Data and Computer Communications

Chapter 5 – Signal Encoding Techniques

Eighth Edition

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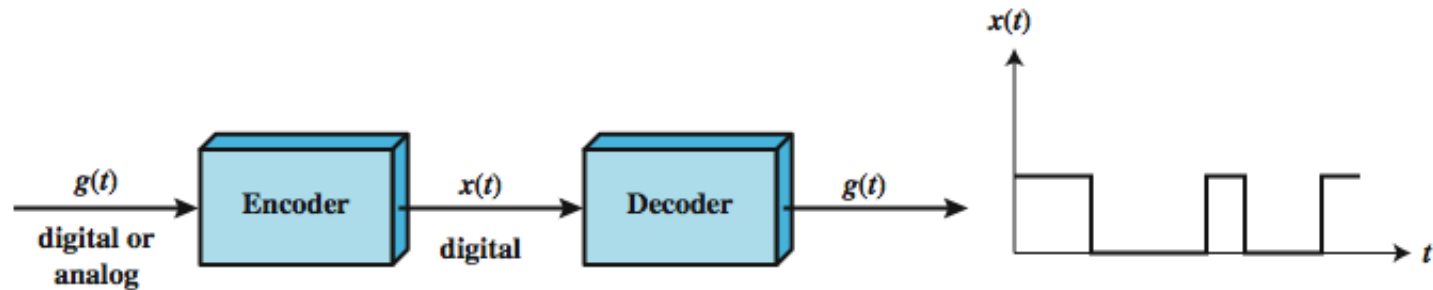
Signal Encoding Techniques

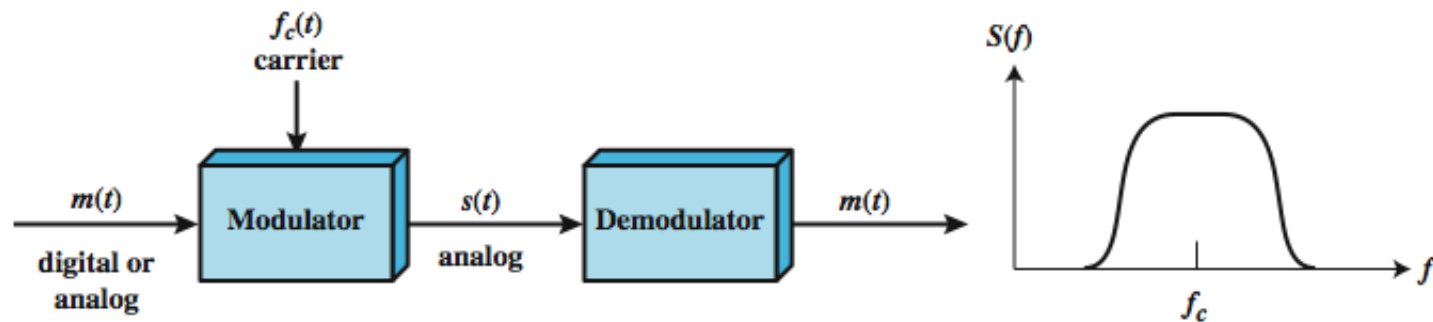*Even the natives have difficulty mastering this peculiar vocabulary*

    —The Golden Bough, Sir James George Frazer

Signal Encoding Techniques
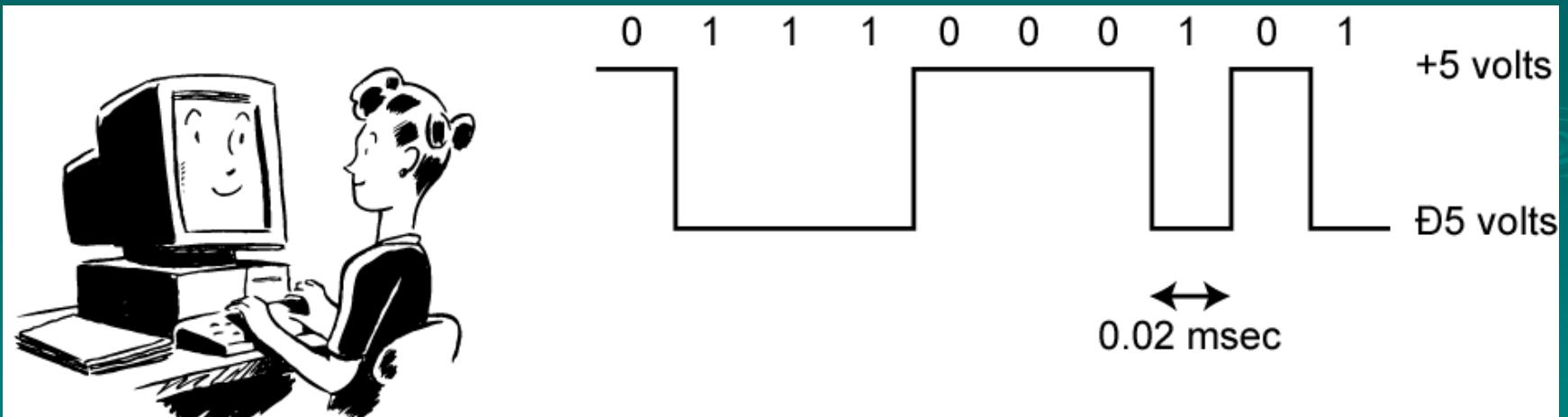

(a) Encoding onto a digital signal

(b) Modulation onto an analog signal

Figure 5.1 Encoding and Modulation Techniques

Digital Data, Digital Signal

➢ Digital signal
  - discrete, discontinuous voltage pulses
  - each pulse is a signal element
  - binary data encoded into signal elements

Some Terms

➢ unipolar

➢ polar

➢ data rate

➢ duration or length of a bit

➢ modulation rate

➢ mark and space

Interpreting Signals

➢ need to know
- timing of bits - when they start and end
- signal levels

➢ factors affecting signal interpretation
- signal to noise ratio
- data rate
- bandwidth
- encoding scheme

Comparison of Encoding Schemes

- signal spectrum
- clocking
- error detection
- signal interference and noise immunity
- cost and complexity

Encoding Schemes
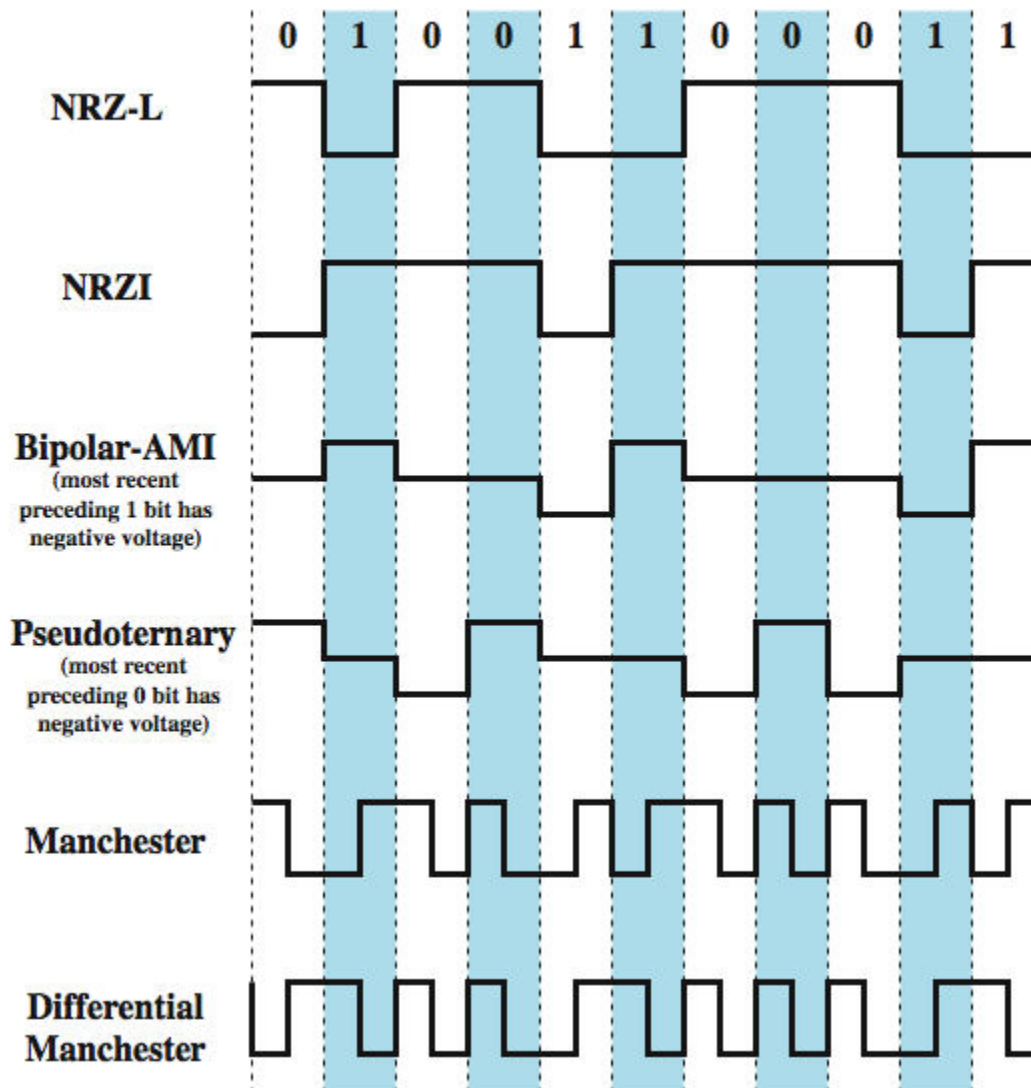
Nonreturn to Zero-Level (NRZ-L)

