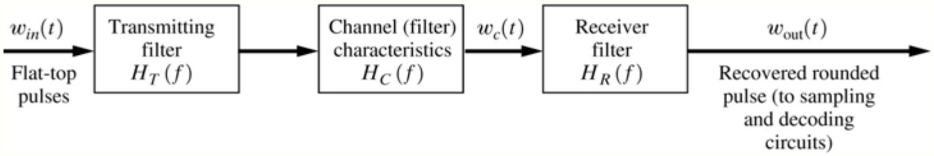
ISI- Inter-symbol Interference
Nyquist filters

Lecture 13

Figure 3–24 Baseband pulse-transmission system.

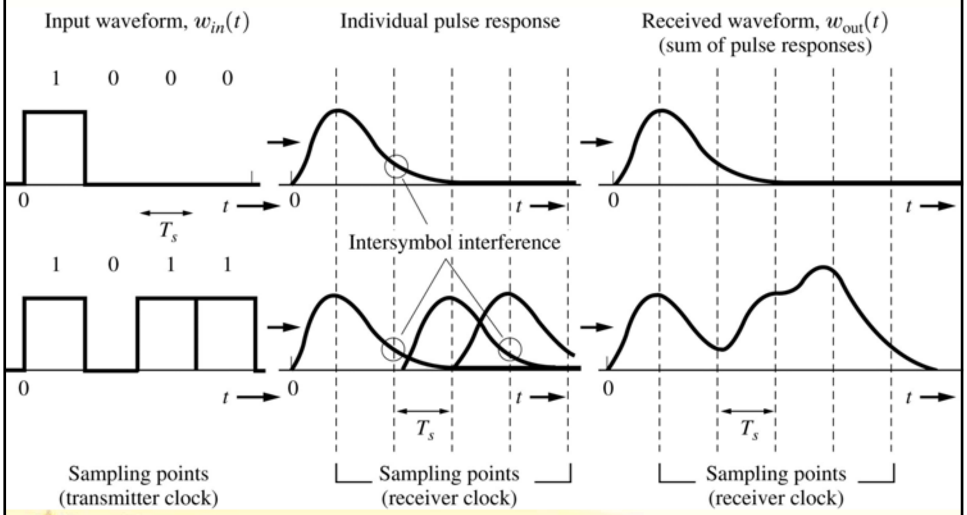


- **H_T(f) shapes the rectangular pulses to the desired pulse shape transmitted to control the Bandwidth**

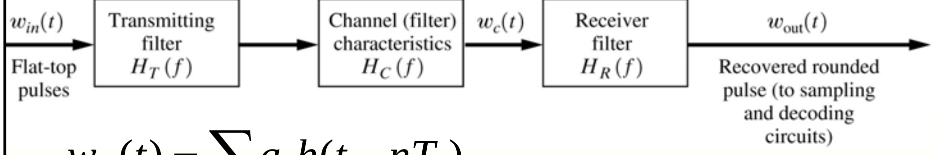
- **H_c(f) is the channel response modeled as a filter**

- **H_R(f) is the receiver filter designed to remove the pulse distortion caused by the channel and maximize the S/N**

Examples of ISI on received pulses in a binary communication system.



System Transfer Functions



$$w_{in}(t) = \sum_n a_n h(t - nT_s)$$

$$w_{out}(t) = \left[\sum_n a_n \delta(t - nT_s)\right] \otimes h_e(t)$$

$$h_e(t) = h(t) \otimes h_T(t) \otimes h_C(t) \otimes h_r(t)$$

$$H_e(f) = H(f) H_T(f) H_C(f) H_r(f)$$

System Transfer Function

Receive Equalization Filter

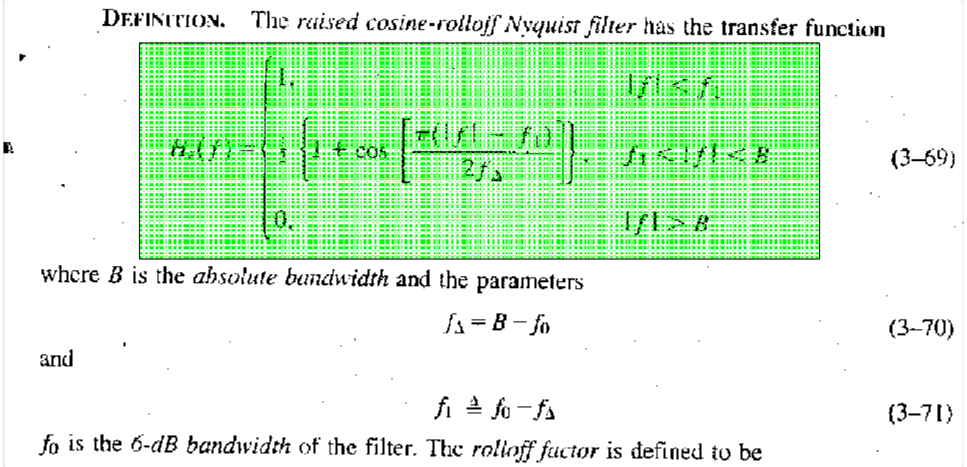
$$H_r(f) = \frac{H_e(f) = 1}{H(f)H_T(f)H_C(f)}$$

- H_r is designed to minimize ISI
- it may be fixed or adaptive
- Adaptive Filter
  - trained by using known symbol sequences called preambles

MONTANA STATE UNIVERSITY

Mountains & Minds

Raised Cosine-Rolloff Nyquist Filter



Definition. The *raised cosine-rolloff Nyquist filter* has the transfer function

$$H_e(f) = \begin{cases} 1, & |f| < f_1 \\ \frac{1}{2}\left\{1 + \cos\left[\frac{\pi(|f| - f_1)}{2f_\Delta}\right]\right\}, & f_1 < |f| < B \\ 0, & |f| > B \end{cases} \qquad (3\text{–}69)$$

where B is the *absolute bandwidth* and the parameters

$$f_\Delta = B - f_0 \qquad (3\text{–}70)$$

and

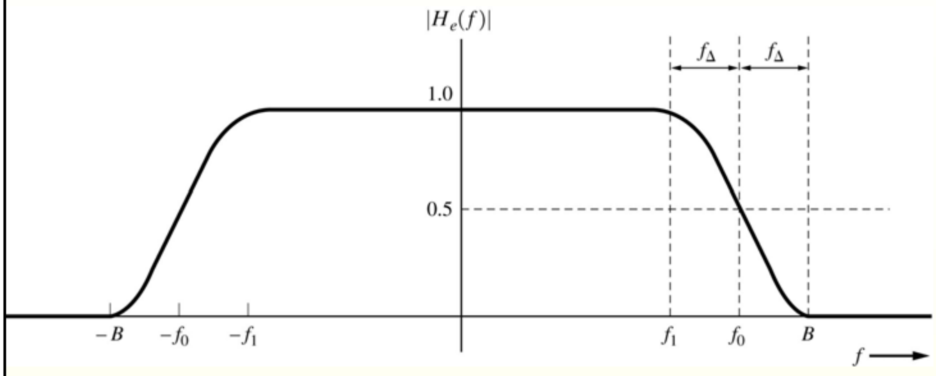
$$f_1 \triangleq f_0 - f_\Delta \qquad (3\text{–}71)$$

