TT TEXTBOOK TESTBANKS

Solutions Manual for Digital Communications 3rd Sklar

SOLUTIONS MANUAL SAMPLE PREVIEW

PUBLISHER
Pearson

COPYRIGHT
2021

RESOURCE TYPE
Solutions Manual

ISBN
9780134588568

Solutions Manual

Answers to End-of-Chapter Problems

Digital Communications

Third Edition

Bernard Sklar
fred harris

This Solutions Manual provides answers to the Problems that appear at the end of Chapters 1-17.

The pages contain a mix of typeset and handwritten text. The handwritten text is comprised of updates and solutions new to this edition.

Chapter 1

Answers to Problems

The pages in Chapter 1 contain a mix of typeset and handwritten text. The handwritten text is comprised of updates and solutions new to this edition.

Chapter 1

1.1 (a) $x(t) = A \cos 2\pi f_0 t$: Power signal

$$P_x = \frac{1}{T_0}\int_{-T_0/2}^{T_0/2} x^2(t)\,dt = \frac{1}{T_0}\int_{-T_0/2}^{T_0/2} A^2 \cos^2 2\pi f_0 t\,dt$$

$$= \frac{1}{T_0}\int_{-T_0/2}^{T_0/2} \frac{A^2}{2}\,dt = \frac{A^2}{2}$$

(b)

$$x(t) = \begin{cases} A\cos 2\pi f_0 t & \text{for } -T_0/2 \le t \le \frac{T_0}{2} \\ 0 & \text{elsewhere} \end{cases}$$

Energy signal

$$E_x = \int_{-\infty}^{\infty} x^2(t)\,dt = \int_{-T_0/2}^{T_0/2} A^2 \cos^2 2\pi f_0 t\,dt = \frac{A^2 T_0}{2}$$

(c)

$$x(t) = \begin{cases} A\exp(-at) & \text{for } t > 0,\ a > 0 \\ 0 & \text{elsewhere} \end{cases}$$

Energy signal

$$E_x = \int_{-\infty}^{\infty} x^2(t)\,dt = \int_0^{\infty} A^2 \exp(-2at)\,dt$$

$$= \left[\frac{A^2 \exp(-2at)}{-2a}\right]_0^{\infty} = \frac{A^2}{2a}$$

(d) $x(t) = \cos t + 5\cos 2t \quad \text{for } -\infty < t < \infty$

Power signal

$$P_x = \frac{1}{T_0}\int_{-T_0/2}^{T_0/2} \cos^2 t + 25\cos^2 2t \, dt\,; \quad 2\pi f_0 = 1, \quad T_0 = 2\pi$$

$$= \frac{1}{2\pi}\int_{-\pi}^{\pi}\left(\frac{1}{2} + \frac{25}{2}\right) dt = \frac{1}{2\pi}(26\pi) = 13$$

1.2 $x(t) = \text{rect}(t/T)$

$$= \begin{cases} 1 & \text{for } -T/2 \le t \le T/2 \\ 0 & \text{elsewhere} \end{cases}$$

ESD $\psi(f) = |X(f)|^2 = T^2 \,\text{sinc}^2(fT)$

$$E_x = \int_{-\infty}^{\infty} x^2(t)\,dt = \int_{-T/2}^{T/2} dt = T$$

1.3 Using Equations (1.18) and (1.19)

$$G_x(f) = \sum_{n=-\infty}^{\infty} |c_n|^2 \delta(f - nf_0)$$

$$P_x = \int_{-\infty}^{\infty} G_x(f)\,df = \int_{-\infty}^{\infty} \sum_{n=-\infty}^{\infty} |c_n|^2 \delta(f - nf_0)\,df$$

$$P_x = \sum_{n=-\infty}^{\infty} |c_n|^2$$

1.4 $$P_x = \frac{1}{T_0}\int_{-T_0/2}^{T_0/2} x^2(t)\,dt\,; \qquad 2\pi f_0 = 10$$

$$f_0 = 5/\pi$$

$$T_0 = \pi/5$$

$$P_x = \frac{5}{\pi}\int_{-\pi/10}^{\pi/10} 100\cos^2 10t + 400\cos^2 20t\,dt$$

$$= \frac{5}{2\pi}\int_{-\pi/10}^{\pi/10} 100\,(1+\cos 20t) + 400\,(1+\cos 40t)\,dt$$

$$= \frac{5}{2\pi}\Big[100t + 400t\Big]_{-\pi/10}^{\pi/10} = 250\ \text{W}$$

1.5 $$G_x(f) = \sum_{n=-\infty}^{\infty} |c_n|^2\,\delta(f - nf_0)$$

$$c_1 = c_{-1} = \frac{10}{2} = 5\,; \qquad c_2 = c_{-2} = \frac{20}{2} = 10$$

$$c_n = 0 \quad \text{for} \quad n = 0,\ \pm 3,\ \pm 4,\ \ldots$$

$$G_x(f) = (5)^2\,\delta\!\left(f - \tfrac{5}{\pi}\right) + (5)^2\,\delta\!\left(f + 5/\pi\right)$$

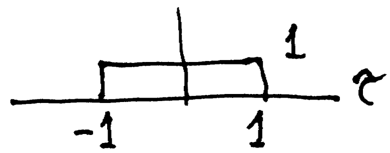
$$+ (10)^2\,\delta\!\left(f - 10/\pi\right) + (10)^2\,\delta\!\left(f + 10/\pi\right)$$

$$P_x = \int_{-\infty}^{\infty} G_x(f)\,df = 25 + 25 + 100 + 100$$

$$= 250\ \text{W}$$

1.6 $\mathcal{F}\{R(\tau)\}$ must be a nonnegative function because $\mathcal{F}\{R(\tau)\} = G(f)$; and, the power spectral density, $G(f)$, must be a nonnegative function.

(a) $x(\tau) = \begin{cases} 1 & \text{for } -1 \le \tau \le 1 \\ 0 & \text{otherwise} \end{cases}$



NO
1. $x(\tau) = x(-\tau)$ ✓
2. $x(0) \ge x(\tau)$ ✓
3. $\mathcal{F}\{x(\tau)\}$ is a positive <u>and</u> <u>negative</u> going function.

