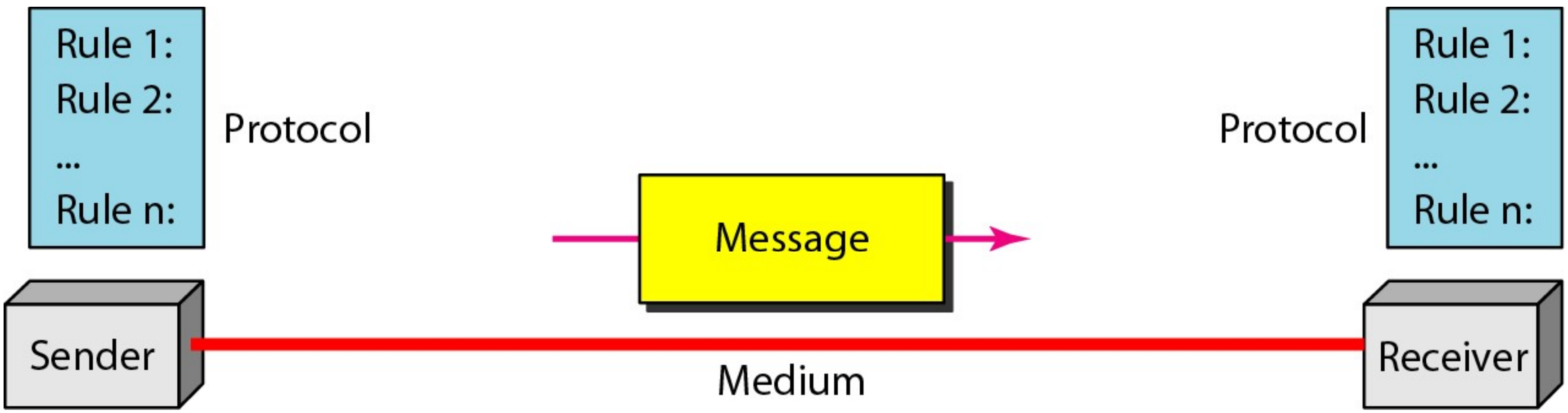
Data communications

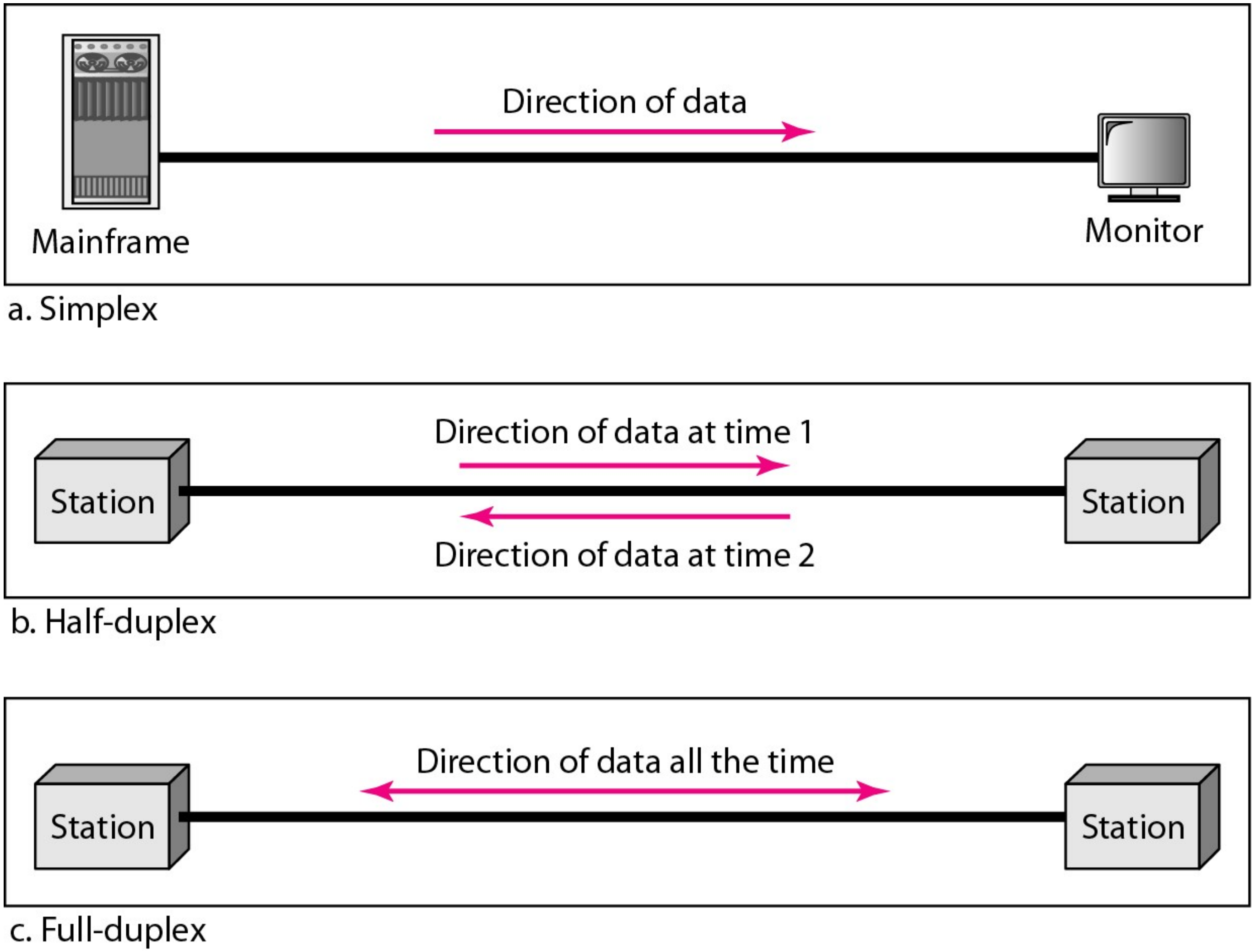
- ✓ The term **telecommunication** means communication at a distance.
- ✓ The word **data** refers to information presented in whatever form is agreed upon by the parties creating and using the data.
- ✓ **Data communications** are the exchange of data between two devices via some form of transmission medium such as a wire cable.

Module 1: *Data Communication Networks:*



Components of a data communication system

Module 1: *Data Communication Networks:*



Data flow (simplex, half-duplex, and full-duplex)

Network:

- ✓ A **network** is a set of devices (often referred to as **nodes**) connected by communication **links**.
- ✓ A node can be a computer, printer, or any other device capable of sending and/or receiving data generated by other nodes on the network.
- ✓ A link can be a cable, air, optical fiber, or any medium which can transport a signal carrying information.

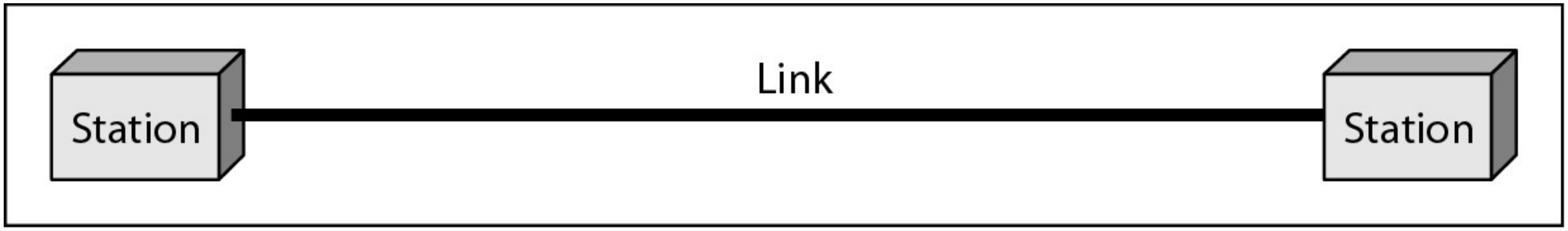
Network Criteria

- ✓ Performance
  - o Depends on Network Elements
  - o Measured in terms of Delay and Throughput
- ✓ Reliability
  - o Failure rate of network components
  - o Measured in terms of availability/robustness
- ✓ Security
  - o Data protection against corruption/loss of data due to:
    - Errors
    - Malicious users

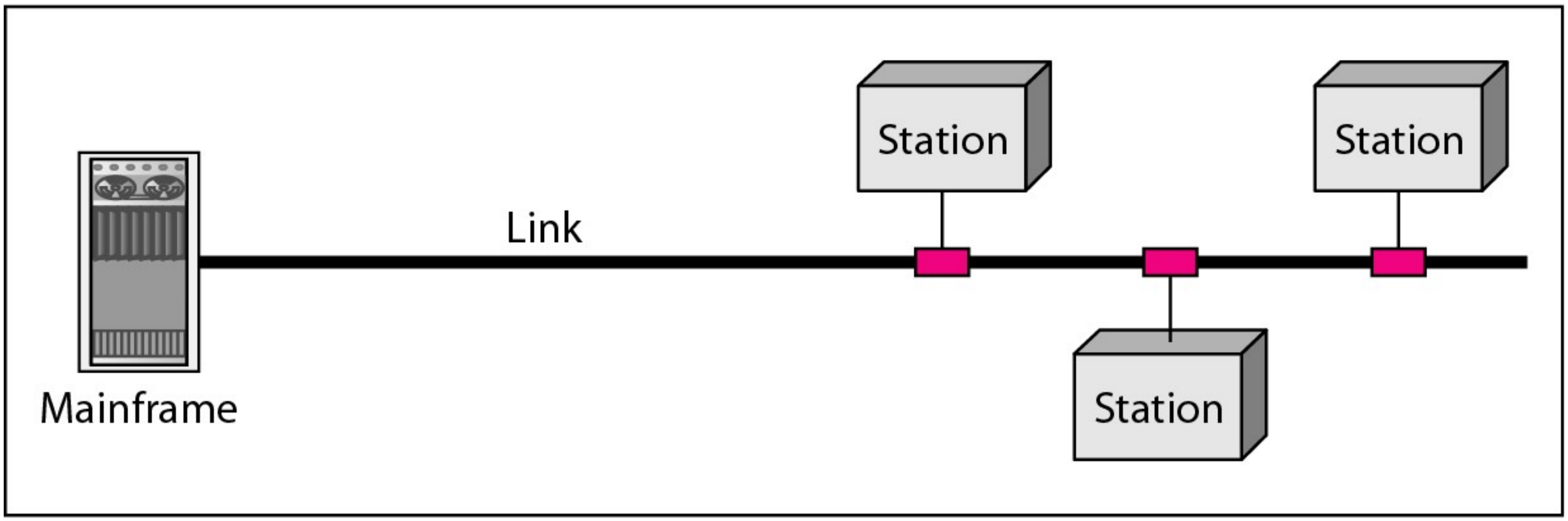
Physical Structures

- ✓ Type of Connection
  - Point to Point - single transmitter and receiver
  - Multipoint - multiple recipients of single transmission
- ✓ Physical Topology
  - Connection of devices
  - Type of transmission - unicast, mulitcast, broadcast

Module 1: *Data Communication Networks:*



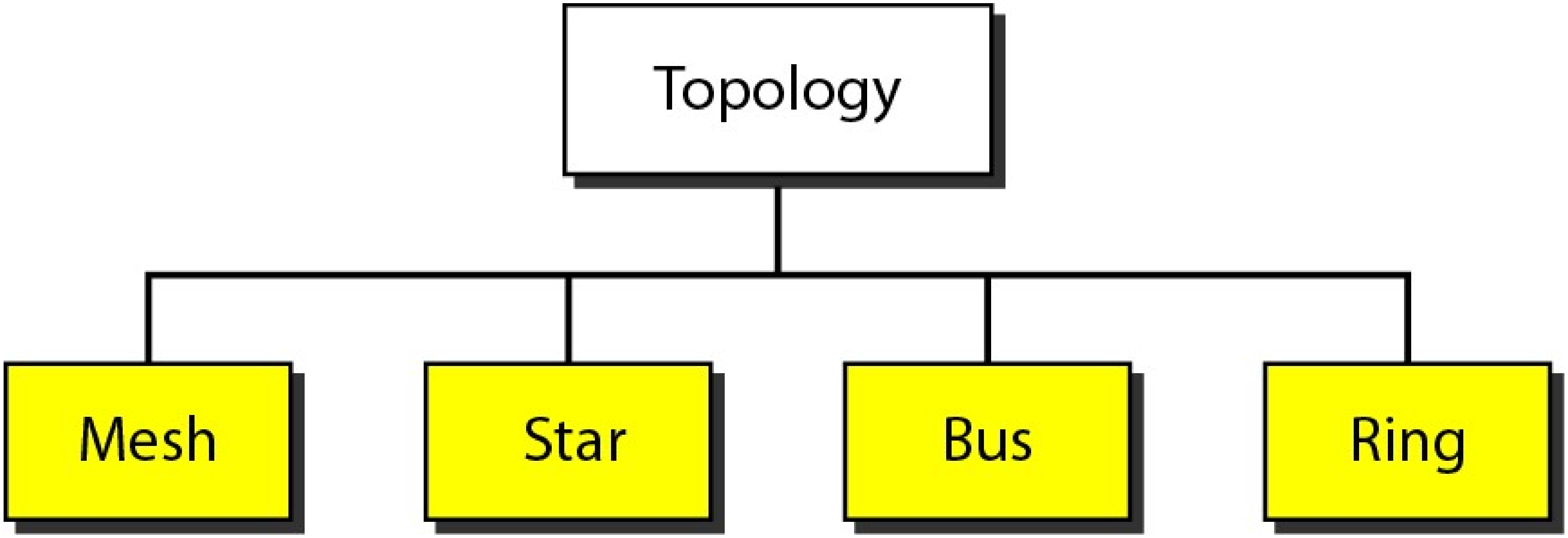
a. Point-to-point



b. Multipoint

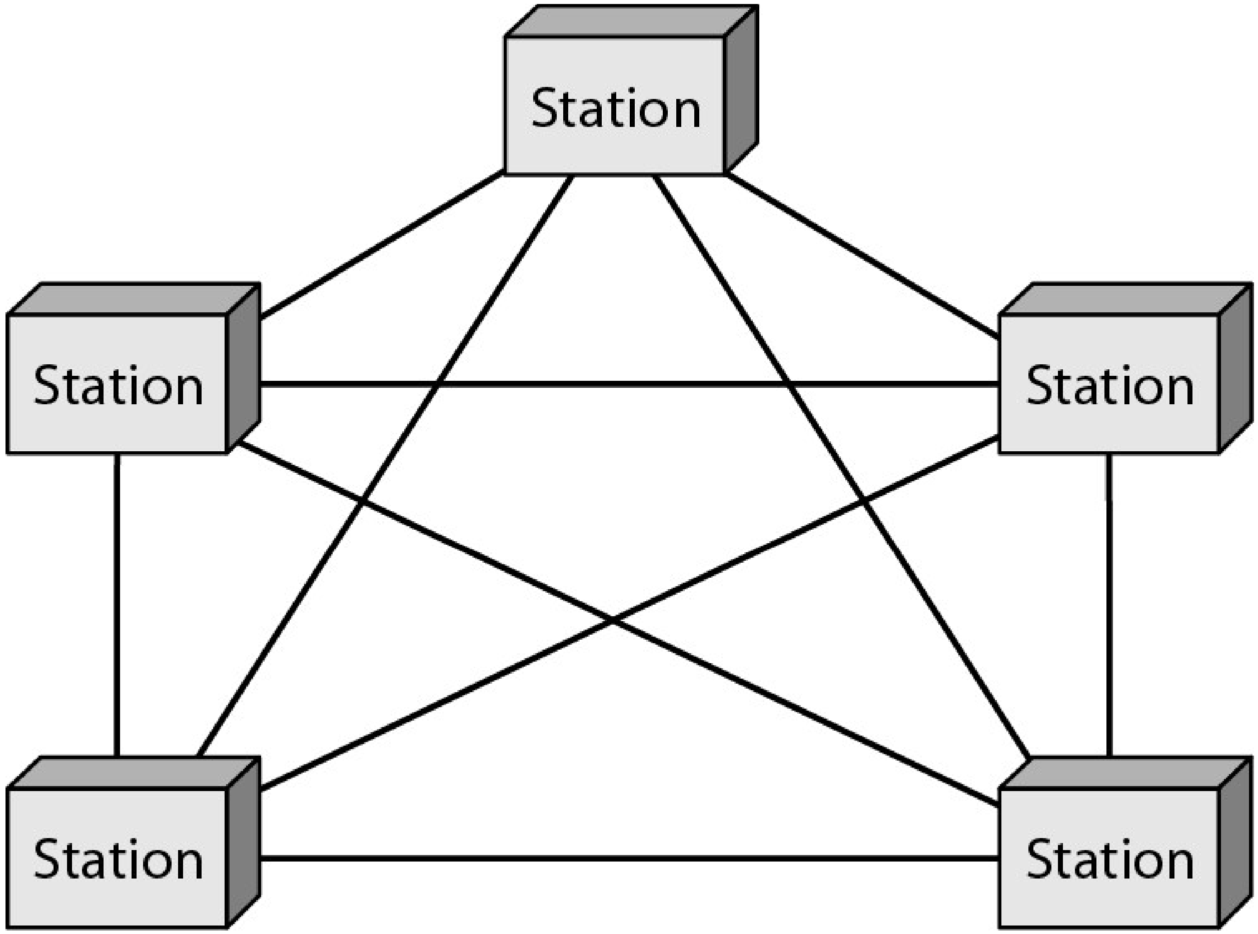
Types of connections: point-to-point and multipoint

Module 1: *Topology:*



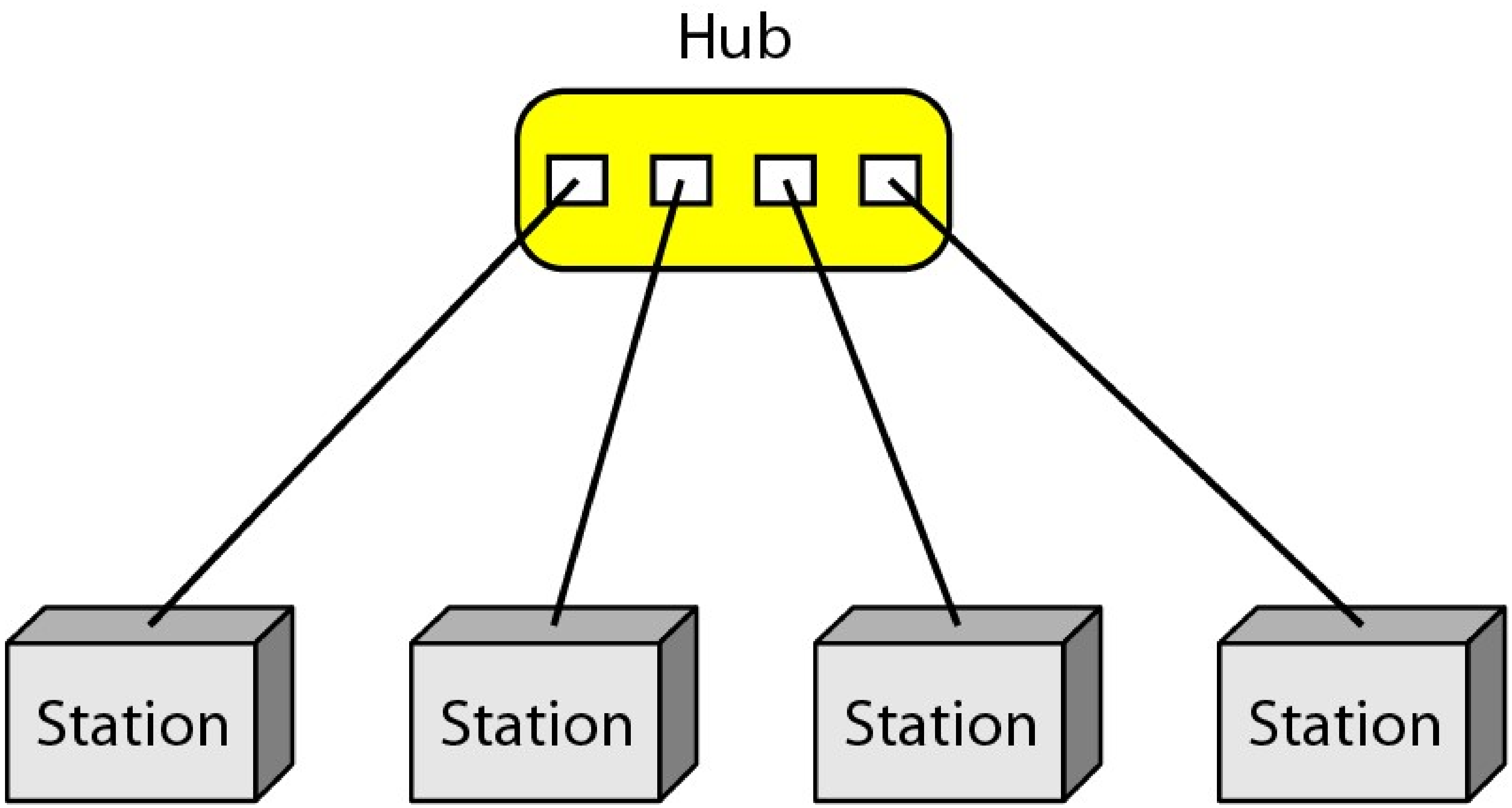
Categories of topology

Module 1: *Data Communication Networks:*



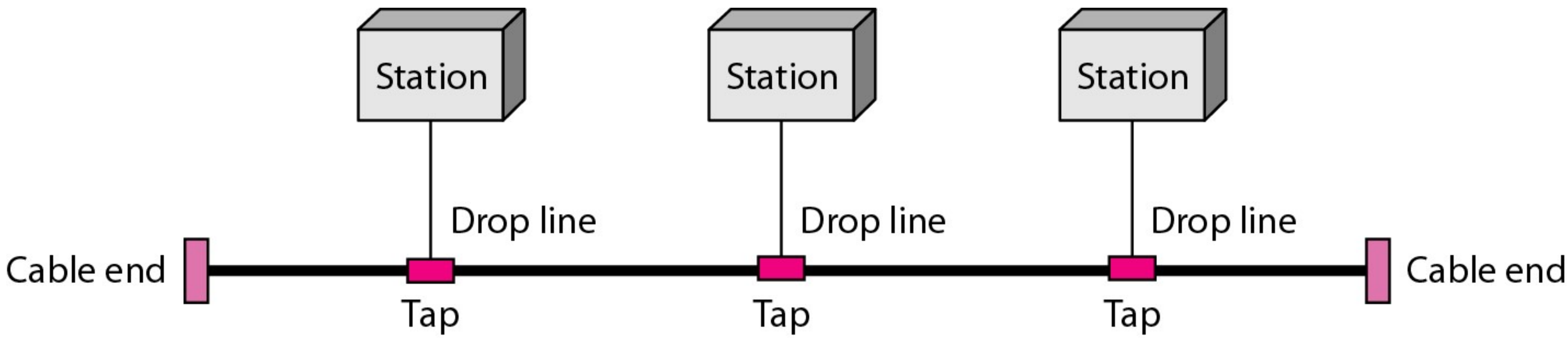
A fully connected mesh topology (five devices)

Module 1: *Topology:*



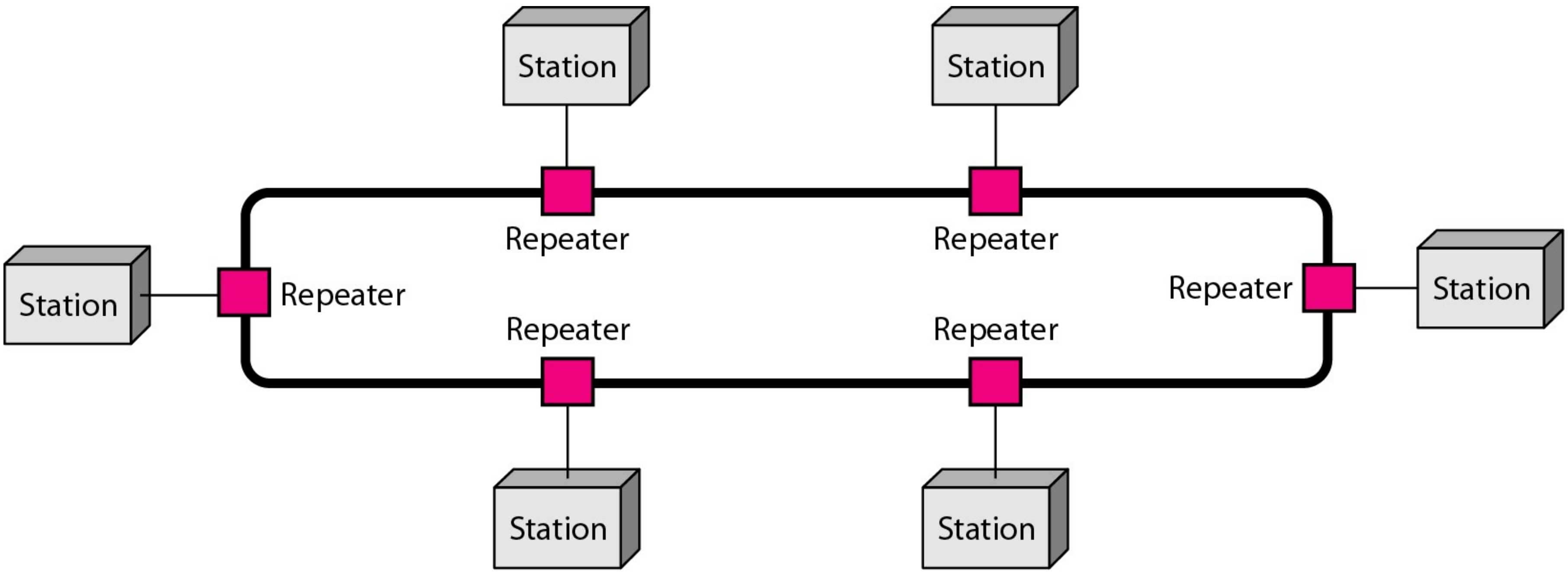
A star topology connecting four stations

Module 1: *Topology:*



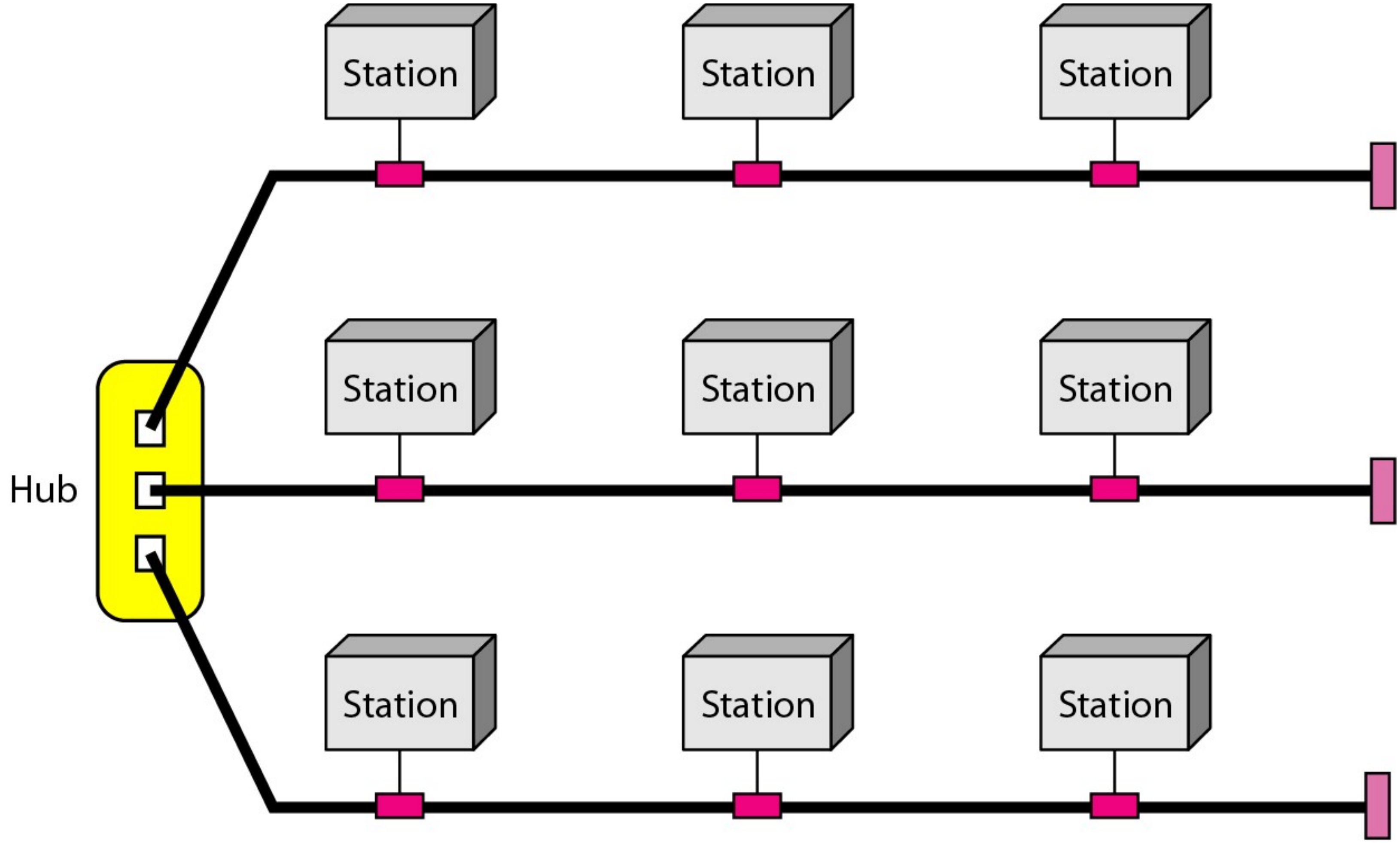
A bus topology connecting three stations

Module 1: *Topology:*



A ring topology connecting six stations

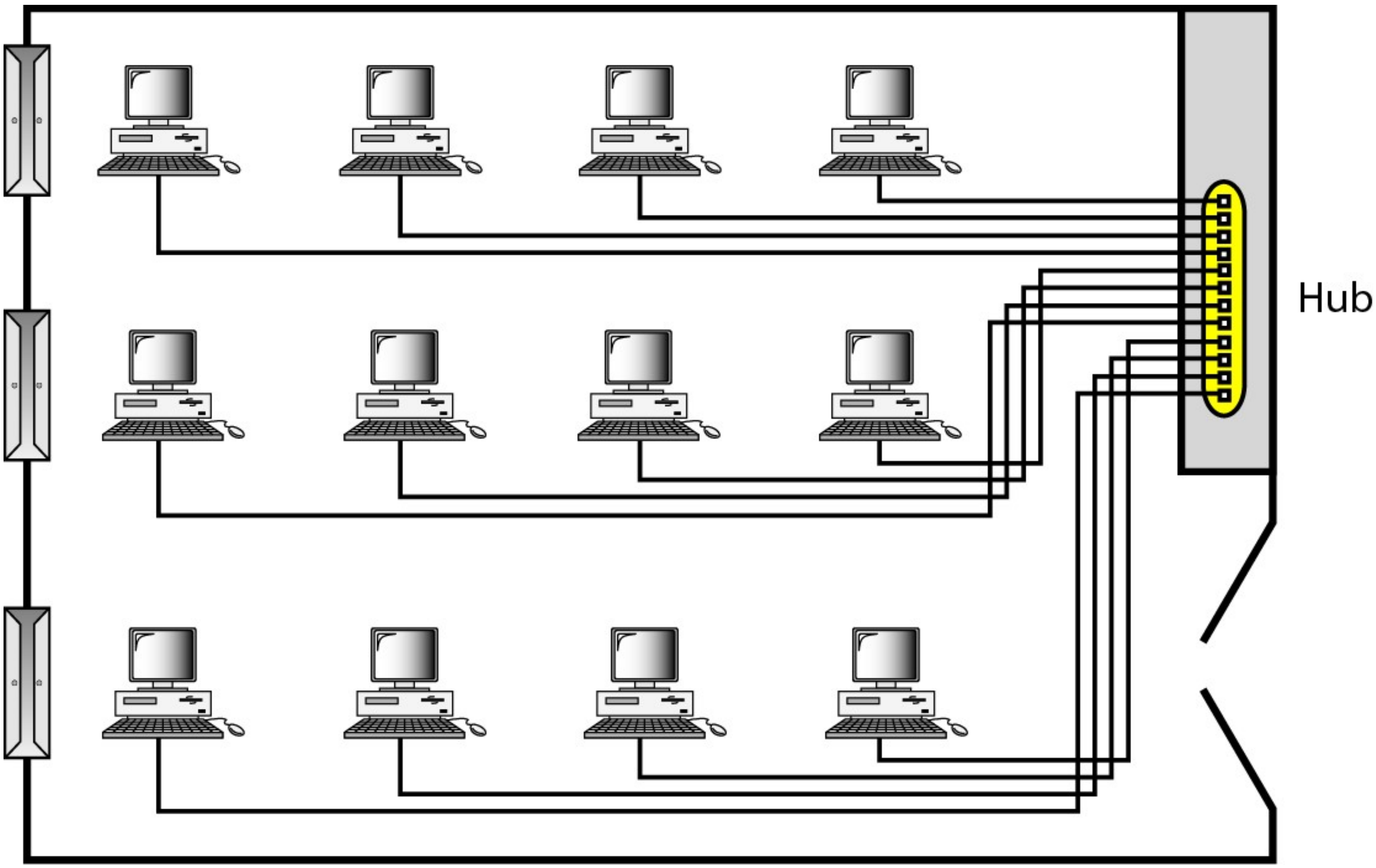
Module 1: *Topology:*



A hybrid topology: a star backbone with three bus networks

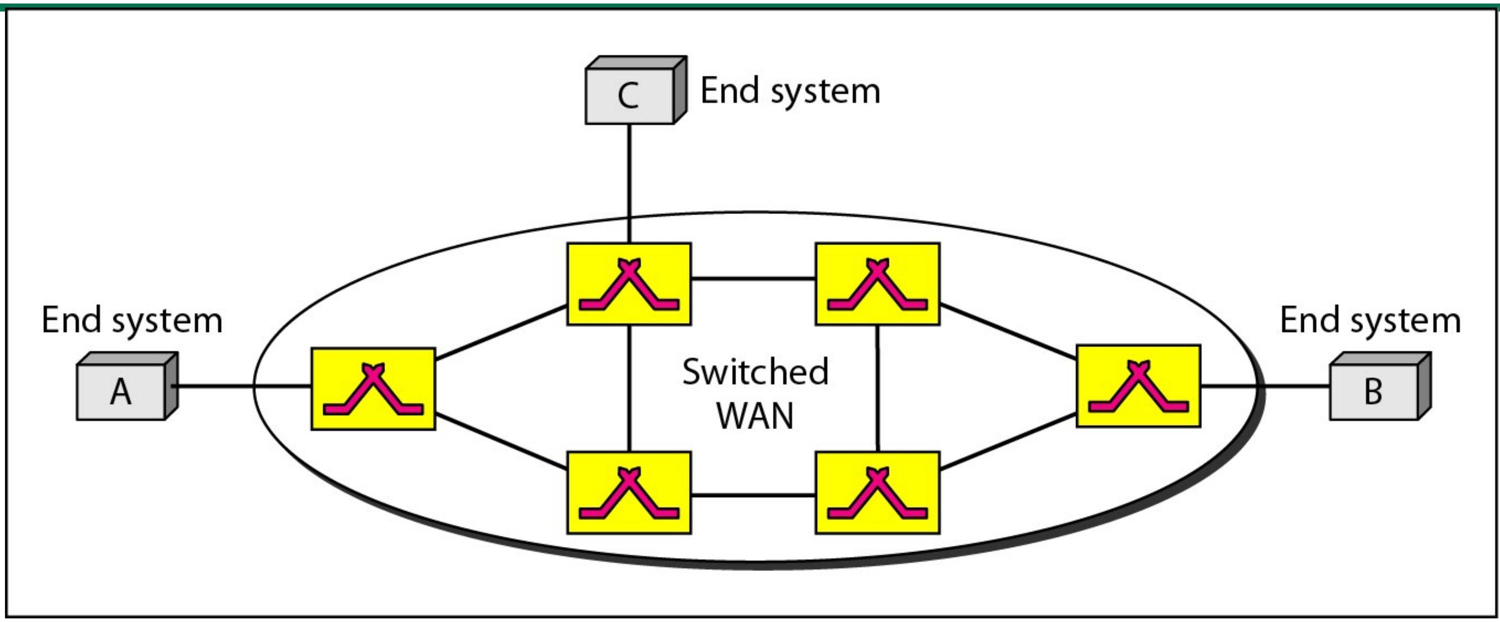
Categories of Networks

- ✓ Local Area Networks (LANs)
  - Short distances
  - Designed to provide local interconnectivity
- ✓ Wide Area Networks (WANs)
  - Long distances
  - Provide connectivity over large areas
- ✓ Metropolitan Area Networks (MANs)
  - Provide connectivity over areas such as a city, a campus

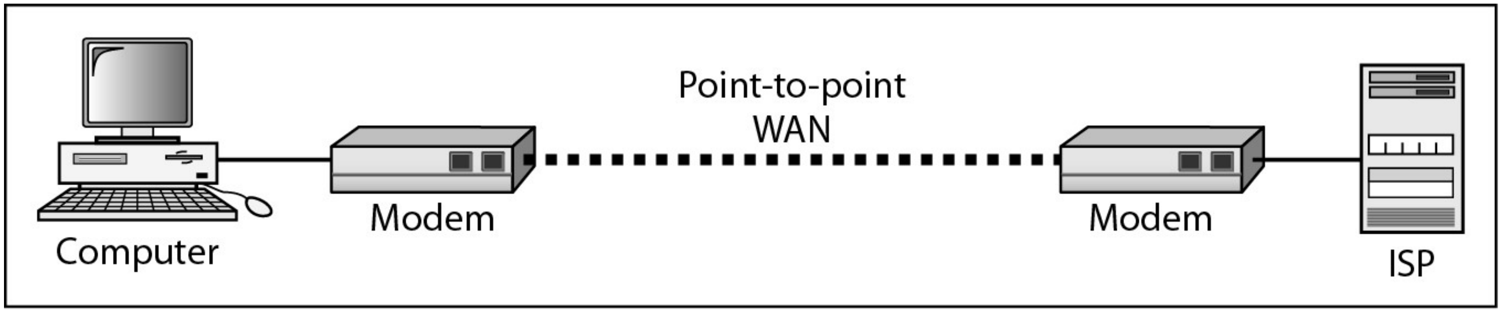


An isolated LAN connecting 12 computers to a hub in a closet

Module 1: *WAN:*



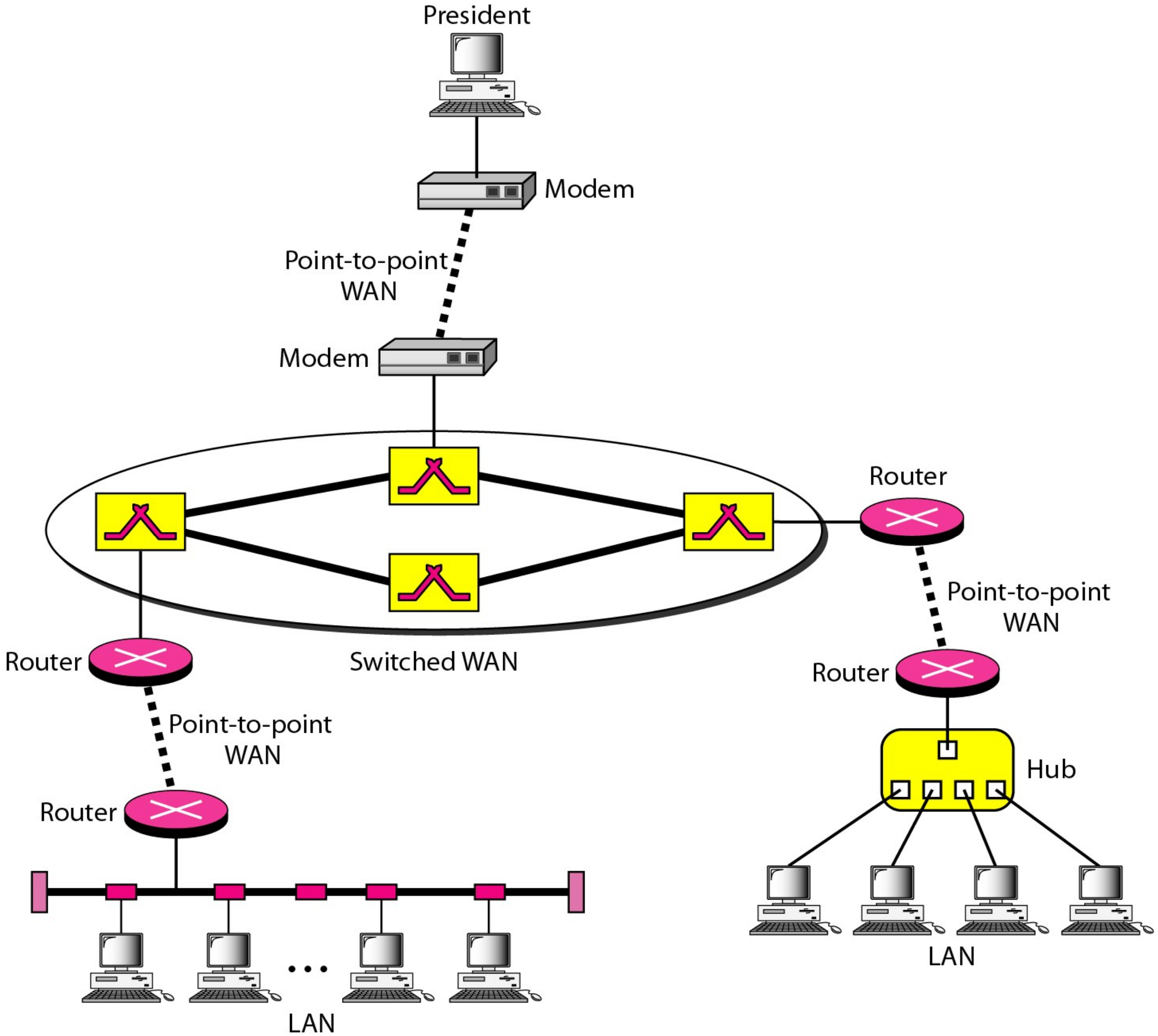
a. Switched WAN



b. Point-to-point WAN

WANs: a switched WAN and a point-to-point WAN

Module 1: *WAN:*

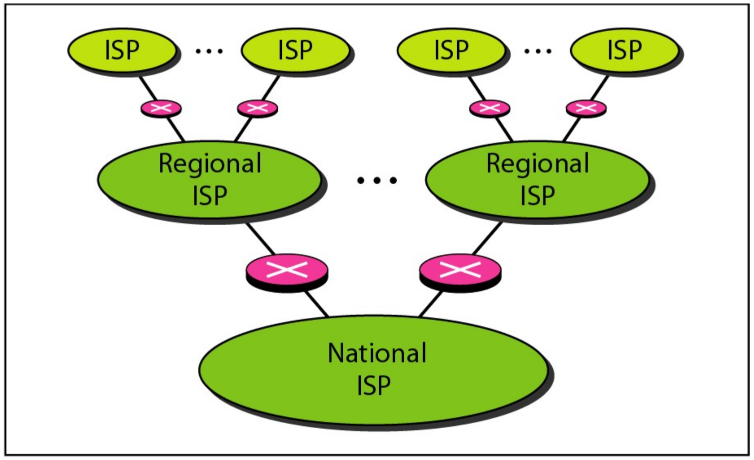


A heterogeneous network made of four WANs and two LANs

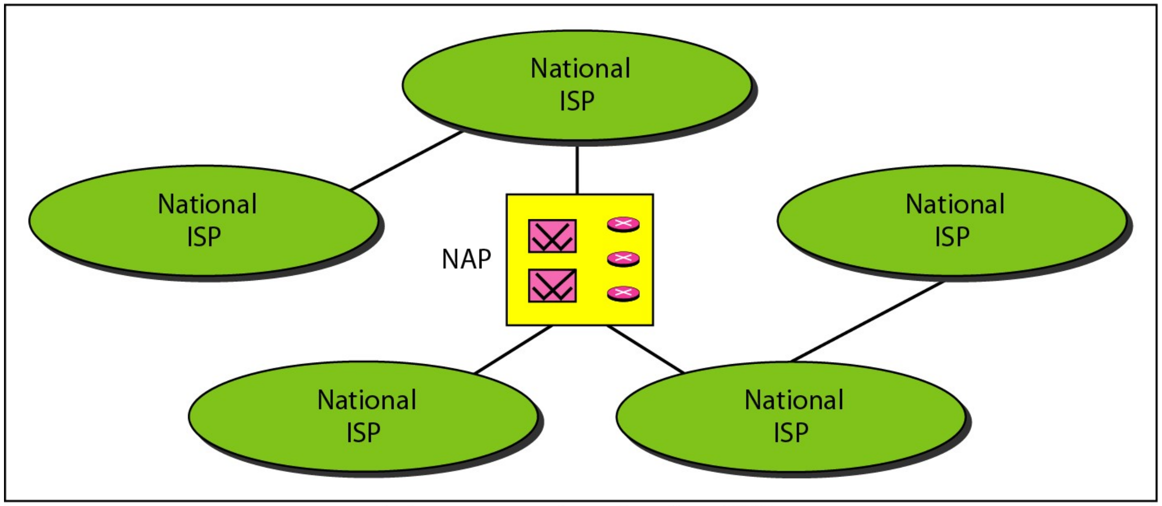
The Internet

- ✓ The Internet has revolutionized many aspects of our daily lives.
- ✓ It has affected the way we do business as well as the way we spend our leisure time.
- ✓ The Internet is a communication system that has brought a wealth of information to our fingertips and organized it for our use.

Module 1: *Internet:*



a. Structure of a national ISP



b. Interconnection of national ISPs

Hierarchical organization of the Internet

Protocol

- ✓ A protocol is synonymous with rule.
- ✓ It consists of a set of rules that govern data communications.
- ✓ It determines what is communicated, how it is communicated and when it is communicated.
- ✓ The key elements of a protocol are syntax, semantics and timing.

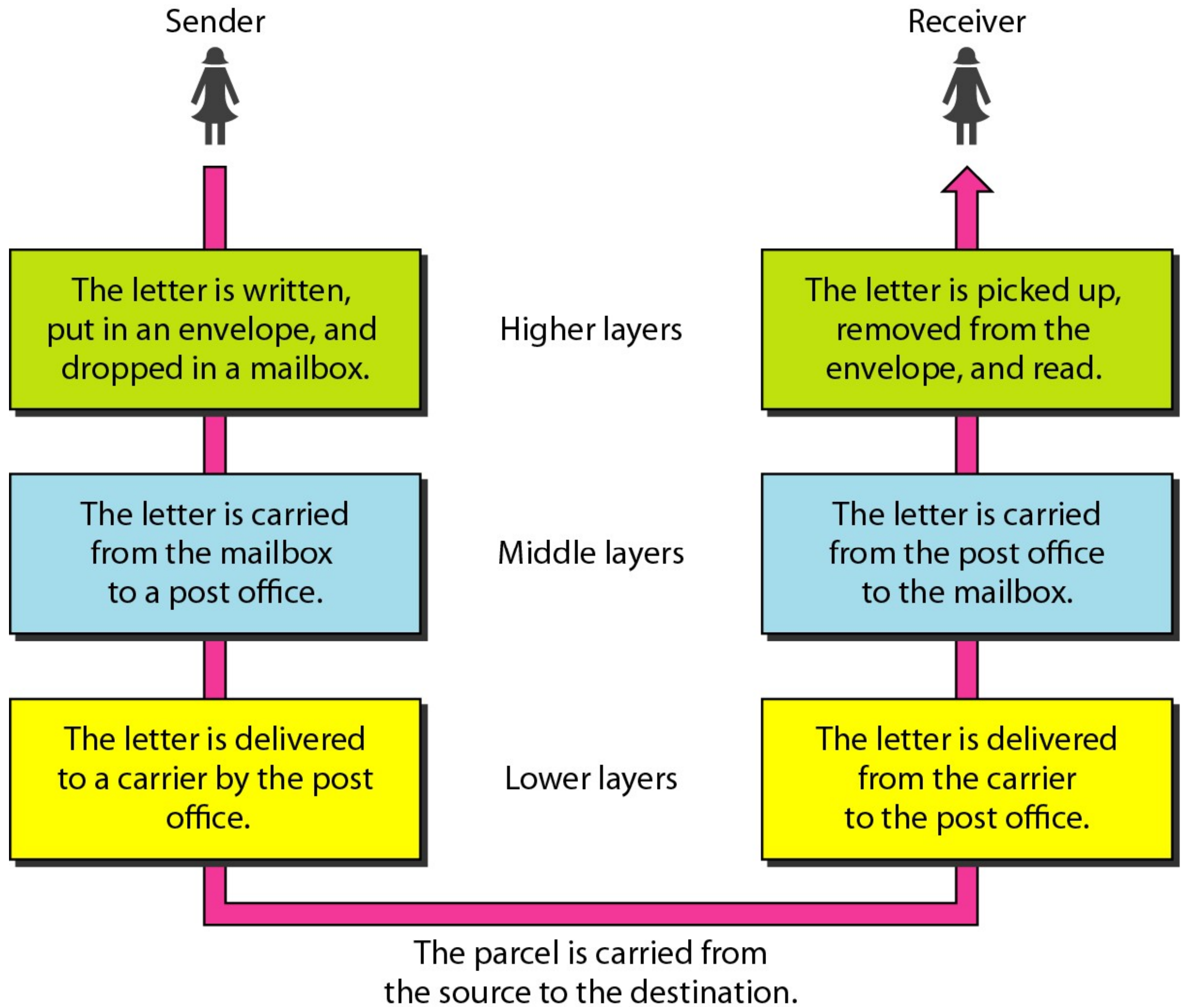
Elements of a Protocol

- ✓ Syntax
  - Structure or format of the data
  - Indicates how to read the bits - field delineation
- ✓ Semantics
  - Interprets the meaning of the bits
  - Knows which fields define what action
- ✓ Timing
  - When data should be sent and what
  - Speed at which data should be sent or speed at which it is being received.

Layered Tasks:

- ✓ We use the concept of layers in our daily life.
- ✓ As an example, let us consider two friends who communicate through postal mail.
- ✓ The process of sending a letter to a friend would be complex if there were no services available from the post office.

Module 1: *OSI Reference Model:*

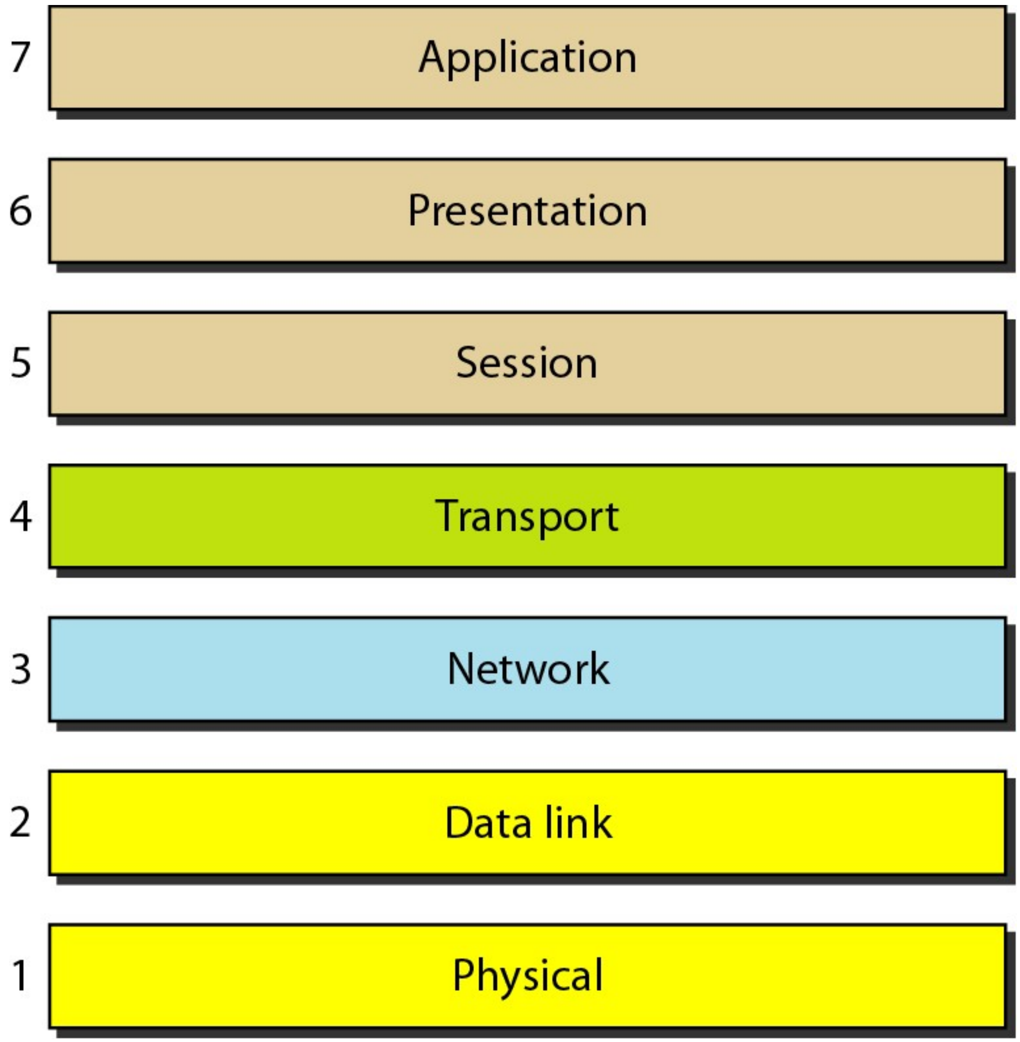


Tasks involved in sending a letter

The OSI Model:

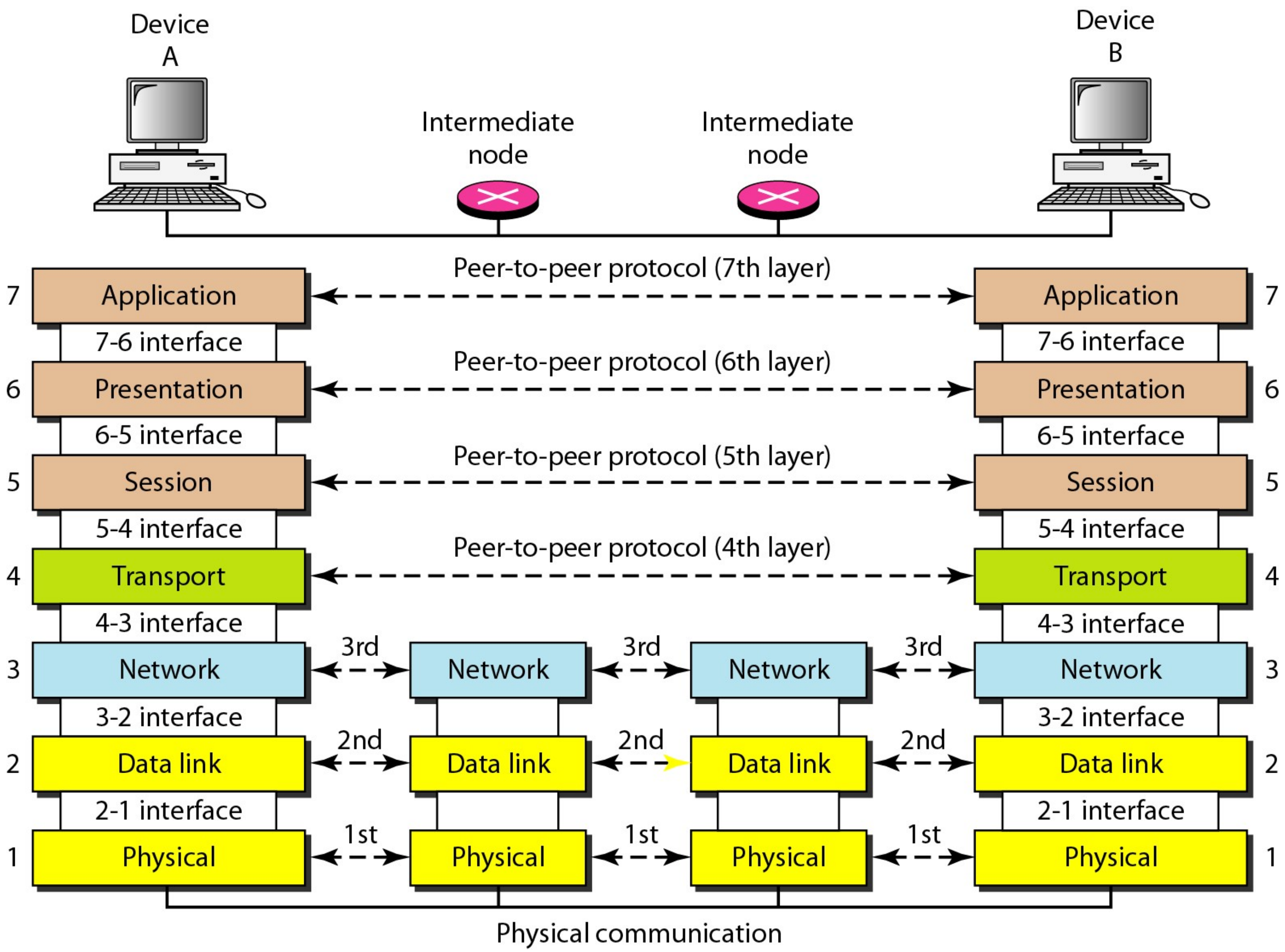
- ✓ Established in 1947 ,**International Organization for Standardization** is an independent, non-profitable, non-governmental organization that provides international standards.
- ✓ Internationally, a product or service, which is ISO certified is trusted and considered safe to use.
- ✓ An ISO standard that covers all aspects of network communications is the **Open Systems Interconnection** (OSI) model.
- ✓ It was first introduced in the late 1970s.

Module 1: *OSI Reference Model:*



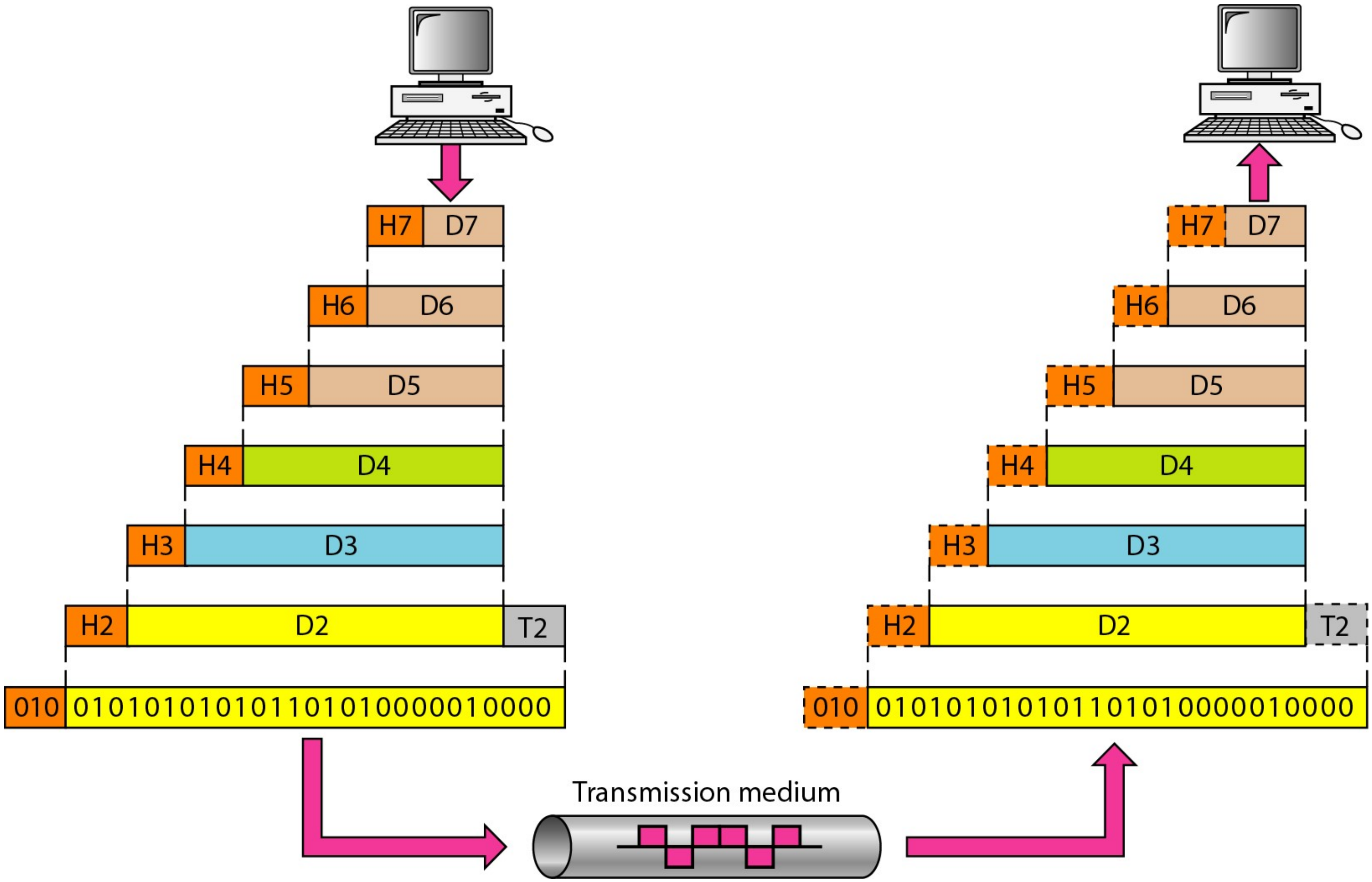
Seven layers of the OSI model

Module 1: *OSI Reference Model:*



The interaction between layers in the OSI model

Module 1: *OSI Reference Model:*



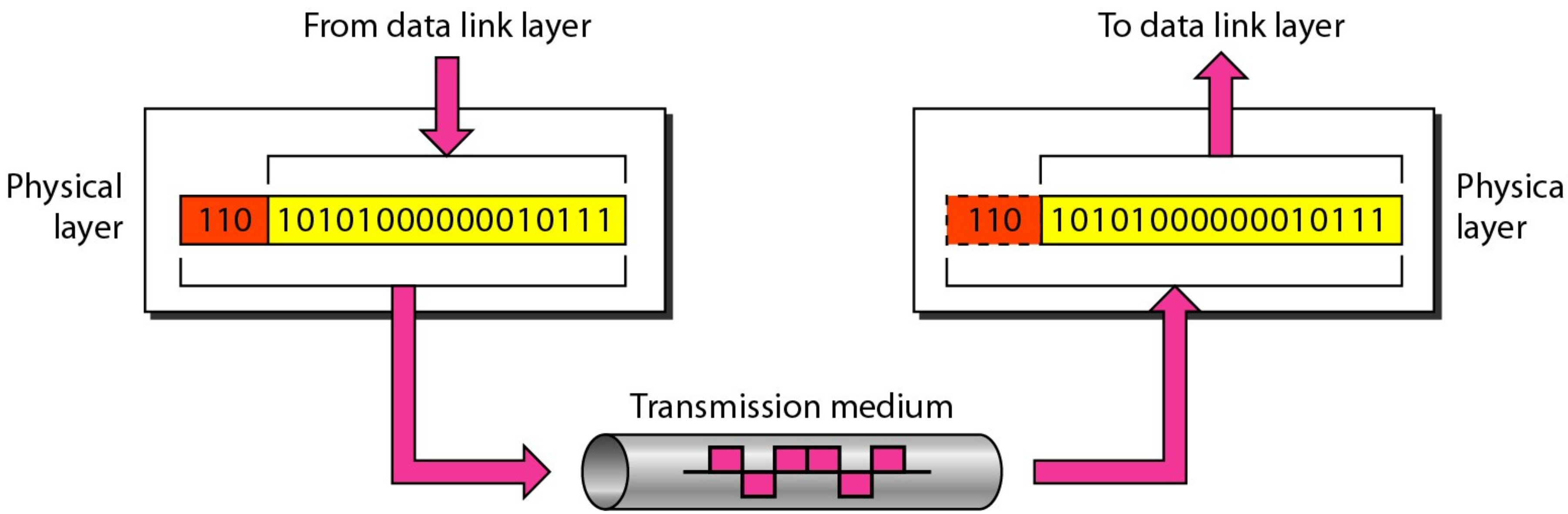
An exchange using the OSI model

Layers in the OSI model:

In this section we briefly describe the functions of each layer in the OSI model.

