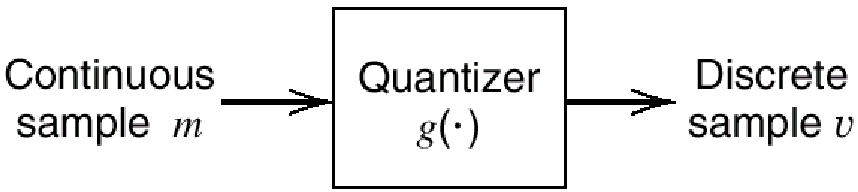
PULSE CODE MODULATION

Pulse Code Modulation (PCM)

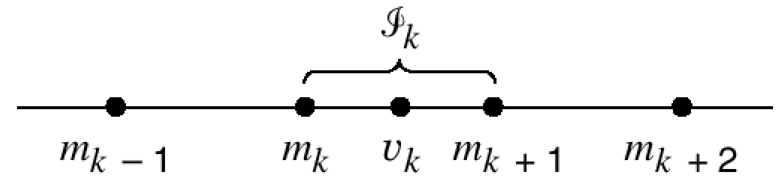
- **Pulse code modulation (PCM) is produced by analog-to-digital conversion process.**
- **As in the case of other pulse modulation techniques, the rate at which samples are taken and encoded must conform to the Nyquist sampling rate.**
- **The sampling rate must be greater than, twice the highest frequency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

$$f_s > 2f_A(\max)$$

3.6 Quantization Process



(a)



(b)

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 $\nu(nT_s)$ 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 $\nu = g(m) \qquad (3.22)$