➢ two different voltages for 0 and 1 bits

➢ voltage constant during bit interval

- no transition I.e. no return to zero voltage

- such as absence of voltage for zero, constant positive voltage for one

- more often, negative voltage for one value and positive for the other

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 binary 1
- no transition denotes binary 0

➢ example of differential encoding since have

- data represented by changes rather than levels
- more reliable detection of transition rather than level
- easy to lose sense of polarity

NRZ Pros & 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 Bipolar-AMI

➢ 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
- long runs of zeros still a problem
- no net dc component
- lower bandwidth
- easy error detection

Multilevel Binary Pseudoternary

➢ one represented by absence of line signal

➢ zero represented by alternating positive and negative

➢ no advantage or disadvantage over bipolar-AMI

➢ each used in some applications

Multilevel Binary Issues

- synchronization with long runs of 0's or 1's
  - can insert additional bits, cf ISDN
  - scramble data (later)
- not as efficient as NRZ
  - each signal element only represents one bit
    - receiver distinguishes between three levels: +A, -A, 0
  - a 3 level system could represent $\log_2 3 = 1.58$ bits
  - requires approx. 3dB more signal power for same probability of bit error

Manchester Encoding

- ➤ has 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.

Manchester Encoding
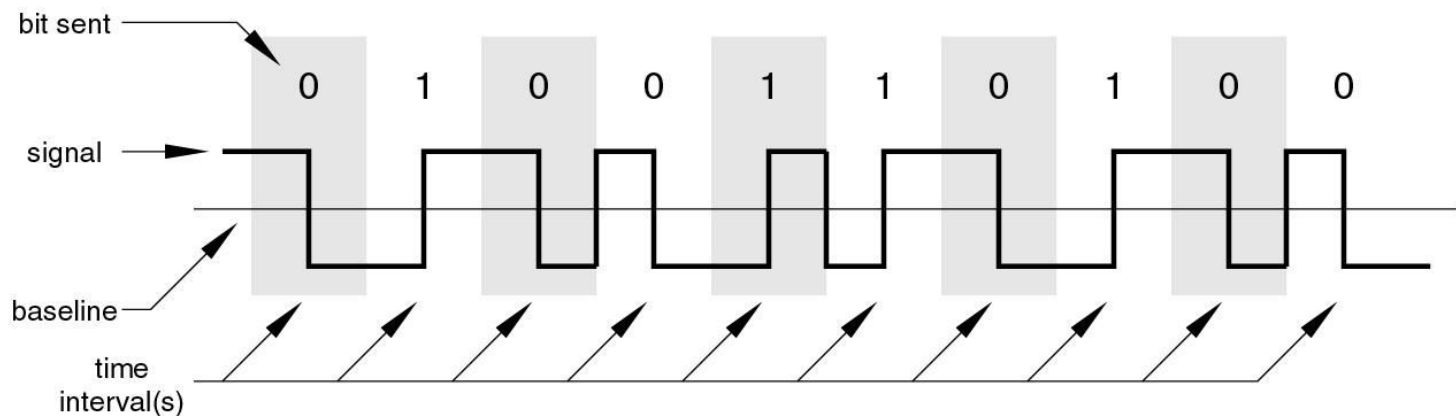
Differential Manchester Encoding

➢ midbit transition is clocking only

➢ transition at start of bit period representing 0

➢ no transition at start of bit period representing 1

  ● this is a differential encoding scheme

➢ used by IEEE 802.5

Differential Manchester Encoding

bit sent — 0 1 0 0 1 1 0 1 0 0

signal →

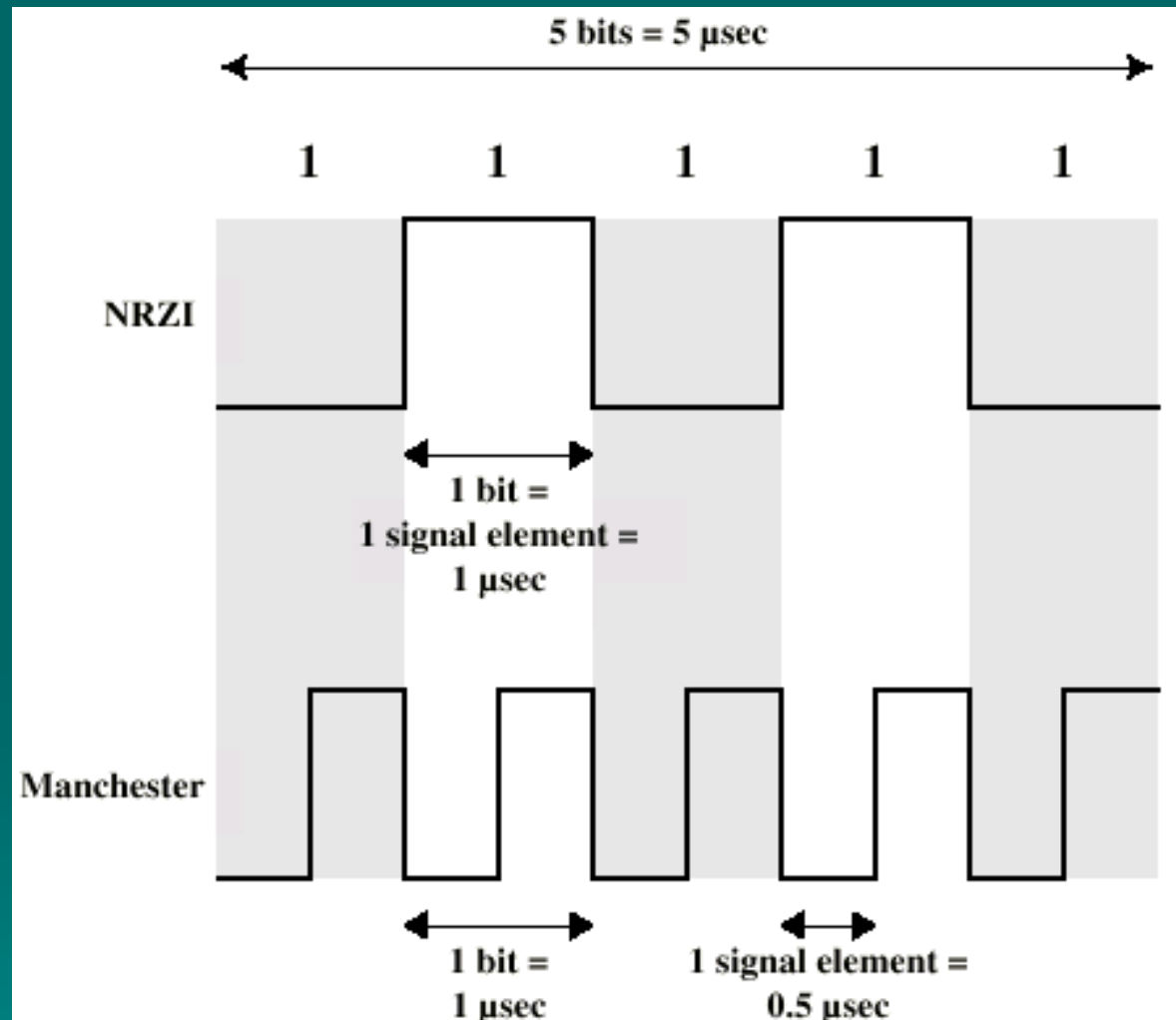baseline
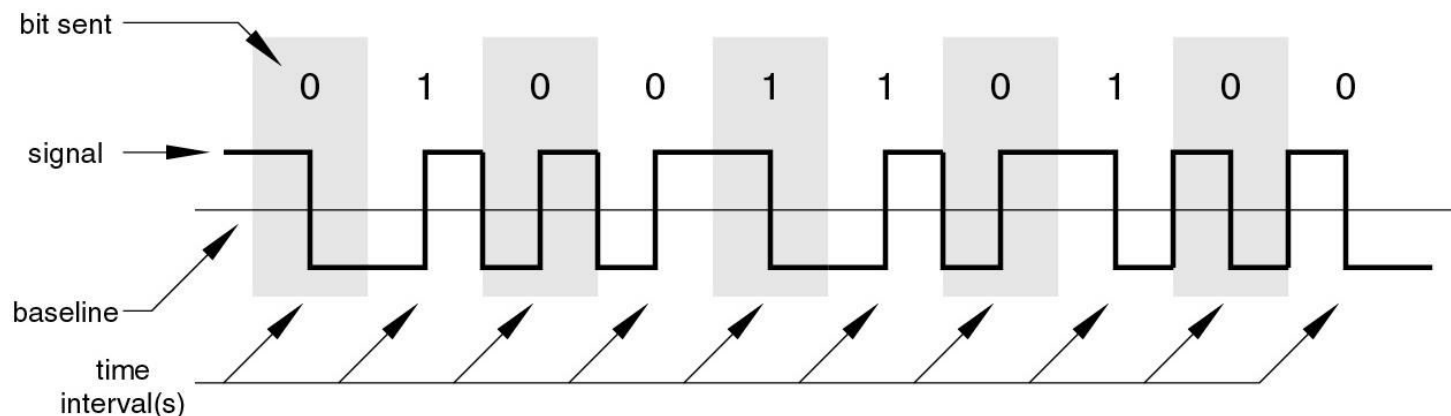
time
interval(s)

