William Stallings
Data and Computer Communications
7th Edition

Chapter 5
Signal Encoding Techniques

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Encoding Techniques

- Digital data, digital signal
- Analog data, digital signal
- Digital data, analog signal
- Analog data, analog signal

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Digital Data, Digital Signal

- Digital signal
  - —Discrete, discontinuous voltage pulses
  - —Each pulse is a signal element
  - —Binary data encoded into signal elements

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Terms (1)

- Unipolar
  - —All signal elements have same sign
- Polar
  - —One logic state represented by positive voltage the other by negative voltage
- Data rate
  - —Rate of data transmission in bits per second
- Duration or length of a bit
  - —Time taken for transmitter to emit the bit

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Terms (2)

- Modulation rate
  - —Rate at which the signal level changes
  - —Measured in baud = signal elements per second
- Mark and Space
  - —Binary 1 and Binary 0 respectively

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Interpreting Signals

- Need to know
  - —Timing of bits - when they start and end
  - —Signal levels
- Factors affecting successful interpreting of signals
  - —Signal to noise ratio
  - —Data rate
  - —Bandwidth

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Comparison of Encoding Schemes (1)

- Signal Spectrum
  - —Lack of high frequencies reduces required bandwidth
  - —Lack of dc component allows ac coupling via transformer, providing isolation
  - —Concentrate power in the middle of the bandwidth
- Clocking
  - —Synchronizing transmitter and receiver
  - —External clock
  - —Sync mechanism based on signal

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Comparison of Encoding Schemes (2)

- Error detection
  - —Can be built in to signal encoding
- Signal interference and noise immunity
  - —Some codes are better than others
- Cost and complexity
  - —Higher signal rate (& thus data rate) lead to higher costs
  - —Some codes require signal rate greater than data rate

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Encoding Schemes

- Nonreturn to Zero-Level (NRZ-L)
- Nonreturn to Zero Inverted (NRZI)
- Bipolar -AMI
- Pseudoternary
- Manchester
- Differential Manchester
- B8ZS
- HDB3

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Nonreturn to Zero-Level (NRZ-L)

- Two different voltages for 0 and 1 bits
- Voltage constant during bit interval
  - —no transition I.e. no return to zero voltage
- e.g. Absence of voltage for zero, constant positive voltage for one
- More often, negative voltage for one value and positive for the other
- This is NRZ-L

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Nonreturn to Zero Inverted

- Nonreturn to zero inverted on ones
- Constant voltage pulse for duration of bit
- Data encoded as presence or absence of signal transition at beginning of bit time
- Transition (low to high or high to low) denotes a binary 1
- No transition denotes binary 0
- An example of differential encoding

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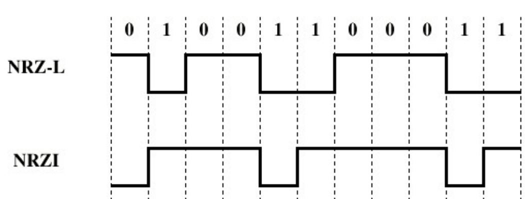
NRZ



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Differential Encoding

- Data represented by changes rather than levels
- More reliable detection of transition rather than level
- In complex transmission layouts it is easy to lose sense of polarity

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NRZ pros and cons

- Pros
  - —Easy to engineer
  - —Make good use of bandwidth
- Cons
  - —dc component
  - —Lack of synchronization capability
- Used for magnetic recording
- Not often used for signal transmission

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Multilevel Binary

- Use more than two levels
- Bipolar-AMI
  - —zero represented by no line signal
  - —one represented by positive or negative pulse
  - —one pulses alternate in polarity
  - —No loss of sync if a long string of ones (zeros still a problem)
  - —No net dc component
  - —Lower bandwidth
  - —Easy error detection

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Pseudoternary

- One represented by absence of line signal
- Zero represented by alternating positive and negative
- No advantage or disadvantage over bipolar-AMI

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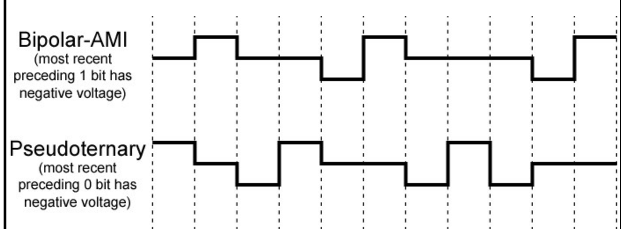
Bipolar-AMI and Pseudoternary