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

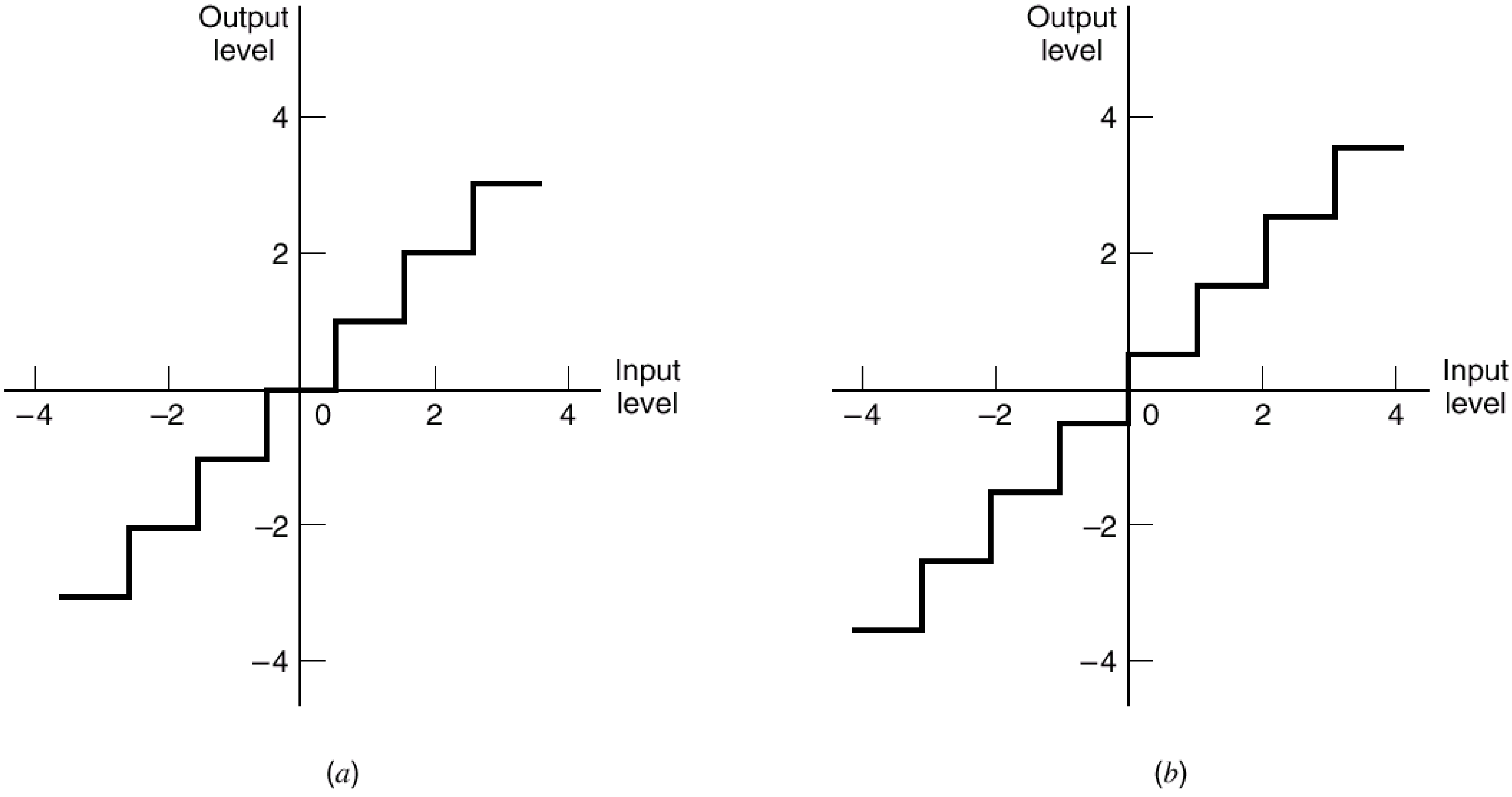


Figure 3.10 Two types of quantization: (*a*) midtread and (*b*) midrise.

Quantization Noise

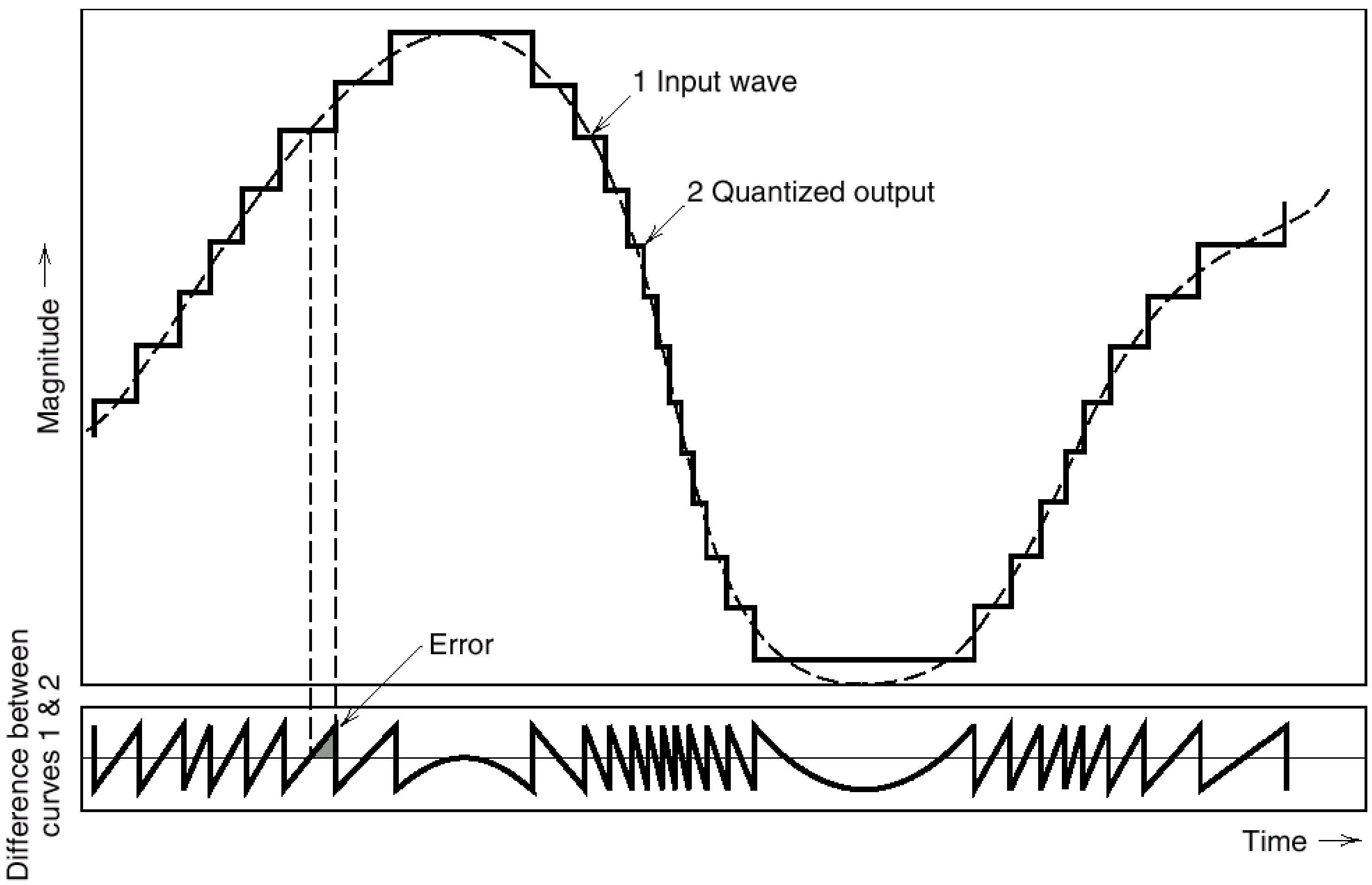


Figure 3.11 Illustration of the quantization process.

