

Chapter 3: Data Encoding

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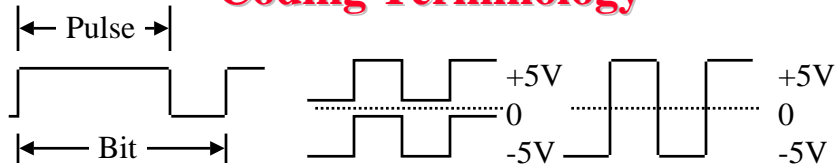
- ❑ Coding design consideration
- ❑ Codes for
 - ❑ digital data to digital signal
 - ❑ Digital data, analog signal
 - ❑ Analog signal, digital data
 - ❑ Analog signal, analog data

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Coding Terminology



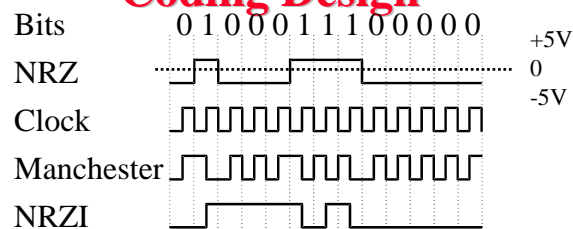
- ❑ Signal element: Pulse
- ❑ Unipolar: All positive or
All negative voltage
- ❑ Bipolar: Positive and negative voltage
- ❑ Mark/Space: 1 or 0
- ❑ Modulation Rate: $1/\text{Duration of the smallest element}$
=Baud rate
- ❑ Data Rate: Bits per second
- ❑ Data Rate = $f_n(\text{Bandwidth, signal/noise ratio, encoding})$

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Coding Design



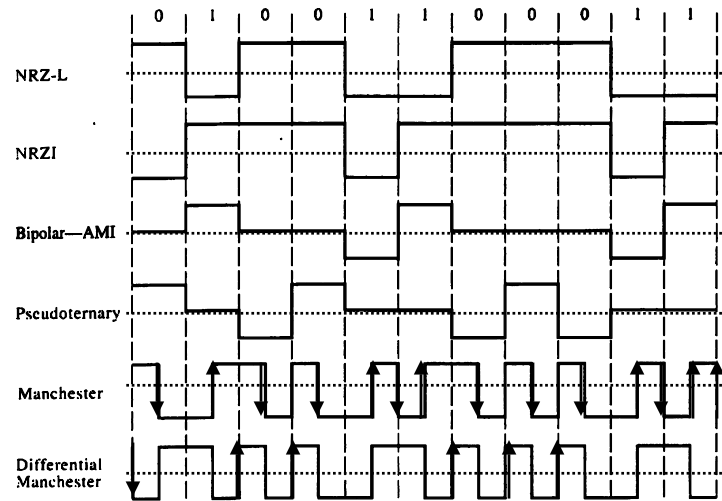
- ❑ Pulse width indeterminate: Clocking
- ❑ DC, Baseline wander
- ❑ No line state information
- ❑ No error detection/protection
- ❑ No control signals
- ❑ High bandwidth
- ❑ Polarity mix-up \Rightarrow Differential (compare polarity)

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Digital Signal Encoding Formats



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Figure 3.2

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Digital Signal Encoding Formats

- ❑ **Nonreturn-to-Zero-Level (NRZ-L)**
 - 0= high level
 - 1= low level
- ❑ **Nonreturn to Zero Inverted (NRZI)**
 - 0= no transition at beginning of interval (one bit time)
 - 1= transition at beginning of interval
- ❑ **Bipolar-AMI**
 - 0=no line signal
 - 1= positive or negative level, alternating for successive ones

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Encoding Formats (Cont)

- ❑ **Pseudoternar**
 - 0=positive or negative level,alternating for successive zeros
 - 1=no line signal
- ❑ **Manchester**
 - 0=transition from high to low in middle of interval
 - 1= transition from low to high in middle of interval
- ❑ **Differential Manchester**
 - Always a transition in middle of interval
 - 0= transition at beginning of interval
 - 1= no transition at beginning of interval

