Analog Communication Systems
EC-413-F

Lecture no. 4,5,6

Topics to be covered

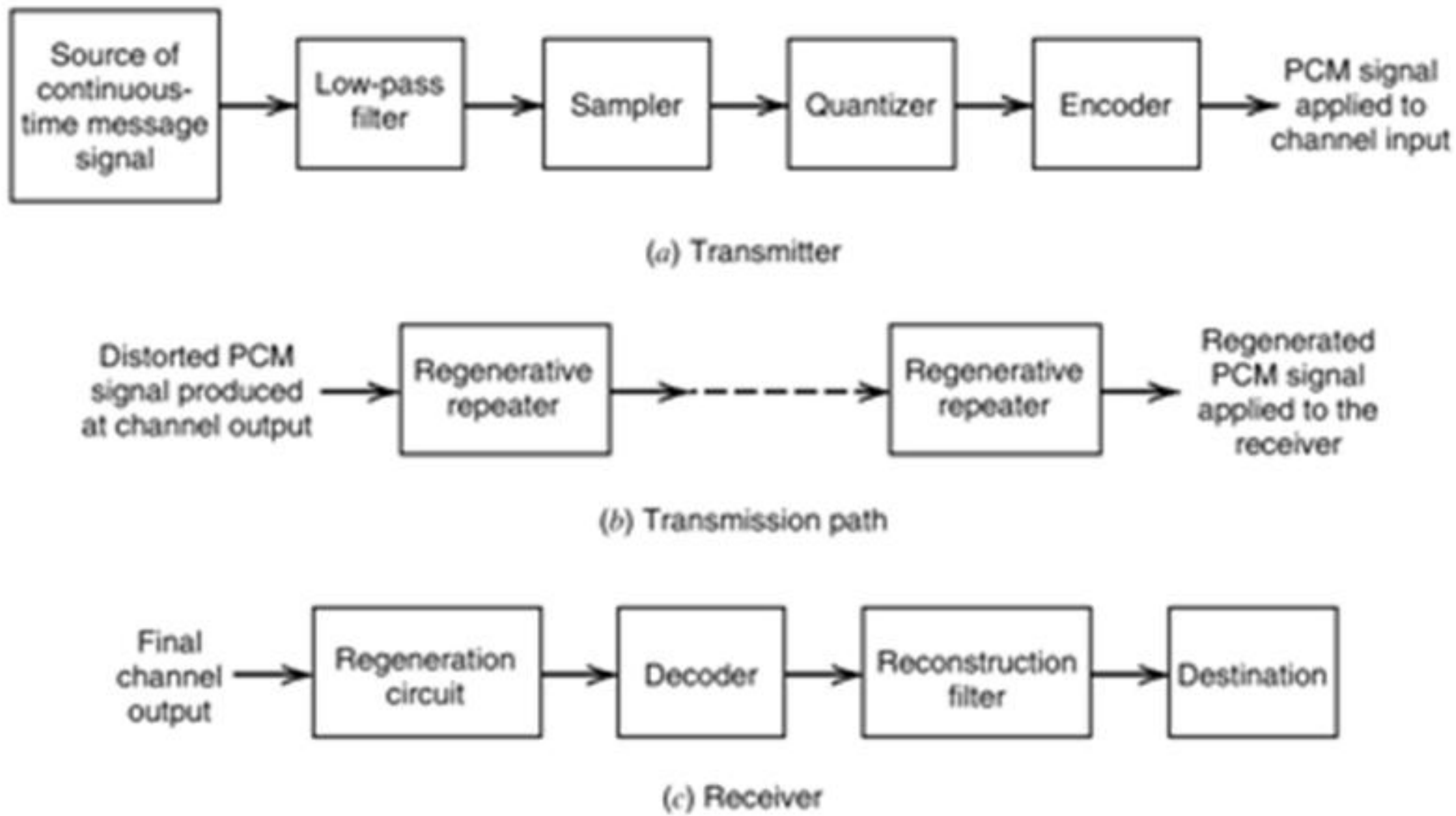
Pulse Code Modulation

Sampling, Quantizing, and Encoding

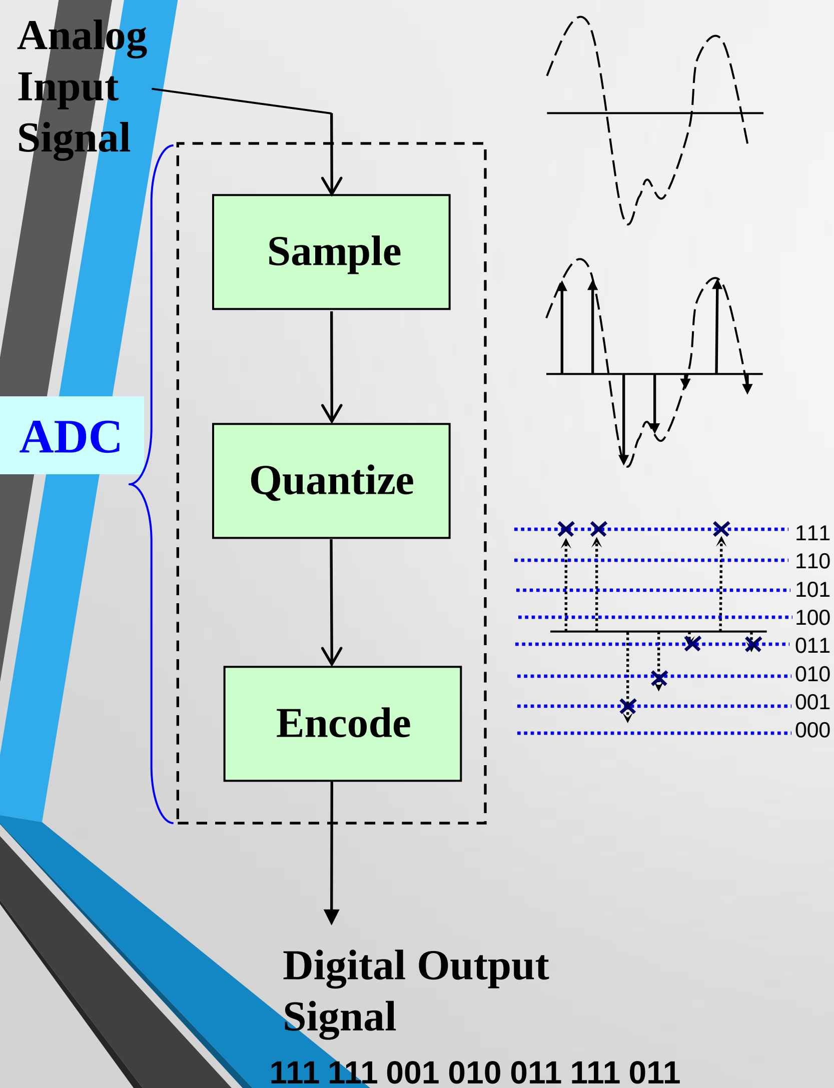
- The PCM signal is generated by carrying out three basic operations:
  1. Sampling
  2. Quantizing
  3. Encoding

1. Sampling operation generates a flat-top PAM signal.
2. Quantizing operation approximates the analog values by using a finite number of levels. This operation is considered in 3 steps
   a) Uniform Quantizer
   b) Quantization Error
   c) Quantized PAM signal output
3. PCM signal is obtained from the quantized PAM signal by encoding each quantized sample value into a digital word.

