Chapter 3: Signals

Analog and Digital Signals

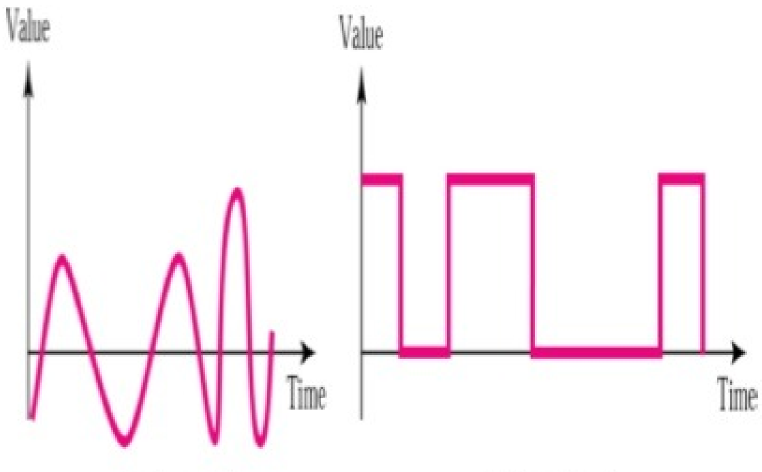
To be transmitted, data must be transformed to electromagnetic signals.

Analog and Digital

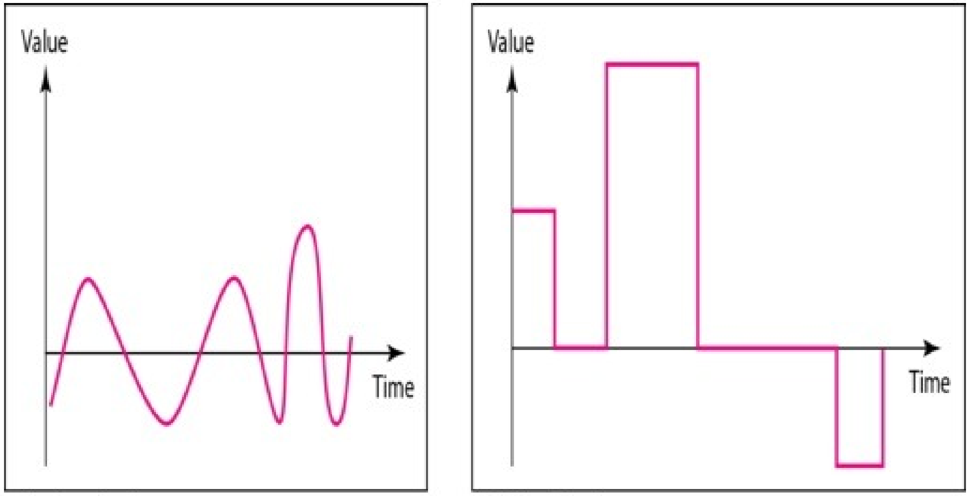
- Analog and Digital Data
- Analog and Digital Signals
- Periodic and Aperiodic Signal

Data

- Data can be
  - Analog
    - infinite number of values in a range
  - Digital
    - limited number of defined values



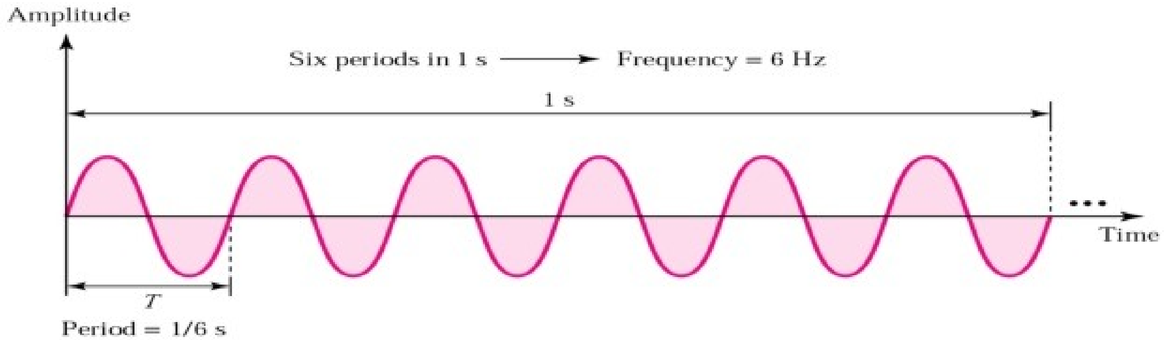
a. Analog signal b. Digital signal



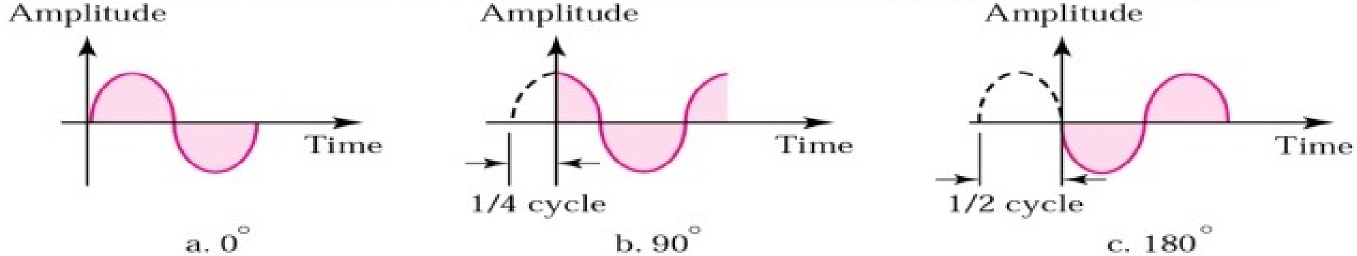
a. Analog signal b. Digital signal

Analog Signals

- **Sine wave :** most fundamental form of a periodic analog signal

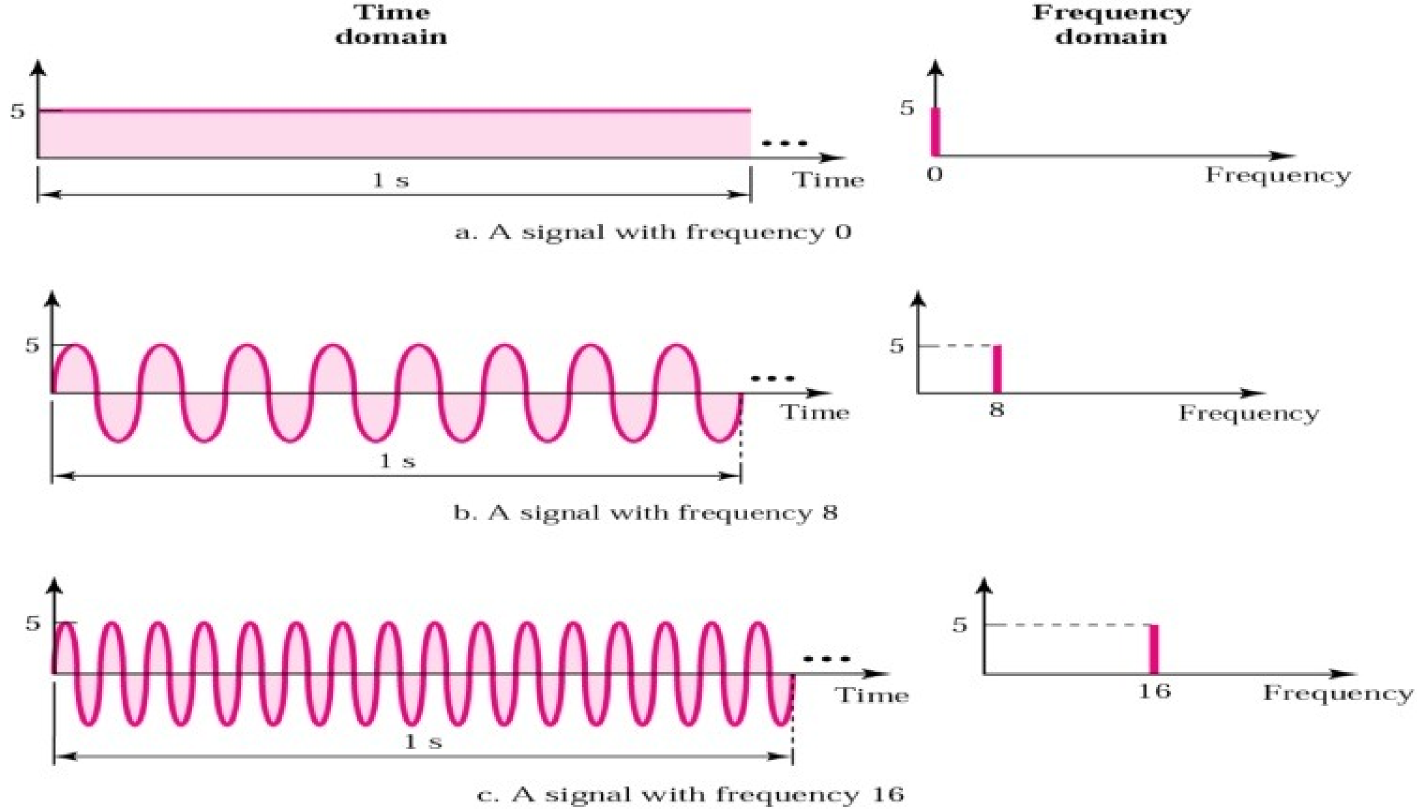


- **Amplitude**
  - Absolute value of a signal's highest intensity, Normally in volts
- **Frequency**
  - number of periods in one second, inverse of period
  - Change in a short span of time means **high frequency**
- **Phase**
  - Position of the waveform relative to time zero (degrees or radians)



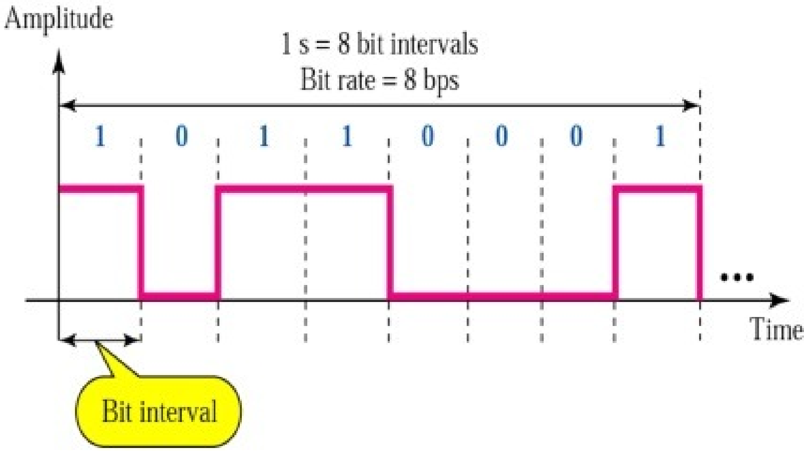
Time and Frequency Domains

- Time-domain plot
  - displays changes in signal amplitude with respect to time
- Frequency-domain plot
  - compares time domain and frequency domain



Digital Signals

- Use binary (0s and 1s) to encode information
- Less affected by interference (noise)
- Fewer errors
- Describe digital signals by
  - **Bit interval**
    - time required to send one bit
  - **Bit rate**
    - number of bit intervals per sec (bps)



- **Analog bandwidth**
  - range of frequencies a medium can pass (hertz)
- **Digital bandwidth**
  - maximum bit rate that a medium can pass (bps)

Data Rate Limits

- **How to determine the maximum bit rate (bps) over a channel?**
  - Data rate depends on 3 factors
    - Bandwidth available
    - Levels of signals we can use
    - Quality of the channel (level of noise)
- Two theoretical formulas were developed to calculate the data rate
  - Nyquist for a **noiseless** channel
  - Shannon for **noisy** channel

Noiseless Channel

Nyquist Bit Rate

- **Defines the theoretical maximum bit rate**

$$\text{Bit Rate} = 2 \times \text{Bandwidth} \times \log_2 L$$

***L* is the number of signal levels used to represent data**

Example

Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as

$$\text{Bit Rate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}$$

Noisy Channel
Shannon Capacity

- Determine the theoretical highest data rate for a noisy channel $C = B \log_2 (1 + SNR)$

Example

We can calculate the theoretical highest bit rate of a regular telephone line. A telephone line normally has a bandwidth of 3000 Hz (300 Hz to 3300 Hz). The signal-to-noise ratio is usually 3162. then

$$\text{Channel capacity} = 3000 \log_2 (1 + 3162)$$
$$= 3000 \log_2 (3163)$$
$$= 3000 \times 11.62$$
$$= 34{,}860 \text{ bps}$$

Transmission Impairment

- Imperfections cause impairment, which means that a signal at the beginning and the end of the medium are not the same
- **Three types of impairments**

  1) Attenuation

  - Loss of energy, Amplifiers are used to strengthen
  - To show that a signal has lost or gained strength, engineers use the concept of decibel (db)
  - The Decibel measures the relative strength of two signals or a signal at two different points

Example

A signal travels through a transmission medium and its power is reduced to half. This means that P2 = 1/2 P1. Calculate the attenuation (loss of power)?

attenuation = 10 log10 (P2/P1)

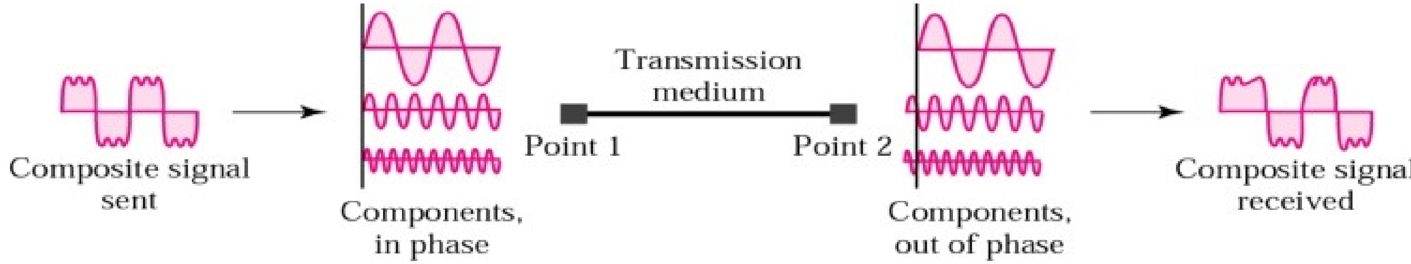
= 10 log10 (0.5P1/P1)

= 10 log10 (0.5)

= 10(–0.3) = –3 dB

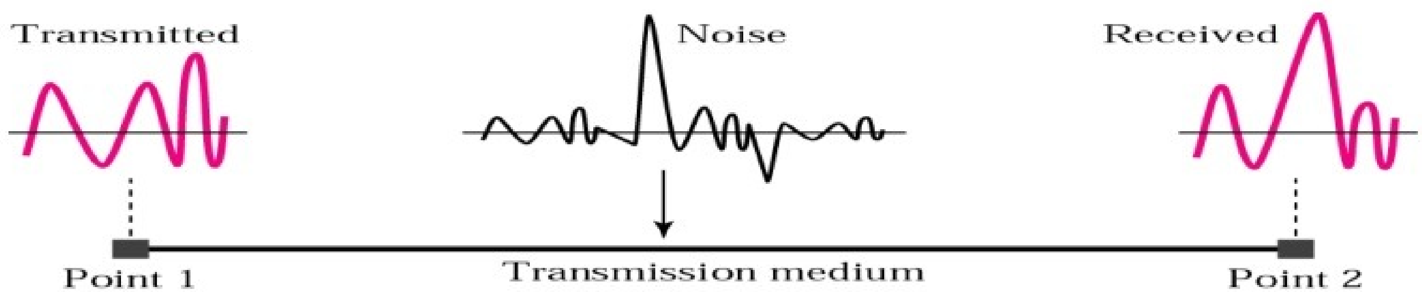
2) Distortion

- Signal changes form or shape
- Each component has its own propagation speed, therefore its own delay in arriving



3) Noise

- **Thermal noise** – random motion of electrons, creating an extra signal
- **Induced noise** – outside sources such as motors and appliances
- **Crosstalk** – effect of one wire on another
- **Impulse noise** – a spike for a short period from power lines, lightning



Digital Transmission

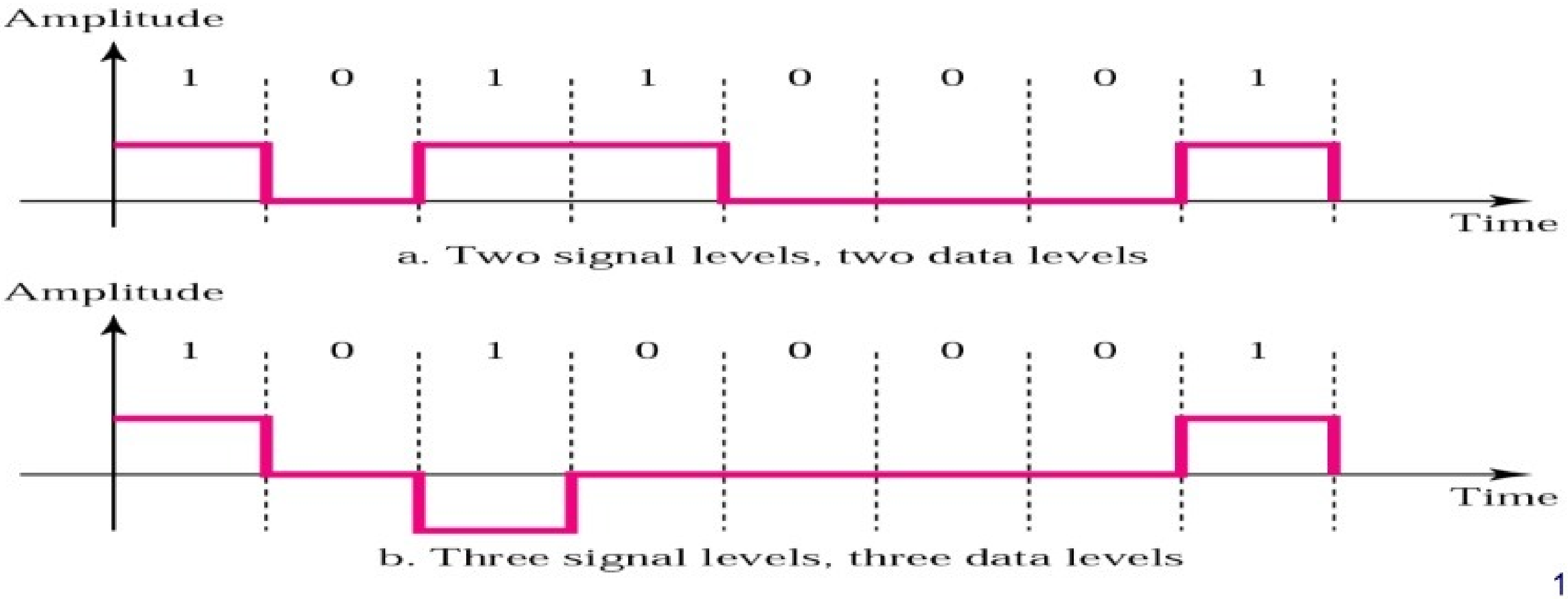
Ch4

- **Methods to transmit data digitally**
  1) **Line coding**
     - Process of converting binary data to a digital signal
  2) **Block coding**
     - Coding method to ensure synchronization and detection of errors
     - Three steps
       - Division
       - Substitution
       - Line coding
  3) **Sampling**
     - is process of obtaining amplitudes of a signal at regular intervals

