Chapter 5: Signal Encoding Techniques

Encoding Techniques

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

Digital Data, Digital Signal

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

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

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

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
  - —Synchronization

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

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

Encoding Schemes

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

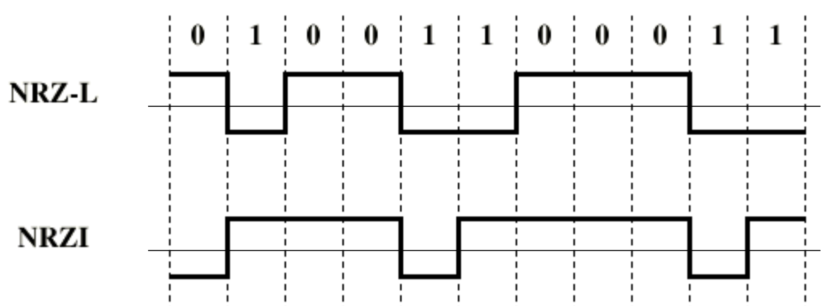
Nonreturn to Zero-Level (NRZ-L)

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

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 denotes a binary 1
    - (low to high or high to low)
  - —No transition denotes binary 0
  - —An example of differential encoding

NRZ



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

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

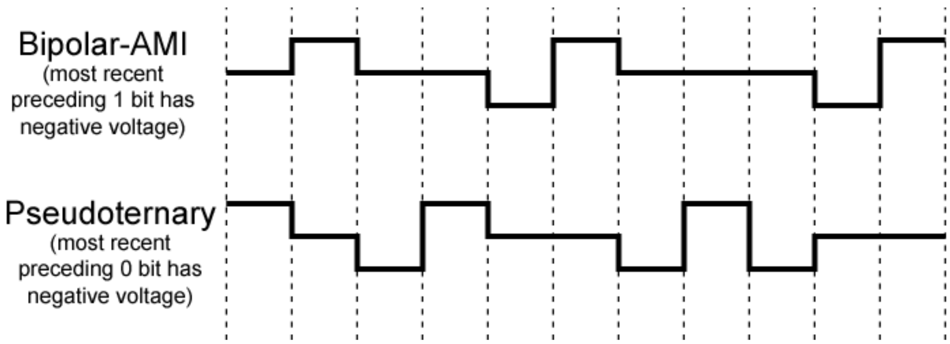
Multilevel Binary

- Use more than two levels
- Bipolar-AMI
  - —"0" represented by no line signal
  - —"1" represented by positive or negative pulse
  - —"1" pulses alternate in polarity
  - —No loss of sync if a long string of "1"s ("0" still a problem)
  - —No net dc component
  - —Lower bandwidth
  - —Easy error detection

Pseudoternary

- "1" represented by absence of line signal
- "0" represented by alternating positive and negative
- No advantage or disadvantage over bipolar-AMI

Bipolar-AMI and Pseudoternary



CS420/520 Axel Krings Page 17 Sequence 5

Trade-Off for Multilevel Binary

- Not as efficient as NRZ
  - Each signal element only represents one bit
  - 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

CS420/520 Axel Krings Page 18 Sequence 5

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 (CSMA/CD, i.e. Ethernet)

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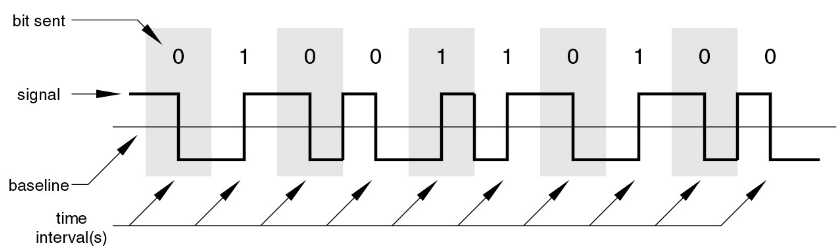
Manchester Encoding

Manchester Encoding



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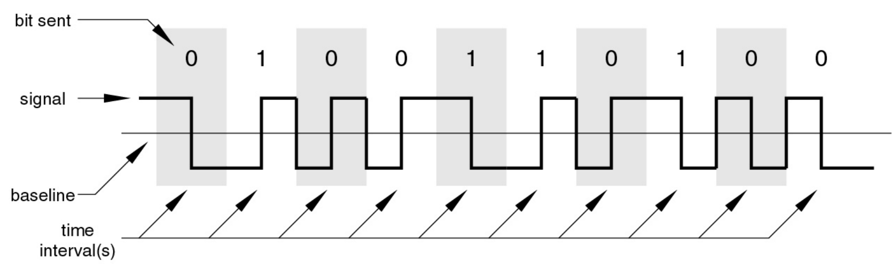
Biphase

- Differential Manchester
  - —Mid-bit 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 (token ring)

Differential Manchester Encoding

Differential Manchester Encoding

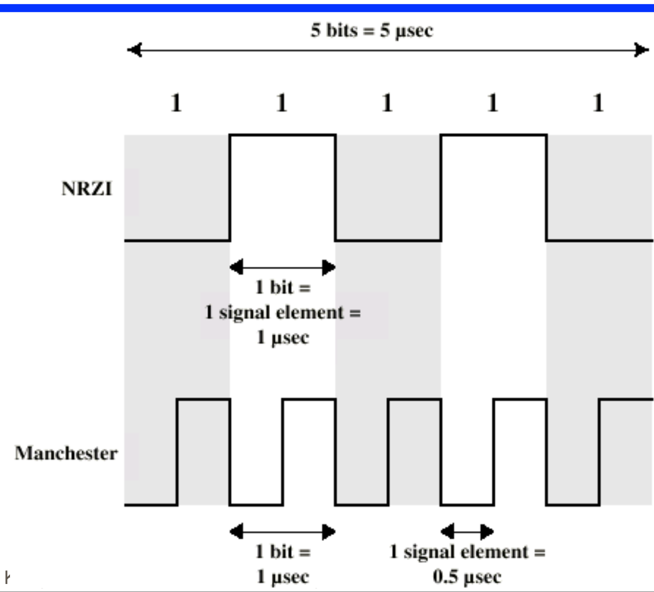


BTW: does anything seem wrong here?