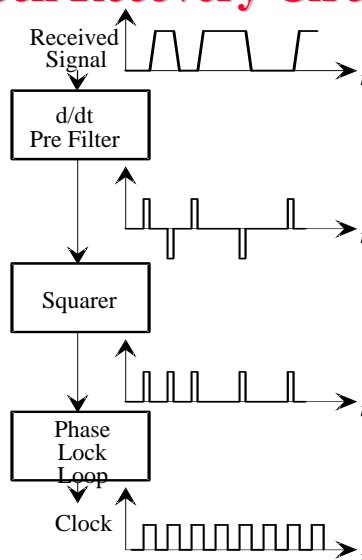
Multilevel Binary

- ❑ **Bipolar-AMI (Alternative Mark Inversion)**
 - ❑ No loss of sync with 1's, zeros are a problem
 - ❑ No net dc component
 - ❑ Error detection, noise \Rightarrow violation
 - ❑ Two bits/Hz
 - ❑ 3 levels \Rightarrow 3 dB higher signal than 2 levels
 - ❑ 3 levels: $2\log_2 3 = 3.16$ bits/Hz possible
- ❑ **Pseudoternary: Inverse of AMI**
 - ❑ No advantage over AMI

Biphase

- ❑ Manchester: 1=Low to High, 0=High to Low
Used in IEEE 802.3/Ethernet
- ❑ Differential Manchester:
0 = Transition at the beginning
1 = No transition at the beginning
Used in IEEE 802.5/Token ring
- ❑ No DC
- ❑ Clock synchronization
- ❑ Error detection
- ❑ 1 bit/Hz, baud rate = $2 \times$ bit rate

Clock Recovery Circuit



Encoding Formats (Cont)

- ❑ **B8ZS**
 Same as bipolar AMI, except that any string of eight zeros is replaced by a string with two code violations
 $0000\ 0000 = 000V\ 10V1$
- ❑ **HDB3**
 Same as bipolar AMI, except that any string of four zeros is replaced by a string with one code violation
 $0000 = 000V$ if odd number of ones since last substitution
 $100V$ otherwise

Scrambling Techniques

- ❑ Bipolar with 8-zeros substitution (B8ZS)
- ❑ High-density bipolar - 3 zeros (HDB3)

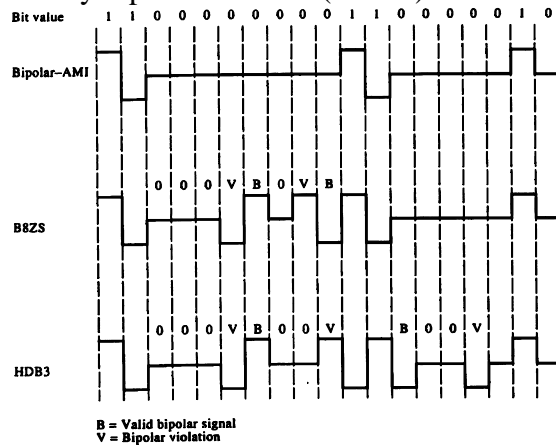
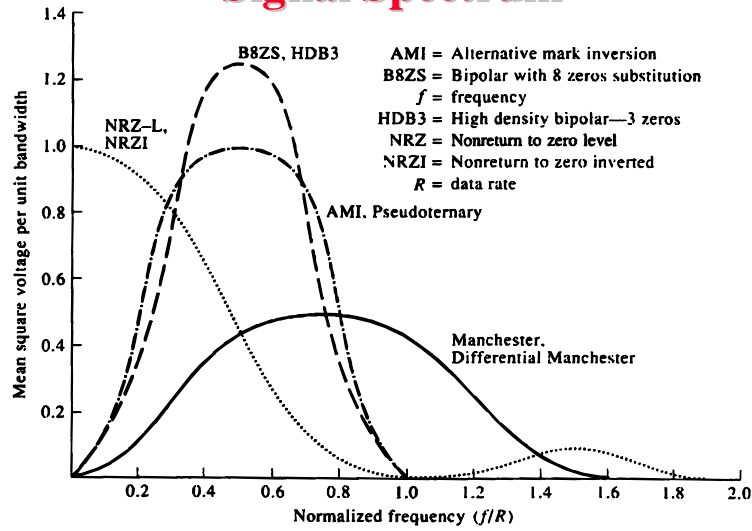