- **Transmission modes**
  - **Parallel**
  - **Serial**
    - **Synchronous**
    - **Asynchronous**

Signal Level versus Data Level

- Signal level
  - number of values allowed in a particular signal
- Data level
  - number of values used to represent data
- *Note: figure b should say three signal levels, two data levels*



Pulse Rate versus Bit Rate

- Pulse
  - minimum amount of time required to transmit a symbol
- Pulse rate
  - defines number of pulses per second
- Bit rate
  - defines number of bits per second
  - BitRate = PulseRate x $\log_2 L$
  - *where* **L** *is the number of* ***data levels***

A signal has four data levels with a pulse duration of 1 ms. We calculate the pulse rate and bit rate as follows:

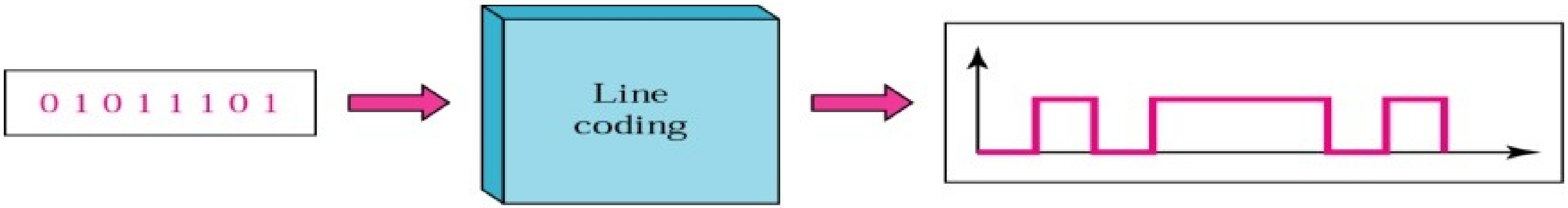
Pulse Rate = 1000 pulses/s

Bit Rate = PulseRate x $\log_2 L$

= 1000 x $\log_2 4$ = 2000 bps

Line Coding

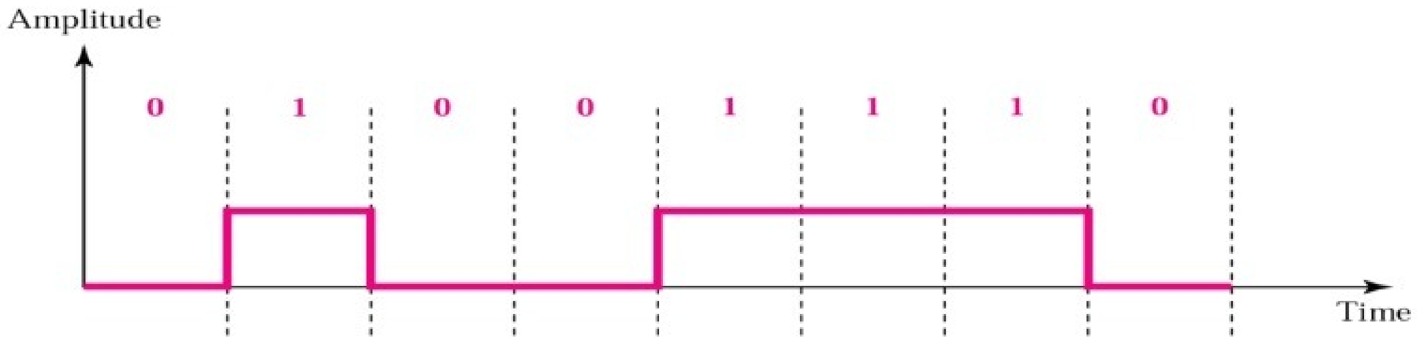
- Process of converting binary data to a digital signal



- Line Coding schemes
  - Unipolar
  - Polar
  - Bipolar

Unipolar

- Uses only one voltage level
- Polarity is usually assigned to binary 1; a 0 is represented by zero voltage



- Potential problems:
  - DC component
  - Lack of synchronization

Polar

- NRZ
  - Value of signal is always positive or negative
- NRZ-L
  - Signal level depends on bit represented
    - positive usually means 0
    - negative usually means 1
  - Problem: synchronization of long streams of 0s or 1s
- NRZ-I (NRZ-Invert)
  - Inversion of voltage represents a 1 bit
  - 0 bit represented by no change
  - Allows for synchronization
  - Long strings of 0s may still be a problem

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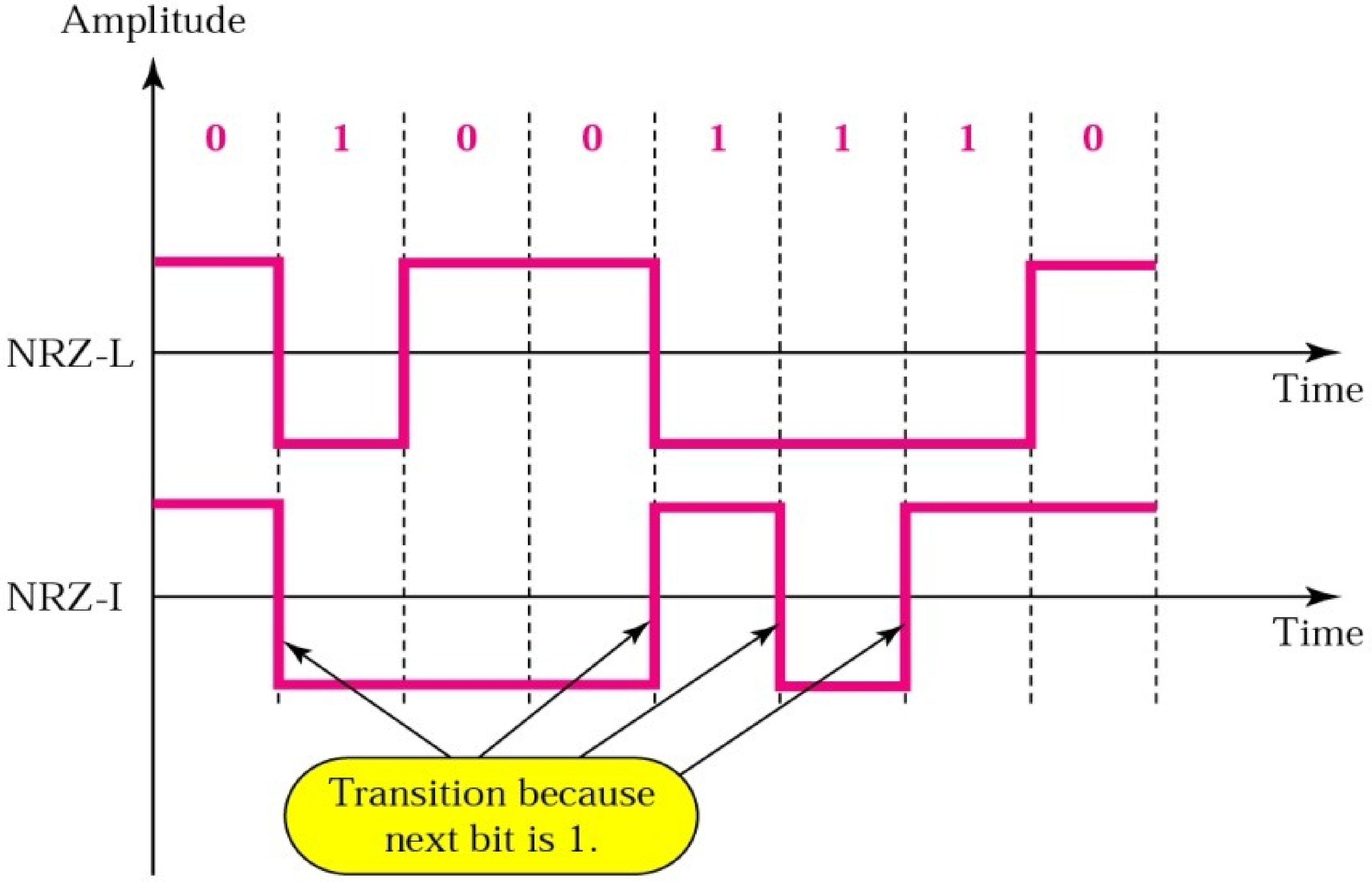
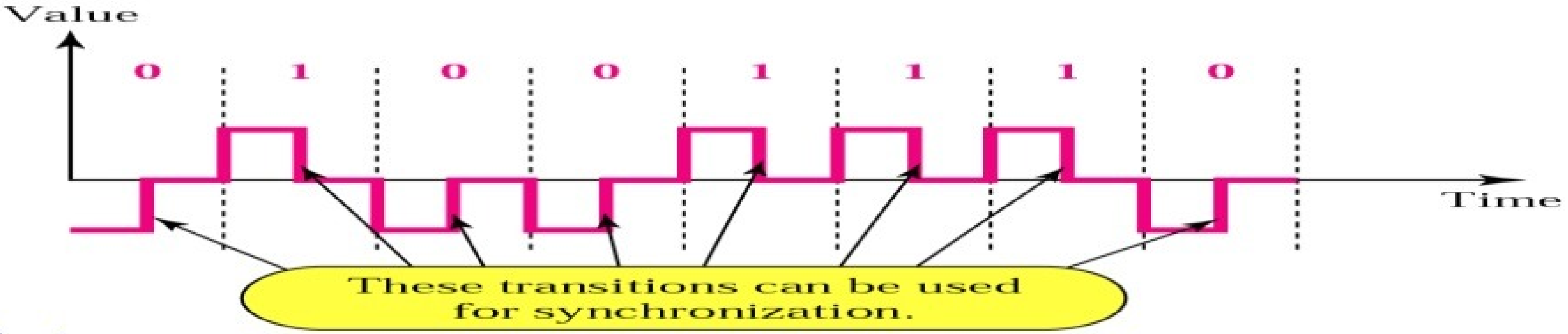
NRZ-L and NRZ-I Encoding



Return to Zero (RZ)

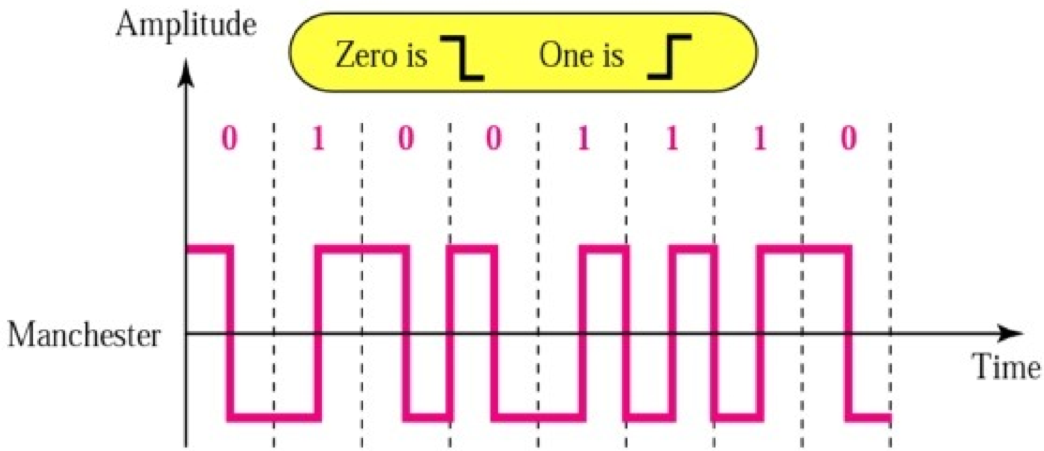
- May include synchronization as part of the signal for both 1s and 0s
- How?
  - Must include a signal change during each bit
  - Uses three values: positive, negative, and zero
  - 1 bit represented by pos-to-zero
  - 0 bit represented by neg-to-zero



- Disadvantage
  - Requires two signal changes to encode each bit; more bandwidth necessary

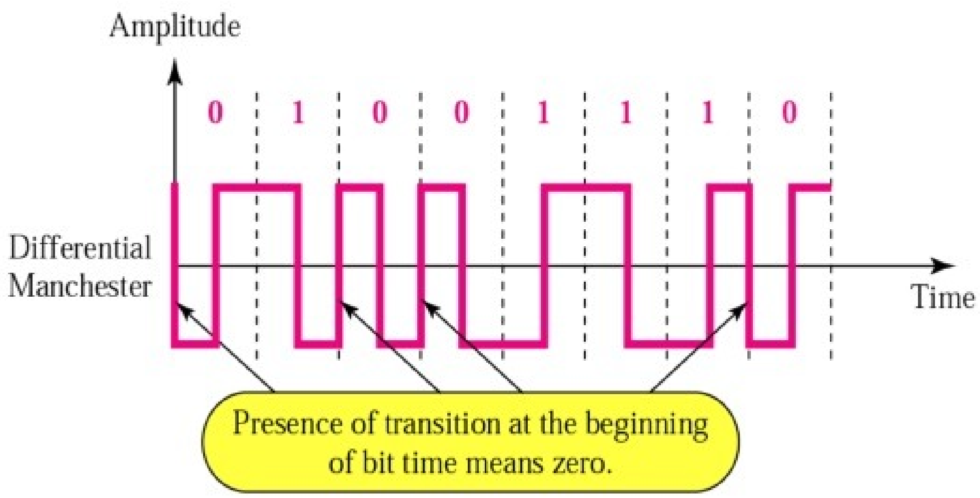
Manchester

- Uses an inversion at the middle of each bit interval for both synchronization and bit representation
- Negative-to-positive represents binary 1
- Positive-to-negative represents binary 0
- Achieves same level of synchronization with only 2 levels of amplitude



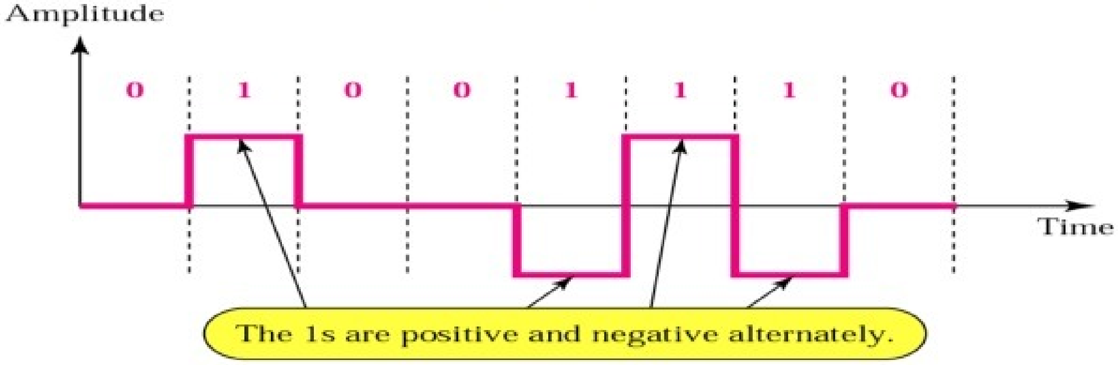
Differential Manchester

- Inversion at middle of bit interval is used for synch
- Presence or absence of additional transition at beginning of interval identifies the bit
- Transition 0; no transition 1
- Requires two signal changes to represent binary 0; only one to represent 1



Bipolar Encoding

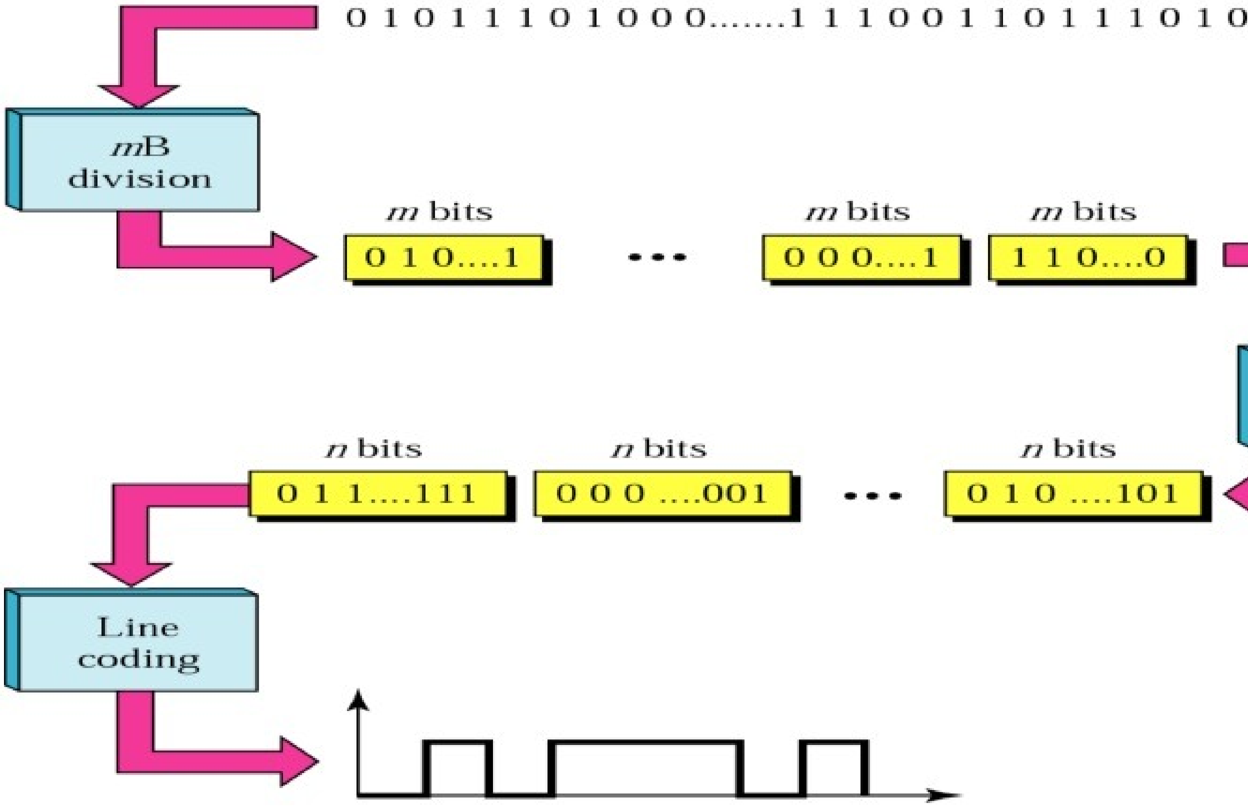
- Uses 3 voltage levels: pos, neg, and zero
  - Zero level 0
  - 1s are represented with alternating positive and negative voltages, even when not consecutive
- Two schemes
  - Alternate mark inversion (AMI)



