Pulse Code Modulation

PULSE CODE MODULATION (PCM)

- **DEFINITION:** Pulse code modulation (PCM) is essentially analog-to-digital conversion of a special type where the information contained in the instantaneous samples of an analog signal is represented by digital words in a *serial bit stream.*

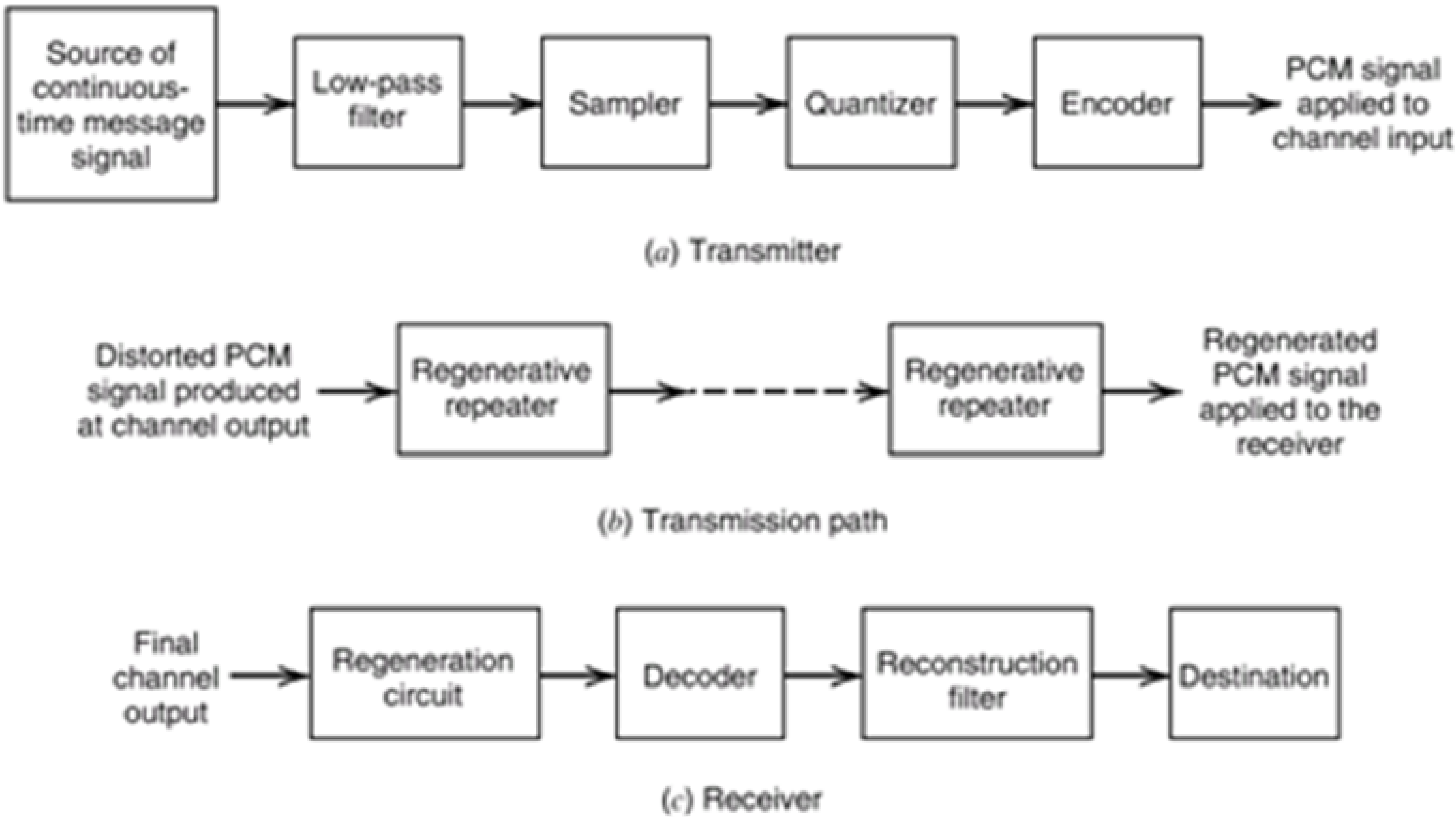
- The advantages of PCM are:
  - Relatively inexpensive digital circuitry may be used extensively.
  - PCM signals derived from all types of analog sources may be merged with data signals and transmitted over a common high-speed digital communication system.
  - In long-distance digital telephone systems requiring repeaters, a clean PCM waveform can be regenerated at the output of each repeater, where the input consists of a noisy PCM waveform.
  - The noise performance of a digital system can be superior to that of an analog system.
  - The probability of error for the system output can be reduced even further by the use of appropriate coding techniques.

