Topics

- Bits, Signals, Frames, and Codes
- Transmission Modes
- Multiplexing

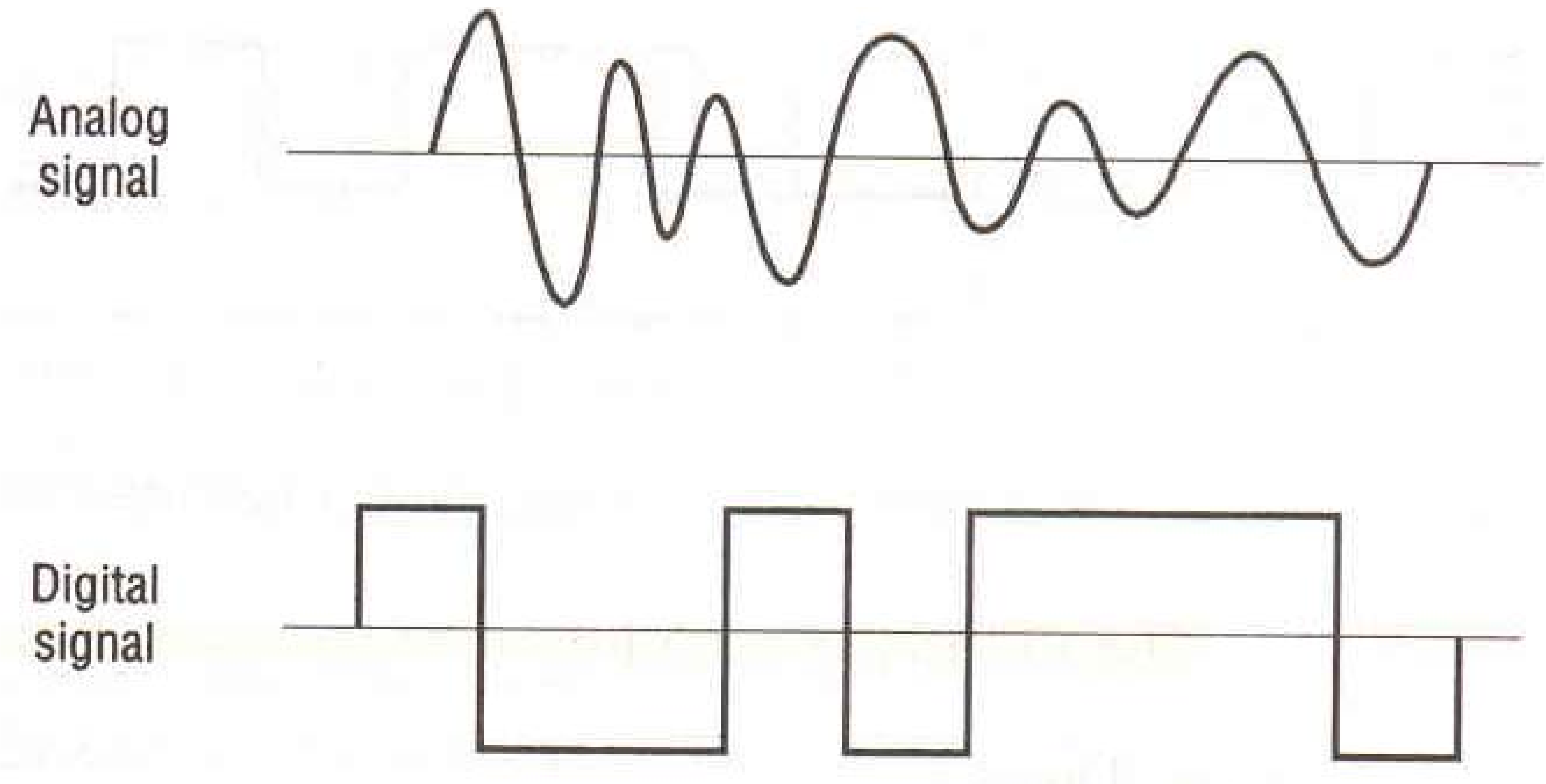
Bits, Signals, and Codes

- A bit (binary digit) is the smallest unit of information
- $N = 2^n$ where N is the number of representations and n is the number of bits (ex. ASCII, Unicode, PCM code etc.)
- Data communications transfer information using codes that are transmitted as signals (either analog or digital)
- In general, analog lines provide a slow service that contains high error rates. However, digital lines cannot transmit analog data unless it is converted to a binary format first
- Encoder is used to convert the information transmitted by the sender and decoder converts the information back to its original form for the receiver

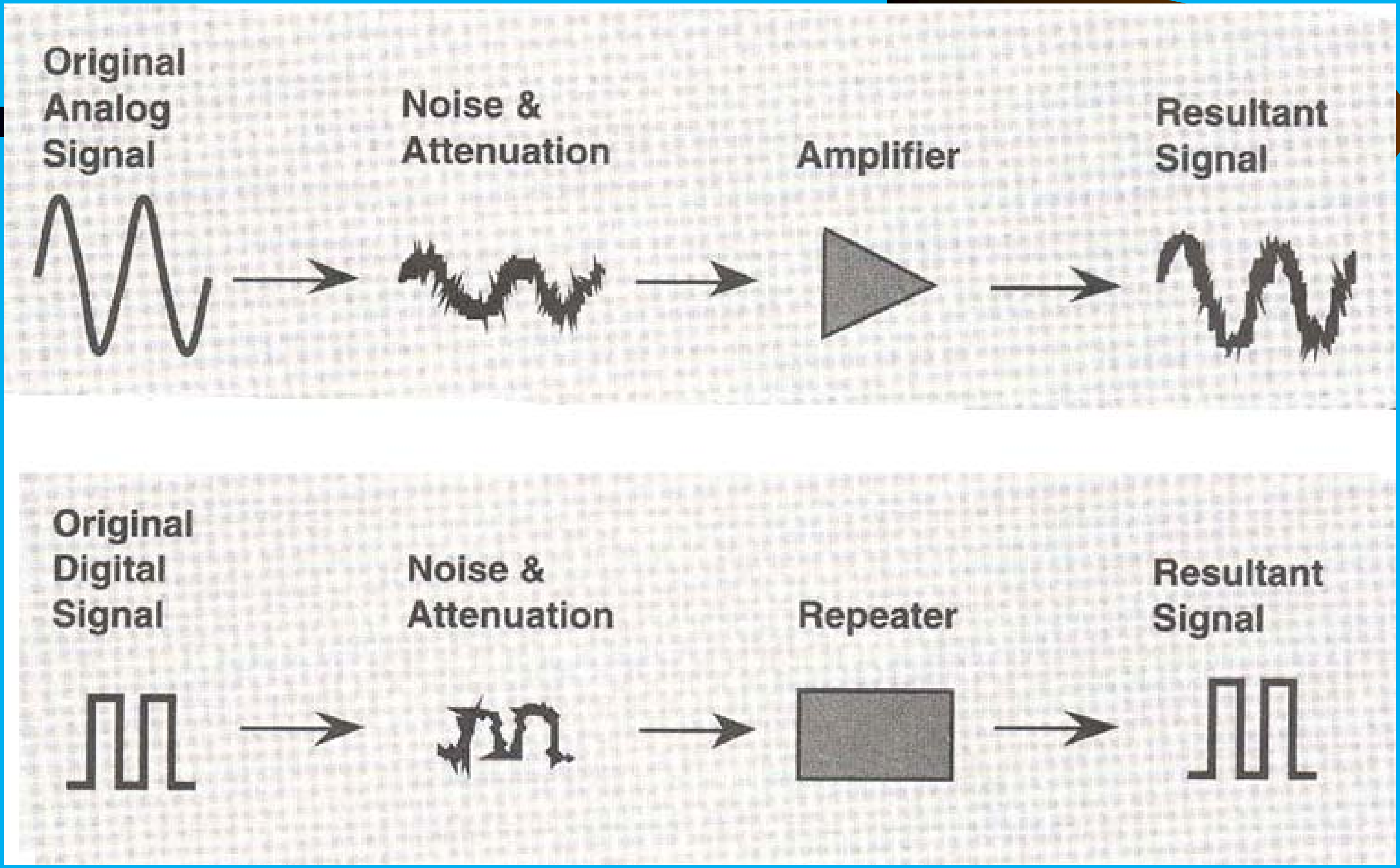
Basic Concepts of Signals

- All data can be represented by electromagnetic signals. Depending on the transmission medium and the communications environment, either analog or digital signals can be used to convey information
- Any electromagnetic signal, analog or digital, is made up of a number of constituent frequencies. A key parameter is bandwidth. In general, the greater bandwidth of the signal, the greater its information-carrying capacity
- A frame contains data and control information. To distinguish between the two, data transparency is desired
- The designer of a communications facility must deal with four factors: bandwidth of the signal, data rate, transmission impairments, and the level of error rate that is acceptable

Analog vs. Digital



Analog vs. Digital (cont.)



Transmission at high bit rates can only be sustained for a relatively short distance due to transmission impairments

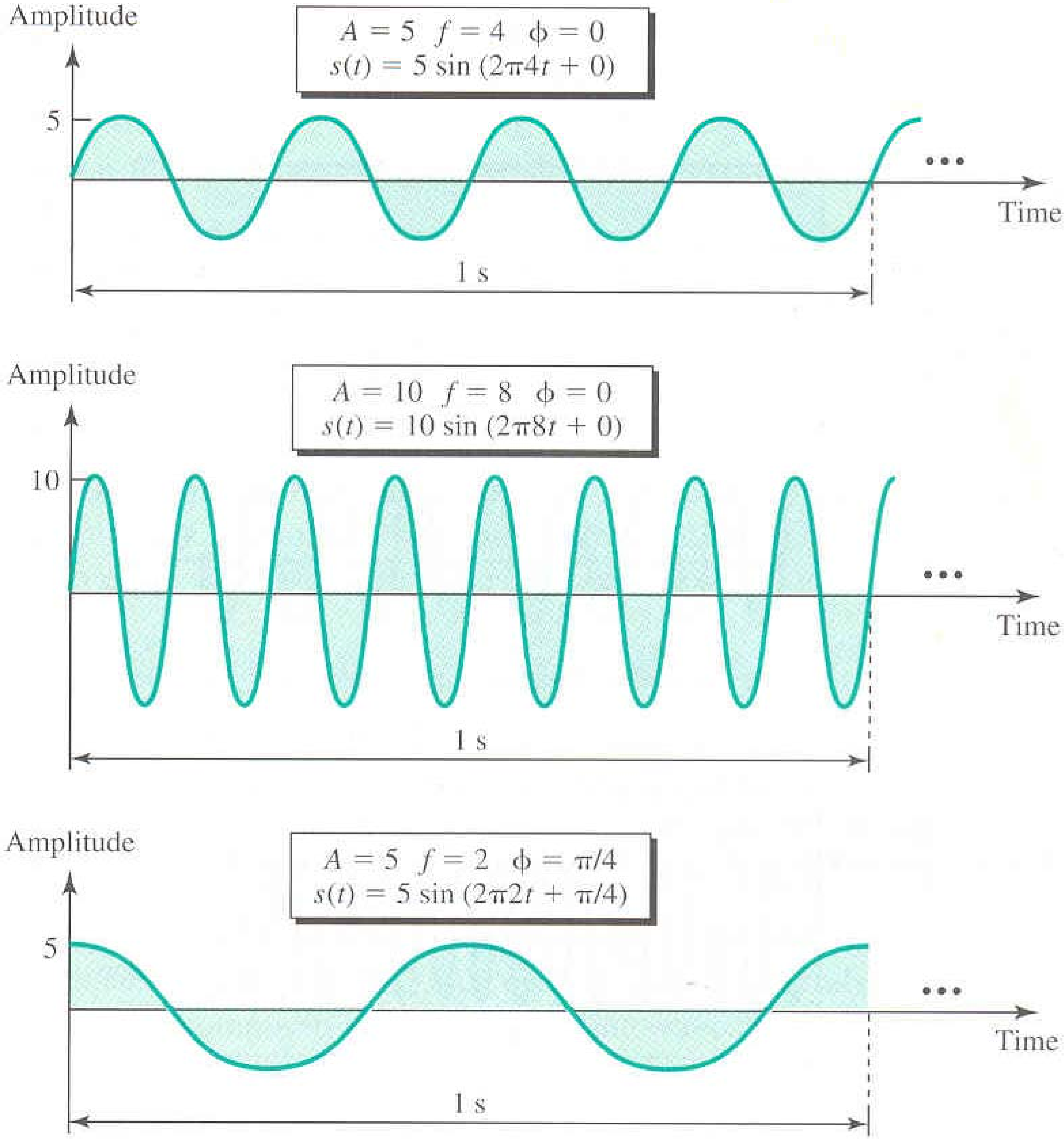
Analog Signals

- An analog signal is continuous and it can have an infinite number of values in a range. The primary shortcomings of analog signals is the difficulty to separate noise from the original waveform
- An example is a sine wave which can be specified by three characteristics:

$$\theta(t) = A \sin(2 \pi f t + \phi)$$

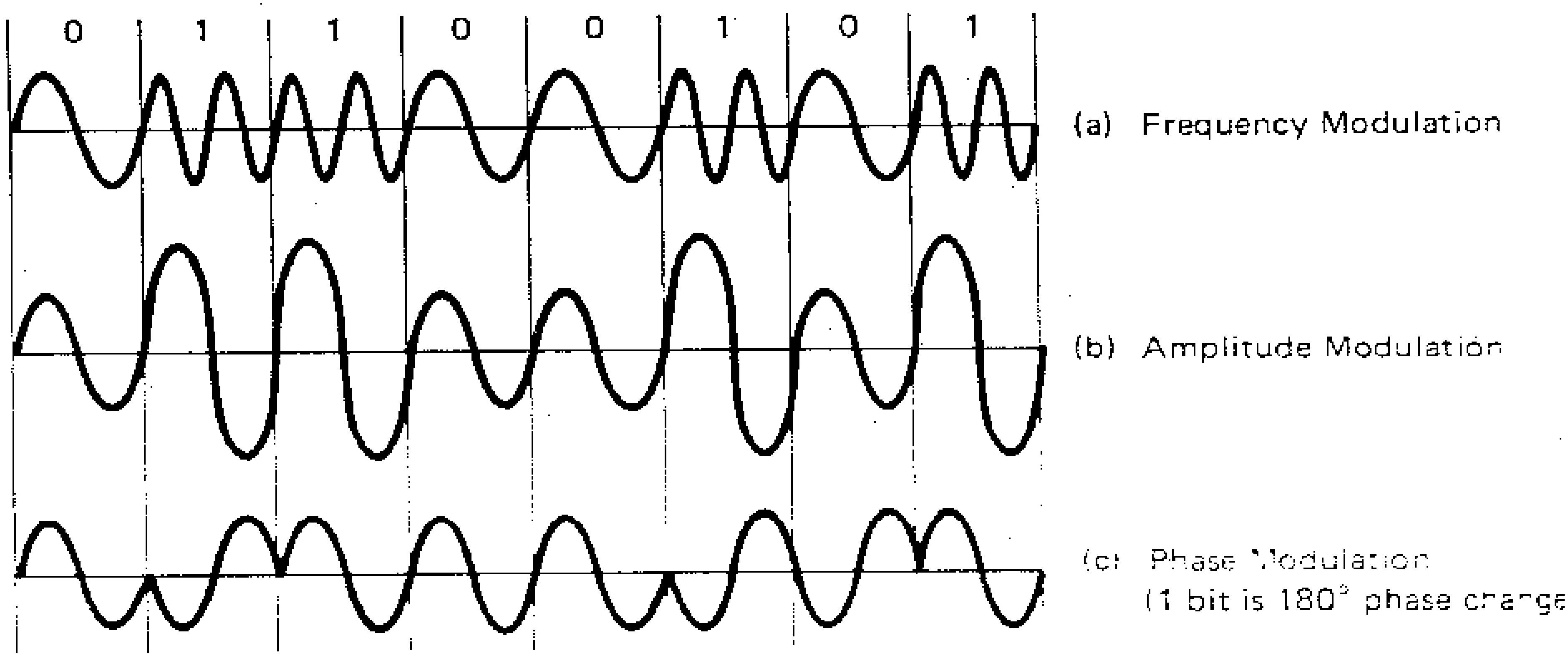
A: amplitude f : frequency ϕ : phase

Sine Wave Examples



Analog Signal Modulation

The amplitude, frequency, or phase of the standardized sine wave carrier is changed or modulated to transmit digital information