Pulse Code Modulation

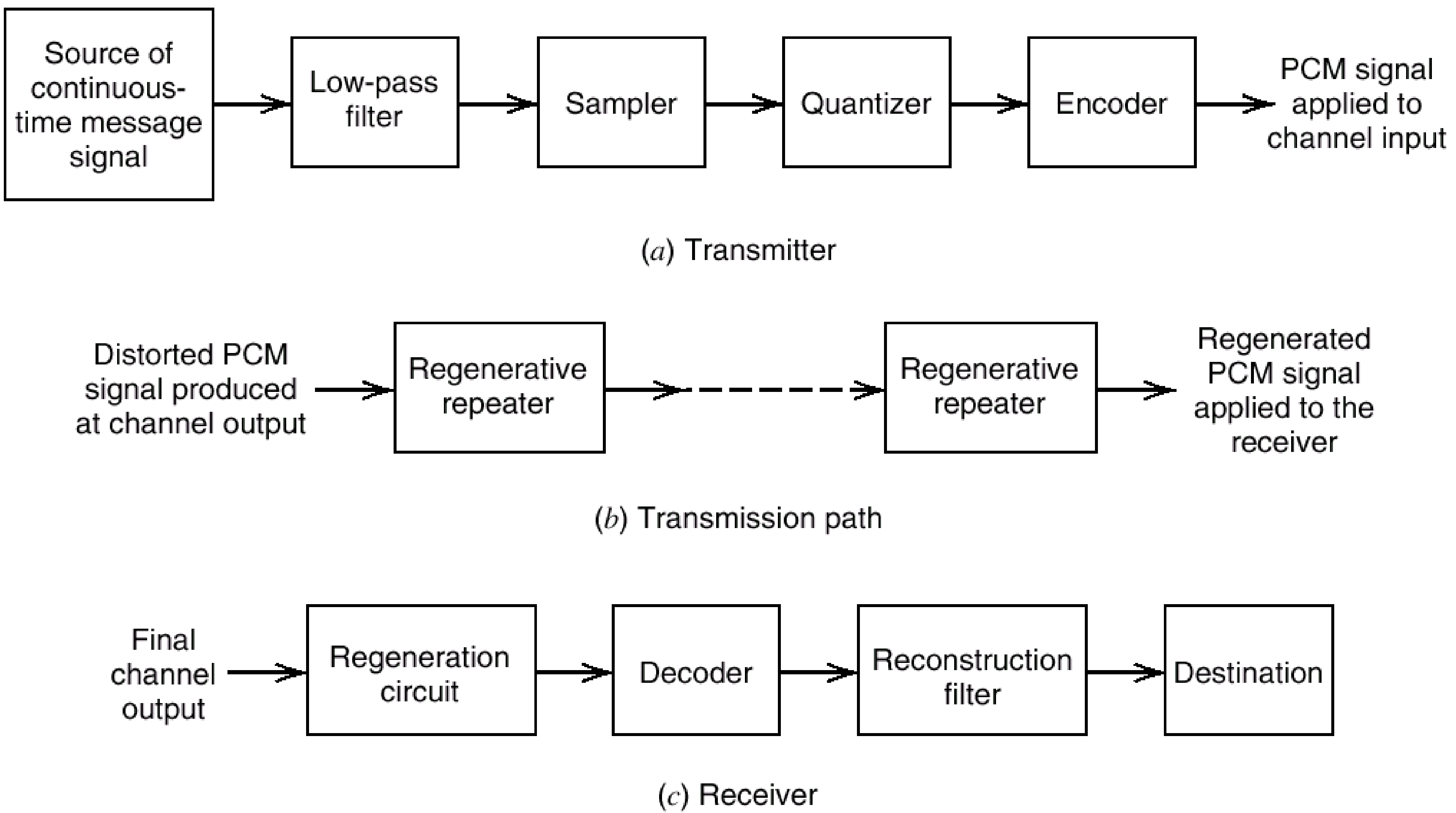


Figure 3.13 The basic elements of a PCM system.

Quantization (nonuniform quantizer)

