Data and Computer Communications

Chapter 1 – Data Communications, Data Networks, and the Internet

Eighth Edition

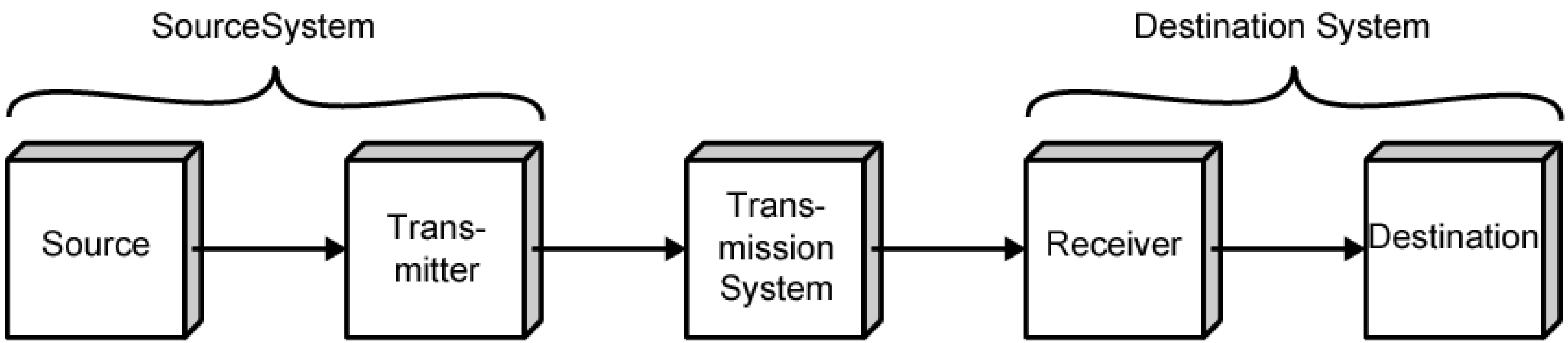
by William Stallings

Lecture slides by Lawrie Brown

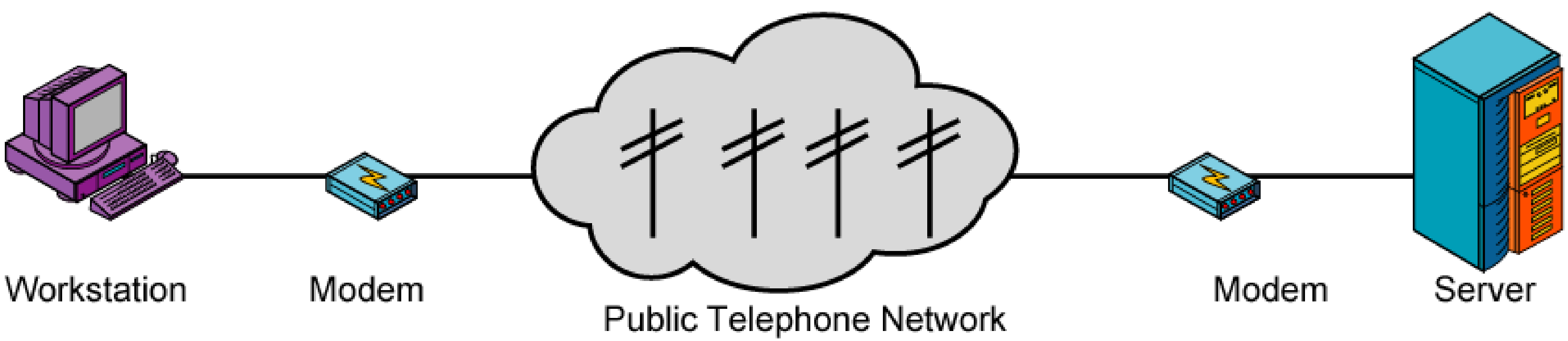
Contemporary Data Comms

- trends
  - traffic growth at a high & steady rate
  - development of new services
  - advances in technology
- significant change in requirements
  - emergence of high-speed LANs
  - corporate WAN needs
  - digital electronics

A Communications Model



(a) General block diagram

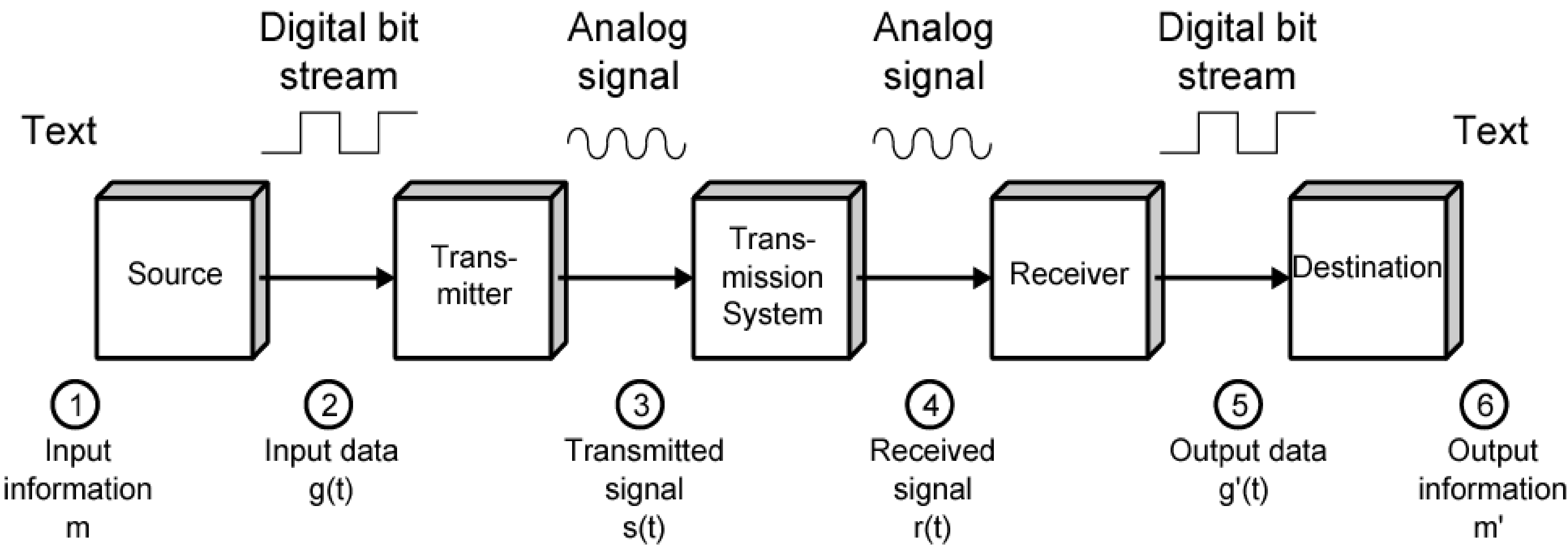


(b) Example

Communications Tasks

Transmission system utilization	Addressing
Interfacing	Routing
Signal generation	Recovery
Synchronization	Message formatting
Exchange management	Security
Error detection and correction	Network management
Flow control	

Data Communications Model



Transmission Medium

- selection is a basic choice
  - internal use entirely up to business
  - long-distance links made by carrier
- rapid technology advances change mix
  - fiber optic
  - wireless
- transmission costs still high
- hence interest in efficiency improvements

Networking

- growth of number & power of computers is driving need for interconnection
- also seeing rapid integration of voice, data, image & video technologies
- two broad categories of communications networks:
  - Local Area Network (LAN)
  - Wide Area Network (WAN)

Wide Area Networks

- span a large geographical area
- cross public rights of way
- rely in part on common carrier circuits
- alternative technologies used include:
  - circuit switching
  - packet switching
  - frame relay
  - Asynchronous Transfer Mode (ATM)

Circuit Switching

- uses a dedicated communications path established for duration of conversation
- comprising a sequence of physical links
- with a dedicated logical channel
- eg. telephone network

Packet Switching

- data sent out of sequence
- small chunks (packets) of data at a time
- packets passed from node to node between source and destination
- used for terminal to computer and computer to computer communications

Frame Relay

- packet switching systems have large overheads to compensate for errors
- modern systems are more reliable
- errors can be caught in end system
- Frame Relay provides higher speeds
- with most error control overhead removed

Asynchronous Transfer Mode

- ATM
- evolution of frame relay
- fixed packet (called cell) length
- with little overhead for error control
- anything from 10Mbps to Gbps
- constant data rate using packet switching technique with multiple virtual circuits

Local Area Networks

- smaller scope
  - Building or small campus
- usually owned by same organization as attached devices
- data rates much higher
- switched LANs, eg Ethernet
- wireless LANs

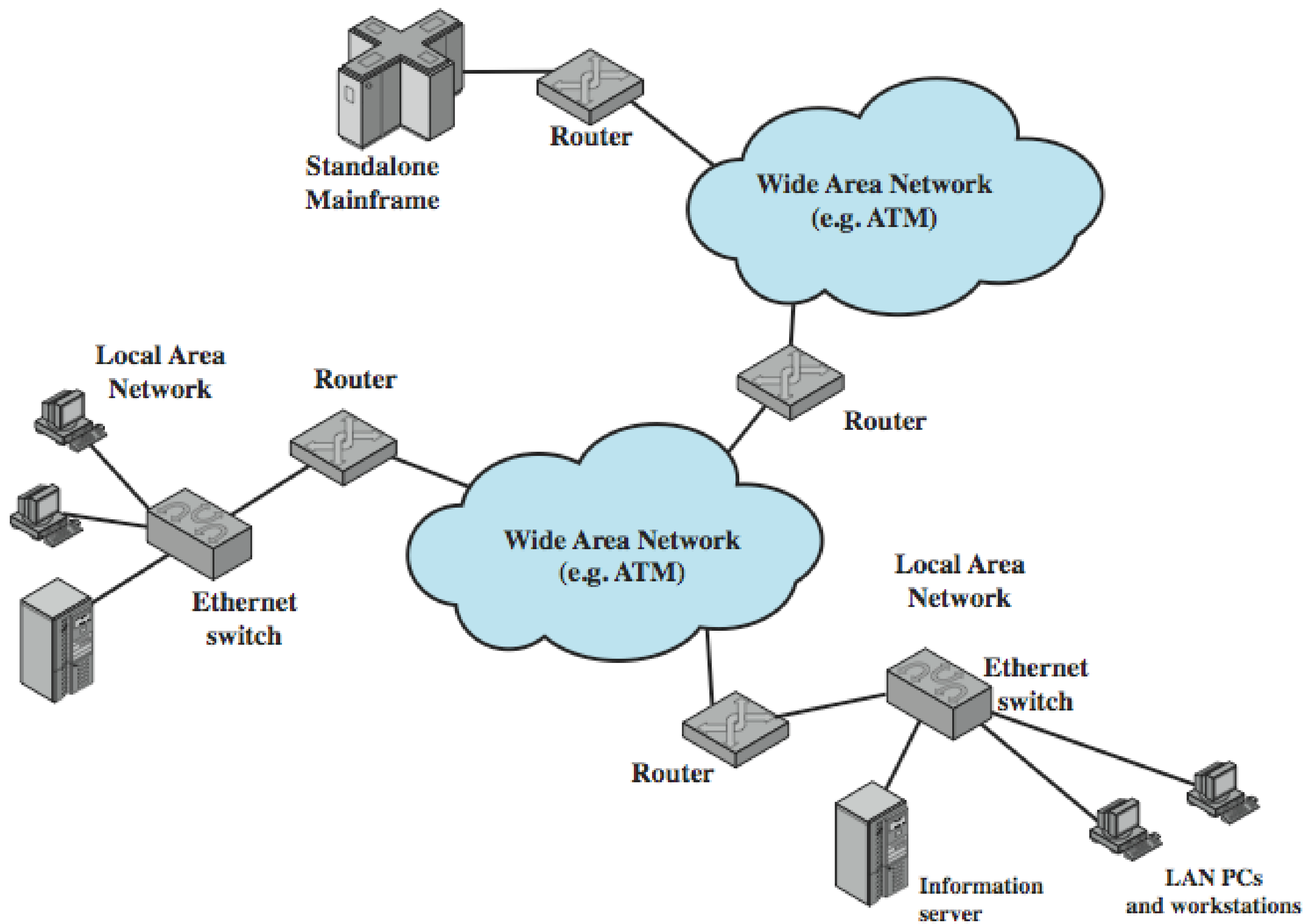
Metropolitan Area Networks

- MAN
- middle ground between LAN and WAN
- private or public network
- high speed
- large area

The Internet

- Internet evolved from ARPANET
  - first operational packet network
  - applied to tactical radio & satellite nets also
  - had a need for interoperability
  - led to standardized TCP/IP protocols

Internet Elements



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Chapter 2 – Protocol Architecture, TCP/IP, and Internet-Based Applications

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Need For Protocol Architecture

- data exchange can involve complex procedures, e.g. file transfer
- better if task broken into subtasks
- implemented separately in layers in stack
  - each layer provides functions needed to perform tasks for layers above
  - using functions provided by layers below
- peer layers communicate with a protocol

Key Elements of a Protocol

- syntax – data format
- semantics – control info & error handling
- timing – speed matching & sequencing

TCP/IP Protocol Architecture

- no official model but a working one
  - Application layer
  - Host-to-host, or transport layer
  - Internet layer
  - Network access layer
  - Physical layer

Physical Layer

- concerned with physical interface between computer and network
- concerned with issues like:
  - characteristics of transmission medium
  - signal levels
  - data rates
  - other related matters

Network Access Layer

- exchange of data between an end system and attached network
- concerned with issues like :
  - destination address provision
  - invoking specific services like priority
  - access to & routing data across a network link between two attached systems
- allows layers above to ignore link specifics

Internet Layer (IP)

- routing functions across multiple networks
- for systems attached to different networks
- using IP protocol
- implemented in end systems and routers
- routers connect two networks and relays data between them

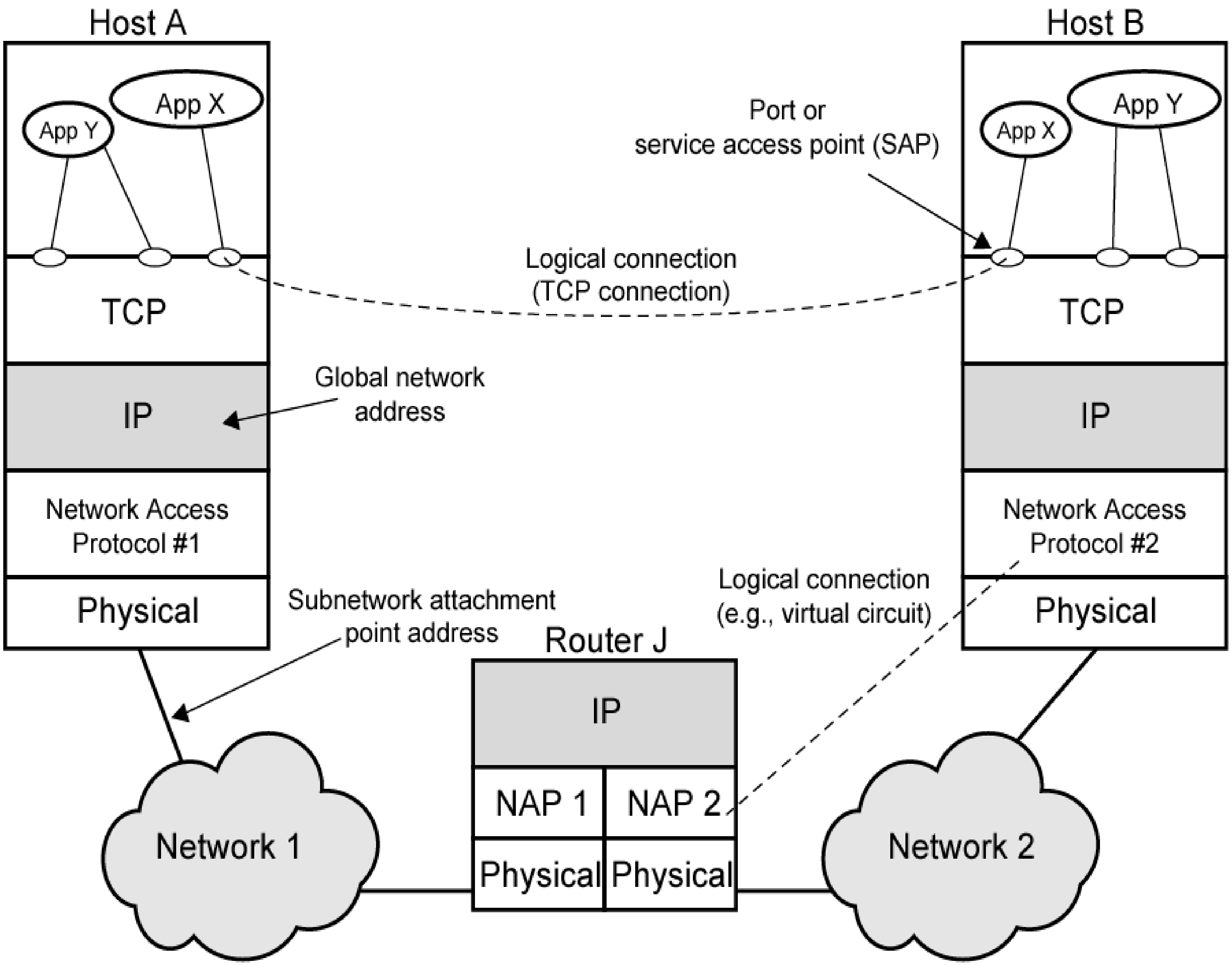
Transport Layer (TCP, UDP)

- common layer shared by all applications
- provides reliable delivery of data
- in same order as sent
- commonly uses TCP
  - Connection oriented
  - Error control, flow control
- Alternative protocol UDP
  - No overhead like TCP

Application Layer

- provide support for user applications
- need a separate module for each type of application
- Large number of protocols
  - SMTP for electronic mail transfer
  - HTTP for web access
  - FTP for file transfer
  - SIP, H.323 for voice and video communication
  - RTP for transporting real-time data

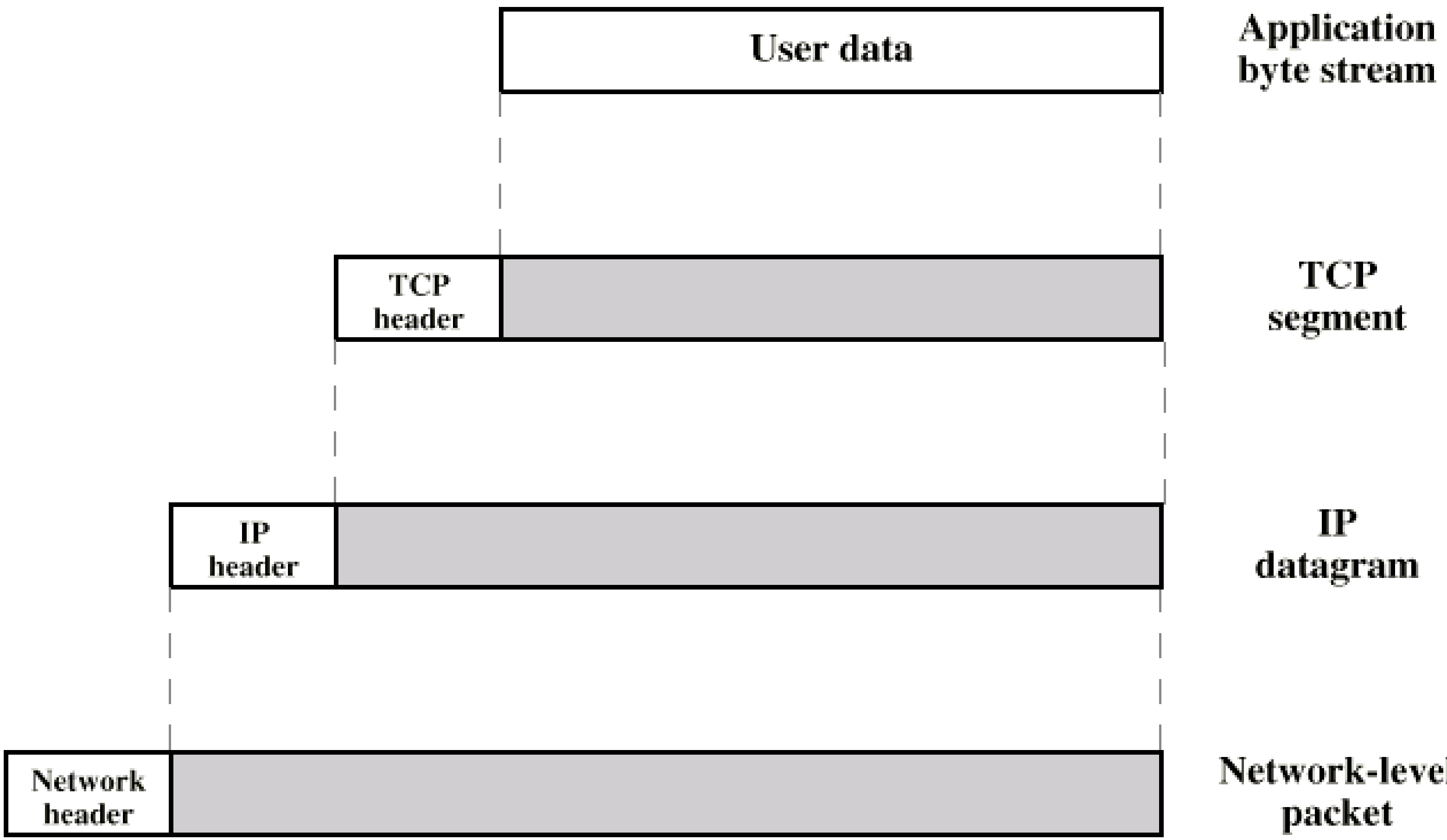
Operation of TCP and IP



Addressing Requirements

- two levels of addressing required
- each host on a subnet needs a unique global network address
  - its IP address
- each application on a (multi-tasking) host needs a unique address within the host
  - known as a port

Operation of TCP/IP



OSI

- Open Systems Interconnection
- developed by the International Organization for Standardization (ISO)
- has seven layers
- is a theoretical system delivered too late!
- TCP/IP is the de facto standard