f_0 is the *6-dB bandwidth* of the filter. The *rolloff factor* is defined to be

MONTANA STATE UNIVERSITY

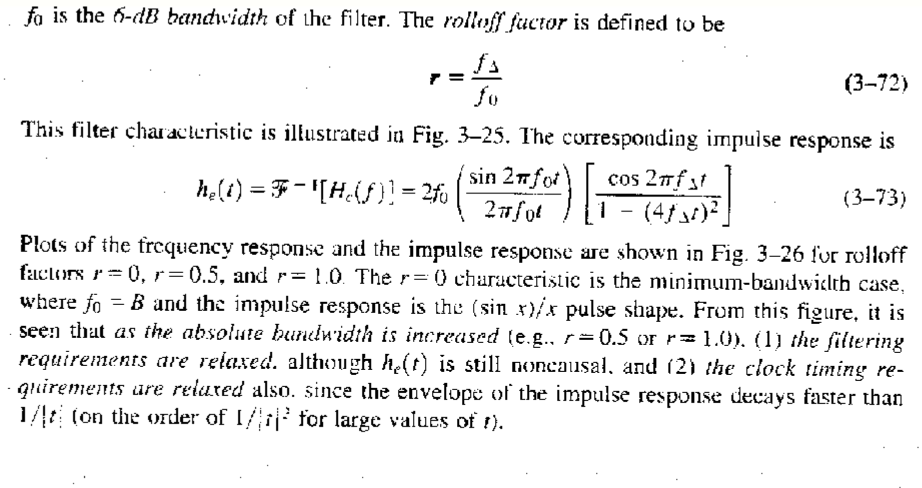
Mountains & Minds

Raised Cosine-Rolloff Nyquist Filter



Couch, Digital and Analog Communication Systems, Seventh Edition

Raised Cosine-Rolloff Nyquist Filter



f_0 is the *6-dB bandwidth* of the filter. The *rolloff factor* is defined to be

$$r = \frac{f_\Delta}{f_0} \qquad (3\text{–}72)$$

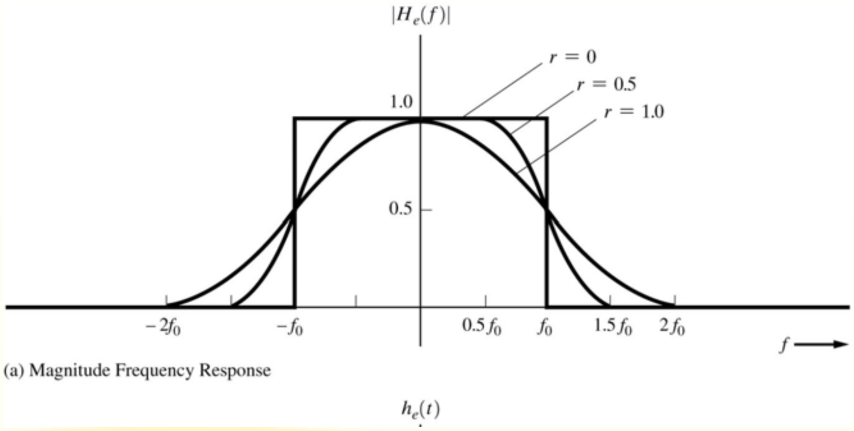
This filter characteristic is illustrated in Fig. 3–25. The corresponding impulse response is

$$h_e(t) = \mathcal{F}^{-1}[H_e(f)] = 2f_0 \left(\frac{\sin 2\pi f_0 t}{2\pi f_0 t}\right) \left[\frac{\cos 2\pi f_\Delta t}{1 - (4f_\Delta t)^2}\right] \qquad (3\text{–}73)$$

Plots of the frequency response and the impulse response are shown in Fig. 3–26 for rolloff factors $r = 0$, $r = 0.5$, and $r = 1.0$. The $r = 0$ characteristic is the minimum-bandwidth case, where $f_0 = B$ and the impulse response is the $(\sin x)/x$ pulse shape. From this figure, it is seen that *as the absolute bandwidth is increased* (e.g., $r = 0.5$ or $r = 1.0$), (1) *the filtering requirements are relaxed*, although $h_e(t)$ is still noncausal, and (2) *the clock timing requirements are relaxed* also, since the envelope of the impulse response decays faster than $1/|t|$ (on the order of $1/|t|^2$ for large values of t).

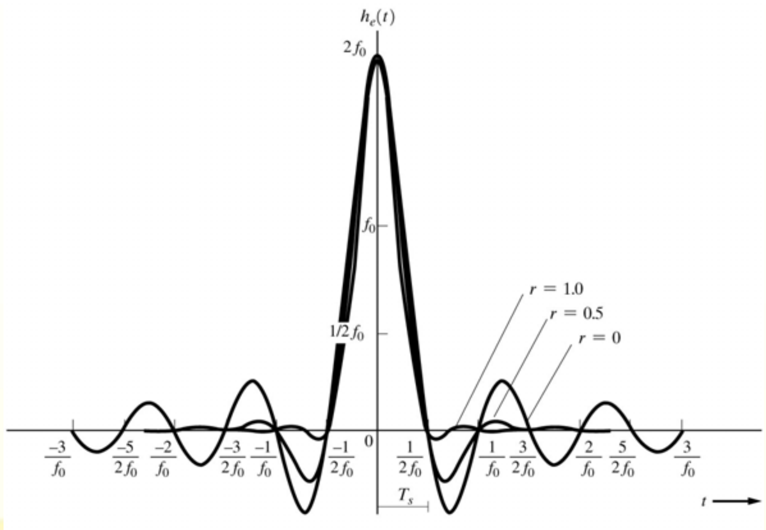
Raised Cosine-Rolloff Nyquist Filter

Figure 3–26 Frequency and time response for different rolloff factors.