Bit Rate vs. Baud Rate

Bit rate is the number of bits per second. Baud rate is the number of signal units (one or more bits) per second which determines the bandwidth required and is limited by the medium

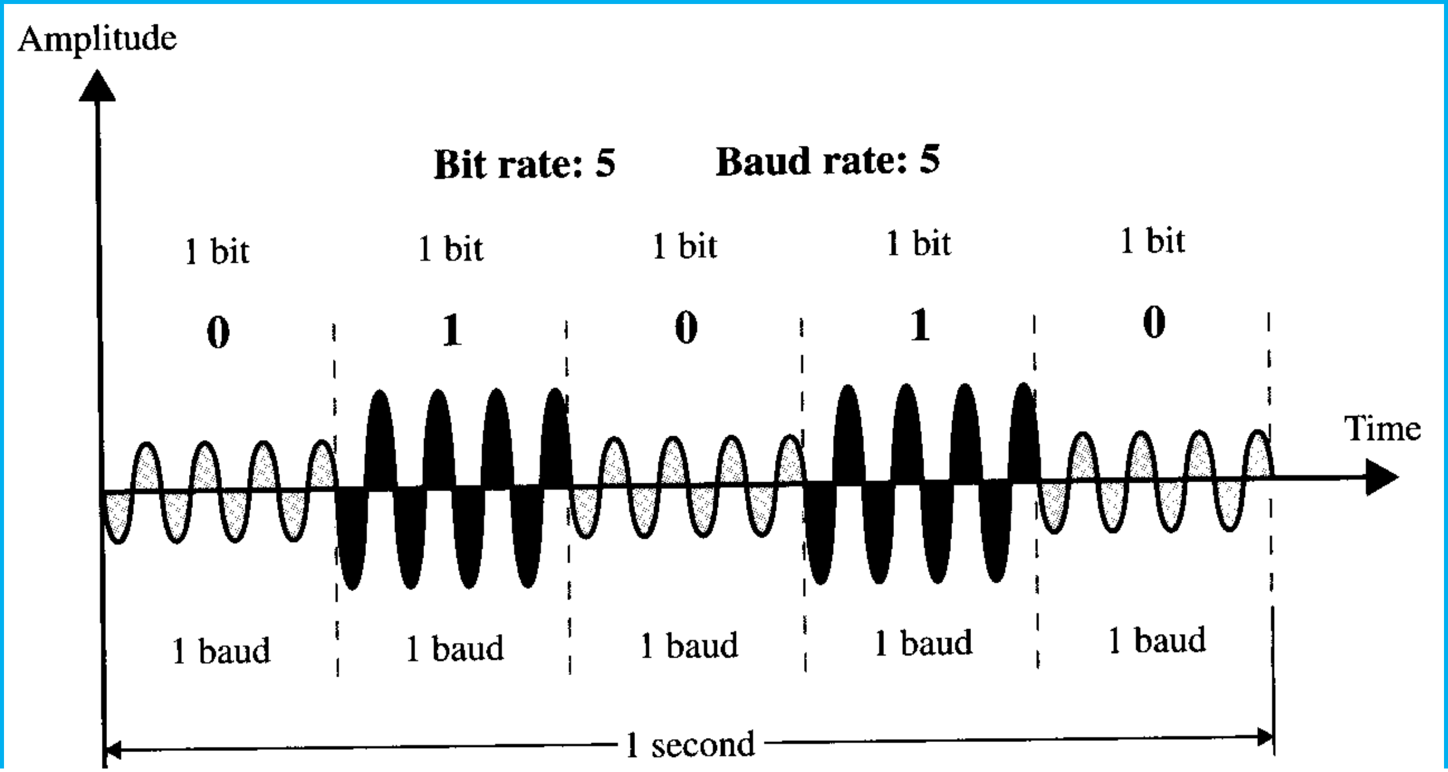
baud = 1 / (signal switch time)

bps = n * baud   where n is # of bits per signal

For a modem with a baud rate of 2400 and a bit rate of 14.4 Kbps, the number of bits per signal is ______ and the modem must be able to transmit ________ different signals

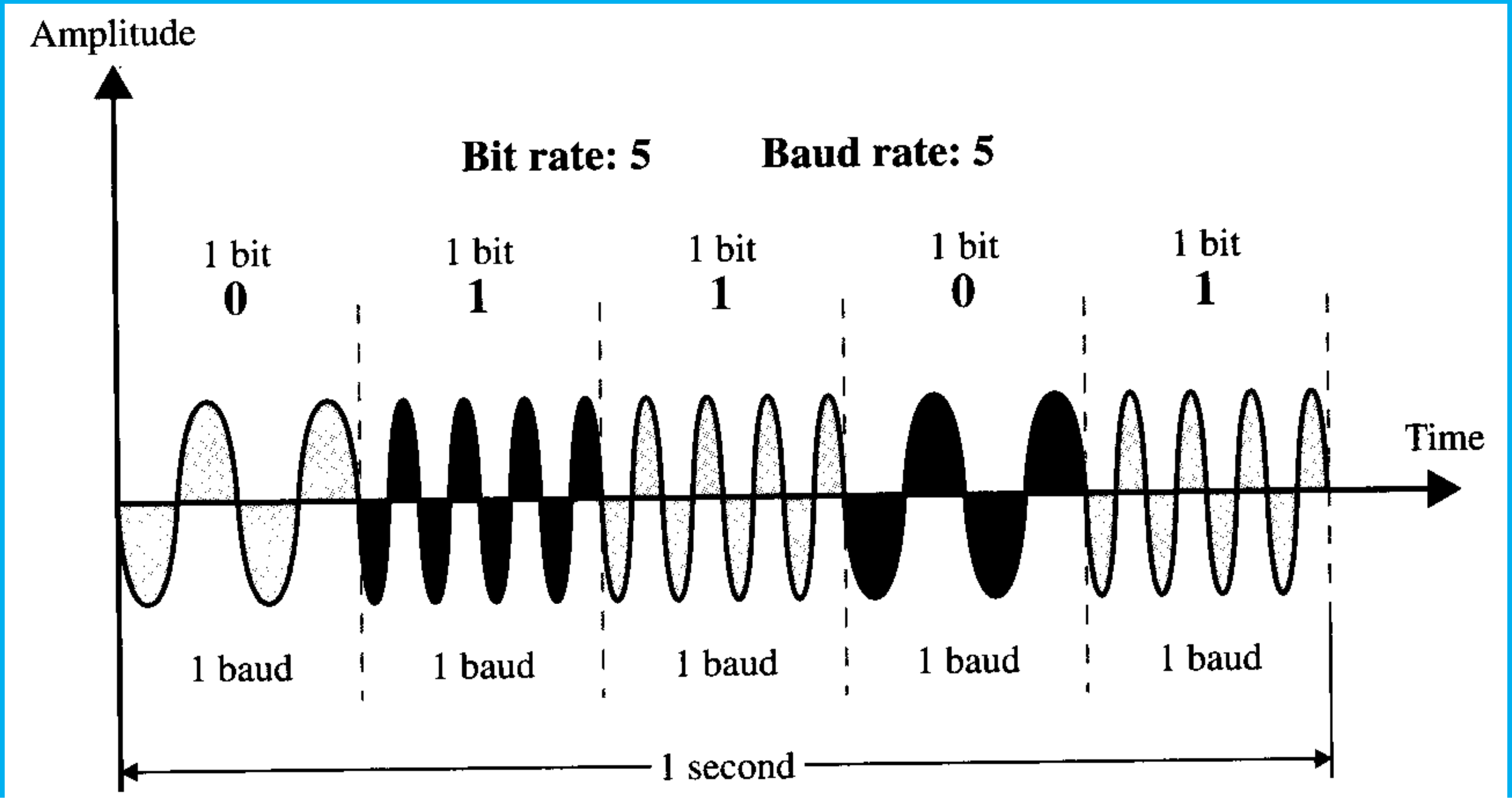
Amplitude Shift Keying

- ASK transmission is highly susceptible to noise interference
- A popular ASK technique is called OOK (on/off keying) where one of the bit value is represented by no voltage to save energy



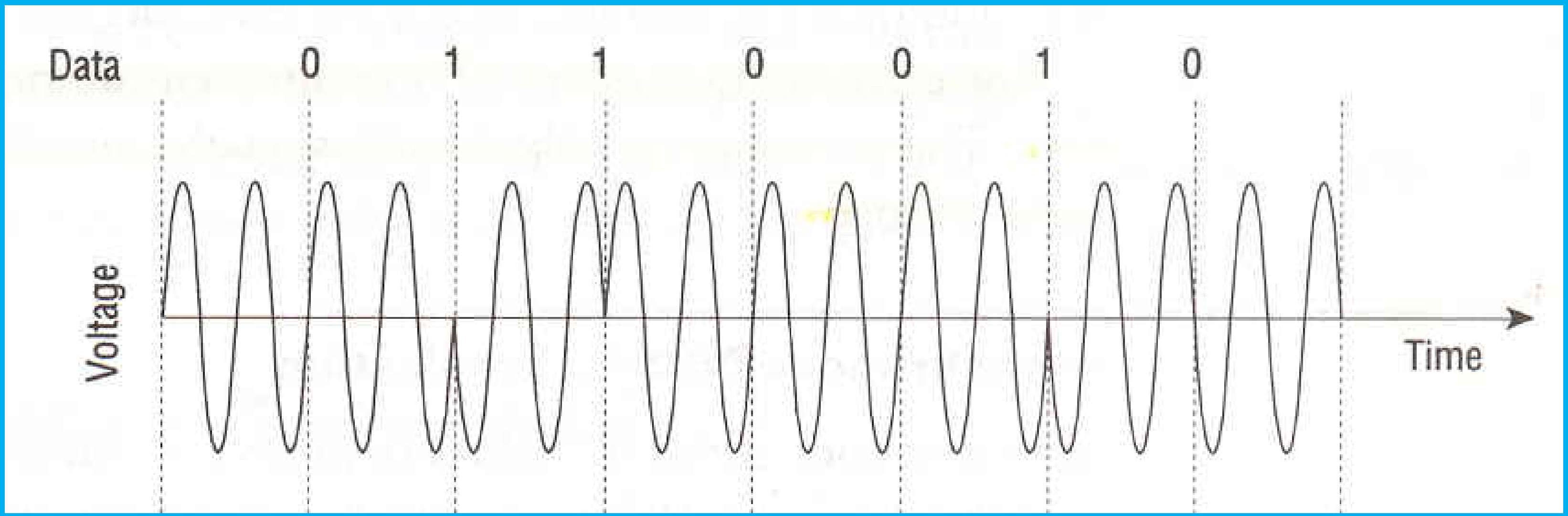
Frequency Shift Keying

- FSK avoids noise problems of ASK but requires more bandwidth
- BW = baud + $(f_1 - f_0)$ where f_1 and f_0 are the two carrier frequencies



Phase Shift Keying

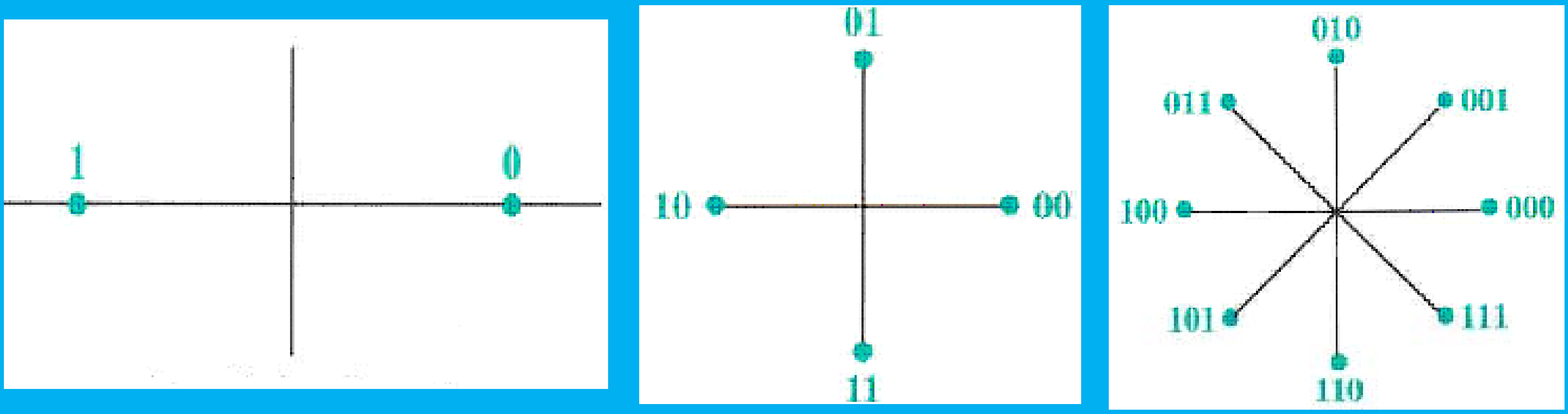
- PSK is not susceptible to noise degradation that affects ASK
- PSK bandwidth requirement is the same as ASK transmission



Bit 0 has a phase 0 and bit 1 has a phase of 180

PSK Constellation Diagram

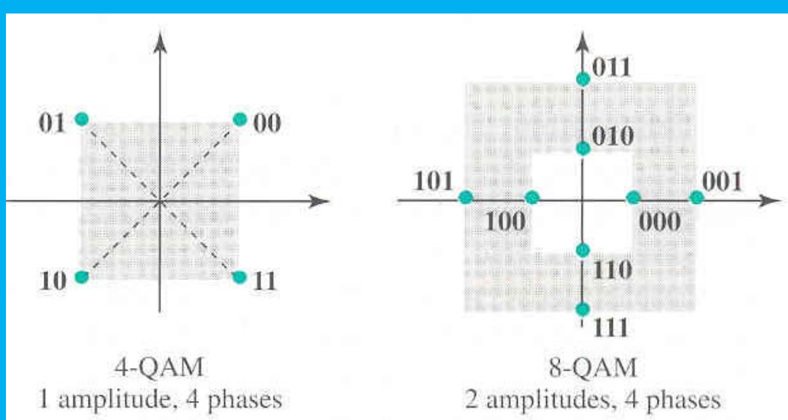
PSK bit rate can be greater as multiple signals using different phase shift can be used: BPSK, QPSK, and multilevel PSK

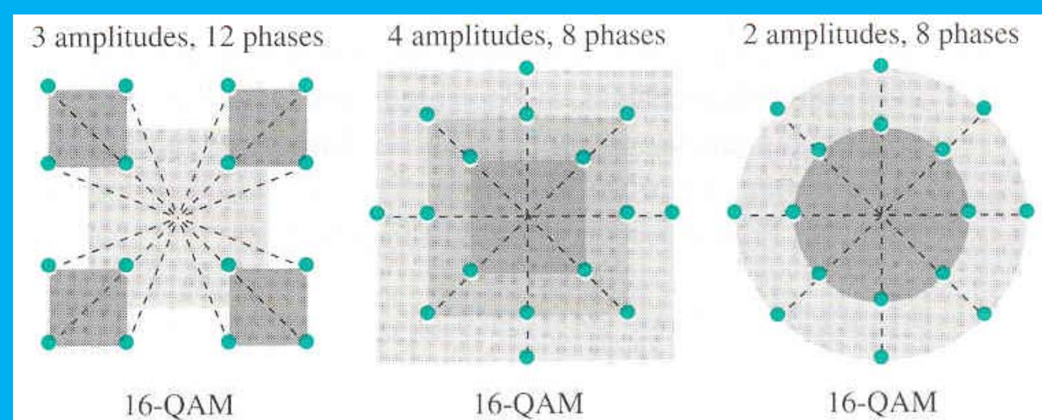


Given a bandwidth of 5000 Hz for an 8-PSK signal, what are the baud rate and bit rate?