OSI Layers

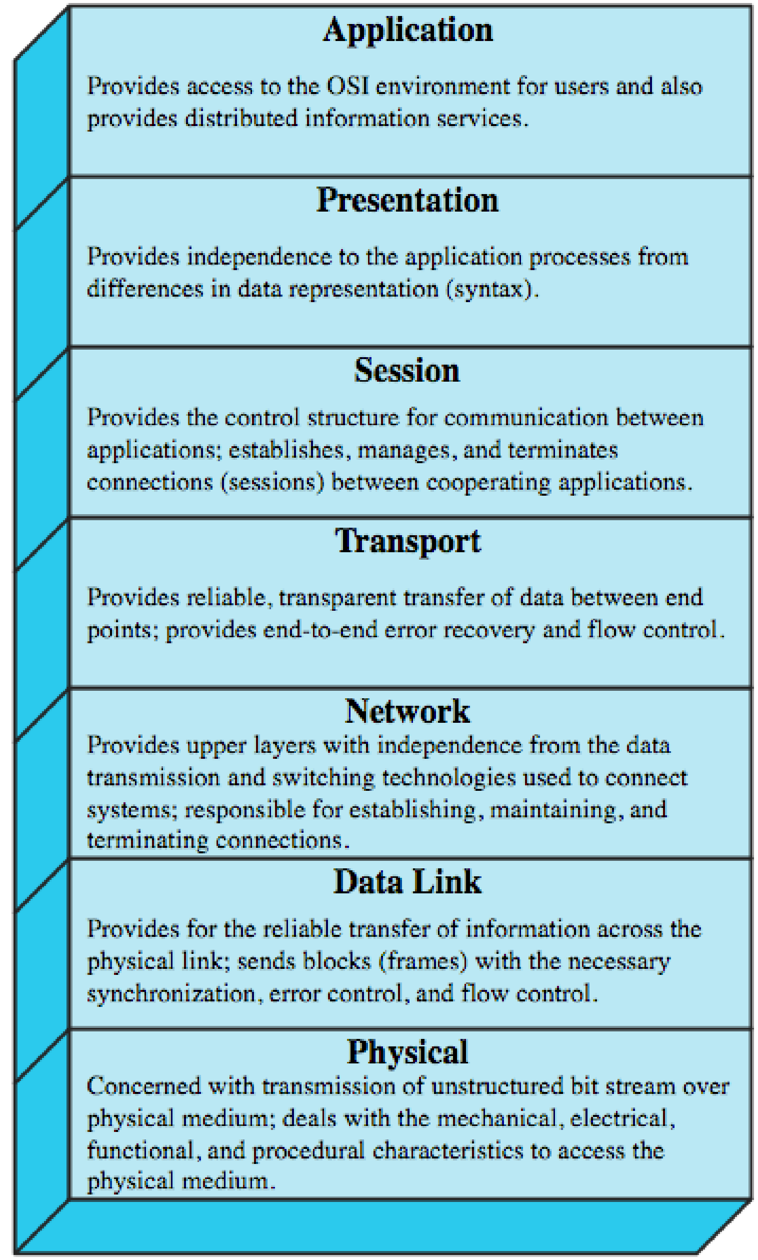
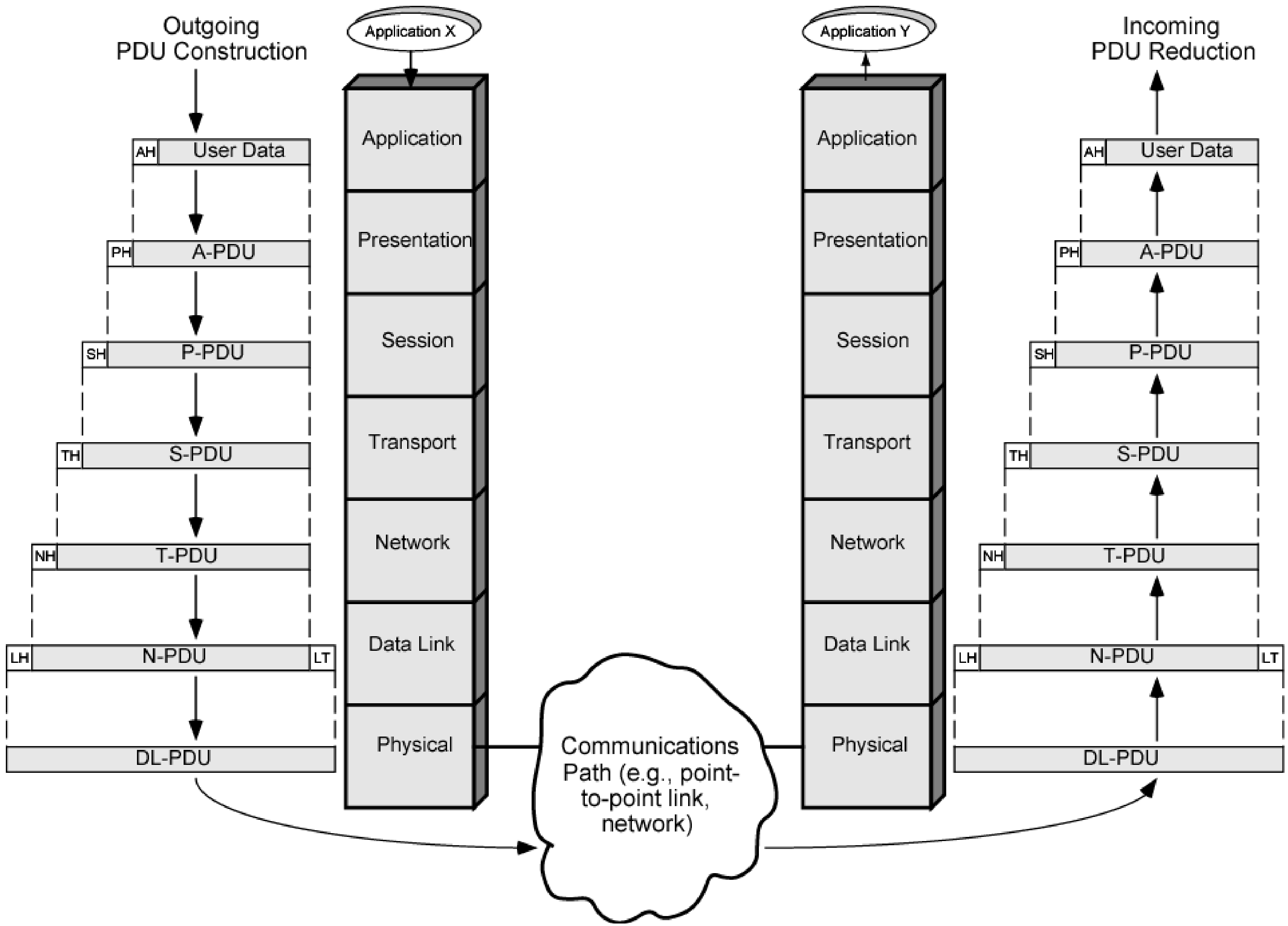


Figure 2.6 The OSI Layers

The OSI Environment



OSI Layers (1)

- Physical: Physical interface between devices
  - Mechanical – Physical connector dimensions
  - Electrical – Voltage levels for 1 and 0
  - Functional – Functions of each conductor in a connector
  - Procedural – Sequence of events for exchange of bits
- Data Link
  - Means of activating, maintaining and deactivating a reliable link
  - Error detection and control
  - Higher layers may assume error free transmission
  - Framing or grouping 1s and 0s into *frames*

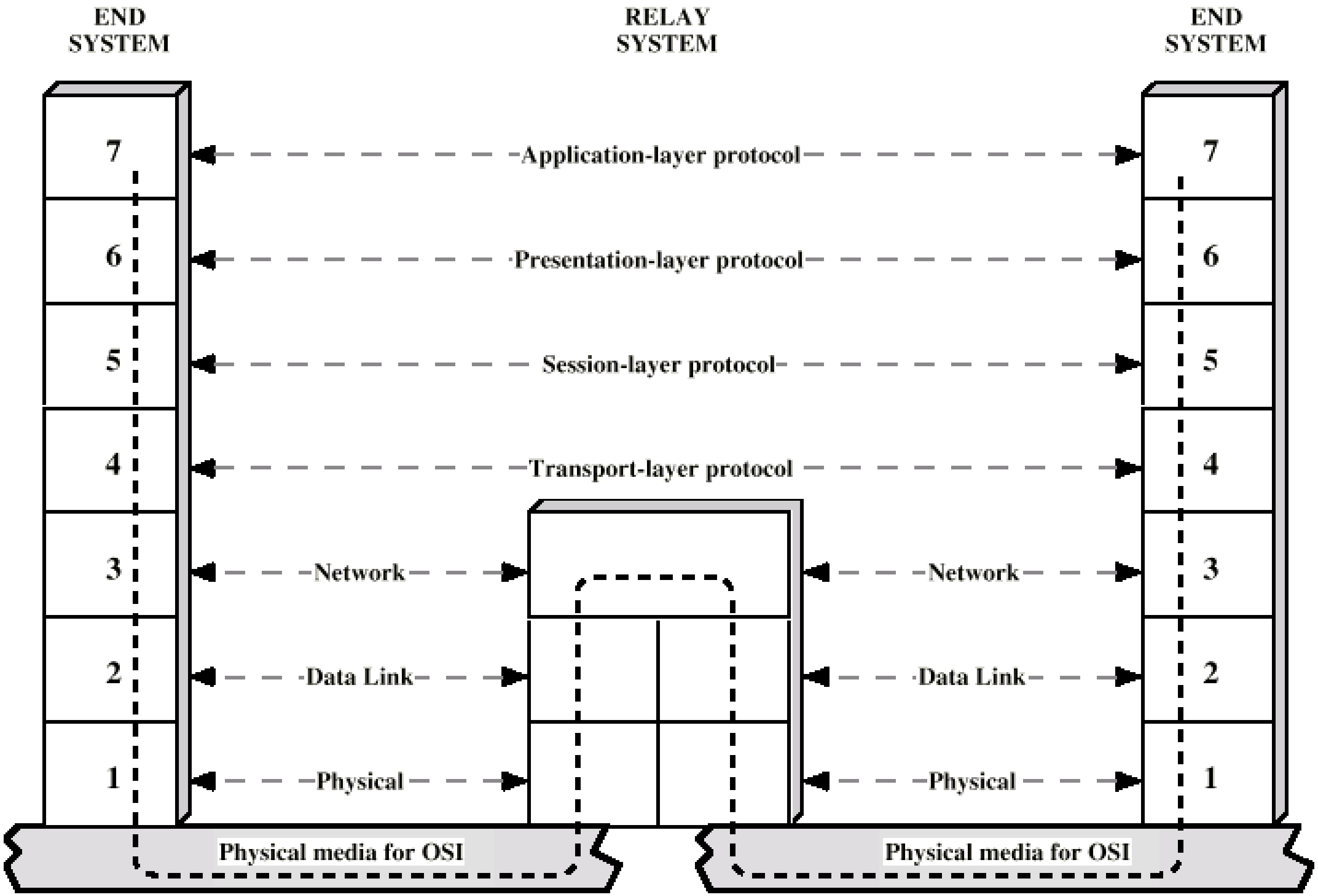
OSI Layers (2)

- Network
  - Transport of information
  - Higher layers do not need to know about underlying technology
  - Not needed on direct links
- Transport
  - Exchange of data between end systems
  - Error free
  - In sequence
  - No losses
  - No duplicates
  - Quality of service (performance guarantees)

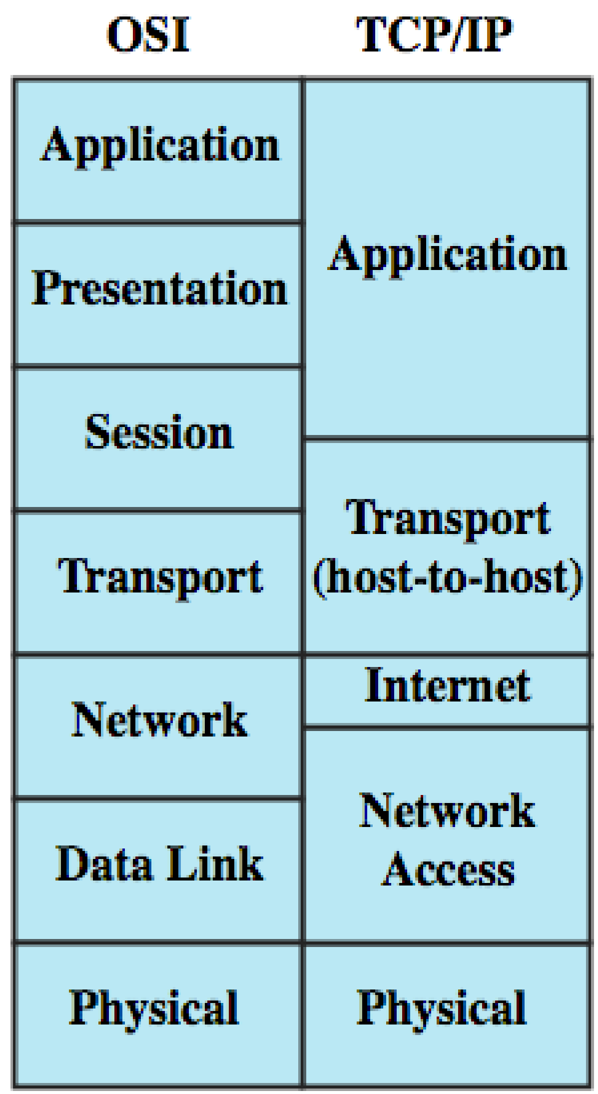
OSI Layers (3)

- Session
  - Control of dialogues between applications
  - Dialogue discipline (half duplex or full duplex)
  - Grouping (grouped data with some separator in between)
  - Recovery (e.g. use markers or checkpoints in stream)
- Presentation
  - Data formats and coding
  - Data compression
  - Encryption
- Application
  - Means for applications (user programs) to access OSI environment

Use of a Relay



OSI v TCP/IP


OSI
TCP/IP
Application
Presentation
Session
Transport
Network
Data Link
Physical
Application
Transport
(host-to-host)
Internet
Network
Access
Physical

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Chapter 3 – Data Transmission

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Transmission Terminology

- data transmission occurs between a transmitter & receiver via some medium
- guided medium
  - eg. twisted pair, coaxial cable, optical fiber
- unguided /wireless medium
  - eg. air, water, vacuum

Transmission Terminology

- direct link
  - no intermediate devices
- point-to-point
  - direct link
  - only 2 devices share link
- multi-point
  - more than two devices share the link

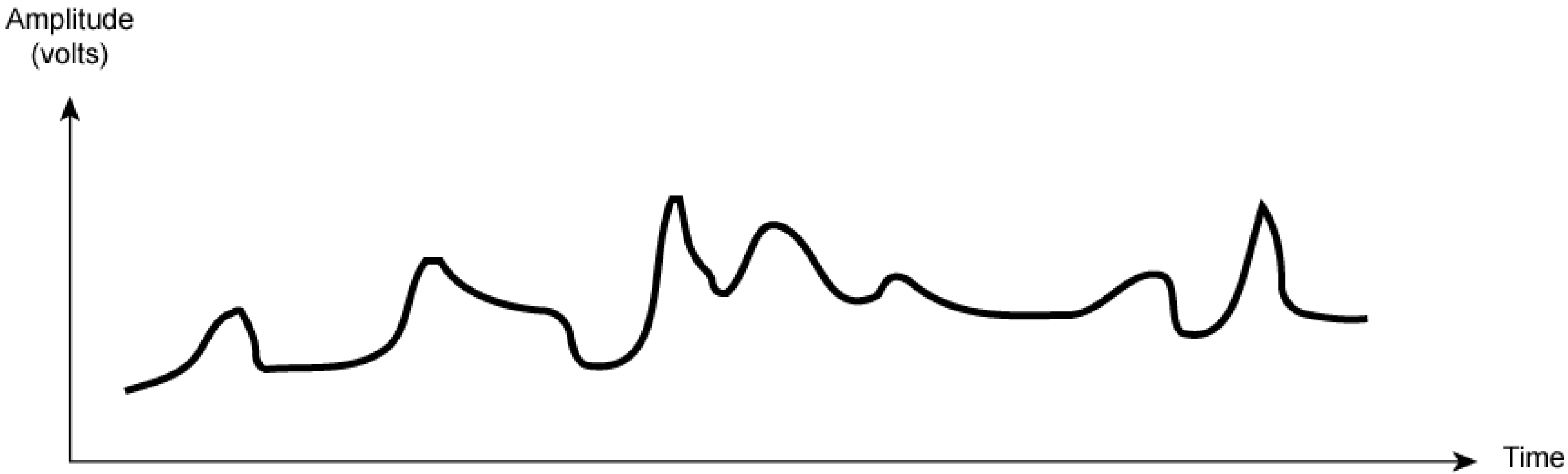
Transmission Terminology

- simplex
  - one direction
    - eg. television
- half duplex
  - either direction, but only one way at a time
    - eg. police radio
- full duplex
  - both directions at the same time
    - eg. telephone

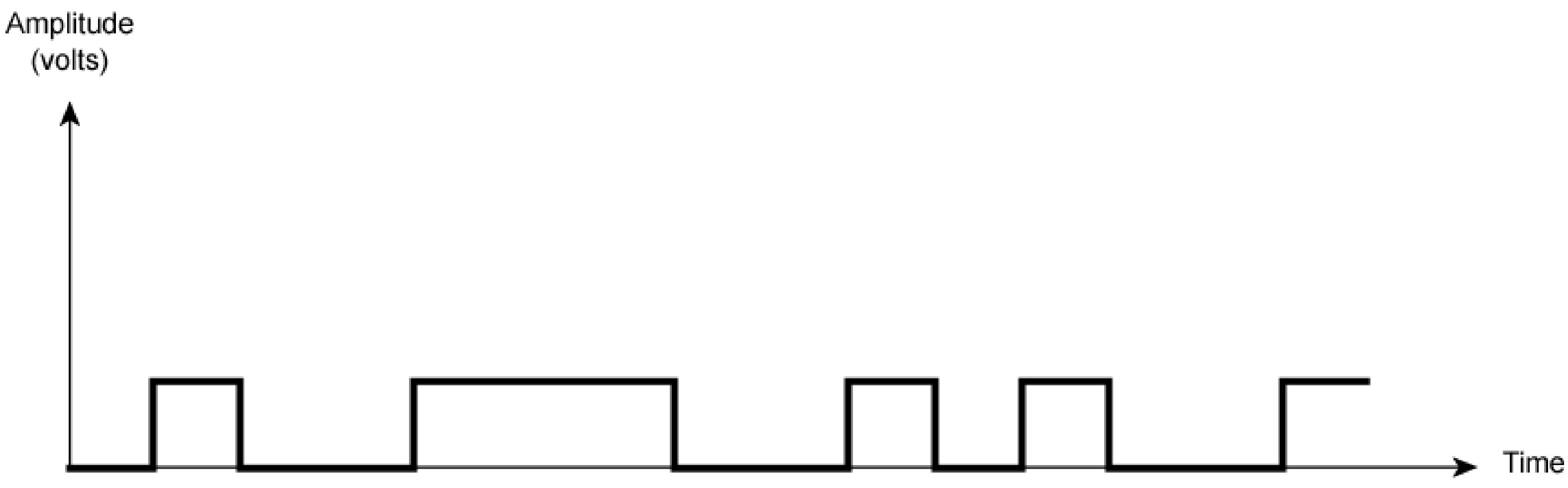
Frequency, Spectrum and Bandwidth

- time domain concepts
  - analog signal
    - various in a smooth way over time
  - digital signal
    - maintains a constant level then changes to another constant level
  - periodic signal
    - pattern repeated over time
  - aperiodic signal
    - pattern not repeated over time

Analogue & Digital Signals



(a) Analog



(b) Digital

Spectrum & Bandwidth

- spectrum
  - range of frequencies contained in signal
- absolute bandwidth
  - width of spectrum
- effective bandwidth
  - often just *bandwidth*
  - narrow band of frequencies containing most energy
- DC Component
  - component of zero frequency

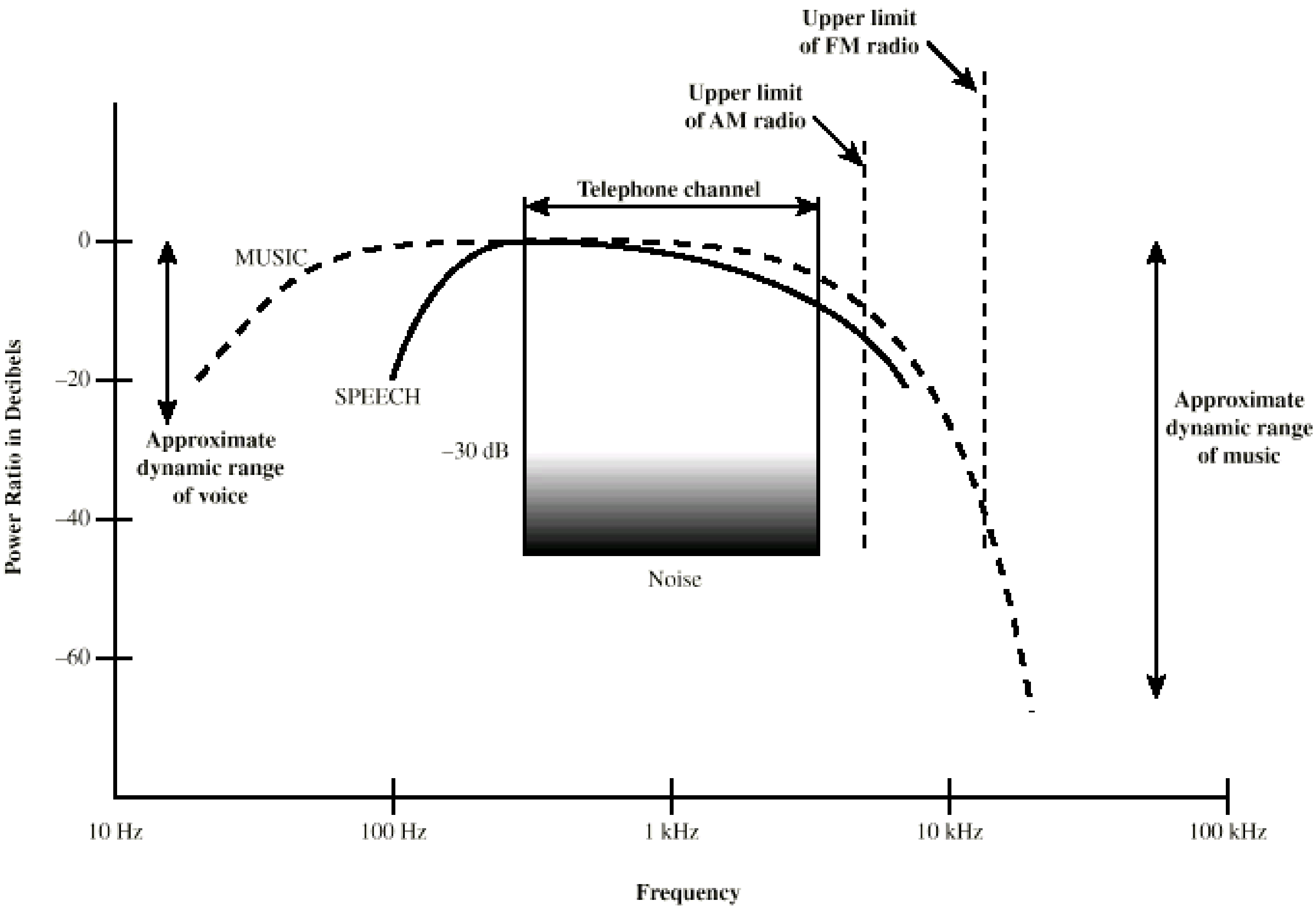
Data Rate and Bandwidth

- any transmission system has a limited band of frequencies
- this limits the data rate that can be carried
- square have infinite components and hence bandwidth
- but most energy in first few components
- limited bandwidth increases distortion
- have a direct relationship between data rate & bandwidth

Analog and Digital Data Transmission

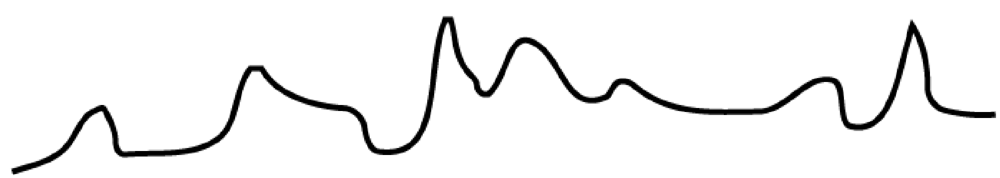
- data
  - entities that convey meaning
- signals & signalling
  - electric or electromagnetic representations of data, physically propagates along medium
- transmission
  - communication of data by propagation and processing of signals

Acoustic Spectrum (Analog)



Audio Signals

- freq range 20Hz-20kHz (speech 100Hz-7kHz)
- easily converted into electromagnetic signals
- varying volume converted to varying voltage
- can limit frequency range for voice channel to 300-3400Hz



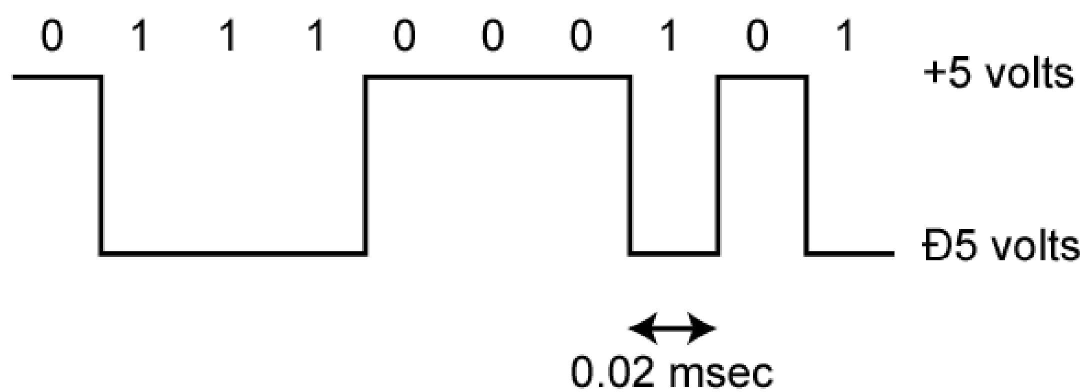
In this graph of a typical analog signal, the variations in amplitude and frequency convey the gradations of loudness and pitch in speech or music. Similar signals are used to transmit television pictures, but at much higher frequencies.

