Introduction to Audio and Music Engineering

Lecture 18

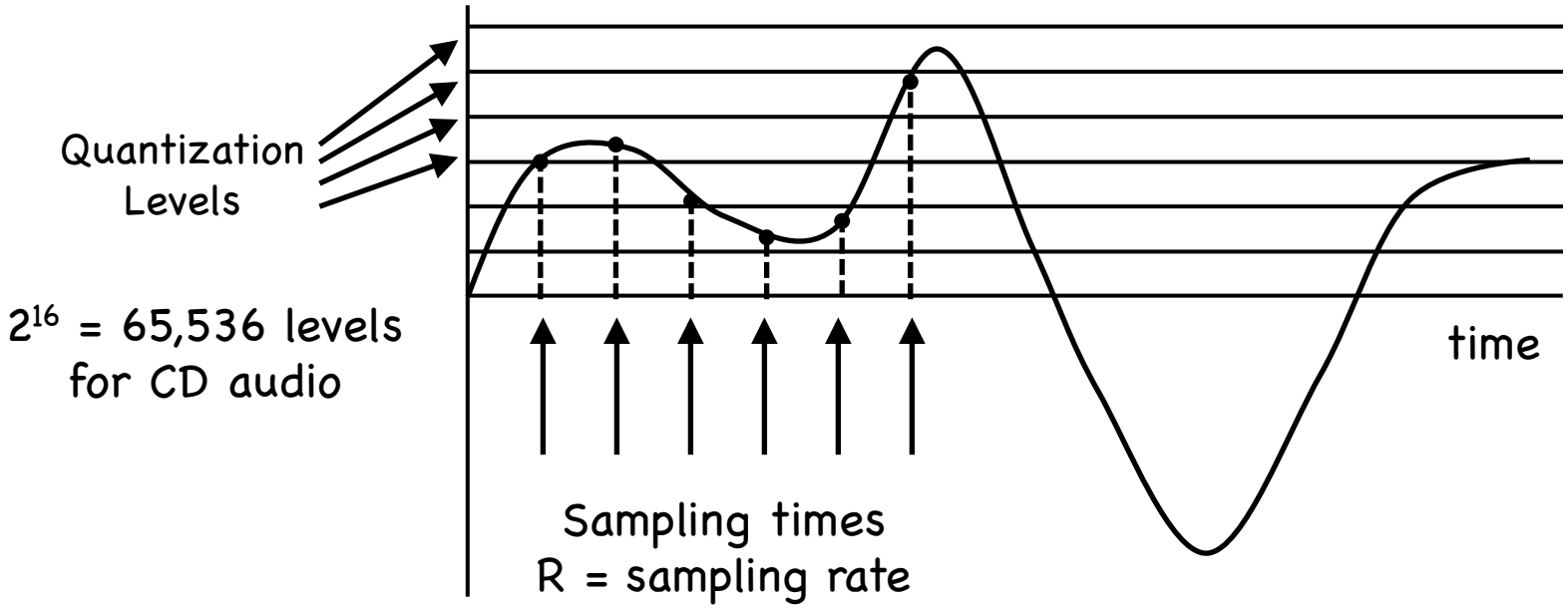
Topics:

- Sampling and quantization
- Analog to digital conversion
- Nyquist's theorem
- Band-limited reconstruction
- Aliasing

Sampling and Quantization

Sampling: Take "snapshots" of a waveform in time.