Fig 3.5

Signal Spectrum

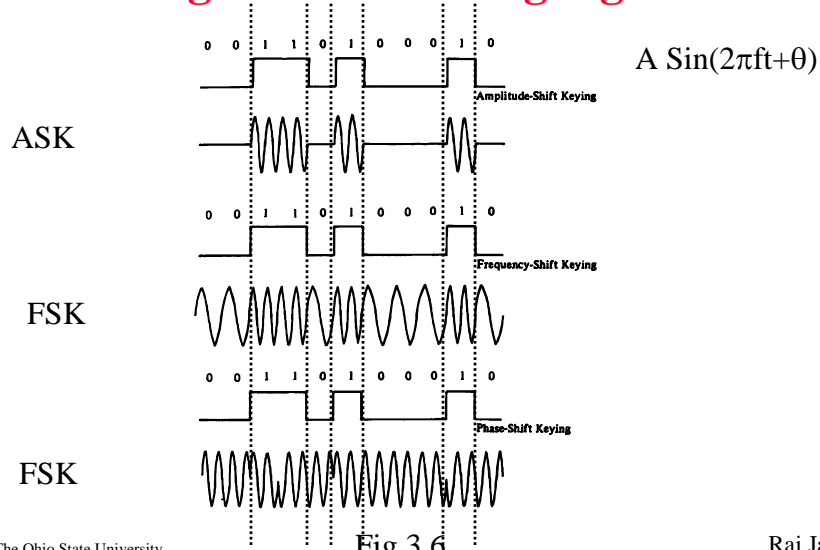


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Fig 3.3

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Digital Data Analog Signals



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Amplitude Shift Keying (ASK)

- ❑ Good for low rate (upto 1200 bps)
- ❑ Used in fiber: LED: No=0; Laser: Low=0

Frequency Shift Keying (FSK)

- ❑ Less susceptible to errors than ASK
- ❑ Used in 300-1200 bps on voice grade lines
- ❑ Used in 3 to 30 MHz radio

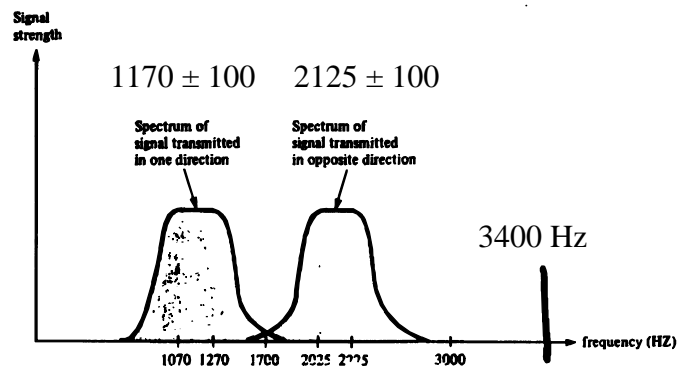


Fig 3.7

Phase-Shift Keying (PSK)

- Differential PSK:
0 = Same phase, 1=Opposite phase
 $A \cos(2\pi ft)$, $A \cos(2\pi ft + \pi)$
- Quadrature PSK (QPSK): Two bits
 $11 = A \cos(2\pi ft + 45^\circ)$, $10 = A \cos(2\pi ft + 135^\circ)$,
 $00 = A \cos(2\pi ft + 225^\circ)$, $01 = A \cos(2\pi ft + 315^\circ)$
- Three bits, four bits, ...
Amplitude and phase combined

