Signal Encoding

CS 6710

Spring 2010

Rajmohan Rajaraman

Reasons for Choosing Encoding Techniques

- Digital data, digital signal
  - Equipment less complex and expensive than digital-to-analog modulation equipment
- Analog data, digital signal
  - Permits use of modern digital transmission and switching equipment

Reasons for Choosing Encoding Techniques

- Digital data, analog signal
  - Some transmission media will only propagate analog signals
  - E.g., unguided media
- Analog data, analog signal
  - Analog data in electrical form can be transmitted easily and cheaply
  - Done with voice transmission over voice-grade lines

Signal Encoding Criteria

- What determines how successful a receiver will be in interpreting an incoming signal?
  - Signal-to-noise ratio
  - Data rate
  - Bandwidth
- An increase in data rate increases bit error rate
- An increase in SNR decreases bit error rate
- An increase in bandwidth allows an increase in data rate

Comparing Encoding Schemes

- Signal spectrum
  - With lack of high-frequency components, less bandwidth required
    - Spectral efficiency (also called bandwidth efficiency)
  - With no dc component, ac coupling via transformer possible
  - Transfer function of a channel is worse near band edges
- Clocking
  - Ease of determining beginning and end of each bit position

Comparing Encoding Schemes

- Signal interference and noise immunity
  - Performance in the presence of noise
    - Power efficiency
- Cost and complexity
  - The higher the signal rate to achieve a given data rate, the greater the cost

Digital Data to Analog Signals

- Amplitude-shift keying (ASK)
  - o Amplitude difference of carrier frequency
- Frequency-shift keying (FSK)
  - o Frequency difference near carrier frequency
- Phase-shift keying (PSK)
  - o Phase of carrier signal shifted

