Introduction to Audio and Music Engineering

Lecture 19

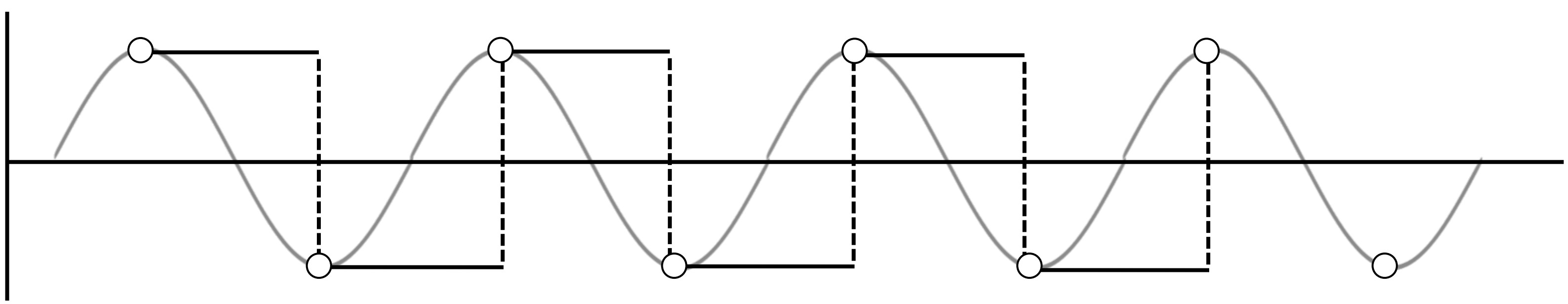
Topics:

- Sampling
- Aliasing
- Quantization
- Signal to quantization noise ratio

Sampling Rate and Nyquist Theorem

Nyquist Theorem: To be able to accurately reconstruct a signal from its samples you need at least 2 samples per period for the highest frequency (sine wave) contained in the signal.

$$R \geq 2\ f_{max}$$

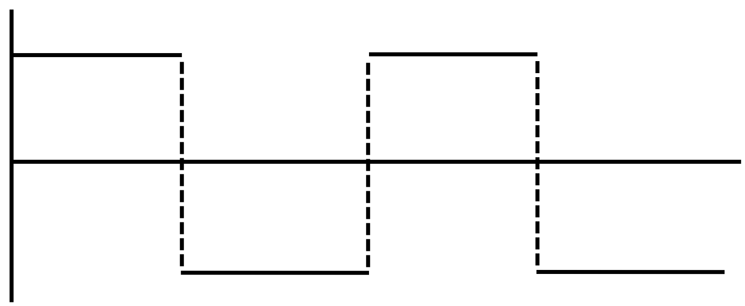


Critical sampling → $R = 2\ f_{max}$

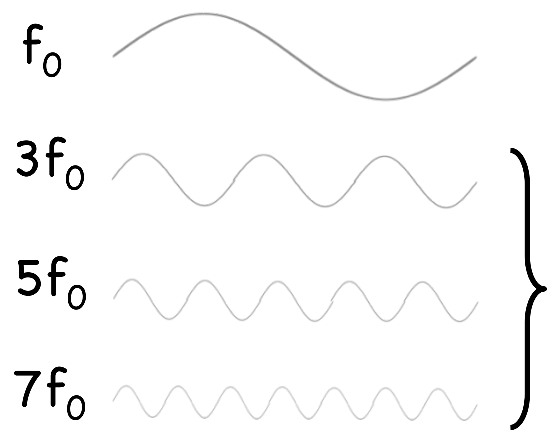
Nyquist frequency = R/2 → highest frequency that can be sampled.

Reconstruction of the waveform from the samples ...

As far as we know the wave was a square wave!



Square wave "recipe"



High frequencies are removed during reconstruction.

Band-limited reconstruction – any frequencies above the Nyquist frequency are removed.