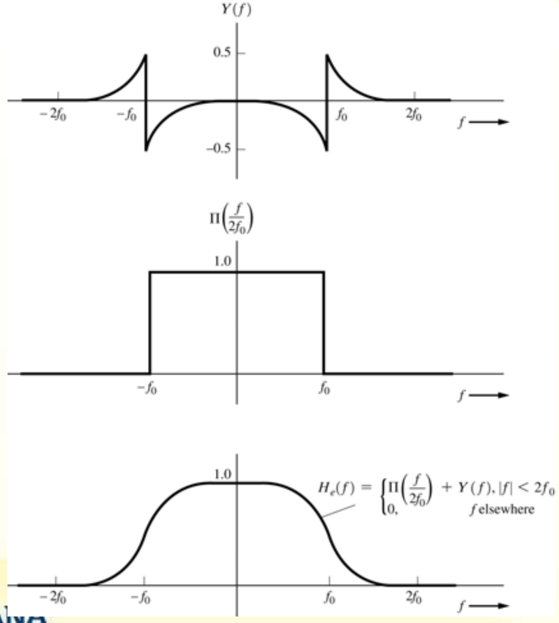
(a) Magnitude Frequency Response

Raised Cosine-Rolloff Nyquist Filter



(b) Impulse Response

Figure 3–27 Nyquist filter characteristic.



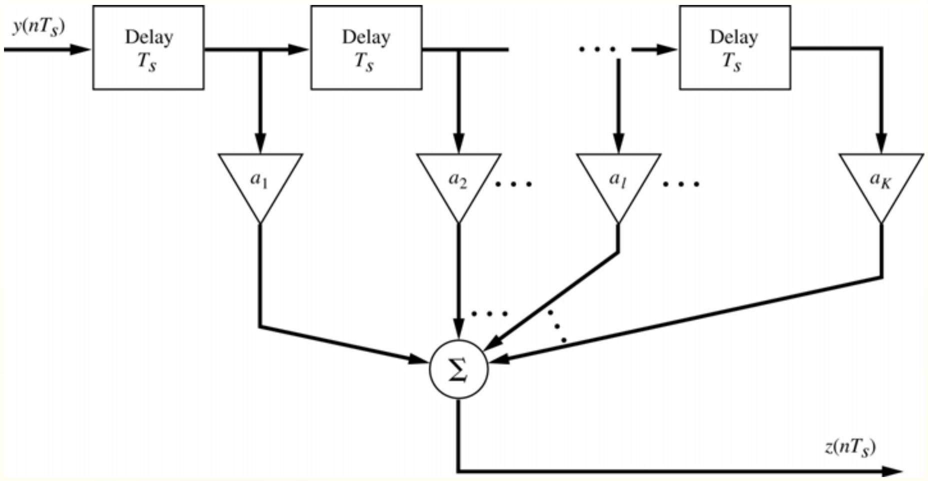
Raised Cosine-Rolloff Nyquist Filter

$$D = \frac{2B}{1+r} \qquad (3-74)$$

Where D is the Supported Data rate without ISI

Look over example in the txt

Figure 3–28 Transversal filter.



Couch, Digital and Analog Communication Systems, Seventh Edition

---

Exam 1solution in class

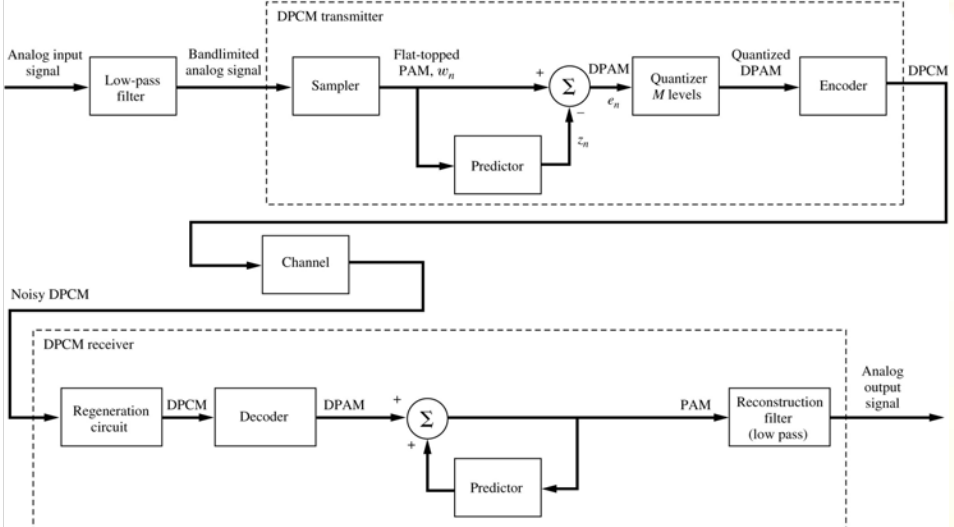
ELE445-14
Lecture 23

DPCM and single bit A/D

EELE445-14

Lecture 23

Differential Pulse code Modulation: DPCM



Differential Pulse code Modulation: DPCM

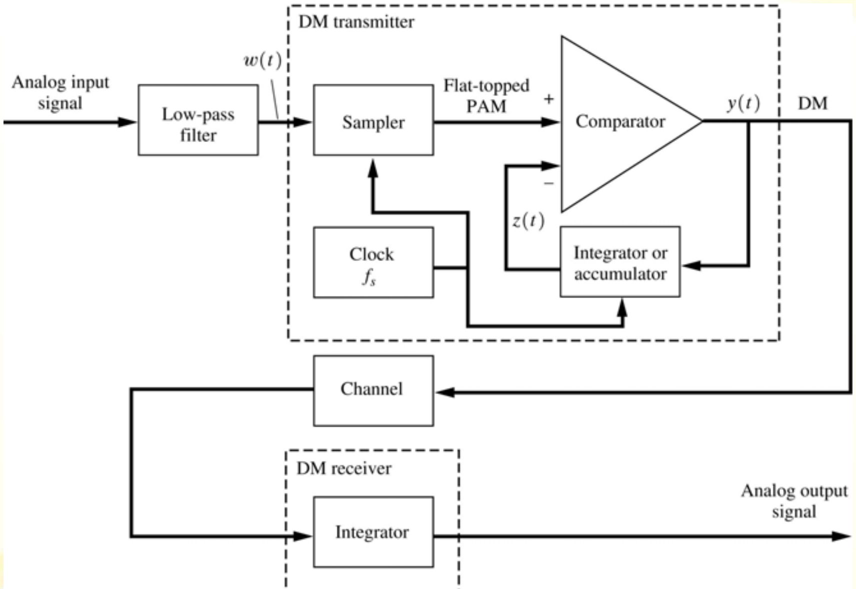
$$\left(\frac{S}{N}\right)_{dB} = 6.02n + \alpha$$