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

Modulation Rate



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

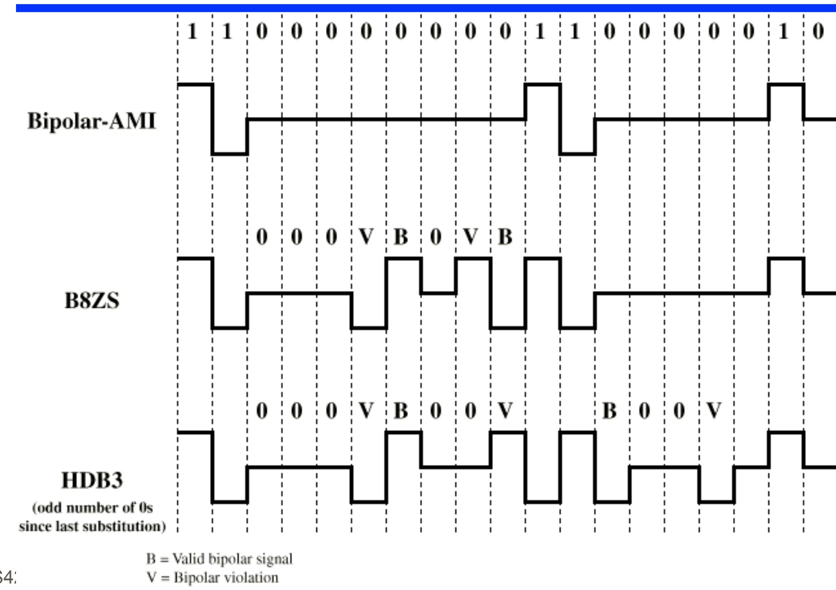
B8ZS

- 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

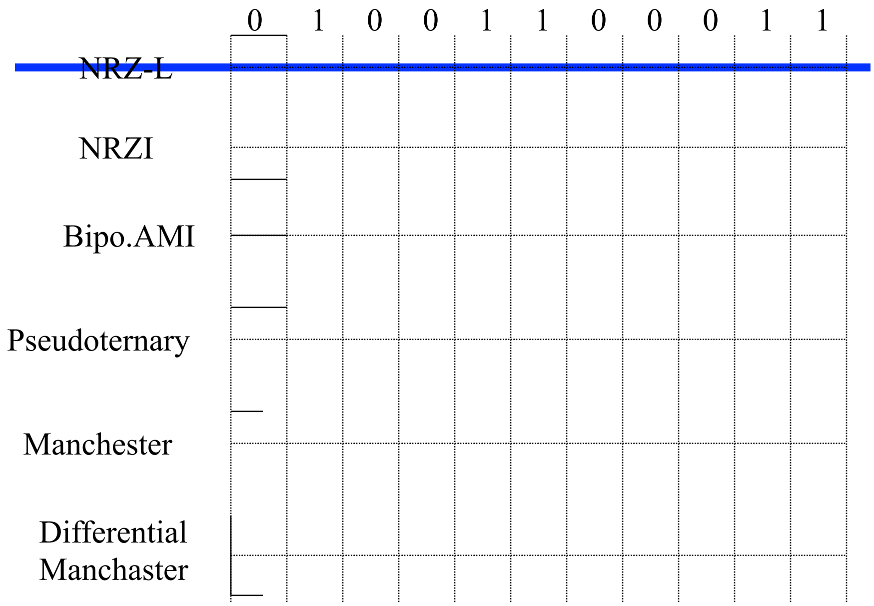
Data Encoding

- HDB3 - (High Density Bipolar 3)
  - Commonly used in Europe and Japan
  - Similar to bipolar AMI, except that any string of four zeros is replaced by a string with one code violation
  - Rules:
    - replace every string of 4 zeros by 000V
      - V is a code violation
    - this might result in DC components if consecutive strings of 4 zeros are encoded -- in this case the pattern B00V is used
      - B is a level inversion and
      - V is the code violation
    - general rule: use patterns 000V and B00V such that the violations alternate, thereby avoiding DC components

