CHAPTER-2
PHYSICAL LAYER

The Purpose of the Physical Layer

- THE PURPOSE OF THE PHYSICAL LAYER IS TO TRANSPORT A RAW BIT STREAM FROM ONE MACHINE TO ANOTHER.

5	Application layer
4	Transport layer
3	Network layer
2	Data link layer
1	Physical layer

Physical Layer's Functions (1/2)

The Physical Layer is concerned with transmitting raw bits over a communication channel.

The typical questions here are:

a) How many volts should be used to represent a 1 and a 0;

b) How many nanoseconds a bit lasts;

c) Whether transmission may proceed simultaneously in both

d) directions;

Physical Layer's Functions (2/2)

d) How the initial connection is established and how it is torn down when both sides are finished;

e) How many pins the network connector has and what each pin is used for;

Physical Layer's Functions (2/2)

d) How the initial connection is established and how it is torn down when both sides are finished;

e) How many pins the network connector has and what each pin is used for;

The design issues here largely deal with mechanical, electrical, and timing interfaces of the network.

The physical transmission medium, which lies below the physical layer, is also studied in scope of physical layer.

The Theoretical Basis for Data Communication (2/1)

- Information can be transmitted on wires by varying some physical property such as voltage or current.
- By representing the value of this voltage or current as a single-valued function of time, $f(t)$, we can model the behavior of the signal and analyze it mathematically.

The Theoretical Basis for Data Communication (2/2)

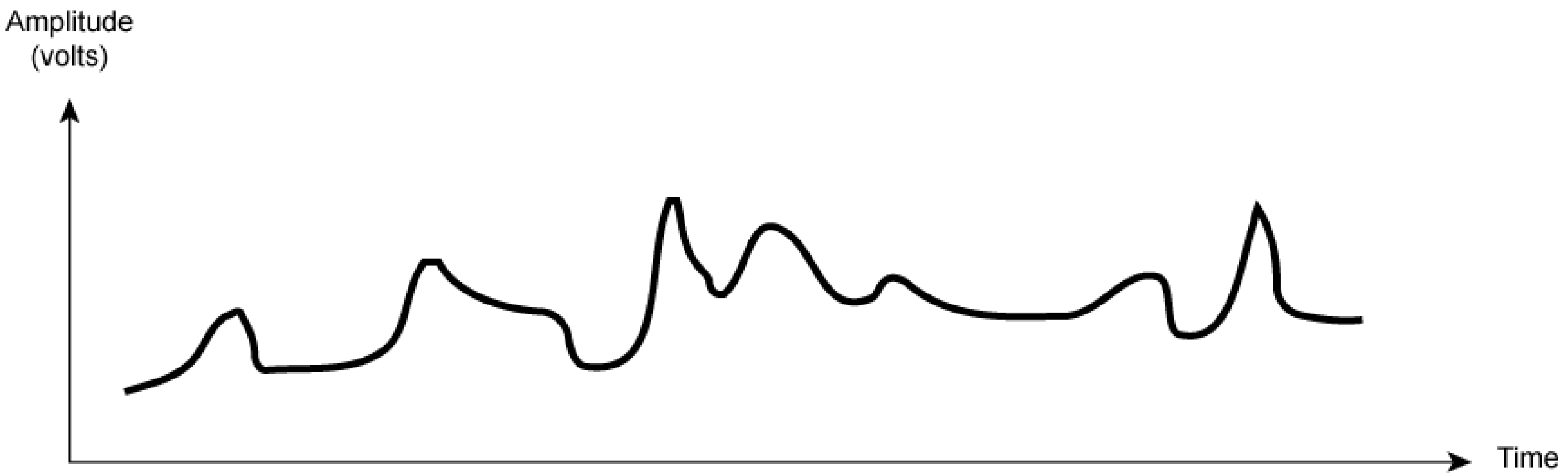
- Fourier Analysis
- Bandwidth-Limited Signals
- Maximum Data Rate of a Channel

- Data transmission occurs between *transmitter* and *receiver* over some *transmission medium*.
- Signal: electromagnetic waves
  - Can propagate along the transmission medium
- Transmission Medium
  - Guided medium: the signals are guided along a physical path
    - e.g., twisted pair, coaxial cable, optical fiber
  - Unguided medium: wireless
    - e.g., air, water, vacuum

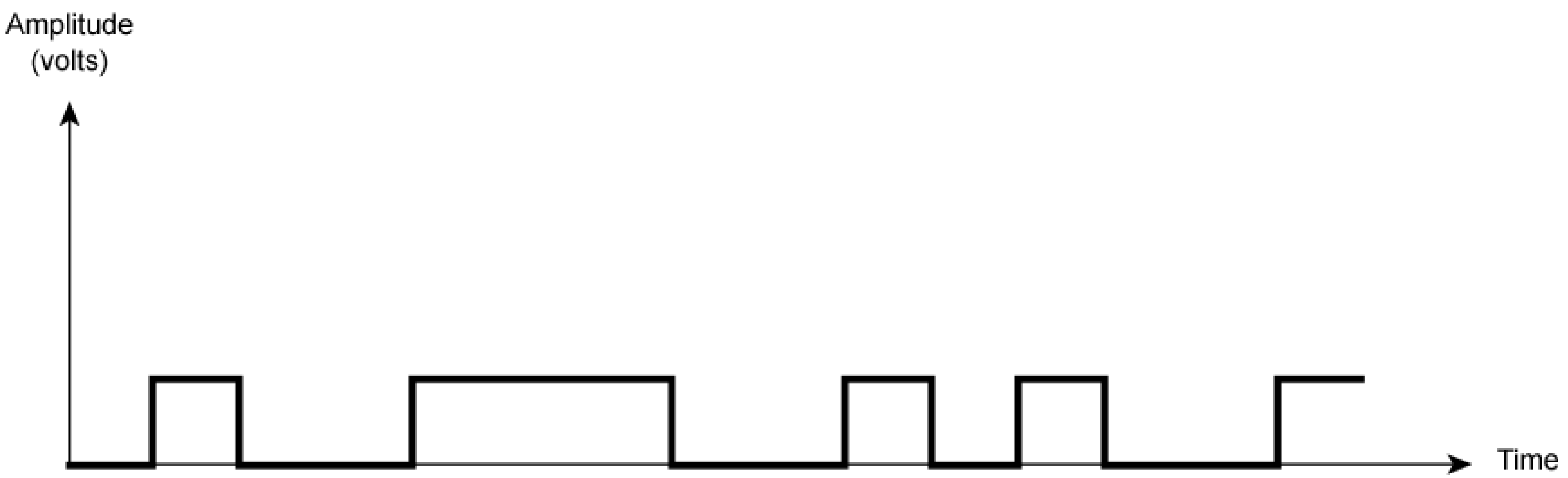
Signals: Time Domain

- We are concerned with electromagnetic signals used as a means to transmit data.
- A signal is generated by the transmitter and transmitted over a medium.
- The signal is a function of time, but it can also be expressed as a function of frequency.
- Time domain concepts: an electromagnetic signal can be either analog or digital
  - Analog signal
    - The signal intensity varies in a smooth fashion over time. Or, there is no breaks or discontinuities in the signal.
  - Digital signal
    - The signal intensity maintains a constant level for some period of time and then changes to another constant level.
- Time domain function of a signal: *s(t)*
  - Specifies the amplitude (in volts) of the signal at each instant in time.

• Analog & Digital Signals



(a) Analog



(b) Digital

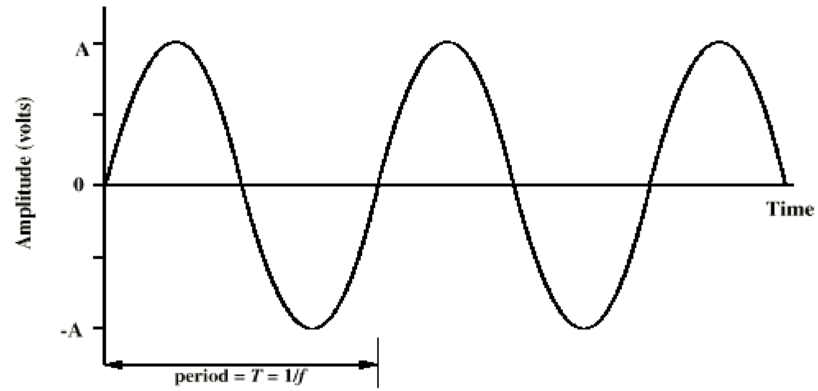
• Periodic Signals:

Concept of **periodic signal**

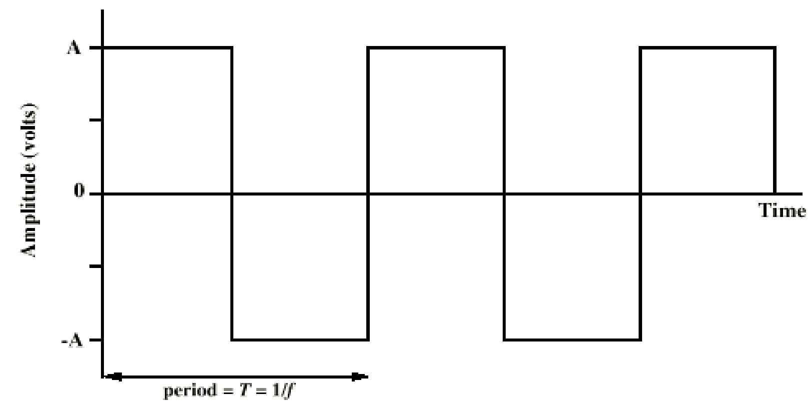
- The same signal pattern repeats over time.
- Otherwise, a signal is aperiodic.

Sine Wave: represented by three parameters, $s(t)=A\sin(2\pi ft+\phi)$

- Peak Amplitude (A)
  - maximum strength of signal
  - measured in volts
- Frequency (f)
  - Rate of change of signal
  - Hertz (Hz) or cycles per second
  - Period = time for one repetition (T)
  - T = 1/f
- Phase (ϕ)
  - Relative position in time within a single period of a signal



(a) Sine wave

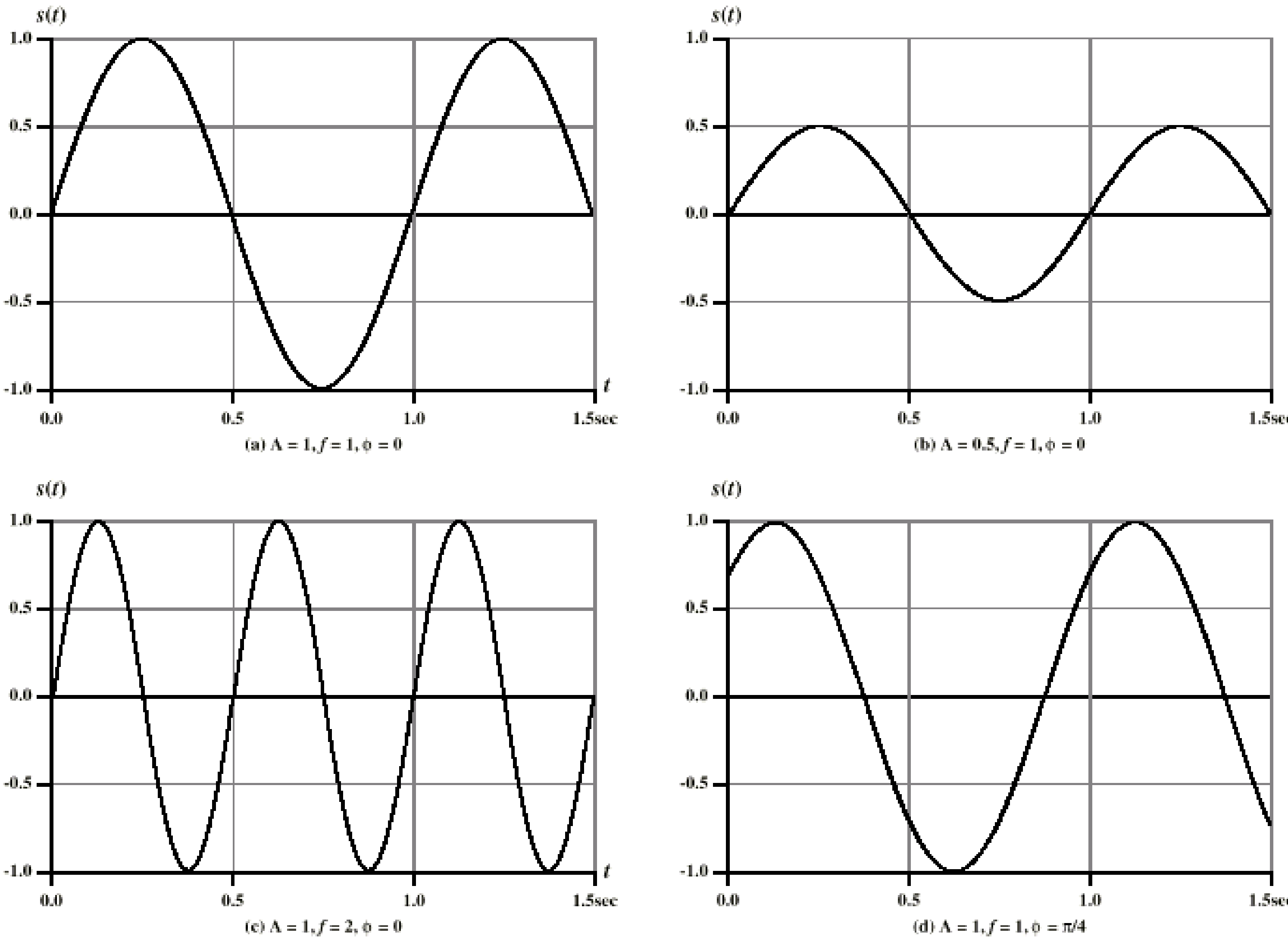


(b) Square wave

Figure (a) displays the value of a signal at a given point in space as a function of time.

• Varying Sine Waves

$s(t) = A \sin(2\pi f t + \Phi)$



(a) A = 1, f = 1, ϕ = 0

(b) A = 0.5, f = 1, ϕ = 0

(c) A = 1, f = 2, ϕ = 0

(d) A = 1, f = 1, ϕ = π/4

Signals: Frequency Domain

- In practice, an electromagnetic signal will be made up of many frequencies.
  - A frequency means a pure sine wave $Asin(2\pi ft+\phi)$
- It can be shown (by Fourier analysis) that any signal is made up of components at various frequencies, in which each component is a sinusoid.
  - By adding together enough sinusoidal signals, each with the appropriate amplitude, frequency, and phase, any electromagnetic signal can be constructed.
  - Any electromagnetic signal can be shown to consist of a collection of periodic analog signals (sine waves) at different amplitudes, frequencies, and phases.
- Frequency domain function of a signal: S(f)
  - Specifies the peak amplitude of the constituent frequencies of the signal.

• Signals: Frequency Domain

- In practice, an electromagnetic signal will be made up of many frequencies called as **Harmonics**.

  — A frequency means a pure sine wave ***Asin(2π ft+ϕ)***

- It can be shown (by Fourier analysis) that any signal is made up of components at various frequencies, in which each component is a sinusoid.

$$g(t) = \frac{c}{2} + \sum_{n}^{\infty} a_n \, sin(2\pi f t) + \sum_{n}^{\infty} b_n \, cos(2\pi f t)$$

$$a_n = \frac{2}{T}\int_0^T g(t)\sin(2\pi nft)\,dt$$

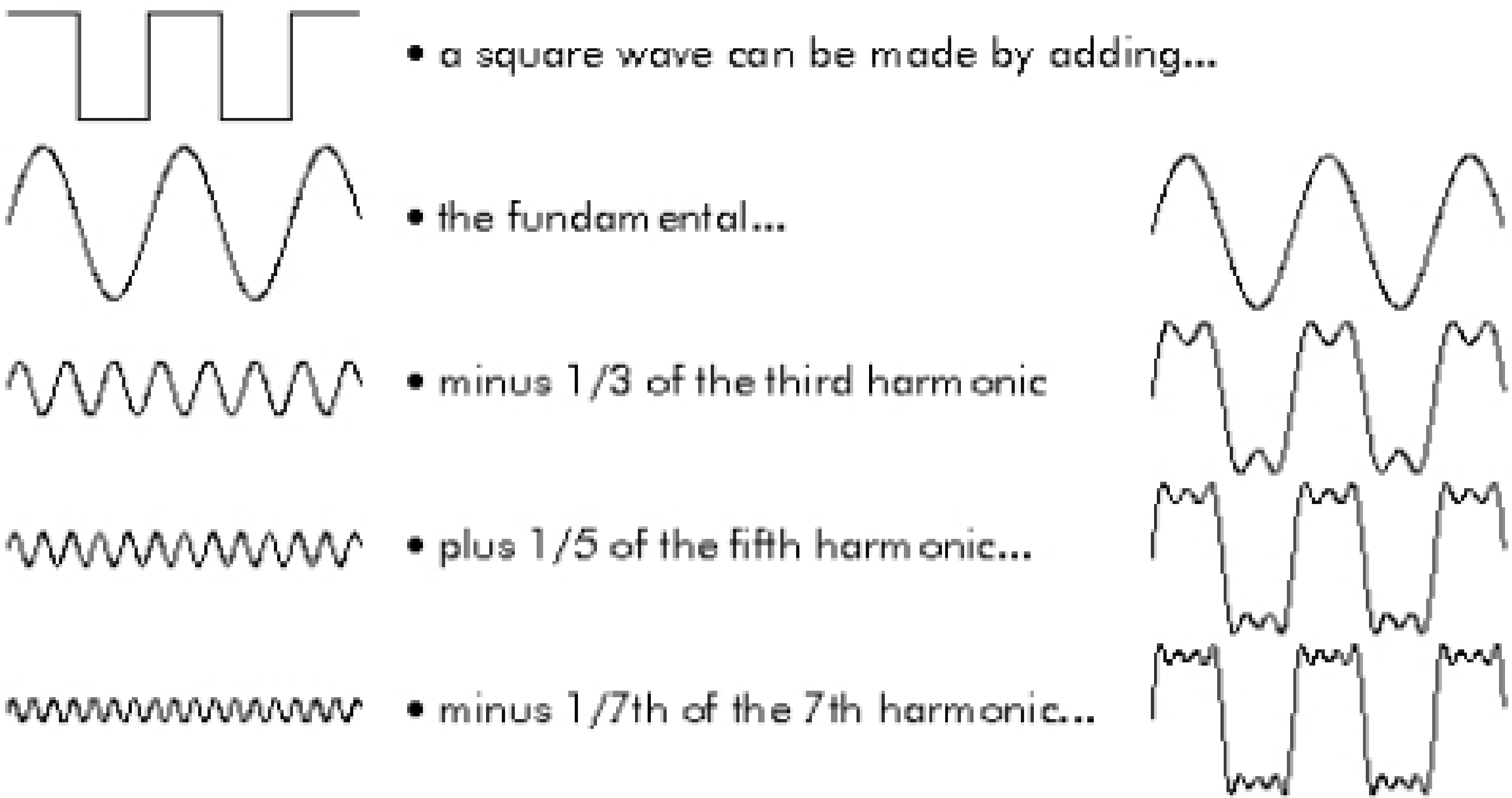
$$b_n = \frac{2}{T}\int_0^T g(t)\cos(2\pi nft)\,dt$$

$$c_n = \frac{2}{T}\int_0^T g(t)\,dt$$

Root mean square amplitude

$$\sqrt{a_n^2 + b_n^2}$$

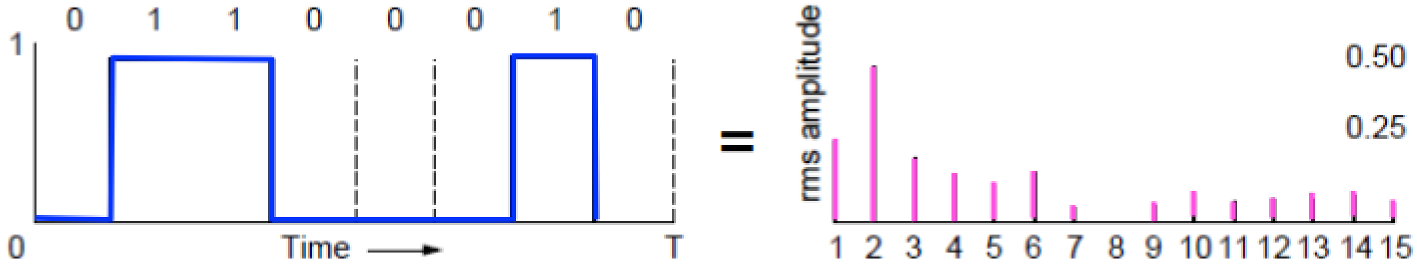
Harmonic Analysis



Fourier Analysis

A time-varying periodic signal can be represented as a series of frequency components (harmonics):

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi n f t) + \sum_{n=1}^{\infty} b_n \cos(2\pi n f t)$$

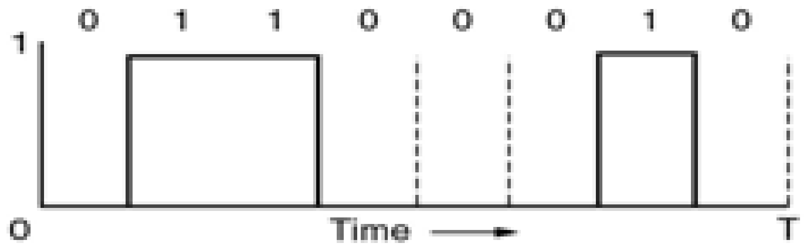


Signal over time ⟶

a, b weights of harmonics

Bandwidth-Limited Signals (1/8)

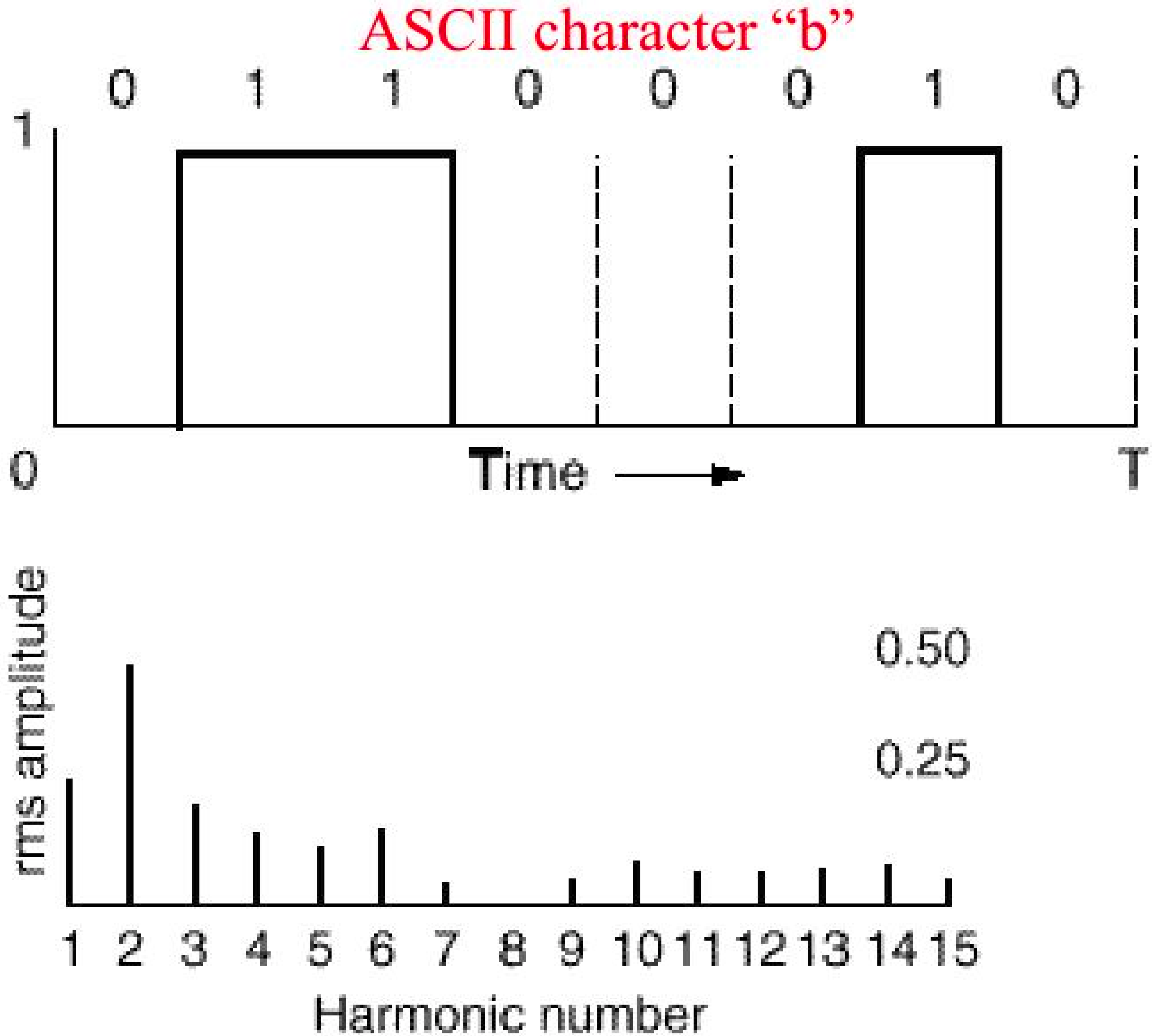
- Let us consider the relation of the Fourier Series with data communication.
- Let us consider how to transmit the ASCII character "b", which can be encoded in an 8-bit: 01100010.



