Transmission of Analog Data

2 Methods

1. Modulate the analog data
2. Digitalize the analog data

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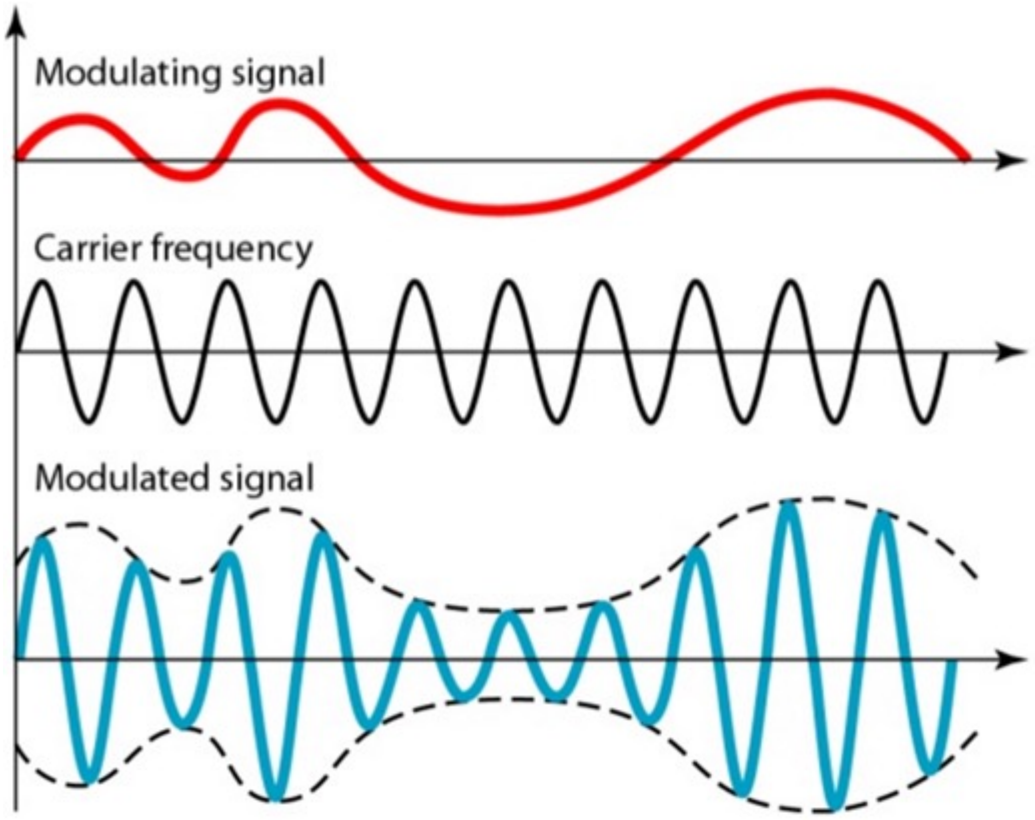
Analog Modulation

- So far, we only consider transmitting digital data
- Sometimes we might want to transmit analog data, e.g., sound
- Why modulating analog signal?

Amplitude Modulation



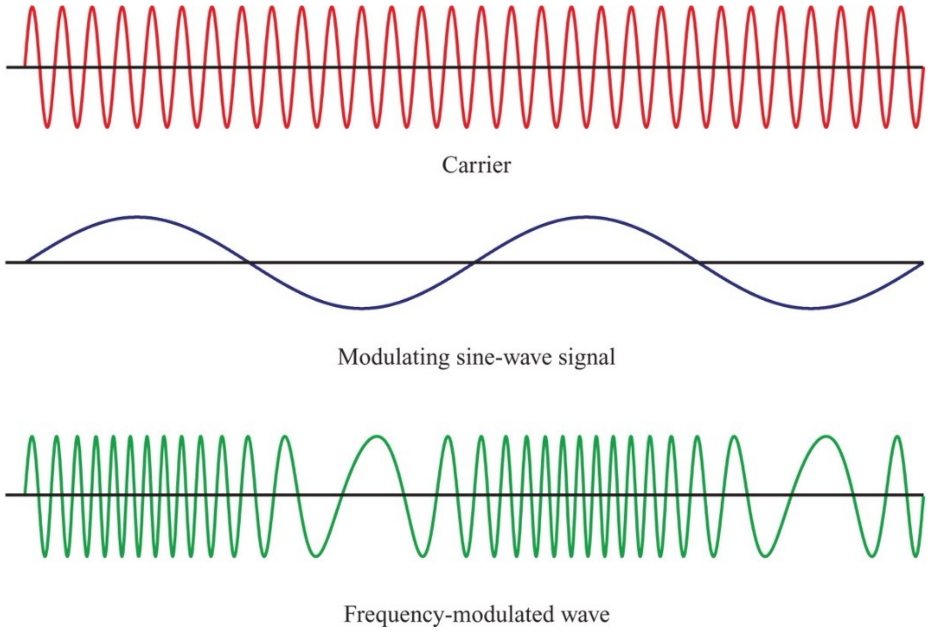
AM

- $x(t)$: input signal
- $s(t) = A_c[1 + Mx(t)]\cos(2\pi f_c t)$
  - A_c: amplitude of carrier signal
  - M: modulation index