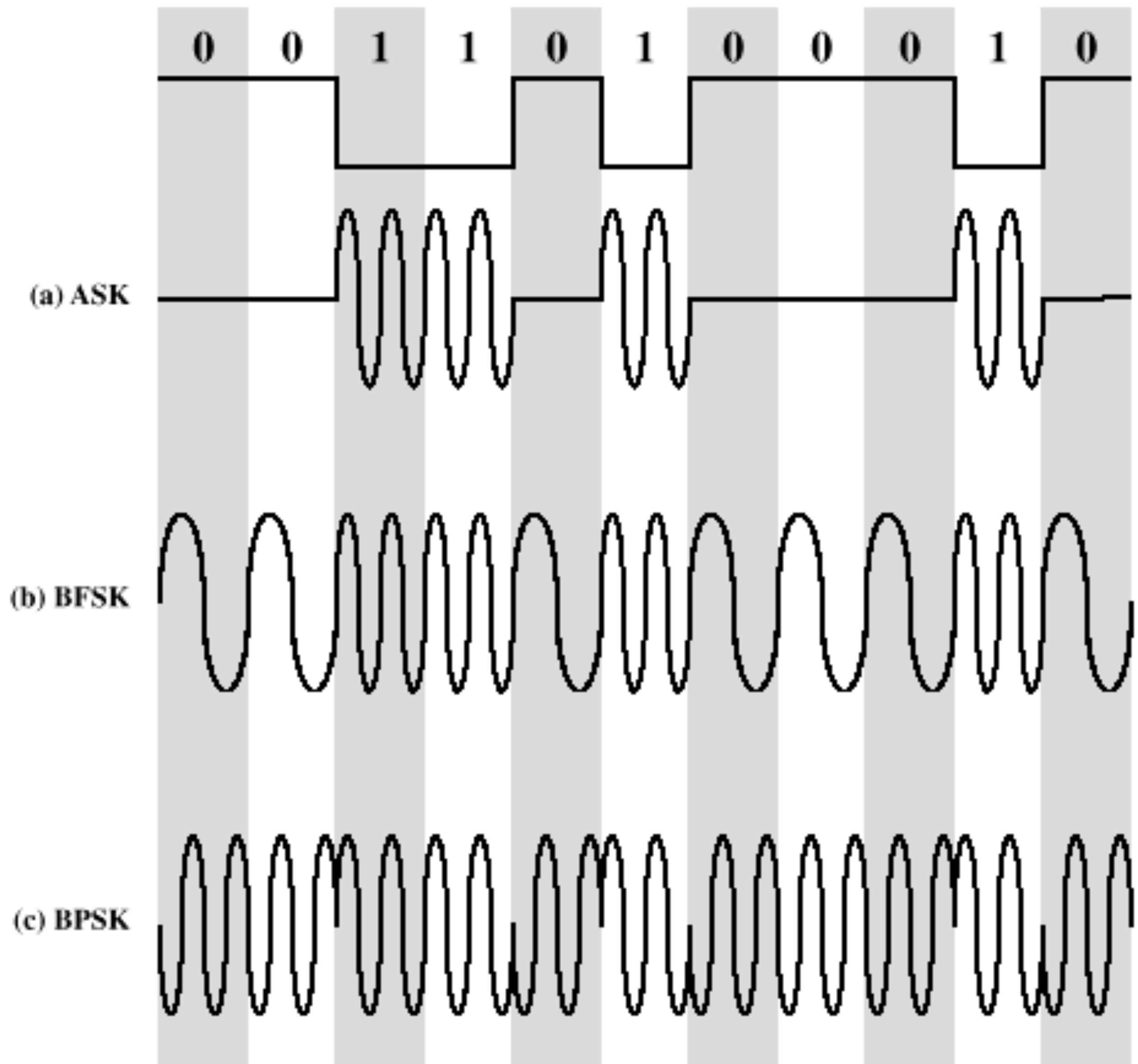


Figure 6.2 Modulation of Analog Signals for Digital Data

Amplitude-Shift Keying

- One binary digit represented by presence of carrier, at constant amplitude
- Other binary digit represented by absence of carrier

$$s(t) = \begin{cases} A\cos(2\pi f_c t) & \text{binary } 1 \\ 0 & \text{binary } 0 \end{cases}$$

- where the carrier signal is $A\cos(2\pi f_c t)$

Amplitude-Shift Keying

- Relatively inexpensive to implement
- Inefficient modulation technique since it is much more susceptible to noise
  - o Atmospheric and impulse noises tend to cause rapid fluctuations in amplitude
- Linear modulation technique
  - o Good spectral efficiency
  - o Low power efficiency
- Used for carrying digital data over optical fiber

Binary Frequency-Shift Keying (BFSK)

- Two binary digits represented by two different frequencies near the carrier frequency

$$s(t) = \begin{cases} A\cos(2\pi f_1 t) & \text{binary } 1 \\ A\cos(2\pi f_2 t) & \text{binary } 0 \end{cases}$$

- where f_1 and f_2 are offset from carrier frequency f_c by equal but opposite amounts

Frequency-Shift Keying (FSK)

- Less susceptible to error than ASK
- Used for high-frequency (3 to 30 MHz) radio transmission
- Can be used at higher frequencies on LANs that use coaxial cable
- Amplitude of the carrier wave is constant
  - Power-efficient

Multiple Frequency-Shift Keying (MFSK)

- More than two frequencies are used
- More bandwidth efficient but more susceptible to error

$$s_i(t) = A\cos 2\pi f_i t \qquad 1 \le i \le M$$

- $f_i = f_c + (2i - 1 - M)f_d$
- f_c = the carrier frequency
- f_d = the difference frequency
- M = number of different signal elements = 2^L
- L = number of bits per signal element

Multiple Frequency-Shift Keying (MFSK)

- To match data rate of input bit stream, each output signal element is held for:

  $$T_s = LT \text{ seconds}$$

  - where T is the bit period (data rate = $1/T$)
- So, one signal element encodes L bits

Multiple Frequency-Shift Keying (MFSK)

- Total bandwidth required

$$2Mf_d$$

- Minimum frequency separation required $2f_d = 1/T_s$
- Therefore, modulator requires a bandwidth of

$$W_d = 2^L/LT = M/T_s$$

Multiple Frequency-Shift Keying (MFSK)