Video Signals

- USA – 483 lines per frame, at frames per sec
  - have 525 lines but 42 lost during vertical retrace
- 525 lines x 30 scans = 15750 lines per sec
  - 63.5μs per line
  - 11μs for retrace, so 52.5 μs per video line
- max frequency if line alternates black and white
- horizontal resolution is about 450 lines giving 225 cycles of wave in 52.5 μs
- max frequency of 4.2MHz

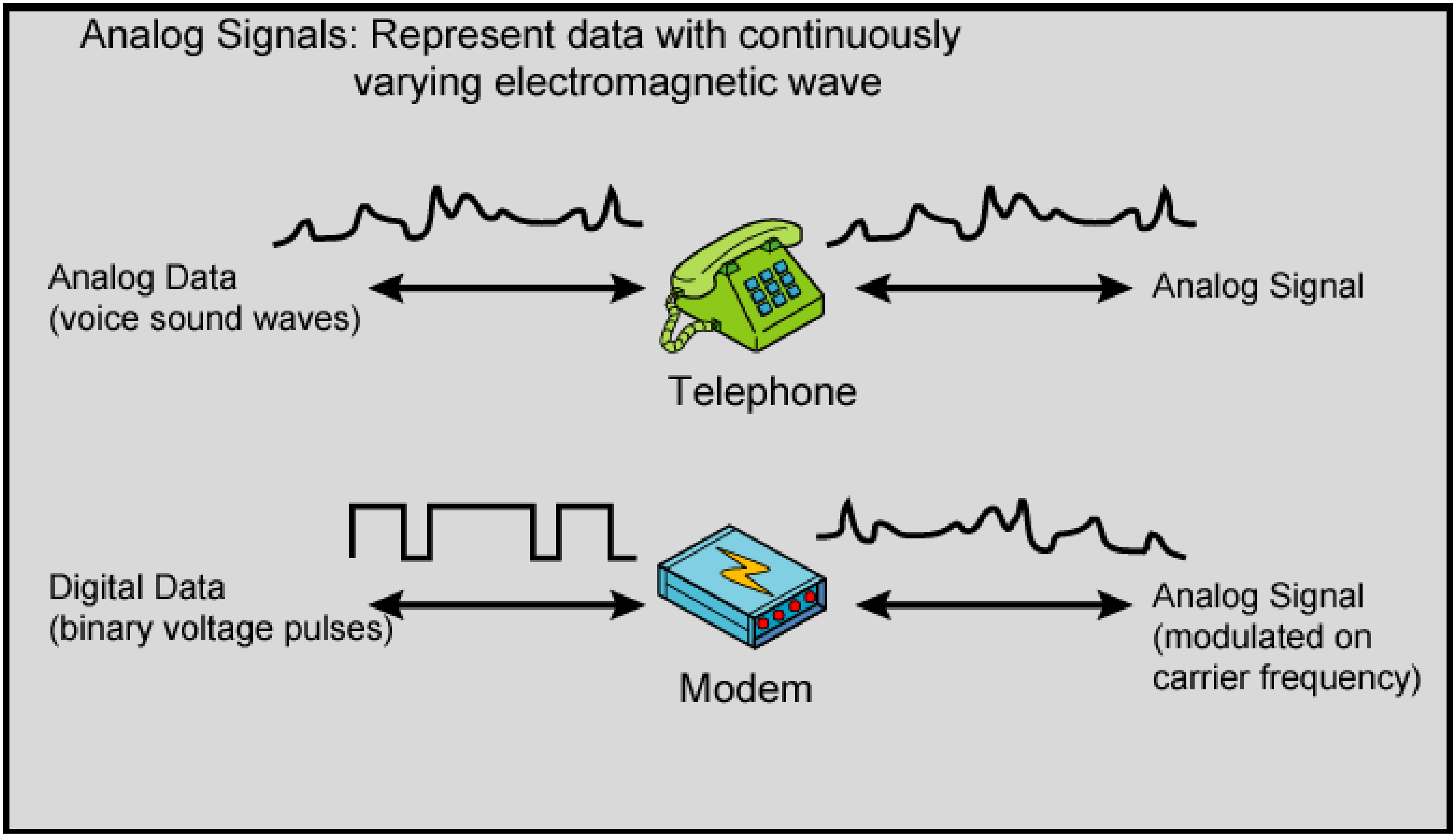
Digital Data

- as generated by computers etc.
- has two dc components
- bandwidth depends on data rate

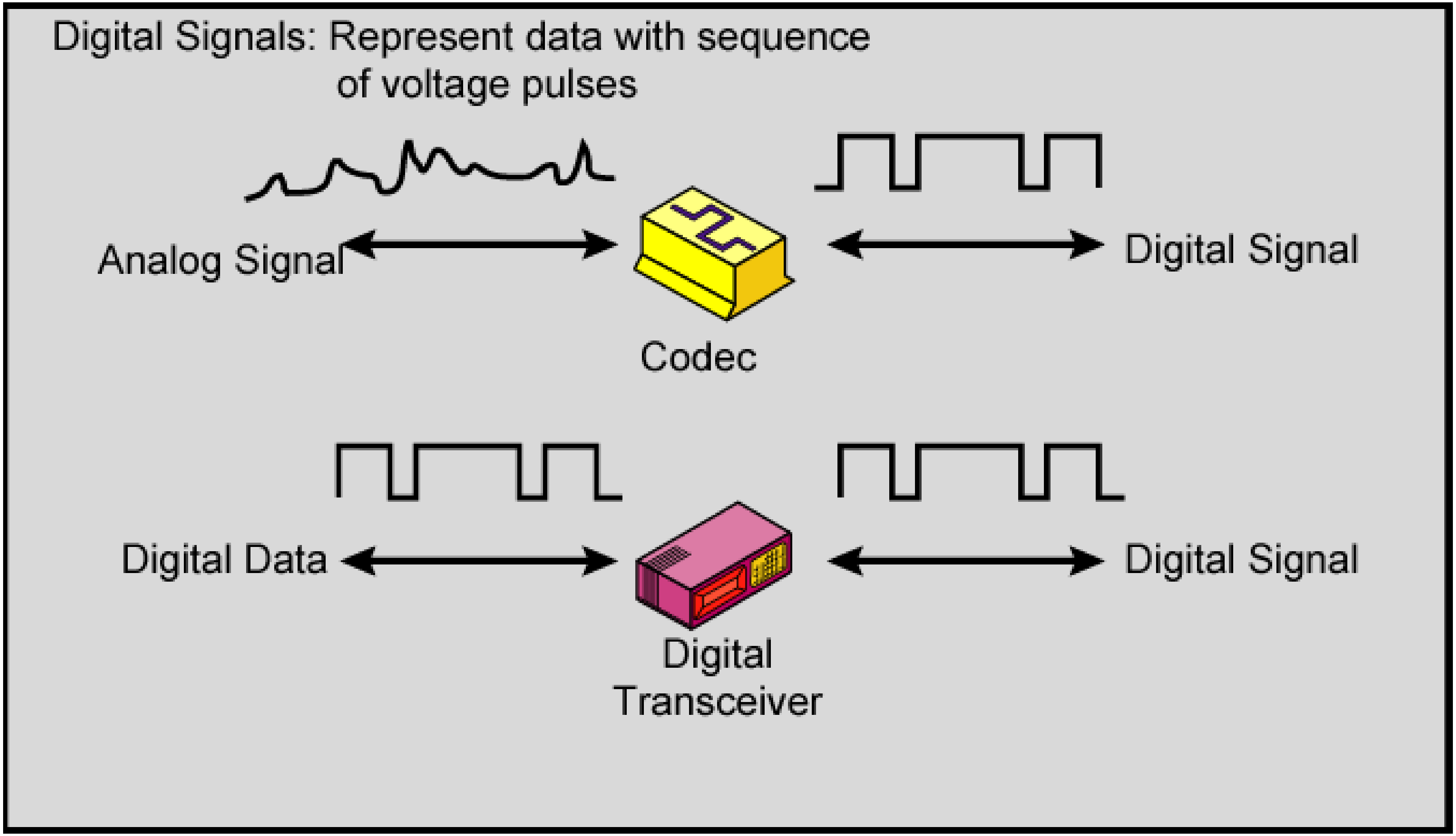


User input at a PC is converted into a stream of binary digits (1s and 0s). In this graph of a typical digital signal, binary one is represented by Ð5 volts and binary zero is represented by +5 volts. The signal for each bit has a duration of 0.02 msec, giving a data rate of 50,000 bits per second (50 kbps).

Analog Signals

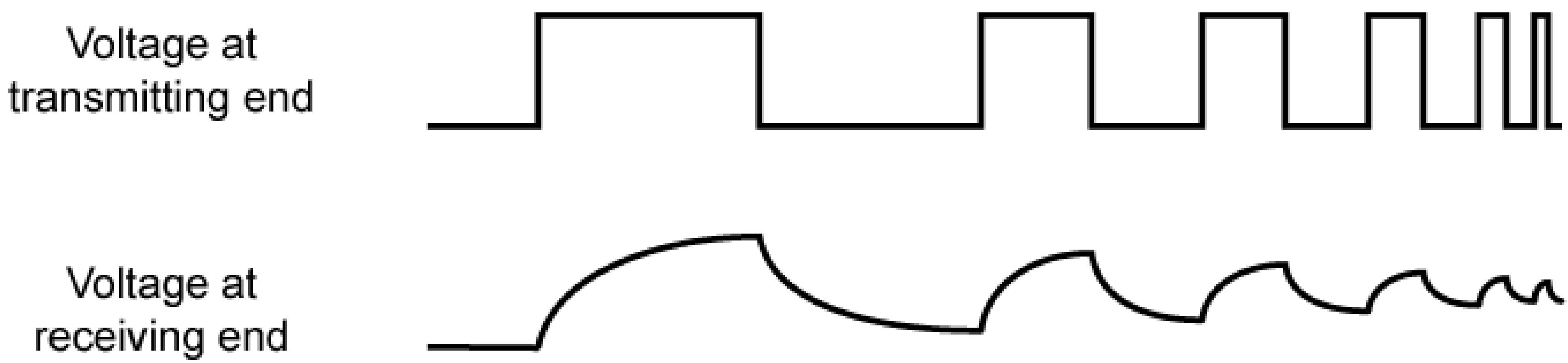


Digital Signals



Advantages & Disadvantages of Digital Signals

- cheaper
- less susceptible to noise
- but greater attenuation
- digital now preferred choice



Transmission Impairments

- signal received may differ from signal transmitted causing:
  - analog - degradation of signal quality
  - digital - bit errors
- most significant impairments are
  - attenuation and attenuation distortion
  - delay distortion
  - noise

Attenuation

- where signal strength falls off with distance
- depends on medium
- received signal strength must be:
  - strong enough to be detected
  - sufficiently higher than noise to receive without error
- so increase strength using amplifiers/repeaters
- is also an increasing function of frequency
- so equalize attenuation across band of frequencies used
  - eg. using loading coils or amplifiers

Delay Distortion

- only occurs in guided media
- propagation velocity varies with frequency
- hence various frequency components arrive at different times
- particularly critical for digital data
- since parts of one bit spill over into others
- causing intersymbol interference

Noise

- additional signals inserted between transmitter and receiver
- thermal
  - due to thermal agitation of electrons
  - uniformly distributed
  - white noise
- intermodulation
  - signals that are the sum and difference of original frequencies sharing a medium

Noise

- crosstalk
  - a signal from one line is picked up by another
- impulse
  - irregular pulses or spikes
    - eg. external electromagnetic interference
  - short duration
  - high amplitude
  - a minor annoyance for analog signals
  - but a major source of error in digital data
    - a noise spike could corrupt many bits

Channel Capacity

- max possible data rate on comms channel
- is a function of
  - data rate –in bits per second
  - bandwidth –in cycles per second or Hertz
  - noise –on comms link
  - error rate –of corrupted bits
- limitations due to physical properties
- want most efficient use of capacity

Nyquist Bandwidth

- consider noise free channels
- if rate of signal transmission is 2B then can carry signal with frequencies no greater than B
  - ie. given bandwidth B, highest signal rate is 2B
- for binary signals, 2B bps needs bandwidth B Hz
- can increase rate by using M signal levels
- Nyquist Formula is: $C = 2B \log_2 M$
- so increase rate by increasing signals
  - at cost of receiver complexity
  - limited by noise & other impairments

Shannon Capacity Formula

- consider relation of data rate, noise & error rate
  - faster data rate shortens each bit so bursts of noise affects more bits
  - given noise level, higher rates means higher errors
- Shannon developed formula relating these to signal to noise ratio (in decibels)
- $SNR_{db} = 10 \log_{10}(signal/noise)$
- Capacity $C = B \log_2(1 + SNR)$
  - theoretical maximum capacity
  - get lower in practise

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Chapter 4 –Transmission Media

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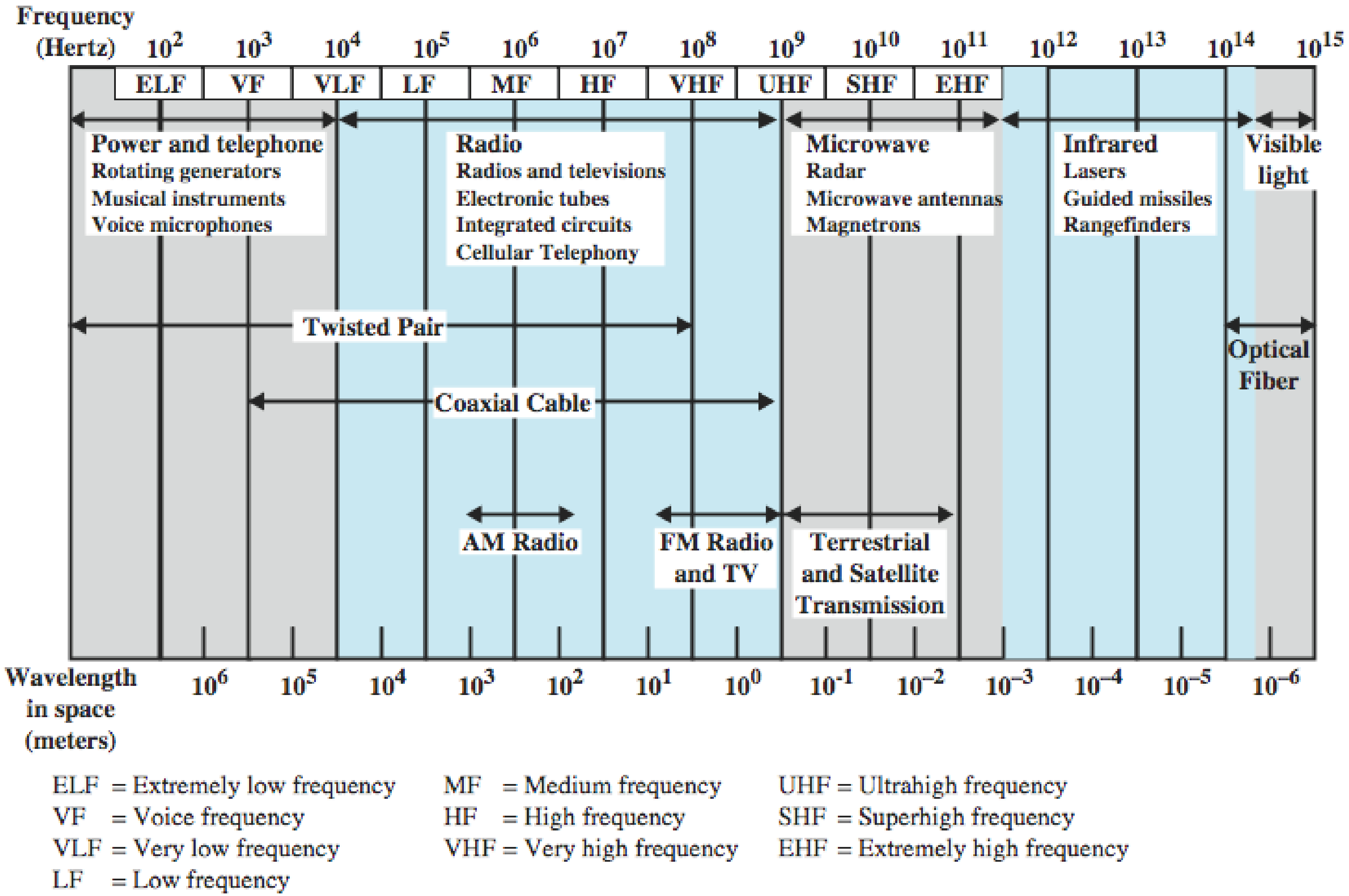
Design Factors

- bandwidth
  - higher bandwidth gives higher data rate
- transmission impairments
  - eg. attenuation
- interference
- number of receivers in guided media
  - more receivers introduces more attenuation

Electromagnetic Spectrum



Transmission Characteristics of Guided Media

	Frequency Range	**Typical Attenuation**	**Typical Delay**	**Repeater Spacing**
Twisted pair (with loading)	0 to 3.5 kHz	0.2 dB/km @ 1 kHz	50 μs/km	2 km
Twisted pairs (multi-pair cables)	0 to 1 MHz	0.7 dB/km @ 1 kHz	5 μs/km	2 km
Coaxial cable	0 to 500 MHz	7 dB/km @ 10 MHz	4 μs/km	1 to 9 km
Optical fiber	186 to 370 THz	0.2 to 0.5 dB/km	5 μs/km	40 km

Twisted Pair

- Separately insulated
- Twisted together
- Often "bundled" into cables
- Usually installed in building during construction

(a) Twisted pair

Twisted Pair – Transmission Characteristics

- analog
  - needs amplifiers every 5km to 6km
- digital
  - can use either analog or digital signals
  - needs a repeater every 2-3km
- limited distance
- limited bandwidth (1MHz)
- limited data rate (100MHz)
- susceptible to interference and noise

Unshielded vs Shielded TP

- unshielded Twisted Pair (UTP)
  - ordinary telephone wire
  - cheapest
  - easiest to install
  - suffers from external EM interference
- shielded Twisted Pair (STP)
  - metal braid or sheathing that reduces interference
  - more expensive
  - harder to handle (thick, heavy)
- in a variety of categories - see EIA-568

UTP Categories

	Category 3 Class C	Category 5 Class D	Category 5E	Category 6 Class E	Category 7 Class F
Bandwidth	16 MHz	100 MHz	100 MHz	200 MHz	600 MHz
Cable Type	UTP	UTP/FTP	UTP/FTP	UTP/FTP	SSTP
Link Cost (Cat 5 =1)	0.7	1	1.2	1.5	2.2

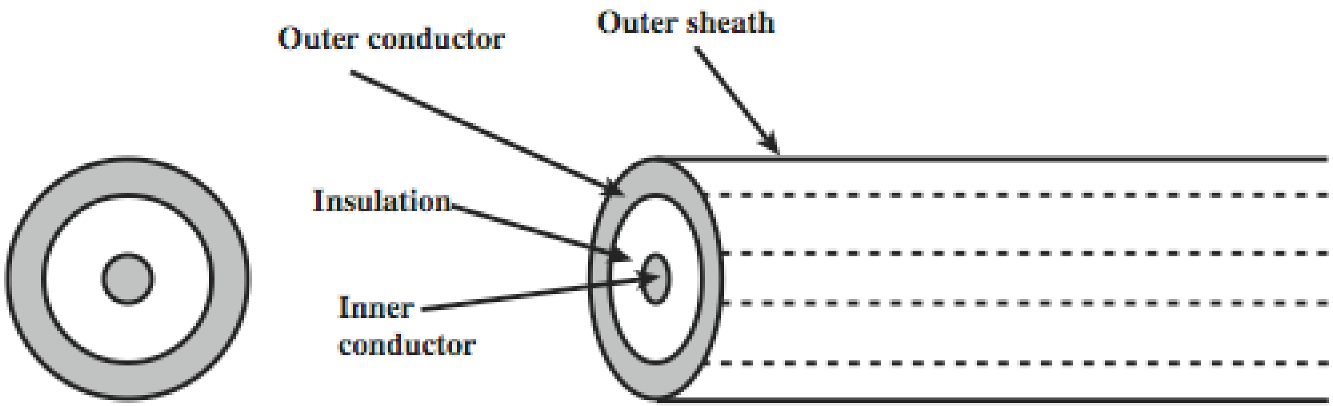
Comparison of Shielded and Unshielded Twisted Pair

	Attenuation (dB per 100 m)			Near-end Crosstalk (dB)		
Frequency (MHz)	**Category 3 UTP**	**Category 5 UTP**	**150-ohm STP**	**Category 3 UTP**	**Category 5 UTP**	**150-ohm STP**
1	2.6	2.0	1.1	41	62	58
4	5.6	4.1	2.2	32	53	58
16	13.1	8.2	4.4	23	44	50.4
25	—	10.4	6.2	—	41	47.5
100	—	22.0	12.3	—	32	38.5
300	—	—	21.4	—	—	31.3

