Signal Encoding Techniques

Raj Jain
Washington University
Saint Louis, MO 63131
Jain@cse.wustl.edu

These slides are available on-line at:
http://www.cse.wustl.edu/~jain/cse473-05/
Overview

1. Coding Terminology and Design issues
2. Digital Data, Digital Signal: AMI, Manchester, etc.
3. Digital Data, Analog Signals: ASK, FSK, PSK, QAM
4. Analog Data, Digital Signals: PCM, Companding
5. Analog Data, Analog Signals: AM, FM
**Coding Terminology**

- **Signal element**: Pulse (of constant amplitude, frequency, phase)
- **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**: $\text{Data Rate} = \text{Fn}(\text{Bandwidth, signal/noise ratio, encoding})$
1. Pulse width indeterminate: Clocking
2. DC, Baseline wander
3. No line state information
4. No error detection/protection
5. No control signals
6. High bandwidth
7. Polarity mix-up ⇒ Differential (compare polarity)
Clock Recovery Circuit

Received Signal

\[ \frac{d}{dt} \text{ Pre Filter} \]

Squarer

Phase Lock Loop

Clock
Digital Signal Encoding Formats

- **Return-to-Zero (RZ)**
  0 = Remain at zero, 1 = +ve for ½ bit duration

- **Nonreturn-to-Zero-Level (NRZ-L)**
  0 = high level, 1 = low level

- **Nonreturn to Zero Inverted (NRZI)**
  0 = no transition at beginning of interval (bit time)
  1 = transition at beginning of interval
Multi-level Binary Encoding

- **Bipolar-AMI:**
  0 = no line signal
  1 = +ve or -ve for successive 1’s

- **Pseudo-ternary:**
  0 = +ve or -ve for successive 0’s
  1 = no line signal
  No advantage over AMI

- 1. No loss of sync with 1’s
- 2. Zeros are a problem
- 3. No net dc component
- 4. Error detection
- Noise ⇒ violation
- 5. Two bits/Hz
- 6. 3 dB higher S/N
- 7. 2b/Hz. Not 3.16 b/Hz
**Bi-phase**

- **Manchester**: Used in Ethernet
  - 0 = High to low transition in middle
  - 1 = Low to high transition in middle

- **Differential Manchester**: Used in Token Ring
  - Always a transition in middle
  - 0 = transition at beginning
  - 1 = no transition at beginning

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No DC</td>
<td></td>
</tr>
<tr>
<td>2. Clock sync</td>
<td></td>
</tr>
<tr>
<td>3. Error detection</td>
<td></td>
</tr>
<tr>
<td>4. 1 bit/Hz,</td>
<td></td>
</tr>
<tr>
<td>5. baud rate</td>
<td>$= 2 \times \text{bit rate}$</td>
</tr>
</tbody>
</table>
Scrambling

- **Bipolar with 8-Zero Substitution (B8ZS):**
  Same as AMI, except eight 0’s replaced with two code violations
  \[0000 \ 0000 = 000V \ 10V1\]

- **High Density Bi-polar w 3 Zeros (HDB3):** Same as AMI, except that four 0’s replaced with one code violation
  \[0000 = 000V \text{ if odd number of ones since last substitution}\]
  \[100V \text{ otherwise}\]
Signal Spectrum

AMI = Alternative mark inversion
B8ZS = Bipolar with 8 zeros substitution
f = frequency
HDB3 = High density bipolar—3 zeros
NRZ = Nonreturn to zero level
NRZI = Nonreturn to zero inverted
R = data rate

Mean square voltage per unit bandwidth vs. normalized frequency ($f/R$).

- AMI, Pseudoternary
- B8ZS, HDB3
- NRZ–L, NRZI
- Manchester, Differential Manchester
Digital Data Analog Signals

\[ A \sin(2\pi ft + \theta) \]

Used in 300-1200 bps modems

Used in Optical Nets

ASK

Frequency-Shift Keying

FSK

Phase-Shift Keying
Frequency Shift Keying (FSK)

- Less susceptible to errors than ASK
- Used in 300-1200 bps on voice grade lines
Phase-Shift Keying (PSK)

- **Differential PSK:**
  0 = Same phase, 1=Opposite phase
  \[ \text{A cos}(2\pi ft), \text{A cos}(2\pi ft+\pi) \]

- **Quadrature PSK (QPSK):** Two bits
  11=\( \text{A cos}(2\pi ft+45^\circ) \), 10=\( \text{A cos}(2\pi ft+135^\circ) \),
  00=\( \text{A cos}(2\pi ft+225^\circ) \), 01=\( \text{A cos}(2\pi ft+315^\circ) \)
  Sum of two signals 90° apart in phase
  (In-phase I, Quadrature Q),
  Up to 180° phase difference between successive intervals

- **Orthogonal QPSK (OQPSK):** Q stream delayed by 1 bit
  Phase difference between successive bits limited to 90°
Multi-level PSK

- 9600 bps Modems use PSK with 4 bits
- 4 bits $\Rightarrow$ 16 combinations
- 4 bits/element $\Rightarrow$ 1200 baud
- 12 Phases, 4 with two amplitudes
QAM

- Quadrature Amplitude and Phase Modulation
- QAM-4, QAM-16, QAM-64, QAM-256
- Used in DSL and wireless networks

QAM-4
- Binary: 0, 1
- QAM-4: 00, 01, 10, 11

QAM-16
- QAM-16: 000, 001, 010, 011, 100, 101, 110, 111

- Used in DSL and wireless networks
Analog Data, Digital Signals

- **Sampling Theorem**: $2 \times$ Highest Signal Frequency
- 4 kHz voice = 8 kHz sampling rate
  - 8 k samples/sec $\times$ 8 bits/sample = 64 kbps
- Quantizing Error with $n$ bits: $S/N = 6.02n + 1.76$ dB
Nonlinear Encoding

- Linear: Same absolute error for all signal levels
- Non-linear: More steps for low signal levels
Companding

- Reduce the intensity range by amplifying weak signals more than the strong signals input
- Opposite is done at output
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
Analog Data, Analog Signals

Amplitude Modulation (AM)
Frequency Modulation (FM)
Phase Modulation (PM)

Both FM and PM are special cases of angle modulation
Summary

- **Coding**: Higher data rate, error control, clock synchronization, line state indication, control signal
- **D-to-D**: RZ, NRZ-L, NRZI, Manchester, Bipolar, Biphase
- **D-to-A**: ASK, FSK, PSK, BPSK, QPSK, OQPSK, QAM
- **A-to-D**: PCM, Delta Modulation, Sampling theorem
- **A-to-A**: Amplitude, angle, frequency, phase modulation
Reading Assignment

- Read Chapter 5 of Stallings 7th edition.
Homework

- Submit answers to 5.10 (Bipolar violations) from Stallings 7th edition.