B8ZS and HDB3



Test your understanding and see solutions on next slide



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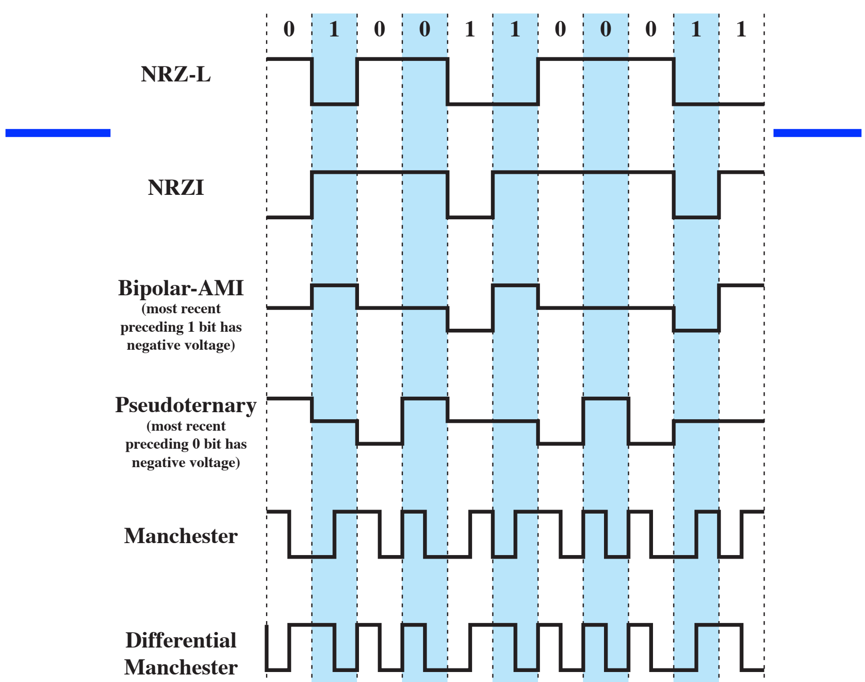
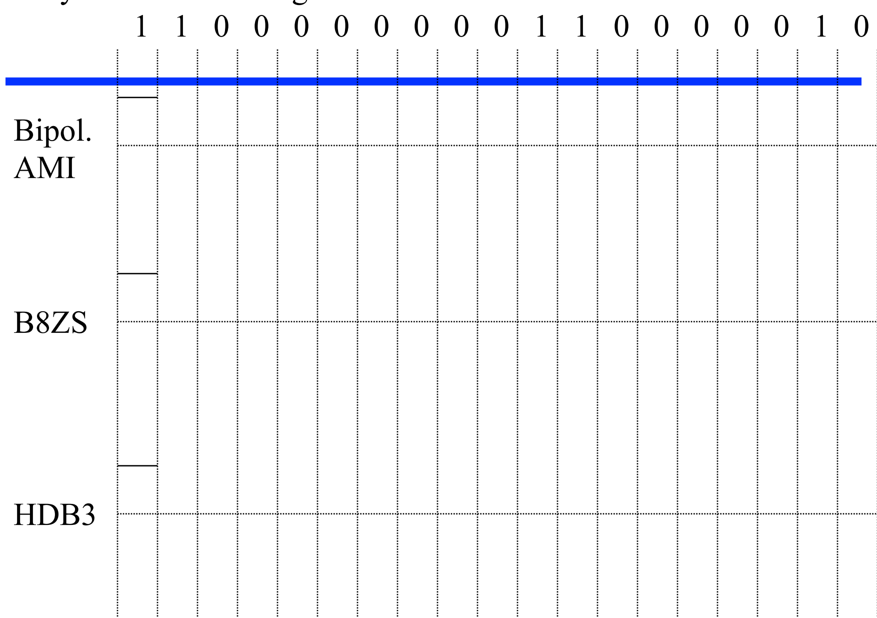
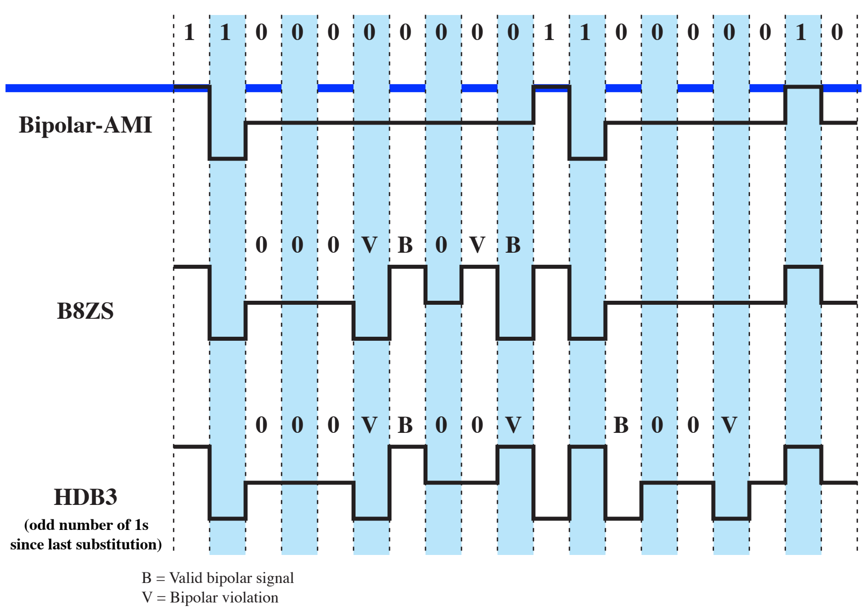


CS420/520 Axel Krings Page 30 Sequence 5

Test your understanding and see solutions on next slide

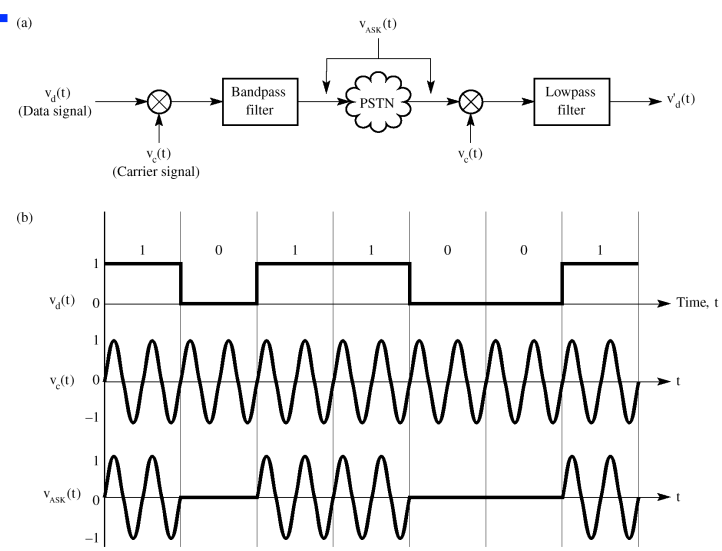




Digital Data, Analog Signal

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

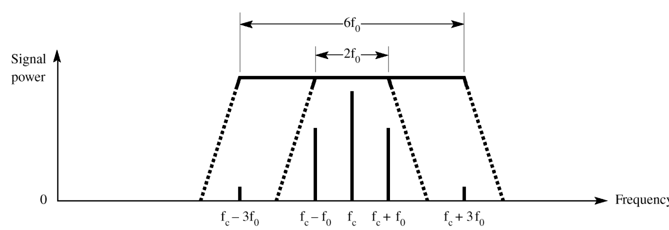
Amplitude Shift Keying



Hal96 fig 2.18

Amplitude Shift Keying

- Amplitude Modulation
  - carrier frequency
  - signal to be modulated
  - spectrum



Hal96 fig 2.18

How does ASK work?

