

- Other sampling techniques have been developed to reduce the complexity of PCM. The simplest is *delta modulation*. PCM finds the value of the signal amplitude for each sample; DM finds the change from the previous sample.
- While there is only one way to send parallel data, there are three subclasses of serial transmission: asynchronous, synchronous, and isochronous.
- In asynchronous transmission, we send 1 start bit (0) at the beginning and 1 or more stop bits (1 s) at the end of each byte.
- In synchronous transmission, we send bits one after another without start or stop bits or gaps. It is the responsibility of the receiver to group the bits.
- The isochronous mode provides synchronized for the entire stream of bits must. In other words, it guarantees that the data arrive at a fixed rate.

4.7 PRACTICE SET

Review Questions

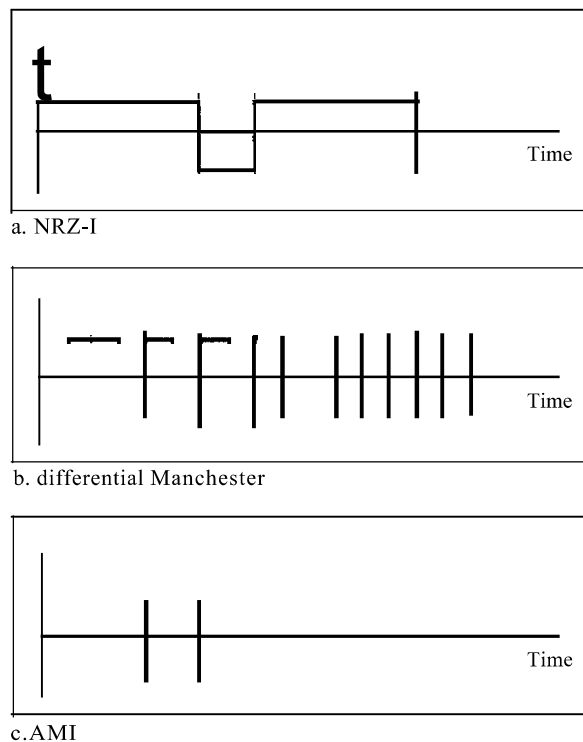
1. List three techniques of digital-to-digital conversion.
2. Distinguish between a signal element and a data element.
3. Distinguish between data rate and signal rate.
4. Define baseline wandering and its effect on digital transmission.
5. Define a DC component and its effect on digital transmission.
6. Define the characteristics of a self-synchronizing signal.
7. List five line coding schemes discussed in this book.
8. Define block coding and give its purpose.
9. Define scrambling and give its purpose.
10. Compare and contrast PCM and DM.
11. What are the differences between parallel and serial transmission?
12. List three different techniques in serial transmission and explain the differences.

Exercises

13. Calculate the value of the signal rate for each case in Figure 4.2 if the data rate is 1 Mbps and $c = 1/2$.
14. In a digital transmission, the sender clock is 0.2 percent faster than the receiver clock. How many extra bits per second does the sender send if the data rate is 1 Mbps?
15. Draw the graph of the NRZ-L scheme using each of the following data streams, assuming that the last signal level has been positive. From the graphs, guess the bandwidth for this scheme using the average number of changes in the signal level. Compare your guess with the corresponding entry in Table 4.1.
 - a. 00000000
 - b. 11111111
 - c. 01010101
 - d. 00110011

16. Repeat Exercise 15 for the NRZ-I scheme.
17. Repeat Exercise 15 for the Manchester scheme.
18. Repeat Exercise 15 for the differential Manchester scheme.
19. Repeat Exercise 15 for the 2B 1Q scheme, but use the following data streams.
 - a. 0000000000000000
 - b. 1111111111111111
 - c. 0101010101010101
 - d. 0011001100110011
20. Repeat Exercise 15 for the MLT-3 scheme, but use the following data streams.
 - a. 00000000
 - b. 11111111
 - c. 01010101
 - d. 00011000
21. Find the 8-bit data stream for each case depicted in Figure 4.36.