Sampling, Quantizing, and Encoding

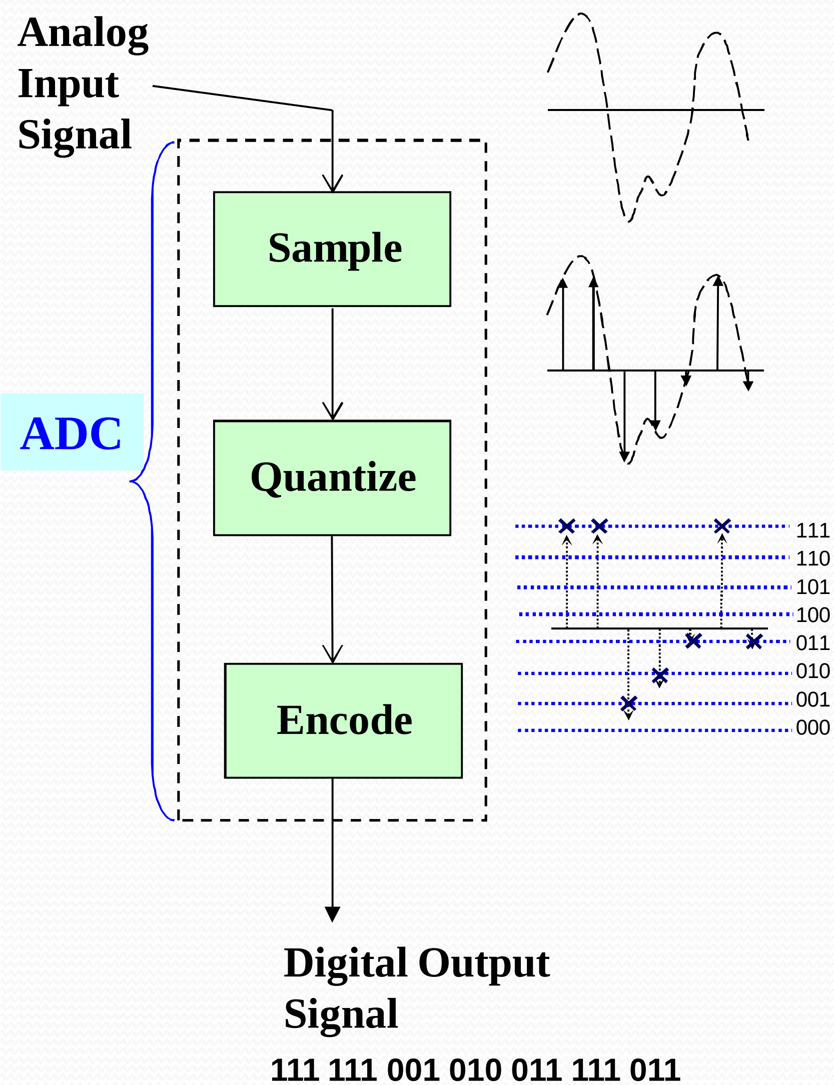
- The PCM signal is generated by carrying out three basic operations:
  1. Sampling
  2. Quantizing
  3. Encoding