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)
  - has no dc component
  - has error detection

Modulation Rate

(Modulation Rate) / (Data Rate)

Table 5.3 Normalized Signal Transition Rate of Various Digital Signal Encoding Schemes

	Minimum	101010. . .	Maximum
NRZ-L	0 (all 0s or 1s)	1.0	1.0
NRZI	0 (all 0s)	0.5	1.0 (all 1s)
Bipolar-AMI	0 (all 0s)	1.0	1.0
Pseudoternary	0 (all 1s)	1.0	1.0
Manchester	1.0 (1010 . . .)	1.0	2.0 (all 0s or 1s)
Differential Manchester	1.0 (all 1s)	1.5	2.0 (all 0s)

Scrambling

- use scrambling to replace sequences that would produce constant voltage
- these filling sequences must
  - produce enough transitions to sync
  - be recognized by receiver & replaced with original
  - be same length as original
- design goals
  - have no dc component
  - have no long sequences of zero level line signal
  - have no reduction in data rate
  - give error detection capability

B8ZS and HDB3

B = Valid bipolar signal
V = Bipolar violation

Violation within the substituted code
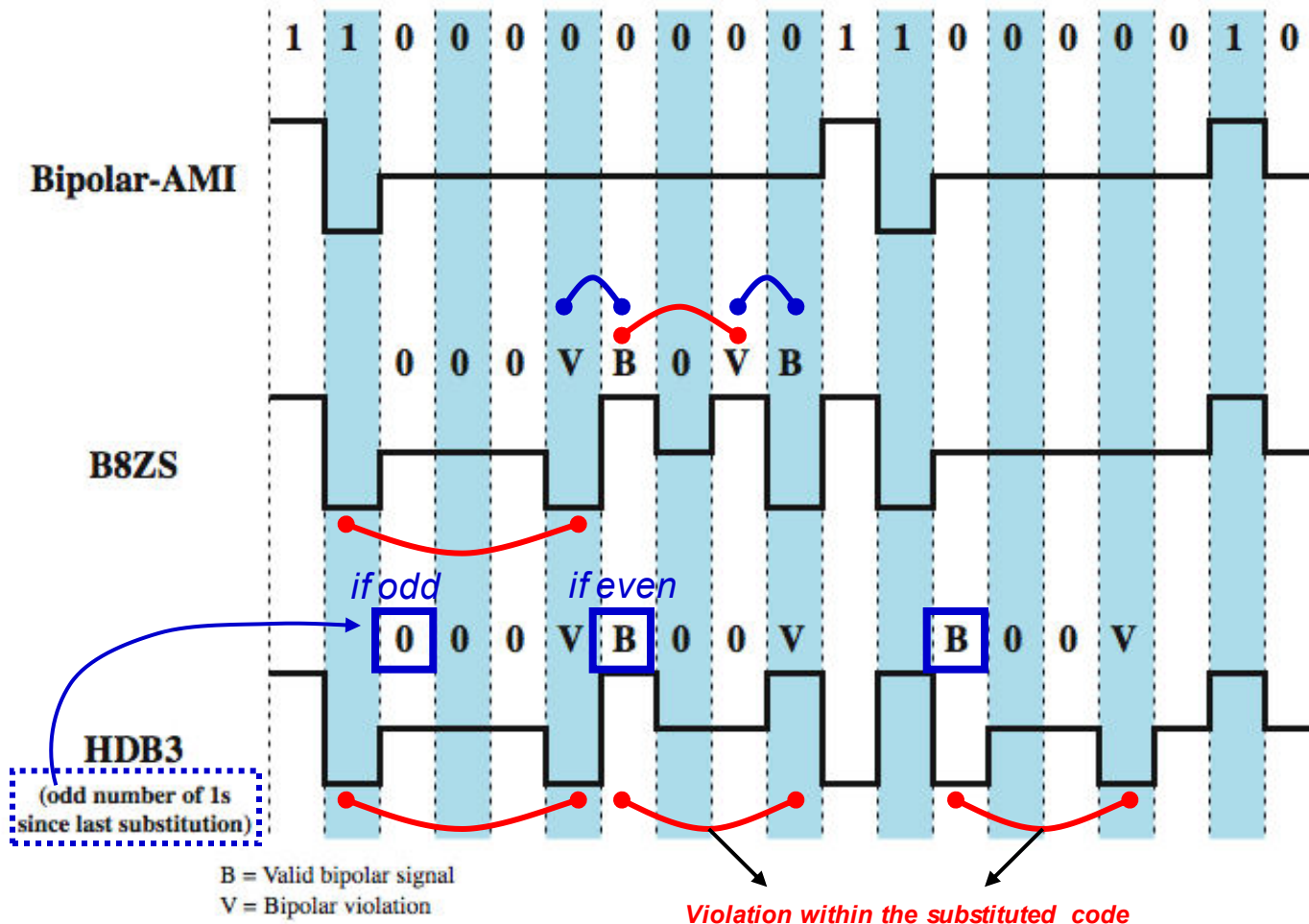
B8ZS: Bipolar with 8-zeros substitution

➤ if an octet of all zeros occurs and the last voltage pulse preceding this octet was positive, then the eight zeros of the octet

are encoded as 000+-0-+

➤ if an octet of all zeros occurs and the last voltage pulse preceding this octet was negative, then the eight zeros of the octet

are encoded as 000-+0+-

HDB3: High-density bipolar-3 zeros

Table 5.4   HDB3 Substitution Rules

Polarity of Preceding Pulse	Number of Bipolar Pulses (ones) since Last Substitution	
	Odd	Even
-	000-	+00+
+	000+	-00-

Check if you know why DC is still zero!