$$-3 < \alpha < 15 \ for\ DPCM\ Speech$$

Used For Speech - up to a 25 dB S/N improvement over μ-law 255

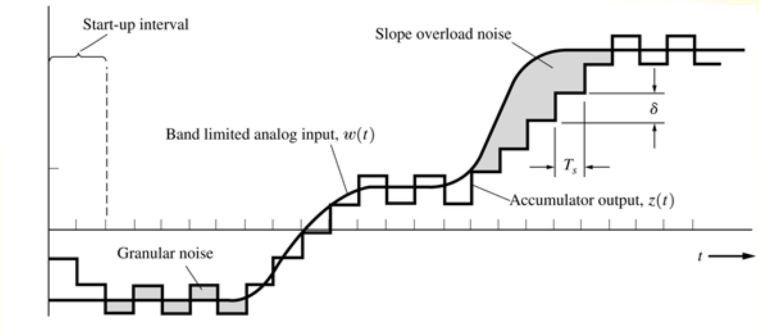
See pp92 in text

Delta Modulation –DM is single bit DPCM

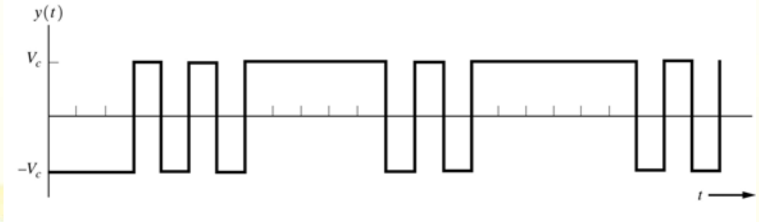


Couch, *Digital and Analog Communication Systems*, Seventh Edition

Figure 3–32 DM system waveforms.

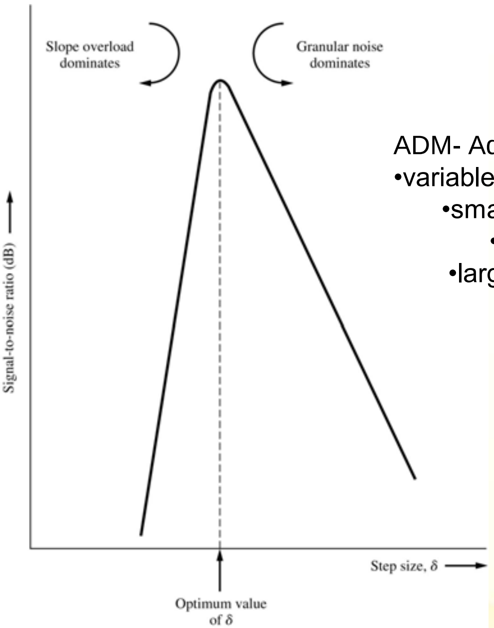


(a) Analog Input and Accumulator Output Waveforms



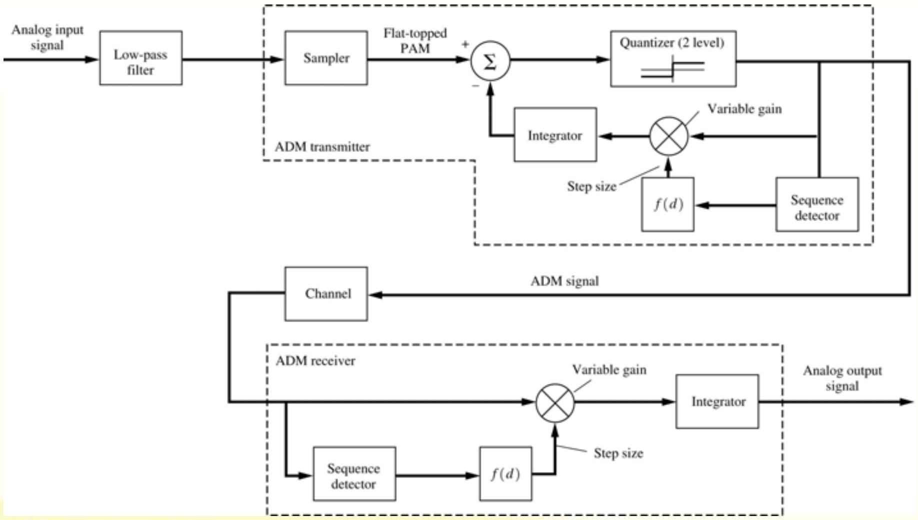
(b) Delta Modulation Waveform

Figure 3–33 Signal-to-noise ratio out of a DM system as a function of step size.



ADM- Adaptive Delta Modulation
- variable step size
  - small step for slow variation
    - reduce granular noise
  - larger step for fast variation
    - reduce slope overload

Figure 3–34 ADM - Adaptive Delta Modulation



Delta Modulation

$$Maximum\ Slope: \frac{\delta}{T_s} = \delta f_s$$

$$\frac{d}{dt} A\sin \omega_a t = A\omega_a \cos \omega_a t \downarrow \downarrow \max slope \downarrow\downarrow \rightarrow A\omega_a$$

$$\delta > \frac{2\pi f_a A}{f_s} \quad to\ prevent\ slope\ overload$$

Delta Modulation

$$\text{Granular Noise, } N = \left\langle n^2 \right\rangle = \int_{-B}^{B} P_n(f)\,df = \frac{\delta^2 B}{3 f_s}$$

$$N = \frac{4\pi^2 A^2 f_a^2 B}{3 f_s^3} \qquad S = P_x = \frac{A^2}{2}$$

$$\left(\frac{S}{N}\right)_{out} = \frac{3 f_s^3}{8\pi^2 f_a^2 B}$$

For the A / D we had:

$$\left\langle q^2 \right\rangle = \frac{(x_{\max})^2}{3 \times 4^n} = P_{nq} \quad A/D$$

