# Analog Communication Systems
# EC-413-F

# Lecture no 7

# Topics to be covered

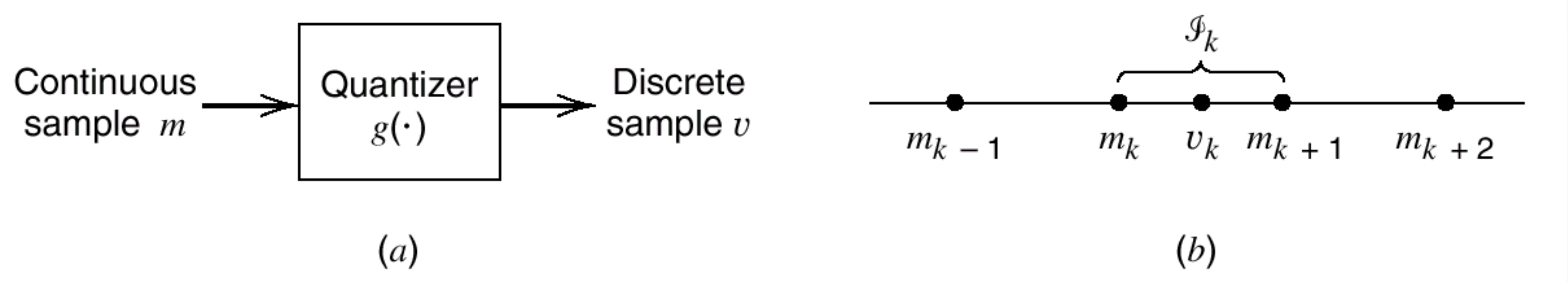
## Pulse Code Modulation

# Pulse Code Modulation (PCM)

- Pulse code modulation (PCM) is produced by analog-to-digital conversion process.
- As in the case of other pulse modulation techniques, the rate at which samples are taken and encoded must conform to the Nyquist sampling rate.
- The sampling rate must be greater than, twice the highest frequency in the analog signal,

$$f_s > 2f_A(\text{max})$$

# 3.6 Quantization Process




Define partition cell

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

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 $m(t) \in \mathscr{J}_k$ 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.