BLOCK DIAGRAM OF PCM



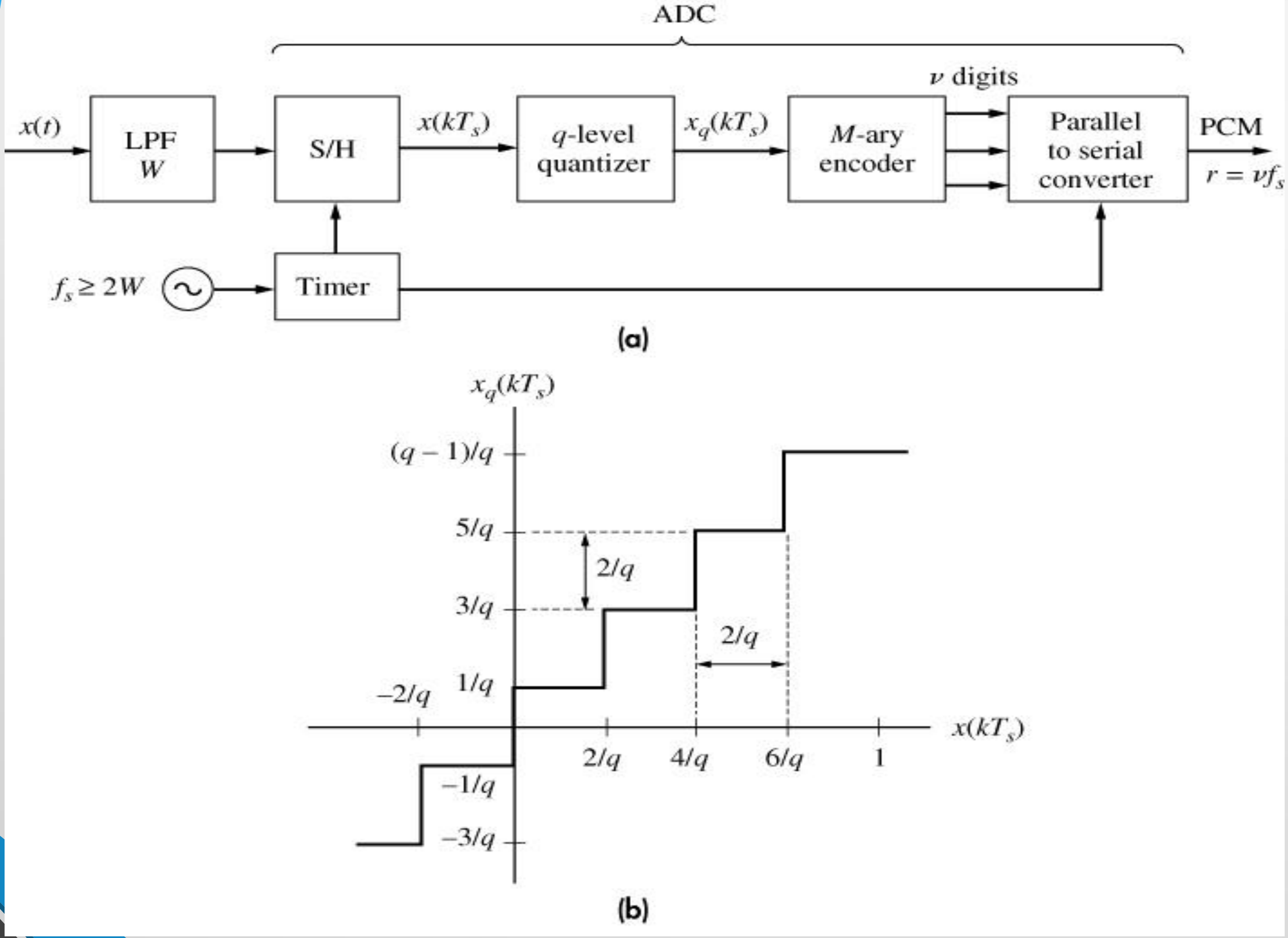
Analog to Digital Conversion



- The ***Analog-to-digital Converter*** **(ADC)** performs three functions:
  - **Sampling**
    - Makes the signal discrete in time.
    - If the analog input has a bandwidth of *W* Hz, then the ***minimum sample frequency*** such that the signal can be reconstructed without distortion.
  - **Quantization**
    - Makes the signal discrete in amplitude.
    - Round off to one of q discrete levels.
  - **Encode**
    - Maps the quantized values to digital words that are ν bits long.