$$v_c(t) = \cos\omega_c t$$

$$v_d(t) = \frac{1}{2} + \frac{2}{\pi}\{\cos\omega_0 t - \frac{1}{3}\cos 3\omega_0 t + \frac{1}{5}\cos 5\omega_0 t - \ldots\}$$

$$v_{ASK}(t) = v_c(t) \cdot v_d(t)$$

$$= \frac{1}{2}\cos\omega_c t + \frac{2}{\pi}\{\cos\omega_c t \cdot \cos\omega_0 t - \frac{1}{3}\cos\omega_c t \cdot \cos 3\omega_0 t + \ldots\}$$

Now, we know that

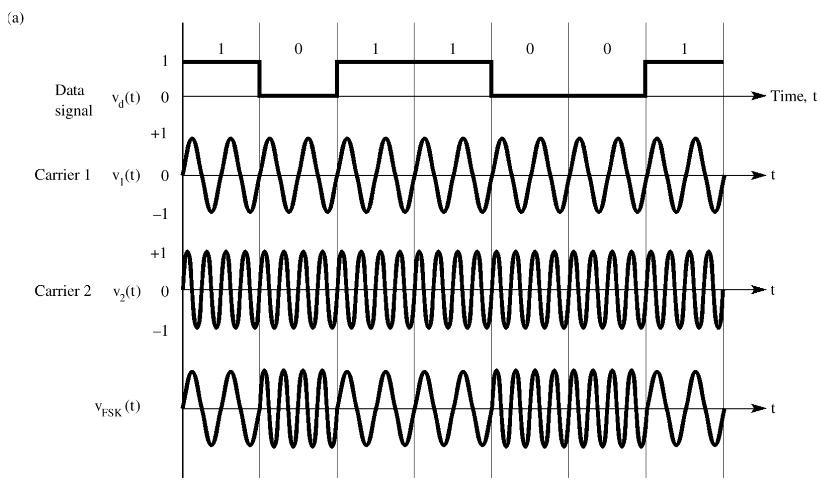
$$2\cos A \cos B = \cos(A - B) + \cos(A + B)$$

Therefore we have: $v_{ASK}(t) = \frac{1}{2}\cos\omega_c t$

$$+\frac{1}{\pi}\{\cos(\omega_c - \omega_0)t + \cos(\omega_c + \omega_0)t$$

$$-\frac{1}{3}[\cos(\omega_c - 3\omega_0)t + \cos(\omega_c + 3\omega_0)t] + \ldots\}$$

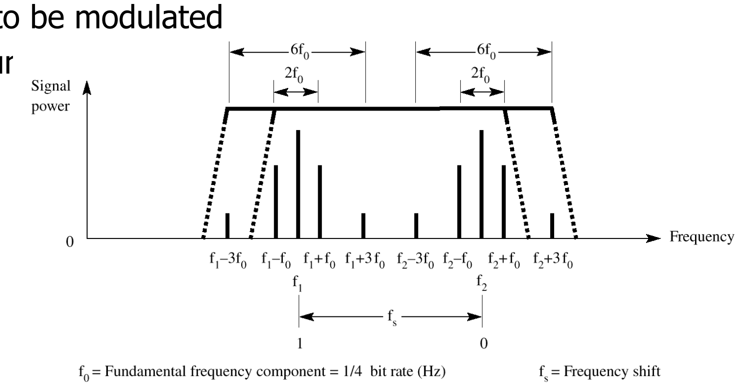
Frequency Shift Keying



Hal96 fig 2.19

Frequency Shift Keying

- Frequency Modulation
  - —different carrier frequencies
  - —signal to be modulated
  - —spectrur



Hal96 fig 2.19

How does FSK work?

$$v_{FSK}(t) = \cos\omega_1 t \cdot v_d(t) + \cos\omega_2 t \cdot v_{d'}(t)$$

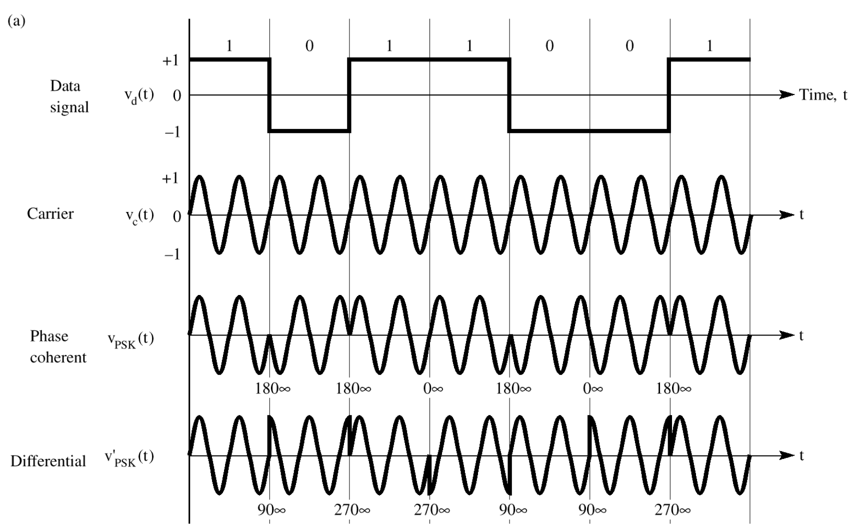
The two carriers are ω_1 and ω_2 and $v_{d'}(t) = 1 - v_d(t)$

$$v_{FSK}(t) = \cos\omega_1 t\{\frac{1}{2} + \frac{2}{\pi}(\cos\omega_0 t - \frac{1}{3}\cos 3\omega_0 t + ...)\}$$
$$+\cos\omega_2 t\{\frac{1}{2} - \frac{2}{\pi}(\cos\omega_0 t - \frac{1}{3}\cos 3\omega_0 t + ...)\}$$

Therefore we have:

$$v_{FSK}(t) = \frac{1}{2}\cos\omega_1 t + \frac{1}{\pi}\{\cos(\omega_1 - \omega_0)t + \cos(\omega_1 + \omega_0)t$$
$$-\frac{1}{3}\cos(\omega_1 - 3\omega_0)t + \cos(\omega_1 + 3\omega_0)t + ...\}$$
$$+\frac{1}{2}\cos\omega_2 t + \frac{1}{\pi}\{\cos(\omega_2 - \omega_0)t + \cos(\omega_2 + \omega_0)t$$
$$-\frac{1}{3}\cos(\omega_2 - 3\omega_0)t + \cos(\omega_2 + 3\omega_0)t + ...\}$$

