CHAPTER 3
Data and Signals

Review Questions

1. What is the relationship between period and frequency?
Ans: The period of a signal is the inverse of its frequency and vice versa, i.e. T=1/f and f=1/T..

2. What does the amplitude of a signal measure? What does the frequency of a signal measure? What does the phase of a signal measure?
Ans: The amplitude of a signal measures the value of the signal at any point.
The frequency of a signal measure the number of periods in one second.
The phase of a signal measure the position of the waveform relative to time zero.

3. How can a composite signal be decomposed into its individual frequencies?
Ans: Here is two facts, Fourier series gives the frequency domain of a periodic signal and Fourier analysis gives the frequency domain of a non-periodic signal.

4. Name three types of transmission impairment.
Ans: Three types of transmission impairment are: Attenuation, Distortion, and Noise.

5. Distinguish between baseband transmission and broadband transmission.
Ans: Baseband transmission means sending a digital or an analog signal without modulation using a low-pass channel.
Broadband transmission means to modulate signal using a band-pass channel.

6. Distinguish between a low-pass channel and a band-pass channel.
Ans: A low-pass channel has a bandwidth starting from zero.
A band-pass channel has a bandwidth that does not start from zero.

7. What does the Nyquist theorem have to do with communications?
Ans: The Nyquist theorem defines the maximum bit rate of a noiseless channel.

8. What does the Shannon capacity have to do with communications?
Ans: The Shannon capacity determines the theoretical maximum bit rate of a noisy channel.

9. Why do optical signals used in fiber optic cables have a very short wave length?
Ans: Optical signals have very high frequencies. when frequency is very high,then the wavelength is very low. Because, $\lambda = v/f$, where v is the propagation speed in the media.

10. Can we say if a signal is periodic or non-periodic by just looking at its frequency domain plot? How?
Ans: Yes, we can say a signal is periodic or non-periodic by just looking at its frequency domain plot. Because of, a signal is periodic if its frequency domain plot is discrete and a signal is non-periodic if its frequency domain plot is continuous.

11. Is the frequency domain plot of a voice signal discrete or continuous?
Ans: The frequency domain of a voice signal is normally continuous because voice is a non-periodic signal.

12. Is the frequency domain plot of an alarm system discrete or continuous?
Ans: An alarm system is normally periodic. That means Its frequency domain plot is discrete.

13. We send a voice signal from a microphone to a recorder. Is this baseband or broadband transmission?
Ans: When we send a voice signal from a microphone to a recorder, here no modulation is involved. That means this is a baseband transmission.

14. We send a digital signal from one station on a LAN to another station. Is this baseband or broadband transmission?
Ans: When we send a digital signal from one station on a LAN to another station, here no modulation is involved. That means this is a baseband transmission.

15. We modulate several voice signals and send them through the air. Is this baseband or broadband transmission?
Ans: When we modulate several voice signals and send them through the air, here modulation is involved. That means this is a broadband transmission.

Exercises

16. Given the frequencies listed below, calculate the corresponding periods.
  a. 24Hz
  b. 8 MHz
  c. 140 KHz

Ans:
a. T = 1 / f = 1 / (24 Hz) = 0.0417 s = 41.7 $\times$ 10–3 s = 41.7 ms
b. T = 1 / f = 1 / (8 MHz) = 0.000000125 = 0.125 $\times$ 10–6 s = 0.125 μ s
c. T = 1 / f = 1 / (140 KHz) = 0.00000714 s = 7.14 $\times$ 10–6 s = 7.14 μ s

17. Given the following periods, calculate the corresponding frequencies.
  a. 5 s
  b. 12 Jls
  c. 220 ns

Ans:
a. f = 1 / T = 1 / (5 s) = 0.2 Hz
b. f = 1 / T = 1 / (12 μs) =83333 Hz = 83.333 × 103 Hz = 83.333 KHz
c. f = 1 / T = 1 / (220 ns) = 4550000 Hz = 4.55× 106 Hz = 4.55 MHz