- ✓ Physical Layer
- ✓ Data Link Layer
  - ○ Media Access Control(MAC)
  - ○ Logical Link Control (LLC)
- ✓ Network Layer
- ✓ Transport Layer
- ✓ Session Layer
- ✓ Presentation Layer
- ✓ Application Layer

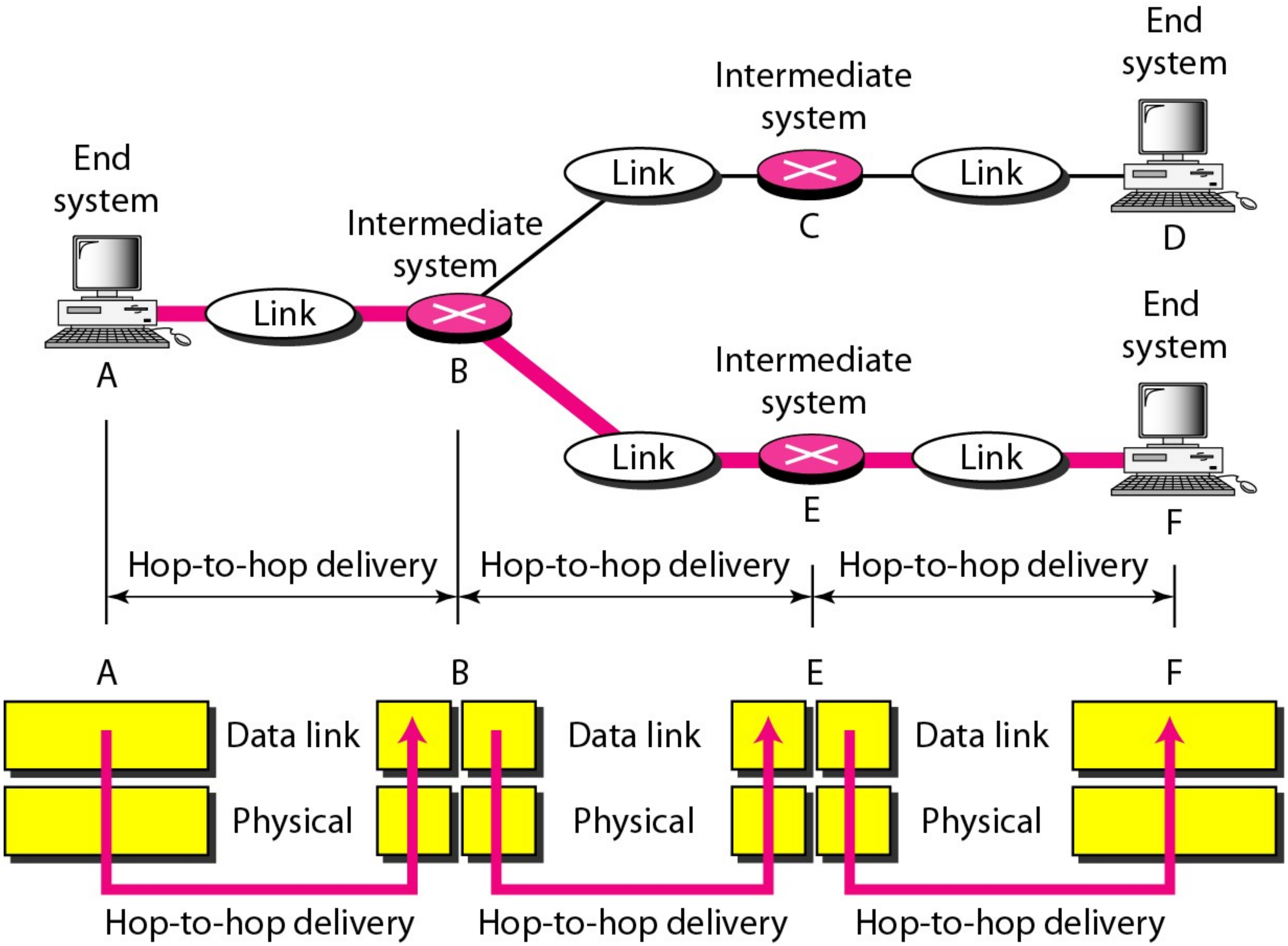
Module 1: *OSI Reference Model:*



Physical layer

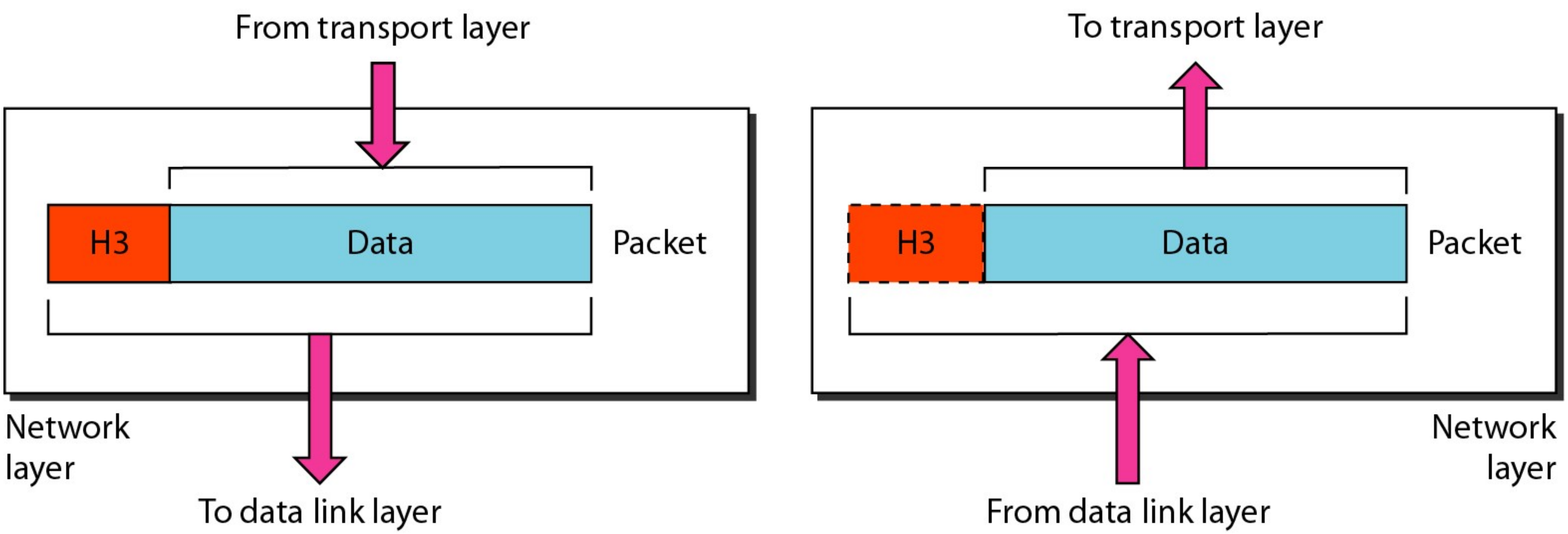
The physical layer is responsible for movements of individual bits from one hop (node) to the next.

Module 1: *OSI Reference Model:*



Hop-to-hop delivery

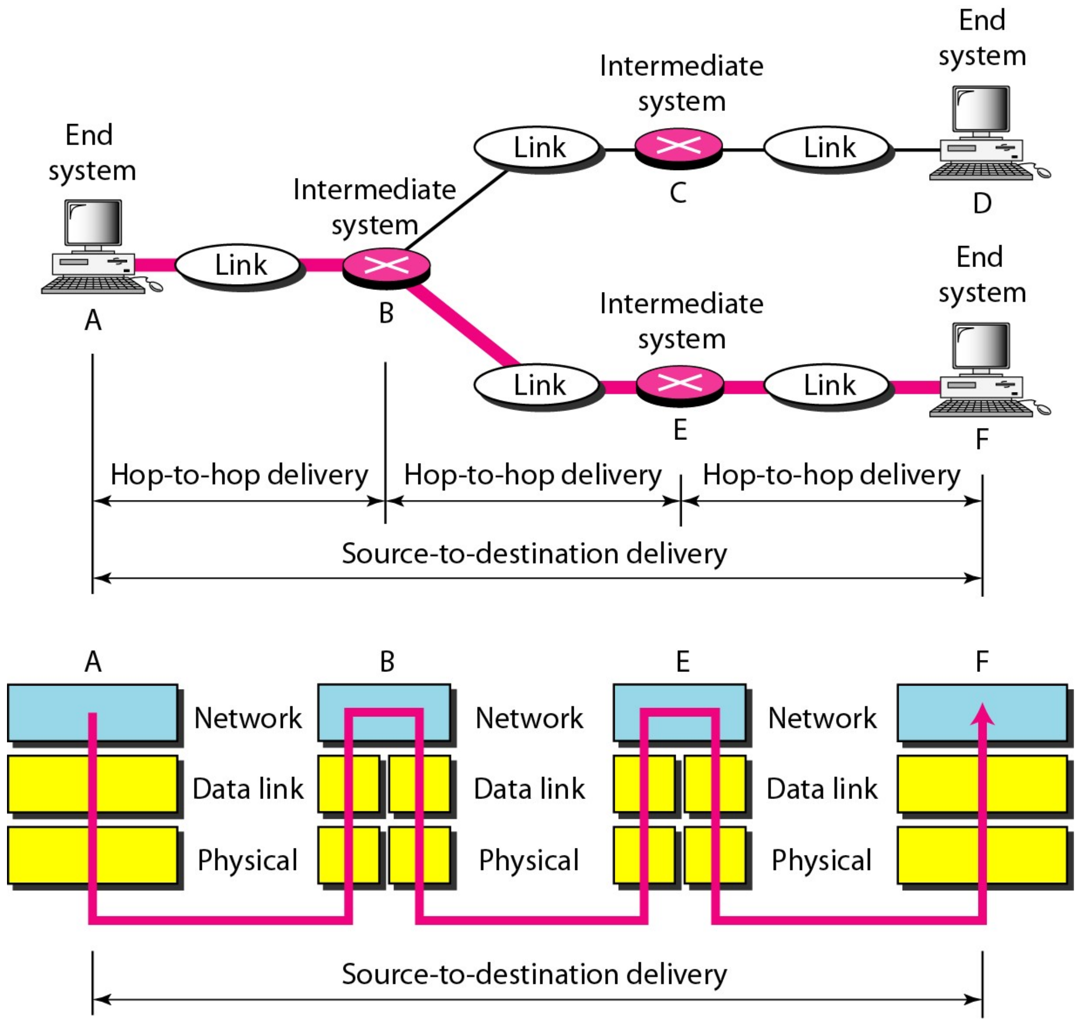
Module 1: *OSI Reference Model:*



Network layer

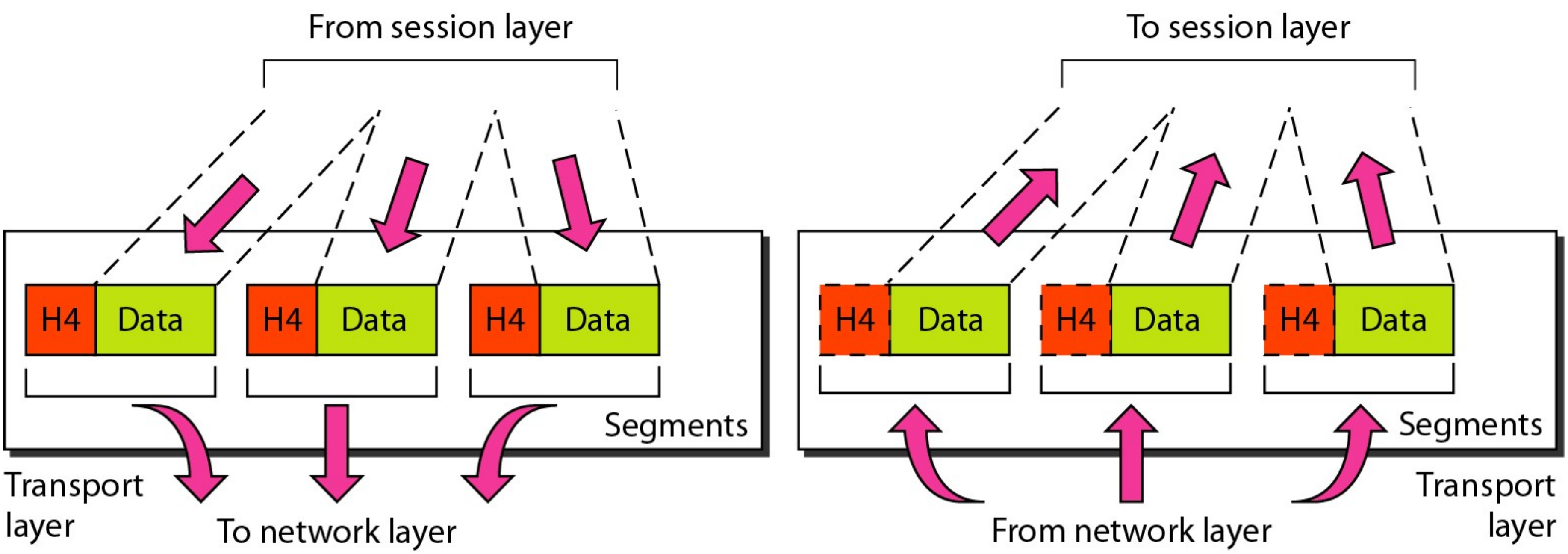
The network layer is responsible for the delivery of individual packets from the source host to the destination host.

Module 1: *OSI Reference Model:*



Source-to-destination delivery

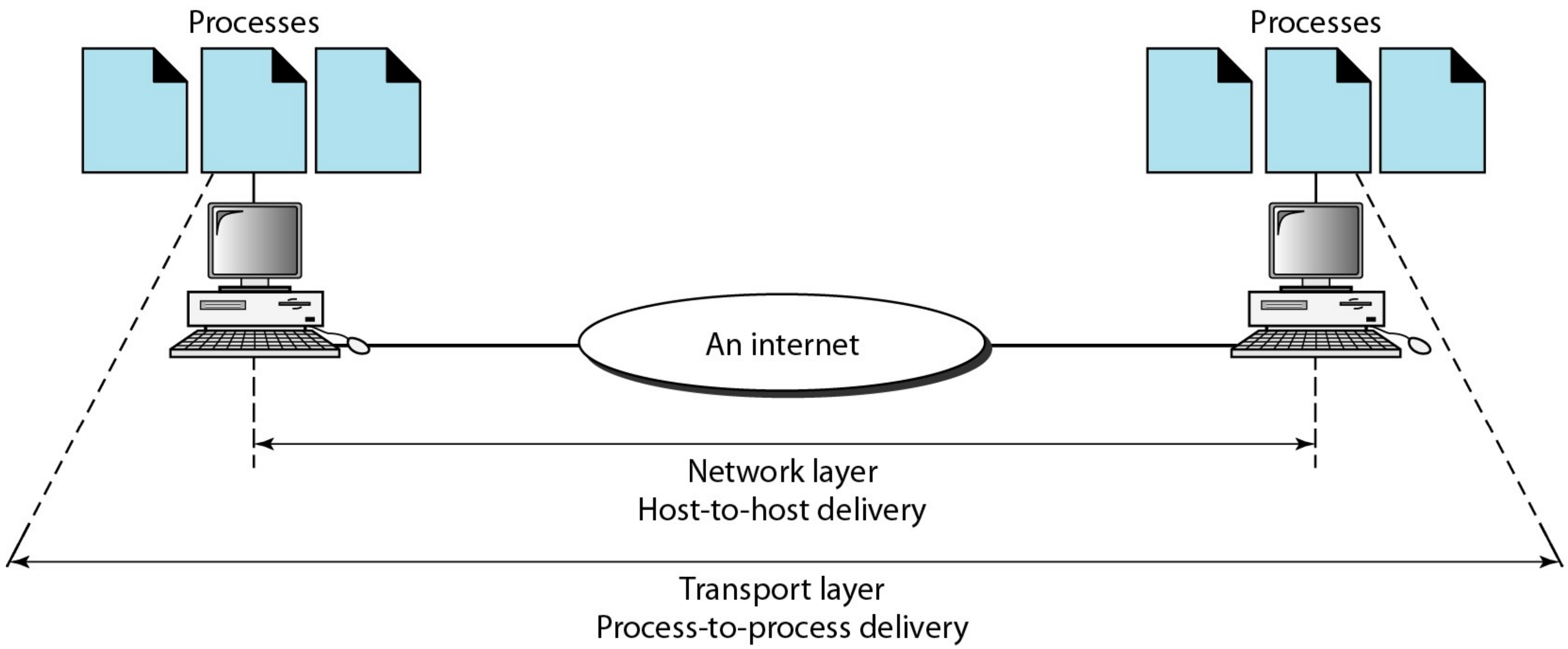
Module 1: *OSI Reference Model:*



Transport layer

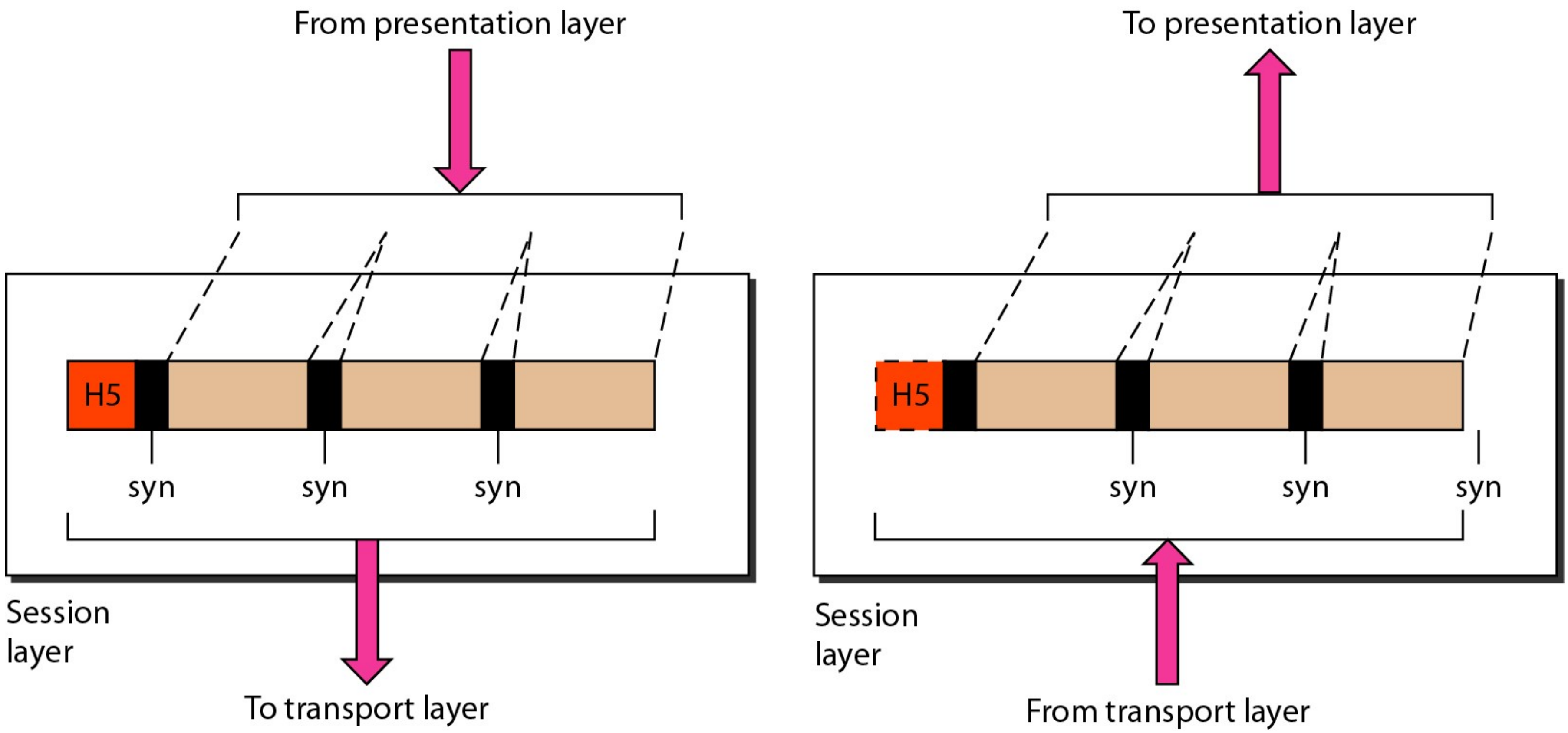
The transport layer is responsible for the delivery of a message from one process to another.

Module 1: *OSI Reference Model:*



Reliable process-to-process delivery of a message

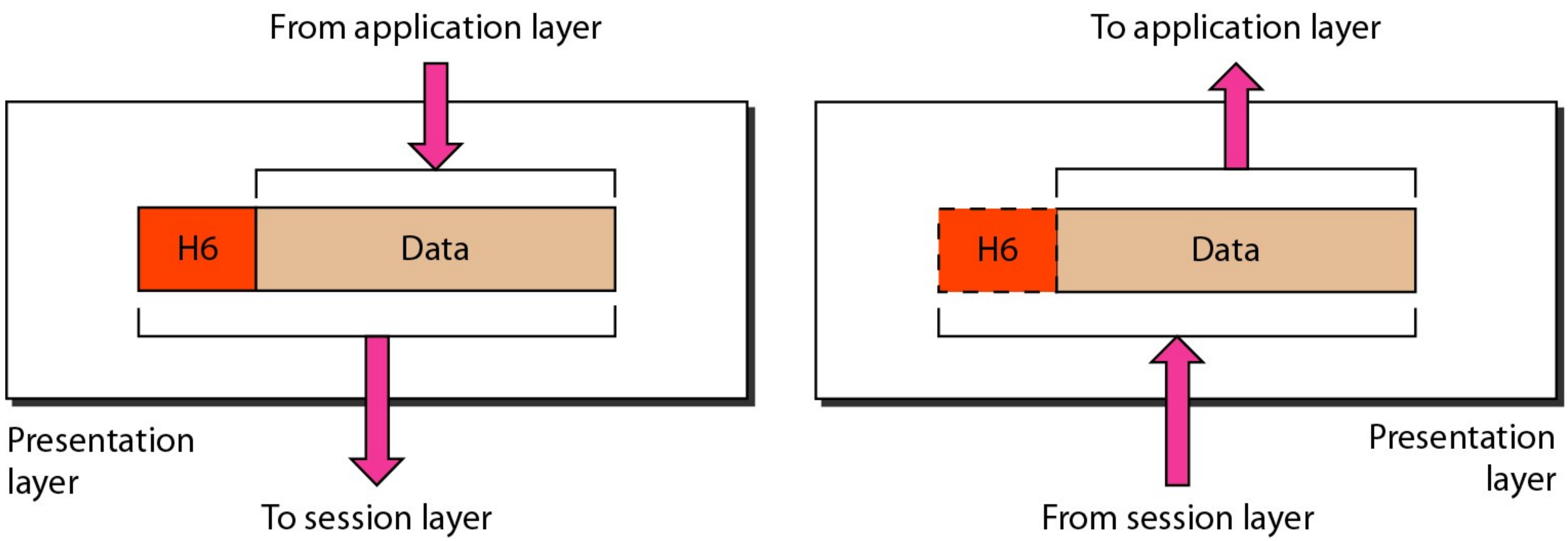
Module 1: *OSI Reference Model:*



Session layer

The session layer is responsible for dialog control and synchronization.

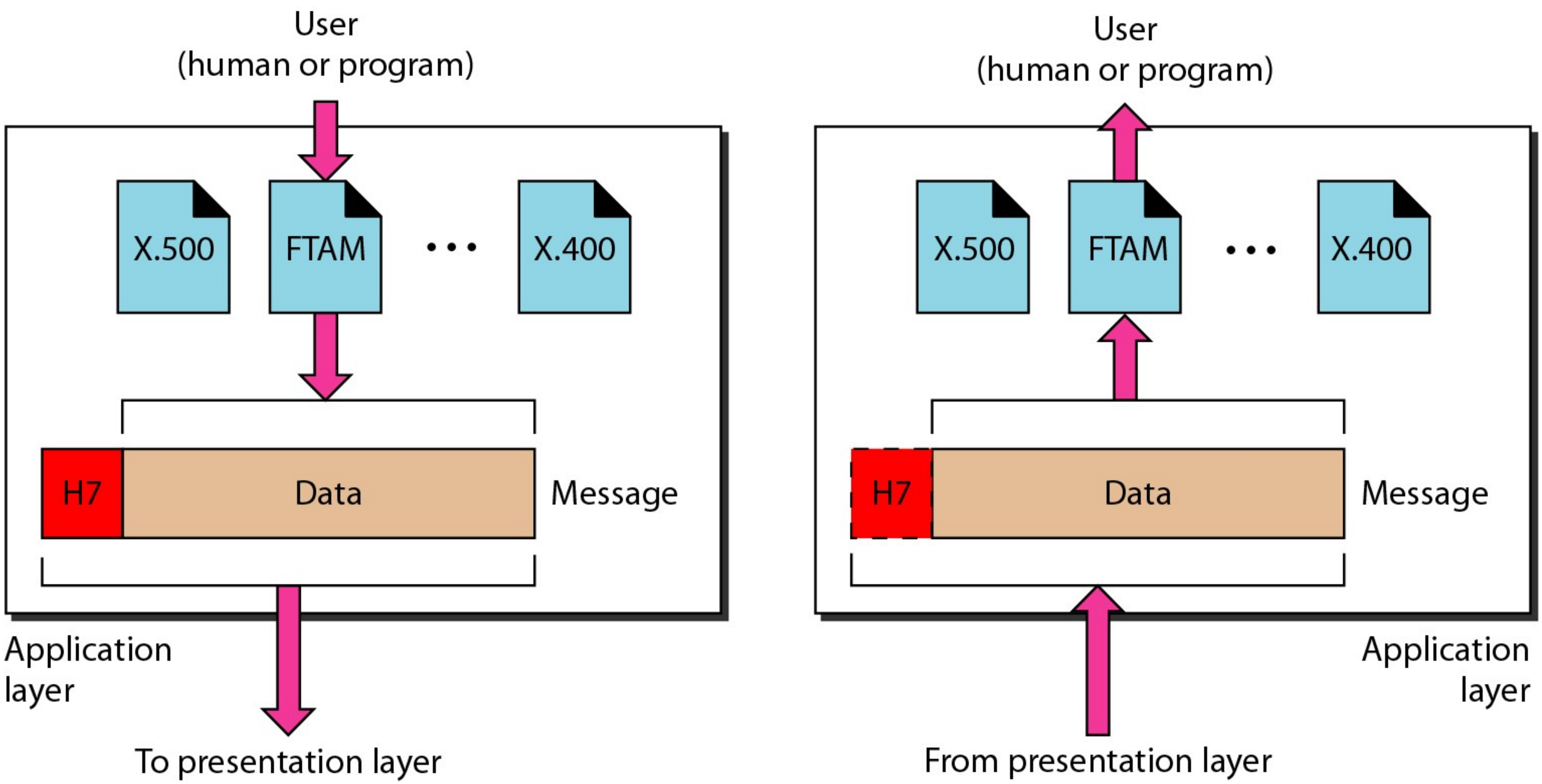
Module 1: *OSI Reference Model:*



Presentation layer

The presentation layer is responsible for translation, compression, and encryption.

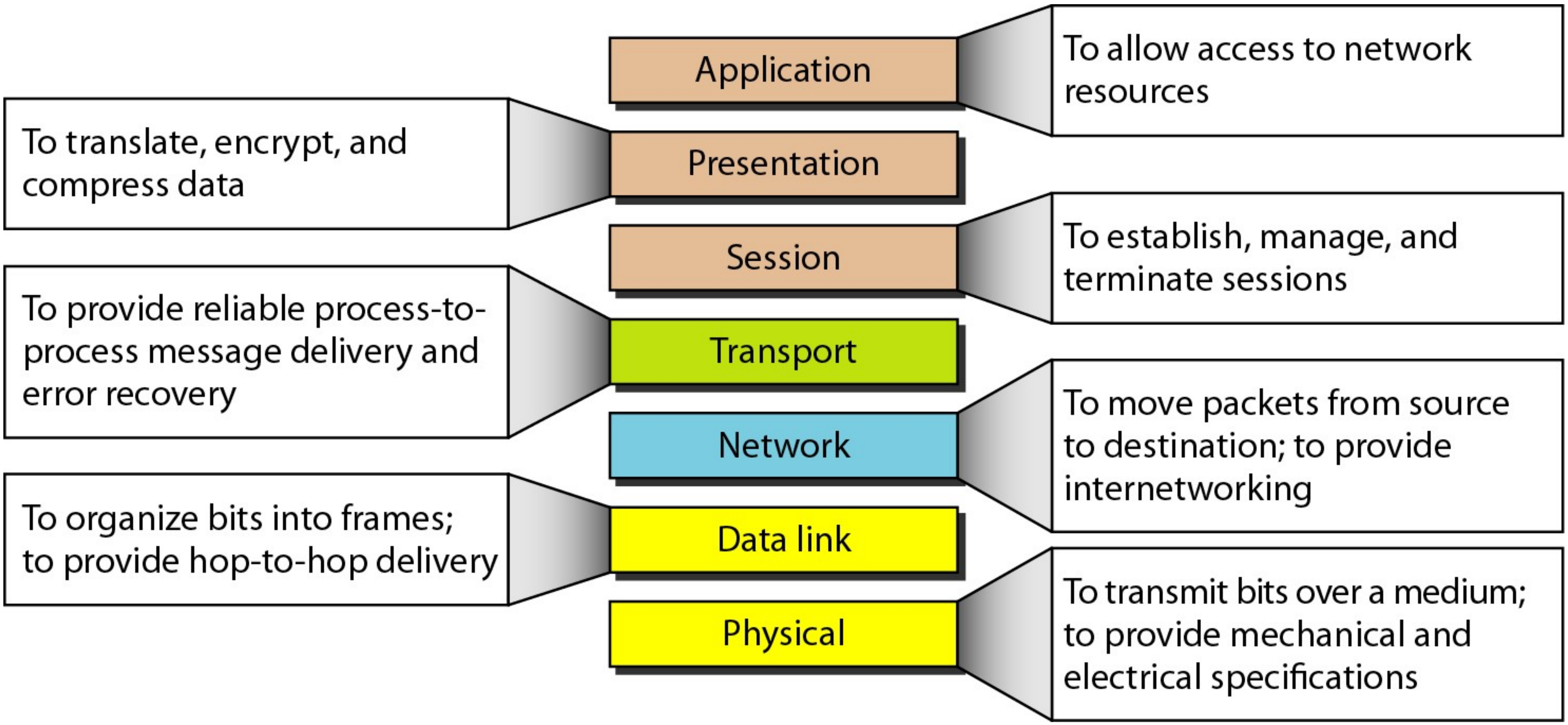
Module 1: *OSI Reference Model:*



Application layer

The application layer is responsible for providing services to the user.

Module 1: *OSI Reference Model:*

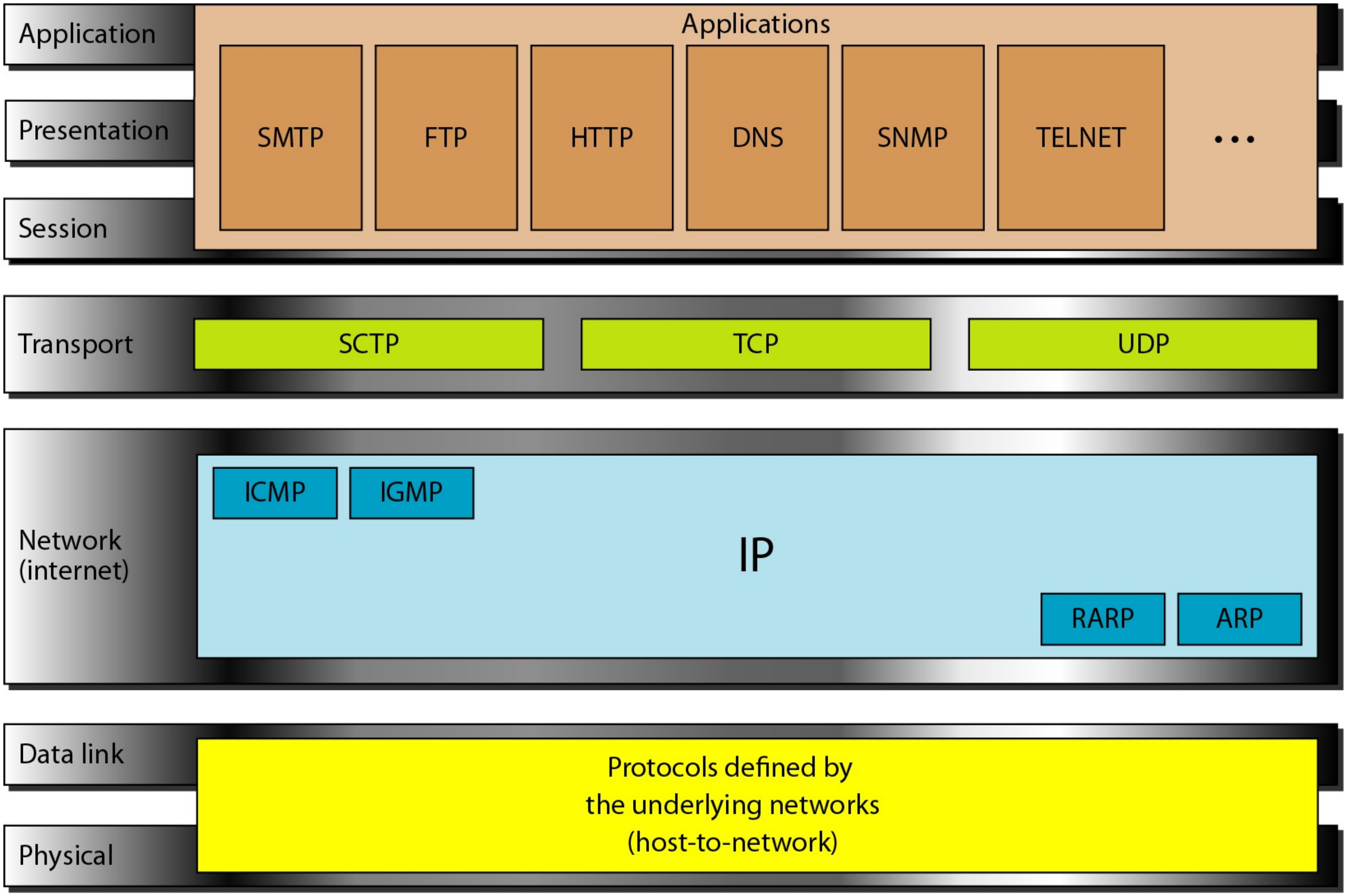


Summary of layers

Module 1: *TCP/IP protocol suite :*

- ✓ The layers in the TCP/IP protocol suite do not exactly match those in the OSI model.
- ✓ The original TCP/IP protocol suite was defined as having four layers: host-to-network, internet, transport, and application.
- ✓ However, when TCP/IP is compared to OSI, we can say that the TCP/IP protocol suite is made of five layers: physical, data link, network, transport, and application.

Module 1: *TCP/IP protocol suite :*



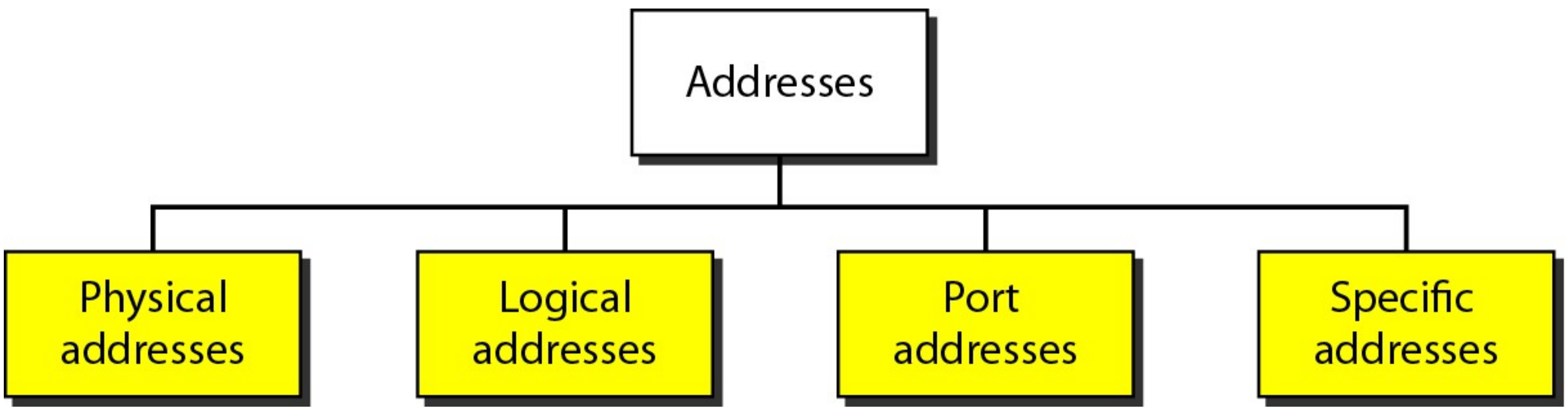
TCP/IP and OSI model

Module 1: *TCP/IP protocol suite :*

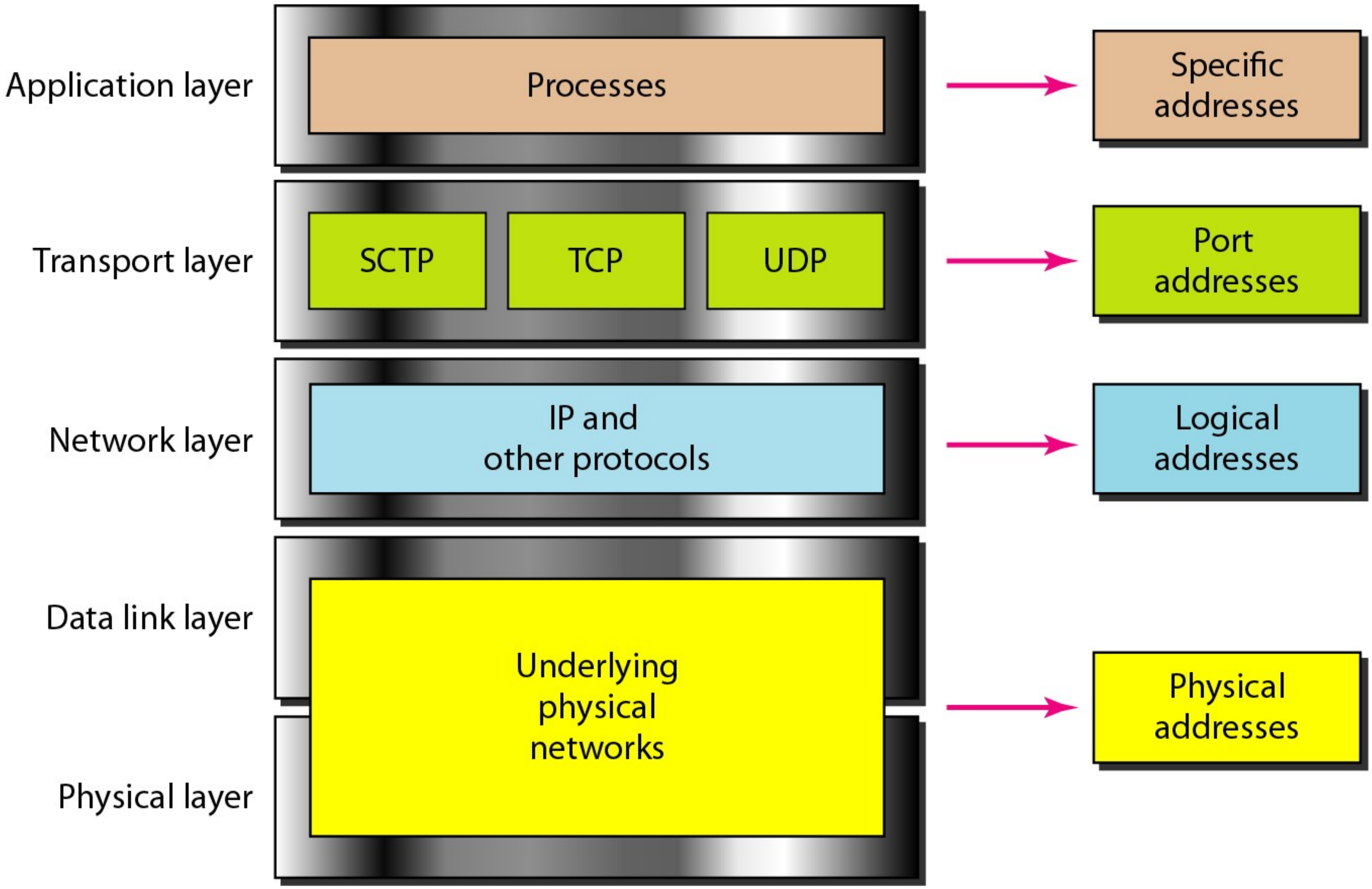
Addressing:

Four levels of addresses are used in an internet employing the TCP/IP protocols:

- ✓ *Physical address*
- ✓ *Logical address*
- ✓ *Port address*
- ✓ *Specific address*



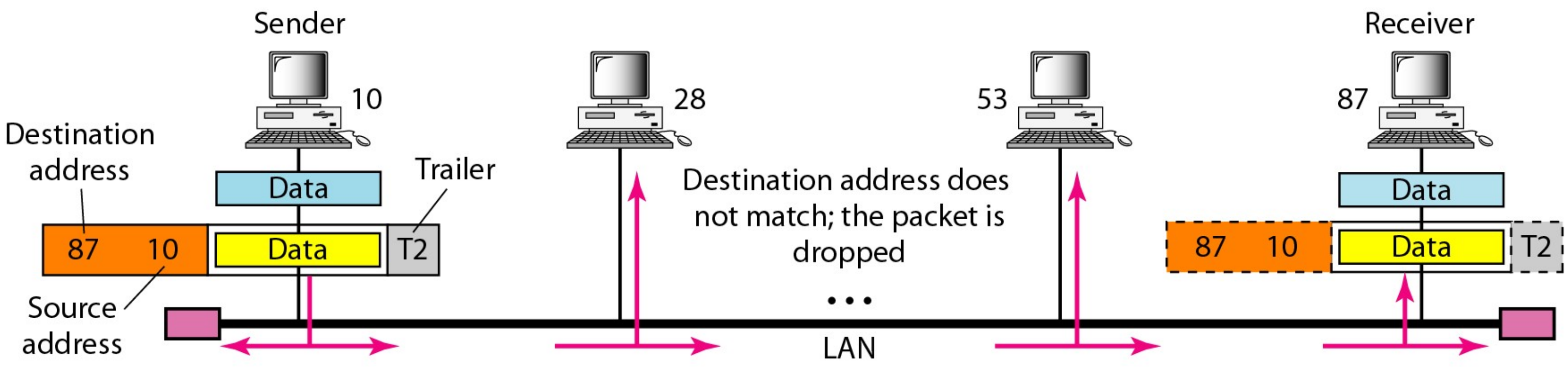
Module 1: *TCP/IP protocol suite :*



Relationship of layers and addresses in TCP/IP

Example:

- ✓ *A node with physical address 10 sends a frame to a node with physical address 87.*
- ✓ *The two nodes are connected by a link (bus topology LAN).*
- ✓ *The computer with physical address 10 is the sender, and the computer with physical address 87 is the receiver.*



Module 1: *TCP/IP protocol suite :*

Most local-area networks use a 48-bit (6-byte) physical address written as 12 hexadecimal digits; every byte (2 hexadecimal digits) is separated by a colon, as shown below:

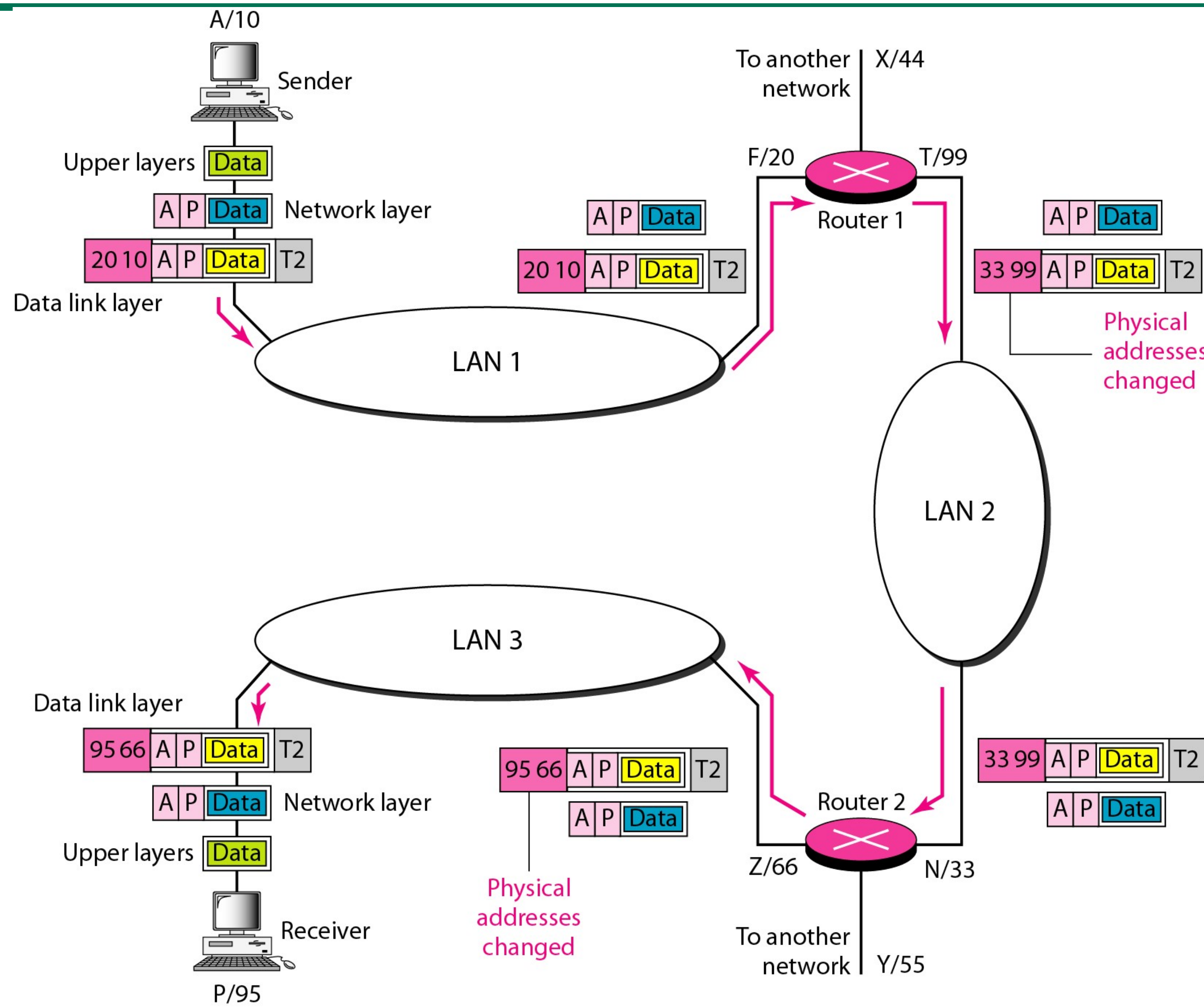
07:01:02:01:2C:4B

A 6-byte (12 hexadecimal digits) physical address.

Example:

- ✓ A part of an internet with two routers connecting three LANs.
- ✓ Each device (computer or router) has a pair of addresses (logical and physical) for each connection.
- ✓ In this case, each computer is connected to only one link and therefore has only one pair of addresses.
- ✓ Each router, however, is connected to three networks (only two are shown in the figure).
- ✓ So each router has three pairs of addresses, one for each connection.

Module 1: *TCP/IP protocol suite :*



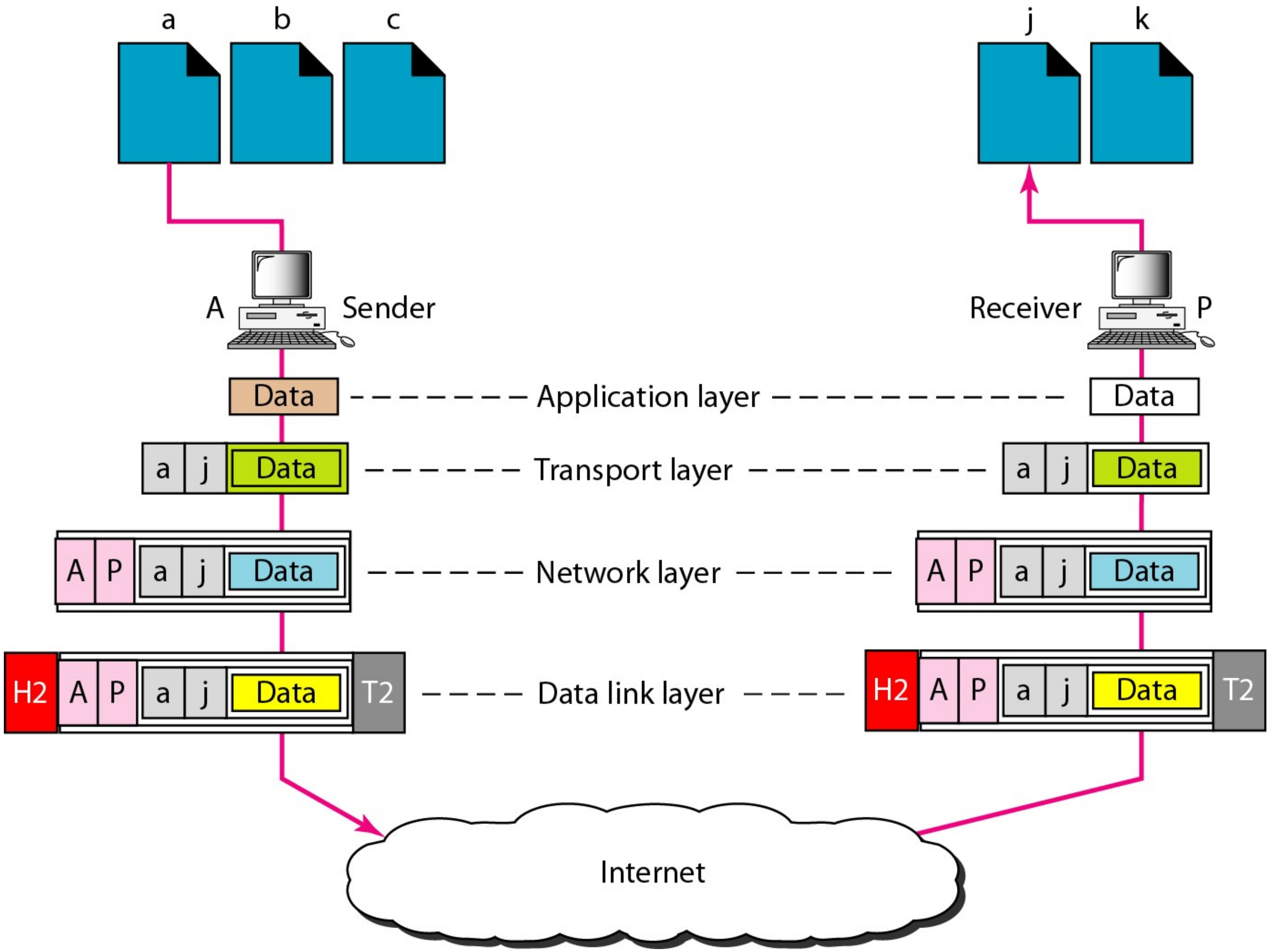
IP addresses

Module 1: *TCP/IP protocol suite :*

Example:

- ✓ Two computers communicating via the Internet.
- ✓ The sending computer is running three processes at this time with port addresses a, b, and c.
- ✓ The receiving computer is running two processes at this time with port addresses j and k.
- ✓ Process a in the sending computer needs to communicate with process j in the receiving computer.
- ✓ Note that although physical addresses change from hop to hop, logical and port addresses remain the same from the source to destination.

Module 1: *TCP/IP protocol suite :*



Port addresses

A port address is a 16-bit address represented by one decimal number as shown.

753

A 16-bit port address represented
as one single number.

Data and Signals

- ✓ Generally, the data usable to a person or application are not in a form that can be transmitted over a network.
- ✓ For example, a photograph must first be changed to a form that transmission media can accept.
- ✓ Transmission media work by conducting energy along a physical path.
- ✓ To be transmitted, data must be transformed to electromagnetic signals.

Analog and Digital Data

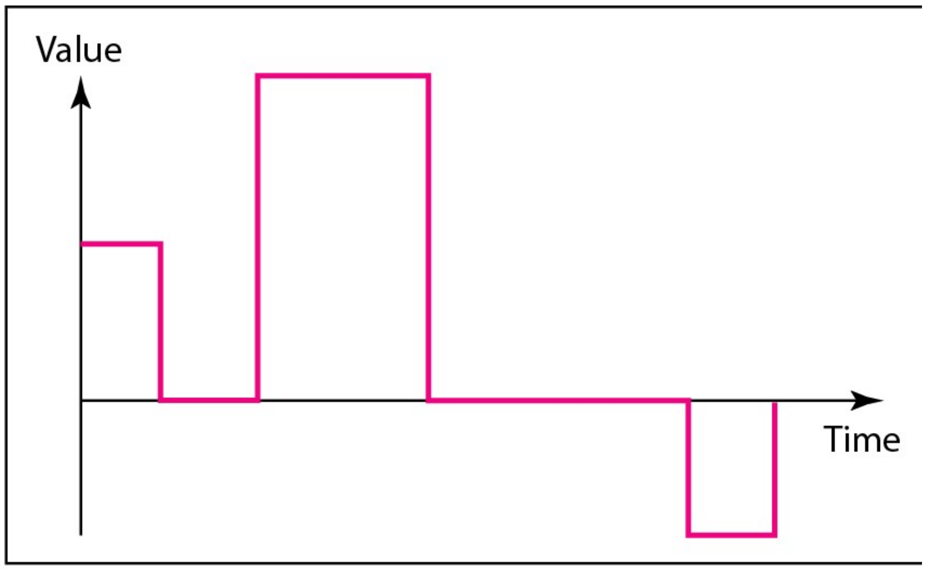
- ✓ Both data and the signals that represent them can be either analog or digital in form.
- ✓ The term analog data refers to information that is continuous .
- ✓ Digital data refers to information that has discrete states.

Analog and Digital Signals

- ✓ Signals can be analog or digital.
- ✓ Analog signals can have an infinite number of values in a range.
- ✓ Digital signals can have only a limited number of values.

Module 1: *Analog and Digital Signals :*

a. Analog signal



b. Digital signal

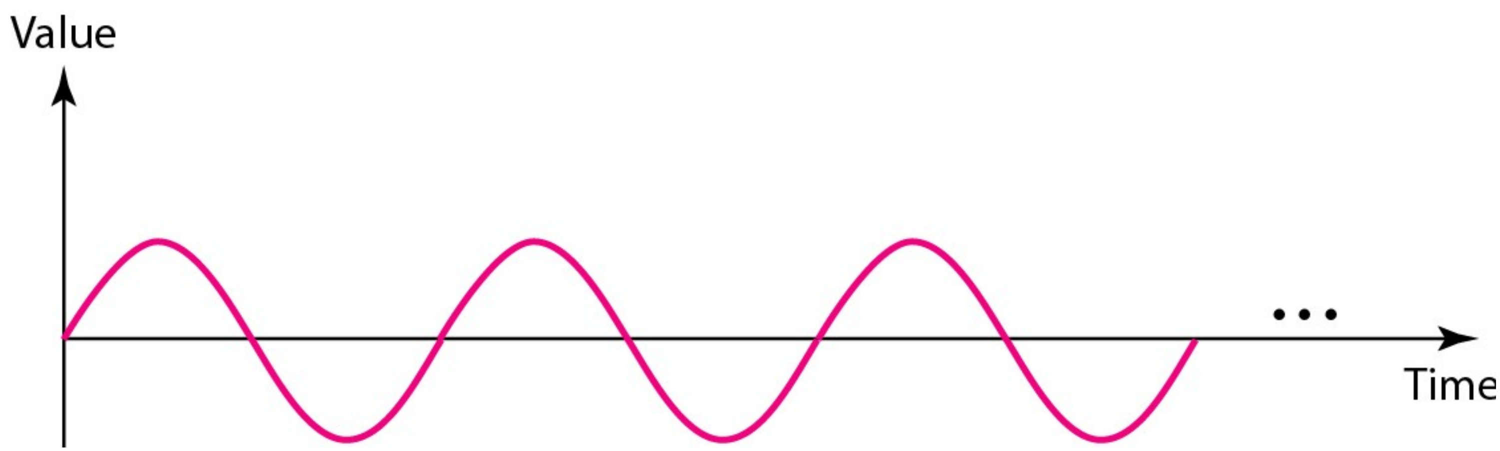
Module 1: *Periodic and Nonperiodic Signals:*

Periodic and Nonperiodic Signals

- ✓ A periodic signal completes a pattern within a measurable time frame, called a period, and repeats that pattern over subsequent identical periods.
- ✓ The completion of one full pattern is called a cycle.
- ✓ A nonperiodic signal changes without exhibiting a pattern or cycle that repeats over time.

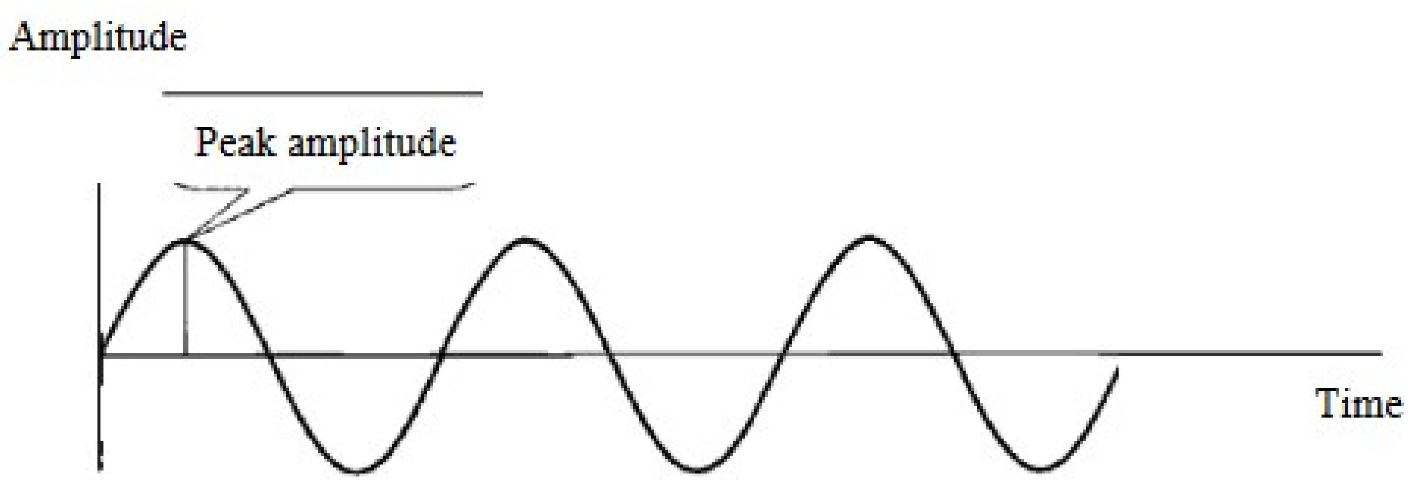
Periodic analog signals

- ✓ Periodic analog signals can be classified as simple or composite.
- ✓ A simple periodic analog signal, a sine wave, cannot be decomposed into simpler signals.
- ✓ A composite periodic analog signal is composed of multiple sine waves.



Peak Amplitude

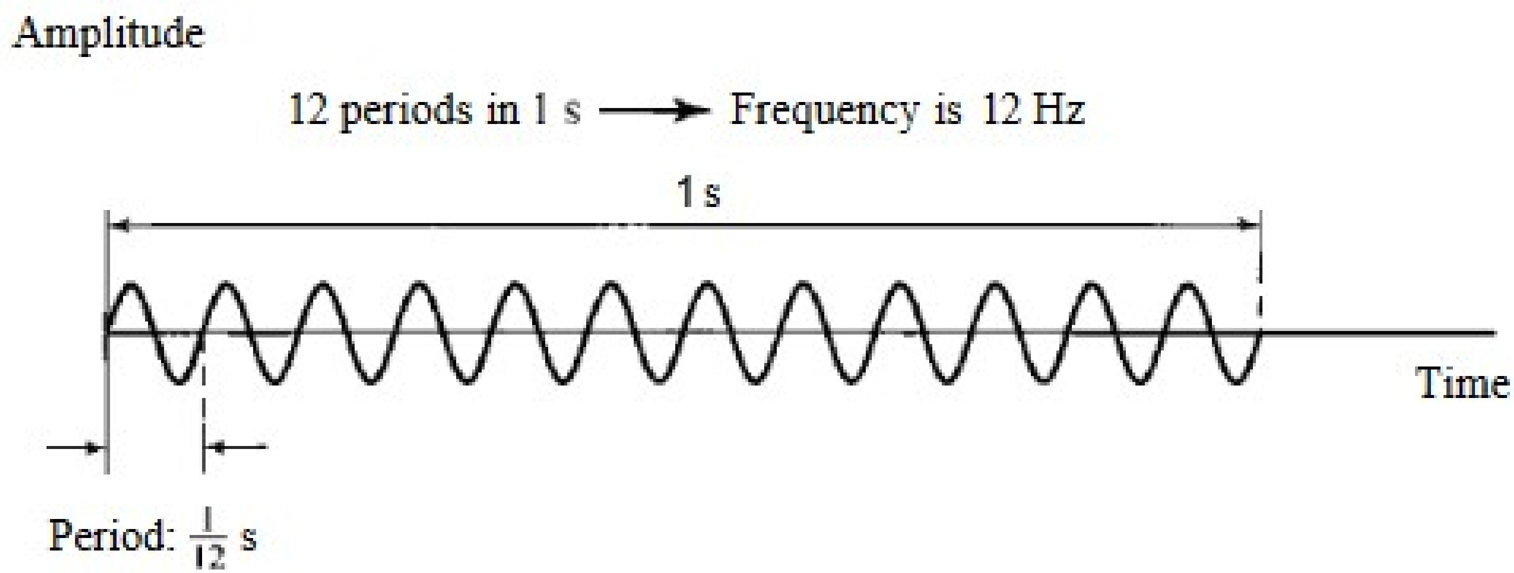
- ✓ The peak amplitude of a signal is the absolute value of its highest intensity, proportional to the energy it carries.
- ✓ For electric signals, peak amplitude is normally measured in volts.



Period and Frequency

- ✓ Period refers to the amount of time, in seconds, a signal needs to complete 1 cycle.
- ✓ Frequency refers to the number of periods in 1 second.
- ✓ Note that period and frequency are just one characteristic defined in two ways.
- ✓ Period is the inverse of frequency, and frequency
- ✓ is the inverse of period.

Module 1: *Period and Frequency :*



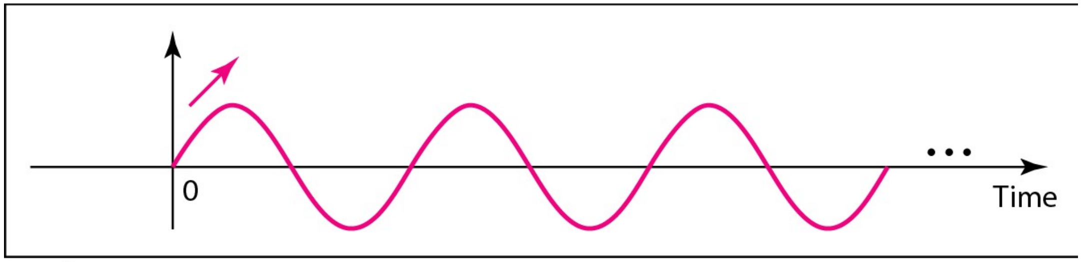
- ✓ Frequency is the rate of change with respect to time.
- ✓ Change in a short span of time means high frequency.
- ✓ Change over a long span of time means low frequency.