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Trade Off for Multilevel Binary

- Not as efficient as NRZ
  - —Each signal element only represents one bit
  - —In a 3 level system could represent $\log_2 3$ = 1.58 bits
  - —Receiver must distinguish between three levels (+A, -A, 0)
  - —Requires approx. 3dB more signal power for same probability of bit error

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Biphase

- Manchester
  - —Transition in middle of each bit period
  - —Transition serves as clock and data
  - —Low to high represents one
  - —High to low represents zero
  - —Used by IEEE 802.3
- Differential Manchester
  - —Midbit transition is clocking only
  - —Transition at start of a bit period represents zero
  - —No transition at start of a bit period represents one
  - —Note: this is a differential encoding scheme
  - —Used by IEEE 802.5

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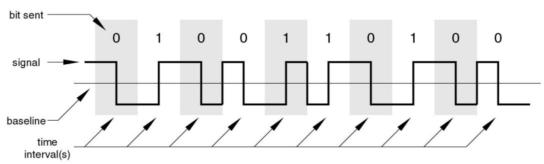
Manchester Encoding

Manchester Encoding



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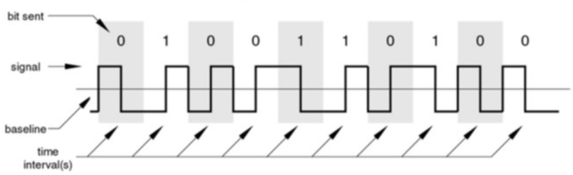
Differential Manchester Encoding

Differential Manchester Encoding



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Biphase Pros and Cons

- Con
  - —At least one transition per bit time and possibly two
  - —Maximum modulation rate is twice NRZ
  - —Requires more bandwidth
- Pros
  - —Synchronization on mid bit transition (self clocking)
  - —No dc component
  - —Error detection
    - Absence of expected transition

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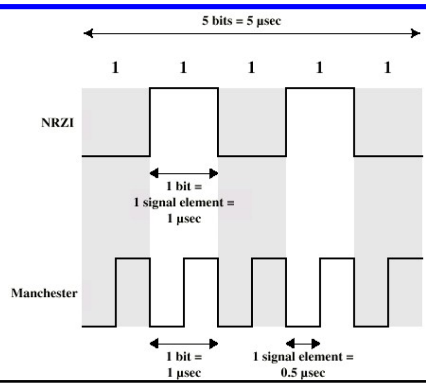
Modulation Rate



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Scrambling

- Use scrambling to replace sequences that would produce constant voltage
- Filling sequence
  - —Must produce enough transitions to sync
  - —Must be recognized by receiver and replace with original
  - —Same length as original
- No dc component
- No long sequences of zero level line signal
- No reduction in data rate
- Error detection capability

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B8ZS

- Bipolar With 8 Zeros Substitution
- Based on bipolar-AMI
- If octet of all zeros and last voltage pulse preceding was positive encode as 000+-0-+
- If octet of all zeros and last voltage pulse preceding was negative encode as 000-+0+-
- Causes two violations of AMI code
- Unlikely to occur as a result of noise
- Receiver detects and interprets as octet of all zeros

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HDB3

- High Density Bipolar 3 Zeros
- Based on bipolar-AMI
- String of four zeros replaced with one or two pulses

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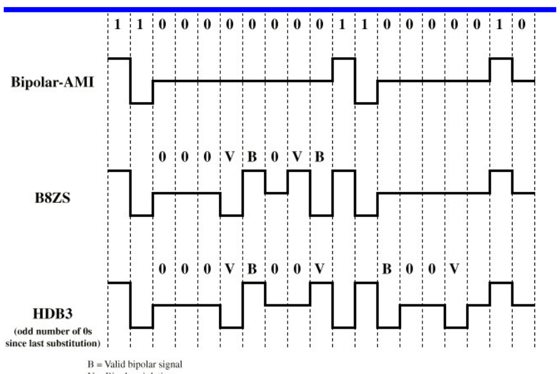
B8ZS and HDB3



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Digital Data, Analog Signal

- Public telephone system
  - 300Hz to 3400Hz
  - Use modem (modulator-demodulator)
- Amplitude shift keying (ASK)
- Frequency shift keying (FSK)
- Phase shift keying (PK)