Near End Crosstalk

- coupling of signal from one pair to another
- occurs when transmit signal entering the link couples back to receiving pair
- ie. near transmitted signal is picked up by near receiving pair

Coaxial Cable



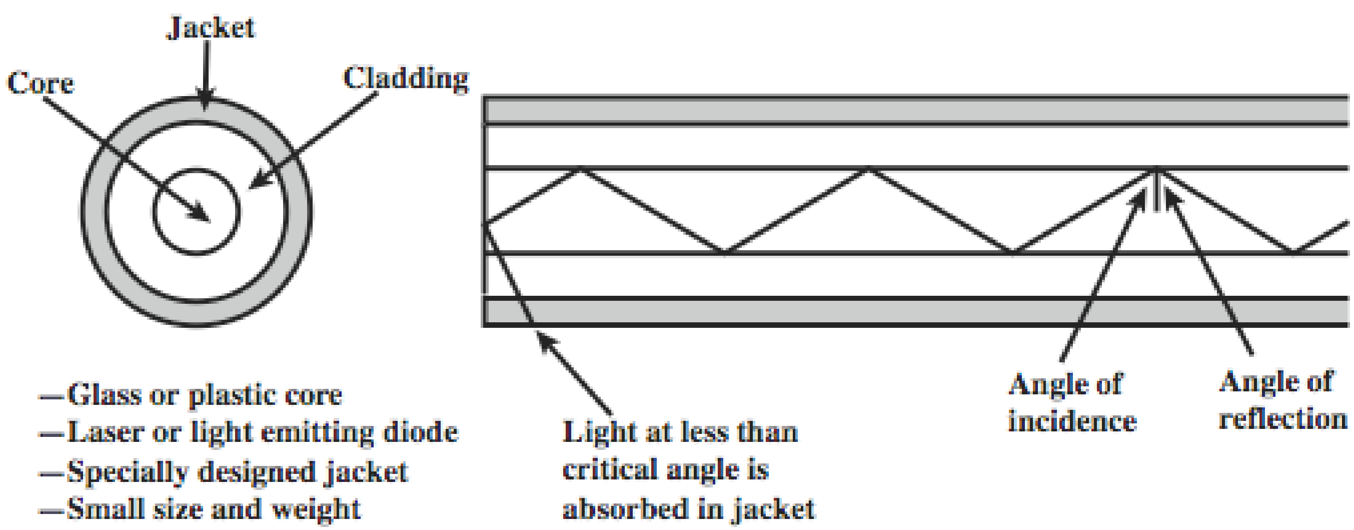
- Outer conductor is braided shield
- Inner conductor is solid metal
- Separated by insulating material
- Covered by padding

(b) Coaxial cable

Coaxial Cable – Transmission Characteristics

- superior frequency characteristics to TP
- performance limited by attenuation & noise
- analog signals
  - amplifiers every few km
  - closer if higher frequency
  - up to 500MHz
- digital signals
  - repeater every 1km
  - closer for higher data rates

Optical Fiber



(c) Optical fiber

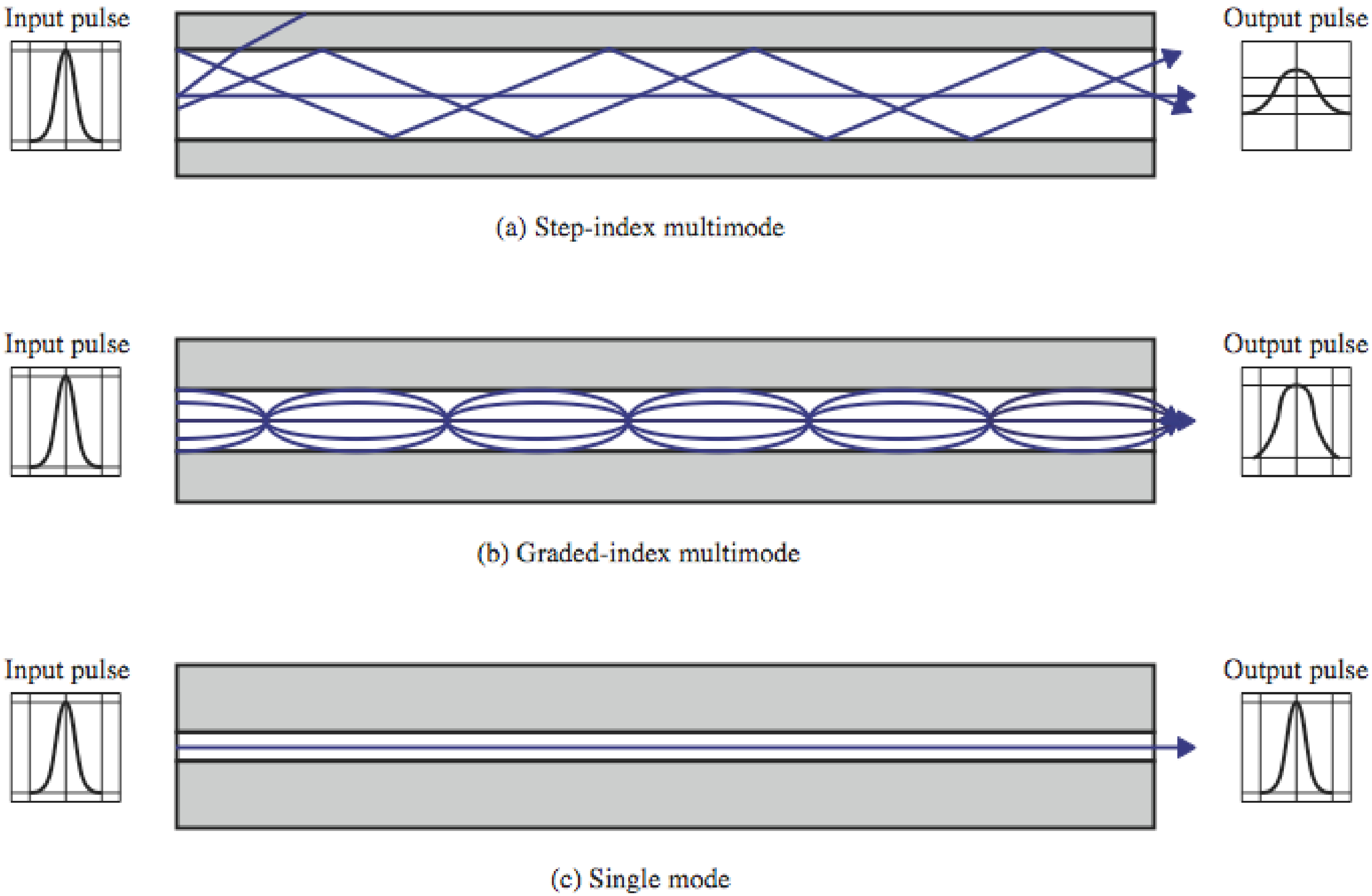
Optical Fiber – Benefits

- greater capacity
  - data rates of hundreds of Gbps
- smaller size & weight
- lower attenuation
- electromagnetic isolation
- greater repeater spacing
  - 10s of km at least

Optical Fiber – Transmission Characteristics

- uses total internal reflection to transmit light
  - effectively acts as wave guide for 10^{14} to 10^{15} Hz
- can use several different light sources
  - Light Emitting Diode (LED)
    - cheaper, wider operating temp range, lasts longer
  - Injection Laser Diode (ILD)
    - more efficient, has greater data rate
- relation of wavelength, type & data rate

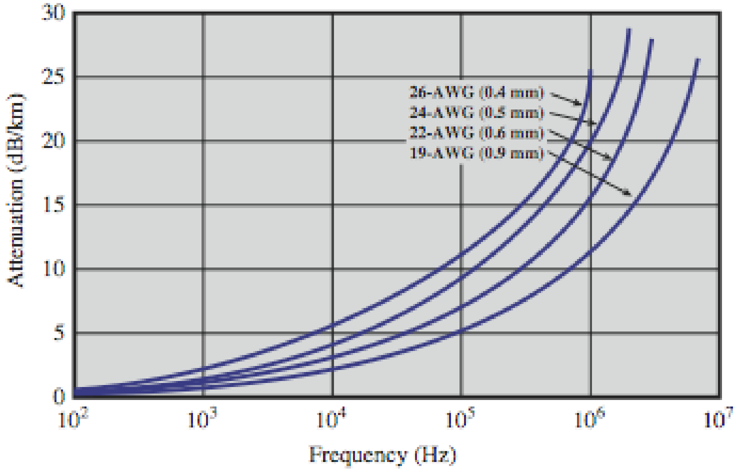
Optical Fiber Transmission Modes



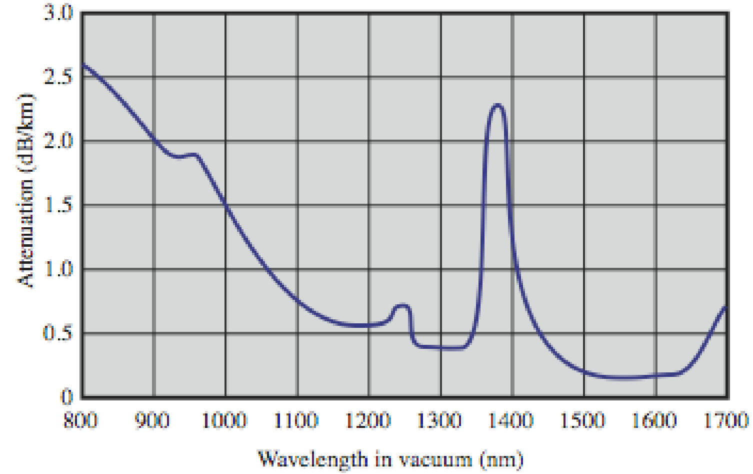
Frequency Utilization for Fiber Applications

Wavelength (in vacuum) range (nm)	Frequency Range (THz)	Band Label	Fiber Type	Application
820 to 900	366 to 333		Multimode	LAN
1280 to 1350	234 to 222	S	Single mode	Various
1528 to 1561	196 to 192	C	Single mode	WDM
1561 to 1620	192 to 185	L	Single mode	WDM

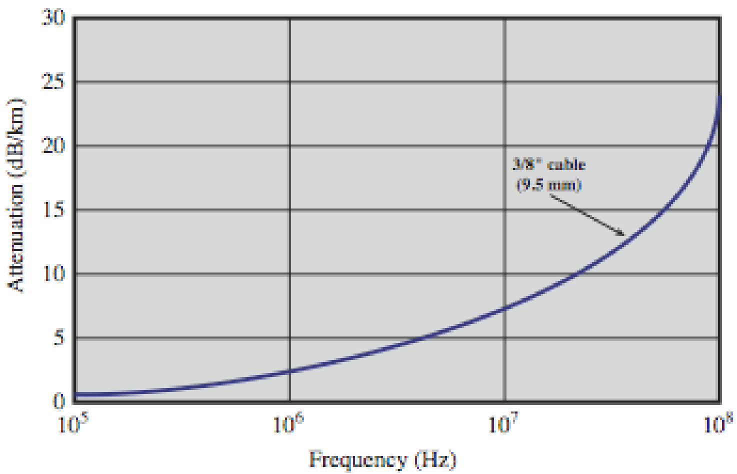
Attenuation in Guided Media



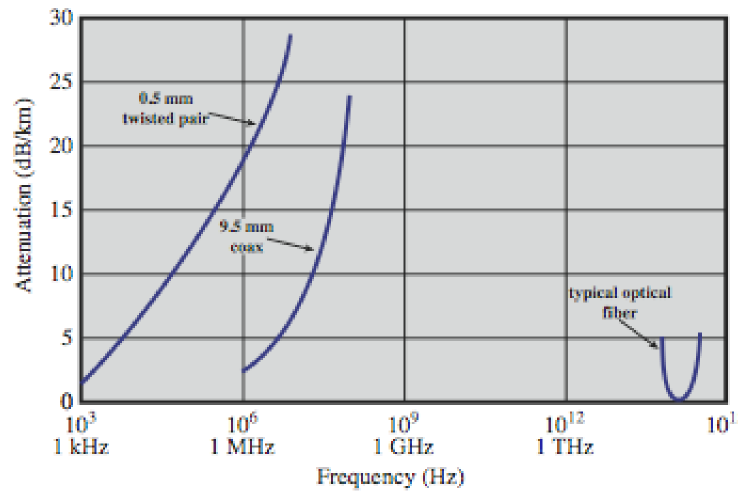
(a) Twisted pair (based on [REEV95])



(c) Optical fiber (based on [FREE02])



(b) Coaxial cable (based on [BELL90])



(d) Composite graph

Wireless Transmission Frequencies

- 2GHz to 40GHz
  - microwave
  - highly directional
  - point to point
  - satellite
- 30MHz to 1GHz
  - omnidirectional
  - broadcast radio
- 3×10^{11} to 2×10^{14}
  - infrared
  - local

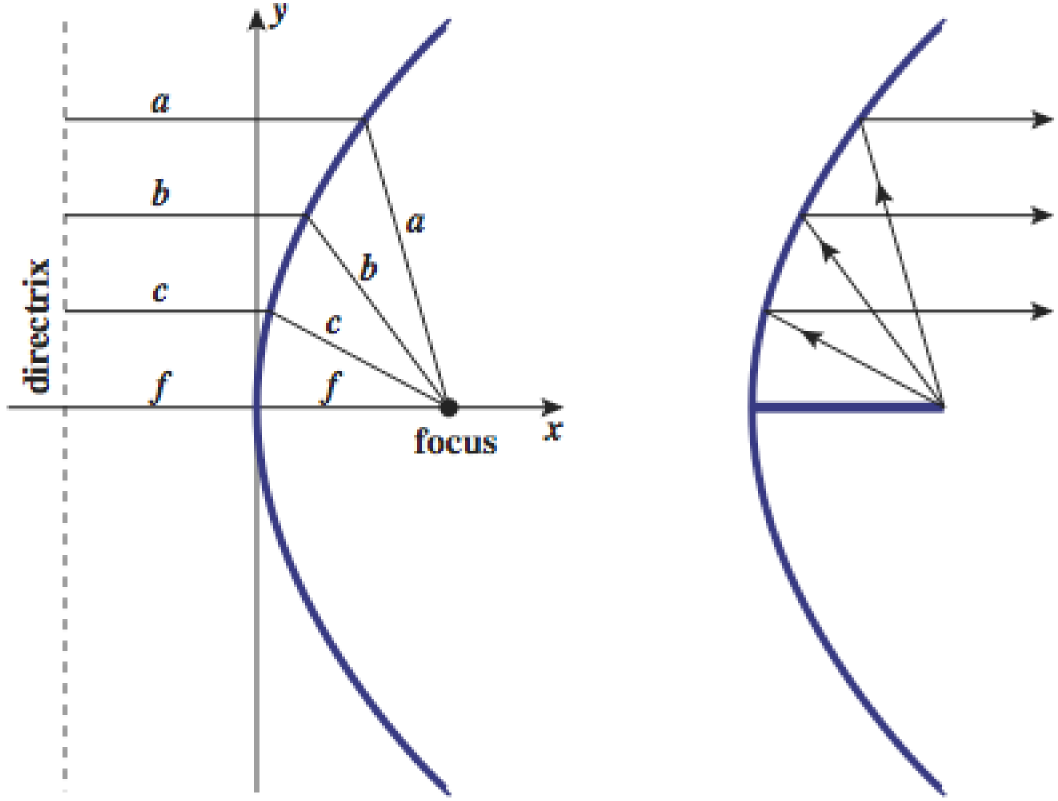
Antennas

- electrical conductor used to radiate or collect electromagnetic energy
- transmission antenna
  - radio frequency energy from transmitter
  - converted to electromagnetic energy byy antenna
  - radiated into surrounding environment
- reception antenna
  - electromagnetic energy impinging on antenna
  - converted to radio frequency electrical energy
  - fed to receiver
- same antenna is often used for both purposes

Radiation Pattern

- power radiated in all directions
- not same performance in all directions
  - as seen in a radiation pattern diagram
- an isotropic antenna is a (theoretical) point in space
  - radiates in all directions equally
  - with a spherical radiation pattern

Parabolic Reflective Antenna



(a) Parabola

(b) Cross-section of parabolic antenna showing reflective property

Antenna Gain

- measure of directionality of antenna
- power output in particular direction verses that produced by an isotropic antenna
- measured in decibels (dB)
- results in loss in power in another direction
- effective area relates to size and shape
  - related to gain

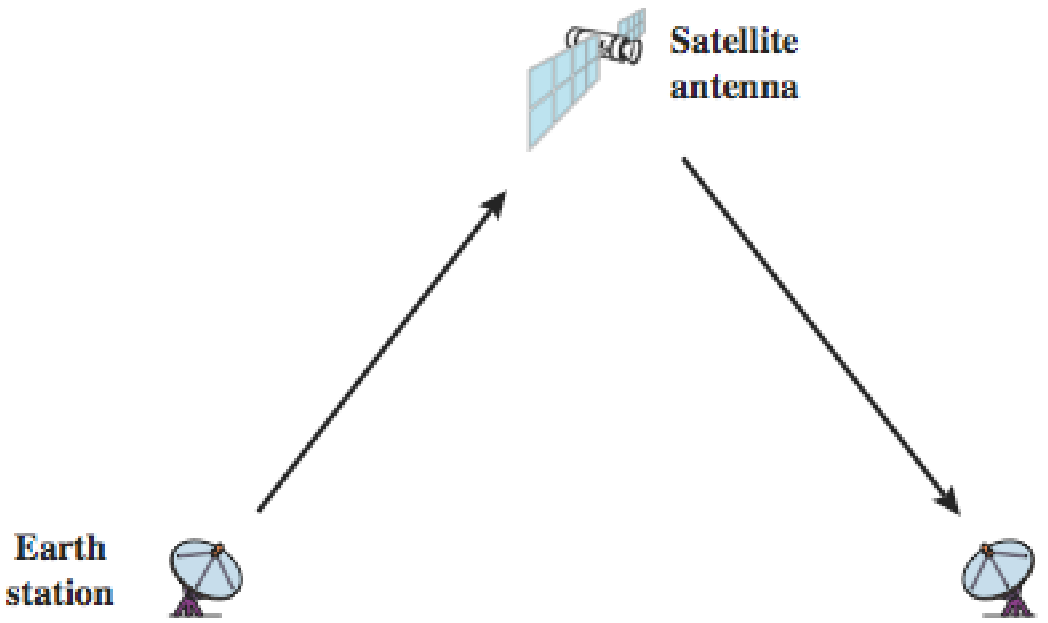
Terrestrial Microwave

- used for long haul telecommunications
- and short point-to-point links
- requires fewer repeaters but line of sight
- use a parabolic dish to focus a narrow beam onto a receiver antenna
- 1-40GHz frequencies
- higher frequencies give higher data rates
- main source of loss is attenuation
  - distance, rainfall
- also interference

Satellite Microwave

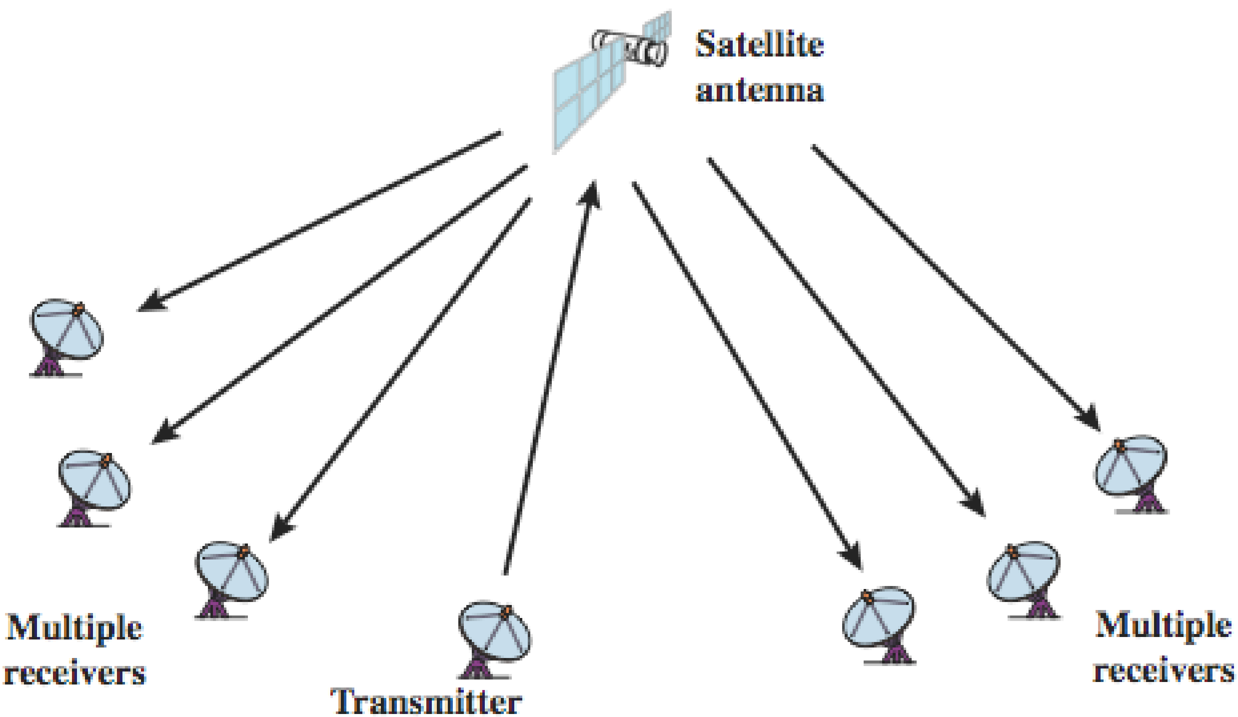
- satellite is relay station
- receives on one frequency, amplifies or repeats signal and transmits on another frequency
  - eg. uplink 5.925-6.425 GHz & downlink 3.7-4.2 GHz
- typically requires geo-stationary orbit
  - height of 35,784km
  - spaced at least 3-4° apart
- typical uses
  - television
  - long distance telephone
  - private business networks
  - global positioning

Satellite Point to Point Link



(a) Point-to-point link

Satellite Broadcast Link



(b) Broadcast link

Broadcast Radio

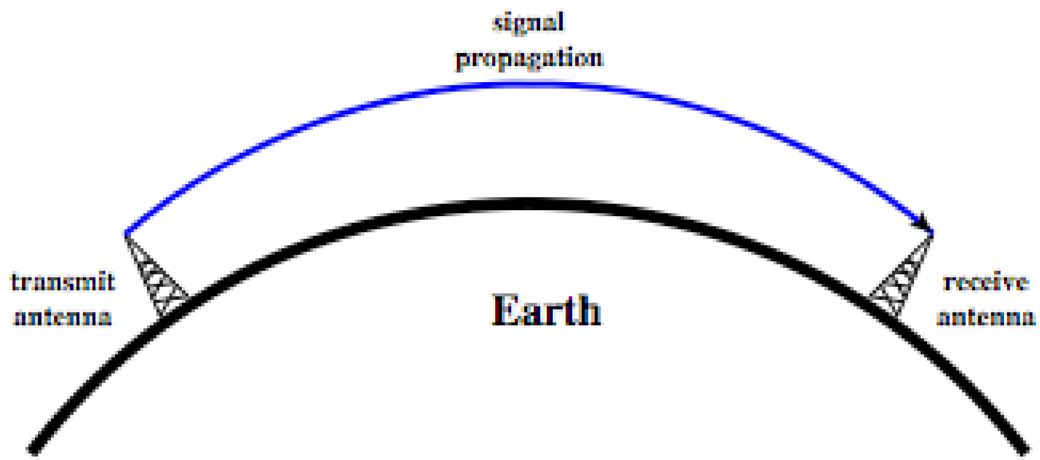
- radio is 3kHz to 300GHz
- use broadcast radio, 30MHz - 1GHz, for:
  - FM radio
  - UHF and VHF television
- is omnidirectional
- still need line of sight
- suffers from multipath interference
  - reflections from land, water, other objects