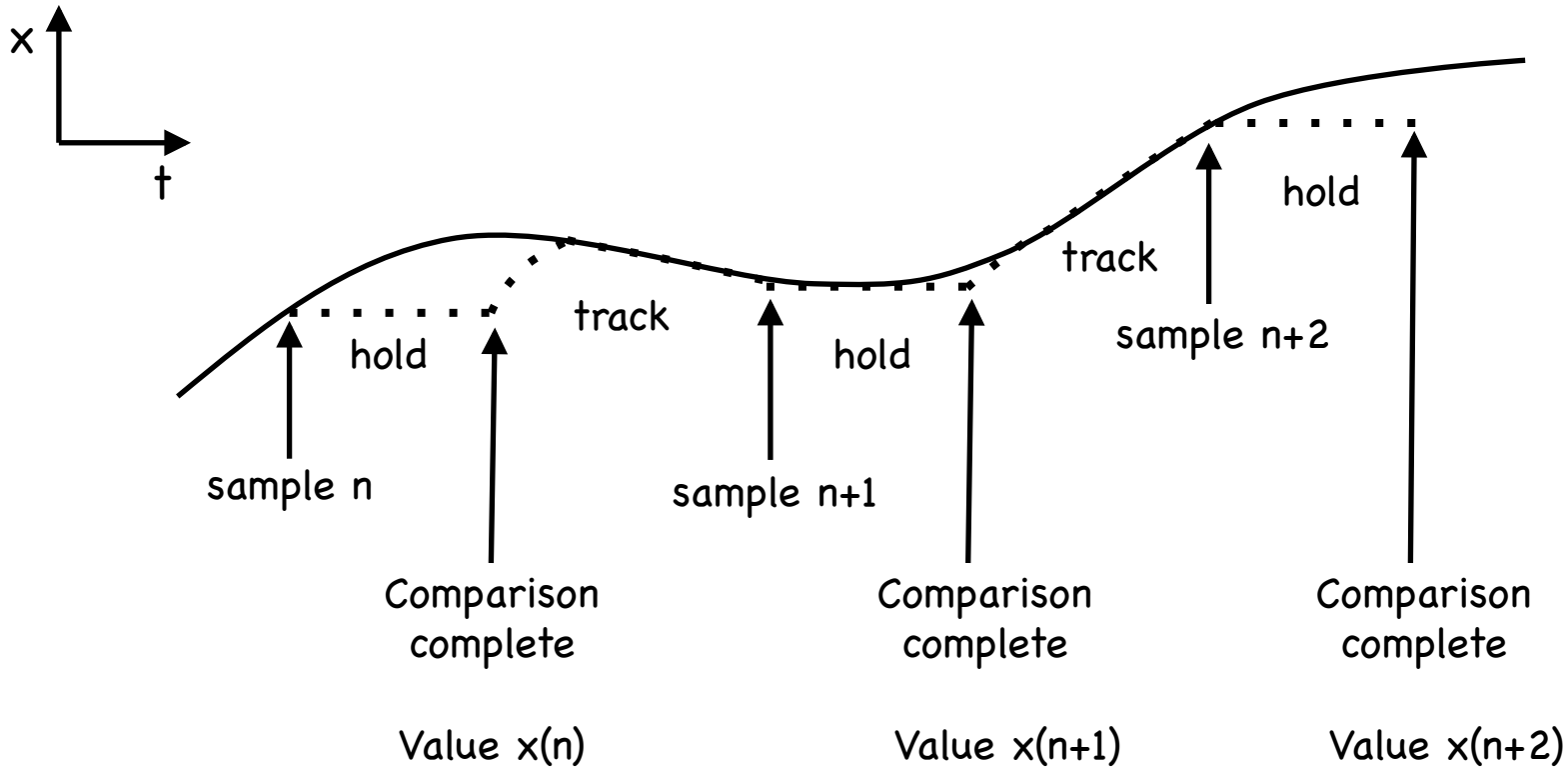
Quantization: Round off sample values to fixed levels.