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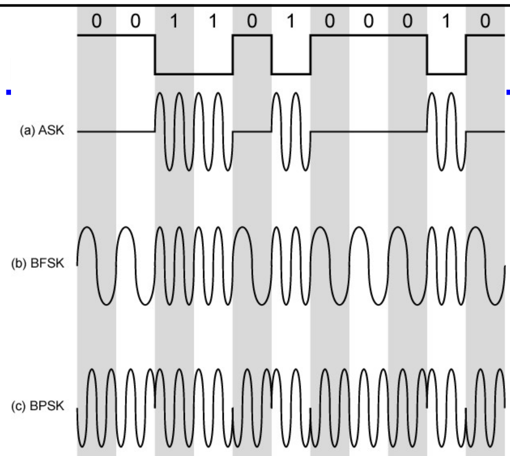

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Amplitude Shift Keying

- Values represented by different amplitudes of carrier
- Usually, one amplitude is zero
  - i.e. presence and absence of carrier is used
- Susceptible to sudden gain changes
- Inefficient
- Up to 1200bps on voice grade lines
- Used over optical fiber

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Binary Frequency Shift Keying

- Most common form is binary FSK (BFSK)
- Two binary values represented by two different frequencies (near carrier)
- Less susceptible to error than ASK
- Up to 1200bps on voice grade lines
- High frequency radio
- Even higher frequency on LANs using co-ax

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Multiple FSK

- More than two frequencies used
- More bandwidth efficient
- More prone to error
- Each signalling element represents more than one bit

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FSK on Voice Grade Line

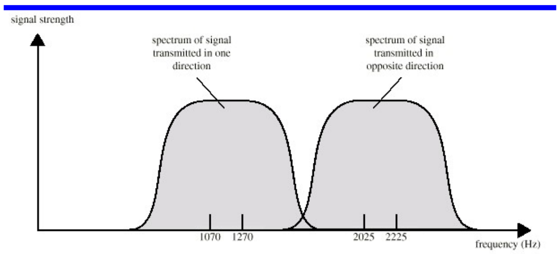

Figure 5.8 Full-Duplex FSK Transmission on a Voice-Grade Line

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Phase Shift Keying

- Phase of carrier signal is shifted to represent data
- Binary PSK
  - —Two phases represent two binary digits
- Differential PSK
  - —Phase shifted relative to previous transmission rather than some reference signal

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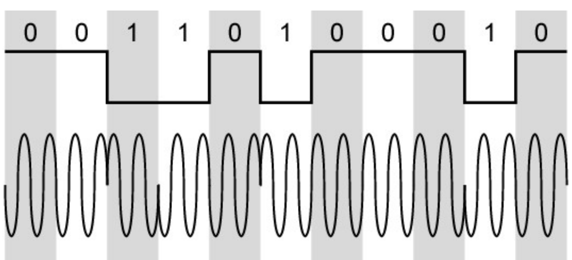
Differential PSK



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Quadrature PSK

- More efficient use by each signal element representing more than one bit
  - —e.g. shifts of $\pi/2$ (90°)
  - —Each element represents two bits
  - —Can use 8 phase angles and have more than one amplitude
  - —9600bps modem use 12 angles , four of which have two amplitudes
- Offset QPSK (orthogonal QPSK)
  - —Delay in Q stream

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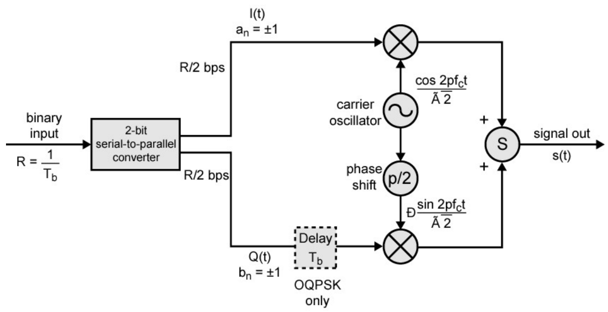
QPSK and OQPSK Modulators