Module 1: *Phase:*

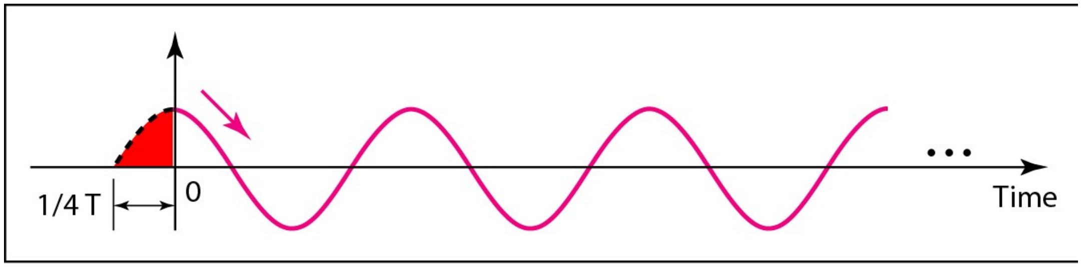
Phase

- ✓ The term phase describes the position of the waveform relative to time 0.
- ✓ A sine wave with a phase of 0° starts at time 0 with a zero amplitude.
- ✓ The amplitude is increasing.
- ✓ A sine wave with a phase of 90° starts at time 0 with a peak amplitude.
- ✓ The amplitude is decreasing.
- ✓ A sine wave with a phase of 180° starts at time 0 with a zero amplitude.
- ✓ The amplitude is decreasing.

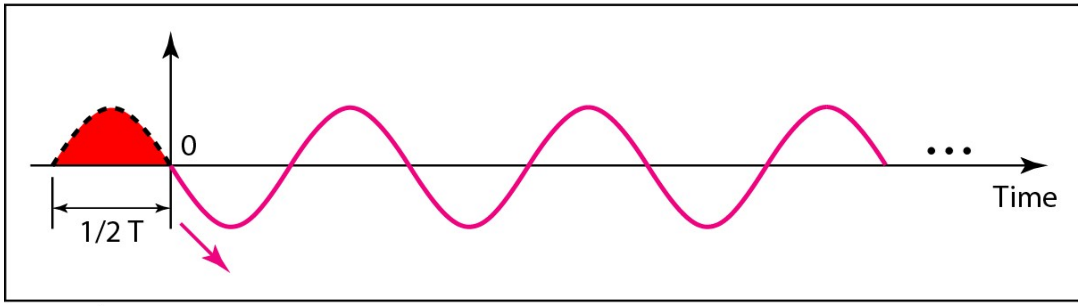
Module 1: *Phase :*



a. 0 degrees



b. 90 degrees



c. 180 degrees

Module 1: *Phase :*

Example:

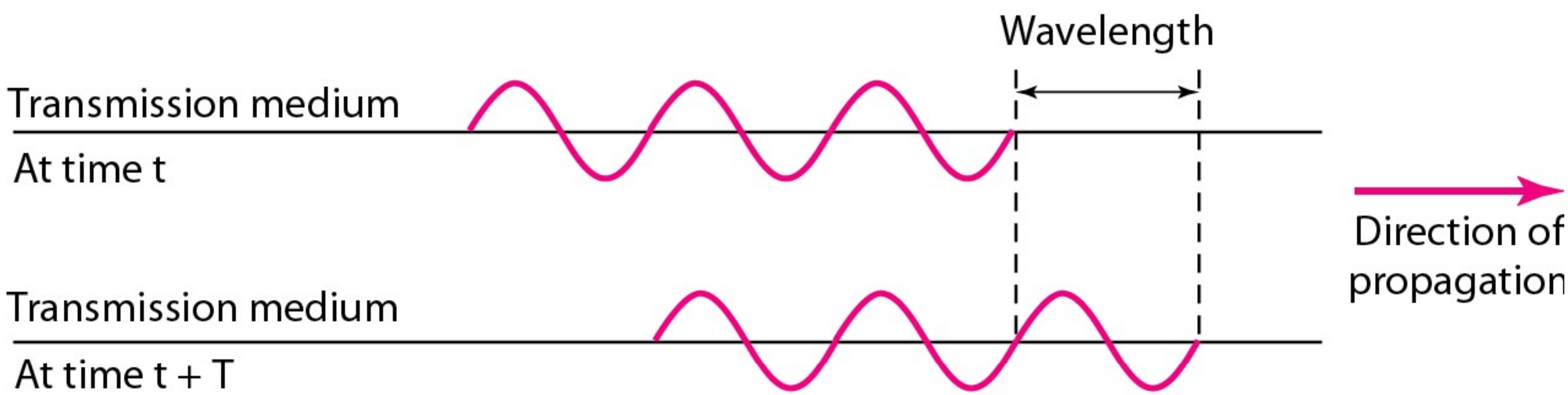
A sine wave is offset 1/6 cycle with respect to time 0. What is its phase in degrees and radians?

Solution

We know that 1 complete cycle is 360°. Therefore, 1/6 cycle is

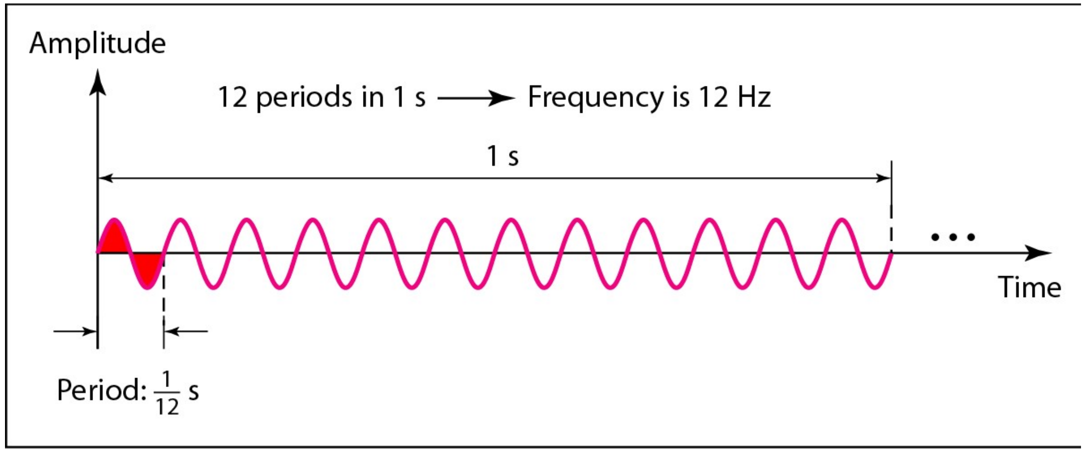
$$\frac{1}{6} \times 360 = 60^\circ = 60 \times \frac{2\pi}{360} \text{ rad} = \frac{\pi}{3} \text{ rad} = 1.046 \text{ rad}$$

Module 1: *Phase :*

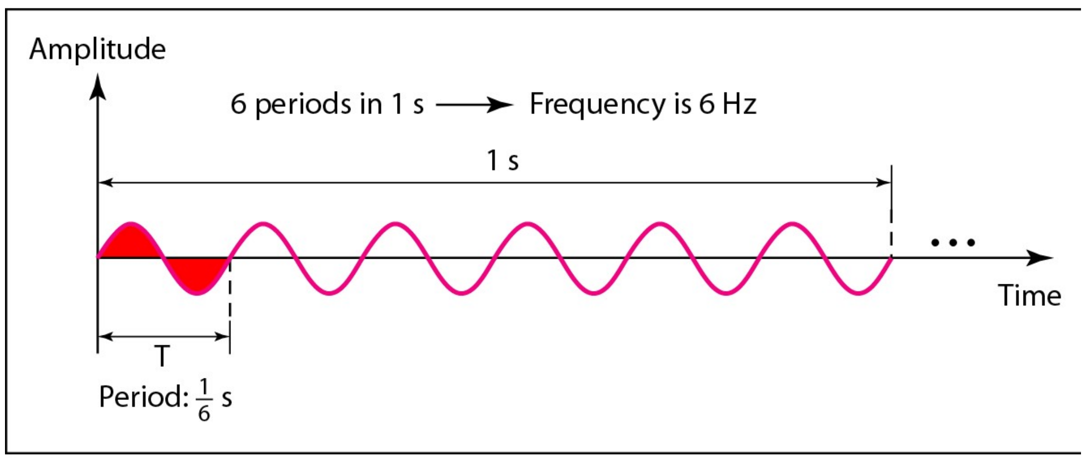


Wavelength and period

Module 1: *Phase :*



a. A signal with a frequency of 12 Hz



b. A signal with a frequency of 6 Hz

Two signals with the same amplitude and phase, but different frequencies

Example:

The power we use at home has a frequency of 60 Hz. The period of this sine wave can be determined as follows:

$$\boxed{T = \frac{1}{f} = \frac{1}{60} = 0.0166\ \text{s} = 0.0166 \times 10^3\ \text{ms} = 16.6\ \text{ms}}$$

Module 1: *Phase :*

Example:

The period of a signal is 100 ms. What is its frequency in kilohertz?

Solution

First we change 100 ms to seconds, and then we calculate the frequency from the period (1 Hz = 10^{-3} kHz).

$$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 10^{-1} \text{ s}$$

$$f = \frac{1}{T} = \frac{1}{10^{-1}} \text{ Hz} = 10 \text{ Hz} = 10 \times 10^{-3} \text{ kHz} = 10^{-2} \text{ kHz}$$

Frequency

- ✓ Frequency is the rate of change with respect to time.
- ✓ Change in a short span of time means high frequency.
- ✓ Change over a long span of time means low frequency.

Module 1: *Time and Frequency Domains:*

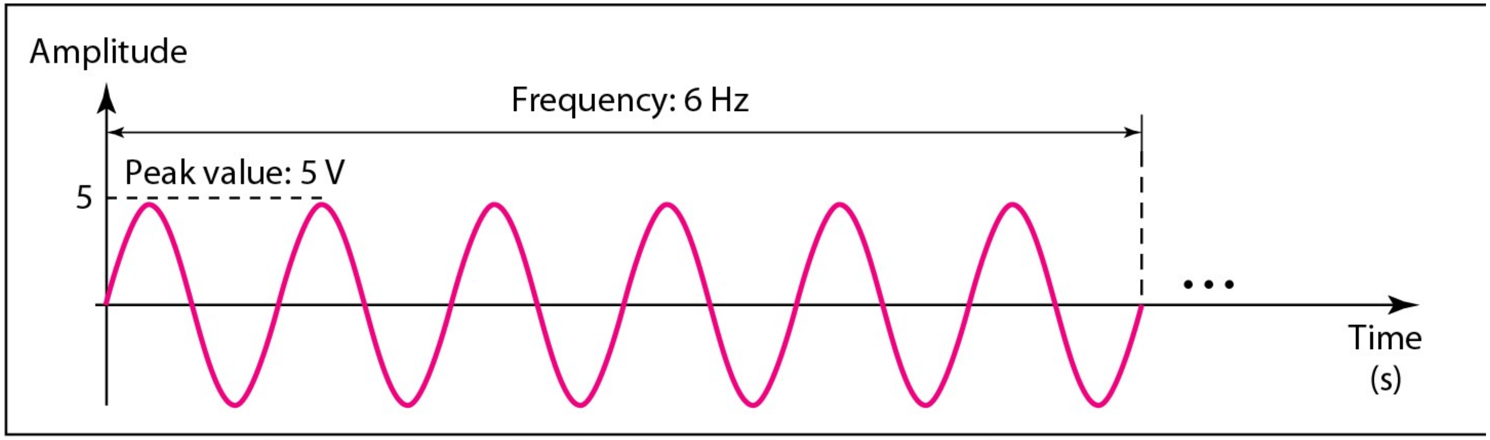
Time and Frequency Domains

- ✓ A sine wave is comprehensively defined by its amplitude, frequency, and phase.
- ✓ We have been showing a sine wave by using what is called a time-domain plot.
- ✓ The time-domain plot shows changes in signal amplitude with respect to time (it is an amplitude-versus-time plot).
- ✓ Phase is not explicitly shown on a time-domain plot.

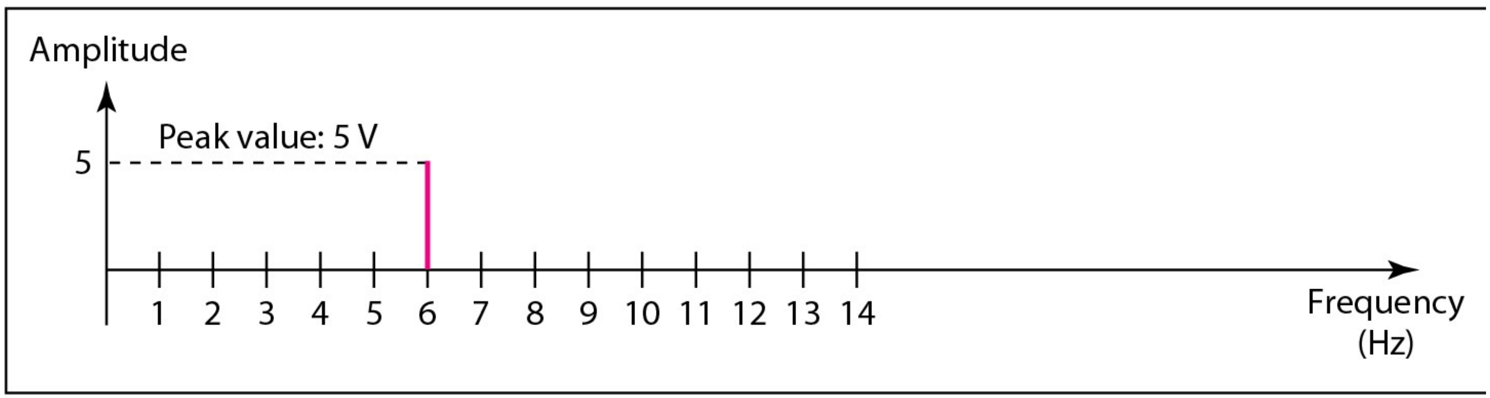
Module 1: *Time and Frequency Domains:*

- ✓ To show the relationship between amplitude and frequency, we can use what is called a frequency-domain plot.
- ✓ A frequency-domain plot is concerned with only the peak value and the frequency.

Module 1: *Time and Frequency Domains :*



a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)



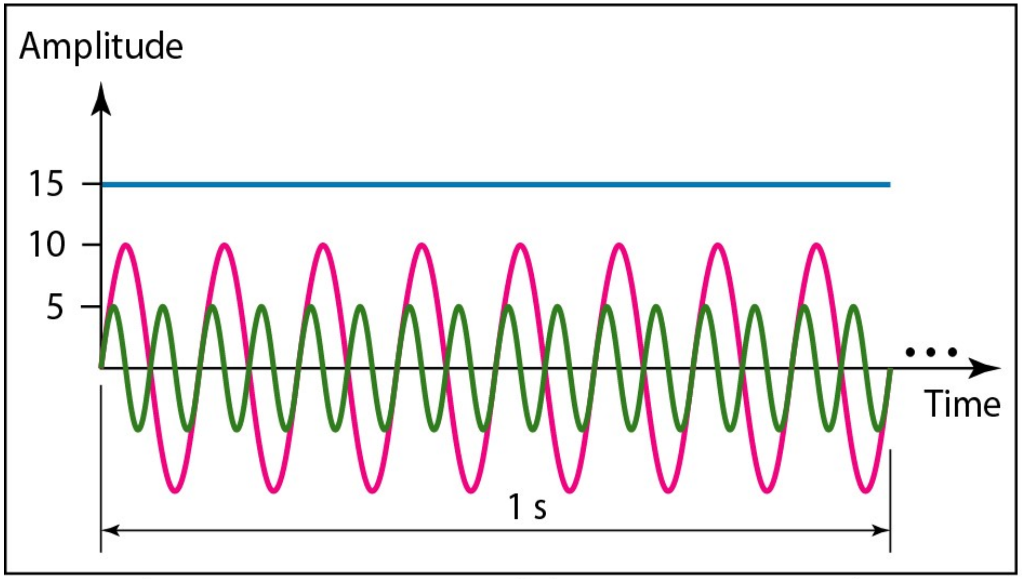
b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

The time-domain and frequency-domain plots of a sine wave

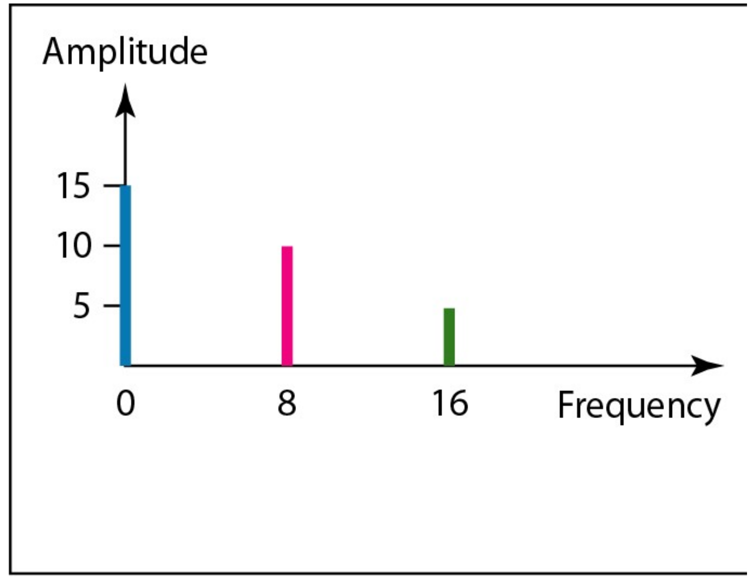
Module 1: *Time and Frequency Domains :*

- ✓ The frequency domain is more compact and useful when we are dealing with more than one sine wave.
- ✓ For example, figure shows three sine waves, each with different amplitude and frequency.
- ✓ All can be represented by three spikes in the frequency domain.

Module 1: *Time and Frequency Domains :*



a. Time-domain representation of three sine waves with frequencies 0, 8, and 16



b. Frequency-domain representation of the same three signals

The time domain and frequency domain of three sine waves

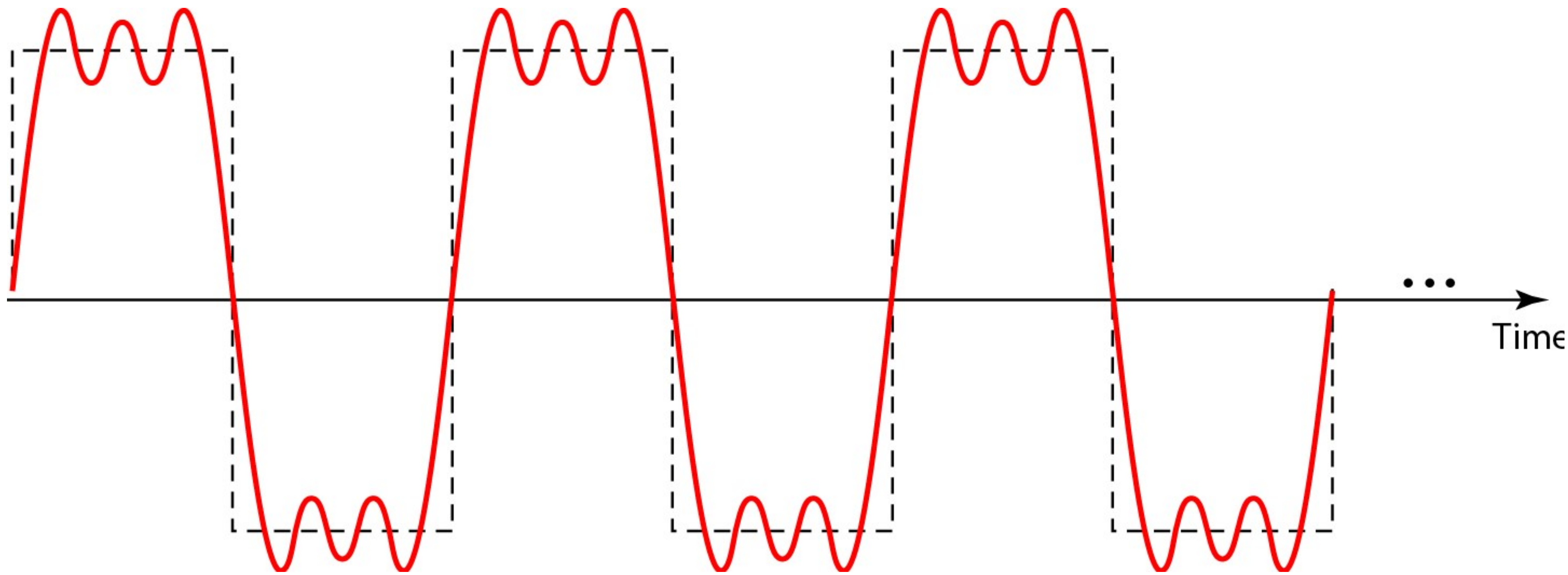
Signals and Communication

- ✓ A single-frequency sine wave is not useful in data communications.
- ✓ We need to send a composite signal, a signal made of many simple sine waves.
- ✓ According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases.

Composite Signals and Periodicity

- ✓ If the composite signal is periodic, the decomposition gives a series of signals with discrete frequencies.
- ✓ If the composite signal is nonperiodic, the decomposition gives a combination of sine waves with continuous frequencies.

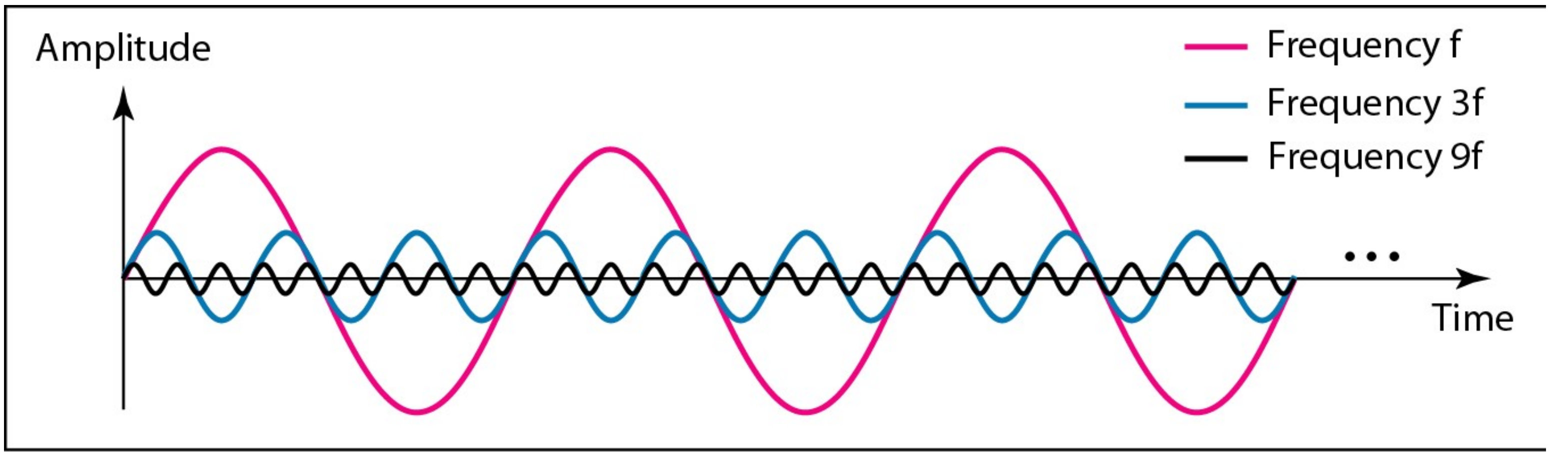
Module 1: *Signals and Communication :*



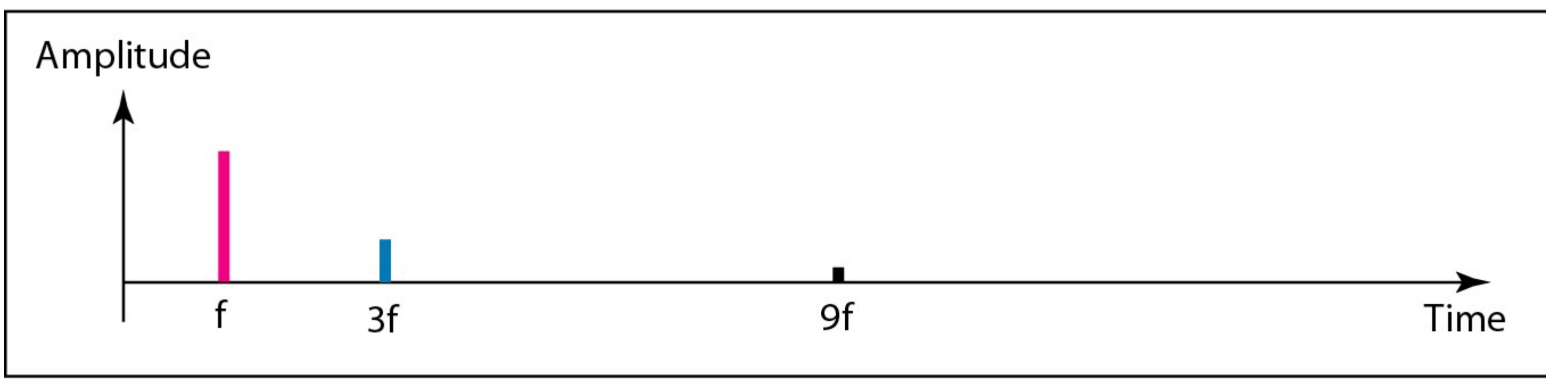
A composite periodic signal

- ✓ Figure shows a periodic composite signal with frequency f.
- ✓ This type of signal is not typical of those found in data communications.
- ✓ We can consider it to be three alarm systems, each with a different frequency.
- ✓ The analysis of this signal can give us a good understanding of how to decompose signals.

Module 1: *Signals and Communication :*



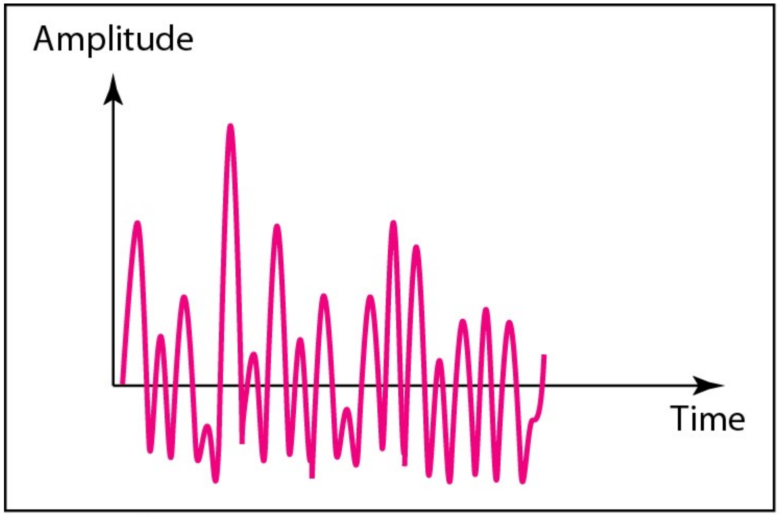
a. Time-domain decomposition of a composite signal



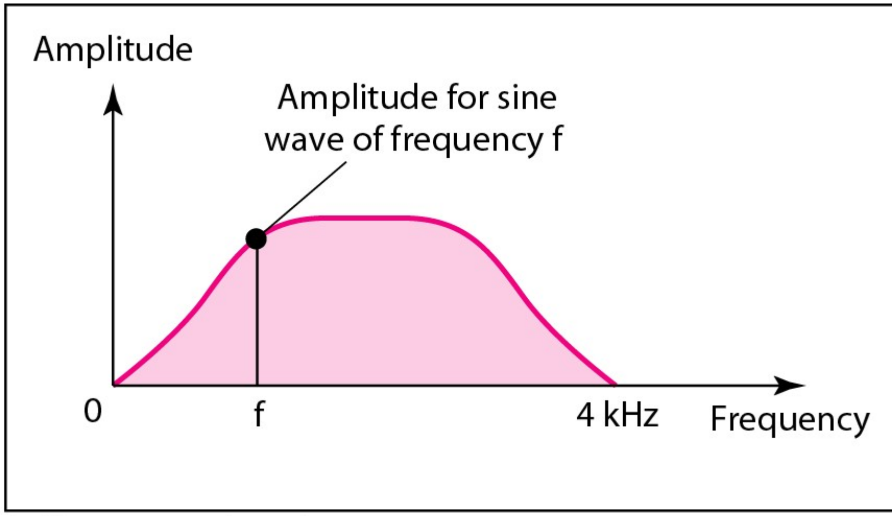
b. Frequency-domain decomposition of the composite signal

Decomposition of a composite periodic signal in the time and frequency domains

Module 1: *Signals and Communication :*



a. Time domain



b. Frequency domain

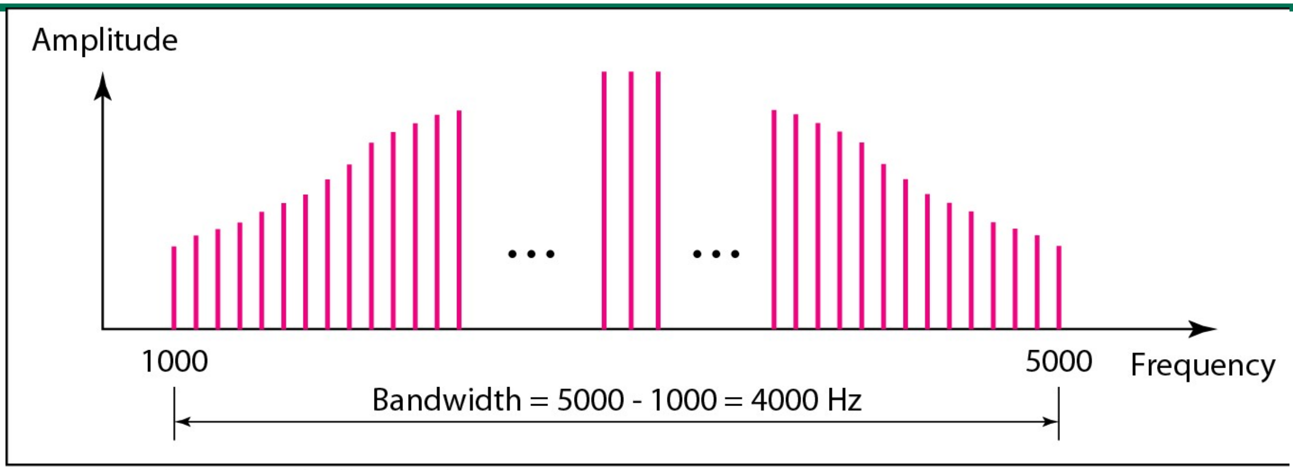
The time and frequency domains of a non periodic signal

Module 1: *Signals and Communication :*

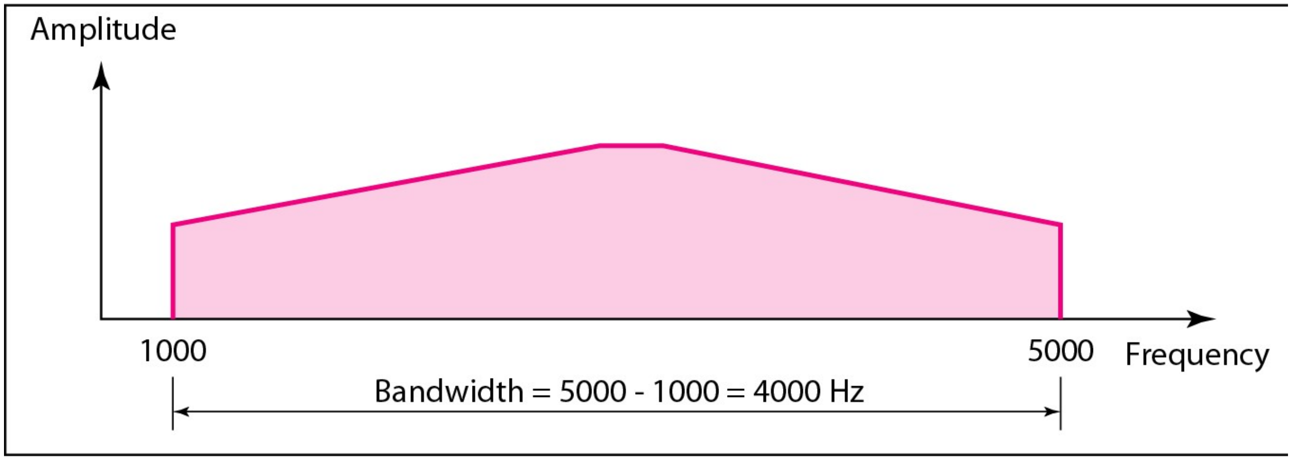
- ✓ Figure shows a non periodic composite signal.
- ✓ It can be the signal created by a microphone or a telephone set when a word or two is pronounced.
- ✓ In this case, the composite signal cannot be periodic, because that implies that we are repeating the same word or words with exactly the same tone.

Bandwidth and Signal Frequency

The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.



a. Bandwidth of a periodic signal



b. Bandwidth of a nonperiodic signal

The bandwidth of periodic and non periodic composite signals

Example:

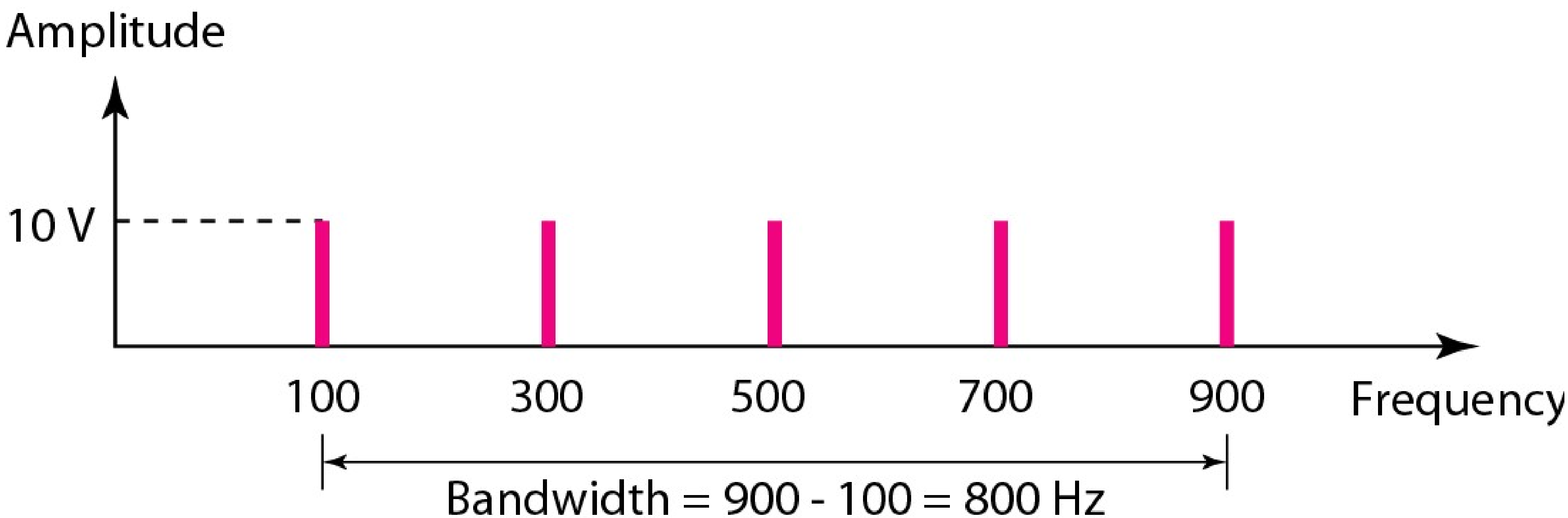
If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V.

Solution

Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$\boxed{B = f_h - f_l = 900 - 100 = 800 \text{ Hz}}$$

The spectrum has only five spikes, at 100, 300, 500, 700, and 900 Hz


Amplitude
10 V
100
300
500
700
900
Frequency
Bandwidth = 900 - 100 = 800 Hz

Example:

A periodic signal has a bandwidth of 20 Hz. The highest frequency is 60 Hz. What is the lowest frequency? Draw the spectrum if the signal contains all frequencies of the same amplitude.

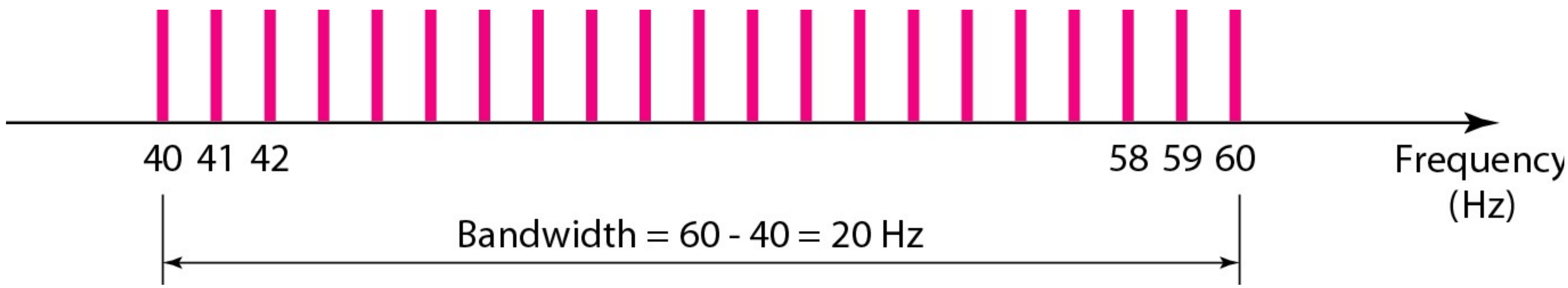
Solution

Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$B = f_h - f_l \;\Rightarrow\; 20 = 60 - f_l \;\Rightarrow\; f_l = 60 - 20 = 40 \text{ Hz}$$

The spectrum contains all integer frequencies. We show this by a series of spikes

Module 1: *Signals and Communication :*



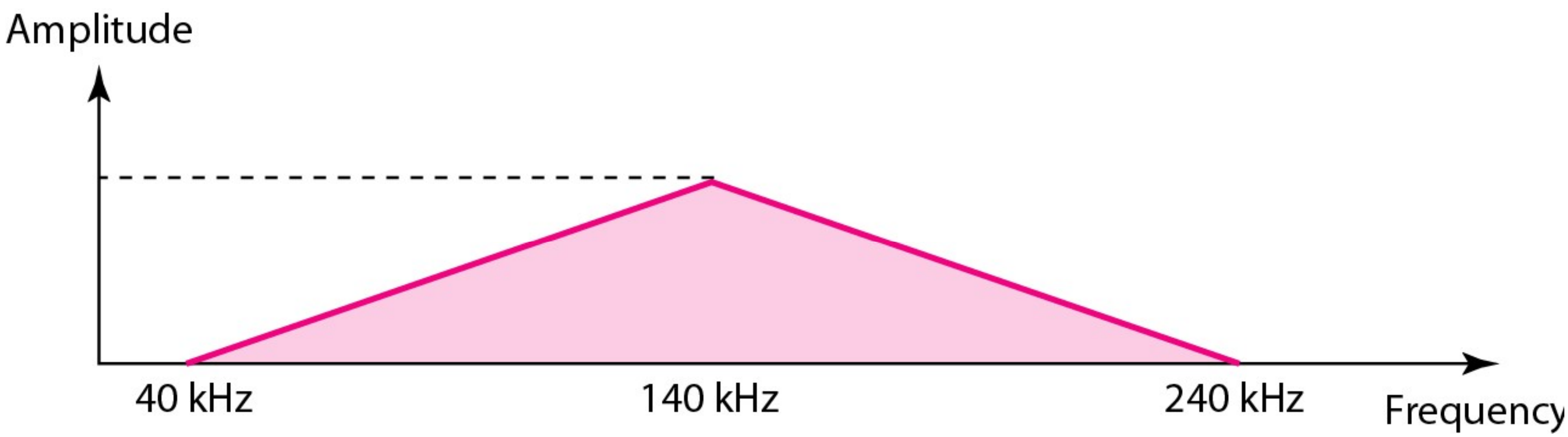
Example:

A non periodic composite signal has a bandwidth of 200 kHz, with a middle frequency of 140 kHz and peak amplitude of 20 V. The two extreme frequencies have an amplitude of 0. Draw the frequency domain of the signal.

Solution

The lowest frequency must be at 40 kHz and the highest at 240 kHz. Figure shows the frequency domain and the bandwidth.

Module 1: *Signals and Communication :*



Fourier Analysis

Fourier analysis is a tool that changes a time domain signal to a frequency domain signal and vice versa.

Fourier Series

- ✓ Every composite periodic signal can be represented with a series of sine and cosine functions.
- ✓ The functions are integral harmonics of the fundamental frequency “f” of the composite signal.
- ✓ Using the series we can decompose any periodic signal into its harmonics.

Module 1: *Fourier Analysis :*

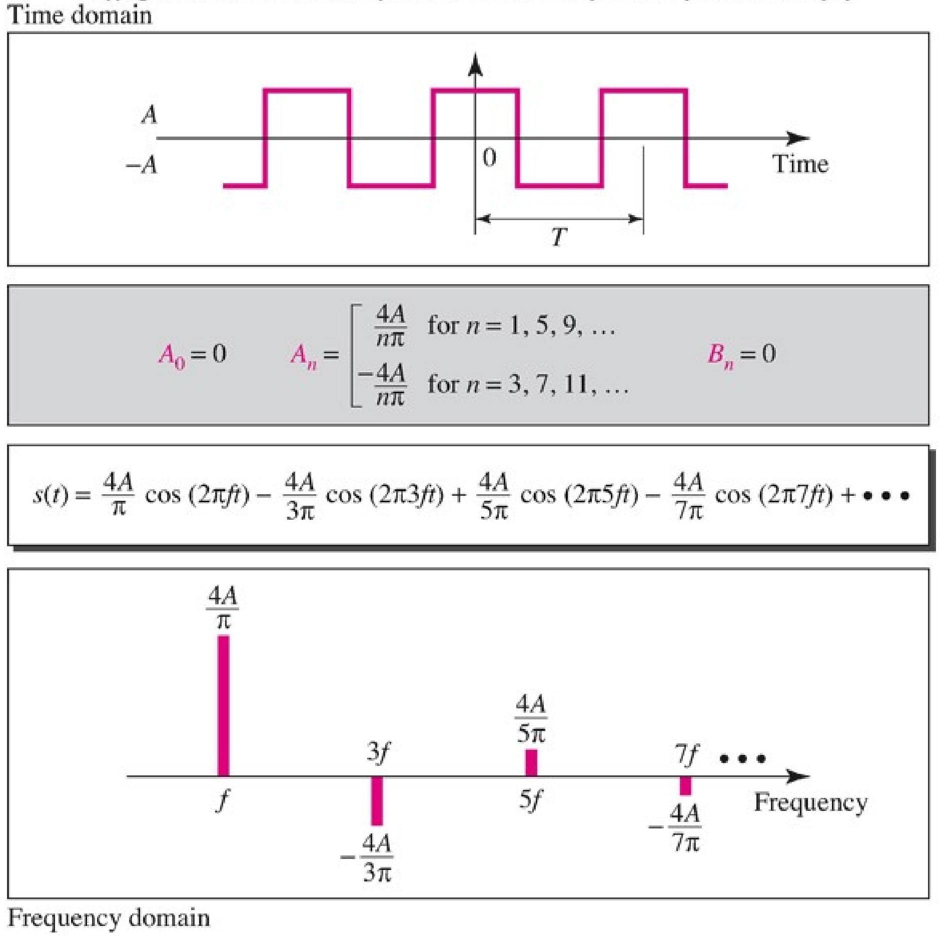
Fourier series

$$s(t) = A_0 + \sum_{n=1}^{\infty} A_n \sin(2\pi nft) + \sum_{n=1}^{\infty} B_n \cos(2\pi nft)$$

$$A_0 = \frac{1}{T}\int_0^T s(t)\,dt \qquad A_n = \frac{2}{T}\int_0^T s(t)\cos(2\pi nft)\,dt$$

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

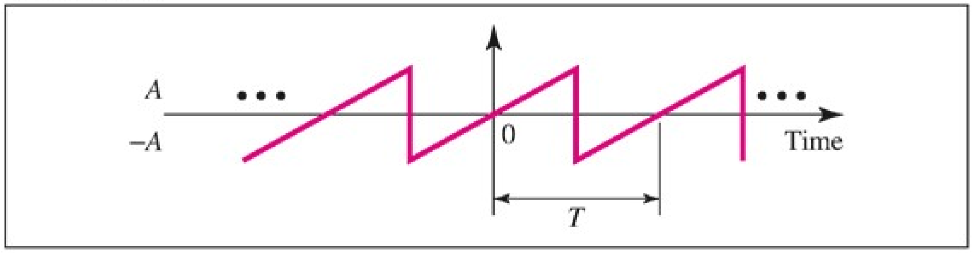
Coefficients



Examples of Signals and the Fourier Series Representation

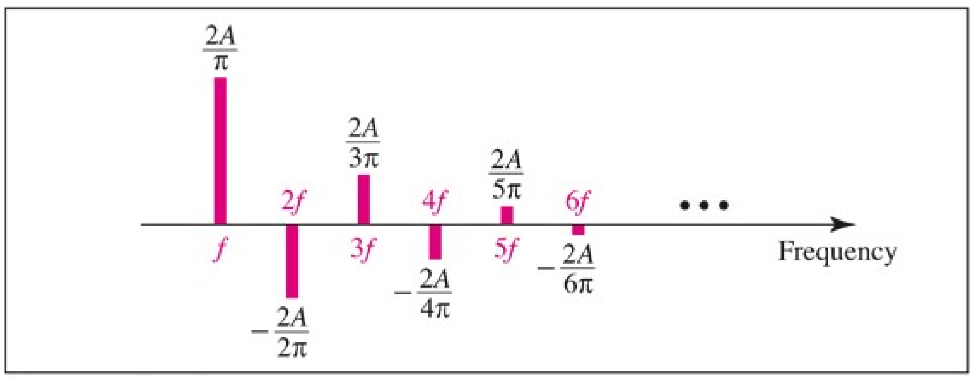
Module 1: *Fourier Analysis :*

Time domain



$A_0 = 0$ $\quad A_n = 0$ $\quad B_n = \begin{cases} \frac{2A}{n\pi} & \text{for } n \text{ odd} \\ -\frac{2A}{n\pi} & \text{for } n \text{ even} \end{cases}$

$$s(t) = \frac{2A}{\pi}\sin(2\pi ft) - \frac{2A}{2\pi}\sin(2\pi 2ft) + \frac{2A}{3\pi}\sin(2\pi 3ft) - \frac{2A}{4\pi}\sin(2\pi 4ft) + \cdots$$

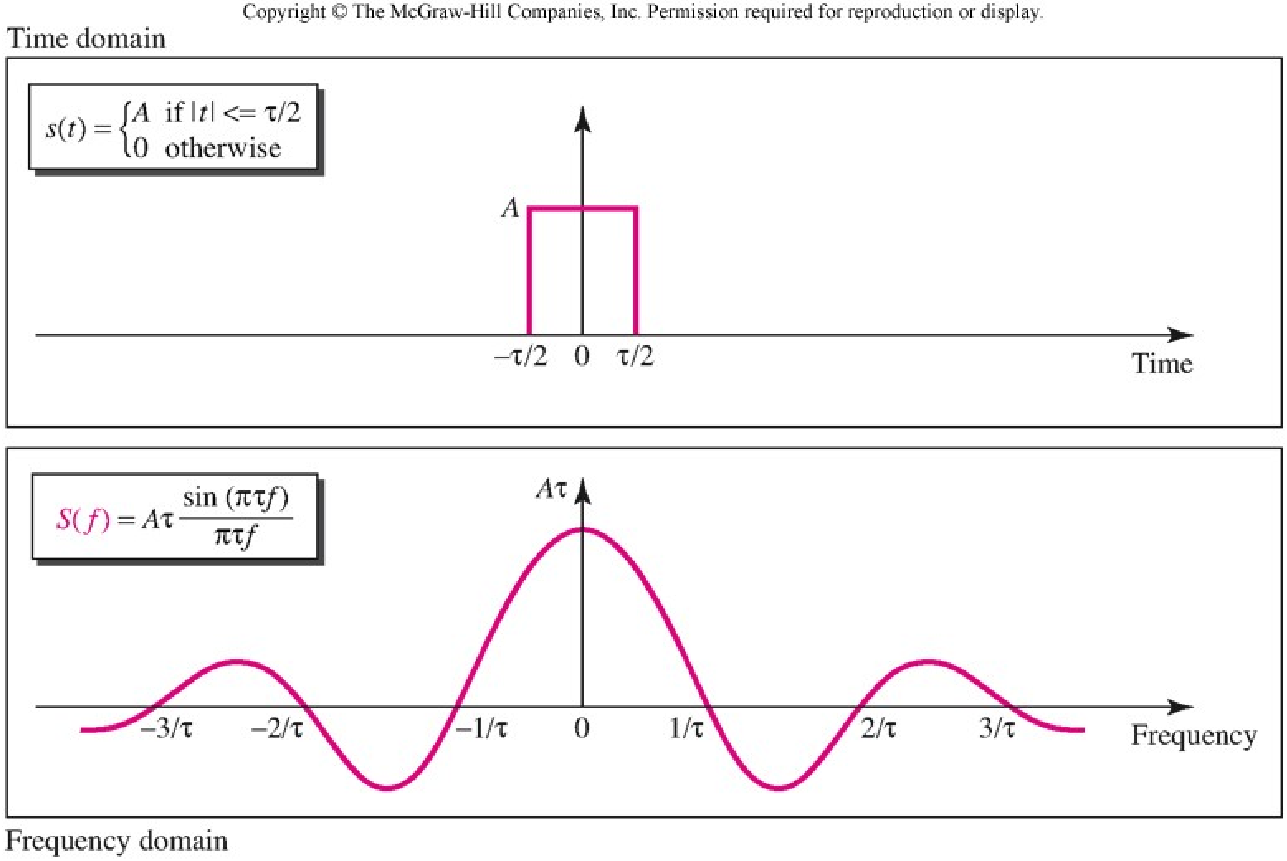


Frequency domain

Sawtooth Signal

Fourier Transform

Fourier Transform gives the frequency domain of a nonperiodic time domain signal.



Inverse Fourier Transform

$$S(f) = \int_{-\infty}^{\infty} s(t)e^{-j2\pi ft}\, dt$$

Fourier transform

$$s(t) = \int_{-\infty}^{\infty} S(f)e^{j2\pi ft}\, dt$$

Inverse Fourier transform

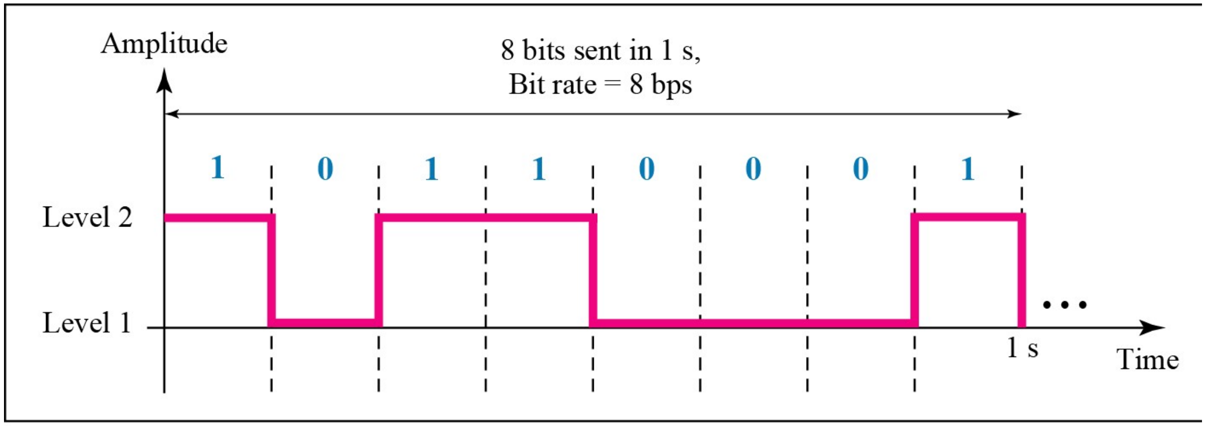
Time limited and Band limited Signals

- ✓ A time limited signal is a signal for which the amplitude $s(t) = 0$ for $t > T_1$ and $t < T_2$
- ✓ A band limited signal is a signal for which the amplitude $S(f) = 0$ for $f > F_1$ and $f < F_2$

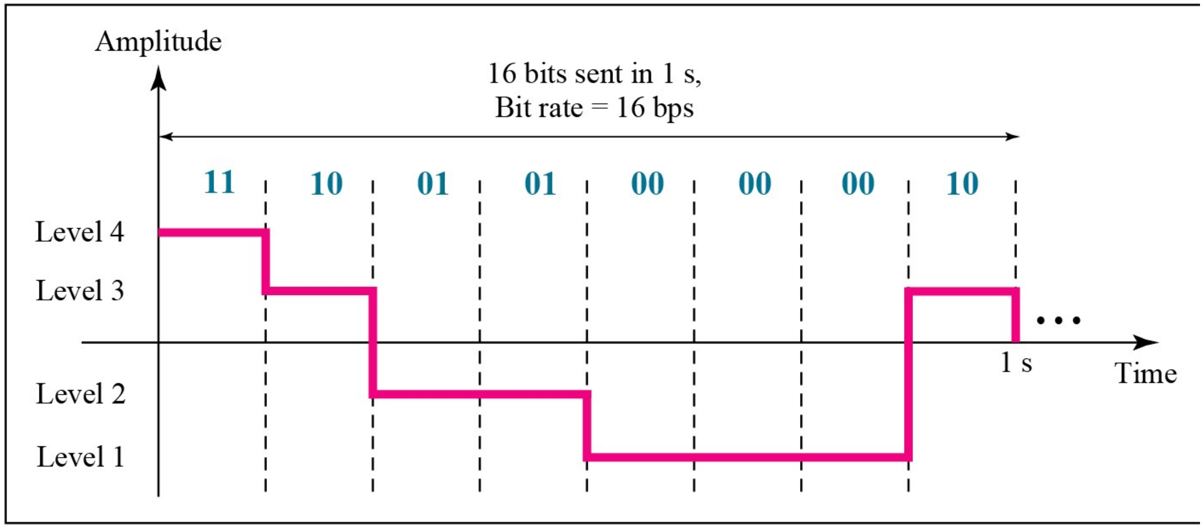
Digital Signal:

- ✓ In addition to being represented by an analog signal, information can also be represented by a digital signal.
- ✓ For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage.
- ✓ A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level.

Module 1: *Digital Signals :*



a. A digital signal with two levels



b. A digital signal with four levels

Two digital signals: one with two signal levels and the other with four signal levels

Module 1: *Digital Signals :*

A digital signal has eight levels. How many bits are needed per level? We calculate the number of bits from the formula:

$$\boxed{\text{Number of bits per level} = \log_2 8 = 3}$$

Each signal level is represented by 3 bits.

Module 1: *Digital Signals :*

A digital signal has nine levels.
How many bits are needed per level?

- ✓ We calculate the number of bits by using the formula. Each signal level is represented by 3.17 bits.
- ✓ However, this answer is not realistic.
- ✓ The number of bits sent per level needs to be an integer as well as a power of 2.
- ✓ For this example, 4 bits can represent one level.

Assume we need to download text documents at the rate of 100 pages per sec. What is the required bit rate of the channel?

Solution

A page is an average of 24 lines with 80 characters in each line. If we assume that one character requires 8 bits (ascii), the bit rate is:

$$\boxed{100 \times 24 \times 80 \times 8 = 1{,}636{,}000 \text{ bps} = 1.636 \text{ Mbps}}$$

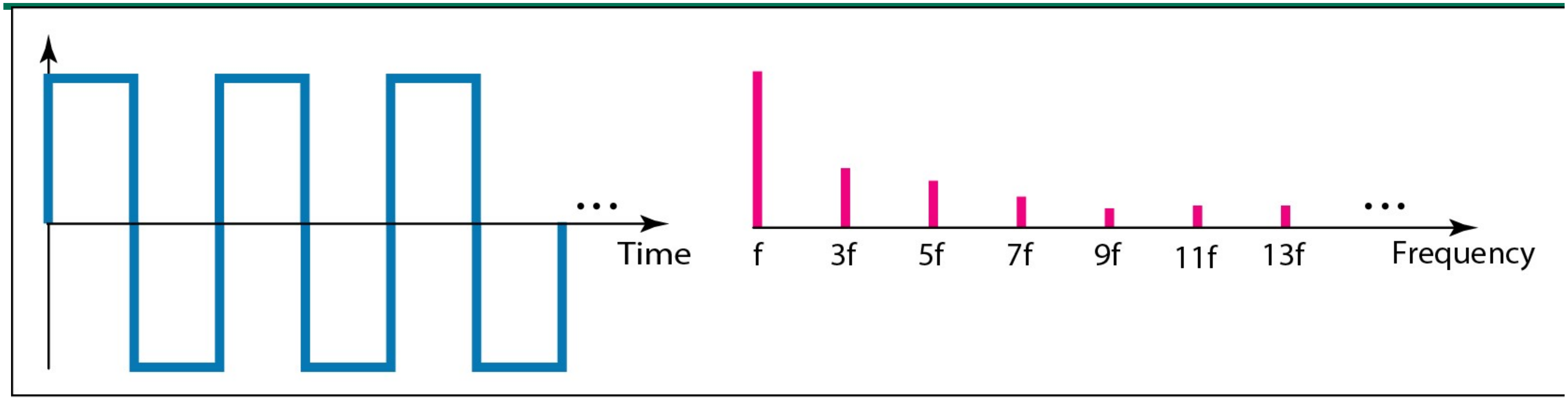
A digitized voice channel, as we will see in Chapter 4, is made by digitizing a 4-kHz bandwidth analog voice signal. We need to sample the signal at twice the highest frequency (two samples per hertz). We assume that each sample requires 8 bits. What is the required bit rate?

Solution

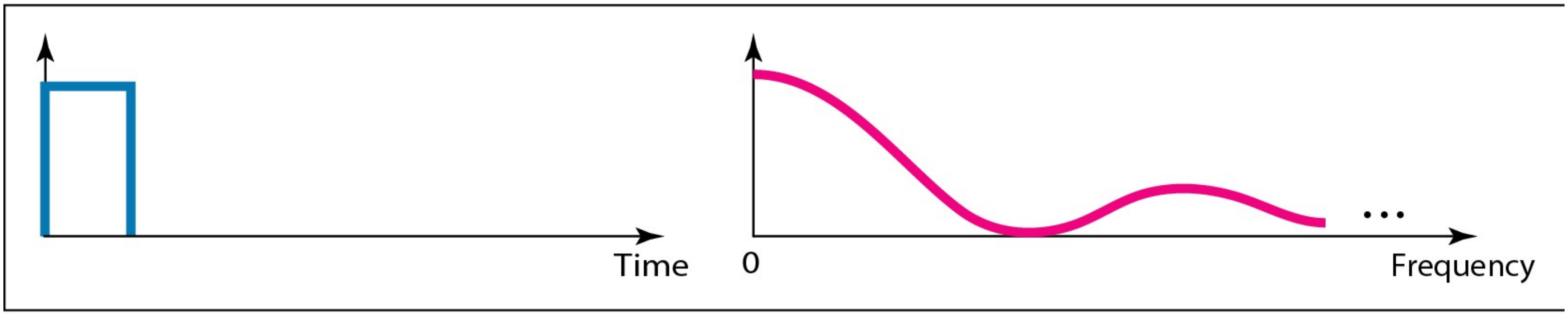
The bit rate can be calculated as

$$\boxed{2 \times 4000 \times 8 = 64{,}000 \text{ bps} = 64 \text{ kbps}}$$

Module 1: *Digital Signals :*



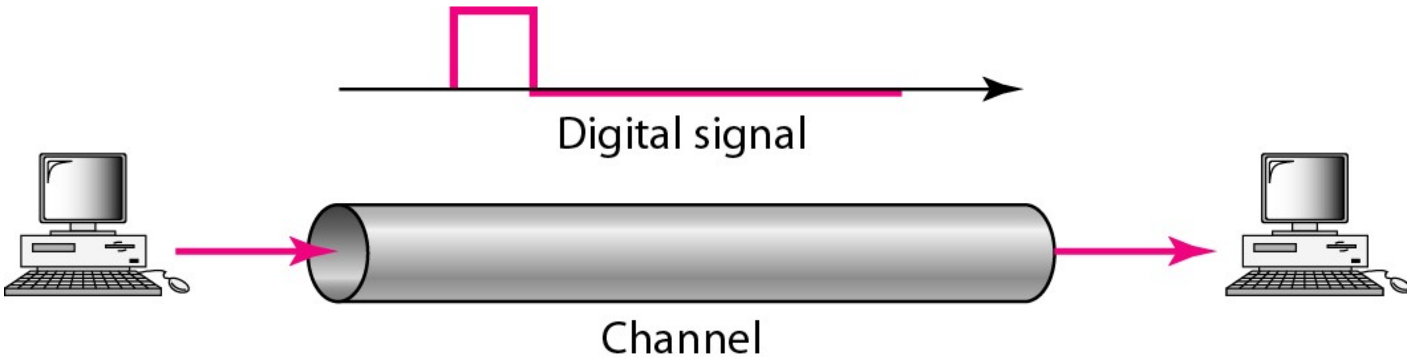
a. Time and frequency domains of periodic digital signal



b. Time and frequency domains of nonperiodic digital signal

The time and frequency domains of periodic and non-periodic digital signals

Module 1: *Digital Signals :*

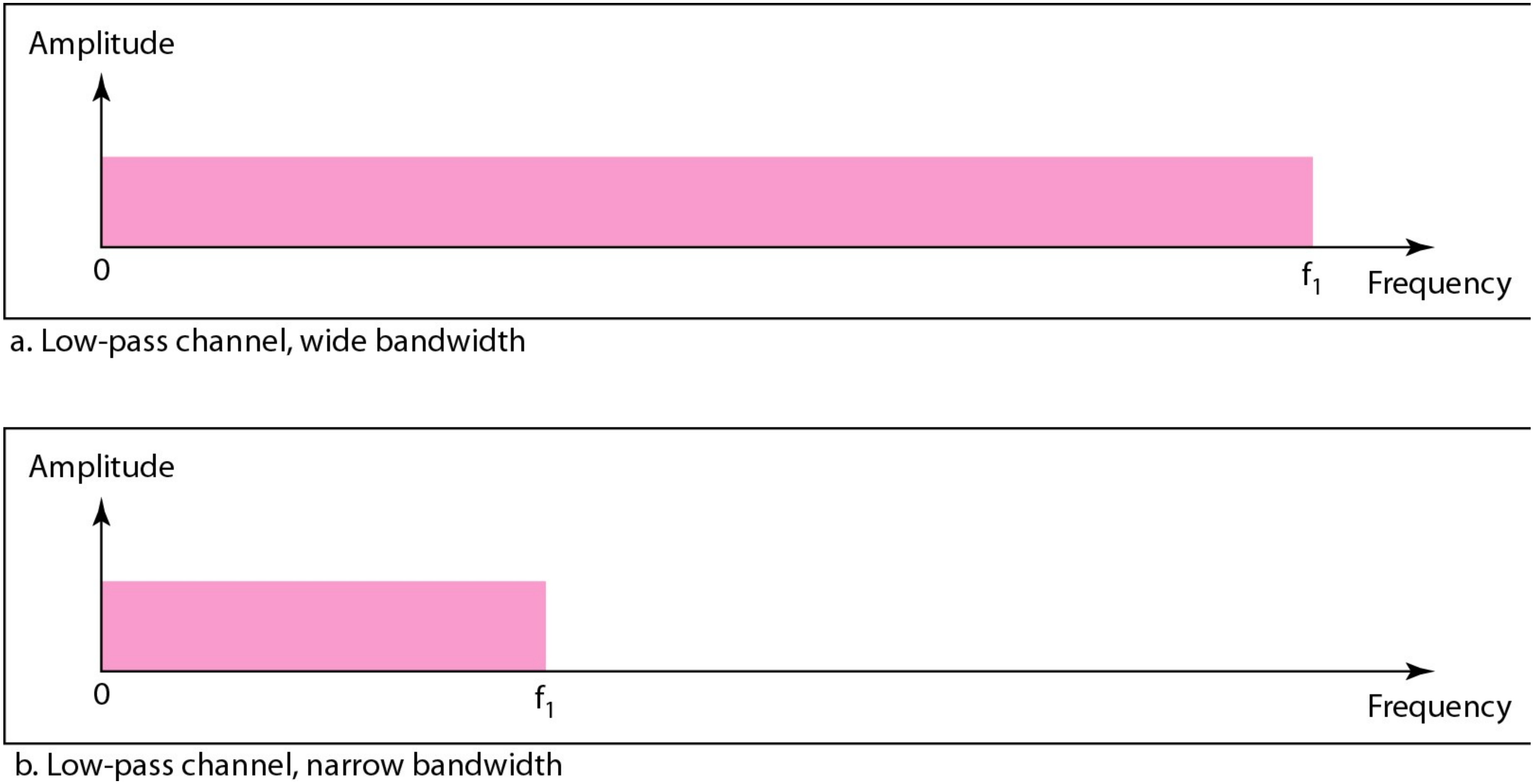


Baseband transmission

Baseband transmission means sending a digital signal over a channel without changing the digital signal to an analog signal.