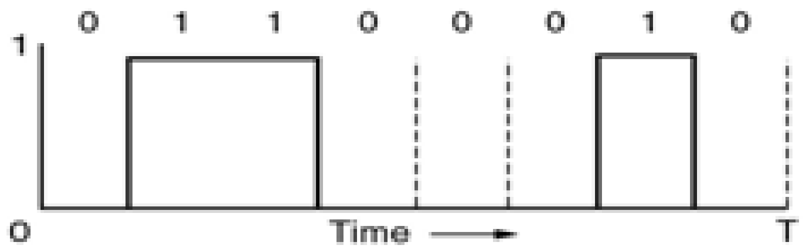
This signal is the voltage output by the transmitting computer

Bandwidth-Limited Signals (2/8)

A binary signal to be transmitted



Bandwidth-Limited Signals (3/8)



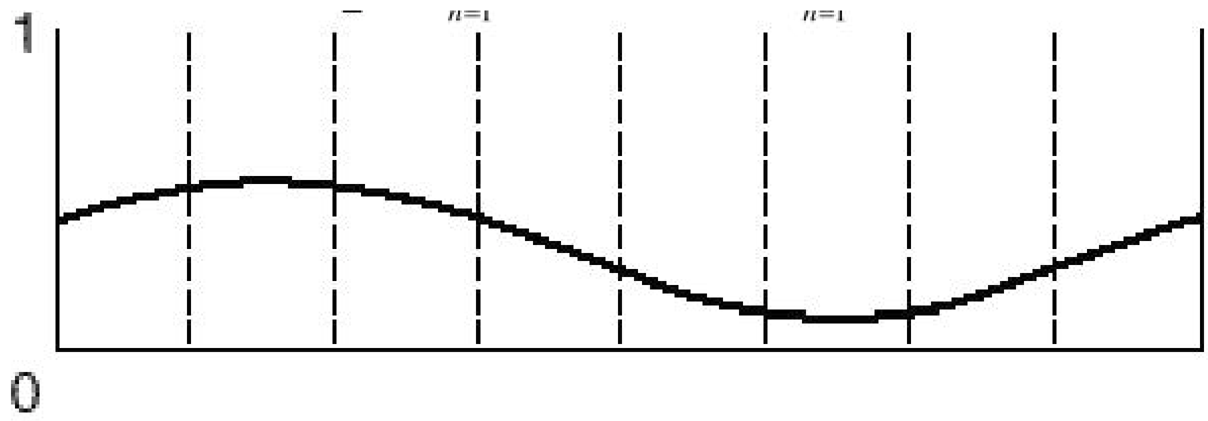
The Fourier analysis of this signal is the voltage output by the transmitting computer gives the following coefficients:

$$a_n = \frac{1}{\pi n}[\cos(\pi n/4) - \cos(3\pi n/4) + \cos(6\pi n/4) - \cos(7\pi n/4)]$$

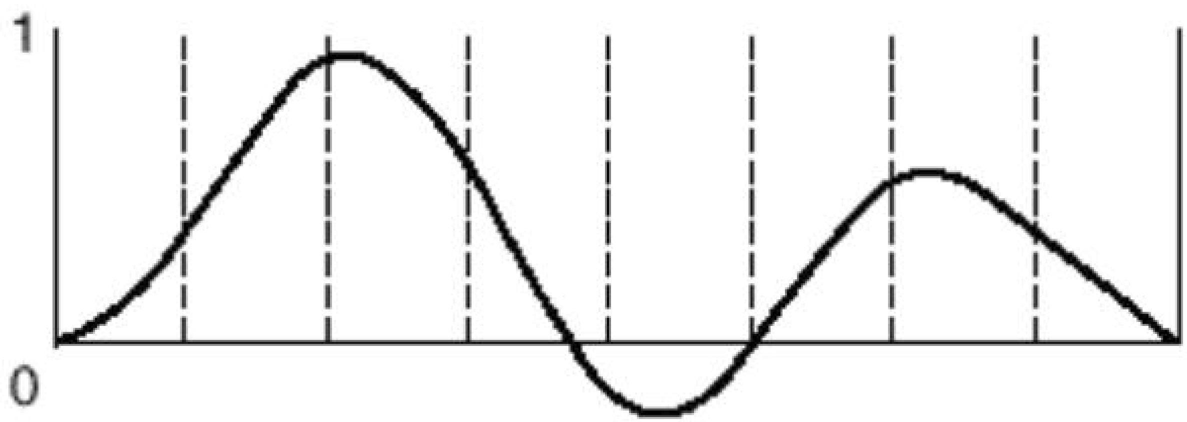
$$b_n = \frac{1}{\pi n}[\sin(3\pi n/4) - \sin(\pi n/4) + \sin(7\pi n/4) - \sin(6\pi n/4)]$$

Bandwidth-Limited Signals (4/8)

One harmonic

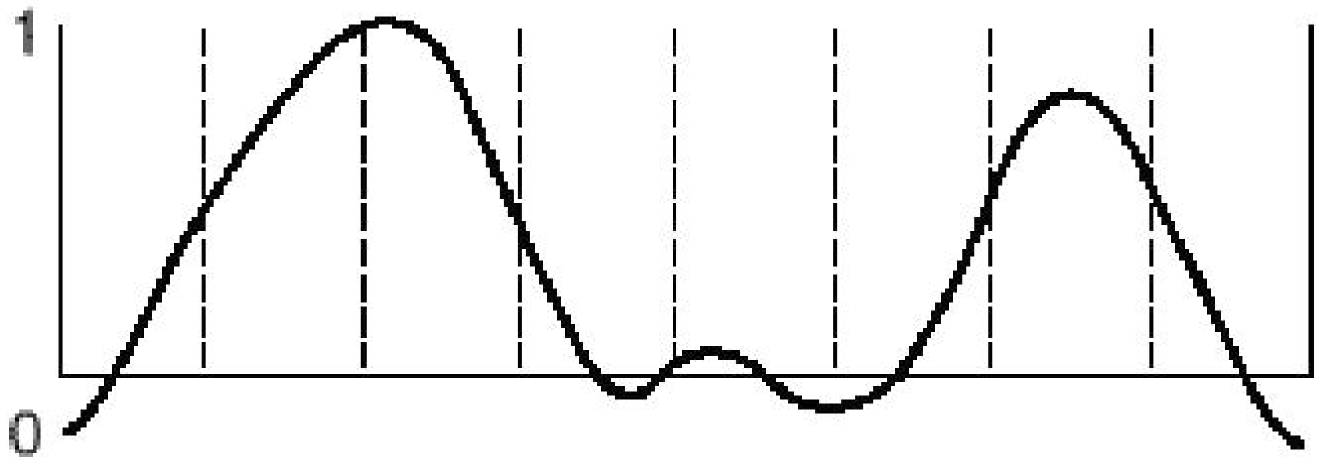


Two harmonics

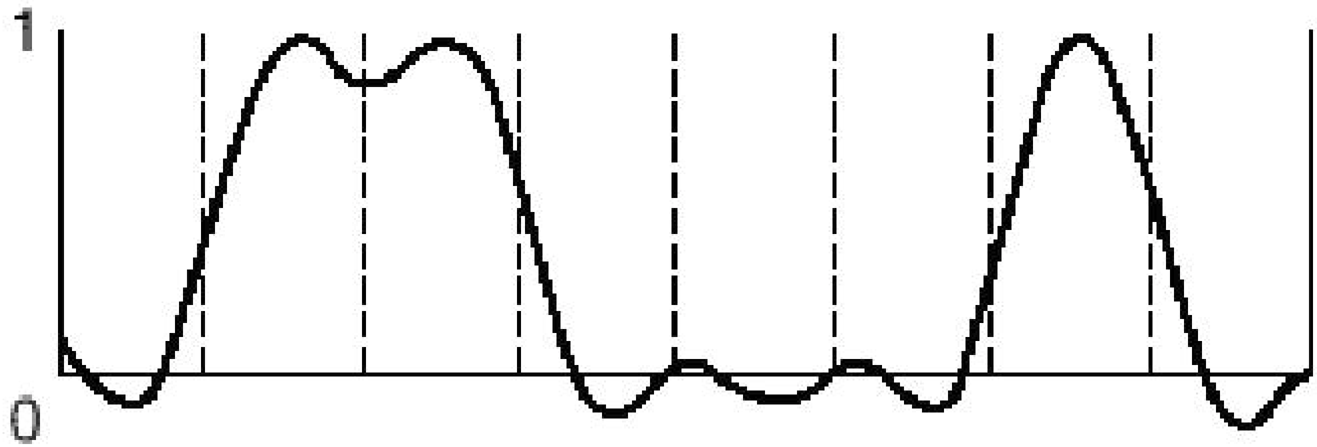


Bandwidth-Limited Signals (5/8)

Four harmonics



Eight harmonics



Bandwidth-Limited Signals (6/8)

- Higher harmonic Fourier components attenuate faster

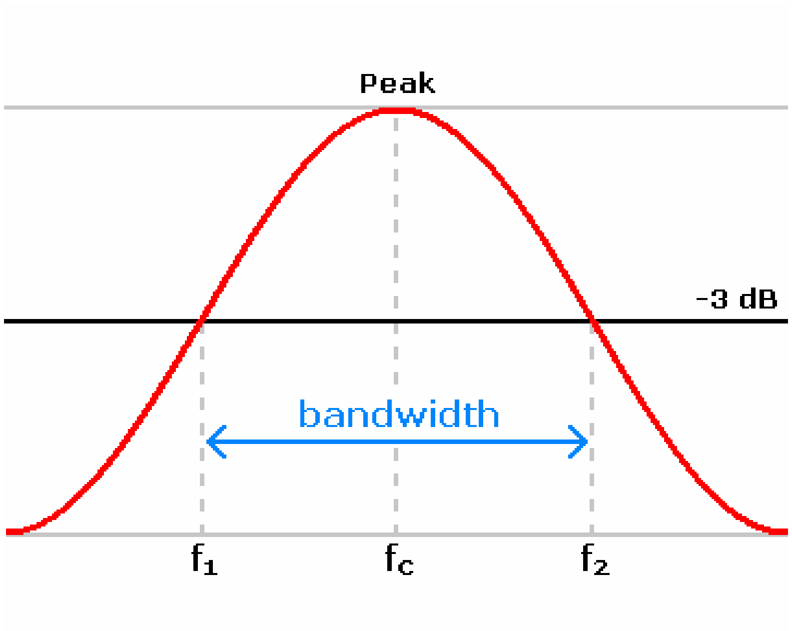
- Usually, the amplitudes are transmitted undiminished from 0 up to some frequency f_c .

- Range of frequencies transmitted without being “strongly” attenuated is denoted the bandwidth of the media

- Often defined from 0 to the frequency at which half the power (amplitude) gets through

- Bandwidth is a physical property of the transmission medium

Bandwidth-Limited Signals (6/8)



For example, suppose Φ(fc) is the maximum

Φ(f1)= Φ(f2) = 1/2 (maximum power)

= 0.5 x Φ(fc) = 10 log (0.5) =3dB

– The figure shows the –3dB bandwidth

Bandwidth-Limited Signals (7/8)

- Assume that a bit rate is *b bits/sec*.
- Then the time required to send 8 bits (for example), 1 bit at a time is $T=8/b$ *sec*.
- So frequency of the first harmonic is $f=1/T=b/8$ *Hz.*
- An ordinary telephone line, often called a **voice-grade line**, has an artificially-introduced cutoff frequency just above *3000 Hz*.
- This restriction means that the number of the highest harmonic passed through is roughly 3000/(b/8) or 24,000/b.

Bandwidth-Limited Signals (8/8)

Bps	T (msec)	First harmonic (Hz)	# Harmonics sent
300	26.67	37.5	80
600	13.33	75	40
1200	6.67	150	20
2400	3.33	300	10
4800	1.67	600	5
9600	0.83	1200	2
19200	0.42	2400	1
38400	0.21	4800	0

Relation between data rate and harmonics to send a constant of 8 bits over a 3KHz channel. .

Maximum Data rate of a channel (1/3)

- Nyquist Theorem: If an arbitrary signal has been run through a low-pass filter of bandwidth *H*, the filtered signal can be completely reconstructed by making only *2H* (exact) samples per second.

$$\text{maximum data rate} = 2H \log_2 V \text{ bits/sec}$$

V is discrete levels of signal, for binary signal *V=2.*

- For example, a noiseless *3-kHz* channel can transmit binary signals at a maximal rate *6000bps*.

Maximum Data rate of a channel (2/3)

- There is always random (thermal) noise present due to the motion of the molecules in the system.
- The amount of noise is measured by the ratio of the signal power to the noise power, called the signal-to- noise-ratio, or S/N.
- Usually, the ratio itself is not quoted; instead, the quantity $\mathbf{10 \log_{10}} \boldsymbol{S / N}$ is given.
- These units are called decibels (dB)
- An S/N ratio of 10 is 10 dB, a ratio of 100 is 20dB.

Maximum Data rate of a channel (3/3)

- Shannon Theorem: The maximum data rate of a noisy channel whose bandwidth is H Hz, and whose signal-to-noise ratio is S/N, i given by:

$$\text{maximum number of bits/sec} = H \log_2 (1 + S/N)$$

- For example, a channel of 3000 Hz bandwidth with a signal to thermal noise ratio of 30 dB can never transmit much more than 30,000 bps.

Nyquist vs. Shannon

- Nyquist:

- For noiseless channel

- Depends on number signal levels per symbol

- Shannon

- For noisy channel

- Depends on S/N ratio, not bits/symbol

Problems:

1. **A noiseless 4-kHz channel is sampled every 1 msec. What is the maximum data rate?**

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ANSWER 1.

Nyquist channel capacity =$2 H \log_2 V$

The 4KHz channel can transmit 8000 samples/ sec

If each sample is 8 bit/256 levels length then the channel can send 64000 bits per second

Problems:

2. **Television channels are 6 MHz wide. How many bits/sec can be sent if four-level digital signals are used? Assume a noiseless channel.**

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ANSWER 2.

Bandwidth of the channel – 6MHz=$6x10^6$ Hz

V is Four level of signal= 2bits/samples

According to Nyquist's theorem,

Maximum data rate (channel capacity) = $2 H \log_2 V$

$= 2 \times 6x10^6$ (samples/sec) x $\log_2 2^2$ (bits/sample)

= 24Mbps

Problems:

3. **If a binary signal is sent over a 3KHz channel whose signal to noise ratio is 20dB ,what is the maximum achievable data rate?**

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3. **If a binary signal is sent over a 3KHz channel whose signal to noise ratio is 20dB ,what is the maximum achievable data rate?**

ANSWER 3.

Bandwidth of the channel = 3KHz=3000 Hz

Signal to noise ratio in dB ($10 \log_{10} S/N$) = 20dB, => $\log_{10} S/N=20/10=2$,

Signal to Noise ratio(S/N)= $10^2 = 100$

According to Shnnon's theorem,

Maximum data rate (channel capacity) = $H \log_2 (1+S/N) = 3000 \times \log_2 (1+100)$

$= 3000 \times 6.658 = 19974$bps =19.974 kbps

For a 3000Hz channel, data rate is restricted to 6kbps only.

Transmission Media

- Various physical media can be used for the actual transmission.
- Each one has its own niche in terms of bandwidth, delay, cost, and
- ease of installation and maintenance.
- There are two groups of transmission media:

1) **Guided media** (copper wire, fiber optics, etc.)
2) **Unguided media** or wireless (terrestrial radio, lasers through the air, satellite, etc.)

Guided Transmission Data

- Magnetic Media
- Twisted Pair
- Coaxial Cable
- Fiber Optics

Magnetic Media

- Common Type of transmission
- Transmission time is measured in hours or minutes
- Magnetic tape;
- Removable media (e.g., recordable DVDs);

Magnetic Media

- **Used:**
  - Where veery less frequent transporation is needed
  - Where amount of data is very high
  - **More cost effective**, especially for applications in which high bandwidth or cost per bit transported is the key factor.
  - Example: Ultrium tape of 800gigabytes

Twisted Pair (1/5)

- Delay characterstics of Magnetic tape is very poor.
- Transmission time is required in miliseconds.
- A twisted pair consists of two insulated copper wires
- Thickness is 1mm

(a)

- Wires are twisted in helical form just ***like DNA molecule***
  - To remove the electromagnetic effect on data

Twisted Pair (2/5)

- Used:
  - Telephone system.
- Can transfer data to several kilometers without amplification
- Amplification needed for longer distance
  - ✓ Repeaters are used
- Many TP cables grouped together and covered by protection material
-

Twisted Pair (3/5)

- Used for analog and digital transmission
- Bandwidth depends on the thickness of the wire and distance traversed
- Widely used

Twisted Pair Types (4/5)

- Types:
- Category 3

(a)

- Category 5

(b)

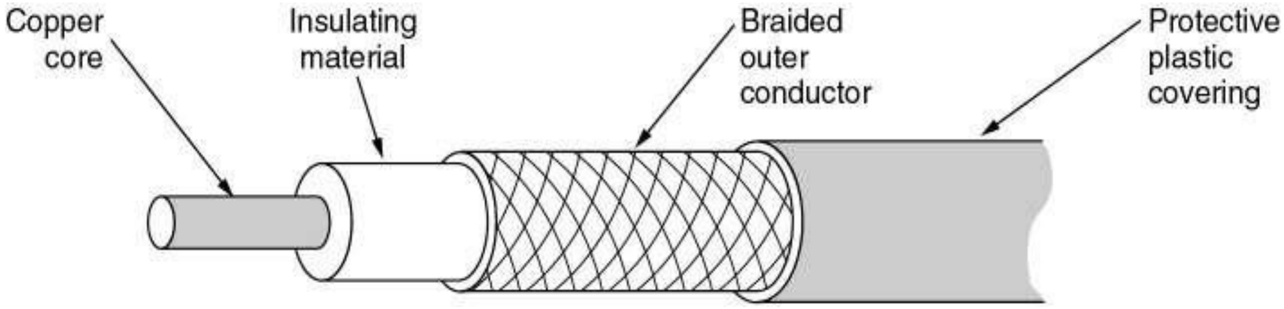
- Category 6
- Category 7

Twisted Pair Types (5/5)

	Category 3	Category 5
Bandwidth	16MHz	100MHz
No of pairs	4	4
Twist pattern	normal	More twist per centimeter. More twist results in less crosstalk and better signal quality
Application	Used in regular telephone lines	Used for high speed computer communication

Coaxial Cable (1/3)

- A coaxial cable has better shielding than twisted pairs, so it can span longer distance at higher speeds.
- The bandwidth depends on the cable quality, length, and signal-to-noise ratio of the data signal.



A coaxial cable: Modern cables have a bandwidth of close to 1 GHz.

Coaxial Cable (2/3)

- **Construction :**
  - Consists of copper wire as the core.
  - Surrounded by insulating material.
  - Insulator is increased is increased by a cyndrical conductor.
    - A closely-woven braided mesh.
  - The outer conductor is covered in a protective plastic sheath.

Advantages :

- Better shielding than twisted pair.
- High Banwidth (1GHz)
- Excellent to noise immunity

Coaxial Cable (3/3)

- **Use :**
  - For MAN
  - For cable television
  - Within telephone system for long distance lines

Fiber Optics (1/4)

Computing Spped: A fctor of 20 per decade.

Communication speed Improvement: a factor of 125 per
Decade, from 56kbps to 1Gbps

In the race between Computing and Communication, **Communication won.** The new conventional wishdom should be that all computers are hopelessly slow and that **networks should try to avoid computation at all cost**, no matter how much bandwidth wastes.