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 SYSTEM



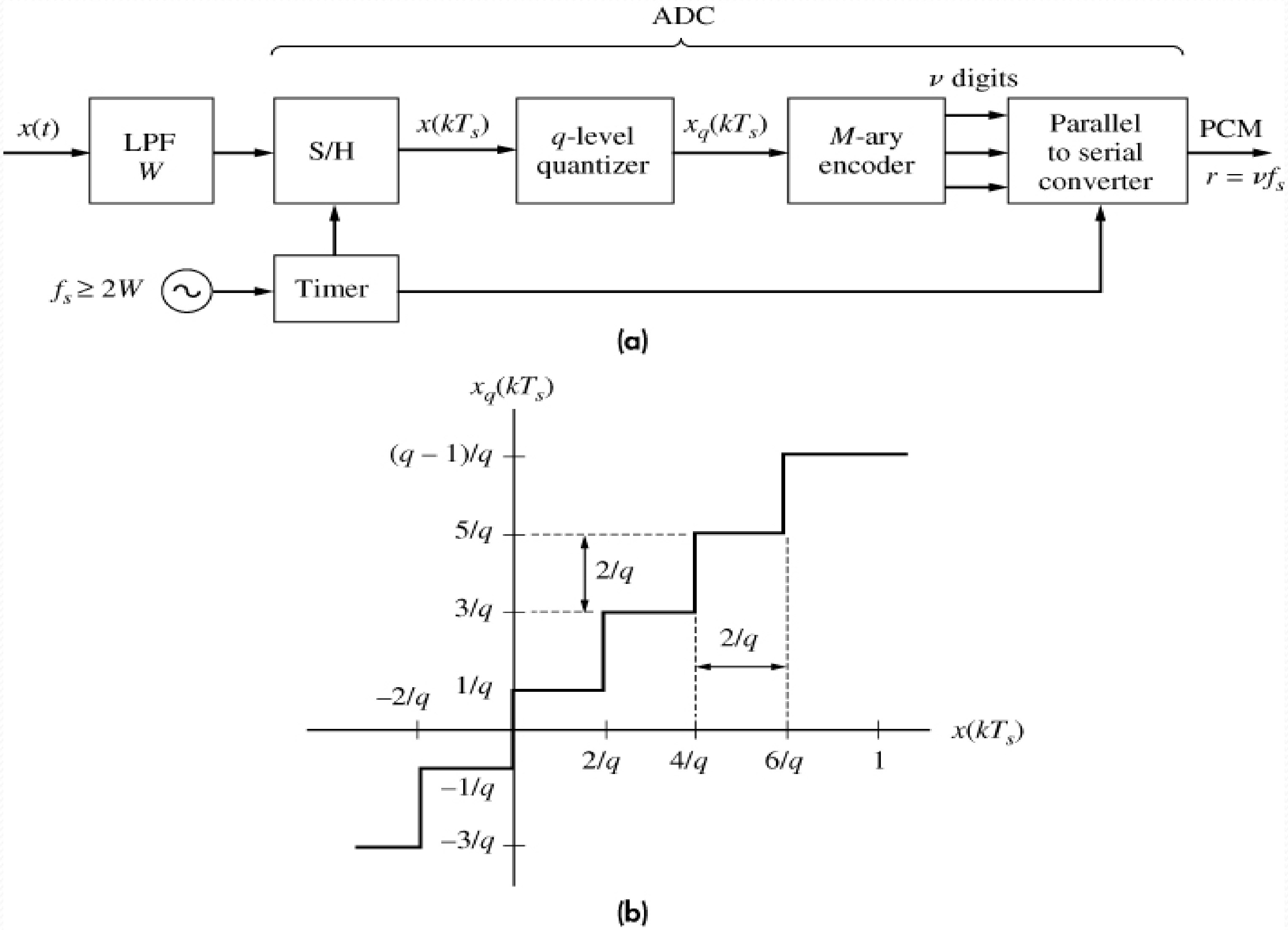
Analog to Digital Conversion



- 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…..

- In Quantization, the total amplitude range which the signal may occupy is divided into number of standard levels.