μ - 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

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

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

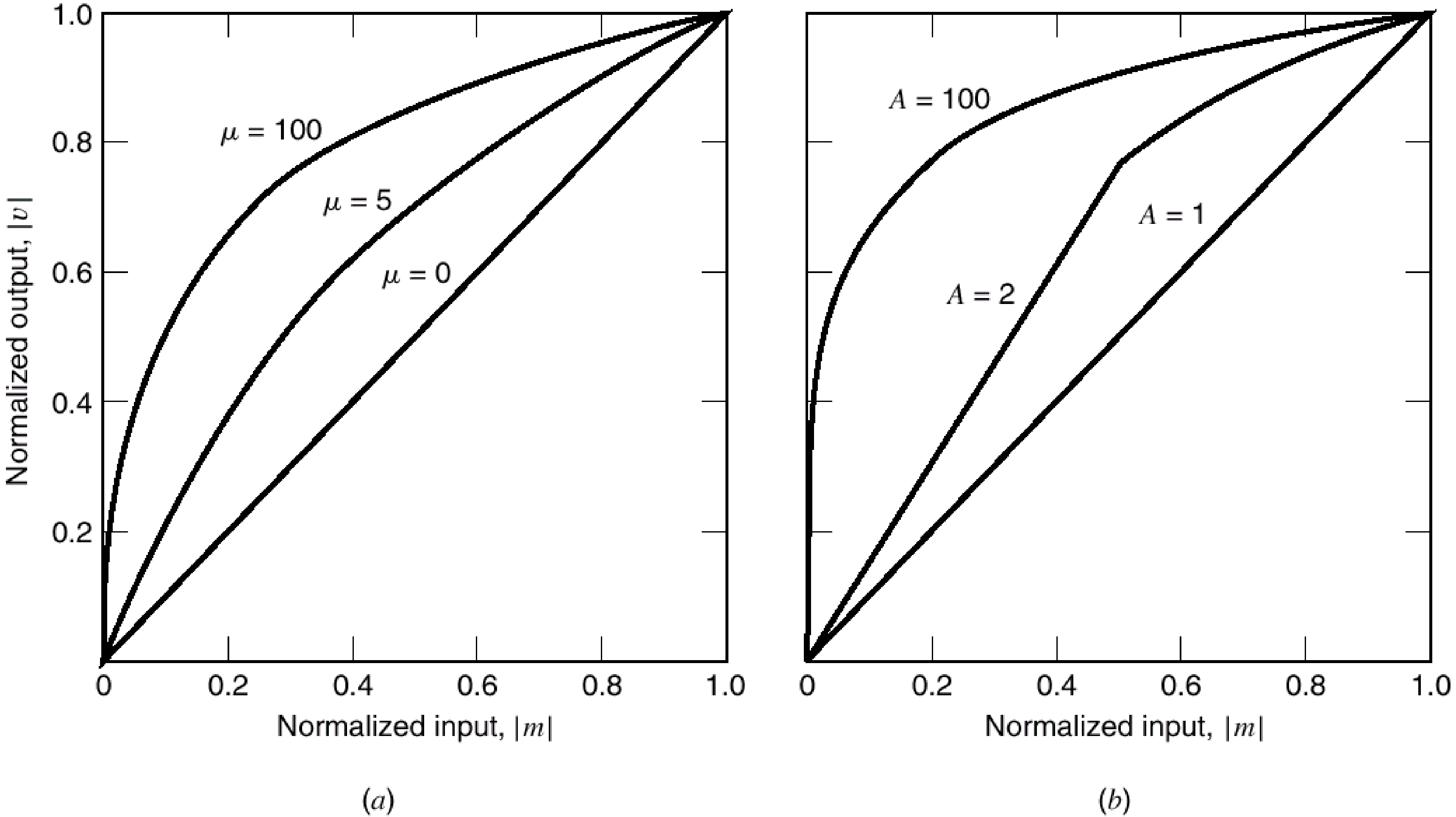


Figure 3.14 Compression laws. (*a*) μ -law. (*b*) A-law.

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)

