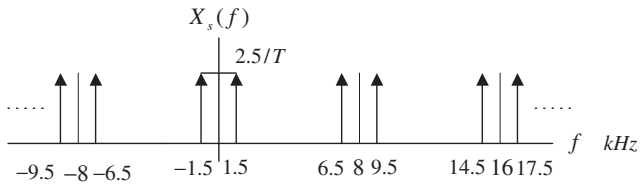
Answers to Selected Problems

CHAPTER 2

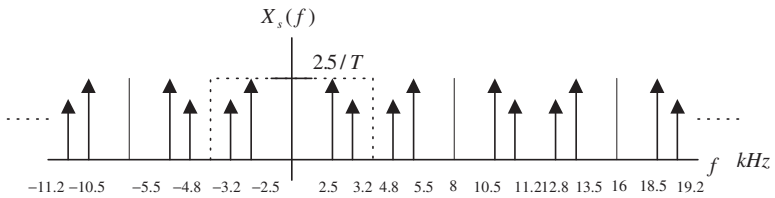
2.1. Hint:

b.

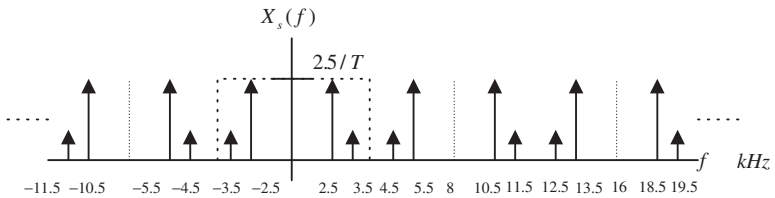


2.2. Hint:

a.

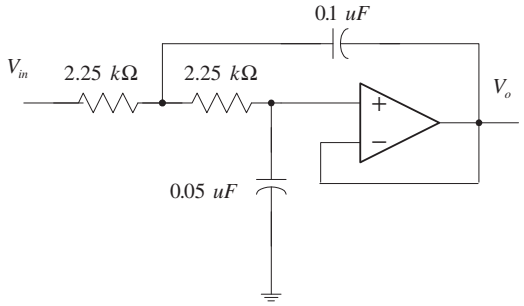


2.5. Hint:



c. The aliasing frequency = 3.5 kHz

2.9.



2.10. % aliasing level $= 8.39\%$

2.13. **a.** % aliasing level $= 57.44\%$

b. % aliasing level $= 20.55\%$

2.17. **a.** % distortion $= 24.32\%$

b. % distortion $= 5.68\%$

2.18. $f_c = 4,686$ Hz

2.21. b1b0 $= 01$

2.22. $V_0 = 1.25$ Volts

2.25. **a.** $L = 2^4 = 16$ levels

b. $\Delta = \dfrac{x_{\max} - x_{\min}}{L} = \dfrac{5}{16} = 0.3125$

c. $x_q = 3.125$

d. binary code $=1010$

e. $e_q = -0.075$

2.27. **a.** $L = 2^3 = 8$ levels

b. $\Delta = \dfrac{x_{\max} - x_{\min}}{L} = \dfrac{5}{8} = 0.625$

c. $x_q = -2.5 + 2 \times 0.625 = -1.25$

d. binary code $= 010$

e. $e_q = -0.05$

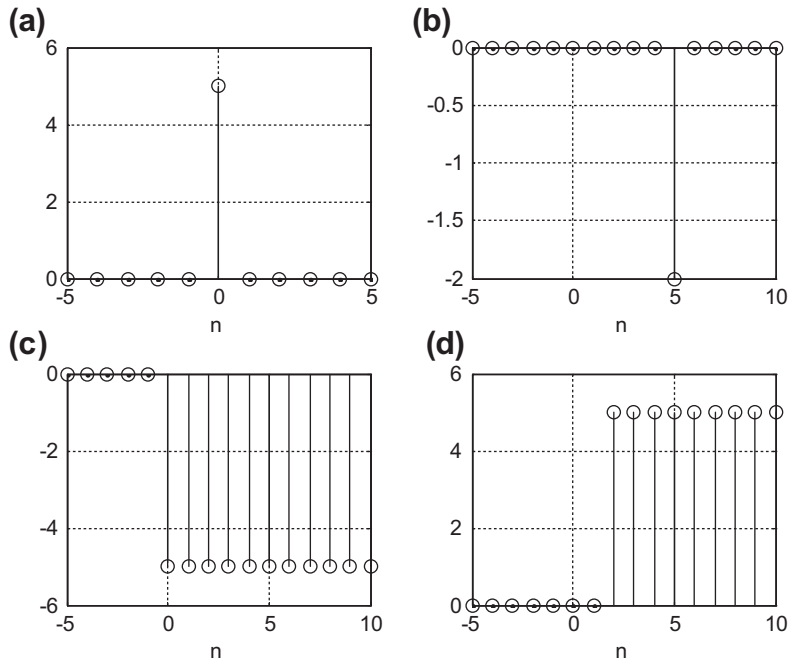
2.29. **a.** $L = 2^6 = 64$ levels

b. $\Delta = \dfrac{x_{\max} - x_{\min}}{L} = \dfrac{20}{64} = 0.3125$

c. $SNR_{dB} = 1.76 + 6.02 \times 6 = 37.88$ dB

CHAPTER 3

3.1.



3.2. Hint:

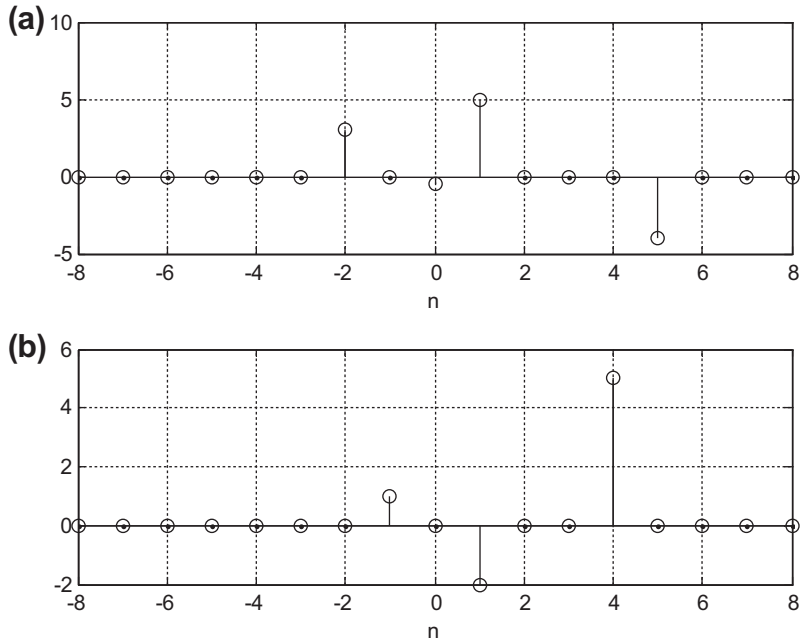
a.

n	0	1	2	3	4	5	6	7
$x(n)$	1.000	0.5000	0.2500	0.1250	0.0625	0.0313	0.0156	0.0078

d.

n	0	1	2	3	4	5	6	7
$x(n)$	0.0000	1.1588	1.6531	1.7065	1.5064	1.1865	0.8463	0.5400

3.5.



3.6. **a.** $x(n) = 3\delta(n) + \delta(n-1) + 2\delta(n-2) + \delta(n-3) + \delta(n-5)$
b. $x(n) = \delta(n-1) - \delta(n-2) + \delta(n-4) - \delta(n-5)$

3.9. **a.** $x(n) = e^{-0.5n}u(n) = (0.6065)^n u(n)$
b. $x(n) = 5\sin(0.2\pi n)u(n)$
c. $x(n) = 10\cos(0.4\pi n + \pi/6)u(n)$
d. $x(n) = 10e^{-n}\sin(0.15\pi n)u(n) = 10(0.3679)^n \sin(0.15\pi n)u(n)$

3.10. **a.** nonlinear system
b. linear system
c. nonlinear system

3.13. **a.** time-invariant

3.15. **a.** causal system
b. noncausal system
c. causal system

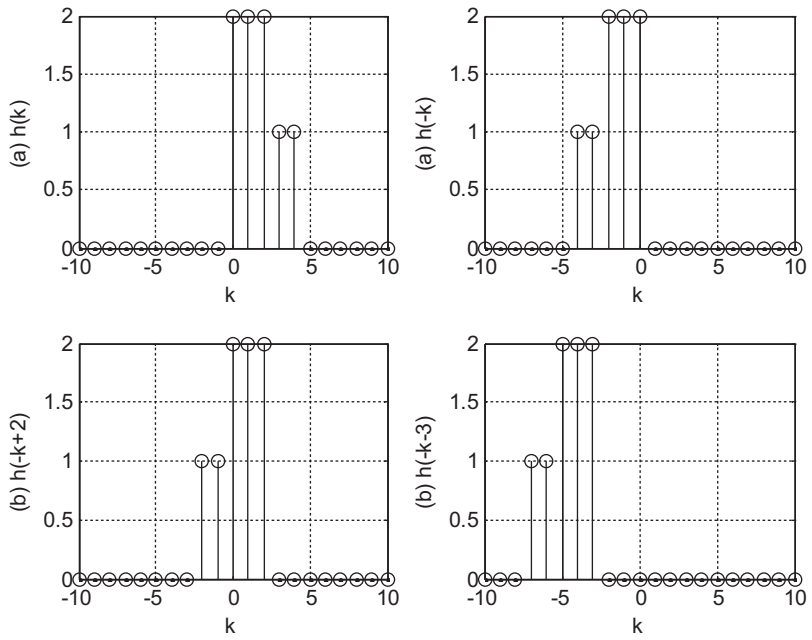
3.16. **a.** $h(n) = 0.5\delta(n) - 0.5\delta(n-2)$
b. $h(n) = (0.75)^n$, $n \geq 0$
c. $h(n) = 1.25\delta(n) - 1.25(-0.8)^n$, $n \geq 0$

3.19. **a.** $h(n) = 5\delta(n-10)$
b. $h(n) = \delta(n) + 0.5\delta(n-1)$

3.20. Since $h(n) = 0.5\delta(n) + 100\delta(n-2) - 20\delta(n-10)$ and $S = 0.5 + 100 + 20 = 120.5 =$ finite number, the system is stable.