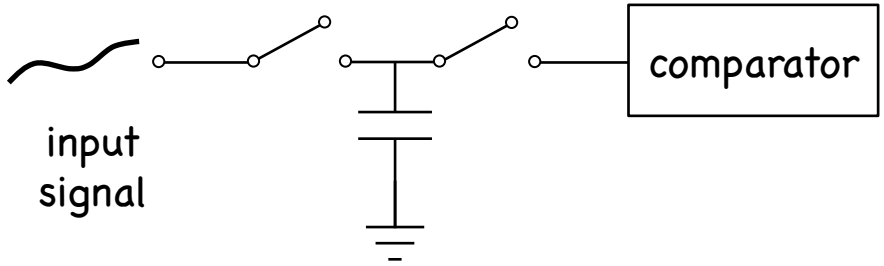
R = 44,100 for CD audio

Analog to digital conversion

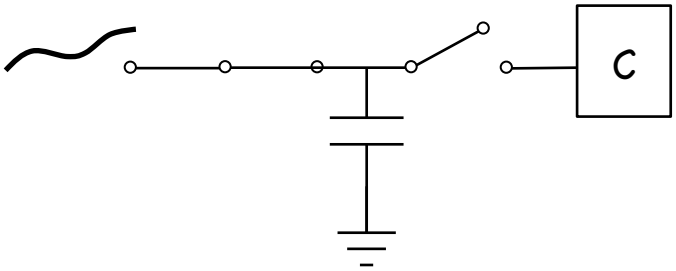
- Track, sample and hold circuit
- Comparator



Track, sample and hold circuit



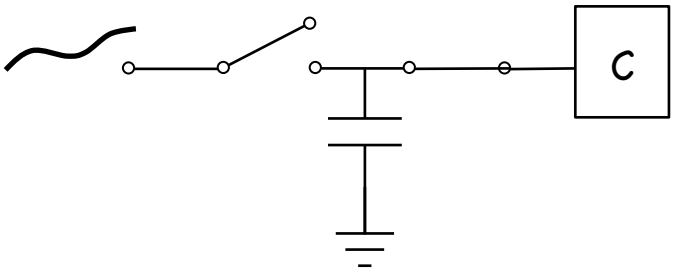
"Track" phase



Capacitor voltage (and charge) follows input signal

Q = CV

Sample and hold

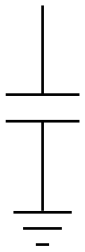


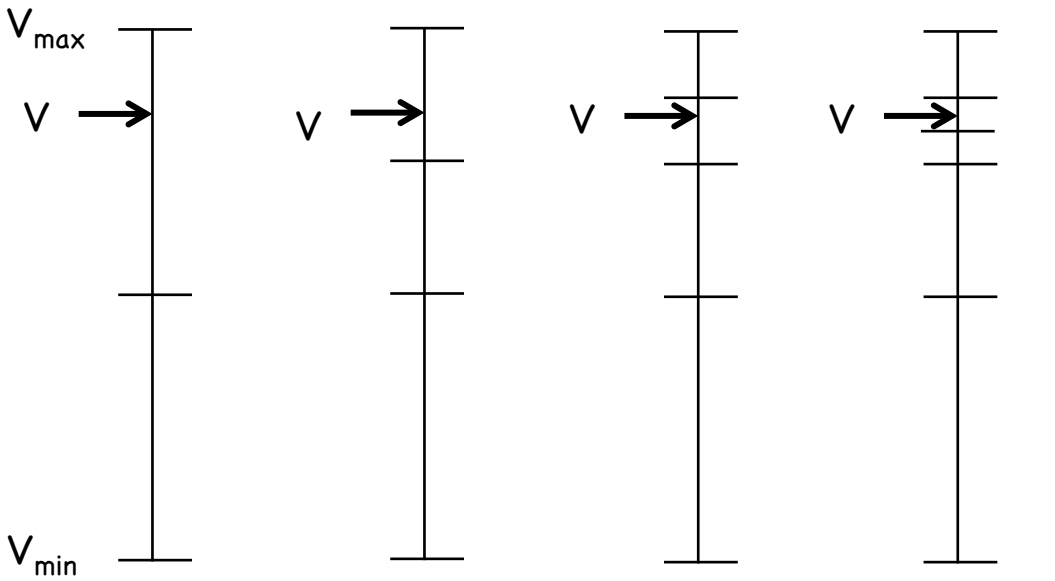
Charge on capacitor (and thus the signal voltage) is held while comparator does its work

Comparator

Comparator has a set of fixed levels against which the input voltage is compared.