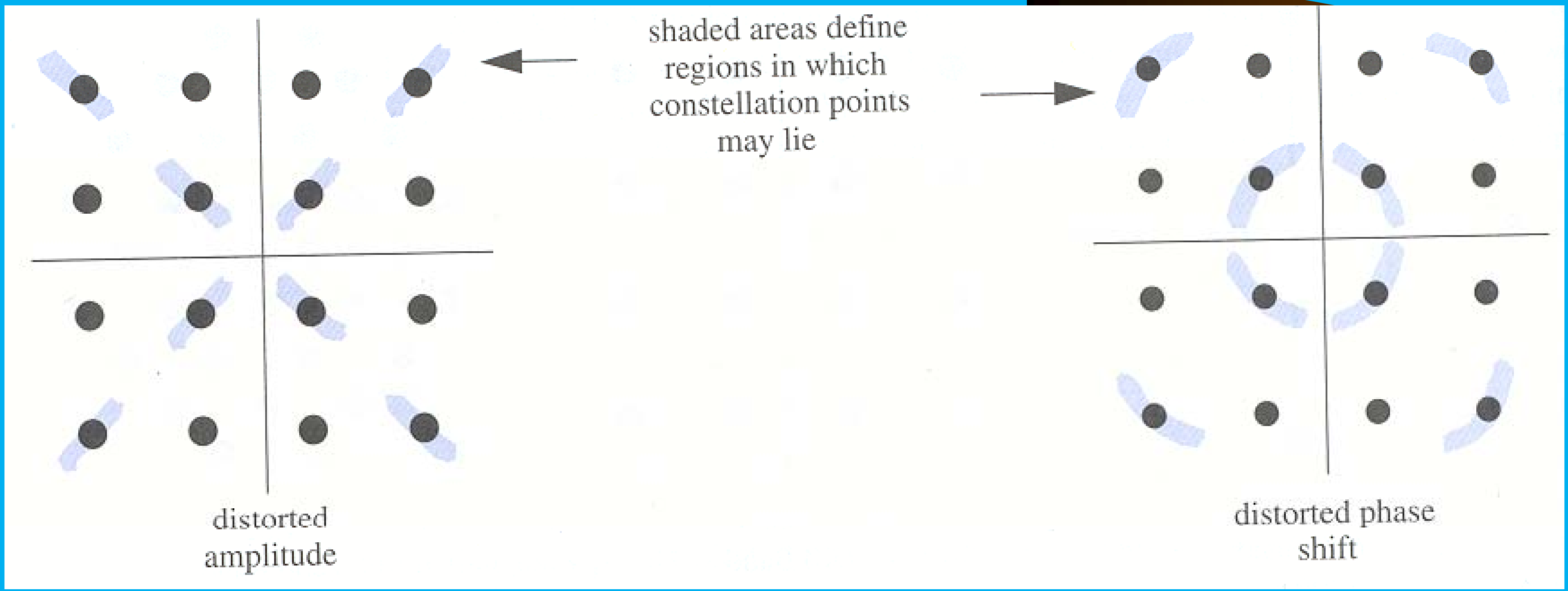
QAM

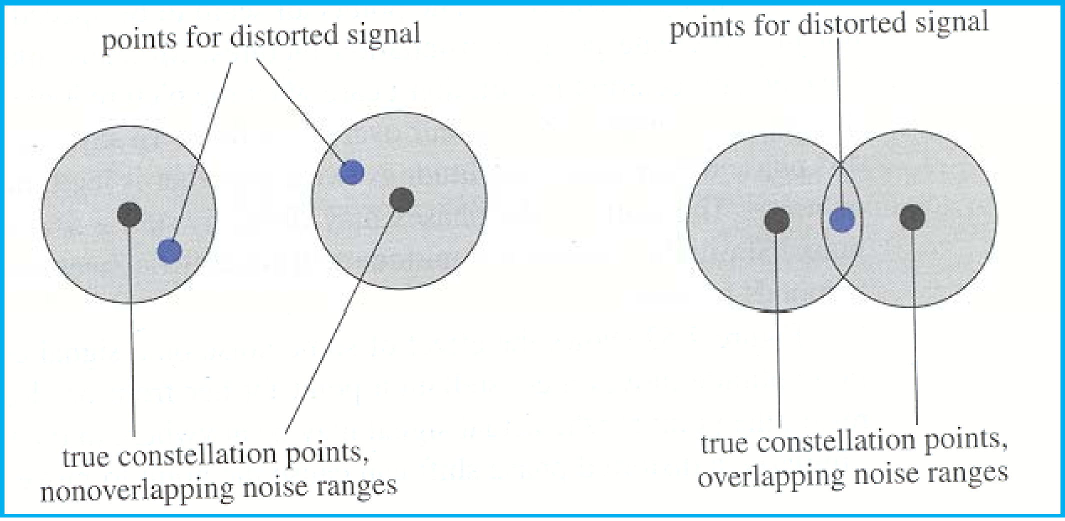
- QAM is a combination of ASK and PSK so that a maximum contrast between each signal unit is achieved
- Possible variations of QAM are numerous
- Bandwidth required for QAM transmission is the same as ASK and PSK





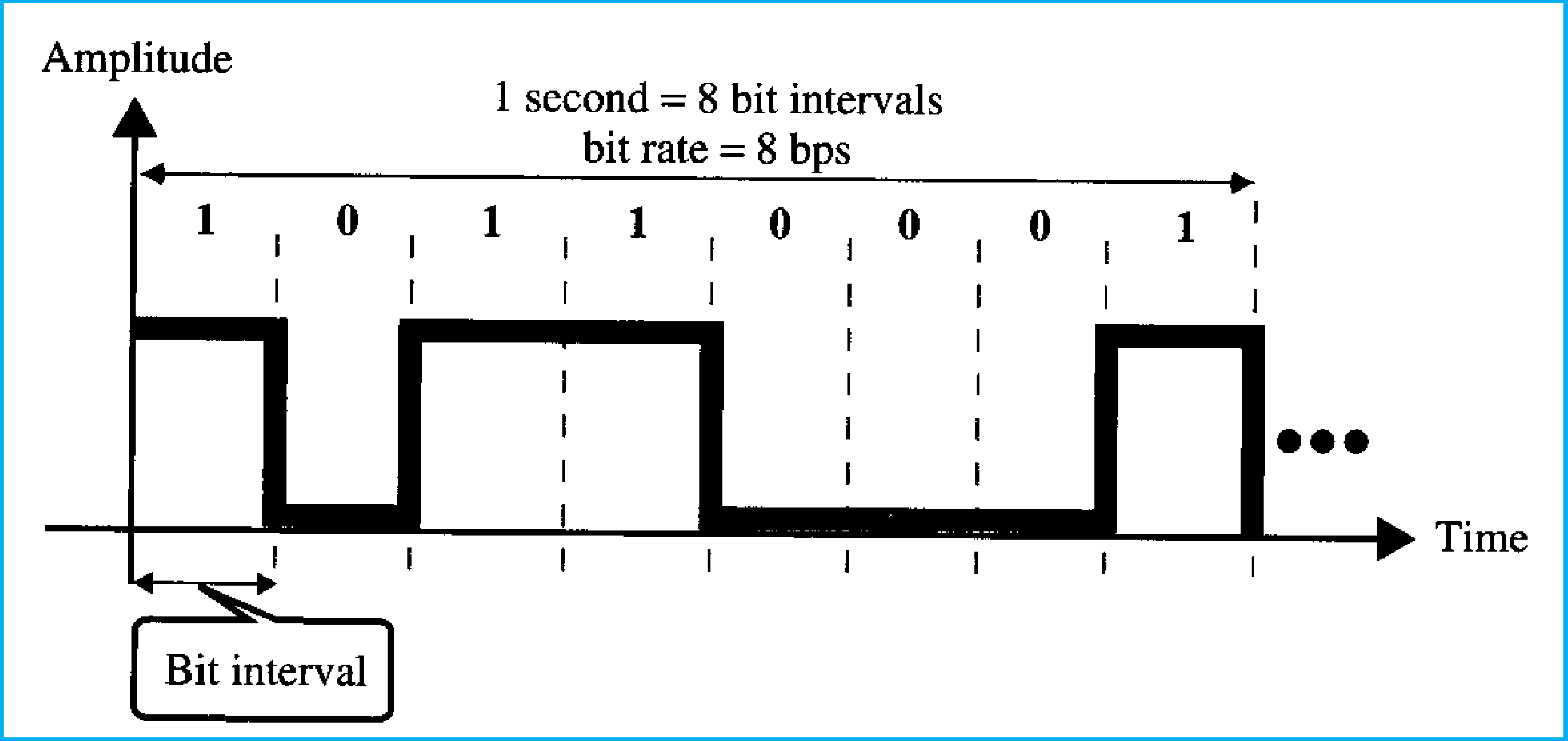
Distortion of signal Constellation Points





Digital Signals

- The ability to separate noise from a digital waveform is one of the great strength of digital systems
- Bit interval: time required to send one single bit (s)
- Bit rate: the number of bit intervals per second (bps)

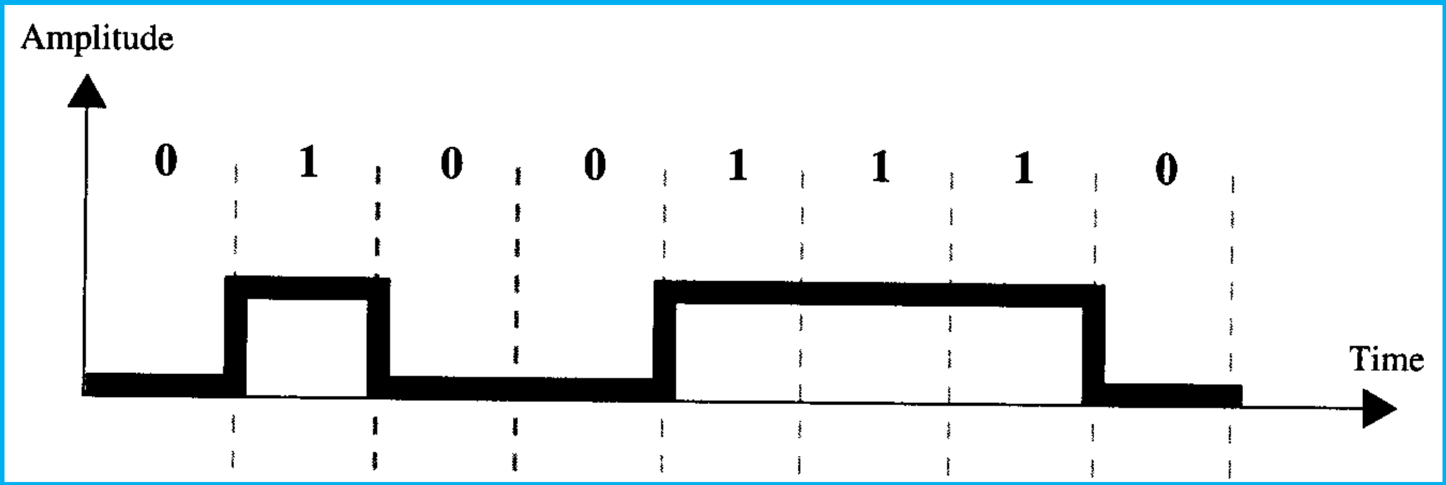


Line Coding

- Line coding is the process of converting binary data (0 and 1) to a digital signal (hi and lo)
- Line coding schemes:
  - Unipolar: uses one voltage level
  - Polar: uses two voltage levels
  - Bipolar: uses three or more voltage levels

Unipolar

- Unipolar uses one polarity which is assigned to one of the two binary states, usually 1
- Unipolar is simple and inexpensive to implement
- DC component and synchronization problems
- Used within a PC, not used for data transmission



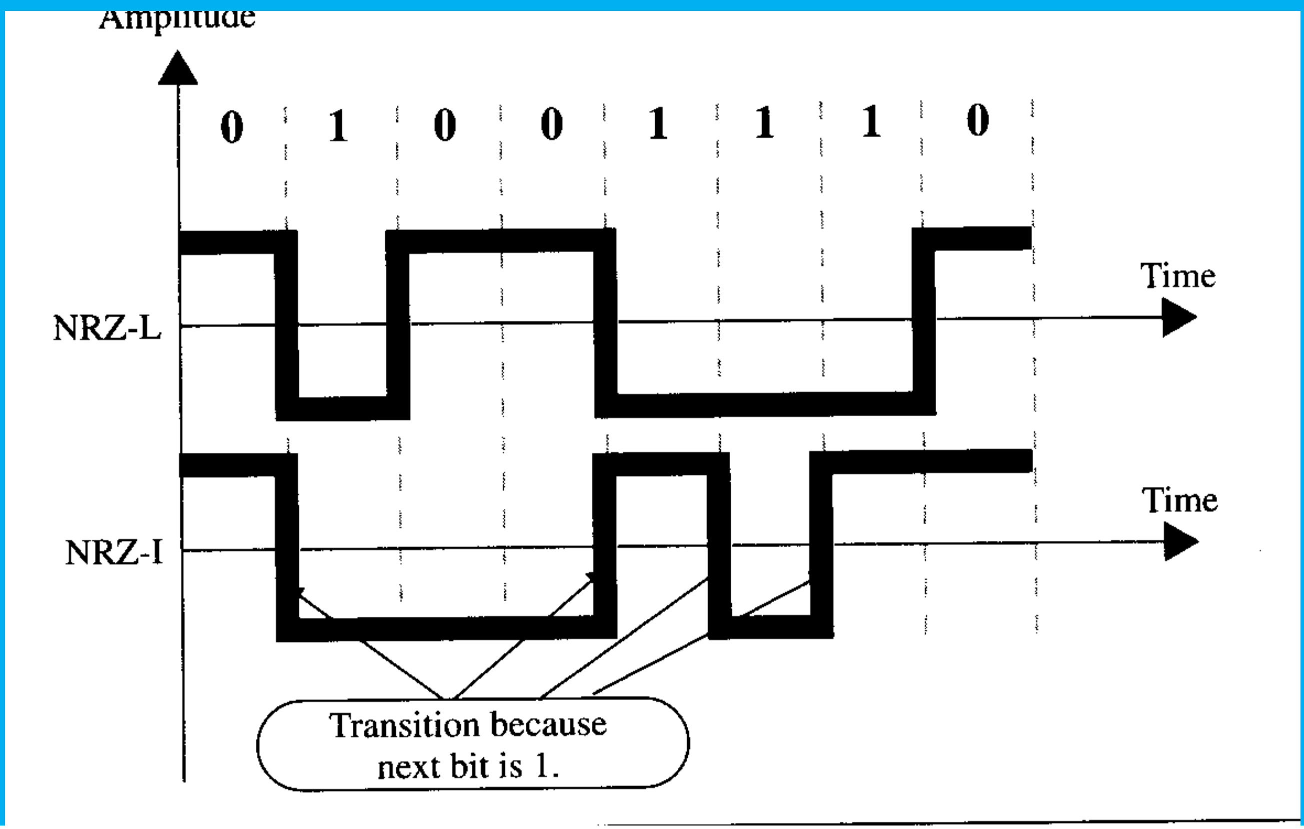
Polar

DC component problem is alleviated and synchronization is provided

1. NRZ: nonreturn to zero
2. RZ: return to zero, uses three values – positive, negative, and zero and requires two signal changes to encode one bit
3. Manchester
4. Differential Manchester