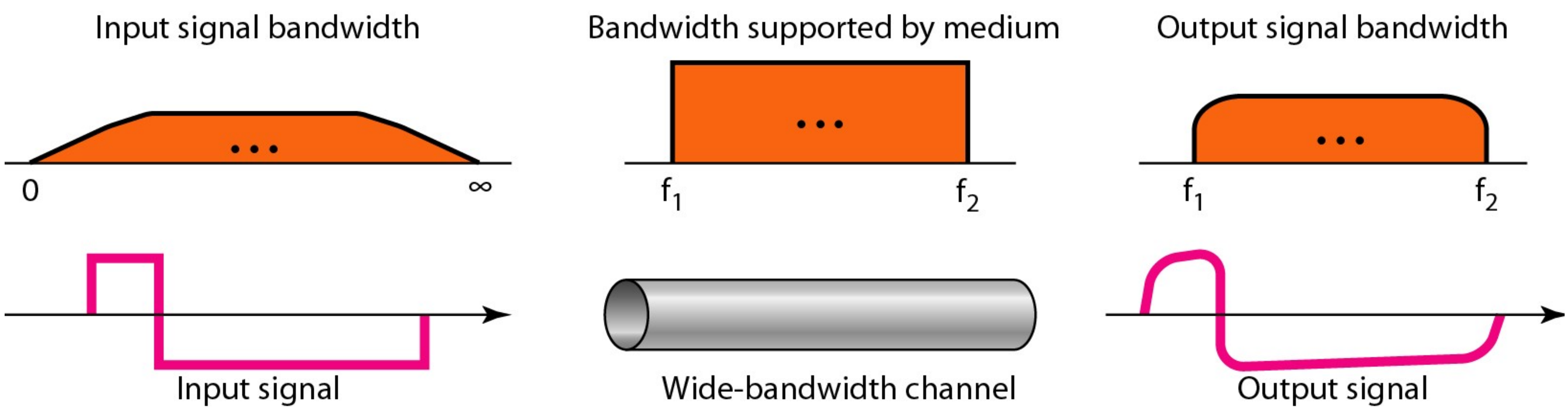
A digital signal is a composite analog signal with an infinite bandwidth.

Module 1: *Digital Signals :*



Bandwidths of two low-pass channels

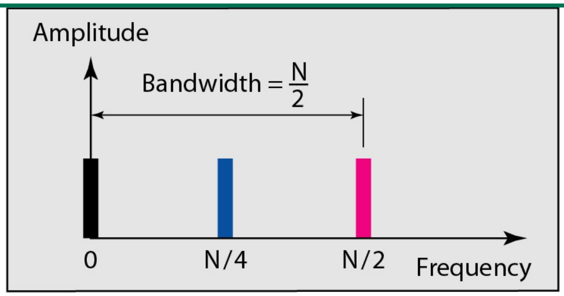
Module 1: *Digital Signals :*

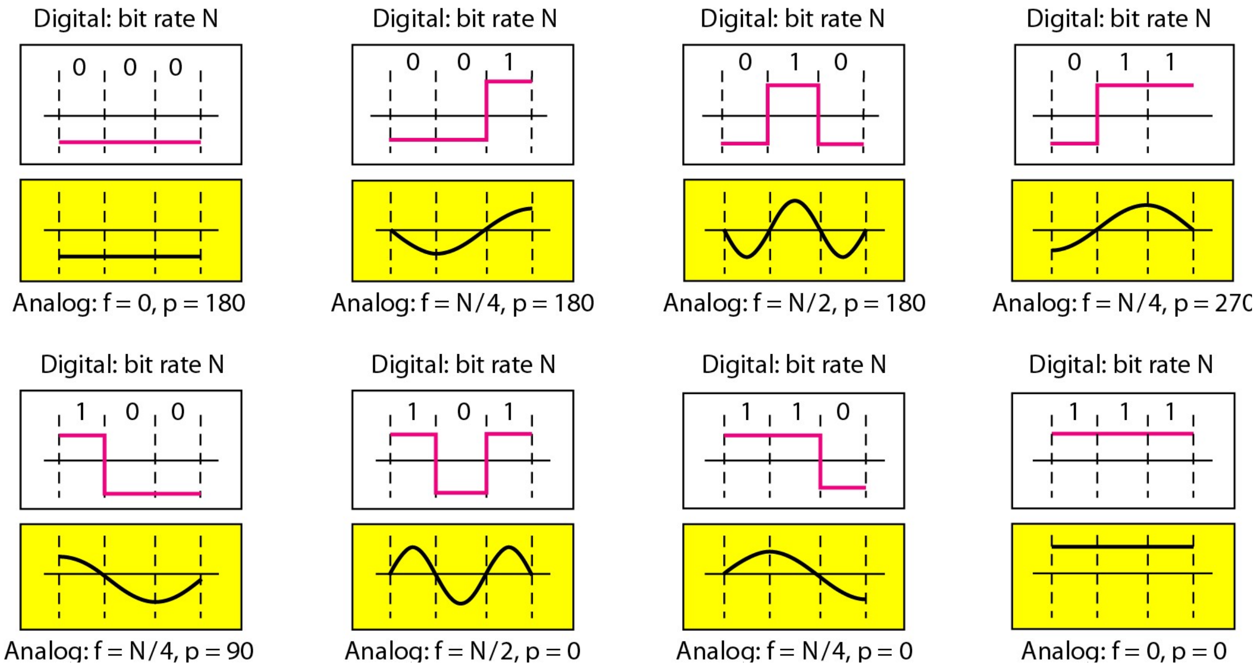


Baseband transmission using a dedicated medium

Baseband transmission of a digital signal that preserves the shape of the digital signal is possible only if we have a low-pass channel with an infinite or very wide bandwidth.

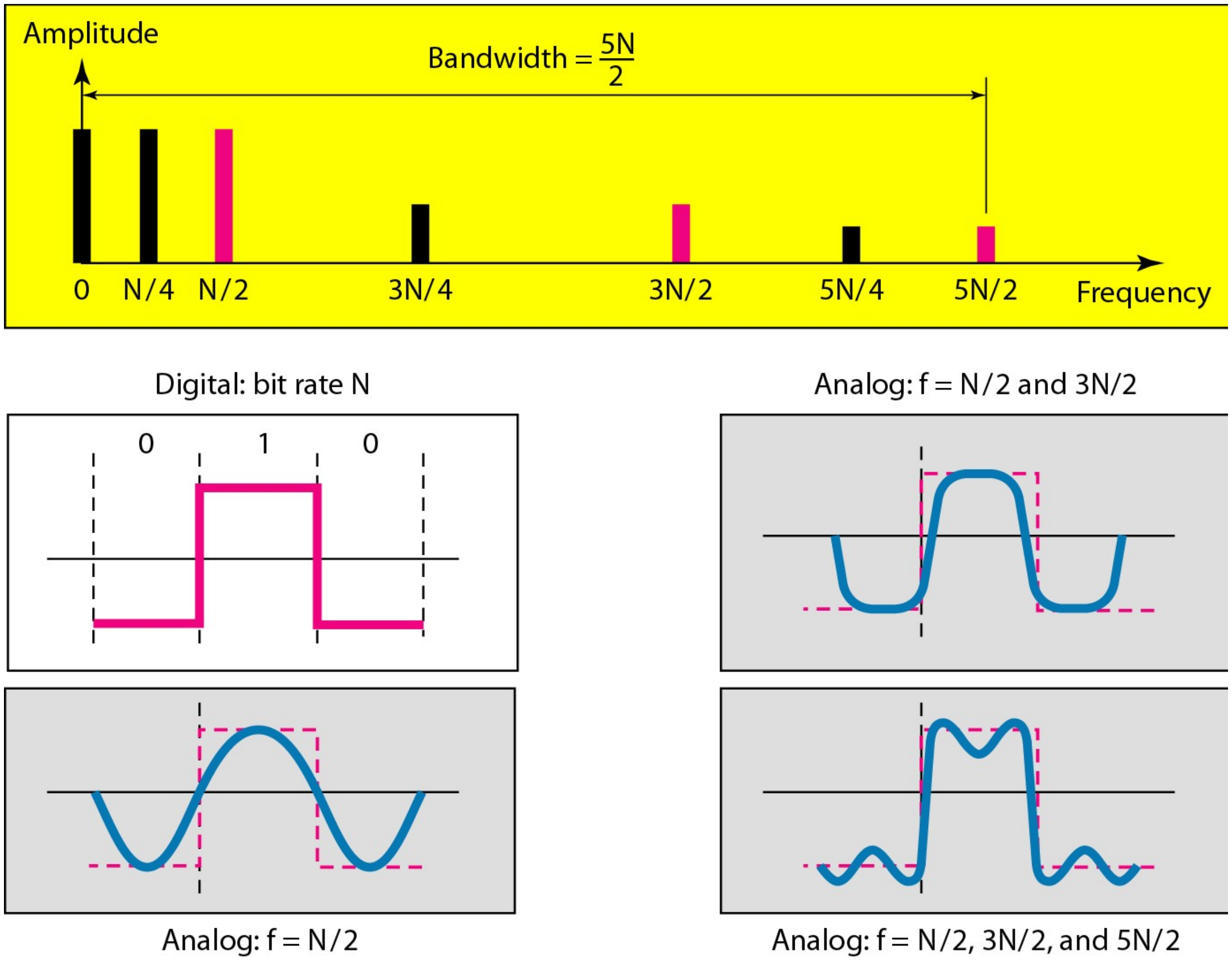
Module 1: *Digital Signals :*





Rough approximation of a digital signal using the first harmonic for worst case

Module 1: *Digital Signals :*



Simulating a digital signal with first three harmonics

In baseband transmission, the required bandwidth is proportional to the bit rate; if we need to send bits faster, we need more bandwidth.

Bit Rate	*Harmonic 1*	*Harmonics 1, 3*	*Harmonics 1, 3, 5*
$n = 1$ kbps	$B = 500$ Hz	$B = 1.5$ kHz	$B = 2.5$ kHz
$n = 10$ kbps	$B = 5$ kHz	$B = 15$ kHz	$B = 25$ kHz
$n = 100$ kbps	$B = 50$ kHz	$B = 150$ kHz	$B = 250$ kHz

Bandwidth requirements

What is the required bandwidth of a low-pass channel if we need to send 1 Mbps by using baseband transmission?

Solution

The answer depends on the accuracy desired.

a. The minimum bandwidth, is B = bit rate /2, or 500 kHz.

b. A better solution is to use the first and the third harmonics with $B = 3 \times 500$ kHz = 1.5 MHz.

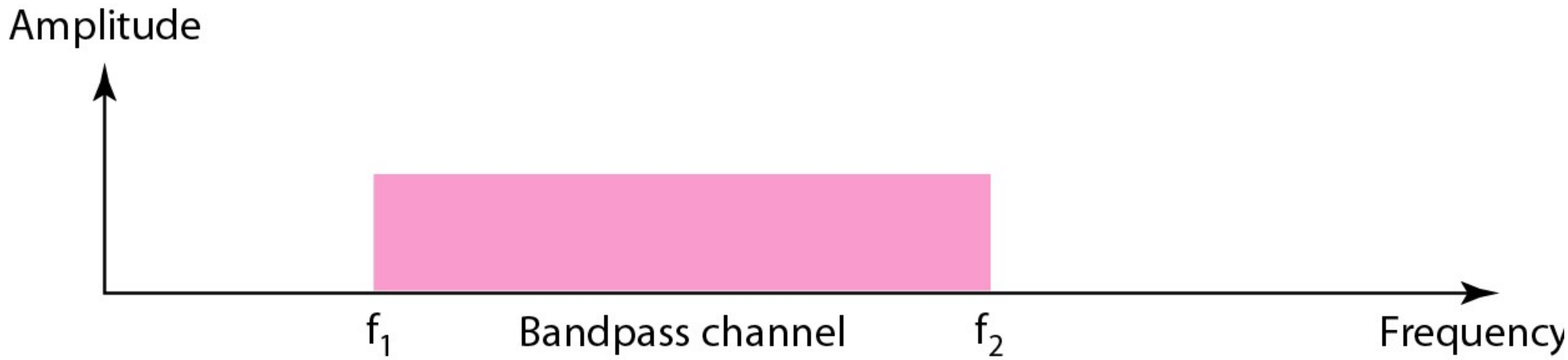
c. Still a better solution is to use the first, third, and fifth harmonics with $B = 5 \times 500$ kHz = 2.5 MHz.

We have a low-pass channel with bandwidth 100 kHz. What is the maximum bit rate of this channel?

Solution

The maximum bit rate can be achieved if we use the first harmonic. The bit rate is 2 times the available bandwidth, or 200 kbps.

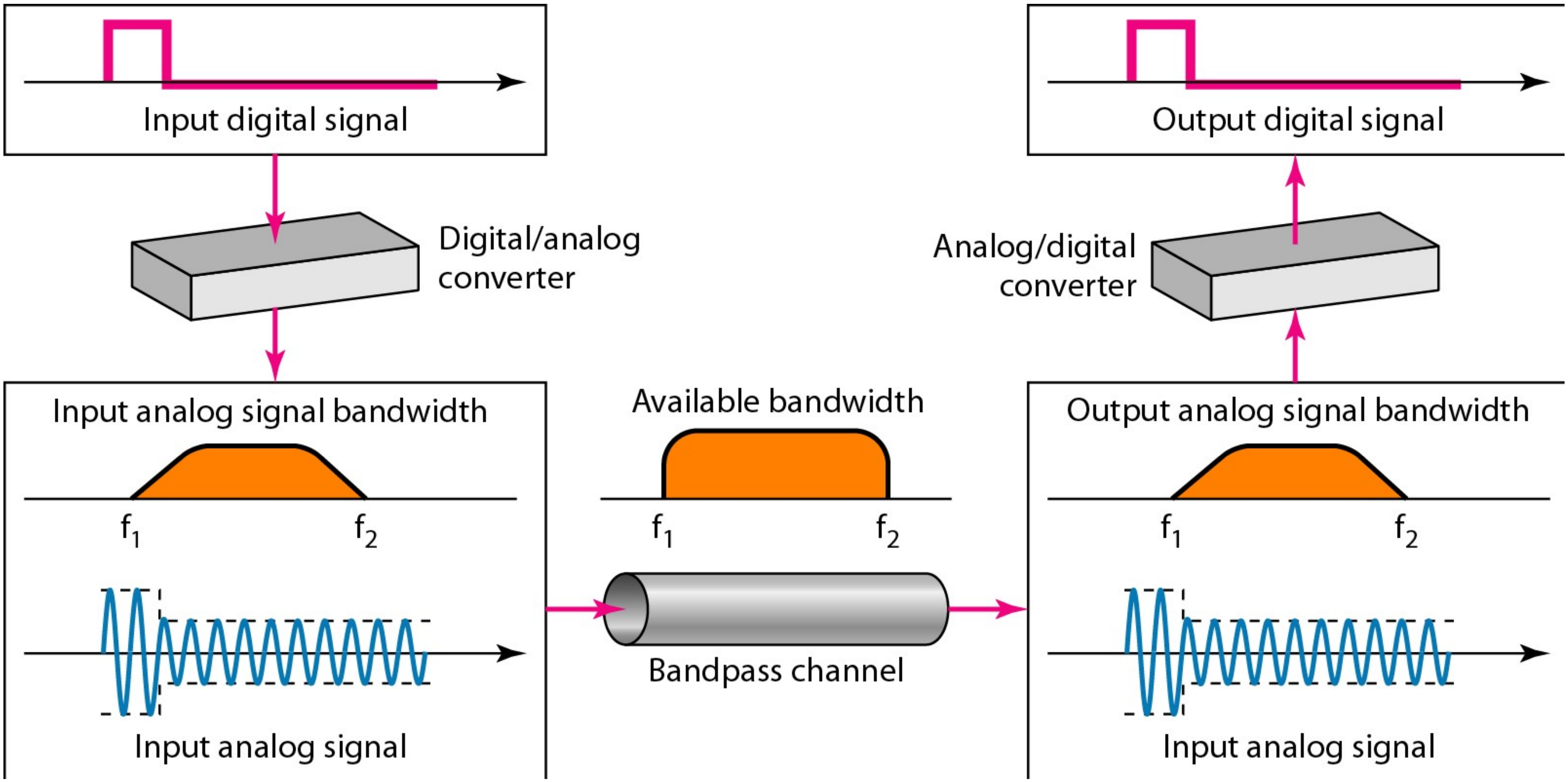
Module 1: *Digital Signals :*



Bandwidth of a bandpass channel

If the available channel is a bandpass channel, we cannot send the digital signal directly to the channel; we need to convert the digital signal to an analog signal before transmission.

Module 1: *Digital Signals :*



Modulation of a digital signal for transmission on a bandpass channel

Module 1: *Digital Signals :*

An example of broadband transmission using modulation is the sending of computer data through a telephone subscriber line, the line connecting a resident to the central telephone office.

These lines are designed to carry voice with a limited bandwidth. The channel is considered a bandpass channel.

We convert the digital signal from the computer to an analog signal, and send the analog signal.

We can install two converters to change the digital signal to analog and vice versa at the receiving end.

The converter, in this case, is called a modem.

Transmission Impairment

- ✓ Signals travel through transmission media, which are not perfect.
- ✓ The imperfection causes signal impairment.
- ✓ This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium.
- ✓ What is sent is not what is received.
- ✓ Three causes of impairment are attenuation, distortion, and noise.

Module 1: *Digital Signals :*

Attenuation

- ✓ It means loss of energy -> weaker signal
- ✓ When a signal travels through a medium it loses energy overcoming the resistance of the medium
- ✓ Amplifiers are used to compensate for this loss of energy by amplifying the signal.

Measurement of Attenuation:

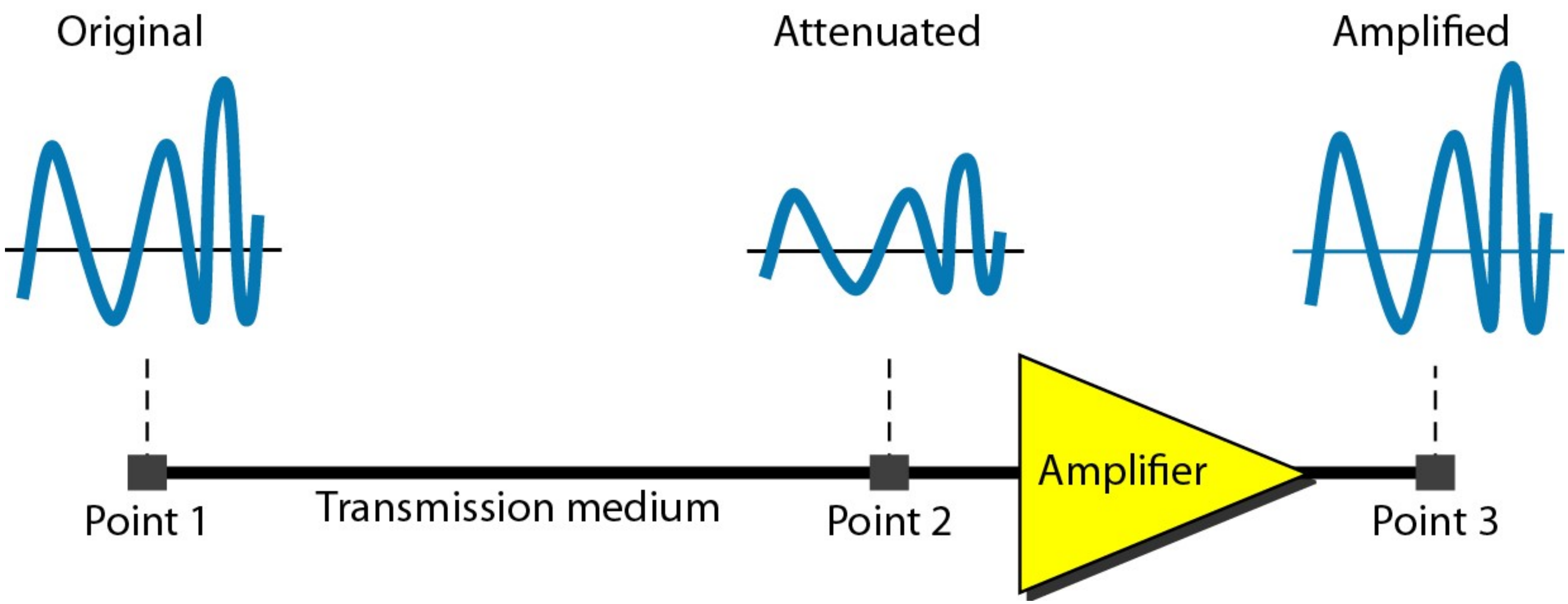
To show the loss or gain of energy the unit “decibel” is used.

$$dB = 10\log_{10} P_2/P_1$$

P_1 - input signal

P_2 - output signal

Module 1: *Digital Signals :*



Module 1: *Digital Signals :*

Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that P2 is (1/2)P1. In this case, the attenuation (loss of power) can be calculated as

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}$$

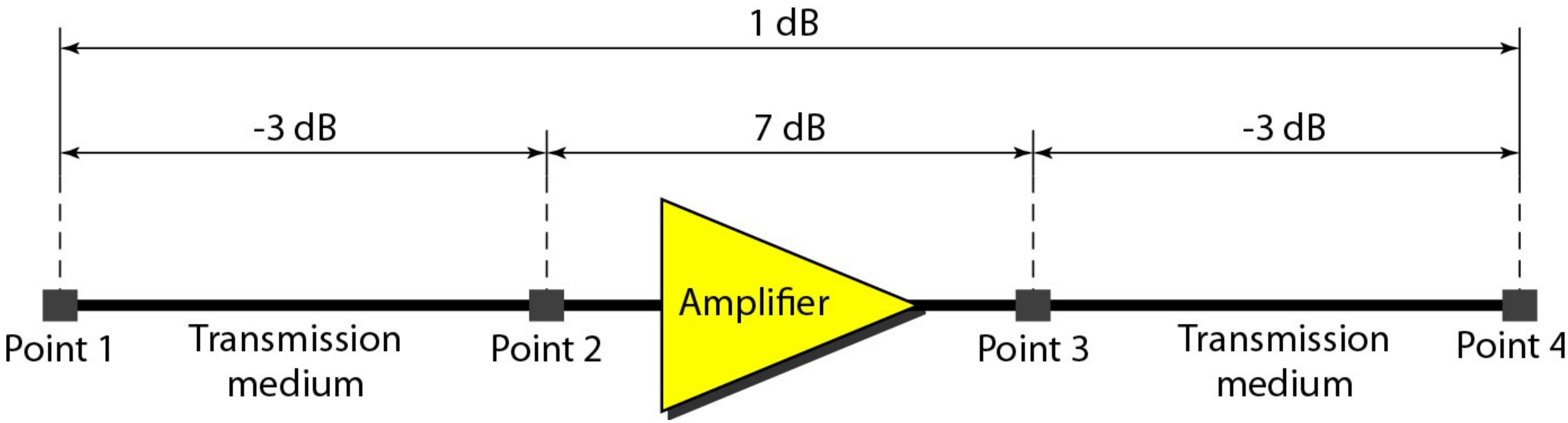
A loss of 3 dB (–3 dB) is equivalent to losing one-half the power.

Module 1: *Digital Signals :*

A signal travels through an amplifier, and its power is increased 10 times. This means that $P_2 = 10P_1$. In this case, the amplification (gain of power) can be calculated as

$$\boxed{10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{10P_1}{P_1}}$$

$$\boxed{= 10 \log_{10} 10 = 10(1) = 10 \text{ dB}}$$



One reason to use the decibel to measure the changes in the strength of a signal is that decibel numbers can be added (or subtracted) when we are measuring several points (cascading) instead of just two. In figure a signal travels from point 1 to point 4. In this case, the decibel value can be calculated as:

$$\mathbf{dB = -3 + 7 + -3 = 1}$$

Sometimes the decibel is used to measure signal power in milliwatts. In this case, it is referred to as dB_m and is calculated as $dB_m = 10 \log10 P_m$, where P_m is the power in milliwatts. Calculate the power of a signal with $dB_m = -30$.

Solution

We can calculate the power in the signal as

$$\boxed{\begin{aligned} &\mathrm{dB_m} = 10 \log_{10} P_m = -30 \\ &\log_{10} P_m = -3 \qquad P_m = 10^{-3}\ \mathrm{mW} \end{aligned}}$$

Module 1: *Digital Signals :*

The loss in a cable is usually defined in decibels per kilometer (dB/km). If the signal at the beginning of a cable with −0.3 dB/km has a power of 2 mW, what is the power of the signal at 5 km?

Solution

The loss in the cable in decibels is 5 × (−0.3) = −1.5 dB. We can calculate the power as

$$\text{dB} = 10 \log_{10} \frac{P_2}{P_1} = -1.5$$

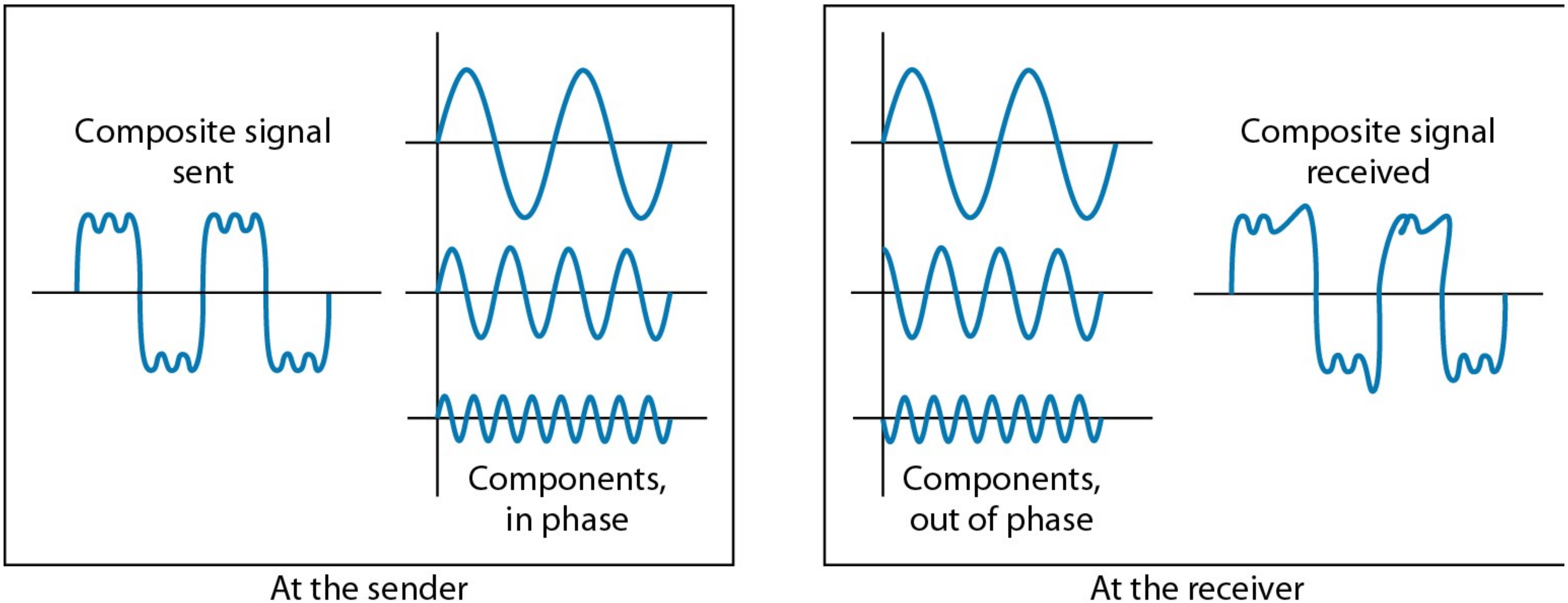
$$\frac{P_2}{P_1} = 10^{-0.15} = 0.71$$

$$P_2 = 0.71 P_1 = 0.7 \times 2 = 1.4 \text{ mW}$$

Distortion

- ✓ Means that the signal changes its form or shape
- ✓ Distortion occurs in composite signals
- ✓ Each frequency component has its own propagation speed traveling through a medium.
- ✓ The different components therefore arrive with different delays at the receiver.
- ✓ That means that the signals have different phases at the receiver than they did at the source.

Module 1: *Digital Signals :*

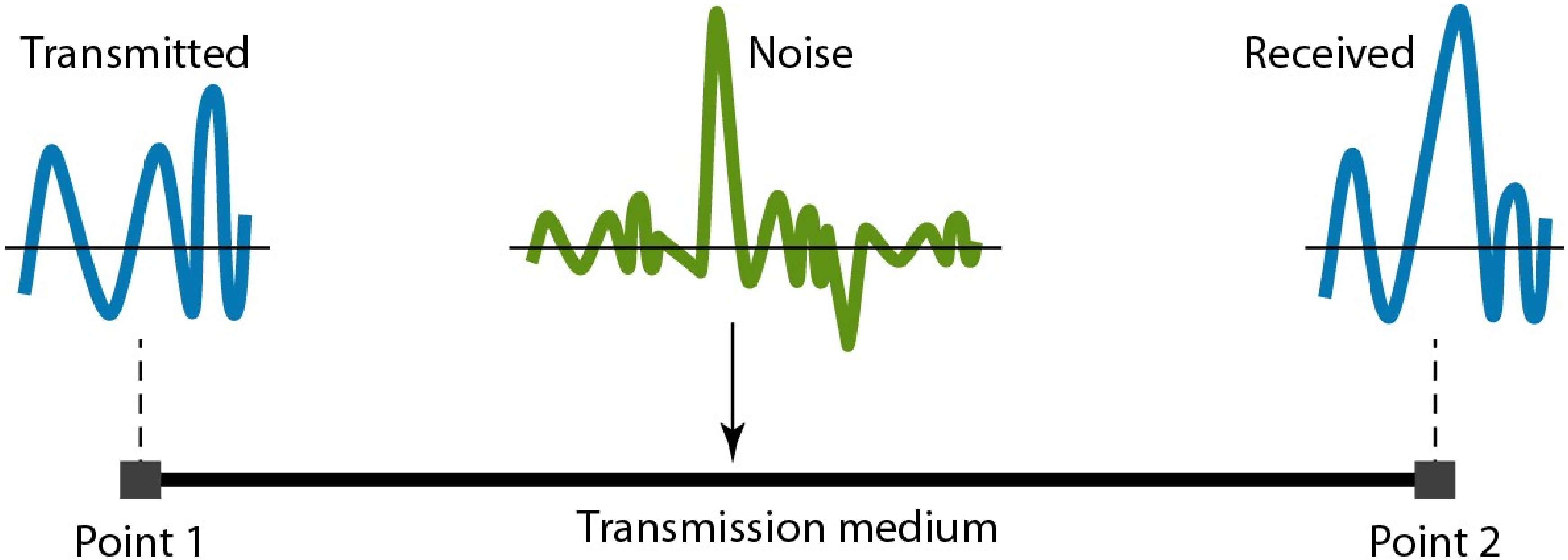


Noise

There are different types of noise

- ✓ Thermal - random noise of electrons in the wire creates an extra signal
- ✓ Induced - from motors and appliances, devices act are transmitter antenna and medium as receiving antenna.
- ✓ Crosstalk - same as above but between two wires.
- ✓ Impulse - Spikes that result from power lines, lighning, etc.

Module 1: *Digital Signals :*



Signal to Noise Ratio (SNR)

- ✓ To measure the quality of a system the SNR is often used.
- ✓ It indicates the strength of the signal with respect to the noise power in the system.
- ✓ It is the ratio between two powers.
- ✓ It is usually given in dB and referred to as SNR_{dB}.

The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNR_{dB} ?

Solution

The values of SNR and SNRdB can be calculated as follows:

$$SNR = \frac{10{,}000\ \mu W}{1\ mW} = 10{,}000$$

$$SNR_{dB} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

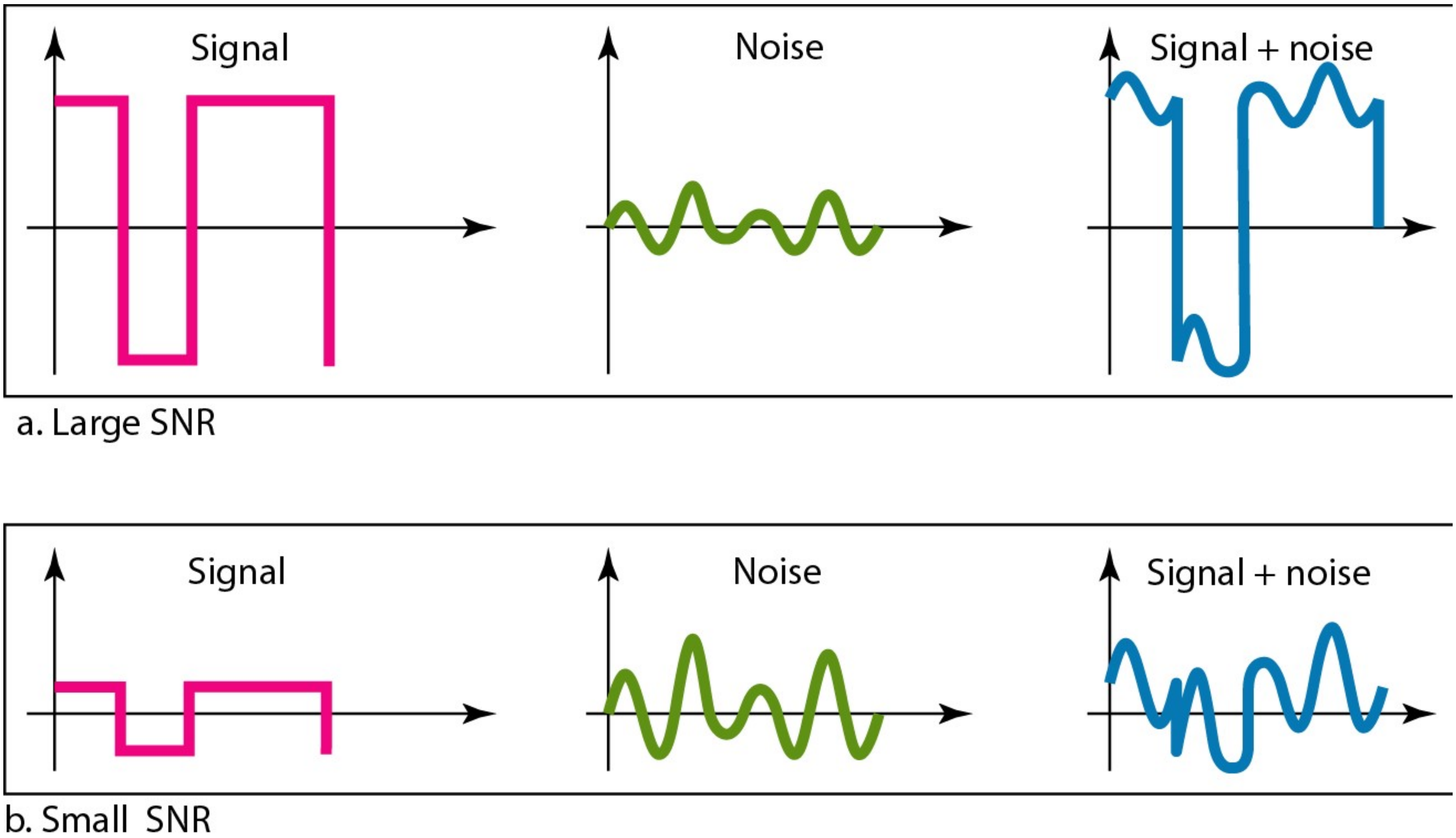
The values of SNR and SNRdB for a noiseless channel are

$$\mathrm{SNR} = \frac{\text{signal power}}{0} = \infty$$

$$\mathrm{SNR_{dB}} = 10 \log_{10} \infty = \infty$$

We can never achieve this ratio in real life; it is an ideal.

Module 1: *Digital Signals :*



Two cases of SNR: a high SNR and a low SNR

Data rate limits

A very important consideration in data communications is how fast we can send data, in bits per second, over a channel. Data rate depends on three factors:

1. The bandwidth available
2. The level of the signals we use
3. The quality of the channel (the level of noise)

Increasing the levels of a signal increases the probability of an error occurring, in other words it reduces the reliability of the system.

Capacity of a System

- ✓ The bit rate of a system increases with an increase in the number of signal levels we use to denote a symbol.
- ✓ A symbol can consist of a single bit or "n" bits.
- ✓ The number of signal levels = 2^n.
- ✓ As the number of levels goes up, the spacing between level decreases -> increasing the probability of an error occurring in the presence of transmission impairments.

Nyquist Theorem

Nyquist gives the upper bound for the bit rate of a transmission system by calculating the bit rate directly from the number of bits in a symbol (or signal levels) and the bandwidth of the system (assuming 2 symbols/per cycle and first harmonic).

Nyquist theorem states that for a noiseless channel:

$$\mathbf{C = 2\,B\,\log_2 2^n}$$

C= capacity in bps

B = bandwidth in Hz

Does the Nyquist theorem bit rate agree with the intuitive bit rate described in baseband transmission?

Solution

They match when we have only two levels. We said, in baseband transmission, the bit rate is 2 times the bandwidth if we use only the first harmonic in the worst case. However, the Nyquist formula is more general than what we derived intuitively; it can be applied to baseband transmission and modulation. Also, it can be applied when we have two or more levels of signals.

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:

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

Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits).
The maximum bit rate can be calculated as:

$$\boxed{\text{BitRate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}}$$

We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?

Solution

We can use the Nyquist formula as shown:

$$265{,}000 = 2 \times 20{,}000 \times \log_2 L$$

$$\log_2 L = 6.625 \qquad L = 2^{6.625} = 98.7 \text{ levels}$$

Since this result is not a power of 2, we need to either increase the number of levels or reduce the bit rate. If we have 128 levels, the bit rate is 280 kbps. If we have 64 levels, the bit rate is 240 kbps.

Shannon's Theorem

Shannon's theorem gives the capacity of a system in the presence of noise.

$$\mathbf{C = B \log_2(1 + SNR)}$$

Module 1: *Digital Signals :*

Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. In other words, the noise is so strong that the signal is faint. For this channel the capacity C is calculated as

$$\boxed{C = B \log_2 (1 + \mathrm{SNR}) = B \log_2 (1 + 0) = B \log_2 1 = B \times 0 = 0}$$

This means that the capacity of this channel is zero regardless of the bandwidth. In other words, we cannot receive any data through this channel.

We can calculate the theoretical highest bit rate of a regular telephone line. A telephone line normally has a bandwidth of 3000. The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as

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

This means that the highest bit rate for a telephone line is 34.860 kbps. If we want to send data faster than this, we can either increase the bandwidth of the line or improve the signal-to-noise ratio.

Module 1: *Digital Signals :*

The signal-to-noise ratio is often given in decibels. Assume that SNR_{dB} = 36 and the channel bandwidth is 2 MHz. The theoretical channel capacity can be calculated as

$$SNR_{dB} = 10 \log_{10} SNR \Rightarrow SNR = 10^{SNR_{dB}/10} \Rightarrow SNR = 10^{3.6} = 3981$$

$$C = B \log_2 (1 + SNR) = 2 \times 10^6 \times \log_2 3982 = 24 \text{ Mbps}$$

Module 1: *Digital Signals :*

For practical purposes, when the SNR is very high, we can assume that SNR + 1 is almost the same as SNR. In these cases, the theoretical channel capacity can be simplified to

$$C = B \times \frac{\mathrm{SNR_{dB}}}{3}$$

For example, we can calculate the theoretical capacity of the previous example as

$$C = 2\ \mathrm{MHz} \times \frac{36}{3} = 24\ \mathrm{Mbps}$$

We have a channel with a 1-MHz bandwidth. The SNR for this channel is 63. What are the appropriate bit rate and signal level?

Solution

First, we use the Shannon formula to find the upper limit.

$$C = B \log_2 (1 + \text{SNR}) = 10^6 \log_2 (1 + 63) = 10^6 \log_2 64 = 6 \text{ Mbps}$$

Module 1: *Digital Signals :*

The Shannon formula gives us 6 Mbps, the upper limit. For better performance we choose something lower, 4 Mbps, for example. Then we use the Nyquist formula to find the number of signal levels.

$$4 \text{ Mbps} = 2 \times 1 \text{ MHz} \times \log_2 L \quad \Rightarrow \quad L = 4$$

Note:

The Shannon capacity gives us the upper limit; the Nyquist formula tells us how many signal levels we need.

Performance

One important issue in networking is the performance of the network—how good is it?

In networking, we use the term bandwidth in two contexts.

- ✓ The first, bandwidth in hertz, refers to the range of frequencies in a composite signal or the range of frequencies that a channel can pass.
- ✓ The second, bandwidth in bits per second, refers to the speed of bit transmission in a channel or link. Often referred to as Capacity.

A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?

Solution

We can calculate the throughput as

$$\boxed{\text{Throughput} = \frac{12{,}000 \times 10{,}000}{60} = 2 \text{ Mbps}}$$

The throughput is almost one-fifth of the bandwidth in this case.

Module 1: *Digital Signals :*

Propagation & Transmission delay

- ✓ Propagation speed - speed at which a bit travels though the medium from source to destination.
- ✓ Transmission speed - the speed at which all the bits in a message arrive at the destination. (difference in arrival time of first and last bit)

- ✓ *Propagation Delay = Distance/Propagation speed*
- ✓ *Transmission Delay = Message size/bandwidth bps*
- ✓ *Latency = Propagation delay + Transmission delay + Queueing time + Processing time*

What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4×10^8 m/s in cable.

Solution

We can calculate the propagation time as

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

The example shows that a bit can go over the Atlantic Ocean in only 50 ms if there is a direct cable between the source and the destination.

What are the propagation time and the transmission time for a 2.5-kbyte message (an e-mail) if the bandwidth of the network is 1 Gbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4 × 108 m/s.

Solution

We can calculate the propagation and transmission time as shown on the next slide:

Module 1: *Digital Signals :*

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

$$\text{Transmission time} = \frac{2500 \times 8}{10^9} = 0.020 \text{ ms}$$

Note that in this case, because the message is short and the bandwidth is high, the dominant factor is the propagation time, not the transmission time. The transmission time can be ignored.

Module 1: *Digital Signals :*

What are the propagation time and the transmission time for a 5-Mbyte message (an image) if the bandwidth of the network is 1 Mbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4×10^8 m/s.

Solution

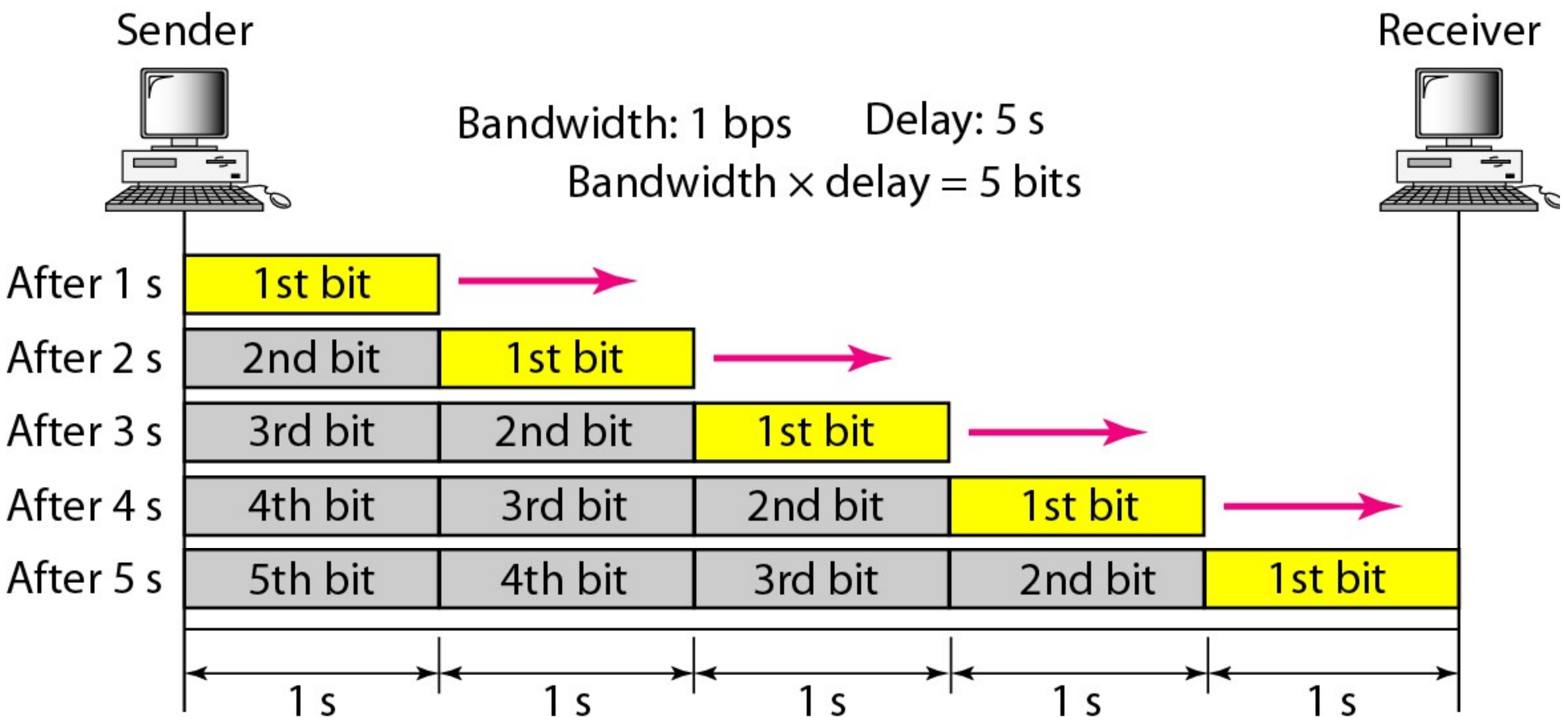
We can calculate the propagation and transmission times as shown on the next slide.

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

$$\text{Transmission time} = \frac{5{,}000{,}000 \times 8}{10^6} = 40 \text{ s}$$

Note that in this case, because the message is very long and the bandwidth is not very high, the dominant factor is the transmission time, not the propagation time. The propagation time can be ignored.

Module 1: *Digital Signals :*

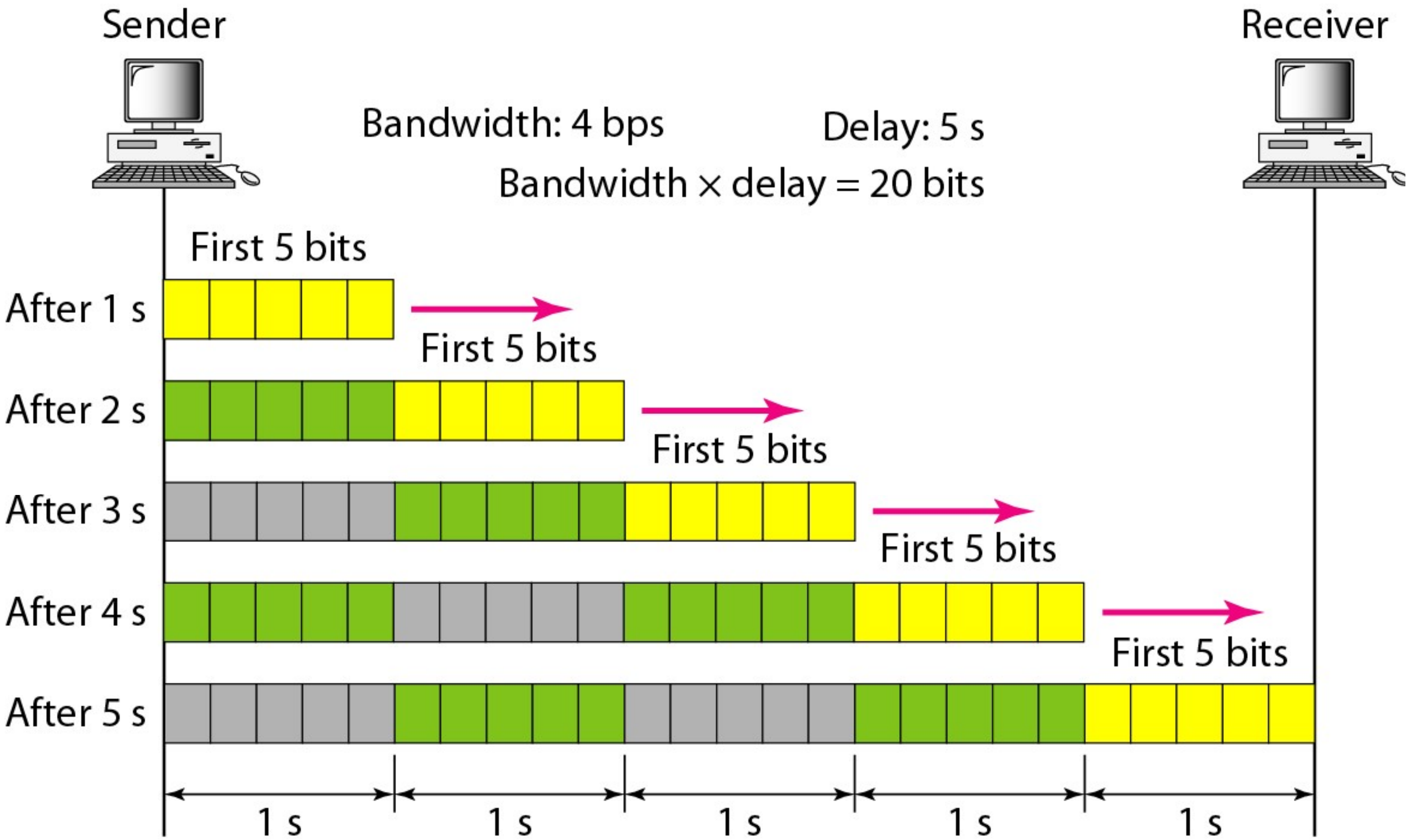


Filling the link with bits for case 1

Module 1: *Digital Signals :*

We can think about the link between two points as a pipe. The cross section of the pipe represents the bandwidth, and the length of the pipe represents the delay. We can say the volume of the pipe defines the bandwidth-delay product, as shown in figure.

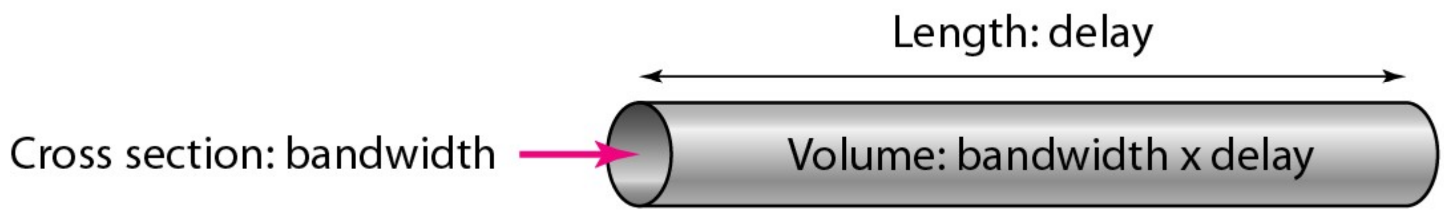
Module 1: *Digital Signals :*



Filling the link with bits in case 2

Module 1: *Digital Signals :*

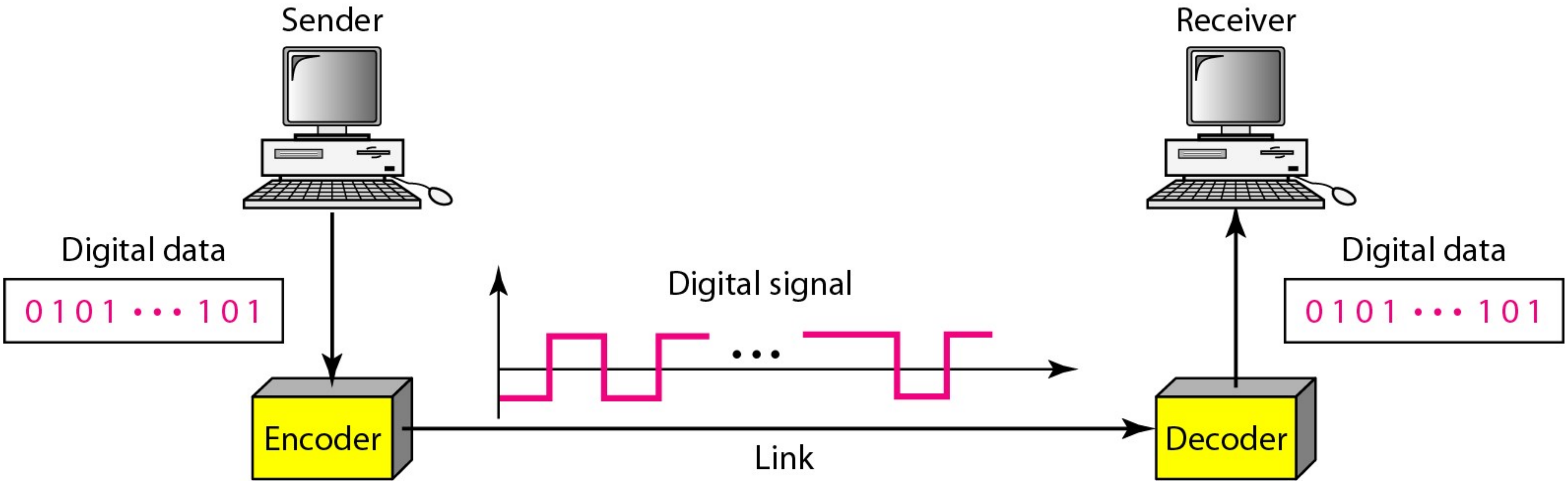
The bandwidth-delay product defines the number of bits that can fill the link.



Module 1: *Digital to Digital Conversion :*

- ✓ Digital data is represented using digital signals.
- ✓ The conversion involves three techniques: line coding, block coding, and scrambling.
- ✓ Line coding is always needed; block coding and scrambling may or may not be needed.

Module 1: *Digital to Digital Conversion :*

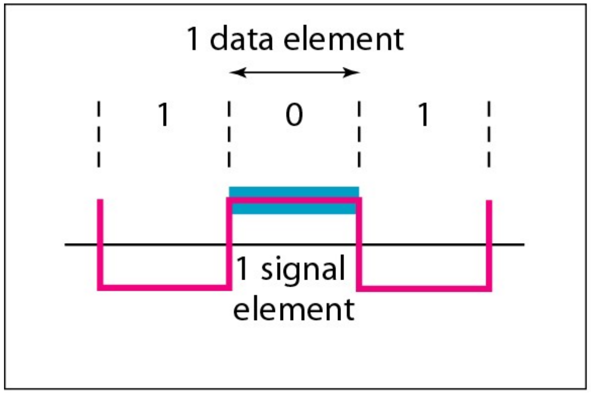


Line coding and decoding

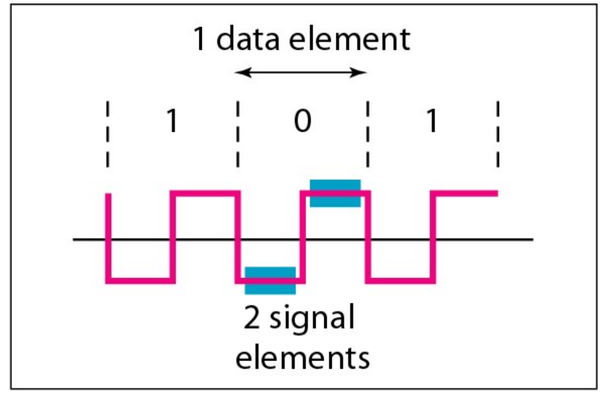
Data and signal elements

- ✓ Data elements are what we need to send
- ✓ Signal Elements are what we can send
- ✓ Data elements are being carried
- ✓ Signal elements are the carriers

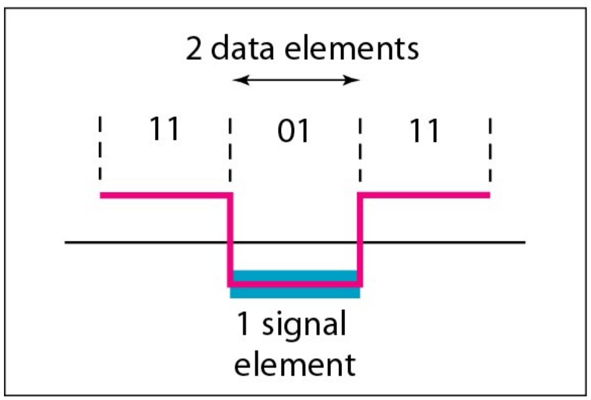
Module 1: *Digital to Digital Conversion :*



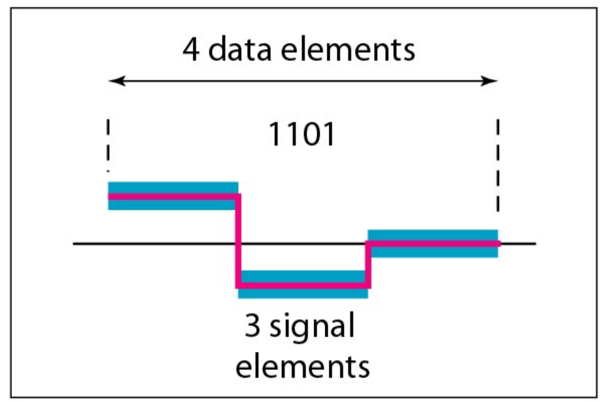
a. One data element per one signal element (r = 1)



b. One data element per two signal elements $\left(r = \frac{1}{2}\right)$



c. Two data elements per one signal element (r = 2)



d. Four data elements per three signal elements $\left(r = \frac{4}{3}\right)$

Signal element versus data element

Data rate/Bit rate

Number of data elements(bits) per second(bps)

Baud rate/Pulse rate/modulation rate

Number of Signal elements per second

$$\mathbf{S = c * N * 1/r}$$

Where,

S = Number of signal elements

N = bit rate

c = case factor(best case/worst case/average case)

r = data element and signal element ratio

Module 1: *Digital to Digital Conversion :*

Example:

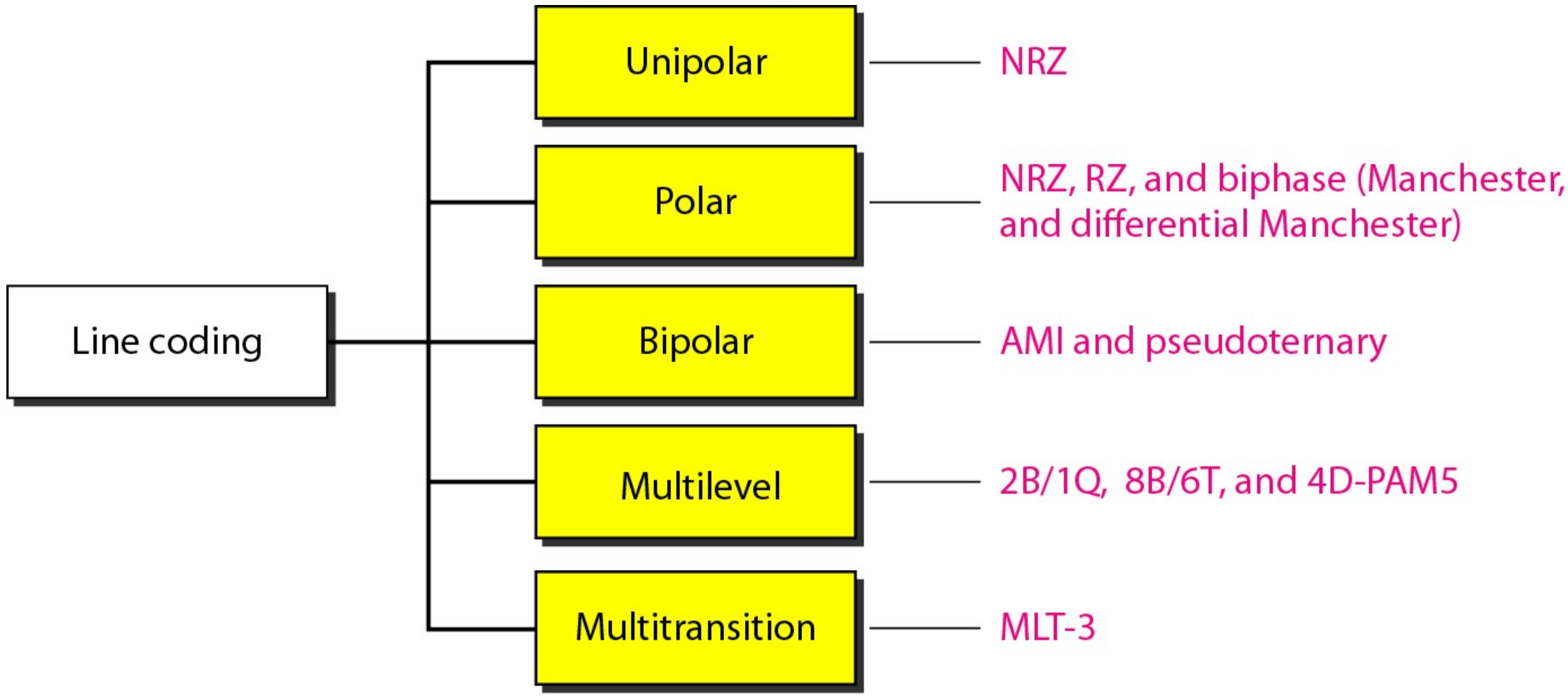
A signal is carrying data in which one data element is encoded as one signal element (r = 1). If the bit rate is 100 kbps, what is the average value of the baud rate if c is between 0 and 1?

Solution

We assume that the average value of c is 1/2 . The baud rate is then

$$\boxed{S = c \times N \times \frac{1}{r} = \frac{1}{2} \times 100{,}000 \times \frac{1}{1} = 50{,}000 = 50 \text{ kbaud}}$$

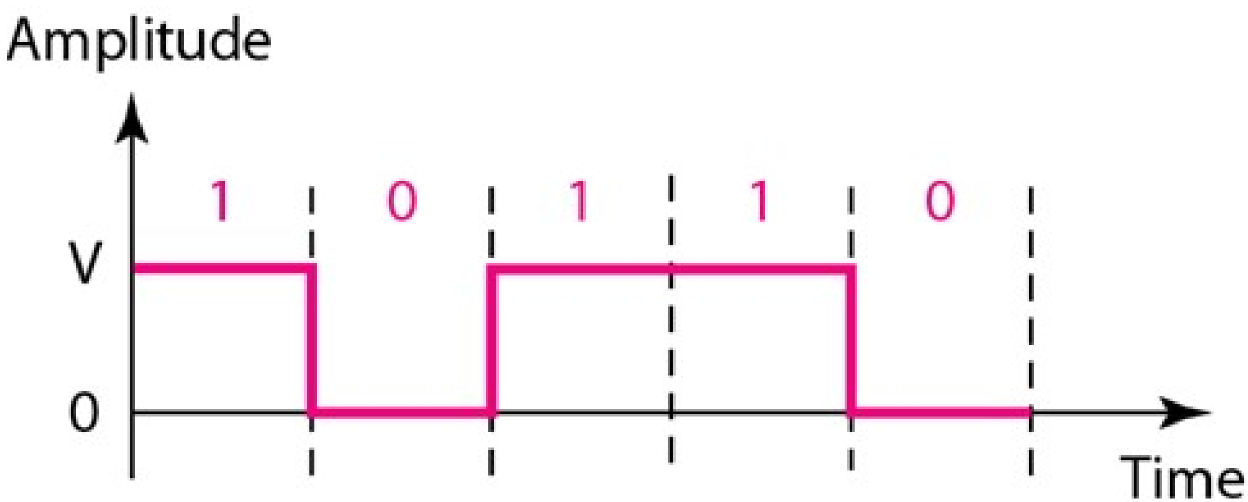
Module 1: *Digital to Digital Conversion :*



Line coding schemes

Module 1: *Digital to Digital Conversion :*

In a ***unipolar*** scheme, all the signal levels are on one side of the time axis, either above or below NRZ (Non-Return-to-Zero): positive voltage defines bit I and the zero voltage defines bit 0

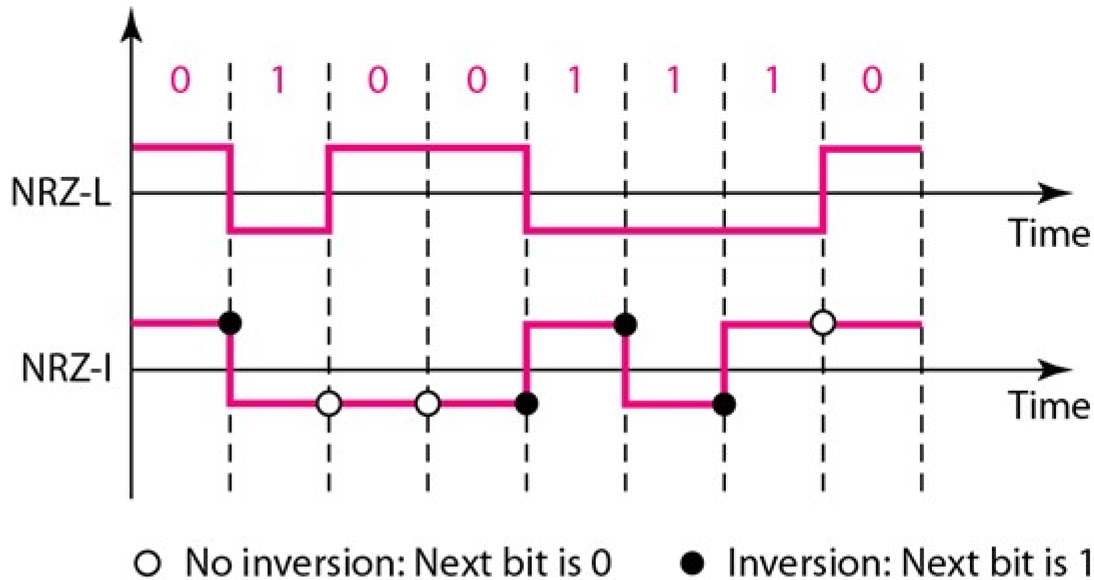


Module 1: *Digital to Digital Conversion :*

In **polar schemes**, the voltages are on the both sides of the time axis.