- If the (Nyquist) ***Sampling Theorem*** is satisfied, then only quantization introduces distortion to the system.

Baseband Transmission

PCM-generation system



Quantization characteristic

Quantizer Continues…..

- Suppose amplitude of signal lies in range –x to +x which is partitioned into L levels, then –

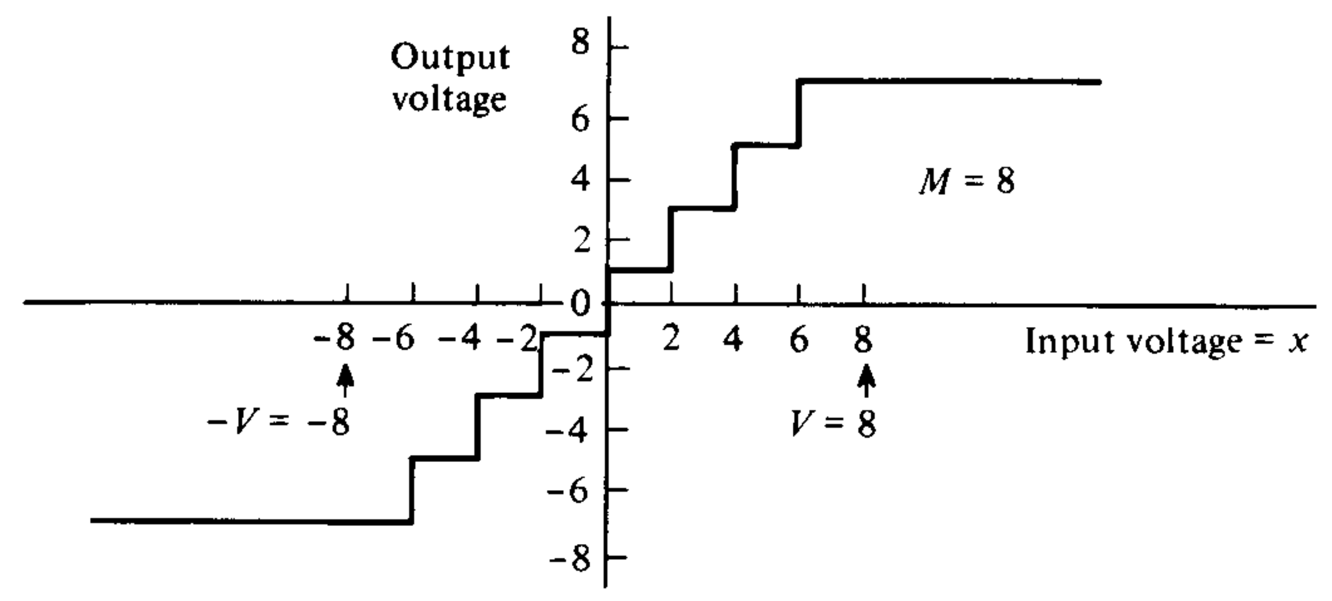
$$\Delta v = 2x / L$$

- Then each sample is approximated to or round off to the nearest quantized level.

- Hence each sample is approximated to one of the numbers & therefore the information is digitized.

