Chapter 3: Data Encoding

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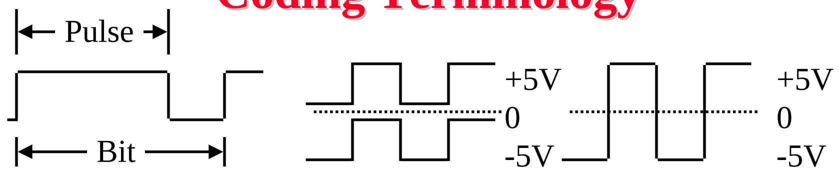
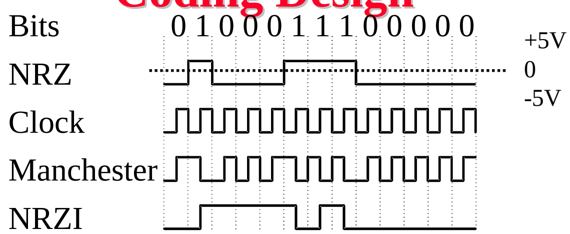
- Coding design consideration
- Codes for
  - digital data to digital signal
  - Digital data, analog signal
  - Analog signal, digital data
  - Analog signal, analog data

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/Duration of the smallest element
  =Baud rate
- Data Rate: Bits per second
- Data Rate = Fn(Bandwidth, signal/noise ratio, encoding)

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 ⇒ Differential (compare polarity)

Digital Signal Encoding Formats

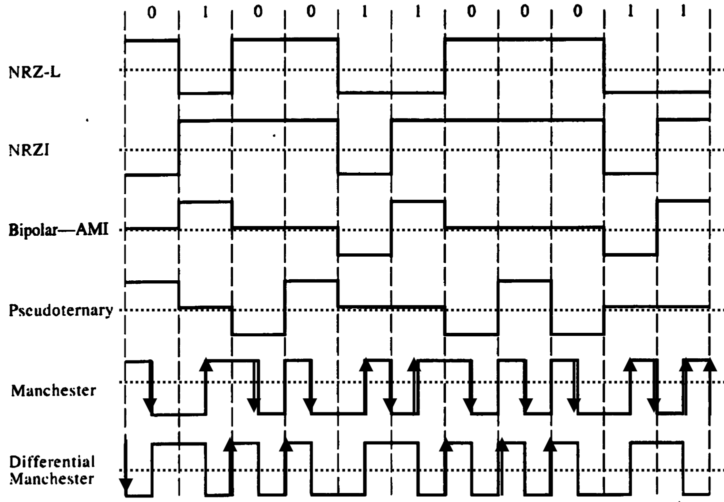


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Figure3.2

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

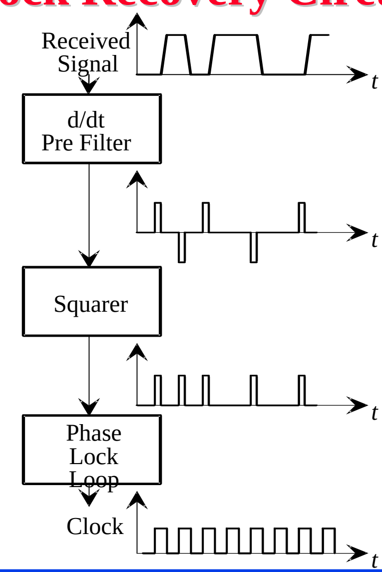
Multilevel Binary

- Bipolar-AMI (Alternative Mark Inversion)
  - No loss of sync with 1's, zeros are a problem
  - No net dc component
  - Error detection, noise ⇒ violation
  - Two bits/Hz
  - 3 levels ⇒ 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 begining
  1 = No transition at the beginning
  Used in IEEE 802.5/Token ring
- No DC
- Clock syncronization
- Error detection
- 1 bit/Hz, baud rate = 2 × 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