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

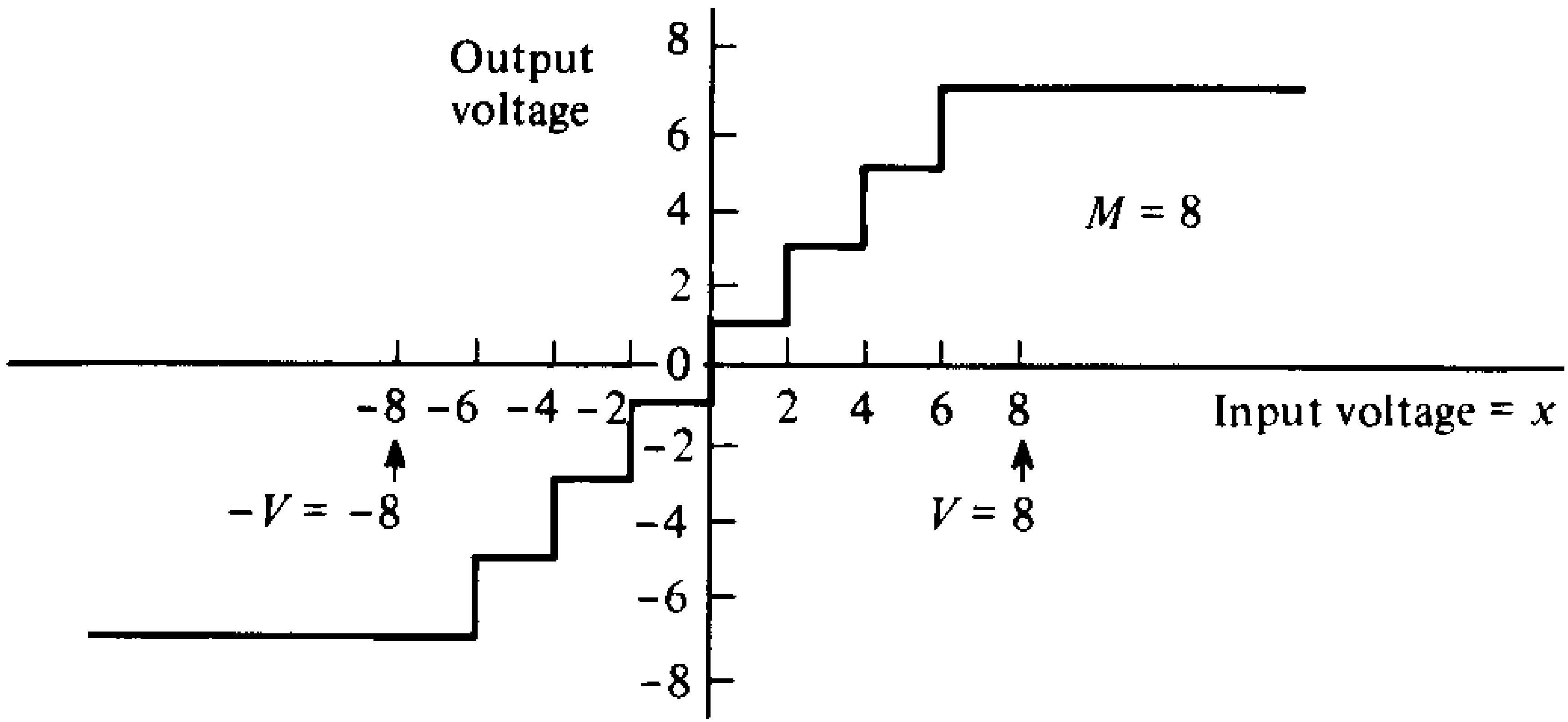
$$\Delta v = 2x / L$$

- 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

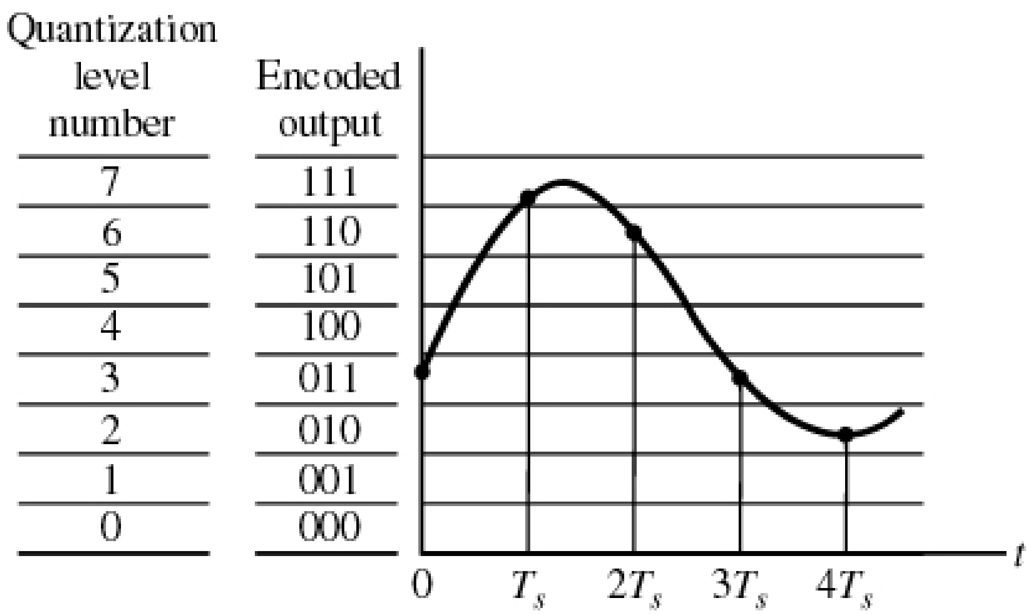


(a) Quantizer Output-Input Characteristics

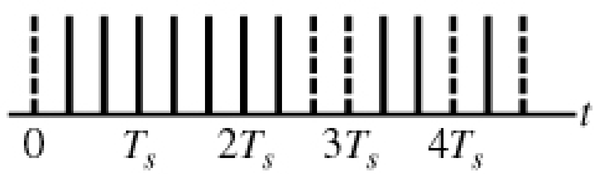
Quantization characteristic

Baseband Transmission

PCM-generation system



(b)