3.23. **a.** $h(n) = (0.75)^n u(n), S = \sum_{k=0}^{\infty}(0.75)^k = 1/(1-0.75) = 4 =$ finite, the system is stable.
b. $h(n) = (2)^n u(n)$, $S = \sum_{k=0}^{\infty}(2)^k = 1 + 2 + 2^2 + \cdots = \infty =$ infinite, the system is unstable.

3.25.



3.27. $y(0) = 4,\ y(1) = 6,\ y(2) = 8,\ y(3) = 6,\ y(4) = 5,\ y(5) = 2,\ y(6) = 1,$
$y(n) = 0 \quad \text{for} \quad n \geq 7$

3.29. $y(0) = 0,\ y(1) = 1,\ y(2) = 2,\ y(3) = 1,\ y(4) = 0$
$y(n) = 0 \quad \text{for} \quad n \geq 4$

CHAPTER 4

4.1. $X(0) = 1,\ X(1) = 2 - j,\ X(2) = -1,\ X(3) = 2 + j$

4.5. $x(0) = 4,\ x(1) = 3,\ x(2) = 2,\ x(3) = 1$

4.6. $X(0) = 10,\ X(1) = 3.5 - 4.3301j,\ X(2) = 2.5 - 0.8660j,\ X(3) = 2,$
$X(4) = 2.5 + 0.8660j,\ X(5) = 3.5 + 4.3301j$

4.9. $\overline{x}(0) = 4,\ \overline{x}(4) = 0$

4.10. $\Delta f = 2.5$ Hz and $f_{\max} = 10$ kHz

4.13. $N = 4096,\ \Delta f = 0.488$ Hz

4.15. **a.** w = [0.0800 0.2532 0.6424 0.9544 0.9544 0.6424 0.2532 0.0800]
b. w = [0 0.1883 0.6113 0.9505 0.9505 0.6113 0.1883 0]

4.16. **a.** xw = [0 0.4000 0 −0.8000 0 0]
b. xw = [0 0.3979 0 −0.9121 0 0.0800]
c. xw = [0 0.3455 0 −0.9045 0 0]

4.19. **a.** $A_0 = 0.1667, A_1 = 0.3727, A_2 = 0.5, A_3 = 0.3727$
$\varphi_0 = 0^0, \varphi_1 = 154.43^0, \varphi_2 = 0^0, \varphi_3 = -154.43^0$
$P_0 = 0.0278, P_1 = 0.1389, P_2 = 0.25, P_3 = 0.1389$

b. $A_0 = 0.2925, A_1 = 0.3717, A_2 = 0.6375, A_3 = 0.3717$
$\varphi_0 = 0^0, \varphi_1 = 145.13^0, \varphi_2 = 0^0, \varphi_3 = -145.13^0$
$P_0 = 0.0586, P_1 = 0.1382, P_2 = 0.4064, P_3 = 0.1382$

c. $A_0 = 0.6580, A_1 = 0.3302, A_2 = 0.9375, A_3 = 0.3302$
$\varphi_0 = 0^0, \varphi_1 = 108.86^0, \varphi_2 = 0^0, \varphi_3 = -108.86^0$
$P_0 = 0.4330, P_1 = 0.1091, P_2 = 0.8789, P_3 = 0.1091$

4.21. $X(0) = 10, X(1) = 2 - 2j, X(2) = 2, X(3) = 2 + 2j$, 4 complex multiplications

4.22. $x(0) = 4, x(1) = 3, x(2) = 2, x(3) = 1$, 4 complex multiplications

4.25. $X(0) = 10, X(1) = 2 - 2j, X(2) = 2, X(3) = 2 + 2j$, 4 complex multiplications

4.26. $x(0) = 4, x(1) = 3, x(2) = 2, x(3) = 1$, 4 complex multiplications

CHAPTER 5

5.1. **a.** $X(z) = \dfrac{4z}{z-1}$,

b. $X(z) = \dfrac{z}{z+0.7}$

c. $X(z) = \dfrac{4z}{z-e^{-2}} = \dfrac{4z}{z-0.1353}$,

d. $X(z) = \dfrac{4z[z - 0.8 \times \cos(0.1\pi)]}{z^2 - [2 \times 0.8z\cos(0.1\pi)] + 0.8^2} = \dfrac{4z(z-0.7608)}{z^2 - 1.5217z + 0.64}$

e. $X(z) = \dfrac{4e^{-3}\sin(0.1\pi)z}{z^2 - 2e^{-3}z\cos(0.1\pi) + e^{-6}} = \dfrac{0.06154z}{z^2 - 0.0947z + 0.00248}$

5.2. **a.** $X(z) = \dfrac{z}{z-1} + \dfrac{z}{z-0.5}$

b. $X(z) = \dfrac{z^{-4}z[z - e^{-3}\cos(0.1\pi)]}{z^2 - [2e^{-3}\cos(0.1\pi)]z + e^{-6}} = \dfrac{z^{-3}(z-0.0474)}{z^2 - 0.0948z + 0.0025}$

5.3. **c.** $X(z) = \dfrac{5z^{-2}}{z-e^{-2}}$

e. $X(z) = \dfrac{4e^{-3}\sin(0.2\pi)}{z^2 - 2e^{-3}\cos(0.2\pi)z + e^{-6}} = \dfrac{0.1171}{z^2 - 0.0806z + 0.0025}$

5.5. **a.** $X(z) = 15z^{-3} - 6z^{-5}$

b. $x(n) = 15\delta(n-3) - 6\delta(n-5)$

5.9. **a.** $X(z) = -25 + \dfrac{5z}{z-0.4} + \dfrac{20z}{z+0.1}$, $x(n) = -25\delta(n) + 5(0.4)^n u(n) + 20(-0.1)^n u(n)$

b. $X(z) = \dfrac{1.6667z}{z-0.2} - \dfrac{1.6667z}{z+0.4}$, $x(n) = 1.6667(0.2)^n u(n) - 1.6667(-0.4)^n u(n)$

c. $X(z) = \dfrac{1.3514z}{z+0.2} + \dfrac{Az}{z-P} + \dfrac{A^*z}{z-P^*}$

where $P = 0.5 + 0.5j = 0.707\angle 45^0, A = 1.1625\angle -125.54^0, x(n) = 1.3514(-0.2)^n u(n) + 2.325(0.707)^n \cos(45^0 \times n - 125.54^0)$

d. $X(z) = \dfrac{4.4z}{z-0.6} + \dfrac{-0.4z}{z-0.1} + \dfrac{-1.2z}{(z-0.1)^2}$,

$x(n) = 4.4(0.6)^n u(n) - 0.4(0.1)^n u(n) - 12n(0.1)^n u(n)$

5.10. $Y(z) = \dfrac{-4.3333z}{z-0.5} + \dfrac{5.333z}{z-0.8}$, $y(n) = -4.3333(0.5)^n u(n) + 5.3333(0.8)^n u(n)$

5.13. $Y(z) = \dfrac{9.84z}{z-0.2} + \dfrac{-29.46z}{z-0.3} + \dfrac{20z}{z-0.4}$

$y(n) = 9.84(0.2)^n u(n) - 29.46(0.3)^n u(n) + 20(0.4)^n u(n)$

5.14. a. $Y(z) = \dfrac{-4z}{z-0.2} + \dfrac{5z}{z-0.5}$, $y(n) = -4(0.2)^n u(n) + 5(0.5)^n u(n)$

b. $Y(z) = \dfrac{5z}{z-1} + \dfrac{-5z}{z-0.5} + \dfrac{z}{z-0.2}$,

$y(n) = 5u(n) - 5(0.5)^n u(n) + (0.2)^n u(n)$

5.17. a. $Y(z) = \dfrac{Az}{z-P} + \dfrac{A^*z}{z-P^*}$, $P = 0.2 + 0.5j = 0.5385\angle 68.20^0, A = 0.8602\angle -54.46^0$