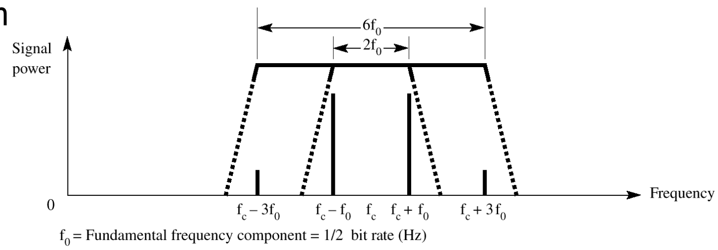
Phase Shift Keying



Hal96 fig 2.21

Phase Shift Keying

- Phase Modulation
  - —phase of carrier defines data
  - —two versions
    - phase coherent
    - differential
  - —spectrum



Hal96 fig 2.21

How does PSK work?

Carrier and bipolar data signal

$$v_c(t) = \cos\omega_c t$$

$$v_d(t) = \frac{4}{\pi}\{\cos\omega_0 t - \frac{1}{3}\cos 3\omega_0 t + \frac{1}{5}\cos 5\omega_0 t - ...\}$$

$$v_{PSK}(t) = v_c(t) \cdot v_d(t)$$

$$= \frac{4}{\pi}\{\cos\omega_c t \cdot \cos\omega_0 t - \frac{1}{3}\cos\omega_c t \cdot \cos 3\omega_0 t + ...\}$$

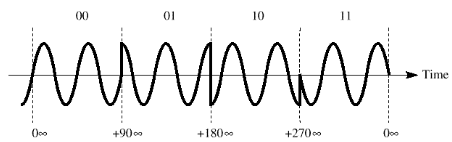
With the usual simplification $2\cos A\cos B = \cos(A-B) + \cos(A+B)$ we get:

$$v_{PSK}(t) = \frac{1}{\pi}\{\cos(\omega_c - \omega_0)t + \cos(\omega_c + \omega_0)t$$

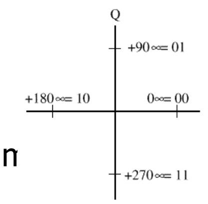
$$-\frac{1}{3}\cos(\omega_c - 3\omega_0)t + \cos(\omega_c + 3\omega_0)t + ...\}$$

Phase Shift Keying

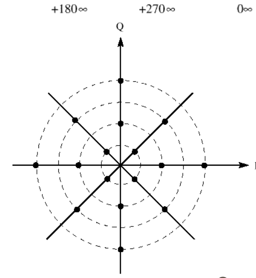
- Multilevel Phase Modulation Methods
  - —use multiple phases
  - —e.g. 4-PSK or quadrature phase shift keying QPSK
    - (0°,90°,180°,270°)
  - —4-PSK phase-time diagram



  - —4-PSK phase diagram



  - —16-QAM phase diagram

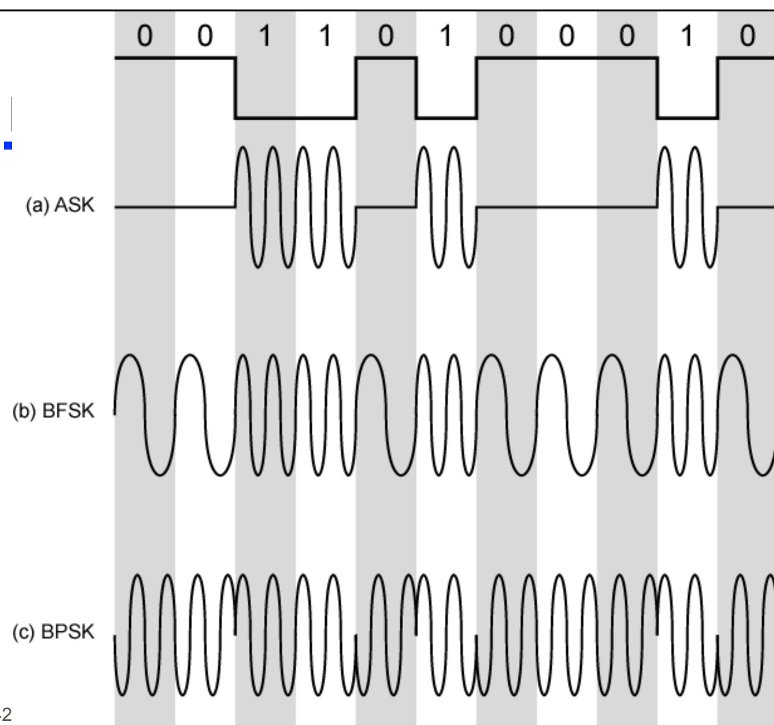


Spread Spectrum

- Spread spectrum digital communication systems
  - —developed initially for military
    - spread the signal to make it hard to jam
    - became known as "frequency-hopping"
    - switches through a pseudo random sequence of frequency assignments

Data Signaling

- Transmitting on Analog Lines
  - —If we use existing telephone lines (PSTN) we have to consider that they were created for voice with effective bandwidth from 300Hz to 3400Hz or total of 3000Hz.
  - —We have to concern ourselves with two forms of data.
    - Analog data
    - Digital data



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

Binary Frequency Shift Keying

- Most common form FSK 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

Multiple FSK

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

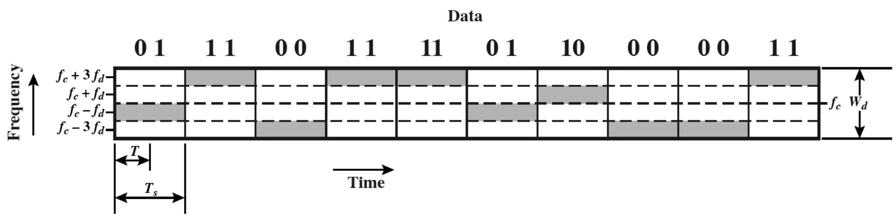


Figure 5.9 MFSK Frequency Use (M = 4)