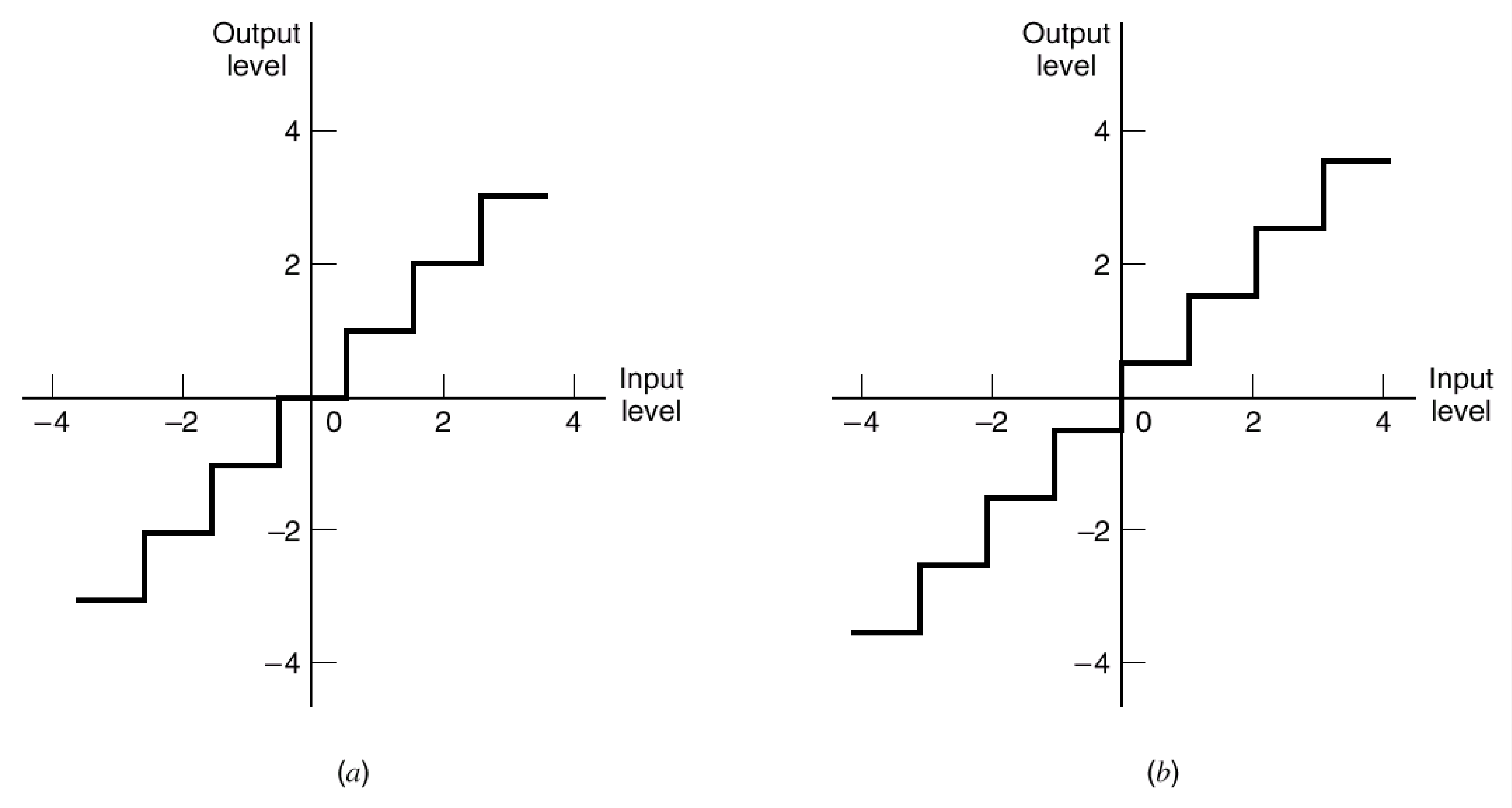



**Figure 3.10** Two types of quantization: (*a*) midtread and (*b*) midrise.

# Quantization Noise

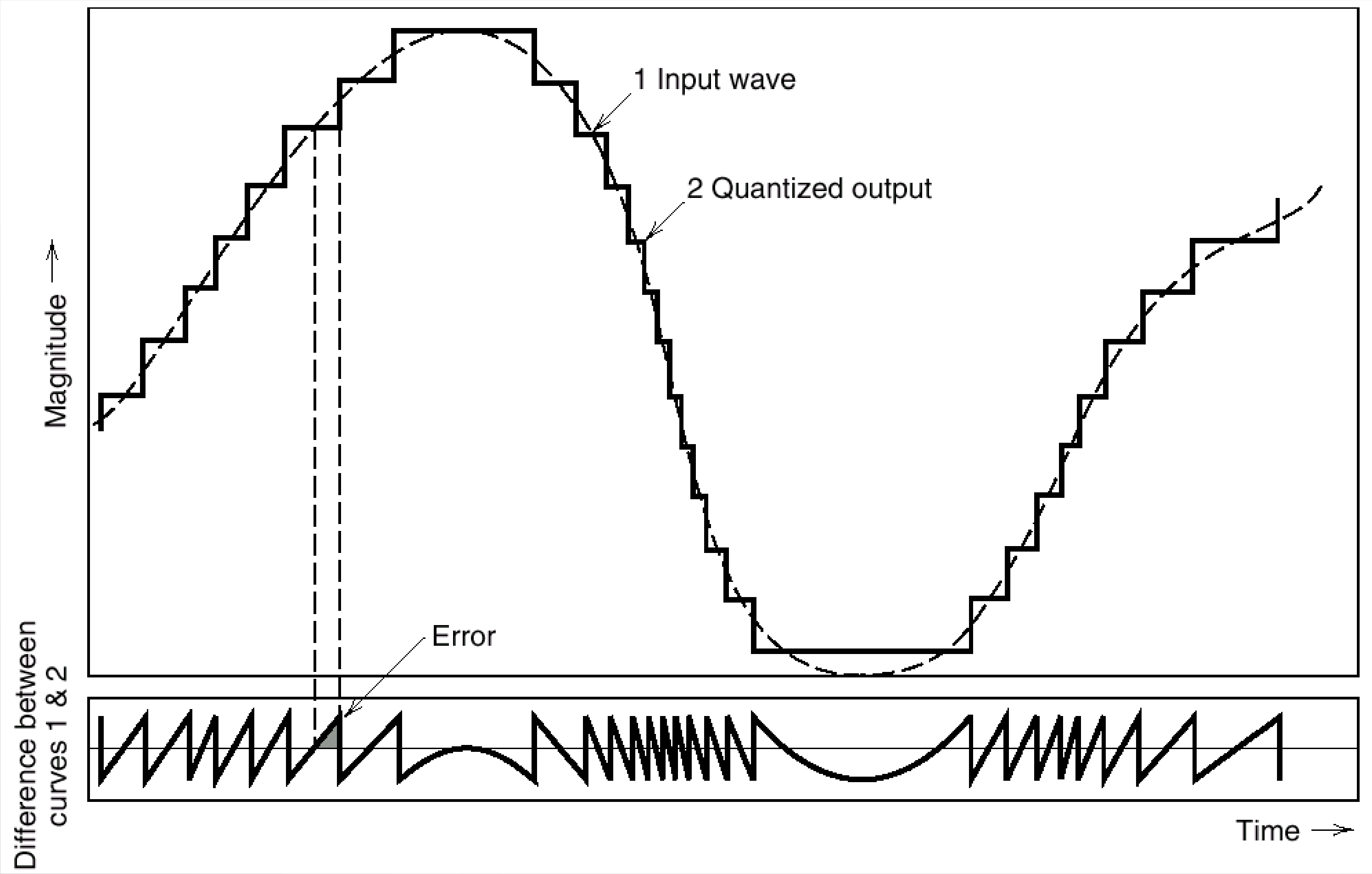



**Figure 3.11** Illustration of the quantization process.

# Pulse Code Modulation

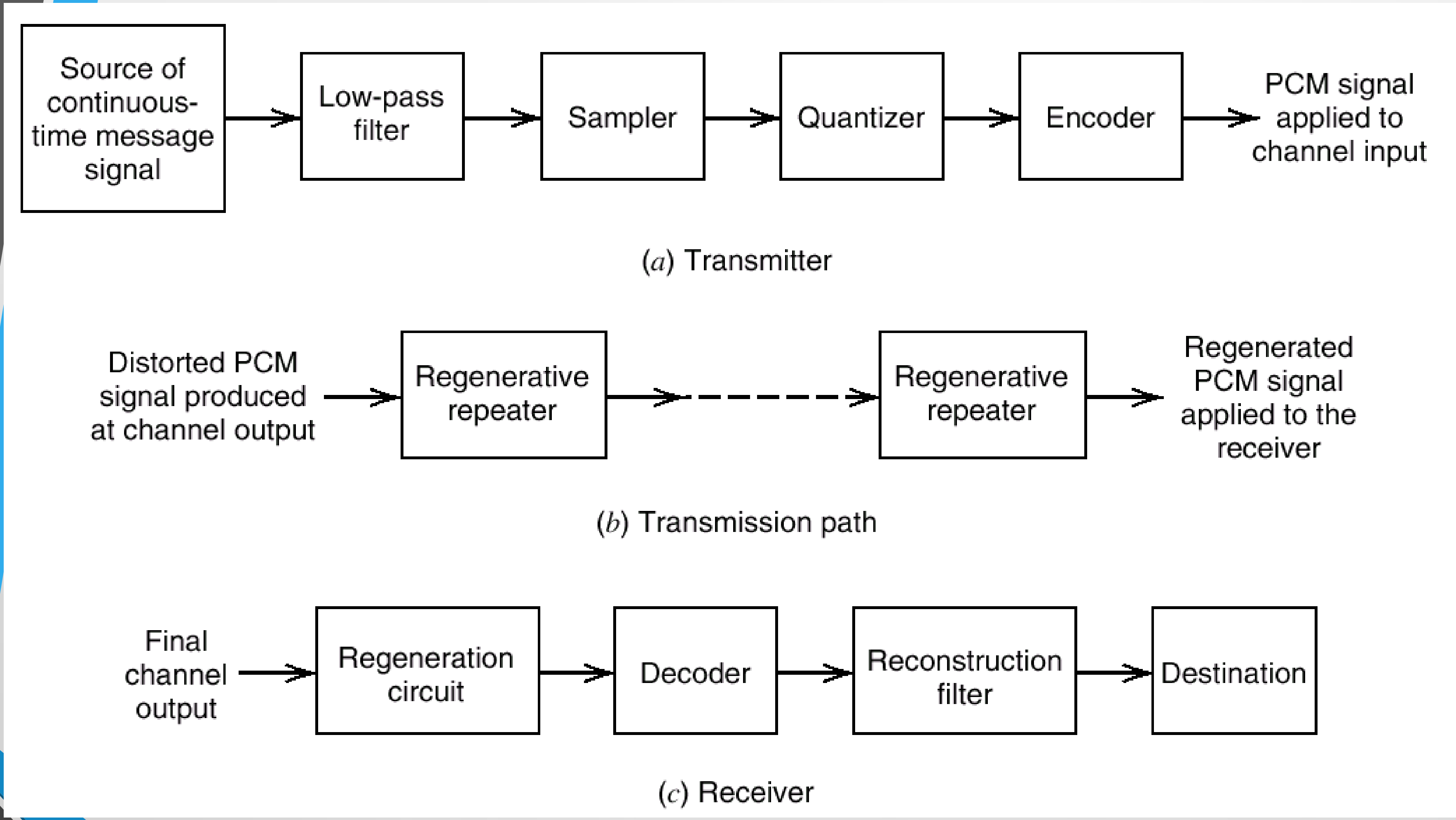



**Figure 3.13** The basic elements of a PCM system.

# Quantization (nonuniform quantizer)

$\mu$ - law

$$|v| = \frac{\log(1+\mu|m|)}{\log(1+\mu)} \qquad (3.48)$$

$$\frac{d|m|}{d|v|} = \frac{\log(1+\mu)}{\mu}(1+\mu|m|) \qquad (3.49)$$

A - law

$$|v| = \begin{cases} \dfrac{A(m)}{1+\log A} & 0 \le |m| \le \dfrac{1}{A} \\ \dfrac{1+\log(A|m|)}{1+\log A} & \dfrac{1}{A} \le |m| \le 1 \end{cases} \qquad (3.50)$$

$$\frac{d|m|}{d|v|} = \begin{cases} \dfrac{1+\log A}{A} & 0 \le |m| \le \dfrac{1}{A} \\ (1+A)|m| & \dfrac{1}{A} \le |m| \le 1 \end{cases} \qquad (3.51)$$