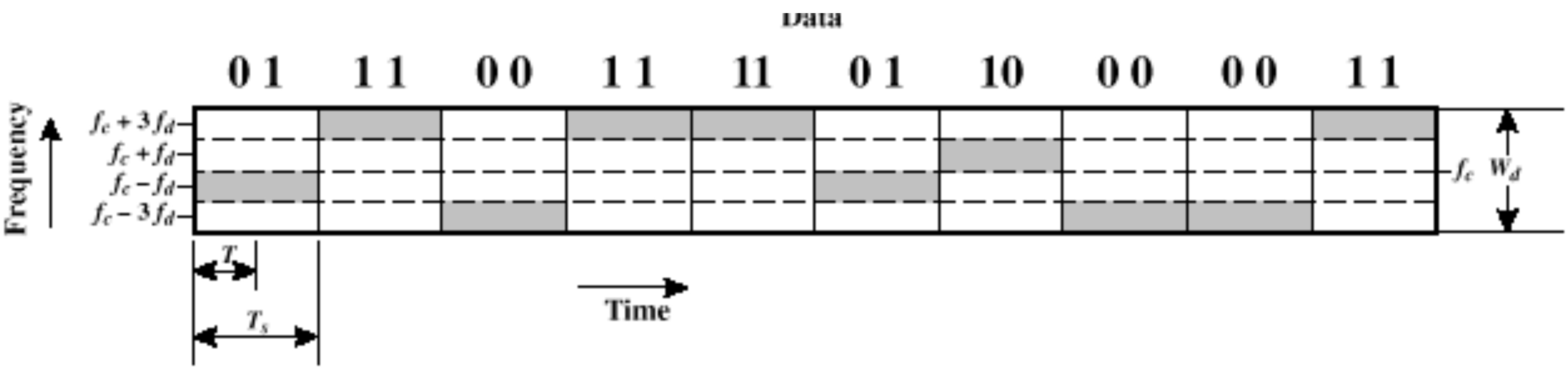


Figure 6.4 MFSK Frequency Use ($M = 4$)

Phase-Shift Keying (PSK)

- Two-level PSK (BPSK)
  - o Uses two phases to represent binary digits

$$s(t) = \begin{cases} A\cos(2\pi f_c t) & \text{binary } 1 \\ A\cos(2\pi f_c t + \pi) & \text{binary } 0 \end{cases}$$

$$= \begin{cases} A\cos(2\pi f_c t) & \text{binary } 1 \\ -A\cos(2\pi f_c t) & \text{binary } 0 \end{cases}$$

  - o Linear modulation technique

Phase-Shift Keying (PSK)

- Differential PSK (DPSK)
  - Phase shift with reference to previous bit
    - Binary 0 – signal burst of same phase as previous signal burst
    - Binary 1 – signal burst of opposite phase to previous signal burst

Phase-Shift Keying (PSK)

- Four-level PSK (QPSK)
  - o Each element represents more than one bit

$$s(t) = \begin{cases} A\cos\left(2\pi f_c t + \frac{\pi}{4}\right) & 11 \\ A\cos\left(2\pi f_c t + \frac{3\pi}{4}\right) & 01 \\ A\cos\left(2\pi f_c t - \frac{3\pi}{4}\right) & 00 \\ A\cos\left(2\pi f_c t - \frac{\pi}{4}\right) & 10 \end{cases}$$

Phase-Shift Keying (PSK)

- Multilevel PSK
  - Using multiple phase angles with each angle having more than one amplitude, multiple signals elements can be achieved

$$D = \frac{R}{L} = \frac{R}{\log_2 M}$$

- D = modulation rate, baud
- R = data rate, bps
- M = number of different signal elements = 2^L
- L = number of bits per signal element

Performance

- Bandwidth of modulated signal (B_T)
  - o ASK, PSK $B_T=(1+r)R$
  - o FSK $B_T=2DF+(1+r)R$

    - R = bit rate
    - $0 < r < 1$; related to how signal is filtered
    - $DF = f_2 - f_c = f_c - f_1$