$$SQNR = \frac{3 \times 4^n P_x}{x_{\max}^2}$$

TDM Time-Division Multiplexing
for
PAM, PCM, DM

EELE445-14

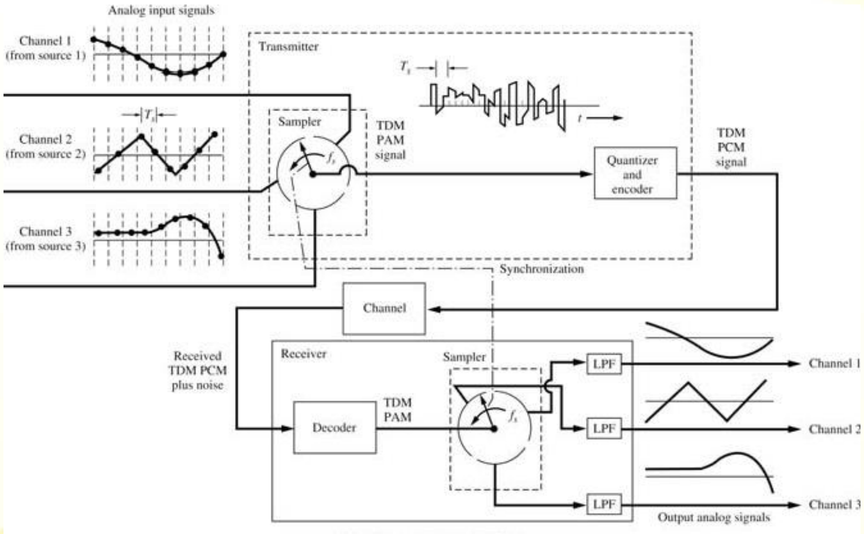
Lecture 24

Time-Division Multiplexing

Definition:

Time-division multiplexing (TDM) *is the time interlieaving of samples from several sources so that the information from these sources can be transmitted serially over a single communication channel.*

Figure 3–35 Three-channel TDM PCM system.



Time-Division Multiplexing

Figure 3–36 TDM frame sync format.

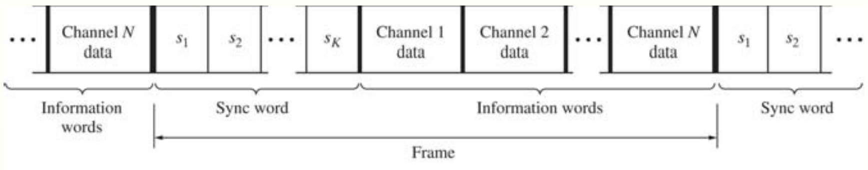


Figure 3–37 Frame synchronizer with TDM receiver front end.

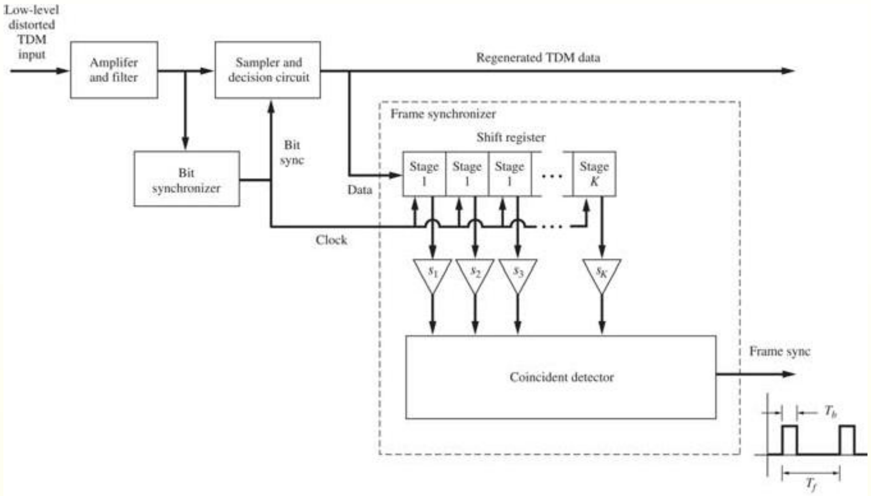


Figure 3–38 Two-channel bit-interleaved TDM with pulse stuffing.

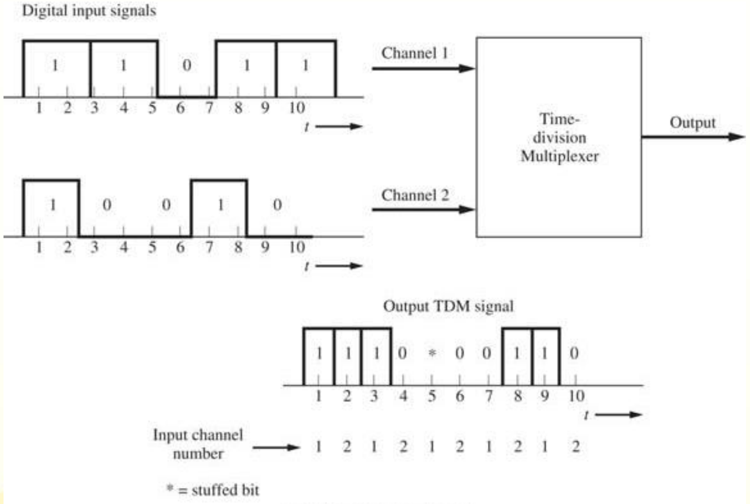
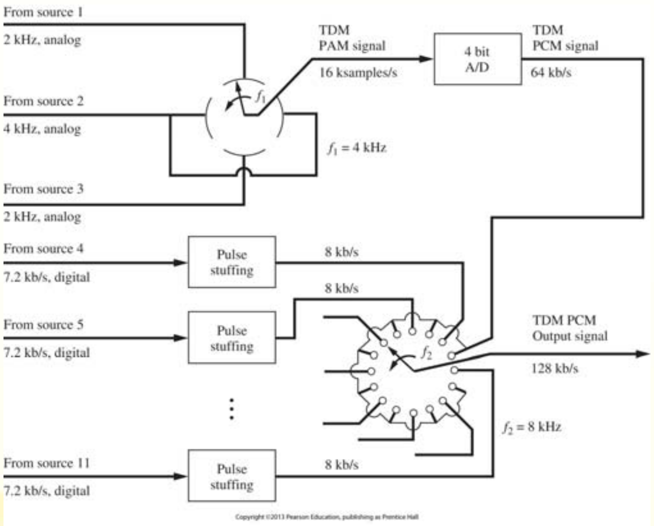


Figure 3–39 TDM with analog and digital inputs as described in Example 3–17.

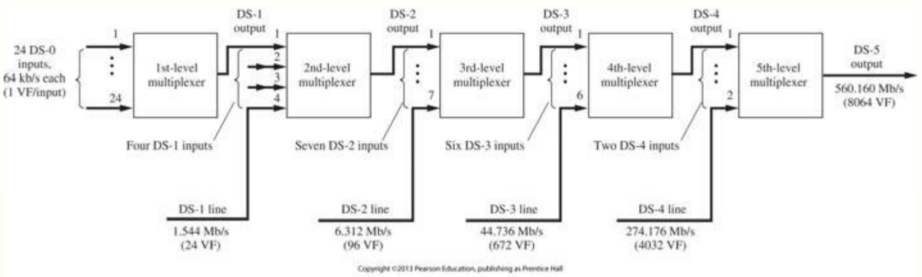


Copyright ©2013 Pearson Education, publishing as Prentice Hall

MONTANA STATE UNIVERSITY

Mountains & Minds

Figure 3–40 North American digital TDM hierarchy.