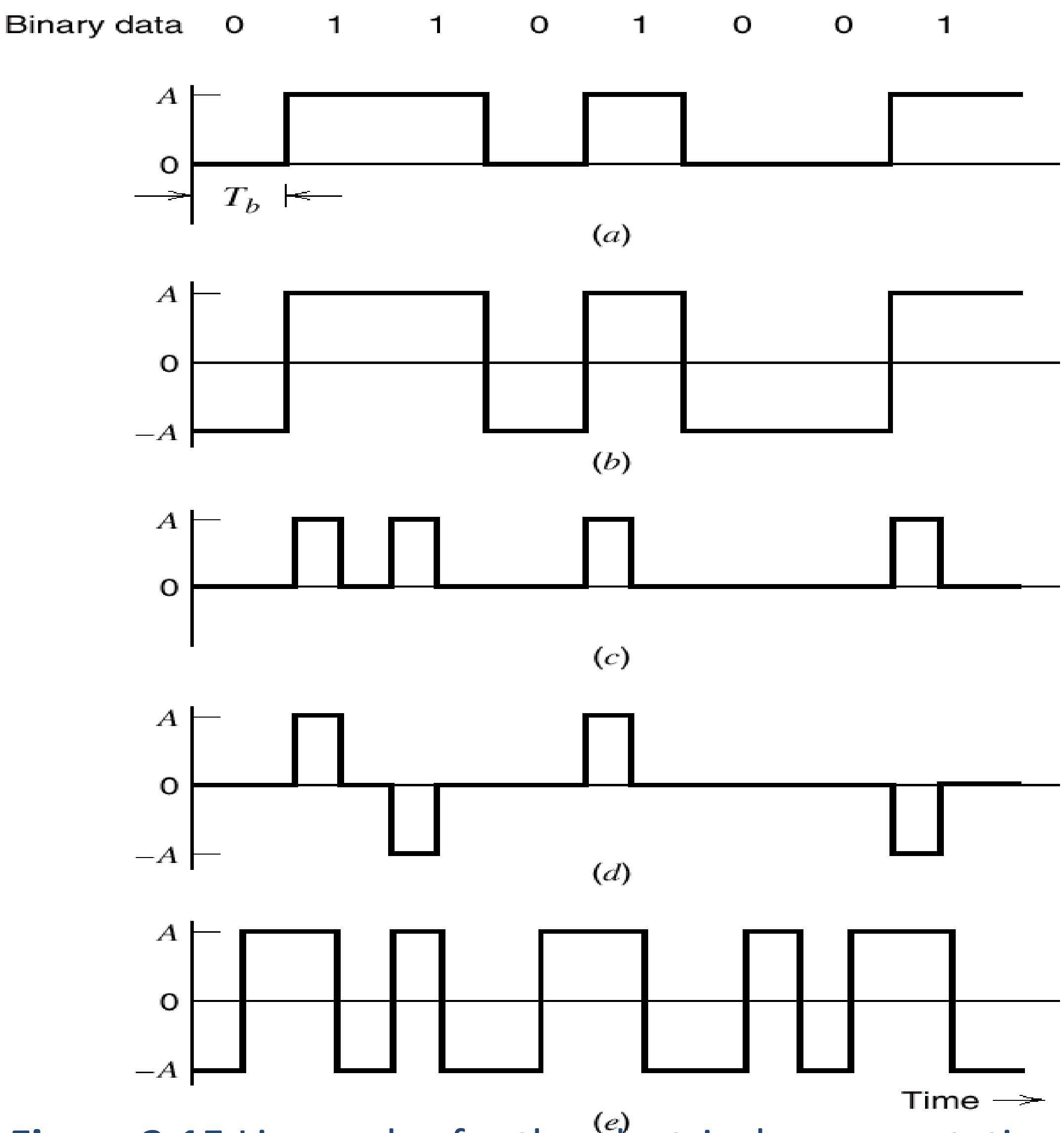


Figure 3.15 Line codes for the electrical representations of binary data. (*a*) Unipolar NRZ signaling. (*b*) Polar NRZ signaling. (c) Unipolar RZ signaling. (*d*) Bipolar RZ signaling. (*e*) Split-phase or Manchester code.