$V = Q/C$





Binary output value: 1110

This example: 1101 → 13

4 bits → 16 levels

0000 → 0
0001 → 1
0010 → 2
0011 → 3
.
.
.
1111 → 15

Upper half interval	Upper half interval	Lower half interval	Upper half interval
"1"	"1"	"0"	"1"

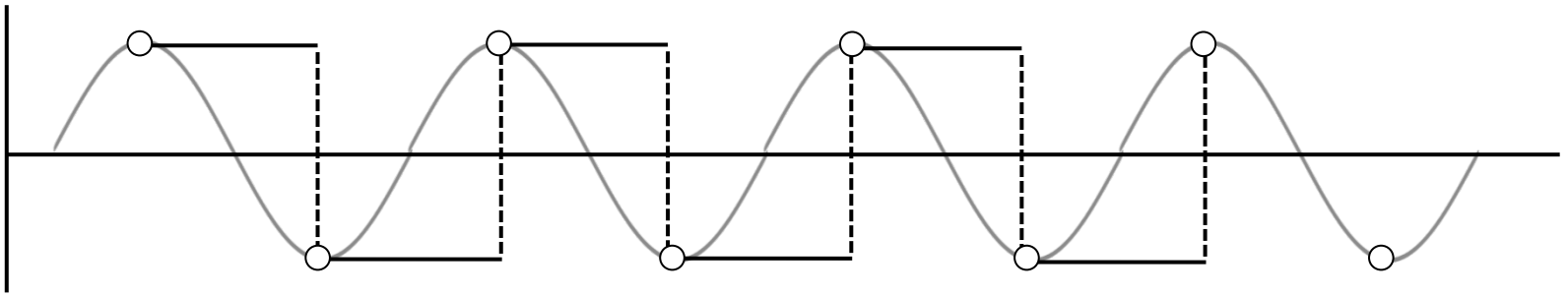
N bits → 2^N levels

CD → 16 bits or 65,536 levels

Sampling Rate

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

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

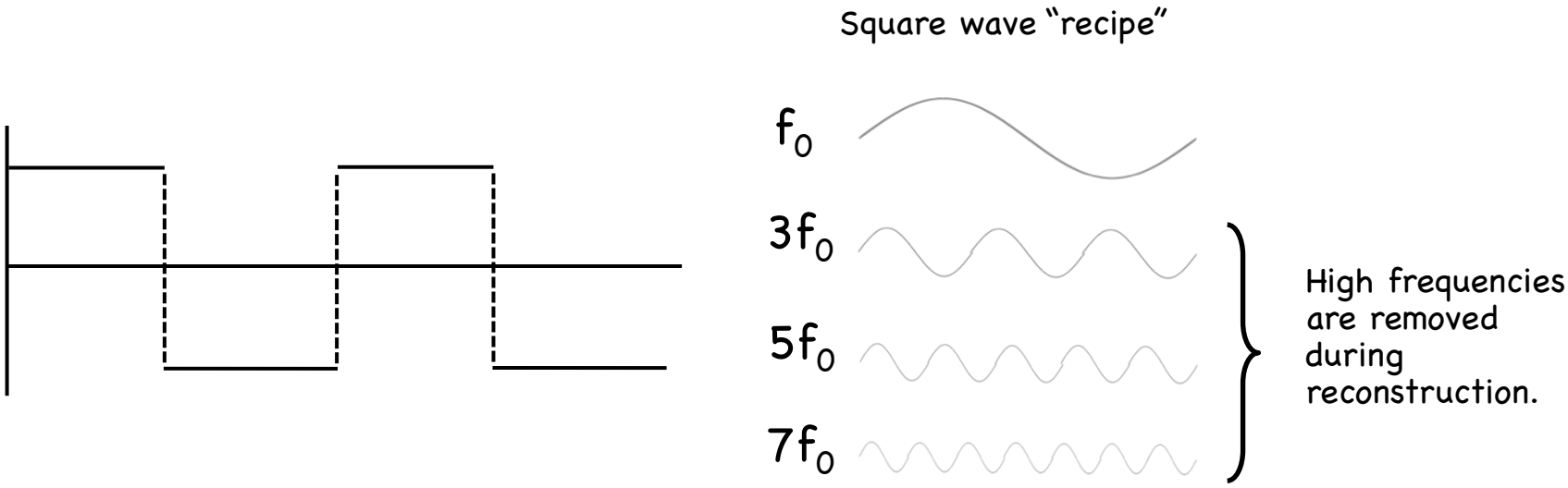


