CHAPTER 3

Data and Signals

Solutions to Review Questions and Exercises

Review Questions

1. Frequency and period are the inverse of each other. T = 1/ f and f = 1/T.
2. The amplitude of a signal measures the value of the signal at any point. The frequency of a signal refers to the number of periods in one second. The phase describes the position of the waveform relative to time zero.
3. Using Fourier analysis. Fourier series gives the frequency domain of a periodic signal; Fourier analysis gives the frequency domain of a nonperiodic signal.
4. Three types of transmission impairment are attenuation, distortion, and noise.
5. Baseband transmission means sending a digital or an analog signal without modulation using a low-pass channel. Broadband transmission means modulating a digital or an analog signal using a band-pass channel.
6. A low-pass channel has a bandwidth starting from zero; a band-pass channel has a bandwidth that does not start from zero.
7. The Nyquist theorem defines the maximum bit rate of a noiseless channel.
8. The Shannon capacity determines the theoretical maximum bit rate of a noisy channel.
9. Optical signals have very high frequencies. A high frequency means a short wavelength because the wavelength is inversely proportional to the frequency (\( \lambda = \frac{v}{f} \)), where v is the propagation speed in the media.
10. A signal is periodic if its frequency domain plot is discrete; a signal is nonperiodic if its frequency domain plot is continuous.
11. The frequency domain of a voice signal is normally continuous because voice is a nonperiodic signal.
12. An alarm system is normally periodic. Its frequency domain plot is therefore discrete.
13. This is baseband transmission because no modulation is involved.
14. This is baseband transmission because no modulation is involved.
15. This is broadband transmission because it involves modulation.
Exercises

16.  
   a. \( T = \frac{1}{f} = \frac{1}{(24 \text{ Hz})} = 0.0417 \text{ s} = 41.7 \times 10^{-3} \text{ s} = 41.7 \text{ ms} \)  
   b. \( T = \frac{1}{f} = \frac{1}{(8 \text{ MHz})} = 0.000000125 = 0.125 \times 10^{-6} \text{ s} = 0.125 \mu \text{s} \)  
   c. \( T = \frac{1}{f} = \frac{1}{(140 \text{ KHz})} = 0.00000714 \text{ s} = 7.14 \times 10^{-6} \text{ s} = 7.14 \mu \text{s} \)

17.  
   a. \( f = \frac{1}{T} = \frac{1}{(5 \text{ s})} = 0.2 \text{ Hz} \)  
   b. \( f = \frac{1}{T} = \frac{1}{(12 \mu \text{s})} = 83.333 \text{ KHz} = 83.333 \times 10^{3} \text{ Hz} = 83.333 \text{ KHz} \)  
   c. \( f = \frac{1}{T} = \frac{1}{(220 \text{ ns})} = 4550000 \text{ Hz} = 4.55 \times 10^{6} \text{ Hz} = 4.55 \text{ MHz} \)

18.  
   a. 90 degrees (\( \pi/2 \text{ radian} \))  
   b. 0 degrees (0 radian)  
   c. 90 degrees (\( \pi/2 \text{ radian} \))

19. See Figure 3.1

20. We know the lowest frequency, 100. We know the bandwidth is 2000. The highest frequency must be \( 100 + 2000 = 2100 \text{ Hz} \). See Figure 3.2

21. Each signal is a simple signal in this case. The bandwidth of a simple signal is zero. So the bandwidth of both signals are the same.

22.  
   a. bit rate = \( 1 / \text{(bit duration)} = 1 / (0.001 \text{ s}) = 1000 \text{ bps} = 1 \text{ Kbps} \)  
   b. bit rate = \( 1 / \text{(bit duration)} = 1 / (2 \text{ ms}) = 500 \text{ bps} \)
c. bit rate = 1/(bit duration) = 1 / (20 μs/10) = 1 / (2 μs) = 500 Kbps

23.
   a. (10 / 1000) s = 0.01 s
   b. (8 / 1000) s = 0.008 s = 8 ms
   c. ((100,000 × 8) / 1000) s = 800 s

24. There are 8 bits in 16 ns. Bit rate is 8 / (16 × 10⁻⁹) = 0.5 × 10⁻⁹ = 500 Mbps

25. The signal makes 8 cycles in 4 ms. The frequency is 8 / (4 ms) = 2 KHz

26. The bandwidth is 5 × 5 = 25 Hz.

27. The signal is periodic, so the frequency domain is made of discrete frequencies. as shown in Figure 3.3.

![Figure 3.3 Solution to Exercise 27](image)

28. The signal is nonperiodic, so the frequency domain is made of a continuous spectrum of frequencies as shown in Figure 3.4.