Figure 4.36 Exercise 21



22. An NRZ-I signal has a data rate of 100 Kbps. Using Figure 4.6, calculate the value of the normalized energy (P) for frequencies at 0 Hz, 50 KHz, and 100 KHz.
23. A Manchester signal has a data rate of 100 Kbps. Using Figure 4.8, calculate the value of the normalized energy (P) for frequencies at 0 Hz, 50 KHz, 100 KHz.

24. The input stream to a 4B/5B block encoder is 0100 0000 0000 0000 0000 0001. Answer the following questions:
 - a. What is the output stream?
 - b. What is the length of the longest consecutive sequence of 0s in the input?
 - c. What is the length of the longest consecutive sequence of 0s in the output?
25. How many invalid (unused) code sequences can we have in 5B/6B encoding? How many in 3B/4B encoding?
26. What is the result of scrambling the sequence 11100000000000 using one of the following scrambling techniques? Assume that the last non-zero signal level has been positive.
 - a. B8ZS
 - b. HDB3 (The number of nonzero pulses is odd after the last substitution)
27. What is the Nyquist sampling rate for each of the following signals?
 - a. A low-pass signal with bandwidth of 200 KHz?
 - b. A band-pass signal with bandwidth of 200 KHz if the lowest frequency is 100 KHz?
28. We have sampled a low-pass signal with a bandwidth of 200 KHz using 1024 levels of quantization.
 - a. Calculate the bit rate of the digitized signal.
 - b. Calculate the SNR_{dB} for this signal.
 - c. Calculate the PCM bandwidth of this signal.
29. What is the maximum data rate of a channel with a bandwidth of 200 KHz if we use four levels of digital signaling.
30. An analog signal has a bandwidth of 20 KHz. If we sample this signal and send it through a 30 Kbps channel what is the SNR_{dB} ?
31. We have a baseband channel with a 1-MHz bandwidth. What is the data rate for this channel if we use one of the following line coding schemes?
 - a. NRZ-L
 - b. Manchester
 - c. MLT-3
 - d. 2B1Q
32. We want to transmit 1000 characters with each character encoded as 8 bits.
 - a. Find the number of transmitted bits for synchronous transmission.
 - b. Find the number of transmitted bits for asynchronous transmission.
 - c. Find the redundancy percent in each case.

CHAPTER 4

Digital Transmission

Solutions to Review Questions and Exercises

Review Questions

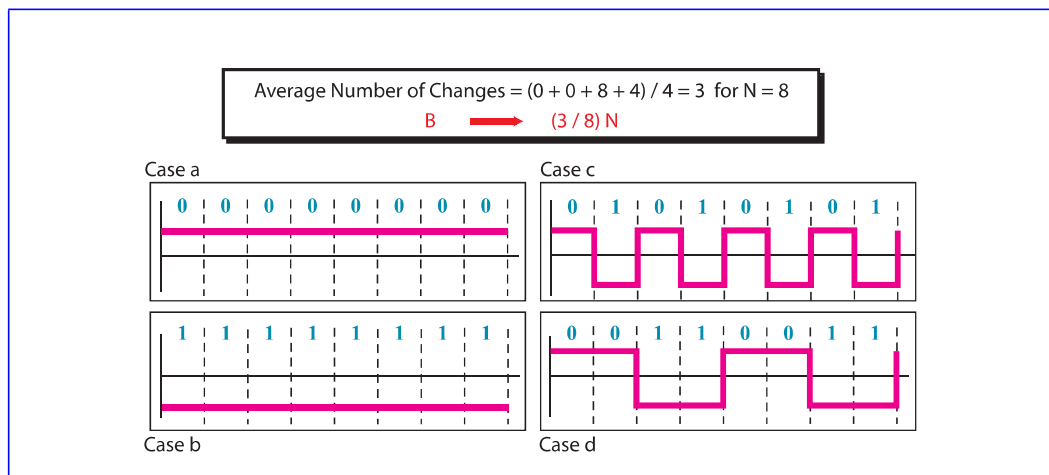
1. The three different techniques described in this chapter are *line coding*, *block coding*, and *scrambling*.
2. A *data element* is the smallest entity that can represent a piece of information (a bit). A *signal element* is the shortest unit of a digital signal. Data elements are what we need to send; signal elements are what we can send. Data elements are being carried; signal elements are the carriers.
3. The *data rate* defines the number of data elements (bits) sent in 1s. The unit is bits per second (bps). The *signal rate* is the number of signal elements sent in 1s. The unit is the baud.
4. In decoding a digital signal, the incoming signal power is evaluated against the *baseline* (a running average of the received signal power). A long string of 0s or 1s can cause *baseline wandering* (a drift in the baseline) and make it difficult for the receiver to decode correctly.
5. When the voltage level in a digital signal is constant for a while, the spectrum creates very low frequencies, called *DC components*, that present problems for a system that cannot pass low frequencies.
6. A *self-synchronizing* digital signal includes timing information in the data being transmitted. This can be achieved if there are transitions in the signal that alert the receiver to the beginning, middle, or end of the pulse.
7. In this chapter, we introduced *unipolar*, *polar*, *bipolar*, *multilevel*, and *multitransition* coding.
8. *Block coding* provides redundancy to ensure synchronization and to provide inherent error detecting. In general, block coding changes a block of m bits into a block of n bits, where n is larger than m .
9. *Scrambling*, as discussed in this chapter, is a technique that substitutes long zero-level pulses with a combination of other levels without increasing the number of bits.