An Example

- $x(t)$: $\cos(2\pi f_m t)$
- $s(t) = [1 + Mx(t)]\cos(2\pi f_c t)$
- Three frequency components: $f_c - f_m, f_c, f_c + f_m$
- Bandwidth: $2f_m$

FM


Carrier
Modulating sine-wave signal
Frequency-modulated wave

Why FM is More Popular than AM

- Noise is additive, and affects the amplitude of the signal
- Noise impairs the signal modulated in amplitude
- Compared to AM, FM is more immune to noise
- However, FM uses a wider bandwidth

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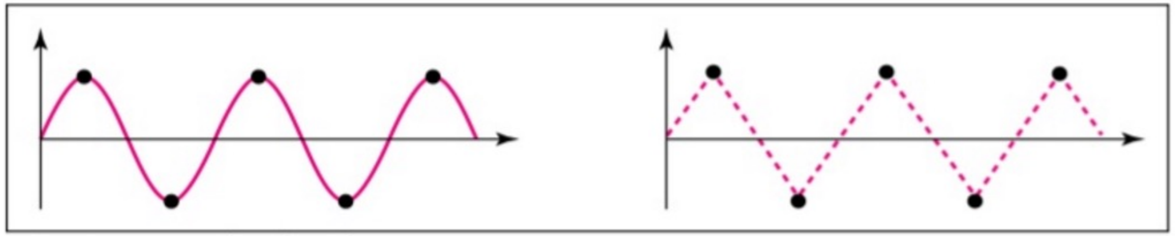
Key Question

- Given a continuous wave, e.g., a song
- Can we send <u>exactly the same</u> wave to someone else by sending a <u>limited number</u> of samples?

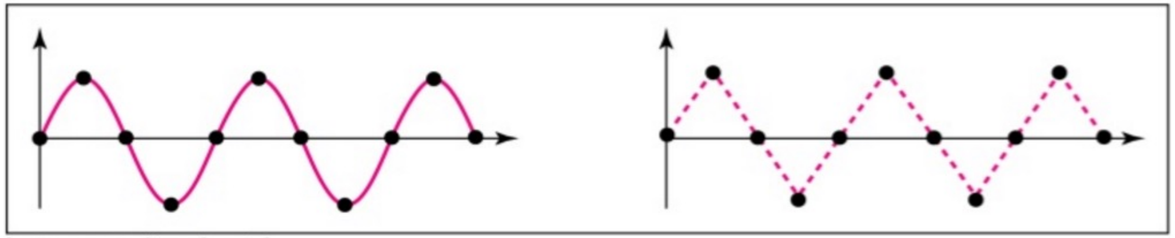
Nyquist Theorem

- According to the Nyquist theorem, **to produce the original signal**, one necessary condition is that the sampling rate is higher than twice the **highest frequency** in the original signal