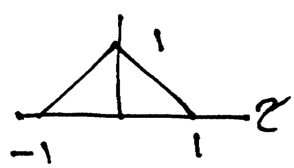
(b) $x(\tau) = \delta(\tau) + \sin 2\pi f_0 \tau$

NO 1. $x(\tau) \ne x(-\tau)$ ×

(c) $x(t) = \exp(|\tau|)$

NO
1. $x(\tau) = x(-\tau)$ ✓
2. $x(0) \not\ge x(\tau)$ ×

(d) $x(\tau) = \begin{cases} -\tau + 1 & \text{for } 0 \le \tau \le 1 \\ \tau + 1 & \text{for } -1 \le \tau \le 0 \end{cases}$



YES
1. $x(\tau) = x(-\tau)$ ✓
2. $x(0) \ge x(\tau)$ ✓
3. $\mathcal{F}\{x(\tau)\} = 2\,\text{sinc}^2 f\tau$ is a nonnegative function. ✓

1.7 (a) $X(f) = \delta(f) + \cos^2 2\pi f$

YES

1. always real ✓
2. $P_x(f) \geq 0$ ✓
3. $P_x(-f) = P_x(f)$ ✓

(b) $X(f) = 10 + \delta(f-10)$

No

1. always real ✓
2. $P_x(f) \geq 0$ ✓
3. $P_x(-f) \neq P_x(f)$ ×

(c) $X(f) = \exp(-2\pi|f-10|)$

No

1. always real ✓
2. $P_x(f) \geq 0$ ✓
3. $P_x(-f) \neq P_x(f)$ ×

(d) $X(f) = \exp[-2\pi(f^2-10)]$

YES

1. always real ✓
2. $P_x(f) \geq 0$ ✓
3. $P_x(-f) = P_x(f)$ ✓

1.8

$$R_x(\tau) = \left\langle A\cos(2\pi f_0 t+\phi)\, A\cos(2\pi f_0 t + 2\pi f_0 \tau + \phi)\right\rangle$$

where $\langle\cdot\rangle$ is the time averaging operator $\frac{1}{T_0}\int_{-T_0/2}^{T_0/2} dt$

Upon expanding (see Appendix D),
$R_x(\tau)$ becomes:

$$R_x(\tau) = A^2\Big[\cos 2\pi f_0\tau \left\langle \cos^2(2\pi f_0 t+\phi)\right\rangle$$
$$-\sin 2\pi f_0\tau \left\langle \cos(2\pi f_0 t+\phi)\sin(2\pi f_0 t+\phi)\right\rangle\Big]$$

The negative term in the above expression goes to zero, and hence

$$R_x(\tau) = \frac{A^2}{2}\cos 2\pi f_0 \tau$$

$$P_x = R_x(0) = A^2/2$$

1.9

(a) $R_x(\tau) = \frac{100}{2}\cos 10\tau + \frac{400}{2}\cos 20\tau$

where $2\pi f_0 = 10$

(b) $P_x = R_x(0) = 50 + 200 = 250$ W

1.10 (a) average value of $x(t)$

$$\langle x(t) \rangle = \frac{1}{T_0} \int_{-T_0/2}^{T_0/2} (1 + \cos 2\pi f_0 t)\, dt = 1$$

(b) the ac power of $x(t)$

$$\langle \sigma^2(t) \rangle = \frac{1}{T_0} \int_{-T_0/2}^{T_0/2} \cos^2 2\pi f_0 t \; dt = 1/2$$

(c) the rms value of $x(t)$

$$\langle x^2(t) \rangle = \frac{1}{T_0} \int_{-T_0/2}^{T_0/2} (1 + \cos 2\pi f_0 t)^2 dt$$

$$= \frac{1}{T_0} \int_{-T_0/2}^{T_0/2} (1 + 2\cos 2\pi f_0 t + \cos^2 2\pi f_0 t)\, dt = \frac{3}{2}$$

$$x_{rms} = \sqrt{3/2}$$

1.11 (a) $$\langle X(t) \rangle = \frac{1}{T_0} \int_{-T_0/2}^{T_0/2} A \cos(2\pi f_0 t + \phi)\, dt = 0$$

$$\langle X^2(t) \rangle = \frac{1}{T_0} \int_{-T_0/2}^{T_0/2} [A \cos(2\pi f_0 t + \phi)]^2 dt$$

$$= \frac{A^2}{2}$$

1.11 (b) $E\{X\} = \int_{-\infty}^{\infty} X(\phi)\, p(\phi)\, d\phi$

$p(\phi) = \frac{1}{2\pi}$ since ϕ is uniformly distributed over $(0, 2\pi)$

$$E\{X\} = \int_0^{2\pi} \left[A \cos(2\pi f_0 t + \phi)\right] \frac{1}{2\pi}\, d\phi = 0$$

$$E\{X^2\} = \int_0^{2\pi} \left[A \cos(2\pi f_0 t + \phi)\right]^2 \frac{1}{2\pi}\, d\phi$$

$$= A^2/2$$

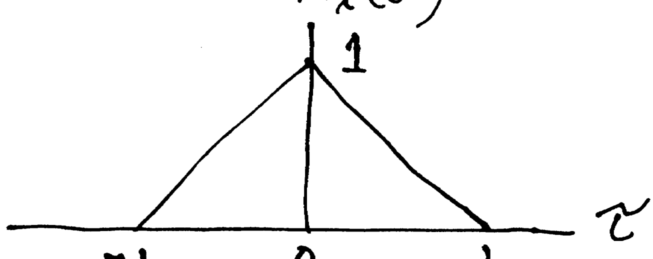
1.12 $X(f) = \operatorname{sinc} f$

$$\Psi_x(f) = |X(f)|^2 = \operatorname{sinc}^2 f$$

$$R_x(\tau) = \mathcal{F}^{-1}\{\Psi_x(f)\}$$

From Table A.1, $R_x(\tau)$ is seen to be the following triangular function:

$$R_x(\tau) = \begin{cases} 1 - |\tau| & \text{for } |\tau| < 1 \\ 0 & \text{elsewhere} \end{cases}$$