Performance

- Bandwidth of modulated signal (B_T)
  - MPSK $$B_T = \left(\frac{1+r}{L}\right)R = \left(\frac{1+r}{\log_2 M}\right)R$$
  - MFSK $$B_T = \left(\frac{(1+r)M}{\log_2 M}\right)R$$
    - L = number of bits encoded per signal element
    - M = number of different signal elements

Quadrature Amplitude Modulation

- QAM is a combination of ASK and PSK
  - o Two different signals sent simultaneously on the same carrier frequency

$$s(t) = d_1(t)\cos 2\pi f_c t + d_2(t)\sin 2\pi f_c t$$

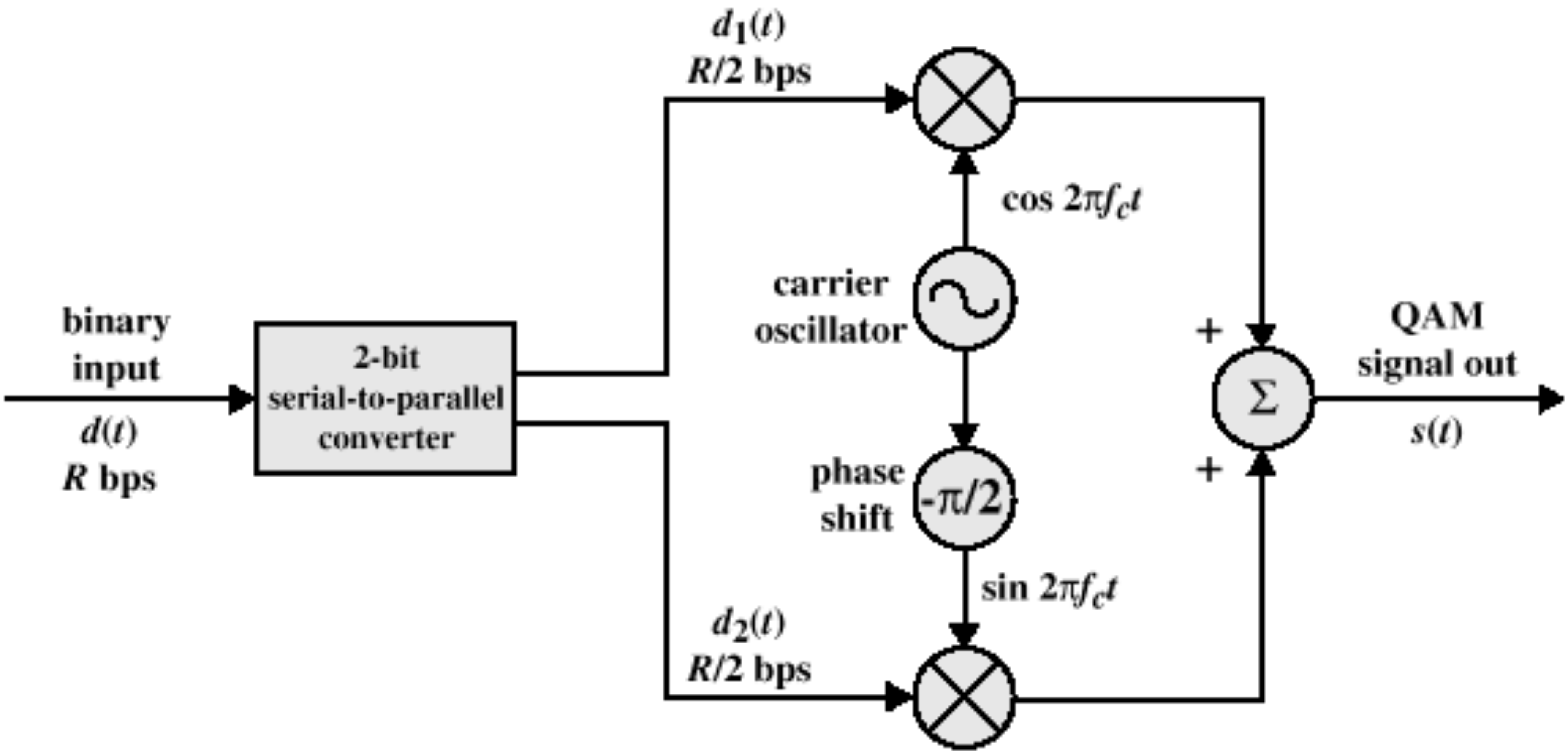


Figure 6.10 QAM Modulator

Analog Data to Analog Signal

- Modulation of digital data
  - When only analog transmission facilities are available, digital to analog conversion required
- Modulation of analog data
  - A higher frequency may be needed for effective transmission
  - Modulation permits frequency division multiplexing

Modulation Techniques

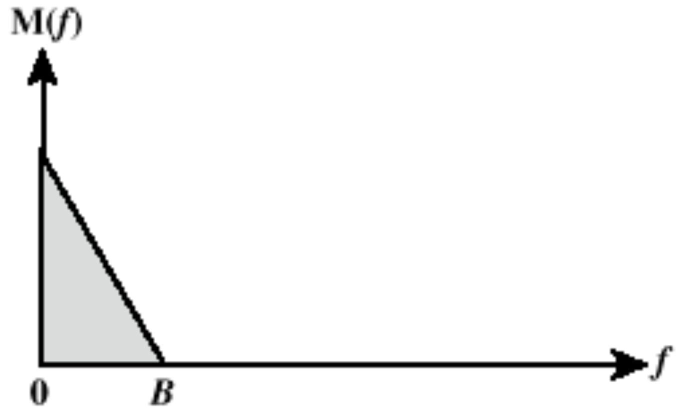
- Amplitude modulation (AM)