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Scrambling Techniques

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

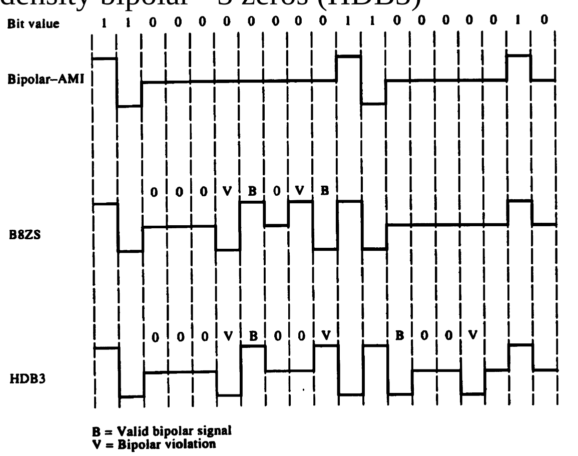

Fig 3.5

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Signal Spectrum

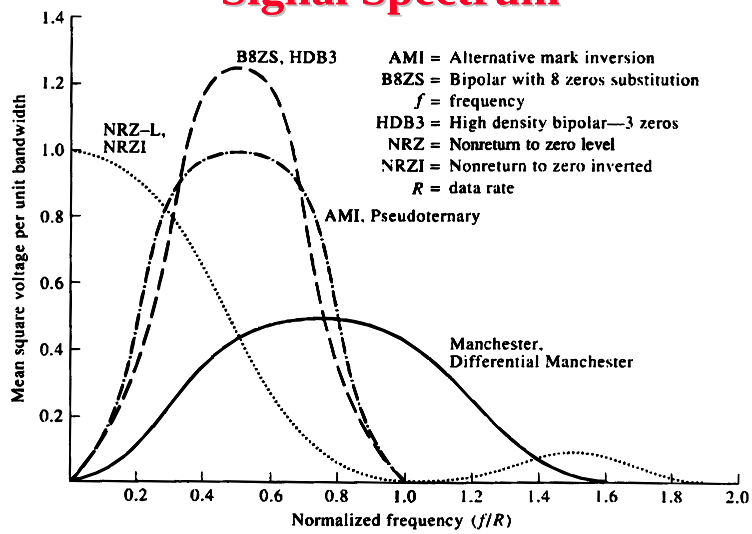

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Fig 3.3

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Digital Data Analog Signals

$A \sin(2\pi f t + \theta)$

ASK

FSK

FSK

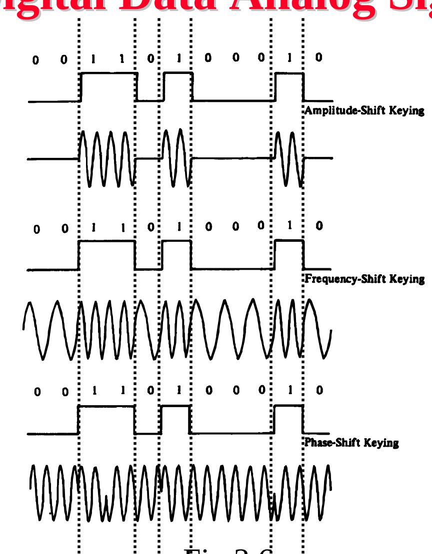

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Fig 3.6

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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

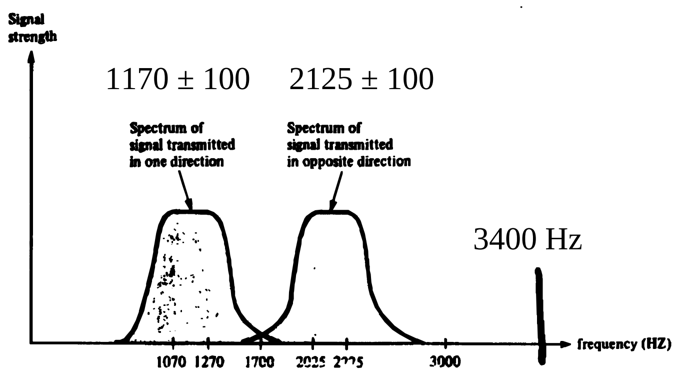

Fig 3.7

Phase-Shift Keying (PSK)

- Differential PSK:
  0 = Same phase, 1=Opposite phase
  A cos(2πft), A cos(2πft+π)
- Quadrature PSK (QPSK): Two bits
  11=A cos(2πft+45°), 10=A cos(2πft+135°),
  00=A cos(2πft+225°), 01=A cos(2πft+315°)
- Three bits, four bits, ...
  Amplitude and phase combined

