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# Signal Encoding Techniques

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## Chapter 6

# ns for Choosing Encoding Techniques

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- 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

# ns for Choosing Encoding Techniques

- Digital data, analog signal
  - Some transmission media will only propagate analog signals
  - E.g., optical fiber and 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

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- 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

# Used to Compare Encoding Schemes

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- Signal spectrum
  - With lack of high-frequency components, less bandwidth required
  - 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

# Used to Compare Encoding Schemes

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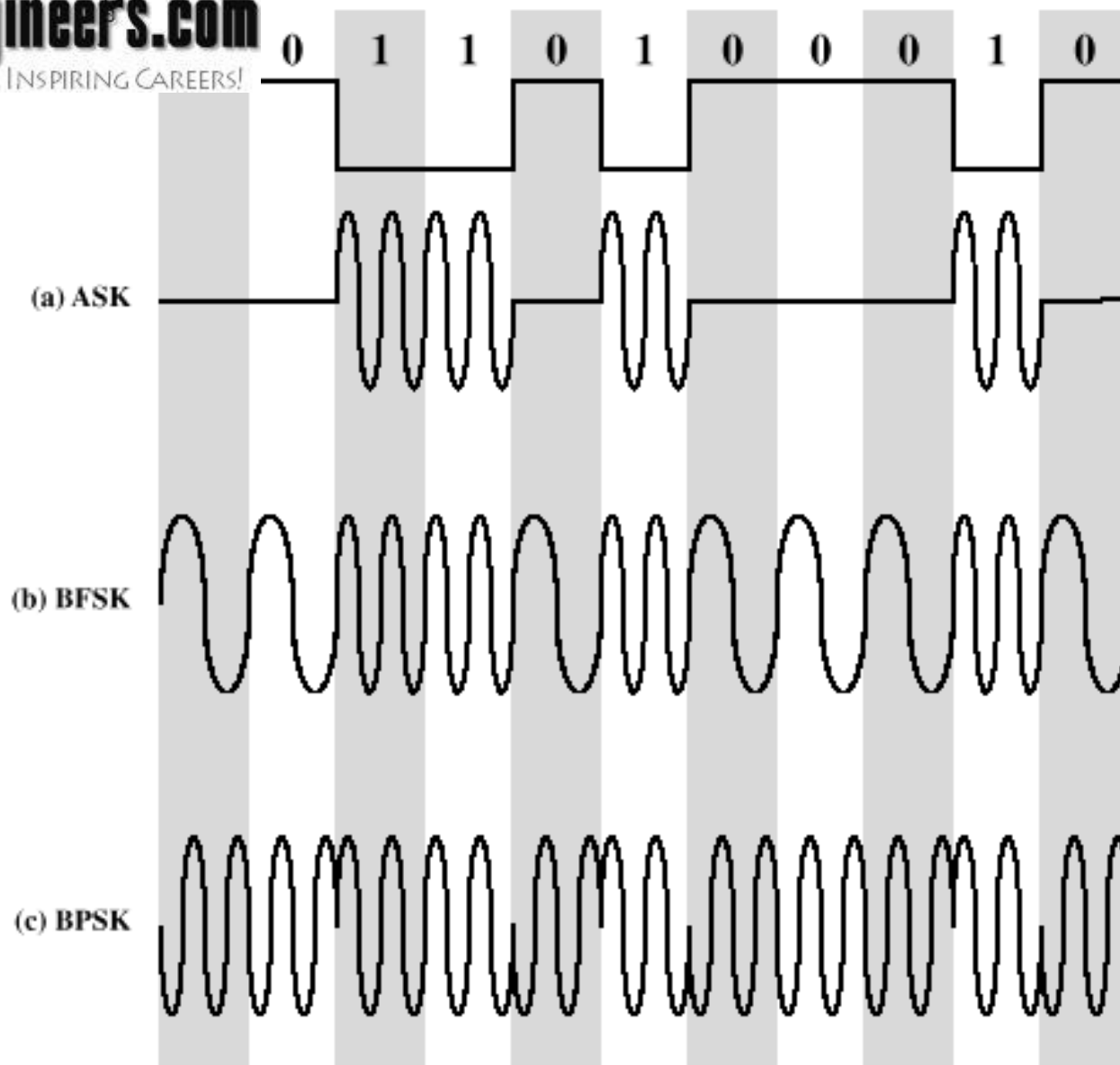
- Signal interference and noise immunity
  - Performance in the presence of noise
- Cost and complexity
  - The higher the signal rate to achieve a given data rate, the greater the cost

