CSE 350
DATA COMMUNICATIONS

Lecture 4: Signal Encoding Techniques

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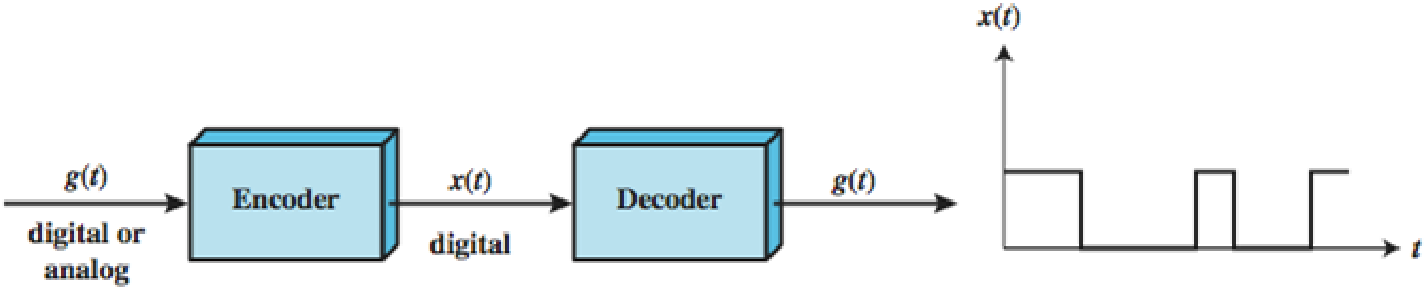
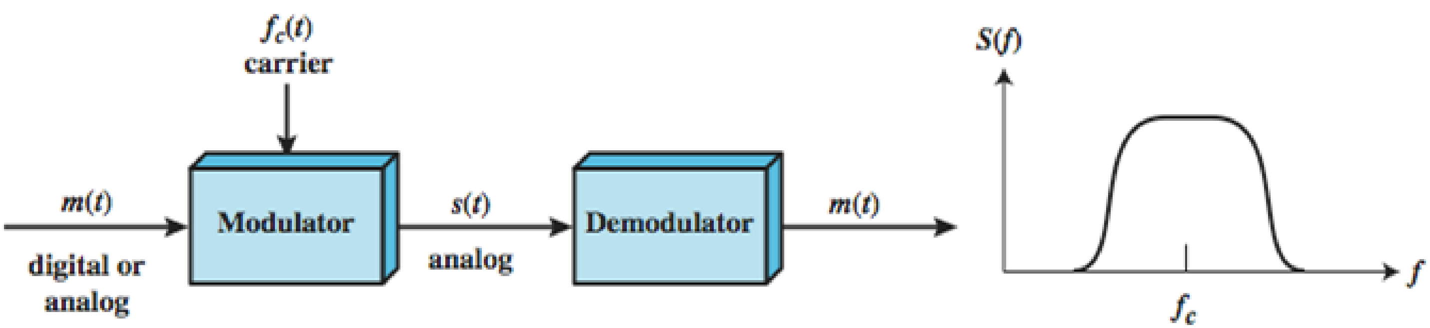
Signal Encoding Techniques



(a) Encoding onto a digital signal

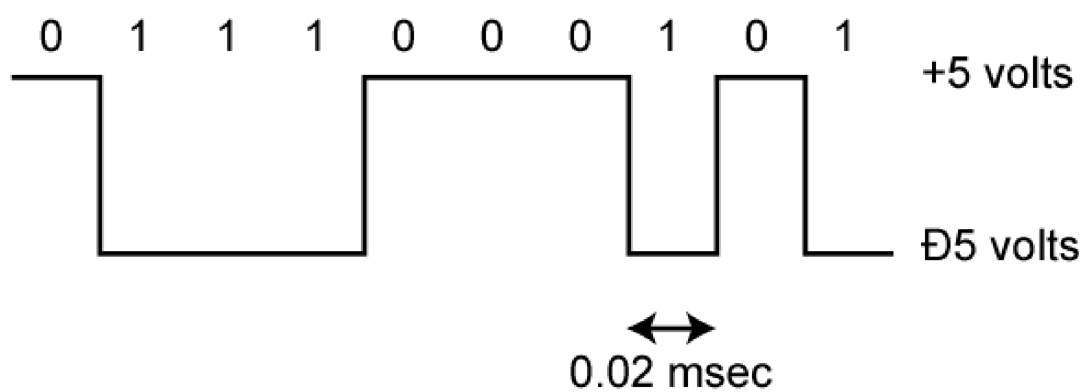


(b) Modulation onto an analog signal

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



Terminology

- **unipolar** – all signal elements have the same sign
- **polar** – one logic state represented by positive voltage and the other by negative voltage
- **data rate** – rate of data (R) transmission in bits per second
- **duration or length of a bit** – time taken for transmitter to emit the bit (1/R)
- **modulation rate** – rate at which the signal level changes, measured in baud = signal elements per second.
- **mark and space** – binary 1 and binary 0

Key Data Transmission Terms

Term	Units	Definition
Data element	Bits	A single binary one or zero
Data rate	Bits per second (bps)	The rate at which data elements are transmitted
Signal element	Digital: a voltage pulse of constant amplitude Analog: a pulse of constant frequency, phase, and amplitude	That part of a signal that occupies the shortest interval of a signaling code
Signaling rate or modulation rate	Signal elements per second (baud)	The rate at which signal elements are transmitted

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

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

Pseudoternary
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

B8ZS
Same as bipolar AMI, except that any string of eight zeros is replaced by a string with two code violations

HDB3
Same as bipolar AMI, except that any string of four zeros is replaced by a string with one code violation

Encoding Schemes

signal spectrum

- good signal design should concentrate the transmitted power in the middle of the transmission bandwidth

clocking

- need to synchronize transmitter and receiver either with an external clock or sync mechanism

error detection

- responsibility of a layer of logic above the signaling level that is known as data link control

signal interference and noise immunity

- certain codes perform better in the presence of noise
- cost and complexity
- the higher the signaling rate the greater the cost

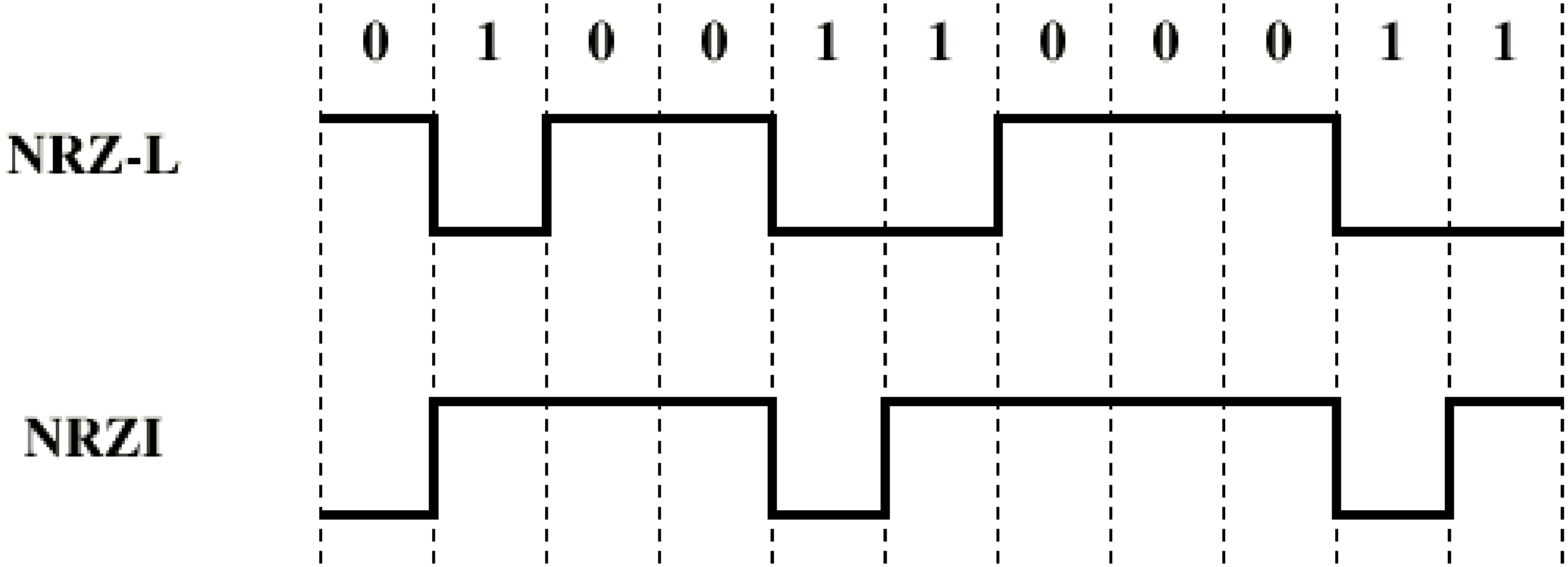
Nonreturn to Zero-Level (NRZ-L)

- easiest way to transmit digital signals is to use two different voltages for 0 and 1 bits
- voltage constant during bit interval
  - no transition (no return to zero voltage)
  - absence of voltage for 0, constant positive voltage for 1
  - more often, a negative voltage represents one value and a positive voltage represents the other(NRZ-L)

Non-return to Zero Inverted (NRZI)

- Non-return to zero, invert 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
  - data represented by changes rather than levels
  - more reliable to detect a transition in the presence of noise than to compare a value to a threshold
  - easy to lose sense of polarity

NRZ



NRZ Pros & Cons

- Pros
  - easy to engineer
  - make efficient use of bandwidth
- Cons
  - presence of a dc component
  - lack of synchronization capability

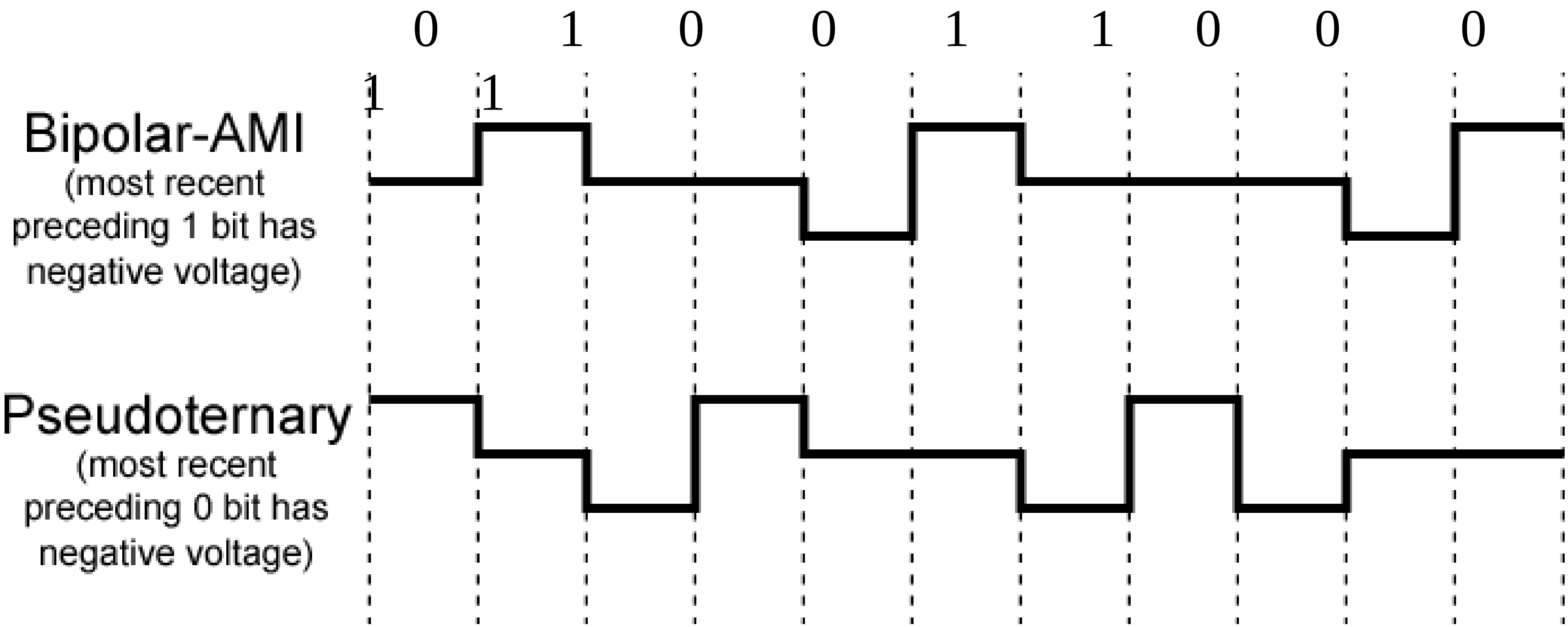
Multilevel Binary
Bipolar-AMI

- use more than two signal levels
- Bipolar-AMI
  - binary 0 represented by no line signal
  - binary 1 represented by positive or negative pulse
  - binary 1 pulses alternate in polarity
  - no loss of sync if a long string of 1s occurs
  - no net dc component
  - lower bandwidth
  - easy error detection