$y(n) = 1.7204(0.5382)^n \cos(n \times 68.20^0 - 54.46^0)$

b. $Y(z) = \dfrac{1.6854z}{z-1} + \dfrac{Az}{z-P} + \dfrac{A^*z}{z-P^*}$, where $P = 0.2 + 0.5j = 0.5385\angle 68.20^0$, $A = 0.4910\angle -136.25^0$

$y(n) = 1.6845u(n) + 0.982(0.5382)^n \cos(n \times 68.20^0 - 136.25^0)$

CHAPTER 6

6.1. a. $y(0) = 0.5, y(1) = 0.25, y(2) = 0.125, y(3) = 0.0625, y(4) = 0.03125$

b. $y(0) = 1, y(1) = 0, y(2) = 0.25, y(3) = 0, y(4) = 0.0625$

6.3. a. $y(0) = -2, y(1) = 2.3750, y(2) = -1.0312, y(3) = 0.7266, y(4) = -0.2910$

b. $y(0) = 0, y(1) = 1, y(2) = -0.2500, y(3) = 0.3152, y(4) = -0.0781$

6.4. a. $H(z) = 0.5 + 0.5z^{-1}$

b. $y(n) = 2\delta(n) + 2\delta(n-1)$, $y(n) = -5\delta(n) + 10u(n)$

6.5. a. $H(z) = \dfrac{1}{1 + 0.5z^{-1}}$

b. $y(n) = (-0.5)^n u(n)$, $y(n) = 0.6667u(n) + 0.3333(-0.5)^n u(n)$

6.9. $H(z) = 1 - 0.3z^{-1} + 0.28z^{-2}$, $A(z) = 1$, $N(z) = 1 - 0.3z^{-1} + 0.28z^{-2}$

6.12. **a.** $y(n) = x(n) - 0.25x(n-2) - 1.1y(n-1) - 0.18y(n-2)$

b. $y(n) = x(n-1) - 0.1x(n-2) + 0.3x(n-3)$

6.13. **b.** $H(z) = \dfrac{(z+0.4)(z-0.4)}{(z+0.2)(z+0.5)}$

6.15. **a.** zero: $z = 0.5$, poles: $z = -0.25$ ($|z| = 0.25$), $z = -0.5 \pm 0.7416j$ ($|z| = 0.8944$), stable

b. zeros: $z = \pm 0.5j$, poles: $z = 0.5$ ($|z| = 0.5$), $z = -2 \pm 1.7321j$ ($|z| = 2.6458$), unstable

c. zero: $z = -0.95$, poles: $z = 0.2$ ($|z| = 0.2$), $z = -0.7071 \pm 0.7071j$ ($|z| = 1$), marginally stable

d. zeros: $z = -0.5, z = -0.5$, poles: $z = 1$ ($|z| = 1$), $z = -1, z = -1$ ($|z| = 1$), $z = 0.36$ ($|z| = 0.36$), unstable

6.17. $H(z) = 0.5z^{-1} + 0.5z^{-2}$, $H(e^{j\Omega}) = 0.5e^{-j\Omega} + 0.5e^{-j2\Omega}$

$$|H(e^{j\Omega})| = 0.5\sqrt{(1+\cos\Omega)^2 + (\sin\Omega)^2},\ \angle H\left(e^{j\Omega}\right) = \tan^{-1}\left(\frac{-\sin\Omega - \sin 2\Omega}{\cos\Omega + \cos 2\Omega}\right)$$

6.19. $H(z) = \dfrac{1}{1+0.5z^{-2}}$, $H\left(e^{j\Omega}\right) = \dfrac{1}{1+0.5e^{-j2\Omega}}$

$$|H(e^{j\Omega})| = \frac{1}{\sqrt{(1+0.5\cos 2\Omega)^2 + (0.5\sin 2\Omega)^2}},\ \angle H\left(e^{j\Omega}\right) = -\tan^{-1}\left(\frac{-0.5\sin 2\Omega}{1+0.5\cos 2\Omega}\right)$$

6.21. **a.** $H(z) = 0.5 + 0.5z^{-1}$, $H(e^{j\Omega}) = 0.5 + 0.5e^{-j\Omega}$

$$|H(e^{j\Omega})| = \sqrt{(0.5+0.5\cos\Omega)^2 + (0.5\sin\Omega)^2},\ \angle H(e^{j\Omega}) = \tan^{-1}\left(\frac{-0.5\sin\Omega}{0.5+0.5\cos\Omega}\right)$$

b. $H(z) = 0.5 - 0.5z^{-1}$, $H(e^{j\Omega}) = 0.5 - 0.5e^{-j\Omega}$

$$|H(e^{j\Omega})| = \sqrt{(0.5-0.5\cos\Omega)^2 + (0.5\sin\Omega)^2},\ \angle H(e^{j\Omega}) = \tan^{-1}\left(\frac{0.5\sin\Omega}{0.5-0.5\cos\Omega}\right)$$

c. $H(z) = 0.5 + 0.5z^{-2}$, $H(e^{j\Omega}) = 0.5 + 0.5e^{-j2\Omega}$

$$|H(e^{j\Omega})| = \sqrt{(0.5+0.5\cos 2\Omega)^2 + (0.5\sin 2\Omega)^2},\ \angle H(e^{j\Omega}) = \tan^{-1}\left(\frac{-0.5\sin 2\Omega}{0.5+0.5\cos 2\Omega}\right)$$

d. $H(z) = 0.5 - 0.5z^{-2}$, $H(e^{j\Omega}) = 0.5 - 0.5e^{-j2\Omega}$

$$|H(e^{j\Omega})| = \sqrt{(0.5-0.5\cos 2\Omega)^2 + (0.5\sin 2\Omega)^2},\ \angle H(e^{j\Omega}) = \tan^{-1}\left(\frac{0.5\sin 2\Omega}{0.5-0.5\cos 2\Omega}\right)$$

6.23. $H(z) = \dfrac{0.5}{1+0.7z^{-1}+0.1z^{-2}}$,

$$y(n) = 0.5556u(n) - 0.111(-0.2)^n u(n) + 0.5556(-0.5)^n u(n)$$

6.25. **a.** $y(n) = x(n) - 0.9x(n-1) - 0.1x(n-2) - 0.3y(n-1) + 0.04y(n-2)$

b. $w(n) = x(n) - 0.3w(n-1) + 0.04w(n-2)$

$y(n) = w(n) - 0.9w(n-1) - 0.1w(n-2)$

c. Hint: $H(z) = \dfrac{(z-1)(z+0.1)}{(z+0.4)(z-0.1)}$

$w_1(n) = x(n) - 0.4w_1(n-1)$
$y_1(n) = w_1(n) - w_1(n-1)$
$w_2(n) = y_1(n) + 0.1w_2(n-1)$
$y(n) = w_2(n) + 0.1w_2(n-1)$

d. Hint: $H(z) = 2.5 + \dfrac{2.1z}{z+0.4} - \dfrac{3.6z}{z-0.1}$

$y_1(n) = 2.5x(n)$
$w_2(n) = x(n) - 0.4w_2(n-1)$
$y_2(n) = 2.1w_2(n)$
$w_3(n) = x(n) + 0.1w_3(n-1)$
$y_3(n) = -3.6w_3(n)$
$y(n) = y_1(n) + y_2(n) + y_3(n)$

6.26. a. $y(n) = x(n) - 0.5x(n-1)$
b. $y(n) = x(n) - 0.7x(n-1)$
c. $y(n) = x(n) - 0.9x(n-1)$
The filter in (c) emphasizes high frequencies most.

CHAPTER 7

7.1. a. $H(z) = 0.2941 + 0.3750z^{-1} + 0.2941z^{-2}$
b. $H(z) = 0.0235 + 0.3750z^{-1} + 0.0235z^{-2}$

7.3. a. $H(z) = 0.1514 + 0.1871z^{-1} + 0.2000z^{-2} + 0.1871z^{-3} + 0.1514z^{-4}$
b. $H(z) = 0.0121 + 0.1010z^{-1} + 0.2000z^{-2} + 0.1010z^{-3} + 0.0121z^{-4}$

7.5. a. $H(z) = -0.0444 + 0.0117z^{-1} + 0.0500z^{-2} + 0.0117z^{-3} - 0.0444z^{-4}$
b. $H(z) = -0.0035 + 0.0063z^{-1} + 0.0500z^{-2} + 0.0063z^{-3} - 0.0035z^{-4}$

7.7. a. Hanning window
b. filter length =63
c. cutoff frequency = 1,000 Hz

7.9. a. Hamming window
b. filter length =45
c. lower cutoff frequency = 1500 Hz, upper cutoff frequency = 2,300 Hz