![Figure 3.4 Solution to Exercise 28](image)

29. Using the first harmonic, data rate = 2 × 6 MHz = 12 Mbps
   Using three harmonics, data rate = (2 × 6 MHz) / 3 = 4 Mbps
   Using five harmonics, data rate = (2 × 6 MHz) / 5 = 2.4 Mbps

30. dB = 10 log₁₀ (90 / 100) = -0.46 dB

31. -10 = 10 log₁₀ (P₂ / 5) → log₁₀ (P₂ / 5) = -1 → (P₂ / 5) = 10⁻¹ → P₂ = 0.5 W

32. The total gain is 3 × 4 = 12 dB. The signal is amplified by a factor 10¹² = 15.85.
33. 100,000 bits / 5 Kbps = 20 s
34. 480 s \times 300,000 \text{ km/s} = 144,000,000 \text{ km}
35. 1 \mu m \times 1000 = 1000 \mu m = 1 \text{ mm}
36. We have
   \[ 4000 \log_2 (1 + 1000) = 40 \text{ Kbps} \]
37. We have
   \[ 4000 \log_2 (1 + 10 / 0.005) = 43,866 \text{ bps} \]
38. The file contains 2,000,000 \times 8 = 16,000,000 bits. With a 56-Kbps channel, it takes 16,000,000/56,000 = 289 s. With a 1-Mbps channel, it takes 16 s.
39. To represent 1024 colors, we need \log_2 1024 = 10 (see Appendix C) bits. The total number of bits are, therefore,
   \[ 1200 \times 1000 \times 10 = 12,000,000 \text{ bits} \]
40. We have
   \[ \text{SNR} = (200 \text{ mW}) / (10 \times 2 \times \mu \text{W}) = 10,000 \]
   We then have
   \[ \text{SNR}_{\text{db}} = 10 \log_{10} \text{SNR} = 40 \]
41. We have
   \[ \text{SNR} = \frac{\text{signal power}}{\text{noise power}}. \]
   However, power is proportional to the square of voltage. This means we have
   \[ \text{SNR} = \frac{[(\text{signal voltage})^2]}{[(\text{noise voltage})^2]} = \frac{[(\text{signal voltage})/ (\text{noise voltage})]^2}{20^2} = 400 \]
   We then have
   \[ \text{SNR}_{\text{db}} = 10 \log_{10} \text{SNR} = 26.02 \]
42. We can approximately calculate the capacity as
   a. \( C = B \times (\text{SNR}_{\text{db}} / 3) = 20 \text{ KHz} \times (40 / 3) = 267 \text{ Kbps} \)
   b. \( C = B \times (\text{SNR}_{\text{db}} / 3) = 200 \text{ KHz} \times (4 / 3) = 267 \text{ Kbps} \)
   c. \( C = B \times (\text{SNR}_{\text{db}} / 3) = 1 \text{ MHz} \times (20 / 3) = 6.67 \text{ Mbps} \)
43. a. The data rate is doubled (\( C_2 = 2 \times C_1 \)).
   b. When the \( \text{SNR} \) is doubled, the data rate increases slightly. We can say that, approximately, \( C_2 = C_1 + 1 \).
44. We can use the approximate formula
   \[ C = B \times (\text{SNR}_{\text{db}} / 3) \text{ or } \text{SNR}_{\text{db}} = (3 \times C) / B \]
   We can say that the minimum
   \[ \text{SNR}_{\text{db}} = 3 \times 100 \text{ Kbps} / 4 \text{ KHz} = 75 \]
This means that the minimum

\[ \text{SNR} = 10^{\frac{\text{SNR}_{\text{dB}}}{10}} = 10^{7.5} = 31,622,776 \]

45. We have

\[ \text{transmission time} = \frac{\text{packet length}}{\text{bandwidth}} = \frac{(8,000,000 \text{ bits})}{(200,000 \text{ bps})} = 40 \text{ s} \]

46. We have

\[ \text{(bit length)} = \frac{\text{(propagation speed)}}{\text{(bit duration)}} \]

The bit duration is the inverse of the bandwidth.

a. Bit length = \( (2 \times 10^8 \text{ m}) \times [\frac{1}{(1 \text{ Mbps})}] = 200 \text{ m} \). This means a bit occupies 200 meters on a transmission medium.

b. Bit length = \( (2 \times 10^9 \text{ m}) \times [\frac{1}{(10 \text{ Mbps})}] = 20 \text{ m} \). This means a bit occupies 20 meters on a transmission medium.

c. Bit length = \( (2 \times 10^9 \text{ m}) \times [\frac{1}{(100 \text{ Mbps})}] = 2 \text{ m} \). This means a bit occupies 2 meters on a transmission medium.

47.

a. Number of bits = bandwidth \times delay = 1 \text{ Mbps} \times 2 \text{ ms} = 2000 \text{ bits}

b. Number of bits = bandwidth \times delay = 10 \text{ Mbps} \times 2 \text{ ms} = 20,000 \text{ bits}

c. Number of bits = bandwidth \times delay = 100 \text{ Mbps} \times 2 \text{ ms} = 200,000 \text{ bits}

48. We have

\[ \text{Latency} = \text{processing time} + \text{queuing time} + \text{transmission time} + \text{propagation time} \]

Processing time = 10 \times 1 \mu s = 10 \mu s = 0.000010 \text{ s}

Queuing time = 10 \times 2 \mu s = 20 \mu s = 0.000020 \text{ s}

Transmission time = 5,000,000 / (5 \text{ Mbps}) = 1 \text{ s}

Propagation time = (2000 \text{ Km}) / (2 \times 10^8) = 0.01 \text{ s}

\[ \text{Latency} = 0.000010 + 0.000020 + 1 + 0.01 = 1.01000030 \text{ s} \]

The transmission time is dominant here because the packet size is huge.