  - Bipolar *n*-zero substitution (B*n*ZS)

Block Coding

- Coding method to ensure synchronization and detection of errors
- Three steps
  - Division
  - Substitution
  - Line coding

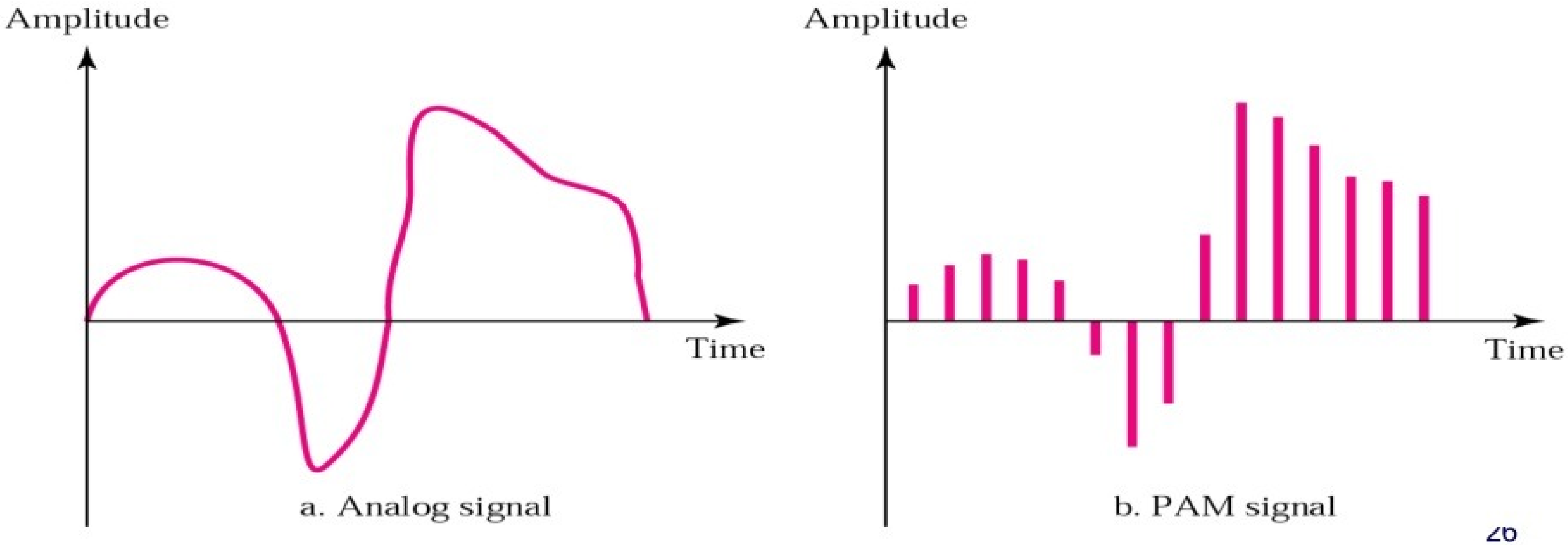


Sampling

- Analog data must often be converted to digital format (ex: long-distance services, audio)
- Sampling is process of obtaining amplitudes of a signal at regular intervals

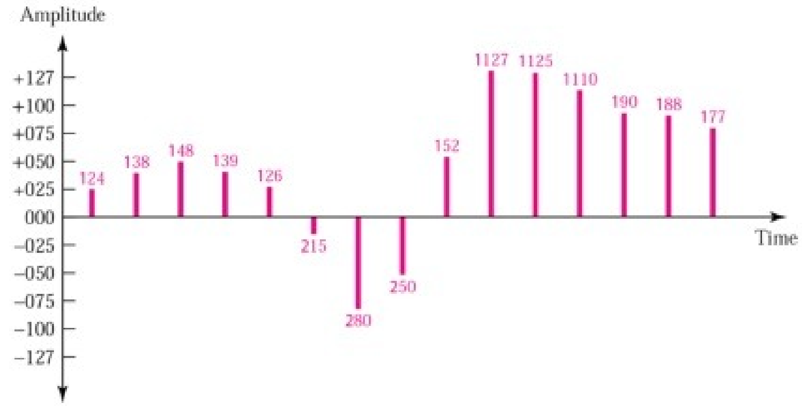
Pulse Amplitude Modulation

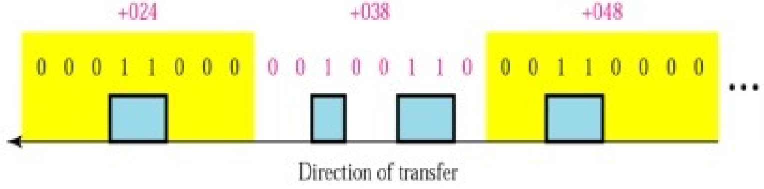
- Analog signal's amplitude is sampled at regular intervals; result is a series of pulses based on the sampled data
- Pulse Coded Modulation (PCM) is then used to make the signal digital



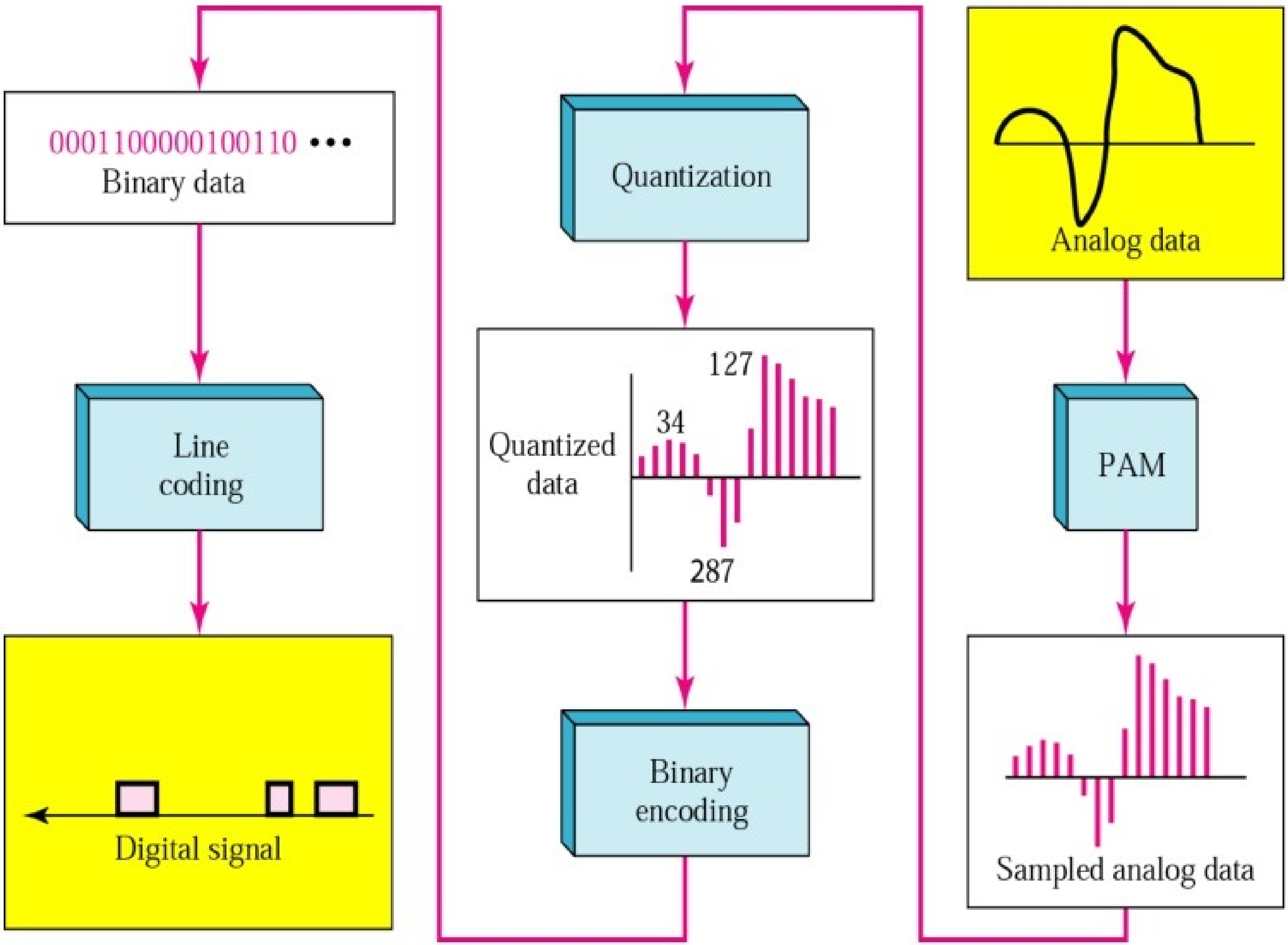
Pulse Coded Modulation

- First quantizes PAM pulses; an integral value in a specific range to sampled instances is assigned
- Each value is then translated to its 7-bit binary equivalent
- Binary digits are transformed into a digital signal using line coding





Digitization of an Analog Signal



Sampling Rate: Nyquist Theorem

- Accuracy of digital reproduction of a signal depends on number of samples
- Nyquist theorem
  - number of samples needed to adequately represent an analog signal is equal to twice the highest frequency of the original signal

Example

What sampling rate is needed for a signal with a bandwidth of 10,000 Hz (1000 to 11,000 Hz)? Each sample is 8 bits

Solution

The sampling rate must be twice the highest frequency in the signal

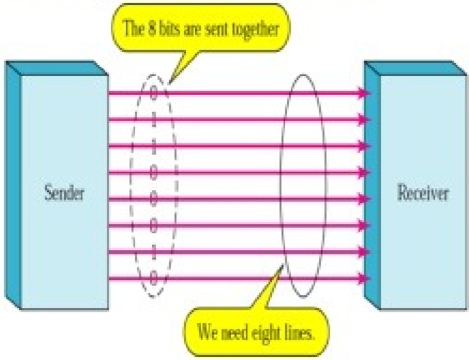
Sampling rate = 2 x (11,000)
= 22,000 samples/sec

Bit rate **= sampling rate x number of bits /sample**
= 22000 x 8
= 172 Kbps

4.4 Transmission Mode

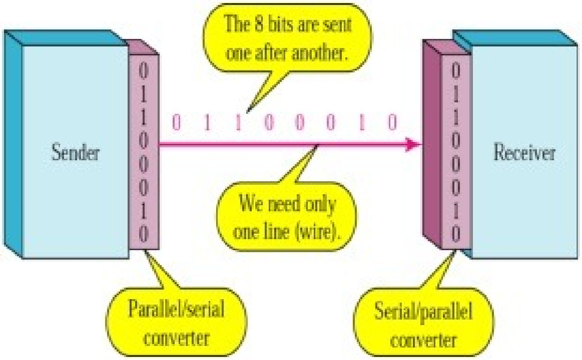
Parallel

- Bits in a group are sent simultaneously, each using a separate link
- n wires are used to send n bits at one time
- **Advantage:** speed
- **Disadvantage:** cost; limited to short distances



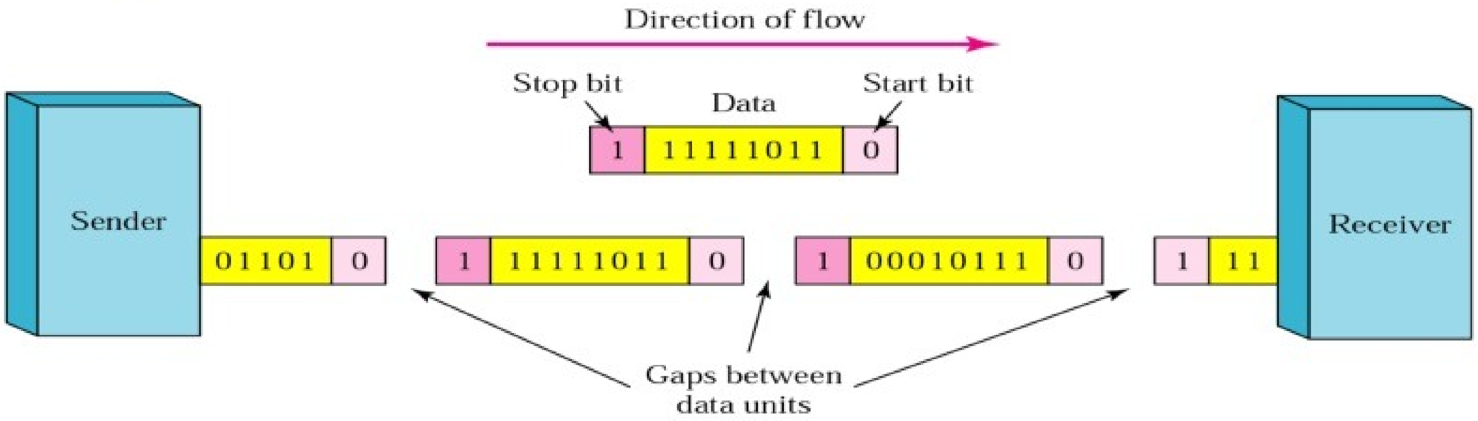
Serial

- Transmission of data one bit at a time using only one single link
- **Advantage:** reduced cost
- **Disadvantage:** requires conversion devices
- Methods:
  - Asynchronous
  - Synchronous



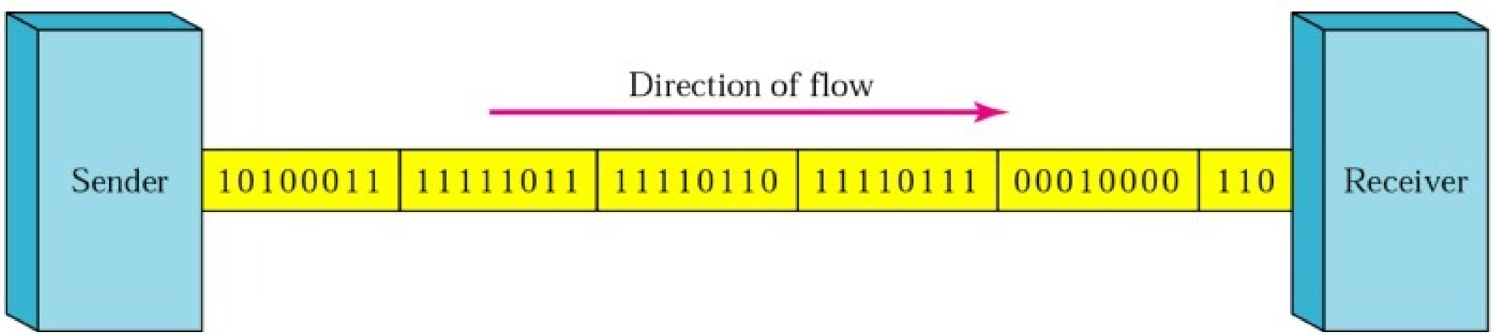
Asynchronous Transmission

- Slower, **ideal for low-speed communication** when **gaps** may occur during transmission (ex: keyboard)
- Transfer of data with start and stop bits and a variable time interval between data units
- Timing is unimportant
- **Start bit** alerts receiver that new group of data is arriving
- **Stop bit** alerts receiver that byte is finished
- **Synchronization** achieved through start/stop bits with each byte received Requires additional overhead (start/stop bits)
- Cheap and effective



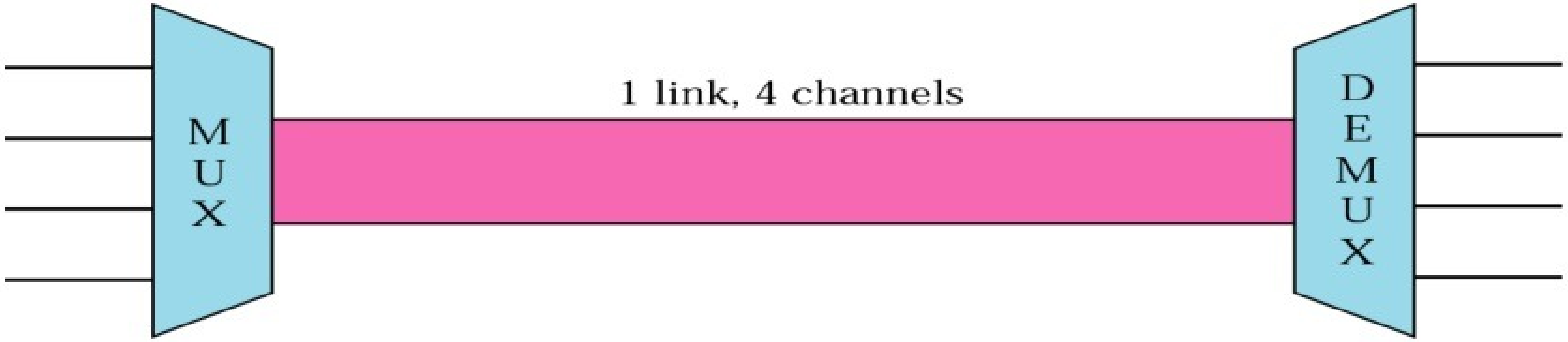
Synchronous Transmission

- **Bit stream is combined into longer frames**, possibly containing multiple bytes
- Requires constant timing relationship
- Any gaps between bursts are filled in with a special sequence of 0s and 1s indicating idle
- **Advantage**: speed, no gaps or extra bits
- **Byte synchronization** accomplished by **data link** layer