Multilevel Binary Pseudoternary

- binary 1 represented by absence of line signal
- binary 0 represented by alternating positive and negative pulses
- no advantage or disadvantage over bipolar-AMI and each is the basis of some applications

Bipolar-AMI and Pseudoternary



Multilevel Binary Issues

- synchronization with long runs of 0's or 1's
  - can insert additional bits that force transitions
  - scramble data
- 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 approximately 3dB more signal power for same probability of bit error

Theoretical Bit Error Rate

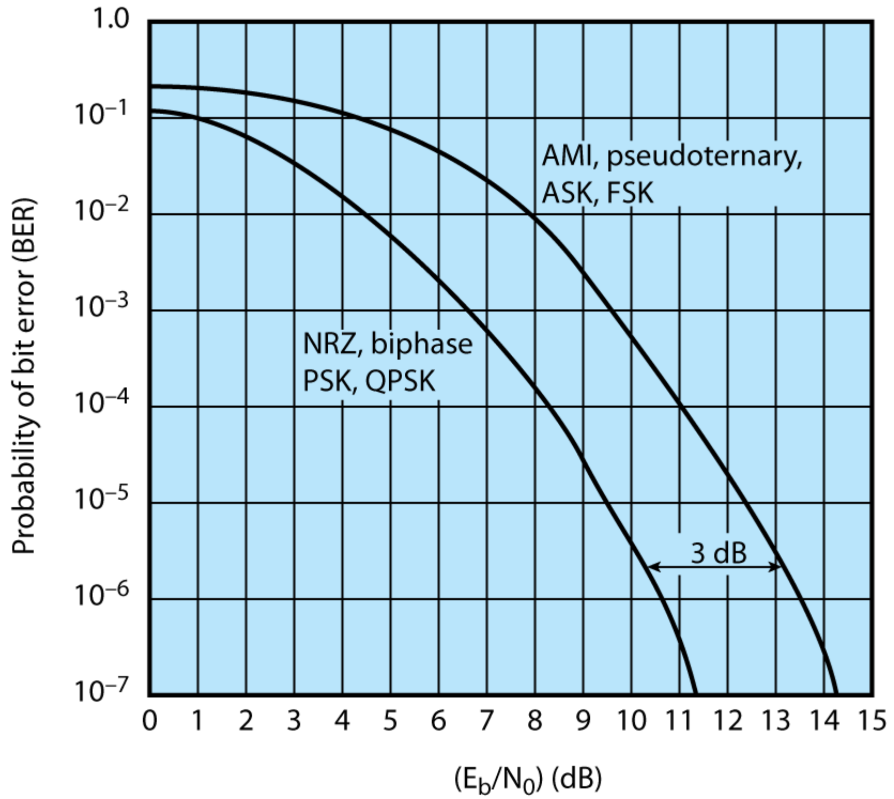
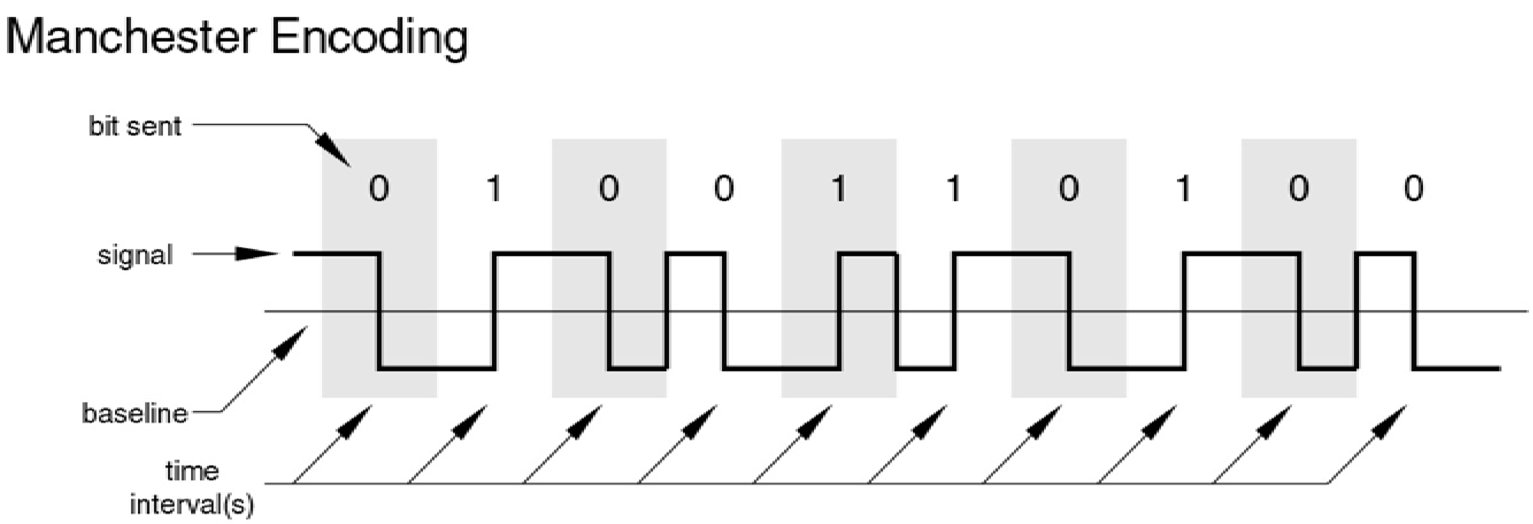


Figure 5.4 Theoretical Bit Error Rate for Various Encoding Schemes

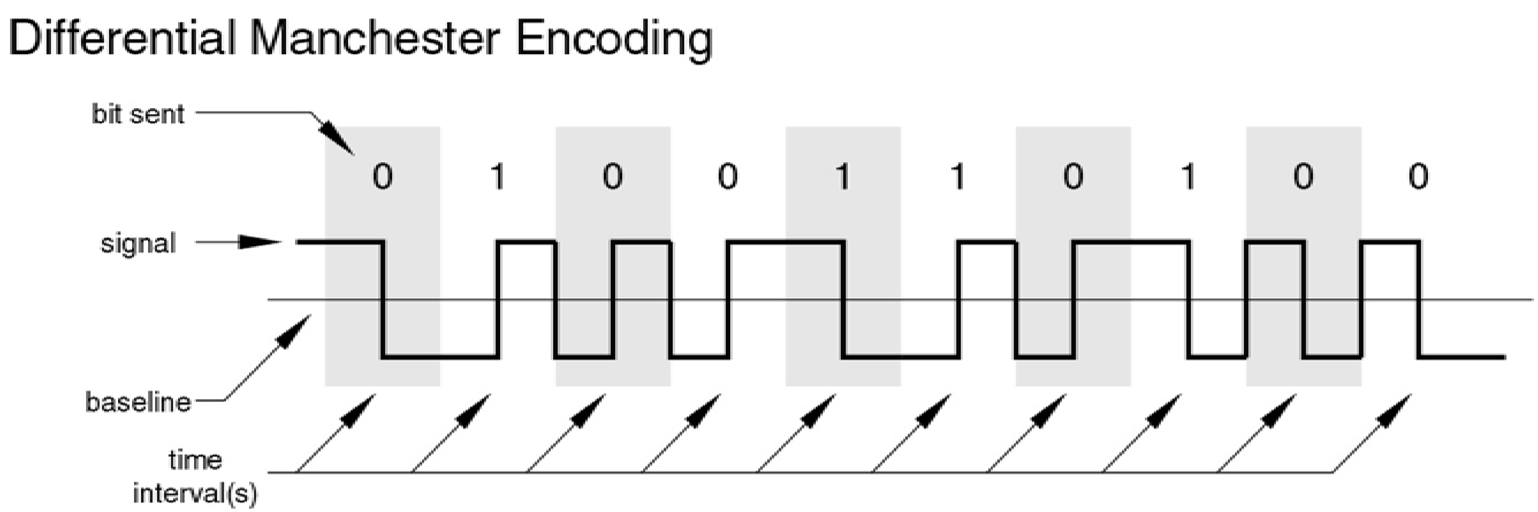
Manchester Encoding

- transition in middle of each bit period
- midbit transition serves as clock and data
- low to high transition represents a 1
- high to low transition represents a 0
- used by IEEE 802.3



Differential Manchester Encoding

- midbit transition is only used for clocking
- 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



Biphase Pros and Cons

Pros

- synchronization on midbit transition (self clocking)
- has no dc component
- has error detection

Cons

- at least one transition per bit time and may have two
- maximum modulation rate is twice NRZ
- requires more bandwidth