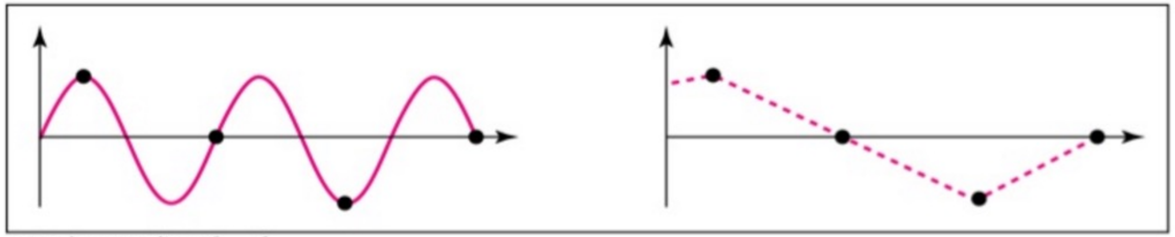
Sampling Rate



a. Nyquist rate sampling: $f_s = 2f$



b. Oversampling: $f_s = 4f$

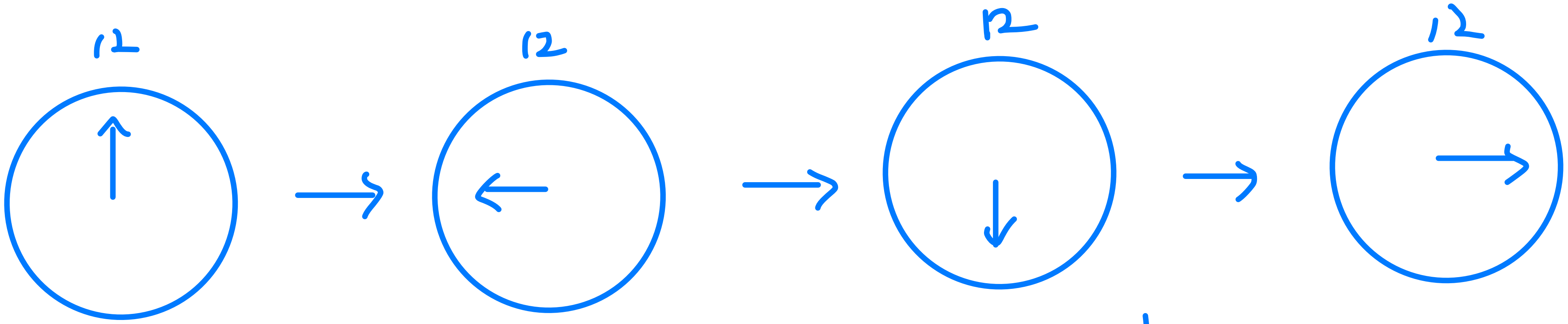


c. Undersampling: $f_s = f$

Example

- Telephone companies digitize voice by assuming a maximum frequency of less than 4000 Hz. The sampling rate is 8000 Hz
- Why do wheels sometimes appear to spin backwards?

Sampling rate of our eyes is too low



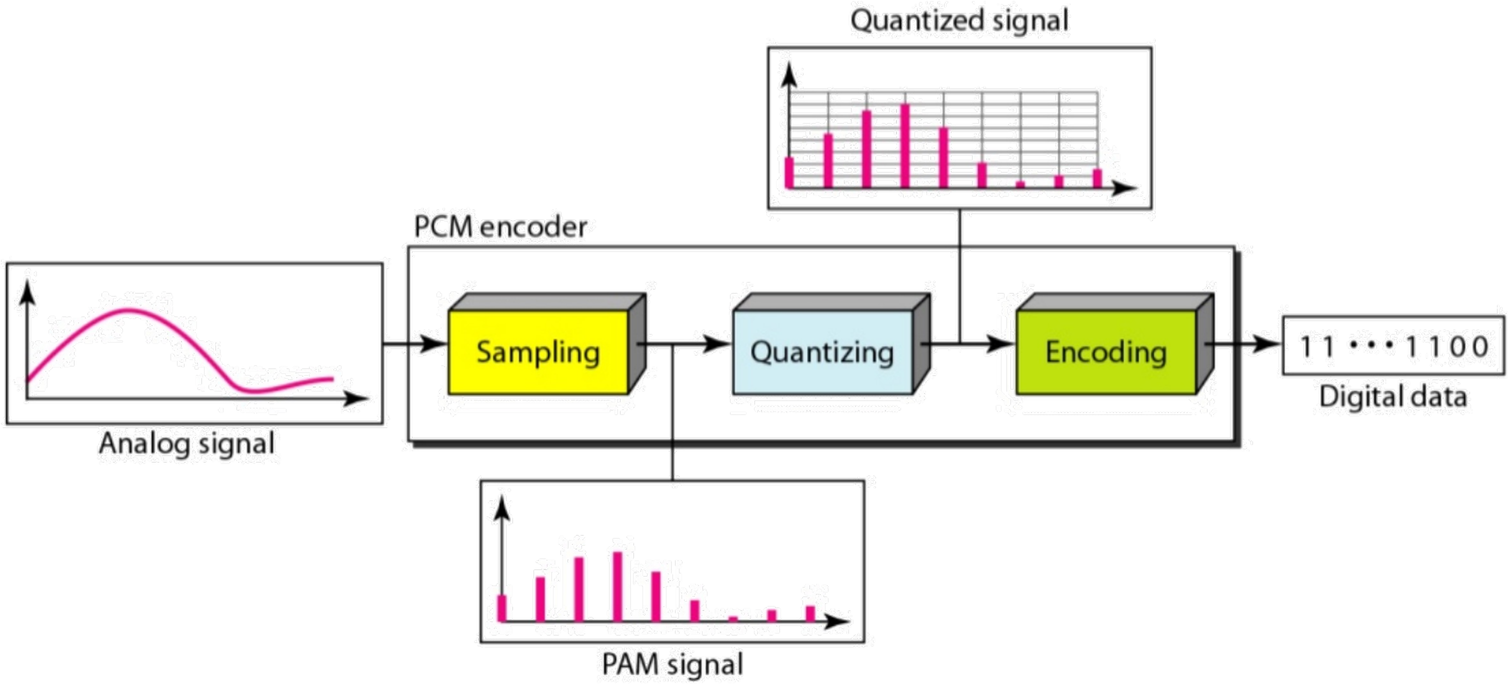
⇒ Wrong direction!