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Fiber Optics (2/4)

An optical transmission system has three key components: the **light source**, the **transmission medium**, and the **detector.**

Light Source: LED (**L**ight **E**miiting **D**iode) or LASER (**L**ight **A**mplification by **S**imulated **E**mission **R**adiation)

Transmission Medium: Ulta-thin glass fiber

Detector: Generates an electrical pulse when light falls on it using the light-electricity effect

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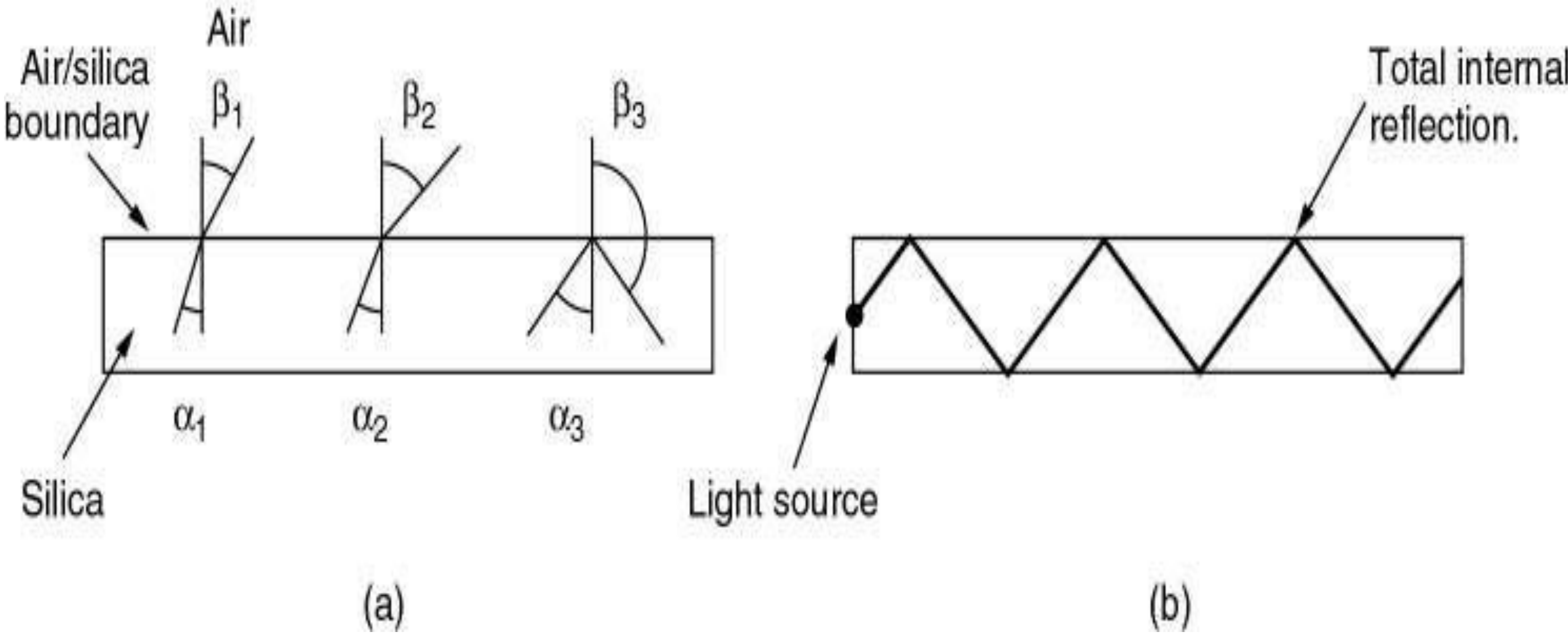
Fiber Optics (3/4)

Item	LED	Semiconductor laser
Data rate	Low	High
Fiber type	Multimode	Multimode or single mode
Distance	Short	Long
Lifetime	Long life	Short life
Temperature sensitivity	Minor	Substantial
Cost	Low cost	Expensive

A comparison of semiconductor diodes and LEDs as light sources.

Fiber Optics (4/4)



a) Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angle
b) Light trapped by total internal reflection.

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- How light travels in a fiber optic cable
  - Hence by attaching a light source on one end of an optical fiber and a detector at the other end, we have a unidirectional data transmission system (Simplex)
  - The light source would accepts an electrical signal, converts and transmits it as light pulses
  - The detector at the far end reconverts the light pulses into an electrical signal to be then interpreted as 1 or a 0.
  - The typical response time of the photodiode when light falls on it is 1 nanosecond. This limits the data rate to 1Gb/sec ($1x10^9$ bits / sec)

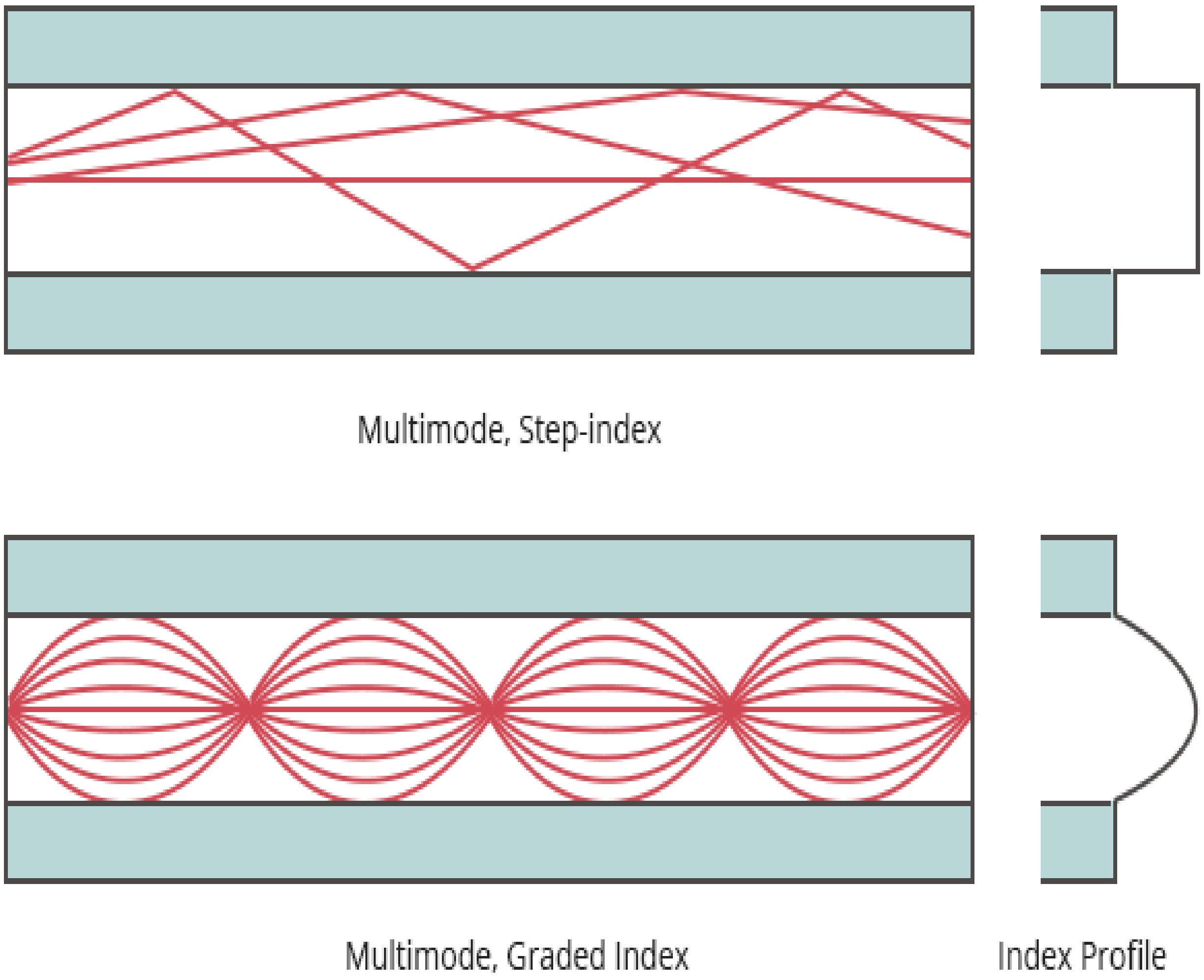
Transmission of Light through Fiber (1/7)

- All rays with an incident angle greater than the critical angle will be trapped in the fiber.
- Not all of these rays will be guided through the fiber, only some directions are allowed.
- These allowed directions are called **modes** and their angles satisfy the conditions for **constructive interference** due to the wave nature of light.
- All the light rays that do not satisfy these conditions will disappear due to destructive interference.

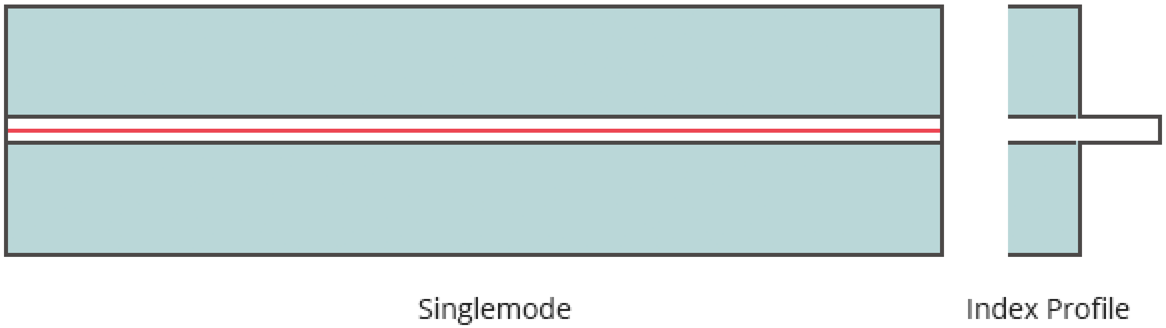
Transmission of Light through Fiber (2/7)

- Each light ray is said to have a different mode, so a fiber that allows a lot of rays to travel through it is called a **multimode** fiber.
- This type of fiber is approximately 50 microns in diameter (width of a human hair) and is used in short distances (up to a few kilometers).
- A **monomode** (or single mode) fiber is one that allows a small number of wavelengths of light to pass down it.
- Monomode fibers are typically 8-10 microns in diameter and light rays travel in a straight line (i.e. no bouncing) through them.
- Monomode fibers are more expensive since they use lasers but they can cover larger distances (approx. 100km).

Transmission of Light through Fiber (3/7)



Transmission of Light through Fiber (4/7)



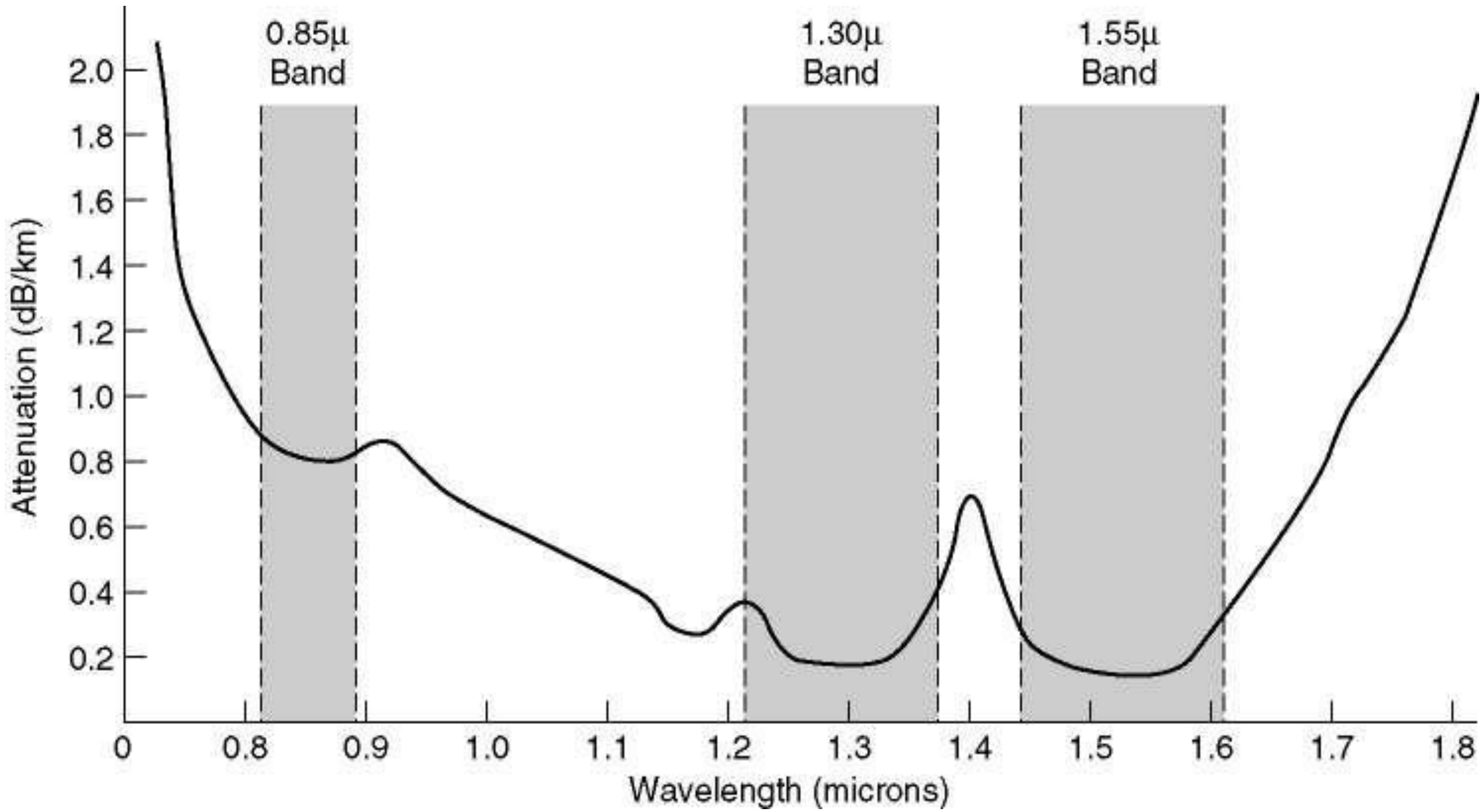
Transmission of Light through Fiber (5/7)

- The attenuation of light through glass depends on the wavelength of the light (as well as on some physical properties of the glass).

- The attenuation in decibels is given by the formula:

$$Attenuation\ in\ decibels = 10\log_{10}\frac{transmitted\ power}{Received\ power}$$

Transmission of Light through Fiber (6/7)



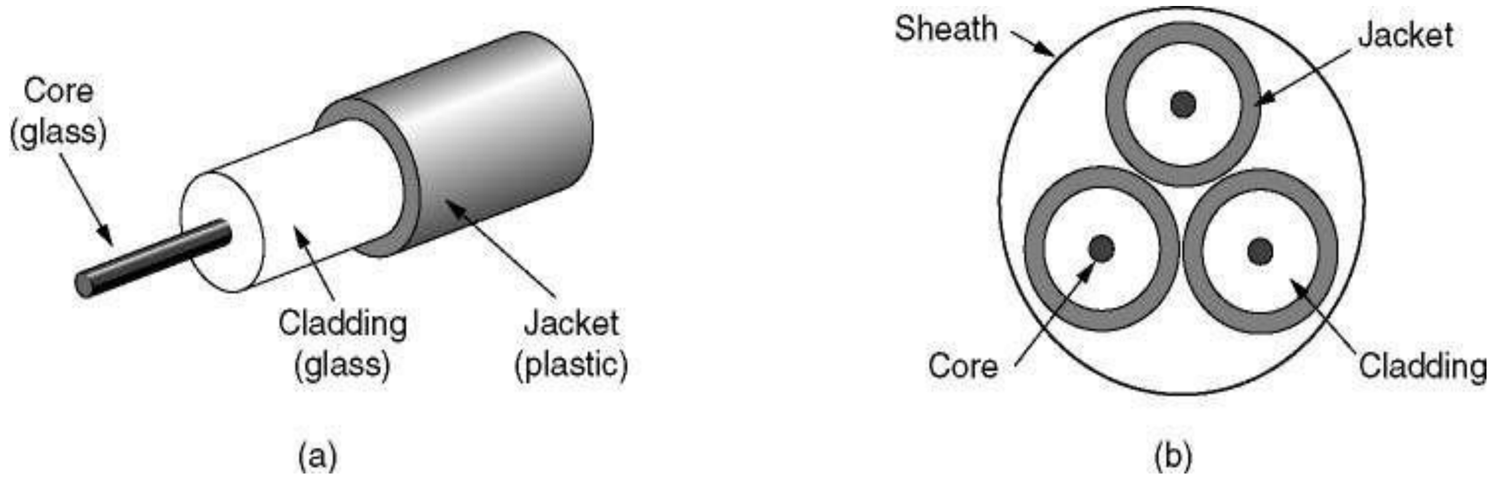
Attenuation of light through fiber in the infrared region.

Transmission of Light through Fiber (7/7)

- Three wavelength bands are used for optical communication.
- They are centered at 0.85, 1.30, and 1.55 microns, respectively.
- The last two have good attenuation properties (less than 5 percent loss per kilometer).
- All three bands are 25,000 to 30,000 GHz.

Fiber Cables (1/2)

Fiber optic cables are similar to coax, except without the braid.



a) Side view of a single fiber: the core is 8 to 10 microns in diameter.
b) End view of a sheath with three fibers: the core is typically 50 microns in diameter.

Fiber Cables (2/2)

Fibers can be connected in three different ways.

1. They can terminate in connectors and be plugged into ***fiber sockets***. Connectors lose about 10 to 20 percent of the light, but they make it easy to reconfigure systems.

2. They can be spliced mechanically. ***Mechanical splices*** take trained personnel about 5 minutes and result in a 10 percent light loss.

3. Two pieces of fiber ***can be fused*** (melted) to form a solid connection. A small amount of attenuation occurs.

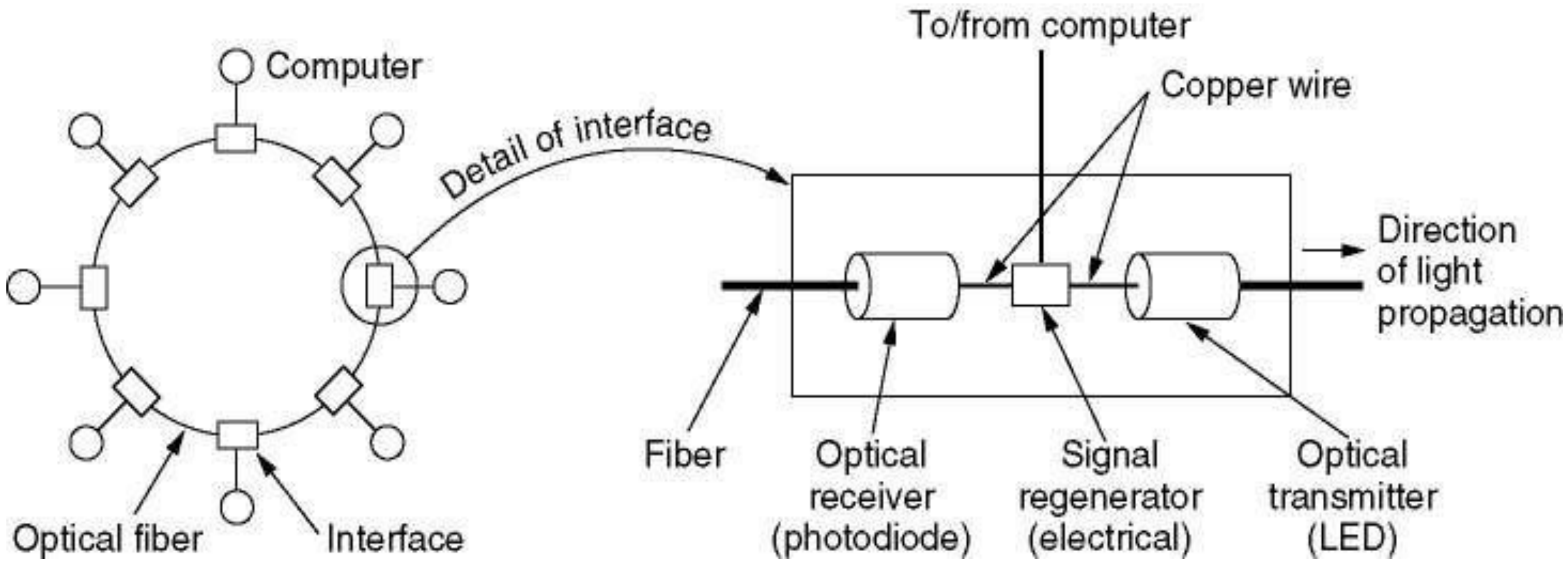
Fiber Optic Networks

Interfaces (with computer):

- The connectors are very difficult to make and substential light is lost.
- Two types of interfaces are used(attenuation)
  - Active interface
  - Passive interface
- Both of them, at each computer, serves as T-Junction to allow the computer to send and receive the message and pass through.

Fiber Optic Networks

Fiber optics can be used for LANs as well as for long-haul transmissions.



A fiber optic ring with active repeaters.

Fiber Optic Networks

Active Repeaters:

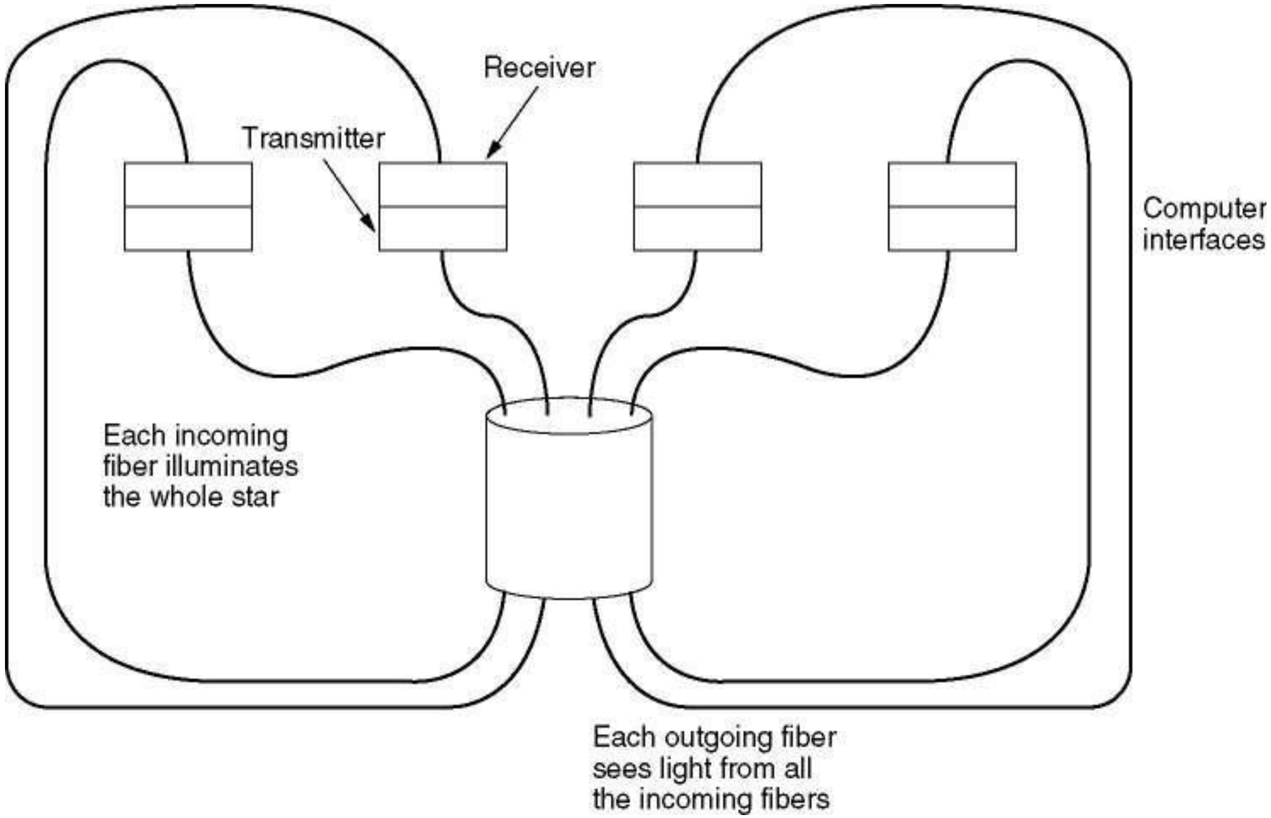
- In active repeaters, light the incoming light is converted to an electrical signal.
  - *It is regenerated to the full strength and retransmitted as signal.*
- Connector is a simple copper wire.
- If an active repeater fails, the ring gets broken and the network goes down
- There is no virtual limit on the size

Fiber Optic Networks

passive interfaces:

- Passive interfaces consists of two tapes fused onto the main fiber.
- One tap has LED or Laser diode at one end of it and the other the photodiode
- It is extreamly relliable because a broken LED or or photodiode doesnot break the ring. It takes one computer off-line.