Spectral Density of Various Signal Encoding Schemes

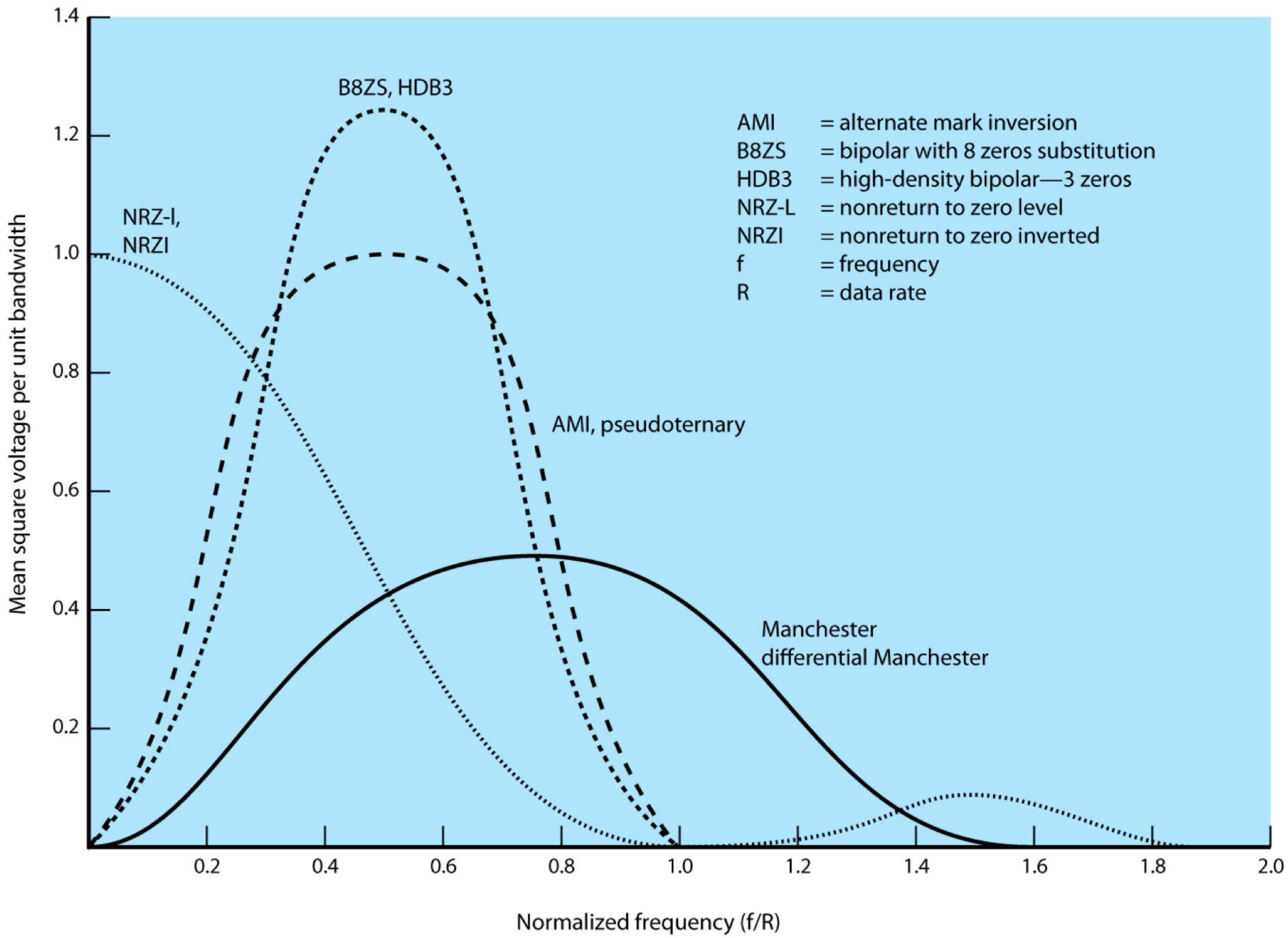


Figure 5.3 Spectral Density of Various Signal Encoding Schemes

Stream of Binary Ones at 1Mbps

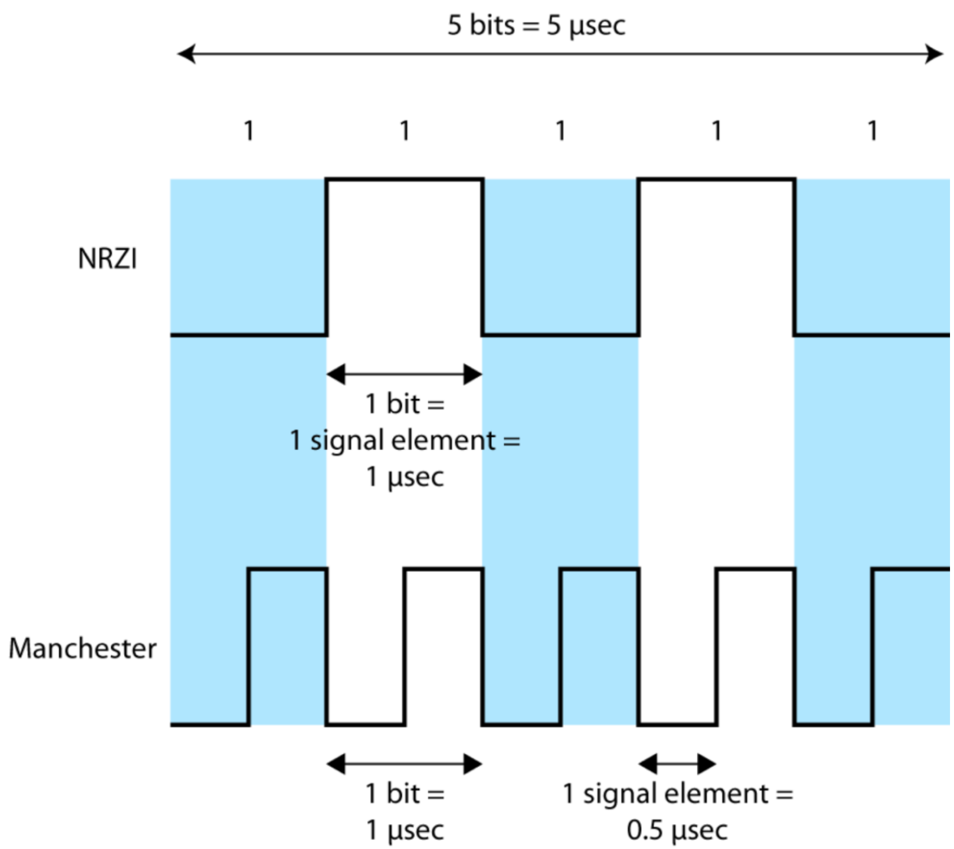


Figure 5.5 A Stream of Binary Ones at 1 Mbps

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)

Table 5.3

Scrambling

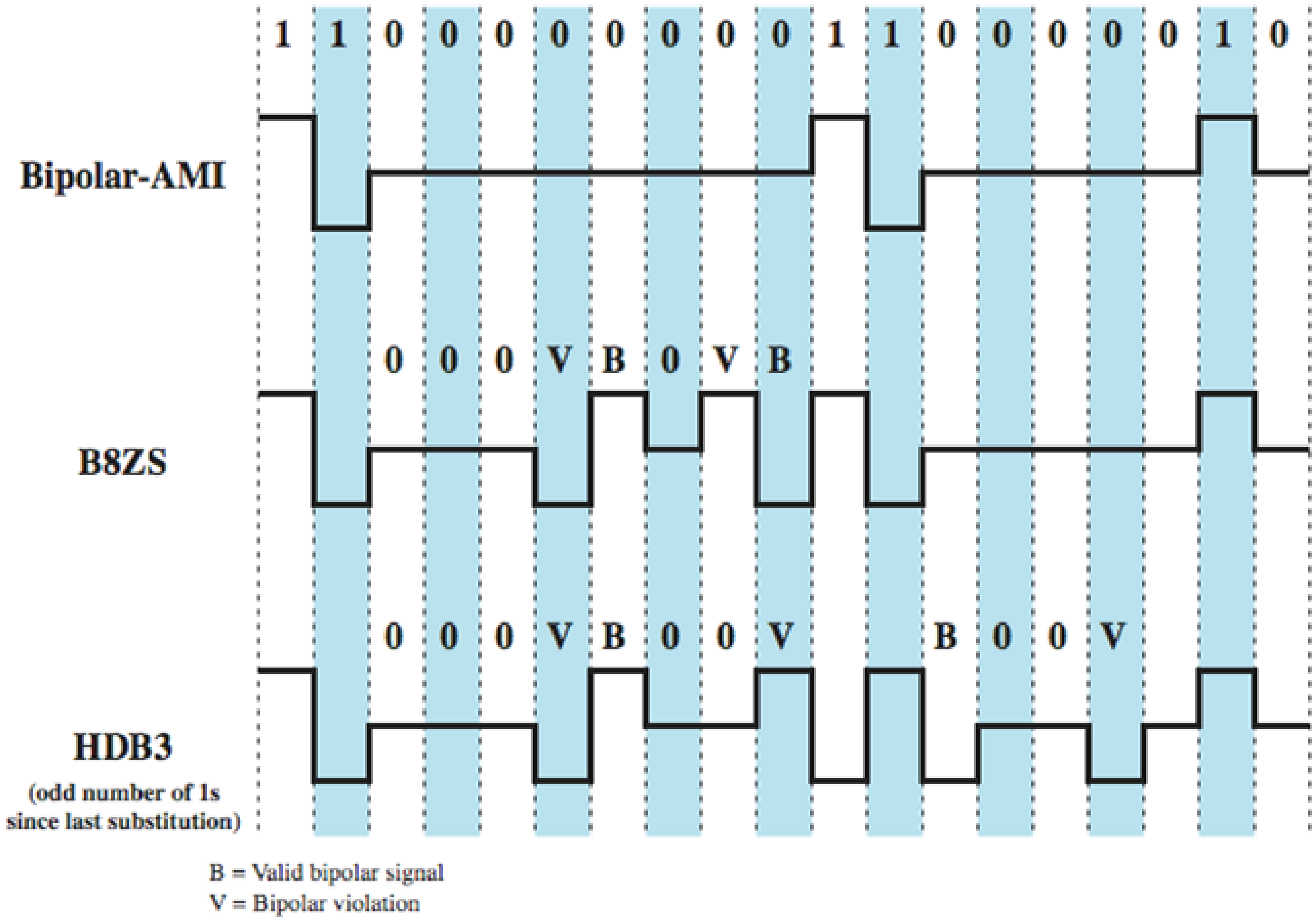
- use scrambling to replace sequences that would produce constant voltage
- these filling sequences must:
  - produce enough transitions to sync
  - be recognized by receiver & replaced with original
  - be same length as original
- design goals
  - have no dc component
  - have no long sequences of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

HDB3 Substitution Rules

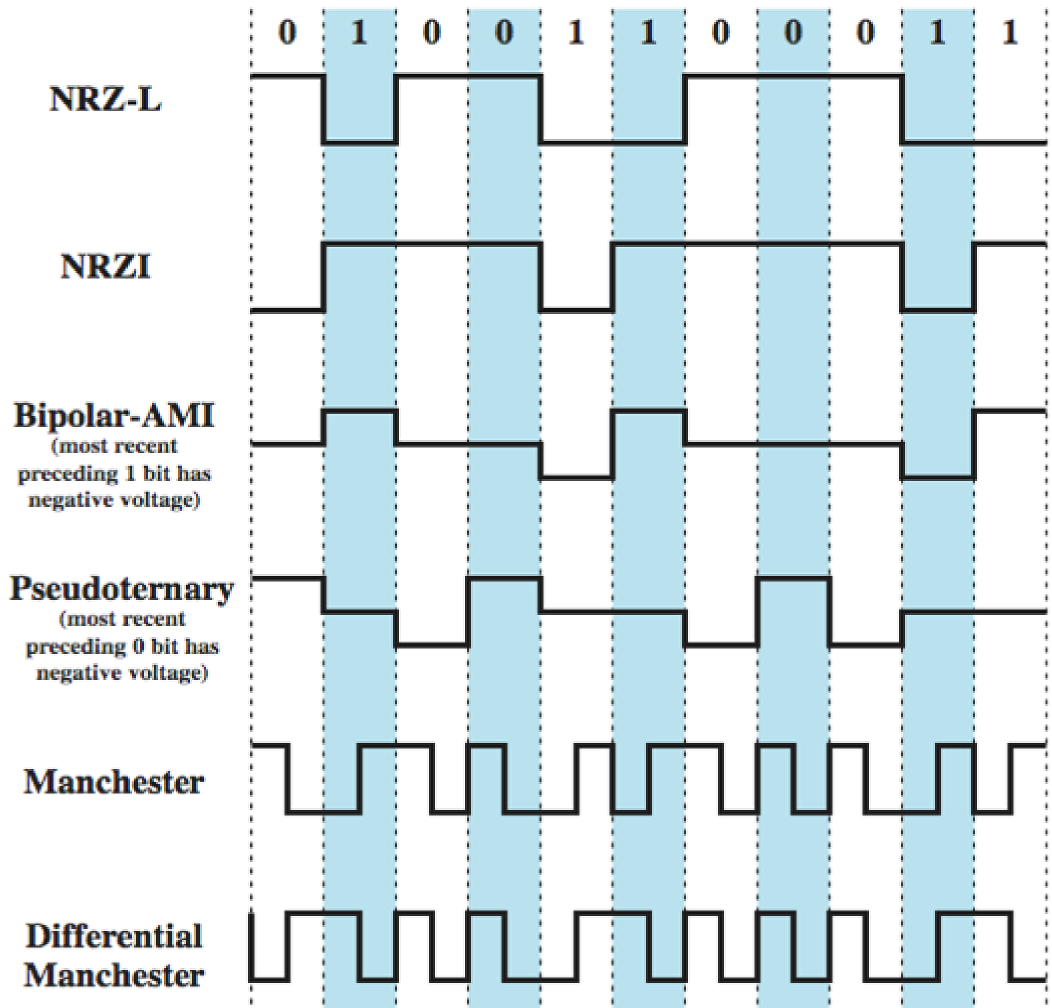
	Number of Bipolar Pulses (ones) since Last Substitution	
Polarity of Preceding Pulse	**Odd**	**Even**
–	000–	+00+
+	000+	–00–