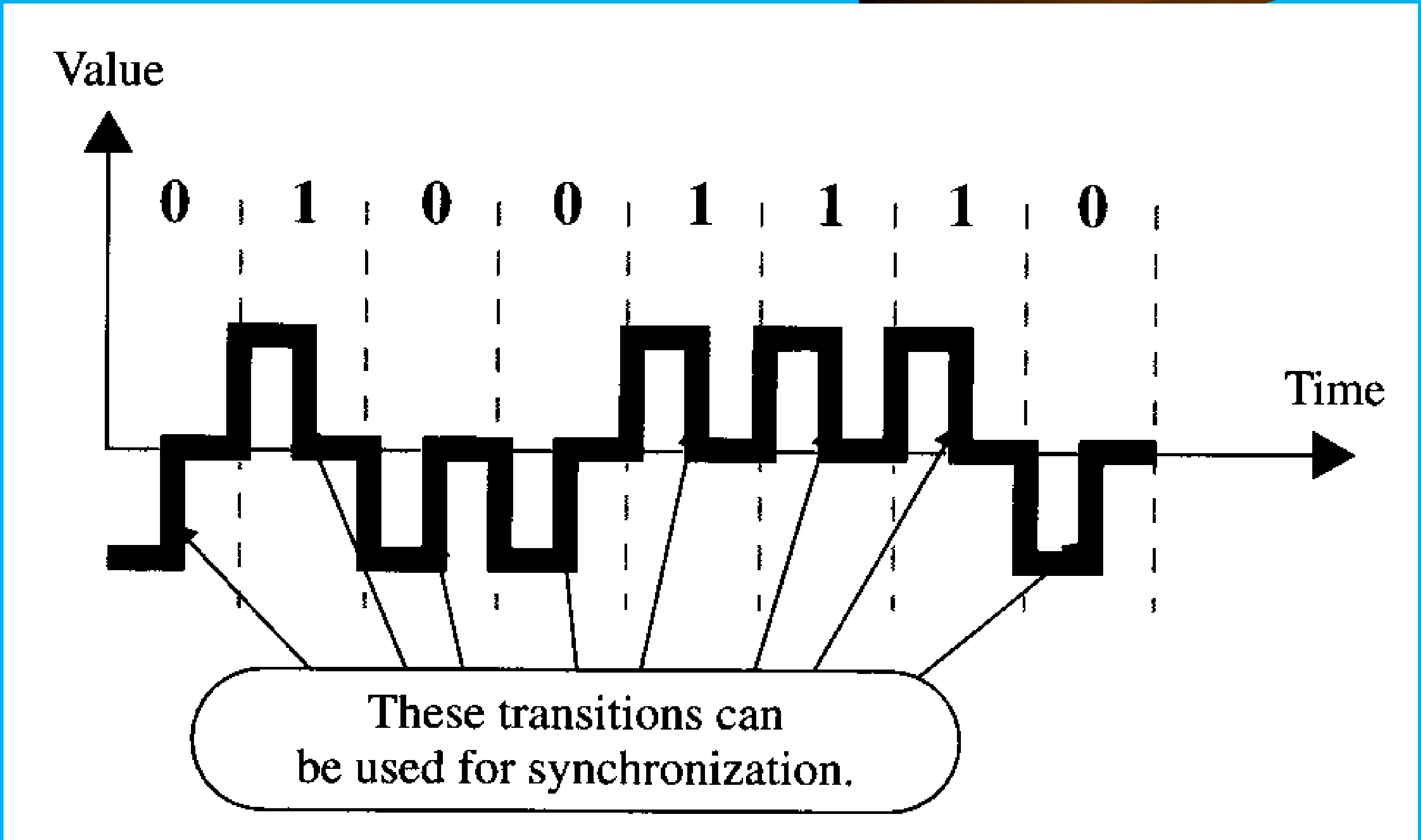
NRZ

- NRZ-L: the level of the signal is dependent upon the state of the bit – synchronization problem
- NRZ-I: signal is inverted if a 1 is encountered, long stream of 0s?



RZ

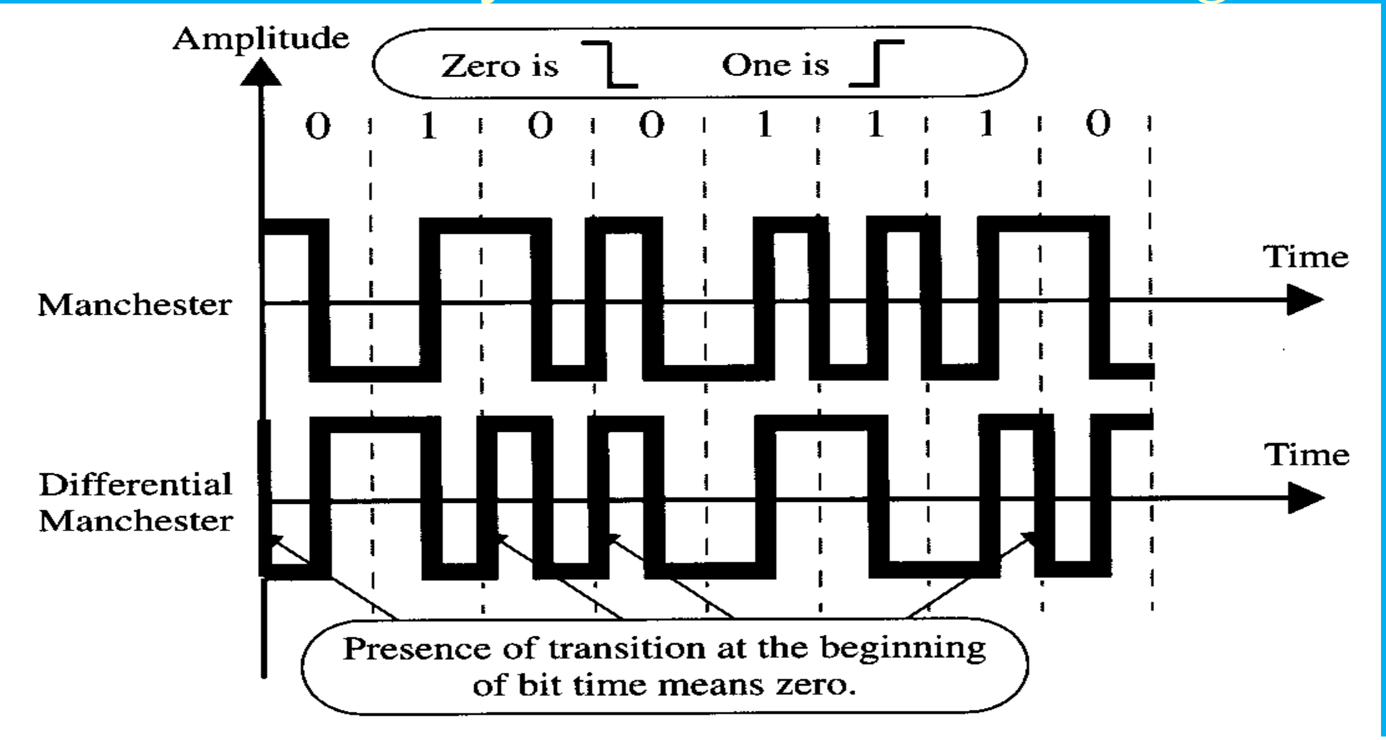
RZ encoding requires two signal changes to encode 1 bit and occupies more bandwidth but provides synchronization



Manchester and Differential Manchester

- Manchester encoding is used by Ethernet LANs. The transition at the middle is used for both synchronization and bit representation
- Differential Manchester is used by Token Ring LANs. The transition at the middle is used for synchronization. The bit representation is defined by the inversion at the beginning of the bit

Price?

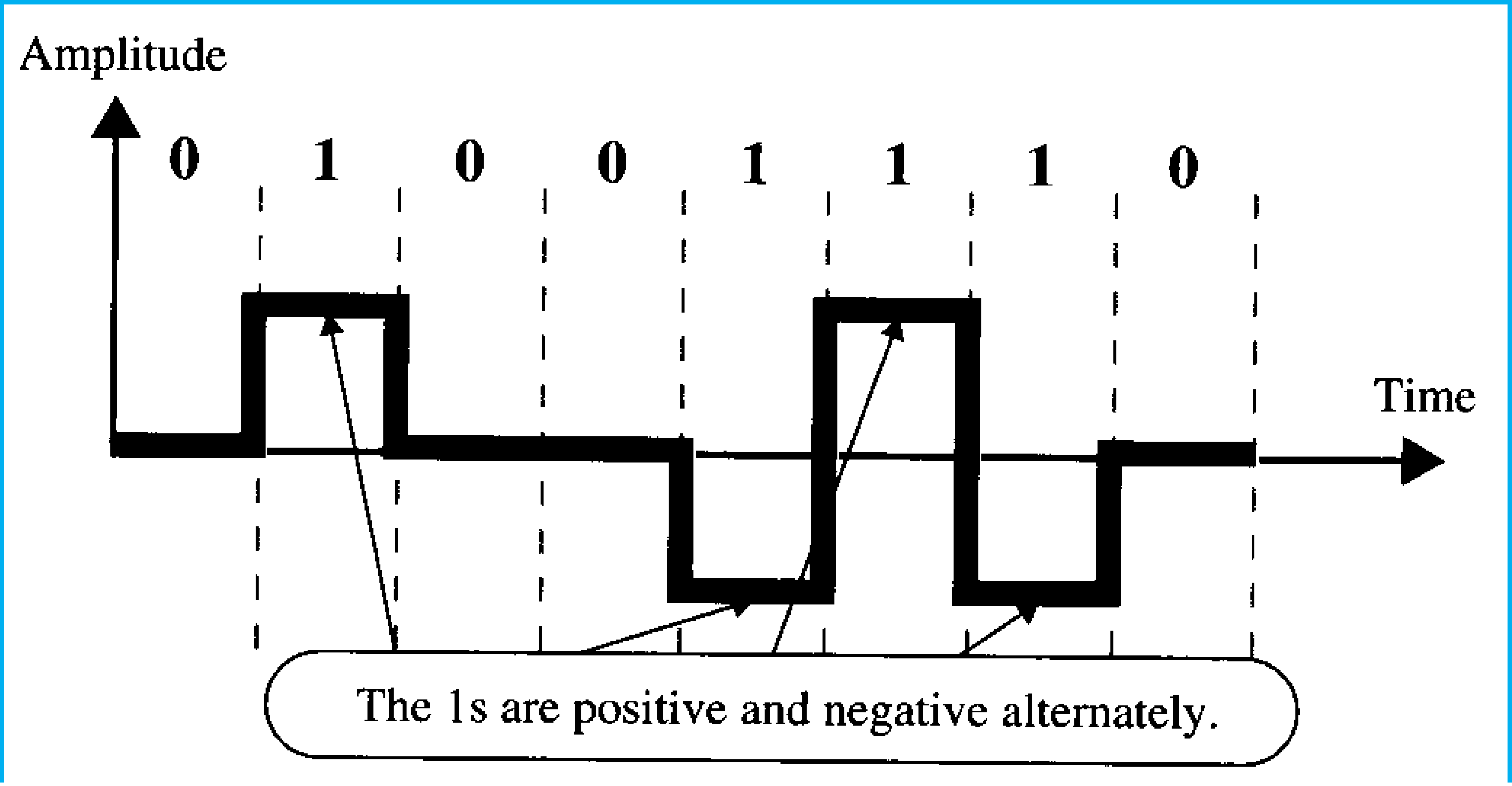


Bipolar

- AMI: alternate mark inversion
- AMI with bit stuffing
- AMI with BnZS: bipolar n-zero substitution

AMI

Since each node must derive its receive clock from the incoming bit stream, a long stream of binary zeroes can cause problems with clock recovery

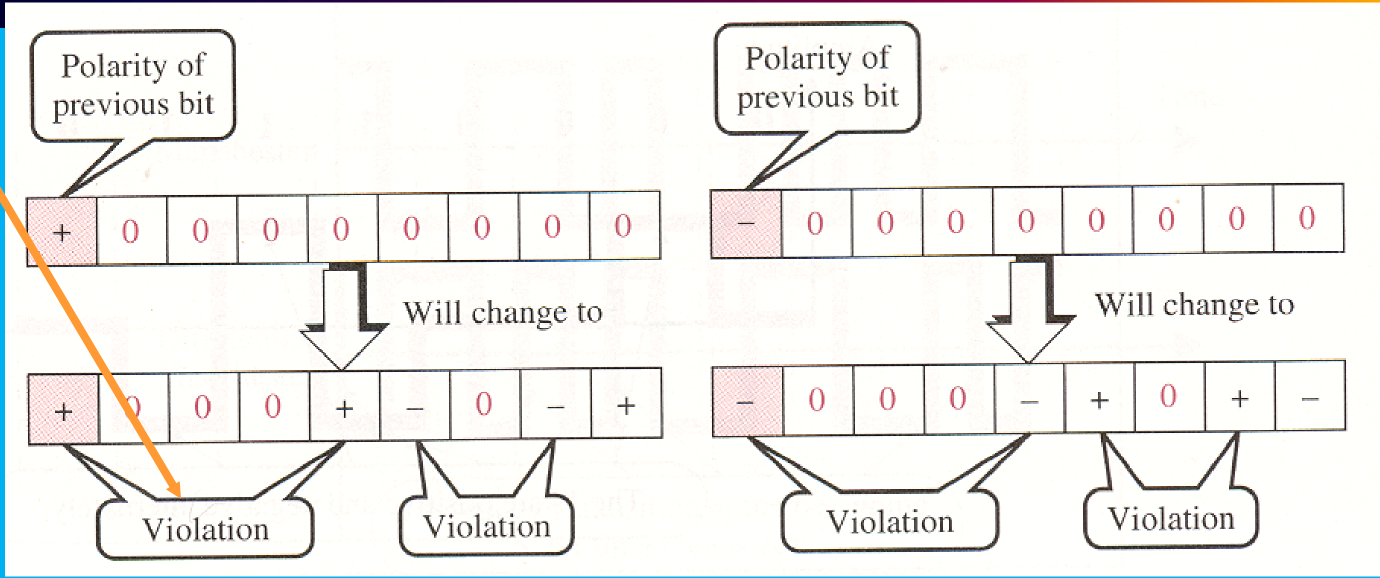


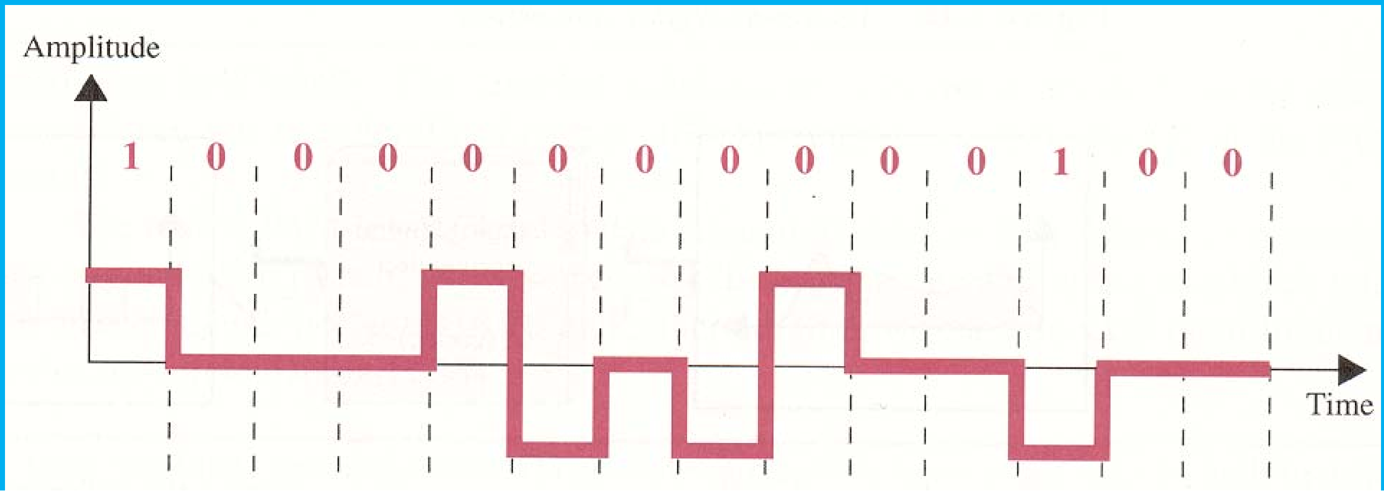
Bit Stuffing

- Insert a binary 1 after every seven data bits
- Simple but high overhead (one of every eight bits), a 64 Kbps DS-0 channel can only provide 56 Kbps user data throughput