Baseband Transmission

PCM-generation system

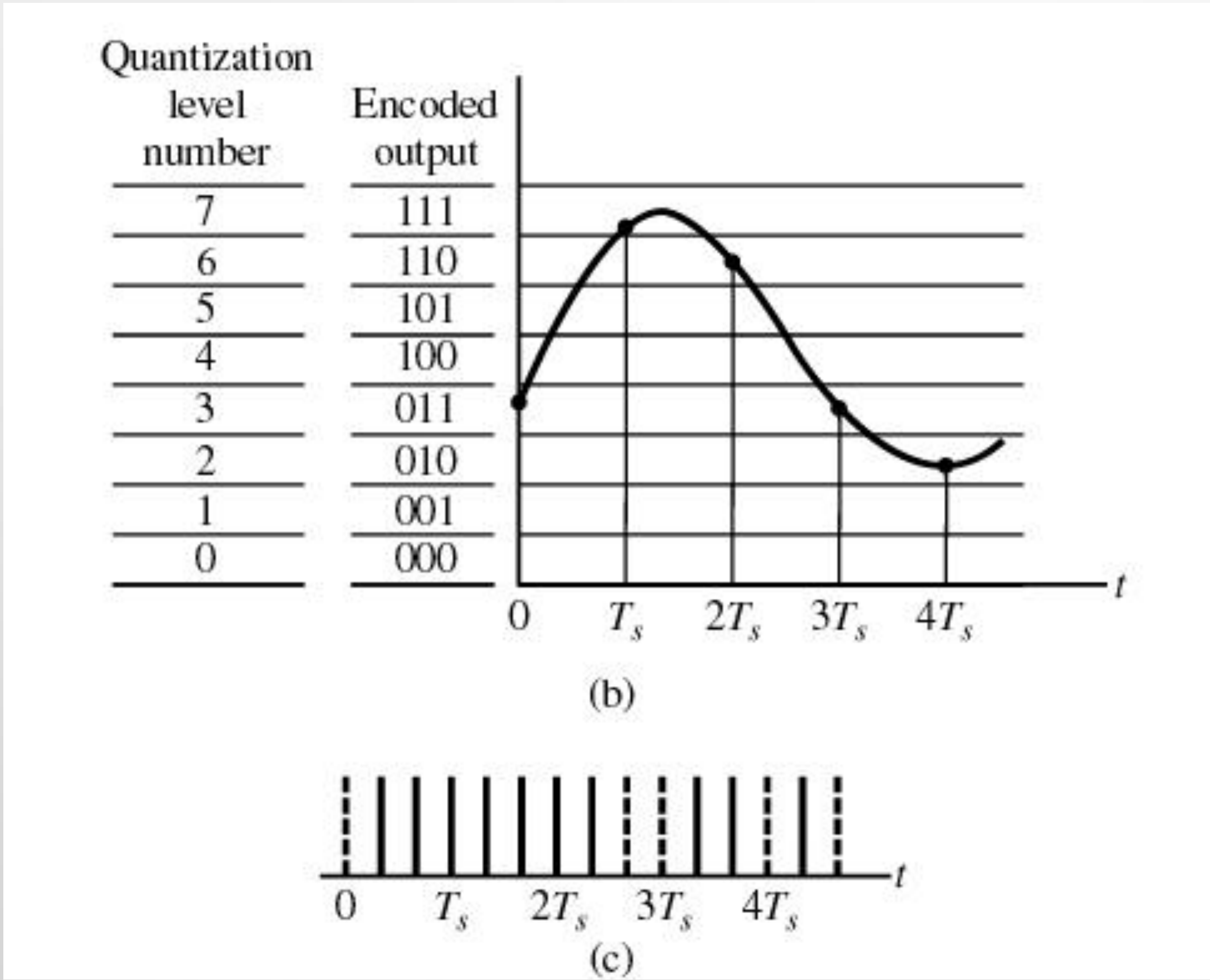


(a) Quantizer Output-Input Characteristics

Quantization characteristic

Baseband Transmission

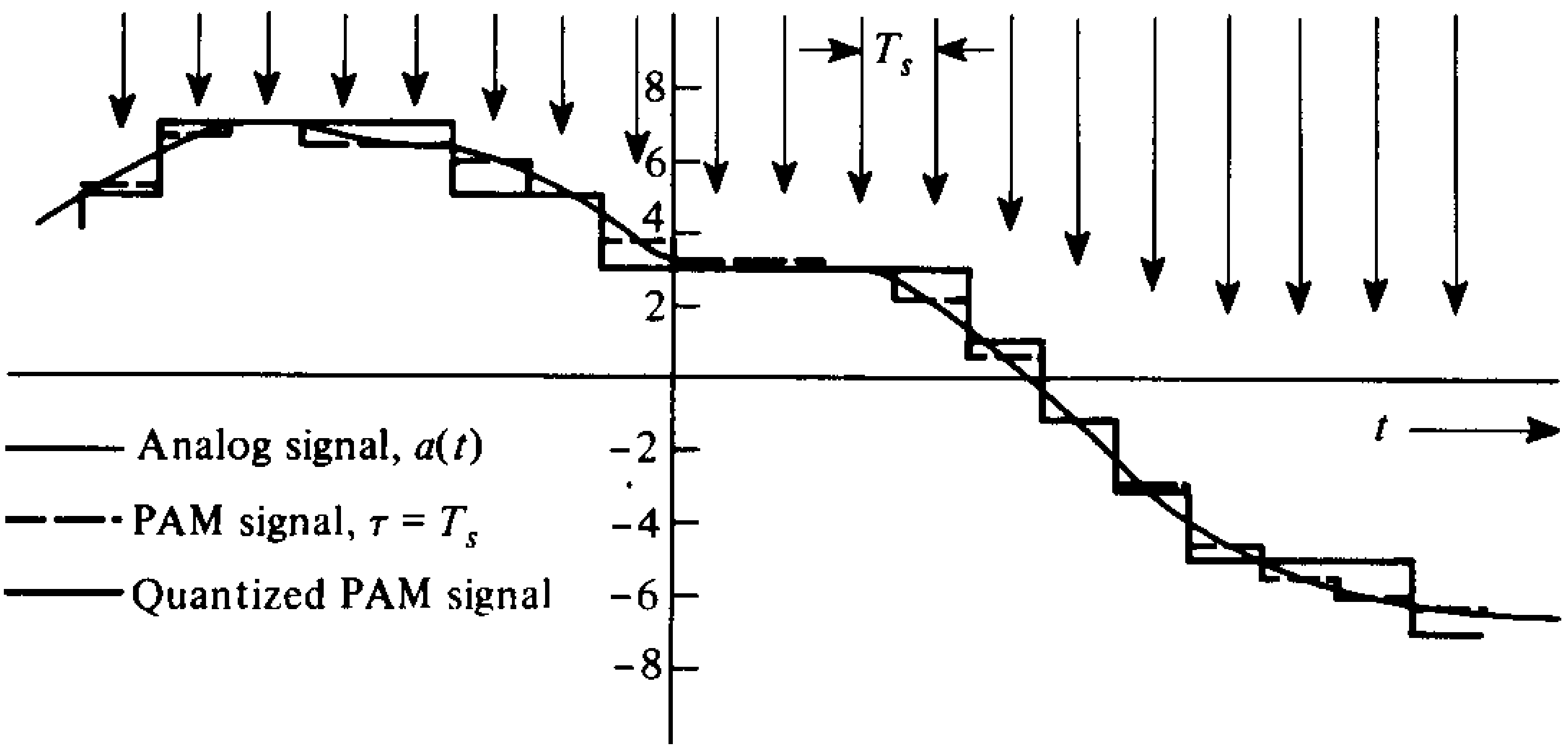
PCM-generation system



Quantization characteristic