FSK on Voice Grade Line

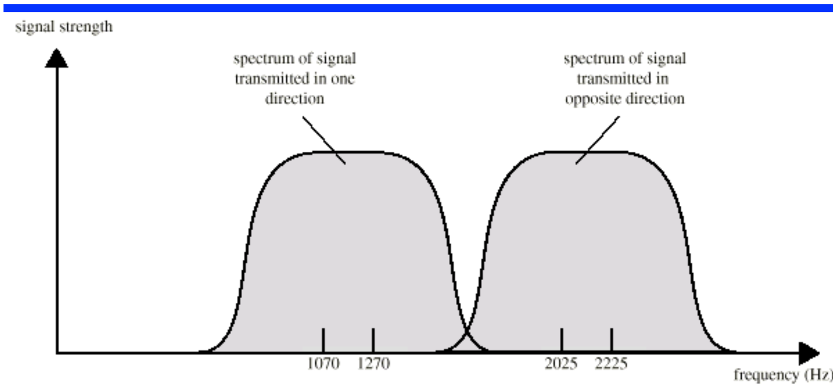
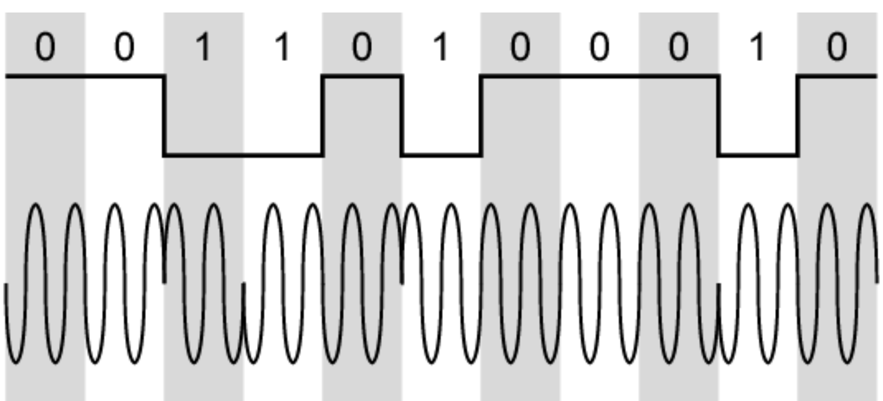


Figure 5.8 Full-Duplex FSK Transmission on a Voice-Grade Line

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

Binary PSK



Quadrature (four-level) PSK

- More efficient use by each signal element representing more than one bit
  - —e.g. shifts of π/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 (OQPSK)
  - —also called "orthogonal QPSK"
  - —Delay in Q stream

Example QPSK

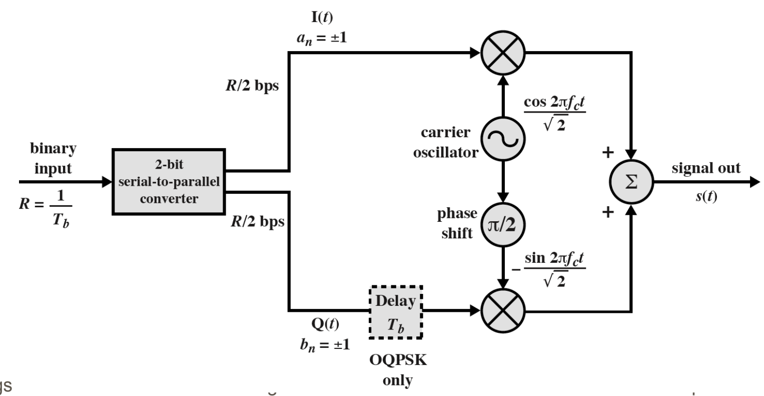
- signals

11	$s(t) = A\cos(2\pi f_c t + \frac{\pi}{4})$
01	$s(t) = A\cos(2\pi f_c t + \frac{3\pi}{4})$
00	$s(t) = A\cos(2\pi f_c t - \frac{3\pi}{4})$
10	$s(t) = A\cos(2\pi f_c t - \frac{\pi}{4})$

QPSK and OQPSK Modulators

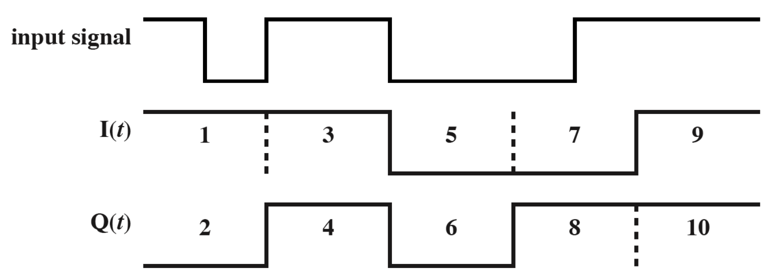
QPSK signal: $s(t) = \frac{1}{\sqrt{2}} I(t)\cos 2\pi f_c t - \frac{1}{\sqrt{2}} Q(t)\sin 2\pi f_c t$

binary 1 and 0



Examples of QPSF Waveforms

bit number	1	2	3	4	5	6	7	8	9	10
value	1	–1	1	1	–1	–1	–1	1	1	1
	I	Q	I	Q	I	Q	I	Q	I	Q



phase of output signal	–π/4	π/4	–3π/4	3π/4	π/4

Performance of Digital to Analog Modulation Schemes

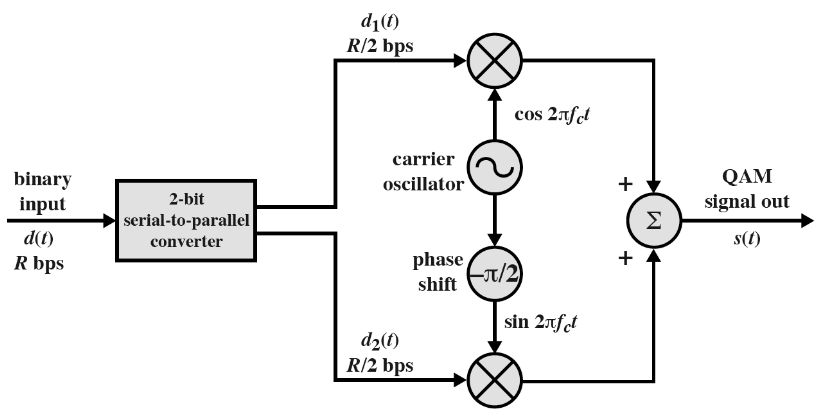
- Bandwidth
  - —ASK and PSK bandwidth directly related to bit rate
  - —FSK bandwidth is larger. Why?
  - —Note the difference in the derivation of the math in Stallings compare to the previous arguments based on the spectrum.
- In the presence of noise, bit error rate of PSK and QPSK are about 3dB superior to ASK and FSK