18. What is the phase shift for the foIlowing ?
  a. A sine wave with the maximum amplitude at time zero

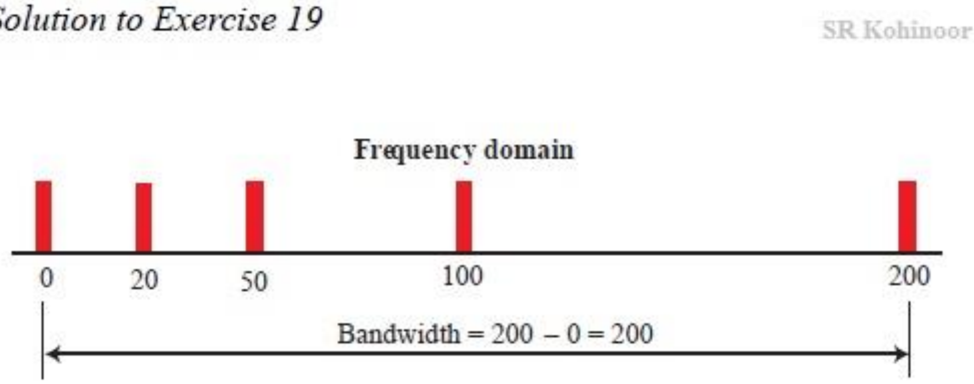
b. A sine wave with maximum amplitude after 1/4 cycle
c. A sine wave with zero amplitude after 3/4 cycle and increasing

Ans:
a. 90 degrees (π/2 radian)
b. 0 degrees (0 radian)
c. 90 degrees (π/2 radian)

19. What is the bandwidth of a signal that can be decomposed into five sine waves with frequencies at 0, 20, 50, 100, and 200 Hz? All peak amplitudes are the same. Draw the bandwidth.

Ans:

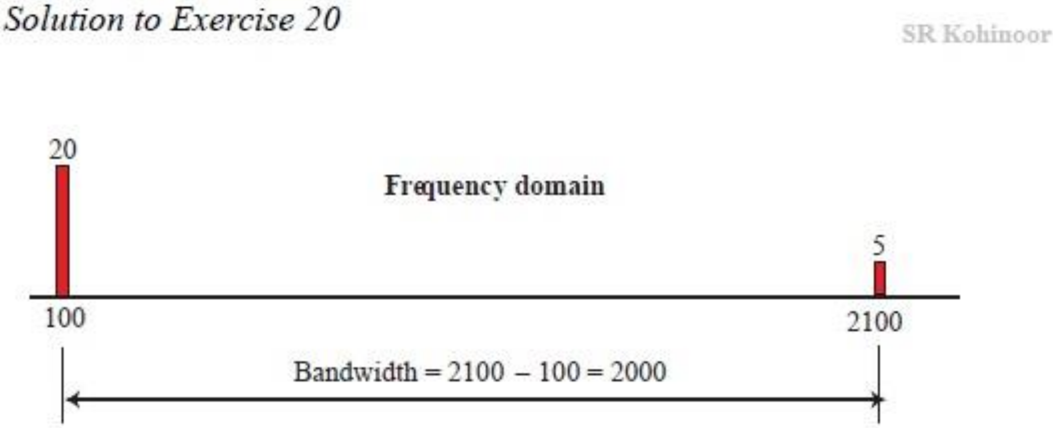
Solution to Exercise 19



20. A periodic composite signal with a bandwidth of 2000 Hz is composed of two sine waves. The first one has a frequency of 100 Hz with a maximum amplitude of 20 V; the second one has a maximum amplitude of 5 V. Draw the bandwidth.

Ans:

Solution to Exercise 20



21. Which signal has a wider bandwidth, a sine wave with a frequency of 100 Hz or a sine wave with a frequency of 200 Hz?