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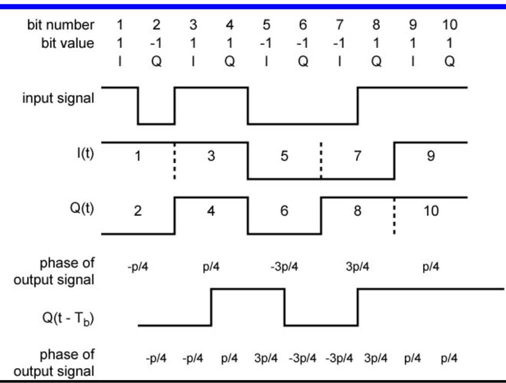
Examples of QPSF and OQPSK Waveforms



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Performance of Digital to Analog Modulation Schemes

- Bandwidth
  - —ASK and PSK bandwidth directly related to bit rate
  - —FSK bandwidth related to data rate for lower frequencies, but to offset of modulated frequency from carrier at high frequencies
  - —(See Stallings for math)
- In the presence of noise, bit error rate of PSK and QPSK are about 3dB superior to ASK and FSK

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Quadrature Amplitude Modulation

- QAM used on asymmetric digital subscriber line (ADSL) and some wireless
- Combination of ASK and PSK
- Logical extension of QPSK
- Send two different signals simultaneously on same carrier frequency
  - —Use two copies of carrier, one shifted 90°
  - —Each carrier is ASK modulated
  - —Two independent signals over same medium
  - —Demodulate and combine for original binary output

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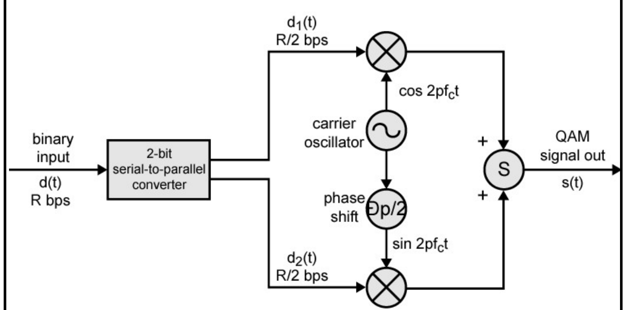
QAM Modulator



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QAM Levels

- Two level ASK
  - —Each of two streams in one of two states
  - —Four state system
  - —Essentially QPSK
- Four level ASK
  - —Combined stream in one of 16 states
- 64 and 256 state systems have been implemented
- Improved data rate for given bandwidth
  - —Increased potential error rate

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Analog Data, Digital Signal

- Digitization
  - —Conversion of analog data into digital data
  - —Digital data can then be transmitted using NRZ-L
  - —Digital data can then be transmitted using code other than NRZ-L
  - —Digital data can then be converted to analog signal
  - —Analog to digital conversion done using a codec
  - —Pulse code modulation
  - —Delta modulation

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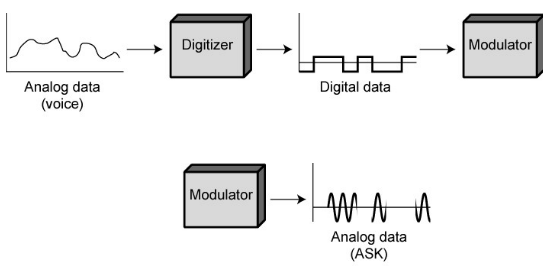
Digitizing Analog Data



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Pulse Code Modulation(PCM) (1)

- If a signal is sampled at regular intervals at a rate higher than twice the highest signal frequency, the samples contain all the information of the original signal
  - —(Proof - Stallings appendix 4A)
- Voice data limited to below 4000Hz
- Require 8000 sample per second
- Analog samples (Pulse Amplitude Modulation, PAM)
- Each sample assigned digital value

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Pulse Code Modulation(PCM) (2)

- 4 bit system gives 16 levels
- Quantized
  - —Quantizing error or noise
  - —Approximations mean it is impossible to recover original exactly
- 8 bit sample gives 256 levels
- Quality comparable with analog transmission
- 8000 samples per second of 8 bits each gives 64kbps

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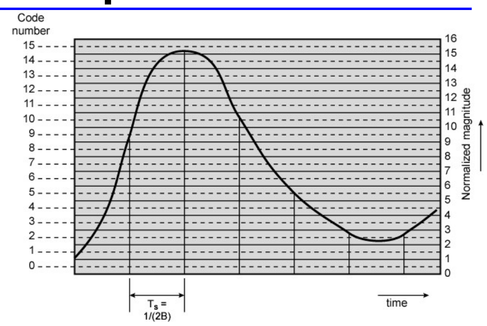
PCM Example



