Chapter 3

(Solution)

Questions

Q3-1. What is the relationship between period and frequency?

Frequency and ***period*** are the inverse of each other. T = 1/ f and f = 1/T.

Q3-2. What does the amplitude of a signal measure? What does the frequency of a signal measure? What does the phase of a signal measure?

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.

Q3-3. How can a composite signal be decomposed into its individual frequencies?

Using Fourier analysis. ***Fourier series*** gives the frequency domain of a periodic signal; ***Fourier analysis*** gives the frequency domain of a nonperiodic signal.

Q3-4. Name three types of transmission impairment.

Three types of transmission impairment are ***attenuation***, ***distortion***, and ***noise***.

Q3-5. Distinguish between baseband transmission and broadband transmission.

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.

Q3-6. Distinguish between a low-pass channel and a band-pass channel.

A ***low-pass channel*** has a bandwidth starting from zero; a ***band-pass*** channel has a bandwidth that does not start from zero.

Q3-7. What does the Nyquist theorem have to do with communications?

The ***Nyquist theorem*** defines the maximum bit rate of a noiseless channel.

Q3-8. What does the Shannon capacity have to do with communications?

The ***Shannon capacity*** determines the theoretical maximum bit rate of a noisy channel.

Q3-9. Why do optical signals used in fiber optic cables have a very short wave length?

Optical signals have very high frequencies. A high frequency means a short wave length because the wave length is inversely proportional to the frequency ($\lambda = v/f$), where v is the propagation speed in the media.

Q3-10. Can we say whether a signal is periodic or nonperiodic by just looking at its frequency domain plot? How?

A signal is ***periodic*** if its frequency domain plot is ***discrete***; a signal is **nonperiodic** if its frequency domain plot is ***continuous***.

Q3-11. Is the frequency domain plot of a voice signal discrete or continuous?

The frequency domain of a voice signal is normally ***continuous*** because voice is a ***nonperiodic*** signal.

Q3-12. Is the frequency domain plot of an alarm system discrete or continuous?

An alarm system is normally ***periodic***. Its frequency domain plot is therefore ***discrete***.

Q3-13. We send a voice signal from a microphone to a recorder. Is this baseband or broadband transmission?

This is ***baseband transmission*** because no modulation is involved.

Q3-14. We send a digital signal from one station on a LAN to another station. Is this baseband or broadband transmission?

This is ***baseband transmission*** because no modulation is involved.

Q3-15. We modulate several voice signals and send them through the air. Is this baseband or broadband transmission?

This is ***broadband transmission*** because it involves modulation.

Problems

P3-1. Given the frequencies listed below, calculate the corresponding periods.

a. 24 Hz **b. 8 MHz** **c. 140 KHz**

a. **T = 1 / f** = 1 / (24 Hz) = 0.0417 s = 41.7 × 10^-3 s = **41.7 ms**
b. **T = 1 / f** = 1 / (8 MHz) = 0.000000125 = 0.125 × 10^-6 s = **0.125** µs
c. **T = 1 / f** = 1 / (140 KHz) = 0.00000714 s = 7.14 × 10^-6 s = **7.14** µs

P3-2. Given the following periods, calculate the corresponding frequencies.

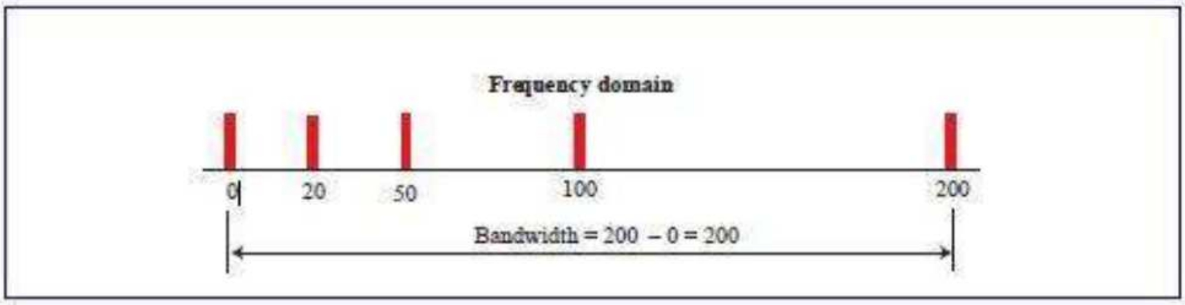
a. 5 s **b. 12µs** **c. 220 ns**

a. **f = 1 / T** = 1 / (5 s) = **0.2 Hz**
b. **f = 1 / T** = 1 / (12 µs) =83333 Hz = 83.333 × 10^3 Hz = **83.333 KHz**
c. **f = 1 / T** = 1 / (220 ns) = 4550000 Hz = 4.55× 10^6 Hz = **4.55 MHz**