1.13 (a) $\int_{-\infty}^{\infty} \cos 6t \, \delta(t-3) \, dt = \cos 18$

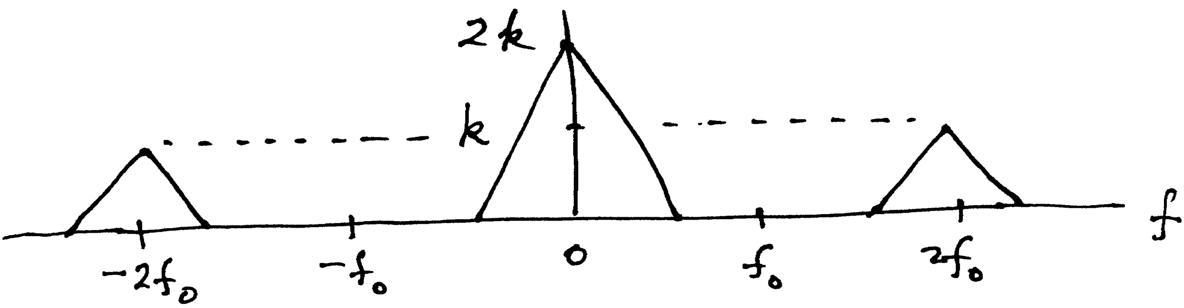
(b) $\int_{-\infty}^{\infty} 10 \, \delta(t) \, (1+t)^{-1} \, dt = 10$

(c) $\int_{-\infty}^{\infty} \delta(t+4) \, (t^2+6t+1) \, dt = -7$

(d) $\int_{-\infty}^{\infty} \exp(-t^2) \, \delta(t-2) \, dt = 0.0183$

1.14 $X_2(f) = k\left[\delta(f-f_0) + \delta(f+f_0)\right]$

$$X_1(f) * X_2(f) = X_1(f) * k\left[\delta(f-f_0) + \delta(f+f_0)\right]$$



1.15 (a) $P_x = 2\int_0^{10\text{ kHz}} G_x \, df = 2\int_0^{10\text{ kHz}} 10^{-6} f^2 \, df$

$$= 2\left[\frac{10^{-6} f^3}{3}\right]_0^{10^4} = 667 \text{ kW}$$

(b) $P_x = 2\int_{5\text{ kHz}}^{10\text{ kHz}} 10^{-6} f^2 \, df = 2\left[\frac{10^{-6} f^3}{3}\right]_{5000}^{10000}$

$$= 583 \text{ kW}$$

1.16 $$10 \log_{10}\left[\frac{100 \times 2 \times 1/2}{1/2}\right] = 23\text{ dB}$$

1.17 (a) Since $|H(f)|$ decreases monotonically with $|f|$, and $|H(0)| = 1$, we can write the following relationship in terms of the -1dB frequency, f_1.

$$10 \log_{10} |H(f_1)|^2 = -1\text{ dB}$$

$$\log_{10}\left[\frac{1}{(1 + f_1/f_u)^{2n}}\right] = -\frac{1}{10}$$

$$\left[1 + f_1/f_u\right]^{2n} = 10^{1/10}$$

$$\left[f_1/f_u\right]^{2n} = 10^{1/10} - 1 = 0.2584$$

$$\therefore\ n \geq \frac{1}{2}\left[\frac{\log 0.2584}{\log (f_1/f_u)}\right]$$

For $f_1/f_u = 0.9$, $n \geq 6.4$

Thus, $n = 7$

1.17 (b) In the limit, as $n \to \infty$

$\left(f/f_u\right)^{2n} \to 0$, $|H(f)| \to 1$, for $|f/f_u| < 1$

$\left(f/f_u\right)^{2n} \to \infty$, $|H(f)| \to 0$, for $|f/f_u| > 1$

Hence, $|H(f)|$ approaches the transfer characteristic of an ideal low-pass filter with a cut-off frequency at f_u, as n approaches infinity.

1.18 $\quad y(t) = \delta(t) * h(t)$

$Y(f) = 1 \times H(f)$

since $\mathcal{F}\{\delta(t)\} = 1$.

Hence, $y(t) = \mathcal{F}^{-1}\{Y(f)\} = \mathcal{F}^{-1}\{H(f)\}$

$= h(t)$

1.19 Let $x(t) = \delta(t)$

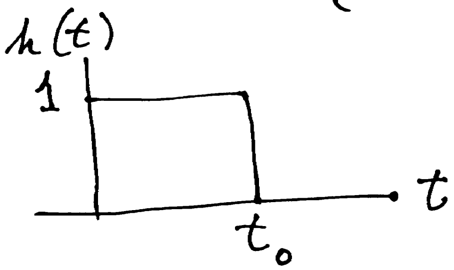
$$g(t) = \delta(t) - \delta(t - t_0)$$

$$h(t) = \int_{-\infty}^{t} [\delta(\tau) - \delta(\tau - t_0)]\, d\tau$$

$$= u(t) - u(t - t_0)$$

where $u(t)$ is the unit step function defined as follows:

$$u(t) = \begin{cases} 1 & t > 0 \\ 0 & \text{elsewhere} \end{cases}$$



1.20 (a) Half-power bandwidth is the bandwidth from half-power point to half-power point. $BW = 2f_0$

where $\frac{1}{2} = \left[\frac{\sin(\pi f_0 10^{-4})}{\pi f_0 10^{-4}}\right]^2$

$$0.707 = \frac{\sin x_0}{x_0}, \quad x_0 = \pi f_0 10^{-4}$$

$$x_0 \cong 1.4 \Rightarrow f_0 = 4.46\ \text{kHz} \Rightarrow BW \cong 9\ \text{kHz}$$

1.20 (b) Noise equivalent bandwidth

$$BW = 2\int_0^{\infty}\left[\frac{\sin(\pi f 10^{-4})}{\pi f\, 10^{-4}}\right]^2 df$$

$$= \frac{2\times 10^4}{\pi}\underbrace{\int_0^{\infty}\left[\frac{\sin x}{x}\right]^2 dx}_{\pi/2}$$

$$= 10\ kHz$$

(c) Null-to-null bandwidth: $BW = 2f_0$ where f_0 is the frequency where

$$\frac{\sin(\pi f_0 10^{-4})}{\pi f_0\, 10^{-4}} = 0$$

The minimum f_0 corresponding to the first null is found by:

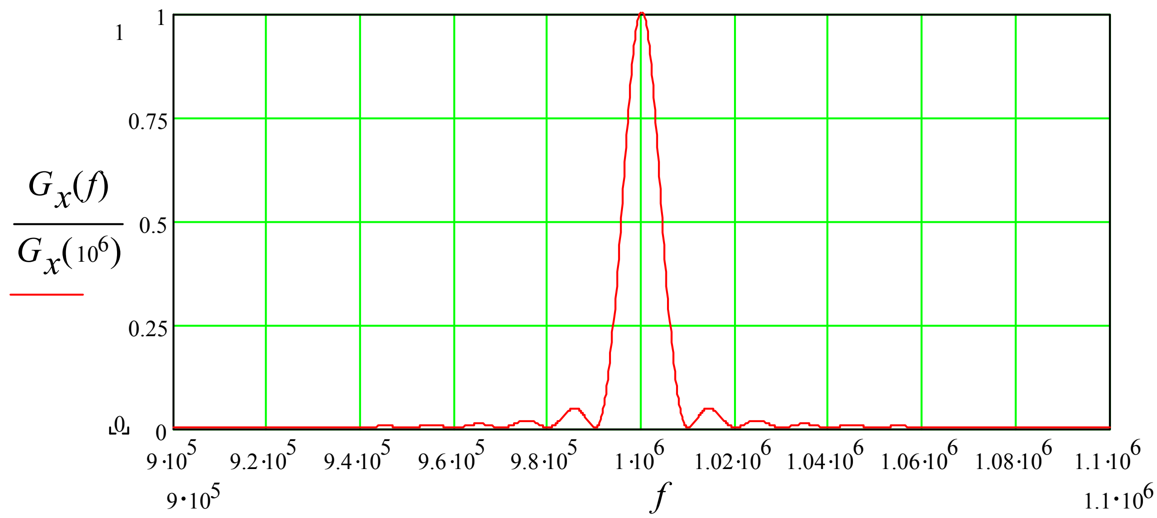
$$\pi f_0 10^{-4} = \pi$$

$$BW = 2f_0 = 20\ kHz$$

(d) 99% of power bandwidth. $BW = 2f_0$ where

$$0.995 = \frac{10^{-4}\int_0^{f_0}\left(\frac{\sin \pi f 10^{-4}}{\pi f 10^{-4}}\right)^2 df}{10^{-4}\int_0^{\infty}\left(\frac{\sin \pi f 10^{-4}}{\pi f 10^{-4}}\right)^2 df}$$

1.20 (d) The normalized spectrum, $G_x(f)/G_x(10^6)$, appears as:



Applying numerical methods with Mathcad ®, the two-sided 99% bandwidth can be found by numerical integration as:

$$\frac{\int_{10^6-f_1}^{10^6+f_1} G_x(f)\,df}{\int_{-\infty}^{\infty} G_x(f)\,df} = 0.99$$

where f_1 is found to be equal to 103 kHz. Thus, the two-sided 99% bandwidth is equal to 206 kHz.

Since this bandwidth corresponds to the given spectrum (with signaling rate = 10,000 symbols/s), normalizing it relative to one symbol per second, yields the two-sided 99% bandwidth as $(206\times10^3/10^4) = 20.6$ Hz for one symbol per second, or in general the 99% bandwidth in terms of the signaling rate, R, is $20.6\times R$ Hz.

1.20 (e)

35-dB Bandwidth:

35-dB attenuation $\Rightarrow 10^{-3.5} = 3.16 \times 10^{-4}$

Since $\sin^2 x$ is unity for $x = \frac{\pi}{2}(2k+1)$, $k = 0, 1, \cdots$, the lobe beyond which the attenuation criterion is guaranteed to be met is the minimum k for which

$$10^{-3.5} \geq \frac{1}{\left[\pi/2\,(2k+1)\right]^2}$$

$$3162.28 \leq \left[\pi/2\,(2k+1)\right]^2$$

$$56.23 \leq \pi/2\,(2k+1)$$

$$35.80 \leq 2k+1 \implies k = 18$$

Thus the 18^{th} sidelobe meets the 35-dB criterion, and the actual 35-dB point will be on the falling edge of the 17^{th} sidelobe. $BW = 2f_0$, where f_0 is the minimum value satisfying:

$$\pi f_0 10^{-4} > \frac{\pi}{2}(35)$$

and $$\left[\frac{\sin(\pi f_0 10^{-4})}{\pi f_0 10^{-4}}\right]^2 = 10^{-3.5}$$

Solving iteratively, we get: $\pi f_0 10^{-4} = 55.171$

$$BW = 2f_0 = 351.2 \text{ kHz}$$

1.20 (f) The absolute bandwidth is <u>infinite</u>, since for any finite test-BW, $10^{-4}\left[\frac{\sin \pi(f-10^6)10^{-4}}{\pi(f-10^6)10^{-4}}\right]^2$ will have positive measure beyond it.

Chapter 2

Answers to Problems

The pages in Chapter 2 contain a mix of typeset and handwritten text. The handwritten text is comprised of updates and solutions new to this edition.

Chapter 2

2.1 (a) $\underbrace{00010010}_{H}$ $\underbrace{11110011}_{O}$ $\underbrace{11101011}_{W}$

(b) $\underbrace{000}_{0}$ $\underbrace{100}_{4}$ $\underbrace{101}_{5}$ $\underbrace{111}_{7}$ $\underbrace{001}_{1}$ $\underbrace{111}_{7}$ $\underbrace{101}_{5}$ $\underbrace{011}_{3}$

8 symbols

(c) 24 bits / 4 bits per symbol = 6 symbols

(d) 24 bits / 8 bits per symbol = 3 symbols

2.2 (a) 800 char/s × 8 bits/char = 6400 bits/s

(b) $\dfrac{6400 \text{ bits/s}}{4 \text{ bits/symbol}} = 1600$ symbols/s.

2.3 (a) 100 char/2 s × 8 bits/char = 400 bits/s.