9600 bps Modems

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

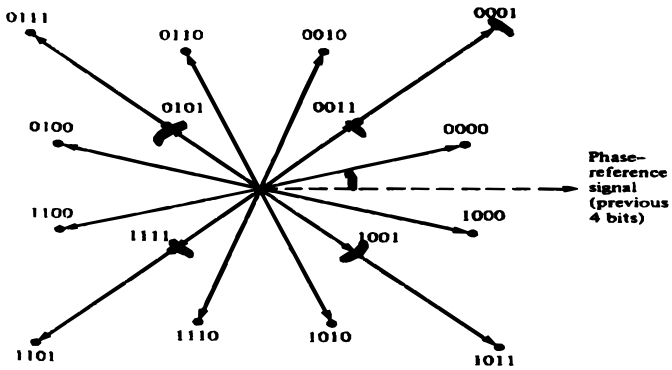

Fig 3.8

Bandwidth Efficiency

- Efficency = 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 = $(\text{Log}_2 L)/(1+\tau)$
- **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.

Bit Error Rate (BER)

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

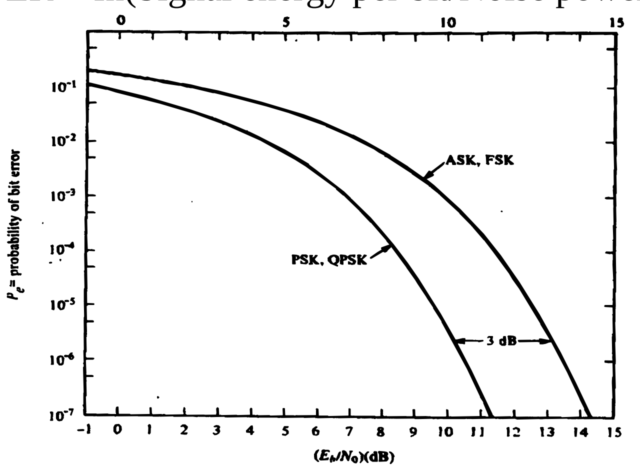

Fig 3.9

Errors Due to Noise

Signal power = S, Modulation rate = D baud,

Signal energy per element E_0= S/D

T=Temperature⇒ 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 in dB = S/N in dB - D/B in dB

Data Rate = R, L elements ⇒ 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 × Highest Signal Frequency
- 4 kHz voice = 8 kHz sampling rate
  8 k samples/sec × 8 bits/sample = 64 kbps
- Quantizing Noise: S/N = 6*n* - *a* dB, *n* bits, *a* = 0 to 1