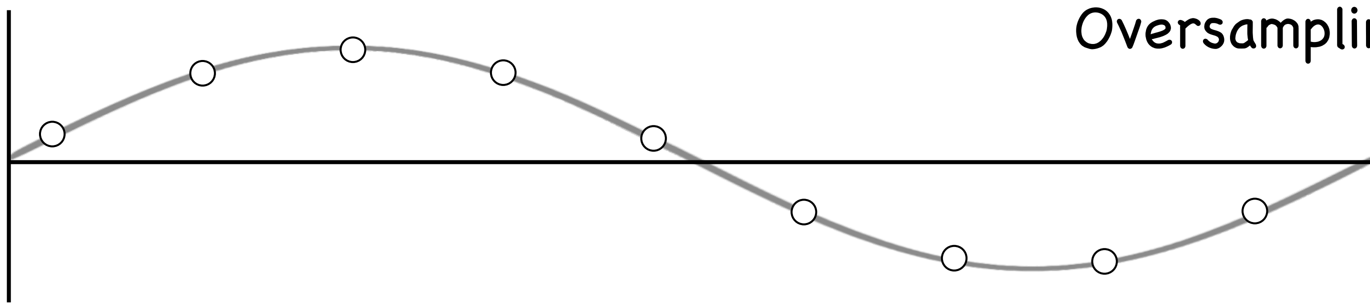
So after band-limited reconstruction we retrieve the original sine wave!

Aliasing

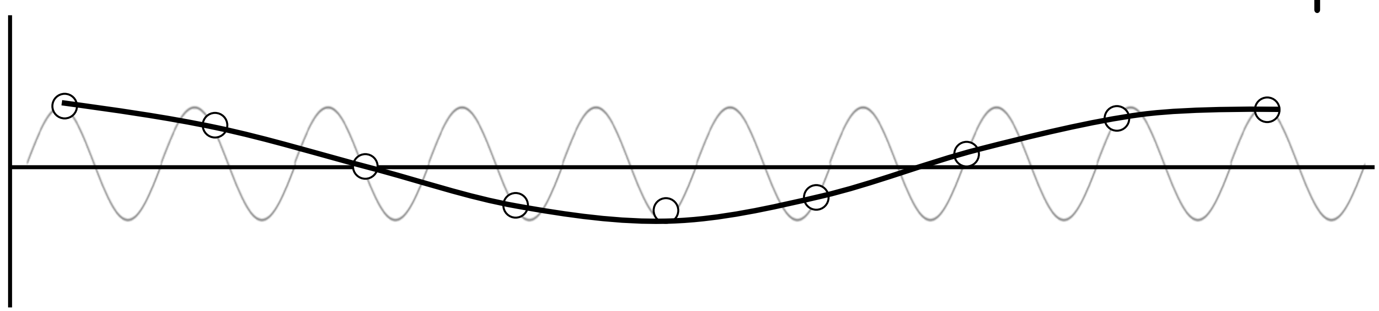
Aliasing occurs when a signal is sampled too slowly.