Baseband Transmission

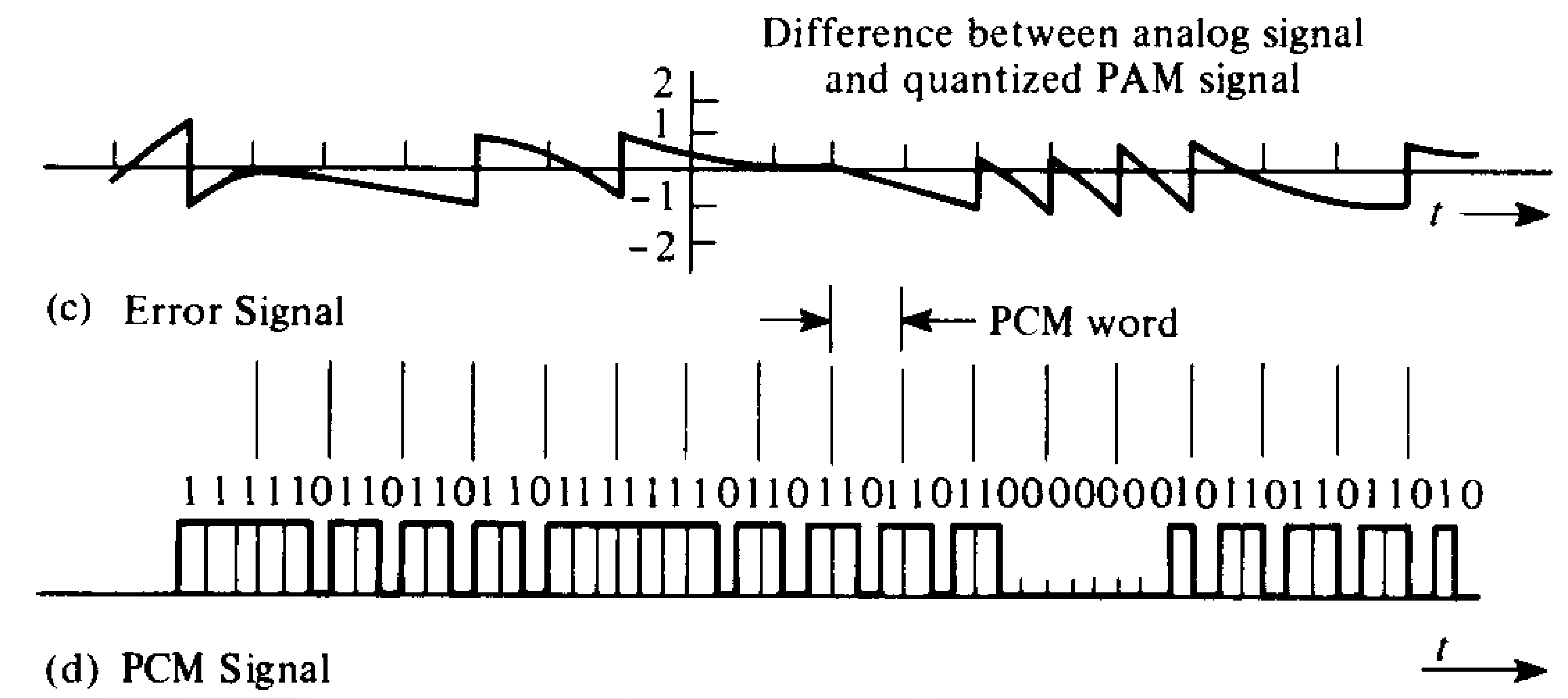
PCM-generation system



(b) Analog Signal, Flat-top PAM Signal, and Quantized PAM Signal

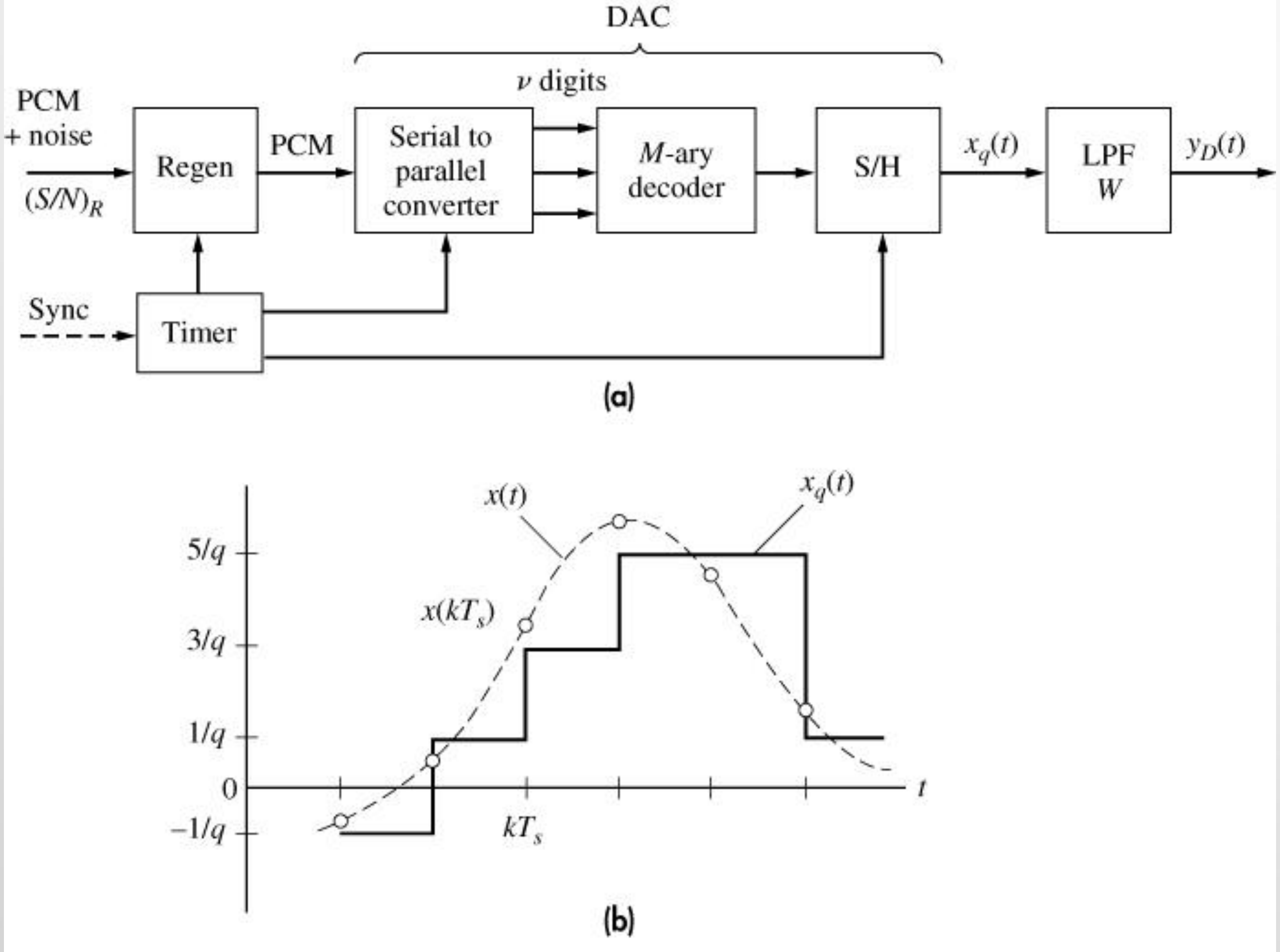
Baseband Transmission

PCM-generation system