NRZ-L (NRZ-Level): level of voltage determines value of the bits

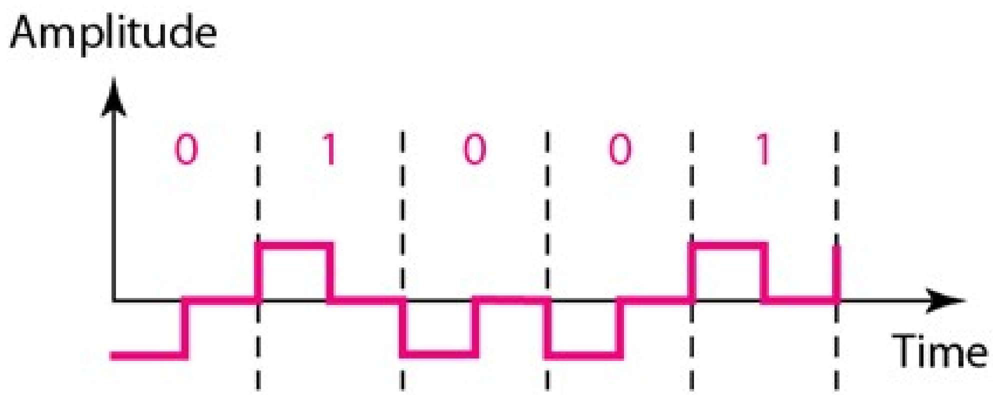
NRZ-I (NRZ-Invert): If there is no change, the bit is 0; if there is a change, the bit is 1.



Return to Zero (RZ)

It requires two signal changes to encode a bit.

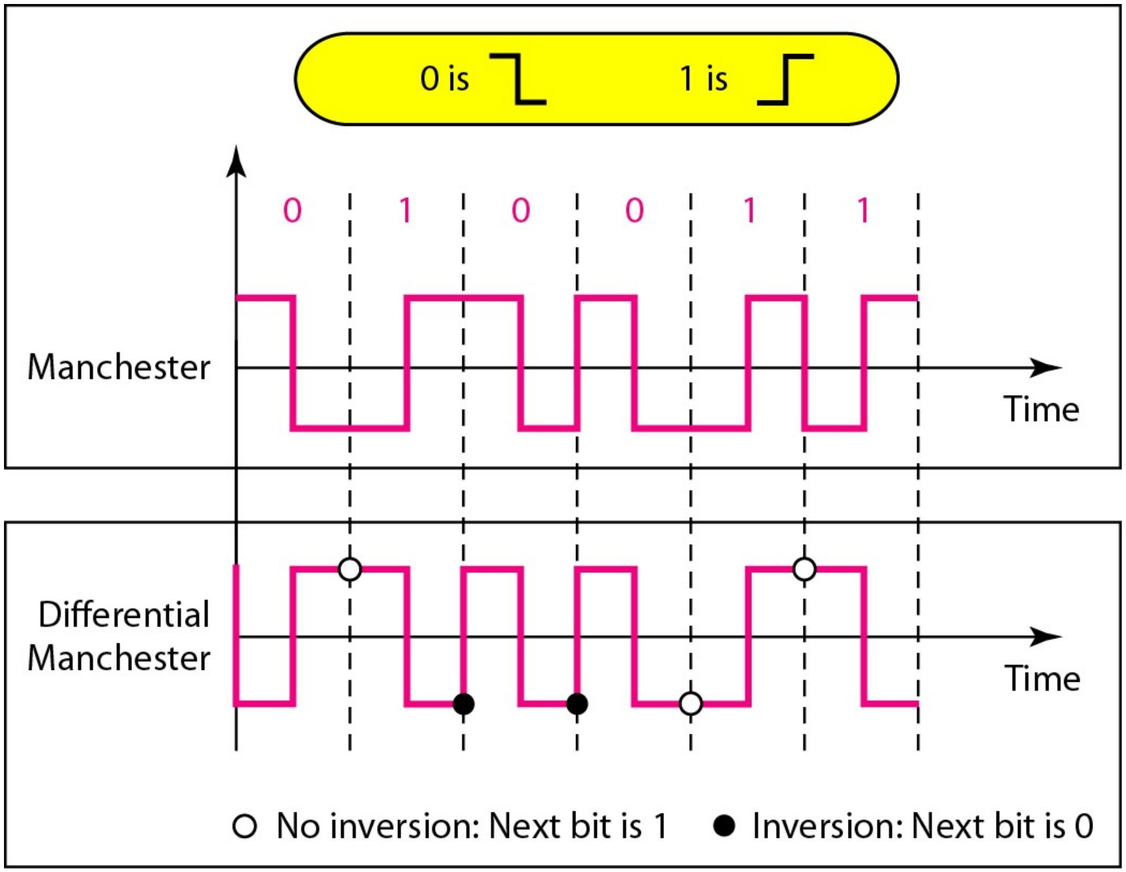
Uses three values: positive, negative, and zero.

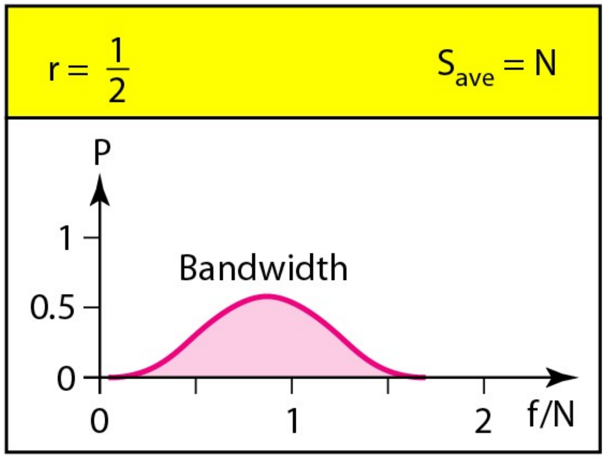


Polar biphase: Manchester and differential Manchester schemes

- ✓ In Manchester and differential Manchester encoding, the transition at the middle of the bit is used for synchronization.
- ✓ The minimum bandwidth of Manchester and differential Manchester is 2 times that of NRZ.

Module 1: *Digital to Digital Conversion :*





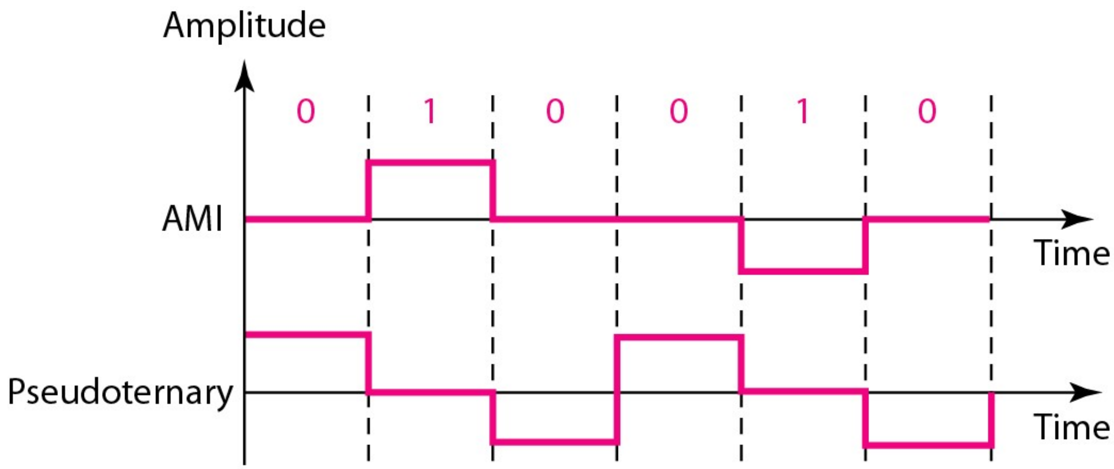
Bipolar schemes

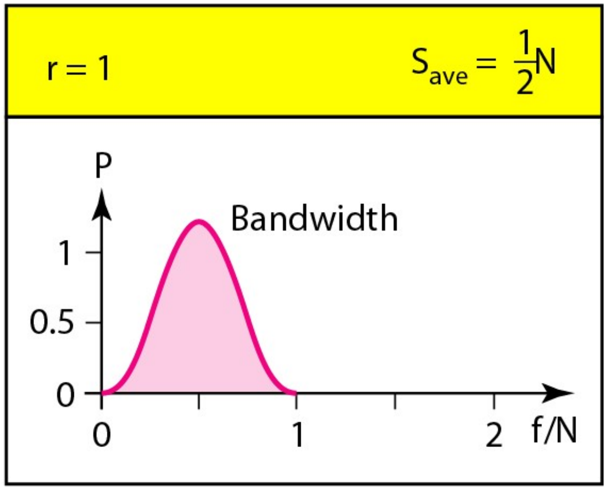
Bipolar encoding uses three levels: positive, zero, and negative.

Bipolar schemes:

- ✓ AMI
- ✓ Pseudoternary

Module 1: *Digital to Digital Conversion :*





AMI: Bit 0 is zero level and 1 bit alternate +ve and –ve voltage

Pseudoternary: Bit 1 is zero level and 0 bit alternate +ve and –ve level

Multilevel scheme :mBnL

In *m*B*n*L schemes, a pattern of *m* data elements is encoded as a pattern of *n* signal elements in which

$$2^m \leq L^n.$$

Where,

m: length of the binary pattern,

B: Binary data

n: Length of the signal pattern.

L: Number of levels in the signaling.

Module 1: *Digital to Digital Conversion :*

A letter is often used in place of L:

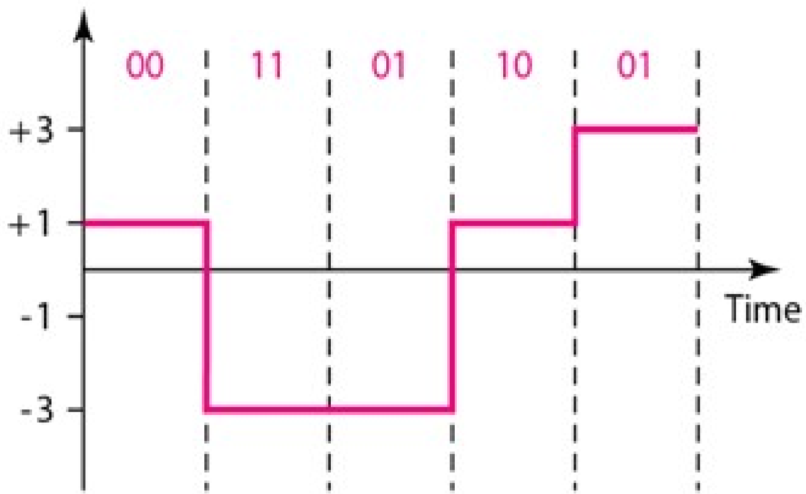
- B (binary) for L =2,
- T (ternary) for L = 3, and
- Q (quaternary) for L =4.

Note that the first two letters define the data pattern, and the second two define the signal pattern.

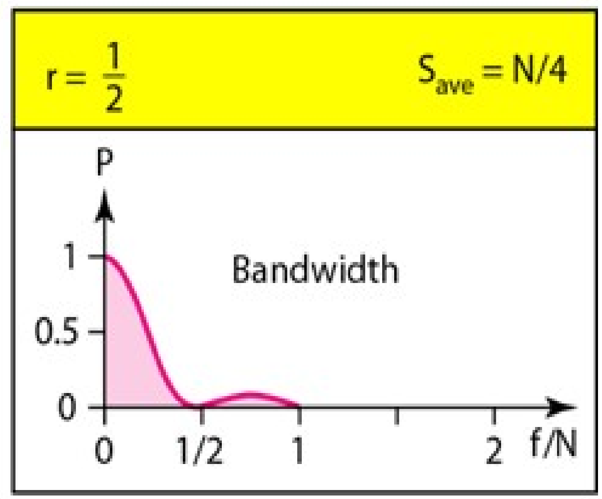
Module 1: *Digital to Digital Conversion :*

	Previous level: positive	Previous level: negative
Next bits	Next level	Next level
00	+1	-1
01	+3	-3
10	-1	+1
11	-3	+3

Transition table

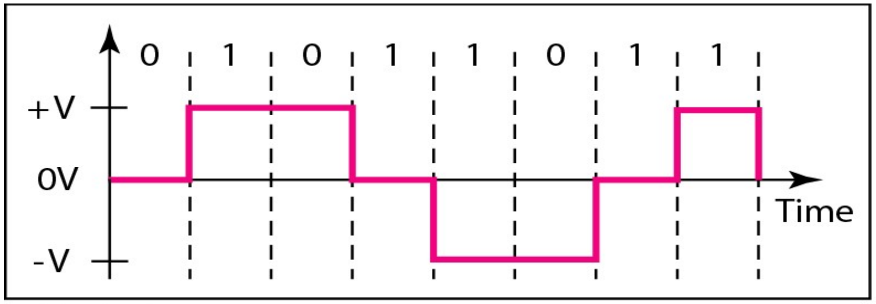


Assuming positive original level

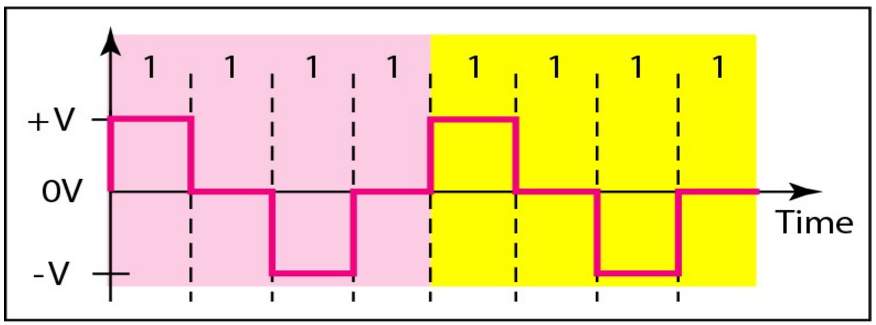


Multilevel: 2B1Q scheme

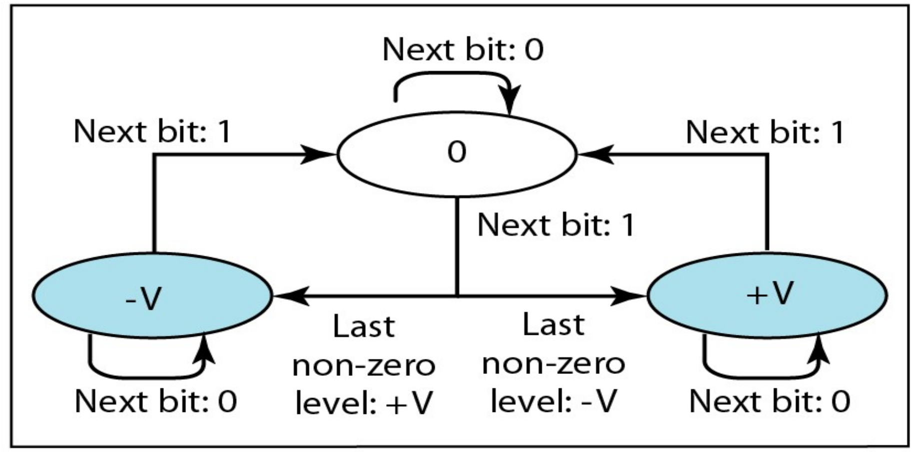
Module 1: *Digital to Digital Conversion :*



a. Typical case



b. Worse case



c. Transition states

Multitransition: MLT-3 scheme

Module 1: *Digital to Digital Conversion :*

- ✓ If the next bit is 0, there is no transition.
- ✓ If the next bit is 1 and the current level is not 0, the next level is 0.
- ✓ If the next bit is 1 and the current level is 0, the next level is the opposite of the last nonzero level.

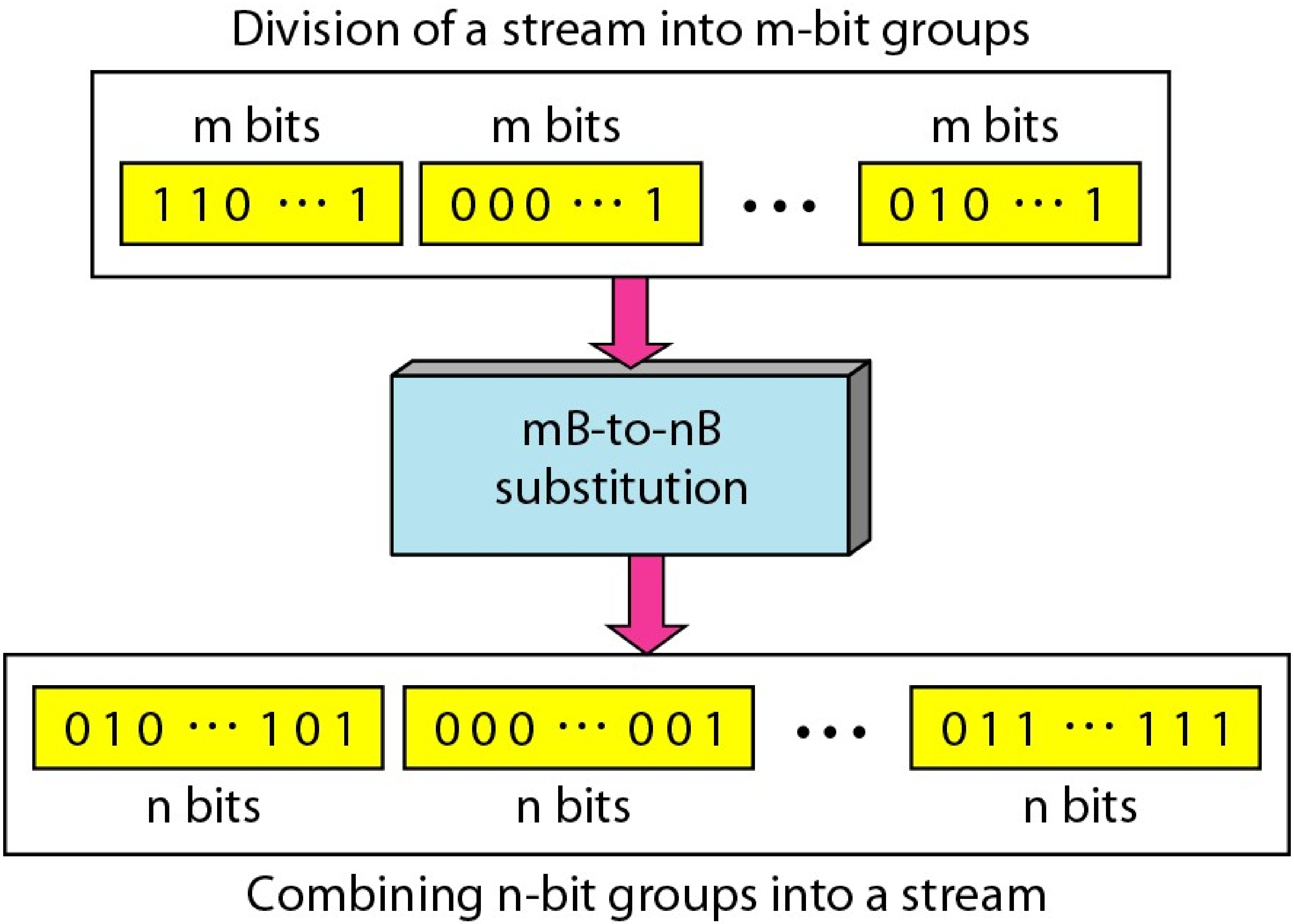
Block Coding

- ✓ Block coding changes a block of *m* bits into a block of *n* bits, where *n* is larger than *m e*xtra bits (redundancy) added to ensure synchronization and to provide error detecting.
- ✓ Block coding is normally referred to as *m*B/*n*B coding.

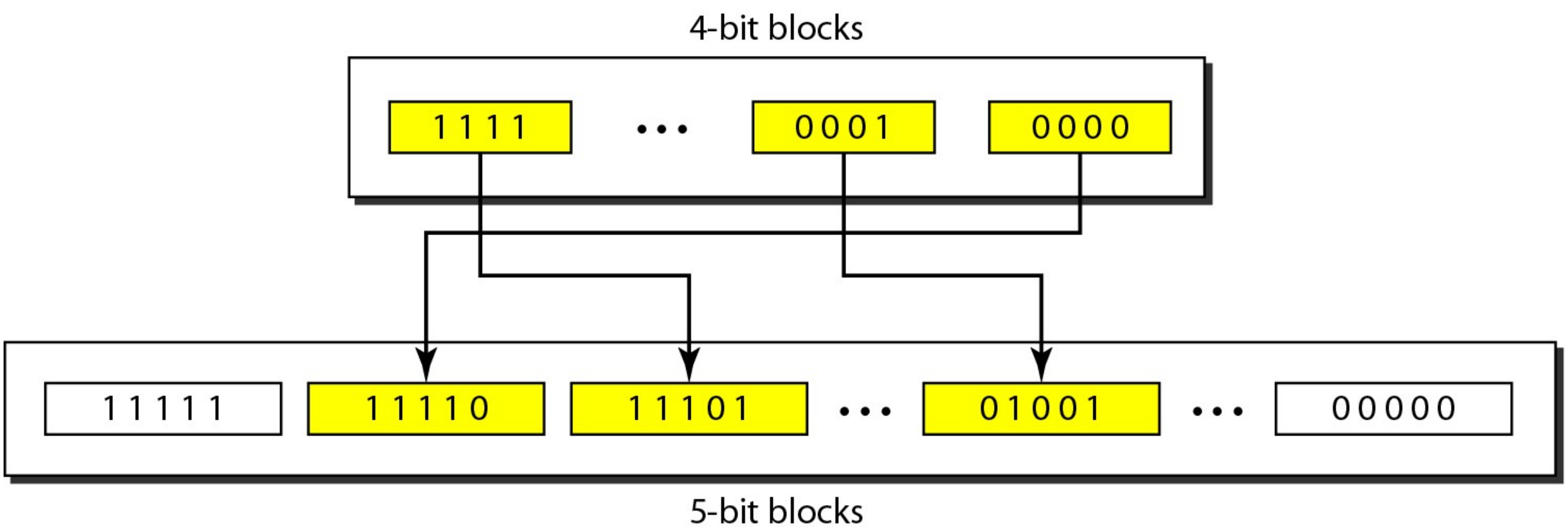
Steps of block coding:

- ✓ Division
- ✓ Substitution
- ✓ Combining

Module 1: *Digital to Digital Conversion :*

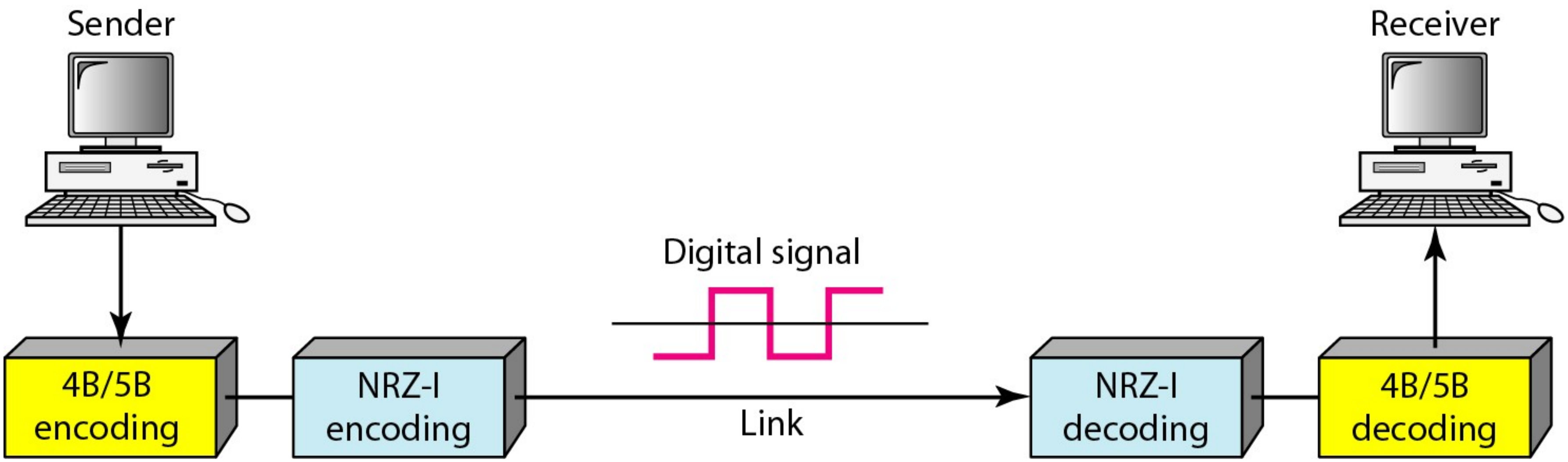


Module 1: *Digital to Digital Conversion :*



Substitution in 4B/5B block coding

Module 1: *Digital to Digital Conversion :*



Using block coding 4B/5B with NRZ-I line coding scheme

Module 1: *Digital to Digital Conversion :*

Scrambling

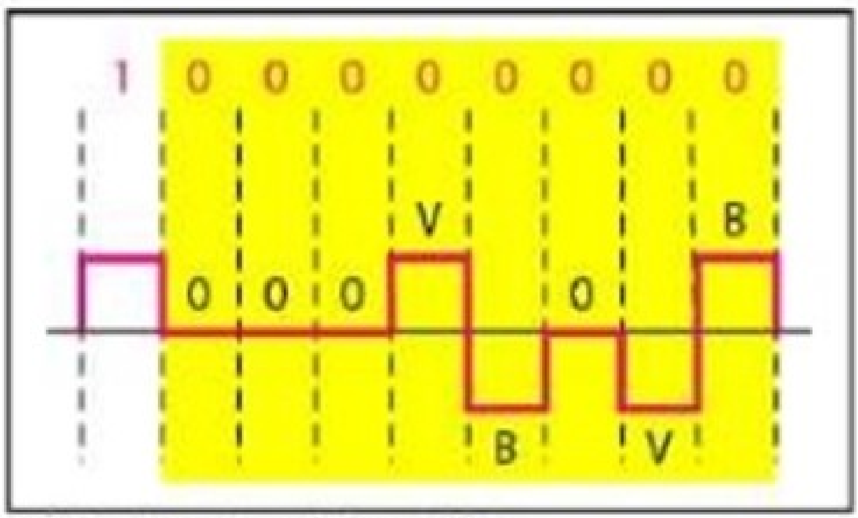
- ✓ Long sequence of 0s present in the data creates synchronization problem.
- ✓ For example in AMI long sequence of 0s represented as 0 voltage level can create synchronization problem.
- ✓ Scrambling can be used to avoid long sequence of 0s in the original stream.

Two schemes available for scrambling

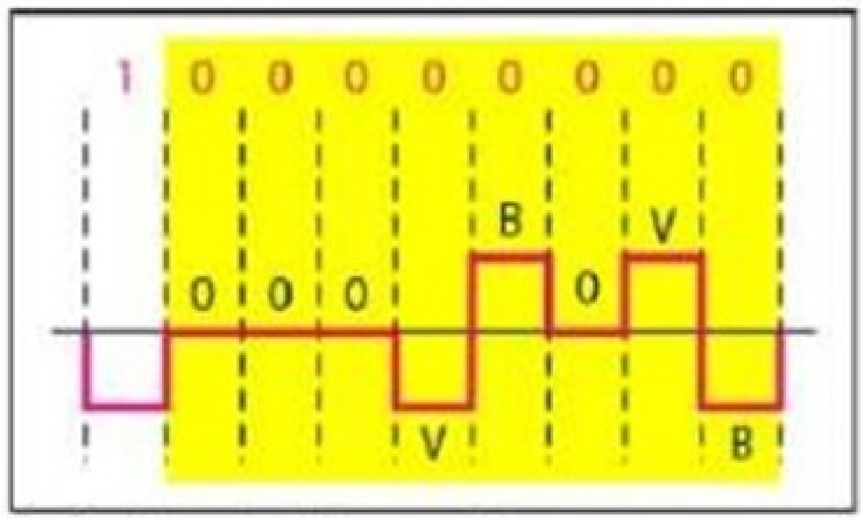
- ✓ B8ZS(Bipolar 8-Zero Substitution)
- ✓ HDB3(High-density bipolar 3-zero)

B8ZS(Bipolar 8-Zero Substitution)

✓ Eight consecutive zero-level voltages are replaced by the sequence 000VB0VB.



a. Previous level is positive.



b. Previous level is negative.

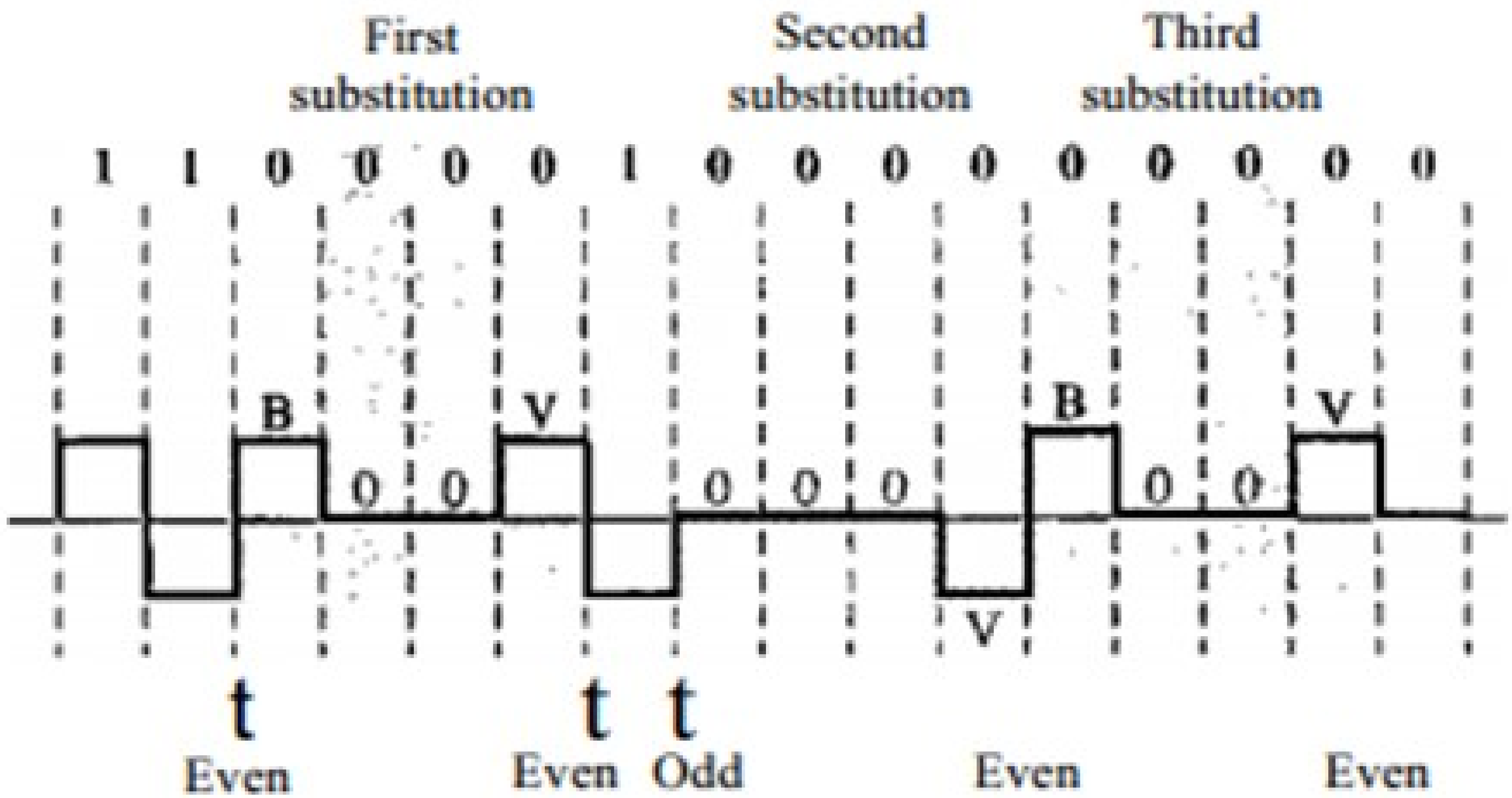
HDB3(High-Density Bipolar 3-Zero)

- ✓ The encoding rules follow AMI, except that a sequence of four consecutive 0's are encoded using a special "violation" bit “V”.
- ✓ Four consecutive zero-level voltages are replaced with a sequence of 000V or B00V.
- ✓ B means bipolar and V means violation of AMI rule

Rules:

1. If the number of nonzero pulses after the last substitution is odd, the substitution pattern will be 000V, which makes the total number of nonzero pulses even.
2. If the number of nonzero pulses after the last substitution is even, the substitution pattern will be B00V, which makes the total number of nonzero pulses even.

Module 1: *Digital to Digital Conversion :*



Example of HDB3 encoding

Encode the pattern of bits " 1 0 0 0 0 1 1 0 "
Using HDB3.

Answer:

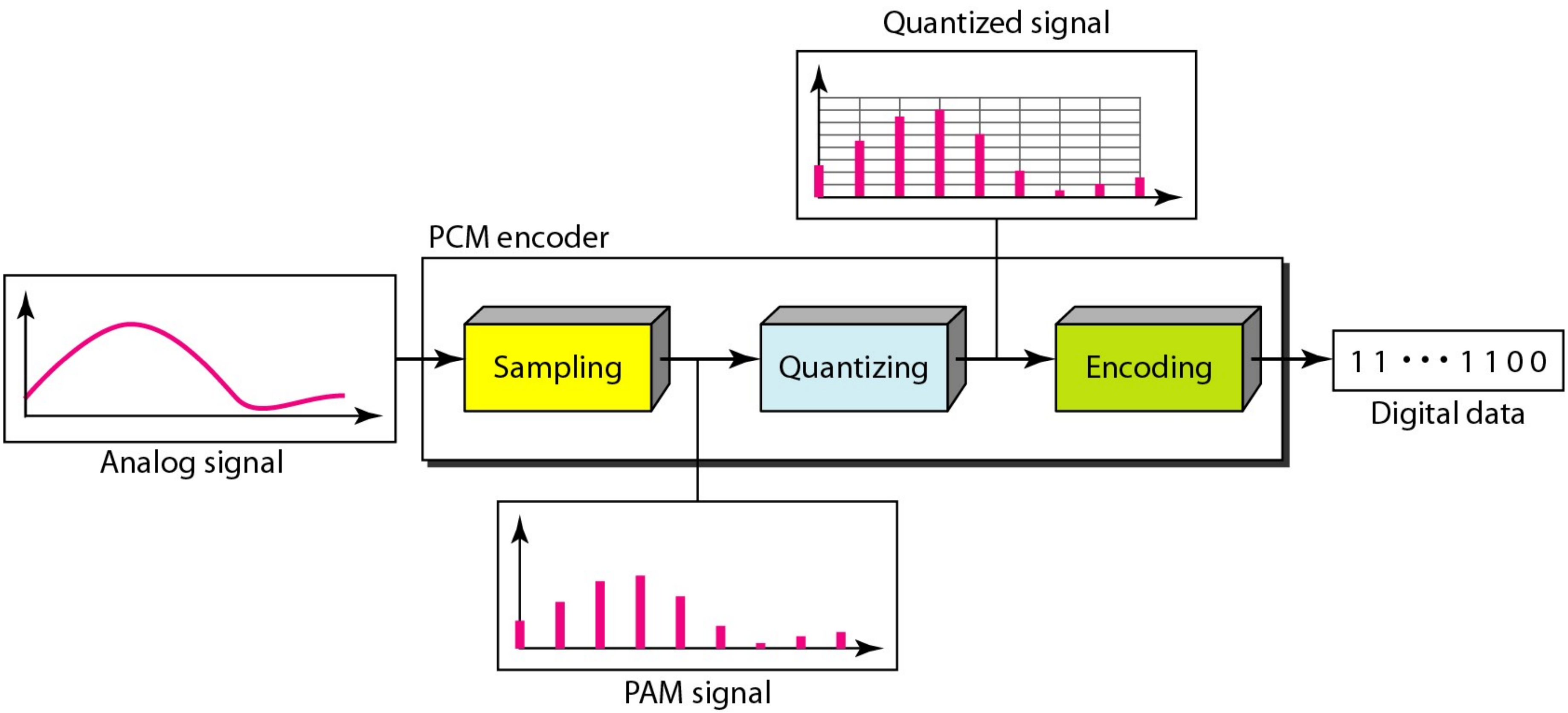
" + 0 0 0 V - + 0 “

Analog-to-Digital conversion

Translation from analog signal to digital data.

- ✓ Pulse Code Modulation (PCM)
- ✓ Delta Modulation (DM)

Pulse Code Modulation (PCM)

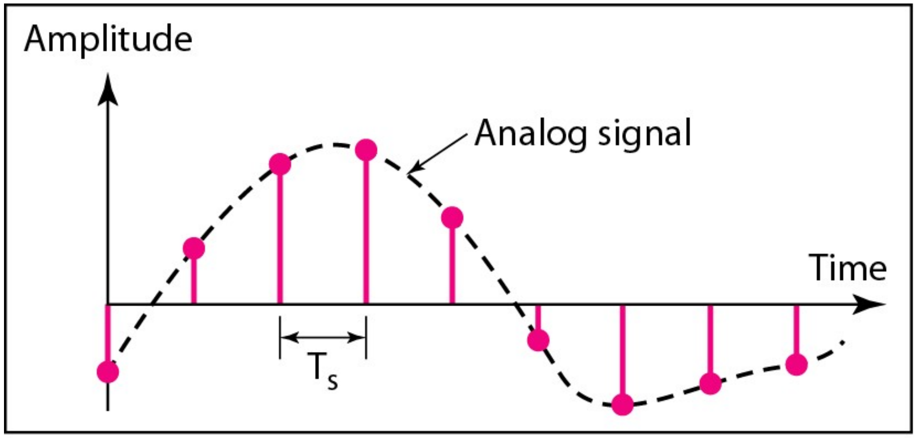


Components of PCM encoder

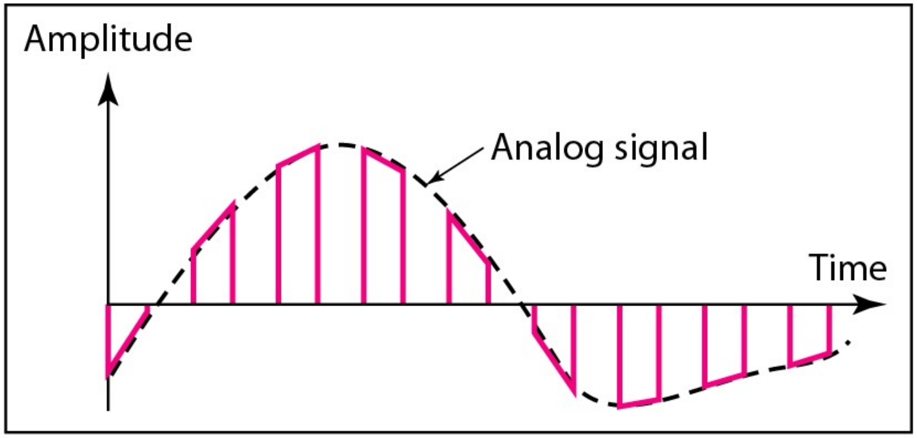
Steps of PCM:

- ✓ **Sampling:** Collect the sample data at instantaneous points of message signal at regular interval. It is also known Pulse Amplitude Modulation(PAM)
- ✓ **Quantizing:** Reduces the redundant bits and compresses the value.
- ✓ **Encoding:** It designates each quantized level by a binary code.

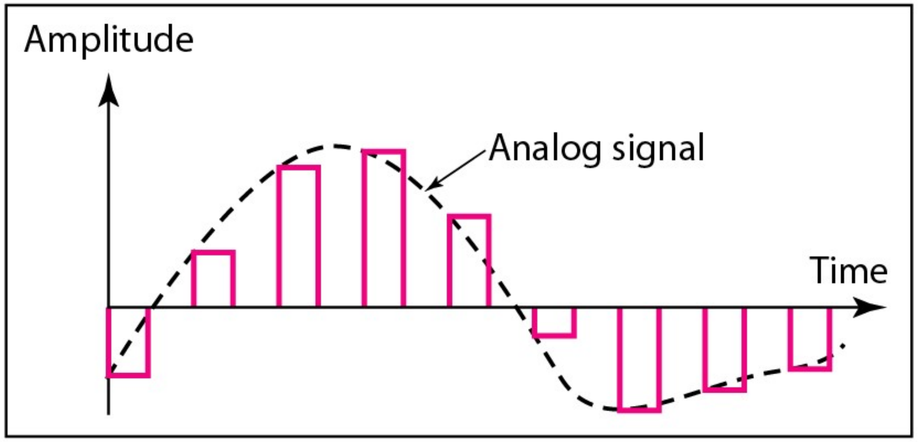
Module 1: *Analog-to-Digital conversion :*



a. Ideal sampling



b. Natural sampling



c. Flat-top sampling

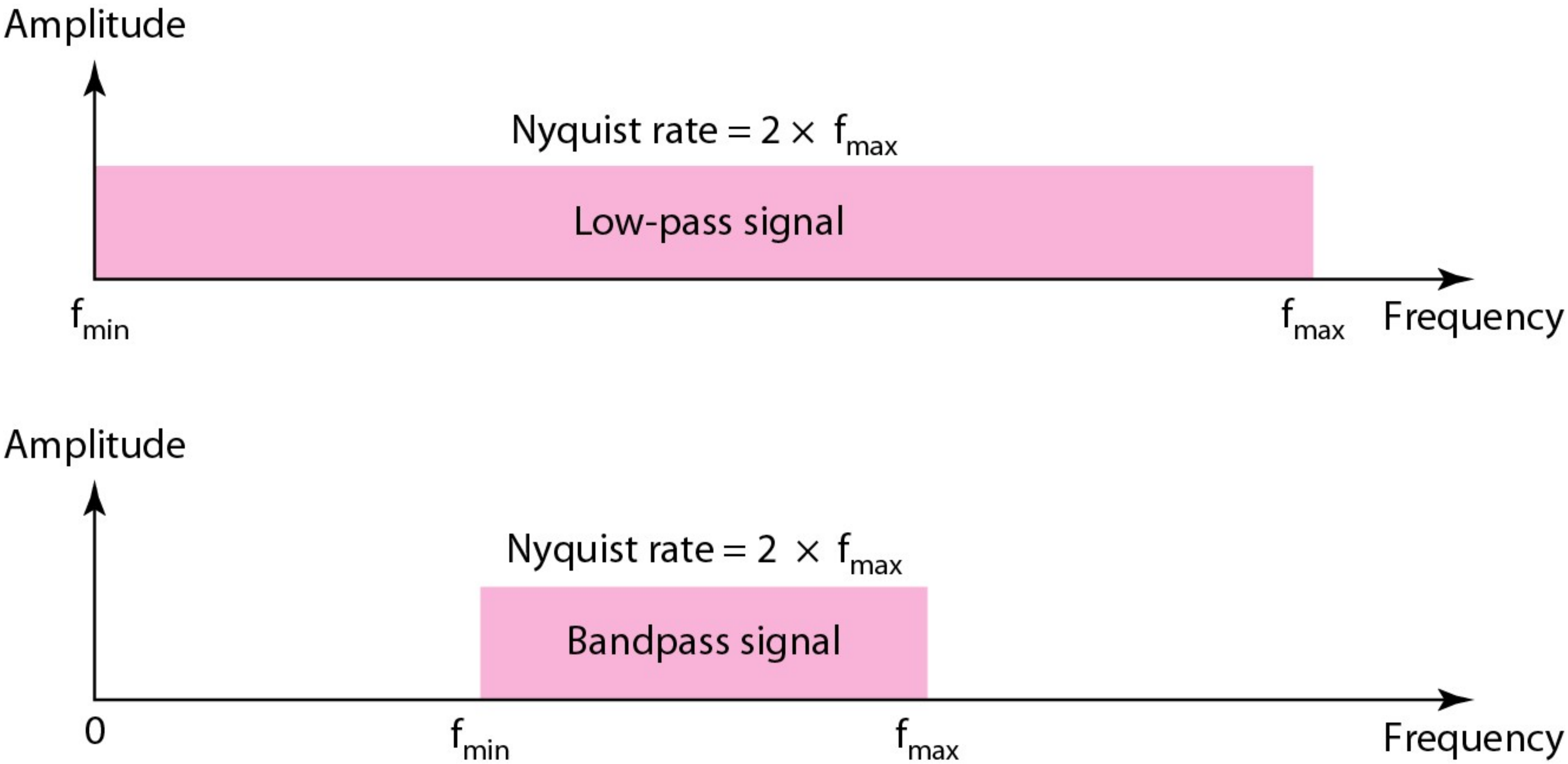
Three different sampling methods for PCM

Module 1: *Analog-to-Digital conversion :*

Sampling rate/ sampling frequency

- ✓ The analog signal is sampled every *Ts second*, where *Ts* is the sample interval or period.
- ✓ The inverse of the sampling interval is called the sampling rate or sampling frequency.
- ✓ According to the Nyquist theorem, the sampling rate must be at least 2 times the highest frequency contained in the signal.

Module 1: *Analog-to-Digital conversion :*



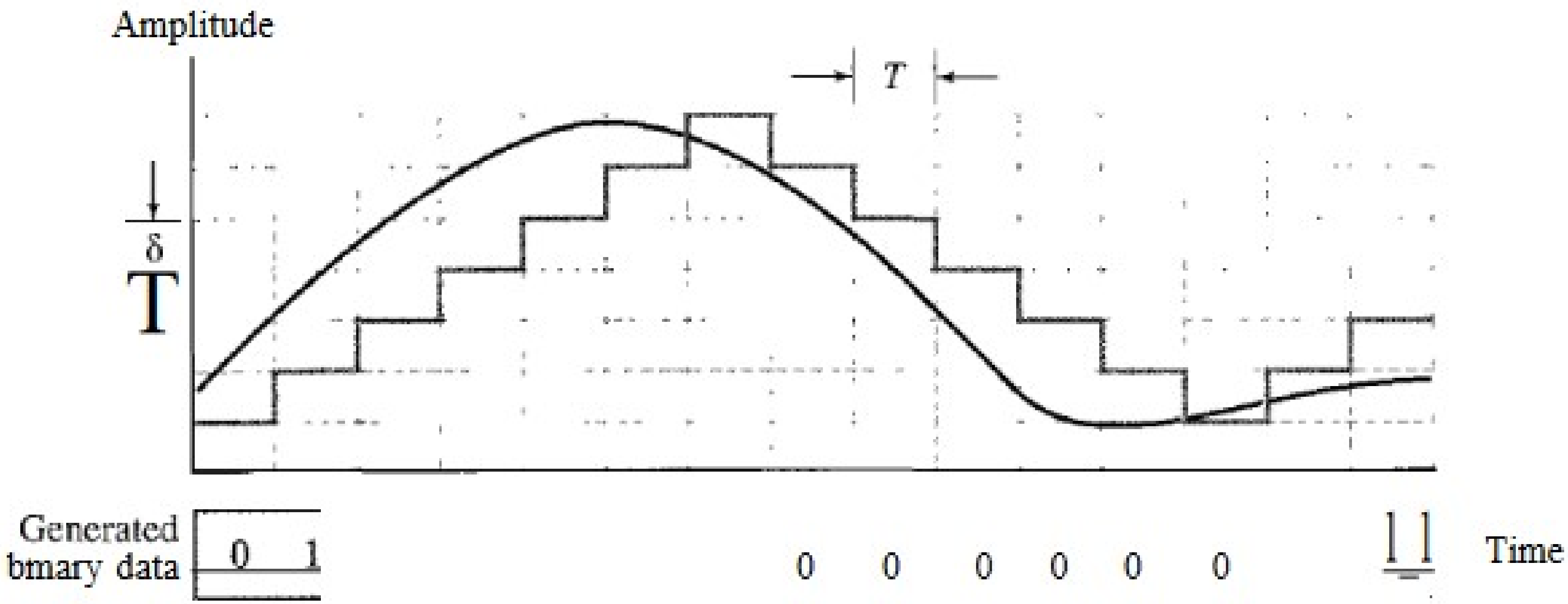
***Nyquist** sampling rate for low-pass and bandpass signals*

Module 1: *Analog-to-Digital conversion :*

Delta Modulation

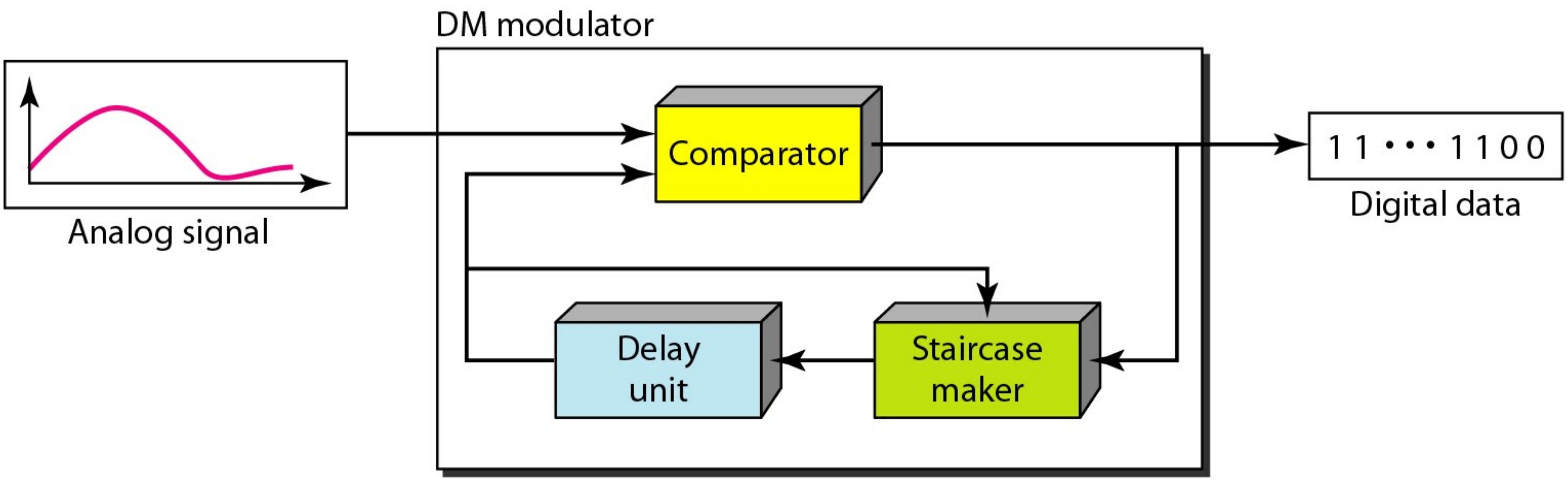
- ✓ The type of modulation, where the sampling rate is much higher and in which the step size after quantization is of a smaller value Δ, such a modulation is termed as delta modulation.
- ✓ The amplitude difference between sample values is very small, as if the difference is 1-bit quantization, then the step-size will be very small i.e., Δ delta.

Module 1: *Analog-to-Digital conversion :*



The process of delta modulation

Module 1: *Analog-to-Digital conversion :*



Delta modulation components

Module 1: *Analog-to-Digital conversion :*

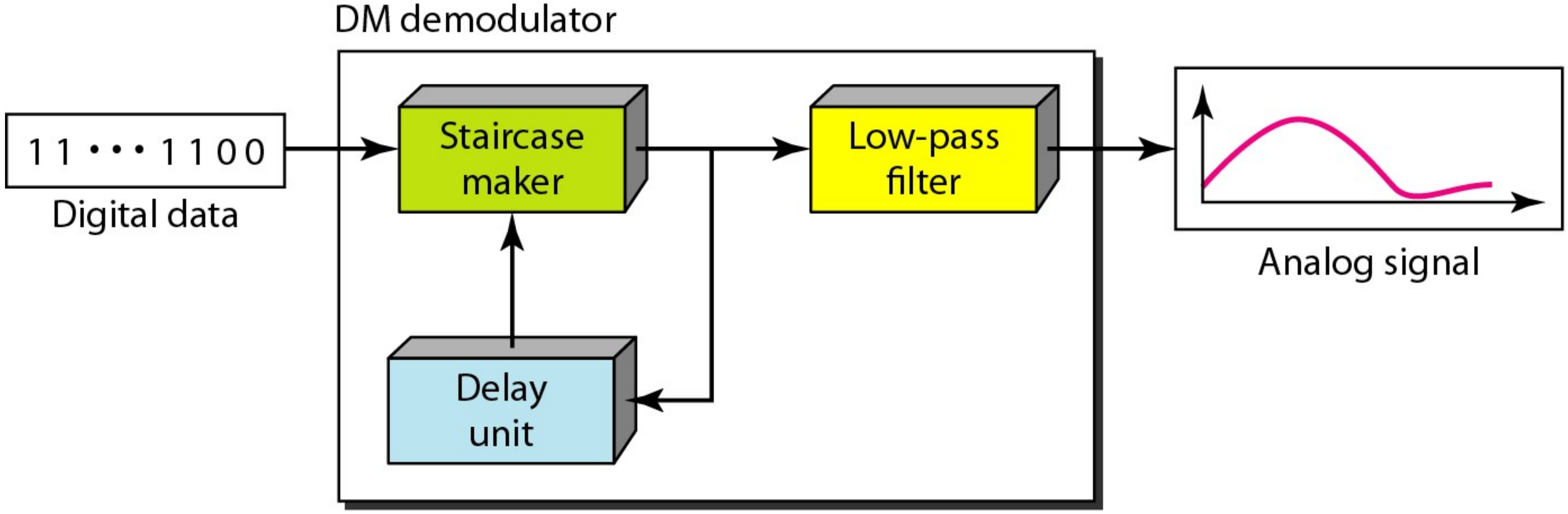
Modulator

- ✓ The modulator is used at the sender site to create a stream of bits from an analog signal.
- ✓ The process records the small positive or negative changes, called “delta”.
- ✓ If the delta is positive, the process records a 1 if it is negative, the process records a 0.
- ✓ However, the process needs a base against which the analog signal is compared.
- ✓ The modulator builds a second signal that resembles a staircase.

Module 1: *Analog-to-Digital conversion :*

- ✓ Finding the change is then reduced to comparing the input signal with the gradually made staircase signal.

Module 1: *Analog-to-Digital conversion :*



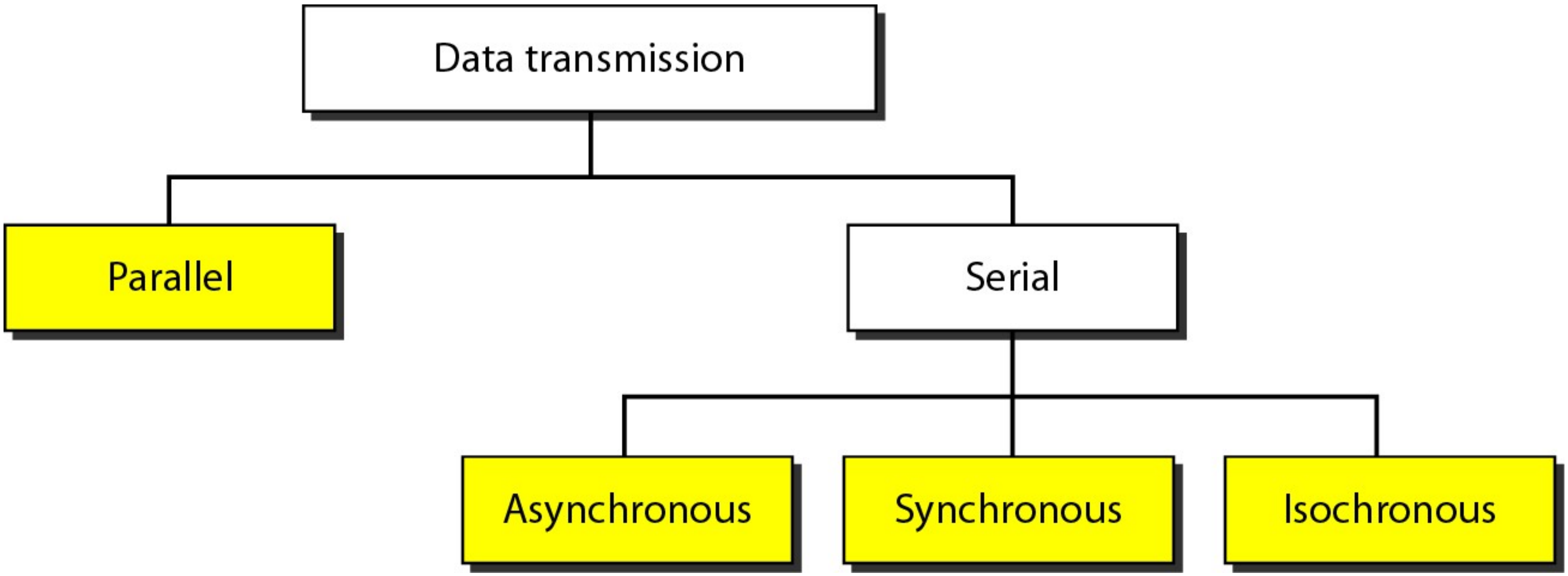
Demodulator

- ✓ The demodulator takes the digital data and, using the staircase maker and the delay unit, creates the analog signal.
- ✓ The created analog signal, however, needs to pass through a low-pass filter for smoothing.

Transmission Modes /Communication Modes

- ✓ The transmission of binary data across a link can be accomplished in either parallel or serial mode.
- ✓ In parallel mode, multiple bits are sent with each clock tick.
- ✓ In serial mode, 1 bit is sent with each clock tick.

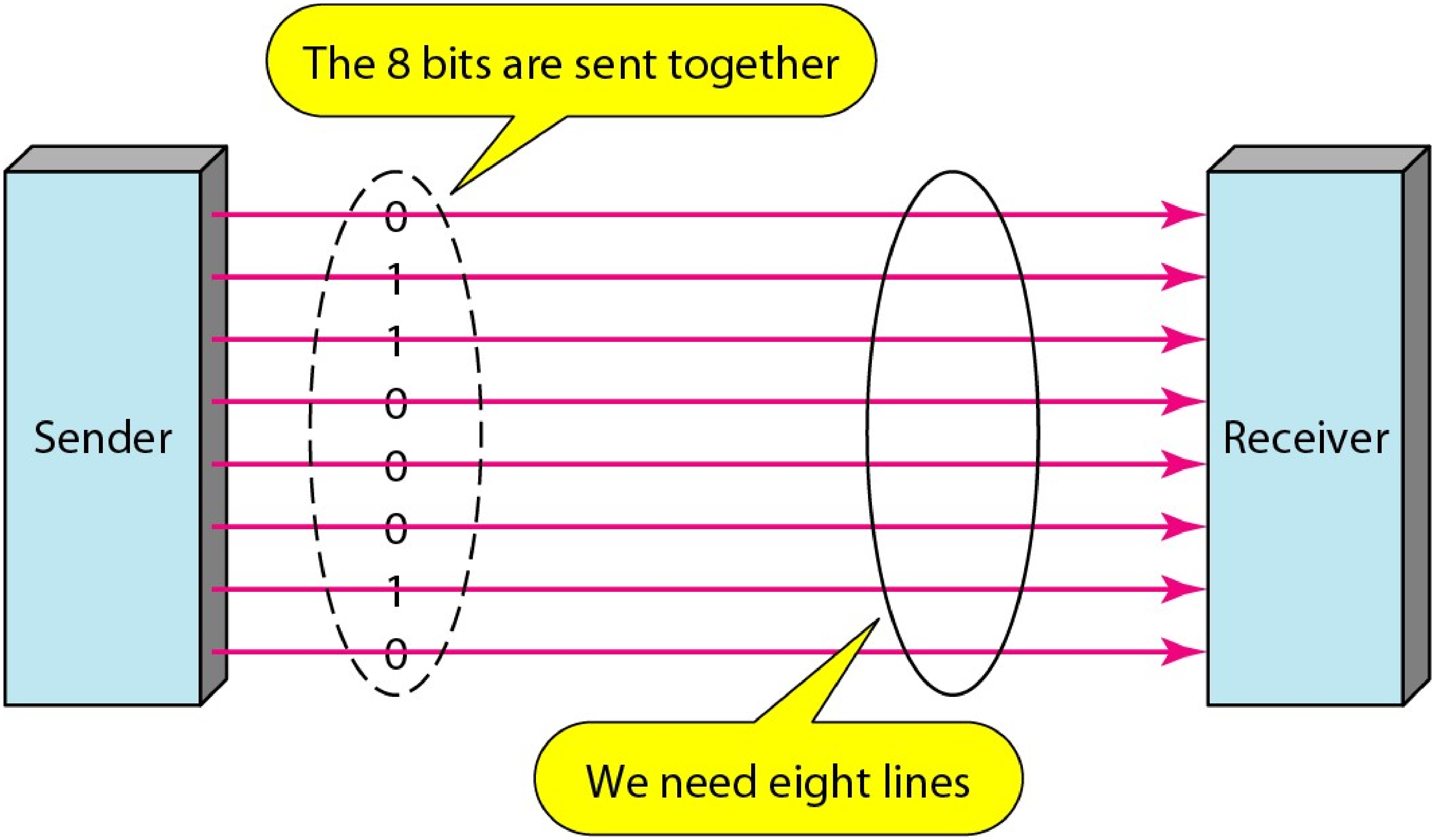
Module 1: *Transmission Modes:*



Data transmission and modes

Module 1: *Transmission Modes:*

Parallel transmission



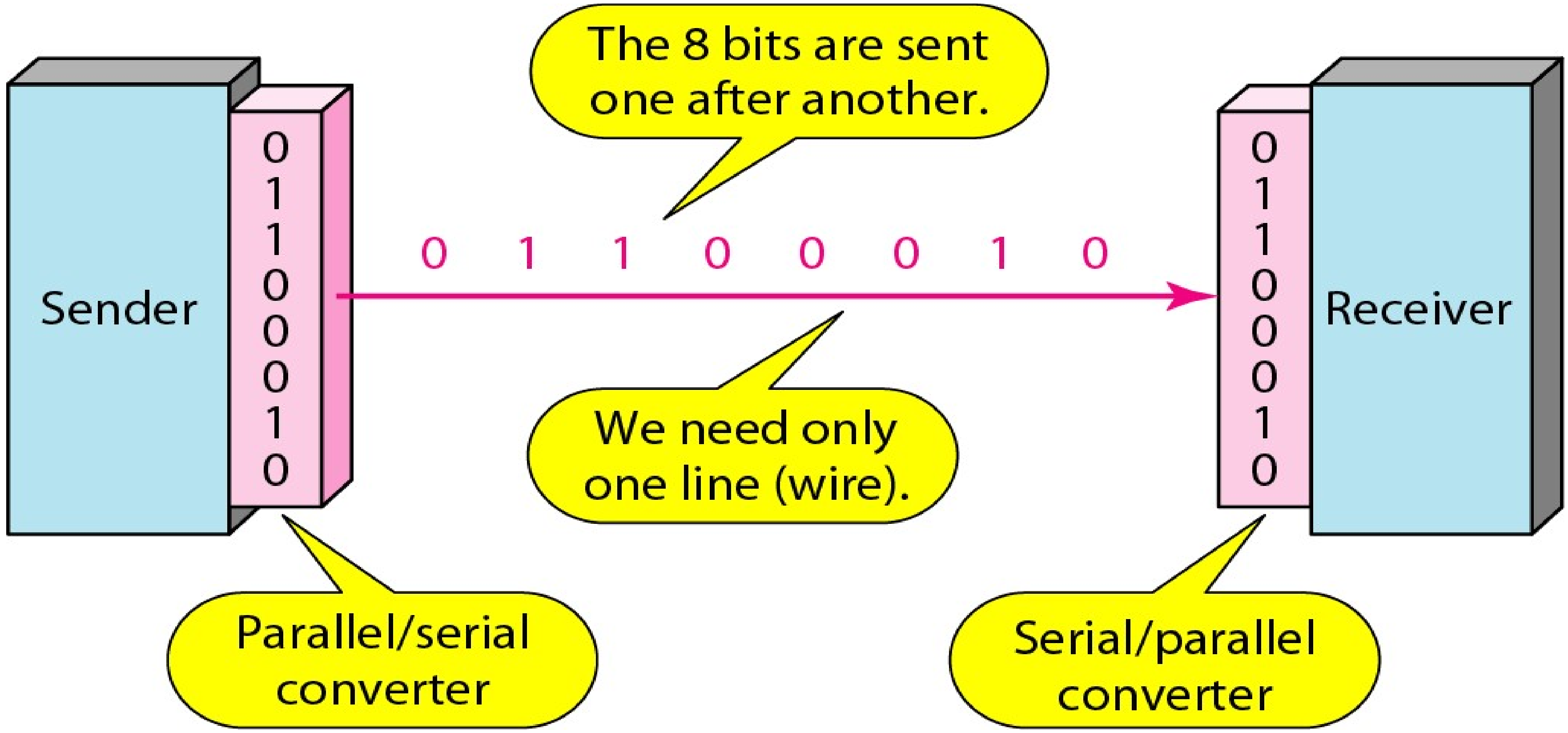
Module 1: *Transmission Modes:*

- ✓ Data bits are transmitted simultaneously through multiple links.
- ✓ Example of parallel mode transmission include connections between a computer and a printer (parallel printer port and cable).