Digital Data, Analog Signal

- main use is public telephone system
  - has freq range of 300Hz to 3400Hz
  - use modem (modulator-demodulator)
- encoding techniques
  - Amplitude shift keying (ASK)
  - Frequency shift keying (FSK)
  - Phase shift keying (PK)

Modulation Techniques
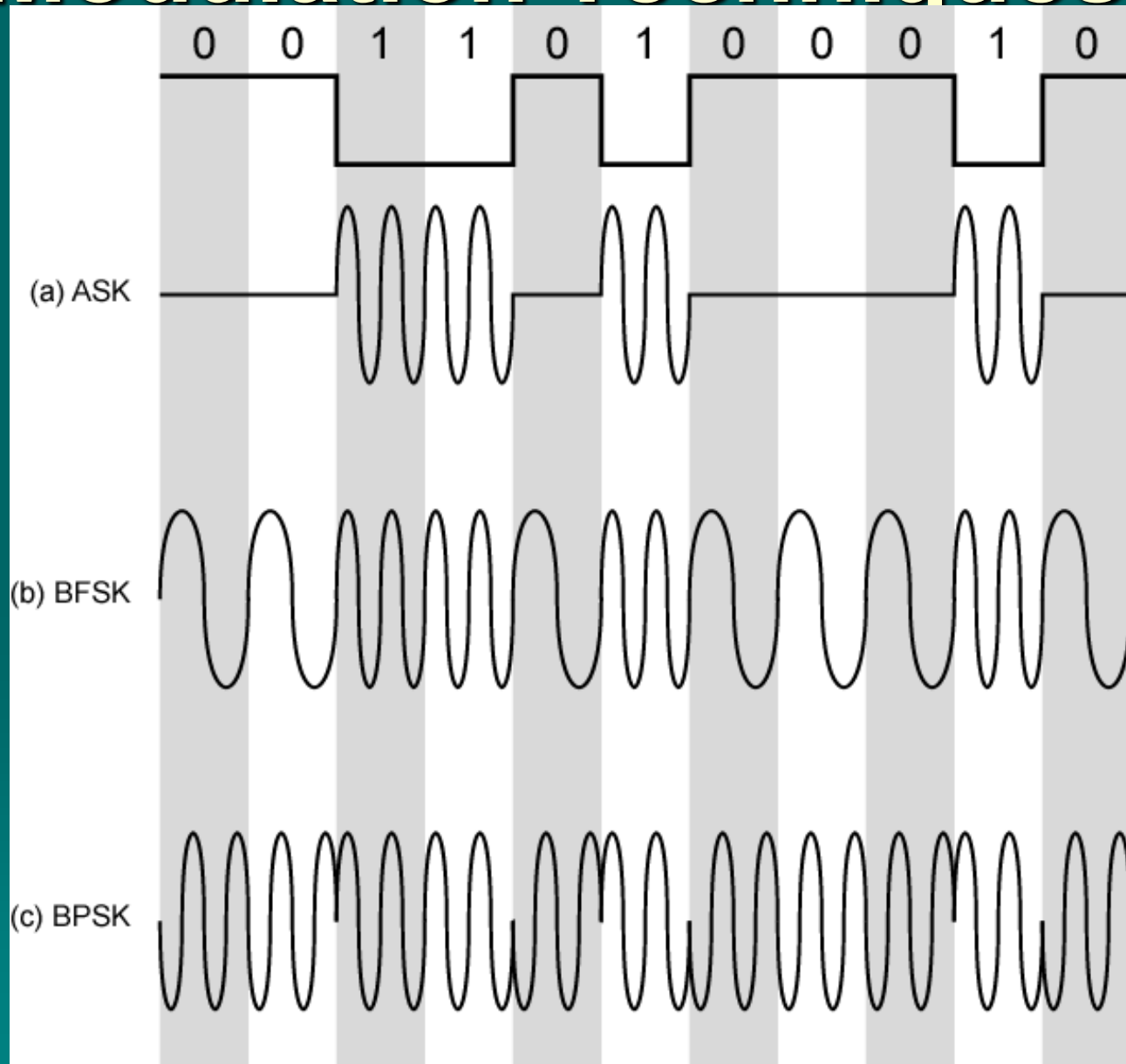
Amplitude Shift Keying

➢ encode 0/1 by different carrier amplitudes
  • usually have one amplitude zero
➢ susceptible to sudden gain changes
➢ inefficient
➢ used for

  • up to 1200bps on voice grade lines
  • very high speeds over optical fiber

(a) ASK
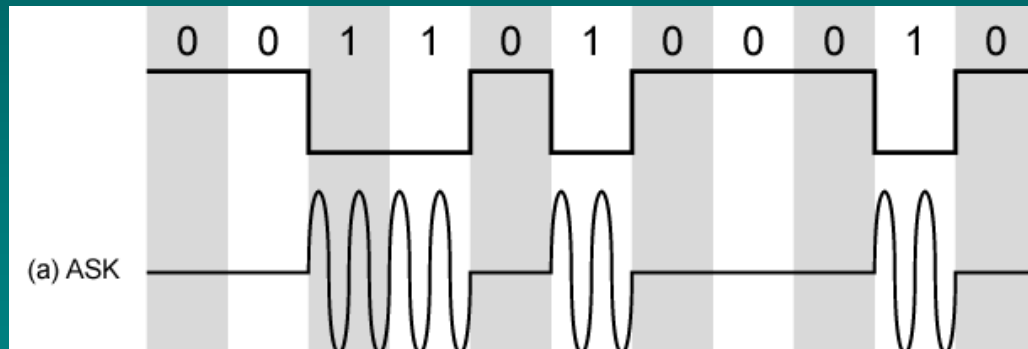
Binary Frequency Shift Keying

➢ most common is binary FSK (BFSK)
➢ two binary values represented by two different frequencies (near carrier)
➢ less susceptible to error than ASK
➢ used for
   ● up to 1200bps on voice grade lines
   ● high frequency radio
   ● even higher frequency on LANs using co-ax

(b) BFSK
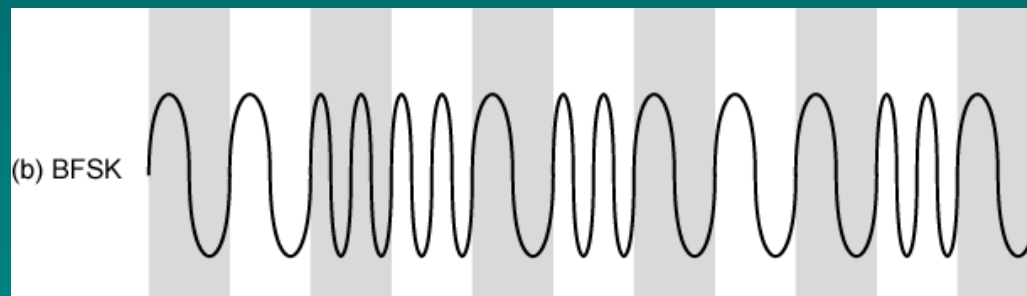
Multiple FSK

➢ each signalling element represents more than one bit

➢ more than two frequencies used

➢ more bandwidth efficient

➢ more prone to error

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

(c) BPSK
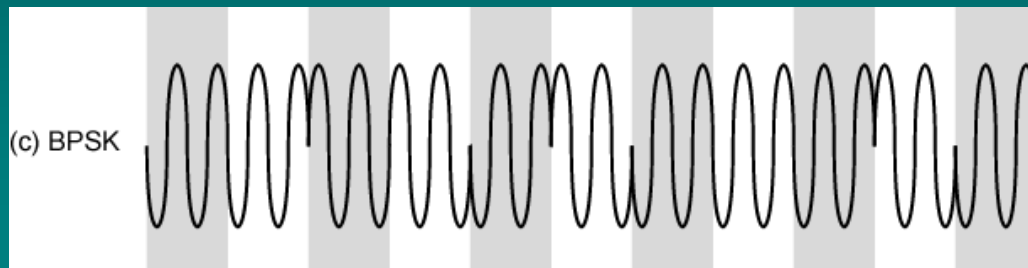
Quadrature PSK

➤ get more efficient use if each signal element represents more than one bit
  - eg. shifts of $\pi/2$ (90°)
  - each element represents two bits
  - split input data stream in two & modulate onto carrier & phase shifted carrier

➤ can use 8 phase angles & more than one amplitude
  - 9600bps modem uses 12 angles, four of which have two amplitudes