7.11. Hint:
a. $y(n) = 0.25x(n) - 0.5x(n-1) + 0.25x(n-2)$
b. $y(n) = 0.25[x(n) + x(n-2)] - 0.5x(n-1)$

7.13. $N = 3$, $\Omega_c = 3\pi/10$, $\Omega_0 = 0$, $H_0 = 1$, $\Omega_1 = 2\pi/3$, $H_1 = 0$
$H(z) = 0.3333 + 0.3333z^{-1} + 0.3333z^{-2}$

7.15. $H(z) = -0.1236 + 0.3236z^{-1} + 0.6z^{-2} + 0.3236z^{-3} - 0.1236z^{-4}$

7.17. $H(z) = 0.1718 - 0.2574z^{-1} - 0.0636z^{-2} + 0.2857z^{-3} - 0.0636z^{-4} - 0.2574z^{-5} + 0.1781z^{-6}$

7.19. $W_p = 1, W_s = 12$
7.21. $W_p = 1, W_s = 122$
7.23. Hamming window, filter length = 33, lower cutoff frequency = 3,500 Hz
7.24. Hamming window, filter length = 53,
lower cutoff frequency = 1,250 Hz, upper cutoff frequency = 2,250 Hz
7.25. Lowpass filter: Hamming window, filter length = 91, cutoff frequency = 2,000 Hz
Highpass filter: Hamming window, filter length = 91, cutoff frequency = 2,000 Hz

CHAPTER 8

8.1. $$H(z) = \frac{0.3333 + 0.3333z^{-1}}{1 - 0.3333z^{-1}}$$

$$y(n) = 0.3333x(n) + 0.3333x(n-1) + 0.3333y(n-1)$$

8.3. a. $$H(z) = \frac{0.6625 - 0.6625z^{-1}}{1 - 0.3249z^{-1}}$$

$$y(n) = 0.6225x(n) - 0.6225x(n-1) + 0.3249y(n-1)$$

8.5. a. $$H(z) = \frac{0.2113 - 0.2113z^{-2}}{1 - 0.8165z^{-1} + 0.5774z^{-2}}$$

$$y(n) = 0.2113x(n) - 0.2113x(n-2) + 08165y(n-1) - 0.5774y(n-2)$$

8.7. a. $$H(z) = \frac{0.1867 + 0.3734z^{-1} + 0.1867z^{-2}}{1 - 0.4629z^{-1} + 0.2097z^{-2}}$$

$$\begin{aligned} y(n) &= 0.1867x(n) + 0.3734x(n-1) + 0.1867x(n-2) \\ &\quad + 0.4629y(n-1) - 0.2097y(n-2) \end{aligned}$$

8.9. a. $$H(z) = \frac{0.0730 - 0.0730z^{-2}}{1 + 0.8541z^{-2}}$$

$$y(n) = 0.0730x(n) - 0.0730x(n-2) - 0.8541y(n-2)$$

8.11. a. $$H(z) = \frac{0.5677 + 0.5677z^{-1}}{1 + 0.1354z^{-1}}$$

$$y(n) = 0.5677x(n) + 0.5677x(n-1) - 0.1354y(n-1)$$

8.13. a. $$H(z) = \frac{0.1321 - 0.3964z^{-1} + 0.3964z^{-2} - 0.1321z^{-3}}{1 + 0.3432z^{-1} + 0.6044z^{-2} + 0.2041z^{-3}}$$

$$\begin{aligned} y(n) &= 0.1321x(n) - 0.3964x(n-1) + 0.3964x(n-2) - 0.1321x(n-3) \\ &\quad - 0.3432y(n-1) - 0.6044y(n-2) - 0.2041y(n-3) \end{aligned}$$

8.15. a. $H(z) = \dfrac{0.9609 + 0.7354z^{-1} + 0.9609z^{-2}}{1 + 0.7354z^{-1} + 0.9217z^{-2}}$

$$\begin{aligned} y(n) = {} & 0.9609x(n) + 0.7354x(n-1) + 0.9609x(n-2) \\ & -0.7354y(n-1) - 0.9217y(n-2) \end{aligned}$$

8.17. a. $H(z) = \dfrac{0.0242 + 0.0968z^{-1} + 0.1452z^{-2} + 0.0968z^{-3} + 0.0242z^{-4}}{1 - 1.5895z^{-1} + 1.6690z^{-2} - 0.9190z^{-3} + 0.2497z^{-4}}$

$$\begin{aligned} y(n) = {} & 0.0242x(n) + 0.0968x(n-1) + 0.1452x(n-2) \\ & + 0.0968x(n-3) + 0.0242x(n-4) + 1.5895y(n-1) - 1.6690y(n-2) \\ & +0.9190y(n-3) - 0.2497y(n-4) \end{aligned}$$

8.19. a. $H(z) = \dfrac{1}{1 - 0.3679z^{-1}}$

$$y(n) = x(n) + 0.3679y(n-1)$$

8.21. a. $H(z) = \dfrac{0.1 - 0.09781z^{-1}}{1 - 1.6293z^{-1} + 0.6703z^{-2}}$

$$y(n) = 0.1x(n) - 0.0978x(n-1) + 1.6293y(n-1) - 0.6703y(n-2)$$

8.23. $H(z) = \dfrac{0.9320 - 1.3180z^{-1} + 0.9320z^{-2}}{1 - 1.3032z^{-1} + 0.8492z^{-2}}$

$$y(n) = 0.9320x(n) - 1.3180x(n-1) + 0.9329x(n-2) + 1.3032y(n-1) - 0.8492y(n-2)$$

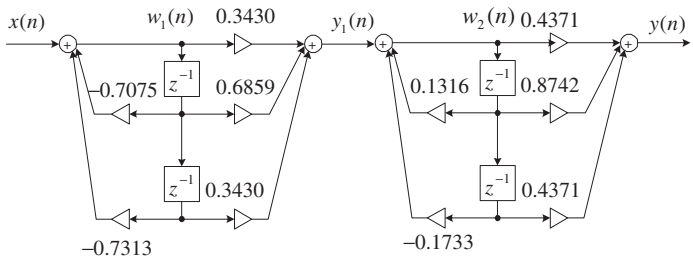
8.25. $H(z) = \dfrac{0.9215 + 0.9215z^{-1}}{1 + 0.8429z^{-1}}$

$$y(n) = 0.9215x(n) + 0.9215x(n-1) - 0.8429y(n-1)$$

8.27. $H(z) = \dfrac{0.9607 - 0.9607z^{-1}}{1 - 0.9215z^{-1}}$

$$y(n) = 0.9607x(n) - 0.9607x(n-1) + 0.9215y(n-1)$$

8.29. a.



b. For section 1: $w_1(n) = x(n) - 0.7075w_1(n-1) - 0.7313w_1(n-2)$

$$y_1(n) = 0.3430w_1(n) + 0.6859w_1(n-1) + 0.3430w_1(n-2)$$

For section 2: $w_2(n) = y_1(n) + 0.1316w_2(n-1) - 0.1733w_2(n-2)$

$$y_2(n) = 0.4371w_2(n) + 0.8742w_2(n-1) + 0.4371w_2(n-2)$$

8.30. $H(z) = \dfrac{0.9511z^{-1}}{1.0000 - 0.6180z^{-1} + z^{-2}}$, $y(n) = 0.9511x(n-1) + 0.618y(n-1) - y(n-2)$

8.32. **a.** $H_{852}(z) = \dfrac{0.6203z^{-1}}{1 - 1.5687z^{-1} + z^{-2}}$, $H_{1477}(z) = \dfrac{0.9168z^{-1}}{1 - 0.7986z^{-1} + z^{-2}}$

b. $y_{852}(n) = 0.6203x(n-1) + 1.5678y_{852}(n-1) - y_{852}(n-2)$

$y_{1477}(n) = 0.9168x(n-1) + 0.7986y_{1477}(n-1) - y_{1477}(n-2)$

$y_9(n) = y_{1477}(n) + y_{852}(n)$

8.34. $X(0) = 2$, $|X(0)|^2 = 4$, $A_0 = 0.5$ (single side)

$X(1) = 1 - j3$, $|X(1)|^2 = 10$, $A_1 = 1.5811$ (single side)

8.36. $A_0 = 2.5, A_2 = 0.5$

8.39. Chebyshev notch filter 1: order = 2

$$H(z) = \frac{0.9915 - 1.9042z^{-1} + 0.9915z^{-2}}{1.0000 - 1.9042z^{-1} + 0.9830z^{-2}}$$

Chebyshev notch filter 2: order = 2

$$H(z) = \frac{0.9917 - 1.3117z^{-1} + 0.9917z^{-2}}{1.0000 - 1.3117z^{-1} + 0.9835z^{-2}}$$

8.41. Filter order = 4

$$H(z) = \frac{0.1103 + 0.4412z^{-1} + 0.6618z^{-2} + 0.4412z^{-3} + 0.1103z^{-4}}{1.0000 + 0.1509z^{-1} + 0.8041z^{-2} - 0.1619z^{-3} + 0.1872z^{-4}}$$

8.43. Filter order = 4

$$H(z) = \frac{0.0300 - 0.0599z^{-2} + 0.0300z^{-4}}{1.0000 - 0.6871z^{-1} + 1.5741z^{-2} - 0.5177z^{-3} + 0.5741z^{-4}}$$