Serial transmission

- ✓ Sends information one bit at a time over a single data channel.
- ✓ Data within a computer system is transmitted via parallel mode on buses with the width of the parallel bus matched to the word size of the computer system.
- ✓ Data between computer systems is usually transmitted in bit serial mode .
- ✓ Example of serial mode transmission include connections between a computer and a modem using the RS-232 protocol .

Module 1: *Transmission Modes:*

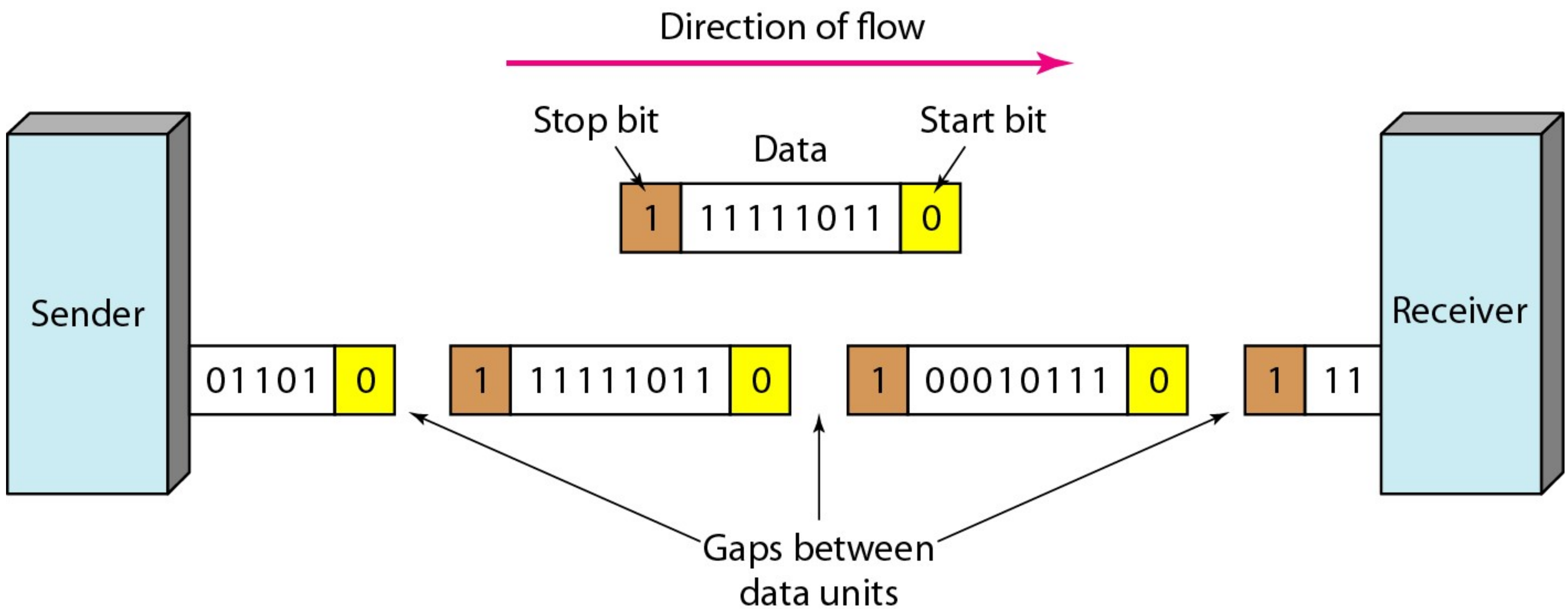


Module 1: *Transmission Modes:*

Asynchronous transmission

- ✓ Asynchronous communication happens when information can be exchanged independent of time.
- ✓ In asynchronous transmission, we send 1 start bit (0) at the beginning and 1 or more stop bits (1s) at the end of each byte. There may be a gap between each byte.

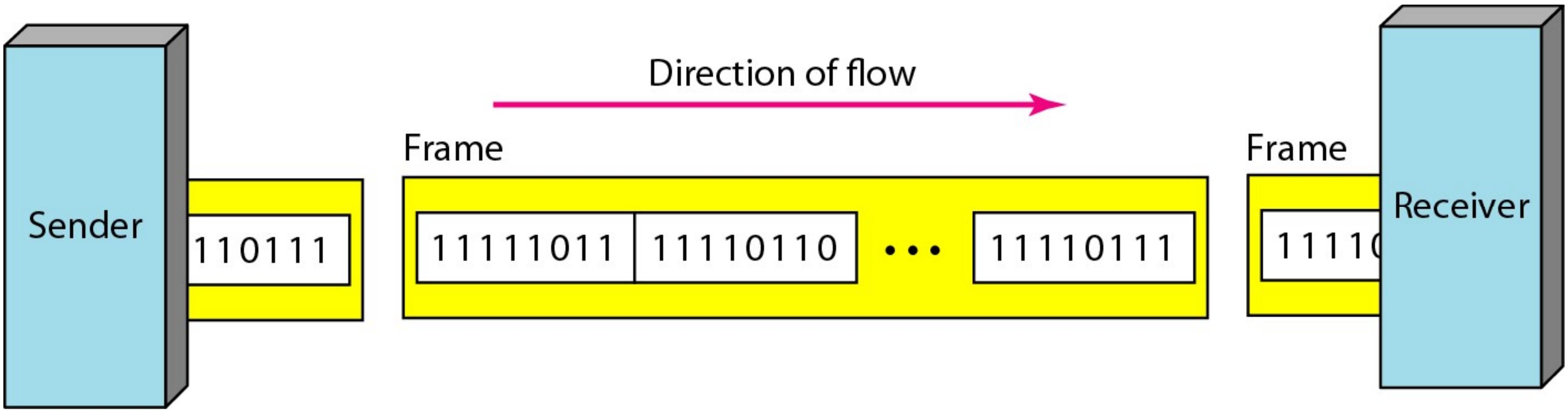
Module 1: *Transmission Modes:*



Synchronous transmission

- ✓ In synchronous transmission, we send bits one after another without start or stop bits or gaps.
- ✓ It is the responsibility of the receiver to group the bits.
- ✓ Synchronous communication happens when messages can only be exchanged in real time.

Module 1: *Transmission Modes:*



Isochronous

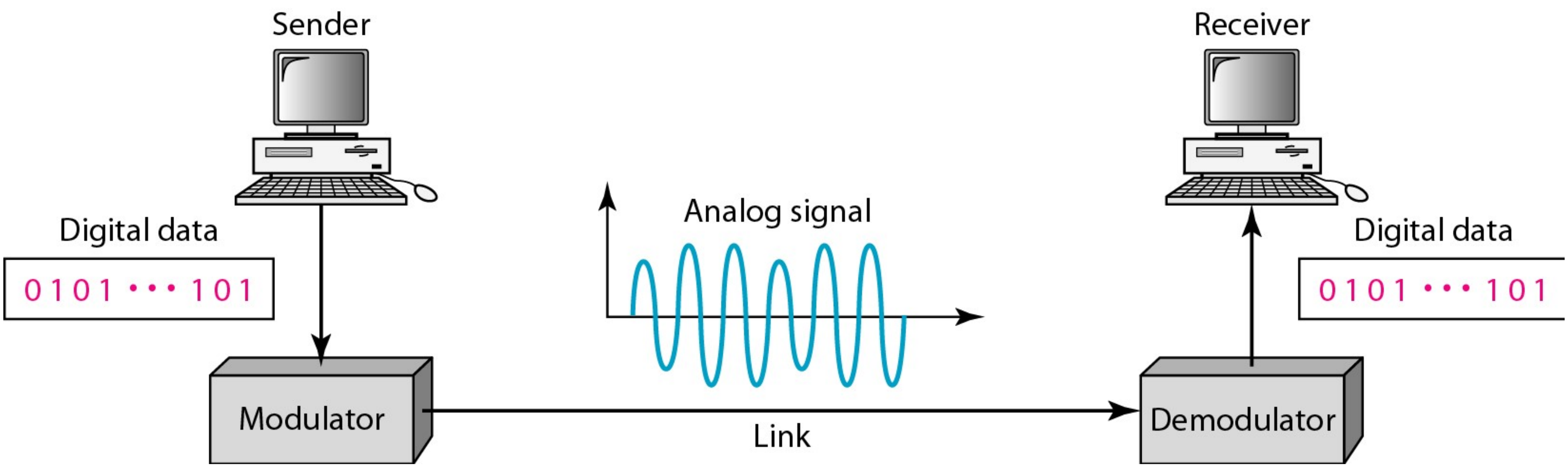
- ✓ The information-bearer channel rate is higher than the input data signaling rate.
- ✓ In real-time audio and video, in which uneven delays between frames are not acceptable, synchronous transmission fails.
- ✓ Isochronous is used to solve the issue.
- ✓ A sequence of events is isochronous if the events occur regularly, or at equal time intervals.

Analog Transmission

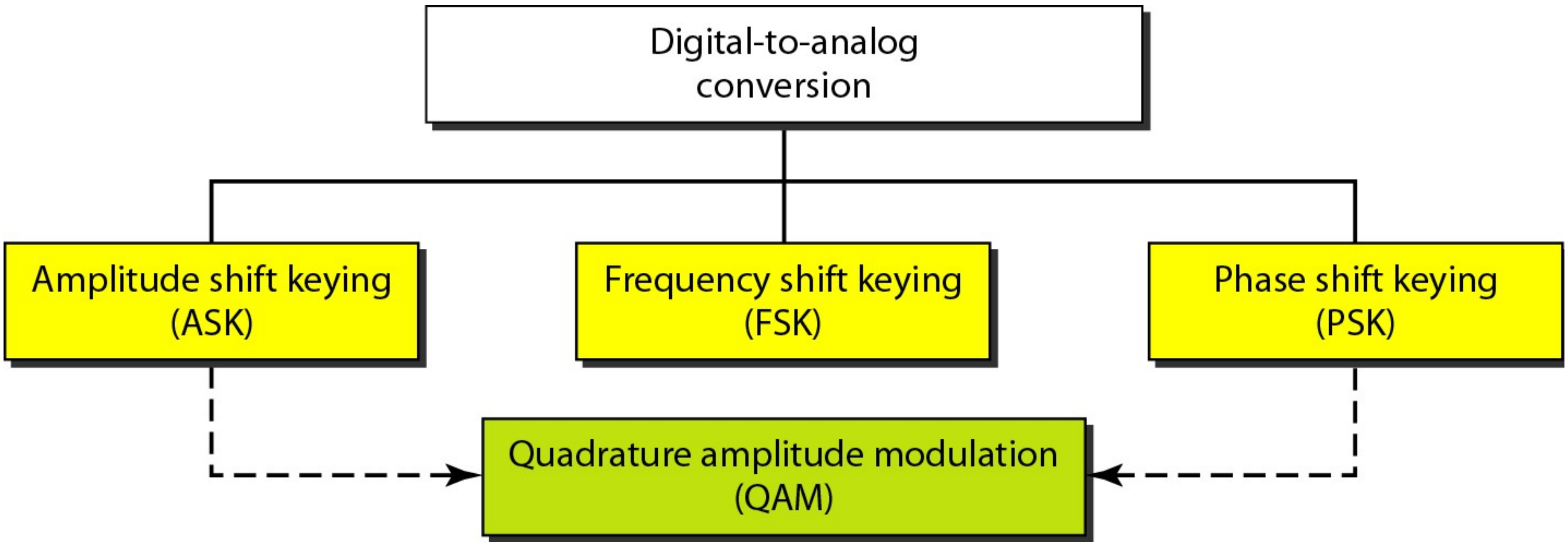
- ✓ Data is transmitted as analog signal.
- ✓ Conversion done before transmission
  1. Digital to Analog conversion
  2. Analog to Analog conversion

Digital to Analog conversion

- ✓ Digital-to-analog conversion is the process of changing one of the characteristics of an analog signal based on the information in digital data.



Module 1: *Digital to Analog conversion:*



Types of digital-to-analog conversion

Aspects of Digital-to-Analog Conversion

- ✓ In the analog transmission of digital data, the baud rate is less than or equal to the bit rate.
- ✓ Bit rate is the number of bits per second.
- ✓ Baud rate is the number of signal elements per second.

S = N * 1/r (Best Case)

Where, S=baud rate, N = Bit rate and r= ratio data to signal element

Example:

An analog signal carries 4 bits per signal element. If 1000 signal elements are sent per second, find the bit rate.

Solution

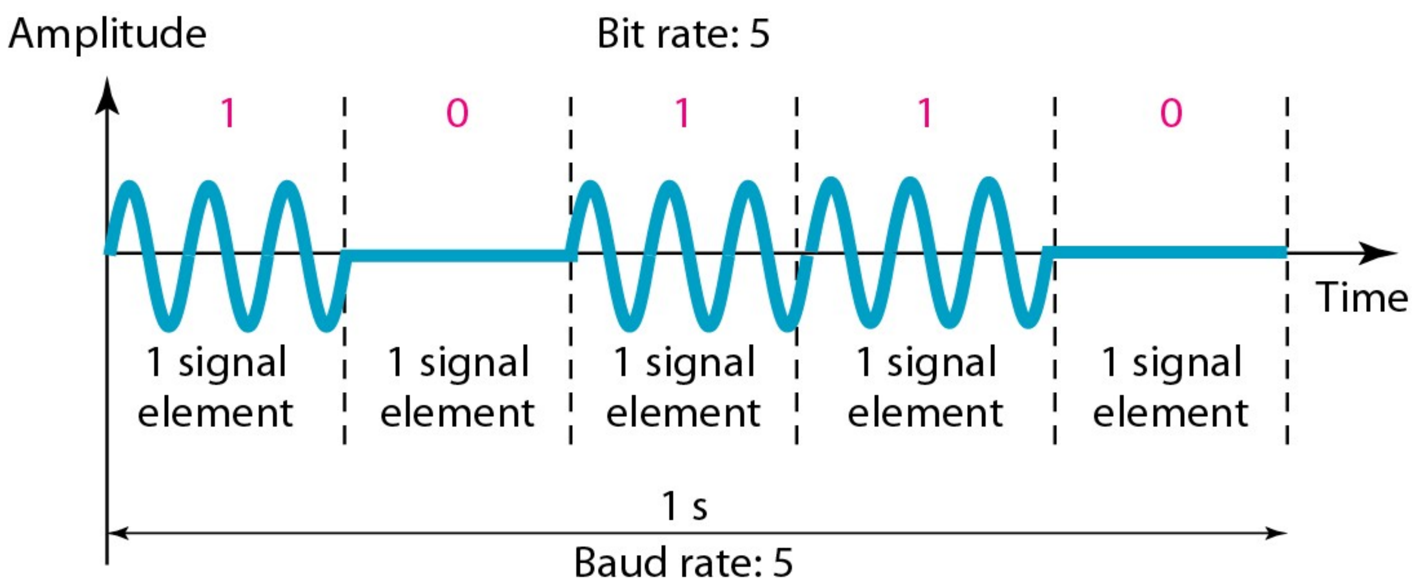
In this case, r = 4, S = 1000, and N is unknown. We can find the value of N from

$$S = N \times \frac{1}{r} \qquad \text{or} \qquad N = S \times r = 1000 \times 4 = 4000 \text{ bps}$$

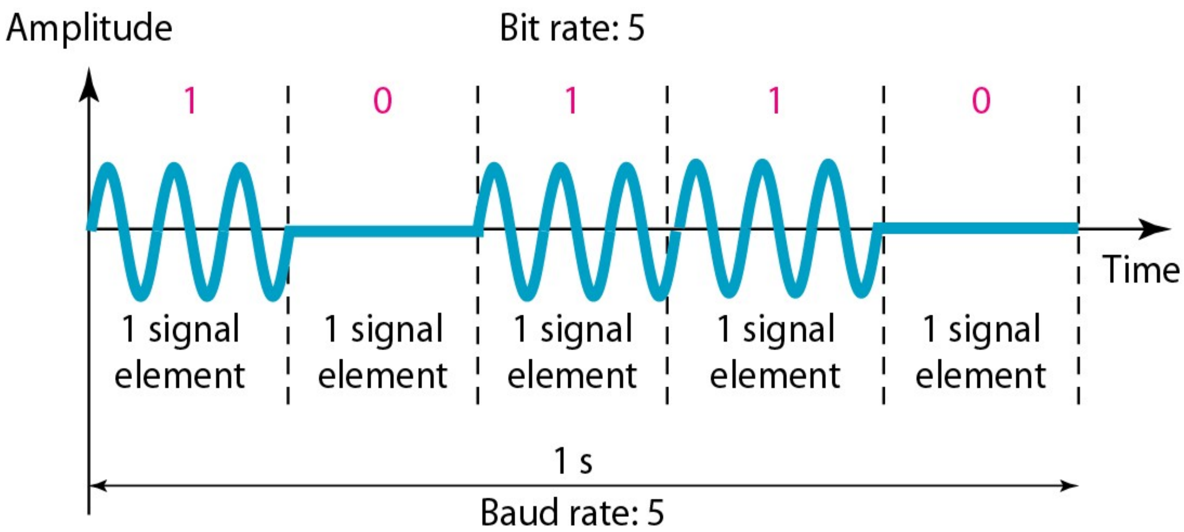
Module 1: *Digital to Analog conversion:*

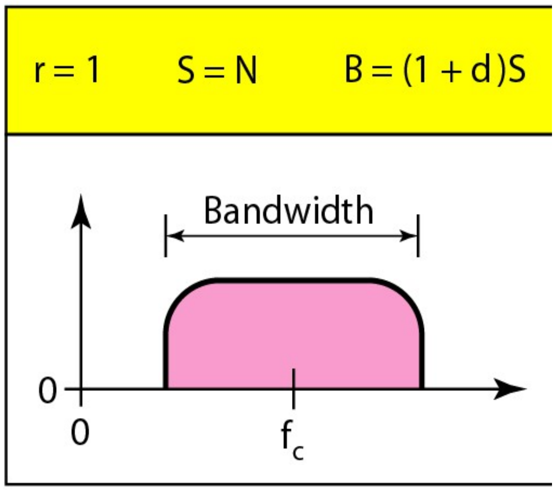
Amplitude Shift Keying

- ✓ Amplitude of the carrier signal changes based on the input data to create signal elements.
- ✓ Both frequency and phase remain constant while the amplitude changes.



Module 1: *Digital to Analog conversion:*





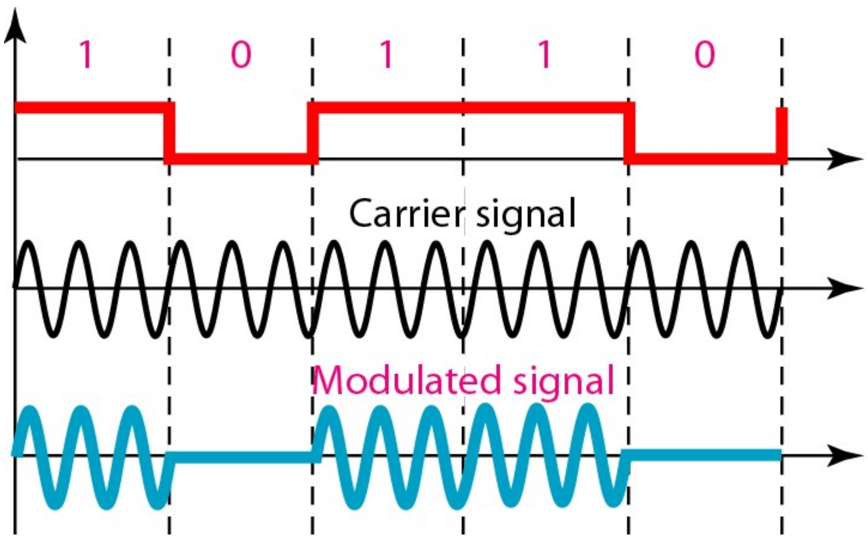
Binary amplitude shift keying

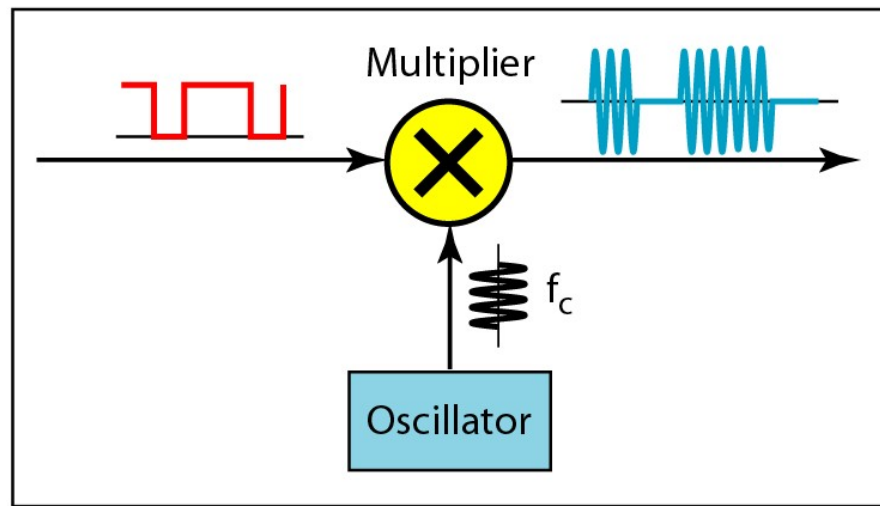
The bandwidth(B) is proportional to the signal rate (baud rate). i.e. $B \propto S$

Required Bandwidth (B)= (1+d) S

Module 1: *Digital to Analog conversion:*

Implementation of binary ASK

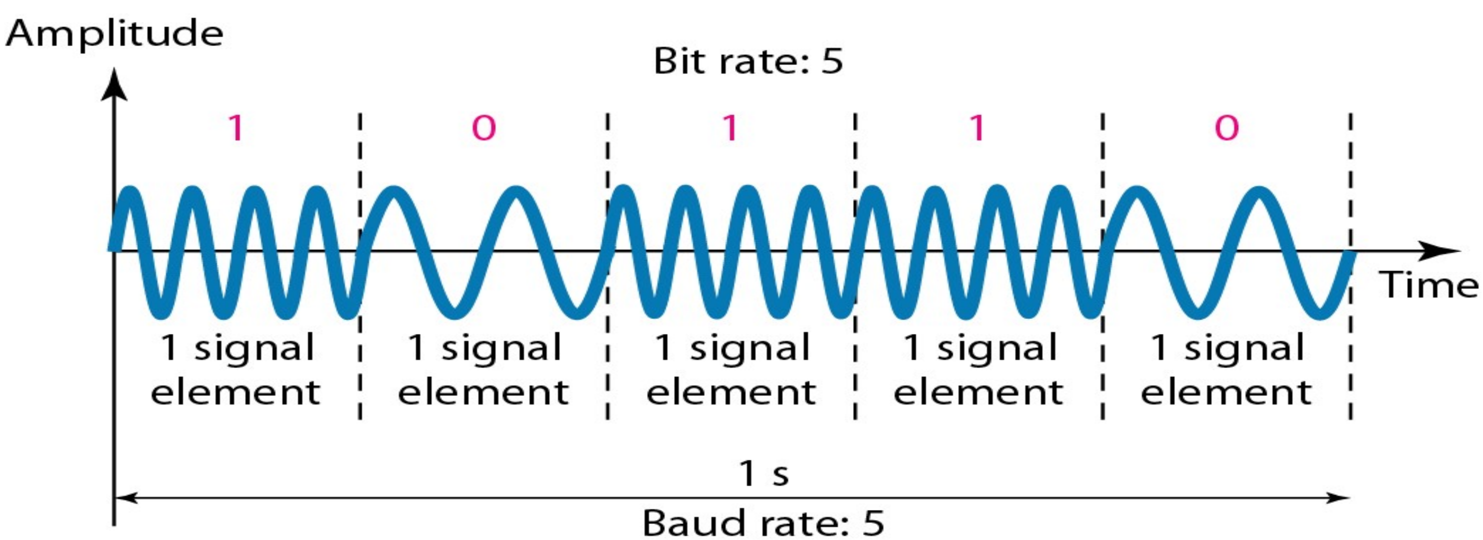




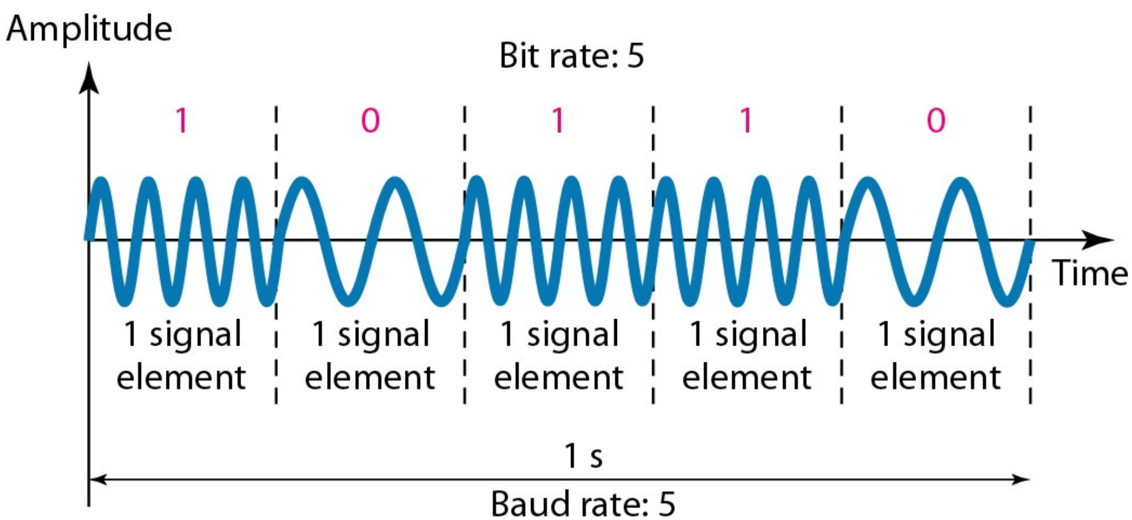
Module 1: *Digital to Analog conversion:*

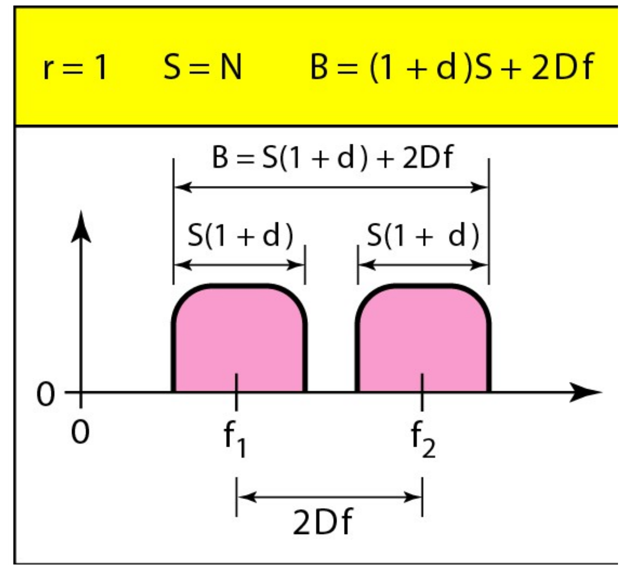
Binary frequency shift keying(BFSK)

- ✓ Frequency of the carrier signal is varied to represent data.
- ✓ Both peak amplitude and phase remain constant for all signal elements.



Module 1: *Digital to Analog conversion:*

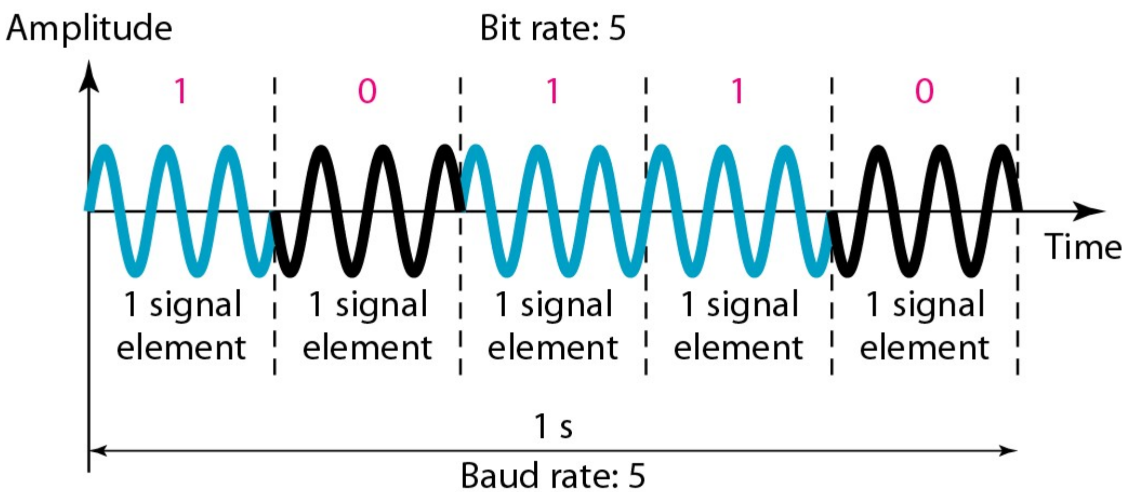


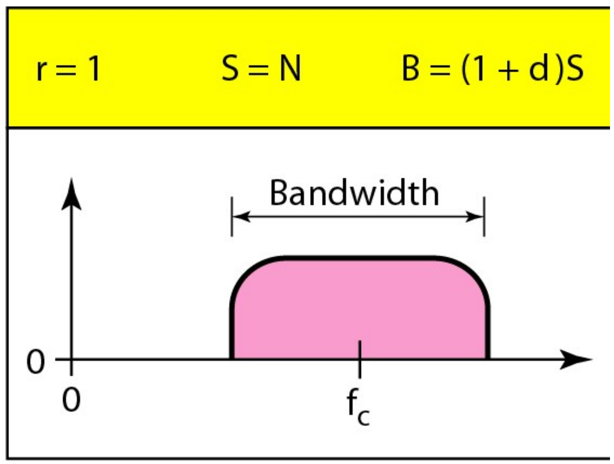


The difference between the two frequencies is 2Df

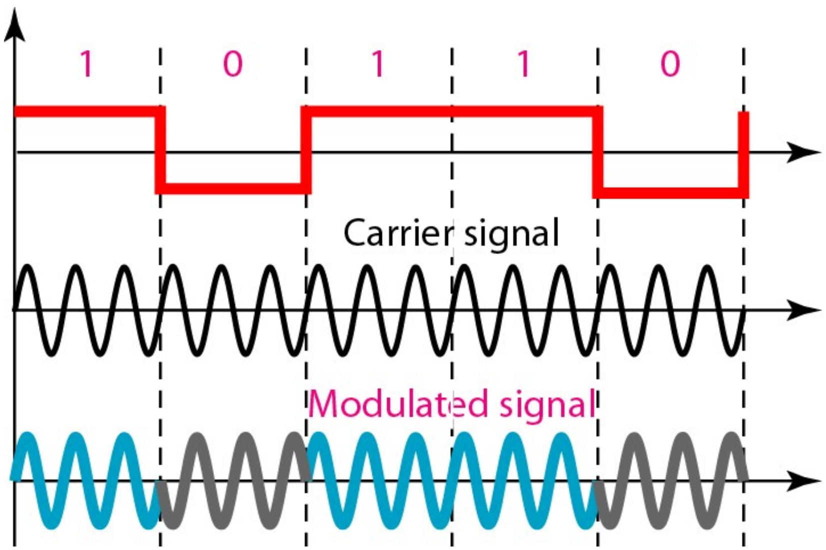
Module 1: *Digital to Analog conversion:*

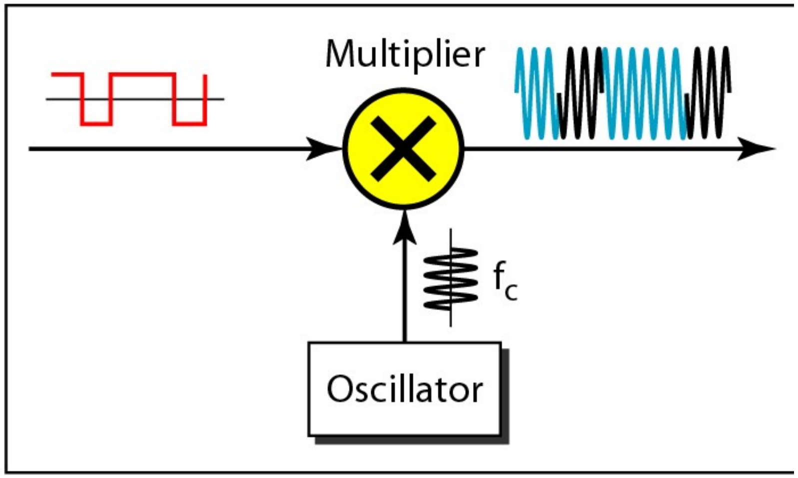
Phase of the carrier is varied to represent two or more different signal elements.





Module 1: *Digital to Analog conversion:*



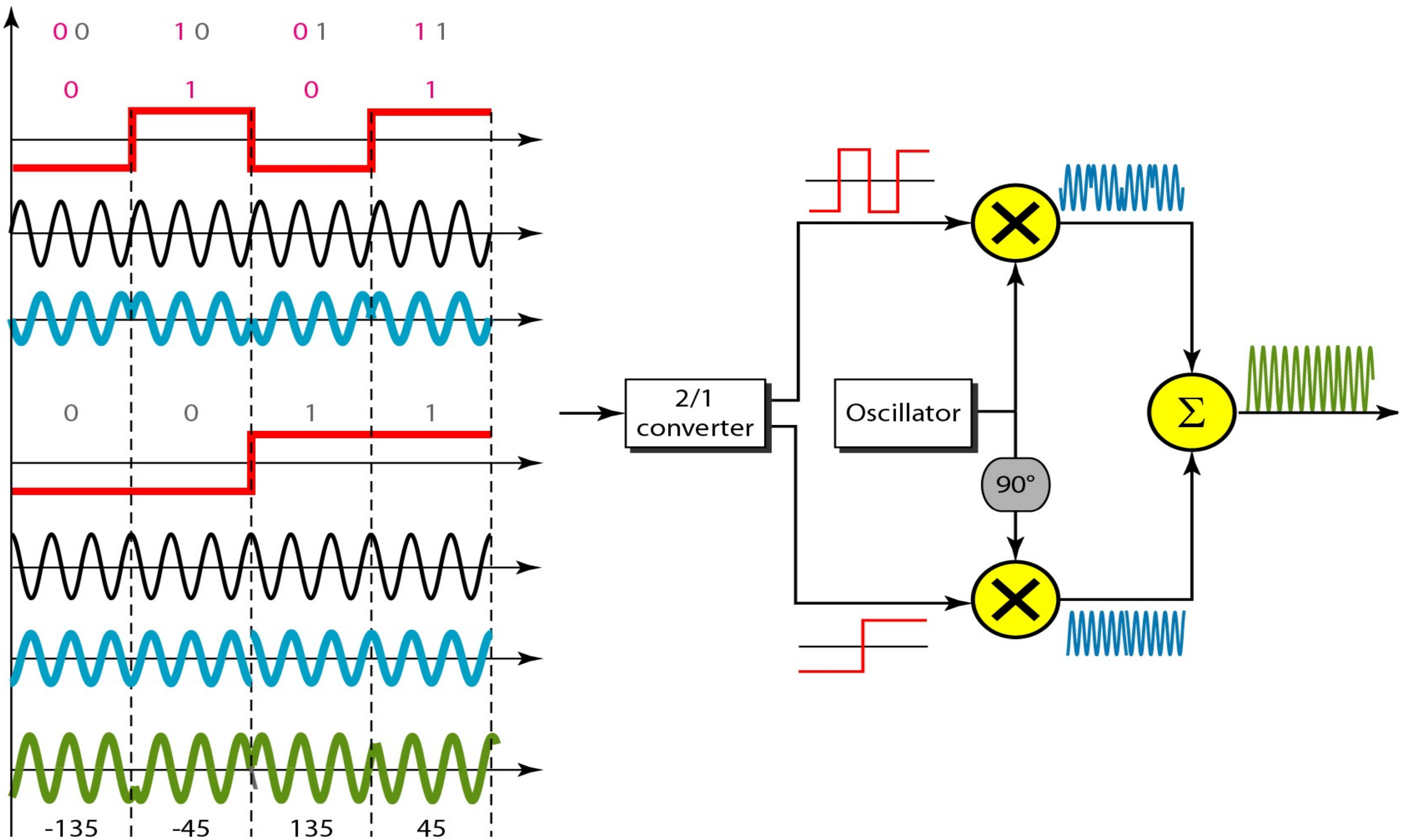


Implementation of BPSK

Quadrature PSK (QPSK)

- ✓ Two bits can be sent using one signal element.
- ✓ 4 phases used with 4 data combination such as 00,01,10,11
- ✓ It is combination of two separate BPSK modulations; one is in-phase, the other quadrature (out-of-phase).

Module 1: *Digital to Analog conversion:*



QPSK and its implementation

Module 1: *Digital to Analog conversion:*

There are four kinds of signal elements in the output signal *(L* = 4), so we can send 2 bits per signal element *(r* = 2).

Quadrature Amplitude Modulation(QAM)

- ✓ Quadrature amplitude modulation is a combination of ASK and PSK.

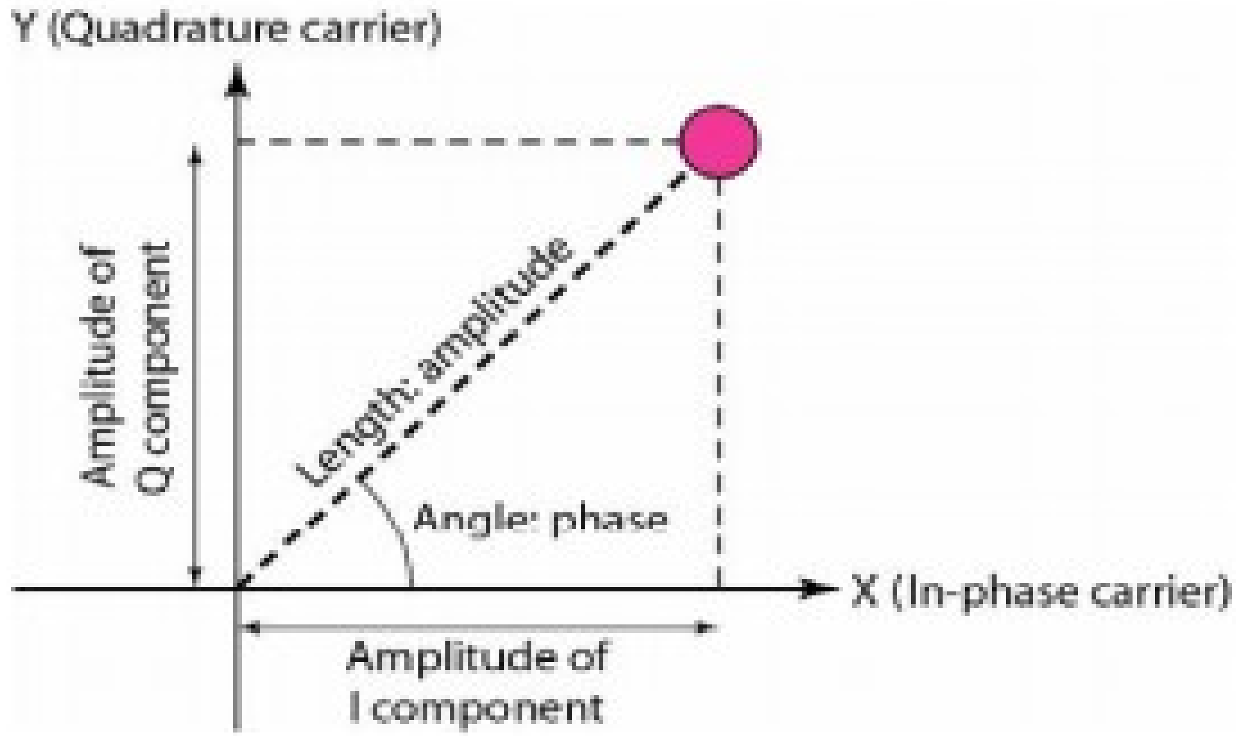
Constellation diagram

- ✓ A constellation diagram used to define the amplitude and phase of a signal element.
- ✓ The diagram is useful when we are dealing with multilevel ASK, PSK, or QAM.
- ✓ The diagram has two axes.
- ✓ The horizontal X axis is related to the in-phase carrier; the vertical *Y* axis is related to the quadrature (out of phase) carrier.

Module 1: *Digital to Analog conversion:*

- ✓ For each point on the diagram, four pieces of information can be deduced.
- ✓ The projection of the point on the X axis defines the peak amplitude of the in-phase component.
- ✓ The projection of the point on the *Y* axis defines the peak amplitude of the quadrature component.
- ✓ The length of the line (vector) that connects the point to the origin is the peak amplitude of the signal element (combination of the X and *Y* components).

Module 1: *Digital to Analog conversion:*



Constellation diagram

Module 1: *Digital to Analog conversion:*

Let us analyze each case separately:

- ✓ For ASK, we are using only an in-phase carrier.
- ✓ Therefore, the two points should be on the X axis.
- ✓ Binary 0 has an amplitude of 0 V; binary 1 has an amplitude of 1 V (for example).
- ✓ The points are located at the origin and at 1 unit.

Module 1: *Digital to Analog conversion:*

- ✓ BPSK also uses only an in-phase carrier.
- ✓ However, we use a polar NRZ signal for modulation.
- ✓ It creates two types of signal elements, one with amplitude 1 and the other with amplitude -1.
- ✓ This can be stated in other words: BPSK creates two different signal elements, one with amplitude I V and in phase and the other with amplitude 1 V and 1800 out of phase.

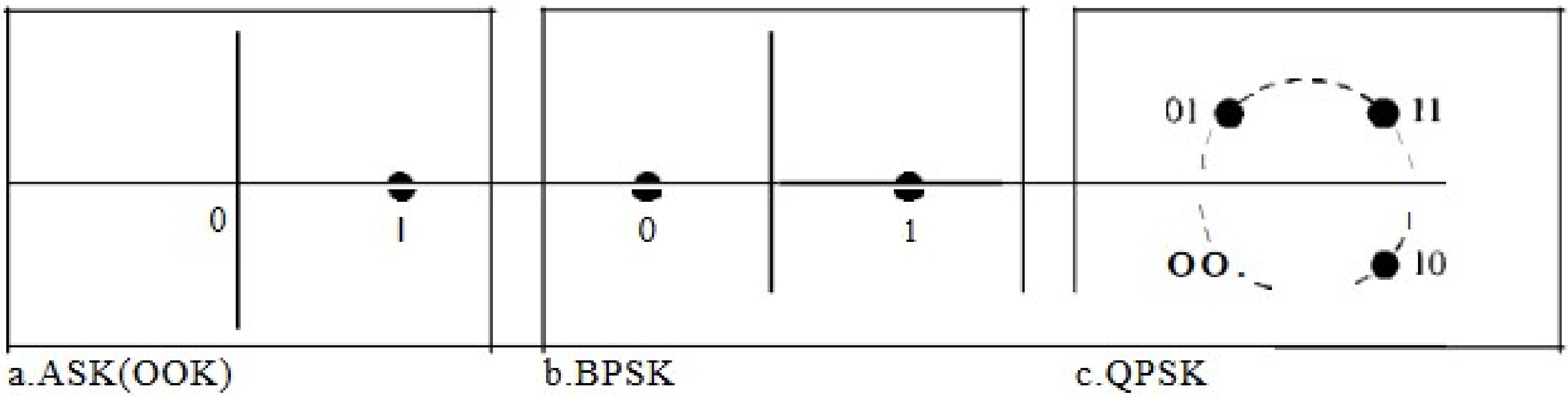
Module 1: *Digital to Analog conversion:*

- ✓ QPSK uses two carriers, one in-phase and the other quadrature.
- ✓ The point representing 11 is made of two combined signal elements, both with an amplitude of 1 V.
- ✓ One element is represented by an in-phase carrier, the other element by a quadrature carrier.
- ✓ The amplitude of the final signal element sent for this 2-bit data element is 2^{112} , and the phase is 45°.

Module 1: *Digital to Analog conversion:*

- ✓ The argument is similar for the other three points.
- ✓ All signal elements have an amplitude of 2^{112} ,
- ✓ but their phases are different (45°, 135°, -135°, and -45°).
- ✓ Of course, we could have chosen the amplitude of the carrier to be 1/(21/2) to make the final amplitudes 1 V.

Module 1: *Digital to Analog conversion:*



Three constellation diagrams

BPSK

1=0 degree, 0=180 degree

QPSK

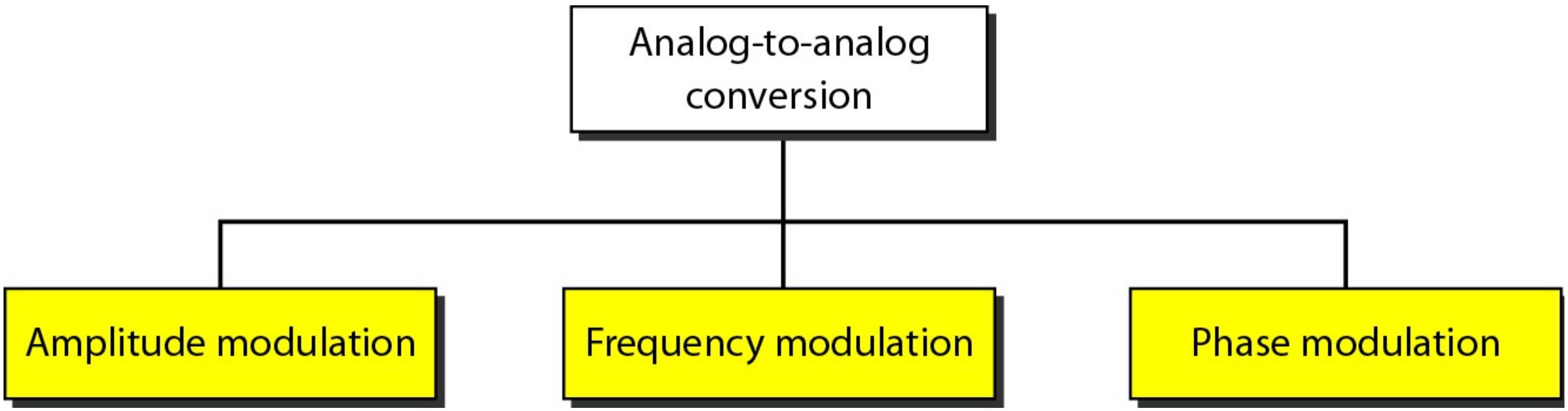
11=45 degree, 01=135 degree,

00=225 degree & -135 degree,

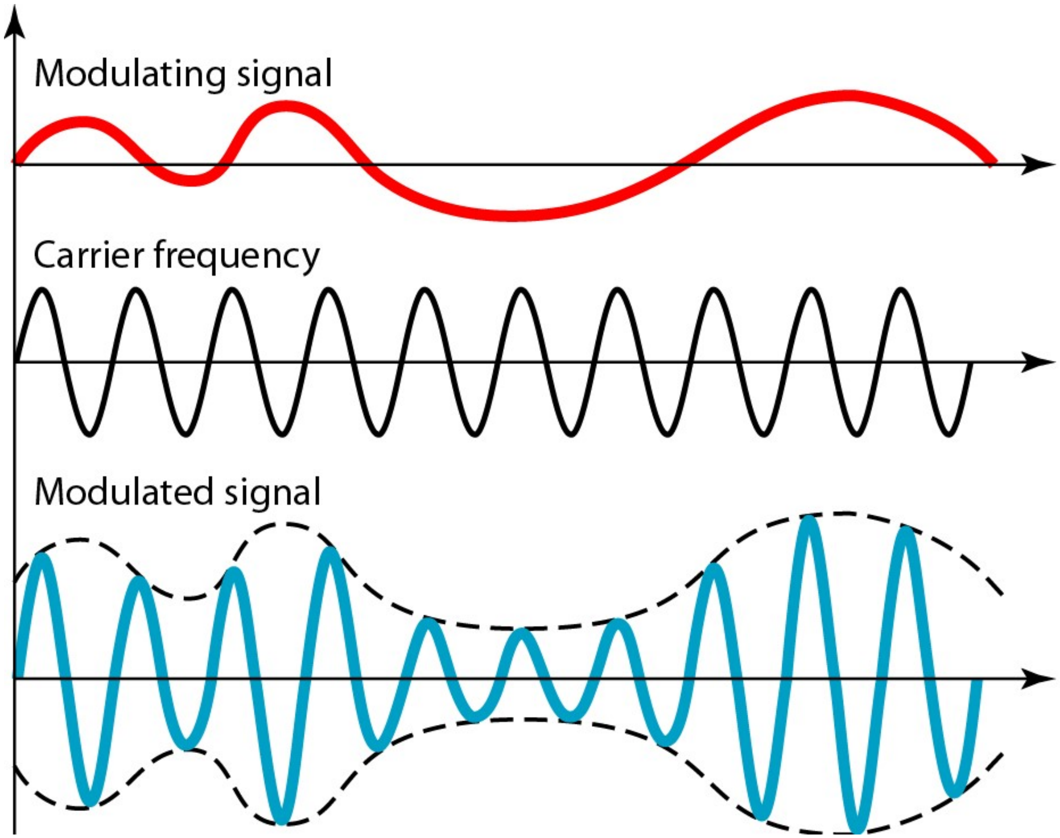
10=315 degree & -45 degree

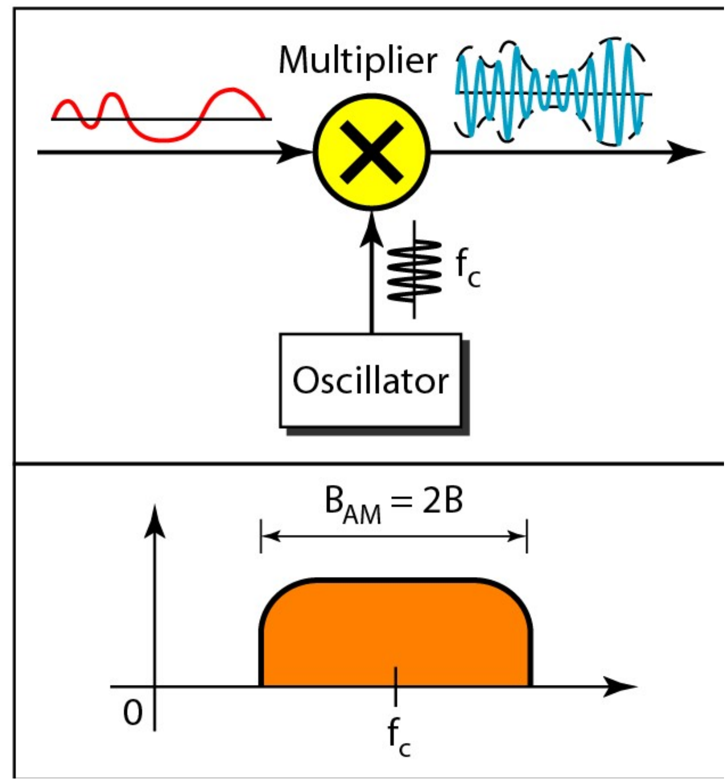
Module 1: *Analog Transmission:*

Analog-to-analog conversion is the representation of analog information by an analog signal.



Amplitude Modulation(AM)

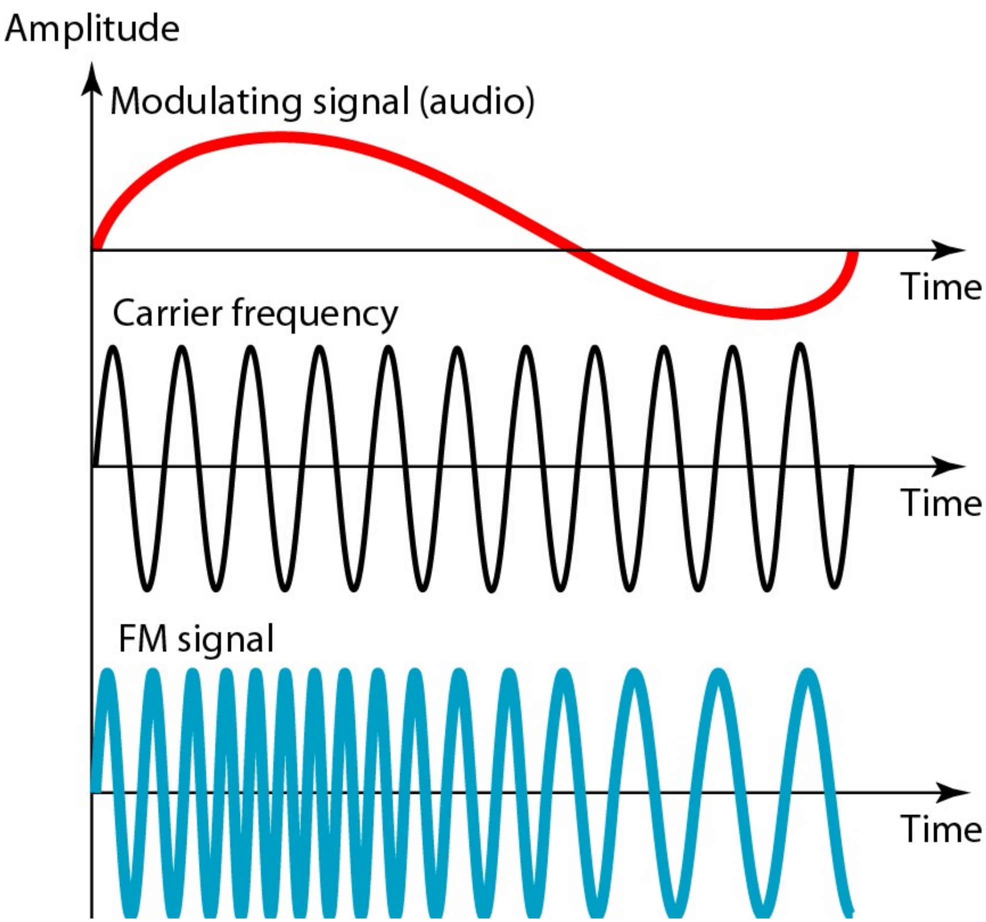


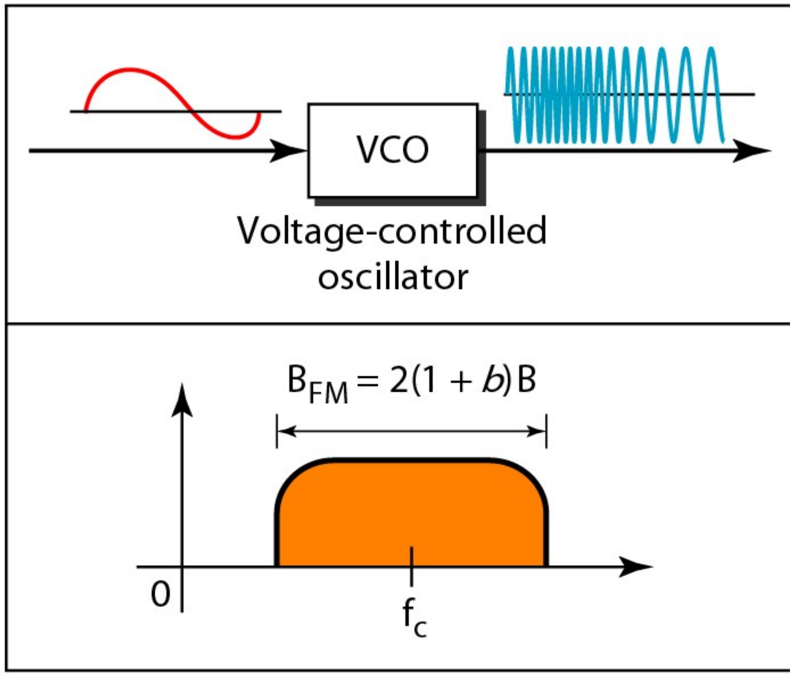


The total bandwidth required for AM(B_{AM}) = 2B.
Where B= bandwidth of the audio signal

Module 1: *Analog Transmission:*

Frequency modulation



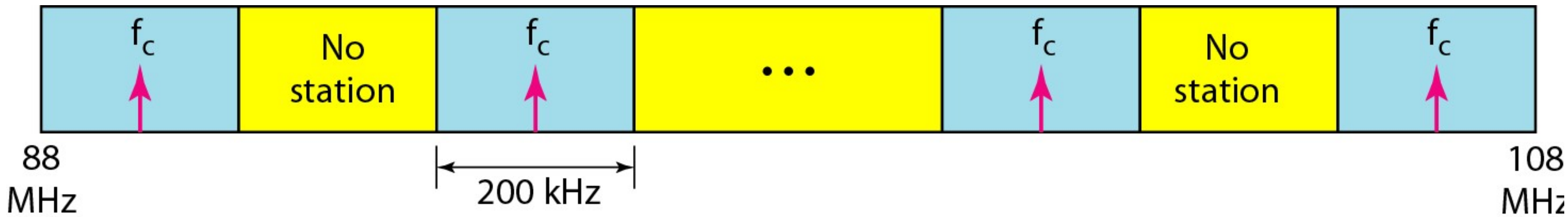


The total bandwidth required for FM can be determined from the bandwidth of the audio signal: $B_{FM} = 2(1 + \beta)B$.

Where, β is a factor(Ratio of frequency deviation to highest frequency).

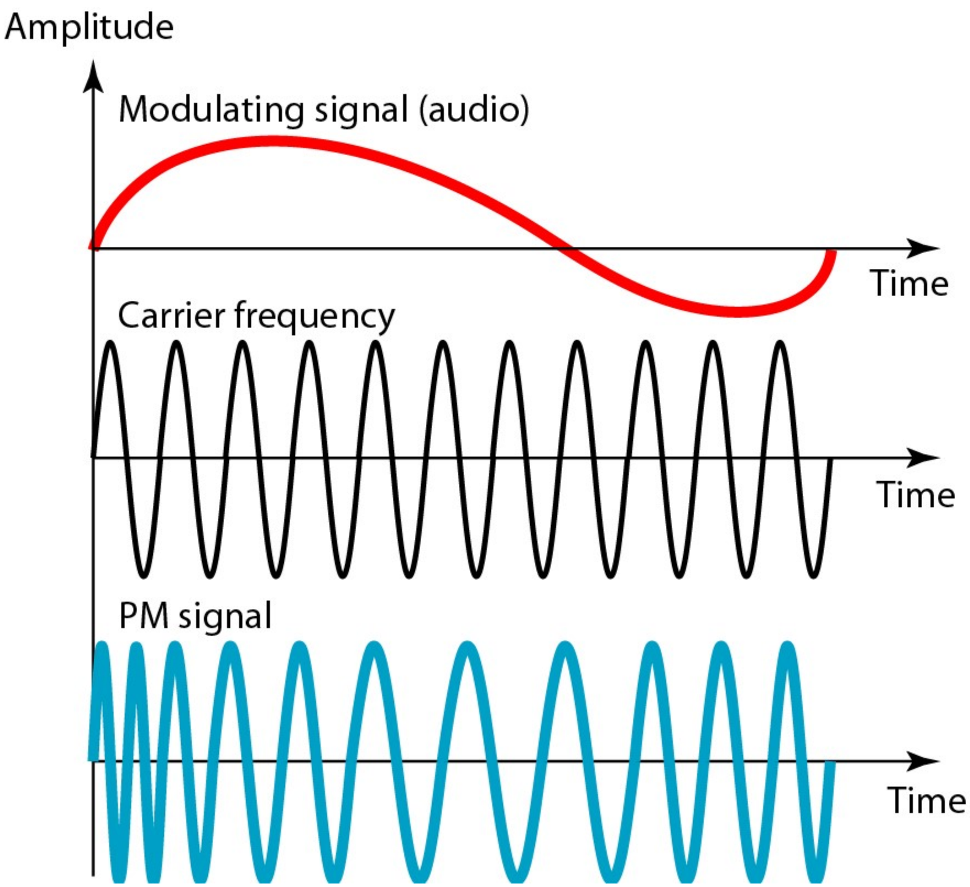
It depends on modulation technique with a common value of 4.

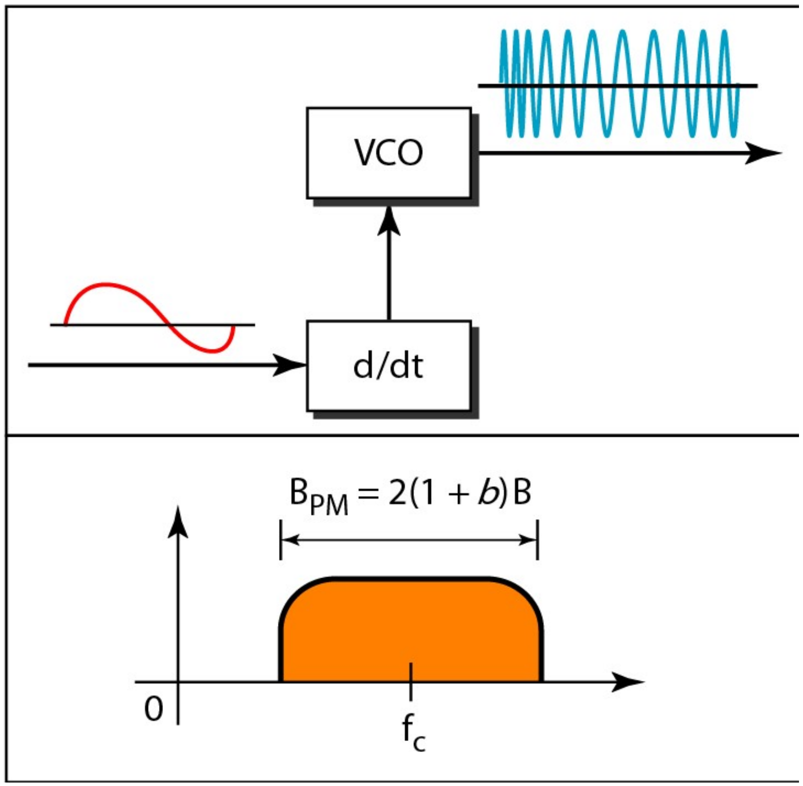
Module 1: *Analog Transmission:*



FM band allocation

Module 1: *Analog Transmission:*





Phase modulation

The total bandwidth required for PM can be determined from the bandwidth and maximum amplitude of the modulating signal:

$$B_{PM} = 2(1 + \beta)B.$$

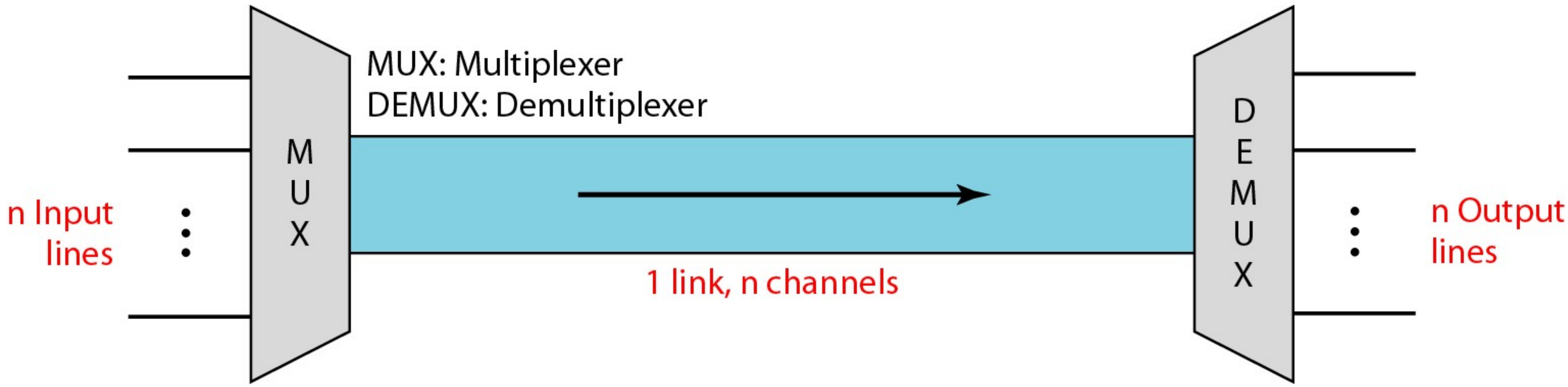
Module 1: *Multiplexing:*

- ✓ Bandwidth utilization is the wise use of available bandwidth to achieve specific goals.