QPSK and OQPSK Modulators
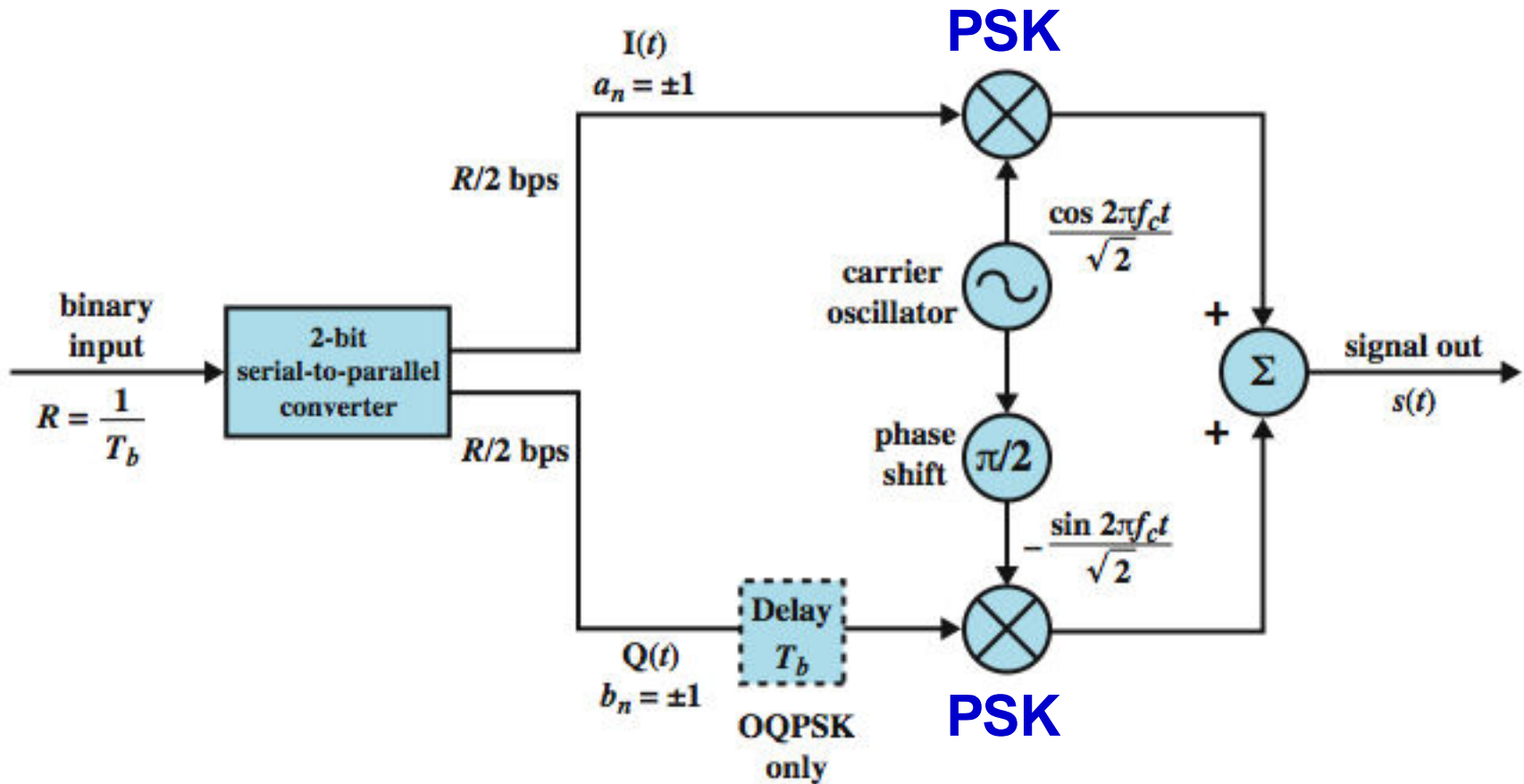
Performance of Digital to Analog Modulation Schemes

- ➤ bandwidth
  - ASK/PSK bandwidth directly relates to bit rate
  - multilevel PSK gives significant improvements
- ➤ in presence of noise:
  - bit error rate of PSK and QPSK are about 3dB superior to ASK and FSK
  - for MFSK & MPSK have tradeoff between bandwidth efficiency and error performance

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

QAM Modulator
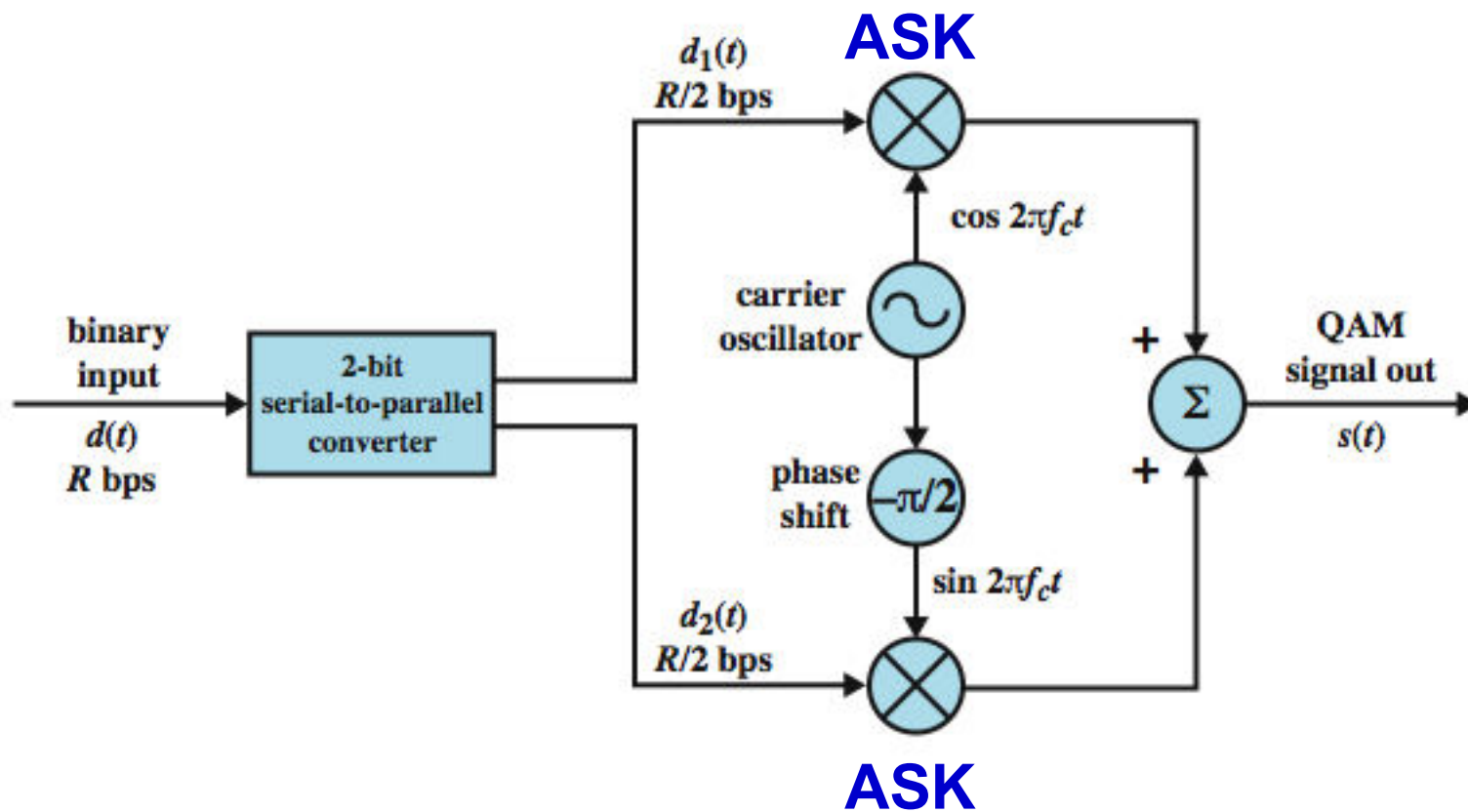
QAM Variants

- 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
- have 64 and 256 state systems
- improved data rate for given bandwidth
  - but increased potential error rate

Analog Data, Digital Signal

➤ digitization is conversion of analog data into digital data which can then:
  - be transmitted using NRZ-L
  - be transmitted using code other than NRZ-L
  - be converted to analog signal

➤ analog to digital conversion done using a codec
  - pulse code modulation
  - delta modulation

Digitizing Analog Data
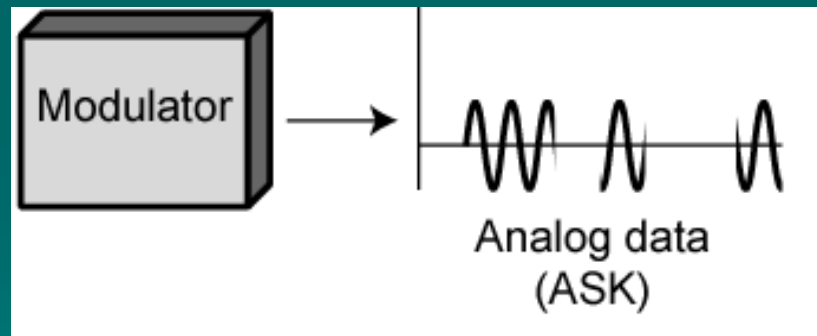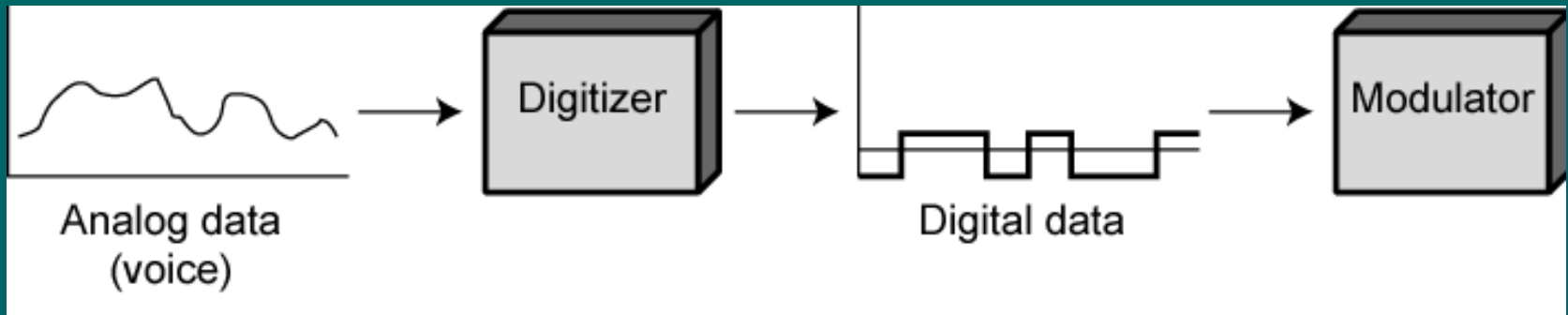
Pulse Code Modulation (PCM)