Nyquist Theorem

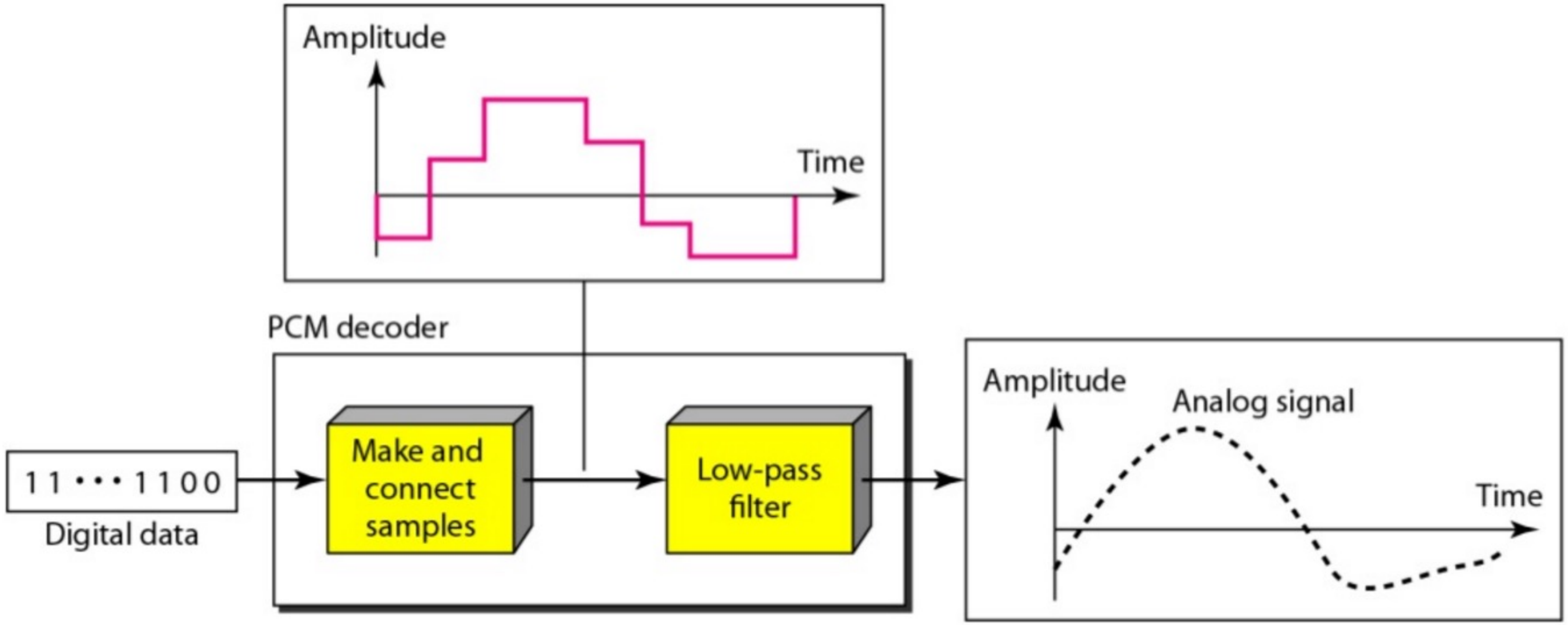
- If a signal $f(t)$ is sampled at a rate higher than twice the highest signal frequency, f_{max}
- Then the original signal can be reconstructed by a low-pass filter with cutoff frequency f_{max}

Pulse Code Modulation

1. The analog signal is sampled
2. The sampled signal is quantized
3. The quantized values are encoded as streams of bits