- ✓ Efficiency can be achieved by multiplexing; i.e., sharing of the bandwidth between multiple users.

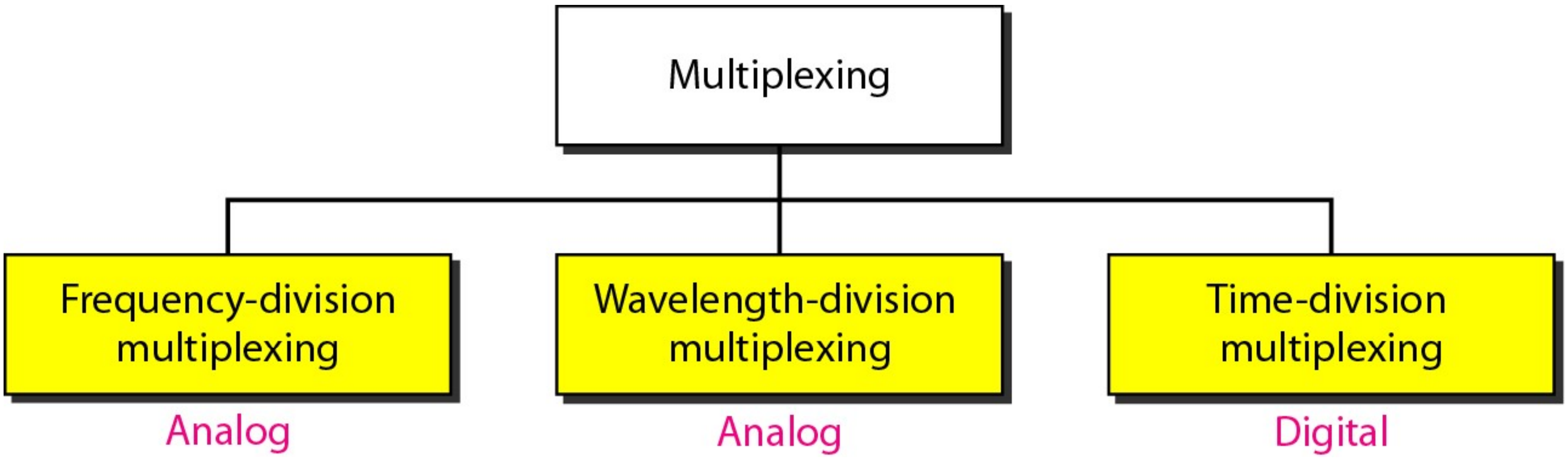
- ✓ Whenever the bandwidth of a medium linking two devices is greater than the bandwidth needs of the devices, the link can be shared.
- ✓ Multiplexing is the set of techniques that allows the (simultaneous) transmission of multiple signals across a single data link.

Module 1: *Multiplexing:*



Dividing a link into channels

Module 1: *Multiplexing:*



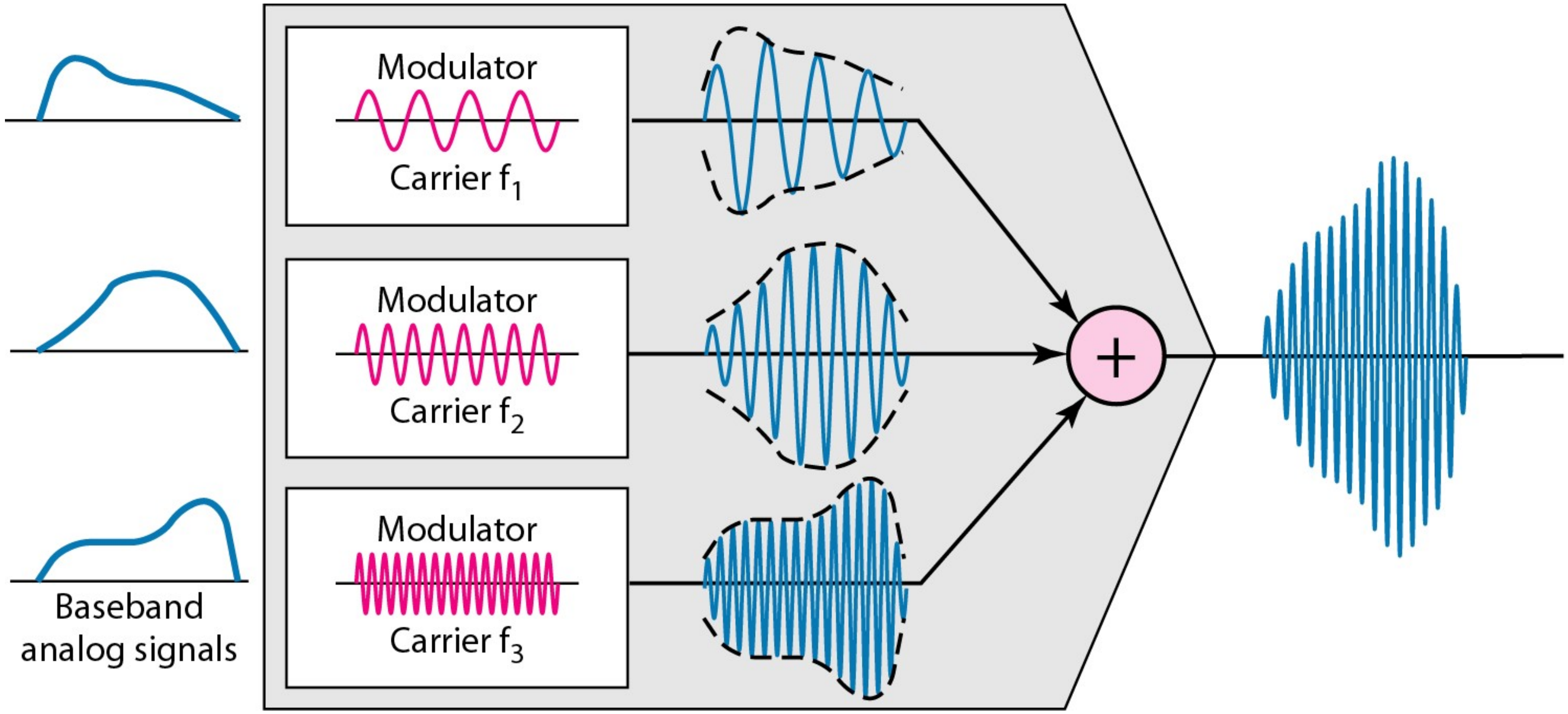
Categories of multiplexing

Module 1: *Multiplexing:*

Frequency-division multiplexing (FDM)

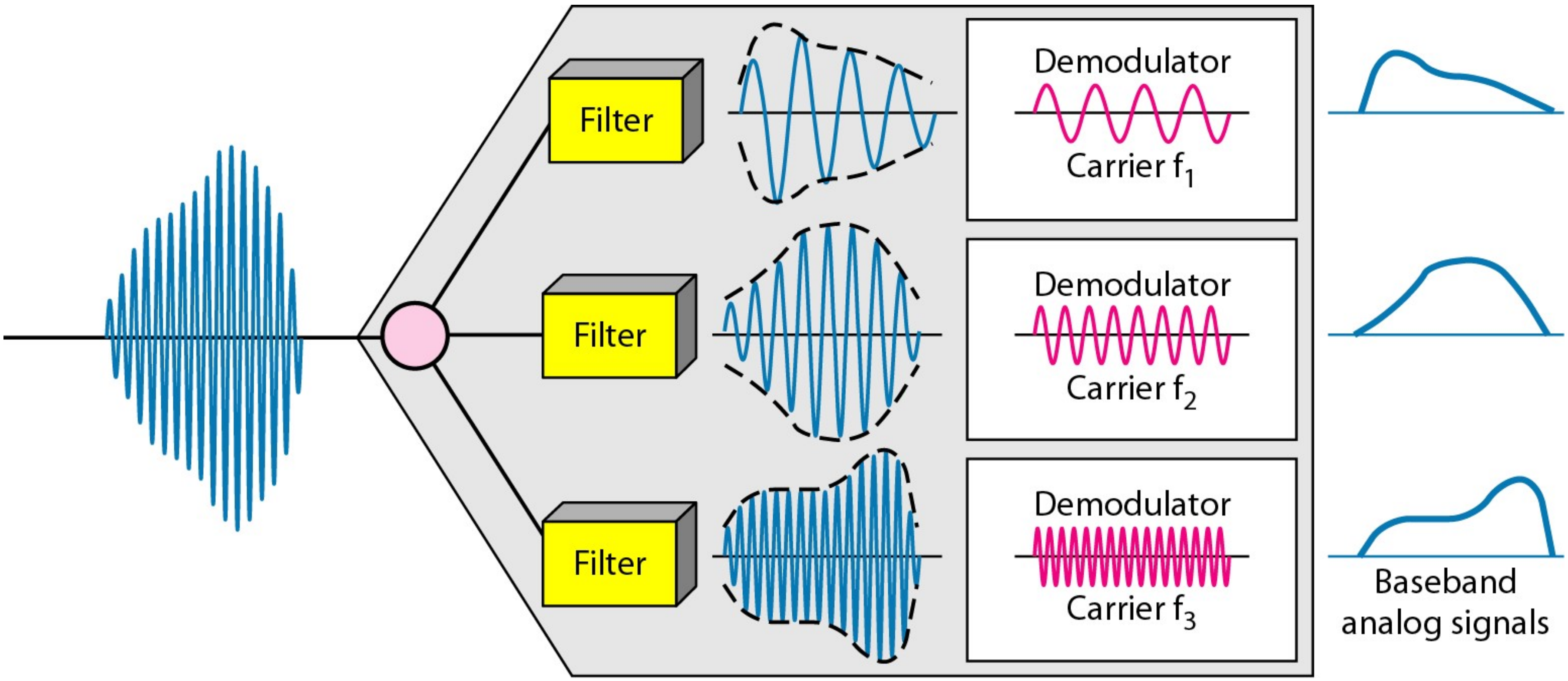
- ✓ FDM is an analog multiplexing technique that combines analog signals.
- ✓ It uses the concept of modulation.

Module 1: *Multiplexing:*



FDM process

Module 1: *Multiplexing:*



FDM demultiplexing example

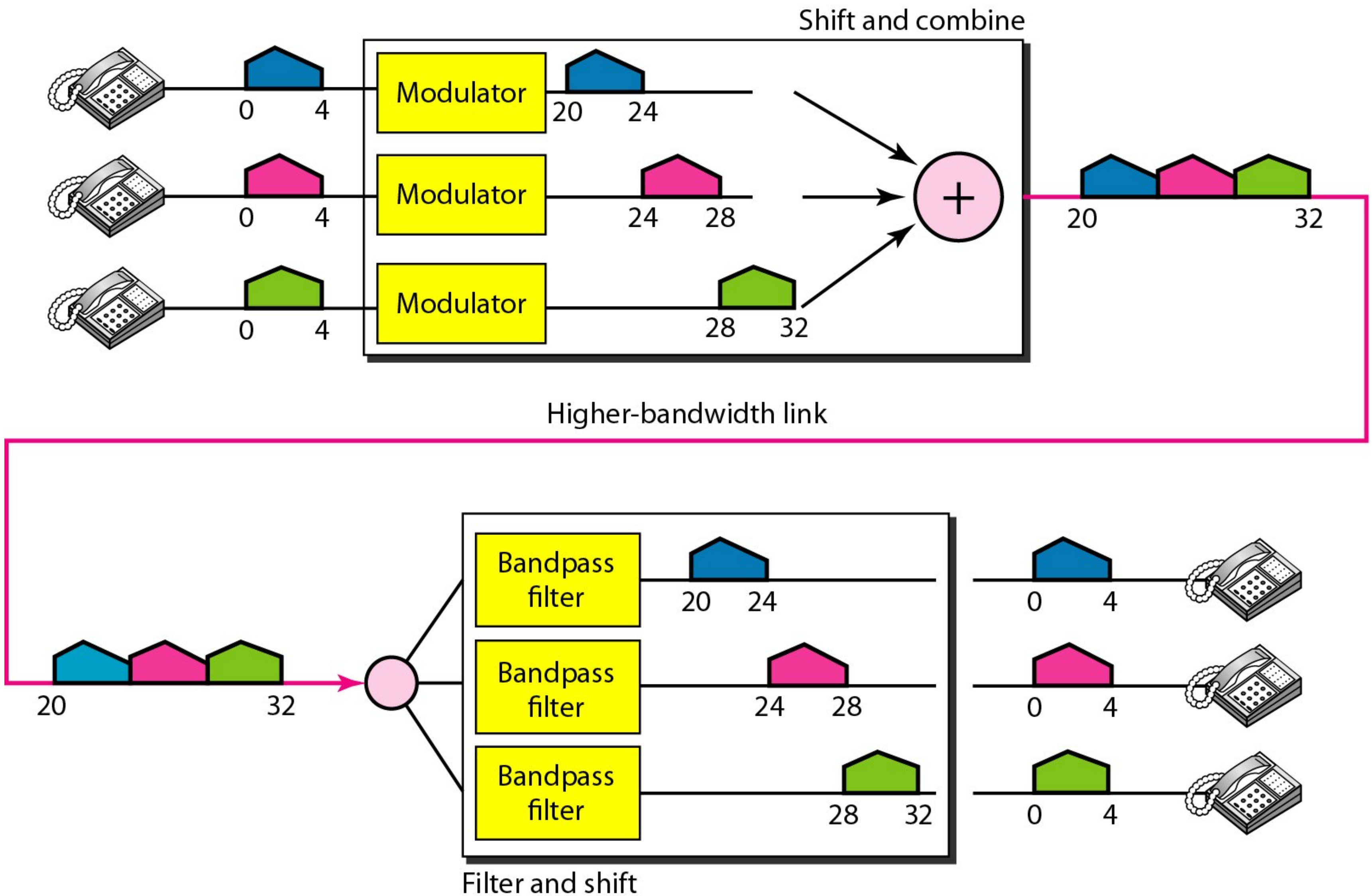
Module 1: *Multiplexing:*

Assume that a voice channel occupies a bandwidth of 4 kHz. We need to combine three voice channels into a link with a bandwidth of 12 kHz, from 20 to 32 kHz. Show the configuration, using the frequency domain. Assume there are no guard bands.

Solution

We shift (modulate) each of the three voice channels to a different bandwidth. We use the 20- to 24-kHz bandwidth for the first channel, the 24- to 28-kHz bandwidth for the second channel, and the 28- to 32-kHz bandwidth for the third one. Then we combine them.

Module 1: *Multiplexing:*



Module 1: *Multiplexing:*

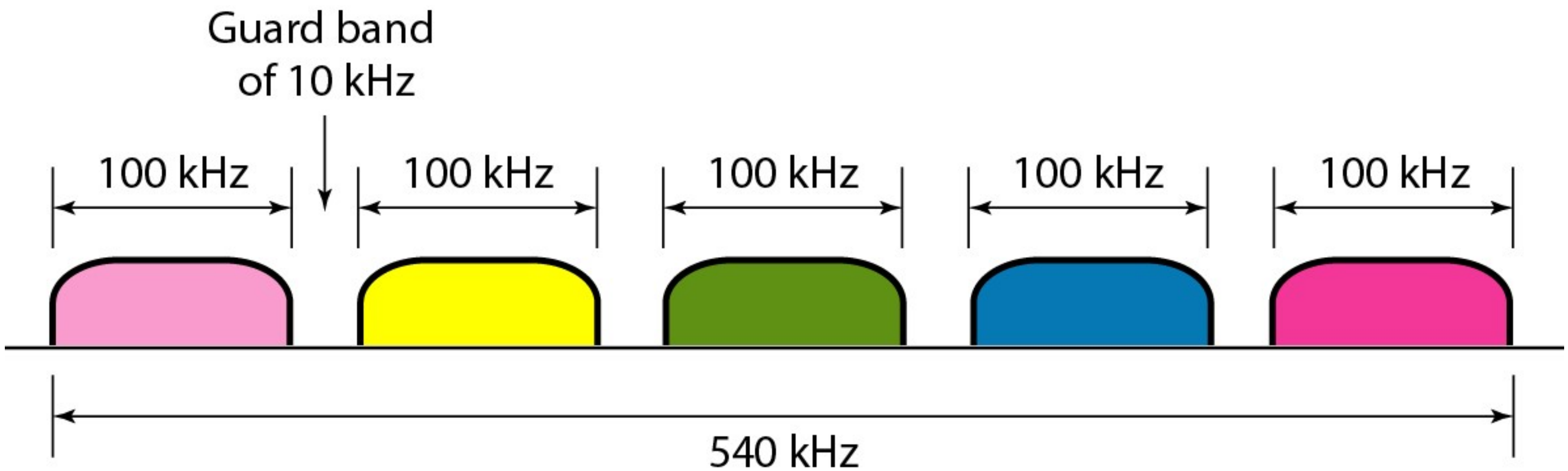
Five channels, each with a 100-kHz bandwidth, are to be multiplexed together. What is the minimum bandwidth of the link if there is a need for a guard band of 10 kHz between the channels to prevent interference?

Solution

For five channels, we need at least four guard bands. This means that the required bandwidth is at least

$$5 \times 100 + 4 \times 10 = 540 \text{ kHz}$$

Module 1: *Multiplexing:*



Module 1: *Multiplexing:*

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

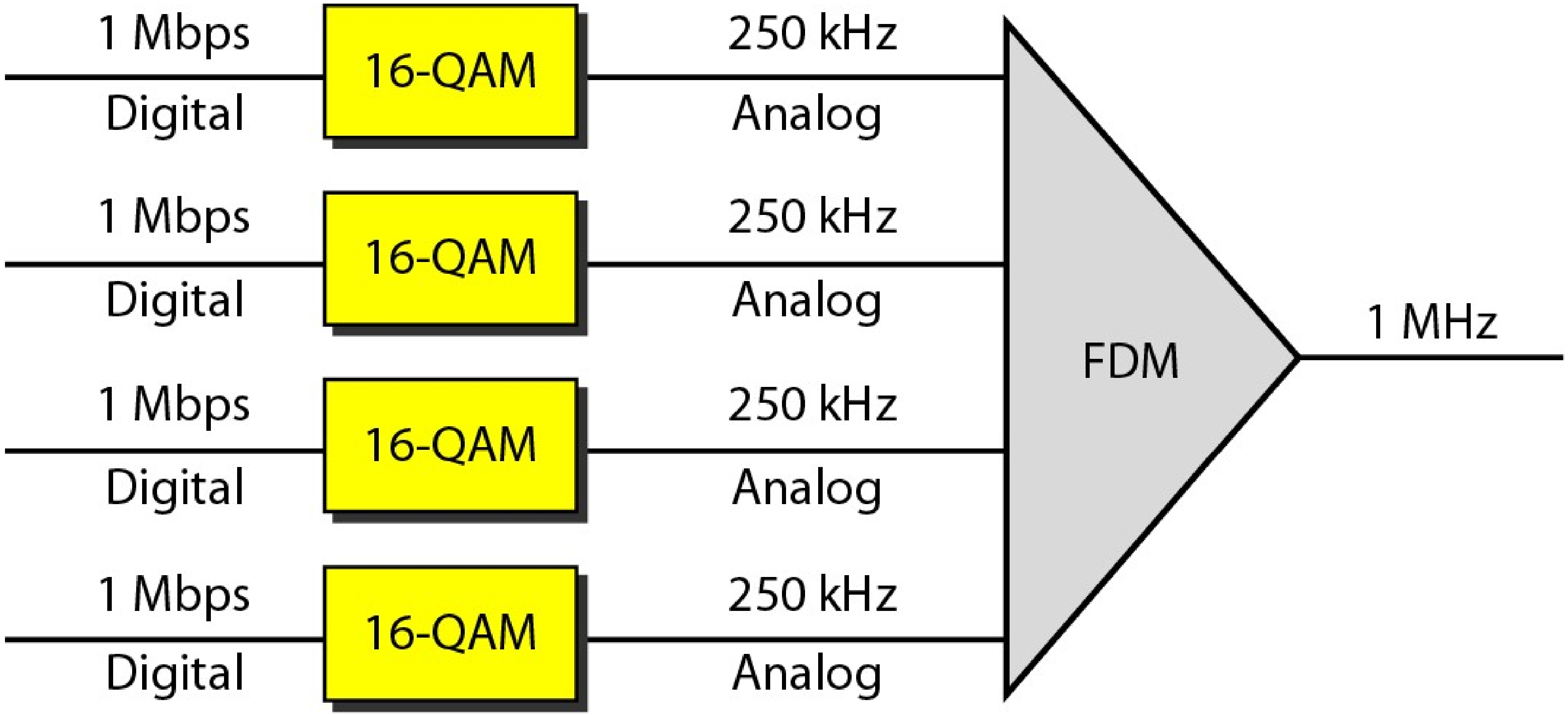
Solution

The satellite channel is analog. We divide it into four channels, each channel having 1M/4=250-kHz bandwidth. Each digital channel of 1 Mbps must be transmitted over a 250KHz channel. Assuming no noise we can use Nyquist to get:

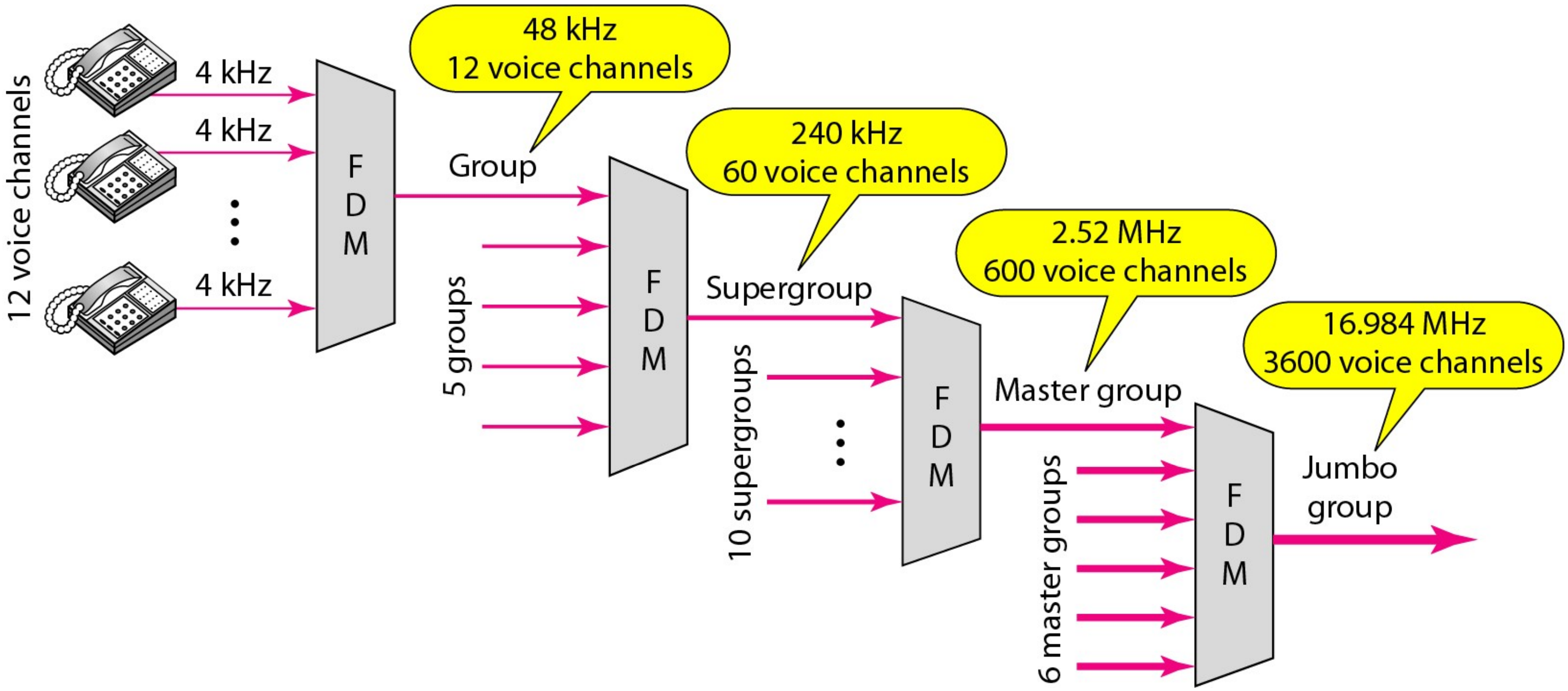
$C = 1\text{Mbps} = 2\text{x}250\text{K x} \log_2 L \rightarrow L = 4$ or $n = 2$ bits/signal element.

One solution is 4-QAM modulation. In figure we show a possible configuration with L = 16.

Module 1: *Multiplexing:*

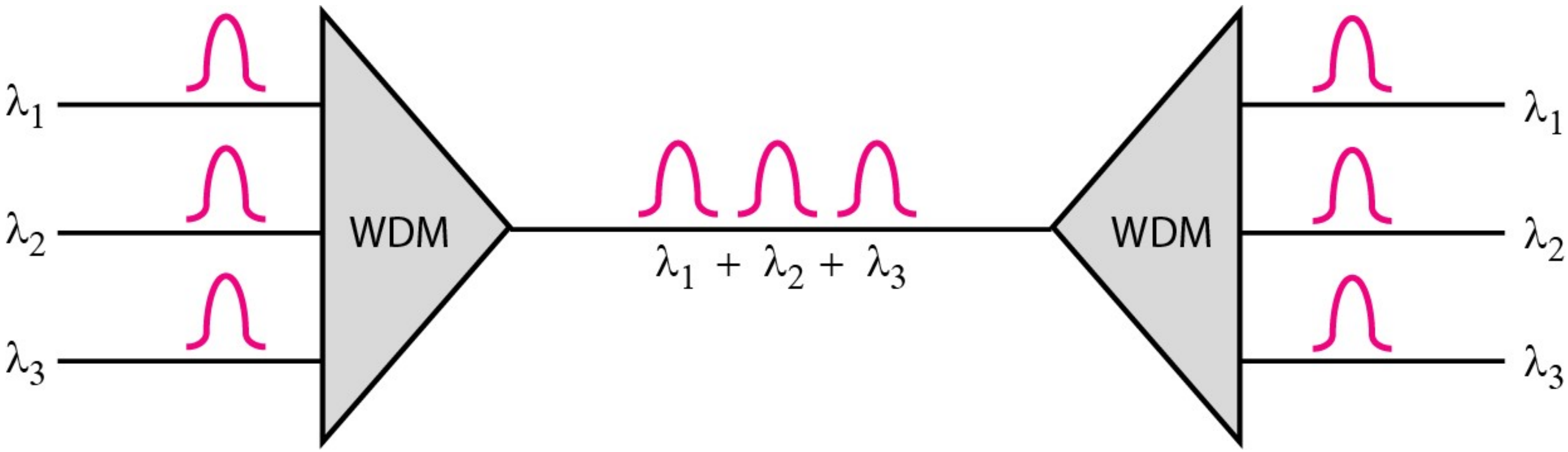


Module 1: *Multiplexing:*



Analog hierarchy

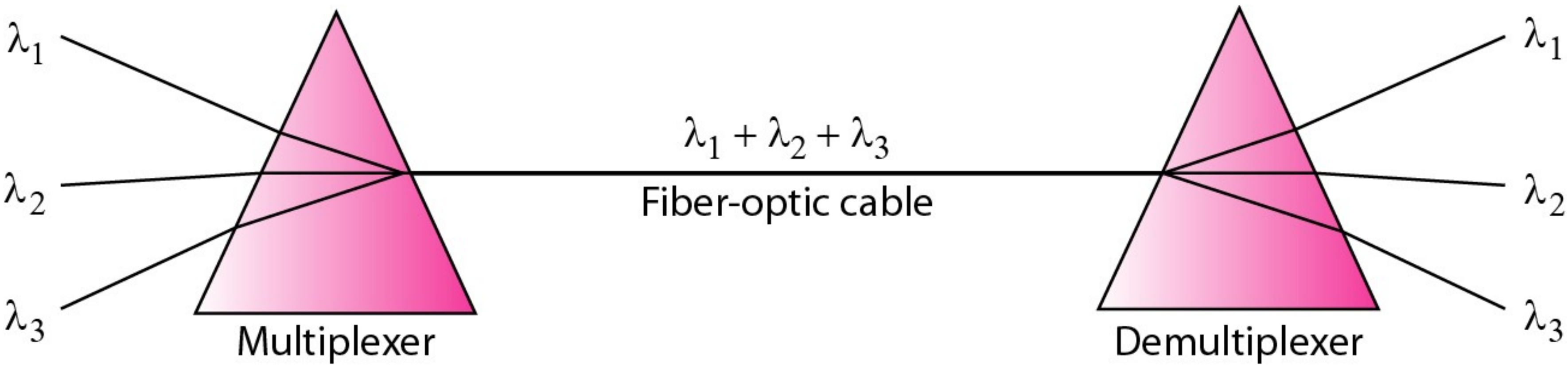
Module 1: *Multiplexing:*



Wavelength-division multiplexing (WDM)

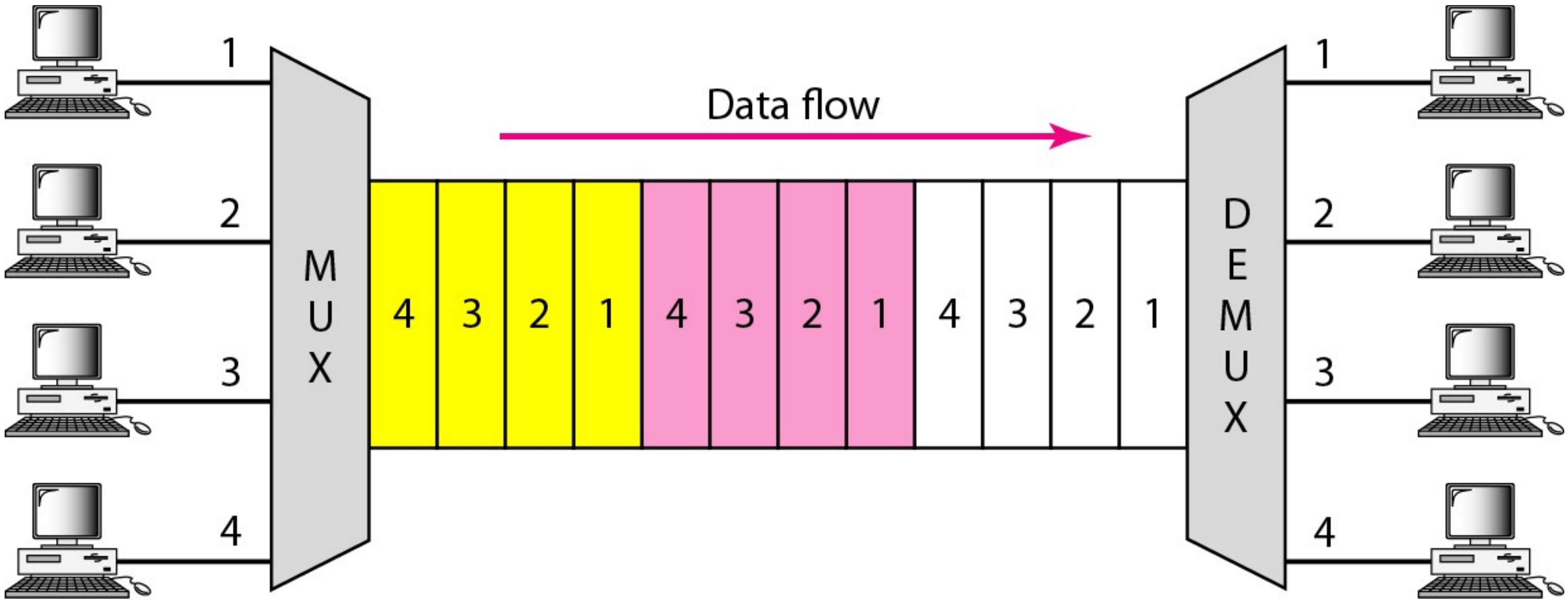
WDM is an analog multiplexing technique to combine optical signals

Module 1: *Multiplexing:*



Prisms in wavelength-division multiplexing and demultiplexing

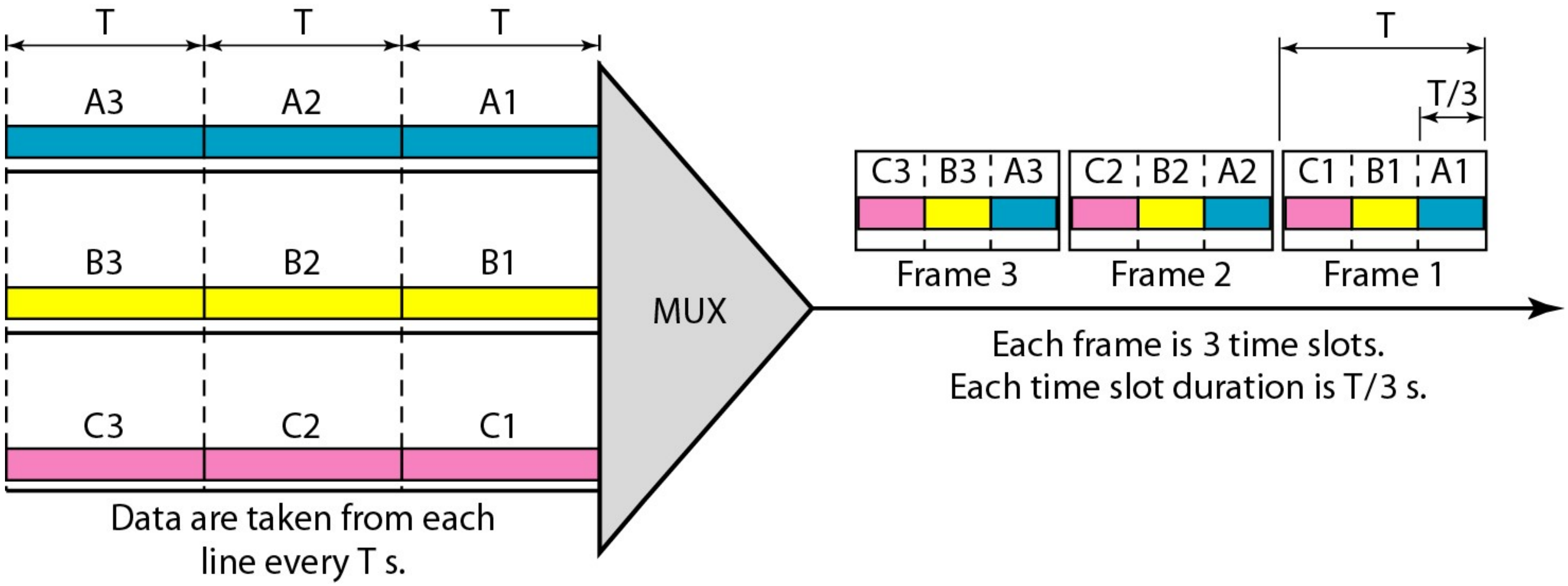
Module 1: *Multiplexing:*



Time Division Multiplexing (TDM)

TDM is a digital multiplexing technique for combining several low-rate digital channels into one high-rate one.

Module 1: *Multiplexing:*



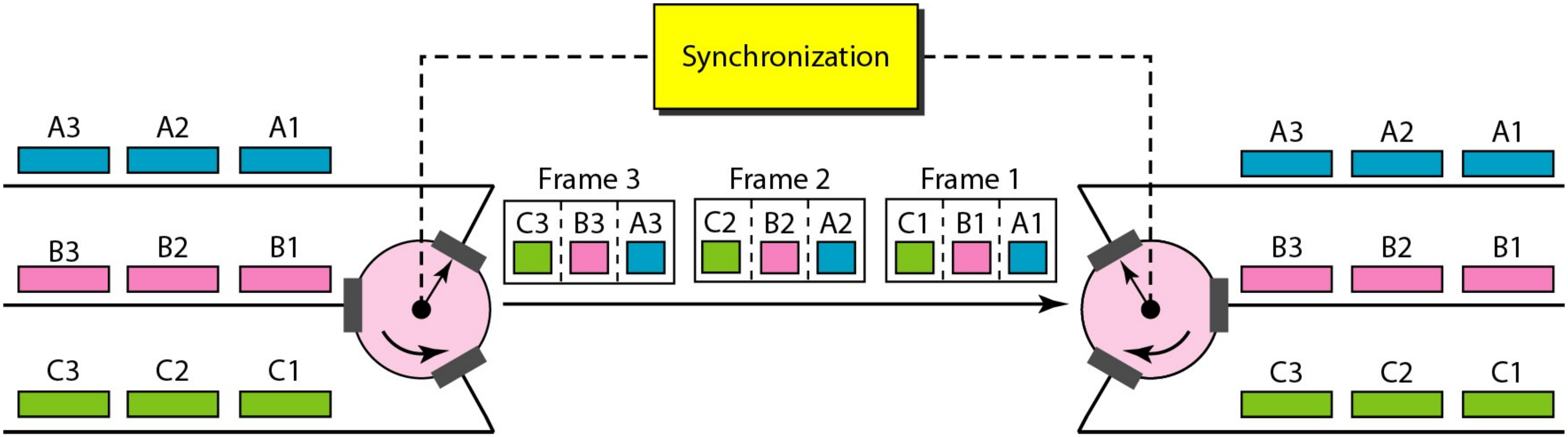
Synchronous time-division multiplexing

In synchronous TDM, the data rate of the link is *n* times faster, and the unit duration is *n* times shorter.

Interleaving

- ✓ The process of taking a group of bits from each input line for multiplexing is called interleaving.
- ✓ We interleave bits (1 - n) from each input onto one output.

Module 1: *Multiplexing:*



Interleaving

Data Rate Management

- ✓ Not all input links maybe have the same data rate.
- ✓ Some links maybe slower.
- ✓ There maybe several different input link speeds.
- ✓ There are three strategies that can be used to overcome the data rate mismatch: multilevel, multislot and pulse stuffing

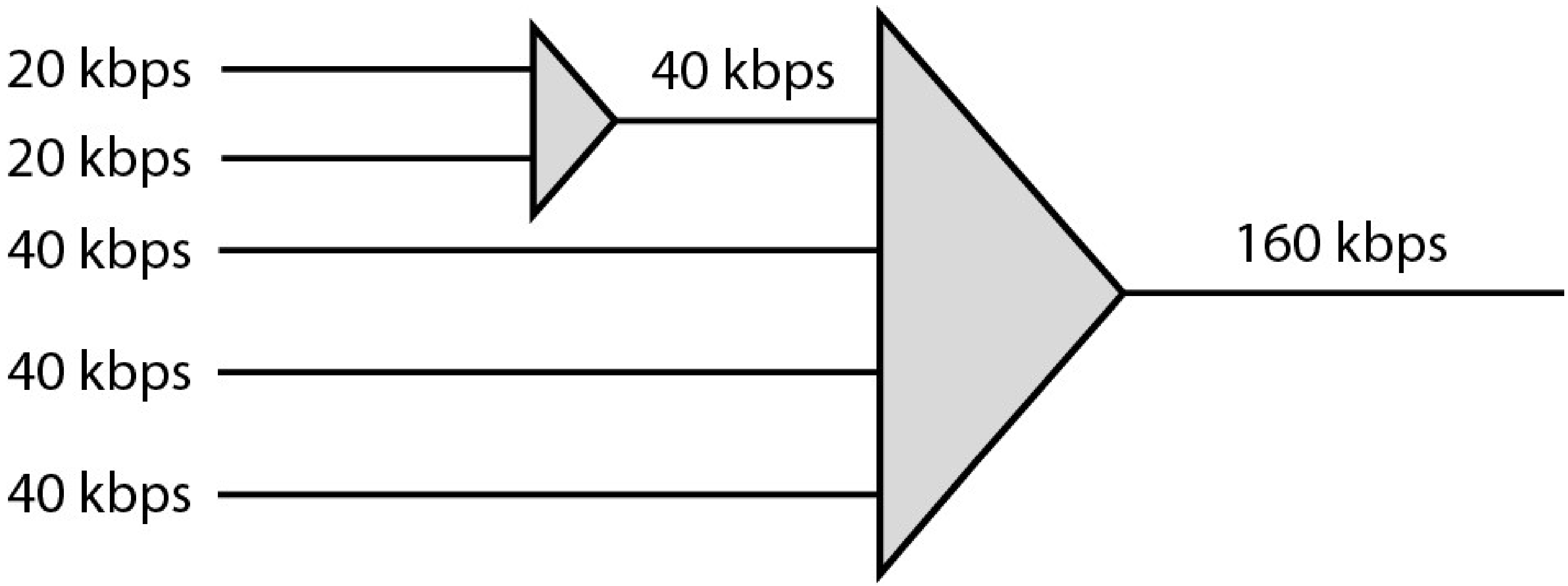
Data rate matching

Multilevel: used when the data rate of the input links are multiples of each other.

Multislot: used when there is a GCD between the data rates. The higher bit rate channels are allocated more slots per frame, and the output frame rate is a multiple of each input link.

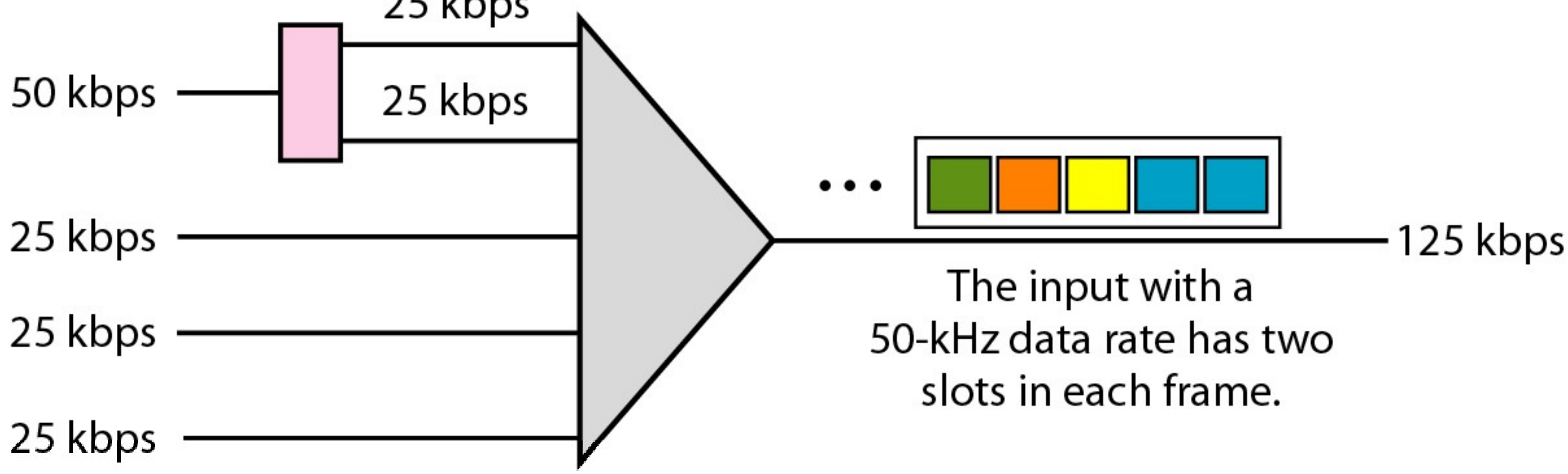
Pulse Stuffing: used when there is no GCD between the links. The slowest speed link will be brought up to the speed of the other links by bit insertion, this is called pulse stuffing.

Module 1: *Multiplexing:*



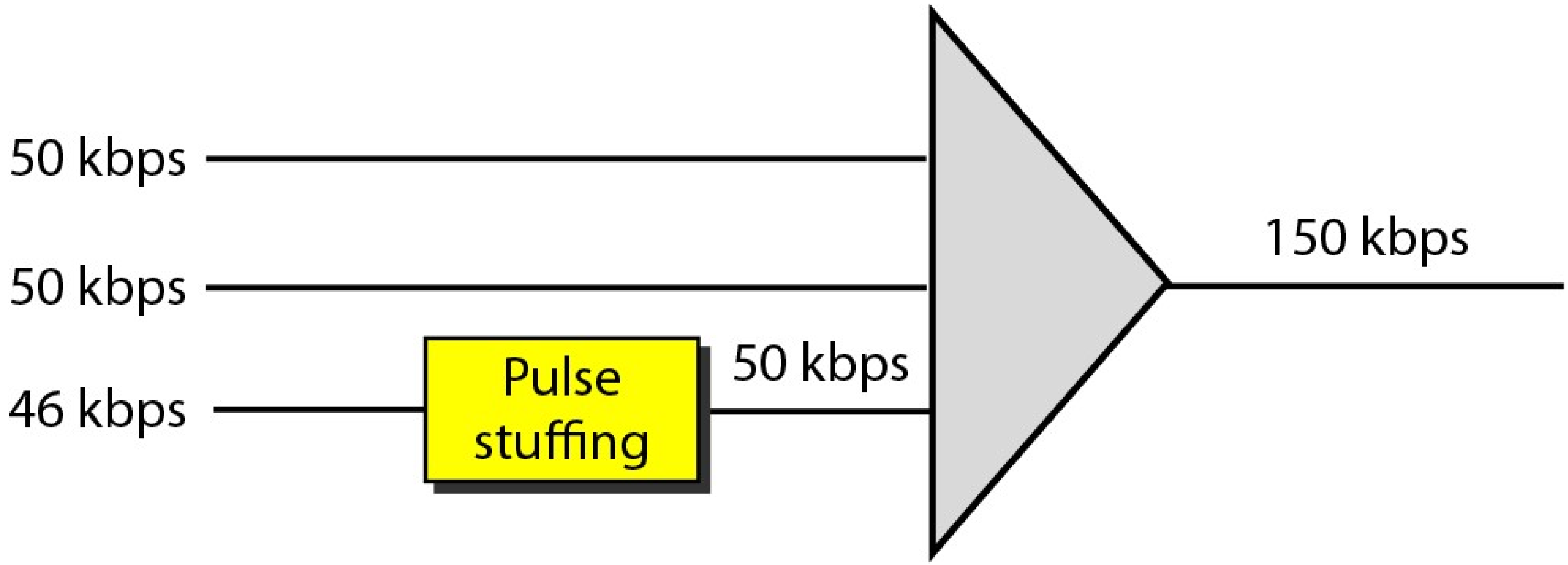
Multilevel multiplexing

Module 1: *Multiplexing:*



Multiple-slot multiplexing

Module 1: *Multiplexing:*

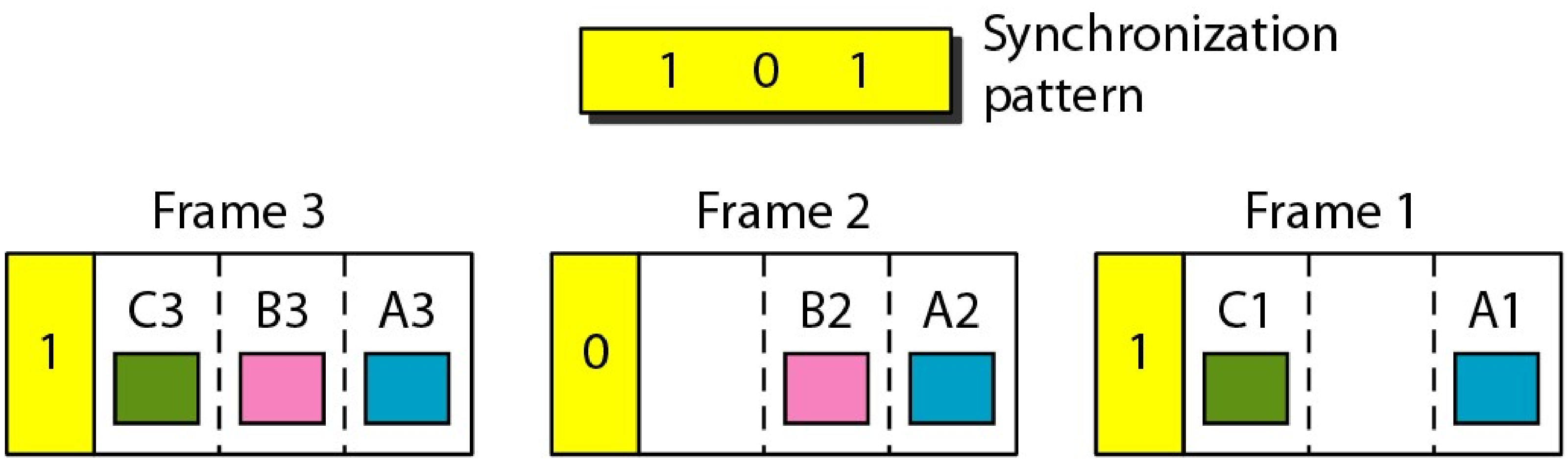


Pulse stuffing

Synchronization

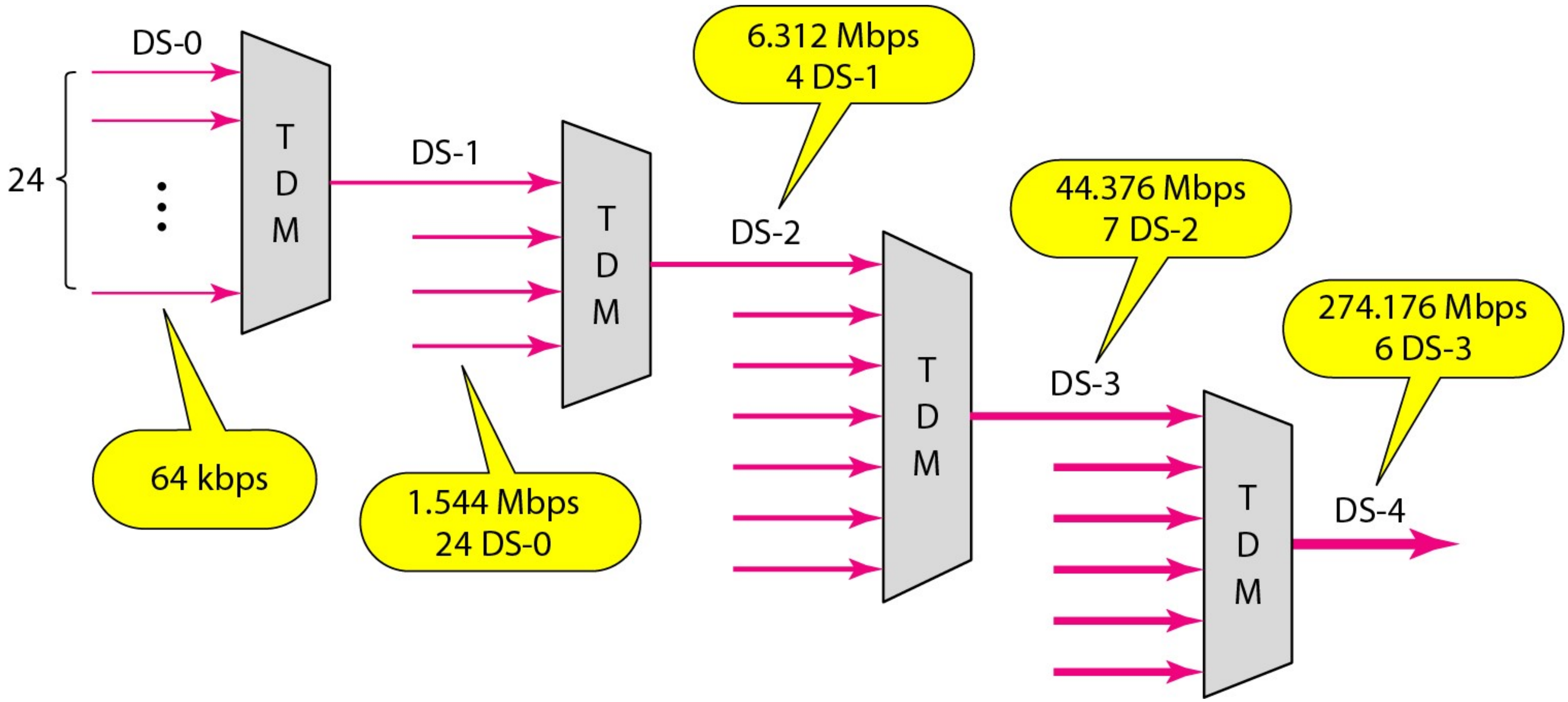
- ✓ To ensure that the receiver correctly reads the incoming bits, i.e., knows the incoming bit boundaries to interpret a “1” and a “0”, a known bit pattern is used between the frames.
- ✓ The receiver looks for the anticipated bit and starts counting bits till the end of the frame.
- ✓ Then it starts over again with the reception of another known bit.
- ✓ These bits (or bit patterns) are called synchronization bit(s).
- ✓ They are part of the overhead of transmission.

Module 1: *Multiplexing:*



Framing bits

Module 1: *Multiplexing:*



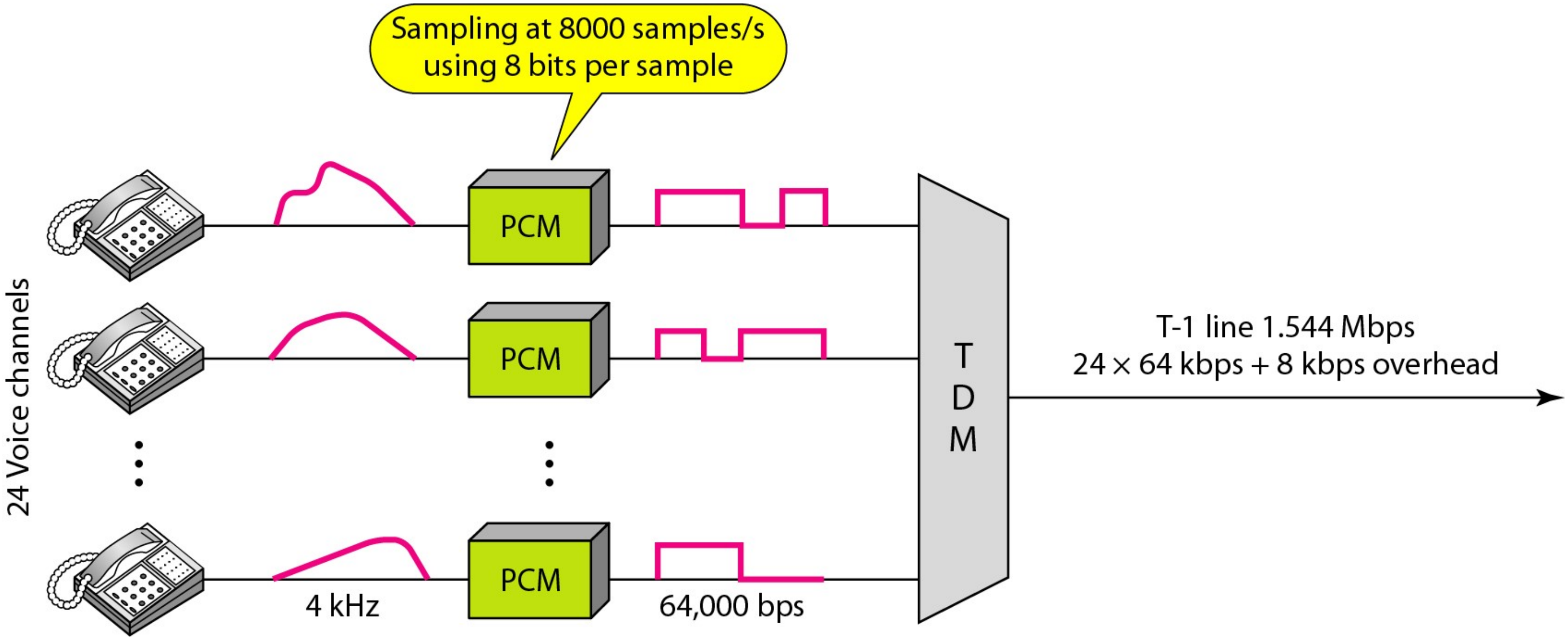
Digital hierarchy

Module 1: *Multiplexing:*

Service	*Line*	*Rate (Mbps)*	*Voice Channels*
DS-1	T-1	1.544	24
DS-2	T-2	6.312	96
DS-3	T-3	44.736	672
DS-4	T-4	274.176	4032

DS and T line rates

Module 1: *Multiplexing:*



T-1 line for multiplexing telephone lines

Module 1: *Multiplexing:*

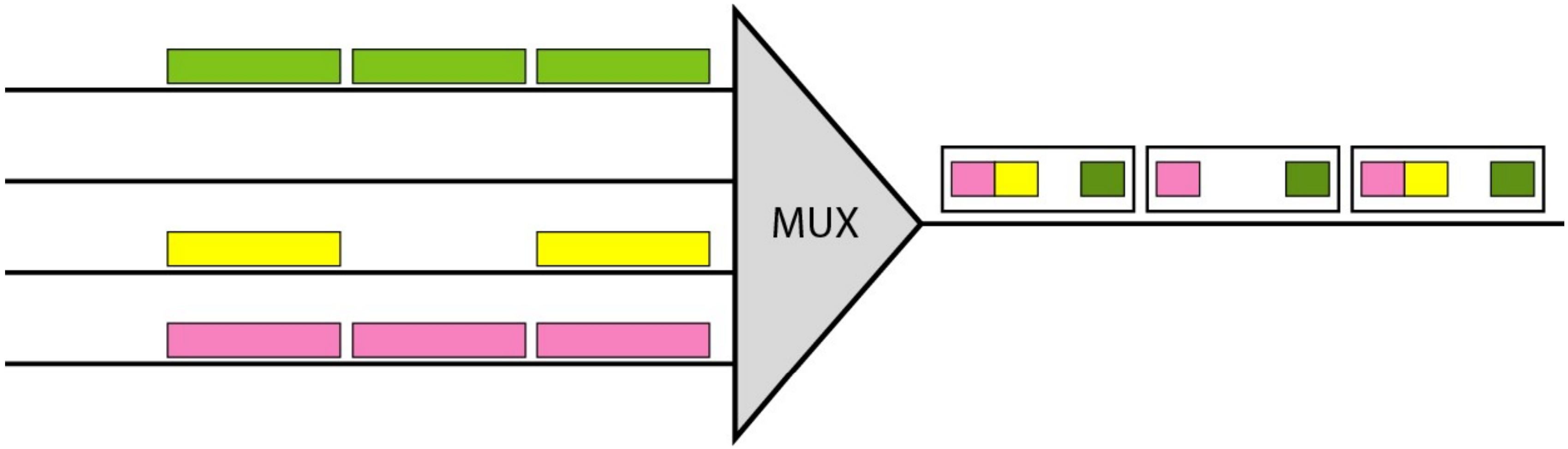
Line	*Rate (Mbps)*	*Voice Channels*
E-1	2.048	30
E-2	8.448	120
E-3	34.368	480
E-4	139.264	1920

E line rates

Inefficient use of Bandwidth

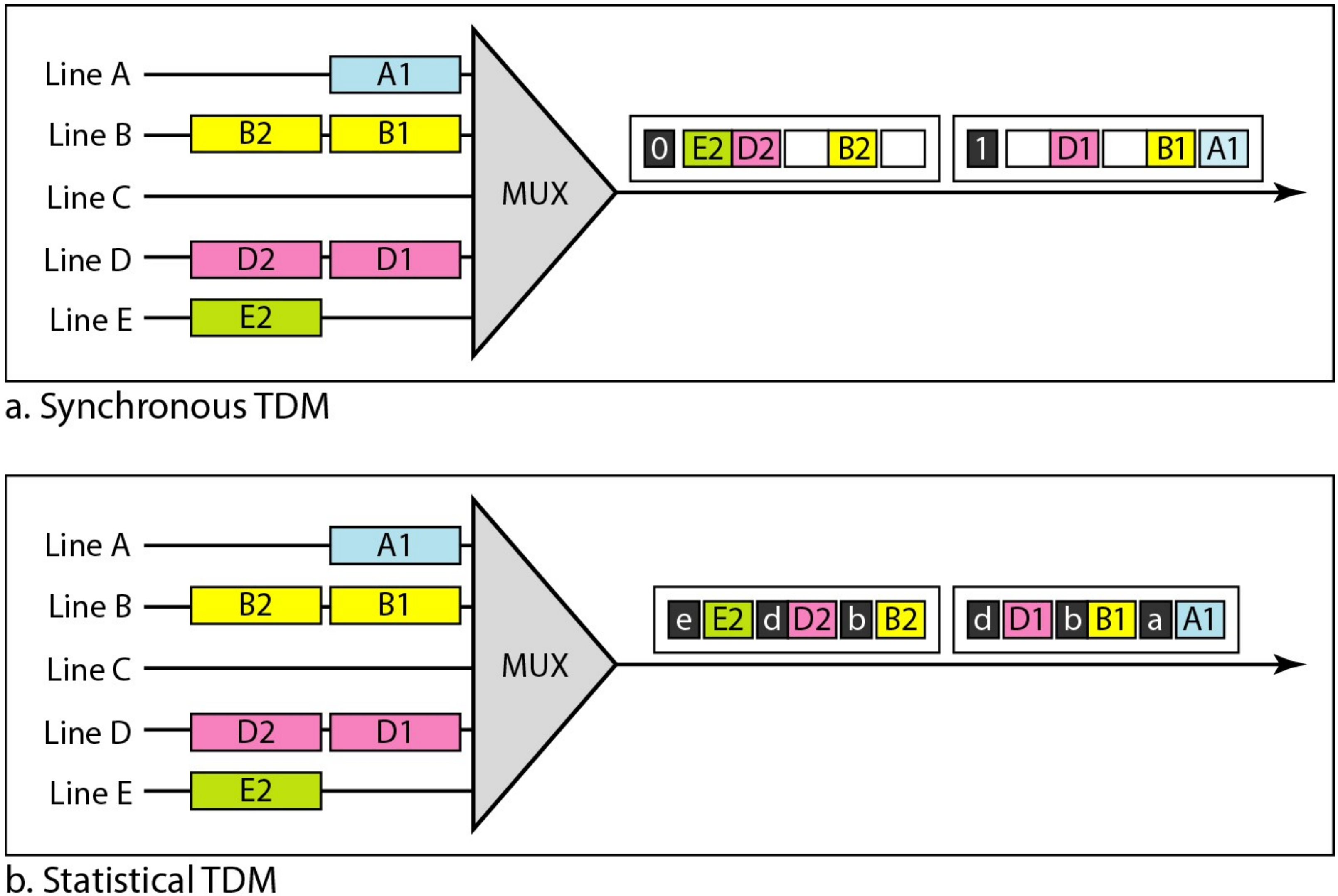
- ✓ Sometimes an input link may have no data to transmit.
- ✓ When that happens, one or more slots on the output link will go unused.
- ✓ That is wasteful of bandwidth.