- sampling theorem:
  - "If a signal is sampled at regular intervals at a rate higher than twice the highest signal frequency, the samples contain all information in original signal"
  - eg. 4000Hz voice data, requires 8000 sample per sec
- strictly have analog samples
  - Pulse Amplitude Modulation (PAM)
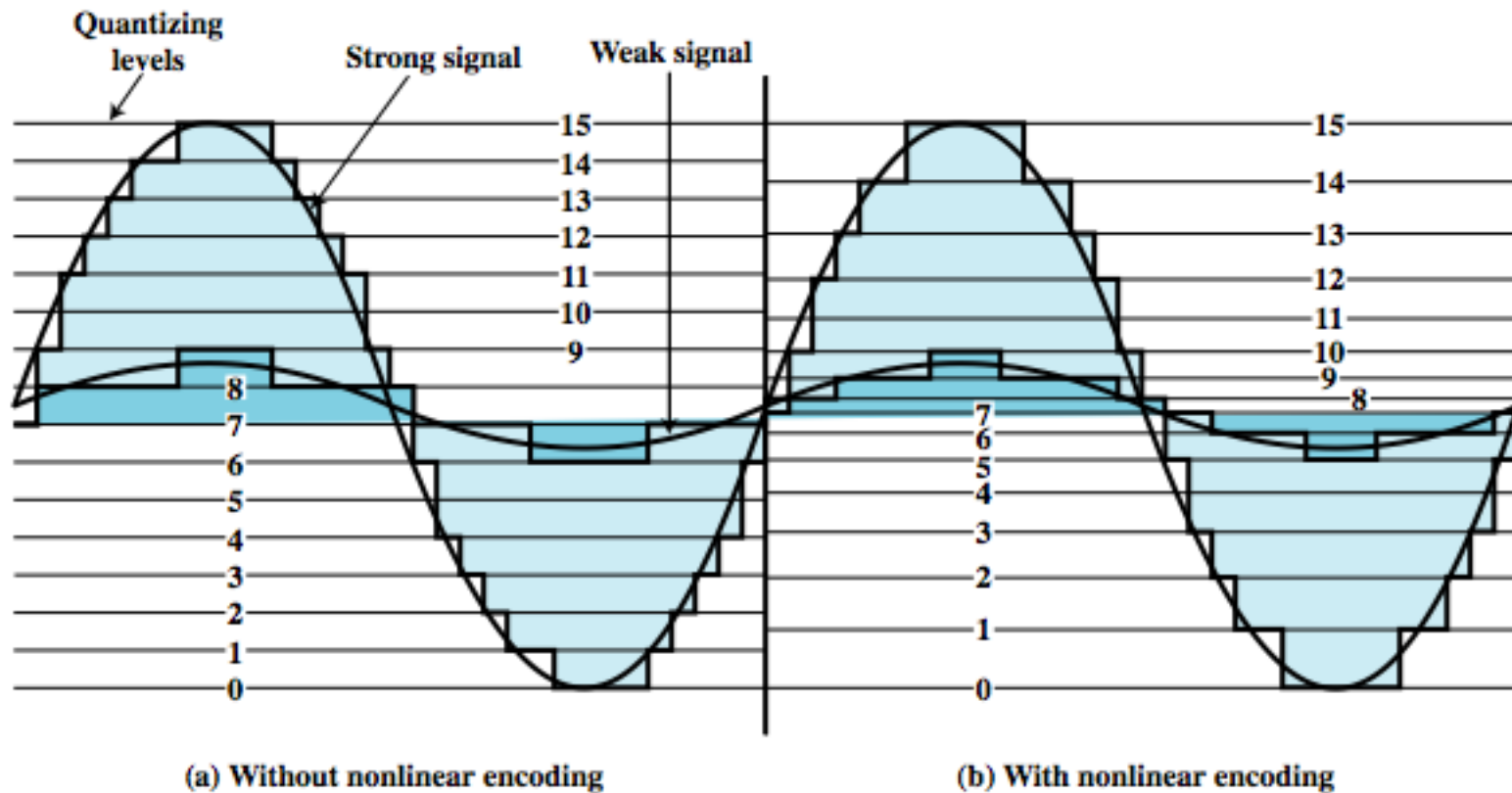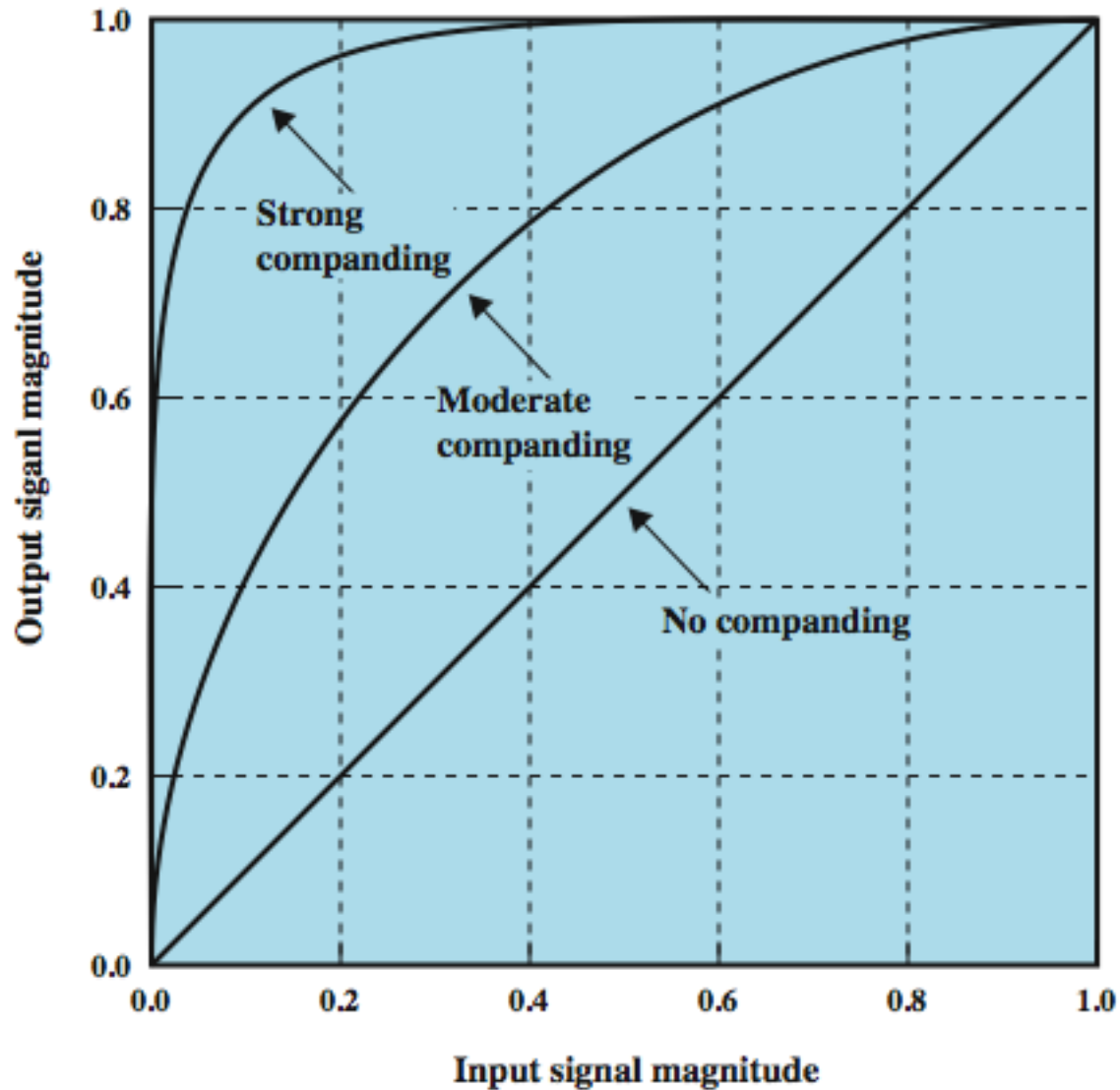- so assign each a digital value