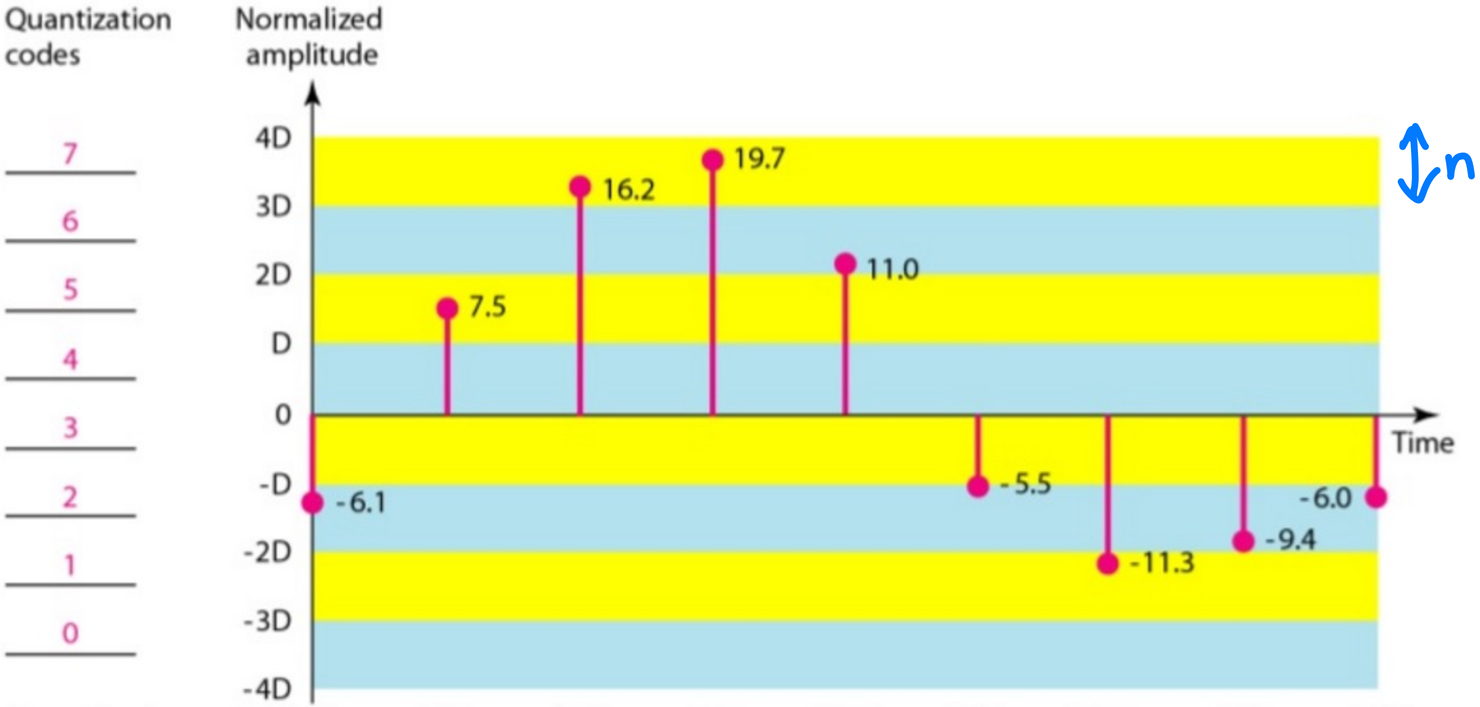


Signal Recovery



Quantization

signal to quantization noise ratio $= \frac{\text{signal amplitude}}{n}$



Normalized PAM values	-1.22	1.50	3.24	3.94	2.20	-1.10	-2.26	-1.88	-1.20
Normalized quantized values	-1.50	1.50	3.50	3.50	2.50	-1.50	-2.50	-1.50	-1.50
Normalized error	-0.38	0	+0.26	-0.44	+0.30	-0.40	-0.24	+0.38	-0.30
Quantization code	2	5	7	7	6	2	1	2	2
Encoded words	010	101	111	111	110	010	001	010	010

PAM:
Pulse
Amplitude
Modulation

Additional Reference

- Wireless Communication Networks and Systems 1st edition, Global edition Cory Beard, William Stallings © 2016 Pearson Education, Ltd.
- https://www.quora.com/What-are-the-advantages-of-differential-phase-shift-keying-DPSK-over-phase-shift-keying-PSK
- http://www.lightwaveonline.com/articles/print/volume-30/issue-5/features/which-optical-modulation-scheme-best-fits-my-application.html
- http://io9.gizmodo.com/why-do-wheels-sometimes-appear-to-spin-backwards-1593807400
- http://www.radio-electronics.com/info/rf-technology-design/pm-phase-modulation/what-is-msk-minimum-shift-keying-tutorial.php
- https://en.wikipedia.org/wiki/Phase-shift_keying
- ECE 414- Wireless Communications - University of Waterloo
- https://en.wikipedia.org/wiki/Envelope_detector