- Angle modulation
  - o Frequency modulation (FM)
  - o Phase modulation (PM)

Amplitude Modulation

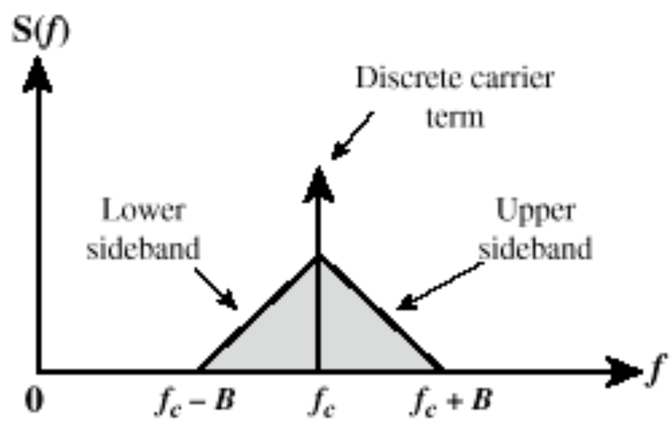
- Amplitude Modulation

$$s(t) = [1 + n_a x(t)] \cos 2\pi f_c t$$

  - $\cos 2\pi f_c t$ = carrier
  - $x(t)$ = input signal
  - n_a = modulation index (< 1)
    - Ratio of amplitude of input signal to carrier
- Double sideband transmitted carrier (DSBTC)



(a) Spectrum of modulating signal



(b) Spectrum of AM signal with carrier at f_c

Figure 6.12 Spectrum of an AM Signal

Amplitude Modulation

❑Transmitted power

$$P_t = P_c\left(1 + \frac{{n_a}^2}{2}\right)$$

- P_t = total transmitted power in $s(t)$
- P_c = transmitted power in carrier

Single Sideband (SSB)

- Variant of AM is single sideband (SSB)
  - Sends only one sideband
  - Eliminates other sideband and carrier
- Advantages
  - Only half the bandwidth is required
  - Less power is required
- Disadvantages
  - Poor performance in fading channels