Table 5.4

B8ZS and HDB3



Encoding Schemes



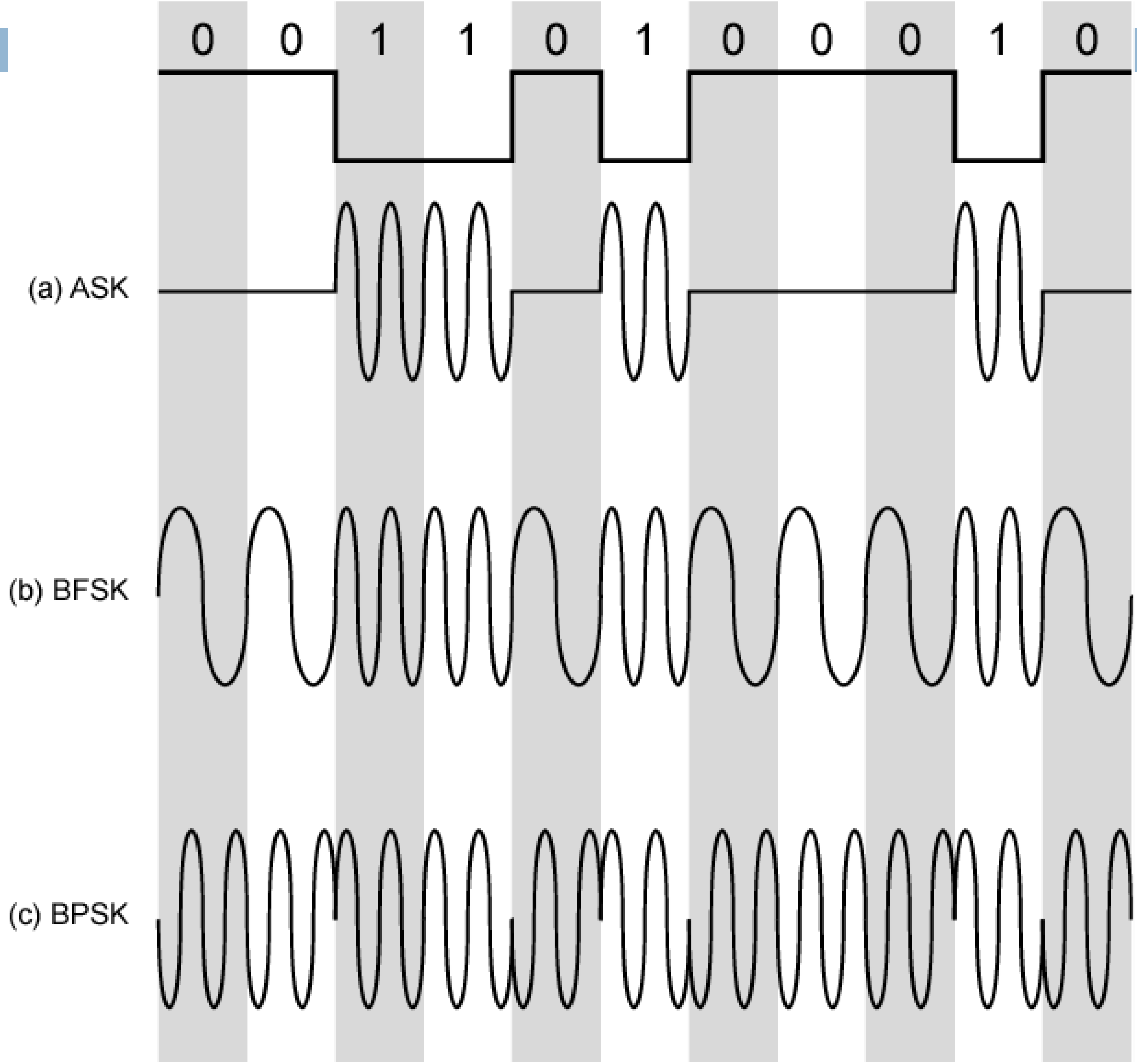
Digital Data, Analog Signal

Encoding Techniques

Amplitude shift keying (ASK)	Frequency shift keying (FSK)	Phase shift keying (PK)
• used to transmit digital data over optical fiber	• most common form is binary FSK (BFSK)	• phase of carrier signal is shifted to represent data

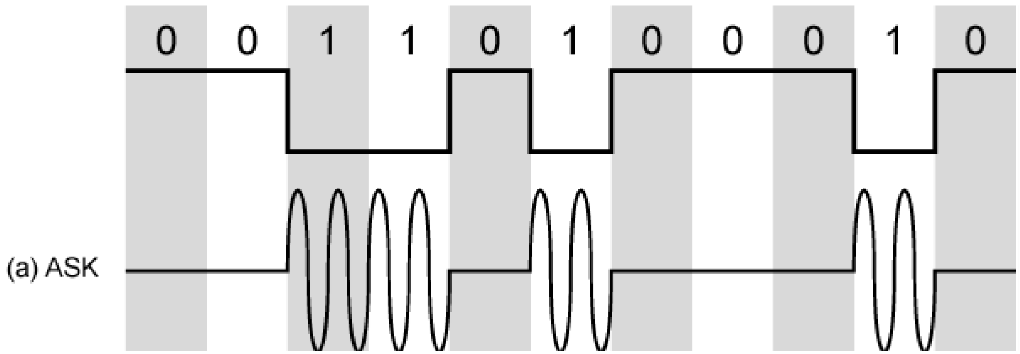
- main use is public telephone system
  - has frequency range of 300Hz to 3400Hz
  - uses modem (modulator-demodulator)

Modulation Techniques



Amplitude Shift Keying

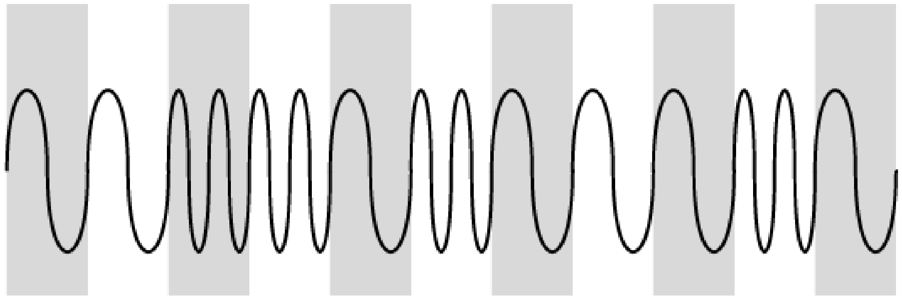
- encode 0/1 by different carrier amplitudes
  - usually have one amplitude zero
- susceptible to sudden gain changes
- inefficient
- used for:
  - up to 1200bps on voice grade lines
  - very high speeds over optical fiber



Binary Frequency Shift Keying

- 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 coaxial cable

(b) BFSK



Multiple FSK

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

FSK Transmission

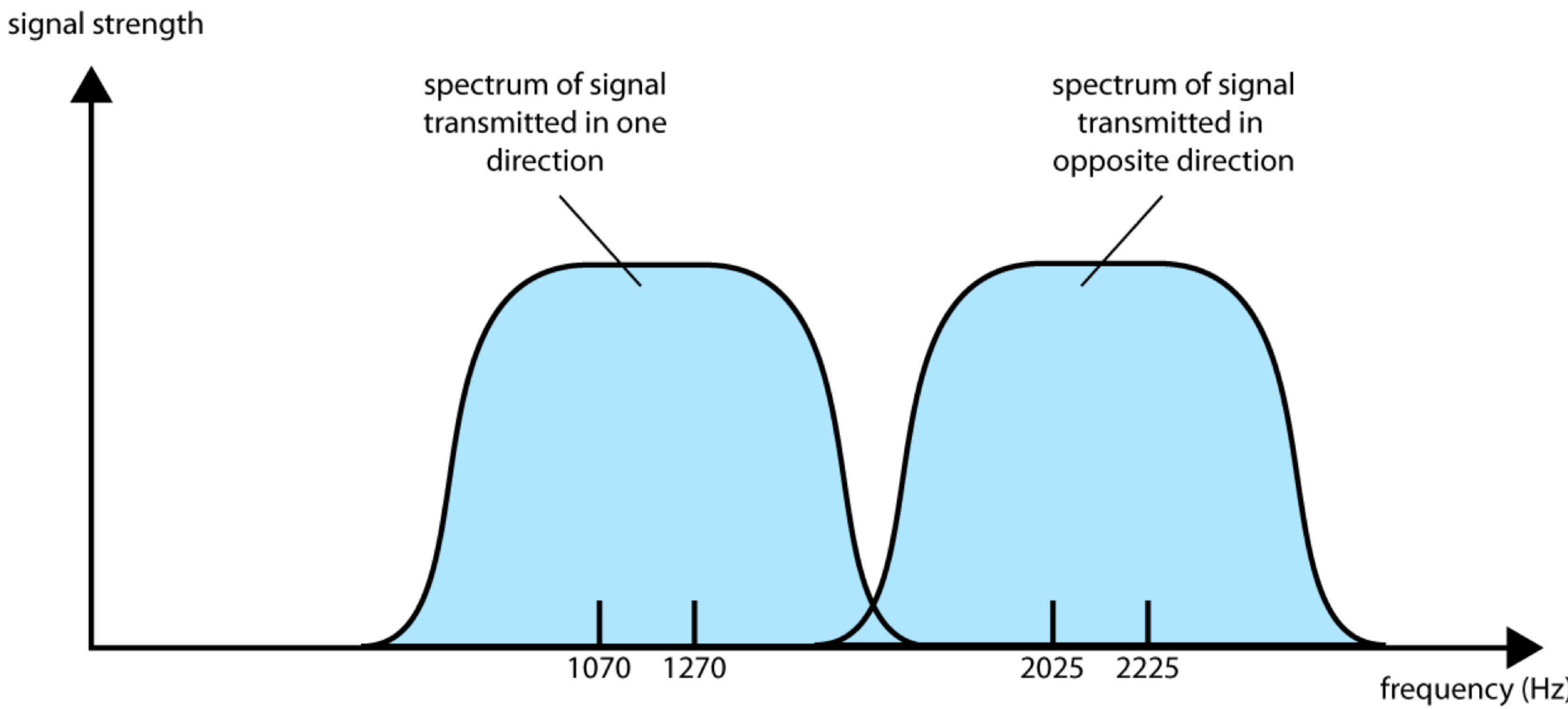
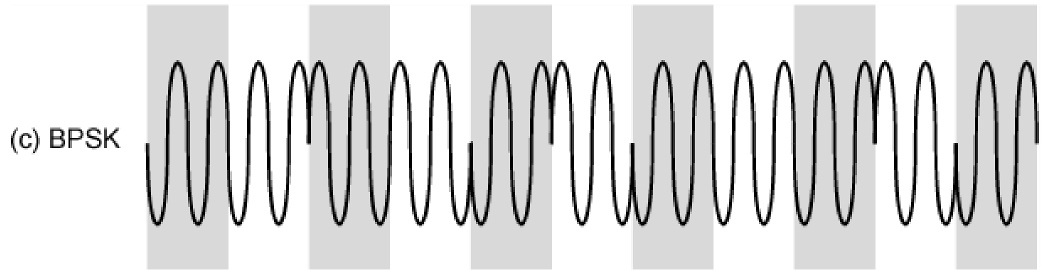