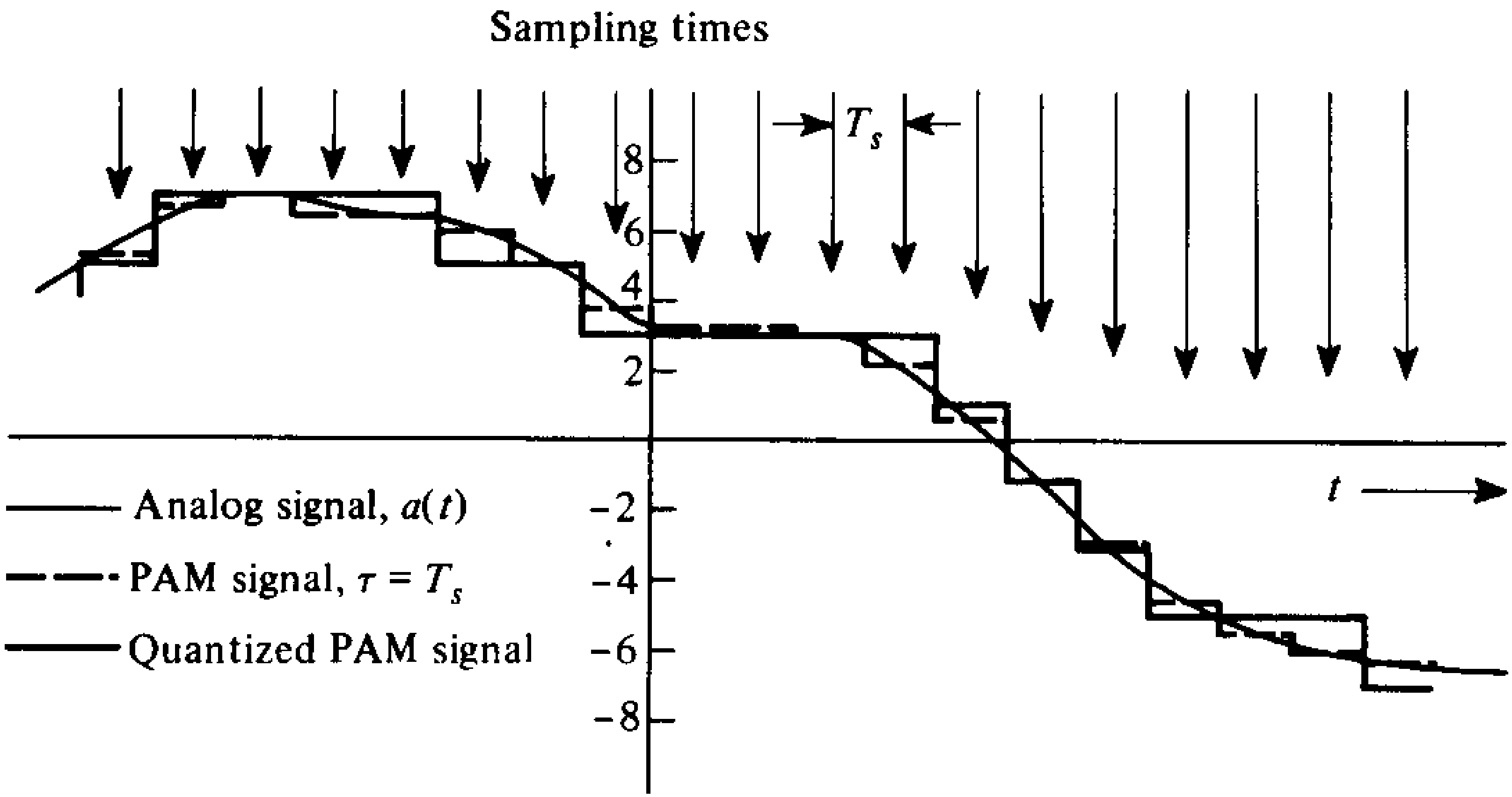


(c)