Fiber Optic Networks



A passive star connection in a fiber optics network.

Comparison of Fiber Optics and Copper Wire (1/2)

Advantages :

- **High data rates** than copper
  - More information can be sent in second
- **Low loss of signal power** (attenuation)
  - So repeaters are used at every 100km instead of 5km as needed for copper
- Not affected by power surges, electromagnetic interference
- Not affected by corrosive chemicals
- High security as difficult to tap
- Fibers are thin and lightweight

Comparison of Fiber Optics and Copper Wire (1/2)

Dissdvantages :

- Fiber optic cabling is a newer technology with not much expertise. So, installation and maintenance is not as easy as copper wires.

- Expensive than copper

- Propagation of signals in fiber optic cables is unidirectional hence, for two way communication two cables are needed.

Wireless Transmission(1/4)

- The future holds only two kinds of communication:
    a) Fiber;
    b) Wireless.
- All fixed (i.e., non-mobile) computers, telephones, faxes, and so on will use fiber, and all mobile ones will use wireless.

Wireless Transmission(2/4)

- The principle of the wireless communication:

-When electrons move, they create electromagnetic waves that can propagate through space (even in a vacuum).

-The number of oscillations per second of a wave is called its frequency, *f*, and is measured in *Hz*.

-The distance between two consecutive maxima (or minima) is called the wavelength – λ *(lambda)*.

Wireless Transmission(3/4)

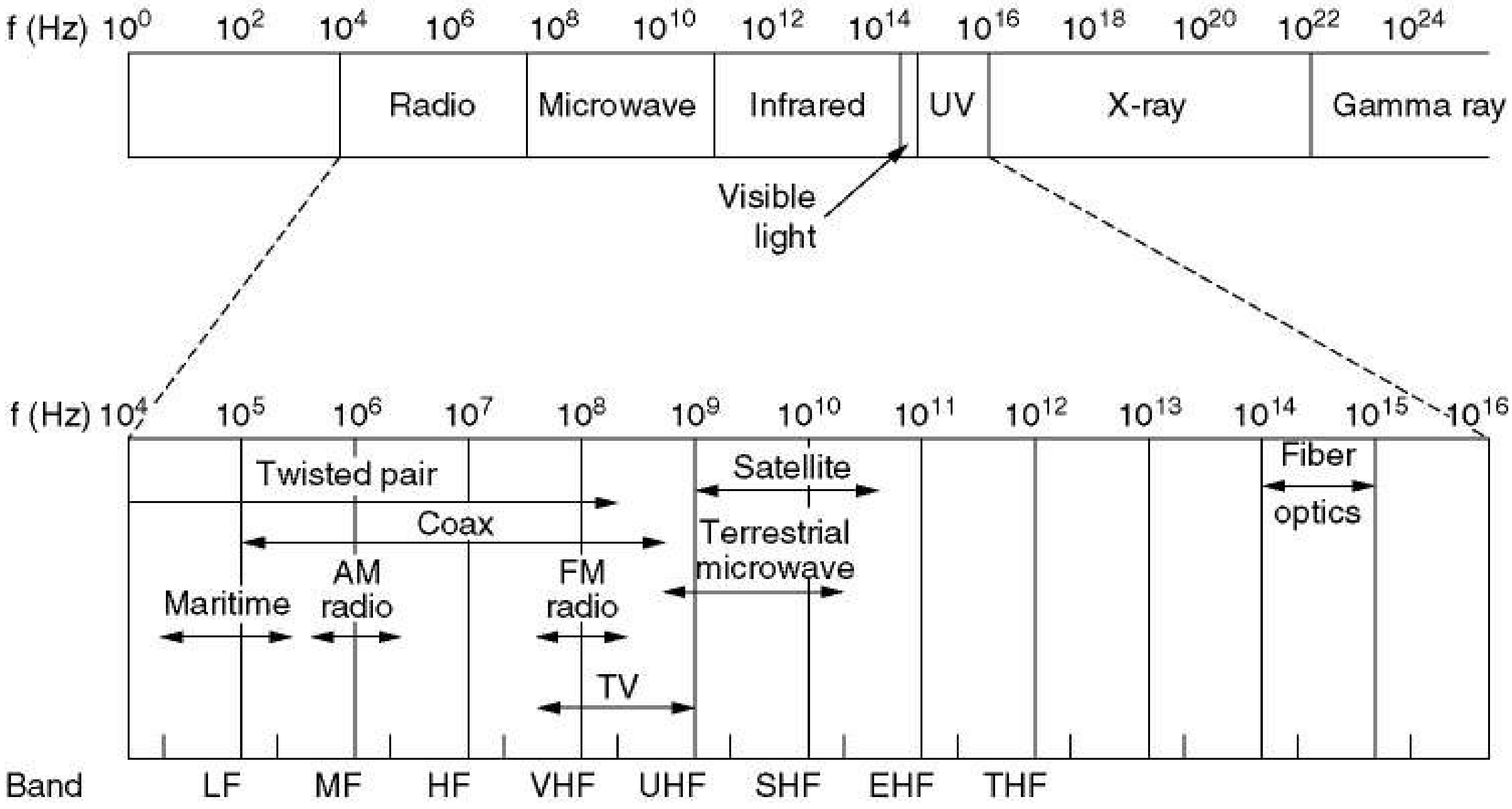
- -When an antenna of the appropriate size is attached to an electrical circuit, the electromagnetic waves can be broadcast efficiently and received by a receiver some distance away.

-All wireless communication is based on this principle.

Wireless Transmission(4/4)

- The Electromagnetic Spectrum
- Radio Transmission
- Microwave Transmissio
- Infrared and Millimeter Waves
- Lightwave Transmission

The Electromagnetic Spectrum (1/6)



The electromagnetic spectrum and its uses for communication.

The Electromagnetic Spectrum (2/6)

- The “radio, microwave, infrared, and visible light portions of the spectrum can of the spectrum can all be used for transmitting information by modulating the amplitude, frequency, or phase of waves.
- Ultraviolet light, X-rays, and gamma rays would be even better, due to their higher frequencies, but they are hard to produce and modulate, do not propagate well through buildings, and are dangerous to living things.

The Electromagnetic Spectrum (3/6)

- The amount of information that an electromagnetic wave can carry is related to its bandwidth.

- With current technology, it is possible to encode a few bits per Herts at low frequencies, but often as many as 8 at high frequencies, so a coaxial cable with a 750 MHz bandwidth can carry several gigabits/sec.

The Electromagnetic Spectrum (4/6)

$$\nabla f = \frac{c \nabla \lambda}{\lambda^2}$$

∇f is the corresponding frequency band

$\boldsymbol{c}$ is speed of light.

$\nabla \lambda$ is the width of a wavelength band.`

λ is the wavelength

As we see the wider the band, the higher the data rate.

The Electromagnetic Spectrum (5/6)

$$\nabla f = \frac{c\nabla\lambda}{\lambda^2}$$

Example: Consider the 1.30-micron band.

Here we have $\boldsymbol{\lambda = 1.3x10^{-6}}$ and $\nabla\lambda = 0.17x10^{-6}$

So, $\boldsymbol{\nabla f}$is about 30 THz.

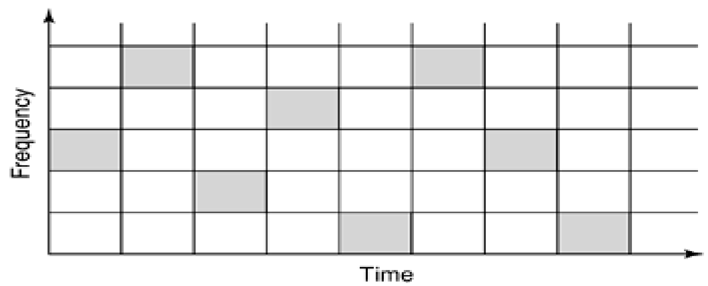
At, say, 8 bits/Hz, we get 240 Tbps.

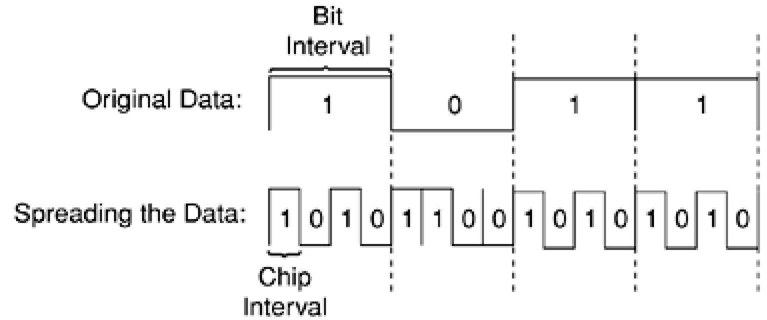
The Electromagnetic Spectrum (6/6)

Most transmissions use a narrow frequency band
(i.e., $\nabla f / f << 1$) to get best reception (many watts/Hz);

However, in some cases, a wide band is used.

a) Frequency hopping spread spectrum;

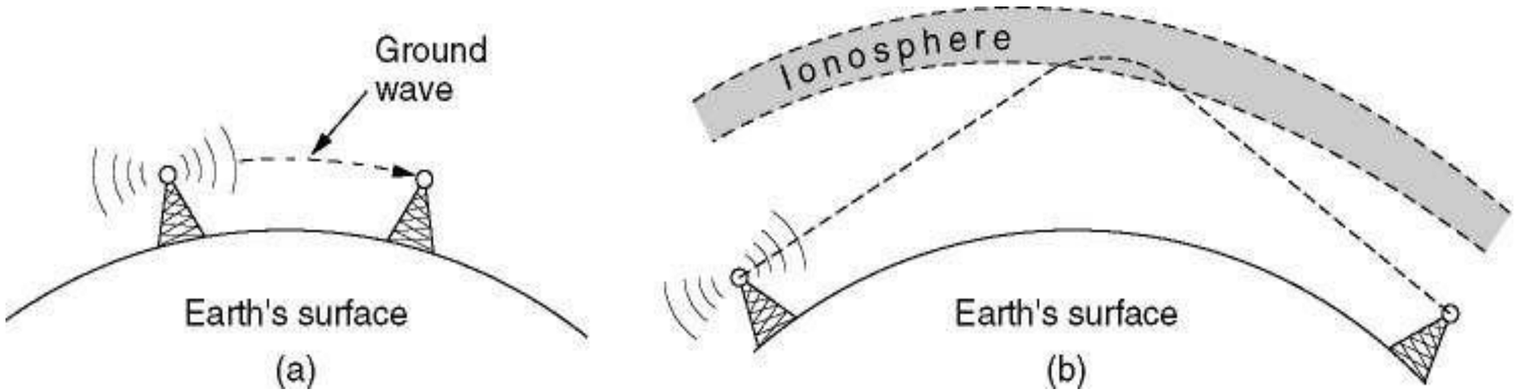




a) Direct sequence spread spectrum.

Radio Transmission (1/3)

Radio waves are easy to generate, can travel long distance, can penetrate buildings and omnidirectional.



a) In the VLF, LF, and MF bands, radio waves follow the curvature of the earth.
b) In the HF band, they bounce off the ionosphere.

Radio Transmission (2/3)

The radio waves are frequency dependent.

- At low frequency radio waves pass through obstacles well, but power sharply falls with $1/r^2$ air distance from the source.

- At high frequency radio waves travel in straight line and bounce back when hit with obstacles. It is also absorbed by rain.

- Radio waves are subject to interference between users at all frequency due to its ability to travel long distance. This is the reason why the radio waves use is licensed.

Radio Transmission (3/3)

- LF and MF radio waves can pass through obstacles and have ground propagation.

- The main problem of using this band is low bandwidth.

- High frequency radio waves travel in straight line and have sky propagation. But they are affected by rain and interference.

- These are used for long distance broadcasting, FM radio and military communication.

MicroWave Transmission

- Above 100 MHz, the waves travel in nearly straight lines and can therefore be narrowly focused.

- Since the microwaves travel in a straight line, if the towers are too far apart, the earth will get in the way. Consequently, repeaters are needed periodically.

- *Microwave communication is widely used for long-distance telephone communication, mobile phone, television distribution*, etc.

MicroWave Transmission

Disadvantages:

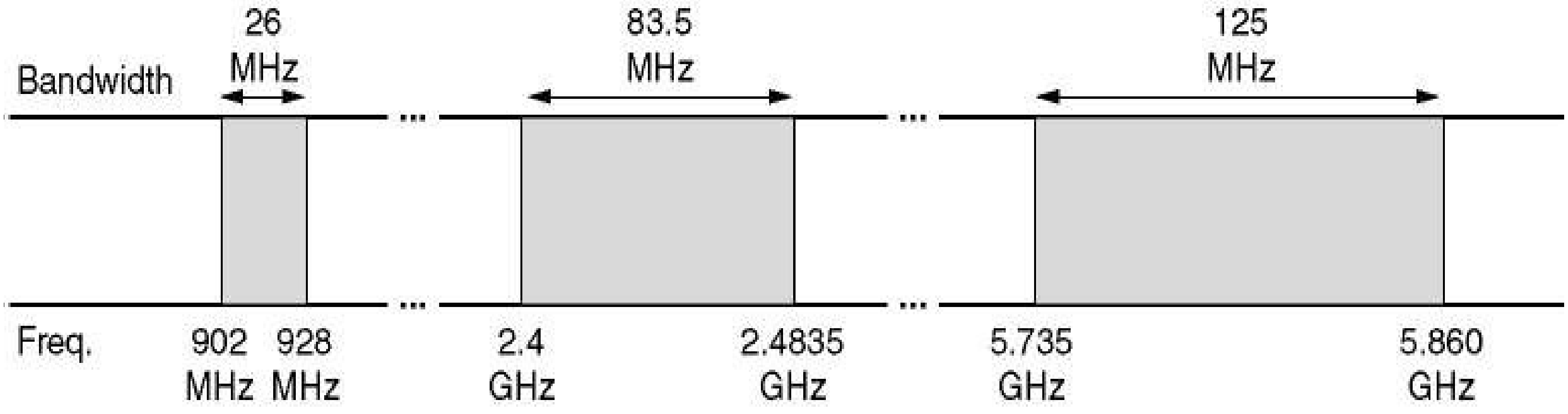
- do not pass through buildings well
- multipath fading problem (the delayed waves cancel the signal)
- absorption by rain above 8 GHz
- severe shortage of spectrum

Advantages:

- no right way is needed (compared to wired media)
- relatively inexpensive
- simple to install

Infrared and Millimeter Waves

- They are *used for short-range communication*.
- The remote controls used on televisions, VCRs, are infrared communication.
- The *infrared waves do not pass through solid walls*.



PSTN (Public Switched Telephone Network)

- Network designers must rely on the existing tele-communication facilities especially **PSTN**

- Designed many years ago, with a completely different goal in mind: **transmitting the human voice**

- Their suitability for use in computer-computer communication is often marginal at best, very slow

- The telephone system is tightly intertwined with wide area computer networks

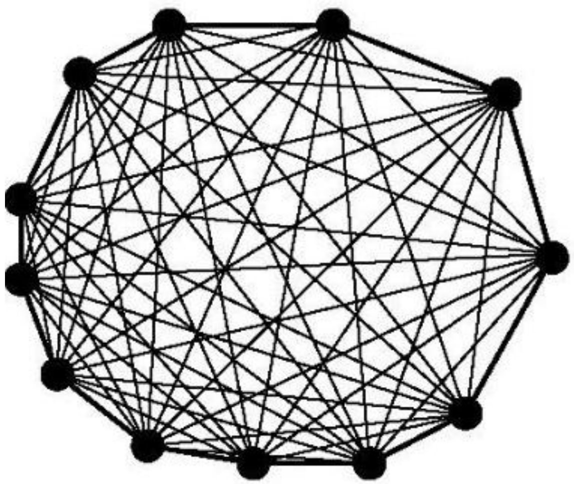
PSTN (Public Switched Telephone Network)

- A cable running between two computers can transfer data at 10^9 bps, maybe more.
- In contrast, a dial-up line has a maximum data rate of 56 kbps, a difference of a factor of almost 20,000.
- With ADSL connection, there is still a factor of 1000–2000 difference.

Structure of the Telephone System

- The initial market was for the sale of telephones, which came in pairs. It was up to the customer to string a single wire between them.

- If a telephone owner wanted to talk to other telephone owners, separate wires had to be strung to all houses.

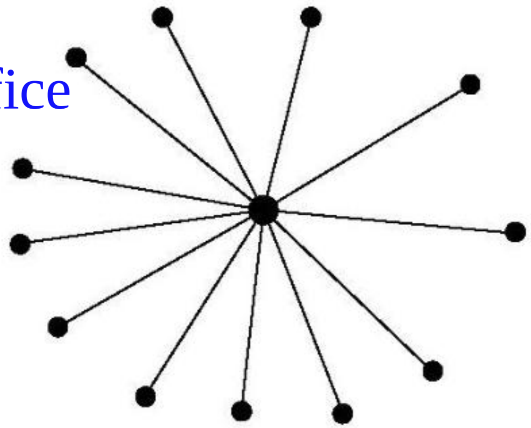


(a)

- Within a year, the cities were covered with wires passing over houses and trees in a wild jumble.

Structure of the Telephone System

- Bell saw this and formed the Bell Telephone Company, which opened its first switching office

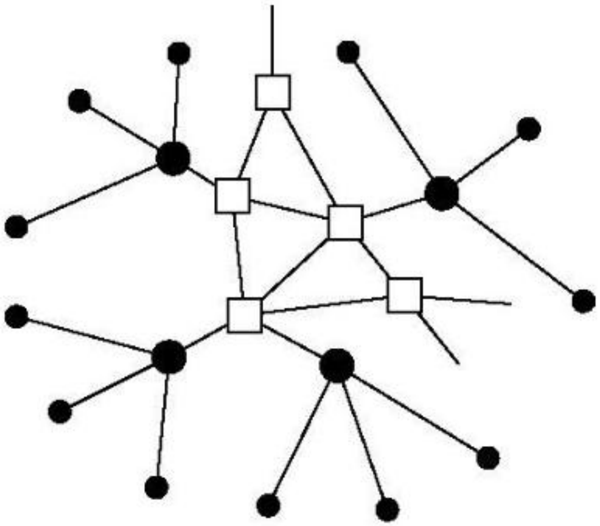


(b)

- The company ran a wire to each customer's house or office. To make a call, the customer would crank the phone to make a ringing sound in the telephone company office to attract the attention of an operator, who would then manually connect the caller to the callee by using a jumper cable.

Structure of the Telephone System

- second-level switching offices were invented. After a while, multiple second-level offices were needed as it became Unmanageable to connect every switching office to every other switching office by Means of wire



(c)

Structure of the Telephone System

- Each telephone has two copper wires coming out of it that go directly to the telephone company's nearest end office (also called a local central office).

- The distance is typically 1 to 10 km, being shorter in cities than in rural areas. In the United States alone there are about 22,000 end offices.

- The two-wire connections between each subscriber's telephone and the end office are known in the trade as the local loop.

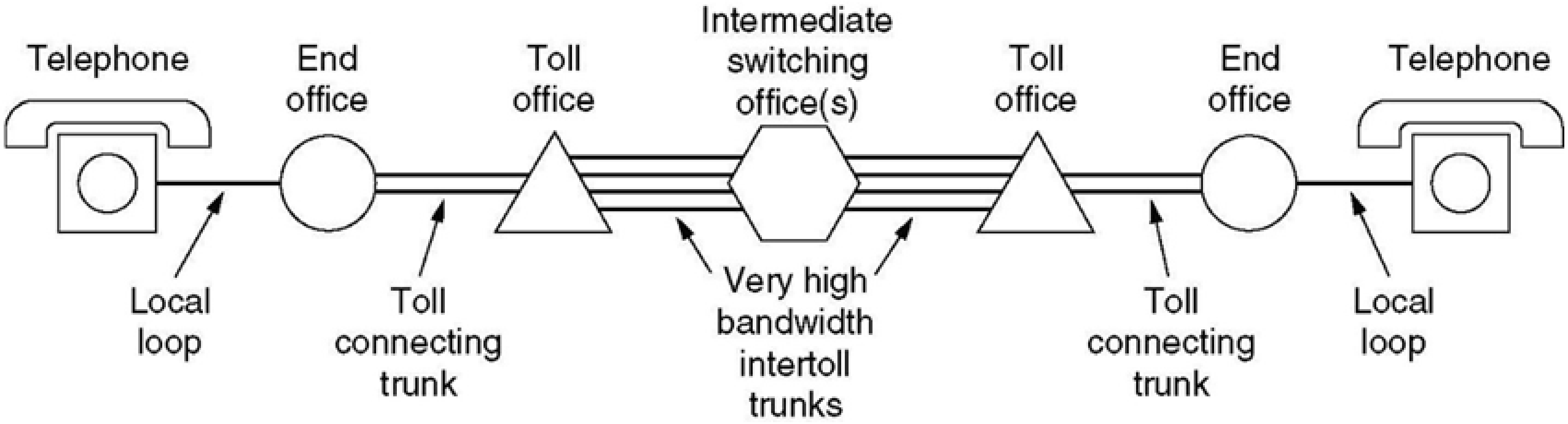
Structure of the Telephone System

- If a subscriber attached to a given end office calls another subscriber attached to the same end office, the switching mechanism within the office sets up a direct electrical connection between the two local loops.

- If the called telephone is attached to another end office, a different procedure has to be used. Each end office has a number of outgoing lines to one or more nearby switching centers, called toll offices. These lines are called toll connecting trunks.

- If the caller and callee do not have a toll office in common, the path will have to be established via high bandwidth inter-toll trunks (also called interoffice trunks).