10. Both **PCM** and **DM** use sampling to convert an analog signal to a digital signal. PCM finds the value of the signal amplitude for each sample; DM finds the change between two consecutive samples.
11. In **parallel transmission** we send data *several* bits at a time. In **serial transmission** we send data *one* bit at a time.
12. We mentioned **synchronous**, **asynchronous**, and **isochronous**. In both synchronous and asynchronous transmissions, a bit stream is divided into independent frames. In synchronous transmission, the bytes inside each frame are synchronized; in asynchronous transmission, the bytes inside each frame are also independent. In isochronous transmission, there is no independency at all. All bits in the whole stream must be synchronized.

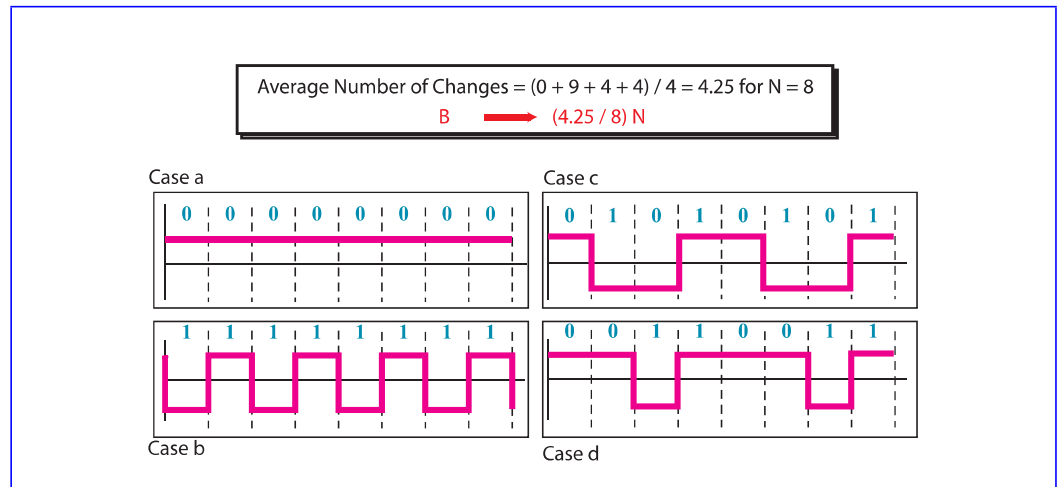