Quantization characteristic

Baseband Transmission

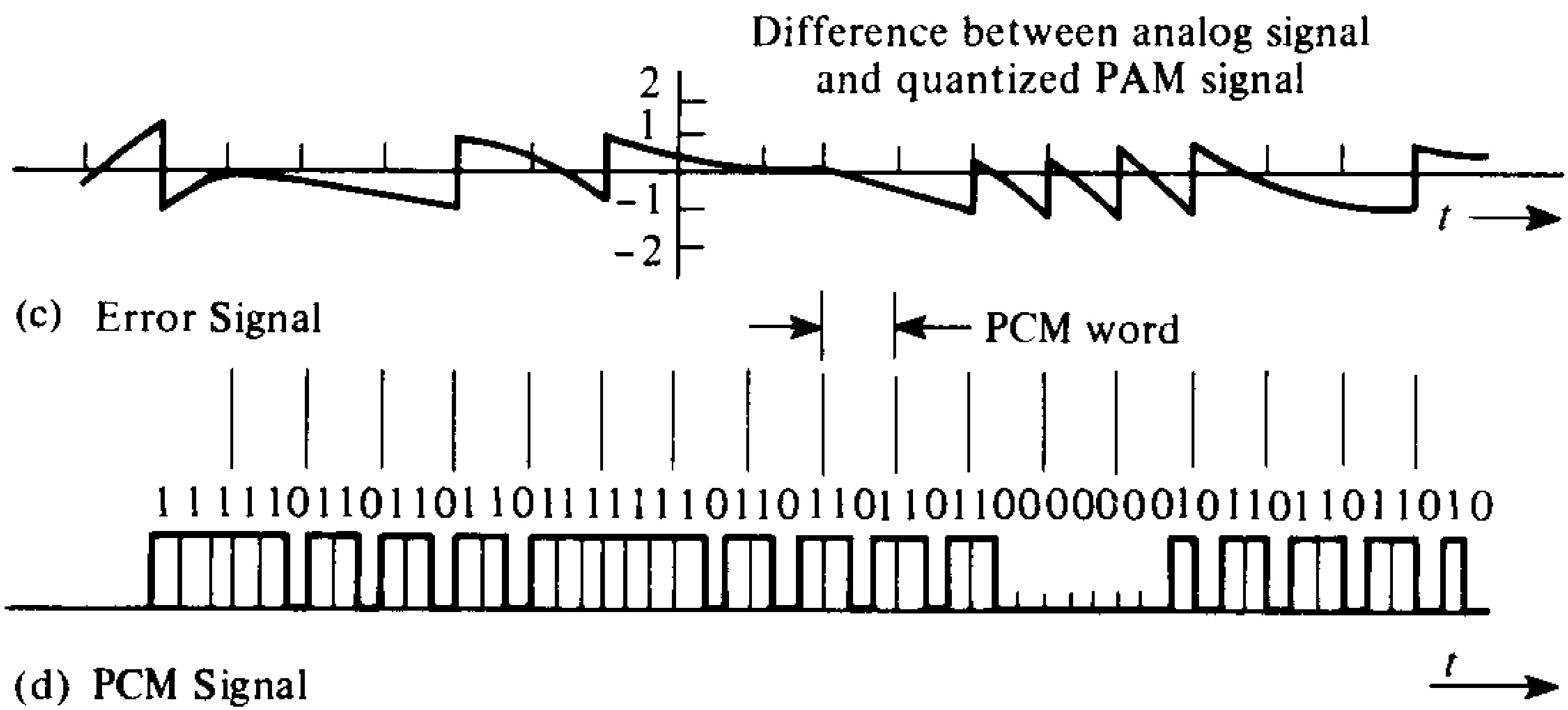
PCM-generation system



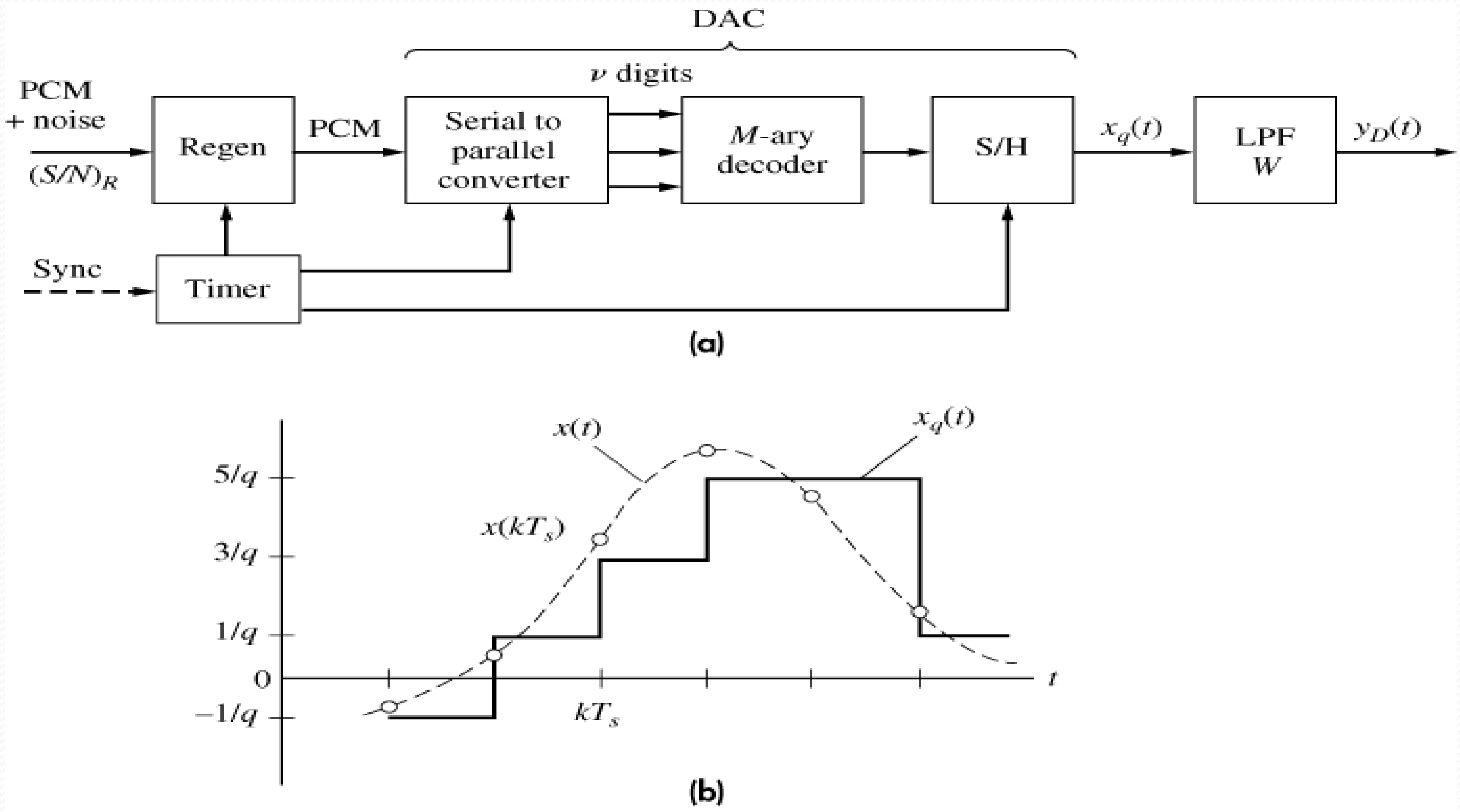
(b) Analog Signal, Flat-top PAM Signal, and Quantized PAM Signal