Infrared

- modulate noncoherent infrared light
- end line of sight (or reflection)
- are blocked by walls
- no licenses required
- typical uses
  - TV remote control
  - IRD port

Wireless Propagation

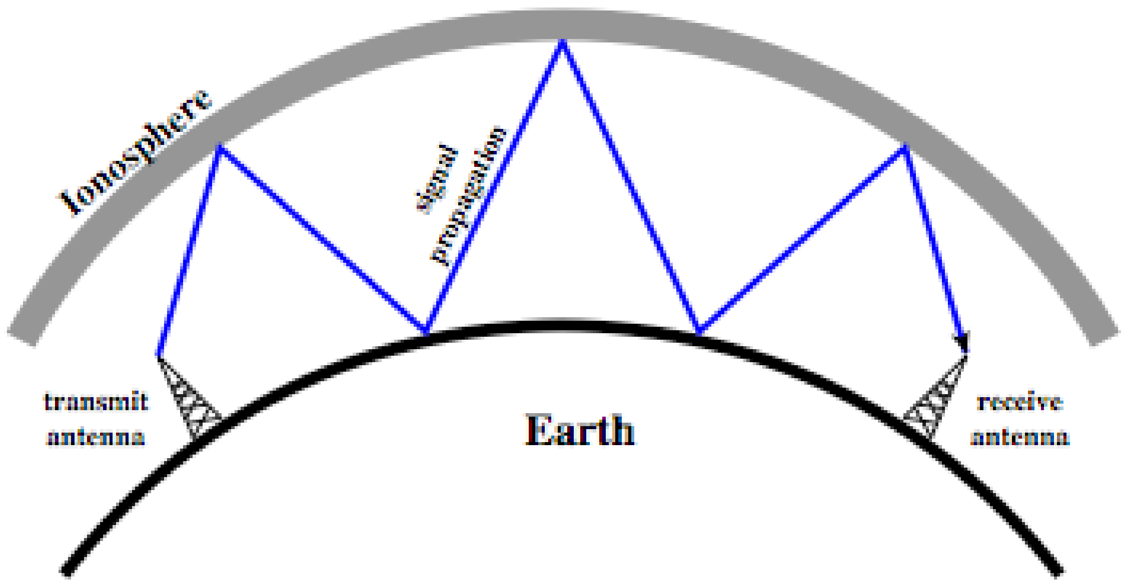
Ground Wave



(a) Ground-wave propagation (below 2 MHz)

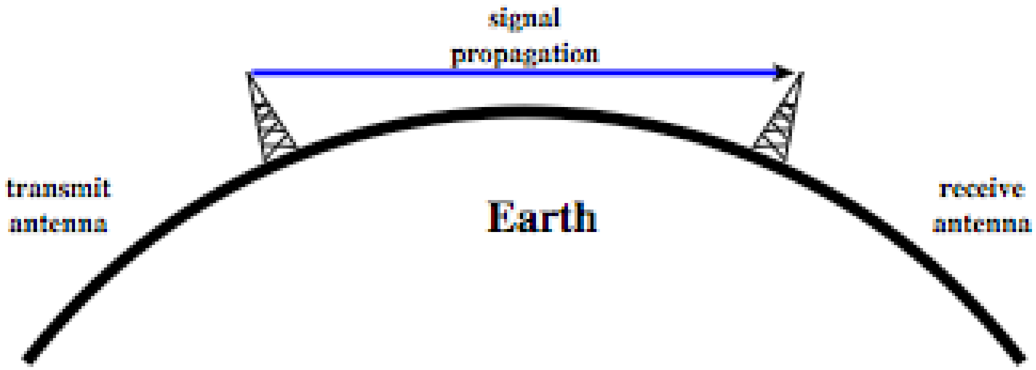
Wireless Propagation

Sky Wave



(b) Sky-wave propagation (2 to 30 MHz)

Wireless Propagation
Line of Sight



(c) Line-of-sight (LOS) propagation (above 30 MHz)

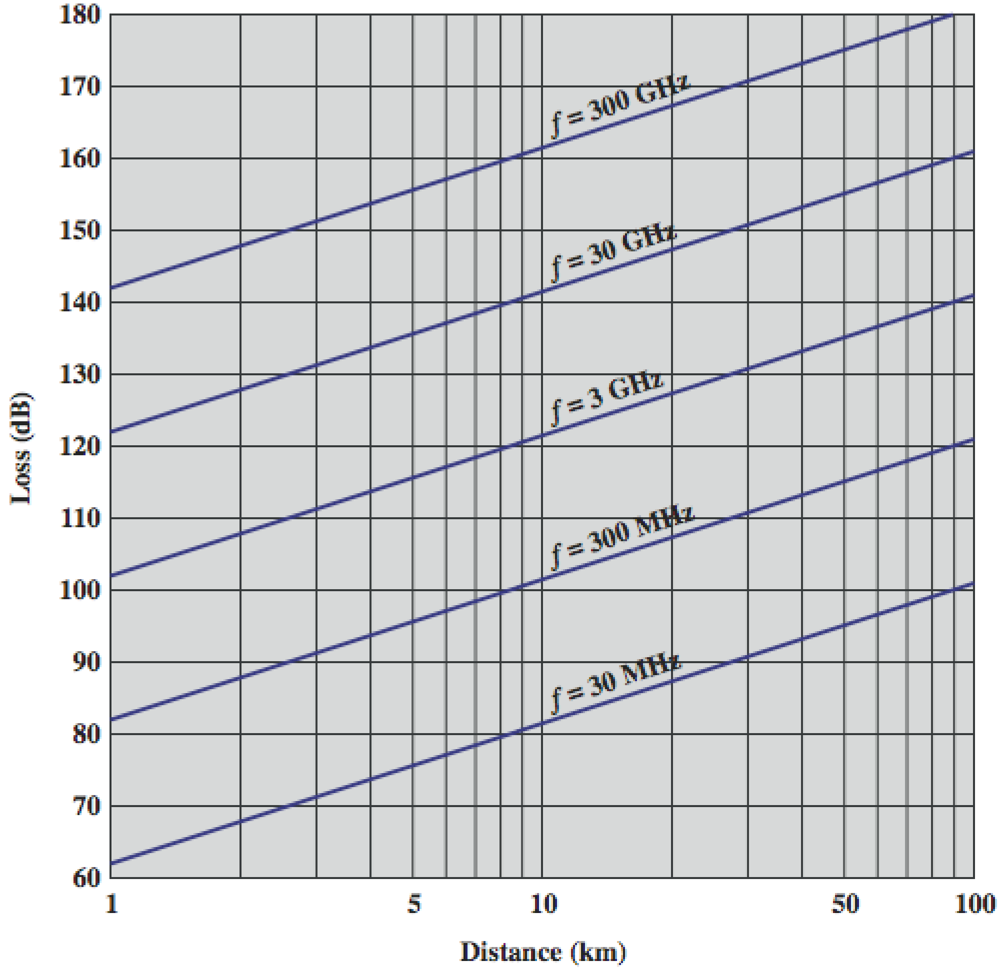
Refraction

- velocity of electromagnetic wave is a function of density of material
  - ~3 x 10^8 m/s in vacuum, less in anything else
- speed changes as move between media
- Index of refraction (refractive index) is
  - sin(incidence)/sin(refraction)
  - varies with wavelength
- have gradual bending if medium density varies
  - density of atmosphere decreases with height
  - results in bending towards earth of radio waves
  - hence optical and radio horizons differ

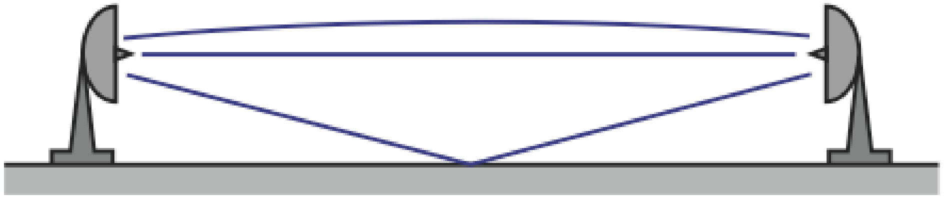
Line of Sight Transmission

- Free space loss
  - loss of signal with distance
- Atmospheric Absorption
  - from water vapour and oxygen absorption
- Multipath
  - multiple interfering signals from reflections
- Refraction
  - bending signal away from receiver

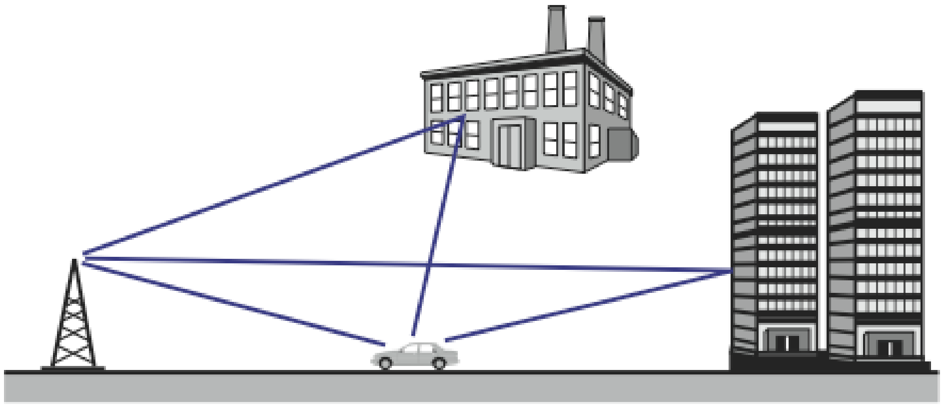
Free Space Loss



Multipath Interference



(a) Microwave line of sight



(b) Mobile radio

Data and Computer Communications

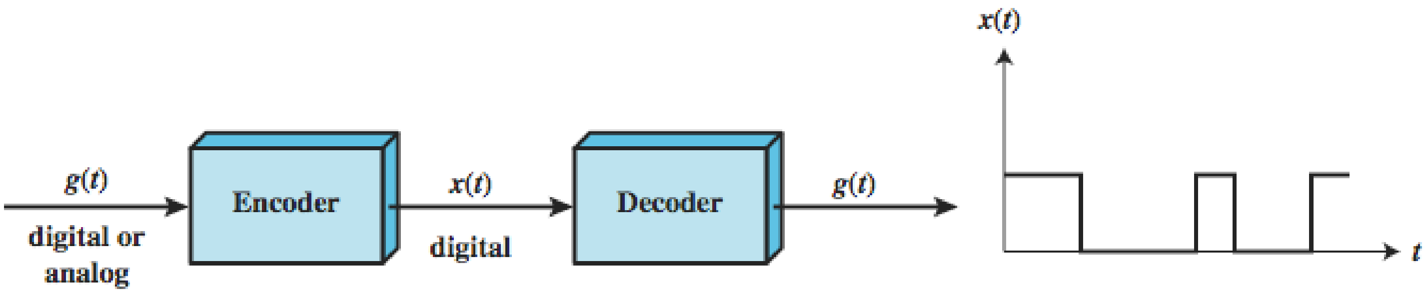
Chapter 5 – Signal Encoding Techniques

Eighth Edition

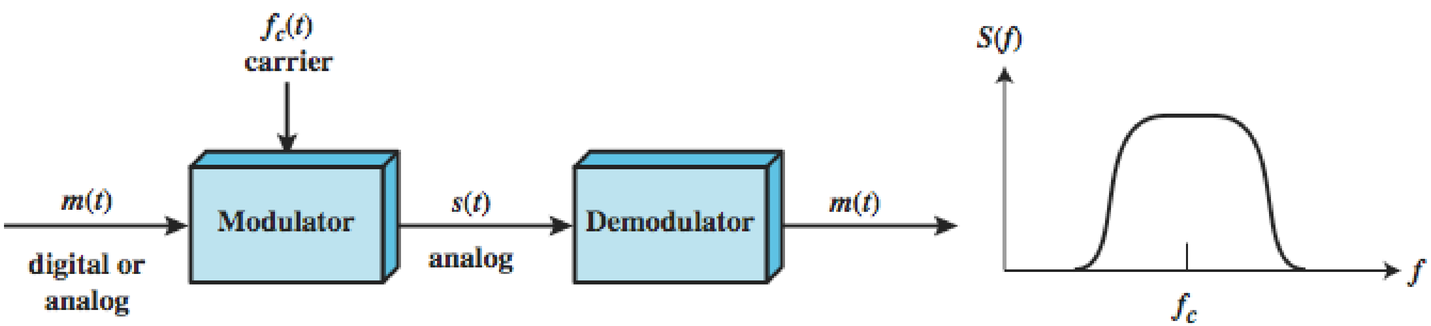
by William Stallings

Lecture slides by Lawrie Brown

Signal Encoding Techniques



(a) Encoding onto a digital signal

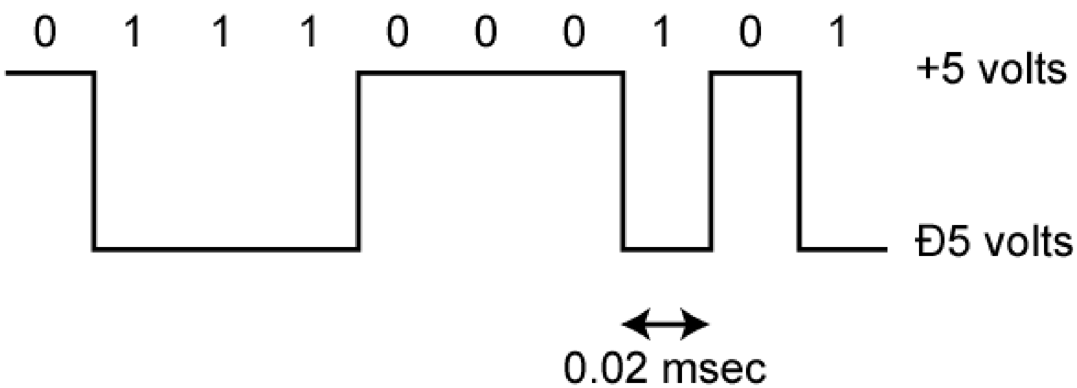


(b) Modulation onto an analog signal

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

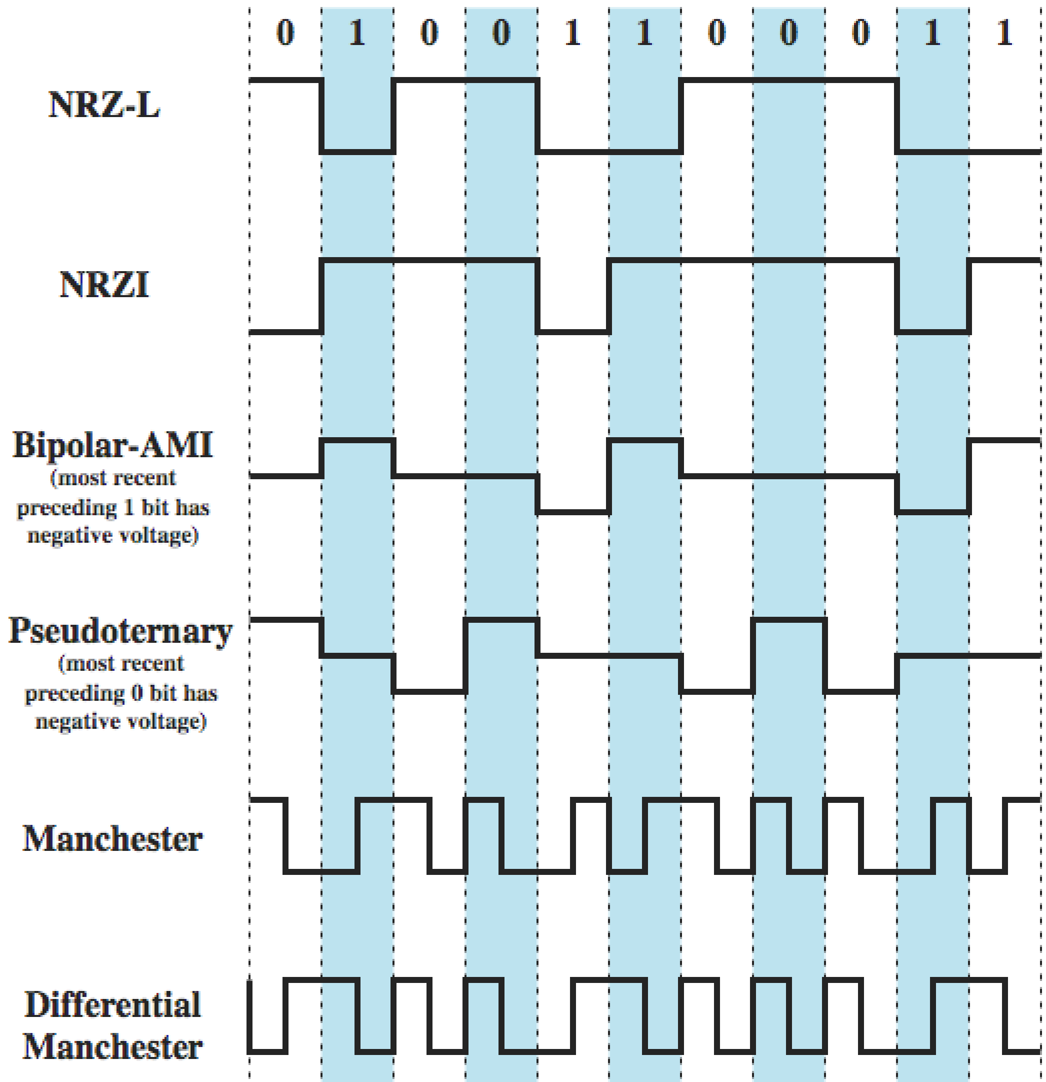
Interpreting Signals

- 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

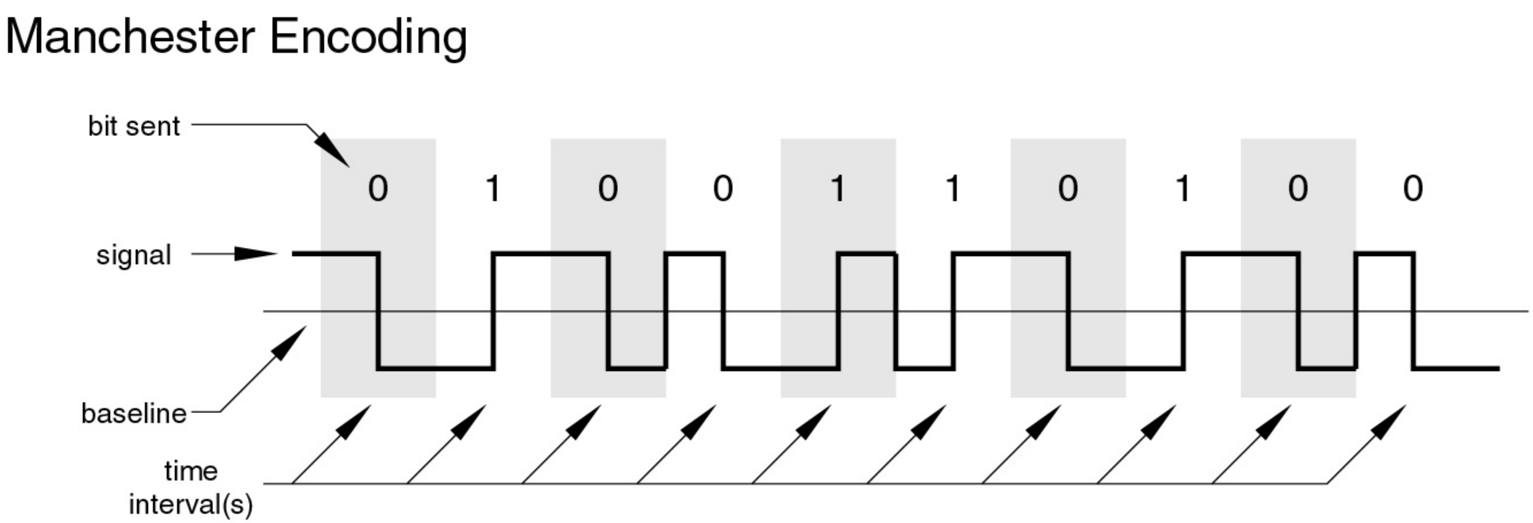
- one represented by absence of line signal
- zero represented by alternating positive and negative
- no advantage or disadvantage over bipolar-AMI
- each used in some applications

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

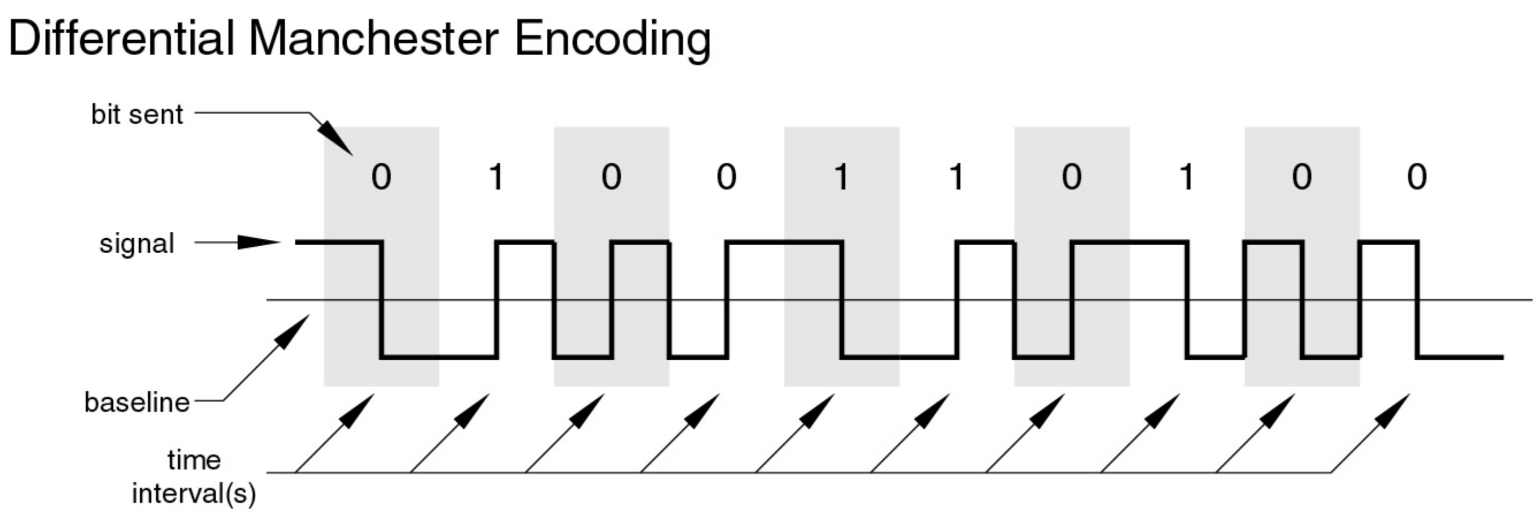
Manchester Encoding

- 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.