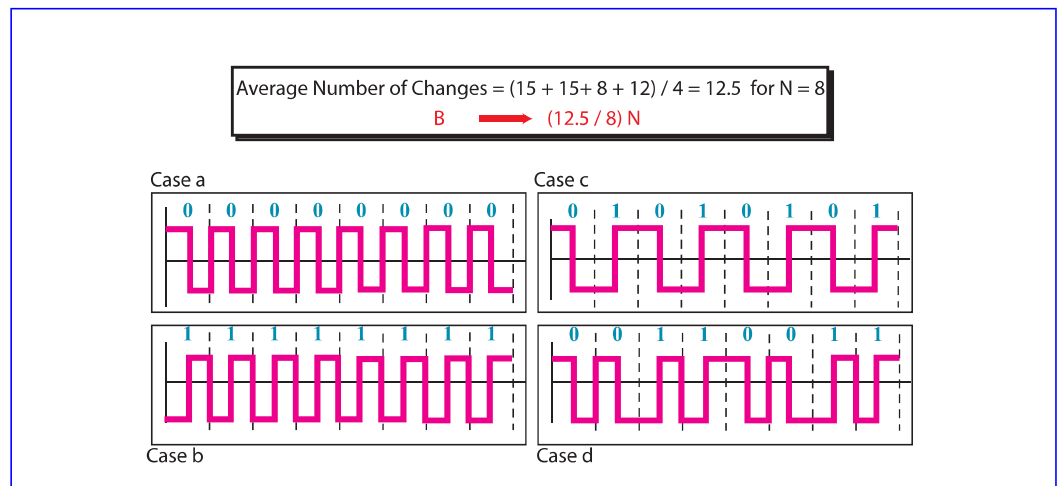
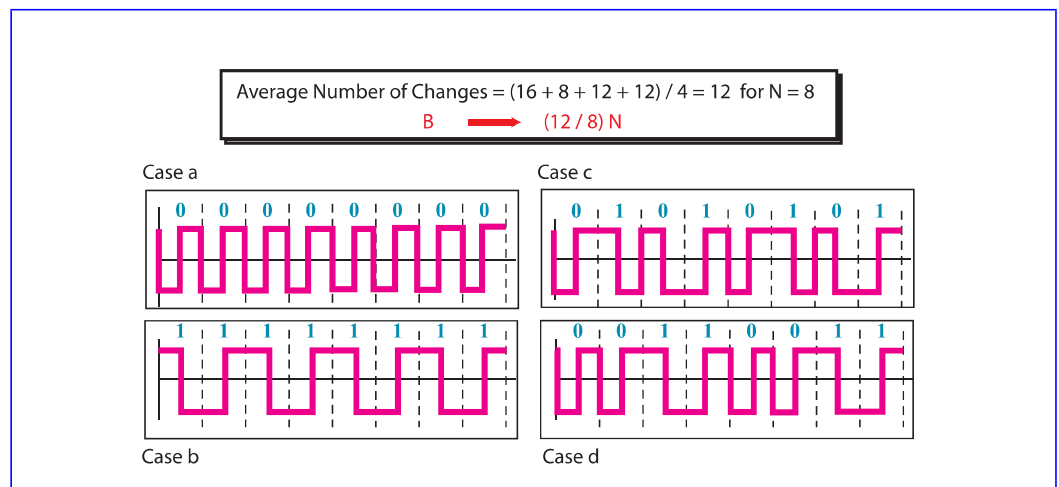
Exercises

13. We use the formula $s = c \times N \times (1/r)$ for each case. We let $c = 1/2$.
 - a. $r = 1 \rightarrow s = (1/2) \times (1 \text{ Mbps}) \times 1/1 = 500 \text{ kbaud}$
 - b. $r = 1/2 \rightarrow s = (1/2) \times (1 \text{ Mbps}) \times 1/(1/2) = 1 \text{ Mbaud}$
 - c. $r = 2 \rightarrow s = (1/2) \times (1 \text{ Mbps}) \times 1/2 = 250 \text{ Kbaud}$
 - d. $r = 4/3 \rightarrow s = (1/2) \times (1 \text{ Mbps}) \times 1/(4/3) = 375 \text{ Kbaud}$
14. The number of bits is calculated as $(0.2 / 100) \times (1 \text{ Mbps}) = 2000 \text{ bits}$
15. See Figure 4.1. Bandwidth is proportional to $(3/8)N$ which is within the range in Table 4.1 ($B = 0$ to N) for the NRZ-L scheme.