Copyright ©2013 Pearson Education, publishing as Prentice Hall

MONTANA STATE UNIVERSITY

Mountains & Minds

TABLE 3–8 TDM STANDARDS FOR NORTH AMERICA

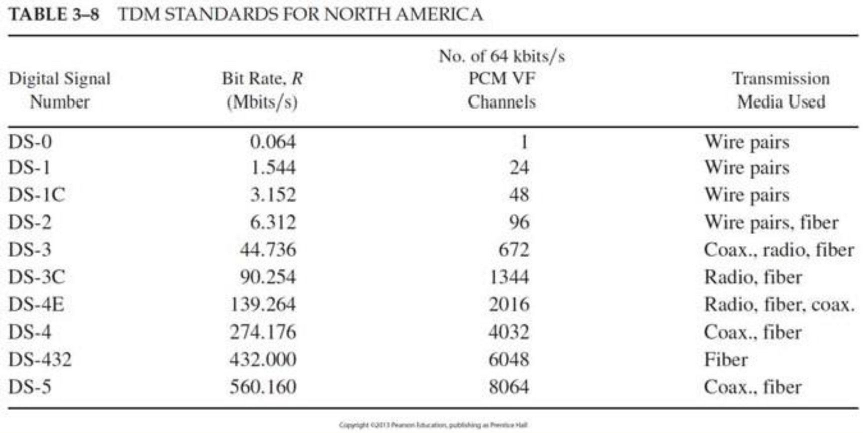


TABLE 3–8 TDM STANDARDS FOR NORTH AMERICA

Digital Signal Number	Bit Rate, *R* (Mbits/s)	No. of 64 kbits/s PCM VF Channels	Transmission Media Used
DS-0	0.064	1	Wire pairs
DS-1	1.544	24	Wire pairs
DS-1C	3.152	48	Wire pairs
DS-2	6.312	96	Wire pairs, fiber
DS-3	44.736	672	Coax., radio, fiber
DS-3C	90.254	1344	Radio, fiber
DS-4E	139.264	2016	Radio, fiber, coax.
DS-4	274.176	4032	Coax., fiber
DS-432	432.000	6048	Fiber
DS-5	560.160	8064	Coax., fiber

TABLE 3–9 SPECIFICATIONS FOR T-CARRIER BASEBAND DIGITAL TRANSMISSION SYSTEMS

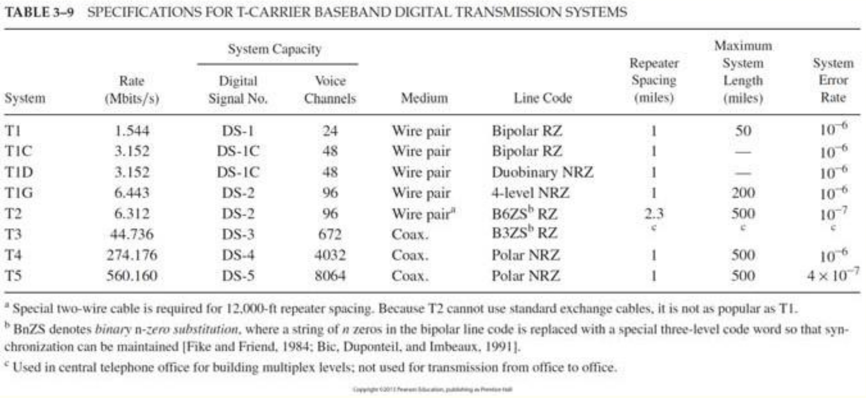


TABLE 3–9 SPECIFICATIONS FOR T-CARRIER BASEBAND DIGITAL TRANSMISSION SYSTEMS

		System Capacity						
System	Rate (Mbits/s)	Digital Signal No.	Voice Channels	Medium	Line Code	Repeater Spacing (miles)	Maximum System Length (miles)	System Error Rate
T1	1.544	DS-1	24	Wire pair	Bipolar RZ	1	50	10^{-6}
T1C	3.152	DS-1C	48	Wire pair	Bipolar RZ	1	—	10^{-6}
T1D	3.152	DS-1C	48	Wire pair	Duobinary NRZ	1	—	10^{-6}
T1G	6.443	DS-2	96	Wire pair	4-level NRZ	1	200	10^{-6}
T2	6.312	DS-2	96	Wire pair[a]	B6ZS[b] RZ	2.3	500	10^{-7}
T3	44.736	DS-3	672	Coax.	B3ZS[b] RZ	[c]	[c]	[c]
T4	274.176	DS-4	4032	Coax.	Polar NRZ	1	500	10^{-6}
T5	560.160	DS-5	8064	Coax.	Polar NRZ	1	500	4×10^{-7}

[a] Special two-wire cable is required for 12,000-ft repeater spacing. Because T2 cannot use standard exchange cables, it is not as popular as T1.

[b] BnZS denotes *binary* n-*zero substitution*, where a string of *n* zeros in the bipolar line code is replaced with a special three-level code word so that synchronization can be maintained [Fike and Friend, 1984; Bic, Duponteil, and Imbeaux, 1991].

[c] Used in central telephone office for building multiplex levels; not used for transmission from office to office.

Figure 3–41 CCITT digital TDM hierarchy.