PCM Example
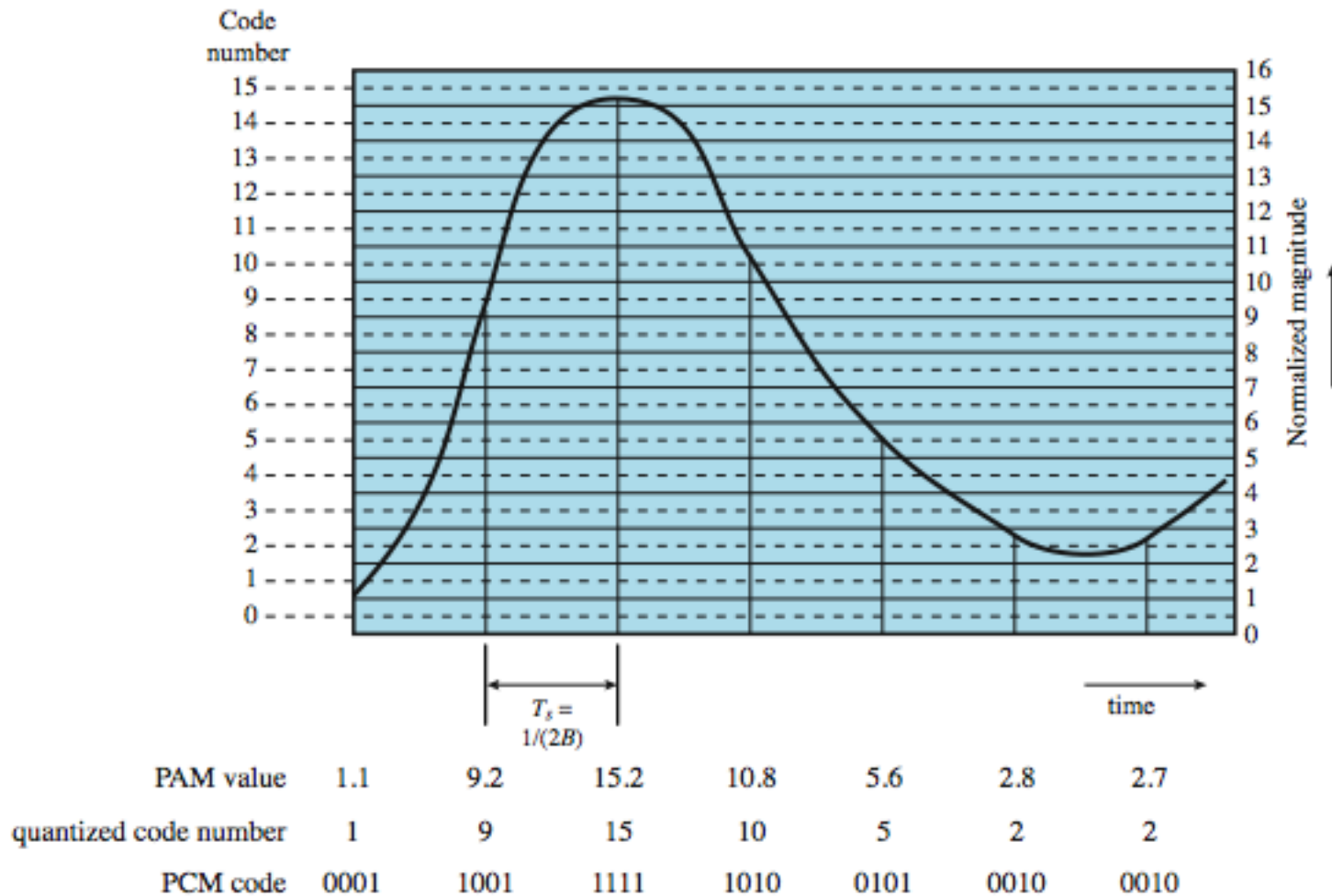
PCM Block Diagram

Non-Linear Coding

(a) Without nonlinear encoding
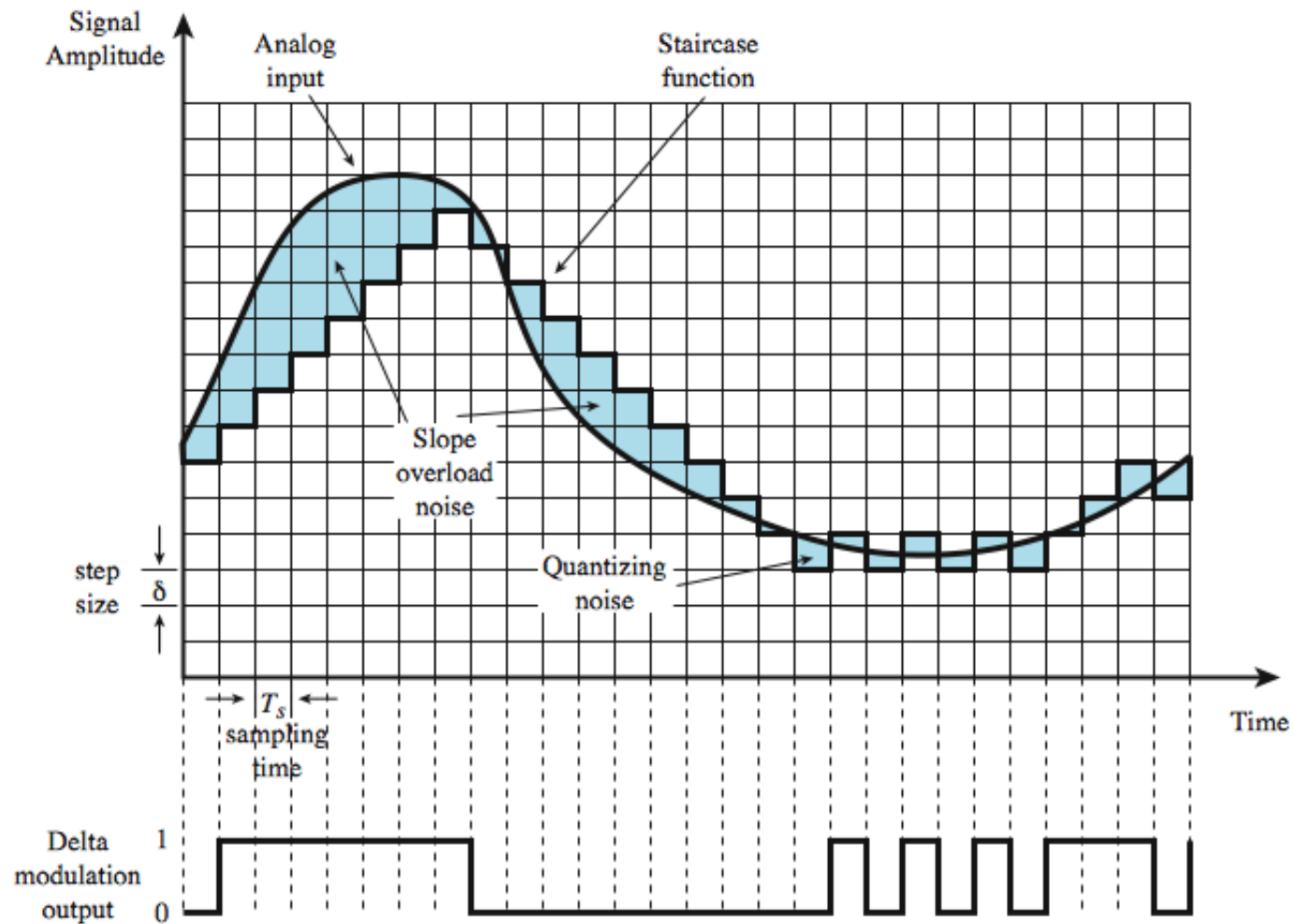
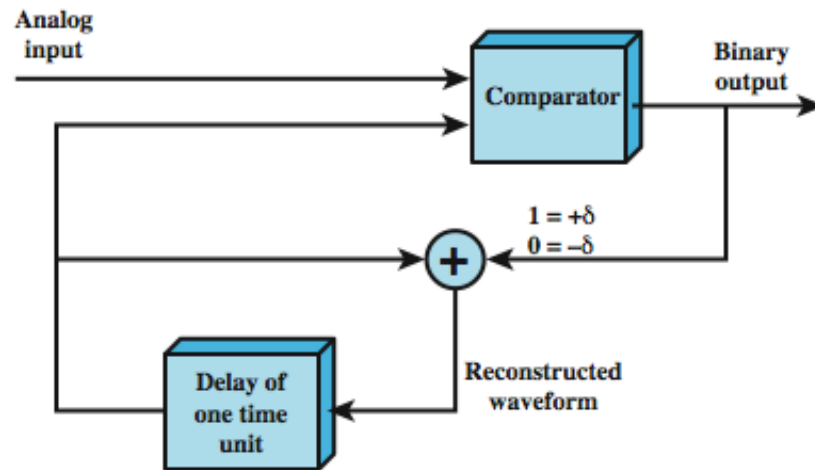(b) With nonlinear encoding
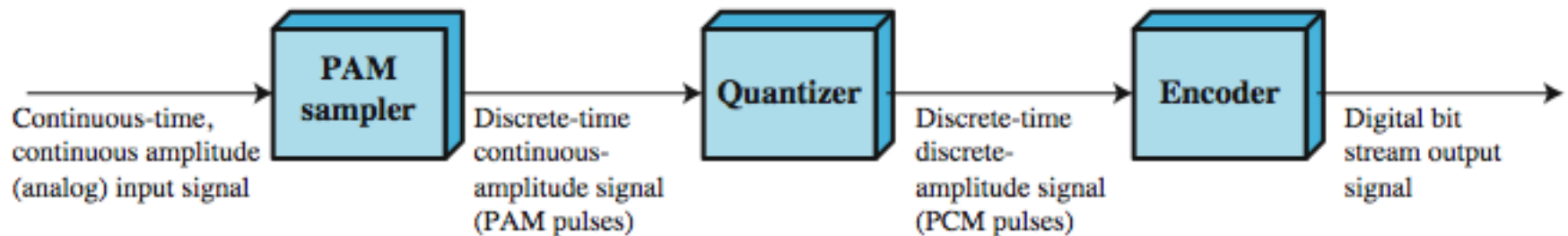
Companding