$\dfrac{400 \text{ bits/s}}{5 \text{ bits/symbol}} = 80$ symbols/s

(b) 16-level PCM: 400 bits/s, 100 symbols/s.

8-level PCM: 400 bits/s, 133.3 symbols/s.

4-level PCM: 400 bits/s, 200 symbols/s.

2-level PCM: 400 bits/s, 400 symbols/s.

2.4 $$x_s(t) = x(t)\, x_p(t)$$

$$= x(t) \left\{ \sum_{n=-\infty}^{\infty} c_n e^{j2\pi n f_s t} \right\}$$

$$= x(t) \left\{ c_0 + 2 \sum_{n=1}^{\infty} c_n \cos 2\pi n f_s t \right\}$$

$$x_1(t) = x_s(t) \cos 2\pi m f_s t$$

$$= x(t) \left\{ \begin{array}{l} \cancel{c_0 \cos 2\pi m f_s t} \quad \text{LPF} \\ + \displaystyle 2 \sum_{\substack{n=1 \\ n \neq m}}^{\infty} \cancel{c_n \cos 2\pi n f_s t \cos 2\pi m f_s t} \quad \text{LPF} \\ + 2 c_m \cos^2 2\pi m f_s t \end{array} \right\}$$

$$x_0(t) = x(t)\, 2c_m \left(\frac{1}{2} + \cancel{\frac{1}{2} \cos 4\pi m f_s t} \right) \quad \text{LPF}$$

$$= c_m x(t)$$

2.5 (a) L quantization levels requires a minimum of $\log_2 L$ bits. It is necessary to transmit at least $\log_2 L$ bits in T_s seconds. Thus, the time duration, T, for one bit is

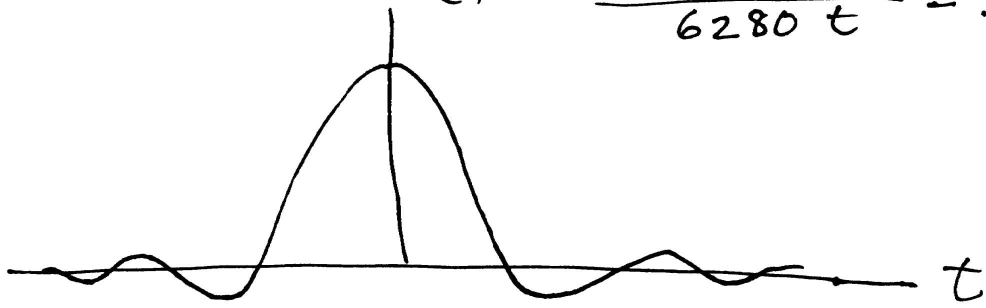
$$T \leq \frac{T_s}{\log_2 L}$$

(b) The equality sign is valid if L is a power of 2.

2.6 (a) $2^5 = 32$ (b) $2^8 = 256$ (c) 2^x

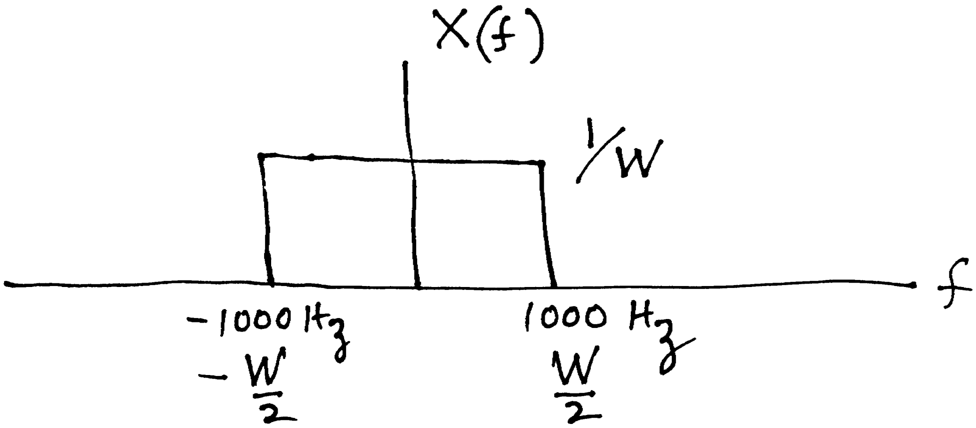
2.7

$$x(t) = \frac{\sin 6280t}{6280t} = \frac{\sin \frac{Wt}{2}}{Wt/2}$$



where $\frac{W}{2} = 2\pi f = 6280$ radians

$f = 1000$ Hz



$$X(f) = \begin{cases} 1/W & \text{for } |f| \leq 1000 \text{ Hz} \\ 0 & \text{elsewhere} \end{cases}$$

$f_m = 1000$ Hz

Minimum sampling rate $f_s = 2f_m$

$= 2000$ samples/s.

2.8 (a) $\left(\frac{S}{N}\right)_q = 3L^2 \geq 30\text{ dB}$

$$10 \log_{10} (3L^2) \geq 30\text{ dB}$$

$$L = \lceil 18.26 \rceil = 19$$

minimum number of quantization levels

$$l = \lceil \log_2 L \rceil = \lceil \log_2 19 \rceil = 5 \text{ bits/sample}$$

(b) $T_b = \frac{T_s}{l} = \frac{1}{l f_s} = \frac{1}{5(8000)} = 25\,\mu s.$

where T_b is the time duration of a bit.

Required bandwidth, W, is

$$W = \frac{1}{T_b} = \frac{1}{25\,\mu s} = 400 \text{ kHz}.$$

2.9 (a) $\omega_m = 2\pi f_m = 2000$

$$f_m = 2000/2\pi = 318.3 \text{ Hz}$$

$f_s \geq 2 f_m = 636.6$ samples/s.