9600 bps Modems

- 4 bits \Rightarrow 16 combinations
- 4 bits/element \Rightarrow 1200 baud
- 12 Phases, 4 with two amplitudes

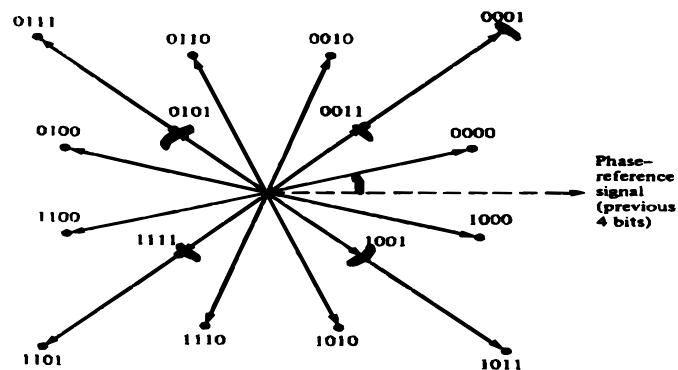


Fig 3.8

Bandwidth Efficiency

- Efficiency = bps per Hz = R/B
- Modulation rate = D baud
- ASK: $B = (1+\tau)D$, $0 < \tau < 1$
- FSK: $B = 2(f_2 - f_1) + (1+\tau)D$
- PSK: $B = (1+\tau)D$
- Bilevel: $R = D$
- Multilevel: L different levels, Bits/level = $\log_2 L$
 $R = D \log_2 L$
- $R/B = (\log_2 L)/(1+\tau)$
- **Example:** 300 bps modems, $f_2 - f_c = 100$ Hz,
 $B = 2(f_2 - f_c) + (1+\tau)D = 200 + (1+\tau)(300) = 500 - 800$ Hz
This assumes no noise.

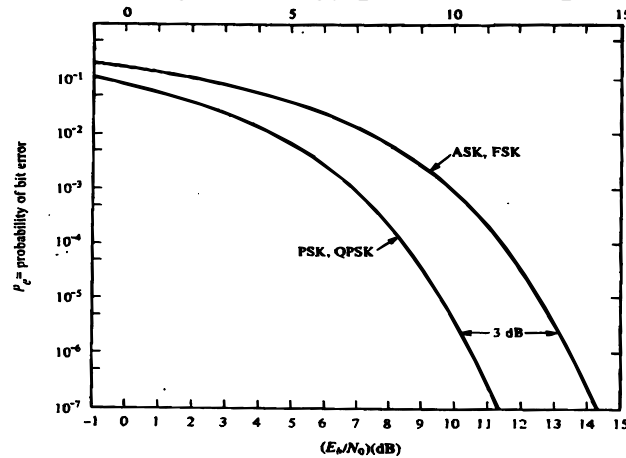
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Bit Error Rate (BER)

- BER = fn(Signal energy per bit/Noise power per Hz)



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Fig 3.9

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Errors Due to Noise

Signal power = S, Modulation rate = D baud,
 Signal energy per element $E_0 = S/D$
 $T = \text{Temperature} \Rightarrow \text{Noise power per Hz } N_0 = kT$
 Bandwidth = B Hz Noise power $N = kTB$
 $E_0/N_0 = S/\{kTD\} = S/\{(N/B)D\} = (S/N)/(D/B)$
 $E_0/N_0 \text{ in dB} = S/N \text{ in dB} - D/B \text{ in dB}$
 Data Rate = R, L elements $\Rightarrow R = D \log_2 L$

Example: BER = 10^{-7} , S/N = 12 dB

ASK, FSK:

D/B = 12 - 14.2 = -2.2 dB = 0.6 baud/Hz = 0.6 bps/Hz

PSK: D/B = 12 - 11.2 = 0.8 dB = 1.2 baud/Hz = 1.2 bps/Hz

QPSK: D/B = 1.2 baud/Hz = 2.4 bps/Hz

Analog Data Digital Signal

- ❑ Sampling Theorem: $2 \times \text{Highest Signal Frequency}$
- ❑ 4 kHz voice = 8 kHz sampling rate
 $8 \text{ k samples/sec} \times 8 \text{ bits/sample} = 64 \text{ kbps}$
- ❑ Quantizing Noise: $S/N = 6n - a \text{ dB}$, n bits, a = 0 to 1

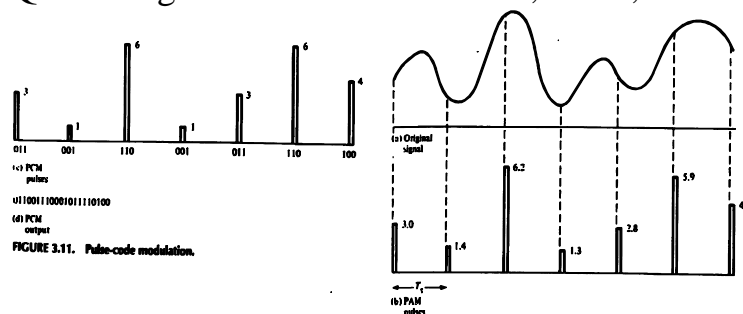
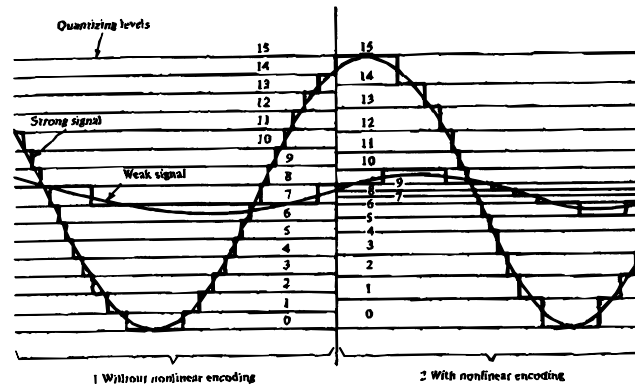


Fig 3.11

Nonlinear Encoding

- ❑ Linear: Same absolute error for all signal levels
- ❑ Nonlinear: More steps for low signal levels



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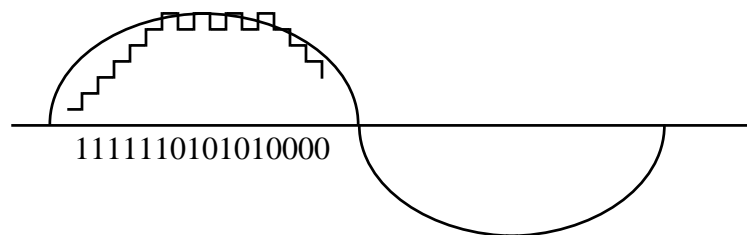
Fig 3.13

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Delta Modulation

- ❑ 1 = Signal up one step, 0 = Signal down one step
- ❑ Larger steps \Rightarrow More quantizing noise,
Less slope overhead noise
- ❑ Higher sampling rate = Lower noise, More bits



