Introduction to Telecommunication Systems
Lecture 9

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Digital Transmission

Analog Data, Digital Signal

- Two techniques are used for analog to digital conversion:
  - Pulse code modulation and
  - Delta modulation

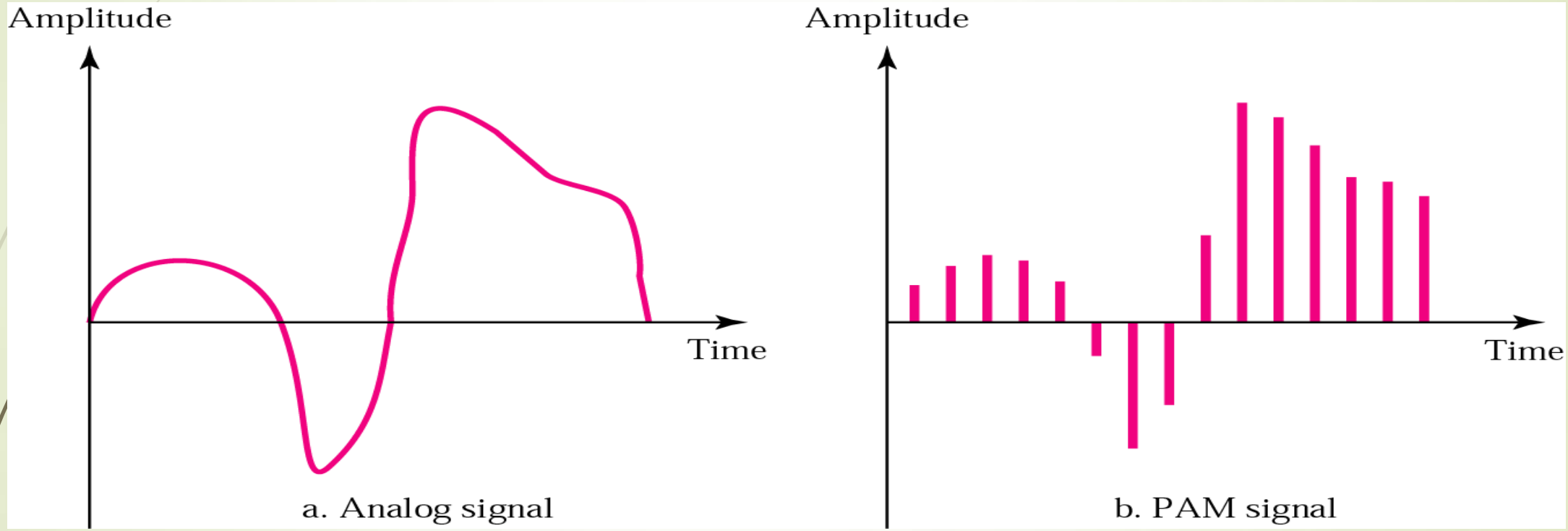
Pulse Code Modulation

- The most common technique to change an analog signal to digital is called pulse code modulation (PCM).
- A PCM encoder has three processes:
  - The analog signal is sampled.
  - The sampled signal is quantized.
  - The quantized values are encoded as streams of bits.

Sampling

- The first step in PCM is sampling.
- The sampling process is sometimes referred to as pulse amplitude modulation (PAM).
- The analog signal is sampled every *Ts* s, where *Ts* is the sample interval or period.
- The inverse of the sampling interval is called the sampling rate or sampling frequency.
- According to Nyquist Theorem, Sampling rate must be at least 2 times the highest frequency.