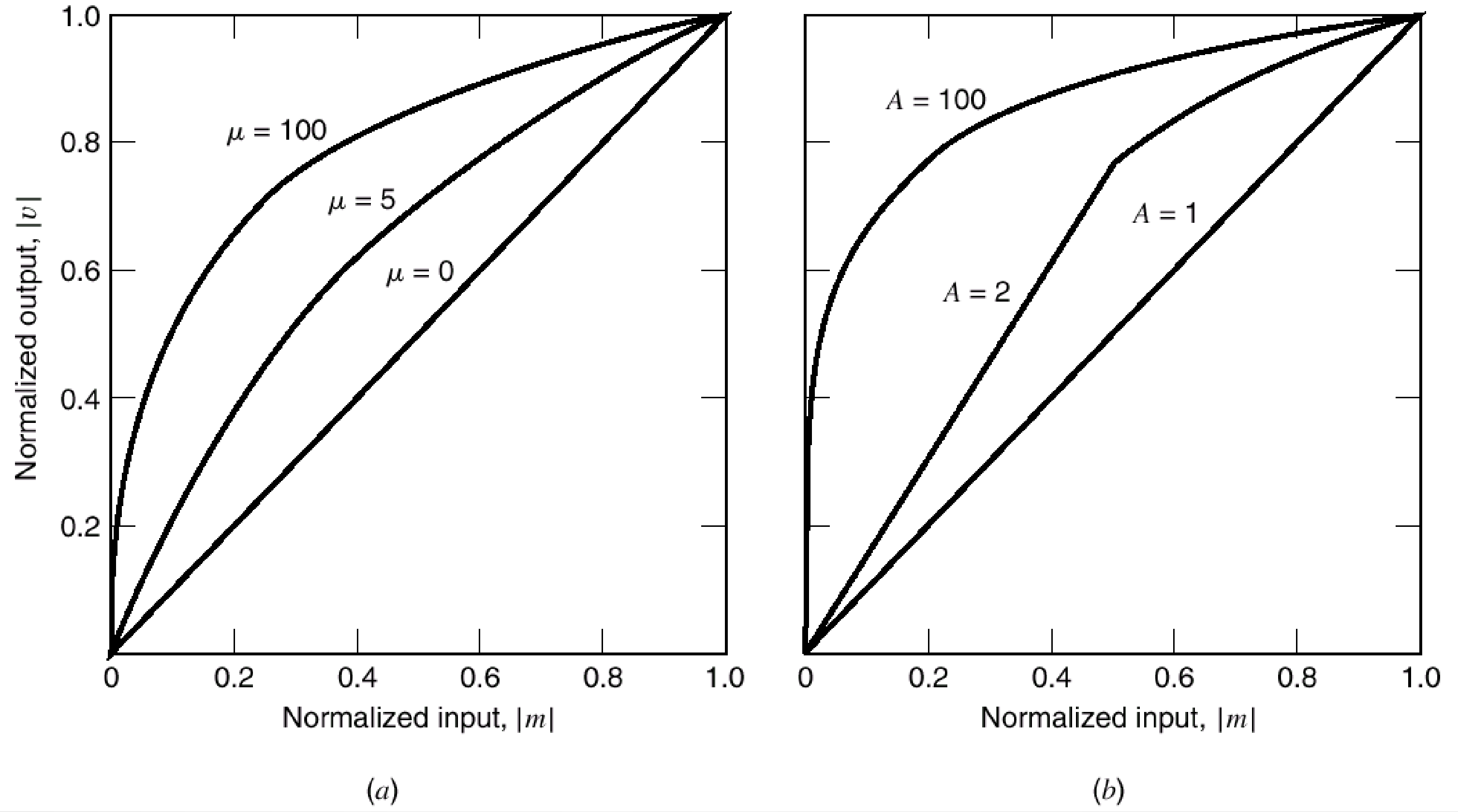



**Figure 3.14** Compression laws. (*a*) $\mu$ -law. (*b*) A-law.

# Encoding

**TABLE 3.2** *Binary number system for R = 4 bits/sample*

| Ordinal Number of Representation Level | Level Number Expressed as Sum of Powers of 2 | Binary Number |
|---|---|---|
| 0 | | 0000 |
| 1 | $2^0$ | 0001 |
| 2 | $2^1$ | 0010 |
| 3 | $2^1 + 2^0$ | 0011 |
| 4 | $2^2$ | 0100 |
| 5 | $2^2 + 2^0$ | 0101 |
| 6 | $2^2 + 2^1$ | 0110 |
| 7 | $2^2 + 2^1 + 2^0$ | 0111 |
| 8 | $2^3$ | 1000 |
| 9 | $2^3 + 2^0$ | 1001 |
| 10 | $2^3 + 2^1$ | 1010 |
| 11 | $2^3 + 2^1 + 2^0$ | 1011 |
| 12 | $2^3 + 2^2$ | 1100 |
| 13 | $2^3 + 2^2 + 2^0$ | 1101 |
| 14 | $2^3 + 2^2 + 2^1$ | 1110 |
| 15 | $2^3 + 2^2 + 2^1 + 2^0$ | 1111 |

# Line codes:

1. Unipolar nonreturn-to-zero (NRZ) Signaling
2. Polar nonreturn-to-zero(NRZ) Signaling
3. Unipor nonreturn-to-zero (RZ) Signaling
4. Bipolar nonreturn-to-zero (BRZ) Signaling
5. Split-phase (Manchester code)