Quadrature Amplitude Modulation

- QAM used on asymmetric digital subscriber line (ADSL) and some wireless
- Combination of ASK and PSK
- 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
    - binary 0 = absence of signal, binary 1 = carrier
    - same holds for path that uses the shifted carrier
  - —Demodulate and combine for original binary output

QAM Modulator

QAM signal: $s(t) = d_1(t)\cos 2\pi f_c t + d_2(t)\sin 2\pi f_c t$



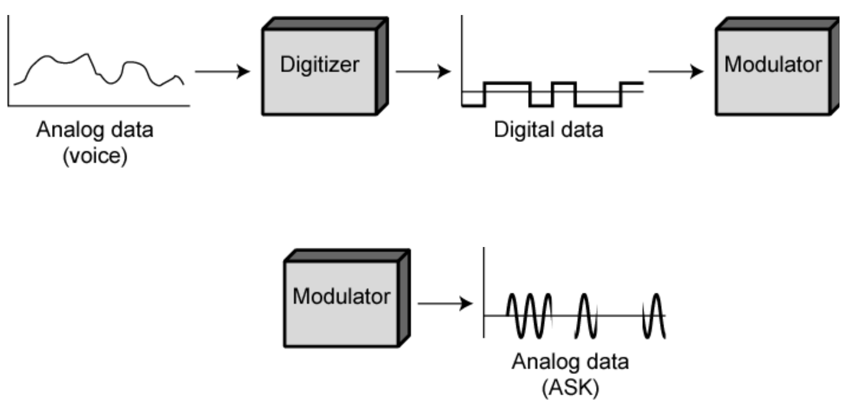
QAM Levels

- Two level ASK
  - —Each of two streams in one of two states
  - —Four state system
- Essentially this is a 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

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

Digitizing Analog Data



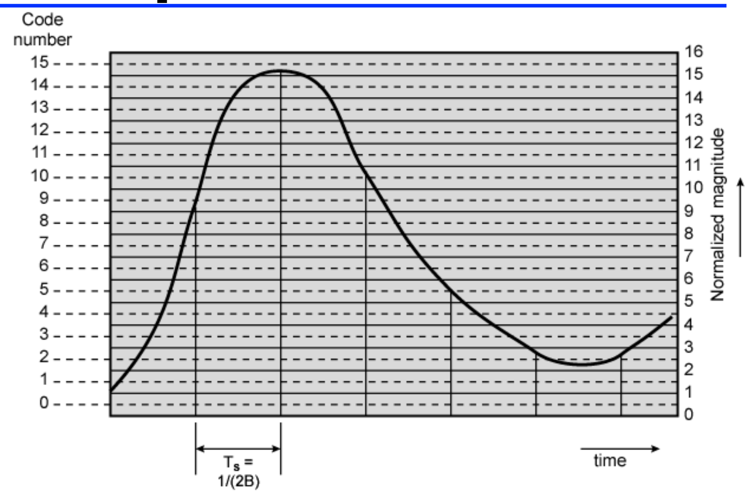
Sampling theorem

- 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
  - —in short: sample with rate more than twice the highest signal frequency
  - —e.g. Voice data limited to below 4000Hz, thus, require 8000 sample per second
  - —the samples are analog samples
    - think of a slice of the signal
  - —the signal can be reconstructed from the samples using a lowpass filter

PAM and PCM

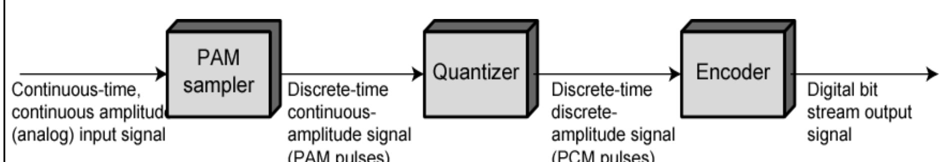
- Pulse Amplitude Modulation (PAM)
  - —"get slices of analog signals"
- Pulse Code Modulation (PCM)
  - —"assign digital code to the analog slice"
  - —n bits give 2^n levels, e.g. 4 bit give 16 levels
- Quantizing error
  - —error depends on granularity of encoding
  - —it is impossible to recover original exactly
- Example
  - —8000 samples per second of 8 bits each gives 64kbps