$$R < 2f_{max}$$

Oversampling → good

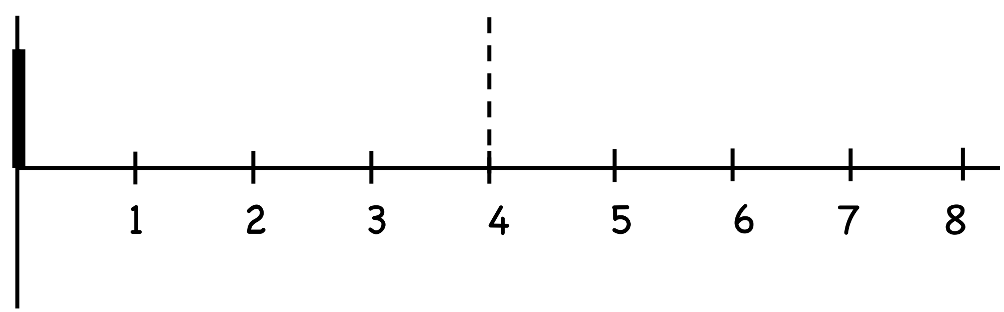


Undersampling → aliasing



Aliasing continued

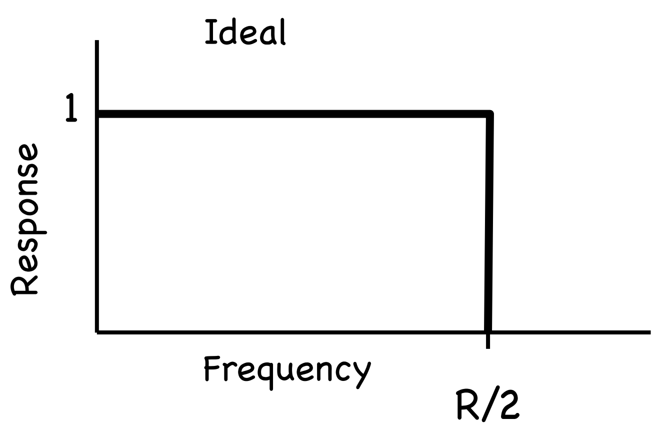
Example:
R = 8 samples per second

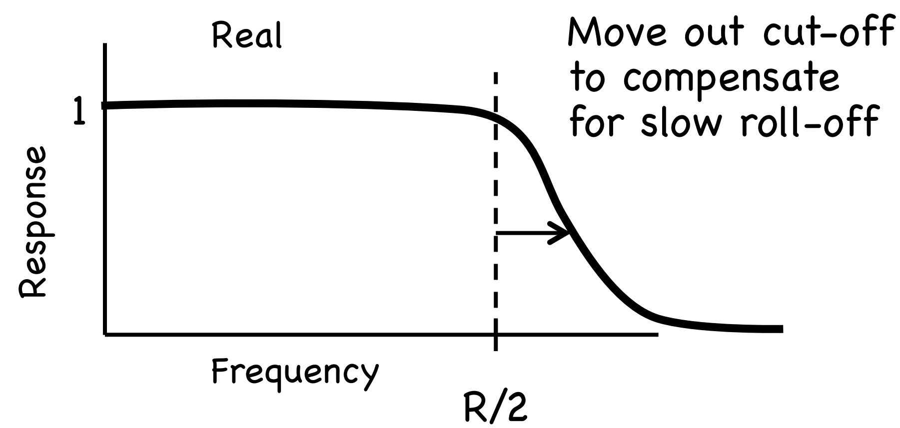


Signal Frequency	Reconstructed Frequency
0	0
1	1
2	2
3	3
4	4
5	3
6	2
7	1
8	0
9	1
10	2
11	3