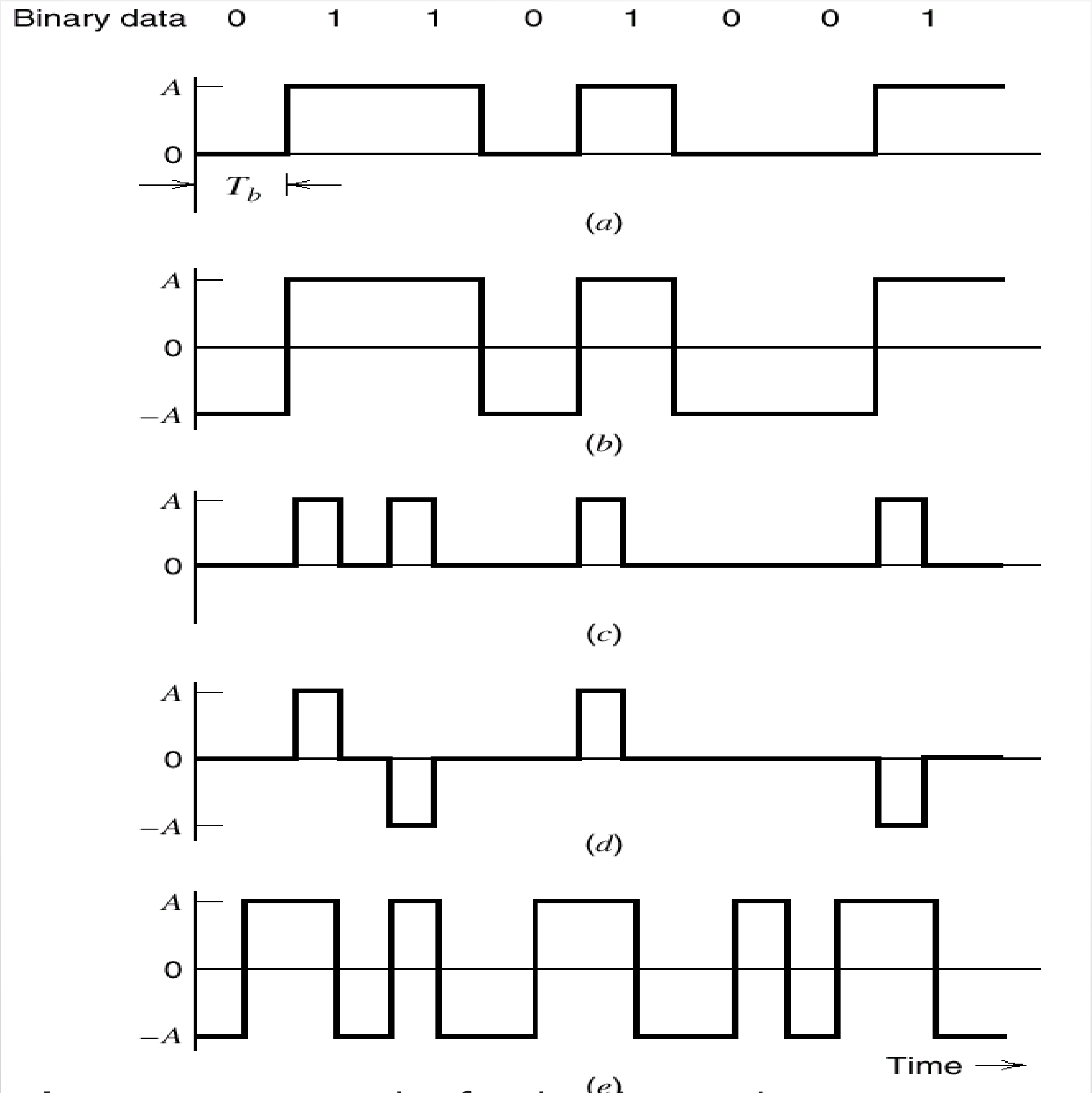



**Figure 3.15** Line codes for the electrical representations of binary data.
(*a*) Unipolar NRZ signaling. (*b*) Polar NRZ signaling.
(c) Unipolar RZ signaling. (*d*) Bipolar RZ signaling.
(*e*) Split-phase or Manchester code.