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

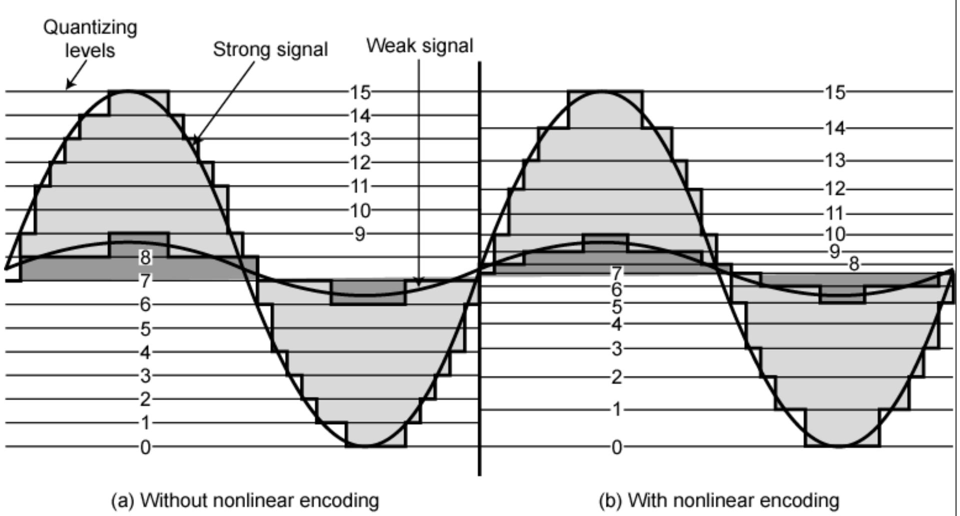
PCM Block Diagram



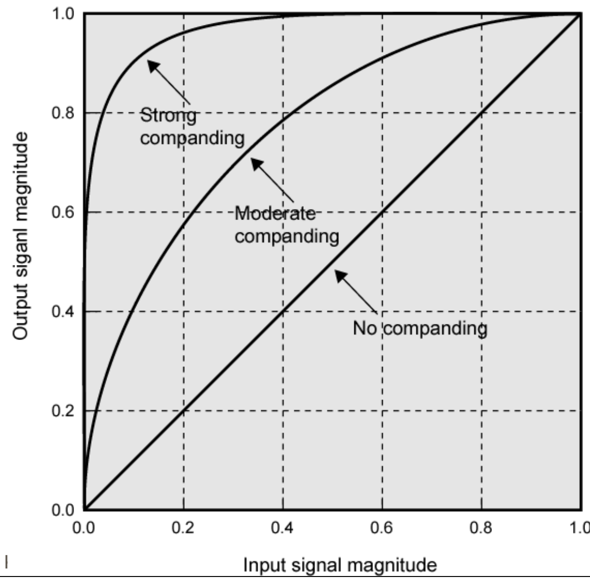
Nonlinear Encoding

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

Effect of Non-Linear Coding



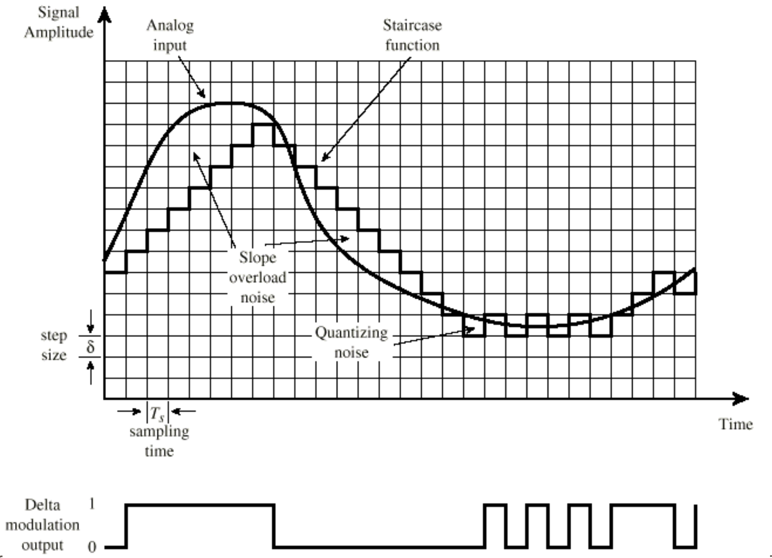
Typical Companding Functions



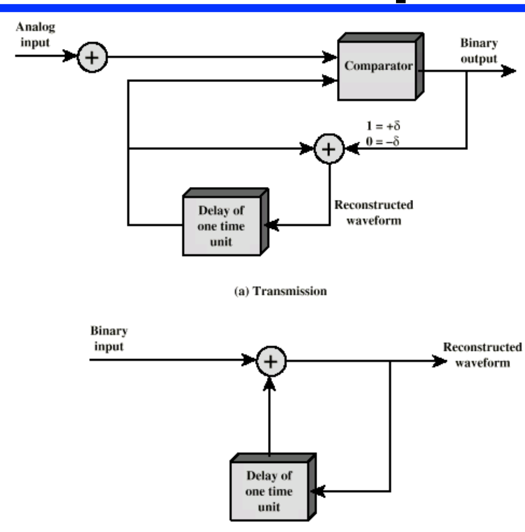
Delta Modulation

- 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

Delta Modulation - example



Delta Modulation - Operation



(a) Transmission

(b) Reception

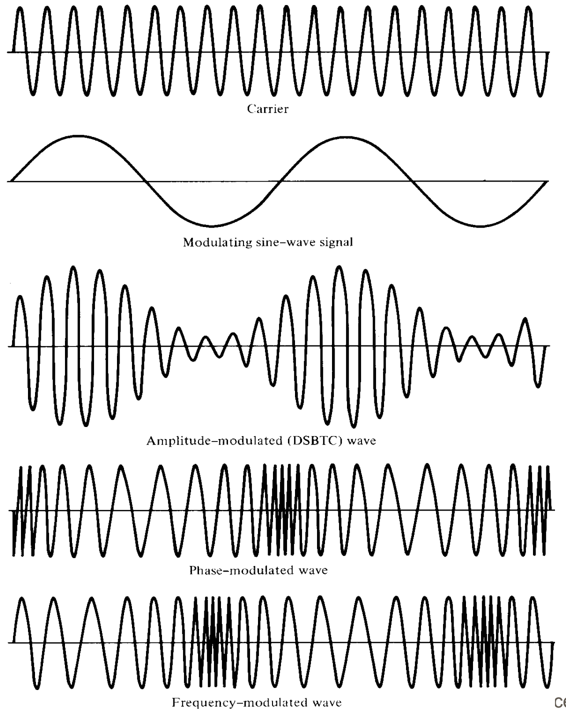
Delta Modulation - Performance

- 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

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

Analog Modulation



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Summary

- looked at signal encoding techniques
  - —digital data, digital signal
  - —analog data, digital signal
  - —digital data, analog signal
  - —analog data, analog signal