Baseband Transmission

PCM-generation system



Baseband Transmission **PCM receiver**



Reconstructed waveform

Quantization Process

(a) (b)

Define partition cell

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

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

The mapping $v = \mathrm{g}(m)$ (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

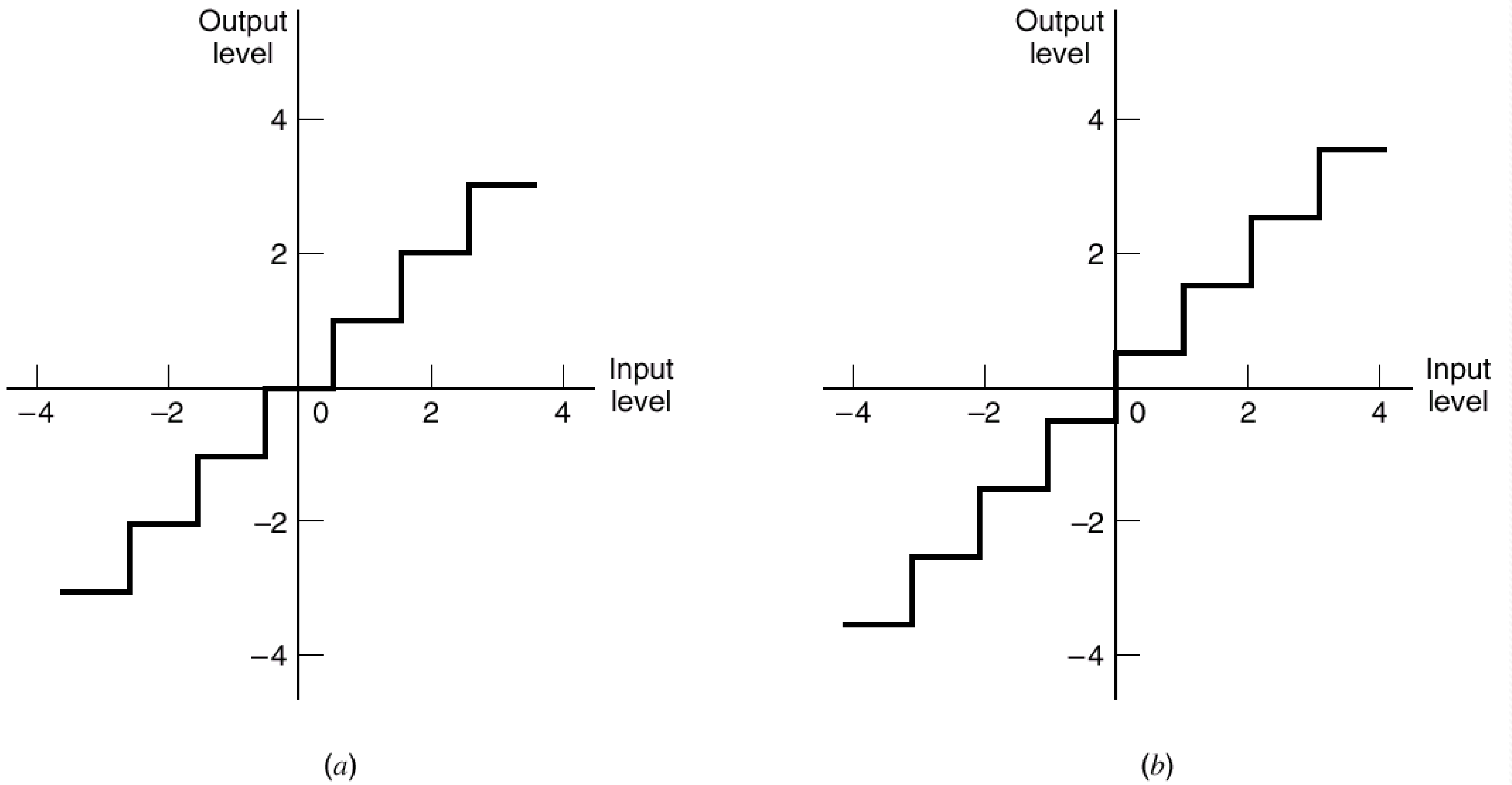


Figure 3.10 Two types of quantization: (*a*) midtread and (*b*) midrise.