P3-3. What is the phase shift for the following?
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

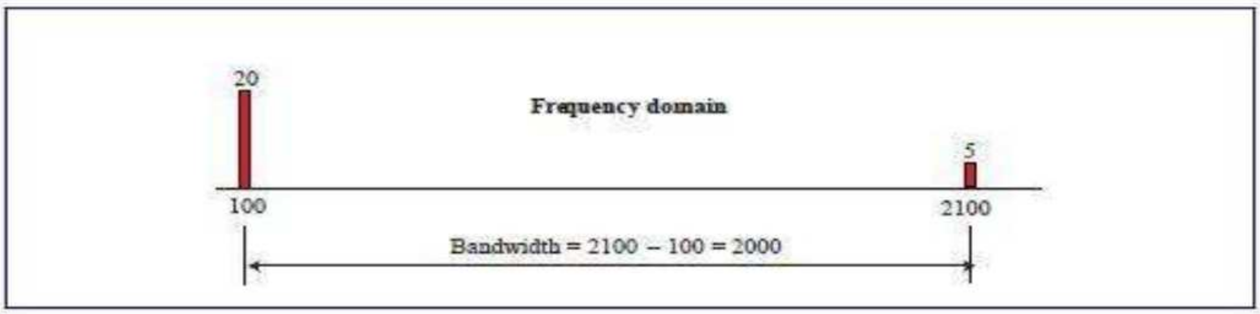
a. 90 degrees (π/2 radian)
b. 0 degrees (0 radian)
c. 90 degrees (π/2 radian)

P3-4. 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.



P3-5. 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.

We know the lowest frequency, 100. We know the bandwidth is 2000. The highest frequency must be 100 + 2000 = **2100 Hz**.



P3-6. 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?

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.

P3-7. 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**~~ **µs**

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**

P3-8. 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**~~**e character (8 bits)?**

~~**c. How long does it take to send a file of 100,000 characters?**~~

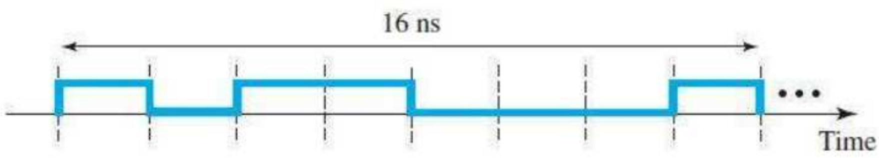
a. (10 / 1000) s = **0.01 s**

b. (8 / 1000) s = 0. 008 s = **8 ms**

c. ((100,000 × 8) / 1000) s = **800 s**

P3-9. What is the bit rate for the signal in Figure 3.35?

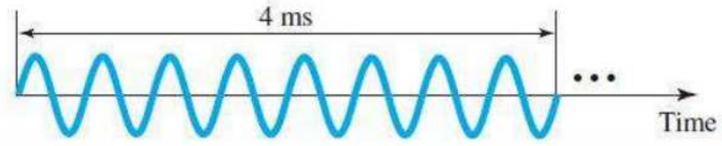
Figure 3.35 *Problem P3-9*



There are 8 bits in 16 ns. Bit rate is $8 / (16 \times 10^{-9}) = 0.5 \times 10^{-9}$ = **500 Mbps**

P3-10. What is the frequency of the signal in Figure 3.36?

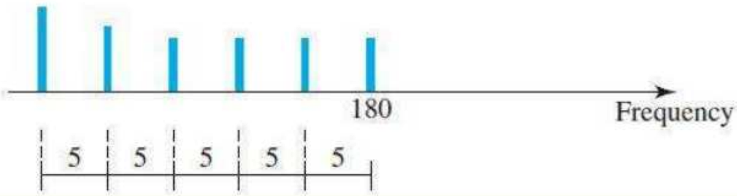
Figure 3.36 *Problem P3-10*



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

P3-11. What is the bandwidth of the composite signal shown in Figure 3.37?