Differential Manchester Encoding

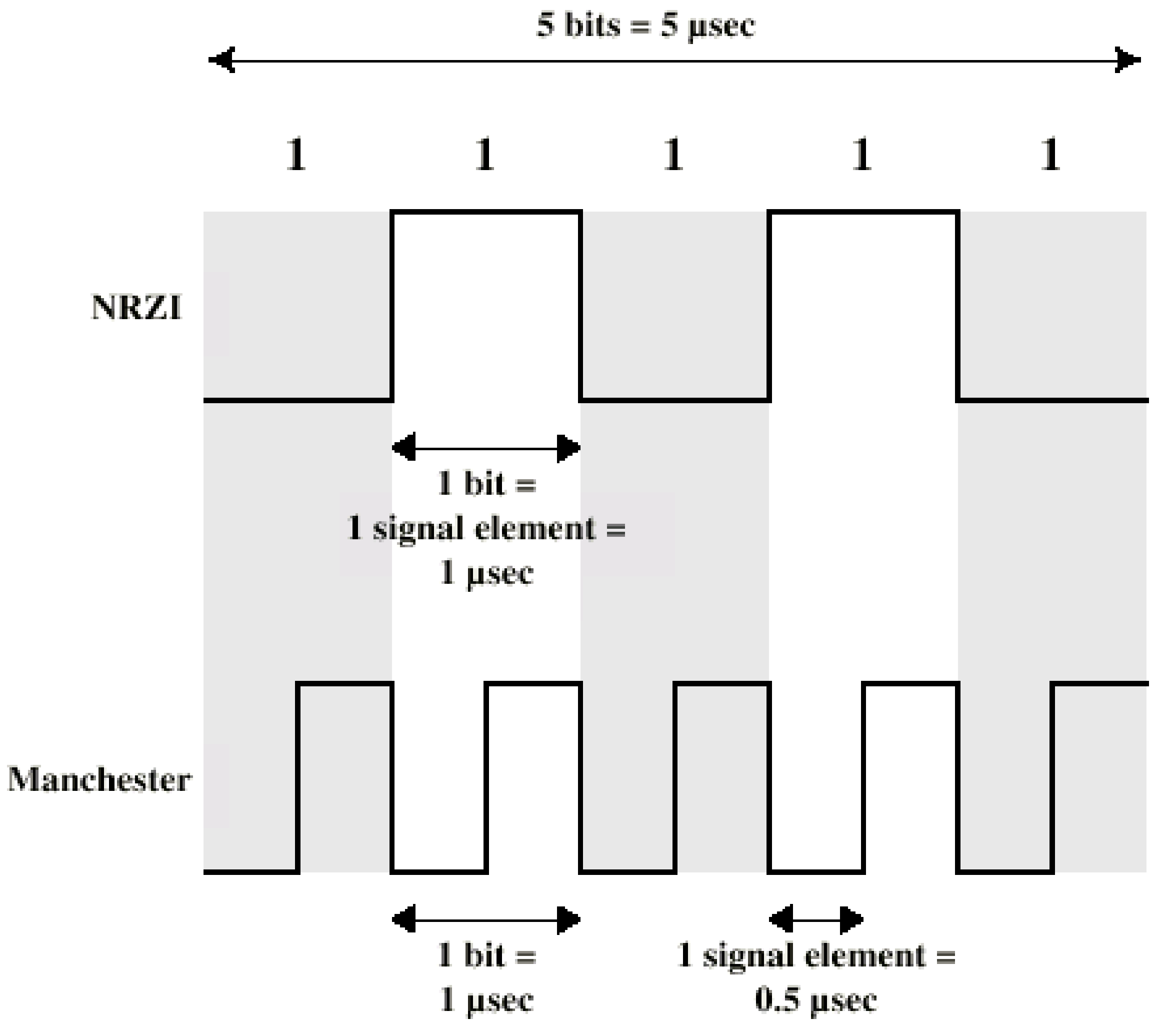
- midbit transition is clocking only
- transition at start of bit period representing 0
- no transition at start of bit period representing 1
  - this is a differential encoding scheme
- used by IEEE 802.5



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

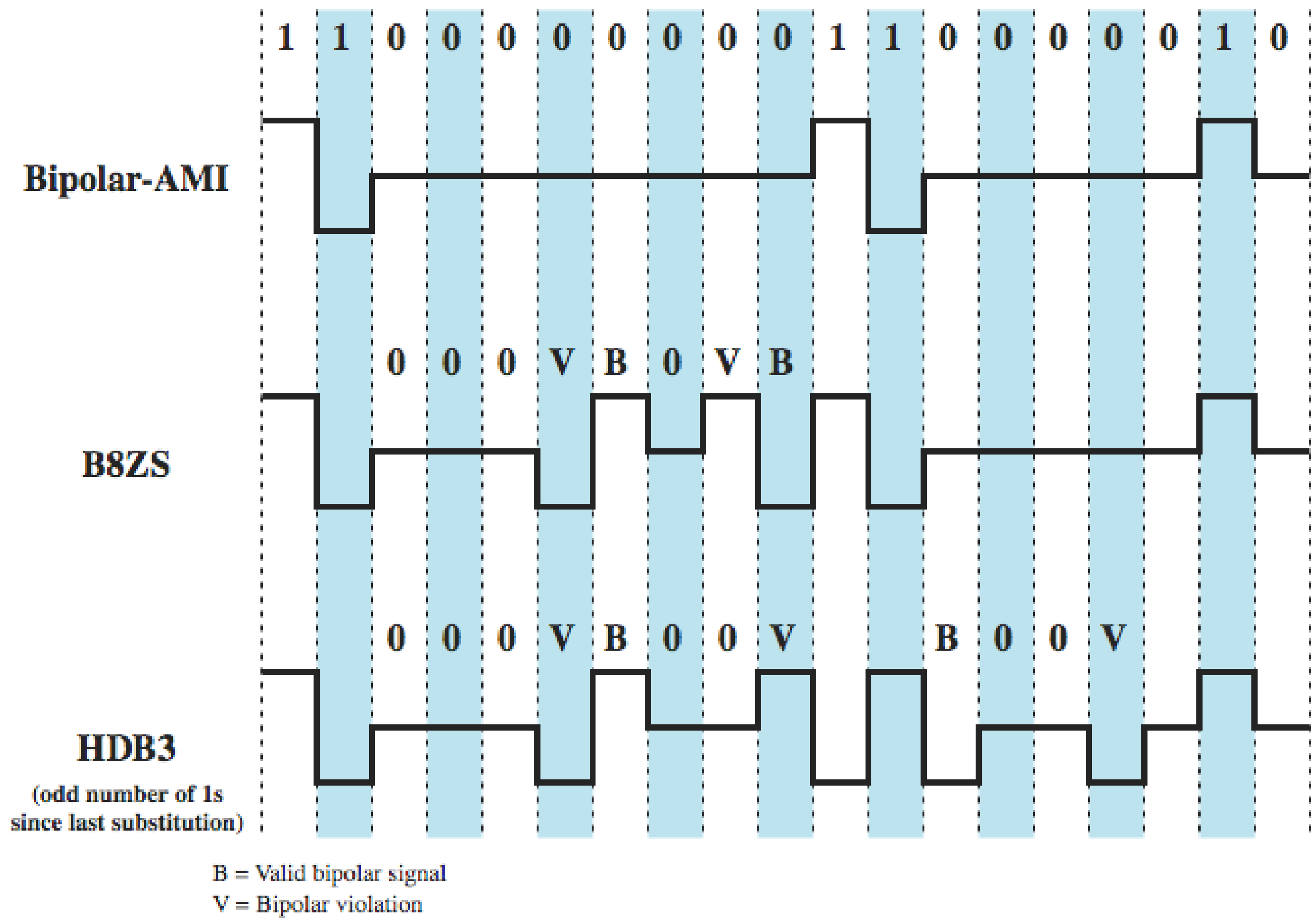
Modulation Rate



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

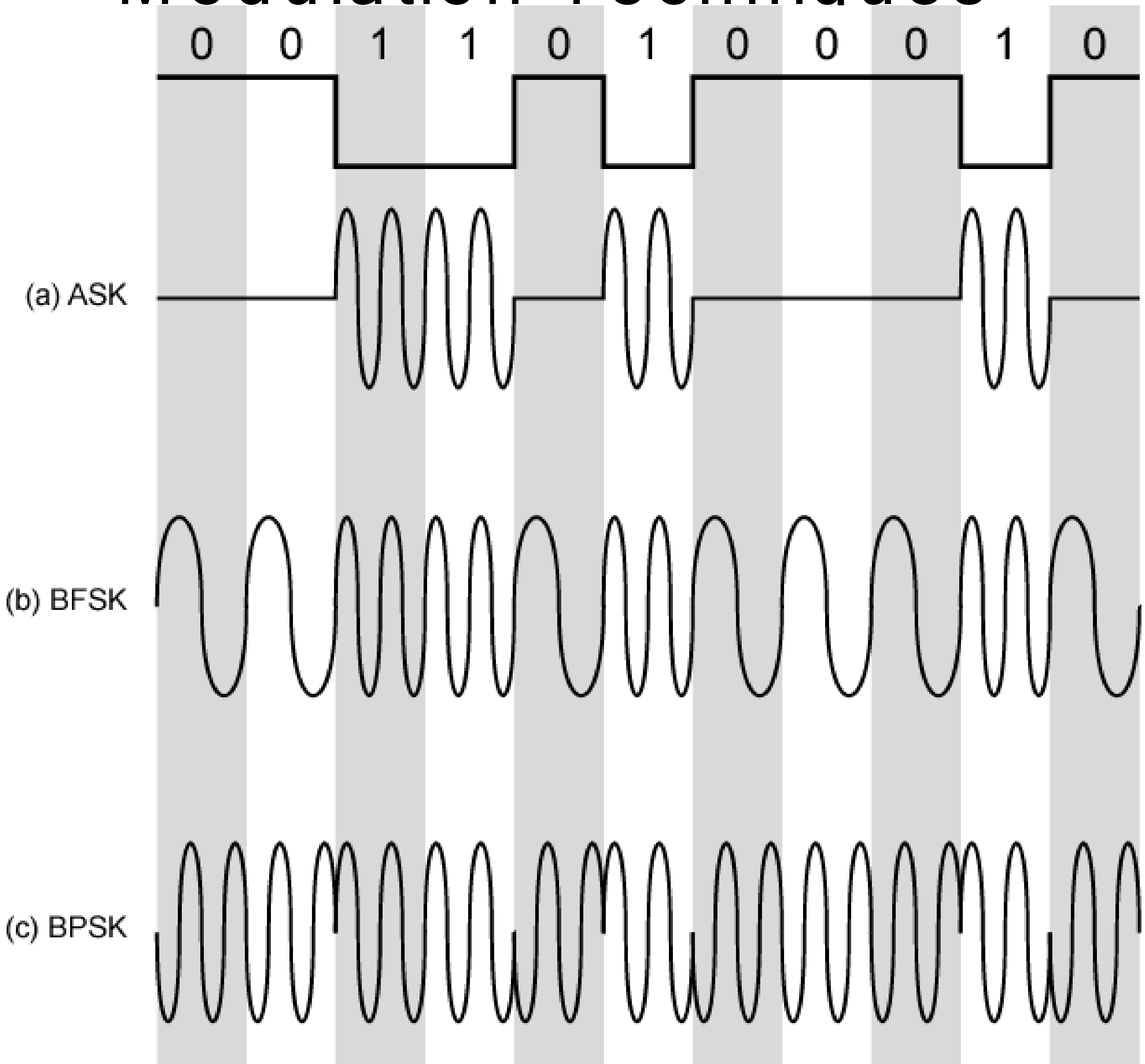
B8ZS and HDB3



Digital Data, Analog Signal

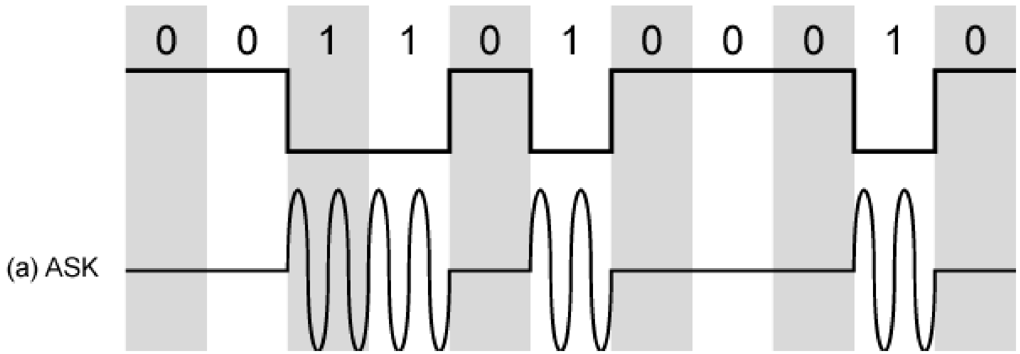
- main use is public telephone system
  - has freq range of 300Hz to 3400Hz
  - use modem (modulator-demodulator)
- encoding techniques
  - Amplitude shift keying (ASK)
  - Frequency shift keying (FSK)
  - Phase shift keying (PK)

Modulation Techniques



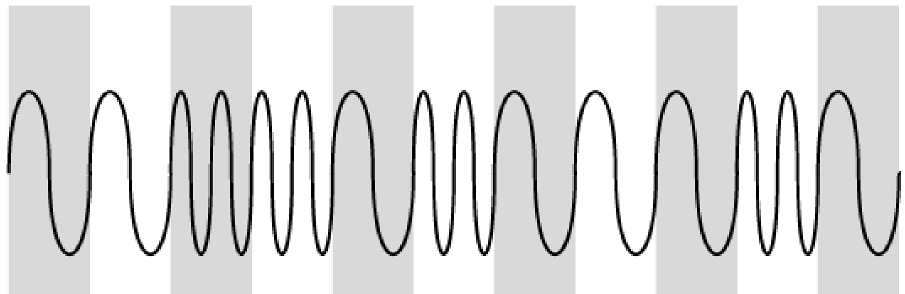
Amplitude Shift Keying

- 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



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



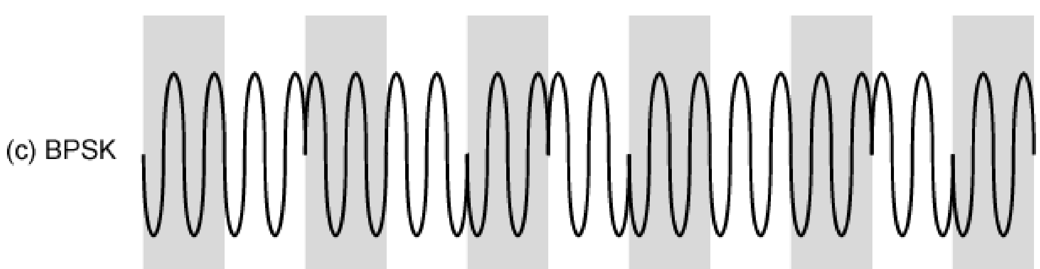
(b) BFSK

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

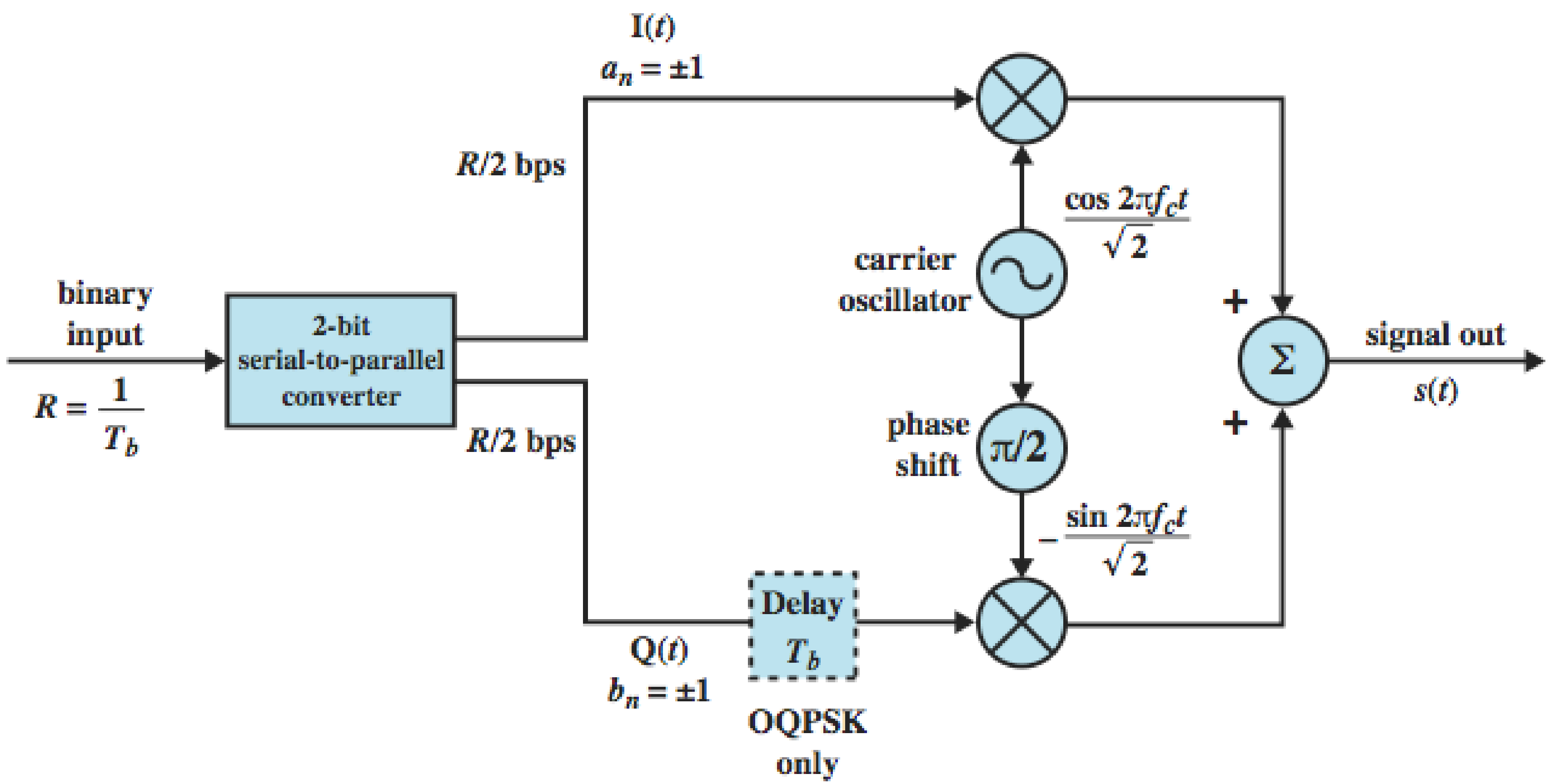
- phase of carrier signal is shifted to represent data
- binary PSK
  - two phases represent two binary digits
- differential PSK
  - phase shifted relative to previous transmission rather than some reference signal



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



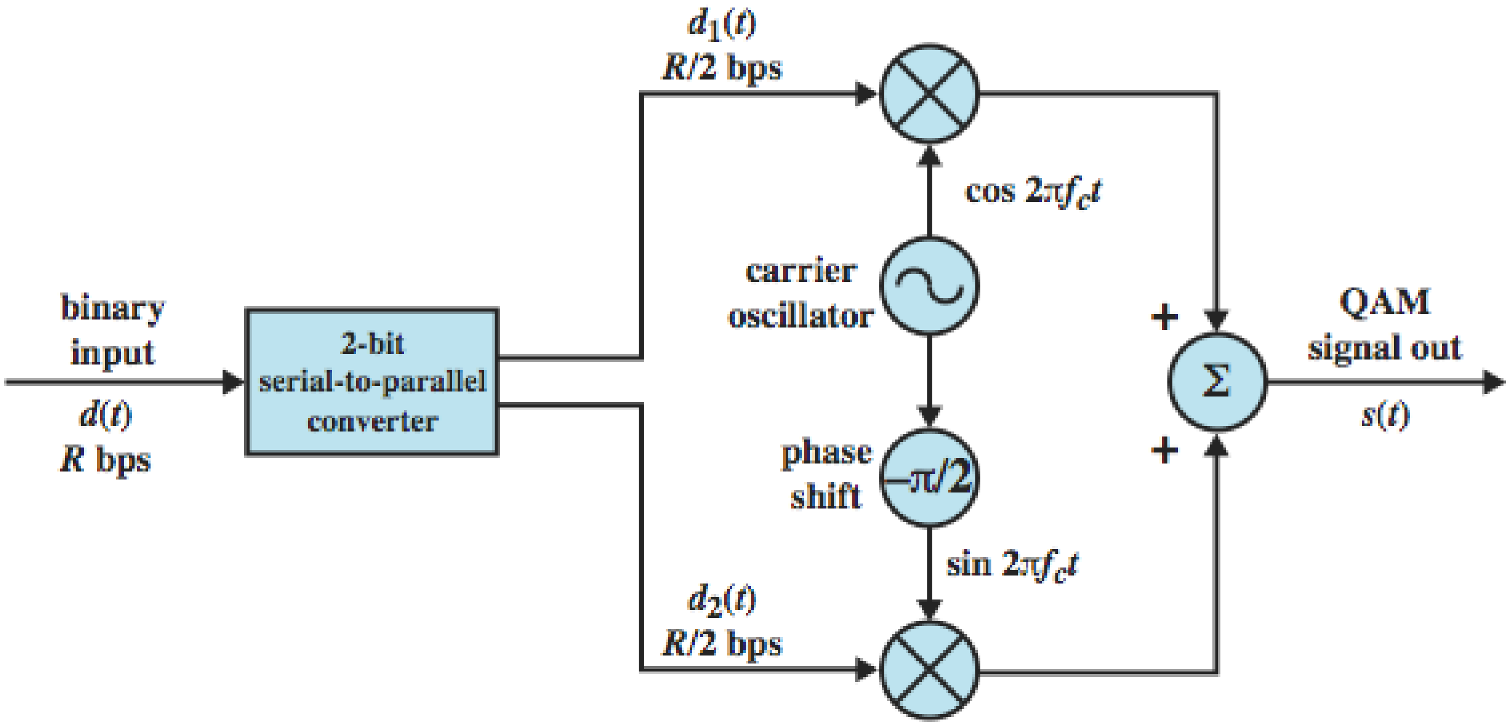
Performance of Digital to Analog Modulation Schemes