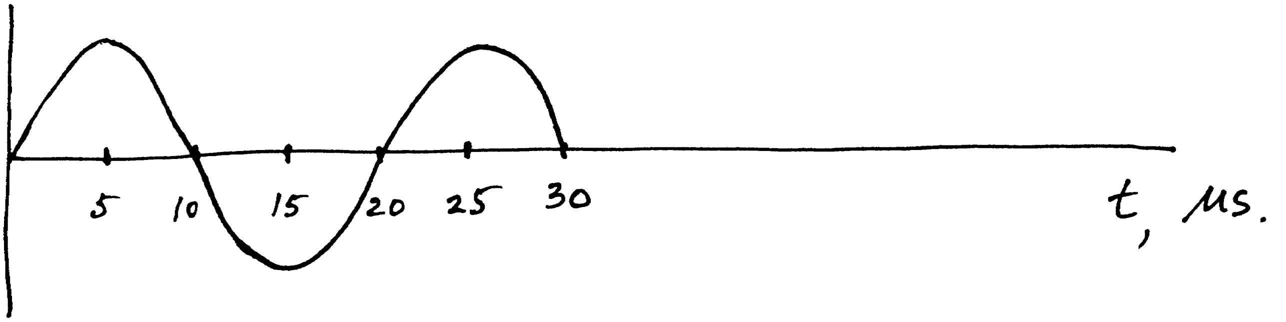
$T_s = \frac{1}{f_s} \leq 0.00157$ s.

(b) 636.6 samples/s × 3600 s

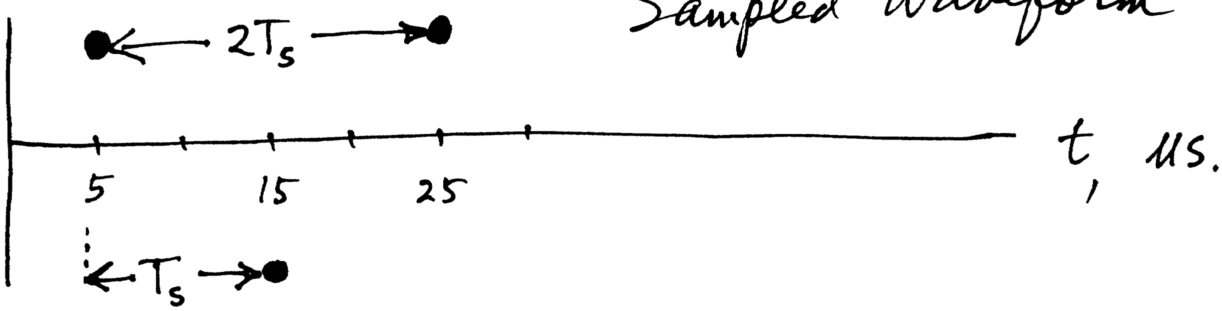
$= 2.29 \times 10^6$

samples

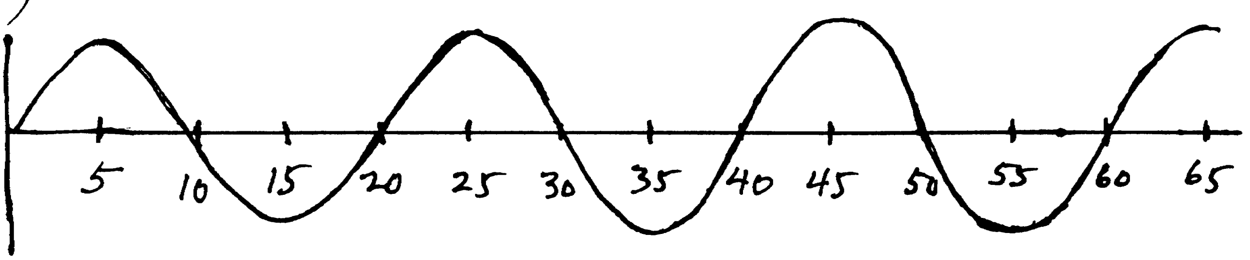
2.10 (a) $f_0 = 50\ kHz$; $T_s = \dfrac{1}{2f_0} = 10\,\mu s.$

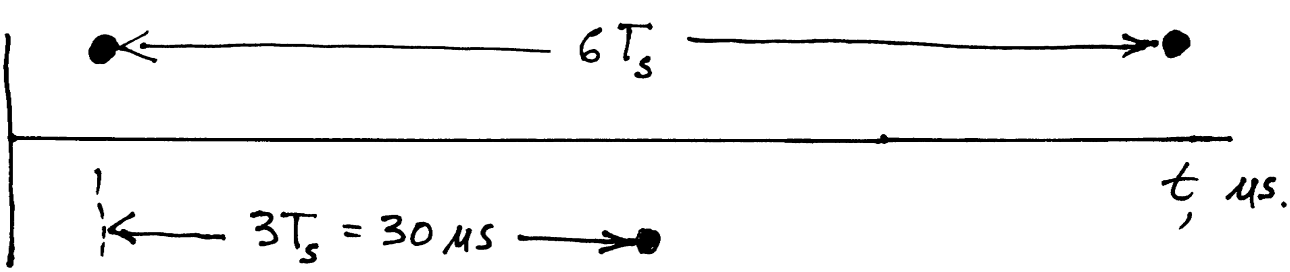


Sampled waveform



(b)



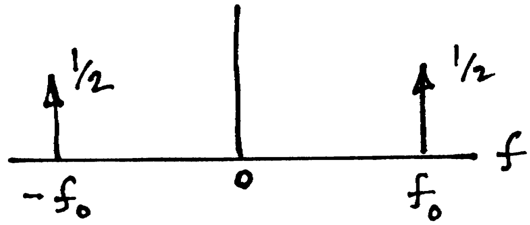


Period of reconstructed waveform $= 6T_s$

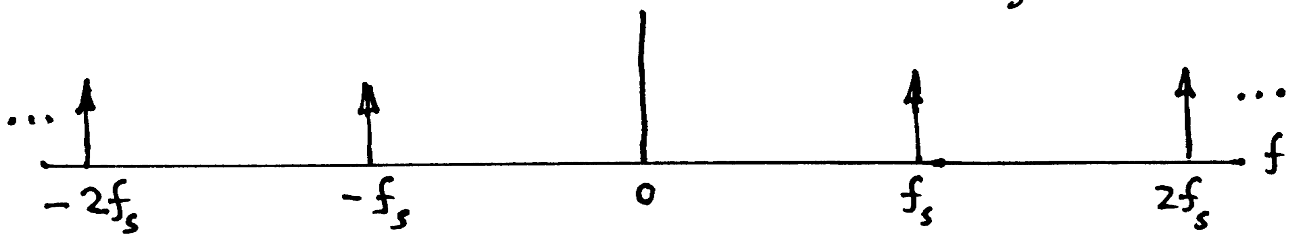
$\therefore\ f = \dfrac{1}{6T_s} = 16.67\ kHz \neq 50\ kHz.$