# Basic Encoding Techniques

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- Digital data to analog signal
  - Amplitude-shift keying (ASK)
    - Amplitude difference of carrier frequency
  - Frequency-shift keying (FSK)
    - Frequency difference near carrier frequency
  - Phase-shift keying (PSK)
    - 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

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- Susceptible to sudden gain changes
- Inefficient modulation technique
- On voice-grade lines, used up to 1200 bps
- Used to transmit digital data over optical fiber

# 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 (BFSK)

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- Less susceptible to error than ASK
- On voice-grade lines, used up to 1200bps
- Used for high-frequency (3 to 30 MHz) radio transmission
- Can be used at higher frequencies on LANs that use coaxial cable

# Multiple Frequency-Shift Keying (MFSK)

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

$$s_i(t) = A \cos 2\pi f_i t \quad 1 \leq i \leq M$$

- $f_i = f_c + (2i - 1 - M)f_d$
- $f_c$  = 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

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



# Multiple Frequency-Shift Keying (MFSK)

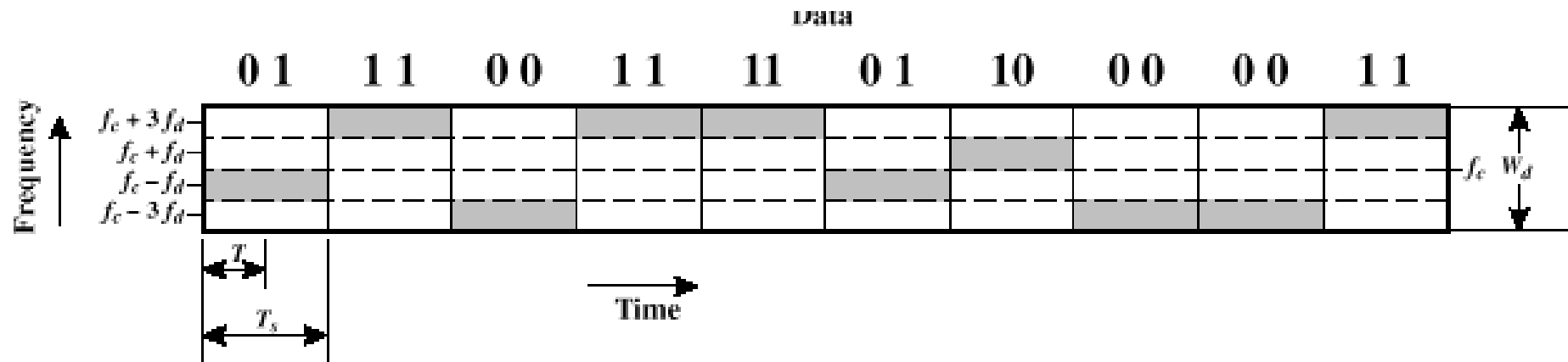


Figure 6.4 MFSK Frequency Use ( $M = 4$ )

# Phase-Shift Keying (PSK)

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

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

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

# Phase-Shift Keying (PSK)

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- 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)
  - 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

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

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- 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