Ans:
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. What is the bit rate for each of the following signals?
   a. A signal in which 1 bit lasts 0.001 s
   b. A signal in which 1 bit lasts 2 ms
   c. A signal in which 10 bits last 20 J-ls

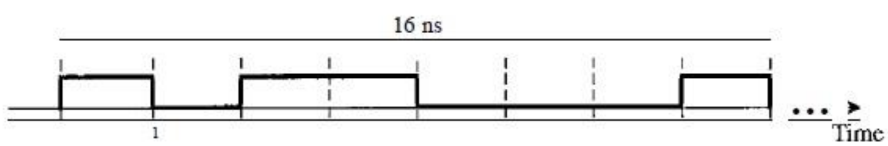
Ans:
a. bit rate = 1/ (bit duration) = 1 / (0.001 s) = 1000 bps = 1 Kbps
b. bit rate = 1/ (bit duration) = 1 / (2 ms) = 500 bps
c. bit rate = 1/(bit duration) = 1 / (20 μs/10) = 1 / (2 μs) = 500 Kbps

23. A device is sending out data at the rate of 1000 bps.
   a. How long does it take to send out 10 bits?
   b. How long does it take to send out a single character (8 bits)?
   c. How long does it take to send a file of 100,000 characters?

Ans:
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. What is the bit rate for the signal in Figure 3.34?

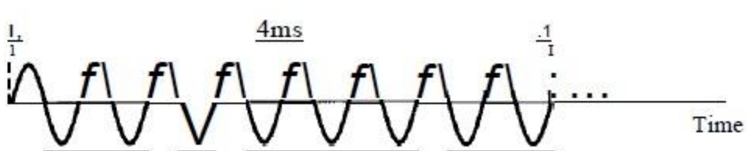
Figure 3.34 *Exercise 24*



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

25. What is the frequency of the signal in Figure 3.35?

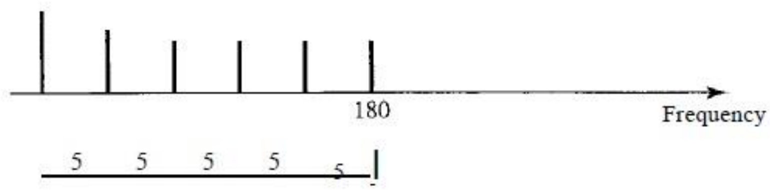
Figure 3.35 *Exercise 25*



Ans: The signal makes 8 cycles in 4 ms.
.: The frequency = 8 /4 = 2 KHz

26. What is the bandwidth of the composite signal shown in Figure 3.36.

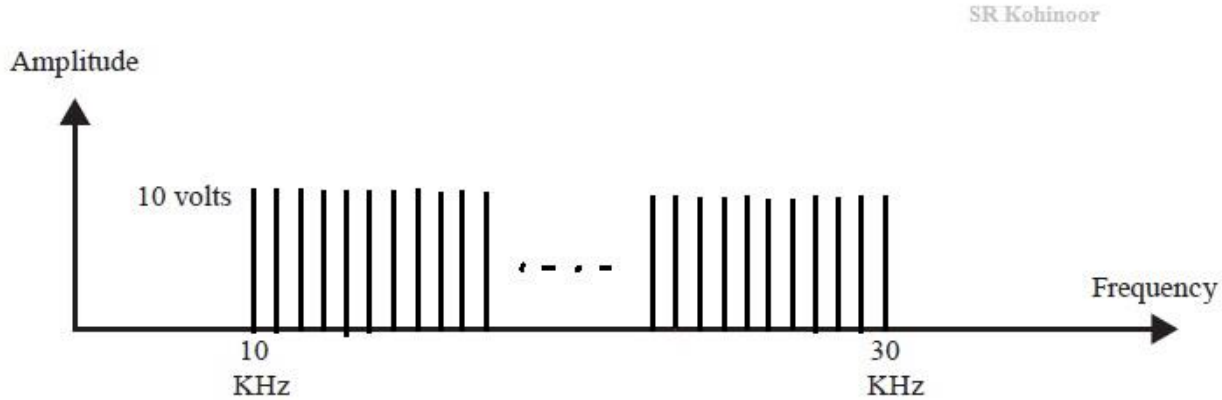
Figure 3.36 *Exercise 26*



Ans: The bandwidth is 5 × 5 = 25 Hz.