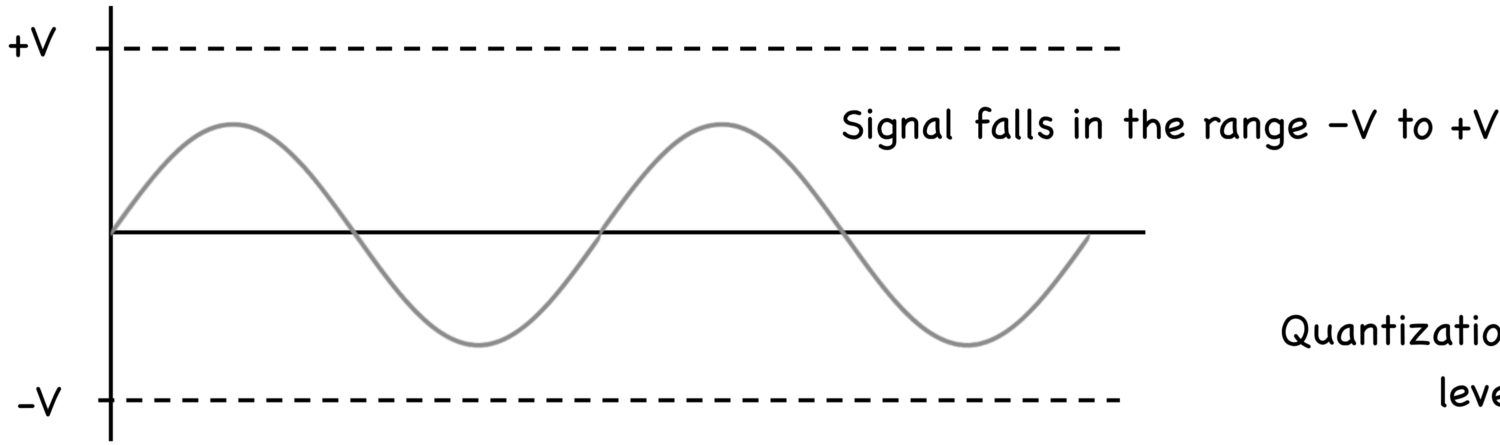
Audio ADC Sample Rate

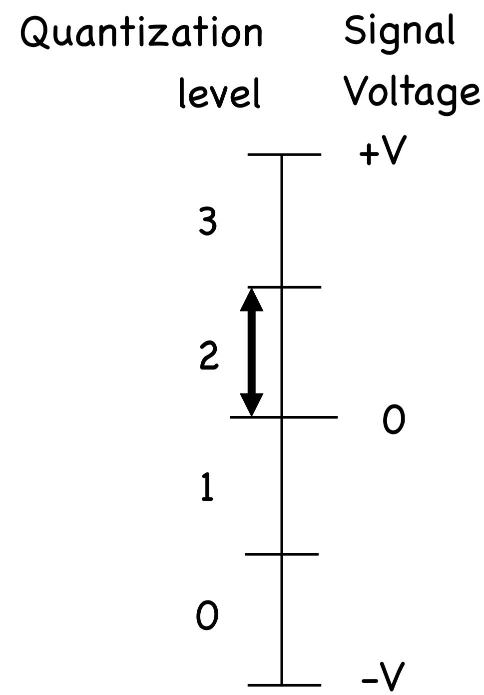
- We need to capture 20 Hz → 20 kHz
- Sample rate 44,100 – standard CD quality
  - 48k, 96k, up to 192k for pro-audio
  - As low as 8k for voice
- Anti-aliasing filter
  - Make sure that there are no signals above one-half of the sample rate





Quantization





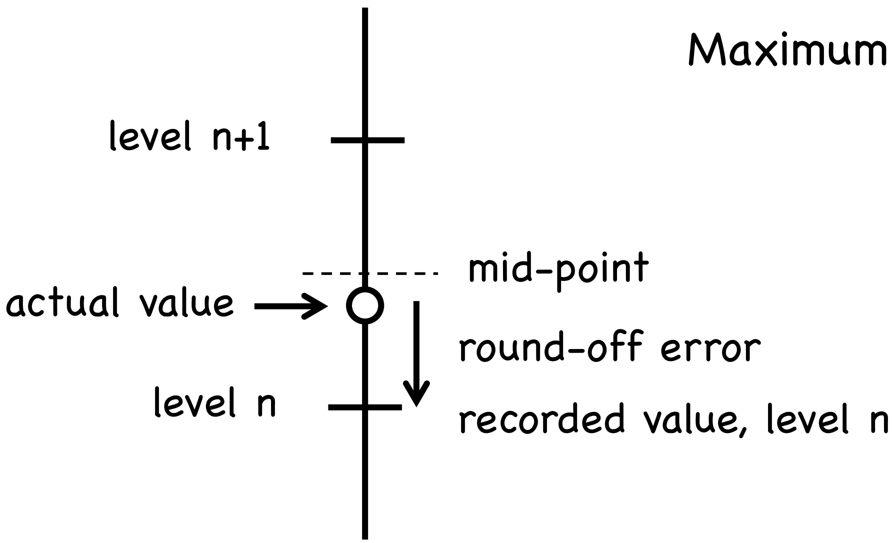
Use an N-bit binary number to map the range 2V onto 2^N levels.

Each region has a size: $\dfrac{2V}{2^N} \Rightarrow \dfrac{Range}{\#\,levels}$

Typical Audio: Line level ≈ 3.472 V peak to peak

16 bits → 2^{16} = 65,536 levels → $3.472/2^{16}$ = 53 μV steps

Quantization “round-off” error



Maximum ound-off error (Quantization error)

$$Q.E. = \frac{1}{2}\left(\frac{2V}{2^N}\right)$$

Maximum round-off is ½ level

Voltage between levels

Quantization is just like adding noise to the signal.

$$\frac{Signal}{Quantization\ Noise} = \frac{V}{\frac{1}{2}\left(\frac{2V}{2^N}\right)} = 2^N$$

SQNR (Signal to quantization Noise Ratio)

SQNR in decibels (for N-bit quantization):