2.11

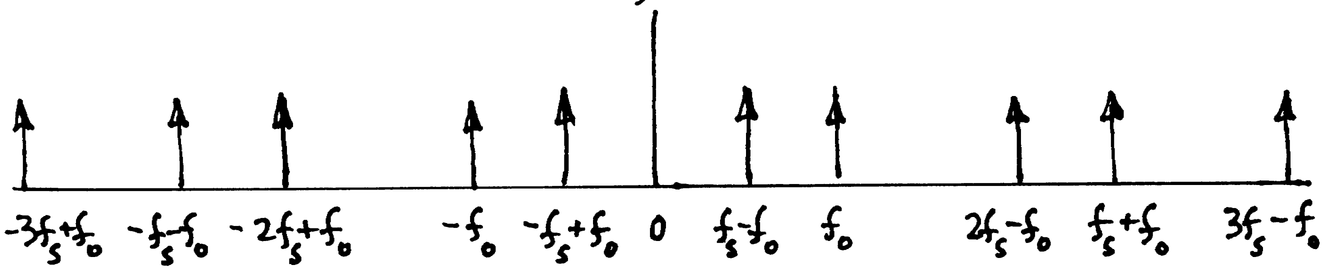
$$X(f) = \frac{1}{2}\left[\delta(f-f_0) + \delta(f+f_0)\right]$$



$X_s(f)$ $\qquad$ $f_s = \frac{3}{2} f_0$



$X(f) * X_s(f)$



2.12

(a) Using Equation (1.65)

$$|H(f)|^2 = \frac{1}{1+(f/f_u)^{2n}}$$

for a 6^{th} order Butterworth filter and the given requirements, we write:

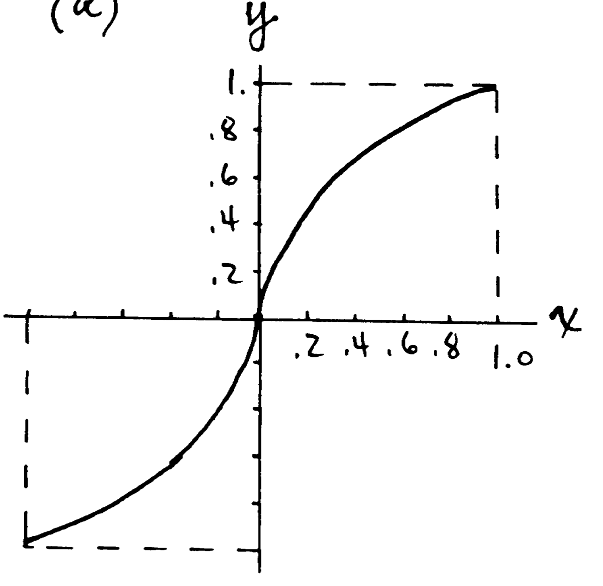
$$10^{-5} = \frac{1}{1+(f/1000)^{12}}$$

This yields $f = 2610$ Hz. Thus, the sampling rate must be at least 5220 samples/s.

(b) Using Equation (1.65) for a 12^{th} order filter and the same requirements yields $f = 1616$ Hz. Thus, the sampling rate must be at least 3232 samples/s.

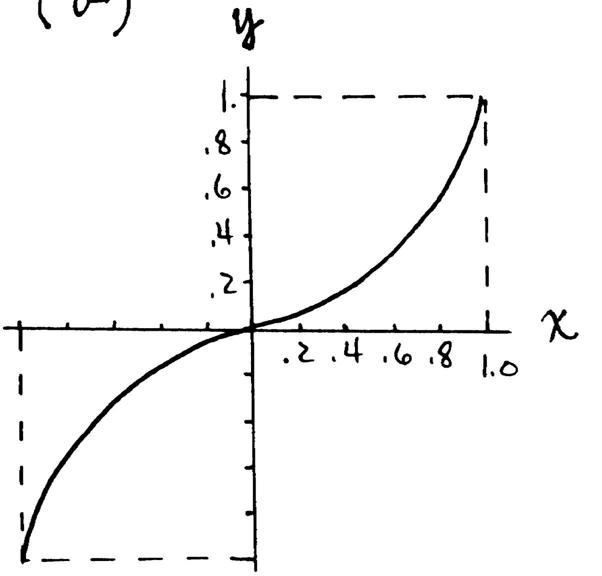
2.13

(a)



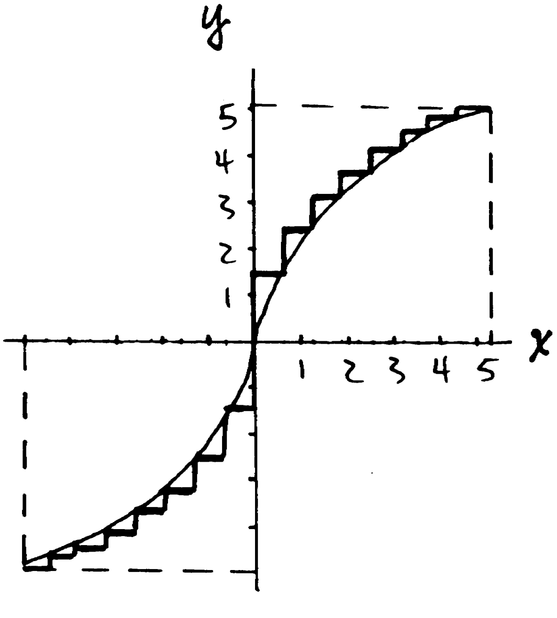
compression characteristic $\mu = 10$

(b)



expansion characteristic $\mu = 10$

(c)



16-level nonuniform quantizer Characteristic

2.14 (a) $L \geq \frac{1}{2p} = \frac{1}{0.02} = 50$ levels

$\ell = \lceil \log_2 50 \rceil = 6$ bits/sample

(b) $f_s = 2f_m = 2 \times 4000 = 8000$ samples/s.