Sampling



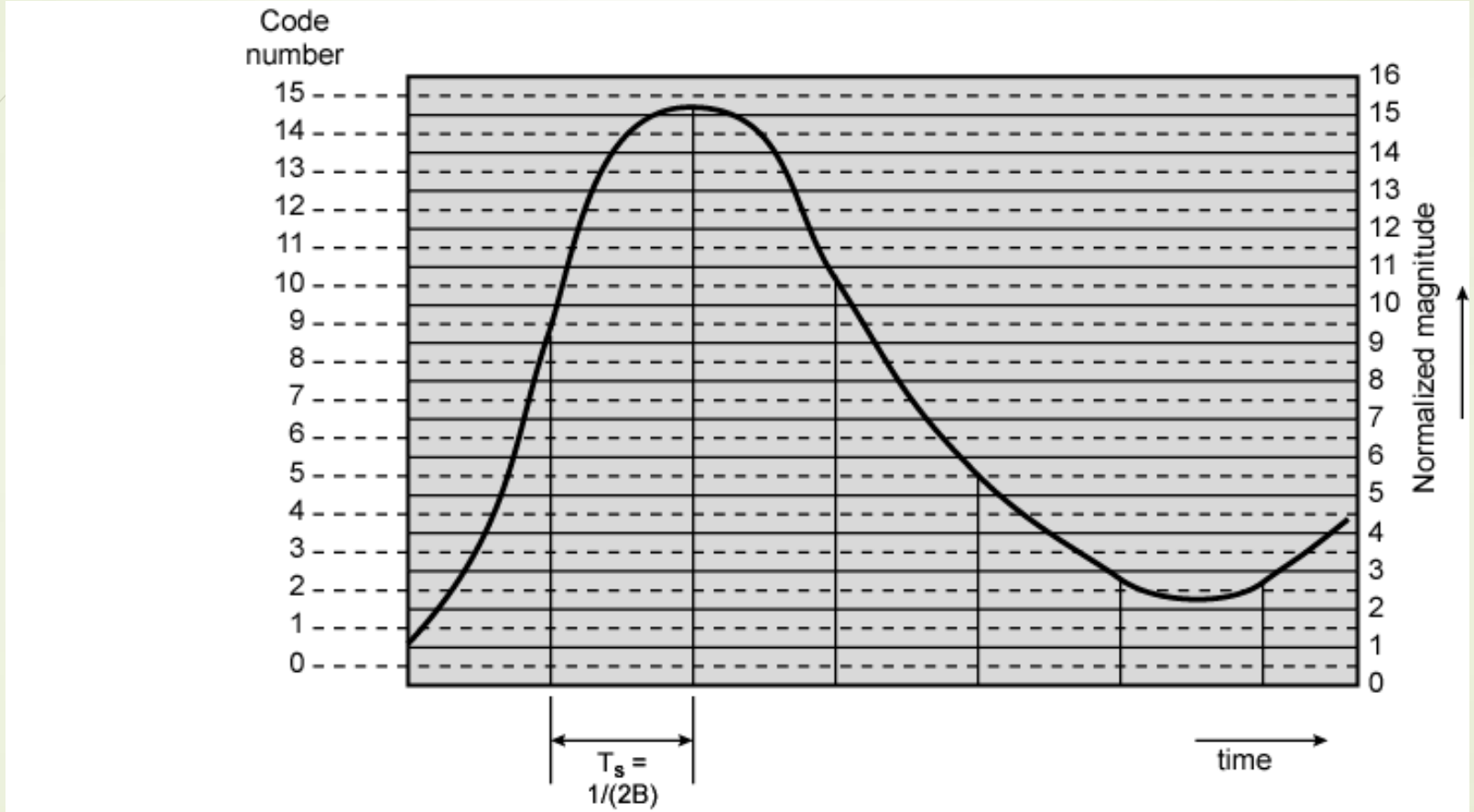
Quantization

- The result of sampling is a series of pulses with amplitude values between the maximum and minimum amplitudes of the signal.
- The set of amplitudes can be infinite with non integral values between the two limits.
- These values cannot be used in the encoding process.
- To convert to digital, each analog sample must be assigned a binary code.

