2.14 (a)

$$L \geq \frac{1}{2p} = \frac{1}{0.02} = 50 \text{ levels}$$

$$l = \left\lceil \log_2 50 \right\rceil = 6 \text{ bits/sample}$$

(b)

$$f_S = 2f_m = 2 \times 4000 = 8000 \text{ samples/second}$$

Bit rate: $$R = 8000 \text{ samples/second} \times 6 \text{ bits/sample} = 48,000 \text{ bits/second}$$

(c)

16-level pulse: $$16 = M = 2^k$$

$$k = 4 \text{ bits/pulse}$$

Symbol rate: $$R_s = \frac{R}{\log_2 M} = \frac{48,000 \text{ bits/second}}{4 \text{ bits/symbol}} = 12,000 \text{ symbols/second}.$$
2.16 (a)

Assume that the \( L \) quantization levels are equally spaced and symmetrical about zero. Then, the maximum possible quantization noise voltage equals \( \frac{1}{2} \) the \( q \) volt interval between any two neighboring levels. Also, the peak quantization noise power, \( N_q \), can be expressed as \( (q/2)^2 \).

The peak signal power, \( S \), can be designated \( (V_{pp}/2)^2 \), where \( V_{pp} = V_p - (-V_p) \) is the peak-to-peak signal voltage, and \( V_p \) is the peak voltage.

Since there are \( L \) quantization levels and \( (L - 1) \) intervals (each interval corresponding to \( q \) volts), we can write:

\[
\left( \frac{S}{N_q} \right)_{\text{peak}} = \frac{(V_{pp}/2)^2}{(q/2)^2} = \frac{q(L-1)/2}{q/2}^2
\]

\[
\approx \frac{q^2L^2/4}{q^2/4} = L^2
\]

Thus, we need to compute how many levels, \( L \), will yield a \( (S/N_q)_{\text{peak}} = 96 \) dB. We therefore write:

\[
96 \text{ dB} = 10 \log_{10} \left( \frac{S}{N_q} \right)_{\text{peak}} = 10 \log_{10} L^2
\]

\[
= 20 \log_{10} L
\]

\[
L = 10^{96/20} = 63,096 \quad \text{levels}
\]

(b)

The number of bits that correspond to 63,096 levels is

\[
\ell = \left\lfloor \log_2 L \right\rfloor = \left\lfloor \log_2 63,096 \right\rfloor = 16 \quad \text{bits/sample}
\]

(c)

\[
R = 16 \text{ bits/sample} \times 44.1 \text{ ksamples/s} = 705,600 \text{ bits/s}.
\]
The data rate for T1 service is:

\[ 24 \text{ samples/frame} \times 8 \text{ bits/sample} \times 8000 \text{ frames/s} + 1 \text{ alignment bit/frame} = 193 \text{ bits/frame} \times 8000 \text{ frames/s} = 1.544 \times 10^6 \text{ bits/s} \]

Bandwidth efficiency is:

\[ \frac{R}{W} = \frac{1.544 \times 10^6}{386 \times 10^3} = 4 \text{ bits/s/Hz} \]

Using Equations (2.26) to (2.28)

\[ 2^l = \frac{L}{2^p} \text{ levels. Given that } p = 0.02, \]

then \[ l = \lceil \log_2 \frac{1}{0.04} \rceil = \lceil \log_2 25 \rceil \]

Thus, there must be at least 25 quantization levels, or 5 bits per sample, to meet the fidelity criterion. The data rate is:

\[ 8000 \text{ samples/s} \times 5 \text{ bits/sample} = 40,000 \text{ bits/s} \]

This data rate needs to be sent in a 4000 Hz bandwidth. Hence, the required bandwidth efficiency is:

\[ \frac{R}{W} = \frac{40,000 \text{ bits/s}}{4000 \text{ Hz}} = 10 \text{ bits/s/Hz} \]
When the analog signal has a 20 kHz bandwidth, the Nyquist sampling rate is 40 ksamples/s, and the bit rate is 40,000 samples/s $\times 5$ bits/sample = 200,000 bits/s. Hence, the required bandwidth efficiency is

$$R = \frac{200,000}{4,000} = 50 \text{ bits/s/Hz},$$

which is a challenging requirement.

3.4

Using Equation (2.41),

$$P_B = Q\left(\frac{a_1-a_2}{2\sigma_0}\right) = Q\left(\frac{1-(-1)}{2}\right) = Q(1)$$

Using Table B.1, we solve for $P_B$: $P_B = 0.1587$

3.5

Using Equation (2.67),

$$P_B = Q\left(\sqrt{\frac{2E_b}{N_0}}\right)$$

where $E_b = A^2 T$ for bipolar signaling, and $A = 1$. Thus, $E_b = T$.

$$P_B = Q(\kappa) \approx 10^{-3}$$

$\kappa = \sqrt{\frac{2E_b}{N_0}} = 3.09$ from Table B.1

$$E_b = 4.77 \; \text{V} \Rightarrow \frac{E_b}{N_0} = \text{is given as} \; 10^{-3}$$

$$E_b = T = 4.77 \times 10^{-3} \times 2$$

Thus, $R = \frac{1}{T} \leq 104.8 \text{ bits/s}$. 