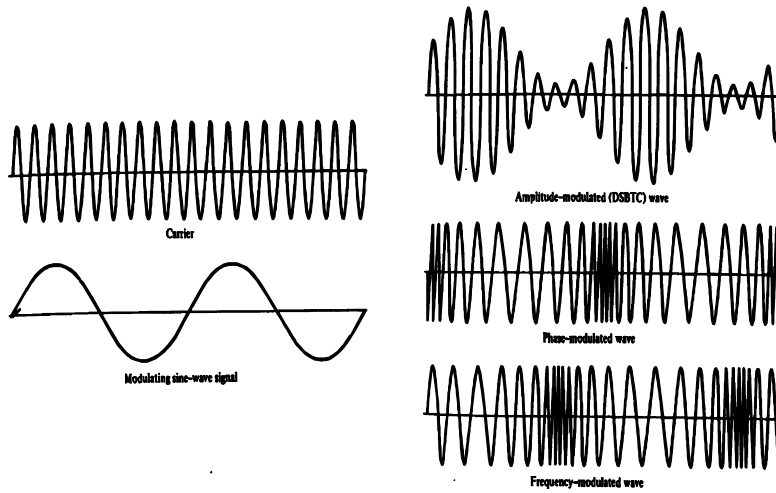
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Fig 3.15

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Analog Data, Analog Signals



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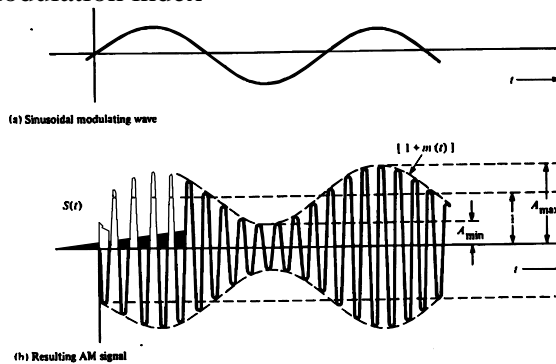
Fig 3.19

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Amplitude Modulation (AM)

- $s(t) = [1 + m \cdot x(t)] \cos(2\pi ft)$
- $n = \text{Signal/carrier amplitude ratio}$
- $= \text{Modulation index}$



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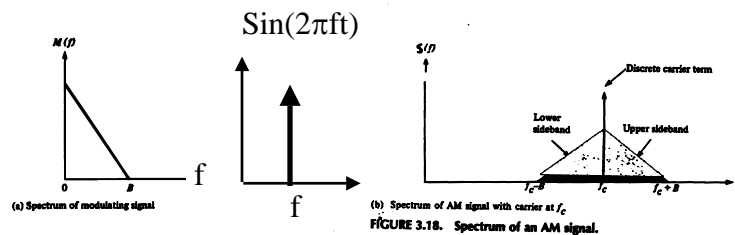
Fig 3.17

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Spectrum of AM Signal

- Signal bandwidth = $2 \times$ Data bandwidth
- Single sideband (SSB): No carrier
- Vestigial sideband (VSB): Reduced carrier+SSB



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Fig 3.18

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Angle Modulation

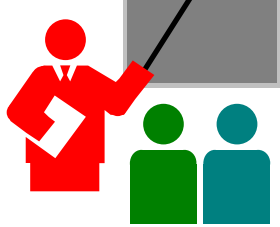
- $s(t) = A \cos[2\pi f t + \phi]$
- Frequency Modulation (FM):
 $s(t) = A \cos[2\pi \{f_c + n m(t)\} t + \phi]$
- Phase modulation (PM):
 $s(t) = A \cos[2\pi f_c t + \{n m(t)\}]$
- For FM: $m(t) = (1/n) [(d/dt)\phi(t) - f_c]$
- For PM: $m(t) = (1/n)[\phi(t) - 2\pi f_c t]$
- Increasing data level
 - ⇒ Same bandwidth, More power for AM
 - ⇒ More bandwidth, Same power for FM/PM

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Summary



- ❑ Coding: Higher data rate, error control, clock synchronization, line state indication, control signal
- ❑ NRZ, NRZI, Manchester, Bipolar, Multilevel
- ❑ Amplitude-, Frequency-, Phase-shift keying
- ❑ Pulse-code modulation, Delta modulation
- ❑ Amplitude, frequency, phase modulation

Homework

- ❑ Exercises 3.7, 3.11, 3.19