Encoding

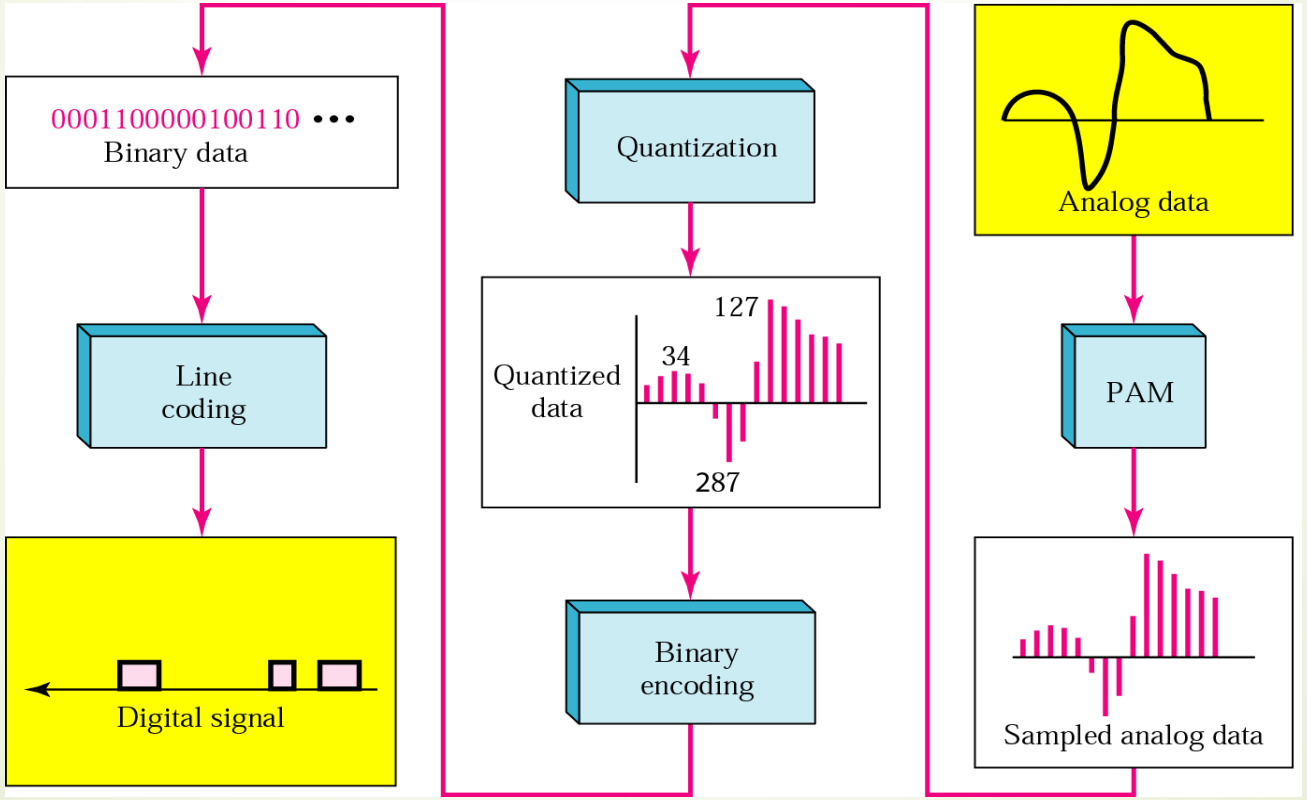
- The last step in PCM is encoding.
- After each sample is quantized and the number of bits per sample is decided, each sample is assigned a binary code.
- Note that the number of bits for each sample is determined from the number of quantization levels.
- For example, 8 bit sample gives 256 levels.
- 8000 samples per second and 8 bits per sample gives 64kbps, for a single voice signal.

Pulse Code Modulation



PAM value	1.1	9.2	15.2	10.8	5.6	2.8	2.7
quantized code number	1	9	15	10	5	2	2
PCM code	0001	1001	1111	1010	0101	0010	0010

Pulse Code Modulation



Pulse Code Modulation

- Examples
  - Q1: What sampling rate is needed for a signal with a bandwidth of 10 KHz (1KHz to 11KHz)
  - A1: Sampling rate = 2 x 11 KHz = 22,000 samples per second

Pulse Code Modulation

- Examples
  - Q2: A signal is sampled. Each sample requires at least 12 levels of precision (+0 to +5 and 0 to -5). How many bits should be sent for each sample?
  - A2: 4-bit
    - 1-bit for sign
    - 3-bit for magnitude (8-levels)