B8ZS

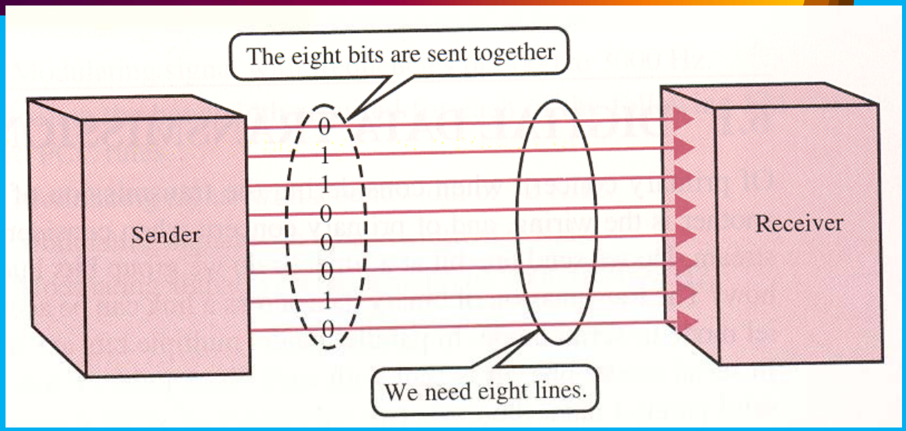
A BPV occurs when a nonzero voltage is followed by a nonzero voltage of the same polarity which is considered a transmission error condition



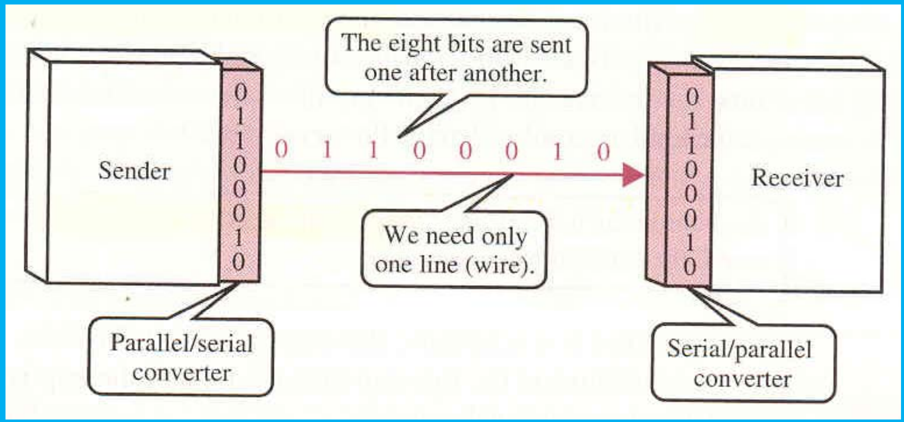


Transmission Mode

- Parallel transmission: faster but more expensive, limited to short distance (printer cable)

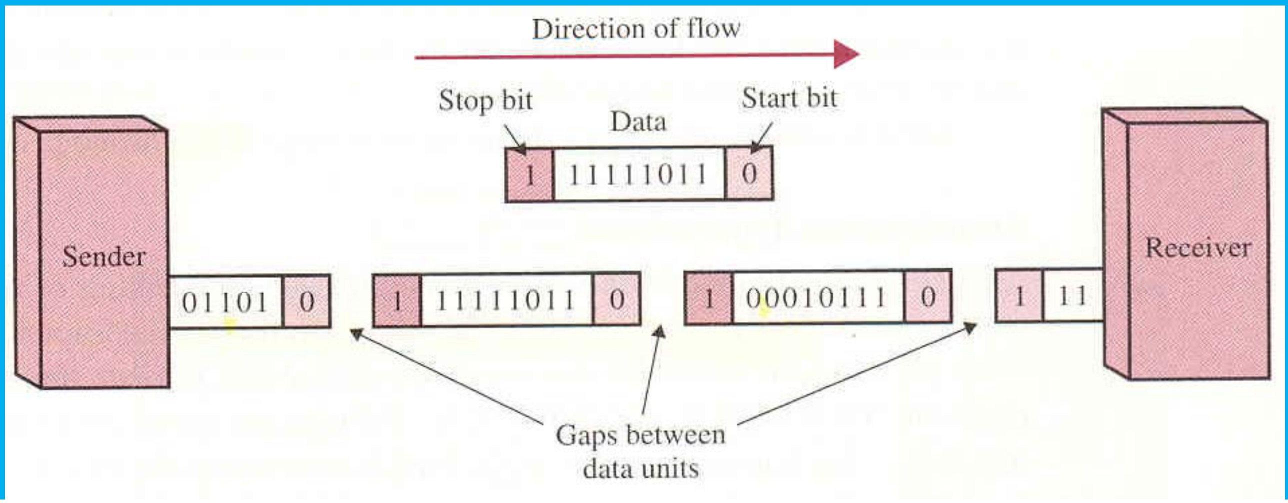


- Serial transmission: bit by bit on one communication channel (network cable)
  - Asynchronous
  - Synchronous



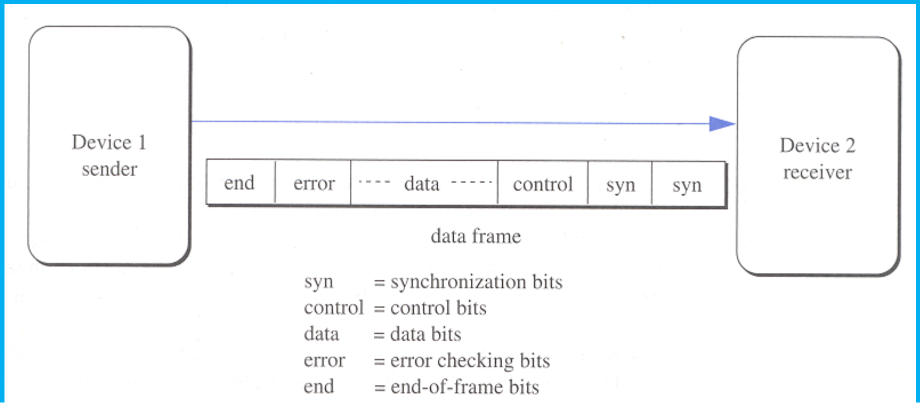
Asynchronous Transmission

- Byte oriented I/O and each byte sent independently
- Asynchronous at the byte level, bits are synchronized for the duration of a byte
- Start/stop transmission; easy to implement, simple (cheap) and effective, but slow with high overhead
- Suitable for slow devices and short transmissions (keyboard to a computer)



Synchronous Transmission

- Larger bit groups (data frame), requires intelligent terminals to distinguish between data and control information and follow special protocol
- Faster and more efficient transmission, useful for high-speed data transmission
- Timing becomes critical
  - Guaranteed state change
  - Separate clock signal - most effective in short-distance transmissions (ex. RS232 interface)



Transmission Example

Suppose a file of 10K bytes is to be sent over a line at 2.4Kbps

a. Calculate the overhead in bits and time in using asynchronous communication (assuming 8-bit character)
b. Calculate the overhead in bits and time in using synchronous communication (assuming 1000-character frame with 50 control bits per frame)
c. What would be the answers in part a and b for a file of 100K characters?
d. What would be the answers in part a and b if the data rate is 9600 bps?

Bandwidth Use

Bandwidth use schemes are based upon the availability and utilization of channel. The transmission capacity the network's transmission media can provide depends on the bandwidth use method one employs

- Baseband
- Broadband

A set of parallel trends in networking is for technologists to deliver ever-higher amounts of bandwidth, and for application developers to build software that requires more bandwidth to operate, ex. Real-time video teleconferencing, voice-only networking services, streaming video and audio

Baseband

- The entire bandwidth of the cable is used to transmit a single data signal (one path, one channel)
- Baseband transmission limits any single cable strand to half-duplex transmission
- Baseband networks can use either analog or digital signaling, but digital is much more common
- Baseband signals can be more reliably interpreted and regenerated than broadband signals
- Although baseband can only support one signal at a time, multiple conversations can be combined on that single signal using a technology called time-division multiplexing

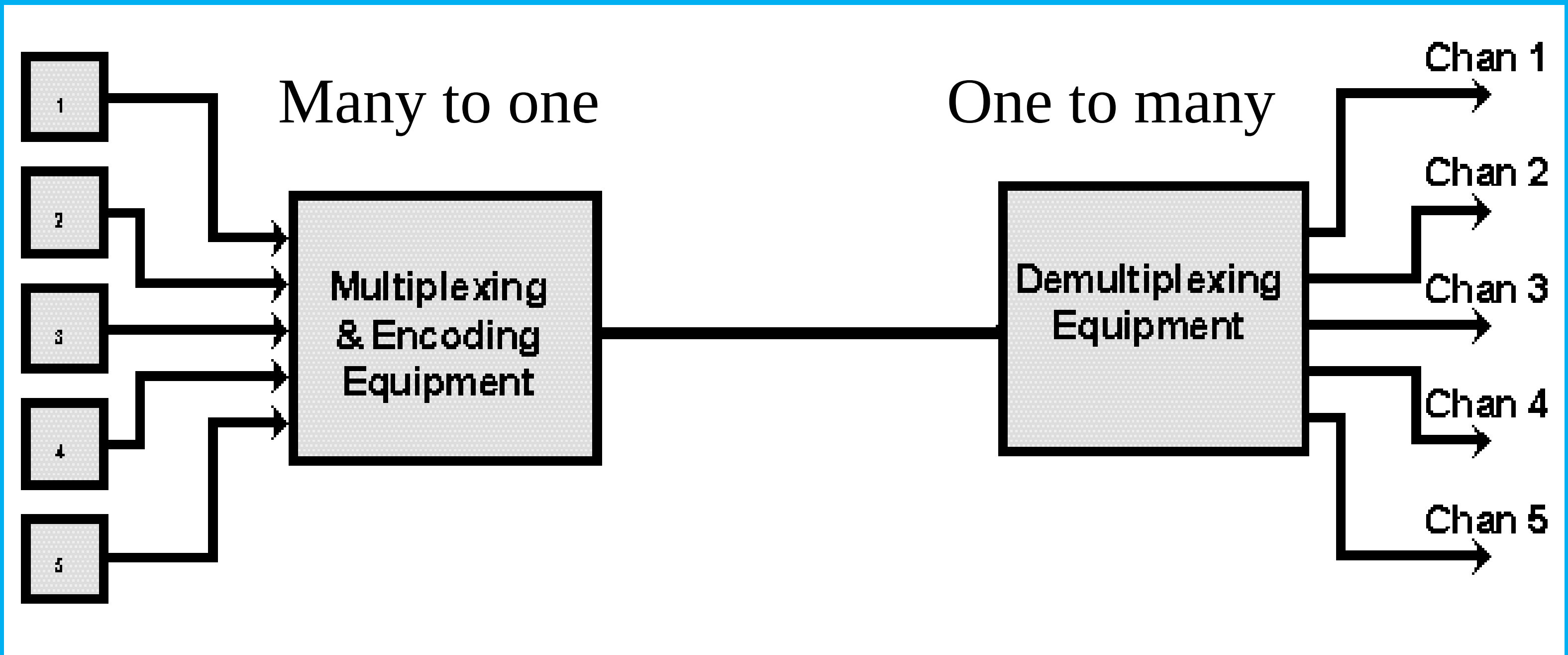
Broadband

- Signals are modulated onto carrier waves before transmission and demodulated after receiving
- One path, many channels
- Cover a larger distance than baseband
- Multiple channels are created by dividing up the medium's bandwidth by using a technology called frequency-division multiplexing, ex. Radio & TV
- Using analog signals, broadband networks can directly support multiple simultaneous conversations
- Due to the uni-directional characteristic of analog amplifiers, either dual cable (dual-cable broadband) or different frequency bands (mid-split broadband) must be used for inbound and outbound communication

Multiplexing

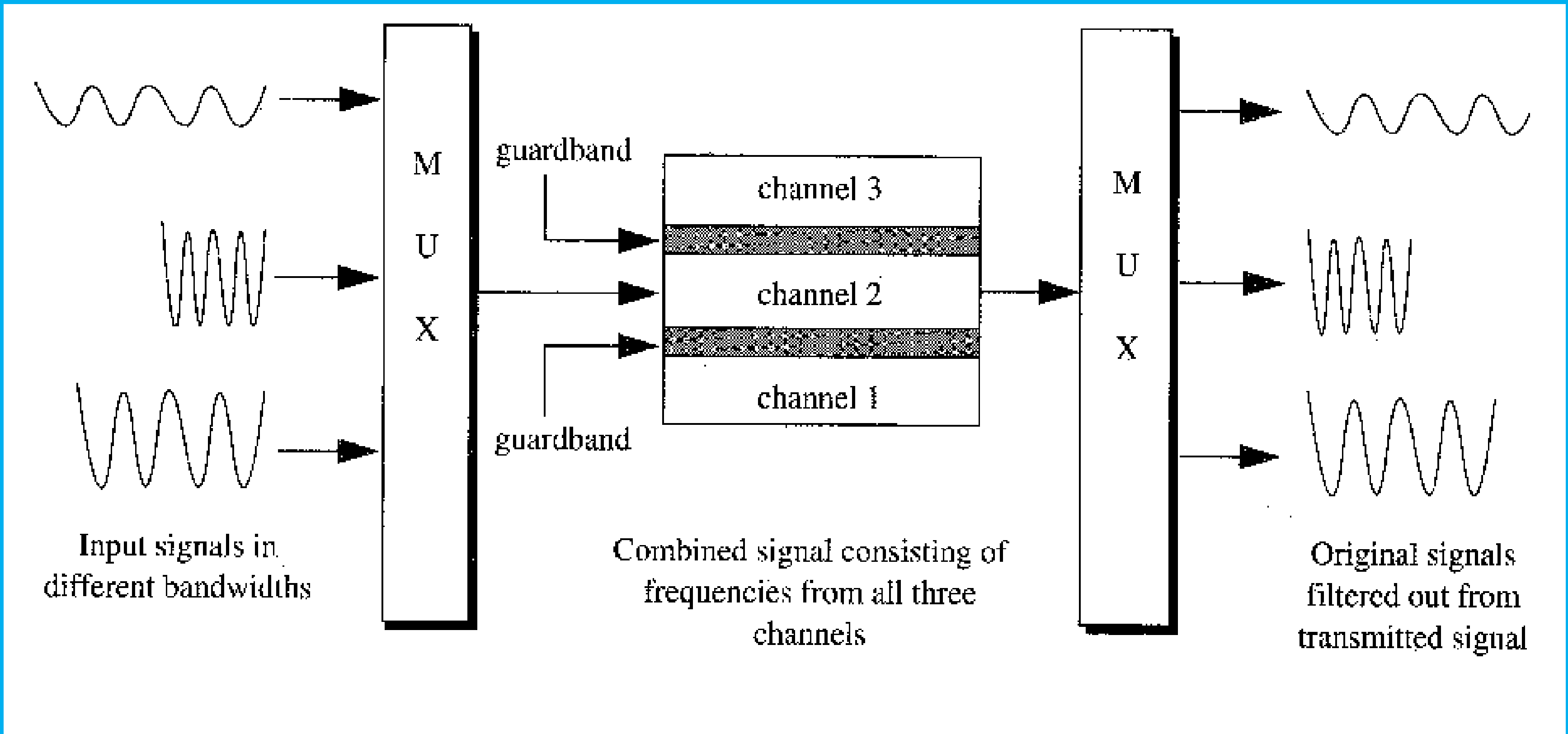
A multiplexer allows multiple devices to communicate simultaneously over a single transmission medium segment