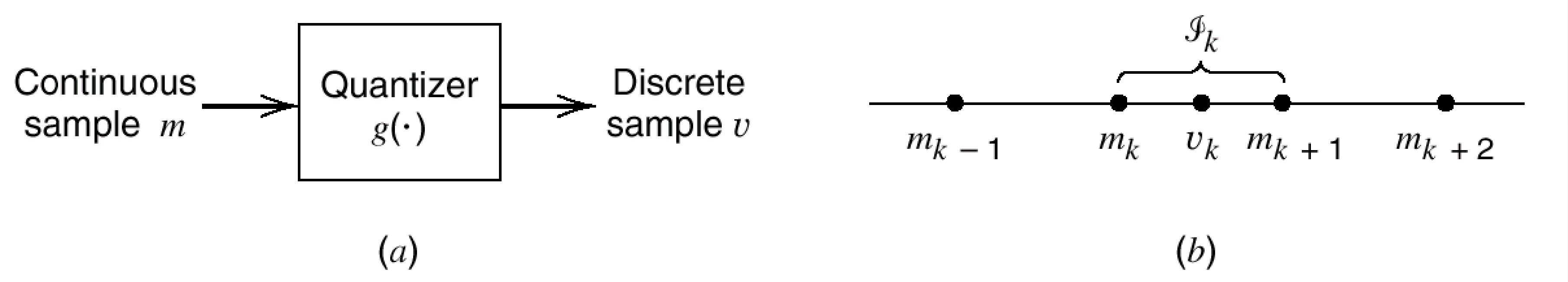
Baseband Transmission

PCM receiver



Reconstructed waveform

Quantization Process



Define partition cell

$$\mathcal{J}_k : \{m_k < m \le m_{k+1}\},\ k = 1,2,\cdots,L \qquad (3.21)$$

Where m_k is the decision level or the decision threshold.