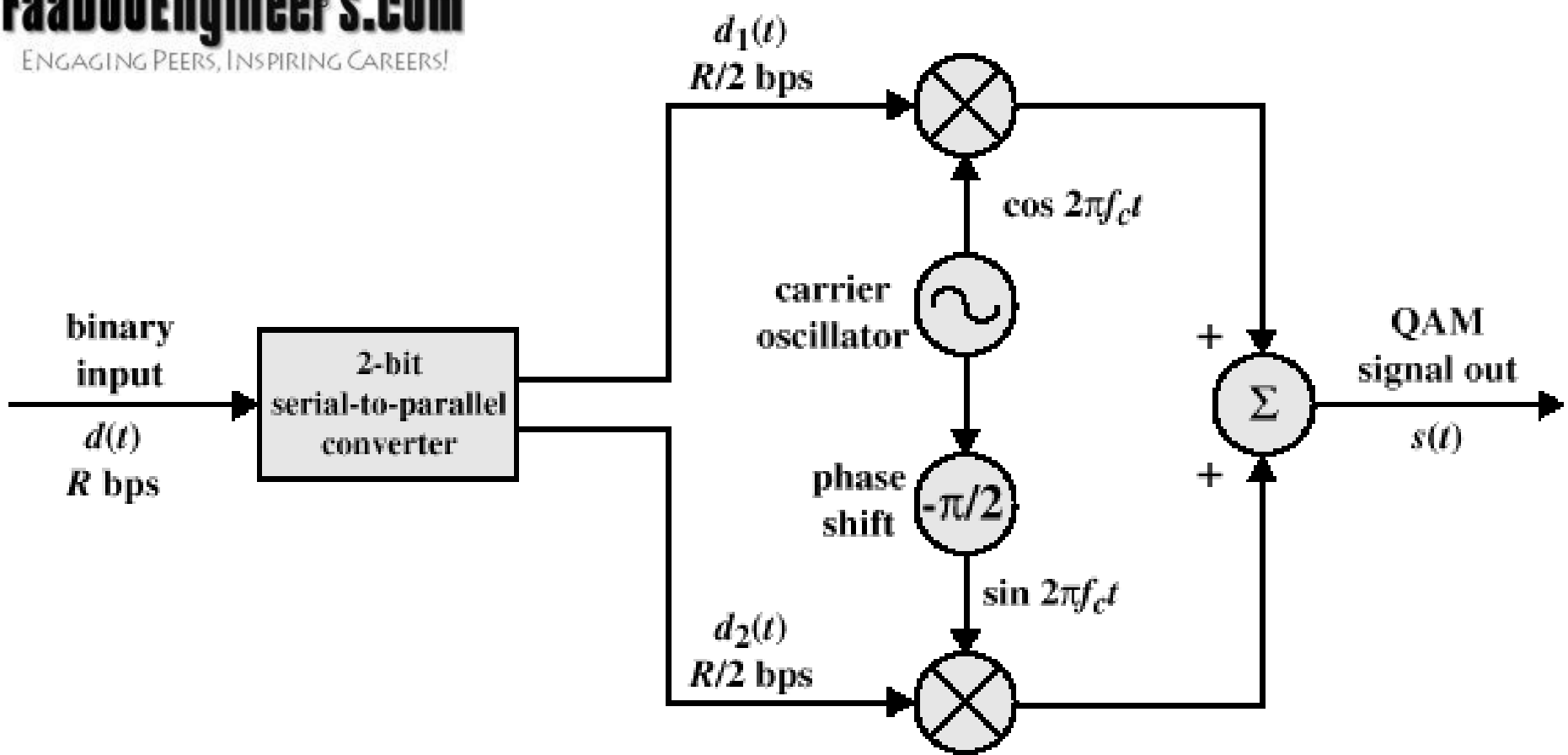
# ature Amplitude Modulation

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- QAM is a combination of ASK and PSK
  - 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**

# Reasons for Analog Modulation

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

# Basic Encoding Techniques

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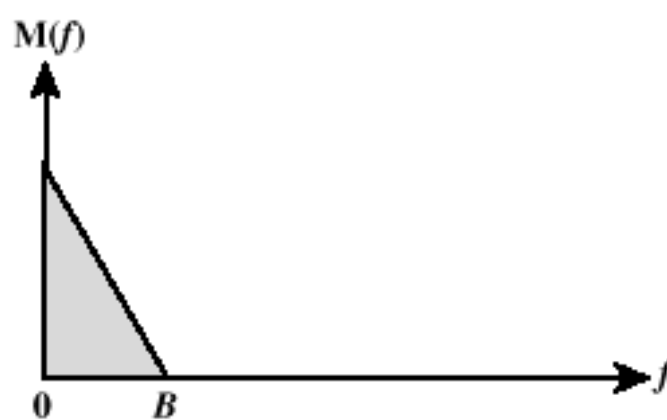
- Analog data to analog signal
  - Amplitude modulation (AM)
  - Angle modulation
    - Frequency modulation (FM)
    - Phase modulation (PM)