Figure 5.8 Full-Duplex FSK Transmission on a Voice-Grade Line

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



DPSK

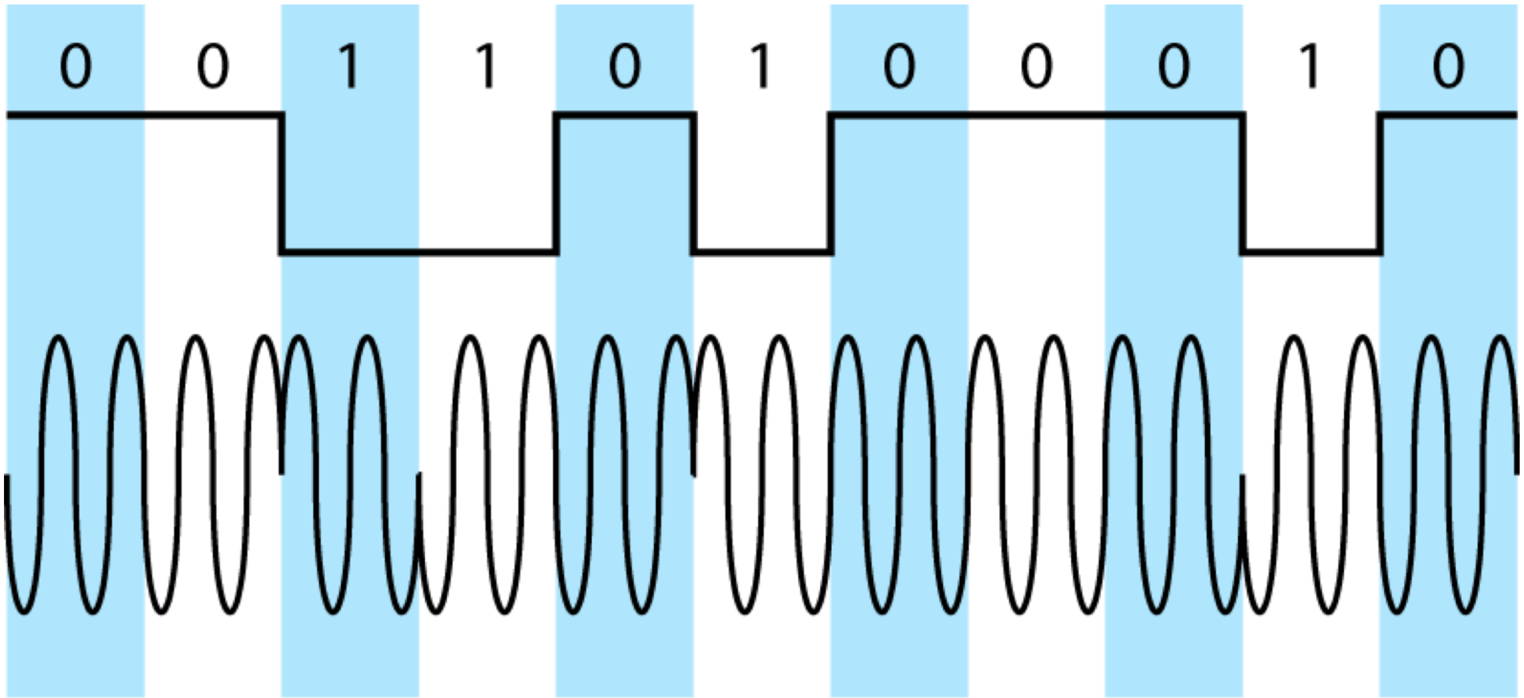


Figure 5.10 Differential Phase-Shift Keying (DPSK)

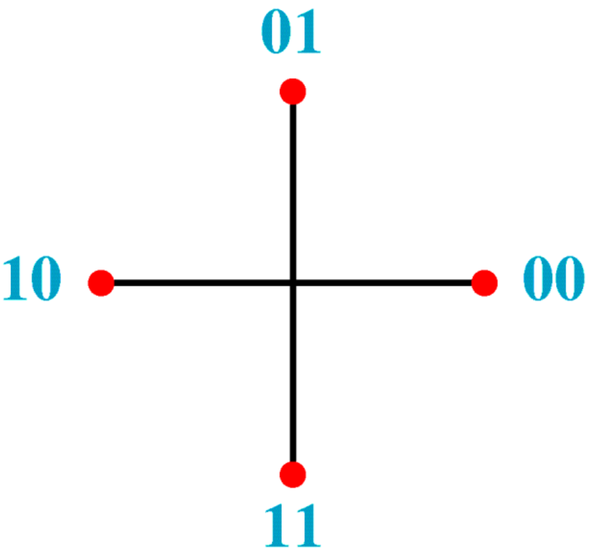
Quadrature PSK

- more efficient use if each signal element represents more than one bit
  - uses phase shifts separated by multiples of $\pi/2$ (90°)
  - each element represents two bits
  - split input data stream in two and modulate onto carrier and phase shifted carrier
- can use 8 phase angles and more than one amplitude
  - 9600bps modem uses 12 angles, four of which have two amplitudes

4-PSK Characteristics

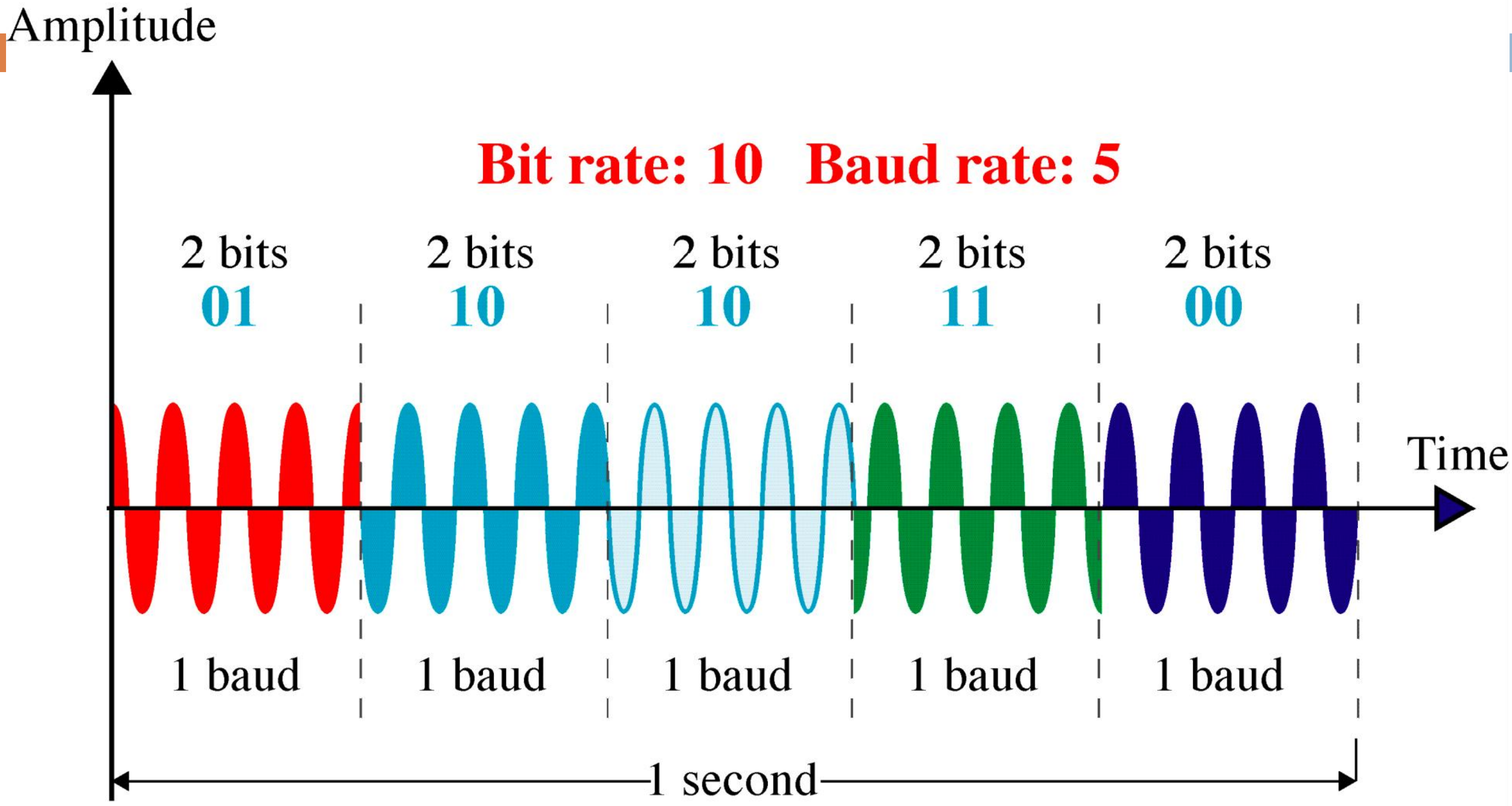
Dibit	Phase
00	0
01	90
10	180
11	270

Dibit
(2 bits)



Constellation diagram

4-PSK

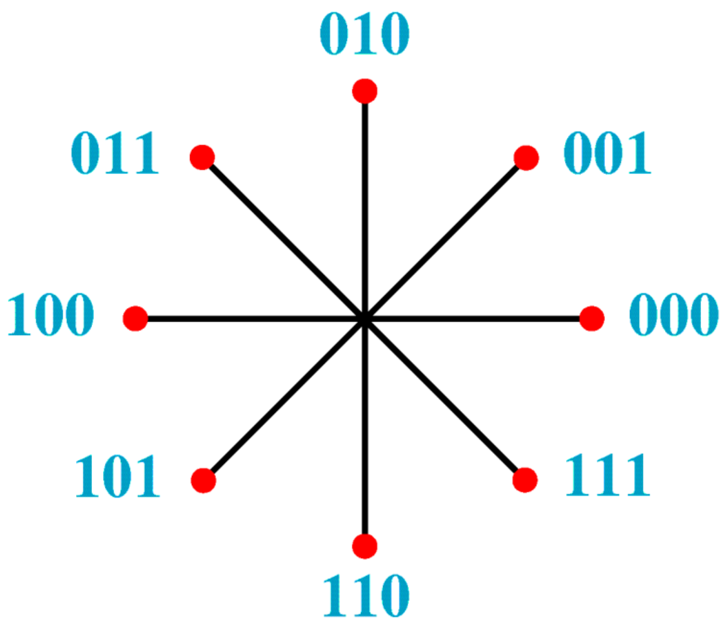


Amplitude
Bit rate: 10
Baud rate: 5
2 bits
01
2 bits
10
2 bits
10
2 bits
11
2 bits
00
Time
1 baud
1 baud
1 baud
1 baud
1 baud
1 second