- 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



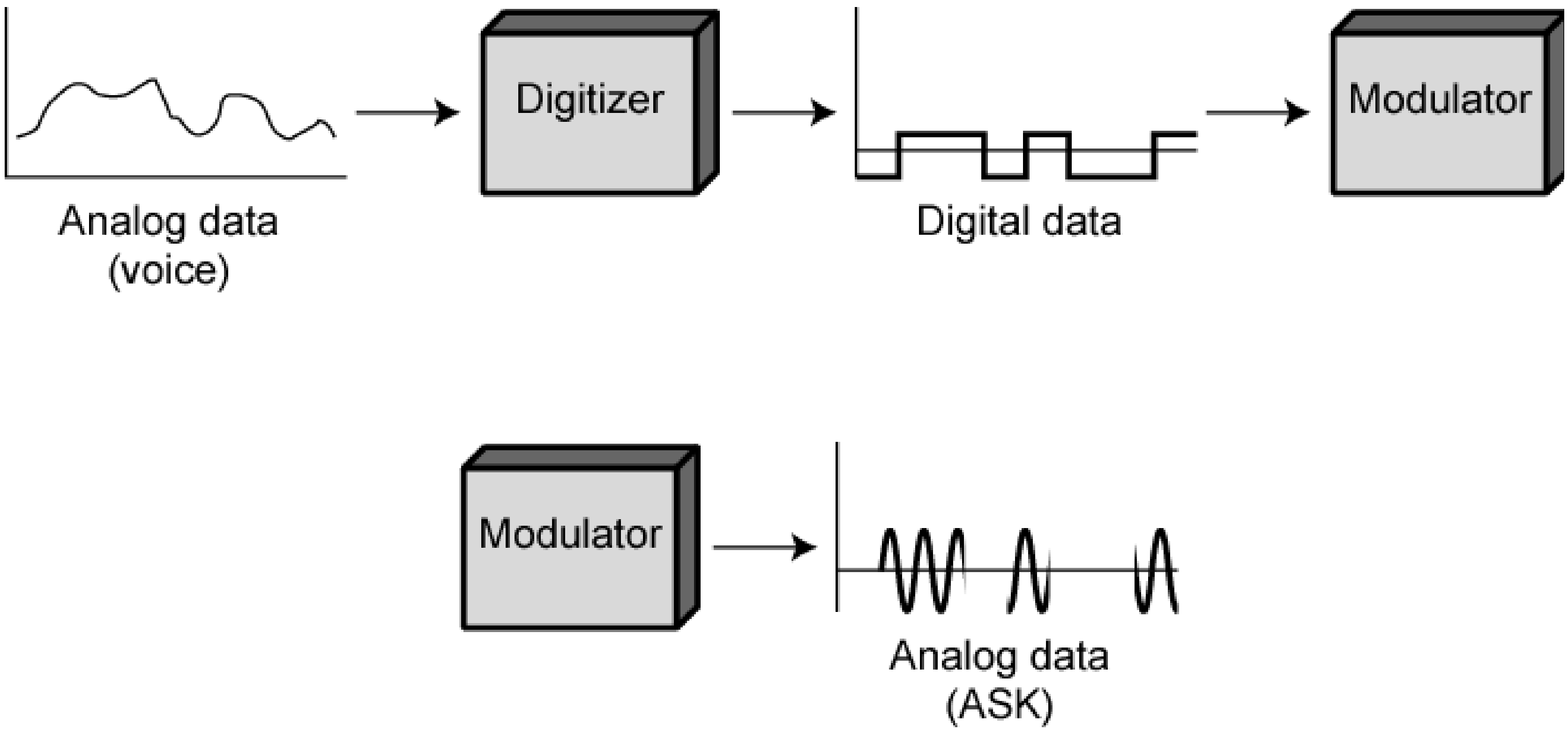
QAM Variants

- 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

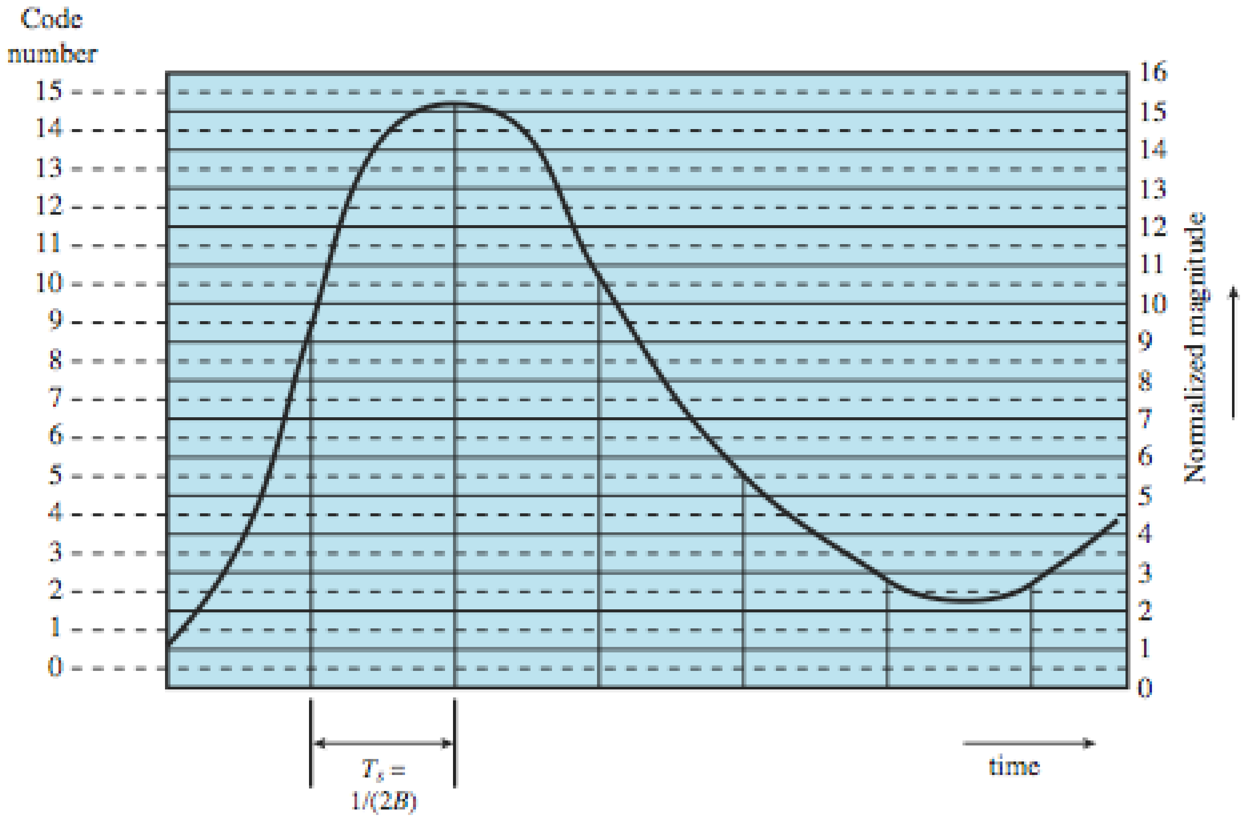
Digitizing Analog Data



Pulse Code Modulation (PCM)

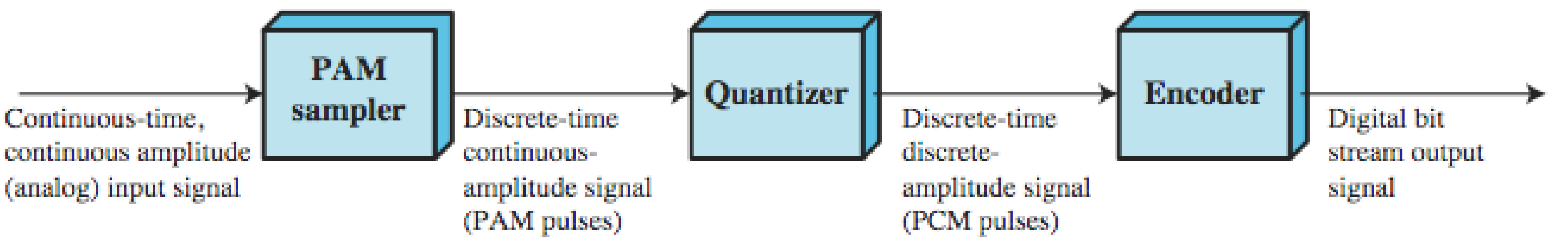
- sampling theorem:
  - "If a signal is sampled at regular intervals at a rate higher than twice the highest signal frequency, the samples contain all information in original signal"
  - eg. 4000Hz voice data, requires 8000 sample per sec
- strictly have analog samples
  - Pulse Amplitude Modulation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

PCM Example

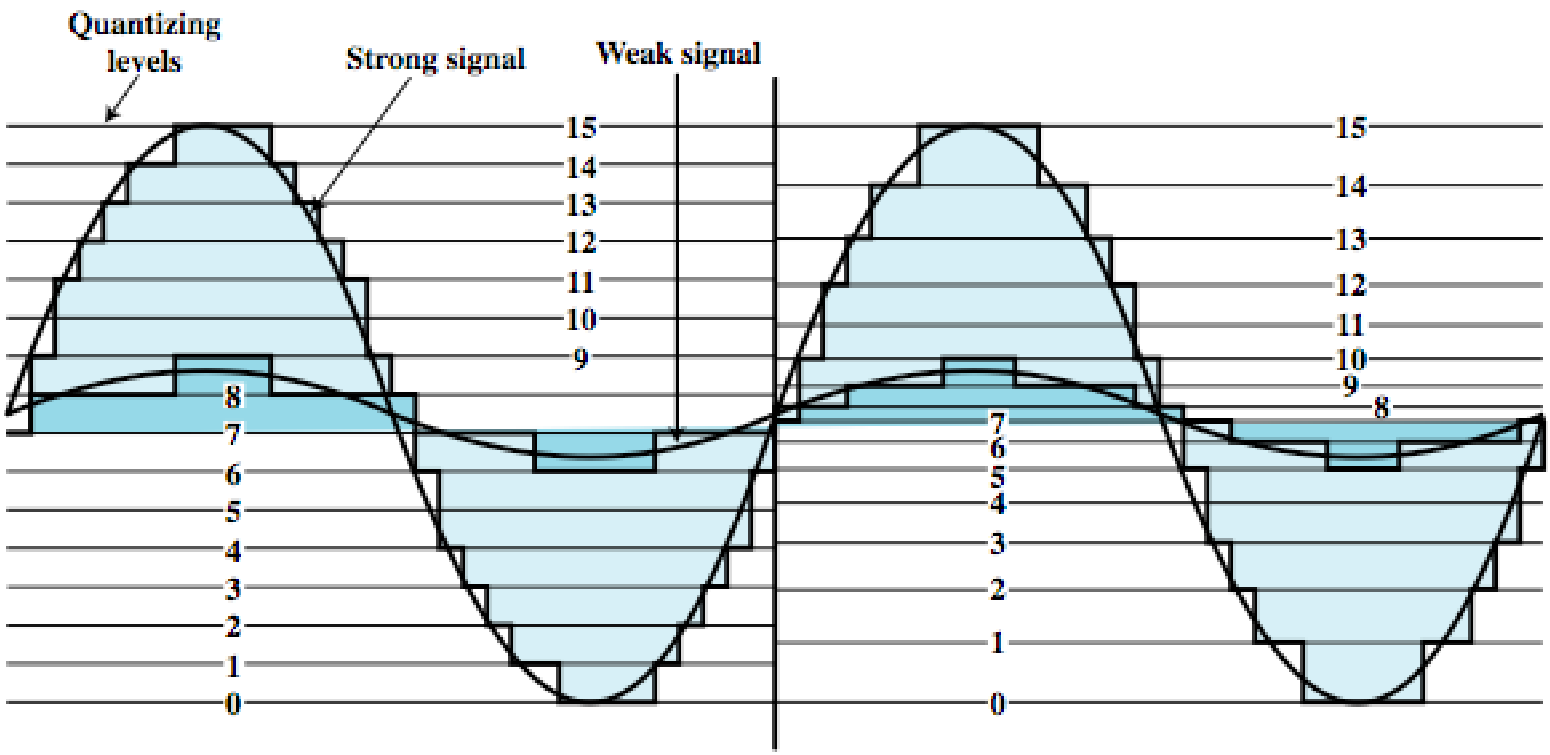


PAM value	1.1	9.2	15.2	10.8	5.6	2.8	2.7
quantized code number	1	9	15	10	5	2	2
PCM code	0001	1001	1111	1010	0101	0010	0010

PCM Block Diagram

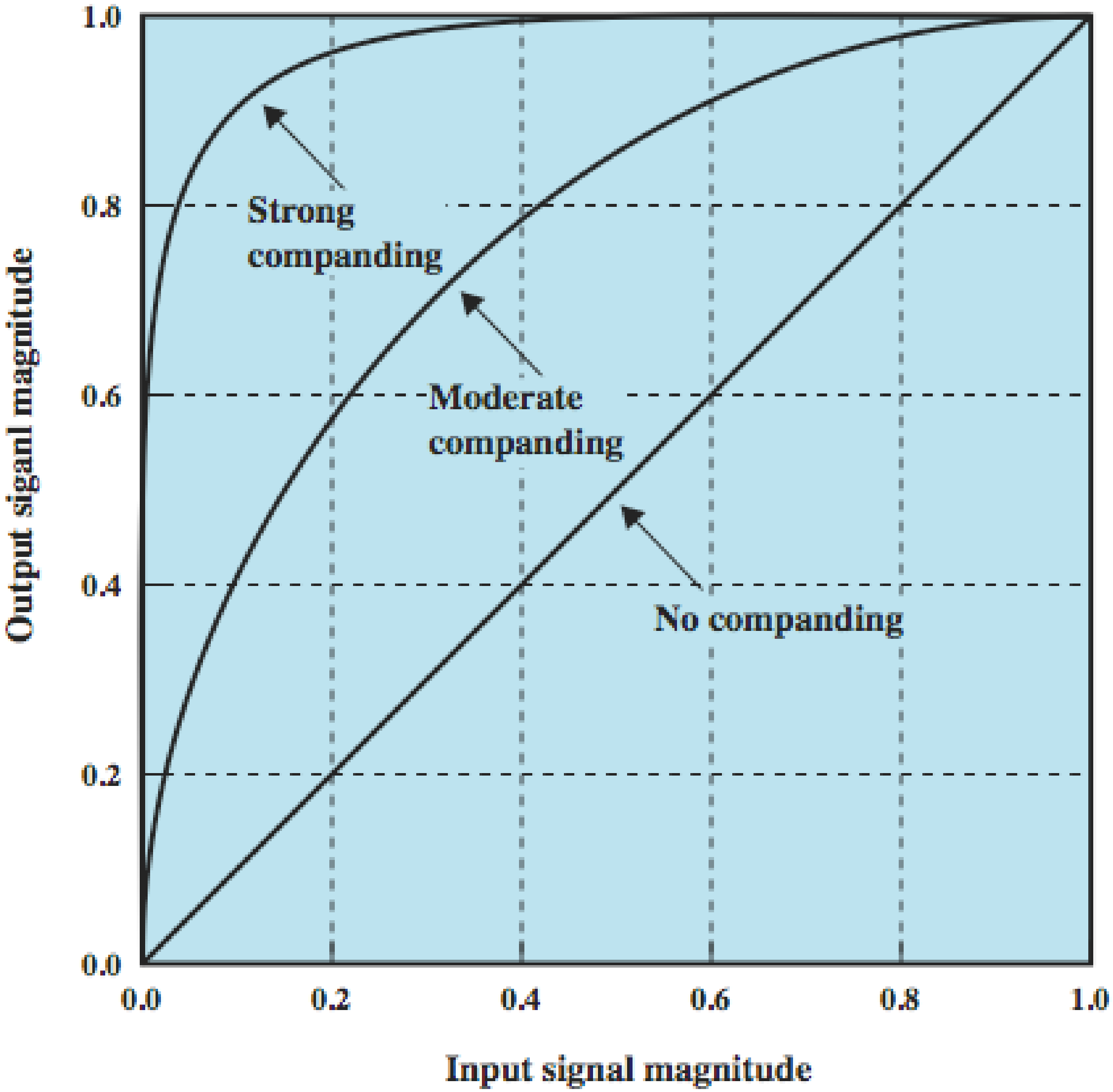


Non-Linear Coding



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

Companding

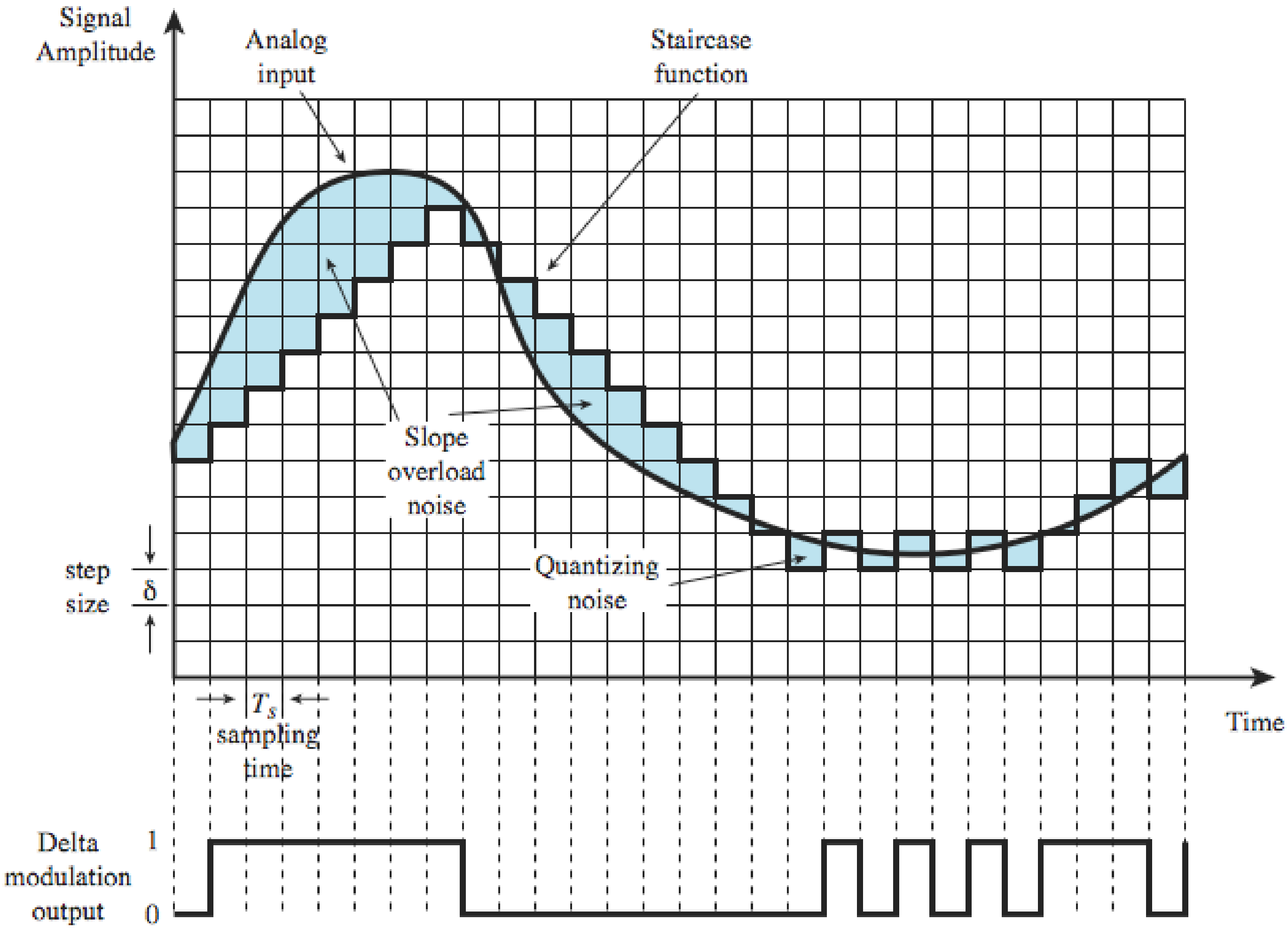


1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Strong companding
Moderate companding
No companding
Output siganl magnitude
Input signal magnitude