- Frequency-Division Multiplexing (FDM)
- Time-Division Multiplexing (TDM)

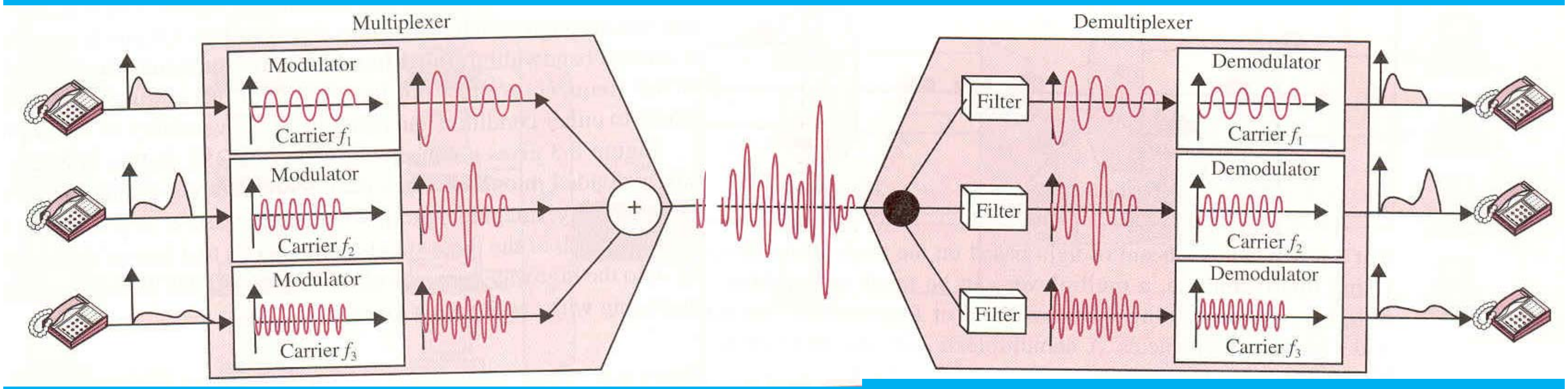


Frequency Division Multiplexing

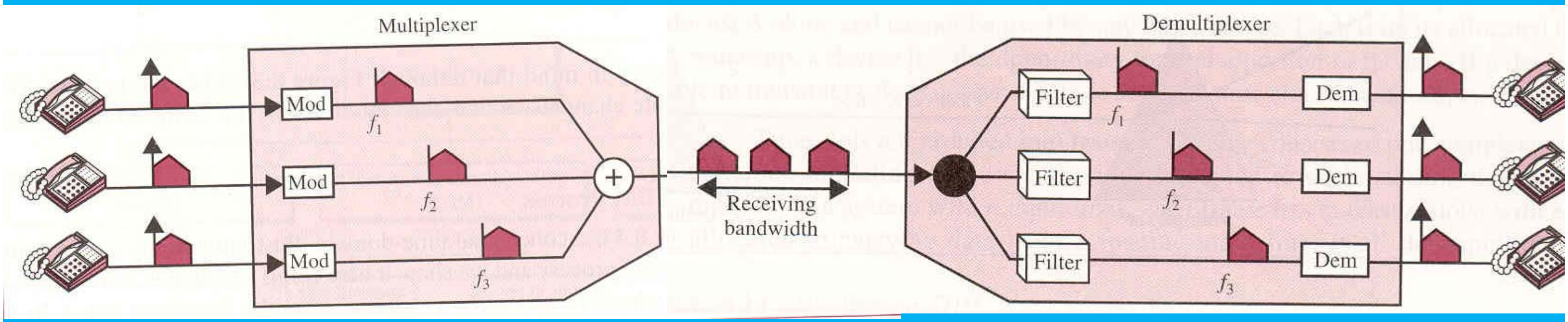
FDM uses different frequencies to combine multiple streams of data for transmission over a communications medium. It assigns a discrete carrier frequency to each data stream and then combines many modulated carrier frequencies for transmission.



FDM – Time Domain



FDM – Frequency Domain



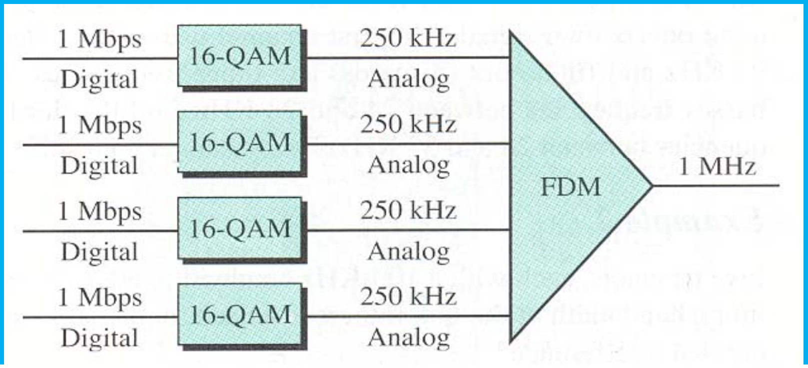
Note that the f_2 and f_3 bands are shifted (modulated)

FDM Exercise

1. A certain medium has a bandwidth of 70 KHz. How many telephone conversations can be simultaneously supported by this medium using FDM with a 300 Hz guard band? Note the human speech has a frequency range from 200 Hz to 3400 Hz.

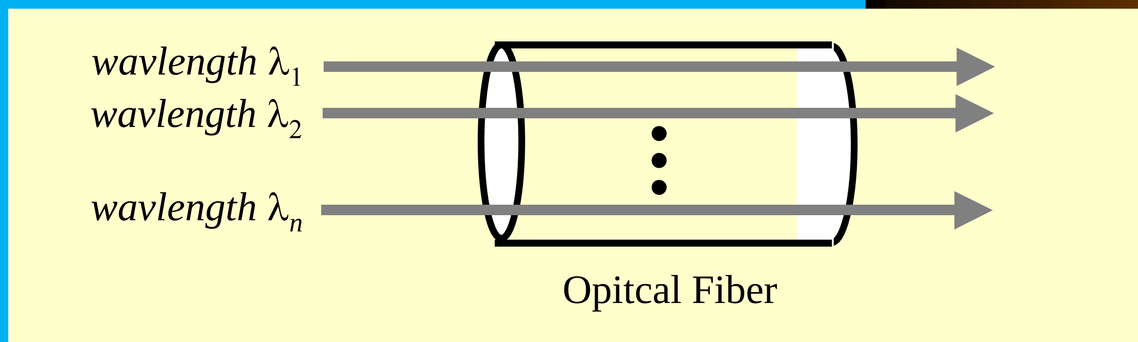
   70000/(3400-200+300) = 20

2. Four digital data channels, each transmitting at 1 Mbps, use a satellite channel of 1 MHz. Design an appropriate configuration using FDM.

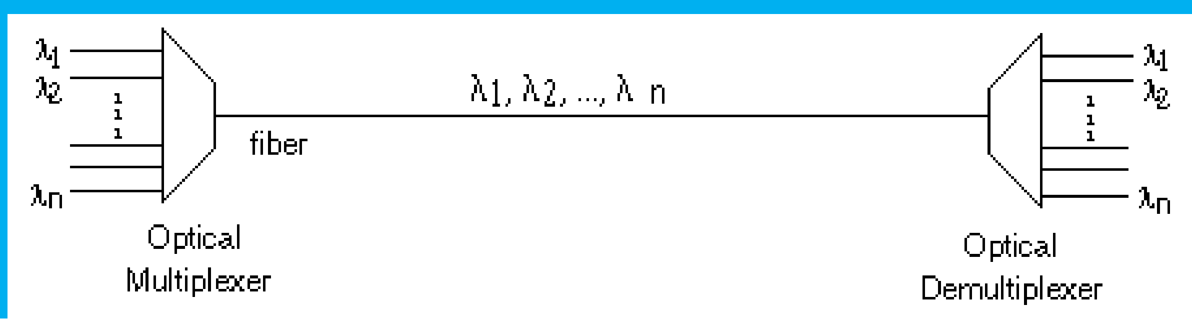


What is WDM?

Wavelength Division Multiplexing (WDM)

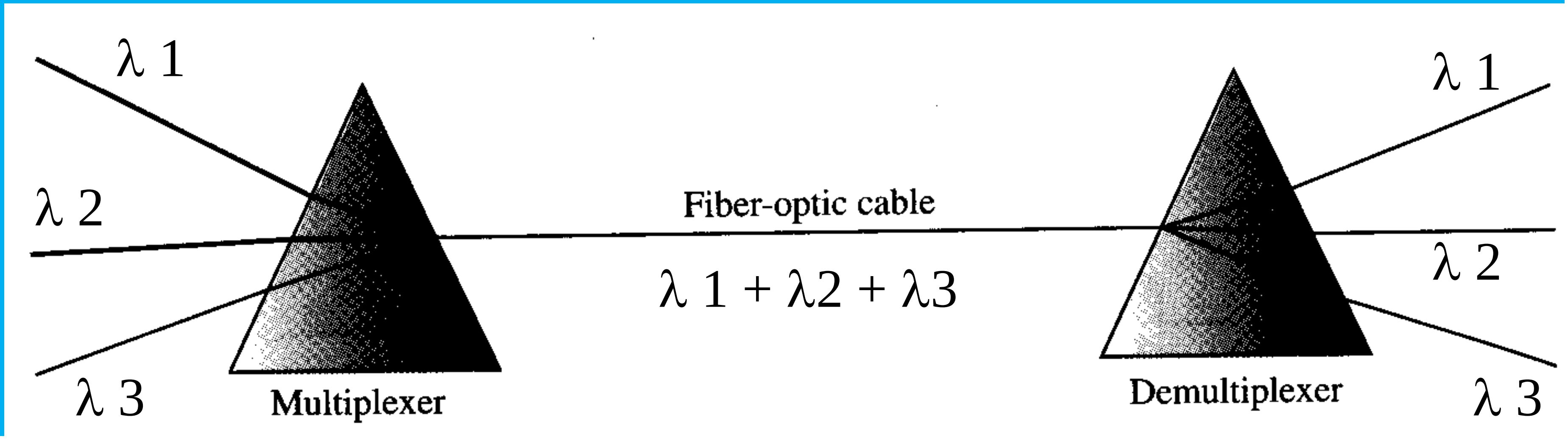


– Each wavelength (color) is an independent communication channel
– Multiple wavelengths channels can be multiplexed into one fiber
– Commercial systems with 160 channels of 10 Gbps are available



Wavelength Division Multiplexing

- Conceptually the same as FDM ($v = f \lambda$), except the frequencies are very high
- To combine multiple light sources into one single light, the principle of prism can be employed

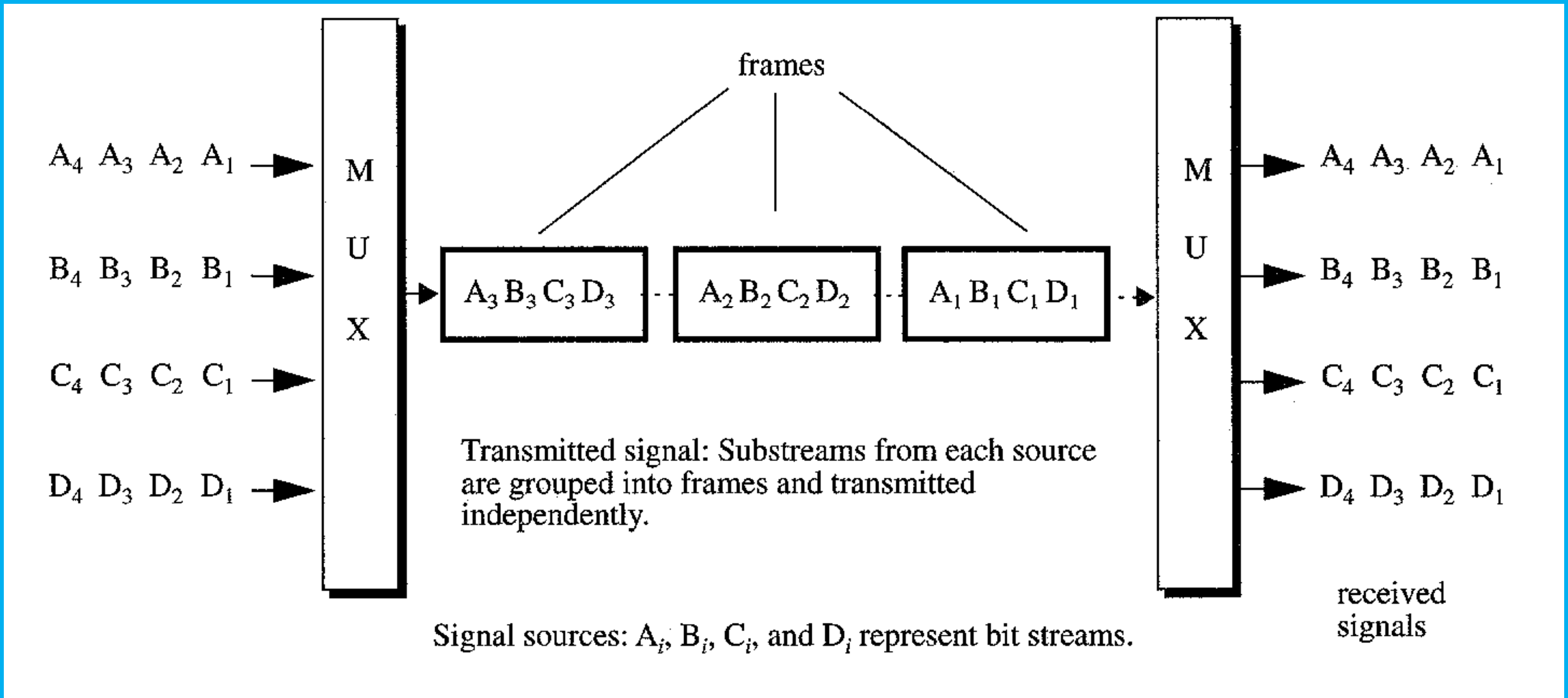


Why WDM?