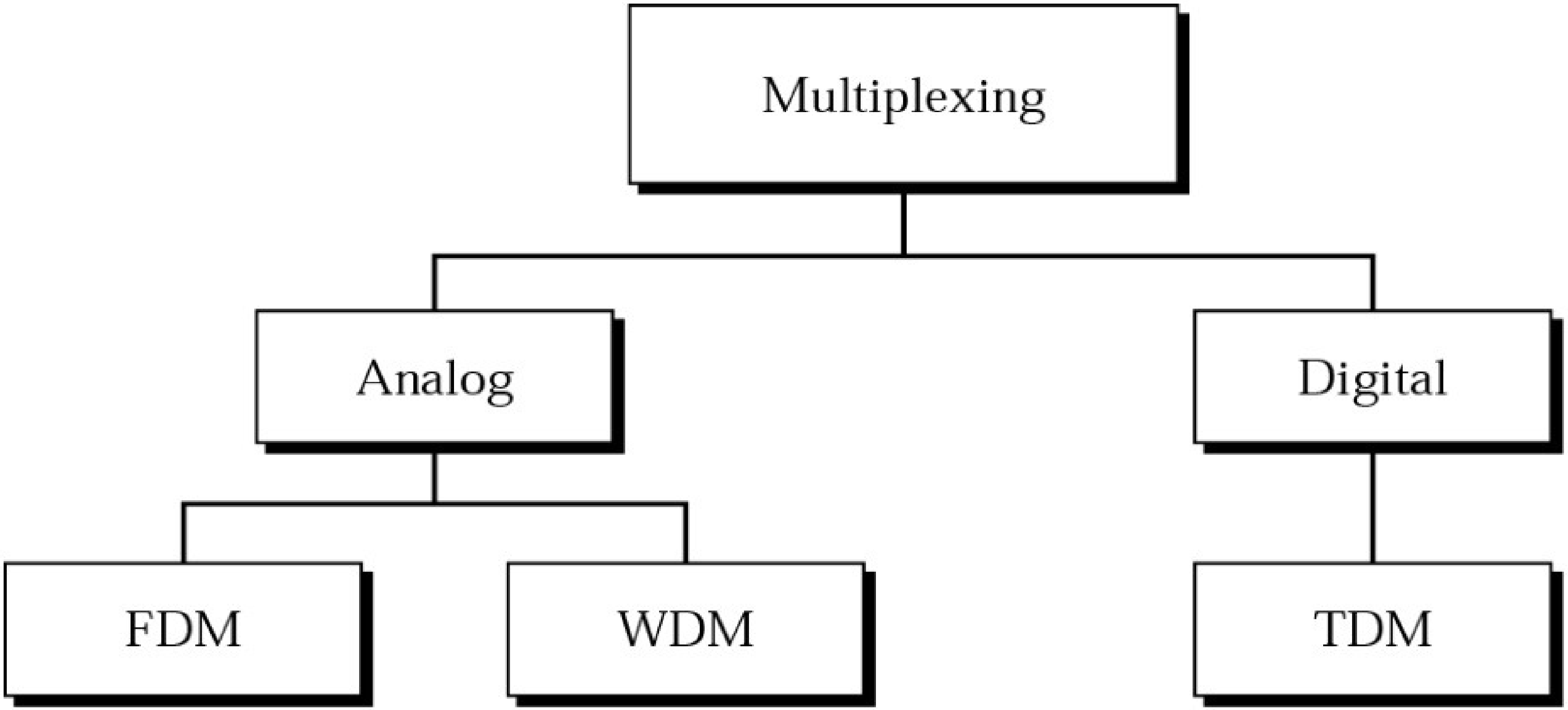


Multiplexing

- Multiplexing
  - A set of techniques that allows the simultaneous transmission of multiple signals across a single data link
  - Can utilize higher capacity links without adding additional lines for each device – better utilization of bandwidth
- Multiplexer (MUX)
  - Combines multiple streams into a single stream (many to one).
- Demultiplexer (DEMUX)
  - Separates the stream back into its component transmission (one to many) and directs them to their correct lines.

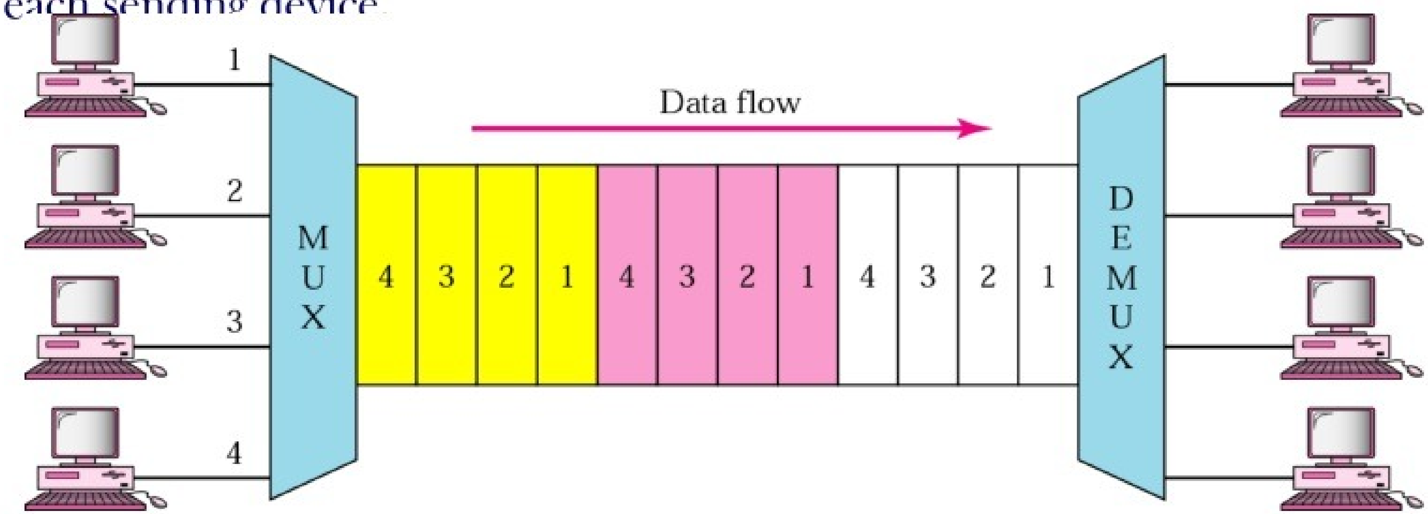


CATEGORIES OF MULTIPLEXING
أصناف المجمعات



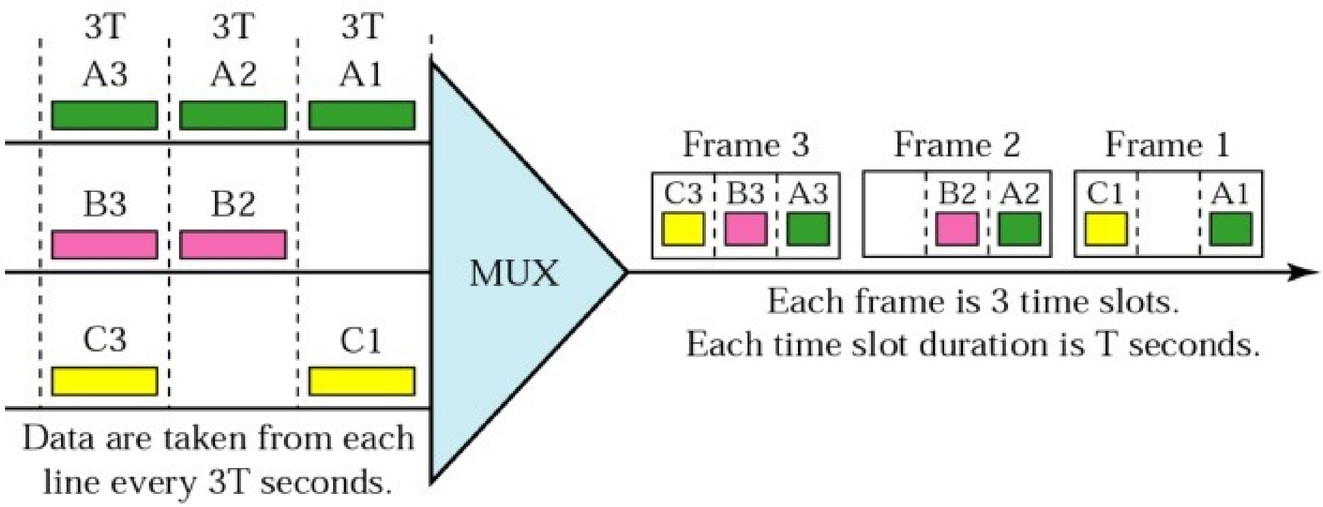
TIME DIVISION MULTIPLEXING

- Digital process that allows several connections to share the high bandwidth of a link
- Time Slots and Frames
  - Each host given a <u>slice of time</u> (time slot)
  - A frame consists of one complete cycle of time slots, with one slot dedicated to each sending device.



TDM Frames

- Mux-to-mux speed = aggregate terminal speeds
  - data rate of the link that carries data from *n* connections must be n times the data rate of a connection to guarantee the flow of data
  - i.e., the duration of a frame in a connection is n times the duration of a time slot in a frame

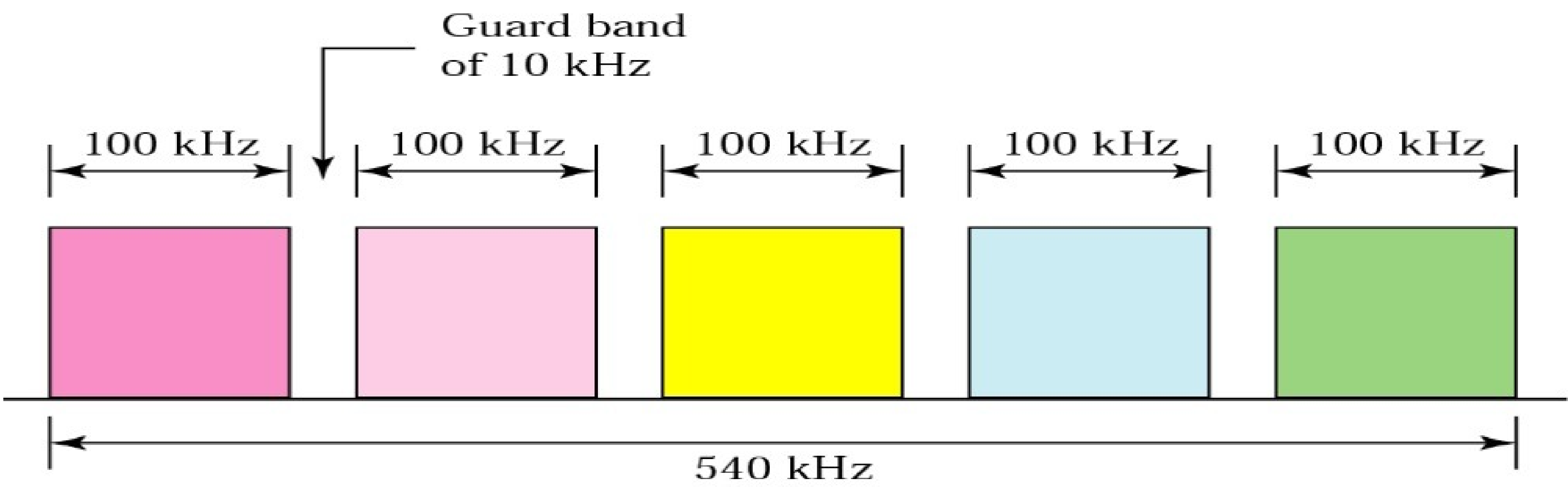


Example

- 5 channels, each with a 100-KHz B.W, are to be multiplexed together. What is the minimum B.W of the link if there is a need for a guard band of 10 KHz between the channels to prevent interference?

Solution

- For 5 channels, we need at least 4 guard bands.
- the required B.W is at least 5 x 100 + 4 x 10 = 540 KHz



INTERLEAVING

- Process of taking a specific amount of data from each device in a regular order
- May be done by bit, byte, or any other data unit
  - Character (byte) Interleaving
    - Multiplexing perform one/more character(s) or byte(s) at a time
  - Bit Interleaving
    - Multiplexing perform on one bit at a time

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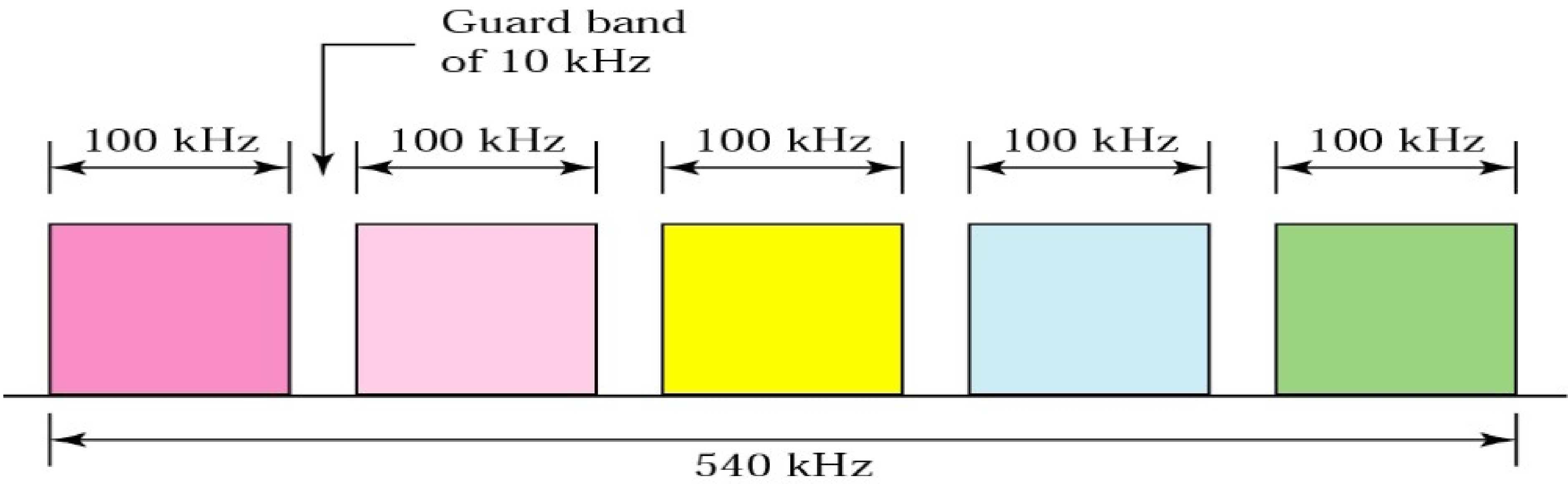

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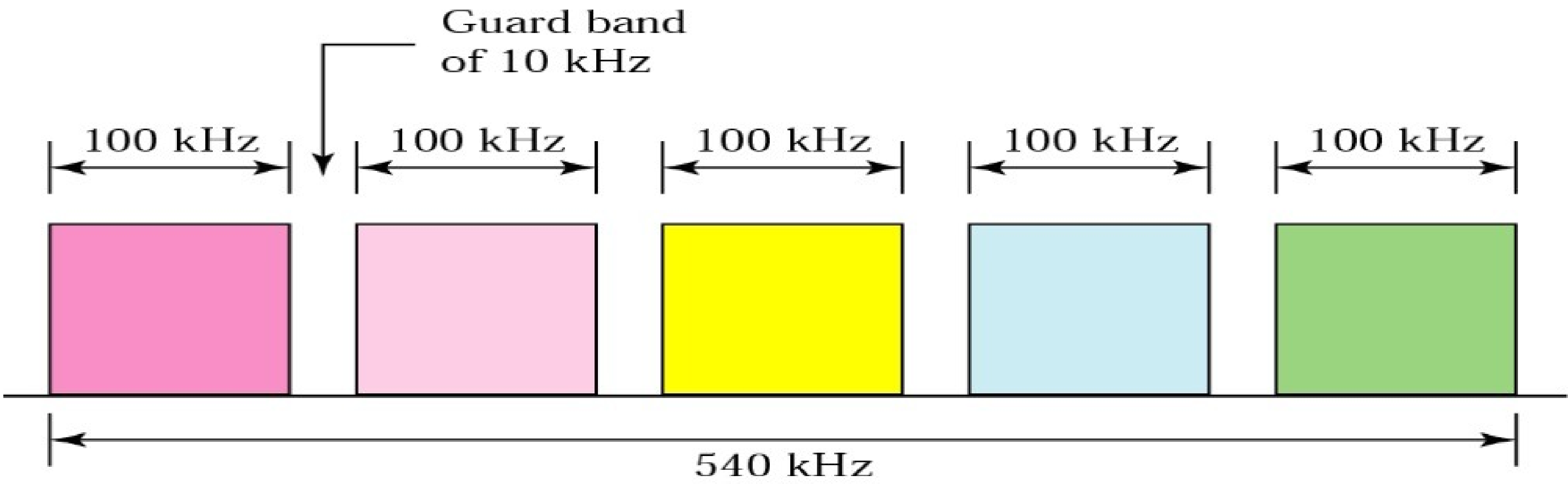
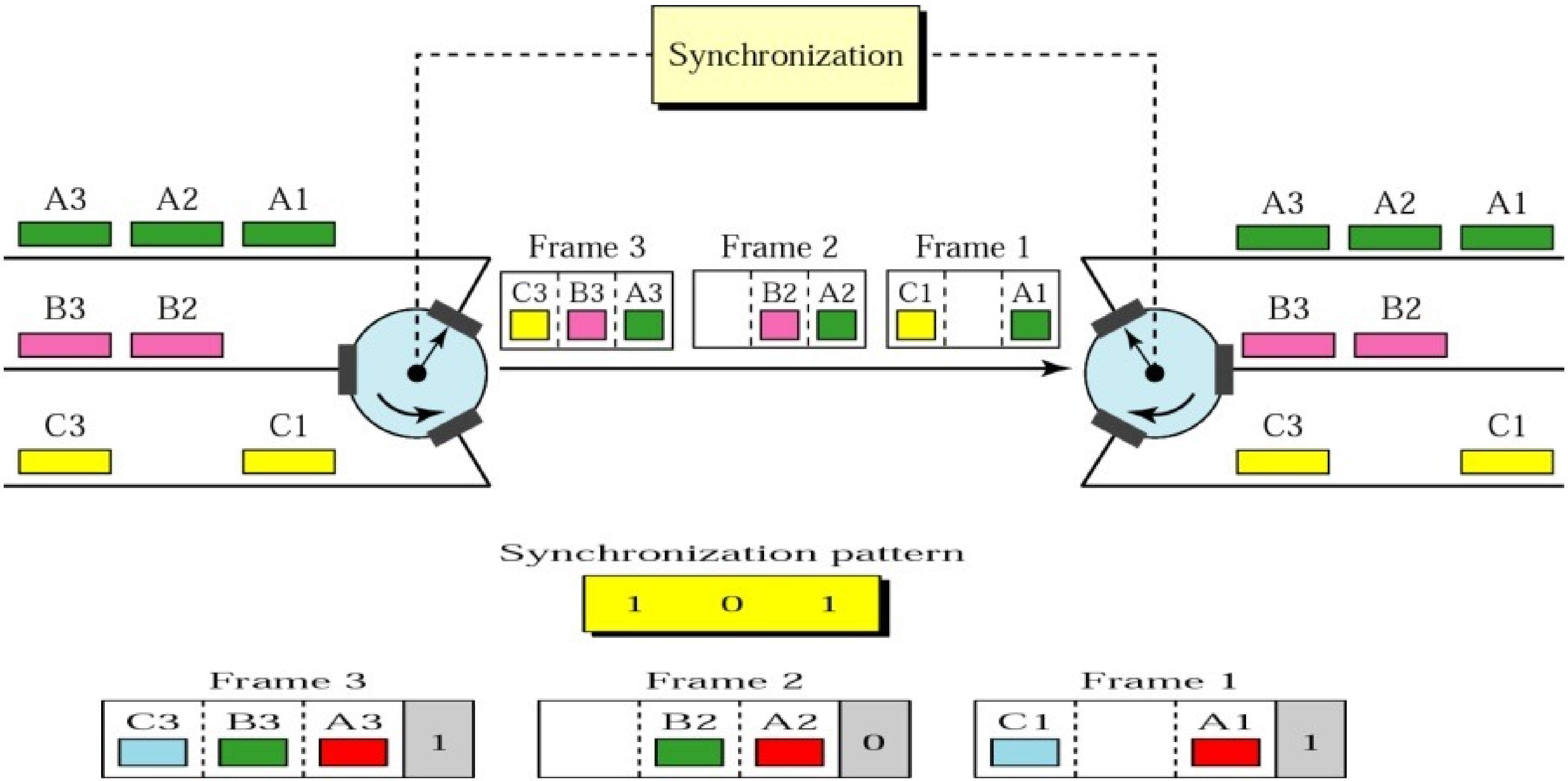