8.45. $H(z) = \dfrac{0.5878z^{-1}}{1 - 1.6180z^{-1} + z^2}$

$y(n) = 0.5878x(n-1) + 1.6180y(n-1) - y(n-2)$

8.47. $X(0) = 1$, $|X(0)|^2 = 1$, $A_0 = 0.25$ (single side)

$X(1) = 1 - j2$; $|X(1)|^2 = 5$; $A_1 = 1.12$ (single side)

CHAPTER 9

9.1. $0.2560123\ (\text{decimal}) = 0.\,0\,1\,0\,0\,0\,0\,0\,1\,1\,0\,0\,0\,1\,0\,1\ (\text{Q}-15)$

9.2. $-0.2160123 \times 2^{15} = -7078_{10} = 1110010001011010$

$-0.2160123\ (\text{decimal}) = 1.\,1\,1\,0\,0\,1\,0\,0\,0\,1\,0\,1\,1\,0\,1\,0\ (\text{Q}-15)$

9.5. $0.1\,0\,1\,0\,1\,0\,0\,0\,1\,0\,1\,1\,1\,1\,0 = 0.6591186$

$1.0\,1\,0\,1\,0\,1\,1\,1\,0\,1\,0\,0\,0\,1\,0(\text{Q}-15) = -0.6591186$

9.6. $0.0\,0\,1\,0\,0\,0\,1\,1\,1\,1\,0\,1\,1\,1\,0(\text{Q}-15) = 0.1400756$

9.9. $1.1\,0\,1\,0\,1\,0\,1\,1\,1\,0\,0\,0\,0\,0\,1 + 0.0\,1\,0\,0\,0\,1\,1\,1\,1\,0\,1\,1\,0\,1\,0$

$= 1.1\,1\,1\,1\,0\,0\,1\,1\,0\,0\,1\,1\,0\,1\,1$

9.13. **a.** 1101 011100001100

b. 0100 101011001001

9.15. $1101\ 011100011011(\text{floating}) = 0.8881835 \times 2^{-3}\ (\text{decimal})$

$0100\ 101111100101\big(\text{floating}\big) = -0.5131835 \times 2^{4}\ (\text{decimal})$

$0.8881835 \times 2^{-3}\ (\text{decimal}) = 0.0069389 \times 2^{4}\ (\text{decimal})$

$= 0100\ 000000001110(\text{floating})$

$0100\ 101111100101(\text{floating}) + 0100\ 000000001110(\text{floating})$

$= 0100\ 101111110011(\text{floating}) = -8.1016(\text{decimal})$

9.18. $(-1)^{1} \times 1.025 \times 2^{160-127} = -8.8047 \times 10^{9}$

9.20. $(-1)^{0} \times 1.625 \times 2^{1,536-1,023} = 4.3575 \times 10^{154}$

9.25. $B = 2,\ S = 2$

$$x_s\big(n\big) = \frac{x(n)}{2}$$

$$y_s(n) = -0.18x_s(n) + 0.8x_s(n-1) + 0.18x_s(n-2)$$

$$y(n) = 4y_s(n)$$

9.26. $S = 1,\ C = 2$

$$x_s\big(n\big) = x\big(n\big),\ y_s\big(n\big) = 0.75x_s\big(n\big) + 0.15y_f\big(n-1\big),\ y_f\big(n\big) = 2y_s\big(n\big),\ y\big(n\big) = y_f\big(n\big)$$

9.29. $S = 8,\ A = 2,\ B = 4$

$$x_s(n) = x(n)/8,\ w_s(n) = 0.5x_s(n) - 0.675w(n-1) - 0.25w(n-2),$$

$$w(n) = 2w_s(n)$$

$$y_s(n) = 0.18w(n) + 0.355w(n-1) + 0.18w(n-2),\ y(n) = 32y_s(n)$$

CHAPTER 10

10.1. $w^* = 2$ and $J_{\min} = 10$

10.3. $w^* = -5$ and $J_{\min} = 50$

10.5. $w^* \approx w_3 = 1.984$ and $J_{\min} = 10.0026$

10.7. $w^* \approx w_3 = -4.992$ and $J_{\min} = 5.0001$

10.9. **a.** $y(n) = w(0)x(n) + w(1)x(n-1)$

$e(n) = d(n) - y(n)$

$w(0) = w(0) + 0.2 \times e(n)x(n)$

$w(1) = w(1) + 0.2 \times e(n)x(n-1)$

b. For $n = 0$:

$$y(0) = 0$$

$$e(0) = 3$$

$$w(0) = 1.8$$

$$w(1) = 1$$

For $n = 1$:

$$y(1) = 1.2$$

$$e(1) = -3.2$$

$$w(0) = 2.44$$

$$w(1) = -0.92$$

For $n = 2$:

$$y(2) = 5.8$$

$$e(2) = -4.8$$

$$w(0) = 0.52$$

$$w(1) = 0.04$$

10.13. **a.** $n(n) = 0.5 \cdot x(n-5)$

b. $xx(n) = 5{,}000 \cdot \delta(n)$, $yy(n) = 0.7071xx(n-1) + 1.4141yy(n-1) - yy(n-2)$

c. $d(n) = yy(n) - n(n)$

d. For $i = 0, \cdots, 24$, $w(i) = 0$

$$y(n) = \sum_{i=0}^{24} w(i)x(n-i)$$

$$e(n) = d(n) - y(n)$$

For $i = 0, \cdots, 24$

$$w(i) = w(i) + 2\mu e(n)x(n-i)$$

10.15. **a.** $w(0) = w(1) = w(2) = 0, \mu = 0.1$
$y(n) = w(0)x(n) + w(1)x(n-1) + w(2)x(n-2)$
$e(n) = d(n) - y(n)$
$w(0) = w(0) + 0.2e(n)x(n)$
$w(1) = w(1) + 0.2e(n)x(n-1)$
$w(2) = w(2) + 0.2e(n)x(n-2)$

b. For $n = 0 : y(0) = 0, e(0) = 0, w(0) = 0, w(1) = 0, w(2) = 0$
For $n = 1 : y(1) = 0, e(1) = 2, w(0) = 0.4, w(1) = 0.4, w(2) = 0$
For $n = 2 : y(2) = 0, e(2) = -1, w(0) = 0.6, w(1) = 0.2, w(2) = -0.2$

10.17. **a.** $w(0) = w(1) = 0, \mu = 0.1$
$x(n) = d(n-3)$
$y(n) = w(0)x(n) + w(1)x(n-1)$
$e(n) = d(n) - y(n)$
$w(0) = w(0) + 0.2e(n)x(n)$
$w(1) = w(1) + 0.2e(n)x(n-1)$

b. For $n = 0 : x(0) = 0, y(0) = 0, e(0) = -1, w(0) = 0, w(1) = 0$
For $n = 1 : x(1) = 0, y(1) = 0, e(1) = 1, w(0) = 0, w(1) = 0$
For $n = 2 : x(2) = 0, y(2) = 0, e(2) = -1, w(0) = 0, w(1) = 0$
For $n = 3 : x(3) = -1, y(3) = 0, e(3) = 1, w(0) = -0.2, w(1) = 0$
For $n = 4 : x(4) = 1, y(4) = -0.2, e(4) = -0.8, w(0) = -0.36, w(1) = 0.16$

10.18. **a.** 30 coefficients

10.20. For $i = 0, \cdots, 19, w(i) = 0$

$$y(n) = \sum_{i=0}^{19} w(i)x(n-i)$$

$$e(n) = d(n) - y(n)$$

For $i = 0, \cdots, 19$

$$w(i) = w(i) + 2\mu e(n)x(n-i)$$

CHAPTER 11

11.1. **a.** $\Delta = 0.714$

b. For $x = 1.6$ volts, binary code = 110, $x_q = 1.428$ volts, and $e_q = -0.172$ volts
For $x = -0.2$ volts, binary code = 000, $x_q = 0$ volts, and $e_q = 0.2$ volts

11.5. For $x = 1.6$ volts, binary code = 111, $x_q = 1.132$ volts, and $e_q = -0.468$ volts
For $x = -0.2$ volts, binary code = 010, $x_q = -0.224$ volts, and $e_q = -0.024$ volts

11.9. **a.** 0 0 0 1 0 1 0 1
b. 1 1 1 0 0 1 1 1

11.10. **a.** 0 0 0 0 0 0 0 0 0 1 1 1
b. 1 0 1 1 0 0 1 1 0 0 0 0

11.13. 010
001
010

11.14. For binary code = 110, $\hat{x}(0) = \tilde{x}(0) + d_q(0) = 0 + 5 = 5$
For binary code = 100, $\hat{x}(1) = \tilde{x}(1) + d_q(1) = 5 + 0 = 5$
For binary code = 110, $\hat{x}(2) = \tilde{x}(2) + d_q(2) = 5 + 2 = 7$