8-PSK Characteristics

Tribit	Phase
000	0
001	45
010	90
011	135
100	180
101	225
110	270
111	315

Tribits
(3 bits)



Constellation diagram

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 and MPSK have tradeoff between bandwidth efficiency and error performance

Bit Error Rates for Multilevel FSK and PSK

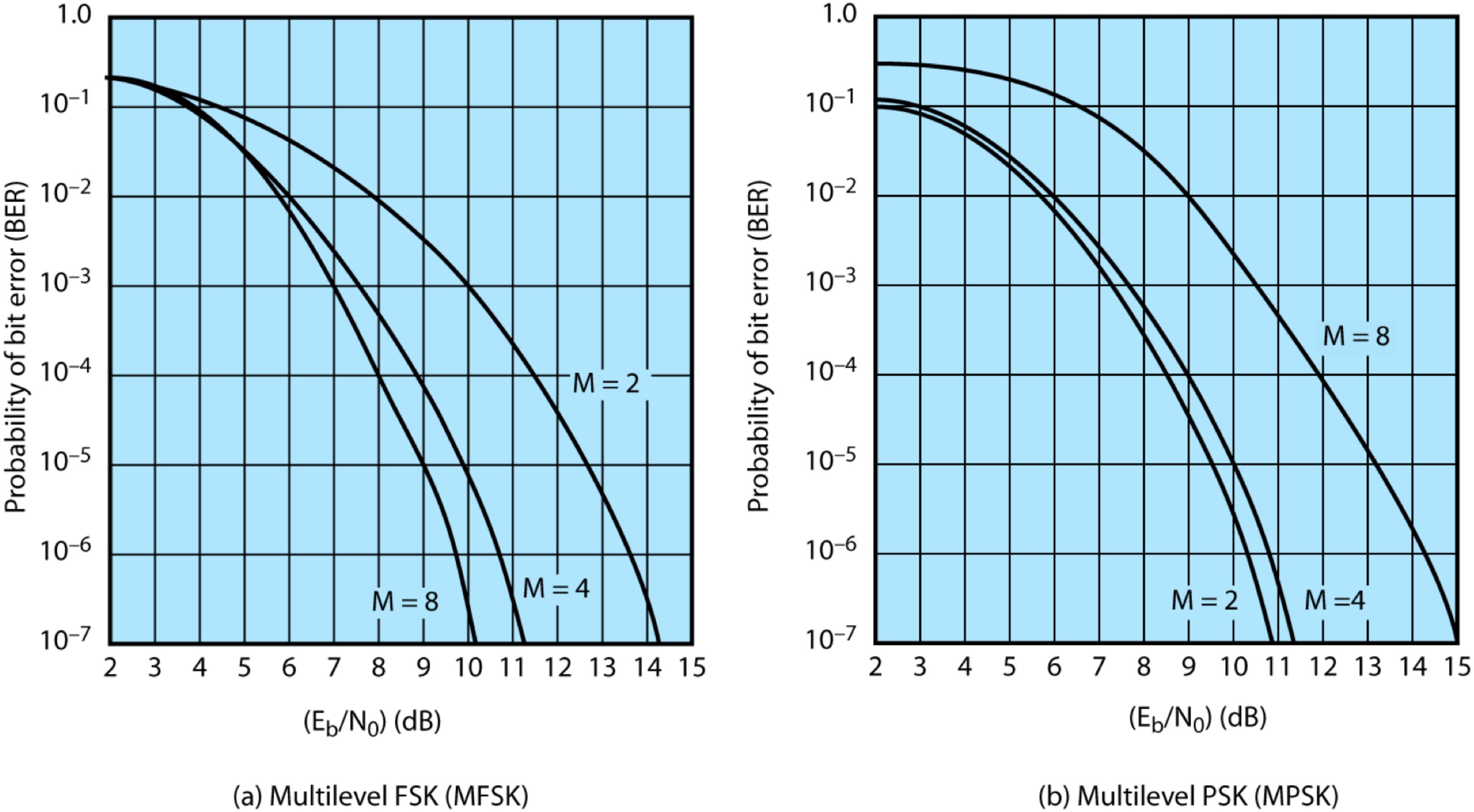
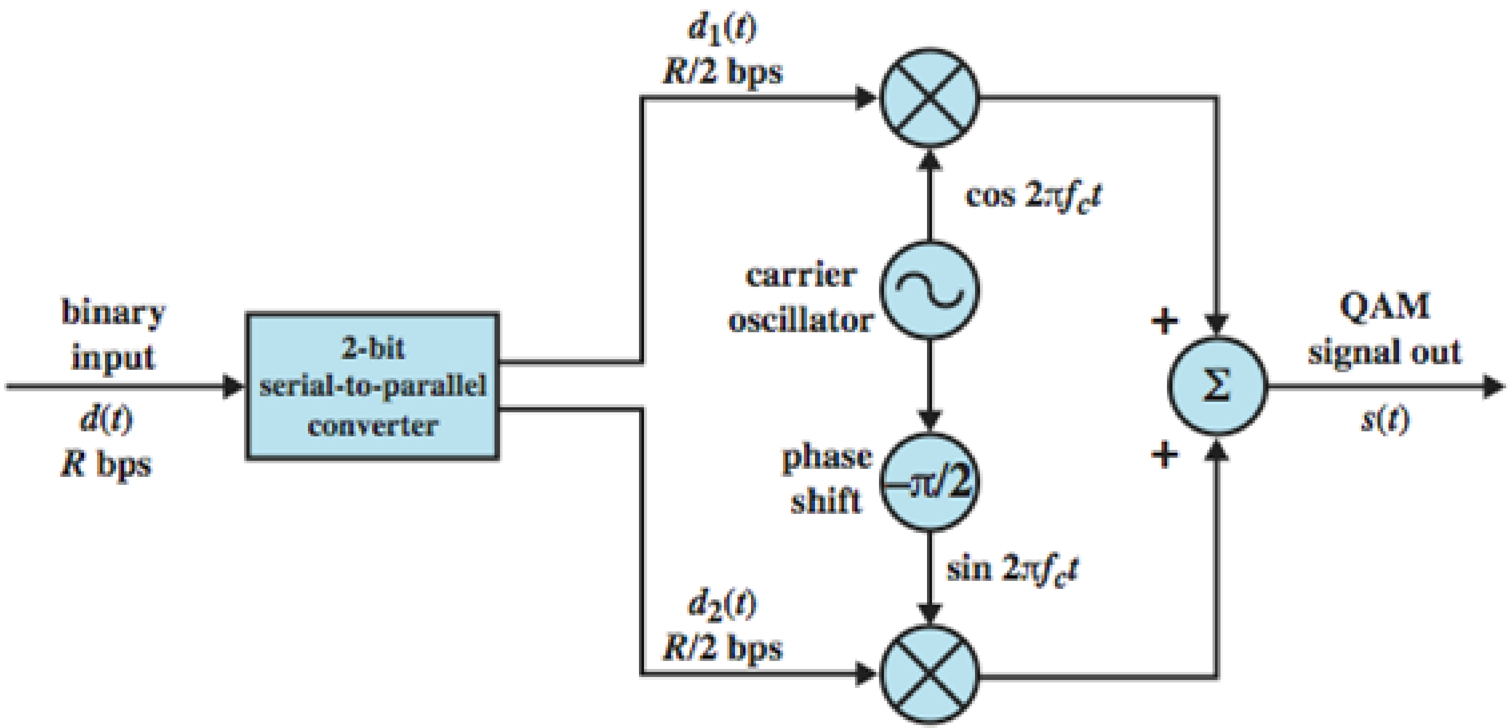


Figure 5.13 Theoretical Bit Error Rate for Multilevel FSK and PSK

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



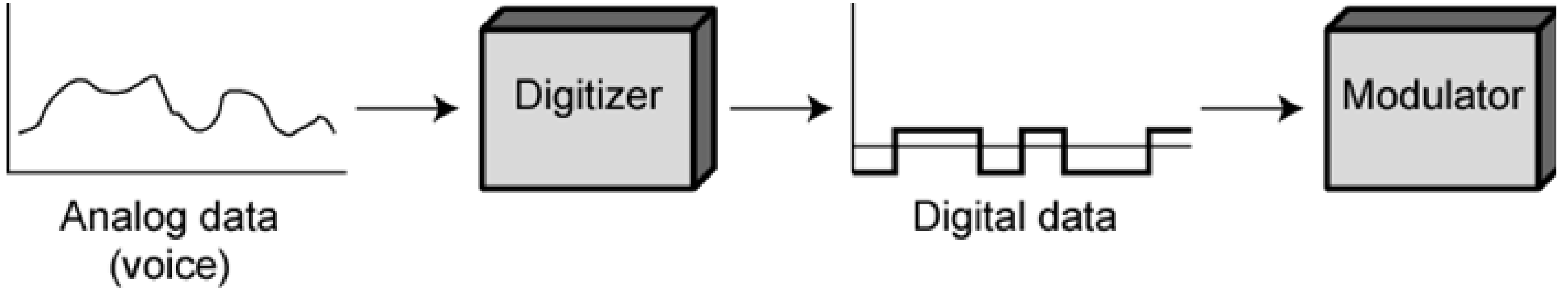
QAM Variants

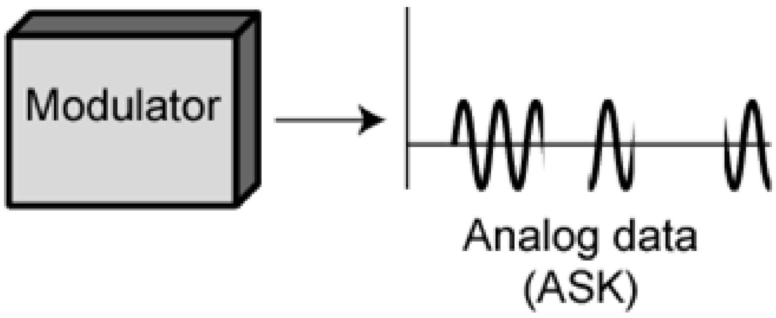
- two level ASK
  - each of two streams in one of two states
  - four state system
  - essentially QPSK
- four level ASK
  - combined stream in one of 16 states
- have 64 and 256 state systems
- improved data rate for given bandwidth
  - increased potential error rate