Delta Modulation

➢ analog input is approximated by a staircase function

- can move up or down one level (δ) at each sample interval

➢ has binary behavior

- since function only moves up or down at each sample interval

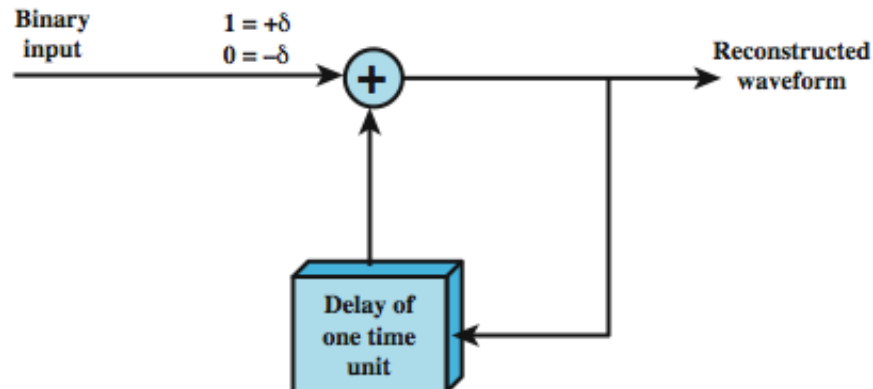- hence can encode each sample as single bit

- 1 for up or 0 for down

Delta Modulation Example

Delta Modulation Operation

(a) Transmission

(b) Reception

PCM verses Delta Modulation

- DM has simplicity compared to PCM
- but has worse SNR
- issue of bandwidth used
  - eg. for good voice reproduction with PCM
    - want 128 levels (7 bit) & voice bandwidth 4khz
    - need 8000 x 7 = 56kbps
- data compression can improve on this
- still growing demand for digital signals
  - use of repeaters, TDM, efficient switching
- PCM preferred to DM for analog signals

Analog Data, Analog Signals

➢ modulate carrier frequency with analog data

➢ 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 Techniques

- Amplitude Modulation
- Frequency Modulation
- Phase Modulation

Carrier

Modulating sine-wave signal

Amplitude-modulated (DSBTC) wave

Phase-modulated wave

Frequency-modulated wave
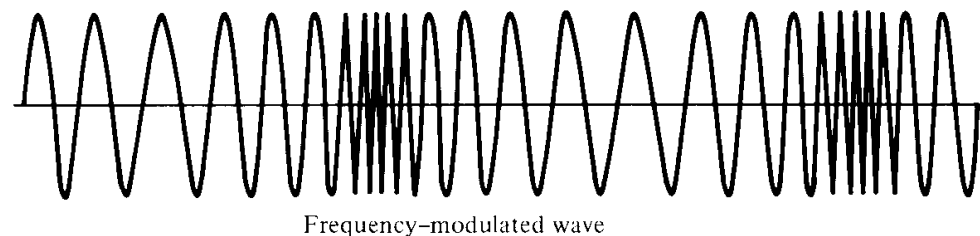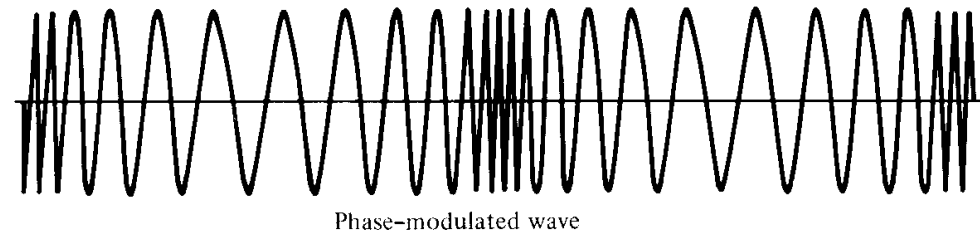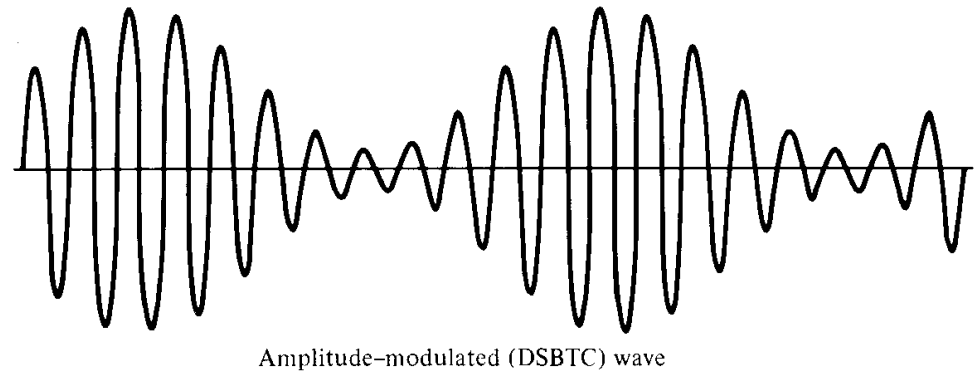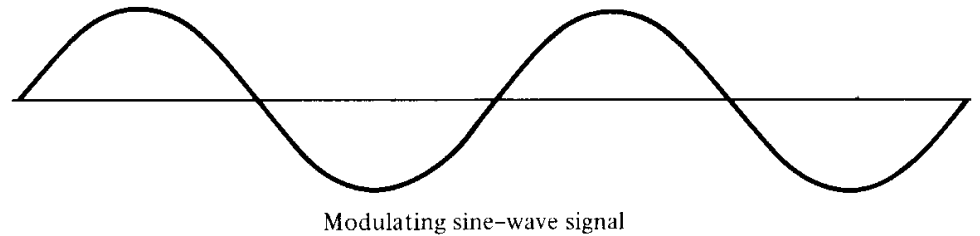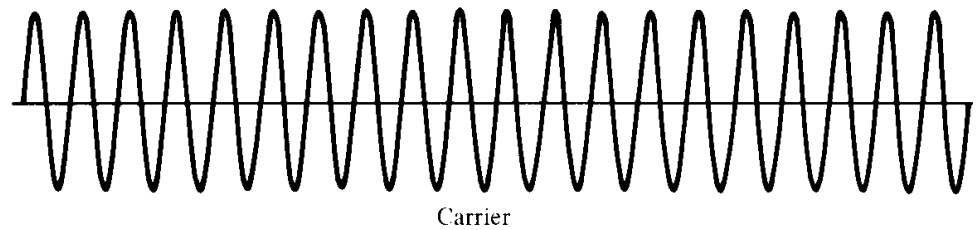
Summary

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