Figure 4.1 Solution to Exercise 15

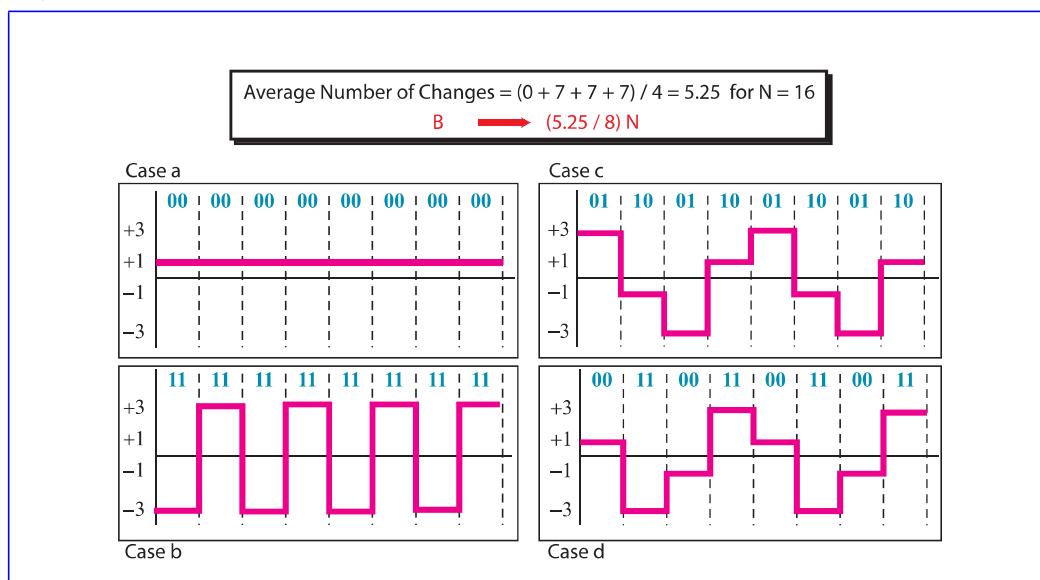


16. See Figure 4.2. Bandwidth is proportional to $(4.25/8)N$ which is within the range in Table 4.1 ($B = 0$ to N) for the NRZ-I scheme.
17. See Figure 4.3. Bandwidth is proportional to $(12.5 / 8) N$ which is within the range in Table 4.1 ($B = N$ to $B = 2N$) for the Manchester scheme.
18. See Figure 4.4. B is proportional to $(12/8) N$ which is within the range in Table 4.1 ($B = N$ to $2N$) for the differential Manchester scheme.

Figure 4.2 *Solution to Exercise 16***Figure 4.3** *Solution to Exercise 17***Figure 4.4** *Solution to Exercise 18*

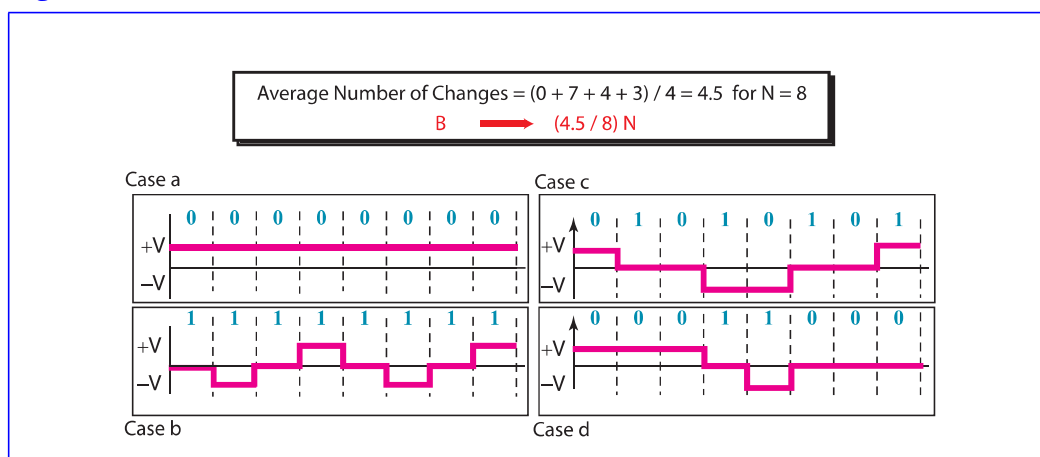
19. See Figure 4.5. B is proportional to $(5.25 / 16) N$ which is inside range in Table 4.1 ($B = 0$ to $N/2$) for $2B/1Q$.