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

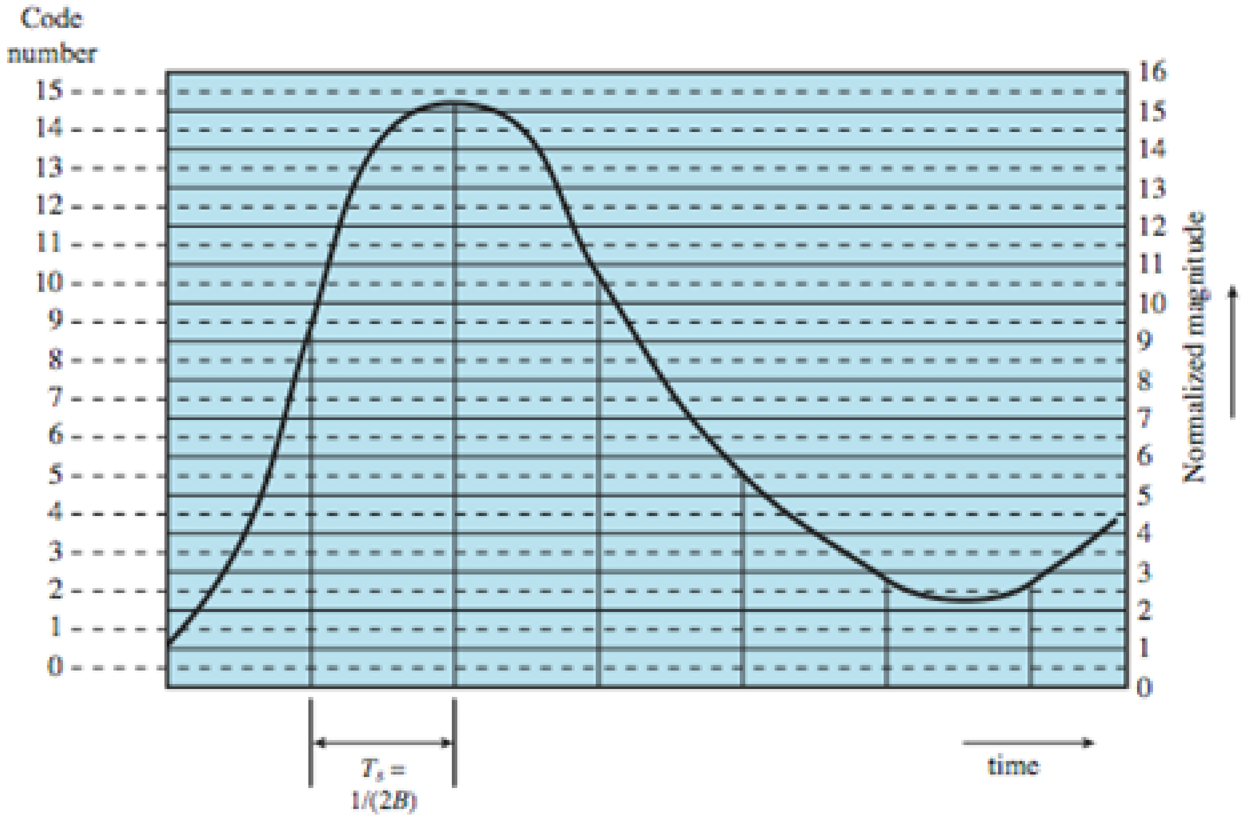




Pulse Code Modulation (PCM)

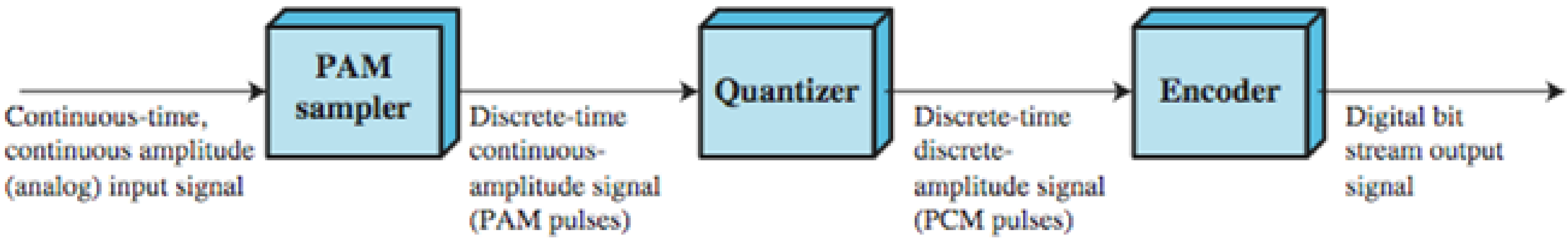
- sampling theorem:
  - "If a signal is sampled at regular intervals at a rate higher than twice the highest signal frequency, the samples contain all information in original signal"
  - eg. 4000Hz voice data, requires 8000 sample per second
- strictly have analog samples
  - Pulse Amplitude Modulation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

PCM Example

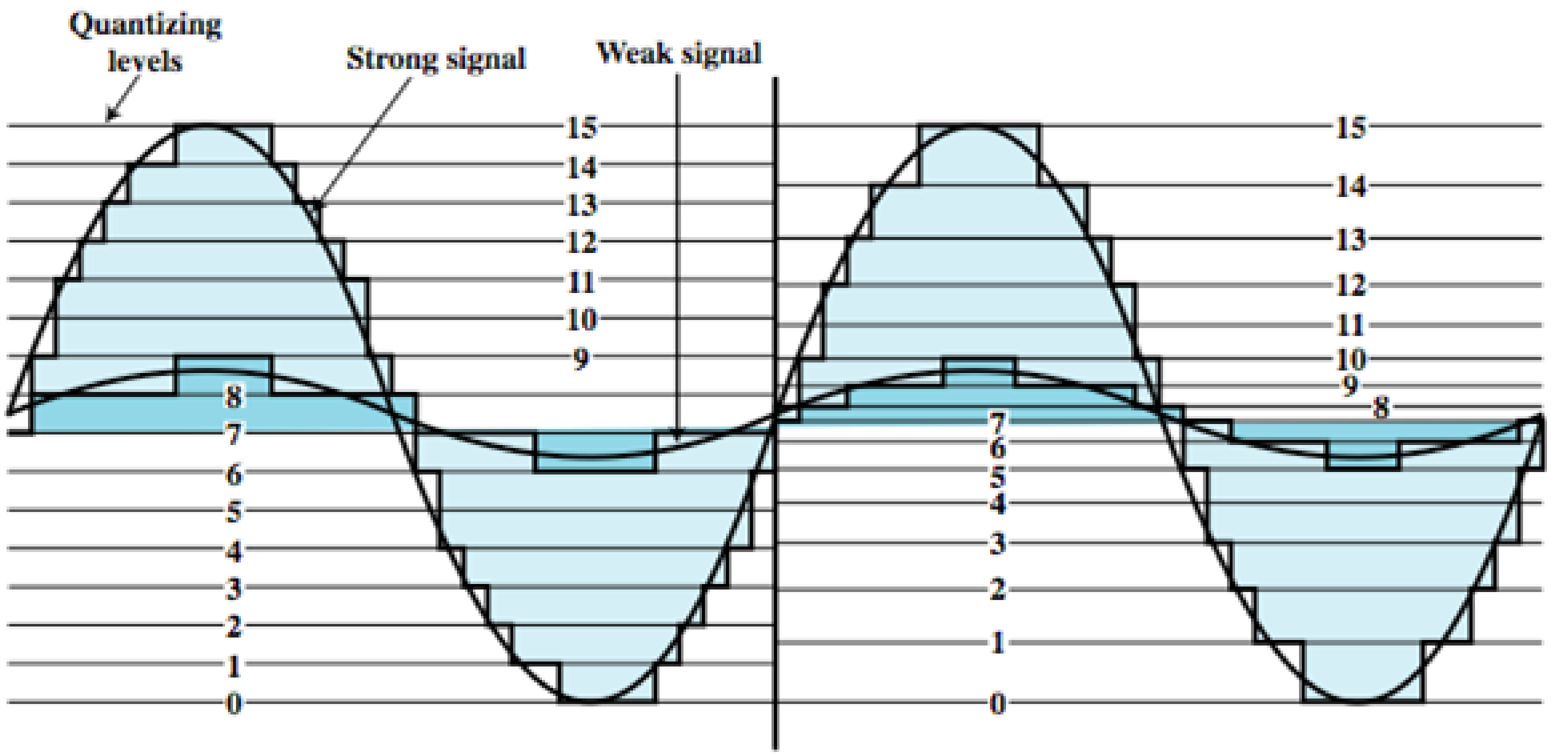


PAM value	1.1	9.2	15.2	10.8	5.6	2.8	2.7
quantized code number	1	9	15	10	5	2	2
PCM code	0001	1001	1111	1010	0101	0010	0010