- Provide huge bandwidth using fiber
  - Fiber has about 50 terabits per second
  - Multiple WDM channels provide huge aggregate bandwidth in a single fiber
- Avoid the bottleneck of increasing baud rate
  - Current peak rate is about only 10 Gbps
  - Implementation of higher bit rate using fiber for long-distance transmission is more difficult
  - Multiple WDM channels with peak rate can achieve huge capacity
- Upgrade network capacity without fiber re-deployment

Time Division Multiplexing (sync.)

- TDM combines data streams by assigning each stream a different time slot in a set and repeatedly transmits a fixed sequence of time slots over a single transmission channel
- Interleaving can be done by bit, by byte, or by any other data unit

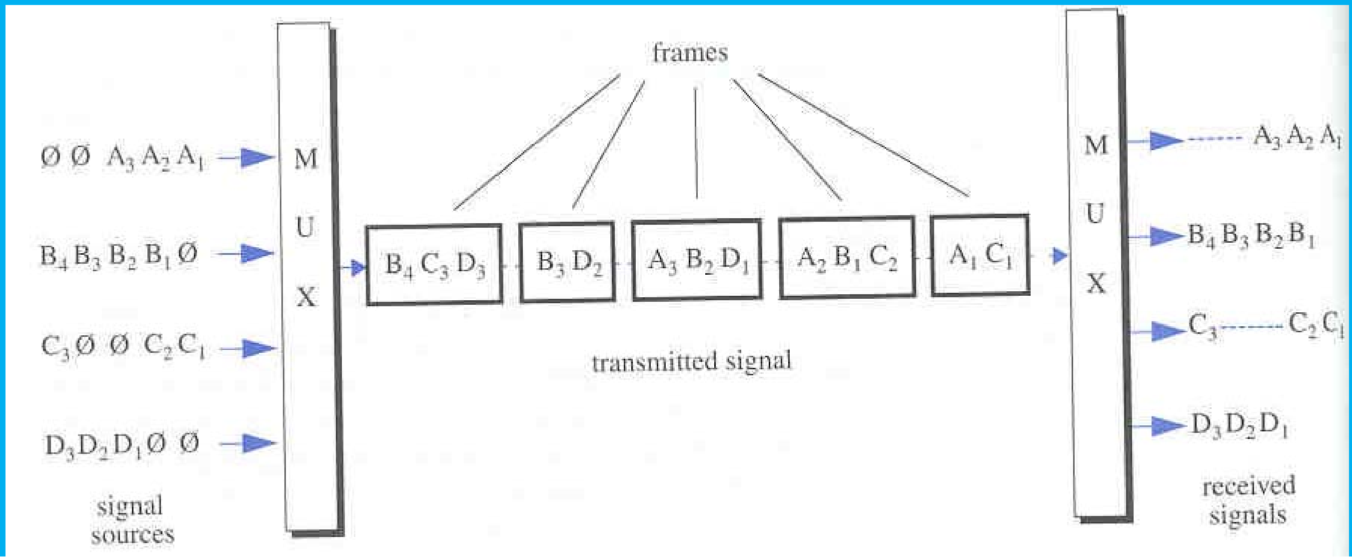


TDM Exercise

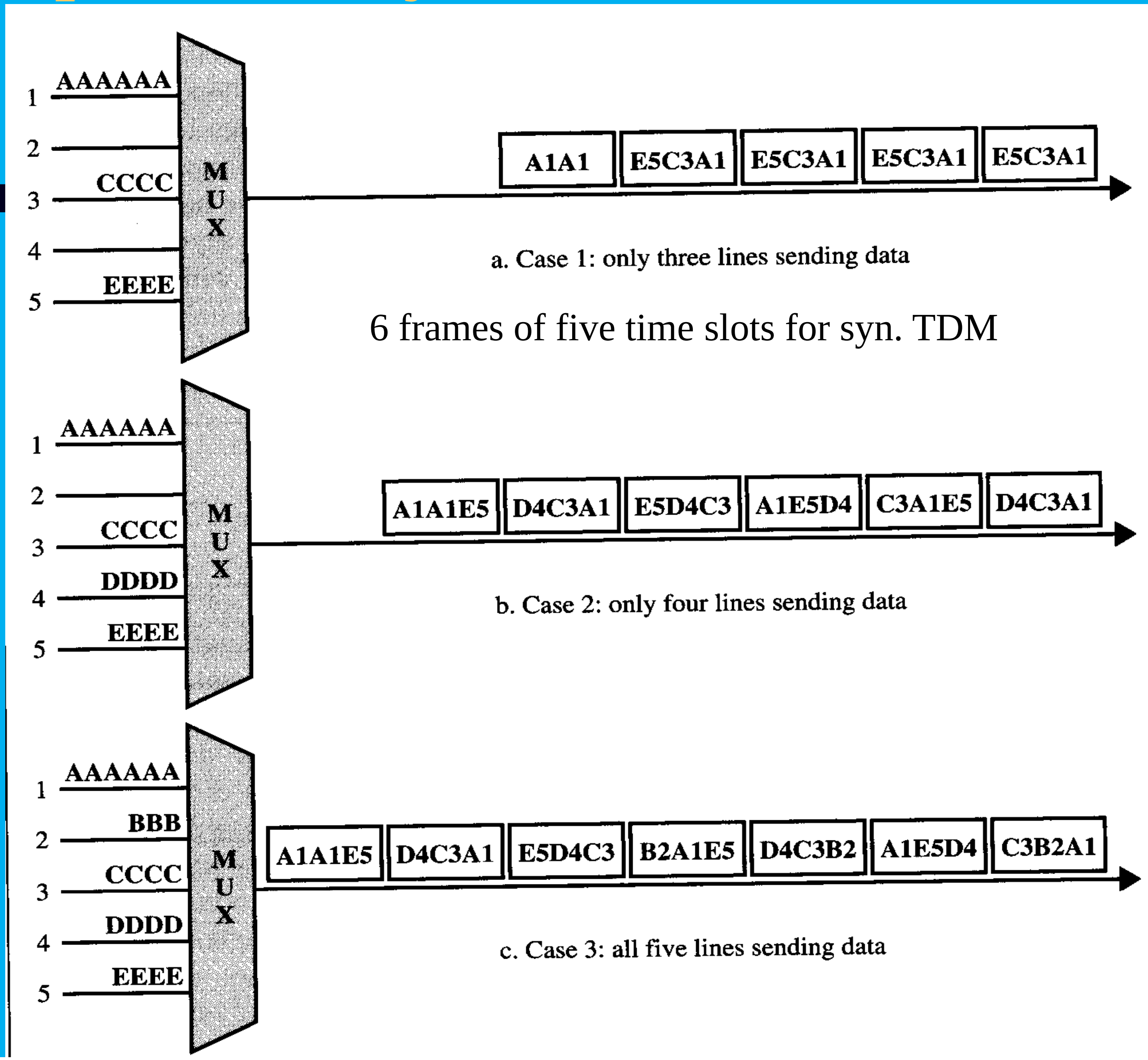
1. A character-interleaved TDM is used to combine the data streams of a number of 2400-baud asynchronous terminals for data transmission over a 128 Kbit/sec digital line. Each terminal sends characters consisting of 7 data bits,1 parity bit, 1 start bit, and 1 stop bit. What's the number of bits per character? ____________. How many characters per second can be sent by one terminal? _____________ What is the maximum number of terminals that can be accommodated by the multiplexer onto the digital line? _____________.
2. Four channels are multiplexed using TDM. If each channel sends 100 Kbps and we multiplex 2 bits per channel, find the size of the frame, the duration of a frame, the frame rate and the bit rate for the link.

Statistical Time Division Multiplexing (Async.)

- Variable-size frame (stations with faster data rate have longer time slots – control bits to indicate length of data)
- Sources are not assigned a fixed position in the frame. Receiving Mux needs additional information to route (addressing overhead)
- Sum of input rates may be larger than output rate. Additional logic and buffers must be designed (queuing theory) to accommodate temporary surges in data



Examples of Asynchronous TDM Frames



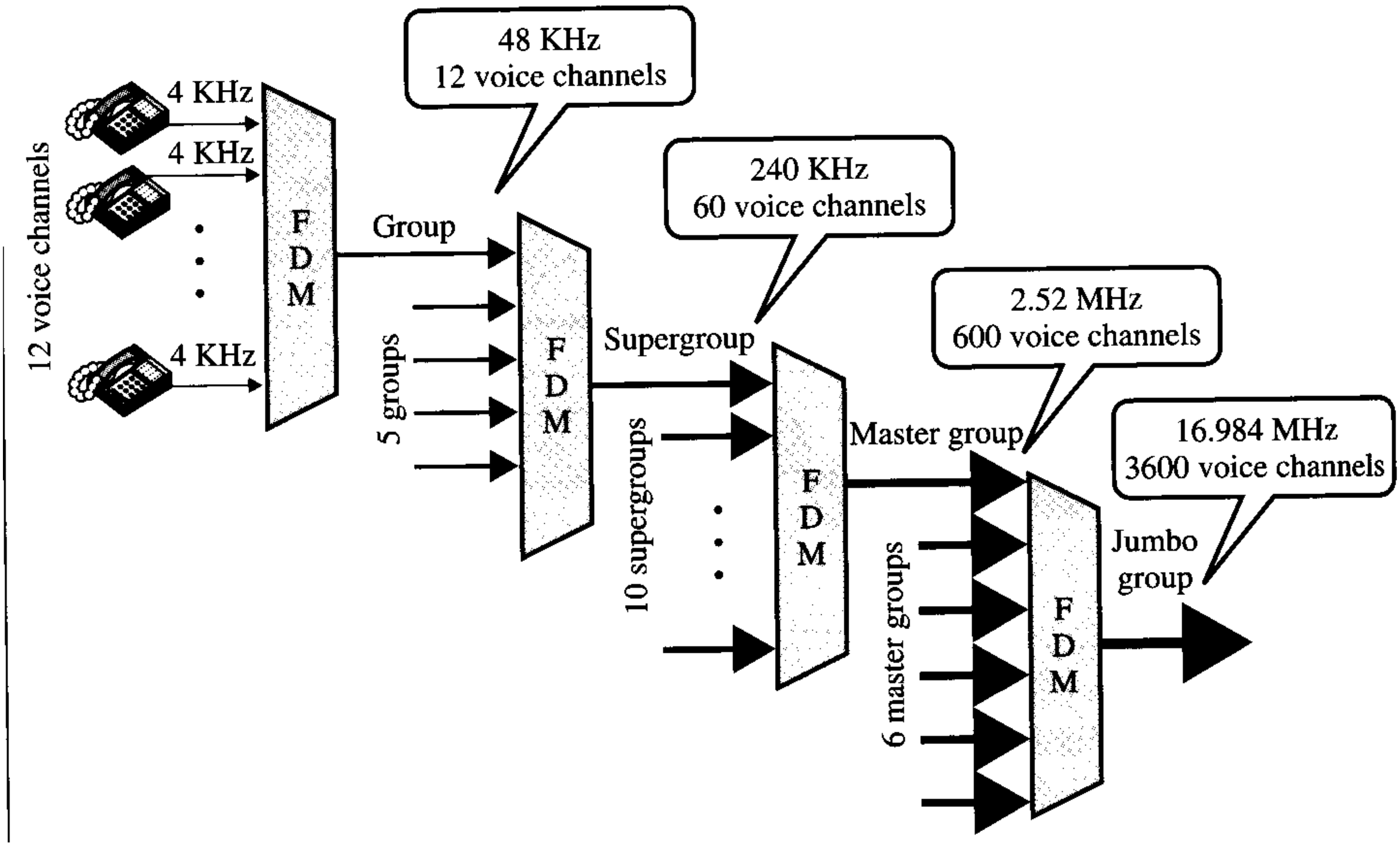
Comparison of Multiplexing Techniques

Multiplexing Technique	Advantages	Disadvantages
Frequency Division Multiplexing	Simple Popular with radio, TV, cable TV All the receivers, such as cellular telephones, do not need to be at the same location	Noise problems due to analog signals Wastes bandwidth Limited by frequency ranges
Synchronous Time Division Multiplexing	Digital signals Relatively simple Commonly used with T-1, ISDN	Wastes bandwidth
Statistical Time Division Multiplexing	More efficient use of bandwidth Frame can contain control and error information Packets can be of varying size	More complex than synchronous time division multiplexing
Wavelength Division Multiplexing	Very high capacities over fiber Signals can have varying speeds Scalable	Cost Complexity
Discrete multitone	Capable of high transmission speeds	Complexity, noise problems
Code Division Multiplexing	Large capacities Scalable	Complexity Primarily a wireless technology

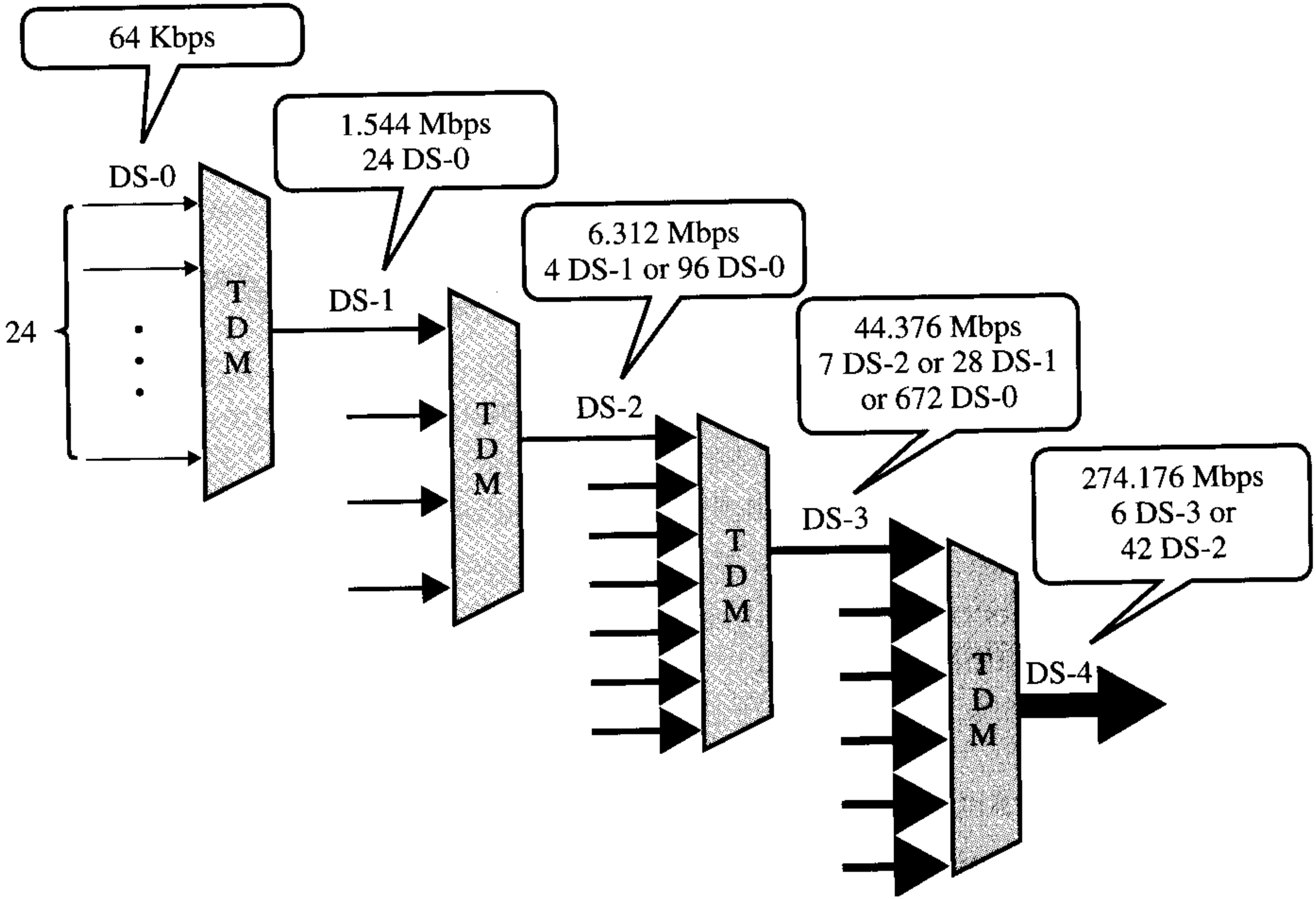
Multiplexing Application

- Telephone System
  - Analog Services
    - Switched
    - Leased (no dialing)
  - Digital Services
    - Switched/56: requires DSU (more $ than modem), supports bandwidth on demand
    - Digital Data Service (DDS): leased line with 64Kbps
    - Digital Signal (DS): a hierarchy of digital signals
- SONET
- DSL and Cable modem