Amplitude quantization : The process of transforming the sample amplitude $m(nT_s)$ into a discrete amplitude $v(nT_s)$ as shown in Fig 3.9

If $m(t) \in \mathcal{J}_k$ then the quantizer output is v_k where $v_k,\ k = 1,2,\cdots,\mathrm{L}$ are the representation or reconstruction levels , $m_{k+1} - m_k$ is the step size.

The mapping $v = g(m)$ (3.22)

is called the quantizer characteristic, which is a staircase function.

Classification of Quantization process

- **Two types –**

a) **Uniform Quantization –**
i. Mid-tread Type
ii. Mid-rise Type
a) **Non-uniform Quantization –**

a) **Uniform Quantizer –** Step Size remain same throughout the input range
b) **Non-uniform Quantizer –** Step size varies according to the Input signal values

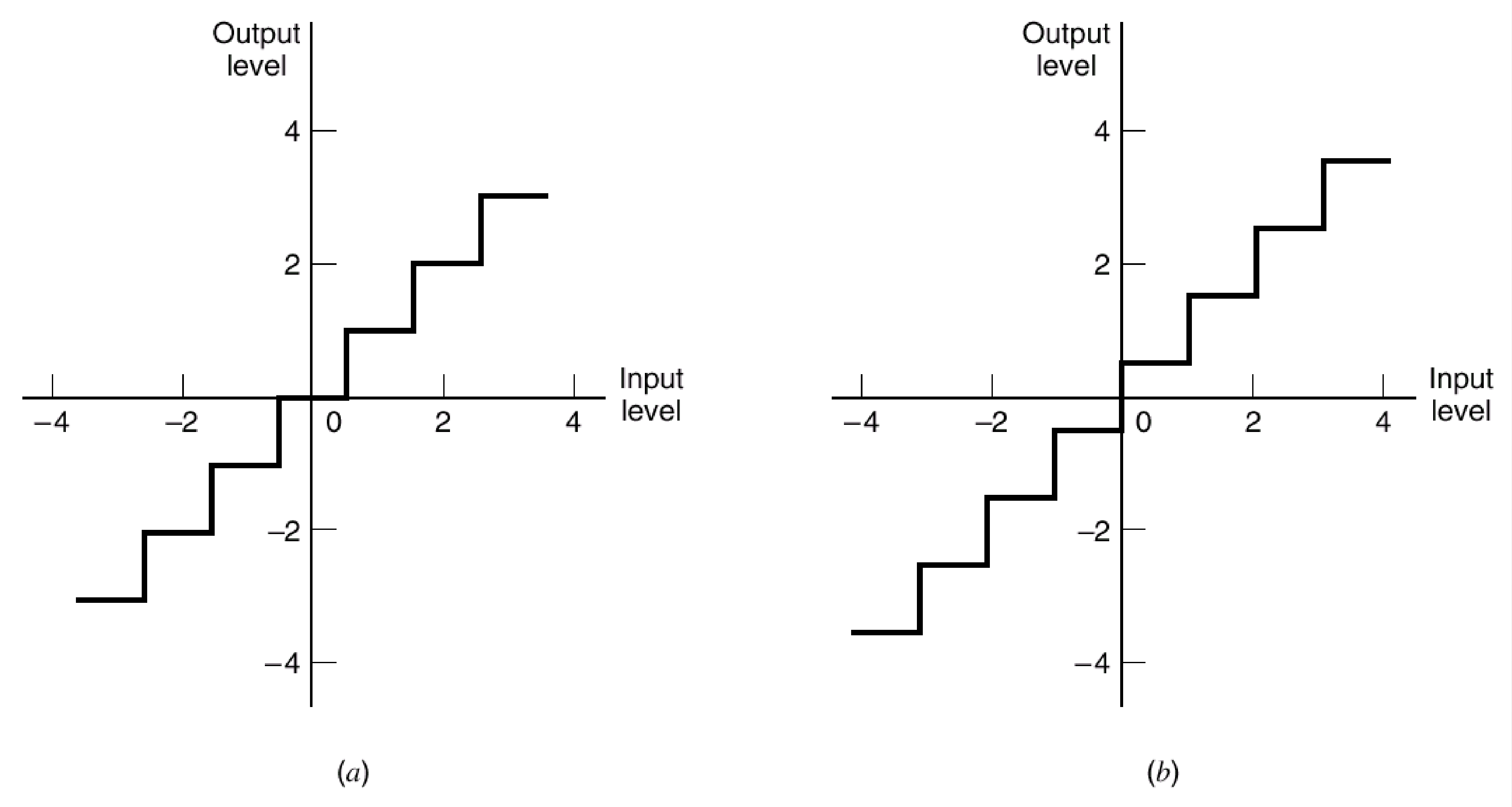


Figure 3.10 Two types of quantization: (*a*) midtread and (*b*) midrise.