SYNCHRONIZING

- *Framing bit (s)* is (are) added to each frame for synchronization between the MUX and DEMUX
  - synchronization bits allows the DEMUX to synchronize with the incoming stream so it can separate time slots accurately
- If 1 framing bit per frame, framing bits are alternating between 0 and 1



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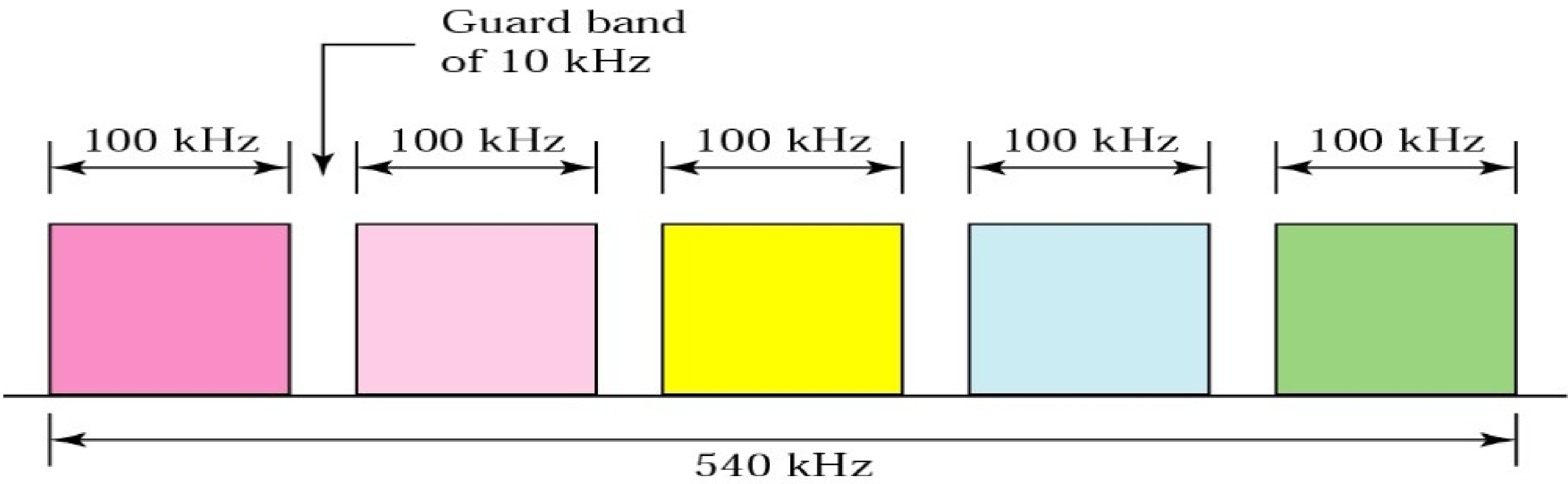

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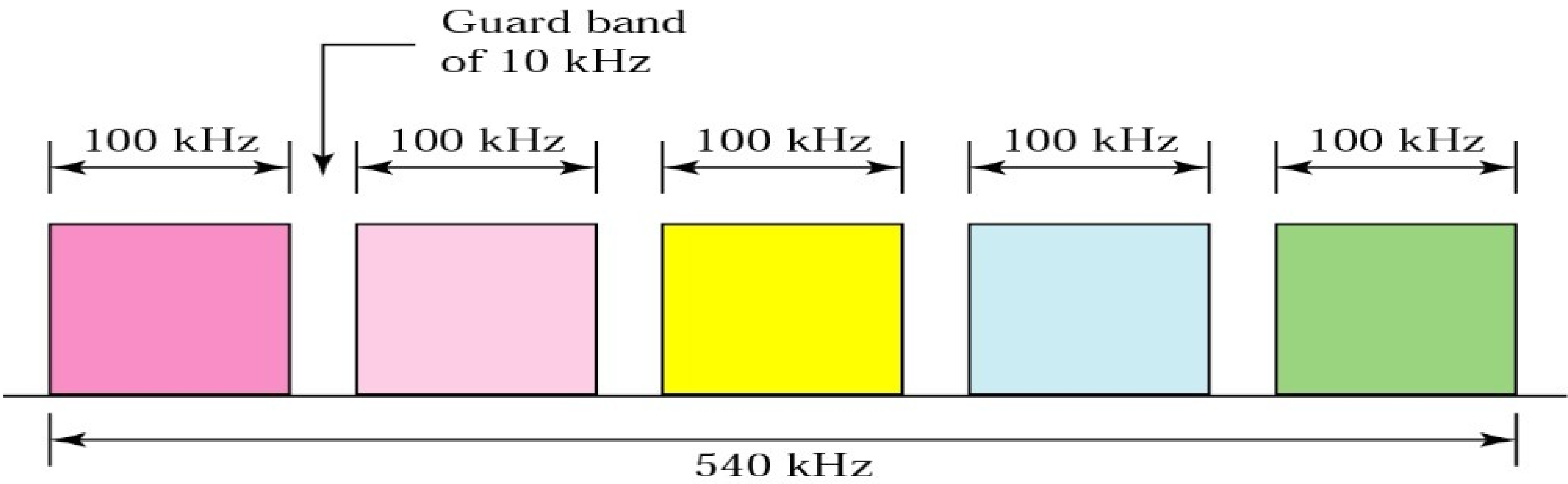
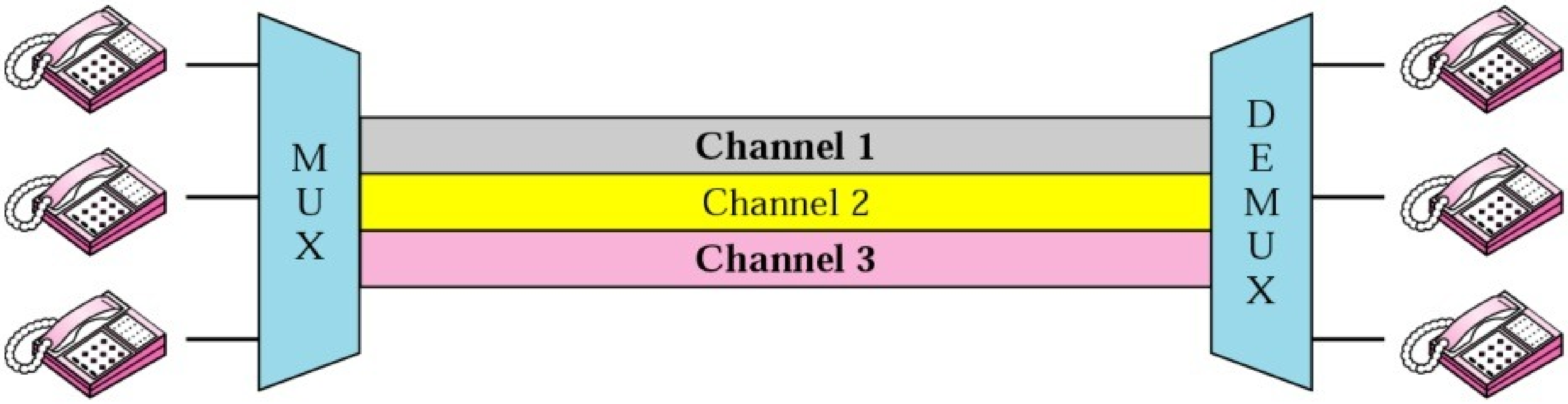


STDM

- Mux-to-Mux speed < aggregate terminal/host speeds
- Time slots allocated based on traffic patterns
  - uses statistics to determine allocation among users
  - must send port address with data (takes additional time slots)
- May Potential loss of data during peak periods
  - may use data buffering and/or flow control to reduce loss
- Not always transparent to user terminals and host/FEP
  - delays and data loss possible
- So why use a stat mux?
  - more economical - need fewer muxes, cheaper lines
  - more efficient - allows more terminals to share same line
  - OK to use in many situations (e.g., terminal users

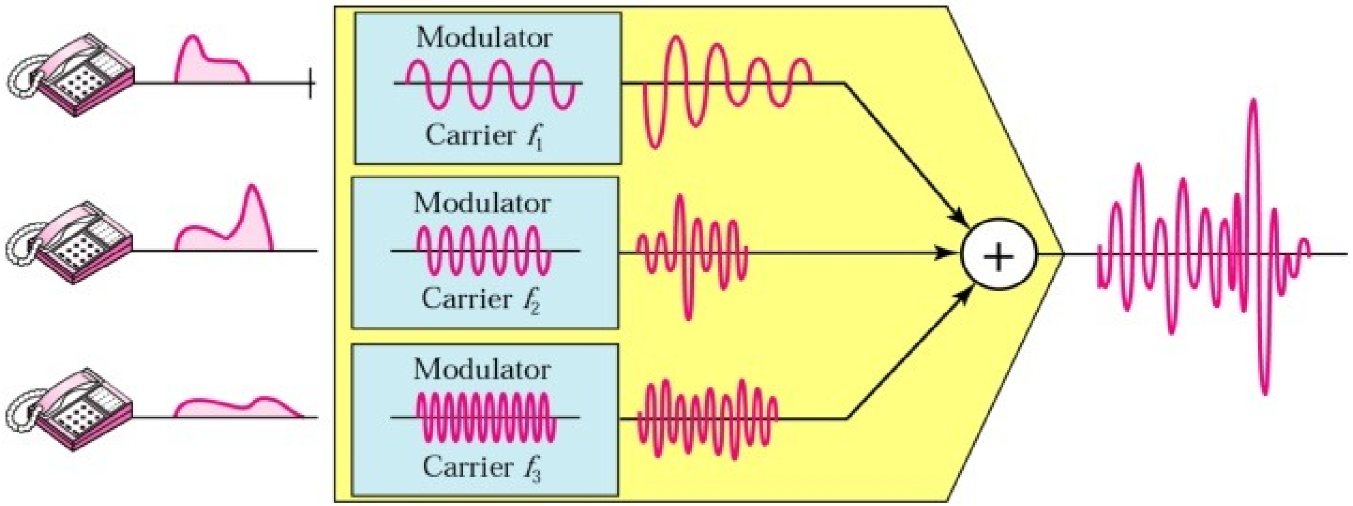
FREQUENCY DIVISION MULTIPLEXING

- Assigns different analog frequencies to each connected device
- Like Pure TDM,
  - mux-to-mux speed = aggregate terminal speeds
  - No loss of data so transparent to users and host/FEP
- Channels must be separated by strips of unused B.W - guard B.W



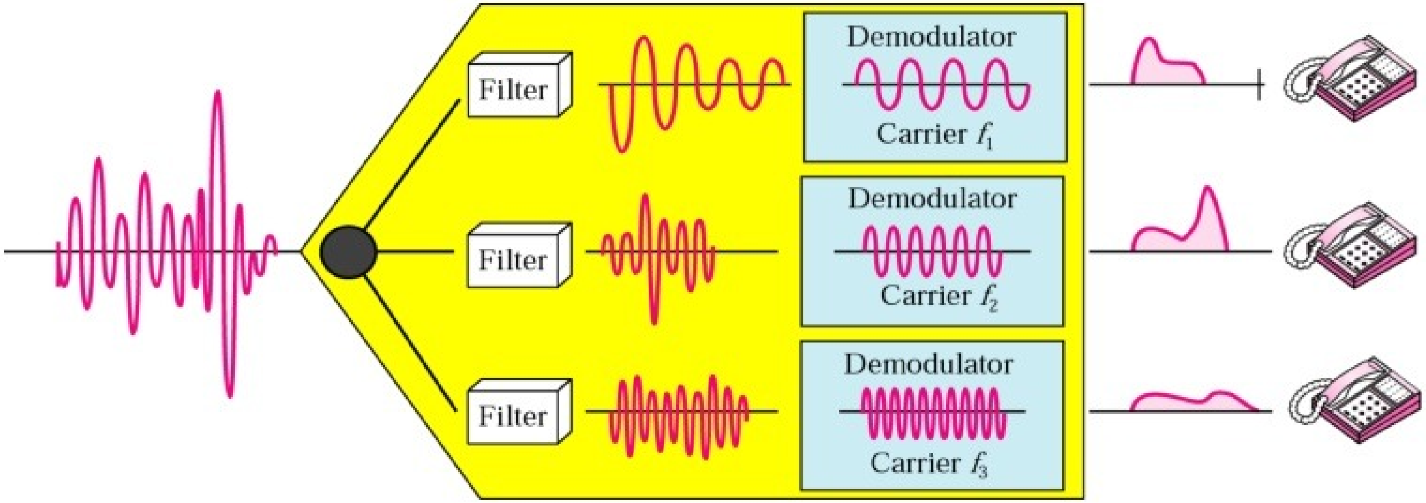
FDM PORCESS

- Signals of each channel are modulated onto different carrier signal
- The resulting modulated signals are then combined into a single composite signal that is sent out over a media link
- The link should have enough bandwidth to accommodate it



FDM DEMULTIPLEXING

- Demultiplexer uses a series of filters to decompose the multiplexed signal into its constituent component signals
- The individual signals are then passed to a demodulator that separates them from their carriers and passes them to the waiting receivers



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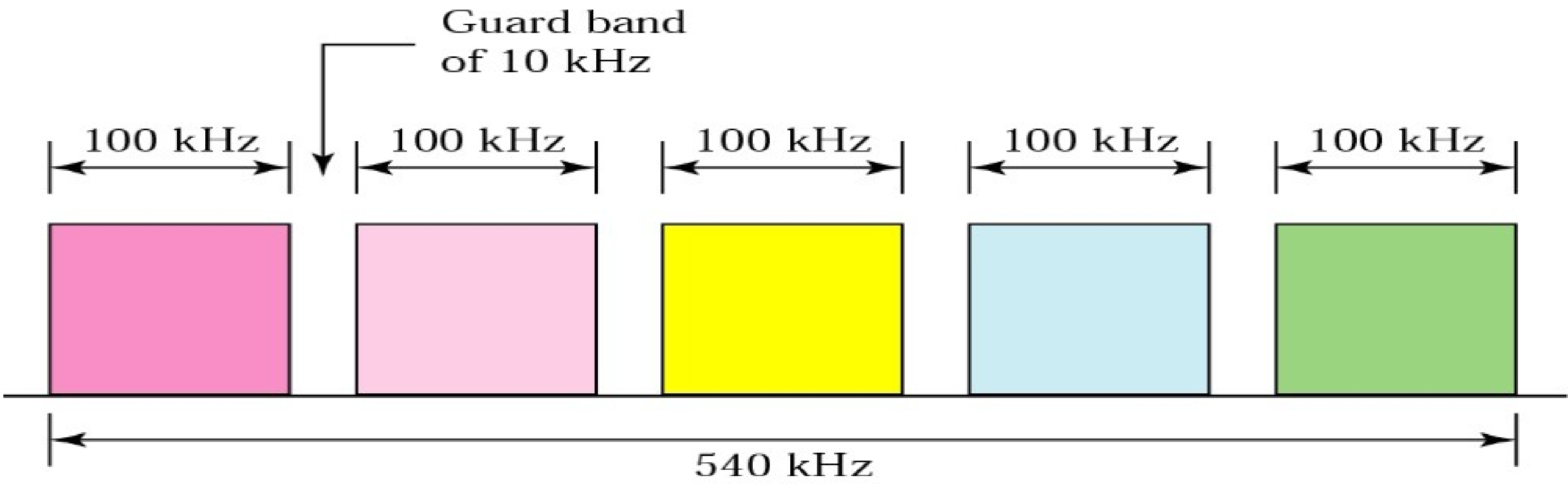
- the required B.W is at least 5 x 100 + 4 x 10 = 540 KHz

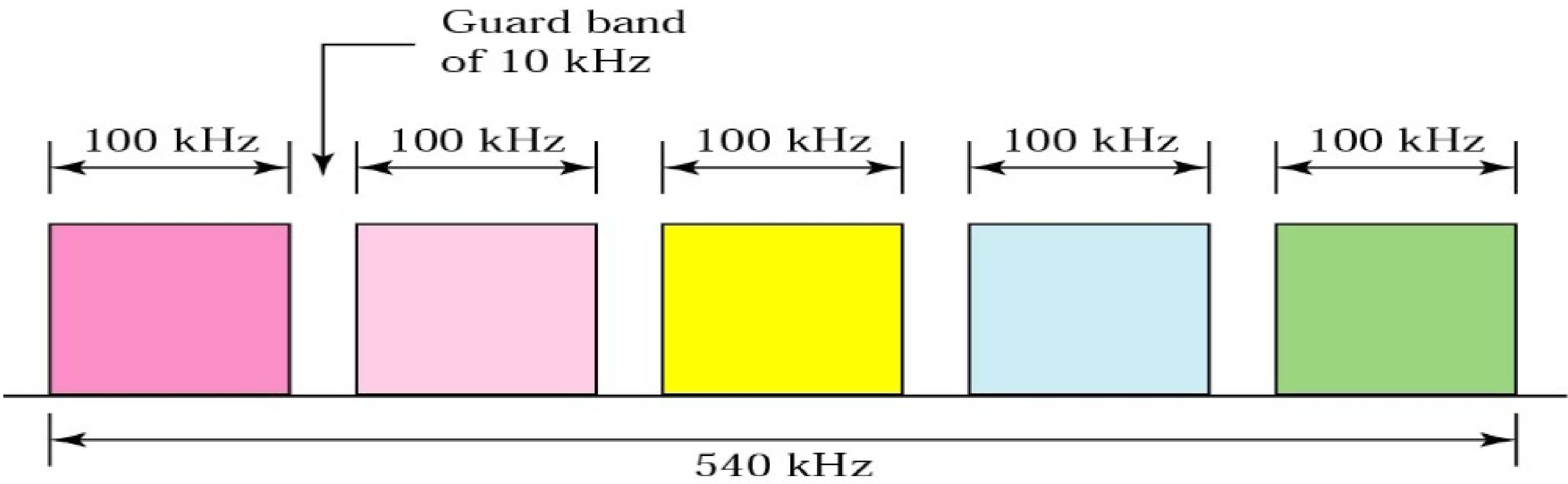


Example

- 5 channels, each with a 100-KHz B.W, are to be multiplexed together. What is the minimum B.W of the link if there is a need for a guard band of 10 KHz between the channels to prevent interference?

