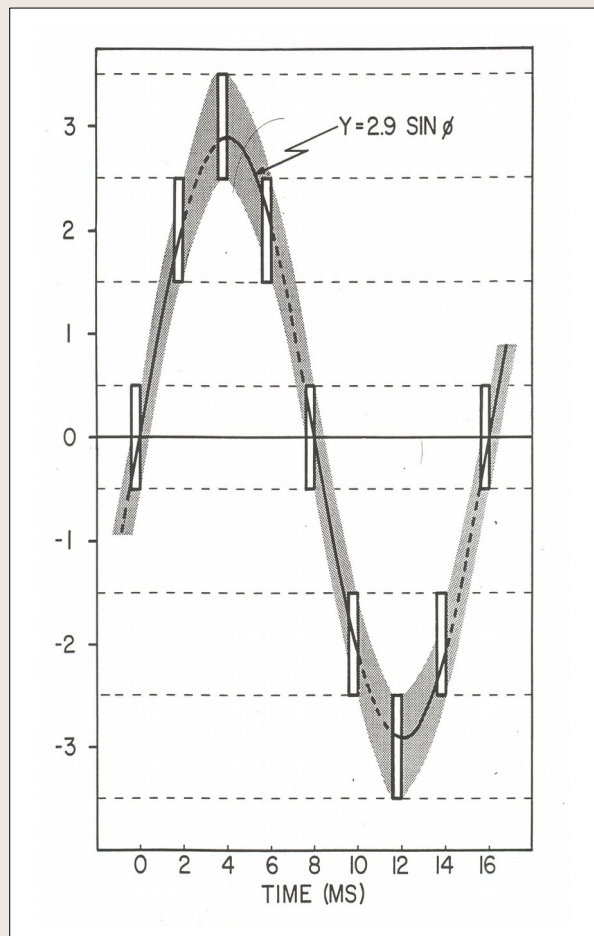
- › Telford *et al.*, Sections 4.7.2-6

Discrete Sampling

- Suppose we need to digitize a continuous signal (vibration caused by a seismic source, gravity or electrical field, *etc.*).
- To design an Analogue-to-Digital (AD) converter, we have to answer two key questions:
 1. Choose the *sampling interval*. How dense the sampling should be?
 2. Choose the *dynamic range*. How *deep* should the amplitude measurement be? How many possible values should the discrete output contain?
 - ♦ In practice, these questions reduce to choosing a '8-bit', '16-bit', or '24-bit' AD converter.

Sampling and Quantizing Process

- Analog-to-Digital (AD) converter compares the levels of the signal to a set of predefined levels;
- Integer values are used as output;
- Need to have sufficient sampling density in *time* and *amplitude*.