- Έ = Xq (nTs) – X(nTs) = [Δ / 2]

Quantization Error

- The maximum quantization error will be [+ Δ / 2]
- Transmission Bandwith:

$q = 2^v$

Where,

v = no of binary digits to represent each level and q = to no of digital levels of q- level quantizer. If v = 4, then; q = 16 levels.
Each sample is converted to v binary bits i.e. no of bits per sample = v

Baseband Transmission

Bandwidth of PCM

The bit rate of PCM data is defined as:

$$R = nf_s$$

n = the number of bits in the PCM word ($M = 2^n$)

The bandwidth of PCM signal,

$$B_{PCM} >= 0.5R = 0.5nf_s$$

Minimal sampling rate $f_s >= 2B$

$$B_{PCM} >= nB$$

Baseband Transmission

Noise in PCM

1. Quantization noise --> M-step quantizing at the transmitter

Quantization noise power,

$$\sigma_q^2 = \overline{\varepsilon_k^2} = \frac{1}{3q^2}$$

2. Channel noise --> causes bit errors at the receiver

PCM performance

Destination signal-to-noise ratio,

$$\left(\frac{S}{N}\right)_D = \frac{S_x}{\sigma_q^2} = 3q^2 S_x$$

Since, $S_x = \overline{x^2} \leq 1$ and $q = 2^v$, *in decibels*

$$\left(\frac{S}{N}\right)_D = 10\log_{10}(3 \times 2^{2v} S_x) \leq 4.8 + 6.0v \qquad \text{dB}$$

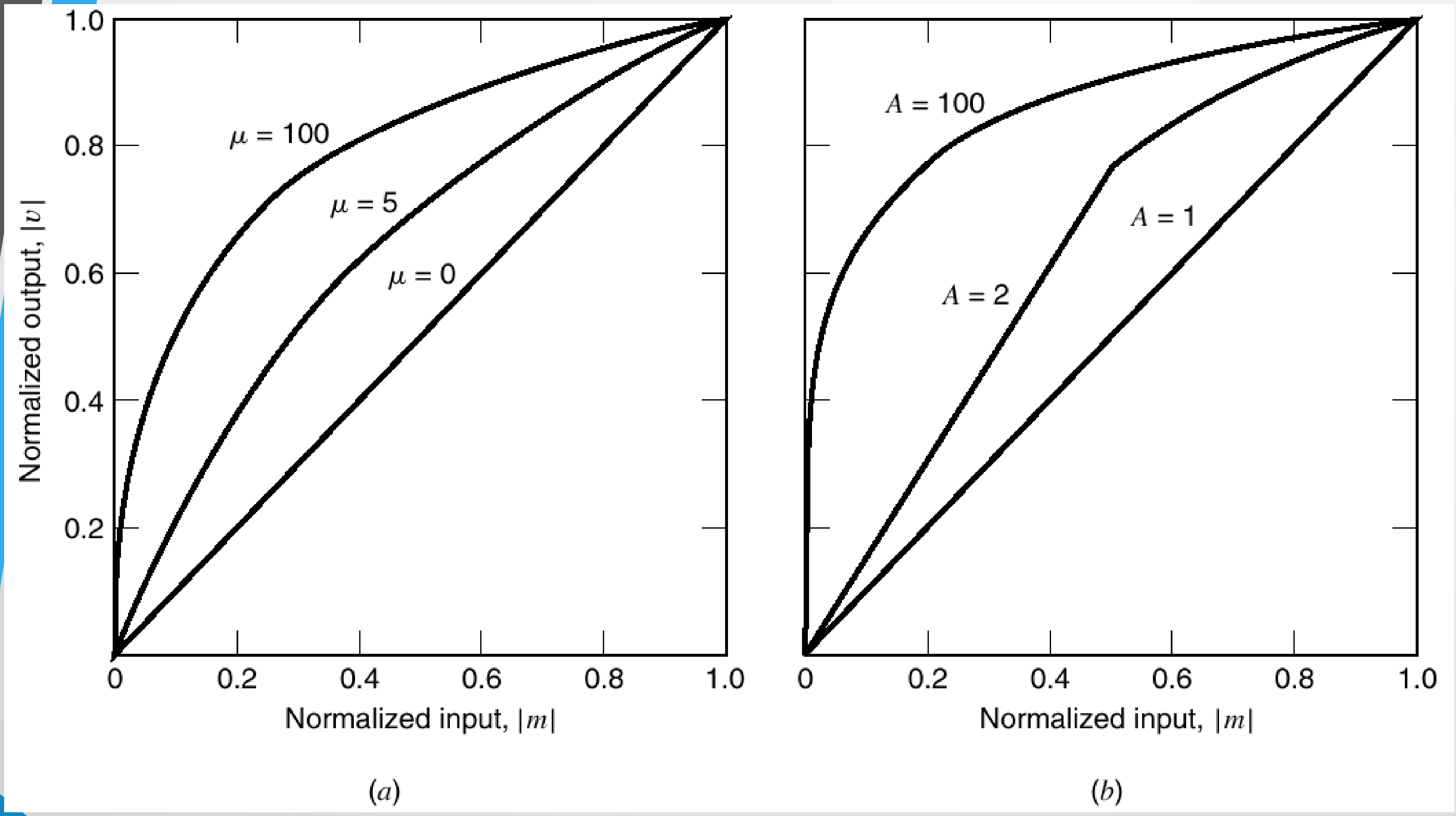


Figure 3.14 Compression laws. (*a*) μ -law. (*b*) A-law.

Baseband Transmission

Noise performance of PCM