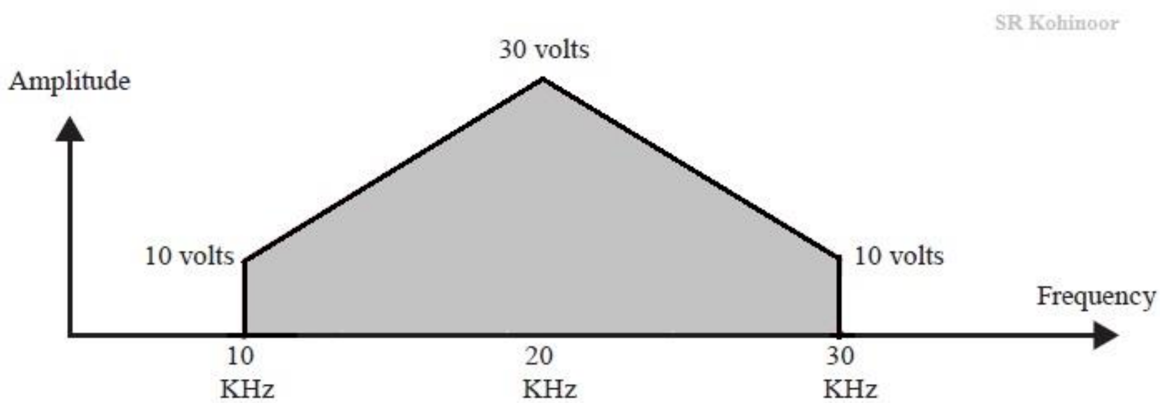
27. A periodic composite signal contains frequencies from 10 to 30 KHz, each with an amplitude of 10 V. Draw the frequency spectrum.

Ans: The signal is periodic and the frequency domain is made of discrete Like as this Diagram:



28. A non-periodic composite signal contains frequencies from 10 to 30 KHz. The peak amplitude is 10 V for the lowest and the highest signals and is 30 V for the 20-KHz signal. Assuming that the amplitudes change gradually from the minimum to the maximum, draw the frequency spectrum.

Ans: The signal is non periodic and the frequency domain is made of a continuous spectrum like as this figure…



29. A TV channel has a bandwidth of 6 MHz. If we send a digital signal using one channel, what are the data rates if we use one harmonic, three harmonics, and five harmonics?

Ans:

For one harmonic, data rate = $2 \times 6 = 12$ Mbps
For three harmonics, data rate = $(2 \times 6) / 3 = 4$ Mbps
For five harmonics, data rate = $(2 \times 6) / 5 = 2.4$ Mbps

30. A signal travels from point A to point B. At point A, the signal power is 100 W. At point B, the power is 90 W. What is the attenuation in decibels?

Ans: The attenuation dB = $10 \log_{10} (90 / 100)$
$= -0.46$ dB

31. The attenuation of a signal is -10 dB. What is the final signal power if it was originally 5 W?

Ans: Here, $-10 \text{ dB} = 10 \log_{10} (P2 / 5)$
$\Rightarrow \log_{10} (P2 / 5) = -1$
$\Rightarrow (P2 / 5) = 10^{-1}$
$\therefore P2 = 0.5$ W

32. A signal has passed through three cascaded amplifiers, each with a 4 dB gain. What is the total gain? How much is the signal amplified?

Ans: Here number of Amplifier = 3.
$\therefore$ The total gain = $3 \times 4 = 12$ dB.
Again, The signal is amplified, $12 = 10 \log (P2/P1)$
$\Rightarrow \log (P2/P1) = 1.2$
$\Rightarrow P2/P1 = 10^{1.2} = 15.85$.