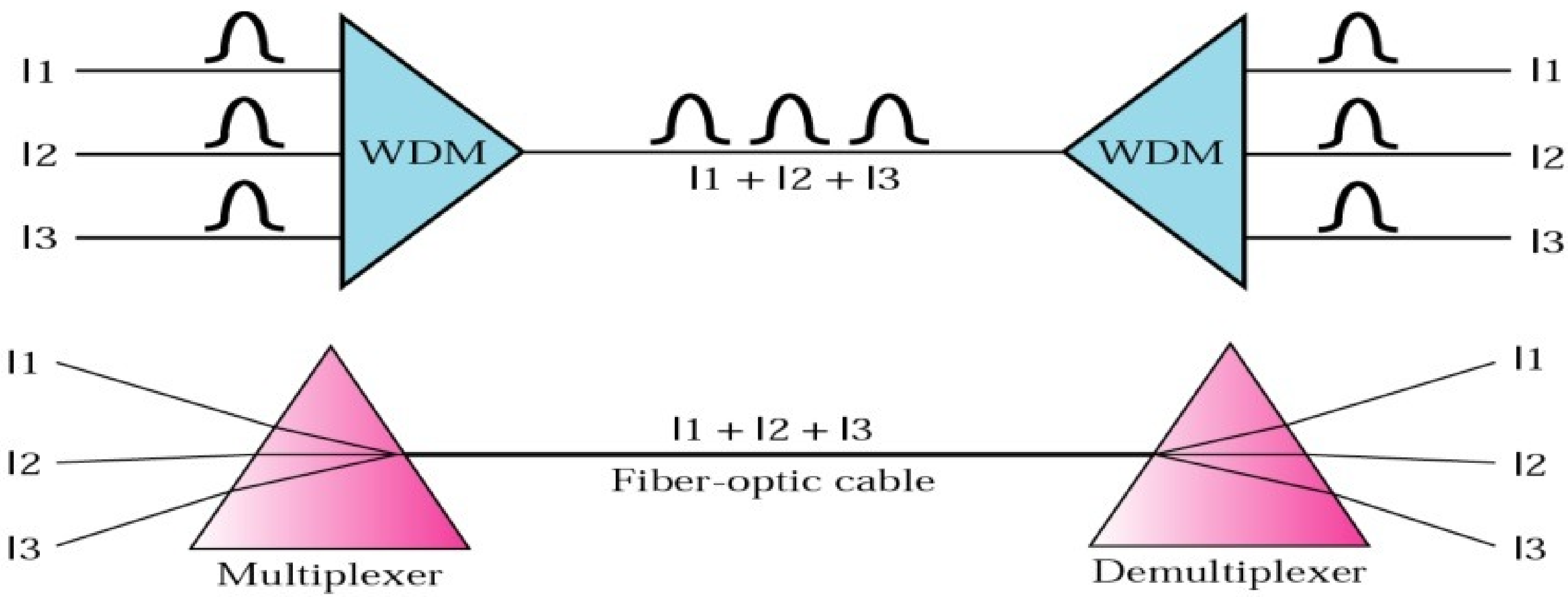
Solution

- For 5 channels, we need at least 4 guard bands.
- the required B.W is at least 5 x 100 + 4 x 10 = 540 KHz



Wave Division Multiplexing

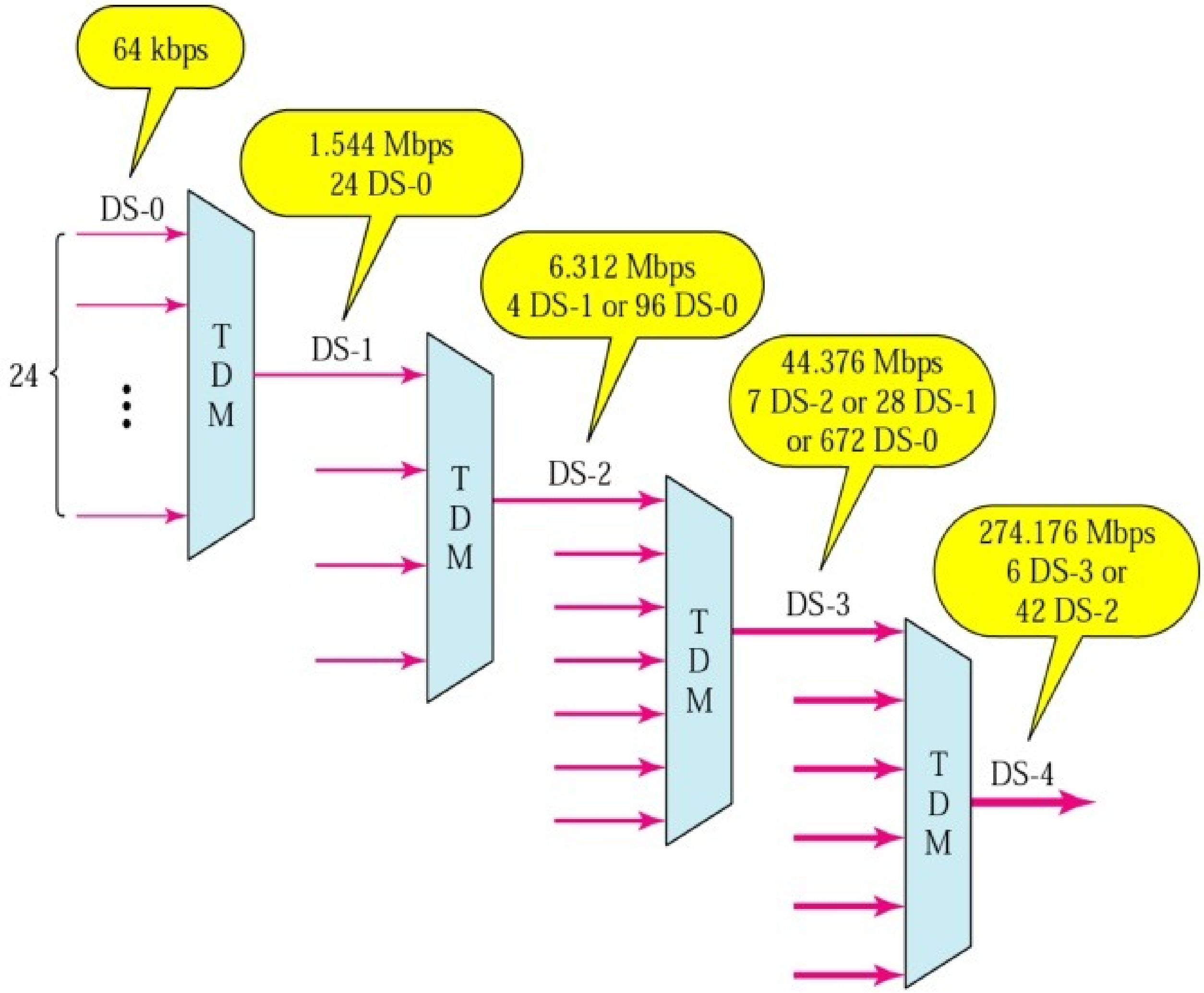
- An analog multiplexing technique to combine optical signals
- Multiple beams of light at different frequency
- Carried by optical fibber
- A form of FDM
- Each color of light (wavelength) carries separate data channel
- Commercial systems of 160 channels of 10 Gbps now available



Digital Signal Service

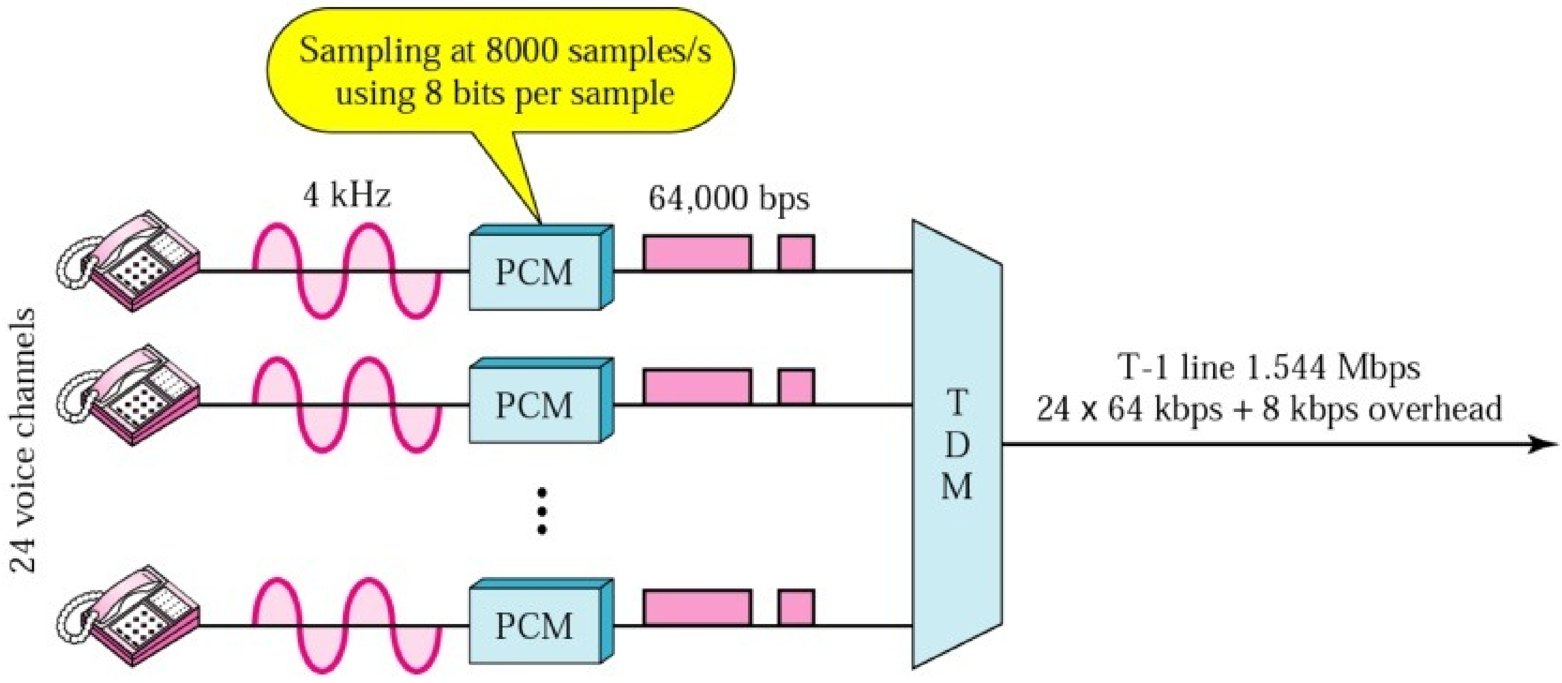
- Hierarchy of digital signals
  - DS-0 single channel of 64 Kbps
  - DS-1 single service or 24 DS-0 channels multiplexed 1.544Mbps
  - DS-2 single service or 4 DS-1 channels = 96 DS-0 channels
    = 6.312 Mbps
  - DS-3 single service, 7 DS-2 channels = 28 DS-1 channels
    = 672 DS-0 channels
    = 44.376 Mbps
  - DS-4 6 DS-3 channels = 42 DS-2 channel
    = 168 DS-1 channels
    = 4032 DS-0
    = 274.176 Mbps

DS Hierarchy

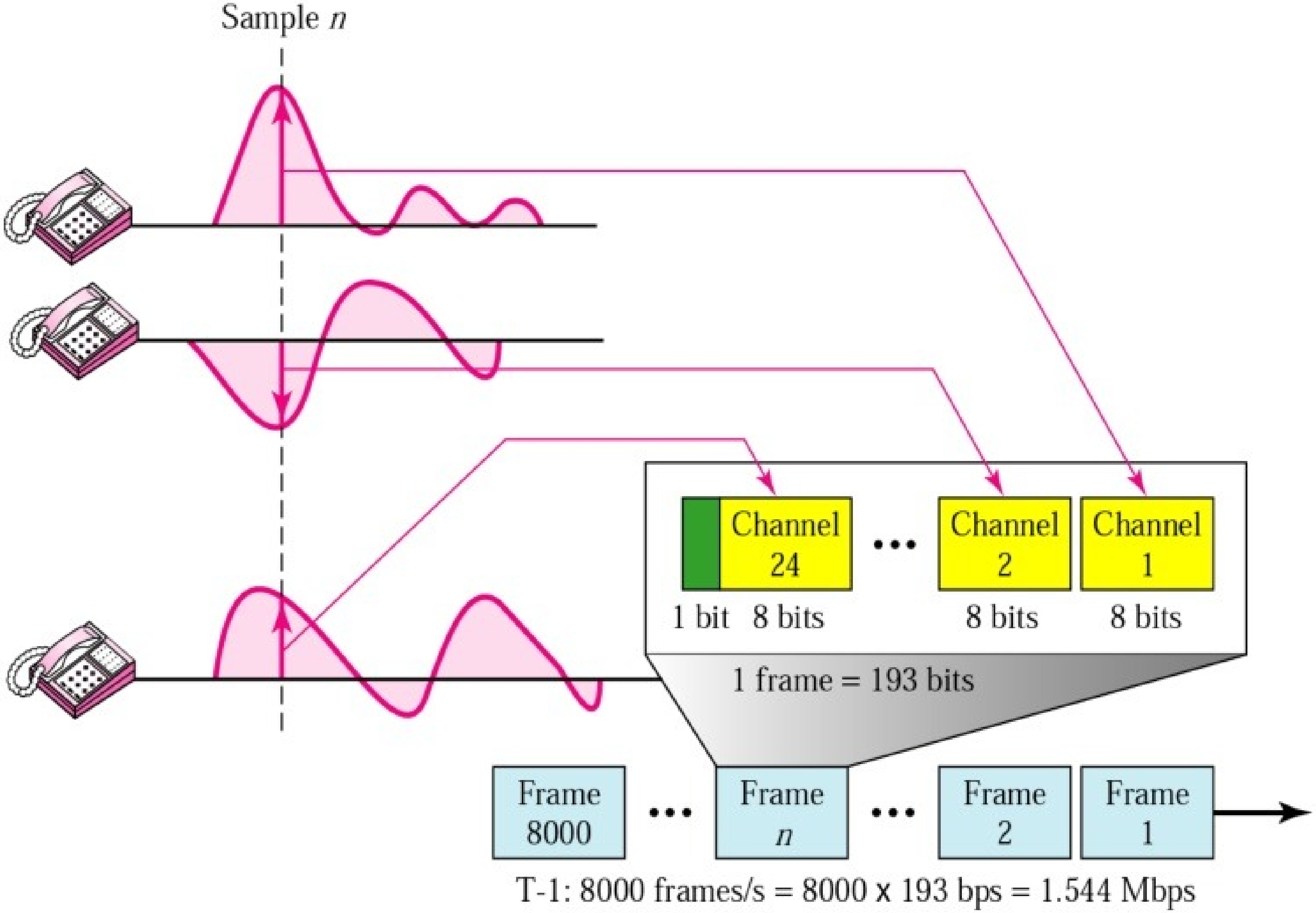


T Lines

- Digital lines designed for digital data, voice, or audio
- May be used for regular analog (telephone lines) if sampled then multiplexed using TDM



T-1 frame structure



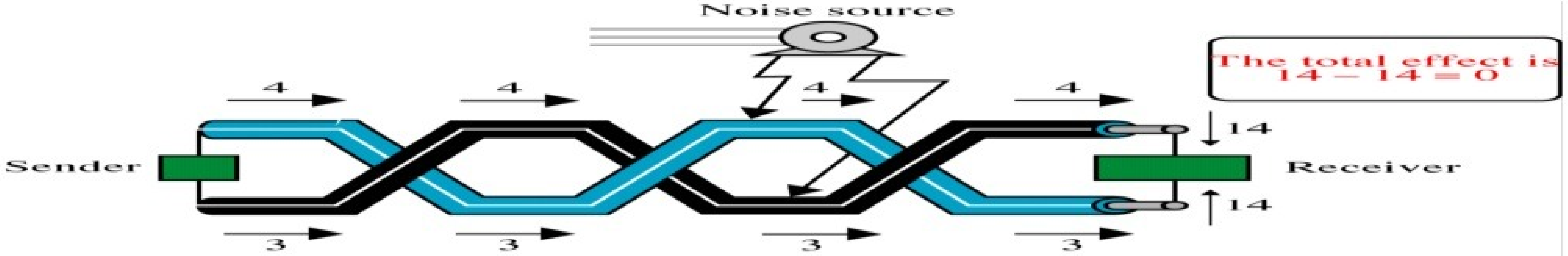
Chapter 7

Communications Media

- **Medium**
  - the physical matter that carries the transmission.
- Two basic categories of media
  - **Guided media**
    - Transmission flows along a physical guide
  - **Unguided media**
    - there is no wave guide and the transmission just flows through the air (or space)