PCM Block Diagram



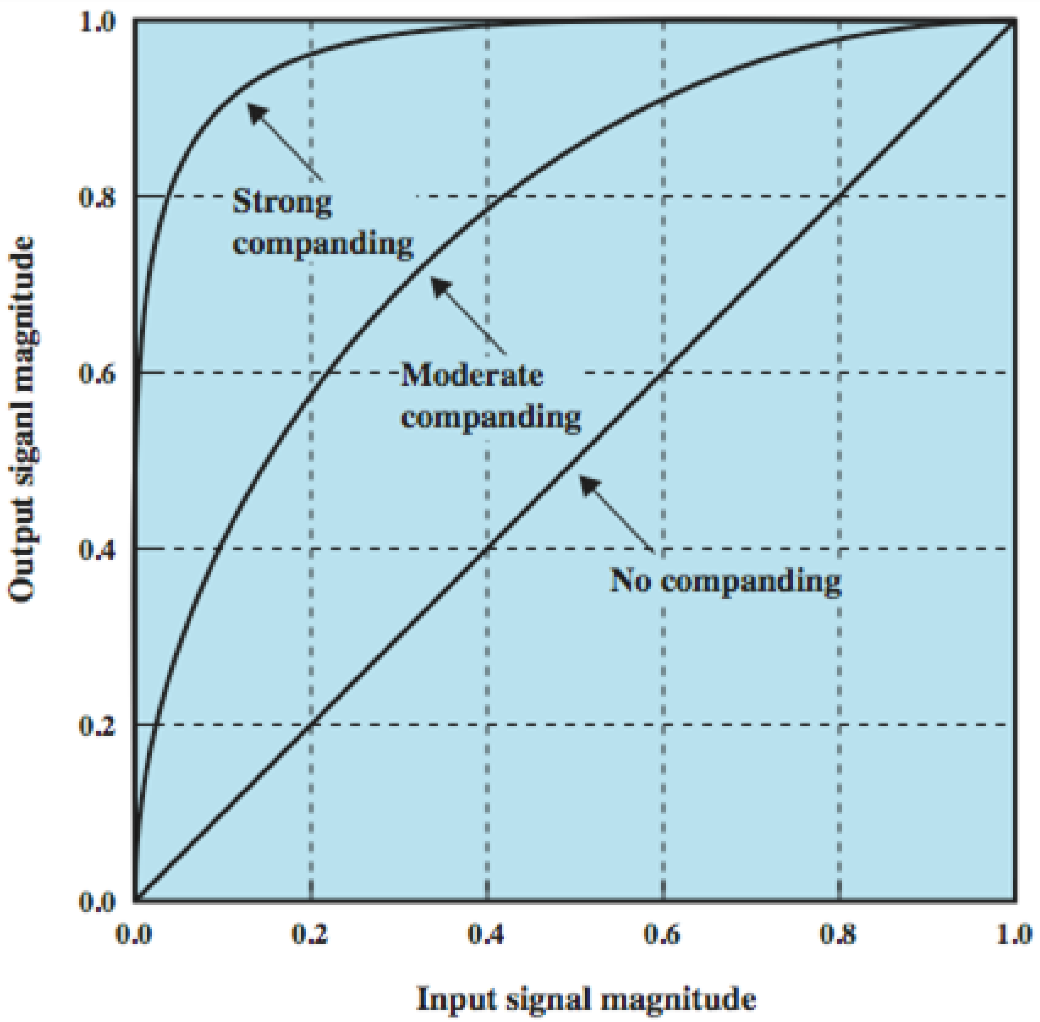
Non-Linear Coding



(a) Without nonlinear encoding

(b) With nonlinear encoding

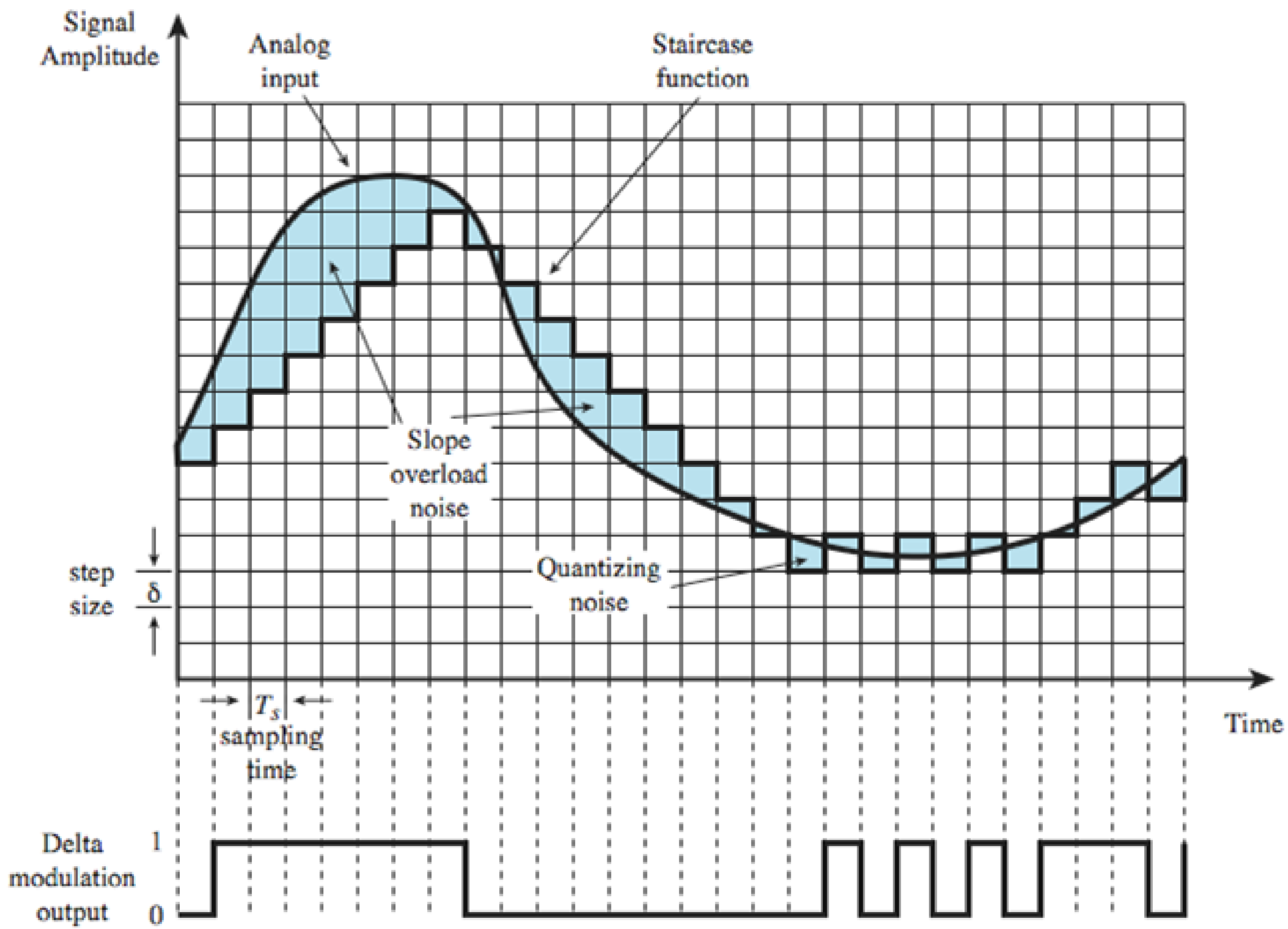
Typical Companding Functions



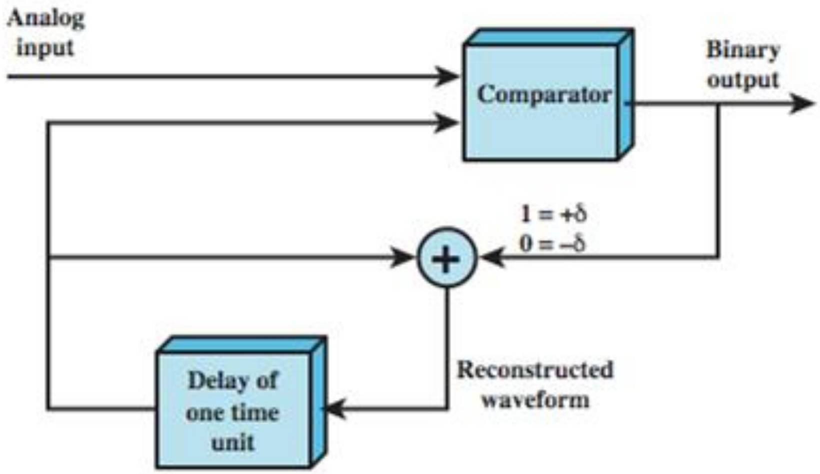
Delta Modulation (DM)

- analog input is approximated by a staircase function
  - can move up or down one level (δ) at each sample interval
- has binary behavior
  - 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

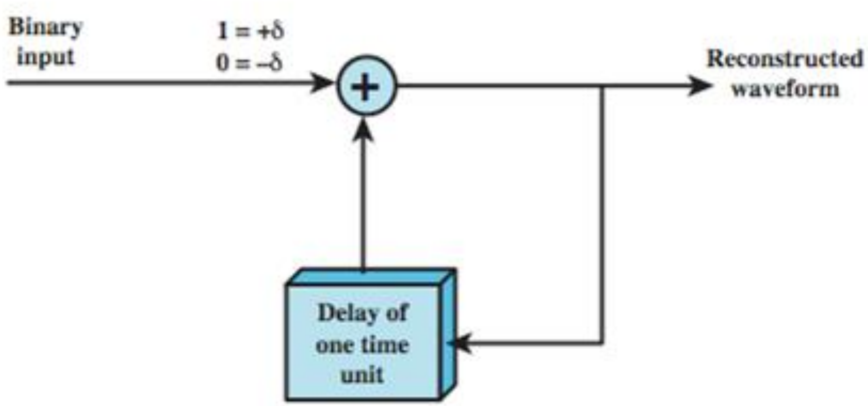
Delta Modulation Example



Delta Modulation Operation



(a) Transmission



(b) Reception

PCM verses Delta Modulation

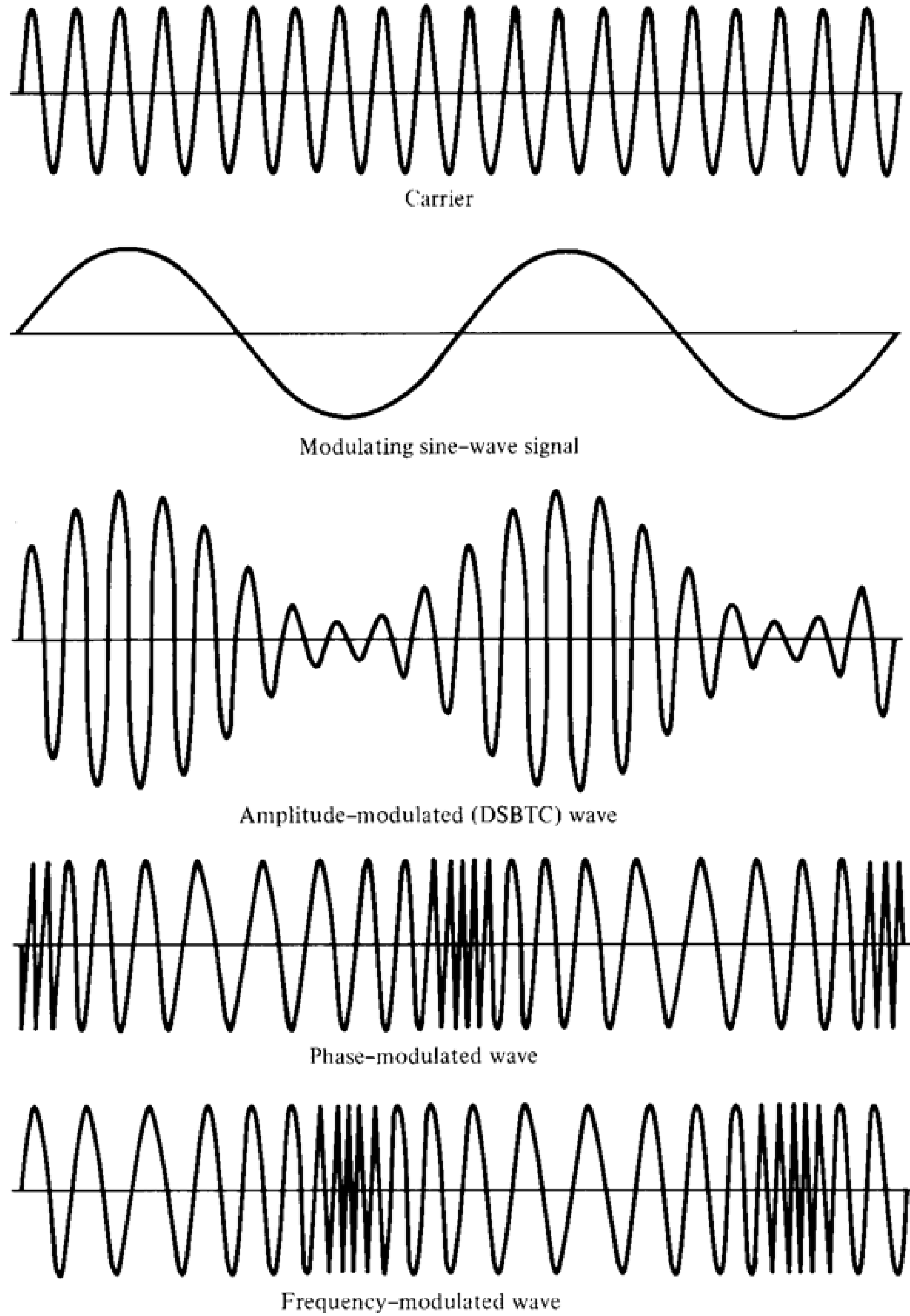
- DM has simplicity compared to PCM but has worse SNR
- issue of bandwidth used
  - for good voice reproduction with PCM:
    - want 128 levels (7 bit) & voice bandwidth 4khz
    - need 8000 x 7 = 56kbps
- data compression can improve on this
- still growing demand for digital signals
  - use of repeaters, 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
- types of modulation:
  - Amplitude
  - Frequency
  - Phase

Analog Modulation Techniques

- Amplitude Modulation
- Frequency Modulation
- Phase Modulation



Summary

- Signal encoding techniques
  - digital data, digital signal
    - NRZ, multilevel binary, biphase, modulation rate, scrambling techniques
  - analog data, digital signal
    - PCM, DM
  - digital data, analog signal
    - ASK, FSK, BFSK, PSK
  - analog data, analog signal
    - AM, FM, PM