# Amplitude Modulation

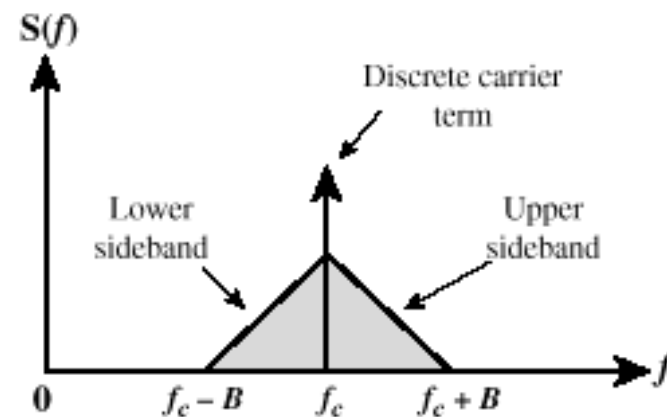
- Amplitude Modulation

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

- $\cos 2\pi f_c t$  = carrier
- $x(t)$  = input signal
- $n_a$  = modulation index
  - Ratio of amplitude of input signal to carrier
- a.k.a 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

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- 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)

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- 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
  - Suppressed carrier can't be used for synchronization purposes



# Angle Modulation

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- Angle modulation

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

- Phase modulation

- 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

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- 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
    - Angle modulation includes  $\cos(\varnothing(t))$  which produces a wide range of frequencies
- Thus, FM and PM require greater bandwidth than AM



# Angle Modulation

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- Carson's rule

where

$$B_T = 2(\beta + 1)B$$
$$\beta = \begin{cases} n_p A_m & \text{for PM} \\ \frac{\Delta F}{B} = \frac{n_f A_m}{2\pi B} & \text{for FM} \end{cases}$$

- The formula for FM becomes

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

# Basic Encoding Techniques

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- Analog data to digital signal
  - Pulse code modulation (PCM)
  - Delta modulation (DM)



# Analog Data to Digital Signal

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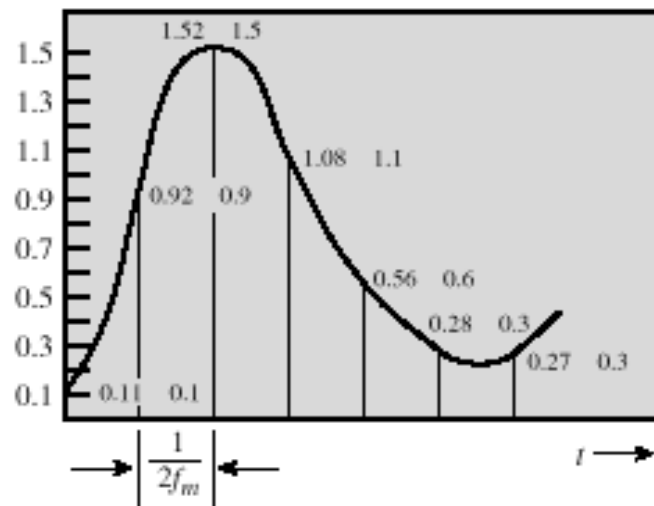
- Once analog data have been converted to digital signals, the digital data:
  - can be transmitted using NRZ-L
  - can be encoded as a digital signal using a code other than NRZ-L
  - can be converted to an analog signal, using previously discussed techniques



# Pulse Code Modulation

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- 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 |
|-------|-------------------|--------------|
| 0     | 0000              | —            |
| 1     | 0001              | —            |
| 2     | 0010              | —            |
| 3     | 0011              | —            |
| 4     | 0100              | —            |
| 5     | 0101              | —            |
| 6     | 0110              | —            |
| 7     | 0111              | —            |

| Digit | Binary Equivalent | PCM waveform |
|-------|-------------------|--------------|
| 8     | 1000              | —            |
| 9     | 1001              | —            |
| 10    | 1010              | —            |
| 11    | 1011              | —            |
| 12    | 1100              | —            |
| 13    | 1101              | —            |
| 14    | 1110              | —            |
| 15    | 1111              | —            |

(b)