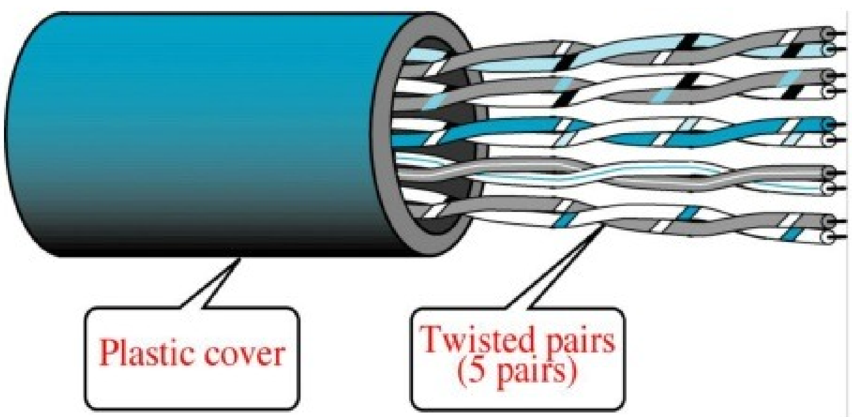
Twisted pair

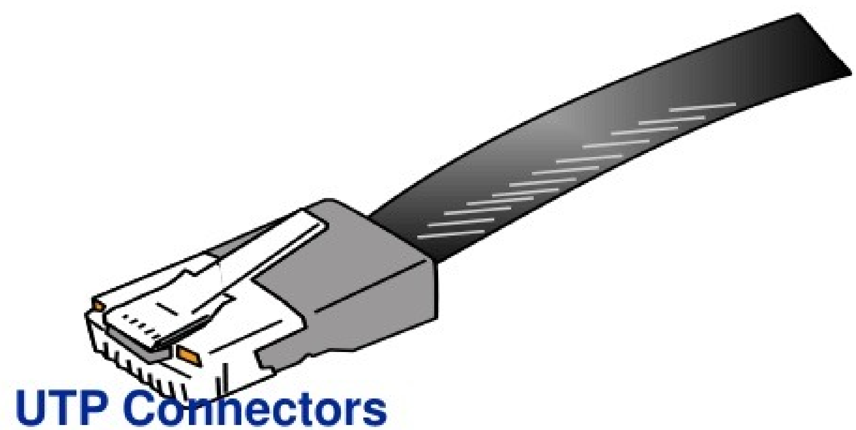
- Use **copper** conductors that accept and transport signal in **electrical** forms
- Twisted pair can carry frequency range from 100Hz to 5MHz
- A twisted pair consists of two conductors (copper) each with coloured plastic insulation
- Twisted pair cable comes in two forms
  - **Unshielded (UTP)**
  - **Shielded (STP)**
- Problems with two parallel flat wires
  - Electromagnetic interference from devices such as motor can create noise affecting them
  - Uneven load may occur that could cause damage result from the wire closest to the source get more interference thus higher voltage level
- The 2 wires twisted around each other at regular intervals
  - Each wire is closer to the noise source for 1/2 the time and farther away for the other ½
  - The cumulative effect of the interference is equal on both wires
  - Twisting does not always eliminate the impact of noise but minimise it



Unshielded (UTP)

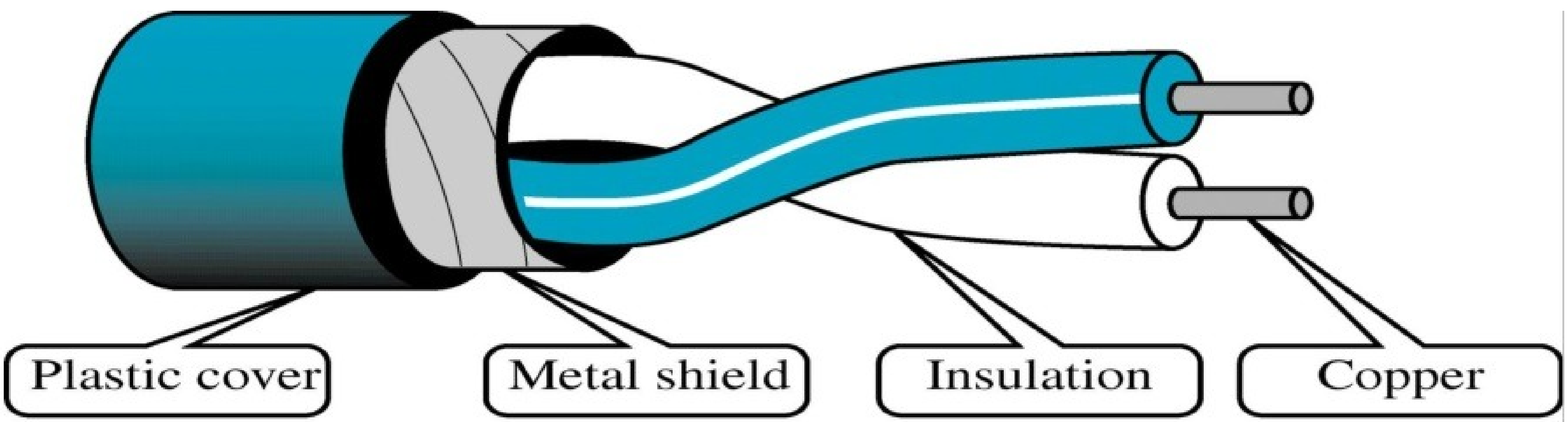
- Most common type of telecommunication medium in use today
- Although is common in telephone systems, its frequency is capable of transmitting both data and voice





Shielded (STP)

- Has a **metal foil** covering that encases each pair of insulated conductors
- The metal casing which is connected to the ground prevents the penetration of electromagnetic noise
- It can also eliminate **crosstalk**
  - Crosstalk occurs when one line picks up some of the signal travelling down another line



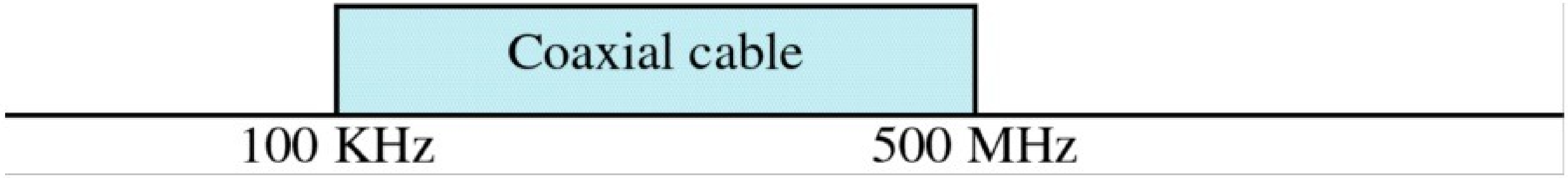
Advantages of UTP and UTP connectors

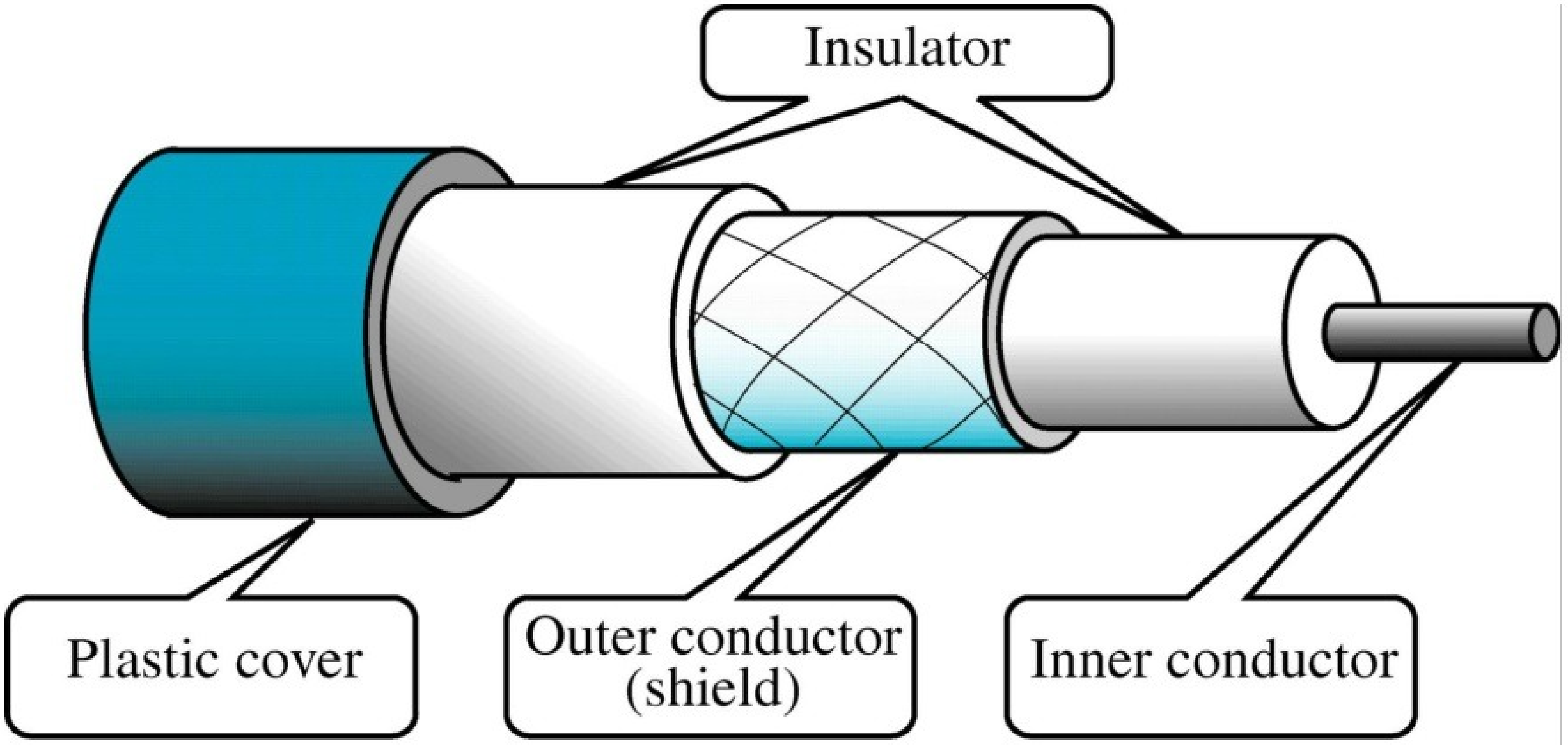
- Advantages:
  - Cheap
  - Flexible and easy to install
- Higher grades of UTP are used in many LANs technologies (Ethernet and Token Ring)

Cable Categories

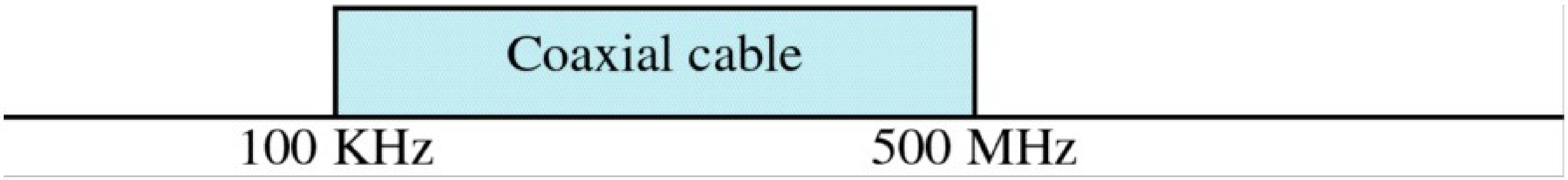
- The EIA (Electronic Industries Association) has developed the following categories with 1 as the lowest quality and 5 as the highest cable quality
  - **Category 1**
    - used in telephone system; is fine for voice but not adequate for all but low-speed data communication
  - **Category 2**
    - suitable for voice and data transmission up to 4Mbps
  - **Category 3**
    - required to have 3 twists per foot can be used for data transmission up to 10Mbps; most standard cable for telephone now
  - **Category 4**
    - possible transmission rate to 16Mbps
  - **Category 5**
    - used for data transmission up to 100Mbps

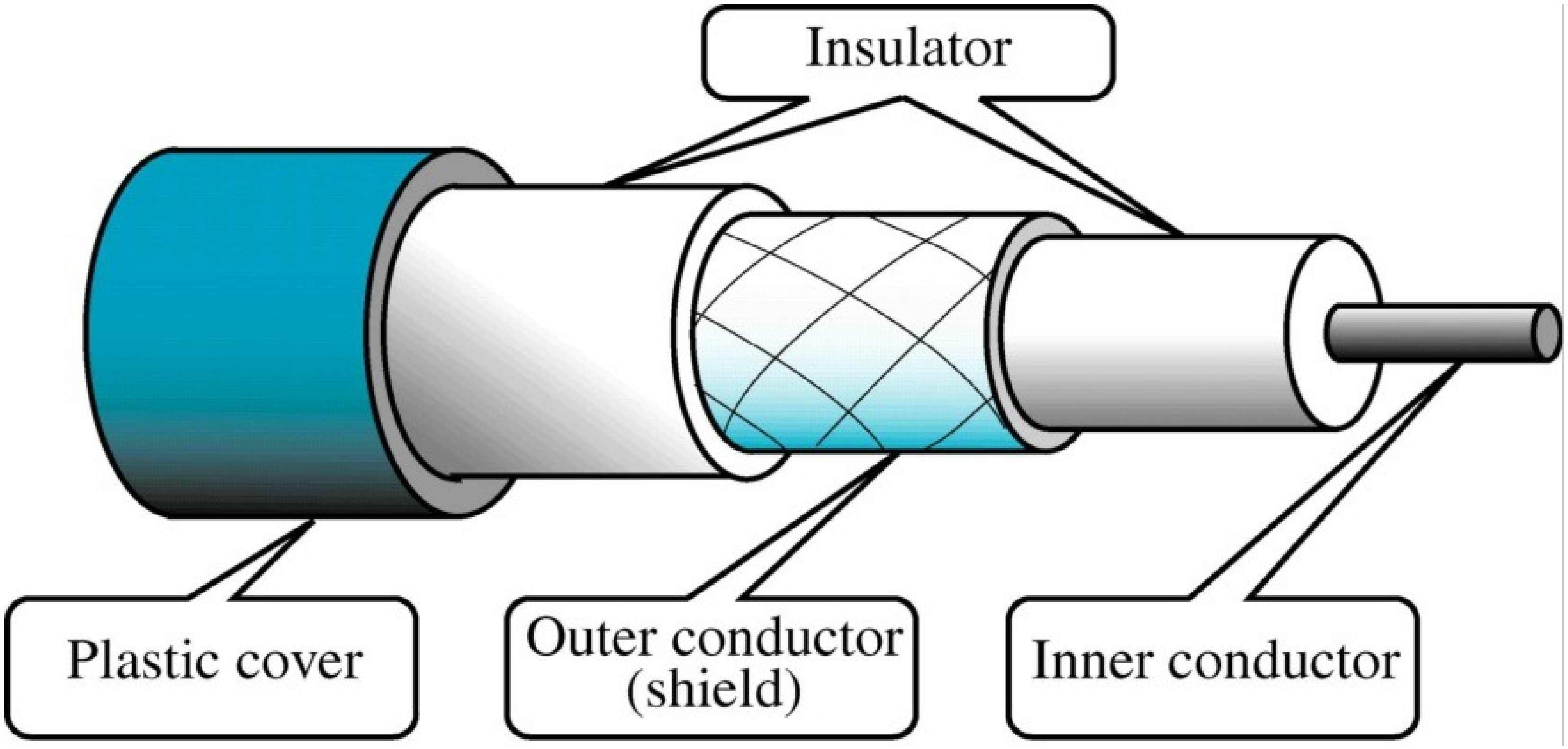
Coaxial Cable





Coaxial Cable



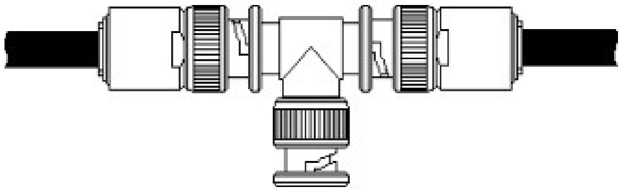


Coaxial Cable Connectors

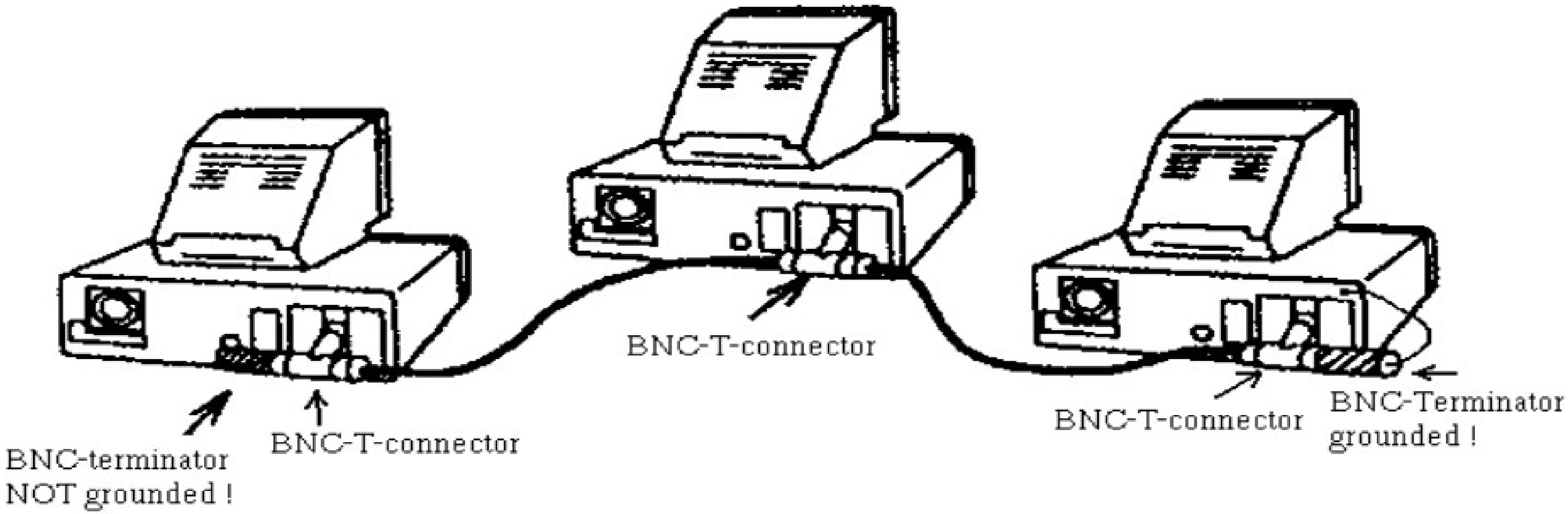
- Barrel connectors:
  - Bayonet network connector (BNC) is the most popular, which pushes on and locks into place with a half turn
  - Other types includes screw on, push on without locking
  - Are familiar from cable TV and VCR hookups

T-connector and Terminators

- **T-connectors** used in Ethernet that allows a secondary cable or cables to branch off from a main line



- **Terminators** are needed where one main cable acts as a backbone with branches to several devices but does not terminate itself; absorbs the wave at the end and eliminates echo-back



Optical Fiber

- Made of glass or plastic and transmits signals in the **form of light.**
- Signal propagates along the inner core **by reflection**
- **Advantages**
  - **Noise resistance:** noise is not a factor as it uses light instead of electricity
  - **Less signal attenuation:** transmission distance is greater than other guide media
  - **Higher bandwidth:** currently the limit is govern by the signal generation and reception technology available
- **Disadvantages**
  - **Cost:** is expensive as manufacturing must be very precise and thus difficult to manufacture
  - **Installation/maintenance:** any roughness or cracking in the core will diffuse the light and alter the signal, therefore care has to be taken when dealing with optical fiber
  - **Fragility:** glass fiber is more easily broken than wire
- Signal propagation can be in 2 modes
  - **Multi mode**
    - multiple beams from a light source
  - **Single Mode**
    - one beam of light