Angle Modulation

- Angle modulation

$$s(t) = A_c \cos\left[2\pi f_c t + \phi(t)\right]$$

- Phase modulation
  - o Phase is proportional to modulating signal

$$\phi(t) = n_p m(t)$$

    - n_p = phase modulation index

Angle Modulation

- Frequency modulation
  - Derivative of the phase is proportional to modulating signal

$$\phi'(t) = n_f m(t)$$

    - n_f = frequency modulation index

Angle Modulation

- Compared to AM, FM and PM result in a signal whose bandwidth:
  - is also centered at f_c
  - but has a magnitude that is much different

- Thus, FM and PM require greater bandwidth than AM

Angle Modulation

- Carson's rule

$$B_T = 2(\beta + 1)B$$

where

$$\beta = \begin{cases} n_p A_m & \text{for PM} \\ \dfrac{\Delta F}{B} = \dfrac{n_f A_m}{2\pi B} & \text{for FM} \end{cases}$$

- The formula for FM becomes

$$B_T = 2\Delta F + 2B$$

Analog Data to Digital Signal

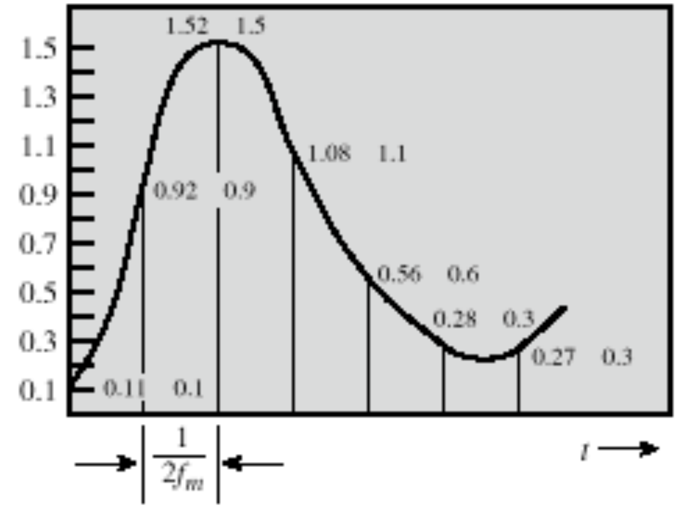
- Digitization: Often analog data are converted to digital form
- Once analog data have been converted to digital signals, the digital data:
  - can be transmitted using NRZ-L
  - can be encoded as a digital signal using a code other than NRZ-L
  - can be converted to an analog signal, using previously discussed techniques

Analog data to digital signal

- Pulse code modulation (PCM)
- Delta modulation (DM)

Pulse Code Modulation

- Based on the sampling theorem
- Each analog sample is assigned a binary code
  - Analog samples are referred to as pulse amplitude modulation (PAM) samples
- The digital signal consists of block of *n* bits, where each *n*-bit number is the amplitude of a PCM pulse



(a)

Digit	Binary Equivalent	PCM waveform	Digit	Binary Equivalent	PCM waveform
0	0000		8	1000	
1	0001		9	1001	
2	0010		10	1010	
3	0011		11	1011	
4	0100		12	1100	
5	0101		13	1101	
6	0110		14	1110	
7	0111		15	1111	

(b)

Figure 6.15 Pulse-Code Modulation

Pulse Code Modulation

- By quantizing the PAM pulse, original signal is only approximated
- Leads to quantizing noise
- Signal-to-noise ratio for quantizing noise

$$\mathrm{SNR}_{\mathrm{dB}} = 20\log 2^{n} + 1.76\,\mathrm{dB} = 6.02n + 1.76\,\mathrm{dB}$$

- Thus, each additional bit increases SNR by 6 dB, or a factor of 4

Delta Modulation

- Analog input is approximated by staircase function
  - Moves up or down by one quantization level (δ) at each sampling interval
- The bit stream approximates derivative of analog signal (rather than amplitude)
  - 1 is generated if function goes up
  - 0 otherwise