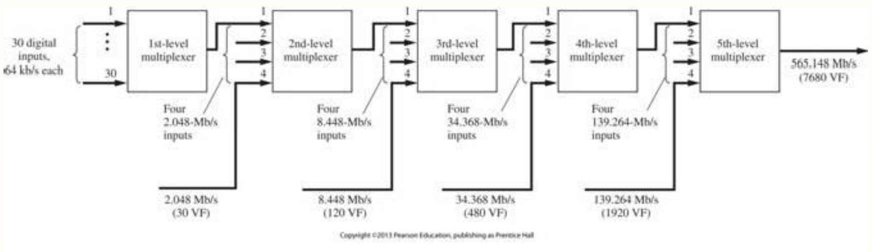


TABLE 3–10 SONET SIGNAL HIERARCHY

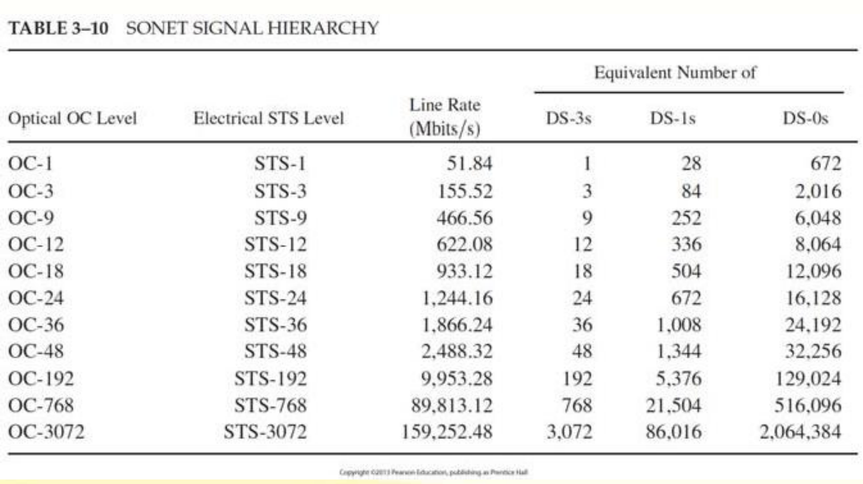


TABLE 3–10 SONET SIGNAL HIERARCHY

			Equivalent Number of		
Optical OC Level	Electrical STS Level	Line Rate (Mbits/s)	DS-3s	DS-1s	DS-0s
OC-1	STS-1	51.84	1	28	672
OC-3	STS-3	155.52	3	84	2,016
OC-9	STS-9	466.56	9	252	6,048
OC-12	STS-12	622.08	12	336	8,064
OC-18	STS-18	933.12	18	504	12,096
OC-24	STS-24	1,244.16	24	672	16,128
OC-36	STS-36	1,866.24	36	1,008	24,192
OC-48	STS-48	2,488.32	48	1,344	32,256
OC-192	STS-192	9,953.28	192	5,376	129,024
OC-768	STS-768	89,813.12	768	21,504	516,096
OC-3072	STS-3072	159,252.48	3,072	86,016	2,064,384

Figure 3–42 T1 TDM format for one frame.
On every sixth frame this VF PCM bit is replaced by a signaling bit for this channel.

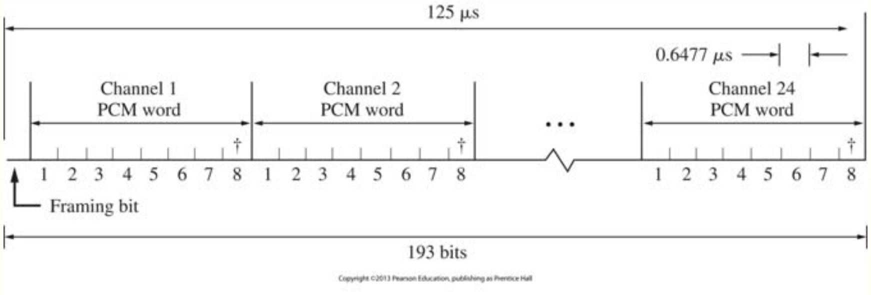
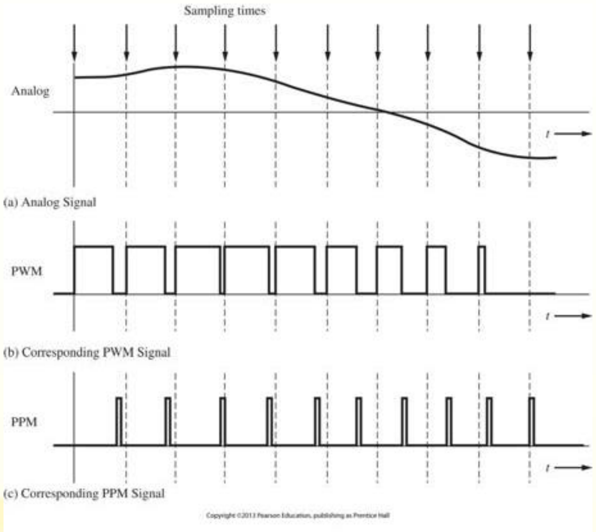


Figure 3–43 Pulse time modulation signaling.



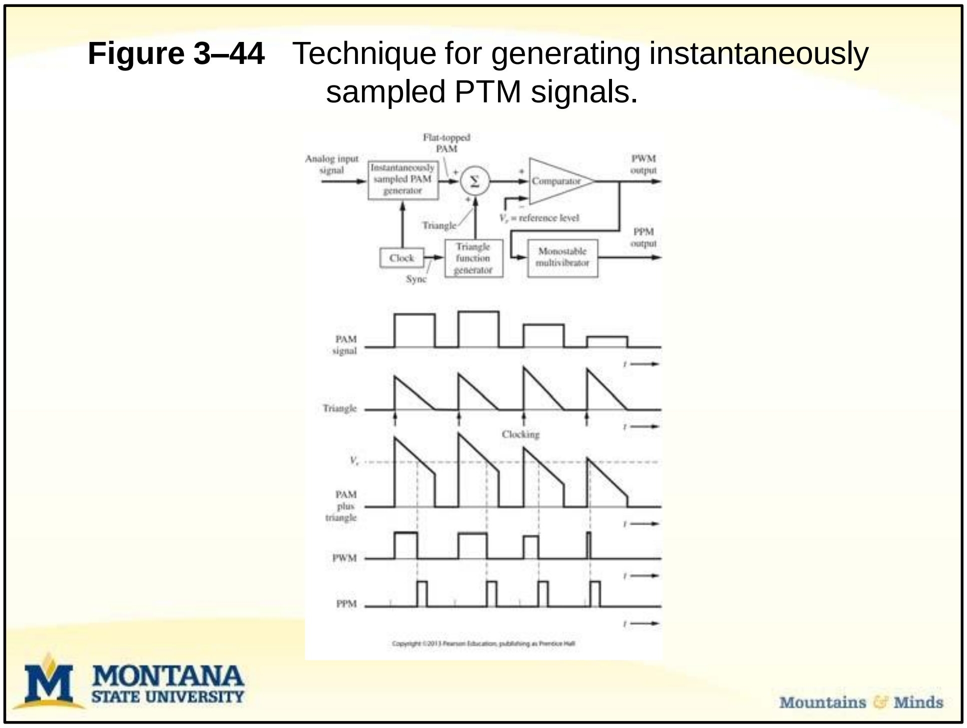


Figure 3–44 Technique for generating instantaneously sampled PTM signals.