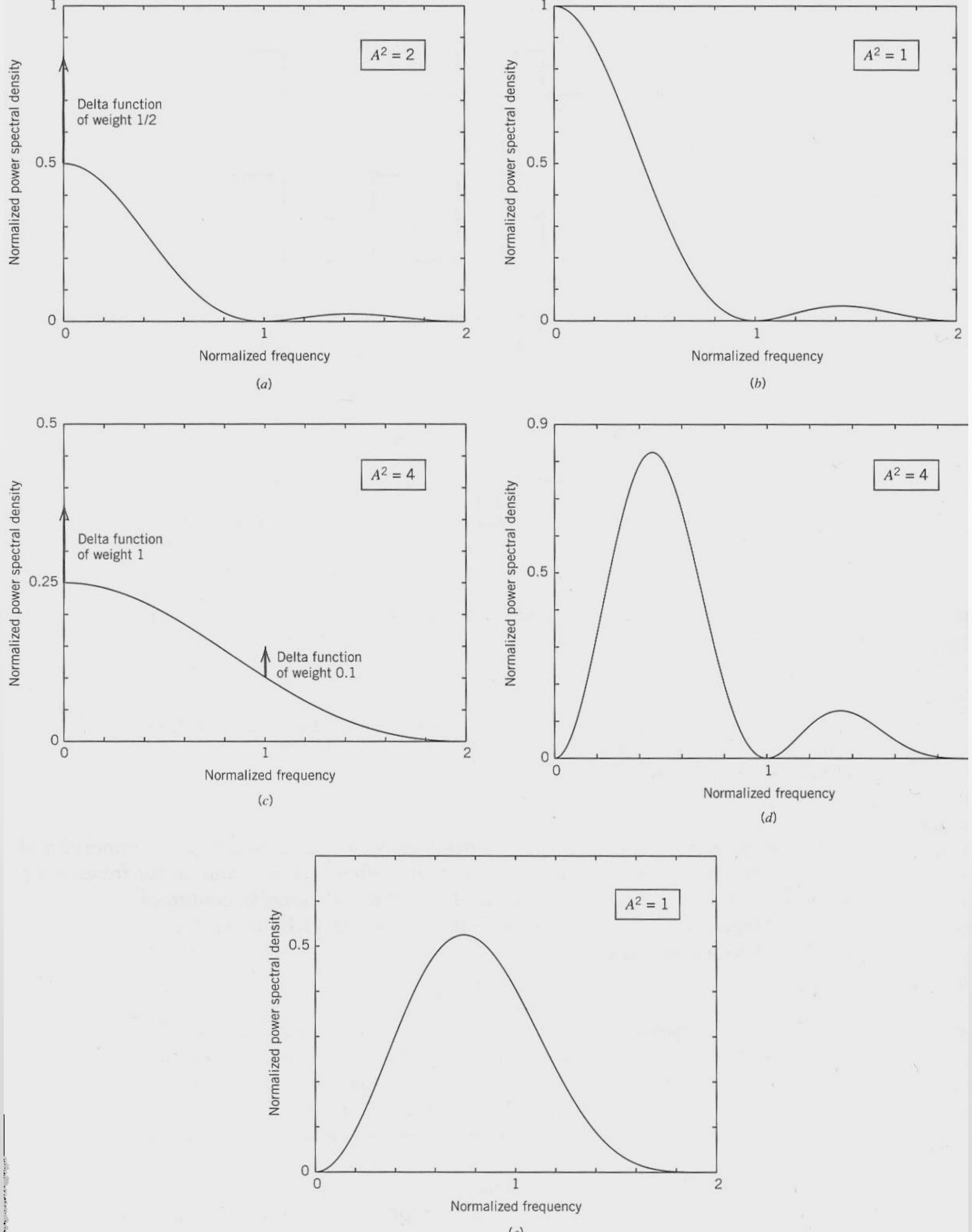
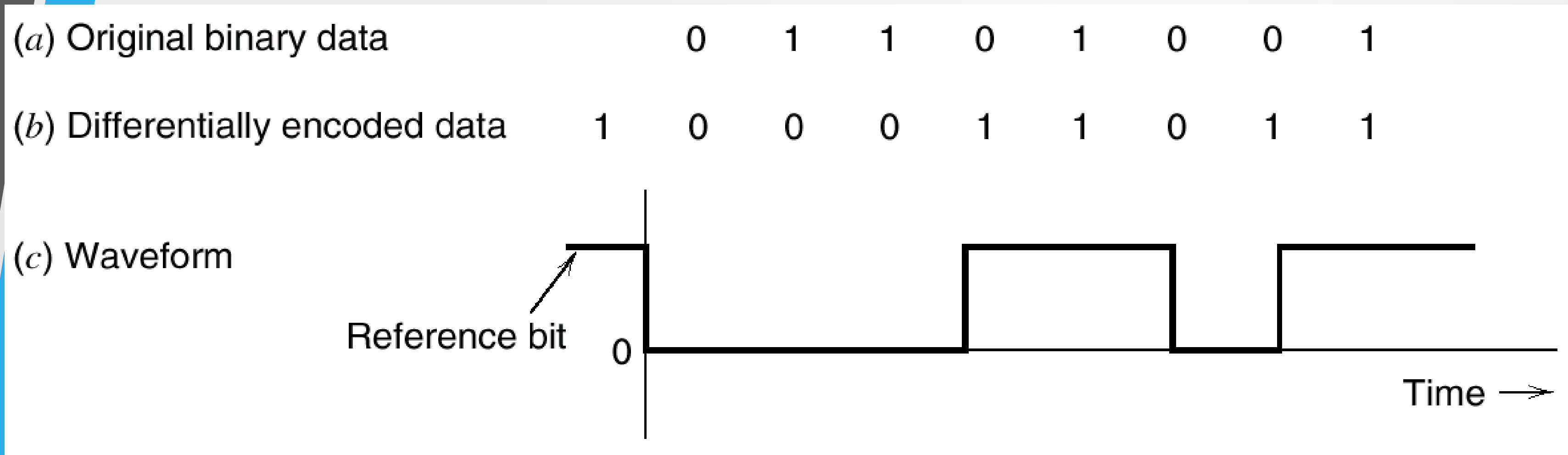
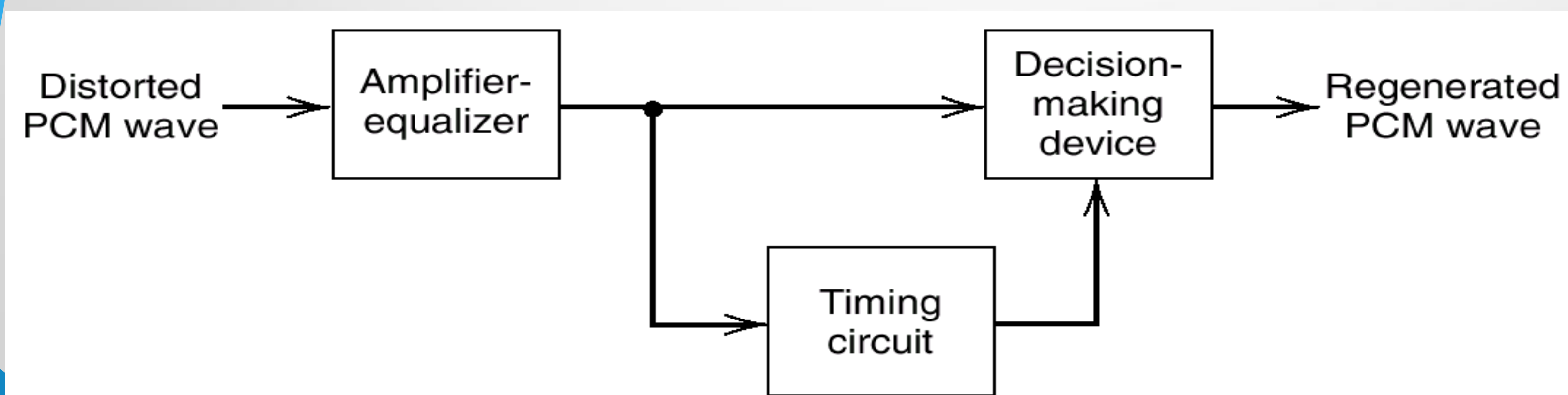