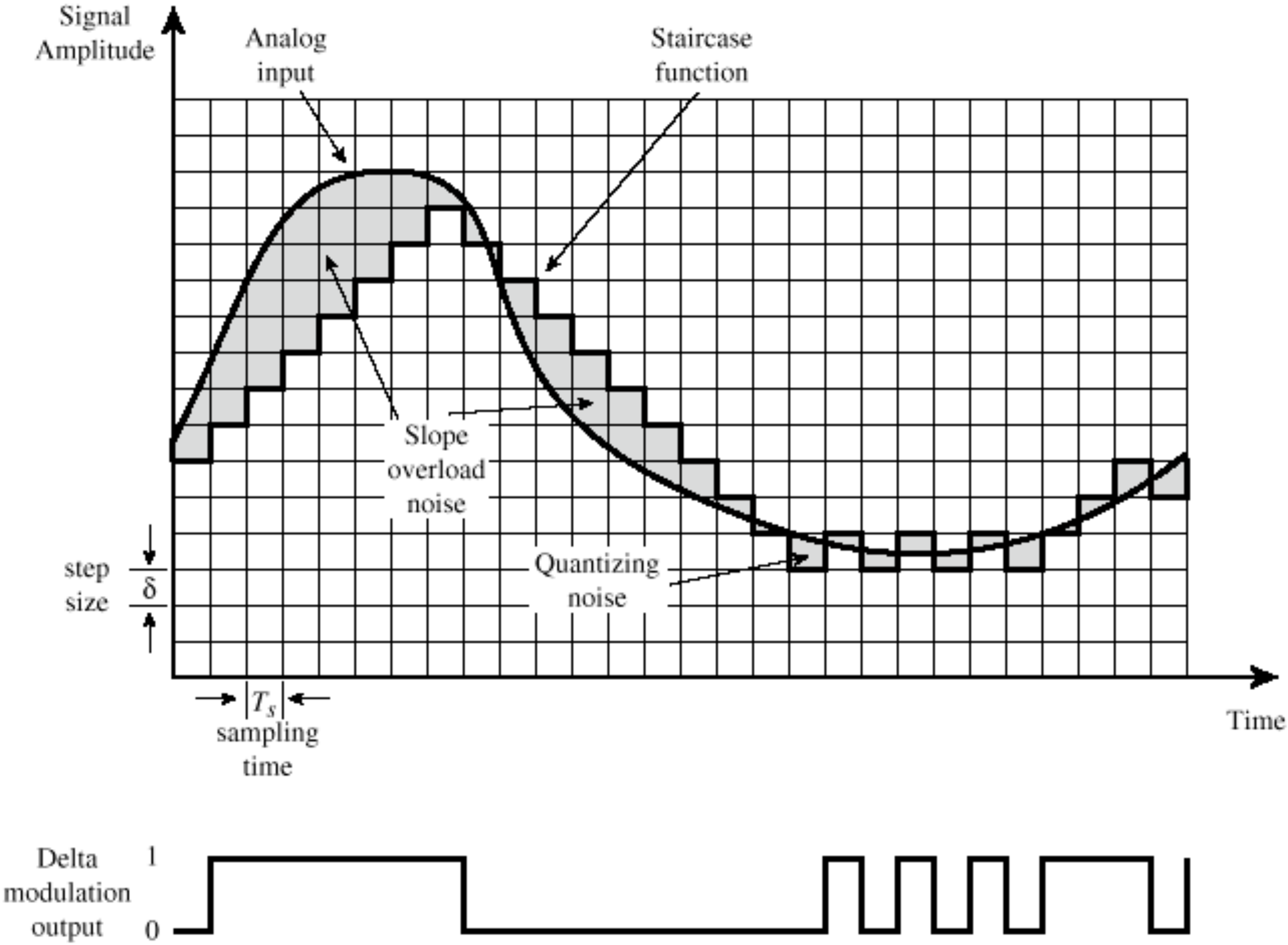


Figure 6.18 Example of Delta Modulation

Delta Modulation

- Two important parameters
  - o Size of step assigned to each binary digit (δ)
  - o Sampling rate
- Accuracy improved by increasing sampling rate
  - o However, this increases the data rate
- Advantage of DM over PCM is the simplicity of its implementation