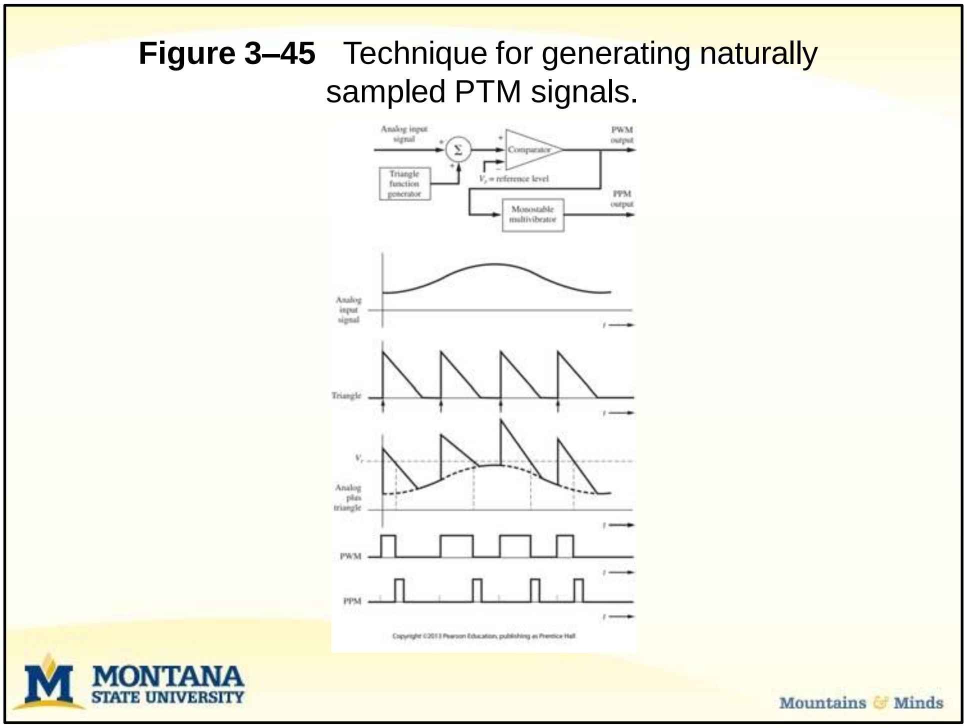
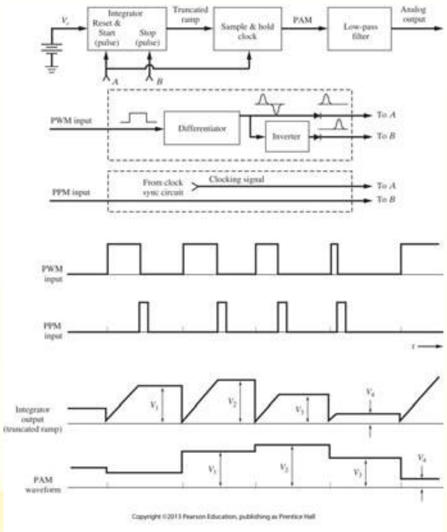


Figure 3–45 Technique for generating naturally sampled PTM signals.

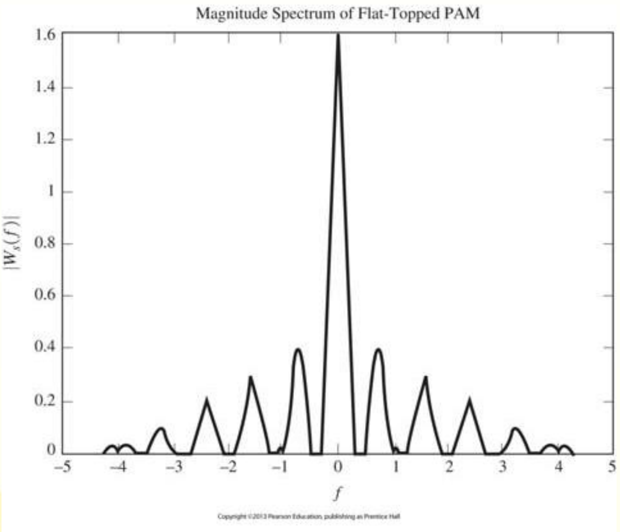
Figure 3–46 Detection of PWM and PPM signals.



Copyright ©2013 Pearson Education, publishing as Prentice Hall

Mountains & Minds

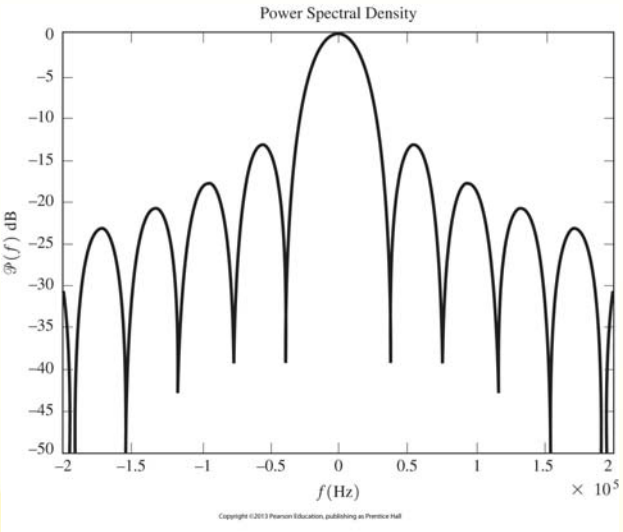
Figure 3–47 Solution for SA3-1. (See SA3_1.m.)



Copyright ©2013 Pearson Education, publishing as Prentice Hall

Mountains & Minds

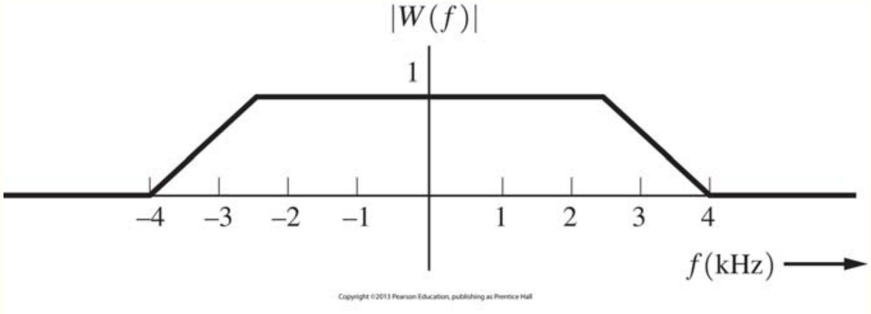
Figure 3–48 PSD of an RS-232 signal with a data rate of 38,400 bits/s. (See SA3_4.m.)



MONTANA STATE UNIVERSITY

Mountains & Minds

Figure P3–3



MONTANA STATE UNIVERSITY

Mountains & Minds