Structure of the Telephone System



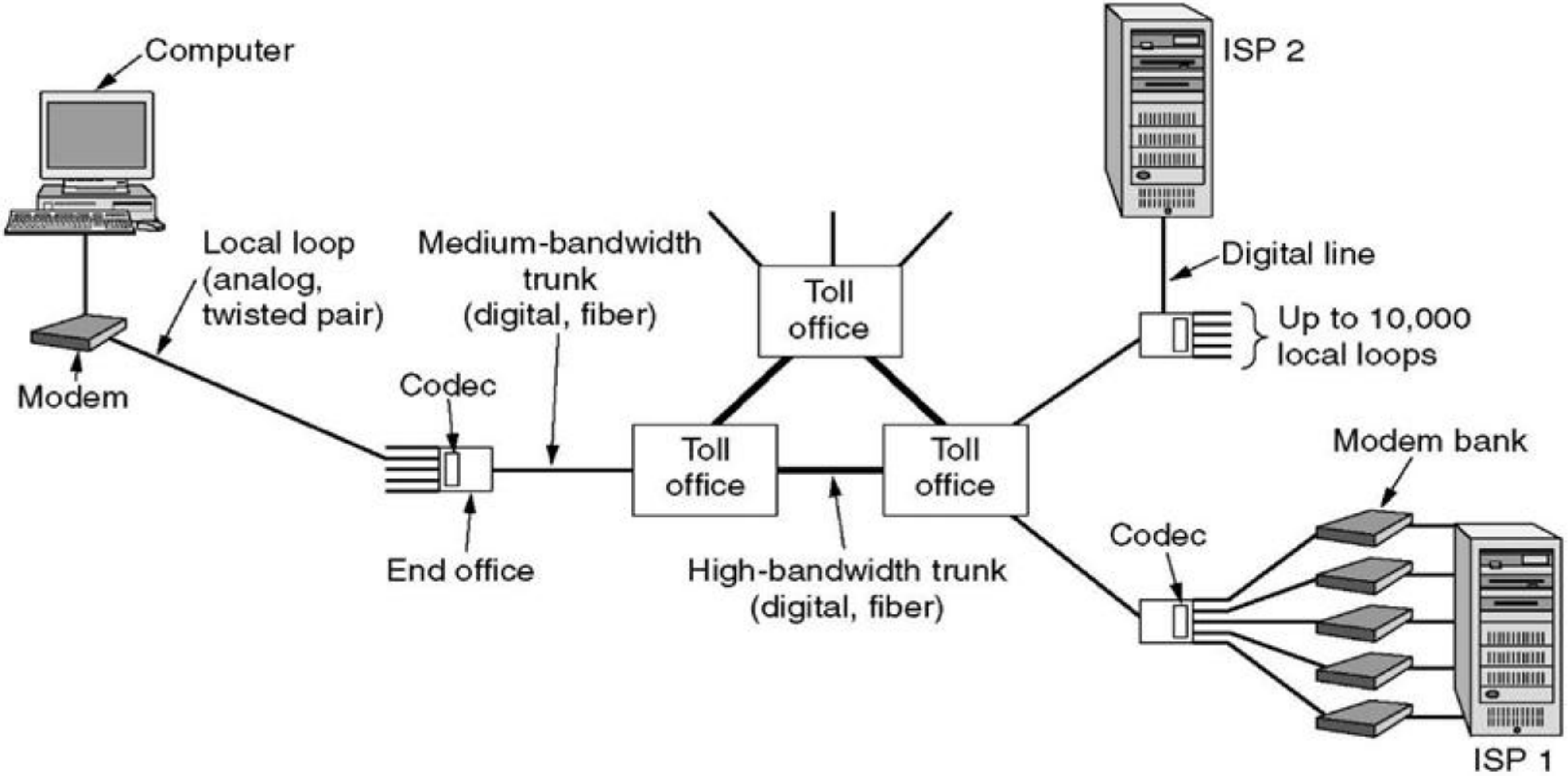
Structure of the Telephone System

- Digital transmission is preferred because as
  - it is not necessary to accurately reproduce an analog waveform.
  - correctly distinguish a 0 from a 1
  - more reliable than analog

- In summary, the telephone system consists of three major components:

1. Local loops (analog twisted pairs going into houses and businesses).
2. Trunks (digital fiber optics connecting the switching offices).
3. Switching offices (where calls are moved from one trunk to another.)

The Local Loop:



The Local Loop:

- When a computer wishes to send digital data over an analog dial-up line, the data must first be converted to analog form for transmission over the local loop.

- This conversion is done by a device called a **modem** – **mo**dulator-**Dem**odulator- a device that accepts a serial stream bit as input and produce a carrier modulated by one (or more) methods (or vice versa- accepts the modulated carrier and produce serial stream of bits.

- At the telephone company end office the data are converted to digital form for transmission over the long-haul trunks. .

The Local Loop:

- Transmission lines suffer from three major problems:
  1. Attenuation
  2. Delay Distortion
  3. Noise

- Attenuation : Attenuation is the loss of energy as the signal propagates

- Distortion: Different Fourier components also propagate at different speed in the wire. This speed difference leads to distortion.

- Noise: Unwanted signal added with the transmitted signal

The Local Loop:

- Noise: Unwanted signal added with the transmitted signal

- Thermal Noise   Impulse Noise

(leads to cross talk) (it can wipe out one or more bit)

The Local Loop: Modem

- The square waves used in digital signals have a wide frequency spectrum

- Thus square waves are subject to strong attenuation and delay distortion.

- These effects make baseband (DC) signaling unsuitable except at slow speeds and over short distances.

- To get around the problems associated with DC signaling, especially on telephone lines, AC signaling is used. A continuous tone in the 1000 to 2000-Hz range, called a sine wave carrier, is introduced.,

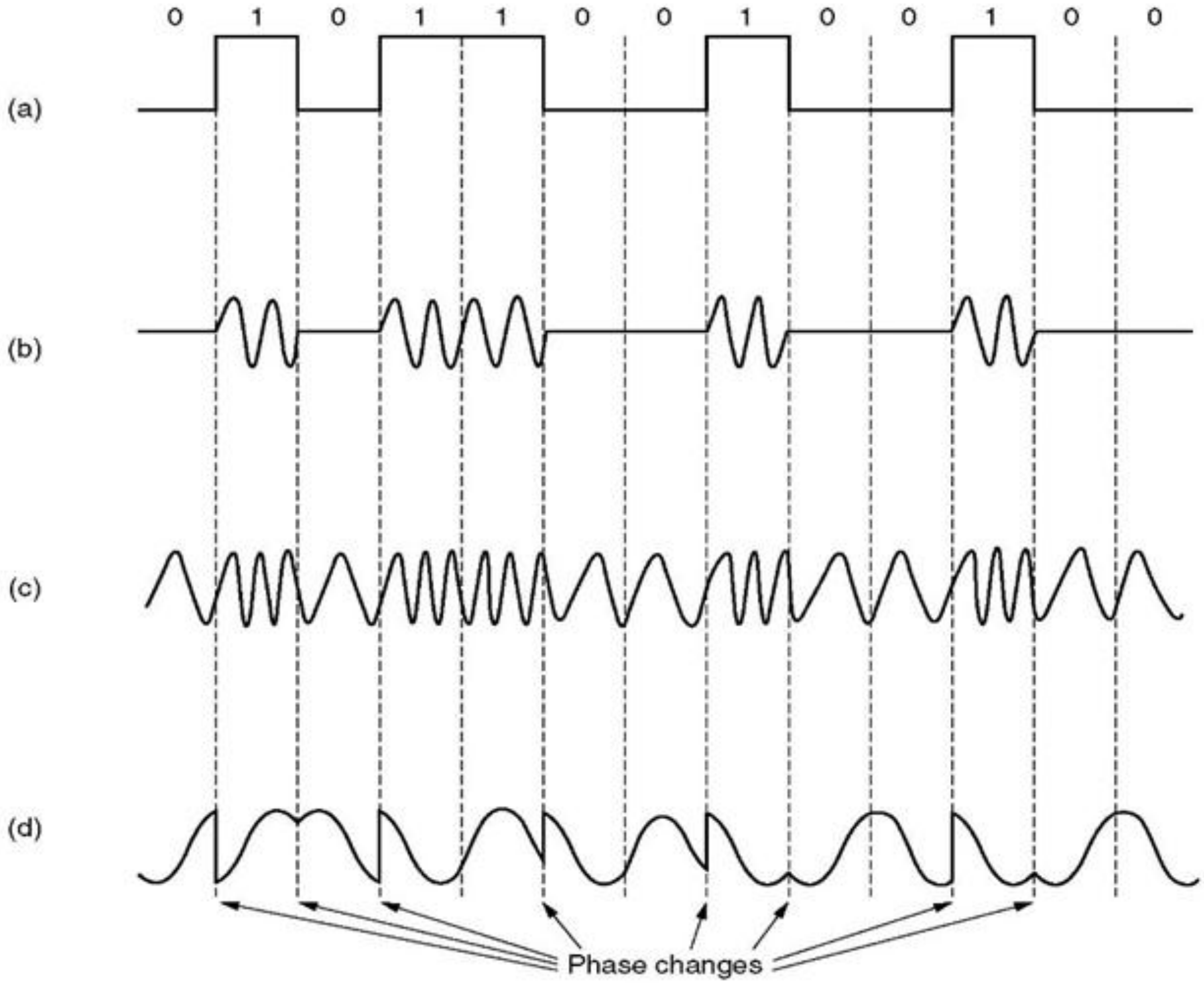
The Local Loop: Modem

- In amplitude modulation, two different amplitudes are used to represent 0 and 1, respectively.

- In frequency modulation, also known as frequency shift keying, two (or more) different tones are used. (The term keying is also widely used in the industry as a synonym for modulation.)

- In phase modulation, the carrier wave is systematically shifted 0 or 180 degrees at uniformly spaced intervals.

The Local Loop: Modem



a) Binary signal b) amplitude modulation c) frequency modulation d) phase modulation

The Local Loop: Modem

- This modulation is done by a device is called as modem.
- To increase the data rate, it is not possible to increase the sampling rate (it is limits to 2H according to Nyquist theorem)
- Most of the modems sample 2400 times/sec
- A sample refers to one of the several voltages/frequency/phase changes.
- Instead of increasing the sampling rate, we focus on increase the bit rate for the given data rate

The Local Loop: Modem

- The baud rate is the number of samples/sec made.

- If a binary signal has two symbols: 0 for each 0 bit
  1 for each 1 bit

- Then for a 2400 baud line, the bit rate is 2400 because

The bit rate = the number of symbols/sec x the number of bits/symbol.

Bit rate for 2400-baud lines and each symbol is represented with 1 bit

= 2400 samples/sec x 1bits/sample = 2400 bits/sec

The Local Loop: Modem

- If, however, the voltages 0, 1, 2, and 3 volts are used, every symbol consists of 2 bits.

- Bit rate for 2400-baud lines and each symbol is represented with 2 bit

  = 2400 samples/sec x 2 bits/sample = 4800 bits/sec

QPSK
(Quadrature Phase Shift Keying)

- All advanced modems use a combination of modulation techniques to transmit multiple bits per baud. Often multiple amplitudes and multiple phase shifts are combined to transmit several bits/symbol.

- For QPSK, four different phase are : 45,135, 225, 315 with constant amplitude (distance of the point from origin)

- It can be used to transmit 2 bits per symbol.

- Each symbol is represented as a point in constellation diagram

- Each high-speed modem standard has its own constellation pattern and can talk only to other modems that use the same one

- Though symbol points can be represented in the constellation pattern, small amount of noise is detected in the amplitude and phase.

- This results in erroneous bits at the receiver bit.

Constellation diagram

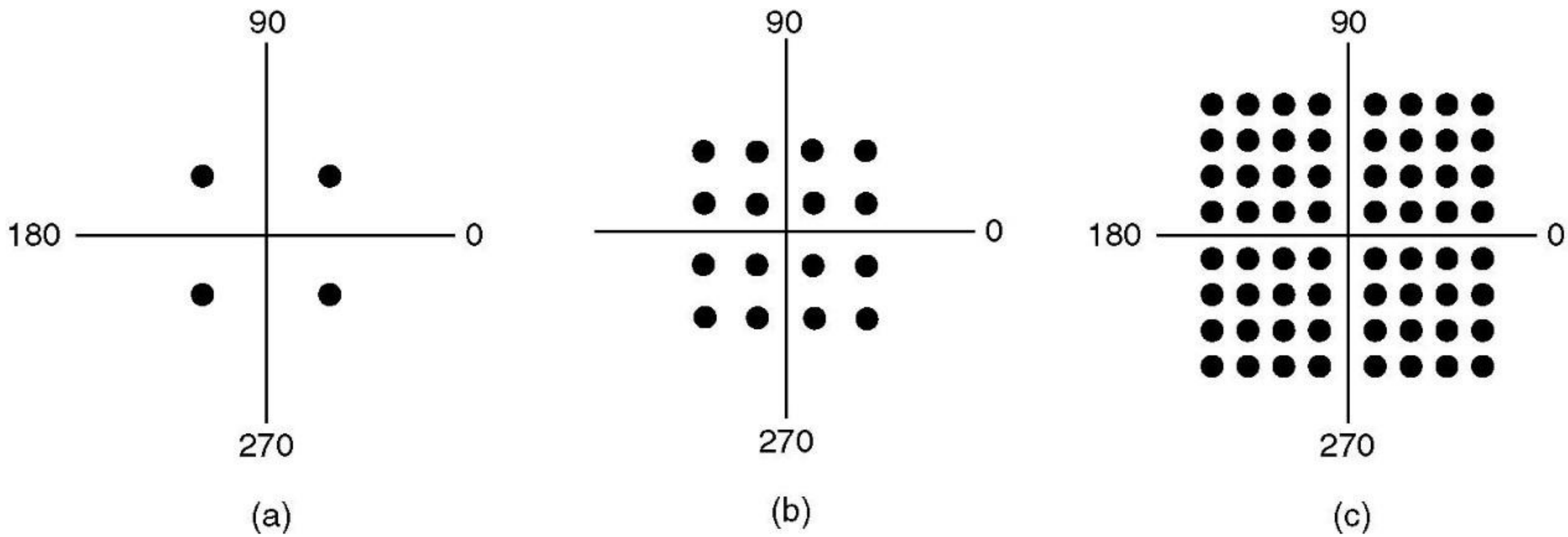
- The digitally modulated signal can be represented graphically called as **constellation diagram**

- They are used for the analysis of digitally modulated waveform and provide valuable insight into the performance of a digital communication diagram.

- The symbol are often represented in the polar format on complex plane with each each possible symbol mapped asa constellation point.

- The location of each point on the diagram is determined by the amplitudeand phase and angle associated with its corresponding symbol.

Modulations



(a) QPSK.
(b) QAM-16.
(c) QAM-64.

QAM

- One unique form of multilevel modulation is QAM (Qudrature Amplitude Modulation.

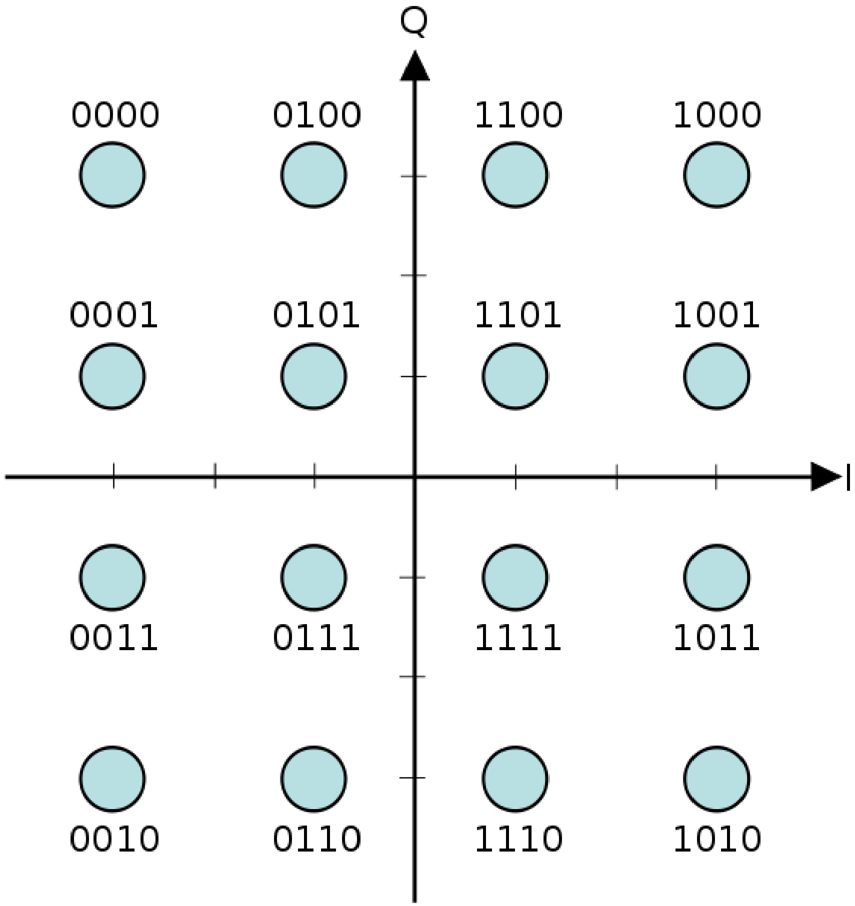
- QAM uses a mix of different amplitude levels and phase shifts to crete a symbol representing multiple bits

- We have different types of QAM i.e. QAM-8, QAM-16, QAM-64 etc.

QAM-16

- In this modulation technique four amplitudes and four phases are used, for a total of 16 different combinations.
- Each combination is a symbol and represented as a point in constellation diagram
- To represent different amplitude and phase, 4-bits are used.
- So, the maximum data rate over a 2400- baud is 9600bps

Constellation diagram of QAM-16

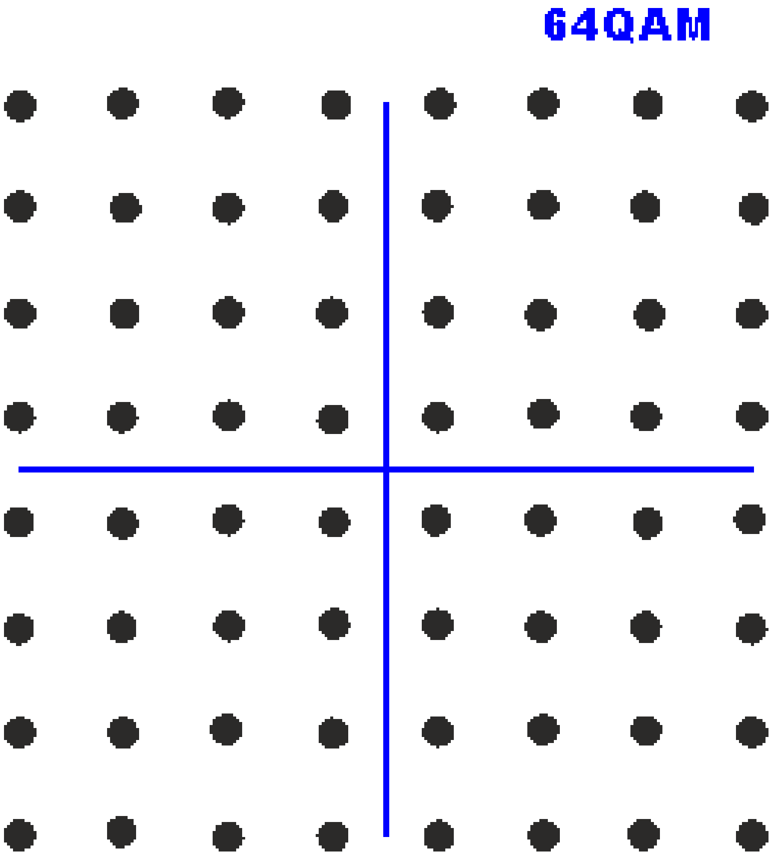


QAM-64:

- It allows 64 different combinations, so 6 bits can be transmitted per symbol

- So, the maximum data rate over a 2400- baud is 14400bps.

Constellation diagram of QAM-64



Modems

- Each high-speed modem standard has its own constellation pattern and can talk only to other modems that use the same one

- Though symbol points can be represented in the constellation pattern, small amount of noise is detected in the amplitude and phase.

- This results in erroneous bits at the receiver bit.

Problems :

Q. 20. Is an oil pipeline a simplex system, a half-duplex system, a full-duplex system, or none of the above?

Ans:

Oil can flow in either direction, but not both ways at once.

Problems :

Q. 22. A modem constellation diagram similar to Fig. 2-25 has data points at the following coordinates: (1, 1), (1, -1), (-1, 1), and (-1, -1). How many bps can a modem with these parameters achieve at 1200 baud?

Ans:

There are four legal values per baud.

Each symbol is represented by 2 bits

so the bit rate is = 1200 samples/sec x 2 bits/samples= 2400 bits/sec

Problems :

Q. 23. A modem constellation diagram similar to Fig. 2-25 has data points at (0, 1) and (0, 2). Does the modem use phase modulation or amplitude modulation?

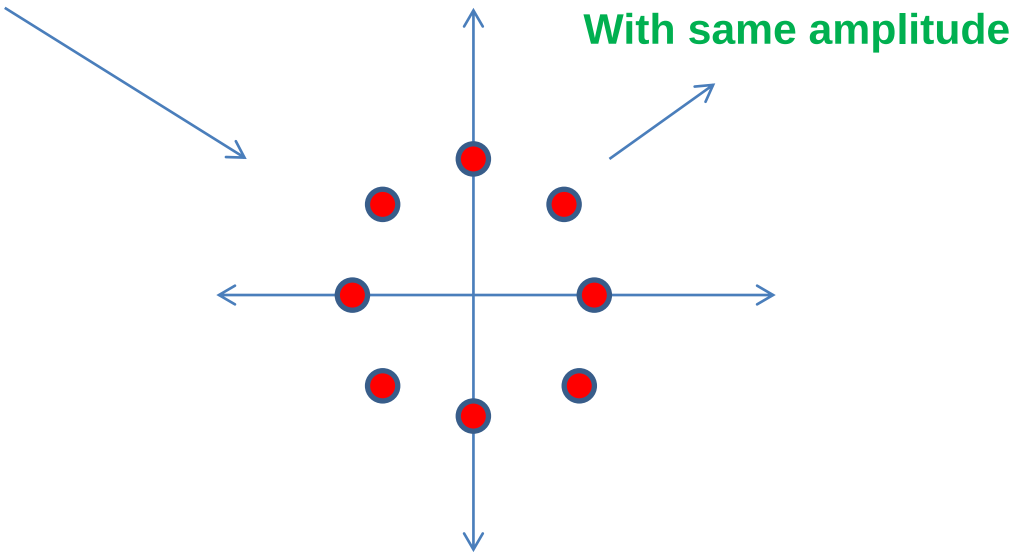
Ans:

The phase shift(1st coordinate value) is always 0, but two amplitudes are used, so this is straight amplitude modulation.

Problems :

- Q. 24. In a constellation diagram, all the points lie on a circle centered on the origin. What kind of modulation is being used?

- Ans: Phase modulation is being used.



Problems :

Q. 25. How many frequencies does a full-duplex QAM-64 modem use?

Ans: Full-duplex QAM-64 uses two frequencies : 1 for upstream channel and other for downstream channel

Modems

- To reduce the chance of an error, standards for the higher speeds modems do error correction by adding extra bits to each sample.