Figure 4.5 Solution to Exercise 19



20. See Figure 4.6. B is proportional to $(5.25/8) \times N$ which is inside the range in Table 4.1 ($B = 0$ to $N/2$) for MLT-3.

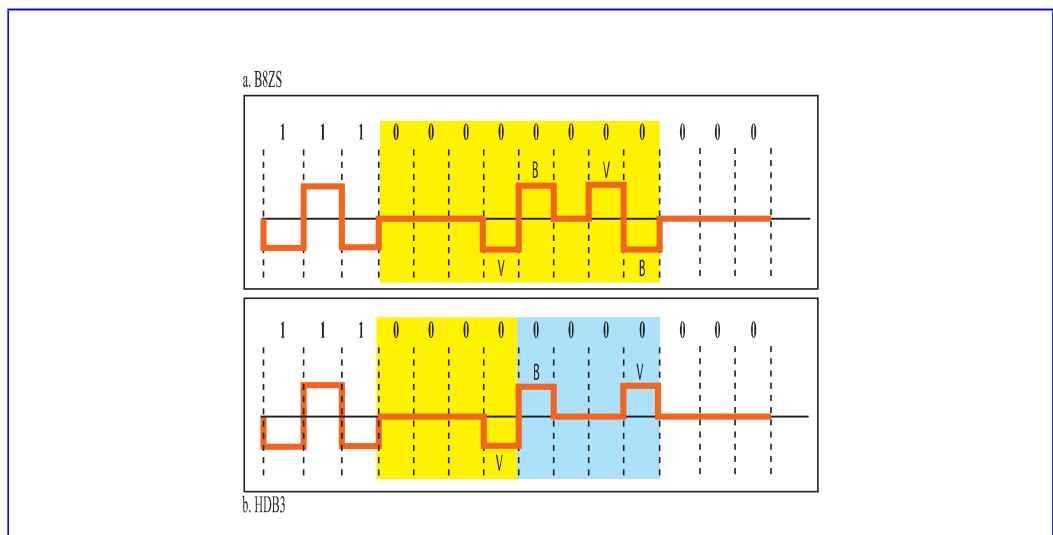
Figure 4.6 Solution to Exercise 20



21. The data stream can be found as
- NRZ-I: **10011001**.
 - Differential Manchester: **11000100**.
 - AMI: **01110001**.
22. The data rate is 100 Kbps. For each case, we first need to calculate the value f / N . We then use Figure 4.6 in the text to find P (energy per Hz). All calculations are approximations.

- a. $f/N = 0/100 = 0 \rightarrow P = 1.0$
 b. $f/N = 50/100 = 1/2 \rightarrow P = 0.5$
 c. $f/N = 100/100 = 1 \rightarrow P = 0.0$
 d. $f/N = 150/100 = 1.5 \rightarrow P = 0.2$
23. The data rate is 100 Kbps. For each case, we first need to calculate the value f/N . We then use Figure 4.8 in the text to find P (energy per Hz). All calculations are approximations.
- a. $f/N = 0/100 = 0 \rightarrow P = 0.0$
 b. $f/N = 50/100 = 1/2 \rightarrow P = 0.3$
 c. $f/N = 100/100 = 1 \rightarrow P = 0.4$
 d. $f/N = 150/100 = 1.5 \rightarrow P = 0.0$
- 24.
- a. The output stream is **01010 11110 11110 11110 11110 01001**.
 b. The maximum length of consecutive 0s in the input stream is **21**.
 c. The maximum length of consecutive 0s in the output stream is **2**.
25. In 5B/6B, we have $2^5 = 32$ data sequences and $2^6 = 64$ code sequences. The number of unused code sequences is $64 - 32 = 32$. In 3B/4B, we have $2^3 = 8$ data sequences and $2^4 = 16$ code sequences. The number of unused code sequences is $16 - 8 = 8$.
26. See Figure 4.7. Since we specified that the last non-zero signal is positive, the first bit in our sequence is positive.