Nature of light

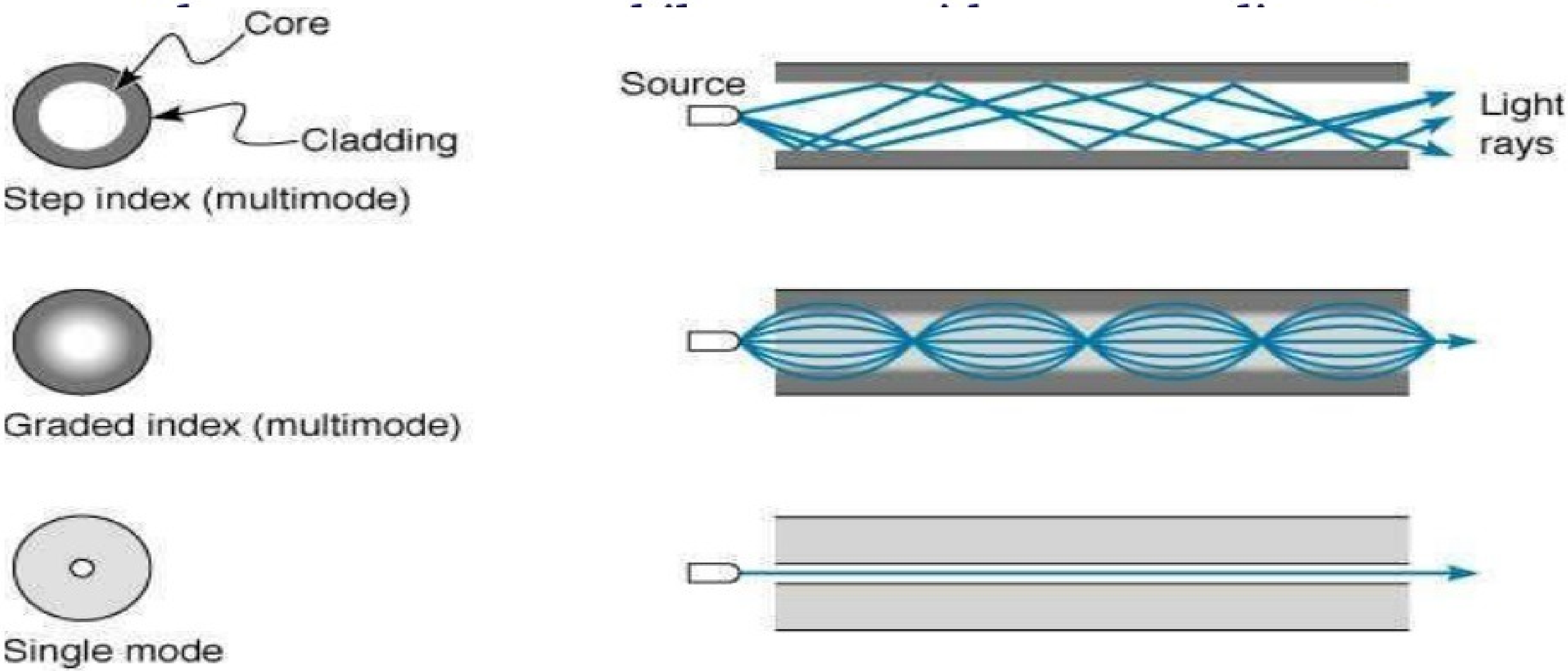
- Light is a form of electromagnetic energy, travels at 300000 Km/sec in vacuum.
- This speed decreases as the medium through which the light travels becomes denser.
- It travels in straight lines through one substance.
- The speed of light changes as rays travels through different substances causing these rays to change direction.
- When the light travels another substance, speed and direction changes (**Refraction**). Fiber optic technology takes advantages of this properties to control the propagation of light
- When light cannot passes into the less dense medium, Optical fibres uses **reflection** to guide light through a channel

Multimode

- Can further be break down into two forms
  - **Step-index:**
    - The density of the core remains constant from the center to the edges until it reaches the interface of the core and the cladding.
    - Beams in the middle travel in straight lines through the core and reach the destination without reflecting or refraction.
    - Other beams strike the interface of the core and cladding(غلاف) at different angles causing the beams to reach the destination at different times
  - **Graded-index:**
    - It is a fiber **with varying density** (highest at the center of the core and decreases gradually to its lowest at the edge)
    - This difference causes the beams to reach the destination at regular intervals
    - can be used over distances of up to about 1000 meters

Single Mode

- Uses step-index fiber and a highly focused source of light that limits beams to a small range of angles, all close to horizontal
- Expensive because it is difficult to manufacture, but **signal**



Fiber-optic

- At the center is the glass core through which the light propagates
- The core is surrounded by a glass cladding with a lower index of refraction than the core, to keep all the light in the core
- For transmission to take place, the sending device must equipped with a light source (LED or injection laser diode)
- The receiving device uses photodiode to translate the received data

Unguided Media

- **Radio**
  - Wireless transmission of electrical waves
  - Includes AM and FM radio bands
  - Microwave is also a form of radio transmission.
- **Infrared**
  - invisible light waves whose frequency is below that of red light.
  - Requires line of sight and are generally subject to interference from heavy rain.
  - Used in remote control units (e.g., TV).
- **Microwave**
  - High frequency form of radio with extremely short wavelength (1 cm to 1 m).
  - Often used for long distance
  - Terrestrial transmissions and cellular telephones
  - Requires line-of-sight.

Radio Transmission

- The properties of radio waves are frequency dependent
  - **low frequencies**
    - radio waves pass through obstacles well
    - power of signal falls off sharply over distance
  - **high frequencies**
    - radio waves tend to travel in straight lines
    - bounce off obstacles
    - absorbed by rain
  - **at all frequencies**
    - subject to interference from electrical equipment
    - interference between users
    - therefore highly regulated

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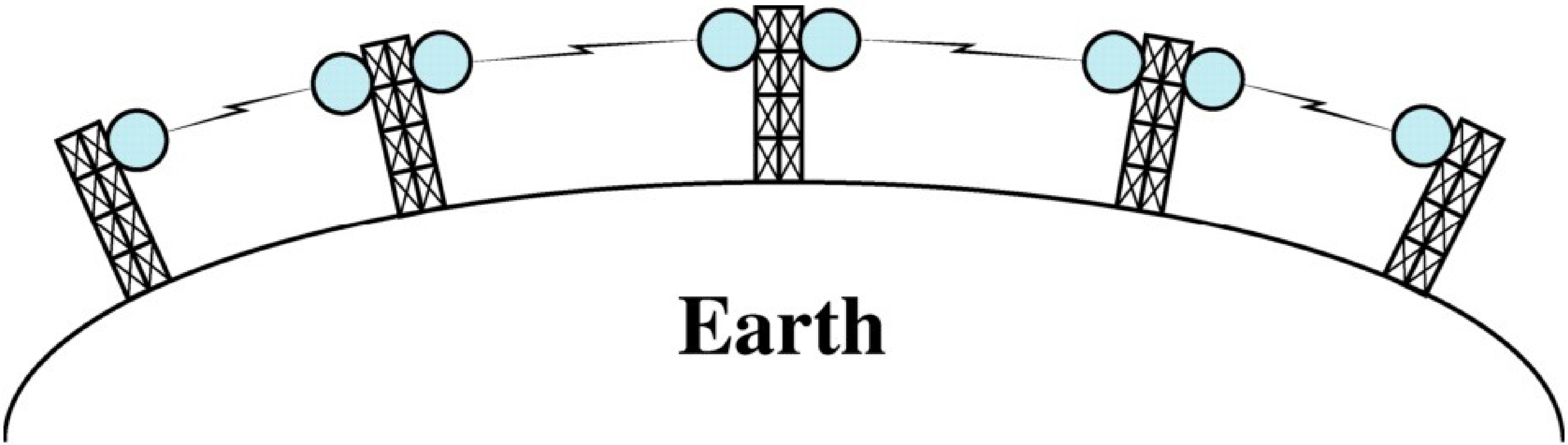
Infra-red

- short-range communication (VCR remotes)
- cheap
- do not pass through solid objects
- will not interfere with a similar system in adjacent rooms
- better security against eavesdroppers

Microwave

- Requires line-of-sight transmission & reception equipment
  Transmission is straight (from antenna-to-antenna)
- Signals propagate in one direction at a time.
- Two frequencies are required for 2-way communication
- For a telephone conversation we need one frequency for transmitting & another frequency for receiving.
- Each frequency requires its own transmitter & receiver.
- Now both are combined in a single piece called transceiver.
- To increase distance served, repeaters installed with each antenna.
- A signal received by one antenna is converted back into transmittable form and relayed to the next antenna.

Terrestrial Microwave



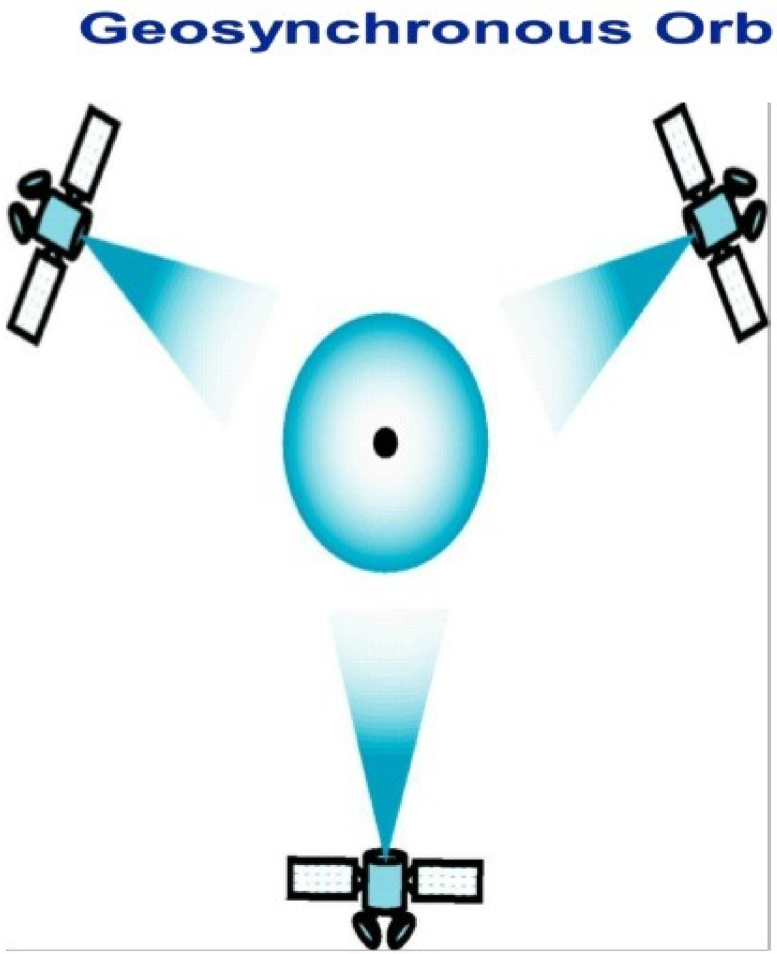
Satellite

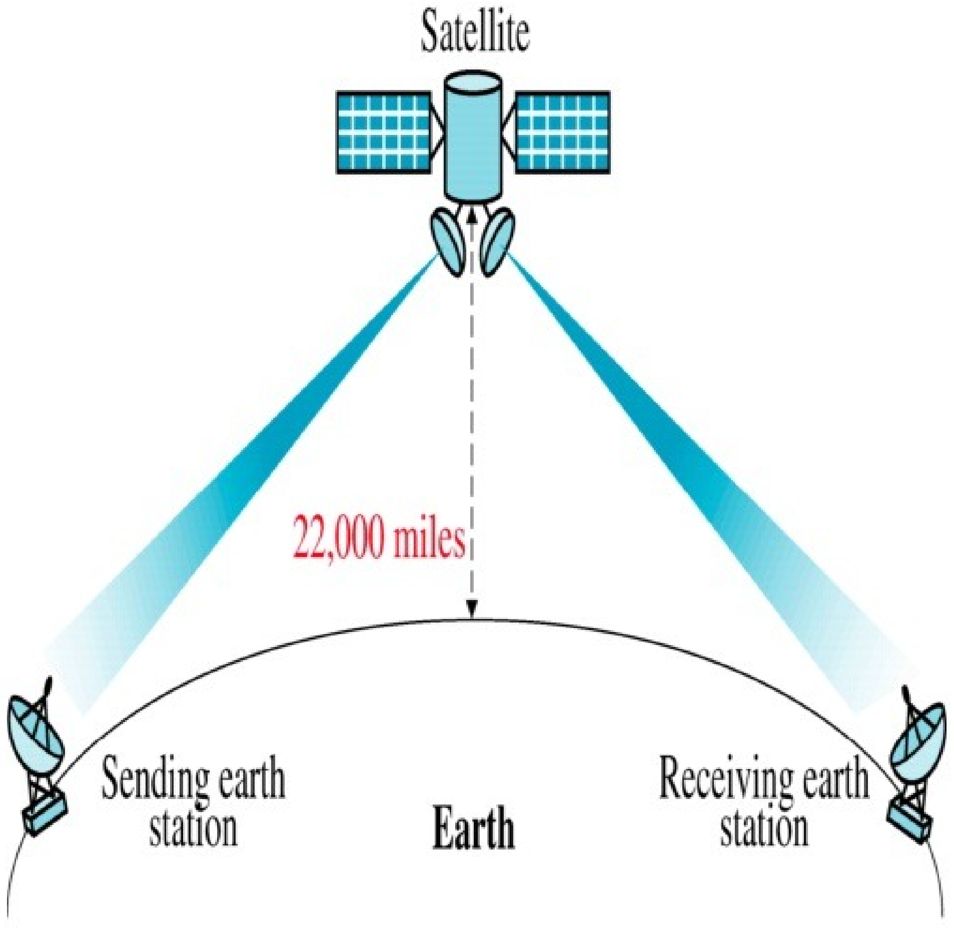
- Same as the terrestrial microwave, with a satellite acting as a super tall antenna and repeater.

Geosynchronous Satellites

- Line-of-sight propagation requires sending & receiving antennas be locked onto each other's location all times.
- To ensure constant communication, satellite must move at same speed as the earth so it seems to remain fixed above a certain spot.
- This satellite called Geosynchronous.
- Transmission from the earth to satellite is called **uplink**.
- Transmission from the satellite to earth is called **Downlink**

Satellite Communication

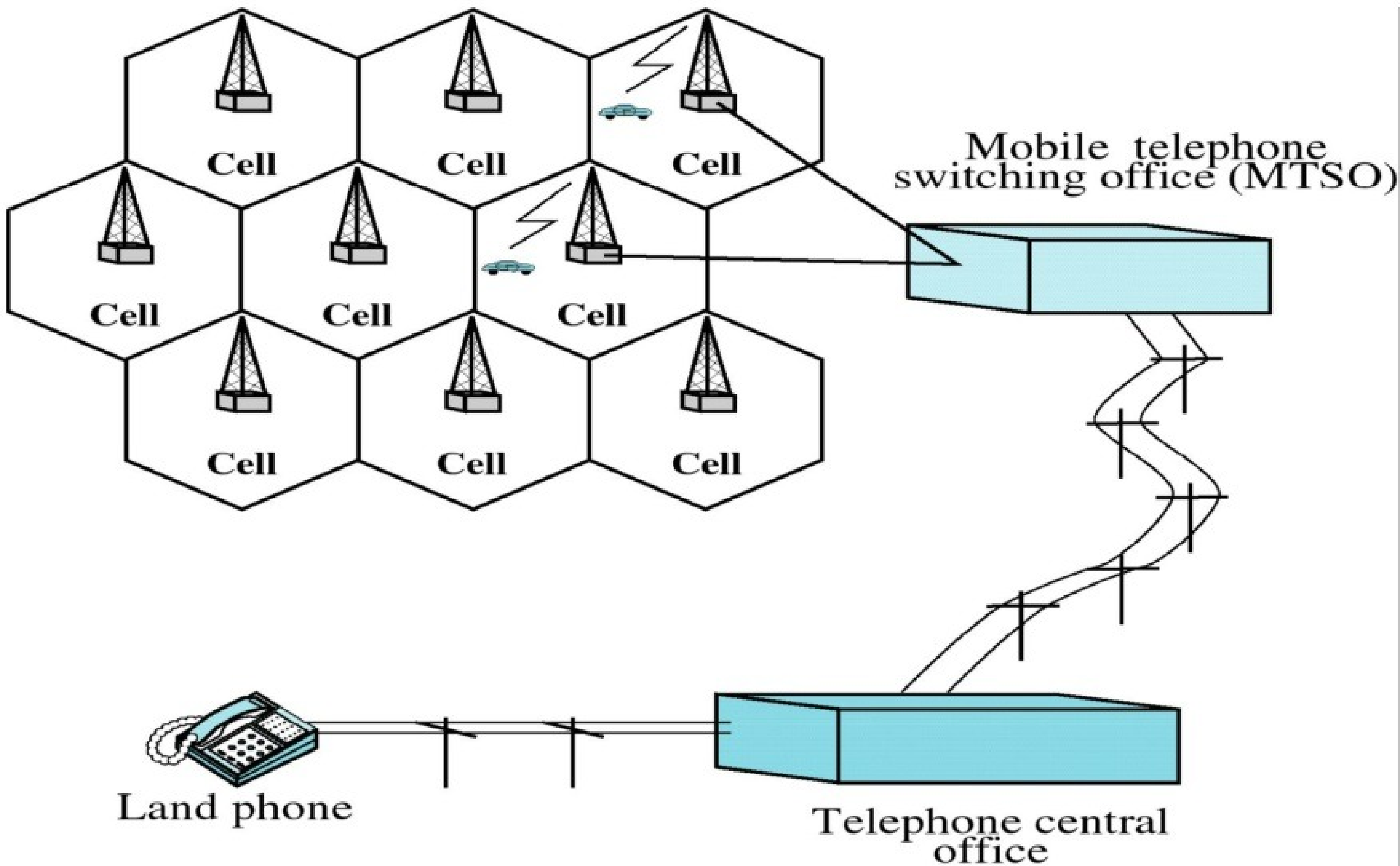




Cellular Telephony

- Provides communications connections between 2 moving devices or between one mobile unit & one land unit.
  - Service area is divided into small regions called cells.
  - Each cell contains an antenna & is controlled by small office called **cell office**
  - Each cell office is controlled by switching office called (MTSO) **mobile telephone switching office.**
  - Typical radius of a cell is 1-12 miles.
  - The transmission power of each cell is kept low to prevent its signal from interfering with those of other cells.

Cellular System



HANDOFF

- During a call, the mobile phone may move from one cell to another, then the signal becomes weak.
- To solve the problem the MTSO **monitors** the level of the signal every few seconds.
- If the strength of the signal diminishes, the MTSO seeks a new cell that can accommodate the communication better, then change the channel carrying the call.