- This technique/ scheme is called as **TCM(Trellis Coded Modulation).**

- We have different types of high speed modem using TCM technique

Modems

Modem type (in V-Series)	Data bits (in bits/symbol)	Parity bit (paritybit/symbol)	Constellation points	Data rate (for 2400 baud)
V.32	4	1	32 (2^5)	9600 bps

Modems

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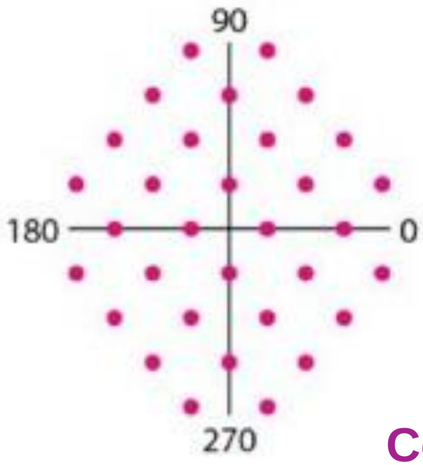
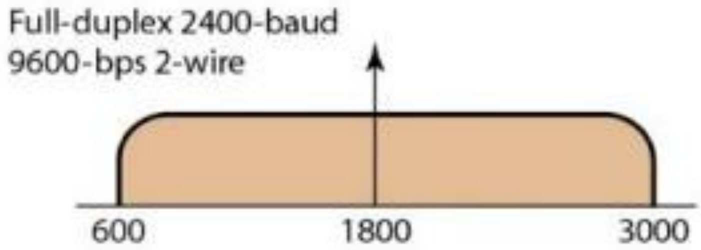
V.32	4	1	32 (2^5)	9600 bps
V.32 bis	6	1	128 (2^7)	14400bps

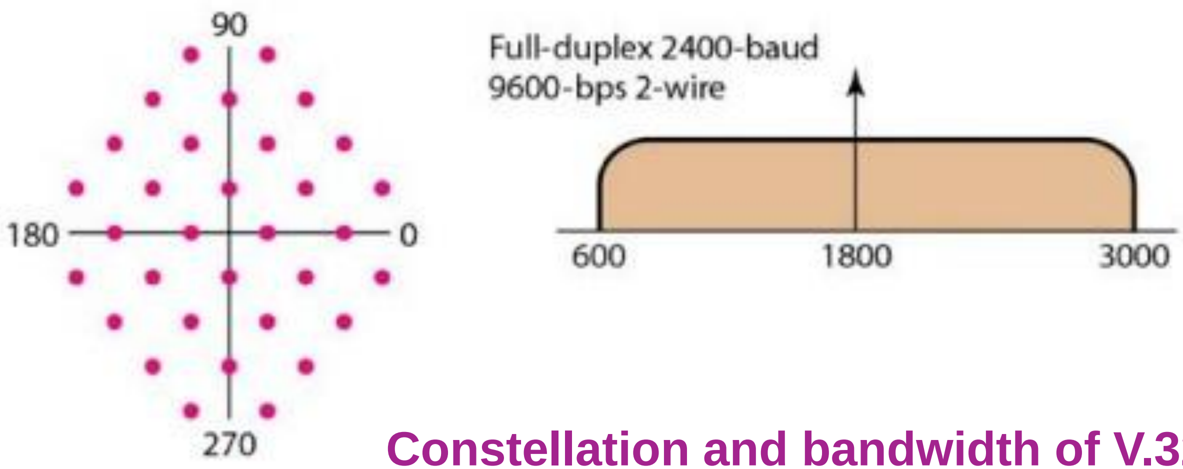
V.32 Modems



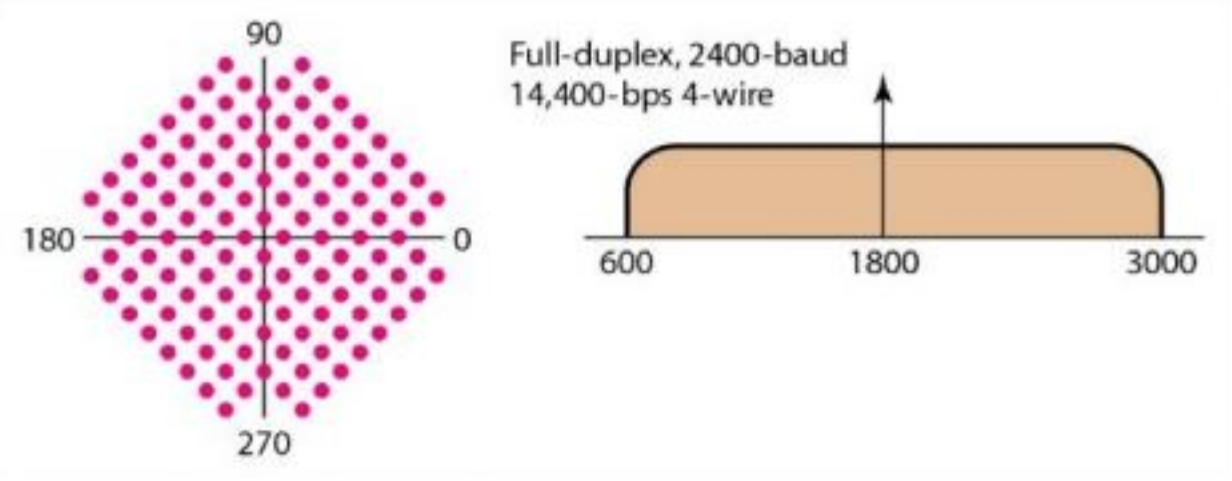


Constellation and bandwidth of V.32

V.32 Modems



Constellation and bandwidth of V.32



Constellation and bandwidth of V.32 bis

Modems

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V.32	4	1	32 (2^5)	9600 bps
V.32 bis	6	1	128 (2^7)	14400bps
V.34	12	1	(2^{13})	28800 bps

Modems

Modem type (in V-Series)	Data bits (in bits/symbol)	Parity bit (paritybit/symbol)	Constellation points	Data rate (for 2400 baud)
V.32	4	1	32 (2^5)	9600 bps
V.32 bis	6	1	128 (2^7)	14400bps
V.34	12	1	(2^{13})	28800 bps
V.34 bis	14	1	(2^{15})	33600 bps

Modems

- To get the effective data rate more than 33600 bps, data is compressed in modem
-
- So, before transmitting the data, the modem checks the transmission line. If it finds quality lacking, then it cut the speeed lower than the rated maximum.

- So, the effective data rate can be lower or equal to or higher than the official rating

Modems

- All modern modems allow traffic in both directions at the same time (by using different frequencies for different directions).
- A connection that allows traffic in both directions simultaneously is called **full duplex**.
- Example: A two-lane road is full duplex.

- A connection that allows traffic either way, but only one way at a time is called **half duplex**.

  Example: A single railwaytrack

- A connection that allows traffic only one way is called **simplex**. Example: optical fiber with a laser on one end and a light detector at the other end

Modems: V.90 & V.92

- According to the shannon limit, the maximum data rateof a telephone line is 35 kbps

- So modem stops at 33600 bps

- 35Kbps depends upon the length of local loops. A call between computer and ISP 1 goes over two local loop as an analog signal. At each end, some amount of noise is added to the signal.

- On the other hand, the digital signal is fed directly to ISP2 thus eliminating modem, codec and analog transmission.

Modems: V.90 & V.92

- So the data rate is as high as 70kbps
- But, according to Nyquist theorem, with a telephone channel of 4000 Hz, the maximum number of samples required to reconstruct is 2H (8000Hz).
- If we use 8-bit/sample, the maximum data rate = 2Hlog2 V
  - = 8000x8
  - = 64kbps
- In USA, 1 bit is for control purpose, data rate obtained is 56Kbps.

Modems: V.90 & V.92

- According to international agreement on standard, modem of 56Kbps was chosen.

- Such modem standard is called as V.90

- It provides → 33.6Kbps upstream channel (USER to ISP)
  → 56Kbps downstream channel (ISP to USER)

Modems: V.90 & V.92

- Another modem standard beyond V.90 is V.92
- Such modems are capable of 48Kbps upstream channel.

DSL: Digital Subscriber Line

POTS:

- During last decades Internet was accessed through modems connected through POTS system.
- Modems were extremely slow by today's standards
- POTS are designed for voice transmission at frequency below 3KHz.
- Limitation for obtainable data rate of the system.
-

DSL: Digital Subscriber Line

ISDN:

- Alternative to POTS.
- Improved Internet access speed
- Transfer both audio and video.
- Required expensive setup
- required special cabling
-

DSL: Digital Subscriber Line

Broadband & DSL:

- In 1980, Josheph Lech discovered the idea of broadband to transfer data

- Improved Internet access speed

- With the idea of broadband, came up with the idea of DSL and ADSL

DSL: Digital Subscriber Line

Overview DSL:

- DSL is a very high speed connection that uses a high speed connection that uses the same wires as a regular telephone line.

- Replacement of ISDN.

DSL: Digital Subscriber Line

Overview DSL:

- DSL technology allows Internet and telephone service to work over the same phone line without requiring customers to disconnect either voice or internet connections.

- DSL internet services are used primarily in homes and small business.

DSL: Digital Subscriber Line

Overview ADSL:

- Asymmetric: The data can flow faster in one direction than the other; data transmission has faster downstream to the subscriber than the upstream.

- Digital: All data is purely digital and it is modulated to be carried over the telephone line.

- Subscriber line: The data is carried over a single twisted pair copper loop to the subscriber premises.

DSL: Digital Subscriber Line

Design goal of ADSL:

- The services must work over the existing category 3 twisted pair local loops.
- They must not affect customers' existing telephones and fax machines.
- They must be much faster than 56 kbps.
- They should be always on, with just a monthly charge but no per-minute charge. : The data is carried over a single twisted pair copper loop to the subscriber premises.

ADSL

There are two standards used for modulation of ADSL signal

- Carrierless Amplitude Phase
- Discrete Multi-Tone

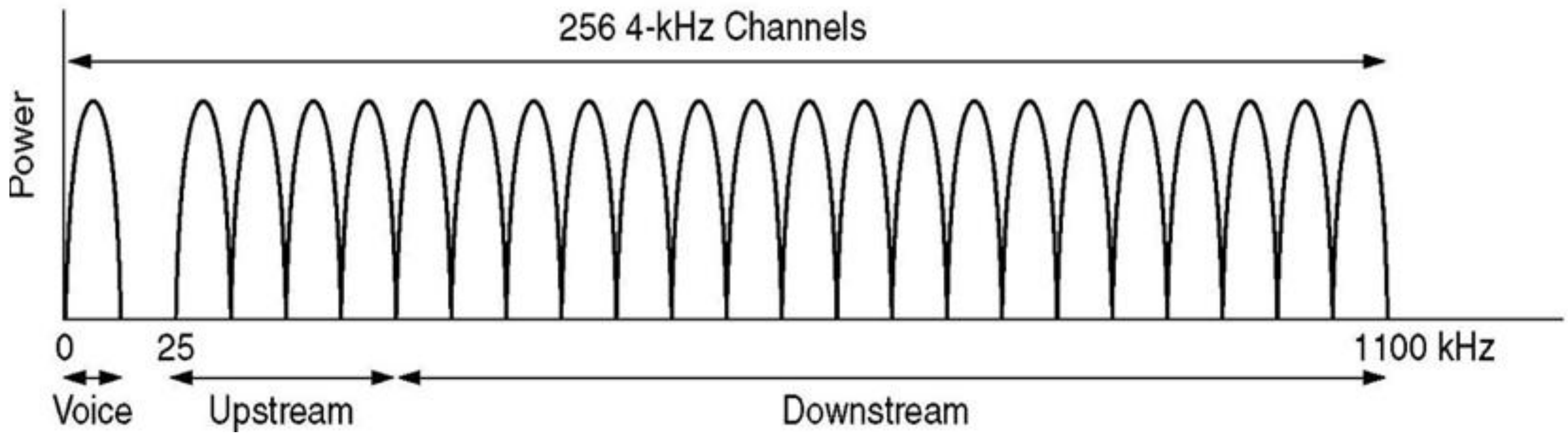
DMT:

- Available 1.1 MHz spectrum on the local loop into 256 independent channels of 4312.5 Hz each.

- Channel 0 is used for POTS.

- Channels 1–5 are not used, to keep the voice signal and data signals from interfering with each other. Of the remaining 250 channels, one is used for upstream control and one is used for downstream control. The rest are available for user data. .

ADSL Modulation:



ADSL Modulation:

- Most providers allocate something like 80%–90% of the bandwidth to the downstream channel since most users download more data than they upload.

- A common split is 32 channels for upstream and the rest downstream

- The ADSL standard (ANSI T1.413 and ITU G.992.1) allows speeds of as much as 8 Mbps downstream and 1 Mbps upstream.

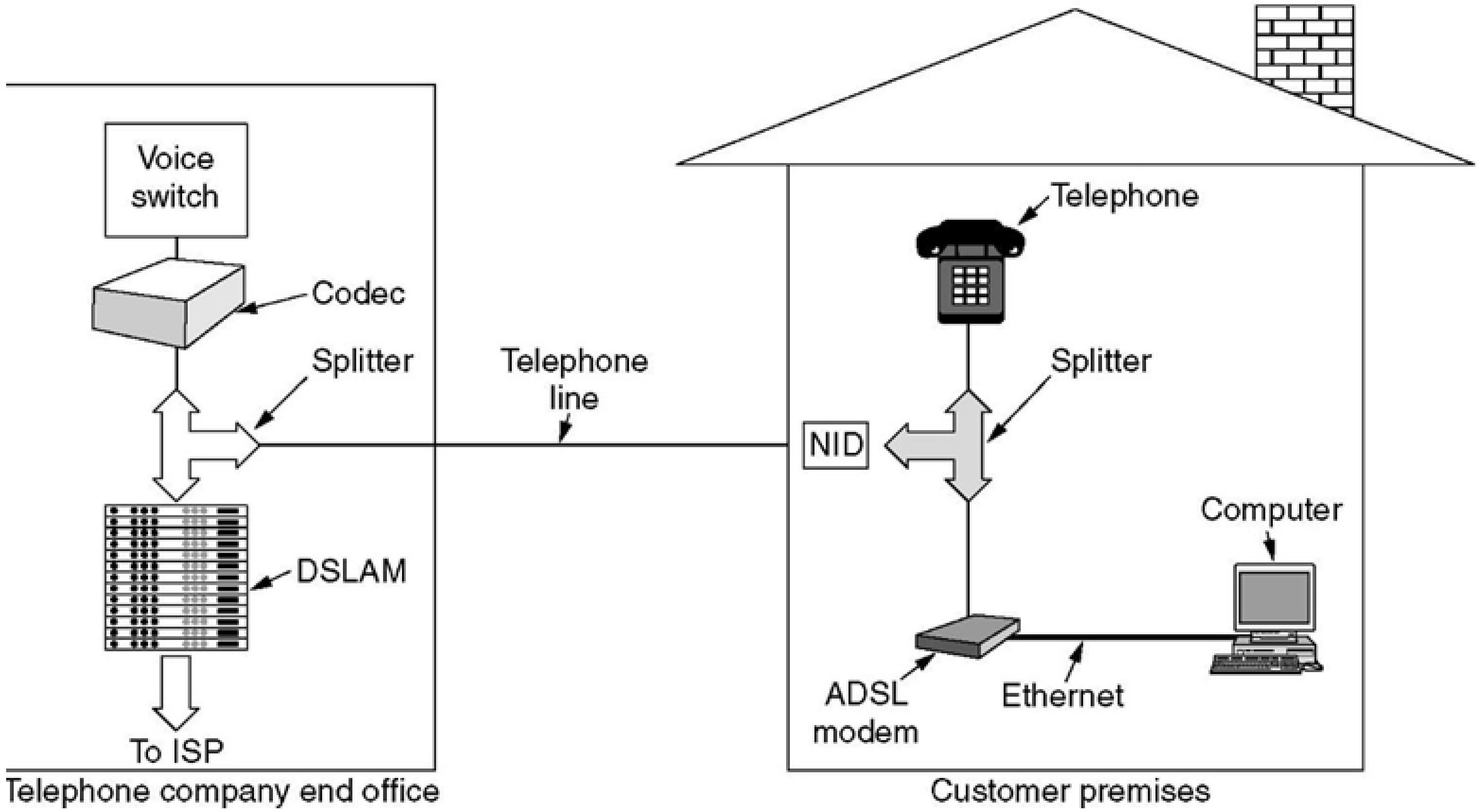
ADSL Modulation:

- Within each channel, a modulation scheme similar to V.34 is used, although the sampling rate is 4000 baud instead of 2400 baud.

- The actual data are sent with QAM modulation, with up to 15 bits per baud, using a constellation diagram analogous

- The ADSL standard (ANSI T1.413 and ITU G.992.1) allows speeds of as much as 8 Mbps downstream and 1 Mbps upstream.

ADSL Configuration :



ADSL Configuration :

- To create a ADSL, there must be a pair of ADSL modems, one at the subscriber site and other at the network operator site (central office).

- During an internet connection, the two ADSL modems communicates, converting signal to a format that can be transferred over telephone line.

- DSLAM (Digital Subscriber Line Access Multiplexer is a device at the operator site that contains ADSL modem and interfaces to backbone network.

ADSL Configuration :

- ADSL signal from each subscriber is split into voice and data signal by a splitter that is usually contained in the same rack with DSLAM.

- The voice signal is forwarded to a telephone switch for further connection to PSTN.

- The data signal that carries internet traffic is sent to the ISP over backbone network for connection to the network.

ADSL Configuration :

- At the receiver site, a splitter separate the data signal from telephone signal.

- Therefore the subscriber can receive or make telephone calls during an internet connection without interference.

- The presence of splitter is required in a full rate ADSL.

- In case of splitterless ADSL known as G.Lite in which external splitter is not required.

Wireless local loop:

- A fixed telephone using a wireless local loop is a bit like a mobile phone, but there are three crucial technical differences.

  - The wireless local loop customer often wants high-speed Internet connectivity, often at speeds at least equal to ADSL.
  - The new customer probably does not mind having a large directional antenna on his roof pointed at the end office.
  - The user does not move, eliminating all the problems with mobility and cell handoff that we will study later in this chapter. And thus a new industry is born: fixed wirelesss

WLL: MMDS

- MMDS(Multichannel Multipoint Distribution Service) - Uses microwaves 198 MHz band at 2.1 GHz frequency range.
- Range of about 50km
- Penetrate vegetation and rain moderately well

WLL: MMDS

Advantage :

- Technology is well established and equipment readily available

Disadv :

- Bandwidth available is not much and must be shared by several users.

WLL: LMDS

The acronym LMDS is derived from the following:

***L* (local)**?denotes that propagation characteristics of signals in this frequency range limit the potential coverage area of a single cell site; ongoing field trials conducted in metropolitan centers place the range of an LMDS transmitter at up to 5 miles

M (multipoint)?indicates that signals are transmitted in a point-to-multipoint or broadcast method; the wireless return path, from subscriber to the base station, is a point-to-point transmission

***D* (distribution)**?refers to the distribution of signals, which may consist of simultaneous voice, data, Internet, and video traffic

***S* (service)**?implies the subscriber nature of the relationship between the operator and the customer; the services offered through an LMDS network are entirely dependent on the operator's choice of business

WLL: LMDS

LMDS(Local Multipoint Distribution Service) :

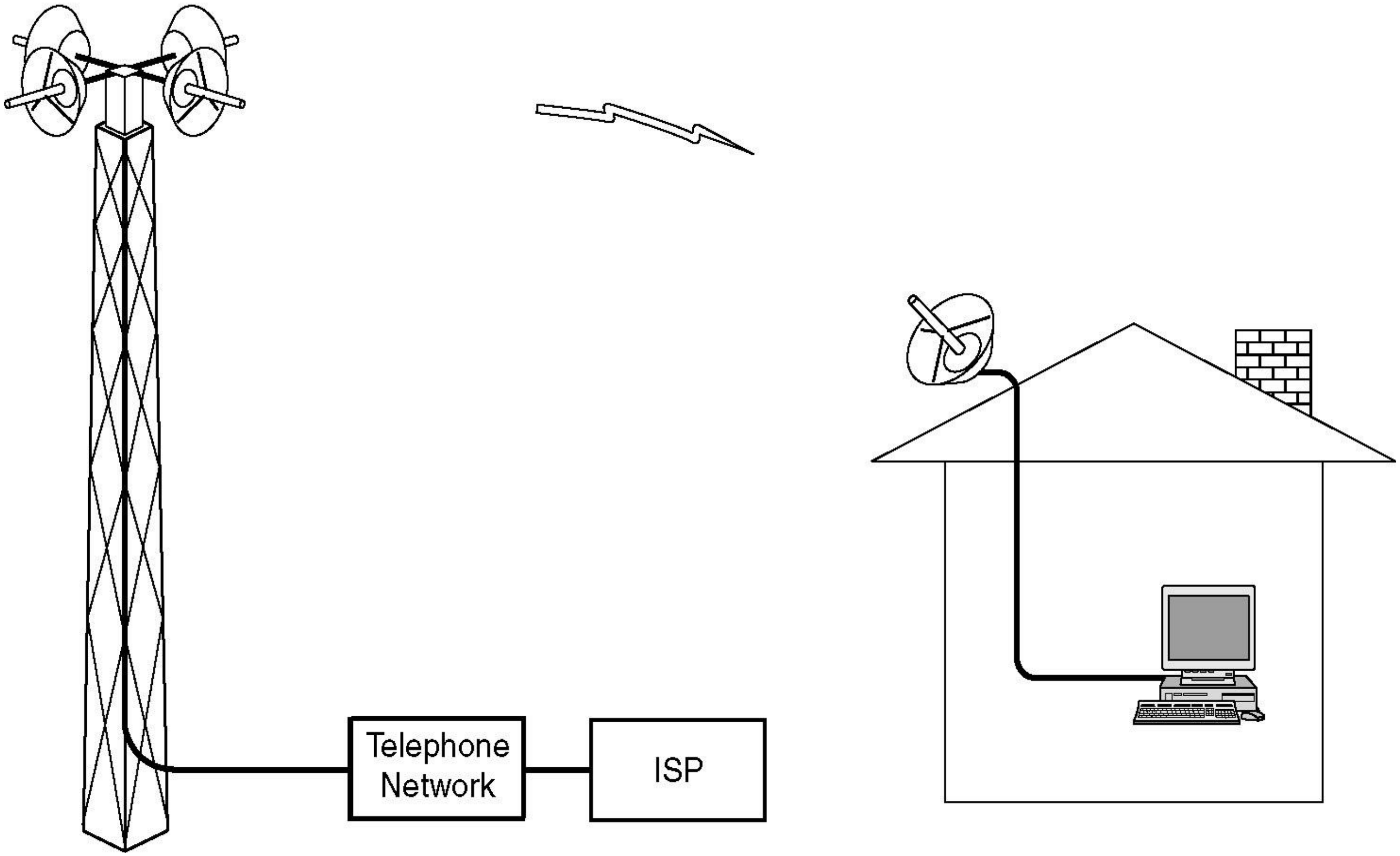
- ✓ uses Millimeter waves (because of low BW of MMDS)
- ✓ 28-31 GHz band in US and 40GHz band in Europe (both MM wave bands) were not allocated because it was difficult to build silicon integrated circuits that operate so fast.
- ✓ With the invention of Gallium arsenide ICs the speed became achievable and hence people started thinking of using MM waves for communication.

Problem with the MM waves

- Highly directional : hence there must be a clear line of sight between the roof top antennas and the tower.