33. If the bandwidth of the channel is 5 Kbps, how long does it take to send a frame of 100,000 bits out of this device?

Ans: Here, Bandwidth = 5 Kbps, Frame = 1,00,000 bits
$\therefore$ 1,00,000 bits / 5 Kbps = 20 s

34. The light of the sun takes approximately eight minutes to reach the earth. What is the distance between the sun and the earth?

Ans: Here, approximate Time = 8 minutes = 8 * 60 = 480 s
Speed of light = $3*10^8$ ms^{-1} = 300000 kms^{-1}
$\therefore$ The Distance = 480 * 300000 = 144000000 km

35. A signal has a wavelength of 1 µm in air. How far can the front of the wave travel during 1000 periods?

Ans: Here, wavelength = 1 µm , periods = 1000
$\therefore$ Distance = 1 * 1000 = 1000 µm = 1 mm

36. A line has a signal-to-noise ratio of 1000 and a bandwidth of 4000 KHz. What is the maximum data rate supported by this line?

Ans: Given, bandwidth, B = 4000 KHz, SNR = 1000
So, We know the Shannon capacity $C = B \log_2 (1 + SNR)$

$\therefore C = 4000 \log_2 (1 + 1000) \approx 40$ Kbps

37. We measure the performance of a telephone line (4 KHz of bandwidth). When the signal is 10 V, the noise is 5 mV. What is the maximum data rate supported by this telephone line?

Ans: Given, bandwidth, B = 4 KHz = 4000 Hz,
Signal = 10 V, Noise = 5 mV = 0.005 V
$\therefore$ SNR = 10 / 0.005 = 2000
So, We know, $C = B \log_2 (1 + SNR)$
$\therefore C = 4000 \log2 (1 + 2000) = 43866$ bps

38. A file contains 2 million bytes. How long does it take to download this file using a 56-Kbps channel? 1-Mbps channel?

Ans: Given, the file contains = 2 million bytes = 2000000 × 8 = 16000000 bits.
$\therefore$ With a 56-Kbps channel, it takes 16000000/56000 = 289 s ≈ 5 minutes.
Again, With a 1-Mbps channel, it takes 16000000/1000000 = 16 s.

39. A computer monitor has a resolution of 1200 by 1000 pixels. If each pixel uses 1024 colors, how many bits are needed to send the complete contents of a screen?

Ans: To represent 1024 colors, we need $\log_2 1024 = 10$ bits.
$\therefore$ The total number of bits are, 1200 × 1000 × 10 = 12000000 bits

40. A signal with 200 milliwatts power passes through 10 devices, each with an average noise of 2 microwatts. What is the SNR? What is the SNR_{dB}?

Ans: Given, signal = 200 mW = 0.2W
Noise = $10 * 2\ \mu W = 2 * 10^{-5}$
$\therefore$ We Know, SNR = (signal power)/(noise power) = $0.2 / (2 * 10^{-5}) = 10000$
$SNR_{dB} = 10 \log_{10} SNR = 10 \log_{10} 10000 = 40$

41. If the peak voltage value of a signal is 20 times the peak voltage value of the noise, what is the SNR? What is the SNRdB?

Ans: We Know, SNR= (signal power) / (noise power).
SNR = $[(\text{signal voltage})^2] / [(\text{noise voltage})^2]$
$= [(\text{signal voltage}) / (\text{noise voltage})]^2 = 20^2 = 400$
Now, $SNR_{dB} = 10 \log_{10} SNR = 10 \log_{10} 400 \approx 26.02$

42. What is the theoretical capacity of a channel in each of the following cases:
   a. Bandwidth: 20 KHz SNR_{dB} =40
   b. Bandwidth: 200 KHz SNR_{dB} =4
   c. Bandwidth: 1 MHz SNR_{dB} =20

Ans: We can approximately calculate the capacity as
a. $C = B * (SNR_{dB} /3) = 20 * (40 /3) = 267$ Kbps
b. $C = B * (SNR_{dB} /3) = 200 * (4 /3) = 267$ Kbps
c. $C = B * (SNR_{dB} /3) = 1 * (20 /3) = 6.67$ Mbps

43. We need to upgrade a channel to a higher bandwidth. Answer the following questions:
   a. How is the rate improved if we double the bandwidth?

b. How is the rate improved if we double the SNR?