**FIGURE 3.16** Power spectra of line codes: (*a*) Unipolar NRZ signal. (*b*) Polar NRZ signal. (*c*) Unipolar RZ signal. (*d*) Bipolar RZ signal. (*e*) Manchester-encoded signal. The frequency is normalized with respect to the bit rate $1/T_b$, and the average power is normalized to unity.

**Differential Encoding** (encode information in terms of signal transition; a transition is used to designate Symbol 0)




**Regeneration** (reamplification, retiming, reshaping )




Two measure factors: bit error rate (BER) and jitter.

**Decoding and Filtering**

# 3.8 Noise consideration in PCM systems

(Channel noise, quantization noise)

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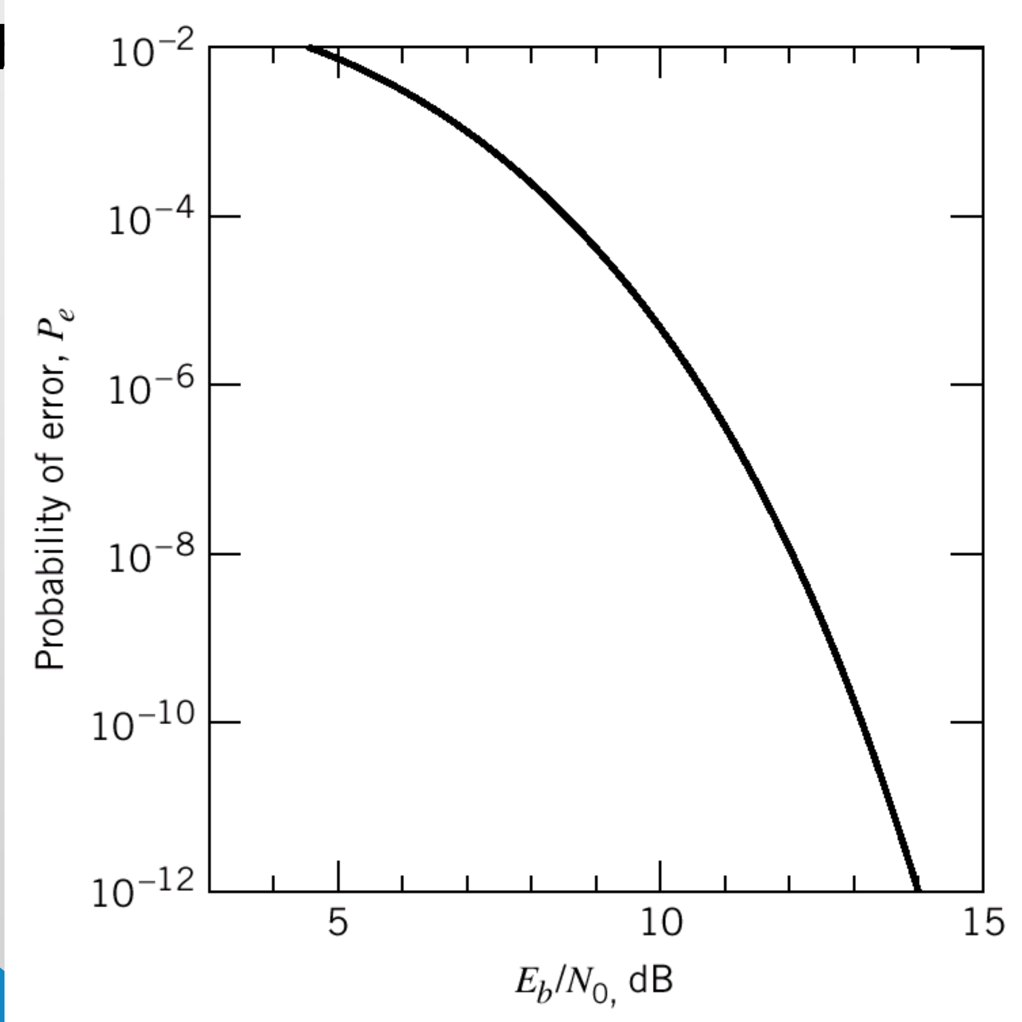