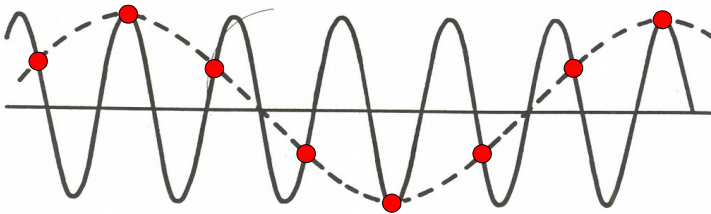


Nyquist Frequency

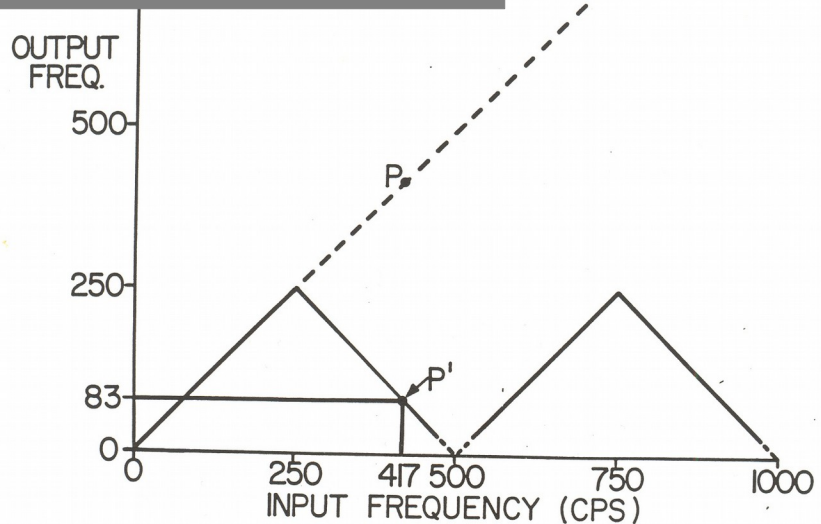
- Consider a seismic record sampled using N samples at a sampling interval of Δt . The *fundamental frequency* (the frequency of sampling) is then $1/\Delta t$
- However, it turns out that the frequency interval $[0...1/\Delta t]$ includes both *positive* and *negative* frequencies that cannot be distinguished in the real-valued signal.
- Consequently, the *highest unambiguously recoverable frequency* is $f_N = 1/(2\Delta t)$. This is called the *Nyquist frequency*.
- Thus, **the rule for choosing the sampling interval is: *the shortest period of interest should include at least 2 samples.***
 - In practice, *twice faster* sampling is typically used

Frequency Folding (Aliasing)

- If sampling is attempted at frequency $<$ twice the frequency of the signal, distortion occurs (called *aliasing*)
 - ♦ High-frequency signal appears as low-frequency:



Aliased readings (red dots) look like a lower-frequency signal (dashed line)

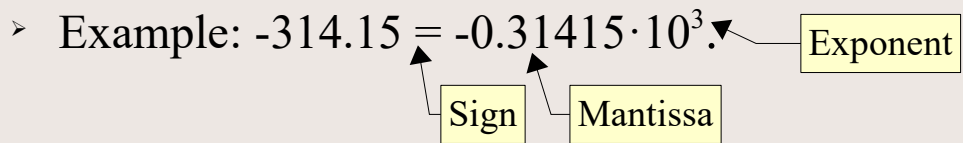


Aliasing

- Inadequate sampling rate results in *aliasing*: the signal above the Nyquist frequency appears as a distorted low-frequency signal.
- It is generally very difficult or impossible to clean up records contaminated with aliasing noise.
- To avoid aliasing, low-pass (called *anti-aliasing*) filters are built into the analogue parts of data loggers.

Binary representation of values

- All digital systems use binary system of representation of integer values.
 - ◆ Floating-point values are represented as three integers: *sign*, *mantissa*, and *exponent*.



- The binary scale uses only two digits, 0 and 1 (corresponding to a digital circuit states 'on' or 'off'). One element of this scale is called *bit*.
 - ◆ A series of 8 bits is called *byte*, bytes are arranged into *words*.
 - ◆ Typical AD converters output 1-, 2-, 3-byte (8-, 16, 24-bit) words.
- Each additional bit doubles the range of possible output values.
 - ◆ Here is how the decimal value of 101 is represented by a 8-bit binary word 01100101:

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
0	1	1	0	0	1	0	1
0	64	32	0	0	4	0	1

Dynamic Range

- The amplitude “depth” of recording is measured by its *dynamic range*, expressed in decibels (dB)
 - ♦ Dynamic range measures the ratio of the maximum and minimum amplitudes that are (or can be) correctly recorded.

$$\left(\frac{A_1}{A_2} \right)_{\text{in dB}} = 20 \log_{10} \left(\frac{A_1}{A_2} \right)$$

- In a digital recorder, the dynamic range is controlled by the *number of bits* used to store or output the values.
 - ♦ Each additional bit allows doubling the recorded values; thus, it corresponds to additional $20 \log_{10} 2 = 6 \text{ dB}$.
 - ♦ Modern data loggers use 24-bit AD converters; this gives about 140 dB of dynamic range