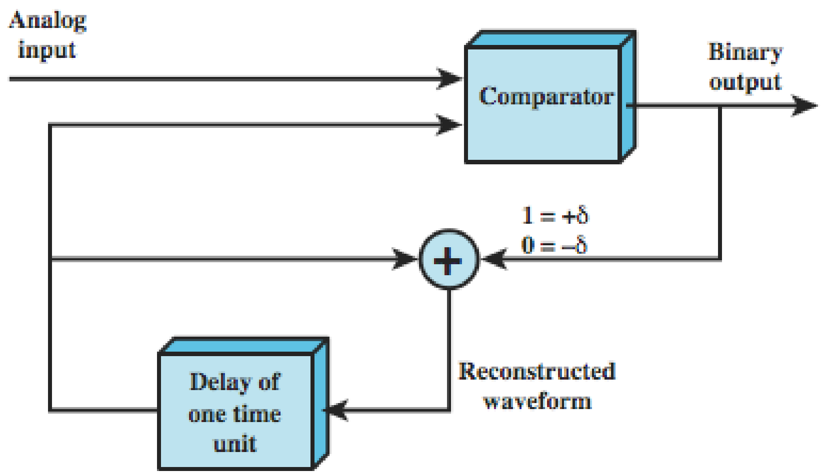
Delta Modulation

- 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

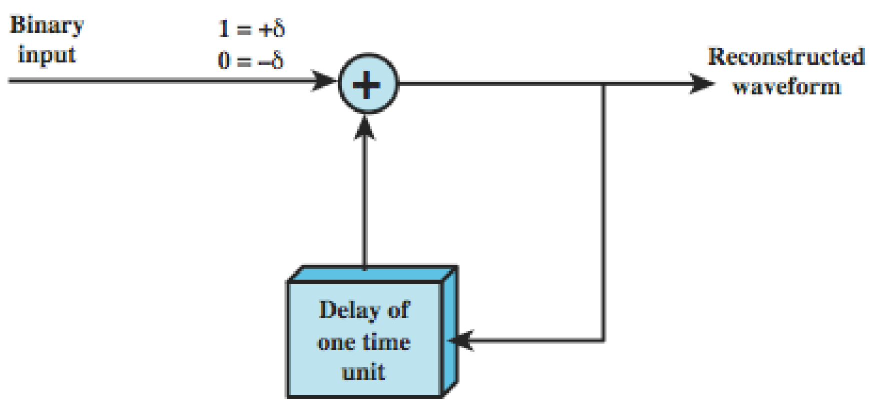
Delta Modulation Example



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

Data and Computer Communications

Chapter 6 – Digital Data Communications Techniques

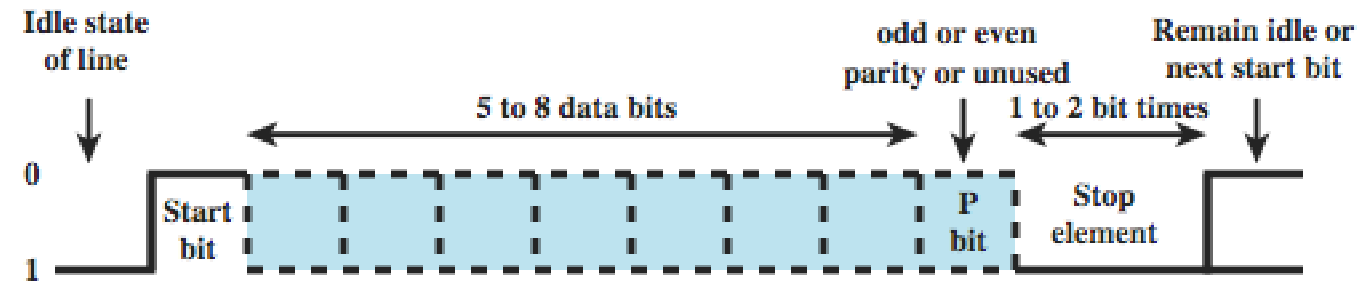
Eighth Edition

by William Stallings

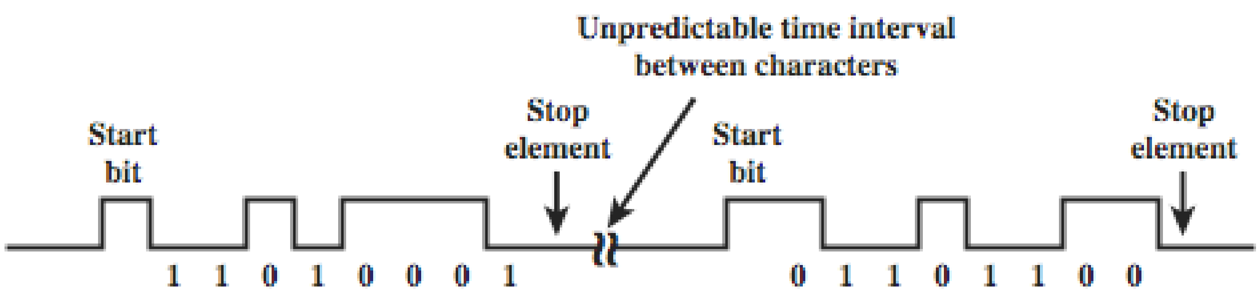
Lecture slides by Lawrie Brown

Asynchronous and Synchronous Transmission

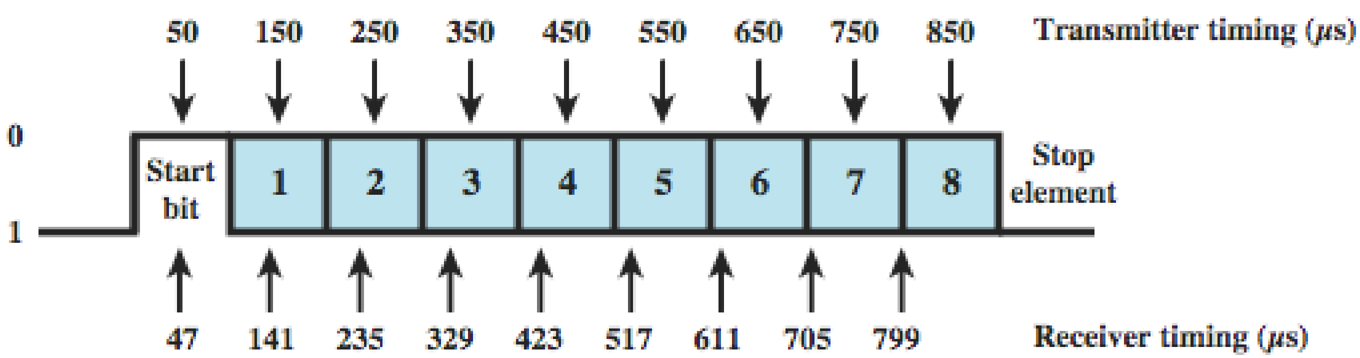
- Transmission of data requires co-operation and agreement bet. transmitter and receiver
- timing problems require a mechanism to synchronize the transmitter and receiver
  - receiver samples stream at bit intervals
  - if the two clocks are not aligned and drifting, receiver will sample at wrong time after sufficient bits are sent
- two solutions to synchronizing clocks
  - asynchronous transmission
  - synchronous transmission



(a) Character format



(b) 8-bit asynchronous character stream



(c) Effect of timing error

Asynchronous Transmission

- Send one character at a time
  - each character begins with a start bit to alert the receiver
  - receiver samples each bit in the character
  - the data bits are usually followed by a parity bit
  - the final element is a *stop element*
  - the stop element is the same as the idle state
- Characteristics
  - simple
  - cheap
  - overhead of 2 or 3 bits per char (~20%)
  - good for data with large gaps (keyboard)

Synchronous Transmission

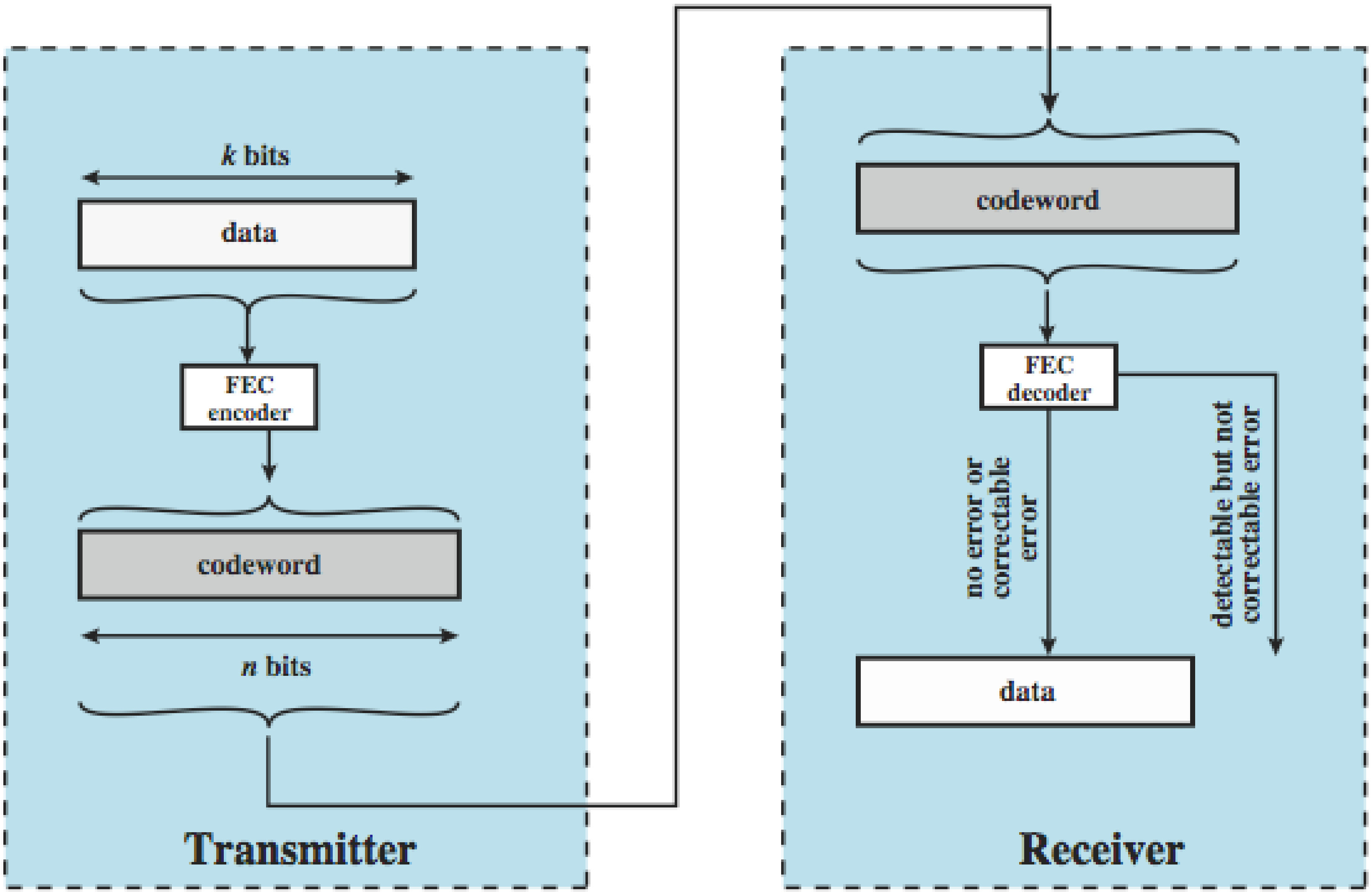
- block of data transmitted as a *frame*
- clocks must be synchronized
  - can use separate clock line
  - or embed clock signal in data
- need to indicate start and end of block
  - use preamble and postamble
- more efficient (lower overhead) than async

Types of Error

- an error occurs when a bit is altered between transmission and reception
- single bit errors
  - only one bit altered
  - caused by white noise
- burst errors
  - contiguous sequence of B bits in which first last and any number of intermediate bits in error
  - caused by impulse noise or by fading in wireless
  - effect greater at higher data rates

Error Detection

- there will be errors introduced by the tx. system
- Error detection done using error-detecting code
- function of data bits, calculated by transmitter and appended to the frame
- recalculated and checked by receiver
- still chance of undetected error
- Error detection using parity
  - parity bit set so character has even (even parity) or odd (odd parity) number of ones
  - even number of bit errors goes undetected

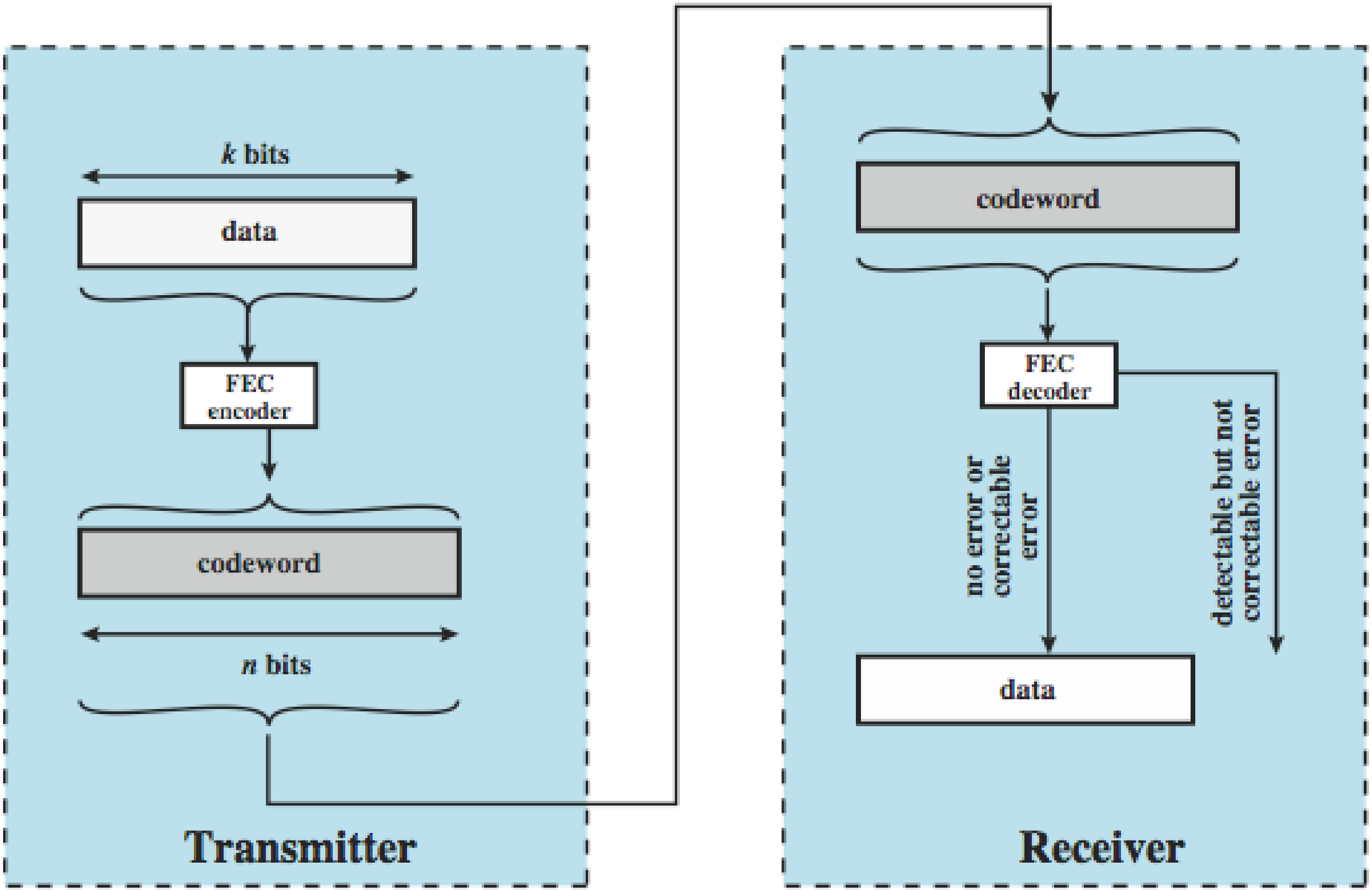

k bits
data
FEC
encoder
codeword
n bits
Transmitter
codeword
FEC
decoder
no error or
correctable
error
detectable but not
correctable error
data
Receiver

Cyclic Redundancy Check

- one of most common and powerful checks
- for block of k bits transmitter generates an n bit frame check sequence (FCS)
- transmits $k+n$ bits which is exactly divisible by some number
- receiver divides frame by that number
  - if no remainder, assume no error
  - for math, see Stallings chapter 6

Error Correction

- correction of detected errors usually requires data block to be retransmitted
- not appropriate for wireless applications
  - bit error rate is high causing lots of retransmissions
  - when propagation delay long (satellite) compared with frame transmission time, resulting in retransmission of frame in error plus many subsequent frames
- instead need to correct errors on basis of bits received
- error correction provides this


k bits
data
FEC encoder
codeword
n bits
Transmitter
codeword
FEC decoder
no error or correctable error
detectable but not correctable error
data
Receiver

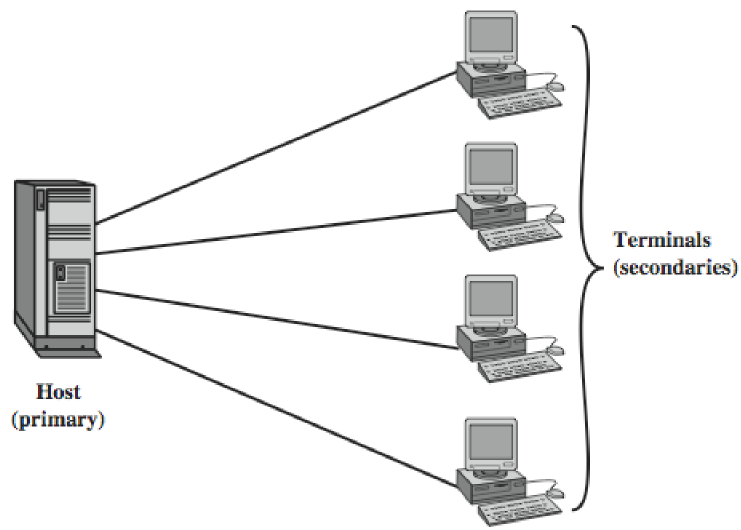
How Error Correction Works

- adds redundancy to transmitted message
- can deduce original despite some errors
- eg. block error correction code
  - map k bit input onto an n bit codeword
  - each distinctly different
  - if get error assume codeword sent was closest to that received
- for math, see Stallings chapter 6
- means have reduced effective data rate

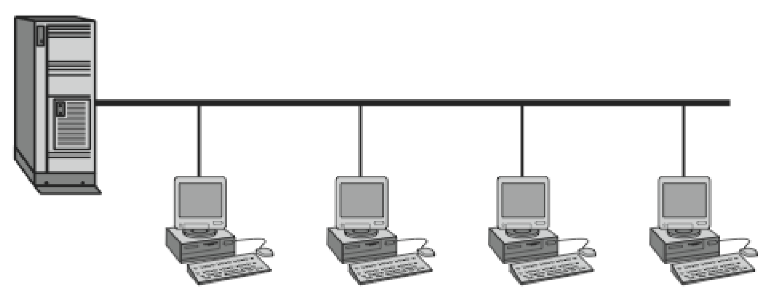
Line Configuration – Topology

- physical arrangement of stations on medium
  - point to point – two stations
    - such as between two routers / computers
  - multi point – multiple stations
    - traditionally mainframe computer and terminals
    - now typically a local area network (LAN)

Line Configuration –Topology



(a) Point-to-point



(b) Multipoint

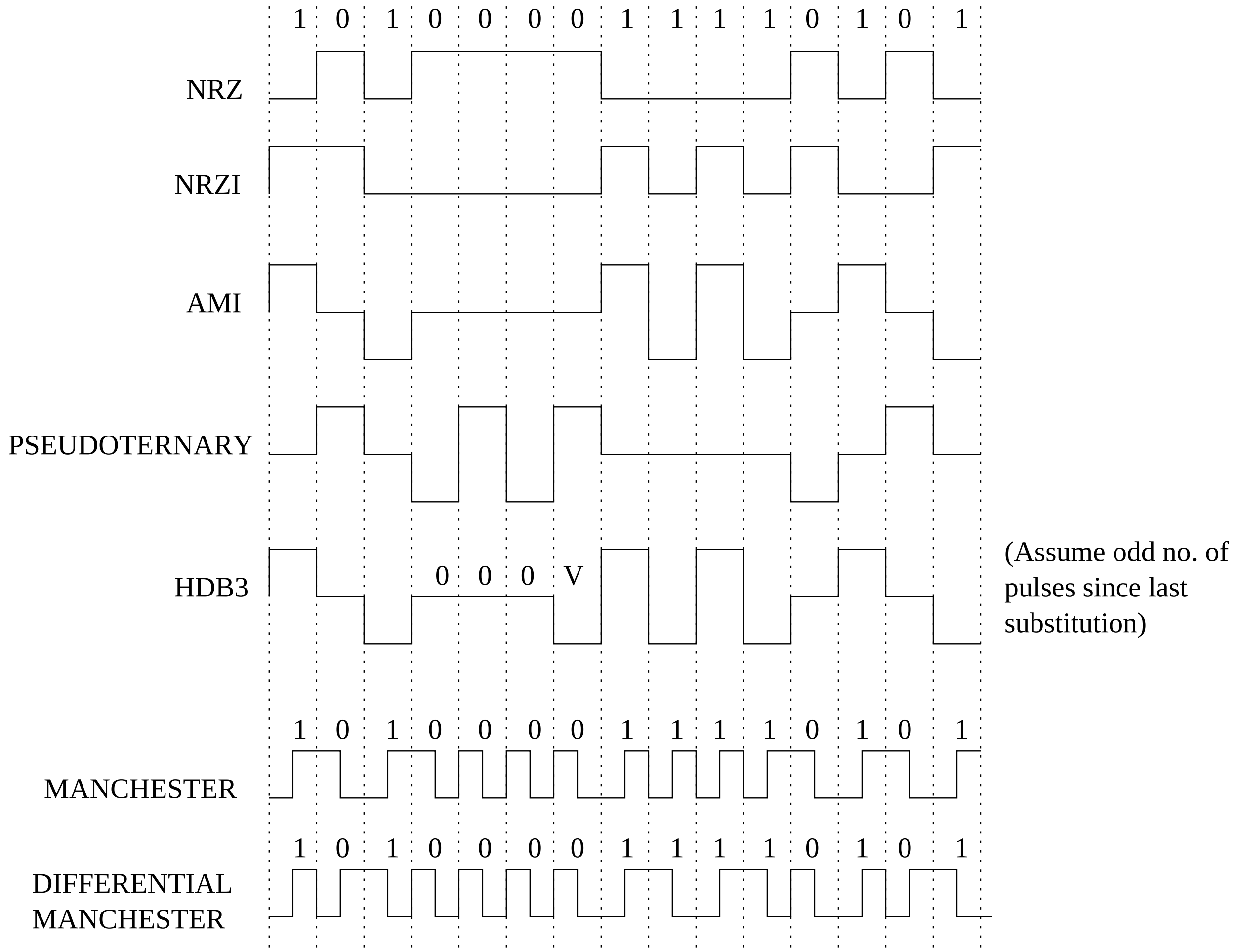
Line Configuration – Duplex

- classify data exchange as half or full duplex
- half duplex (two-way alternate)
  - only one station may transmit at a time
  - requires one data path
- full duplex (two-way simultaneous)
  - simultaneous transmission and reception between two stations
  - requires two data paths
    - separate media or frequencies used for each direction
  - or echo canceling

Summary

- asynchronous verses synchronous transmission
- error detection and correction
- line configuration issues

Q1

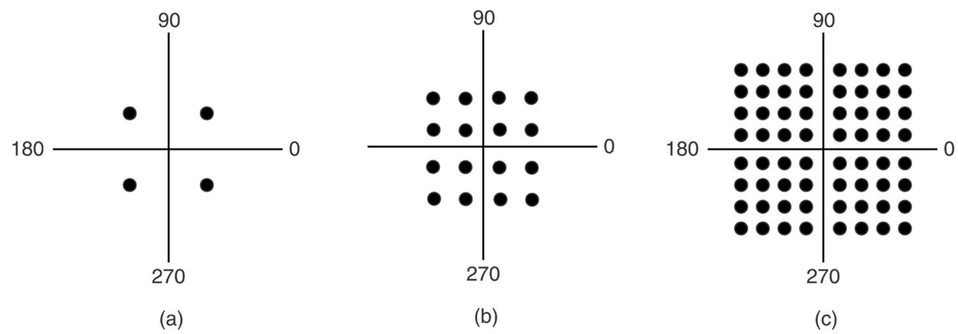


Q2.

Differential manchester encoding scheme:

Minimum modulation rate: 1.0 (bit pattern all 1s)

Maximum modulation rate: 2.0 (bit pattern all 0s)



(a) QPSK - 4 phase shifts

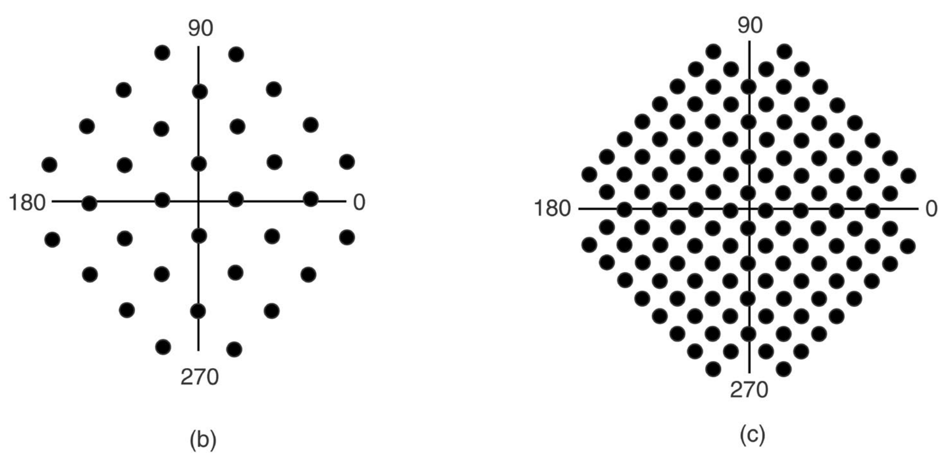
- 4 symbols = 2^2
- bps = 2 baud
- 4800 bps on 2400 baud

(b) QAM-16

- 16 symbols = 2^4
- bps = 4 baud
- 9600 bps on 2400 baud

(c) QAM-64

- 64 symbols = 2^6
- bps = 6 baud
- 14.4 kbps on 2400 baud



(b) V.32. 4 data bits. 1 parity. 9600 bps.

(c) V.32 bis. 6 data bits. 1 parity. 14.4 kbps.