Figure 4.7 Solution to Exercise 26



- 27.
- a. In a low-pass signal, the minimum frequency 0. Therefore, we have
- $$f_{\max} = 0 + 200 = 200 \text{ KHz.} \rightarrow f_s = 2 \times 200,000 = 400,000 \text{ samples/s}$$

- b. In a bandpass signal, the maximum frequency is equal to the minimum frequency plus the bandwidth. Therefore, we have

$$f_{\max} = 100 + 200 = 300 \text{ KHz.} \rightarrow f_s = 2 \times 300,000 = \mathbf{600,000 \text{ samples/s}}$$

28.

- a. In a lowpass signal, the minimum frequency is 0. Therefore, we can say

$$f_{\max} = 0 + 200 = 200 \text{ KHz} \rightarrow f_s = 2 \times 200,000 = \mathbf{400,000 \text{ samples/s}}$$

The number of bits per sample and the bit rate are

$$n_b = \log_2 1024 = 10 \text{ bits/sample} \quad N = 400 \text{ KHz} \times 10 = \mathbf{4 \text{ Mbps}}$$

- b. The value of $n_b = 10$. We can easily calculate the value of SNR_{dB}

$$\text{SNR}_{\text{dB}} = 6.02 \times n_b + 1.76 = \mathbf{61.96}$$

- c. The value of $n_b = 10$. The minimum bandwidth can be calculated as

$$B_{\text{PCM}} = n_b \times B_{\text{analog}} = 10 \times 200 \text{ KHz} = \mathbf{2 \text{ MHz}}$$

29. The maximum data rate can be calculated as

$$N_{\max} = 2 \times B \times n_b = 2 \times 200 \text{ KHz} \times \log_2 4 = \mathbf{800 \text{ kbps}}$$

30. We can first calculate the sampling rate (f_s) and the number of bits per sample (n_b)

$$f_{\max} = 0 + 4 = 4 \text{ KHz} \rightarrow f_s = 2 \times 4 = \mathbf{8000 \text{ sample/s}}$$

We then calculate the number of bits per sample.

$$\rightarrow n_b = 30000 / 8000 = 3.75$$

We need to use the next integer $n_b = 4$. The value of SNR_{dB} is

$$\text{SNR}_{\text{dB}} = 6.02 \times n_b + 1.72 = \mathbf{25.8}$$

31. We can calculate the data rate for each scheme:

- | | | |
|---------------|---------------|---|
| a. NRZ | \rightarrow | $N = 2 \times B = 2 \times 1 \text{ MHz} = \mathbf{2 \text{ Mbps}}$ |
| b. Manchester | \rightarrow | $N = 1 \times B = 1 \times 1 \text{ MHz} = \mathbf{1 \text{ Mbps}}$ |
| c. MLT-3 | \rightarrow | $N = 3 \times B = 3 \times 1 \text{ MHz} = \mathbf{3 \text{ Mbps}}$ |
| d. 2B1Q | \rightarrow | $N = 4 \times B = 4 \times 1 \text{ MHz} = \mathbf{4 \text{ Mbps}}$ |

32.

- a. For synchronous transmission, we have $1000 \times 8 = \mathbf{8000 \text{ bits}}$.
- b. For asynchronous transmission, we have $1000 \times 10 = \mathbf{10000 \text{ bits}}$. Note that we assume only one stop bit and one start bit. Some systems send more start bits.
- c. For case a, the redundancy is 0%. For case b, we send 2000 extra for 8000 required bits. The redundancy is $\mathbf{25\%}$.