**TABLE 3.3** *Influence of $E_b/N_0$ on the probability of error*

| $E_b/N_0$ | *Probability of Error $P_e$* | *For a Bit Rate of $10^5$ b/s, This Is About One Error Every* |
|---|---|---|
| 4.3 dB | $10^{-2}$ | $10^{-3}$ second |
| 8.4 | $10^{-4}$ | $10^{-1}$ second |
| 10.6 | $10^{-6}$ | 10 seconds |
| 12.0 | $10^{-8}$ | 20 minutes |
| 13.0 | $10^{-10}$ | 1 day |
| 14.0 | $10^{-12}$ | 3 months |

# Time-Division Multiplexing

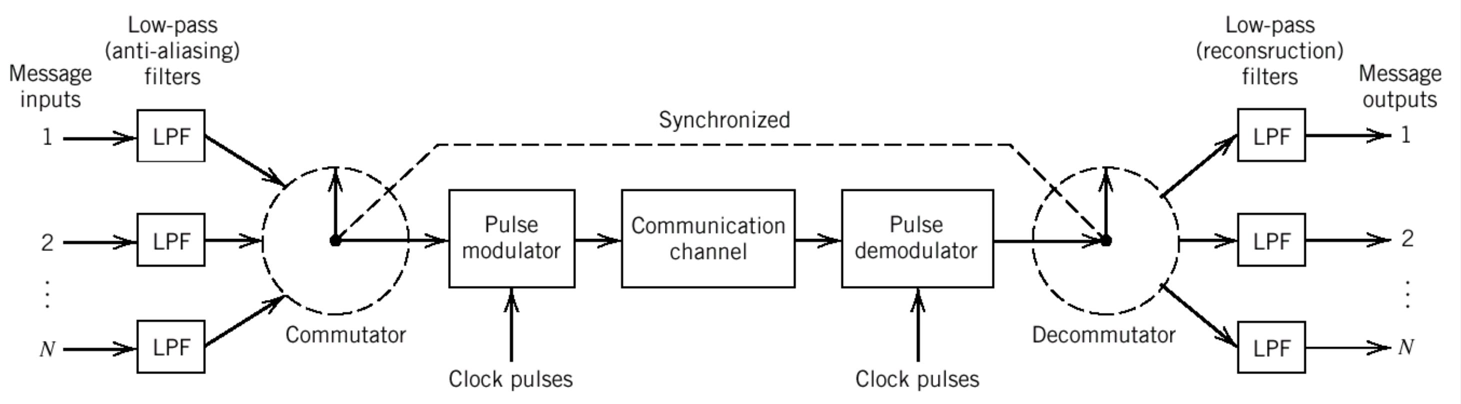
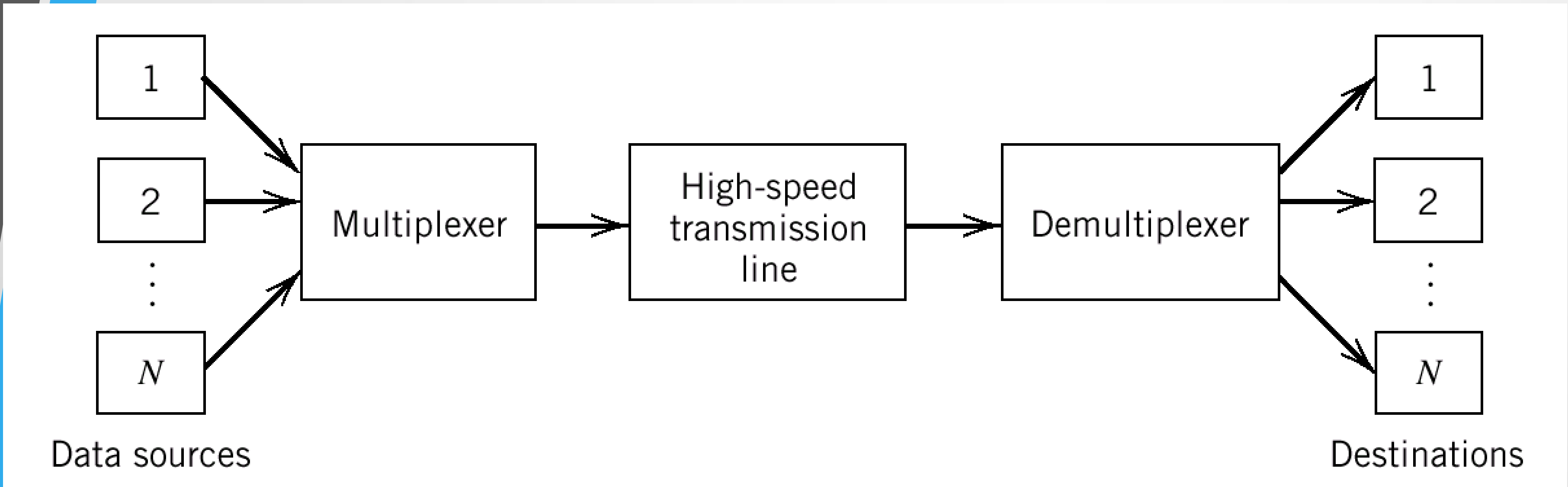



**Figure 3.19** Block diagram of TDM system.

# Synchronization

# 3.10 Digital Multiplexers



## 3.11 Virtues, Limitations and Modifications of PCM

Advantages of PCM

1. Robustness to noise and interference
2. Efficient regeneration
3. Efficient SNR and bandwidth trade-off
4. Uniform format
5. Ease add and drop
6. Secure