11.17. **a.** 1:1
b. 2:1
c. 4:1

11.18. **a.** 128 KBPS
b. 64 KBPS
c. 32 KBPS

11.21. **a.** 12 channels
b. 24 channels
c. 48 channels

11.22. $X_{DCT}(0) = 54$, $X_{DCT}(1) = 0.5412$, $X_{DCT}(2) = -4$, $X_{DCT}(3) = -1.3066$

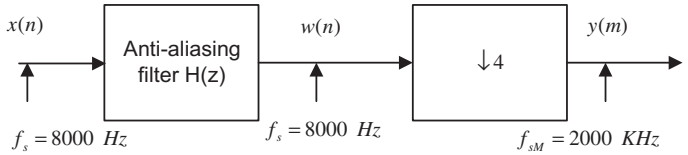
11.25. $X_{DCT}(1) = 33.9730$, $X_{DCT}(3) = -10.4308$, $X_{DCT}(5) = 1.2001$, $X_{DCT}(7) = -1.6102$

11.26. **a.** Inverse DCT: 10.0845 6.3973 13.6027 −2.0845
b. Recovered inverse DCT: 11.3910 8.9385 15.0615 −3.3910
c. Quantization error: 1.3066 2.5412 1.4588 −1.3066

11.29. **a.** −9.0711 −0.5858
−13.3137 − 0.0000
−7.8995 0.5858
b. 3, 4, 5, 4

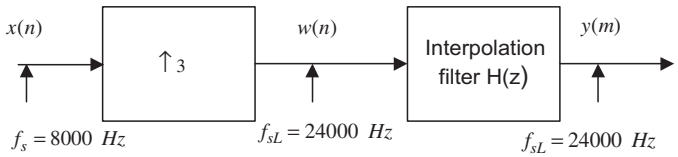
CHAPTER 12

12.3 a.



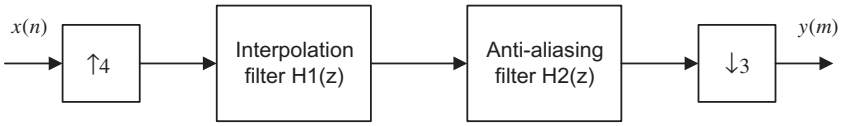
b. Hamming window, $N = 133$, $f_c = 900$ Hz

12.4. a.



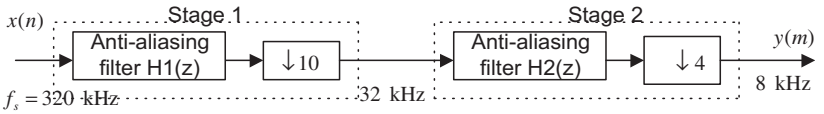
b. Hamming window, $N = 133,\ f_c = 3{,}700$ Hz

12.7. a.



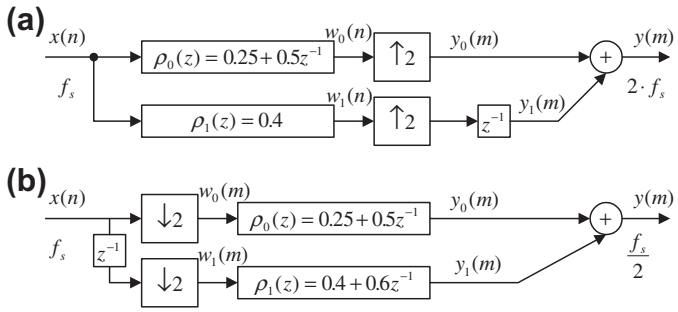
b. Combined filter $H(z)$: Hamming window, $N = 133,\ f_c = 2{,}700$ KHz

12.8. a.

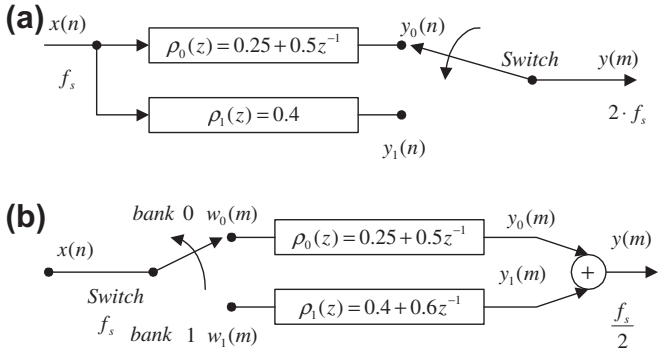


b. $M_1 = 10$ and $M_2 = 4$
c. Filter specification for $H_1(z)$: Hamming window, $N = 43, f_c = 15,700$ Hz
d. Filter specification for $H_2(z)$: Hamming window, $N = 177, f_c = 3,700$ Hz

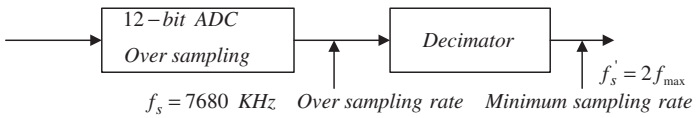
12.9.



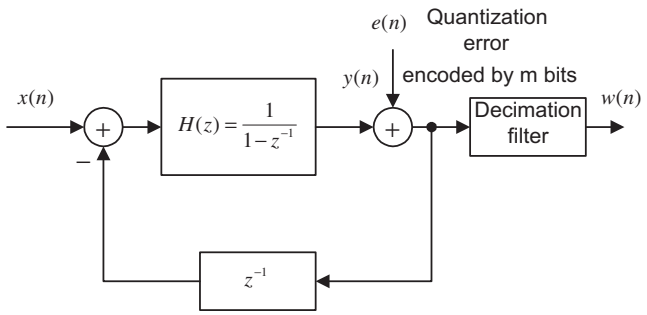
12.10.



12.15. a. $f_s = 2f_{\max}2^{2(n-m)} = 2 \times 15 \times 2^{2\times(16-12)} = 7680$ KHz

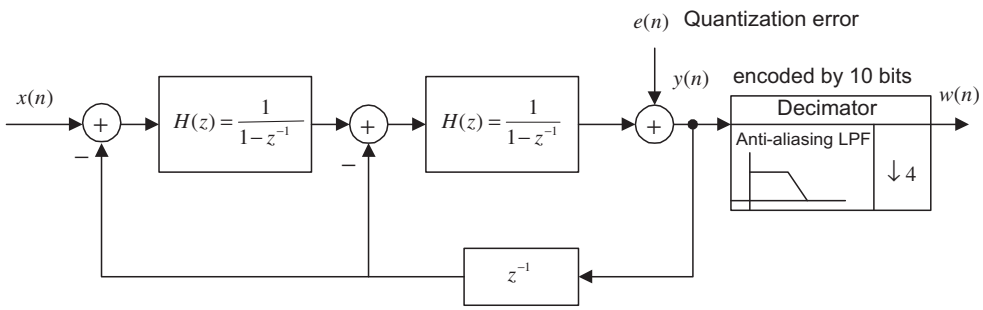


12.17. a.



b. $n = 1 + 1.5 \times \log_2\left(\frac{128}{2 \times 4}\right) - 0.86 \approx 6$ bits

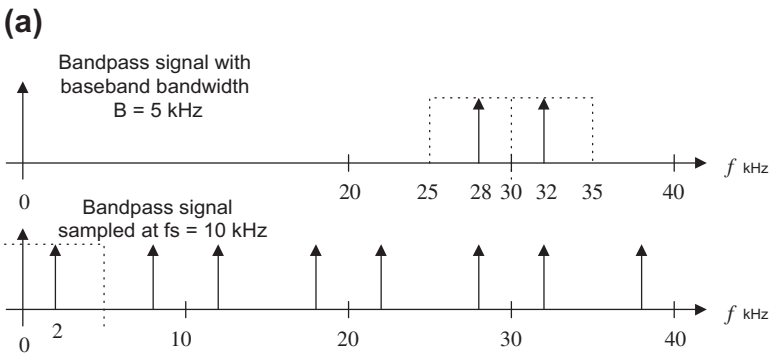
12.18. a.



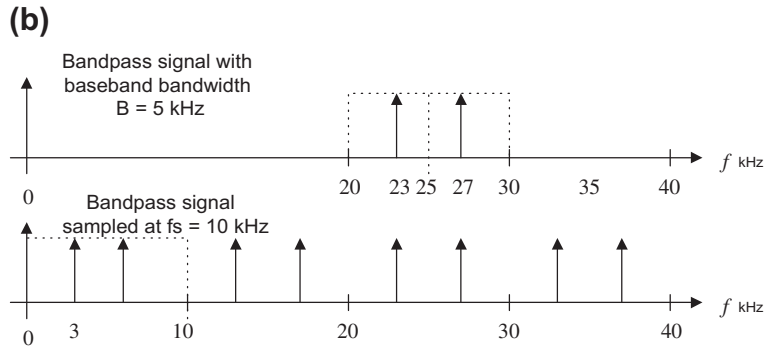
b. $n = m + 2.5 \times \log_2\left(\frac{f_s}{2f_{\max}}\right) - 2.14 = 10 + 2.5 \times \log_2\left(\frac{160}{2 \times 20}\right) - 2.14$

$= 12.86 \approx 13$ bits

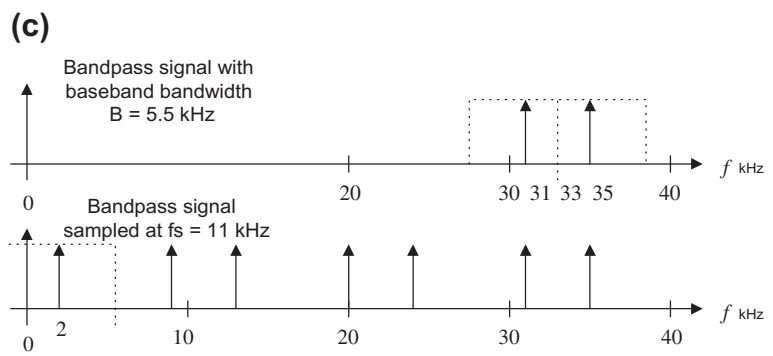
12.21. a. $f_c/B = 6$ is an even number, which is case 1, so we select $f_s = 10$ kHz.



b. Since $f_c/B = 5$ is an odd number, we select $f_s = 10$ kHz.