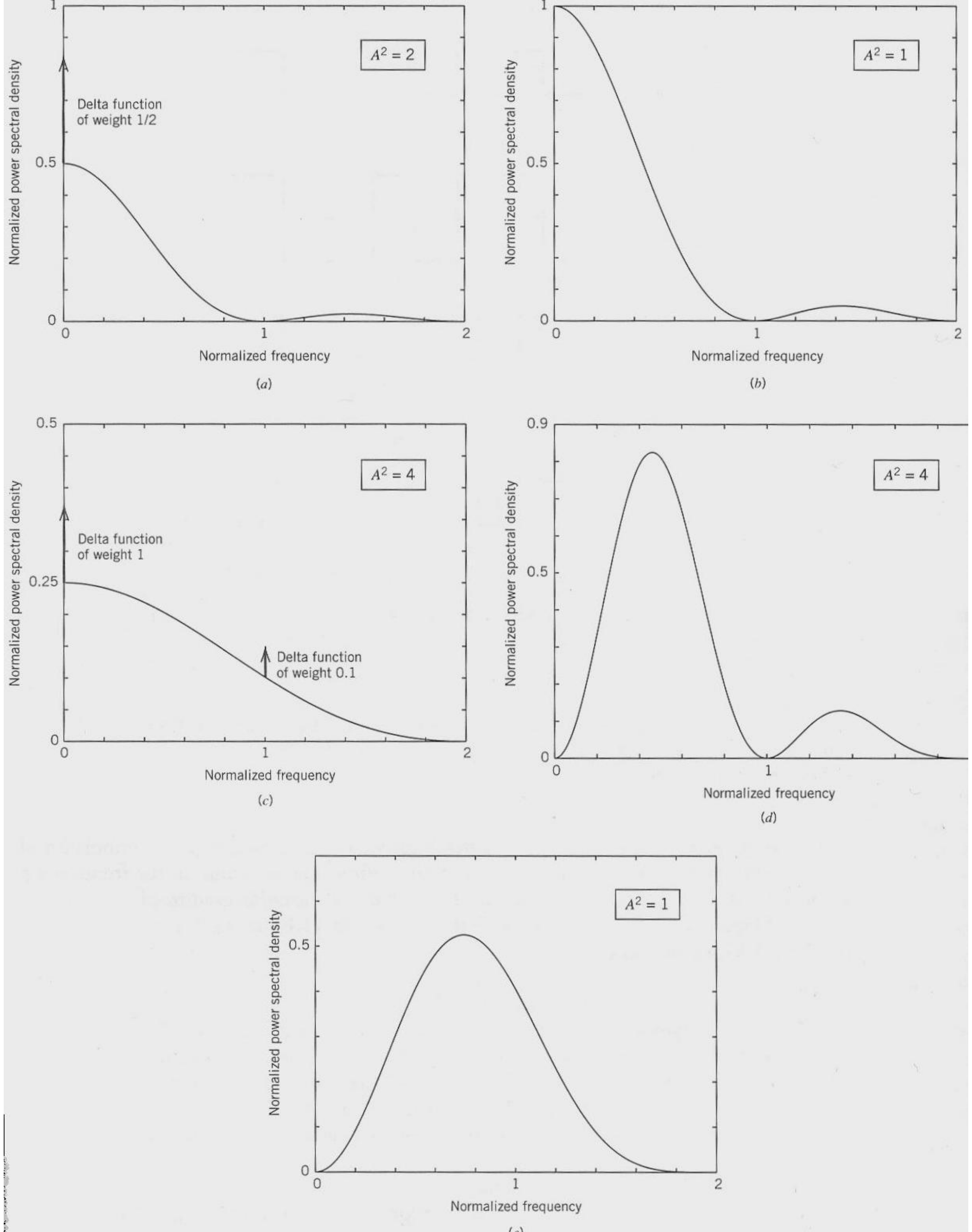
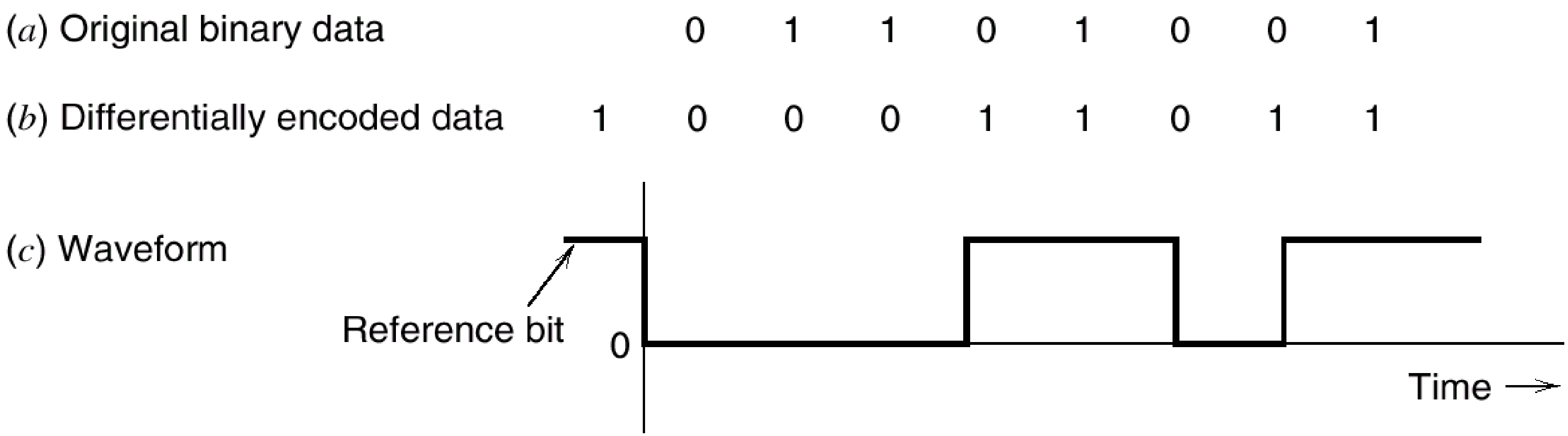
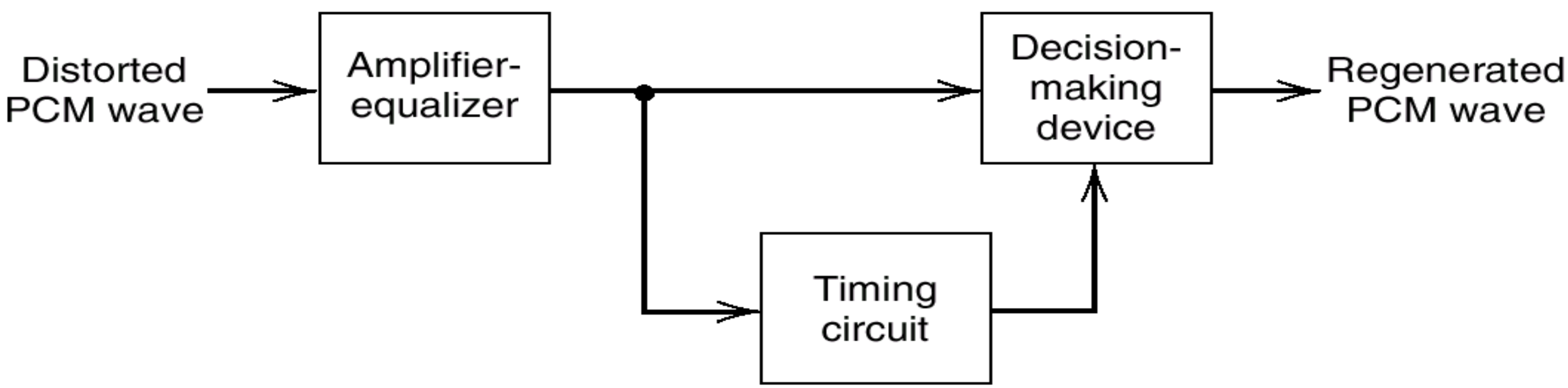