Analog Hierarchy



Digital Hierarchy



T1 (DS-1) line

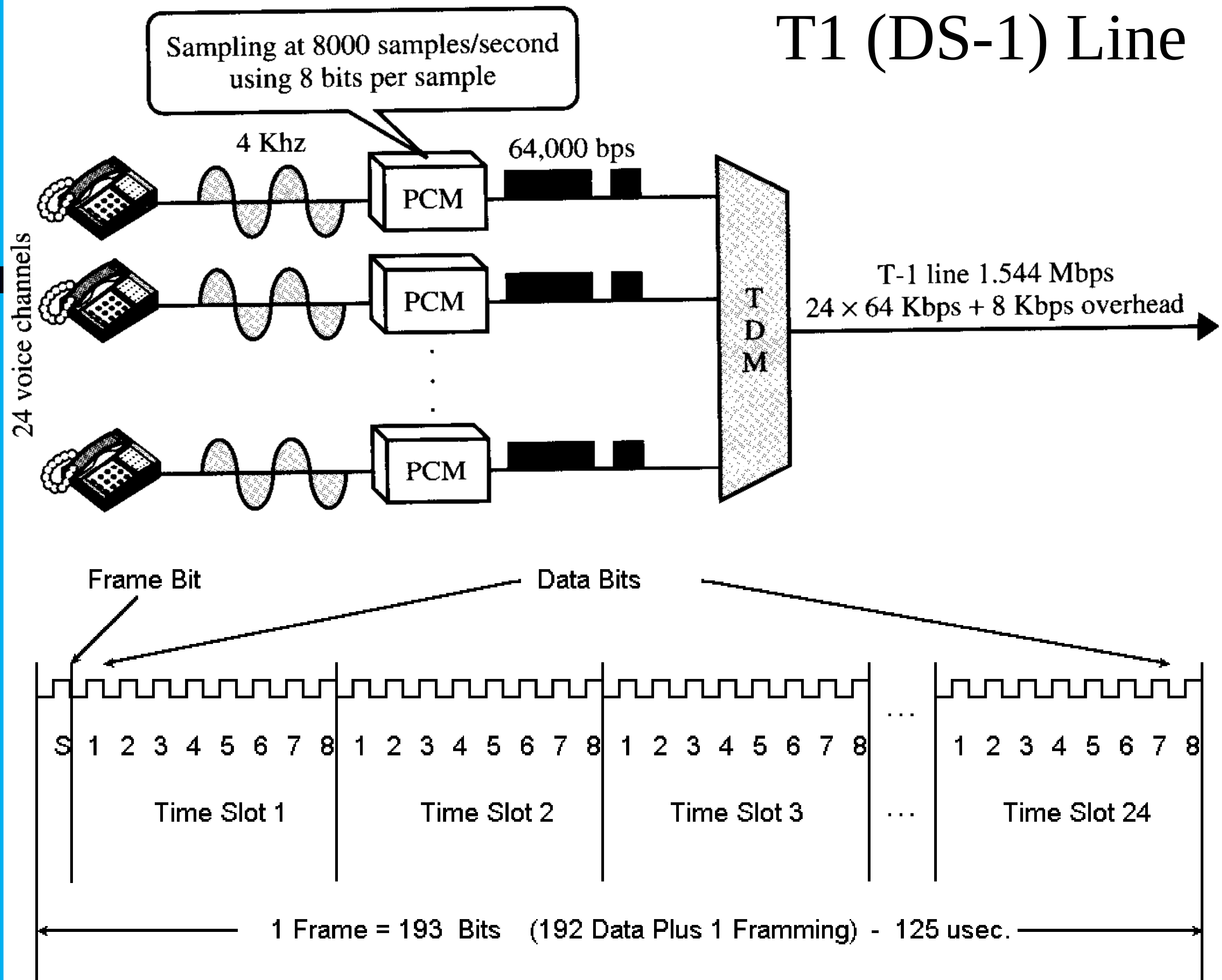
A DS-0 service is a single digital channel of 64 Kbps.
T lines are popular leased line options for businesses connecting to the Internet and for Internet Service Providers (ISPs) connecting to the Internet backbone. A T-1 line provides DS-1 service and actually consists of 24 DS-0 channels, each channel can be configured to carry voice or data traffic. A T-1 line supports data rates of 1.544Mbits per second. How come?

Sample rate

8000 * 8 bit * 24 = 1.536 Mbps ?

resolution

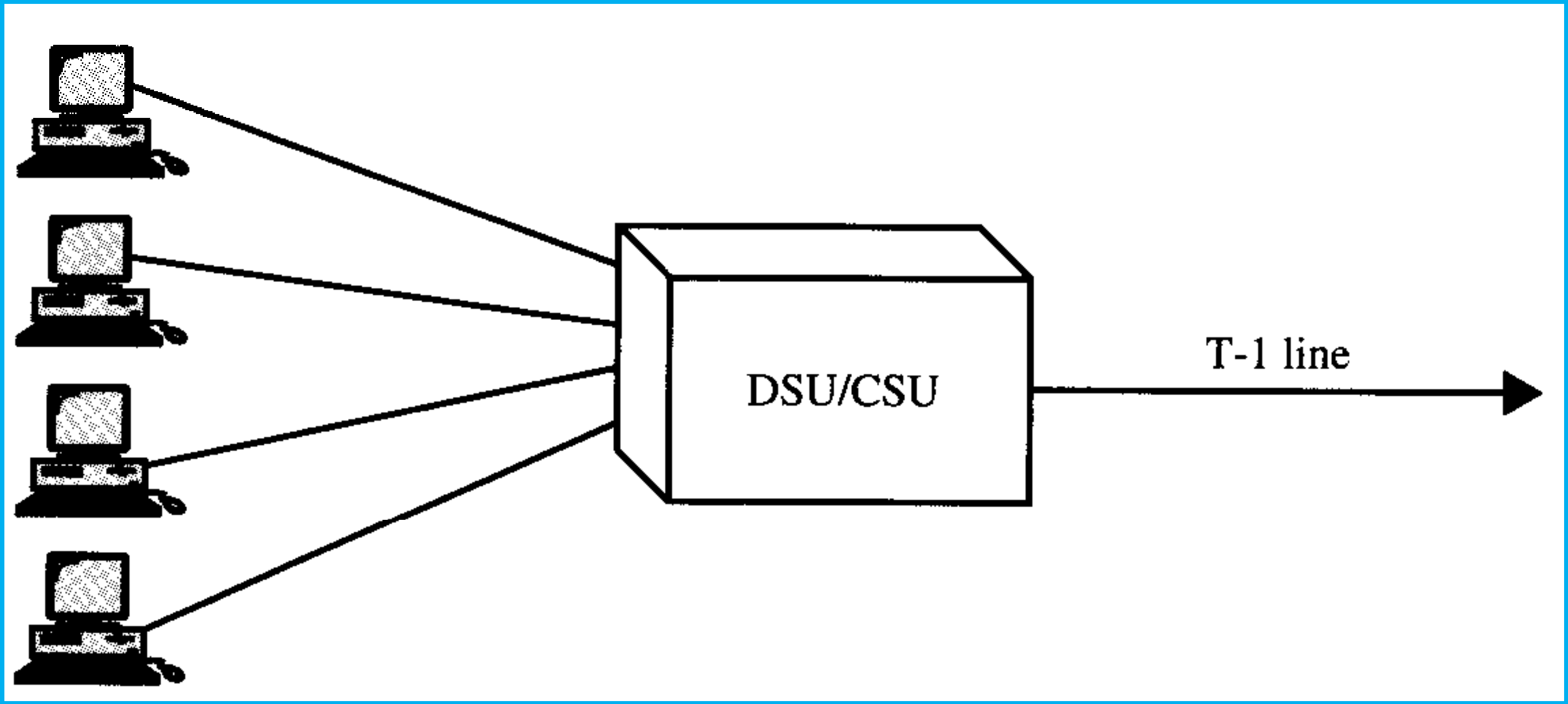
T1 (DS-1) Line



Framing bits are used to synchronize MUX and DEMUX

Fractional T Line Services

Allow several subscribers to share one T-1 line by multiplexing their transmissions



SONET

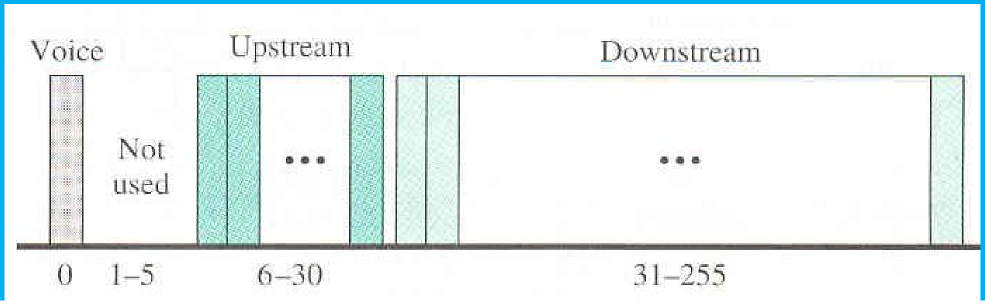
- Synchronous Optical Network is an optical transmission interface proposed by BellCore and standardized by ANSI
- SONET is a synchronous TDM system controlled by a master clock
- Suitable for today's highest data rate technologies (video conferencing)

SONET Designation	ITU-T Designation	Data Rate	Payload Rate (Mbps)
STS-1/OC-1	STM-0	51.84 Mbps	50.112 Mbps
STS-3/OC-3	STM-1	155.52 Mbps	150.336 Mbps
STS-9/OC-9		466.56 Mbps	451.008 Mbps
STS-12/OC-12	STM-4	622.08 Mbps	601.344 Mbps
STS-18/OC-18		933.12 Mbps	902.016 Mbps
STS-24/OC-24		1.24416 Gbps	1.202688 Gbps
STS-36/OC-36		1.86624 Gbps	1.804032 Gbps
STS-48/OC-48	STM-16	2.48832 Gbps	2.405376 Gbps
STS-96/OC-96		4.87664 Gbps	4.810752 Gbps
STS-192/OC-192	STM-64	9.95328 Gbps	9.621504 Gbps
STS-768	STM-256	39.81312 Gbps	38.486016 Gbps
STS-3072		159.25248 Gbps	1.53944064 Gbps

DSL Technology

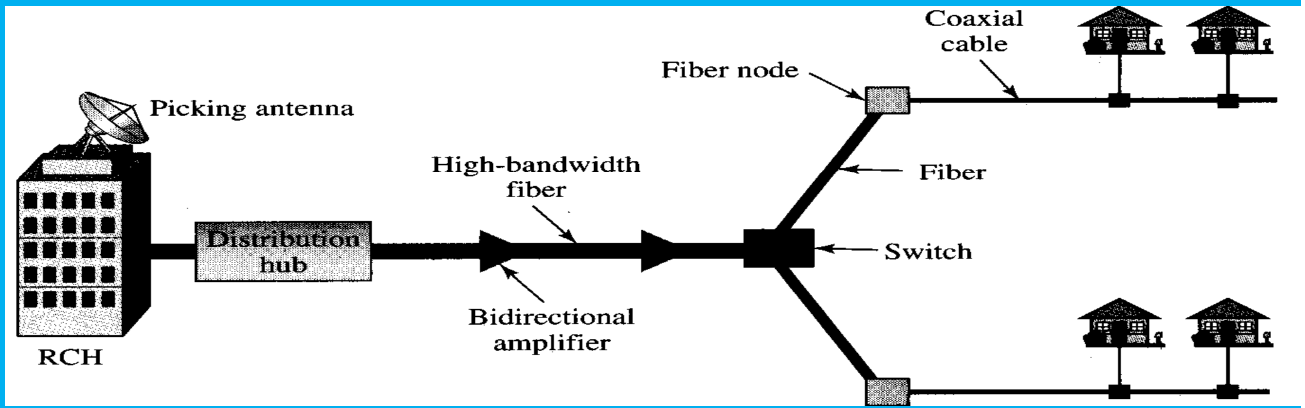
- DSL uses discrete multi-tone technique (DMT) which is a combination of QAM and FDM
- The available bandwidth for each direction is divided into 4-KHz channels, each having its own carrier frequency
- ANSI standard defines a rate of 60 Kbps for each 4-KHz channel (15 bits per baud) using QAM
- The upstream channel usually occupies 25 channels and downstream channel occupies 200 channels

ADSL Bands

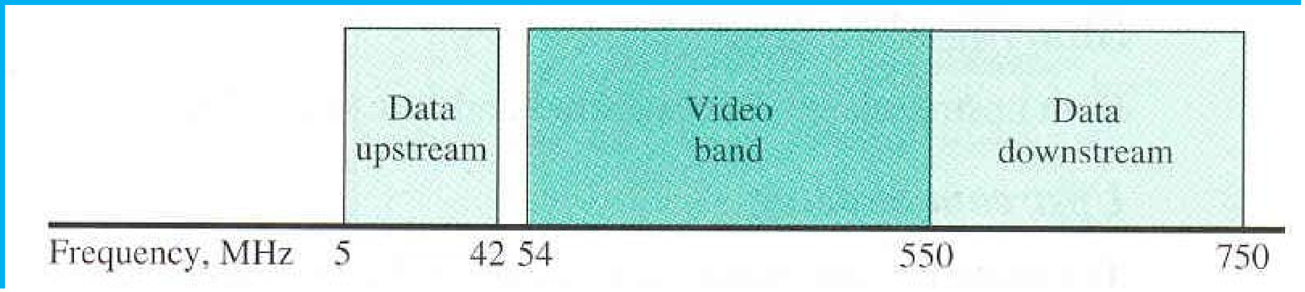


Cable Modem

- The traditional cable TV system used coaxial cable end to end. Communication was unidirectional (simplex)
- The second generation of cable networks, called HFC is capable of bidirectional communication (duplex)



- The bandwidth of coaxial cable is divided into three bands



Downstream/Upstream Data Band

- Downstream data are modulated using 64-QAM with 1-bit for forward error correction. With 6 MHz channel, this gives a theoretical data rate of 30 Mbps
- The upstream data band uses lower frequencies that are more susceptible to noise and interference. QPSK-2 is used for modulation and gives a theoretical date rate of 12 Mbps
- Both upstream and downstream have limited bandwidth and channels. The channels are time-shared by all the subscribers in the same neighborhood and each subscriber must contend for the channel with others who want to access and wait for the channel to become available