Bit rate: $R = 8000$ samples/s $\times$ 6 bits/sam

$= 48{,}000$ bits/s.

(c) 16-level pulses: $16 = M = 2^k$

$k = 4$ bits/pulse

Symbol rate: $R_s = \frac{R}{\log_2 M} = \frac{48{,}000 \text{ bits/s}}{4 \text{ bits/symbol}}$

$= 12{,}000$ symbols/s.

2.15 Binary case:

$R = 8000$ samples/s $\times$ 6 bits/sample $= 48{,}000$ bits/s

$W = \frac{1}{T_b} = R = 48{,}000$ Hz.

$\left(\frac{S}{N}\right)_q = 3L^2 = 3(64)^2 = 12{,}288$

$\cong 41$ dB

Four-level case:

$R_s = \frac{48{,}000 \text{ bits/s}}{2 \text{ bits/symbol}} = 24{,}000$ symbols/s.

$W = \frac{1}{T} = R_s = 24{,}000$ Hz

$\left(\frac{S}{N}\right)_q =$ the same as in the binary case $\cong 41$ dB

2.16 (a) Assume that the L quantization levels are equally spaced and symmetrical about zero. Then, the maximum possible quantization noise voltage equals ½ the q volt interval between any two neighboring levels, Also, the peak quantization noise power, N_q, can be expressed as $(q/2)^2$.

The peak signal power, S, can be designated $(V_{pp}/2)^2$, where $V_{pp} = V_p - (-V_p)$ is the peak-to-peak signal voltage, and V_p is the peak voltage.

Since there are L quantization levels and $(L-1)$ intervals (each interval corresponding to q volts), we can write:

$$\left(\frac{S}{N_q}\right)_{\text{peak}} = \frac{(V_{pp}/2)^2}{(q/2)^2} = \frac{\left[q(L-1)/2\right]^2}{(q/2)^2}$$

$$\approx \frac{q^2L^2/4}{q^2/4} = L^2$$

Thus, we need to compute how many levels, L, will yield a $(S/N_q)_{\text{peak}} = 96$ dB. We therefore write:

$$96\,\text{dB} = 10\log_{10}\left(\frac{S}{N_q}\right)_{\text{peak}} = 10\log_{10} L^2$$

$$= 20\log_{10} L$$

$$L = 10^{96/20} = 63{,}096 \quad \text{levels}$$

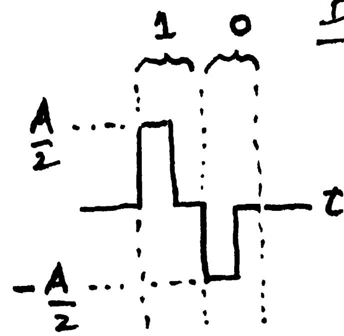
(b) The number of bits that correspond to 63,096 levels is

$$\ell = \lceil \log_2 L \rceil = \lceil \log_2 63{,}096 \rceil = 16 \quad \text{bits/sample}$$

(c) R = 16 bits/sample × 44.1 ksamples/s = 705,600 bits/s.

2.17 Let the peak-to-peak amplitude separation be A volts.

See Figure 2.22

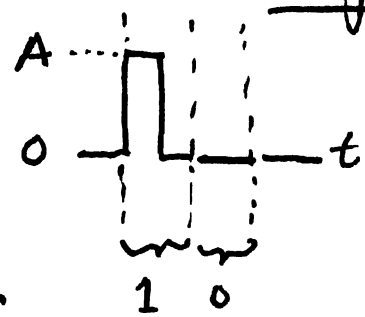


Bipolar RZ

Average power =

$$\frac{1}{2}\left[\frac{1}{2}\left(\frac{A}{2}\right)^2 + \frac{1}{2}(0)^2\right] + \frac{1}{2}\left[\frac{1}{2}\left(-\frac{A}{2}\right)^2 + \frac{1}{2}(0)^2\right] = \frac{A^2}{8}$$

See Figure 2.22



Unipolar RZ

Average power =

$$\frac{1}{2}\left[\frac{1}{2}(A)^2 + \frac{1}{2}(0)^2\right] + \frac{1}{2}\left[(0)^2\right] = A^2/4$$

Bipolar signaling requires half the average power for the same separation between the binary one and zero. The disadvantage in using bipolar signaling is the need for 2 power supplies.

2.18 The data rate for T1 service is:

24 samples/frame × 8 bits/sample × 8000 frames/s
+ 1 alignment bit/frame
= 193 bits/frame × 8000 frames/s = $1,544 \times 10^6$ bits/s

Bandwidth efficiency is:

$$\frac{R}{W} = \frac{1.544 \times 10^6}{386 \times 10^3} = 4 \text{ bits/s/Hz}.$$

2.19 (a) Using Equations (2.26) to (2.28)

$$2^{\ell} = L \geq \frac{1}{2p} \text{ levels.}$$ Given that $p = 0.02$,

then $$\ell = \left\lceil \log_2 \frac{1}{0.04} \right\rceil = \left\lceil \log_2 25 \right\rceil$$

Thus, there must be at least 25 quantization levels, or 5 bits per sample, to meet the fidelity criterion. The data rate is:

8000 samples/s × 5 bits/sample = 40,000 bits/s

This data rate needs to be sent in a 4000 Hz bandwidth. Hence, the required bandwidth efficiency is:

$$\frac{R}{W} = \frac{40{,}000 \text{ bits/s}}{4000 \text{ Hz}} = 10 \text{ bits/s/Hz}$$

(b) When the analog signal has a 20 kHz bandwidth, the Nyquist sampling rate is 40 ksamples/s, and the bit rate is:

40,000 samples/s × 5 bits/sample = 200,000 bits/s

Hence the required bandwidth efficiency is:

$$\frac{R}{W} = \frac{200{,}000}{4{,}000} = 50 \text{ bits/s/Hz},$$

which is a challenging requirement!