Critical sampling → $R = 2\, f_{max}$

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

Reconstruction from samples

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



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

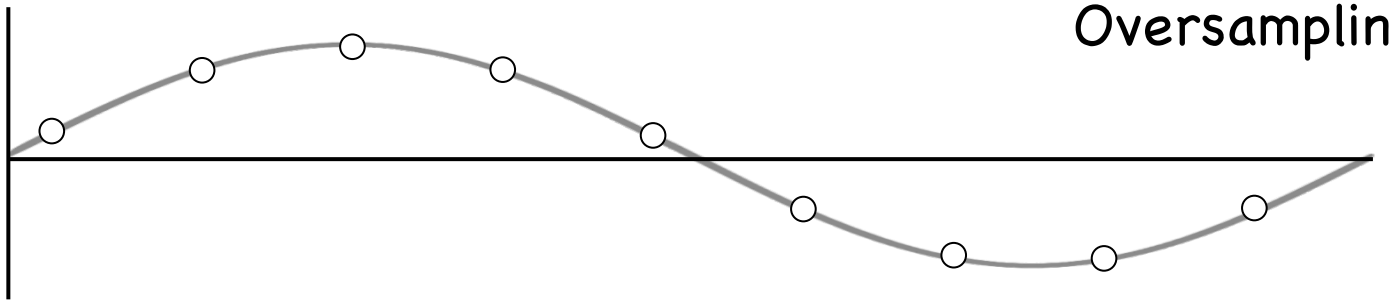
So after band-limited reconstruction we retrieve the original sine wave!

Aliasing

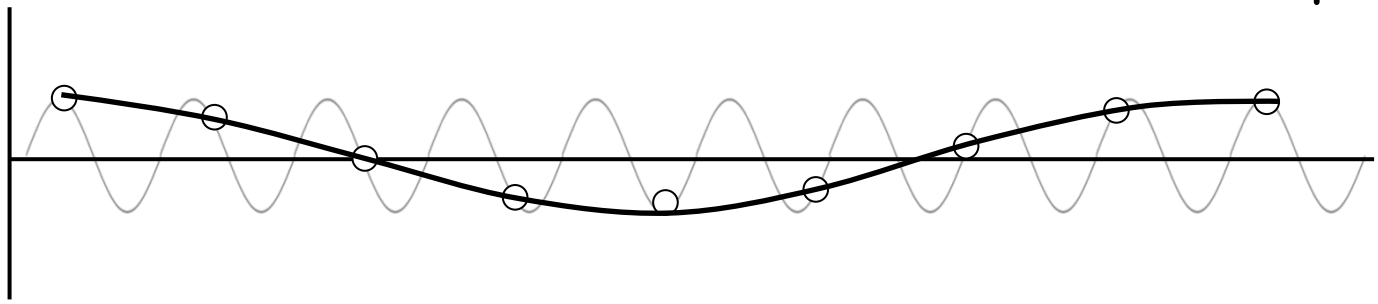
Aliasing occurs when a signal is sampled too slowly.

$$R < 2f_{max}$$

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