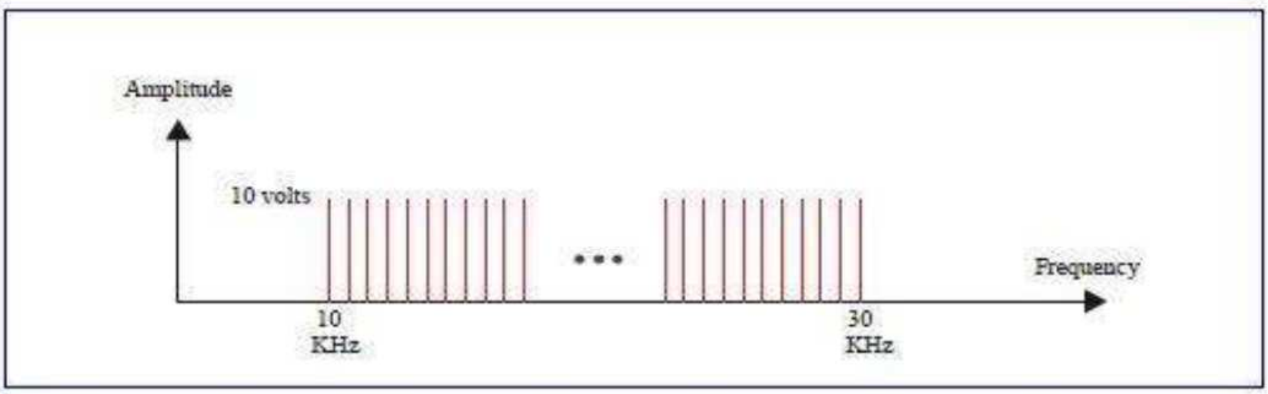
Figure 3.37 *Problem P3-11*



The bandwidth is 5 × 5 = **25 Hz**.

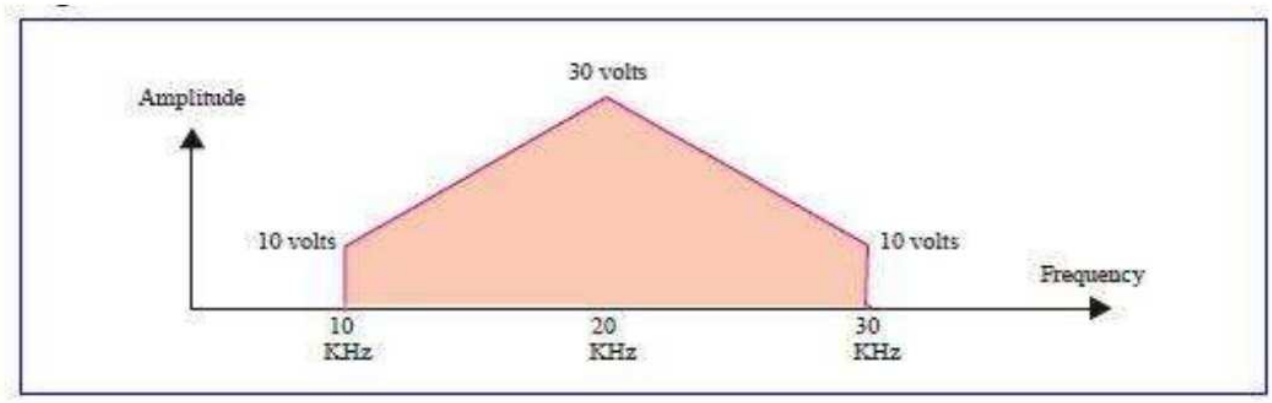
P3-12. A periodic composite signal contains frequencies from 10 to 30 KHz, each with an amplitude of 10 V. Draw the frequency spectrum.

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



P3-13. A nonperiodic 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.

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



P3-14. 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?

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

P3-15. 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?

dB = $10 \log_{10} (90 / 100)$ = **−0.46 dB**

P3-16. The attenuation of a signal is -10 dB. What is the final signal power if it was originally 5 W?