Ans: a. If we double the bandwidth, the data rate is doubled ($C_2 = 2 \times C_1$).

b. When the SNR is doubled, data rate increases slightly, approximately ($C_2 = C_1 + 1$).

44. We have a channel with 4 KHz bandwidth. If we want to send data at 100 Kbps, what is the minimum SNR_{dB}? What is SNR?

Ans: Given, bandwidth = 4 KHz, Data rate = 100 Kbps

We know, $C = B * (SNR_{dB} /3)$

$=> SNR_{dB} = (3 * C) / B$

.˙. minimum of $SNR_{dB} = (3 * 100) / 4 = 75$

So, the minimum SNR = $10^{SNR_{dB}/10} = 10^{7.5}$

≈ 31622776

45. What is the transmission time of a packet sent by a station if the length of the packet is 1 million bytes and the bandwidth of the channel is 200 Kbps?

Ans: Given, packet length = 1 million bytes = 1000000 * 8 bits = 8000000 bits

Bandwidth = 200 Kbps = 200000 bps

.˙. We know, transmission time = (packet length)/(bandwidth)

= 8000000 / 200000 = 40 s

46. What is the length of a bit in a channel with a propagation speed of 2×10^8 m/s if the channel bandwidth is

a. 1 Mbps?
b. 10 Mbps?
c. 100 Mbps?

Ans: We know that,

bit length = propagation speed * bit duration

but, bit duration is the inverse of the bandwidth.

So, bit length = propagation speed * (1 / bandwidth)

a. Given, bandwidth = 1 Mbps = 10^6 bps
   .˙. Bit length = $2*10^8 * (1 / 10^6)$ = 200 m.
b. Given, bandwidth = 10 Mbps = 10^7 bps
   .˙. Bit length = $2*10^8 * (1 / 10^7)$ = 20 m.
c. Given, bandwidth = 100 Mbps = 10^8 bps
   .˙. Bit length = $2 * 10^8 * (1 / 10^8)$ = 2 m.

47. How many bits can fit on a link with a 2 ms delay if the bandwidth of the link is

a. 1 Mbps?
h. 10 Mbps?
c. 100 Mbps?

Ans: We know that, Number of bits = bandwidth * delay

a. Number of bits = $(1*10^6) * (2*10^{-3})$ = 2000 bits

b. Number of bits = $(10*10^6) * (2*10^{-3})$ = 20000 bits

c. Number of bits = $(100*10^6) * (2*10^{-3})$ = 200000 bits

48. What is the total delay (latency) for a frame of size 5 million bits that is being sent on a link with 10 routers each having a queuing time of 2 μs and a processing time of 1 μs. The length of the link is 2000 Km. The speed of light inside the link is 2×10^8 m/s. The link has a bandwidth of 5 Mbps. Which component of the total delay is dominant? Which one is negligible?

Ans: Given,

Processing time = 10×1 μs = 10 μs = 10^{-6} s

Queuing time = 10×2 μs = 20 μs = $20*10^{-6}$ s

Transmission time = frame of size / bandwidth = 5000000 / $(5*10^6)$ = 1 s

Propagation time = distance / speed = $(2000*10^3) / (2 \times 10^8)$ = 0.01 s

We know that,

Latency = processing time + queuing time + transmission time + propagation time

$= 10^{-6} + 20*10^{-6} + 1 + 0.01$

$= 1.01000030$ s

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