- Rain and trees absorb them

Wireless Local Loops



Wireless local loop:

- Like ADSL, LMDS uses an asymmetric bandwidth allocation favoring the downstream channel
- To keep delays reasonable, no more than 9000 active users should be supported
- With four sectors, as shown in the slide above, an active user population of 36,000 could be supported, so one can estimate, that a single tower with four antennas could serve 100,000 people within a 5-km radius of the tower
- The standard by IEEE is 802.16 (2002) has been commercialized under the name “WiMAX” (from "Worldwide Interoperability for Microwave Access")

Long-Haul Trunks

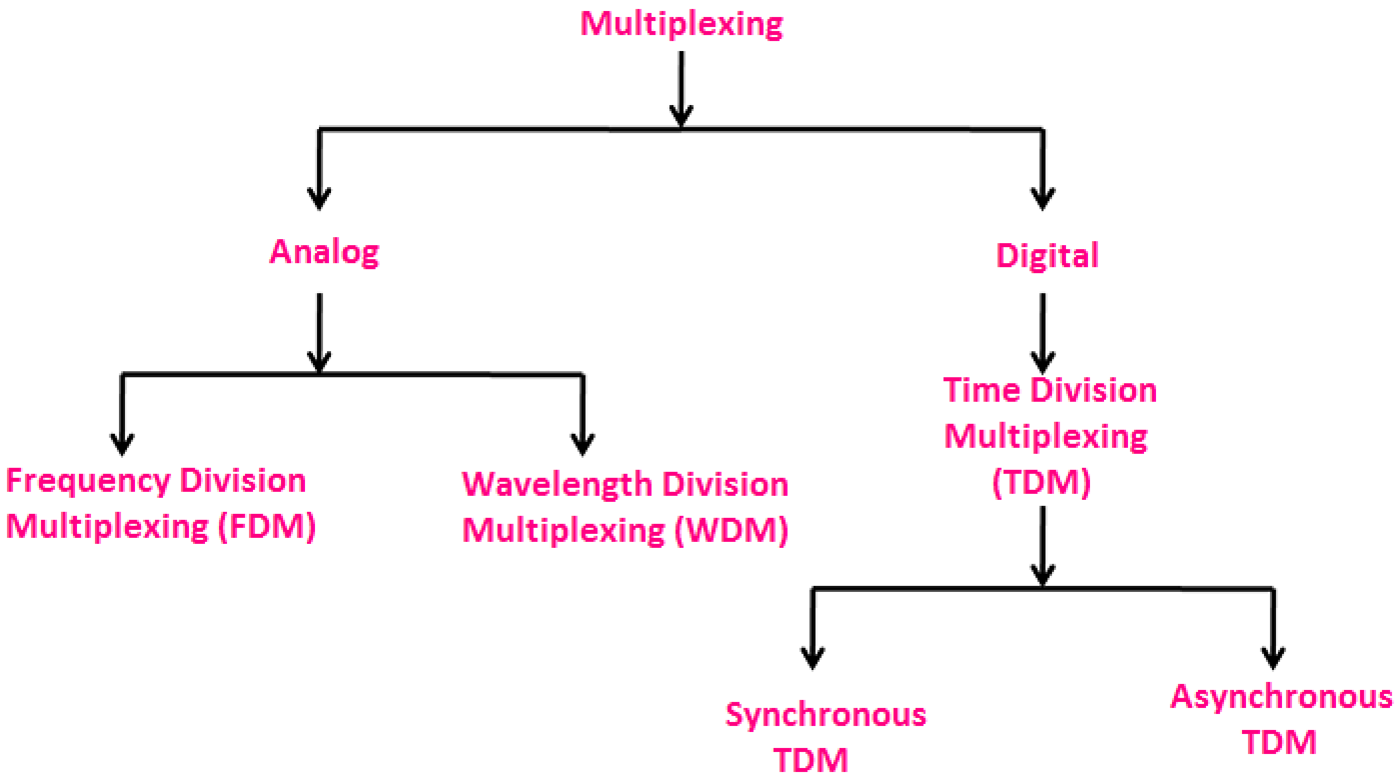
The next thing now is to combine the signals received in the end office(switching offices of the telephone co.s) from various local loops into one signal that is transmitted on the long-haul trunk. This is done with the help of various multiplexing schemes :

FDM

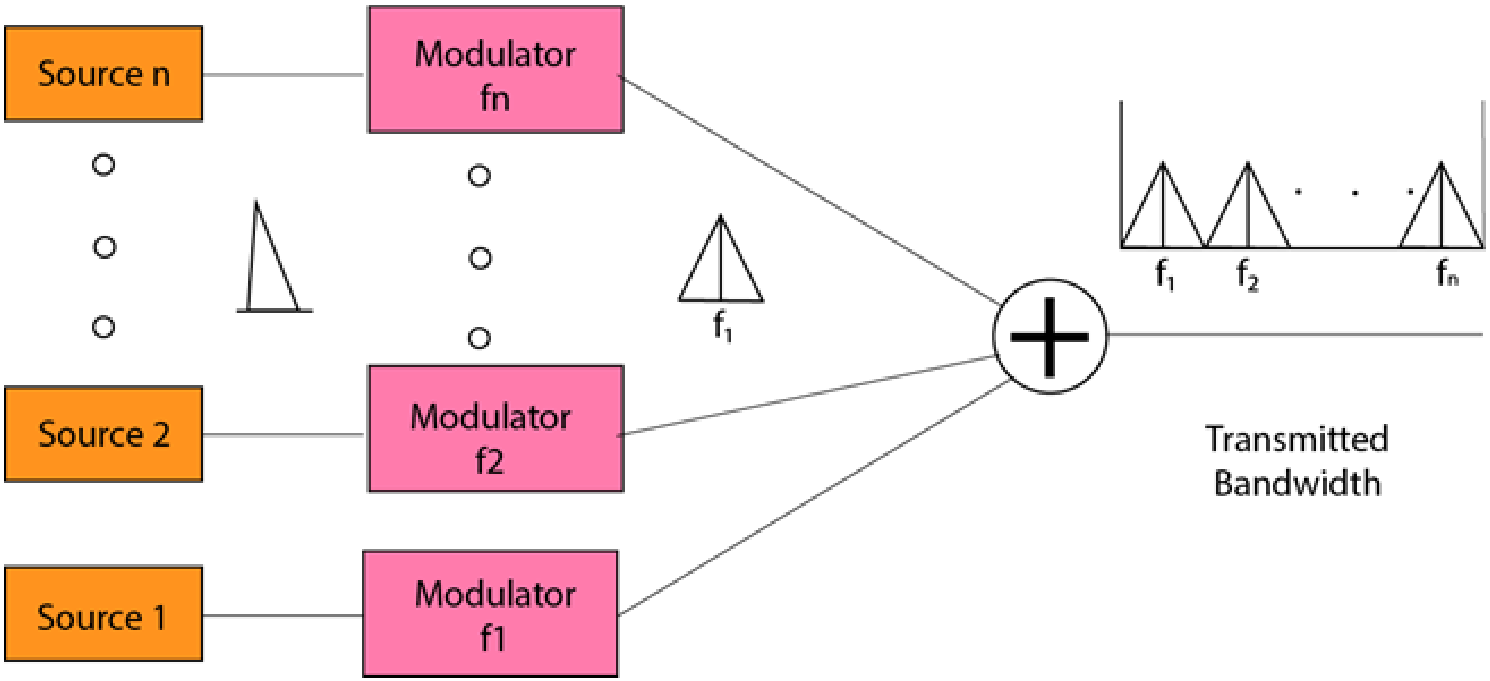
WDM

TDM

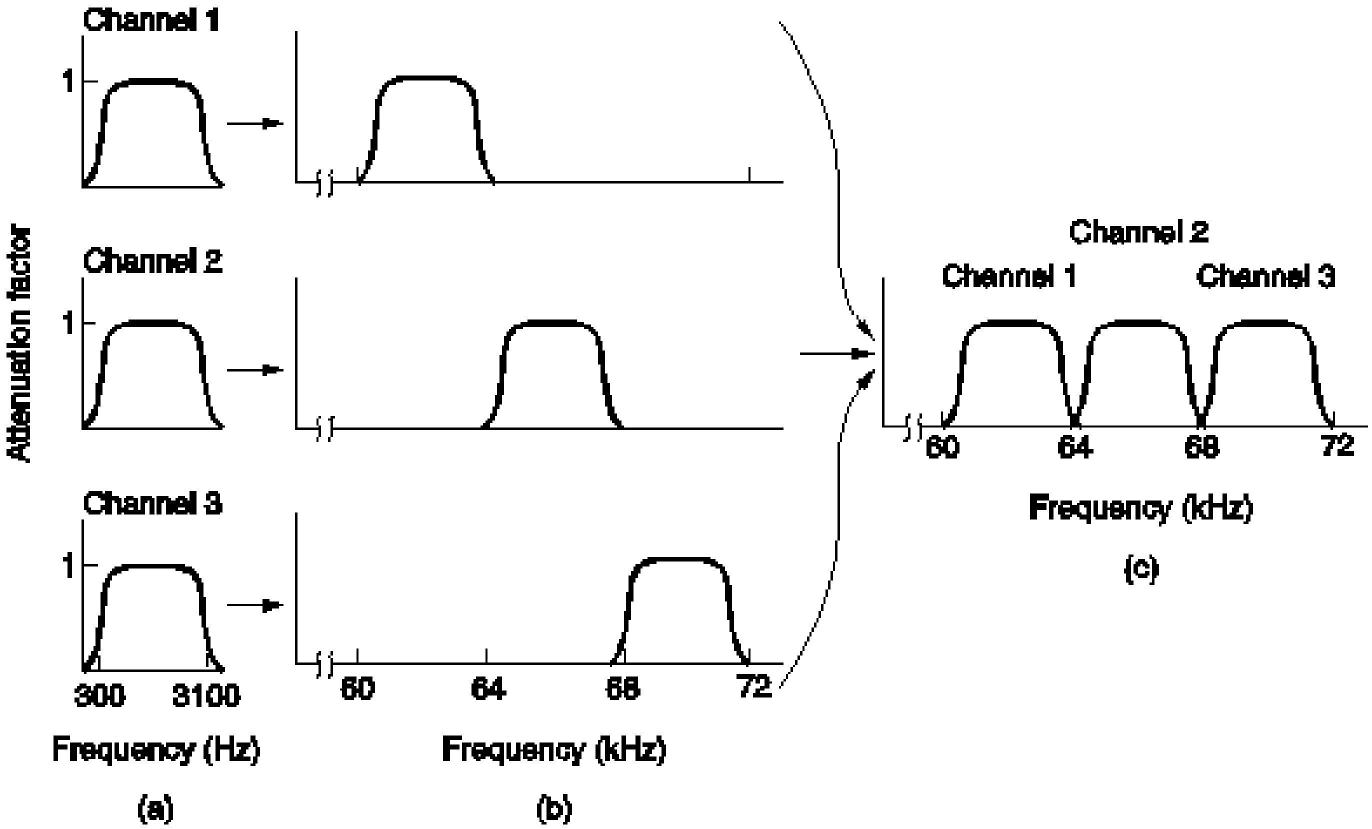
Trunk and Multiplexing:



Frequency Division Multiplexing:

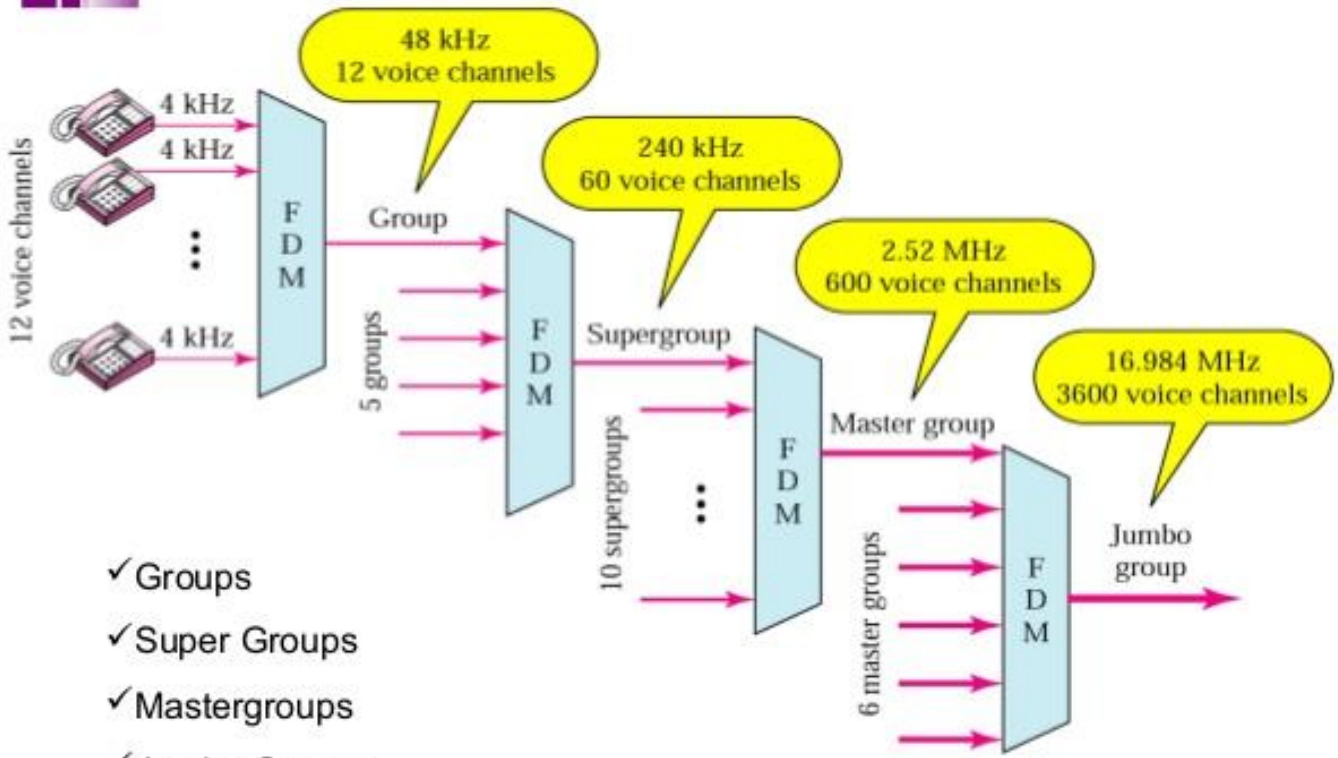


Frequency Division Multiplexing:



Frequency Division Multiplexing:

Figure *Analog hierarchy*



- ✓Groups
- ✓Super Groups
- ✓Mastergroups
- ✓Jumbo Groups

Wavelength Division Multiplexing:

- For fiber optic channels, a variation of frequency division multiplexing is used. It is called WDM (Wavelength Division Multiplexing).

Principle of WDM:

- Four fibers come together at an optical combiner, each with its energy present at a different wavelength.

- The four beams are combined onto a single shared fiber for transmission to a distant destination.

Wavelength Division Multiplexing:

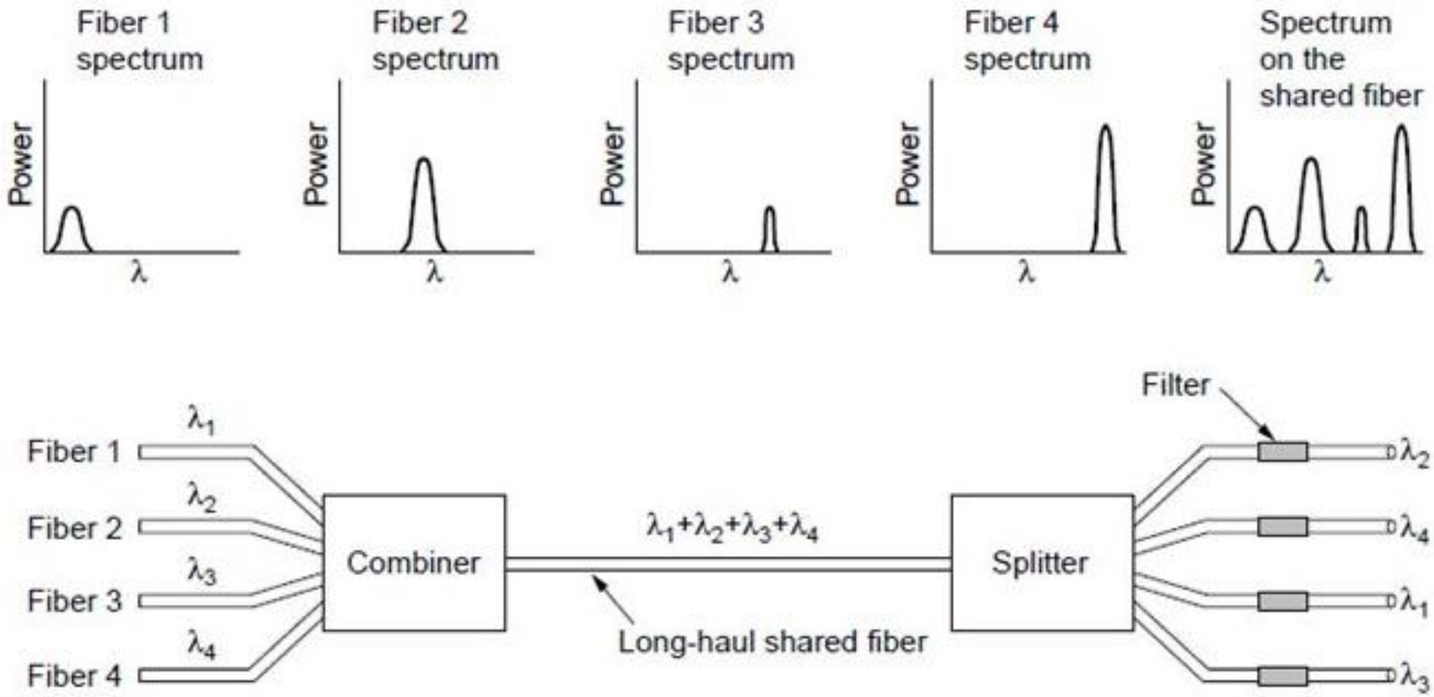
- At the far end, the beam is split up over as many fibers as there were on the input side.

- Each output fiber contains a short, specially-constructed core that filters out all but one wavelength.

- The resulting signals can be routed to their destination or recombined in different ways for additional multiplexed transport.).

- The only difference with electrical FDM is that an optical system using a diffraction grating is completely passive and thus highly reliable.

Wavelength Division Multiplexing:



CN5E by Tanenbaum & Wetherall, © Pearson Education-Prentice Hall and D. Wetherall, 2011

Wavelength Division Multiplexing:

- WDM was invented around 1990. The first commercial systems had eight channels of 2.5 Gbps per channel.

- By 1998, systems with 40 channels of 2.5 Gbps were on the market. By 2001, there were products with 96 channels of 10 Gbps, for a total of 960 Gbps

- When the number of channels is very large and the wavelengths are spaced close together, for example, 0.1 nm, the system is often referred to as **DWDM (Dense WDM)**.

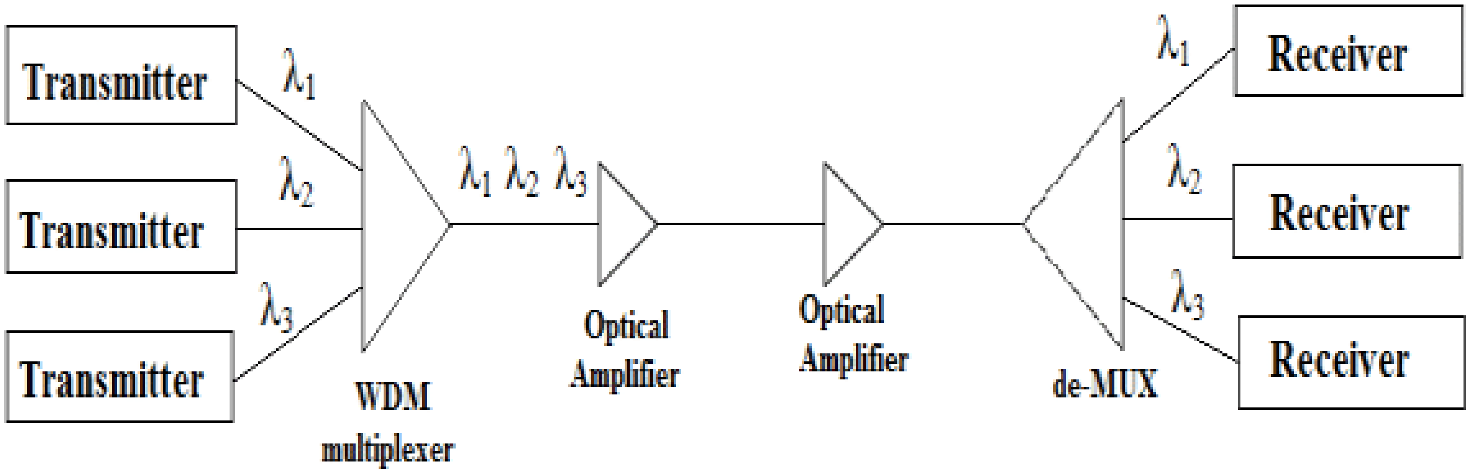
Wavelength Division Multiplexing:

- WDM is popular is that the energy on a single fiber is typically only a few gigahertz wide because it is currently impossible to convert between electrical and optical media any faster.

Example:

- The bandwidth of a single fiber band is about 25,000 GHz, there is theoretically room for 2500 10-Gbps channels

Wavelength Division Multiplexing:



Time Division Multiplexing:

Digital Trunks

What we need is to convert the analog signals received in the end office(switching offices of the telephone co.s) from various local loops into digital signals and combine them into one signal that is transmitted on the digital trunk. This is done with the help of TDM.

CODEC : PCM (Pulse Code Modulation)

The codec makes 8000 samples per sec or one sample per 125 microsec. This is because Nyquist theorem says that this is sufficient to capture all the information from the 4KHz (remember? bit rate = #samples x log L => sample rate = 2B from Nyquist theorem). This technique is called PCM.

All the time intervals (a pulse) within the telephone system are multiples of 125 microsec.