$-10 = 10 \log_{10} (P2 / 5) \rightarrow \log_{10} (P2 / 5) = -1 \rightarrow (P2 / 5) = 10^{-1} \rightarrow P2 =$ **0.5 W**

P3-17. 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?

The total gain is 3 × 4 = 12 dB. The signal is amplified by a factor 10^(1.2) = **15.85**.

P3-18. 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?

100,000 bits / 5 Kbps = **20 s**

P3-19. The light of the sun takes approximately eight minutes to reach the earth. What is the distance between the sun and the earth?

480 s × 300,000 km/s = **144,000,000 km**

P3-20. A signal has a wavelength of 1 μm in air. How far can the front of the wave travel during 1000 periods?

1 μm × 1000 = 1000 μm = **1 mm**

P3-21. 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?

We have **4,000 $\log_2$ (1 + 1,000) ≈ 40 Kbps**

P3-22. 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?

We have **4,000 $\log_2$ (1 + 10 / 0.005) = 43,866 bps**

P3-23. A file contains 2 million bytes. How long does it take to download this file using a 56-Kbps channel? 1-Mbps channel?

The file contains 2,000,000 × 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**.

P3-24. 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?

To represent 1024 colors, we need $\log_2 1024 = 10$ (see Appendix C) bits. The total number of bits are, therefore, **1200 × 1000 × 10 = 12,000,000 bits**

P3-25. 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}?

We have **SNR = (200 mW) / (10 × 2 × µW) = 10,000**
We then have **$SNR_{dB} = 10 \log_{10} SNR = 40$**

P3-26. 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 SNR_{dB}?

We have **SNR= (signal power)/(noise power)**
However, power is proportional to the square of voltage. This means we have

SNR = [(signal voltage)^2] / [(noise voltage)^2] =
[(signal voltage) / (noise voltage)]^2 = 20^2 = 400

We then have **$SNR_{dB} = 10 \log_{10} SNR \approx 26.02$**

P3-27. 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

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

P3-28. 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?

a. The data rate is doubled (C2 = 2 × C1).
b. When the SNR is doubled, the data rate increases slightly. We can say that, approximately, (C2 = C1 + 1).

P3-29. 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 the SNR?

We can use the approximate formula

$C = B \times (SNR_{dB} / 3)$ or $SNR_{dB} = (3 \times C) / B$

We can say that the minimum **$SNR_{dB} = 3 \times 100$ Kbps / 4 KHz = 75**

This means that **SNR = 10^(SNR_{dB}/10) = 10^7.5 ≈ 31,622,776**

P3-30. 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?

transmission time = (packet length)/(bandwidth) = (8,000,000 bits) / (200,000 bps) = 40 s

P3-31. 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?

(bit length) = (propagation speed) × (bit duration)

The bit duration is the inverse of the bandwidth.

a. Bit length = (2 ×10^8) × [(1 / (1 Mbps)] = **200 m**. This means a bit occupies 200 meters on a transmission medium.

b. Bit length = (2 ×10^8) × [(1 / (10 Mbps)] = **20 m**. This means a bit occupies 20 meters on a transmission medium.

c. Bit length = (2 ×10^8) × [(1 / (100 Mbps)] = **2 m**. This means a bit occupies 2 meters on a transmission medium.

P3-32. How many bits can fit on a link with a 2 ms delay if the bandwidth of the link is a. 1 Mbps? b. 10 Mbps? c. 100 Mbps?

a. Number of bits = bandwidth × delay = 1 Mbps × 2 ms = **2000 bits**

b. Number of bits = bandwidth × delay = 10 Mbps × 2 ms = **20,000 bits**

c. Number of bits = bandwidth × delay = 100 Mbps × 2 ms = **200,000 bits**

P3-33. 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 2μs and a processing time of 1μs. 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?

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

Processing time = 10×1 μs = 10 μs = **0.000010 s**
Queuing time = 10×2 μs = 20 μs = **0.000020 s**
Transmission time = 5,000,000 / (5 Mbps) = **1 s**
Propagation time = (2000 Km) / (2×10^8) = **0.01 s**
Latency = 0.000010 + 0.000020 + 1 + 0.01 = 1.01000030 s

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