Pulse Code Modulation

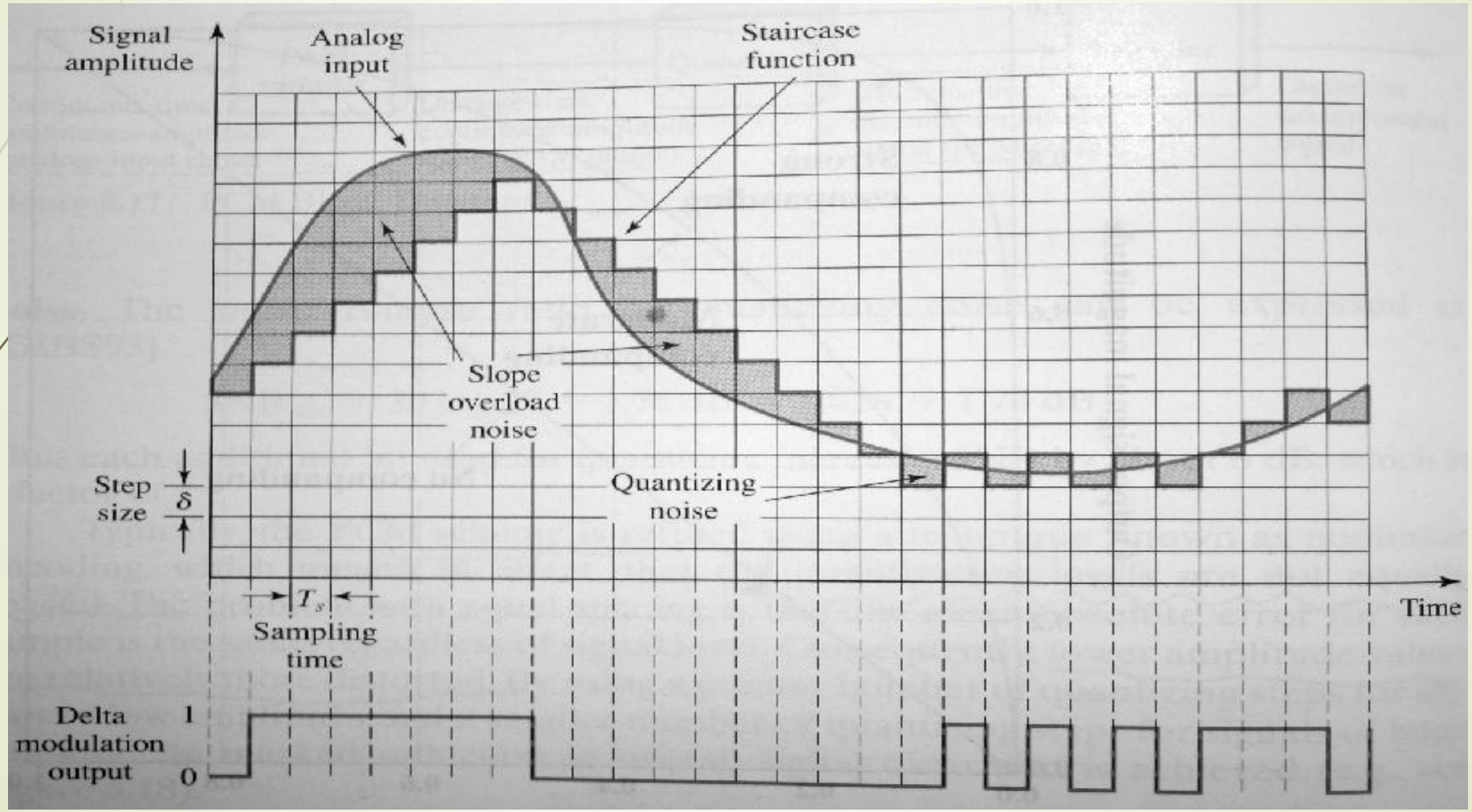
- Examples
  - Q3: We want to digitize the human voice. What is the bit rate, assuming 8-bits per sample?
  - A3: BW of Human voice 0-4000 Hz
    - Sampling rate 4000 x 2 = 8000 samples/sec
    - Bit rate
      - 8000 sample/sec x 8 bit/sample

        = 64,000 bps

Delta Modulation

- Modulation:
  - An analog signal is approximated by a staircase function that moves up or down by quantization level at each sampling interval.
  - If the value of the sampled waveform exceeds that of the staircase function, 1 is generated, otherwise, 0 is generated.
- Two important parameters:
  - The size of the step.
  - The sampling rate.

Delta Modulation



Delta Modulation

- Noise
  - Slope overload noise (when the analog waveform is changing rapidly than the staircase can follow)
  - Quantizing noise (when the analog waveform is changing slowly)
- Trade-off
  - The quantizing noise increases as the size of the step increases.
  - The slope overload noise increases as the size of the step decreases.

End of Slides