FIGURE 3.16 Power spectra of line codes: (*a*) Unipolar NRZ signal. (*b*) Polar NRZ signal. (*c*) Unipolar RZ signal. (*d*) Bipolar RZ signal. (*e*) Manchester-encoded signal. The frequency is normalized with respect to the bit rate $1/T_b$, and the average power is normalized to unity.

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)

(will be discussed in Chapter 4)

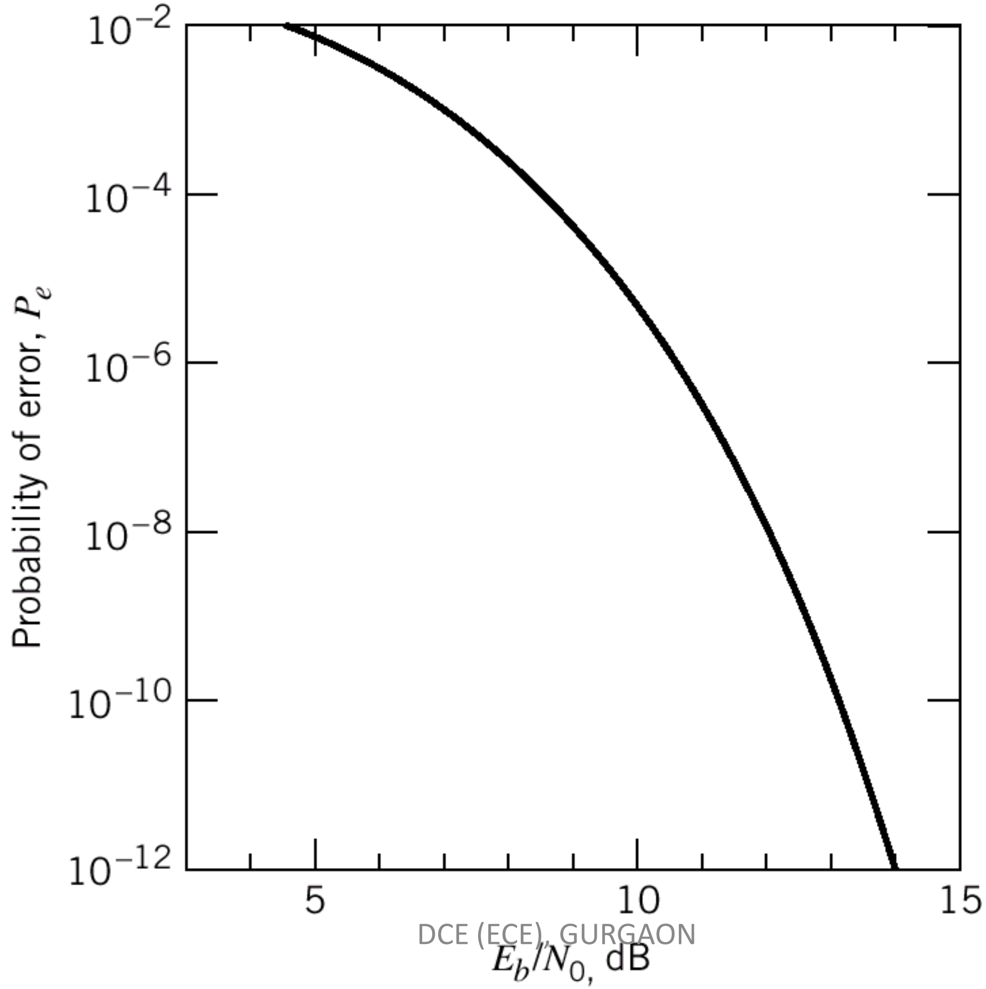


TABLE 3.3 ***Influence of E_b/N_0 on the probability of error***

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

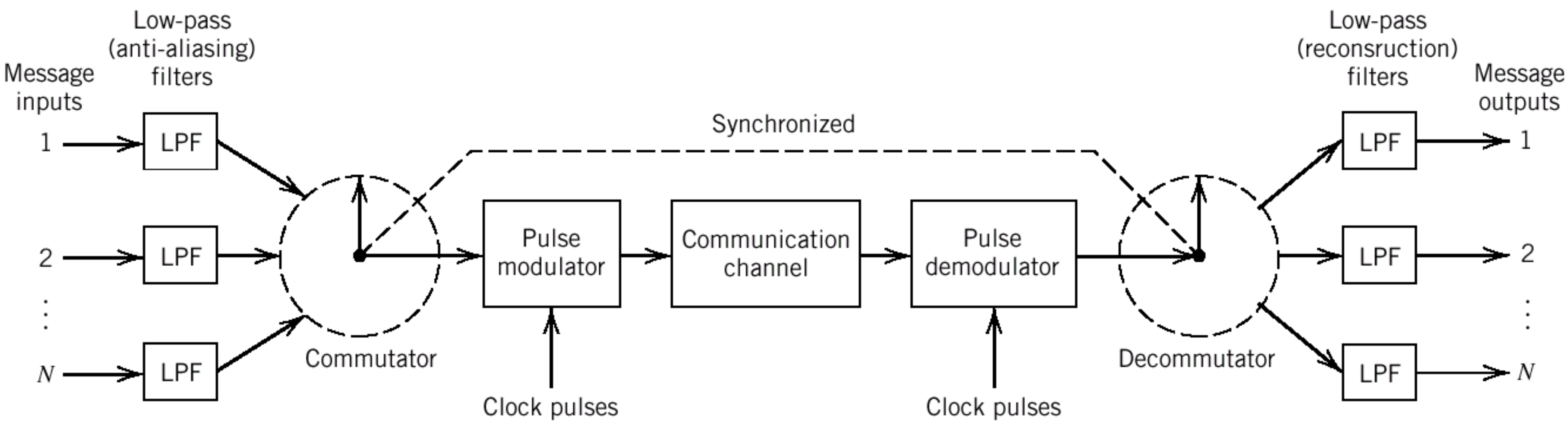
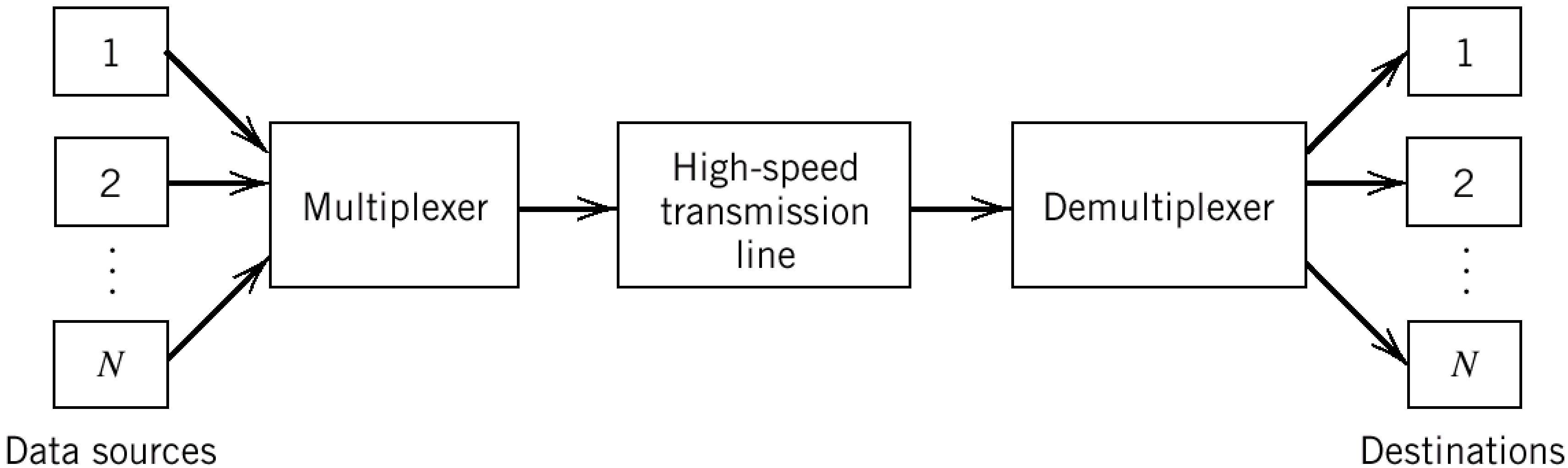


Figure 3.19 Block diagram of TDM system.

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