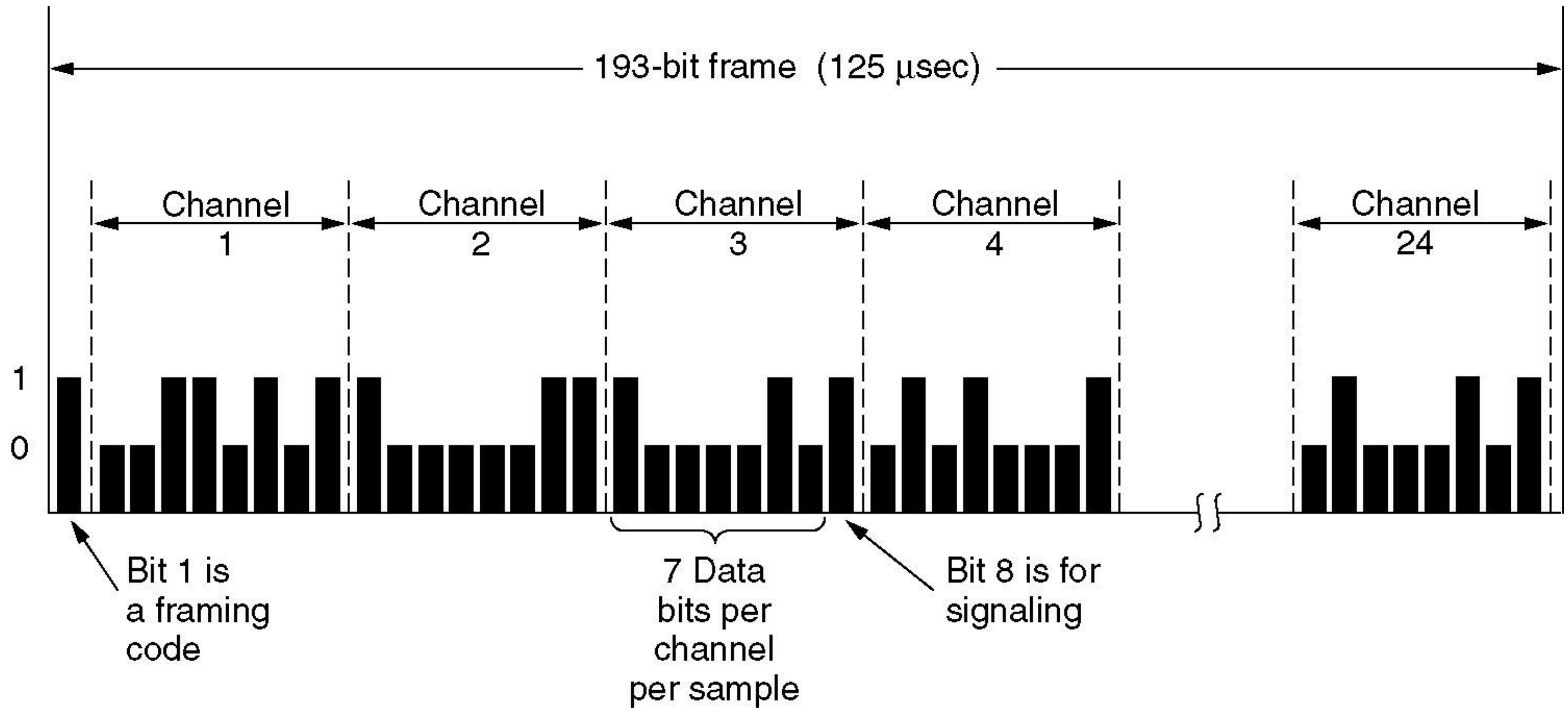
Time Division Multiplexing : T1 Carrier

T1 carrier is used on long-haul trunks.

Supports Codec with 24 Local Loops I.e. 24 channels

Codec picks signals from these 24 channels on a Round Robin basis to insert 8 bits (7 data + 1 control) for each sample(i.e. for each channel)

T1 Carrier



193 x 8000 = 1.544 Mbps

T1 Carrier

193rd bit is used for frame synchronization : a pattern of 010101… is looked for --- analog nodes cannot generate this pattern, digital users can but the chances are less.

Signaling(control) information in T1

Notice : 8000 bps signaling information : too much : two possible approaches to reduce this :

Common channel signaling : use of 193rd bit for signaling in alternate frames say odd frames and for data in even frames.

Channel-associated signaling : each channel has its own private signaling sub channel – one of the eight user bits in every sixth frame is used for signaling

E1 Carrier

32 channels : 30 for data + 2 for signaling

Each group of four frames provides 64 bits of signaling : half for channel specific + half for frame sync

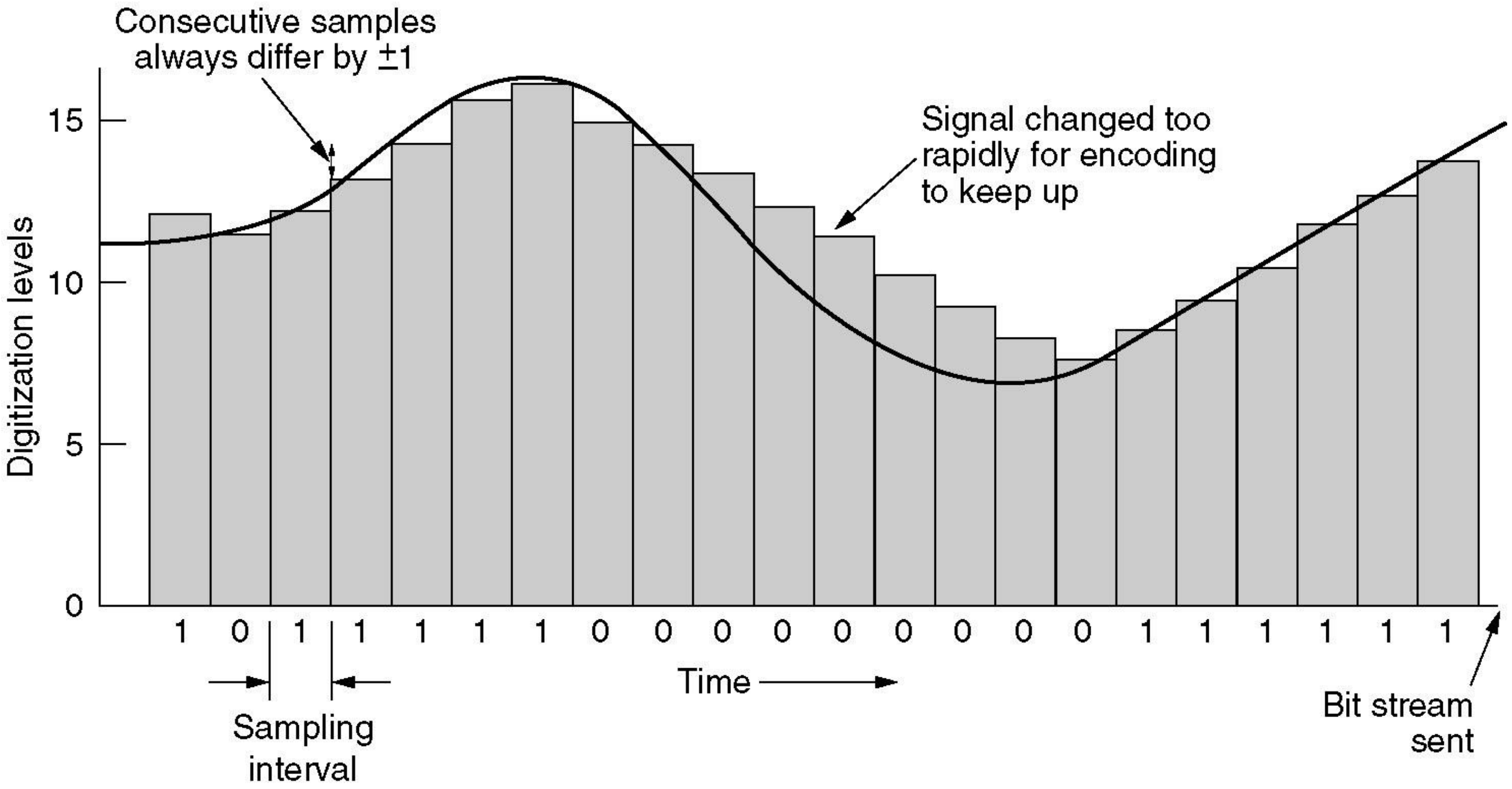
Capacity : 32 x 8 x 8000 = 2.048 Mbps

Differential Pulse Code Modulation

Instead of digitized amplitude, difference is kept and digitized

Jumps of the magnitude of more than +-16 are rare in 128 levels. So 5 instead of 8 bits are sufficient.

Delta Modulation

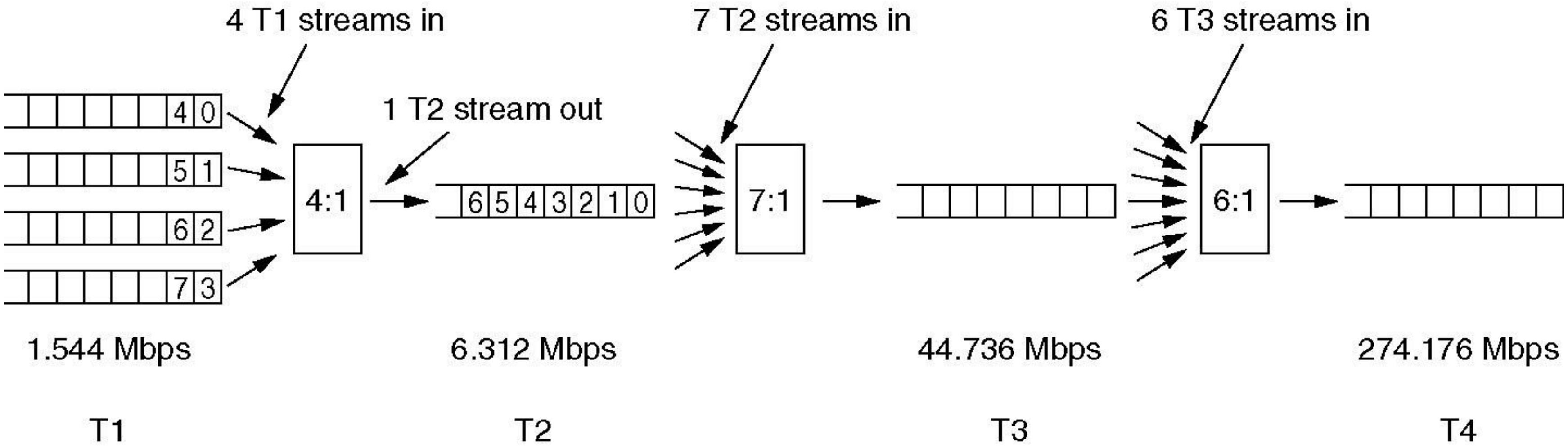


Predictive Encoding

Extrapolate the previous few values to predict the next value.

Encode the difference between actual and the predicted signal

Time Division Multiplexing (3)



Multiplexing T1 streams into higher carriers.

Problems :

Q. 26

An ADSL system using DMT allocates 3/4 of the available data channels to the downstream link. It uses QAM-64 modulation on each channel. What is the capacity of the downstream link?

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Q. 26

An ADSL system using DMT allocates 3/4 of the available data channels to the downstream link. It uses QAM-64 modulation on each channel. What is the capacity of the downstream link?

Solution:

There are 256 channels in ADSL,

1 for POTS, 5 are unused and 2 for control = 8 channels (without data channels),

No of channels= 256-8 = 248 for data.

If 3/4 of 248 = 186 channels for downstream.

ADSL modulation is at 4000 baud, so with QAM-64 (6 bits/baud)

The total bandwidth =4000 x 6 x 186 = 4.464 Mbps downstream.

Problems :

Q. 28

Ten signals, each requiring 4000 Hz, are multiplexed on to a single channel using FDM. How much minimum bandwidth is required for the multiplexed channel? Assume that the guard bands are 400 Hz wide.

Problems :

Q. 28

Ten signals, each requiring 4000 Hz, are multiplexed on to a single channel using FDM. How much minimum bandwidth is required for the multiplexed channel? Assume that the guard bands are 400 Hz wide.

Solution:

- There are ten 4000 Hz signals. We need nine guard bands to avoid any interference. The minimum bandwidth required is $4000 \times 10 + 400 \times 9 = 43{,}600$ Hz.

Problems :

Q. 29

Why has the PCM sampling time been set at 125 μsec?

Problems :

Q. 29

Why has the PCM sampling time been set at 125 μsec?

Solution:

- sampling time of 125 μsec corresponds to 8000 samples per second. According to the Nyquist theorem, this is the sampling frequency needed to capture all the information in a 4 kHz channel, such as a telephone channel.

Problems :

Q. 30

What is the percent overhead on a T1 carrier; that is, what percent of the 1.544 Mbps are not delivered to the end user

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Q. 30

What is the percent overhead on a T1 carrier; that is, what percent of the 1.544 Mbps are not delivered to the end user

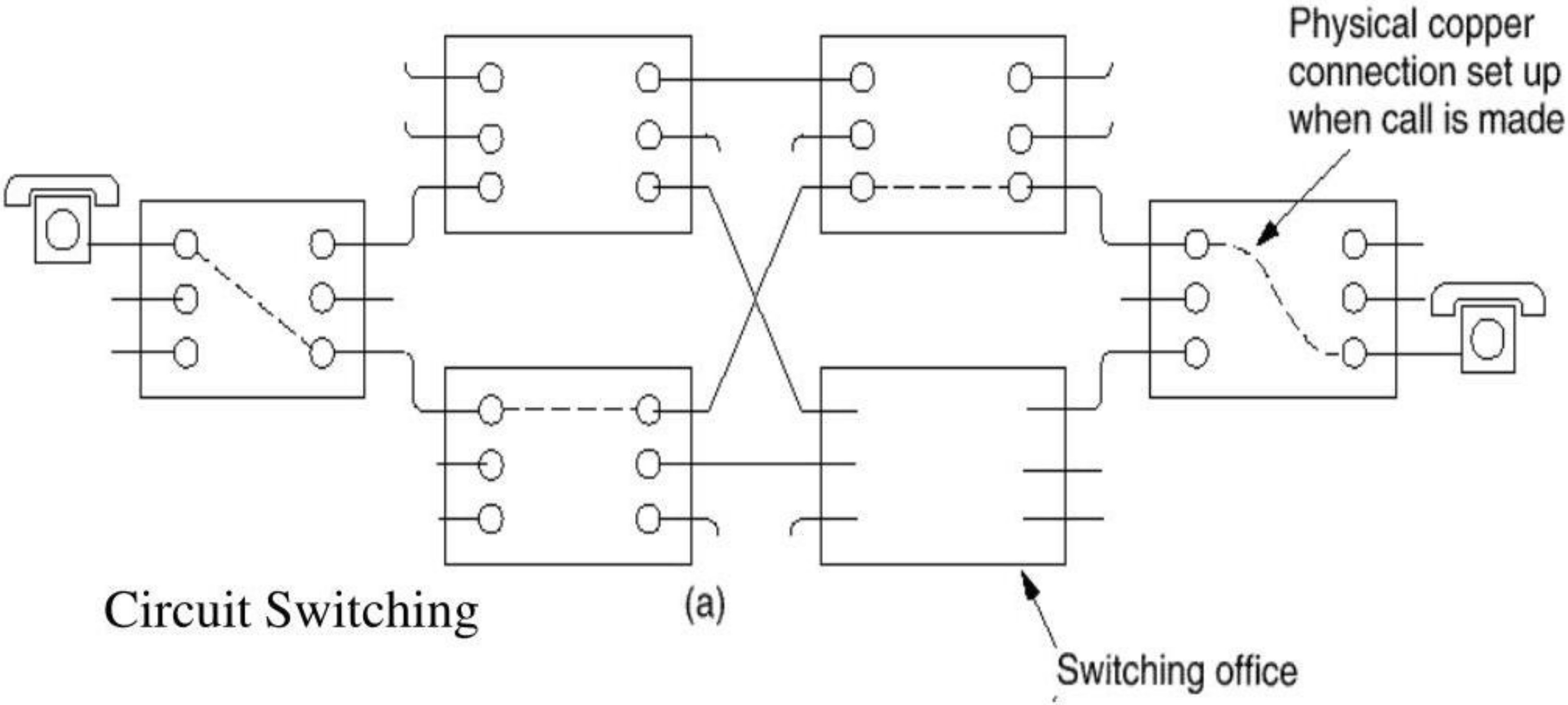
Solution:

The end users get $7 \times 24 = 168$ of the 193 bits (1.544Mbps) in a frame.

The overhead is $193 - 168 = 25$,

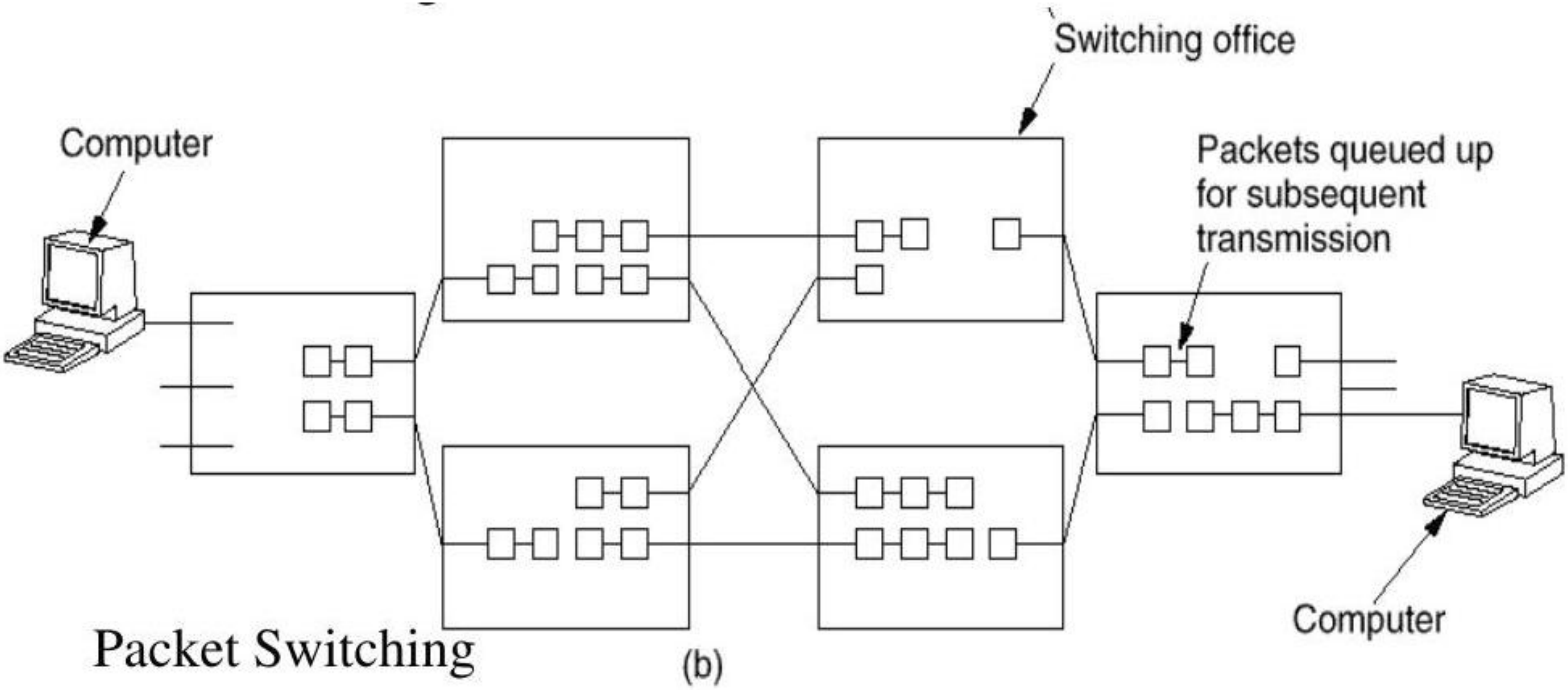
percentage of overhead in T1 carrier system i= $25 / 193 = 13\%$.

Switching



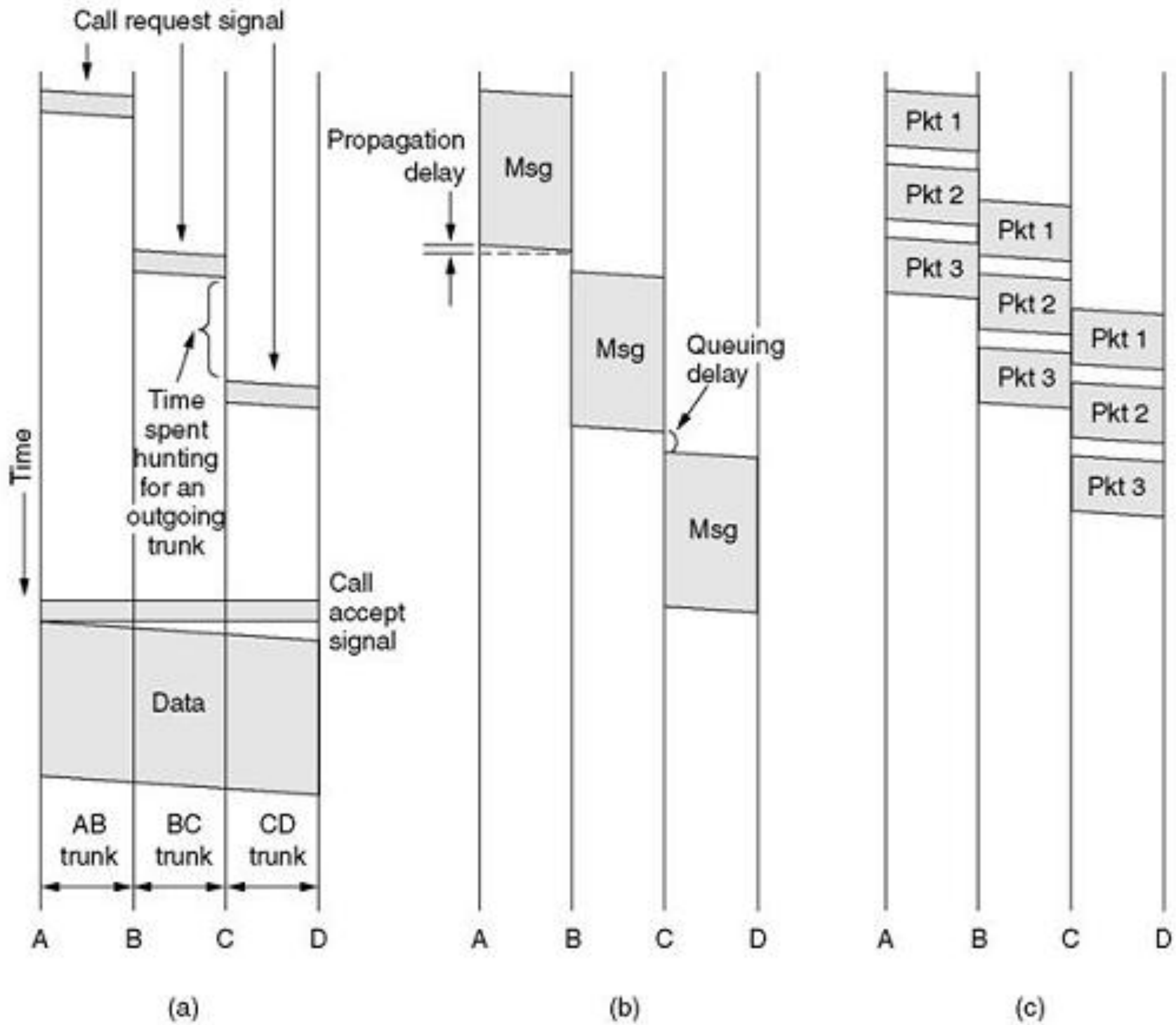
Circuit Switching

Switching



Packet Switching

Switching



(a) Circuit switching (b) Message switching (c) Packet switching

A comparison of circuit switched and packet-switched networks.

Item	Circuit-switched	Packet-switched
Call setup	Required	Not needed
Dedicated physical path	Yes	No
Each packet follows the same route	Yes	No
Packets arrive in order	Yes	No
Is a switch crash fatal	Yes	No
Bandwidth available	Fixed	Dynamic
When can congestion occur	At setup time	On every packet
Potentially wasted bandwidth	Yes	No
Store-and-forward transmission	No	Yes
Transparency	Yes	No
Charging	Per minute	Per packet

End of Chapter 2