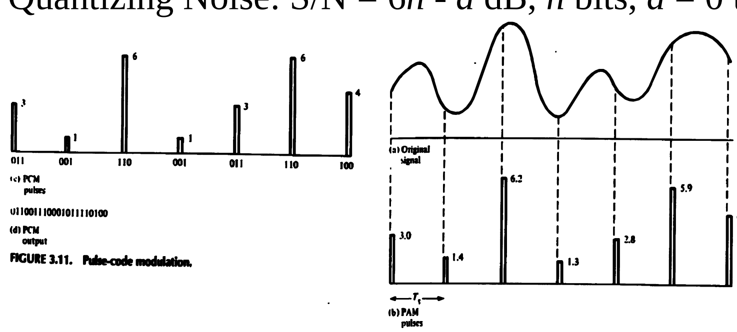

Fig 3.11

Nonlinear Encoding

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

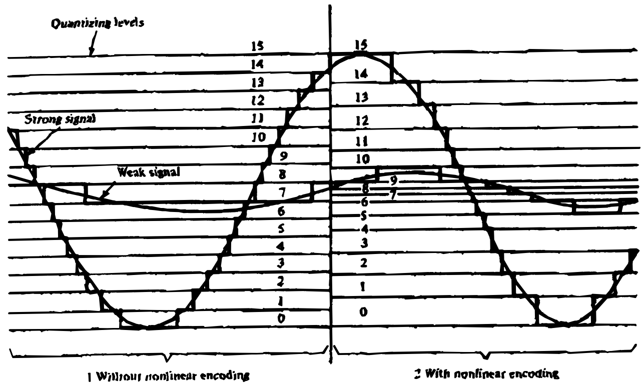

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Fig 3.13

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Delta Modulation

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

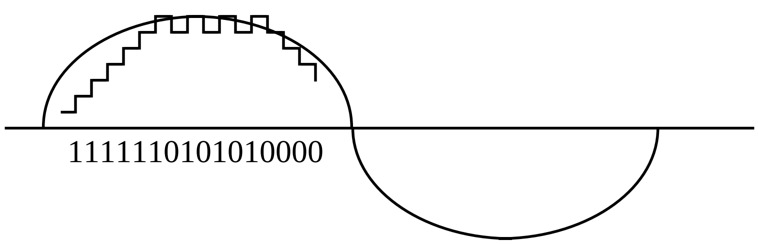

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Fig 3.15

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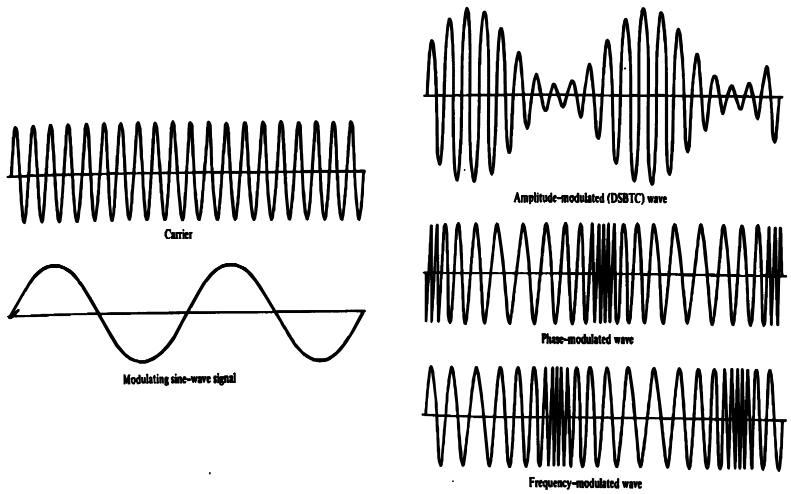
Analog Data, Analog Signals



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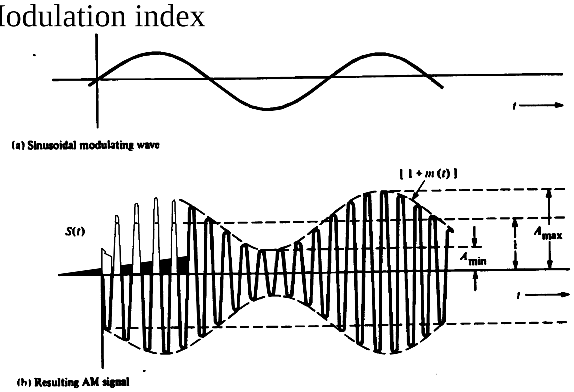
Amplitude Modulation (AM)

- s(t)=[1+n x(t)]cos(2πft)
  n = Signal/carrier amplitude ratio
  = Modulation index



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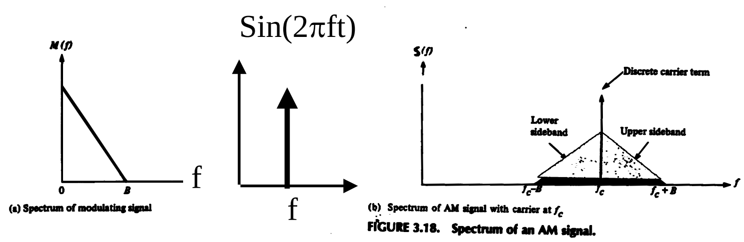
Spectrum of AM Signal

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



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Angle Modulation

- $s(t) = A \cos[2\pi ft + \phi]$
- 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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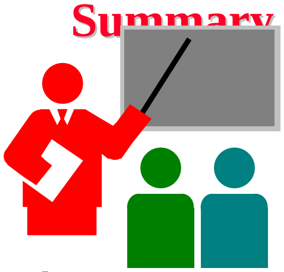
Summary



- Coding: Higher data rate, error control, clock syncronization, 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