$$SQNR(dB) = 20\log_{10}(2^N) = 20N\log_{10}(2)$$

$$\log_{10}(2) = 0.3010$$

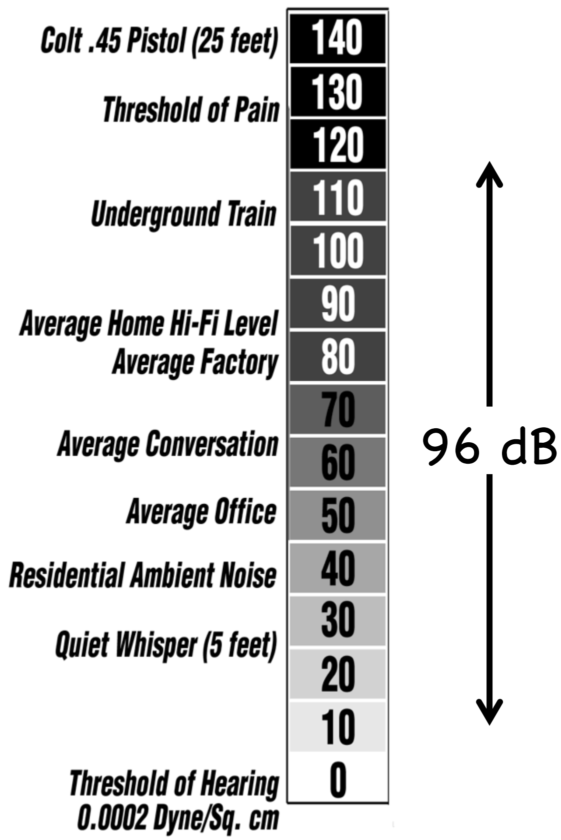
$$SQNR(dB) \approx 6N$$

Each additional bit gives a 6 dB increase in SQNR

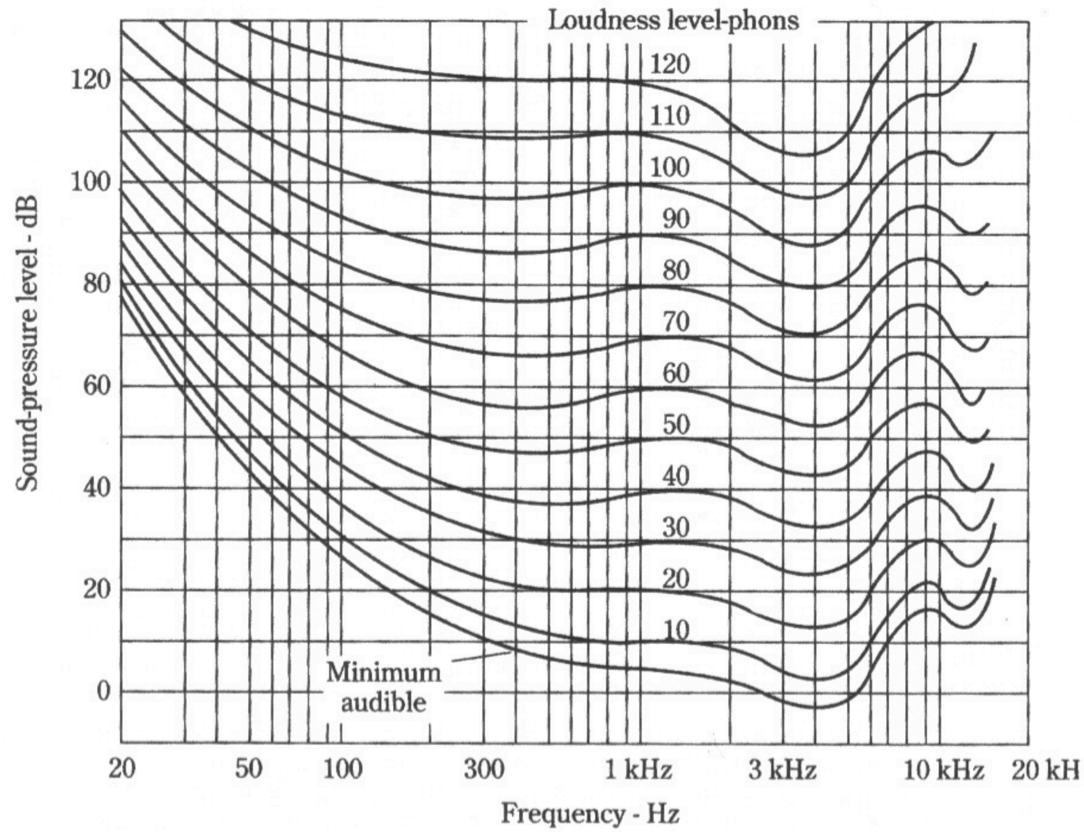
16 bits → 96 dB

Refer back to the Fletcher-Munson curves

SQNR & Fletcher-Munson Curves



dbSPL Table



3-6 Equal-loudness contours of the human ear. These contours reveal the relative lack of sensitivity of the ear to bass tones, especially at lower sound levels. Inverting these curves give the frequency response of the ear in terms of loudness level. (After Robinson and Dadson.[8])