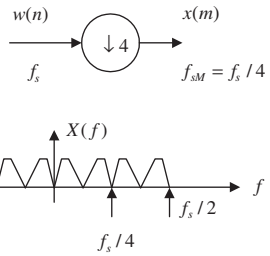


c. Now, $f_c/B = 6.6$, which is a noninteger. We extend the bandwidth to $\overline{B} = 5.5$ kHz, so $f_c/\overline{B} = 6$ and $f_s = 2\overline{B} = 11$ kHz.

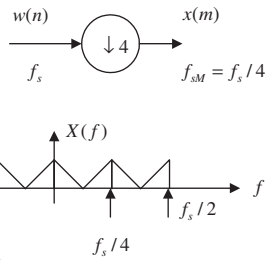


CHAPTER 13

13.1. a. $B = f_{sM}/2 = f_s/(2M), f_c = 2(f_s/(2M)) = 2B, f_c/B = 2 = \text{even}$

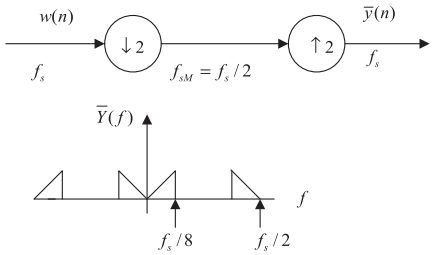


b. $B = f_{sM}/2 = f_s/(2M), f_c = f_s/(2M) = B, f_c/B = 1 = \text{odd}$

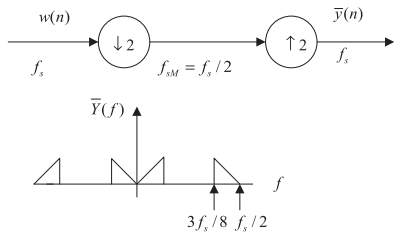


13.3. From Equation (13.7), $\overline{Y}(z) = \frac{1}{2}(W(z) + W(e^{-j\pi}z))$, $\overline{Y}(e^{j\Omega}) = \frac{1}{2}(W(e^{j\Omega}) + W(e^{j(\Omega-\pi)}))$, $W(e^{j(\Omega-\pi)})$ is the shifted version of $W(e^{j\Omega})$ by $f_s/2$.

(a)



(b)



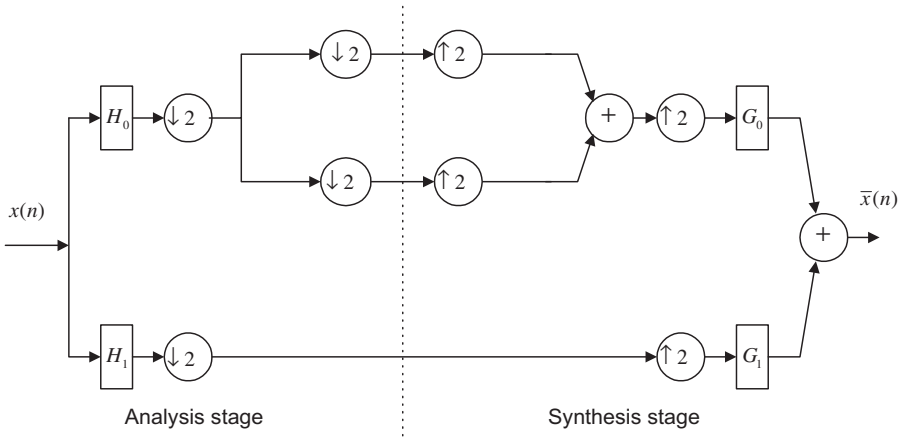
13.5. $H_1(z) = -\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}}z^{-1}$, $G_0(z) = \frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}}z^{-1}$, $G_1(z) = \frac{1}{\sqrt{2}} - \frac{1}{\sqrt{2}}z^{-1}$

13.7. $H_1(z) = 0.129 + 0.224z^{-1} - 0.837z^{-2} + 0.483z^{-3}$

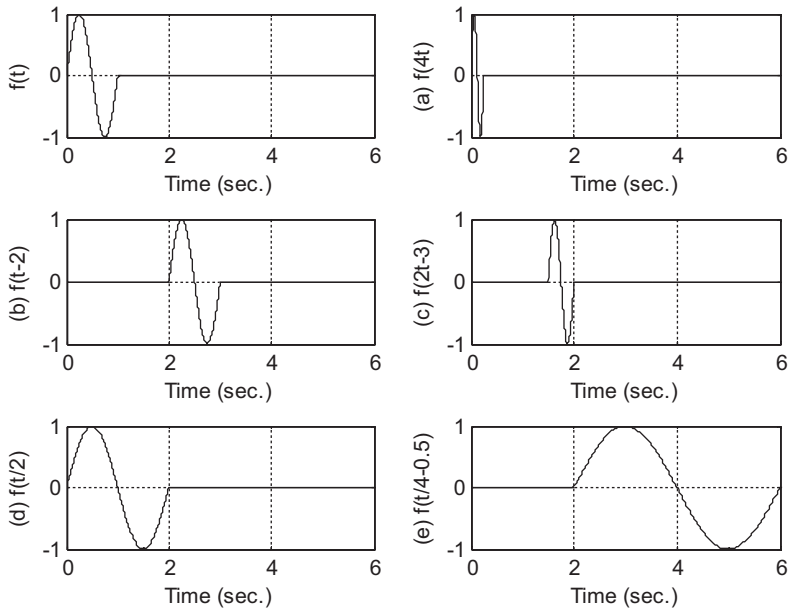
$G_0(z) = -0.129 + 0.224z^{-1} + 0.837z^{-2} + 0.483z^{-3}$

$G_1(z) = 0.483 - 0.837z^{-1} + 0.224z^{-2} + 0.129z^{-3}$

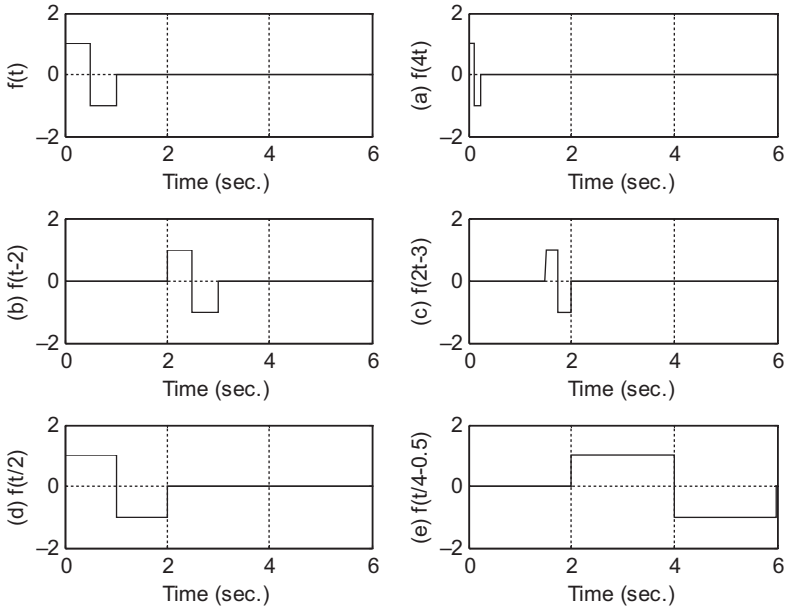
13.9.