**Figure 6.15 Pulse-Code Modulation**



# Pulse Code Modulation

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

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

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

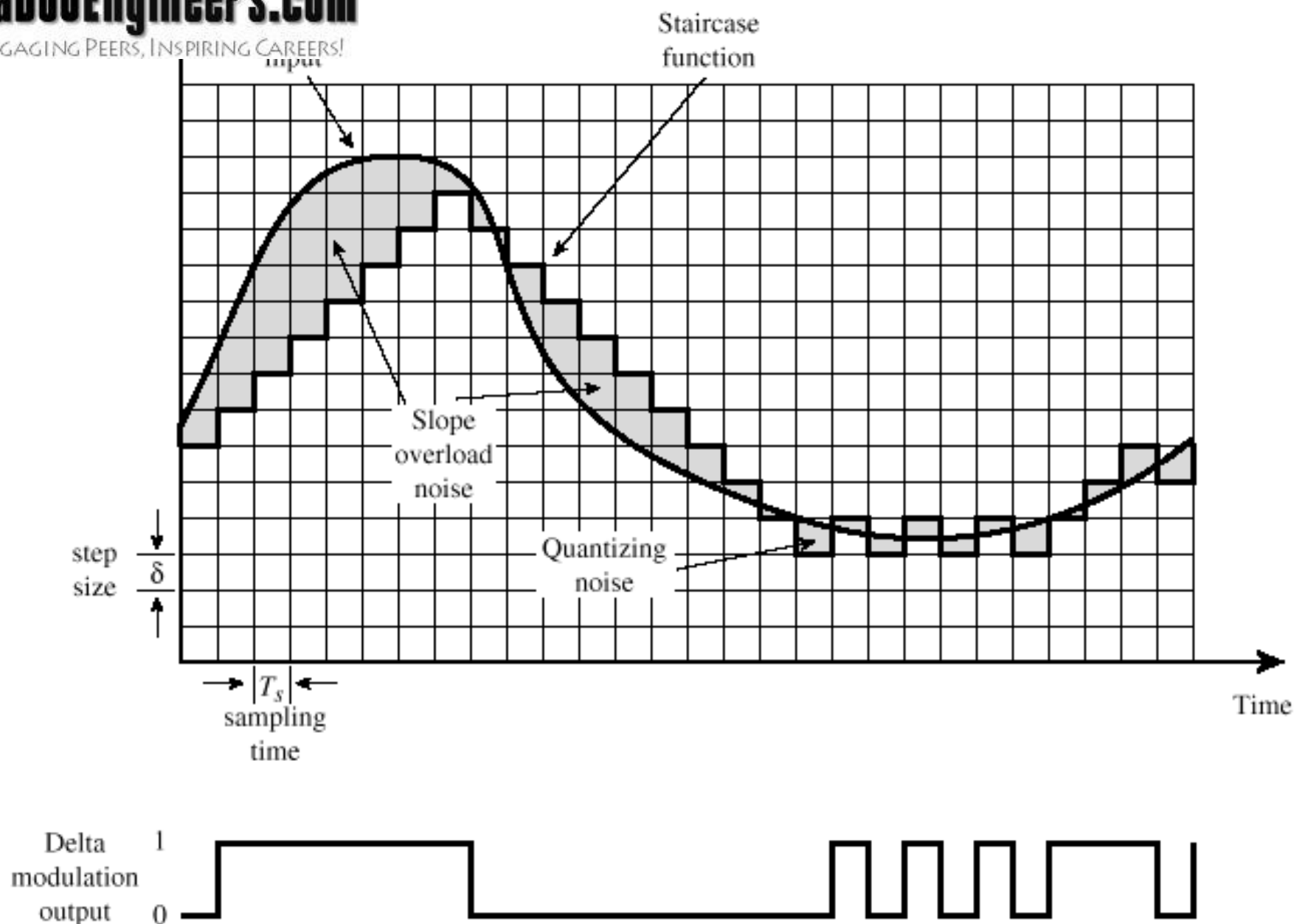




# Delta Modulation

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- Analog input is approximated by staircase function
  - Moves up or down by one quantization level ( $\delta$ ) 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**

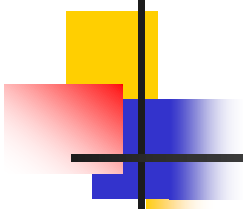
# Delta Modulation

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

# ns for Growth of Digital Techniques

- Growth in popularity of digital techniques for sending analog data
  - Repeaters are used instead of amplifiers
    - No additive noise
  - TDM is used instead of FDM
    - No intermodulation noise
  - Conversion to digital signaling allows use of more efficient digital switching techniques



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