Quantization Error

- $\acute{E}$ **= Xq (nTs) – X(nTs) = [Δ / 2]**
- **The maximum quantization error will be [$\pm$ Δ / 2]**
- **<u>Transmission Bandwith:</u>**

  $q = 2^v$

Where,

v = no of binary digits to represent each level or no of bits per sample ,and

q = total 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

Signaling rate in PCM,

$$R = v f_s$$

v = the number of bits per sample & f_s samples per second

But, $\mathbf{f_s \geq 2 f_m}$

Since, the bandwidth needed for PCM transmission is given half Of the signaling rate, therefore,

$$BW_{PCM} \geq 0.5 R = 0.5 n f_s$$

As, Minimal sampling rate, $f_s >= 2B$

Then, $B_{PCM} \geq nB$

Noise in PCM

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

Quantization noise power,

$$\sigma_q^2 = \overline{\varepsilon_k^2}$$

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

Baseband Transmission 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*

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

Non - Uniform Quantization

- Means quantization characteristics are non linear
- Step size is not constant
- Step size will depend on the amplitude of I/P signal
- Step size is reduced with the reduction of signal level
- For weak signal → step size is small → quantization noise reduces → this improves S/QN for weak signals
- Thus variation of step size according to signal level to keep the S/N ratio adequately high, the quantization method used will be non uniform.
- This process is practically achieved by **COMPANDING** technique

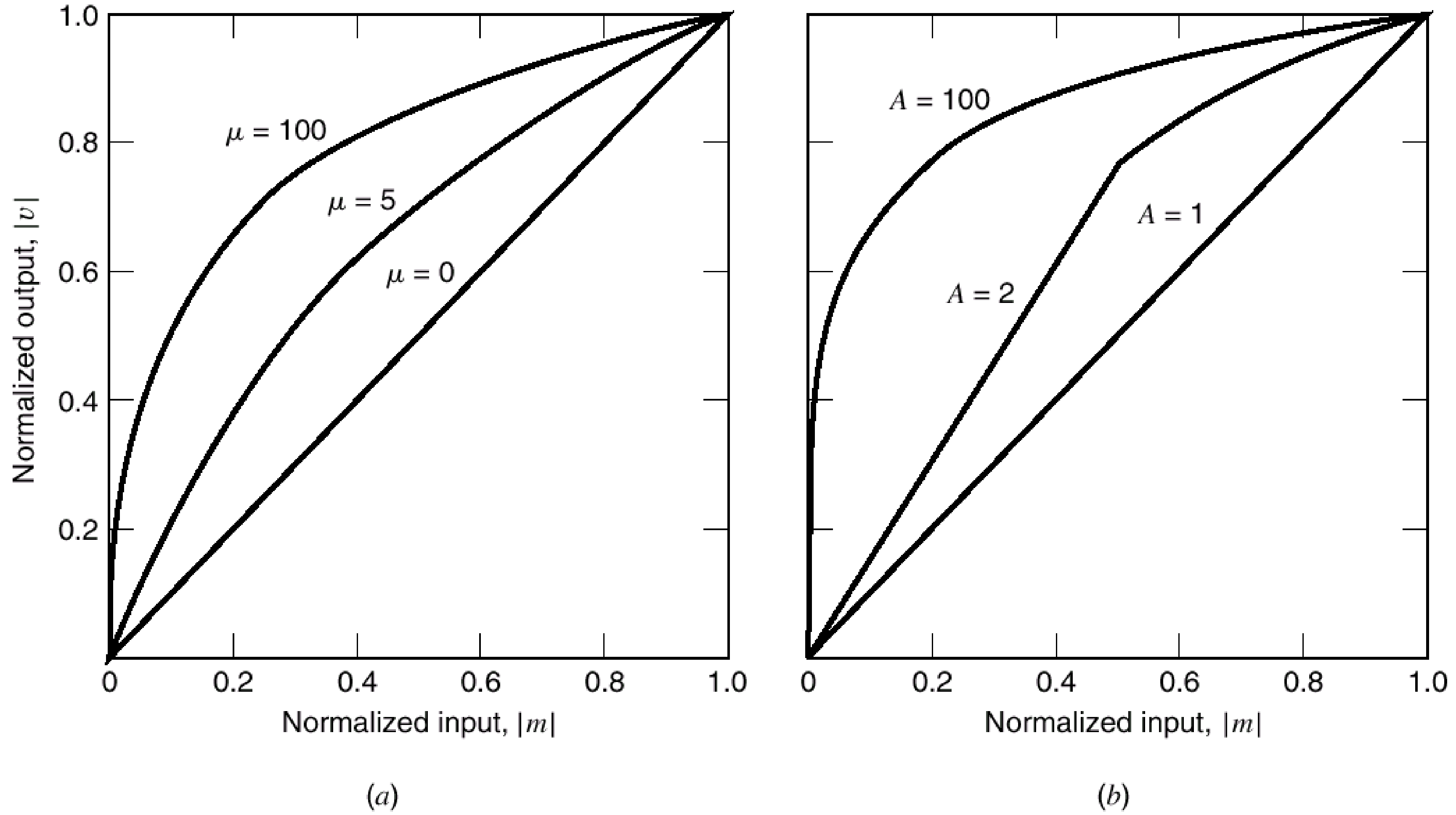


Figure 3.14 Compression laws. (*a*) μ -law. (*b*) A-law.