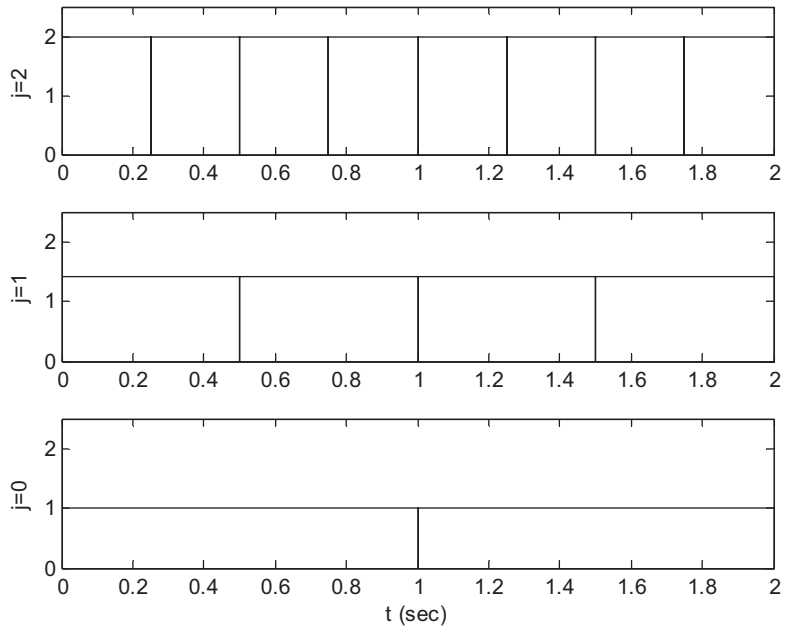
13.11.



13.13.



13.15.



13.17. **a.** $f(t) = 4\phi(2t) - 2\phi(2t-1)$
b. $f(t) = \phi(t) + 3\psi(t)$
13.19. **a.** $f(t) = (2/\pi)\phi(2t) - (2/\pi)\phi(2t-1)$
b. $f(t) = (2/\pi)\psi(t)$
13.21. **a.** $\sum_{k=-\infty}^{\infty} \sqrt{2}h_0(k)\phi(4t-k) = \sqrt{2}h_0(0)\phi(4t) + \sqrt{2}h_0(1)\phi(4t-1)$
b. $= \sqrt{2} \times 0.707\phi(4t) + \sqrt{2} \times 0.707\phi(4t-1) = \phi(4t) + \phi(4t-1) = \phi(2t)$

$$\sum_{k=-\infty}^{\infty} \sqrt{2}h_1(k)\phi(4t-k) = \sqrt{2}h_1(0)\phi(4t) + \sqrt{2}h_1(1)\phi(4t-1)$$
$$= \sqrt{2} \times 0.707\phi(4t) + \sqrt{2}(-0.707)\phi(4t-1) = \phi(4t) - \phi(4t-1) = \psi(2t)$$

13.23. $w(k) = [5.5000 \quad 0.5000 \quad 7.0711 \quad 2.1213]$
13.25. $c(k) = [2.2929 \quad 3.7071 \quad 2.4142 \quad -0.4142]$
13.27. $c(k) = [2.1213 \quad 3.5355 \quad 2.8284 \quad 0]$

CHAPTER 14

14.1. **a.** 76.8 K bytes
b. 921.6 K bytes
c. 1920.768 K bytes
14.3. $Y = 142$, $I = 54$, $Q = 11$
14.5.

$$\begin{bmatrix} 53 & 44 \\ 59 & 50 \end{bmatrix}$$

14.7.

$$\begin{bmatrix} 1 & 4 & 6 & 6 & 1 \\ 6 & 4 & 4 & 6 & 4 \\ 4 & 4 & 6 & 6 & 6 \\ 1 & 6 & 7 & 7 & 4 \end{bmatrix}$$

14.9.

$$\begin{bmatrix} 102 & 109 & 104 & 51 \\ 98 & 101 & 101 & 54 \\ 98 & 103 & 100 & 51 \\ 50 & 55 & 51 & 25 \end{bmatrix}$$

14.10.

$$\begin{bmatrix} 0 & 100 & 100 & 0 \\ 0 & 100 & 100 & 100 \\ 0 & 100 & 100 & 100 \\ 0 & 100 & 0 & 0 \end{bmatrix}$$

14.11. a.

Vertical Sobel detector: $\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$ Processed image: $\begin{bmatrix} 225 & 125 & 130 & 33 \\ 249 & 119 & 136 & 6 \\ 249 & 119 & 136 & 6 \\ 255 & 125 & 130 & 0 \\ 255 & 128 & 128 & 30 \end{bmatrix}$

b.

Laplacian edge detector: $\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$ Processed image: $\begin{bmatrix} 0 & 106 & 106 & 0 \\ 106 & 255 & 255 & 106 \\ 106 & 255 & 255 & 106 \\ 117 & 223 & 223 & 117 \\ 0 & 117 & 117 & 0 \end{bmatrix}$

14.13. Blue is dominant in the area pointed to by the arrow; red is dominant in the background.

14.15.

$$X(u,v) = \begin{bmatrix} 460 & -40 \\ -240 & -140 \end{bmatrix} \text{ and } A(u,v) = \begin{bmatrix} 115 & 10 \\ 60 & 35 \end{bmatrix}$$

14.16.

$$\text{Forward DCT: } F(u,v) = \begin{bmatrix} 230 & -20 \\ -120 & -70 \end{bmatrix}$$

14.17.

$$\text{Inverse DCT: } p(i,j) = \begin{bmatrix} 110 & 100 \\ 100 & 90 \end{bmatrix}$$

14.19. a. (0, −2) (3, 4), (2, −3), (0, 7), (4, −2), (0, 0)

b. (0000, 0010, 01), (0011, 0011, 100), (0010, 0010, 00), (0000, 0011, 111), (0100, 0010, 01), (0000, 0000)

14.19. a. (0, −2) (3, 4), (2, −3), (0, 7), (4, −2), (0, 0)

b. (0000, 0010, 01), (0011, 0011, 100), (0010, 0010, 00), (0000, 0011, 111), (0100, 0010, 01), (0000, 0000)

14.20. w = 230.0000 − 20.0000
−120.0000 − 70.0000

14.21. f = 110.0000 100.0000
100.0000 90.0000

14.23. f = 115.0000 145.0000 25.0000 45.0000
105.0000 135.0000 5.0000 25.0000
30.0000 20.0000 7.5000 27.5000
10.0000 -0.0000 -7.5000 12.5000

14.28. Hint :

$$\textit{Composite} \times 2\sin(2\pi f_{sc}t) = Y \times 2\sin(2\pi f_{sc}t) + I\cos(2\pi f_{sc}t) \times 2\sin(2\pi f_{sc}t)$$
$$+ Q \times 2\sin^2(2\pi f_{sc}t) = Y \times 2\sin(2\pi f_{sc}t) + I\sin(2 \times 2\pi f_{sc}t)$$
$$+ Q - Q\cos(2 \times 2\pi f_{sc}t)$$

Then apply lowpass filtering.

14.35. $\frac{80 \times 80}{16 \times 16}(16^2 \times 32^2 \times 3) = 19.661 \times 10^6$ operations

APPENDIX B

B.1. $A_0 = 0.4$, $A_1 = 0.7916$, $A_2 = 0.7667$, $A_3 = 0.7263$, $A_4 = 0.6719$

$|c_0| = 0.4$, $|c_1| = |c_{-1}| = 0.3958$,

$|c_2| = |c_{-2}| = 0.3834$, $|c_3| = |c_{-3}| = 0.3632$, $|c_4| = |c_{-4}| = 0.3359$

B.3. $x(t) = 2 + 3.7420 \times \cos(2000\pi t) + 3.0273 \times \cos(4000\pi t)$
$+ 2.0182 \times \cos(6000\pi t) + 0.9355 \times \cos(8000\pi t) + \cdots$

$f_2 = 2000$ Hz, $A_2 = 3.0273$

B.5. $X(f) = 5\left(\frac{\sin \pi f}{\pi f}\right)^2$

B.7. **a.** $X(s) = 10$

b. $X(s) = -100/s^2$

c. $X(s) = \frac{10}{s+2}$

d. $X(s) = \frac{2e^{-5s}}{s}$

e. $X(s) = \frac{10s}{s^2+9}$

f. $X(s) = \dfrac{14.14 + 7.07s}{s^2 + 9}$

g. $X(s) = \dfrac{3(s+2)}{(s+2)^2 + 9}$

h. $X(s) = \dfrac{12,000}{s^6}$

B.9. a. $X(s) = \dfrac{7.5}{s(s+1.5)}$

b. $x(t) = 5u(t) - 5e^{-1.5t}u(t)$

B.11. a. zero: $s = 3$, poles: $s = -2$, $s = -2$, stable

b. zeros: $s = 0$, $s = \pm 2.236j$, poles: $s = \pm 3j$, $s = -1 \pm 1.732j$, marginally stable

c. zeros: $s = \pm j$, $s = -1$, poles: $s = 0$, $s = -3$, $s = -4$, $s = -8$, $s = 1$, unstable

B.13. a. $H(j\omega) = \dfrac{1}{\dfrac{j\omega}{5} + 1}$

b. $A(\omega) = \dfrac{1}{\sqrt{1 + \left(\dfrac{\omega}{5}\right)^2}}$, $\beta(\omega) = \angle - \tan\left(\dfrac{\omega}{5}\right)$

c. $Y(j2) = 4.6424 \angle -21.80^0$ that is, $y_{ss}(t) = 4.6424 \sin(2t - 21.80^0)u(t)$