PAM value	1.1	9.2	15.2	10.8	5.6	2.8	2.7
quantized code number	1	9	15	10	5	2	2
PCM code	0001	1001	1111	1010	0101	0010	0010

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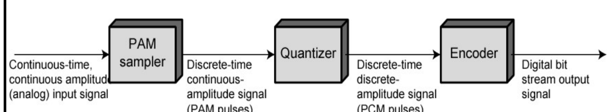
PCM Block Diagram



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Nonlinear Encoding

- Quantization levels not evenly spaced
- Reduces overall signal distortion
- Can also be done by companding

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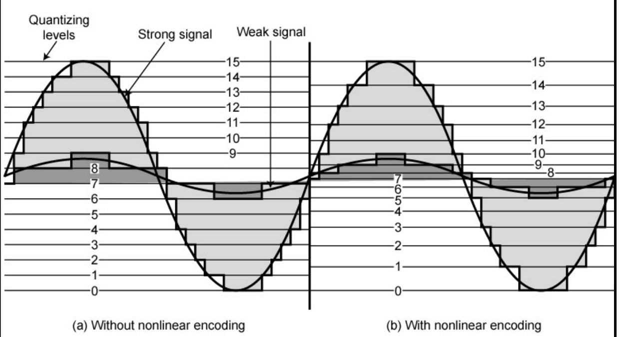
Effect of Non-Linear Coding



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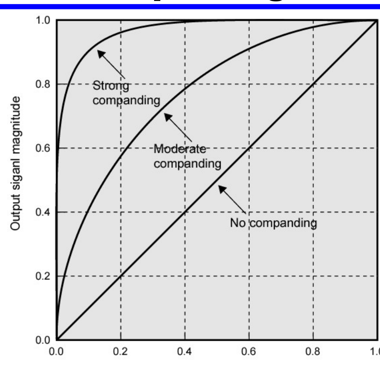
Typical Companding Functions



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Delta Modulation

- Analog input is approximated by a staircase function
- Move up or down one level (δ) at each sample interval
- Binary behavior
  - —Function moves up or down at each sample interval

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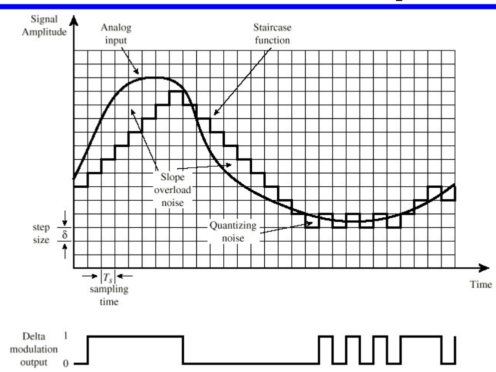
Delta Modulation - example



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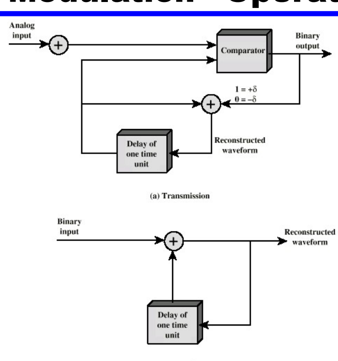
Delta Modulation - Operation



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Delta Modulation - Performance

- Good voice reproduction
  - —PCM - 128 levels (7 bit)
  - —Voice bandwidth 4khz
  - —Should be 8000 x 7 = 56kbps for PCM
- Data compression can improve on this
  - —e.g. Interframe coding techniques for video

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Analog Data, Analog Signals

- Why modulate analog signals?
  - —Higher frequency can give more efficient transmission
  - —Permits frequency division multiplexing (chapter 8)
- Types of modulation
  - —Amplitude
  - —Frequency
  - —Phase

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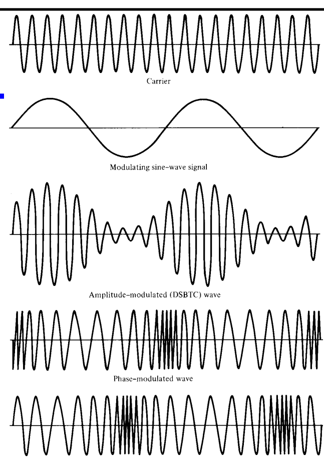
Analog Modulation



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Required Reading

- Stallings chapter 5

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