Module 1: *Multiplexing:*



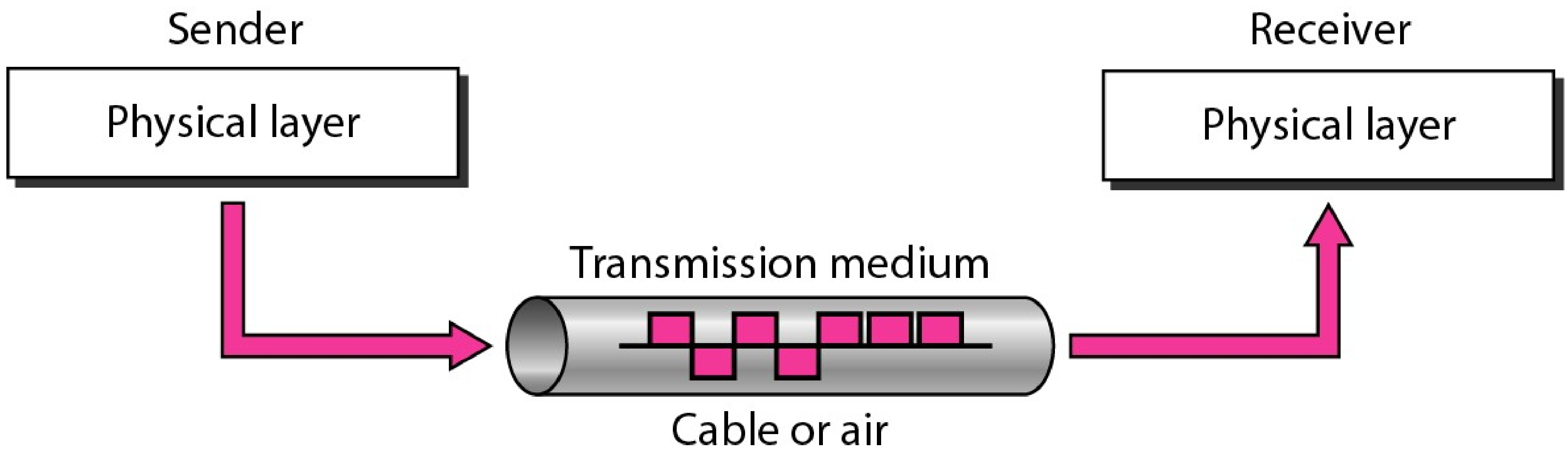
Empty slots

Module 1: *Multiplexing:*



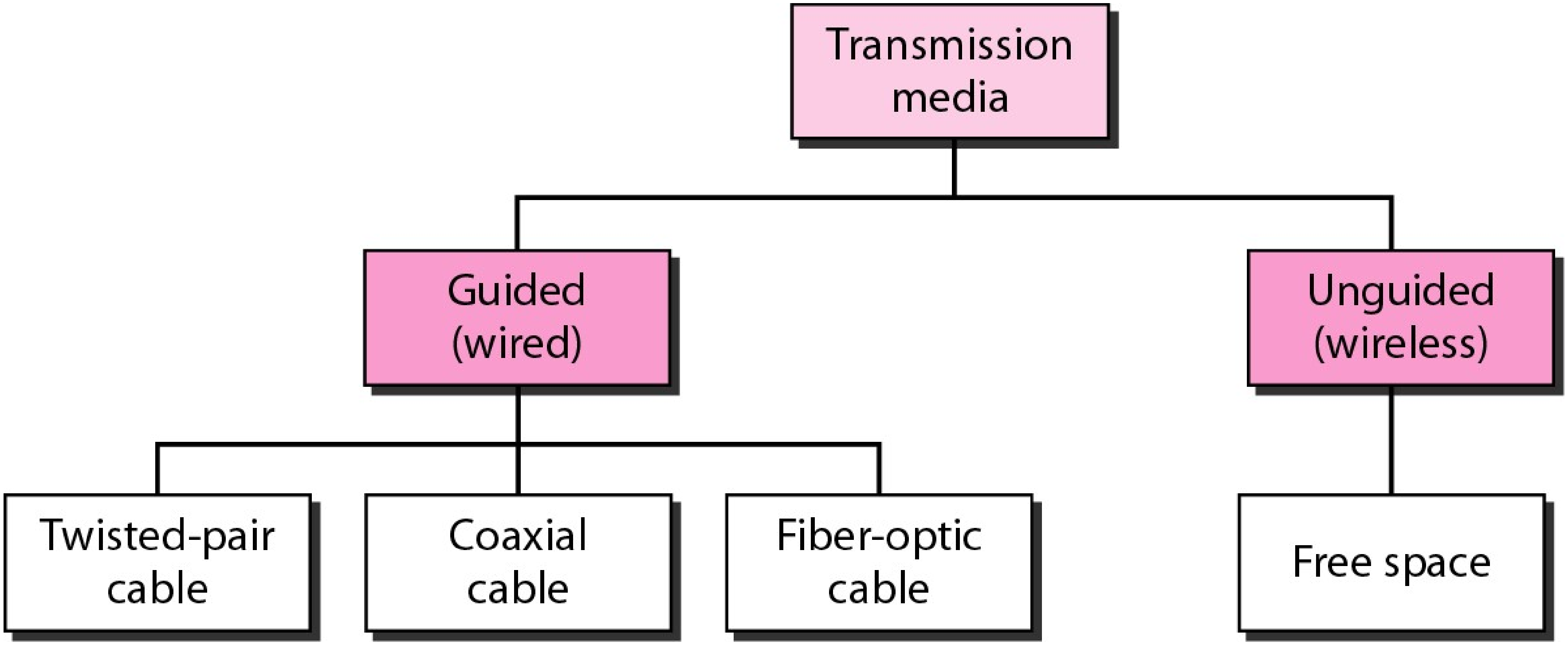
TDM slot comparison

Module 1: *Transmission Media:*



Transmission medium and physical layer

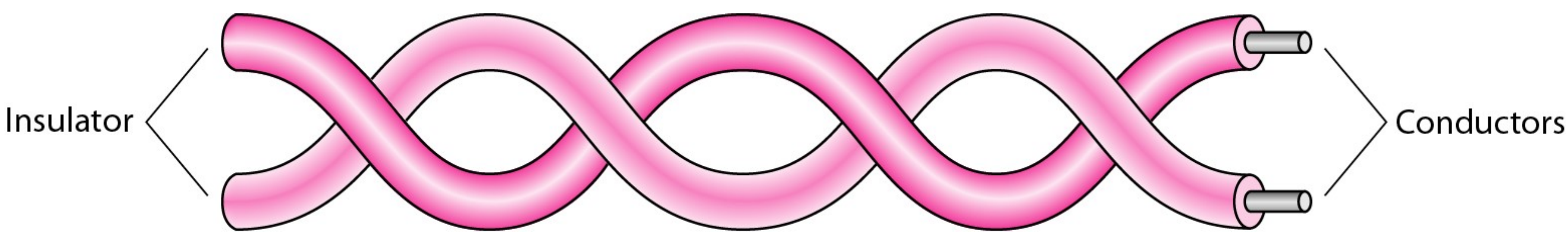
Module 1: *Transmission Media:*



Classes of transmission media

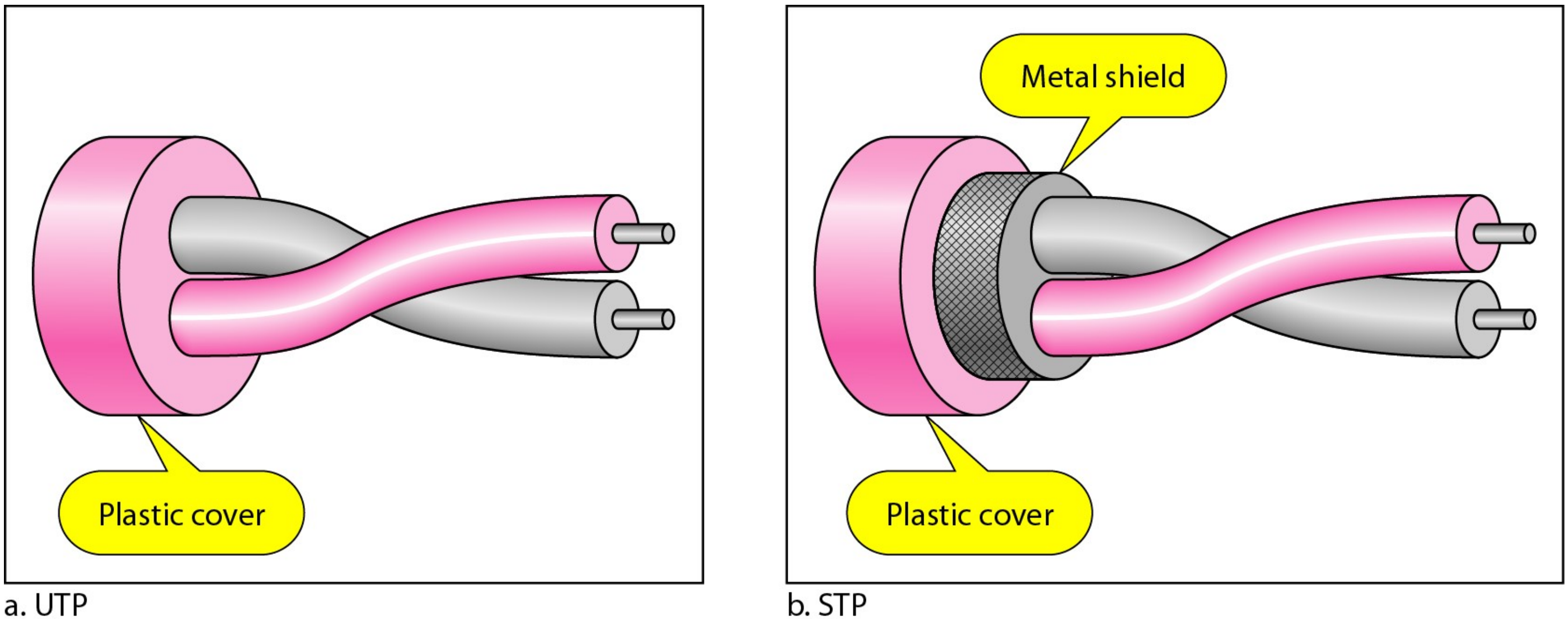
Guided media

Guided media, which are those that provide a conduit from one device to another, include twisted-pair cable, coaxial cable, and fiber-optic cable.



Twisted-pair cable

Module 1: *Transmission Media:*

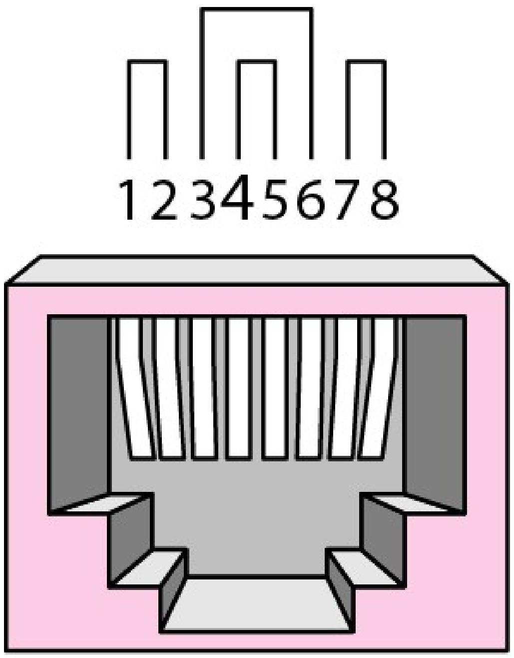


UTP and STP cables

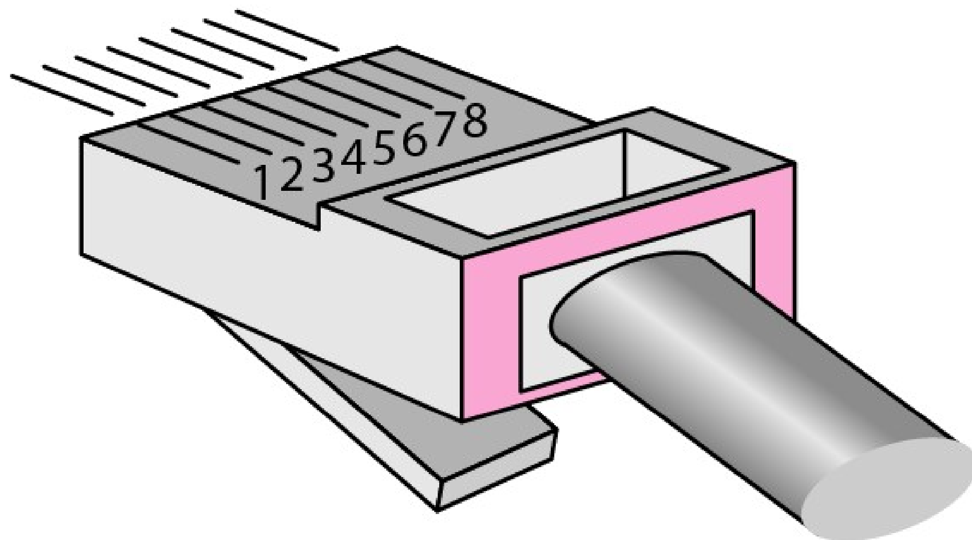
Module 1: *Transmission Media:*

Category	*Specification*	*Data Rate (Mbps)*	*Use*
1	Unshielded twisted-pair used in telephone	< 0.1	Telephone
2	Unshielded twisted-pair originally used in T-lines	2	T-1 lines
3	Improved CAT 2 used in LANs	10	LANs
4	Improved CAT 3 used in Token Ring networks	20	LANs
5	Cable wire is normally 24 AWG with a jacket and outside sheath	100	LANs
5E	An extension to category 5 that includes extra features to minimize the crosstalk and electromagnetic interference	125	LANs
6	A new category with matched components coming from the same manufacturer. The cable must be tested at a 200-Mbps data rate.	200	LANs
7	Sometimes called SSTP (shielded screen twisted-pair). Each pair is individually wrapped in a helical metallic foil followed by a metallic foil shield in addition to the outside sheath. The shield decreases the effect of crosstalk and increases the data rate.	600	LANs

Module 1: *Transmission Media:*



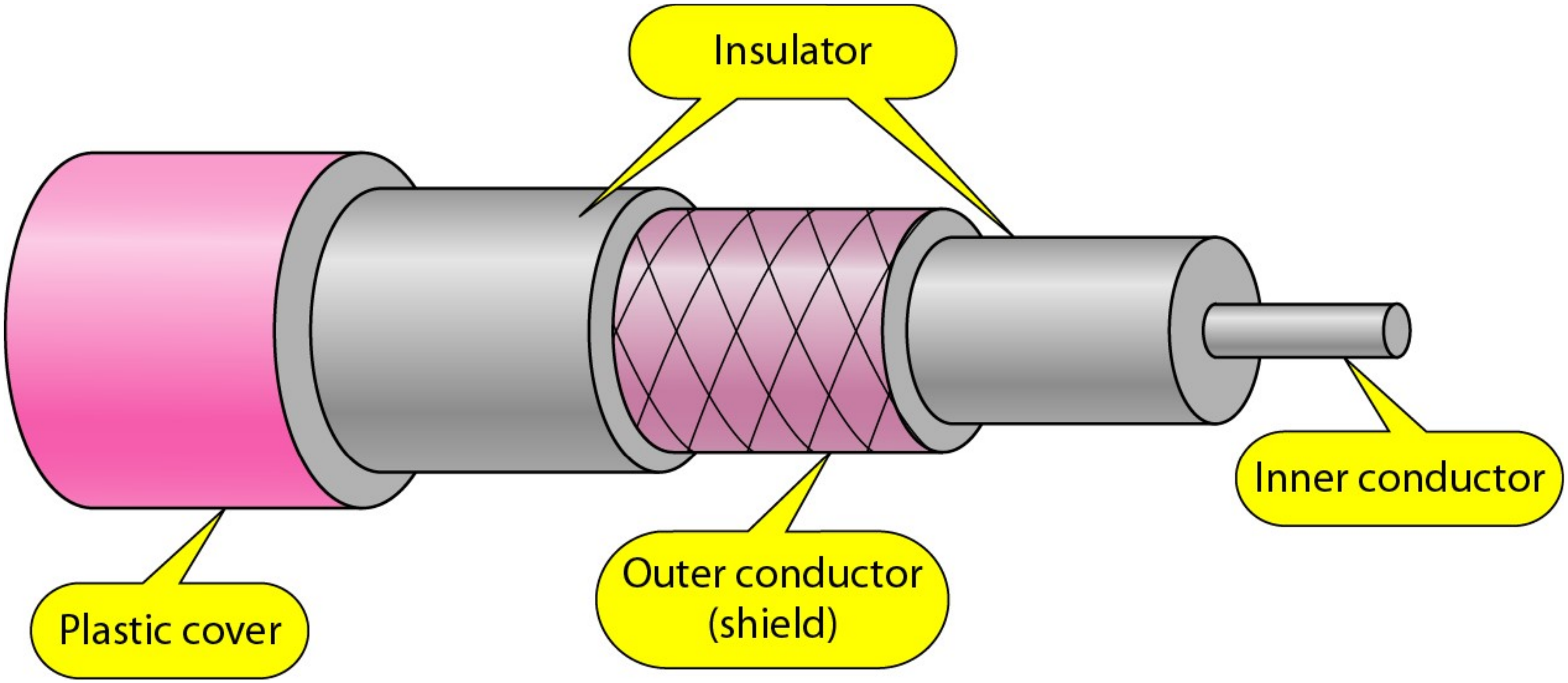
RJ-45 Female



RJ-45 Male

UTP connector

Module 1: *Transmission Media:*

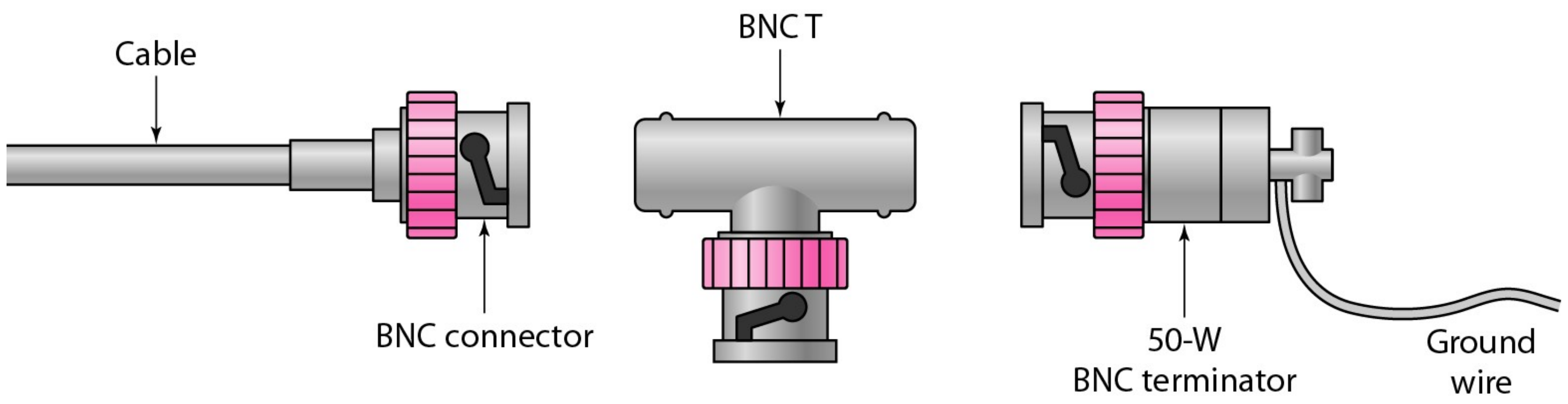


Coaxial cable

Module 1: *Transmission Media:*

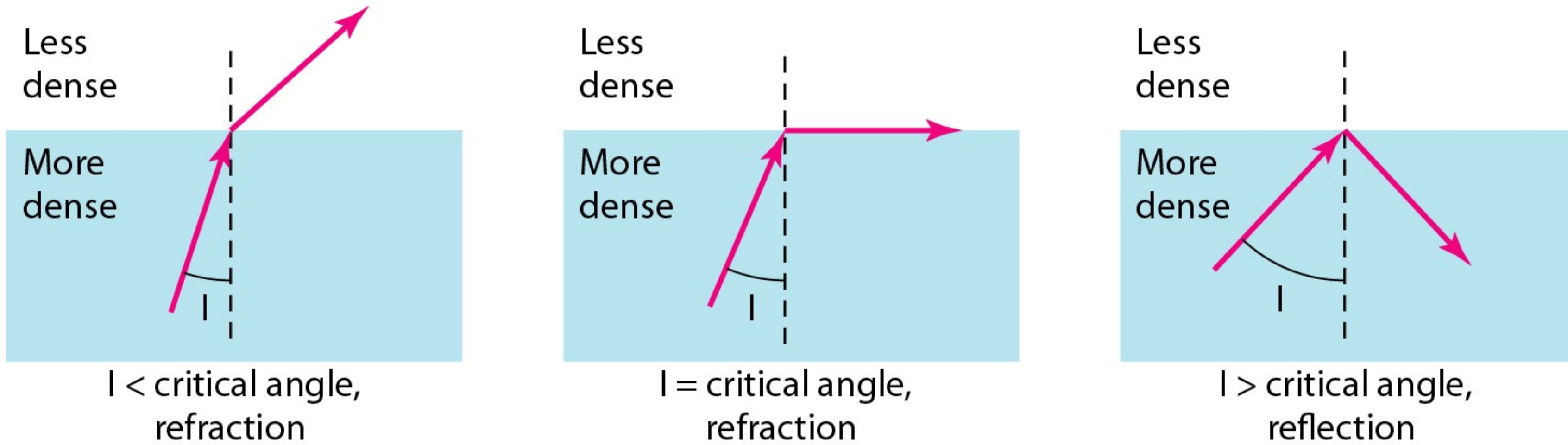
Category	*Impedance*	*Use*
RG-59	75 Ω	Cable TV
RG-58	50 Ω	Thin Ethernet
RG-11	50 Ω	Thick Ethernet

Categories of coaxial cables

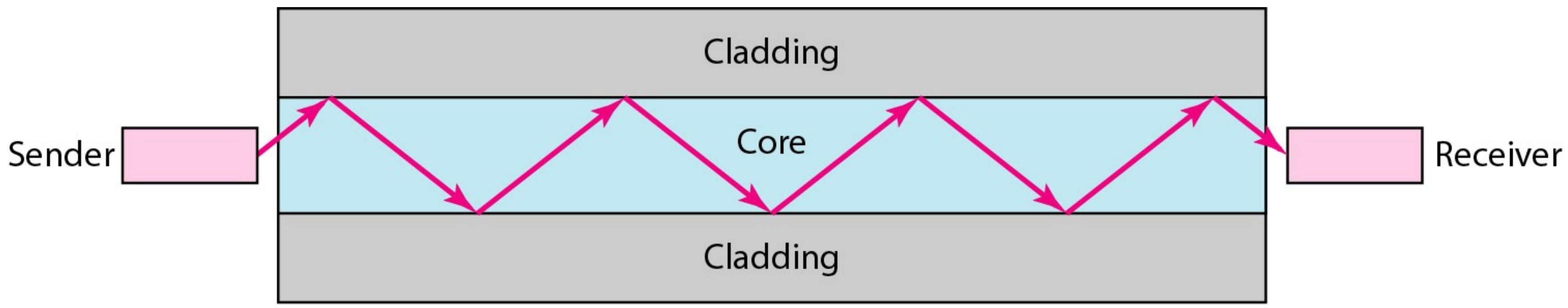


BNC connectors

Module 1: *Transmission Media:*

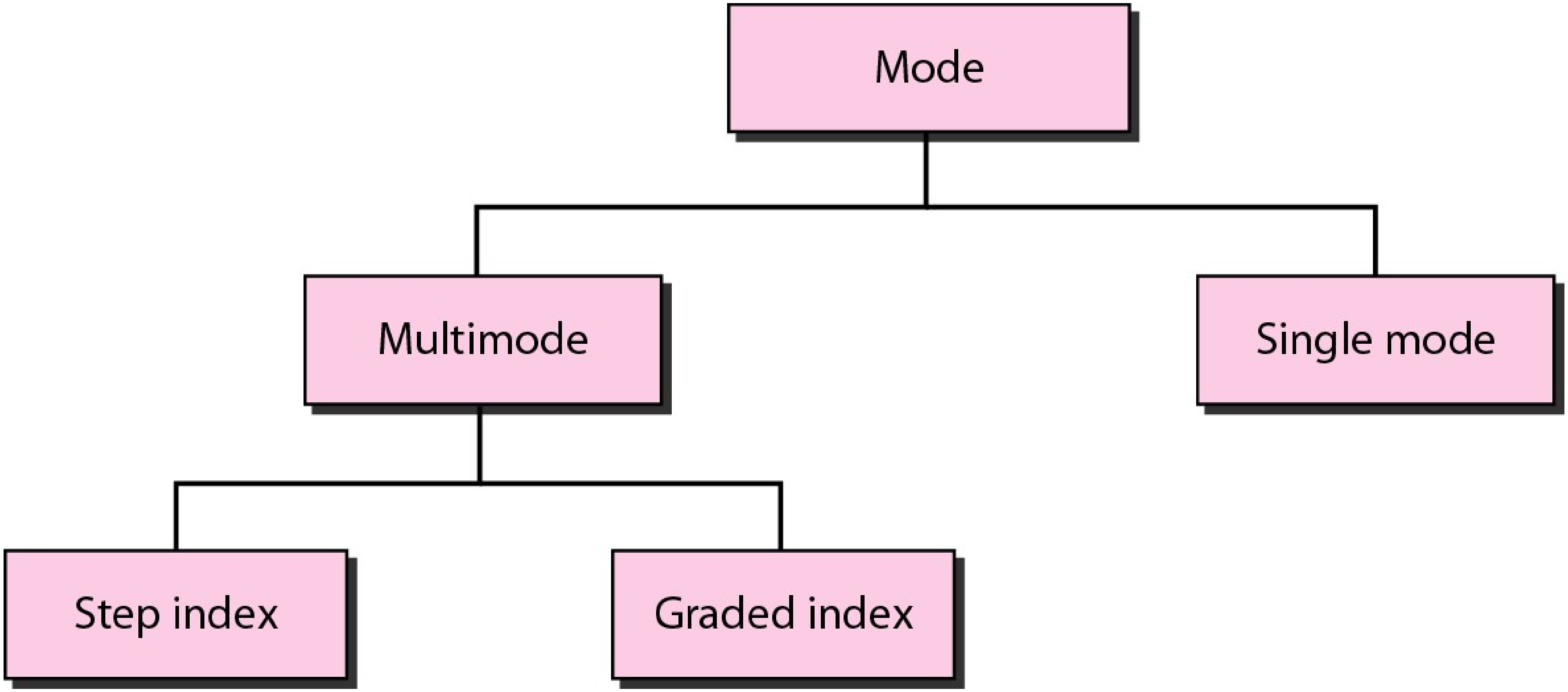


Fiber optics: *Bending of light ray*

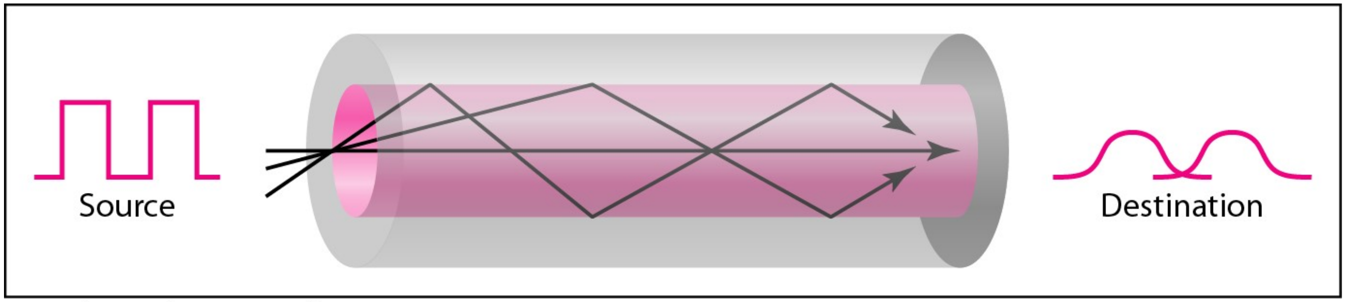


Optical fiber

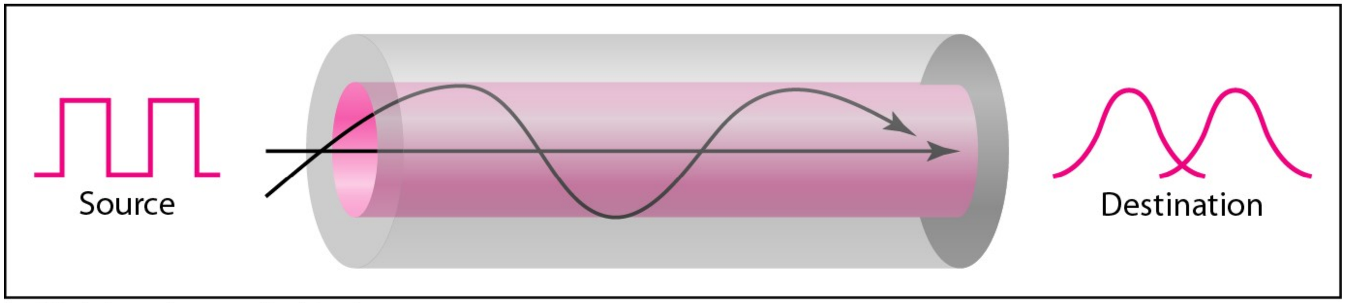
Module 1: *Transmission Media:*



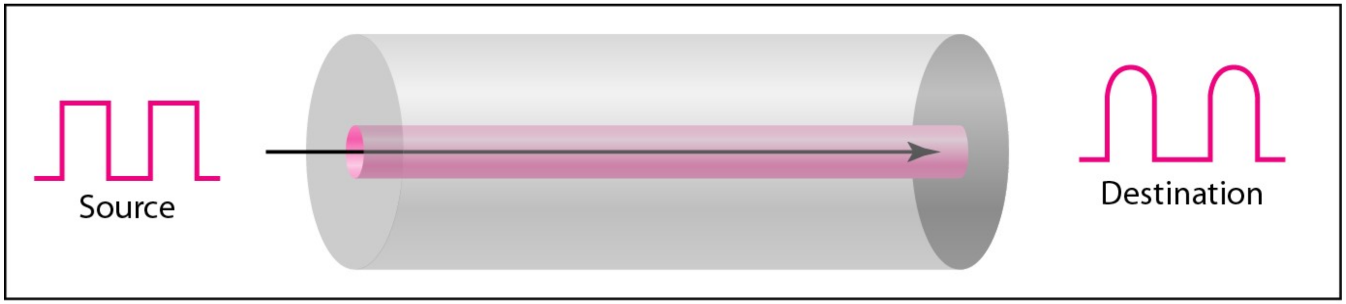
Propagation modes



a. Multimode, step index



b. Multimode, graded index



c. Single mode

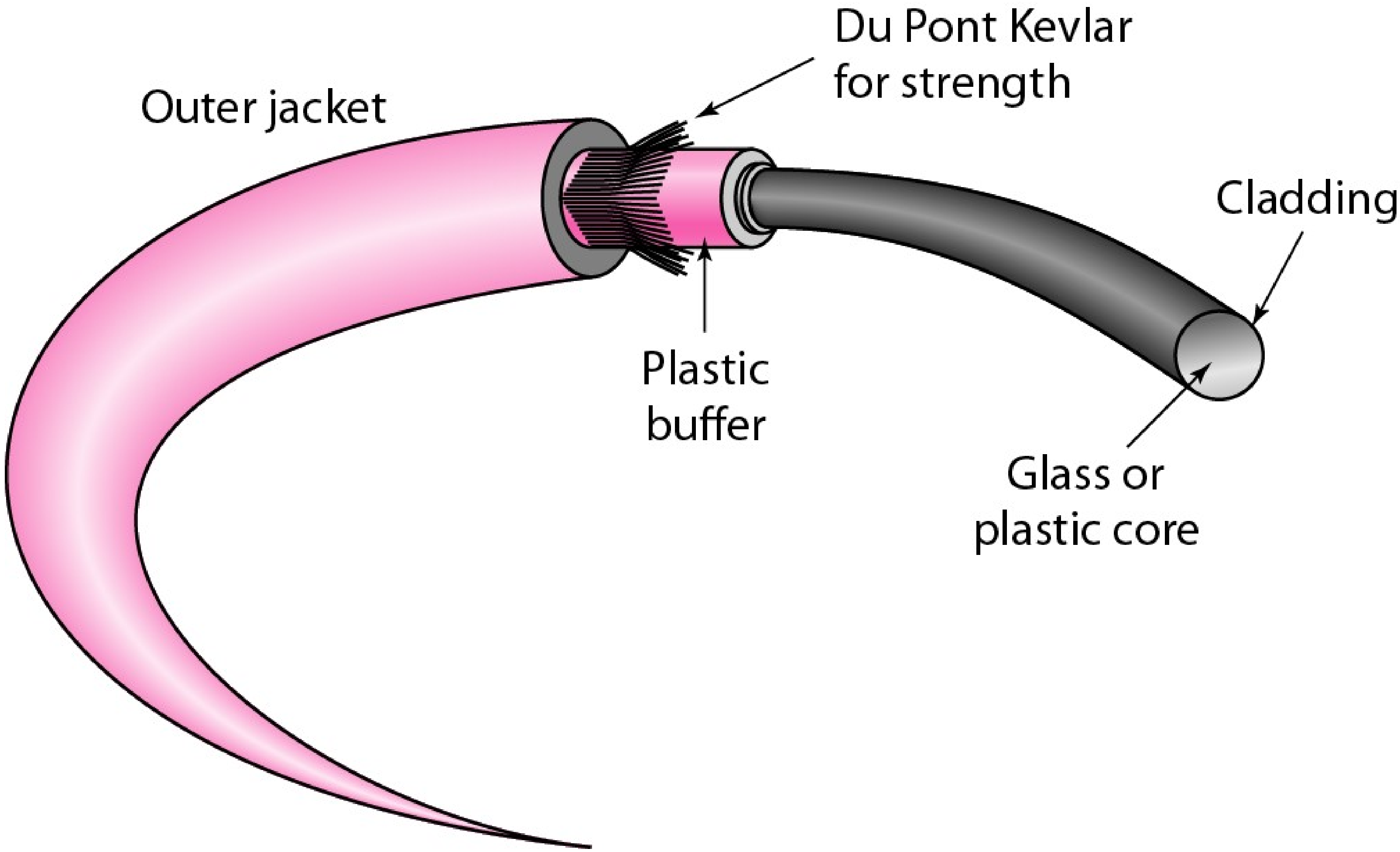
Modes

Module 1: *Transmission Media:*

Type	*Core (µm)*	*Cladding (µm)*	*Mode*
50/125	50.0	125	Multimode, graded index
62.5/125	62.5	125	Multimode, graded index
100/125	100.0	125	Multimode, graded index
7/125	7.0	125	Single mode

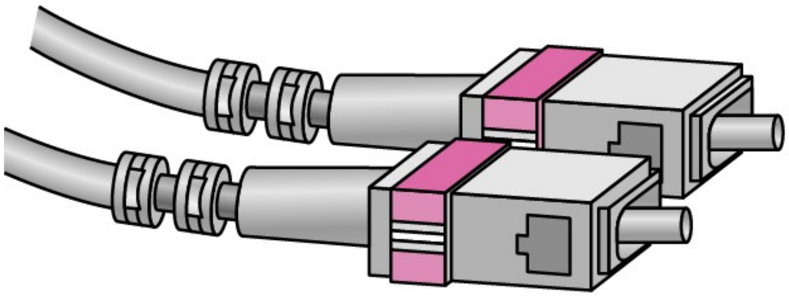
Fiber types

Module 1: *Transmission Media:*

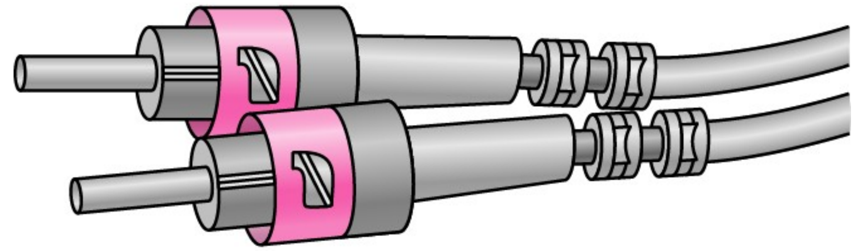


Fiber construction

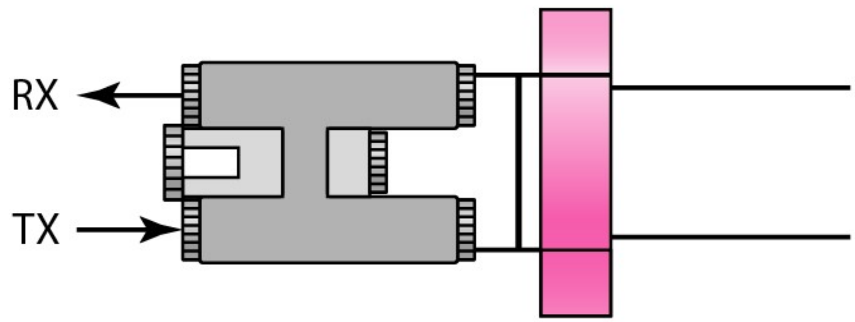
Module 1: *Transmission Media:*



SC connector



ST connector

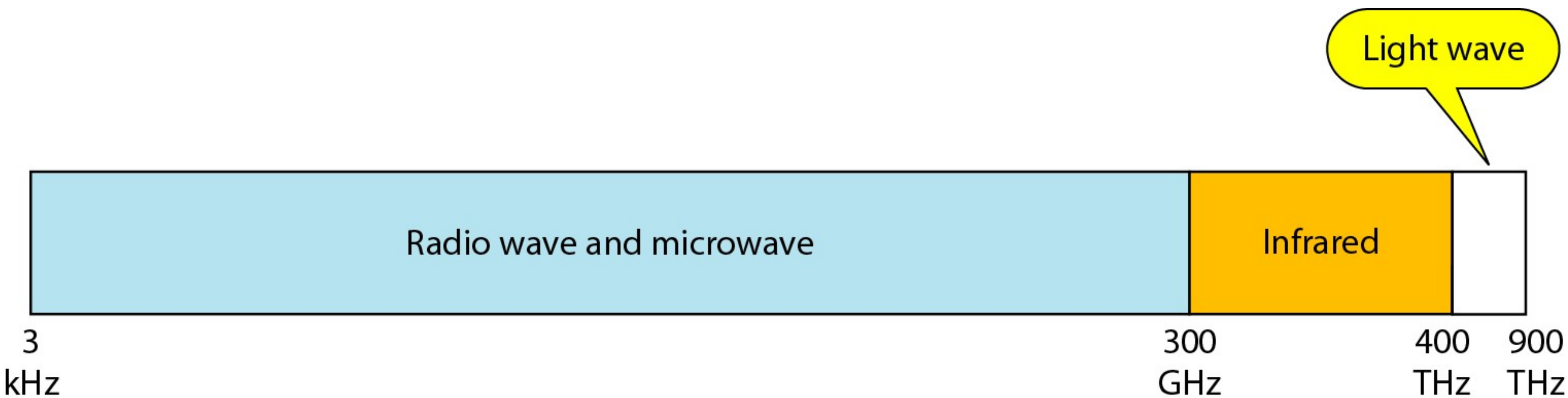


MT-RJ connector

Fiber-optic cable connectors

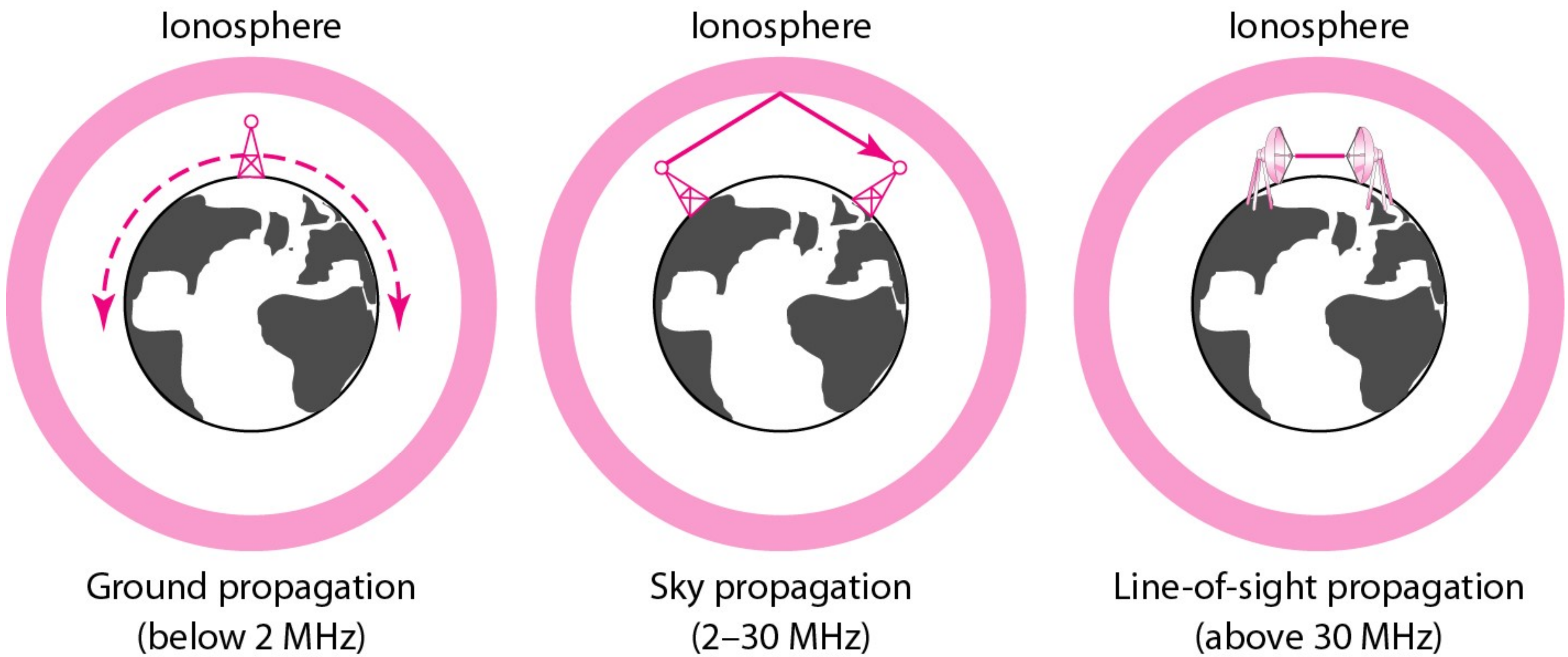
Module 1: *Transmission Media:*

Unguided media transport electromagnetic waves without using a physical conductor. This type of communication is often referred to as wireless communication.



Electromagnetic spectrum for wireless communication

Module 1: *Transmission Media:*

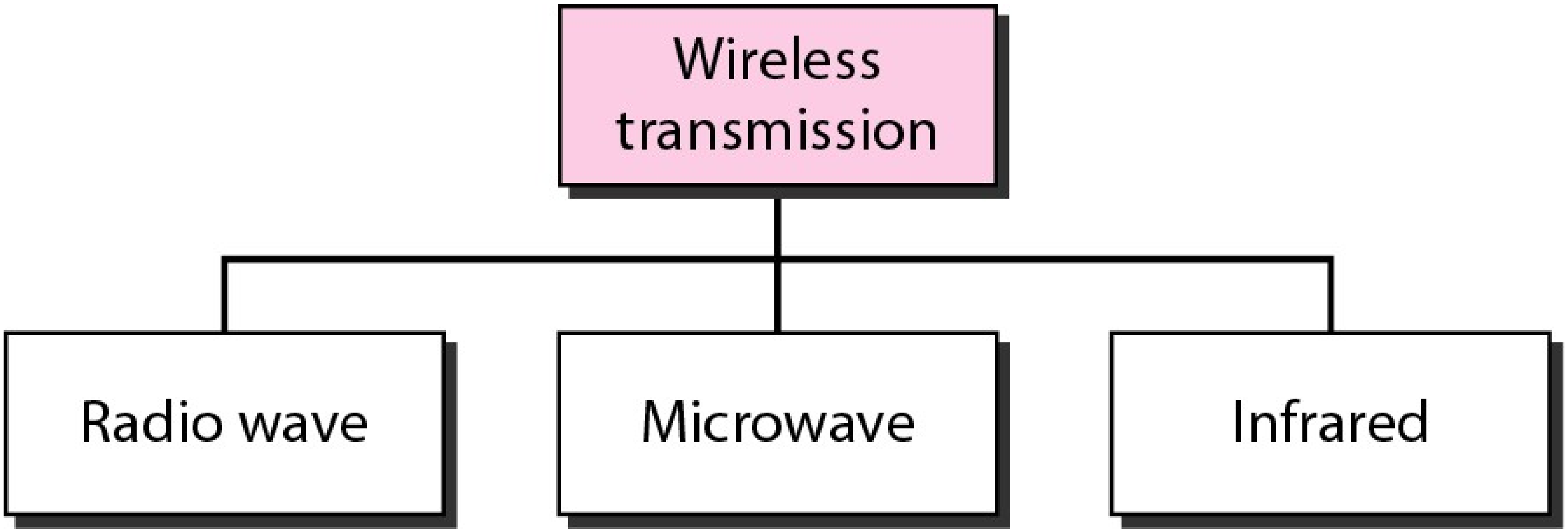


Propagation methods

Module 1: *Transmission Media:*

Band	*Range*	*Propagation*	*Application*
VLF (very low frequency)	3–30 kHz	Ground	Long-range radio navigation
LF (low frequency)	30–300 kHz	Ground	Radio beacons and navigational locators
MF (middle frequency)	300 kHz–3 MHz	Sky	AM radio
HF (high frequency)	3–30 MHz	Sky	Citizens band (CB), ship/aircraft communication
VHF (very high frequency)	30–300 MHz	Sky and line-of-sight	VHF TV, FM radio
UHF (ultrahigh frequency)	300 MHz–3 GHz	Line-of-sight	UHF TV, cellular phones, paging, satellite
SHF (superhigh frequency)	3–30 GHz	Line-of-sight	Satellite communication
EHF (extremely high frequency)	30–300 GHz	Line-of-sight	Radar, satellite

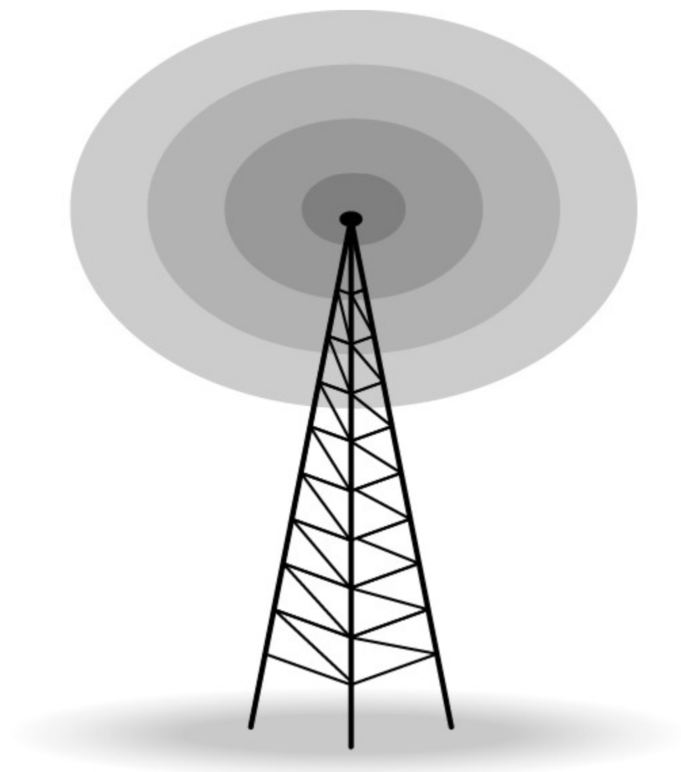
Module 1: *Transmission Media:*



Wireless transmission waves

Module 1: *Transmission Media:*

Radio waves are used for multicast communications, such as radio and television, and paging systems.
They can penetrate through walls.
Highly regulated. Use omni directional antennas.

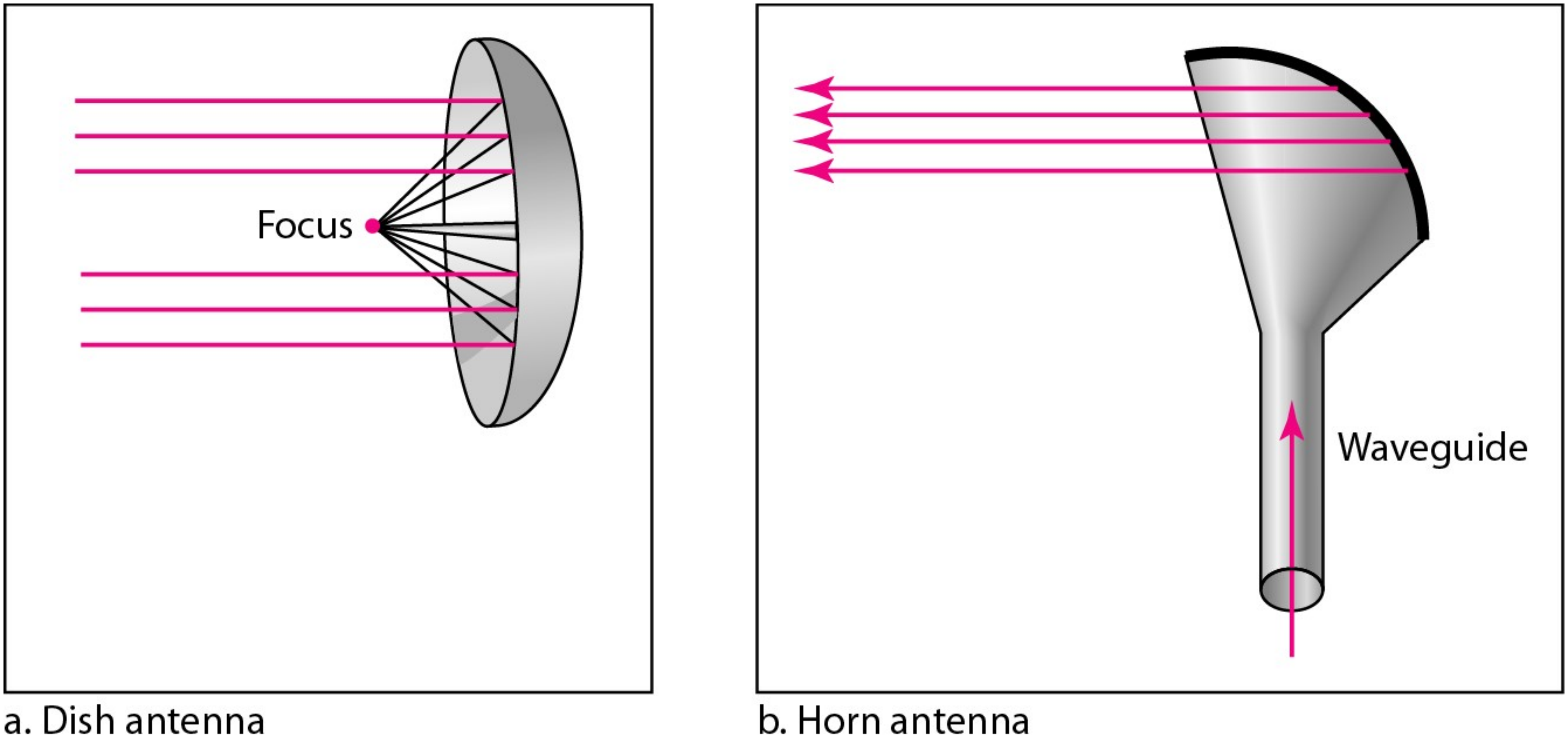


Microwaves are used for unicast communication such as cellular telephones, satellite networks, and wireless LANs.

Higher frequency ranges cannot penetrate walls.

Use directional antennas - point to point line of sight communications.

Module 1: *Transmission Media:*



Unidirectional antennas

Infrared signals can be used for short-range communication in a closed area using line-of-sight propagation.

Wireless Channels

Are subject to a lot more errors than guided media channels.

Interference is one cause for errors, can be circumvented with high SNR.

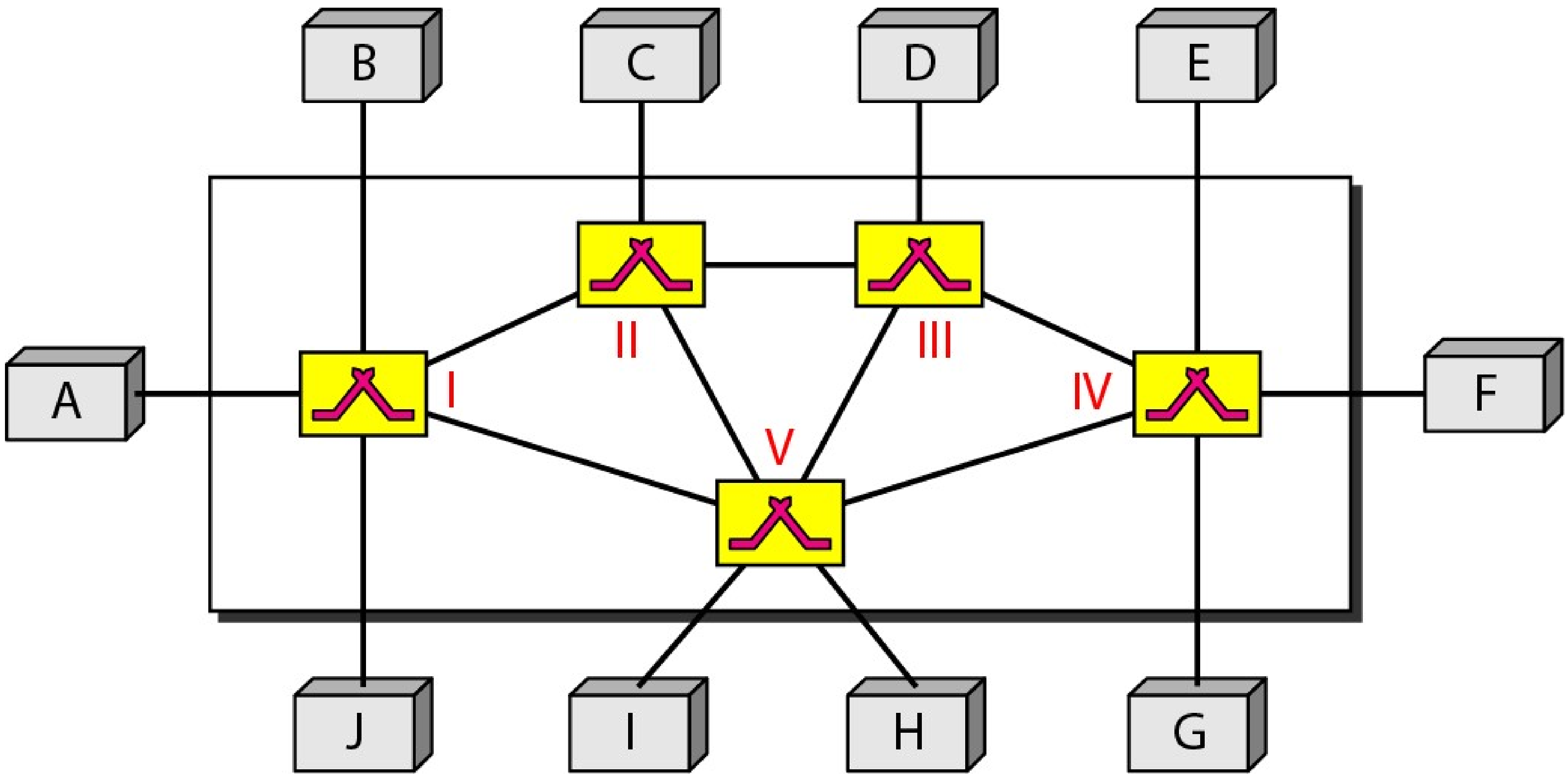
The higher the SNR the less capacity is available for transmission due to the broadcast nature of the channel.

Channel also subject to fading and no coverage holes.

Switching

- ✓ Switching used to connect the systems to make one-to-one communication.
- ✓ It is the process to forward packets coming in from one port to a port leading towards the destination.
- ✓ A switched network consists of a series of switches.

Module 1: *Switching:*

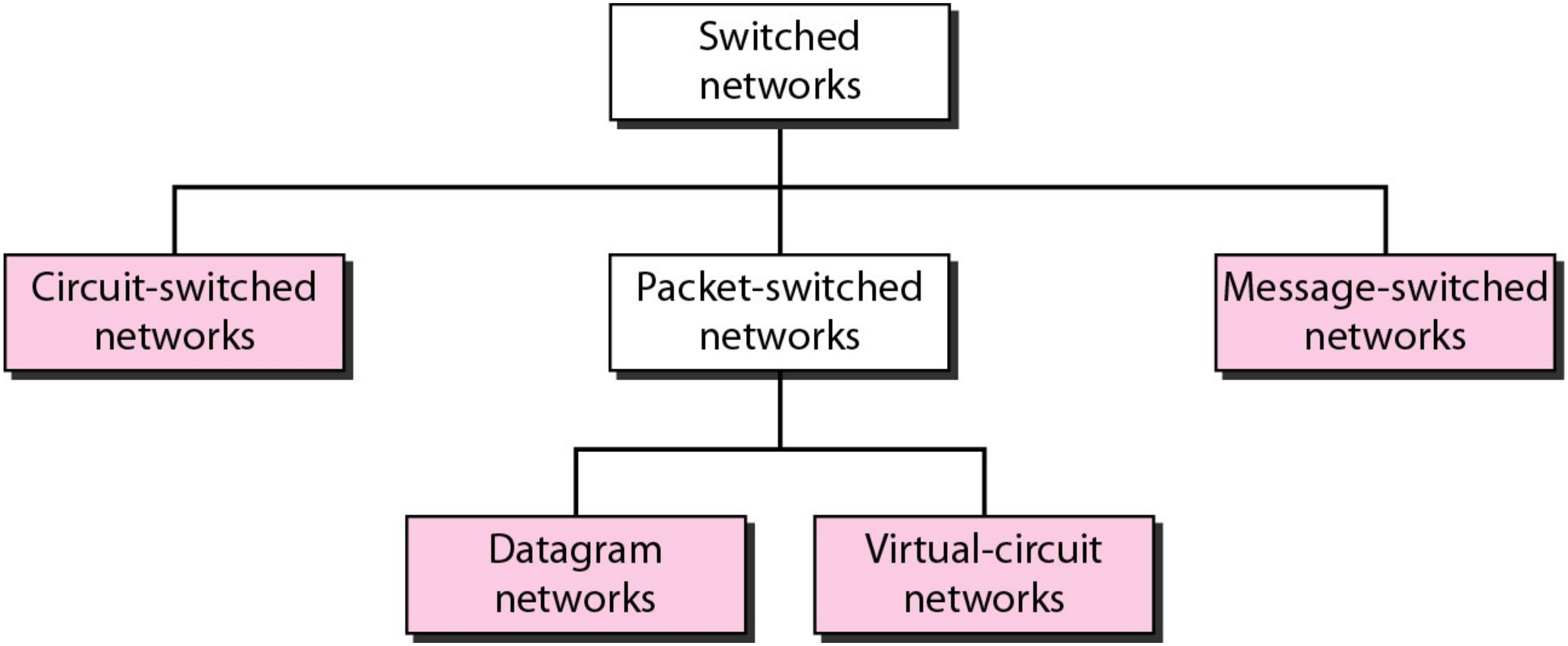


Switched network

Why switching is used?

- ✓ For large networks it is impractical to use star, bus, mesh topologies because of high cost and inefficient use of the network resources.
- ✓ Better solution is switching

Module 1: *Switching:*



Taxonomy of switched networks

Types of switching

- ✓ **Circuit switching**: Connection established before communication
- ✓ **Packet switching**: No connection establishment before communication
- ✓ **Message switching**: Each switch stores the whole message and forwards it to the next switch

Module 1: *Switching:*

Circuit switched network

- ✓ A circuit-switched network consists of a set of switches connected by physical links.
- ✓ When two nodes communicate with each other over a dedicated communication path, it is called circuit switching.
- ✓ There is a need of pre-specified route from which data will travel and no other data is permitted.
- ✓ In circuit switching, to transfer the data, circuit must be established so that the data transfer can take place.

Phases of circuit switched network

- ✓ Setup Phase (Establish a circuit)
- ✓ Data Transfer Phase(Transfer the data)
- ✓ Teardown Phase (Disconnect the circuit)

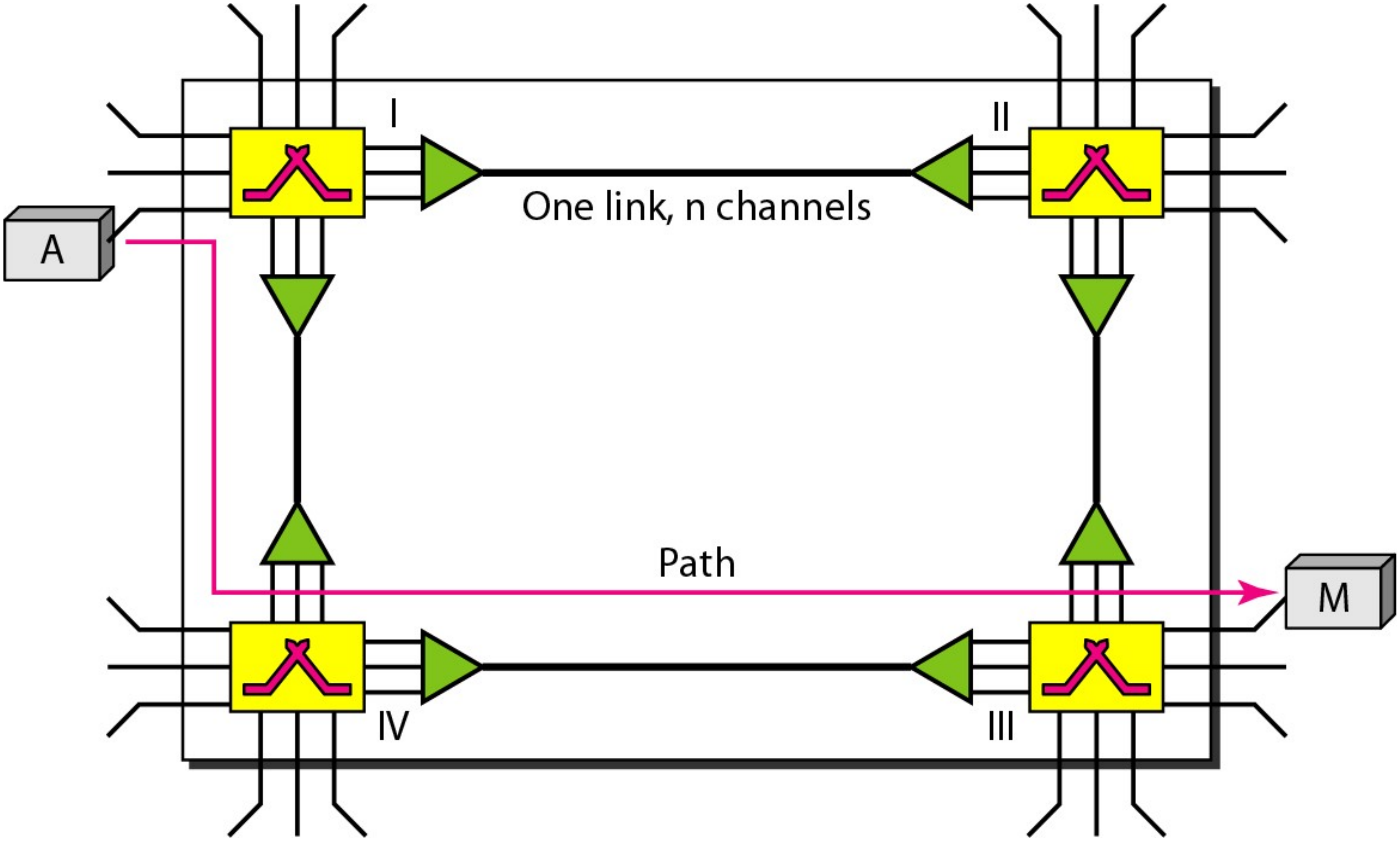
Setup Phase

- ✓ Source sends a connection setup request containing the destination address to the next switch .
- ✓ Dedicated channels are reserved between switches from the source to destination.
- ✓ An acknowledgment from the destination needs to be sent in the opposite direction to the source.
- ✓ After the source receives acknowledgment from the destination, the connection is established.

Module 1: *Switching:*

- ✓ In the next step to making a connection, an acknowledgment from system M needs to be sent in the opposite direction to system A.
- ✓ Only after system A receives this acknowledgment the connection is established.

Module 1: *Switching:*



A trivial circuit-switched network

Module 1: *Switching:*

Data Transfer Phase

After the establishment of the dedicated circuit (channels), the two parties can transfer data

Teardown Phase

When one of the parties needs to disconnect, a signal is sent to each switch to release the resources.

In circuit switching, the resources need to be reserved during the setup phase; the resources remain dedicated for the entire duration of data transfer until the teardown phase.

Module 1: *Switching:*

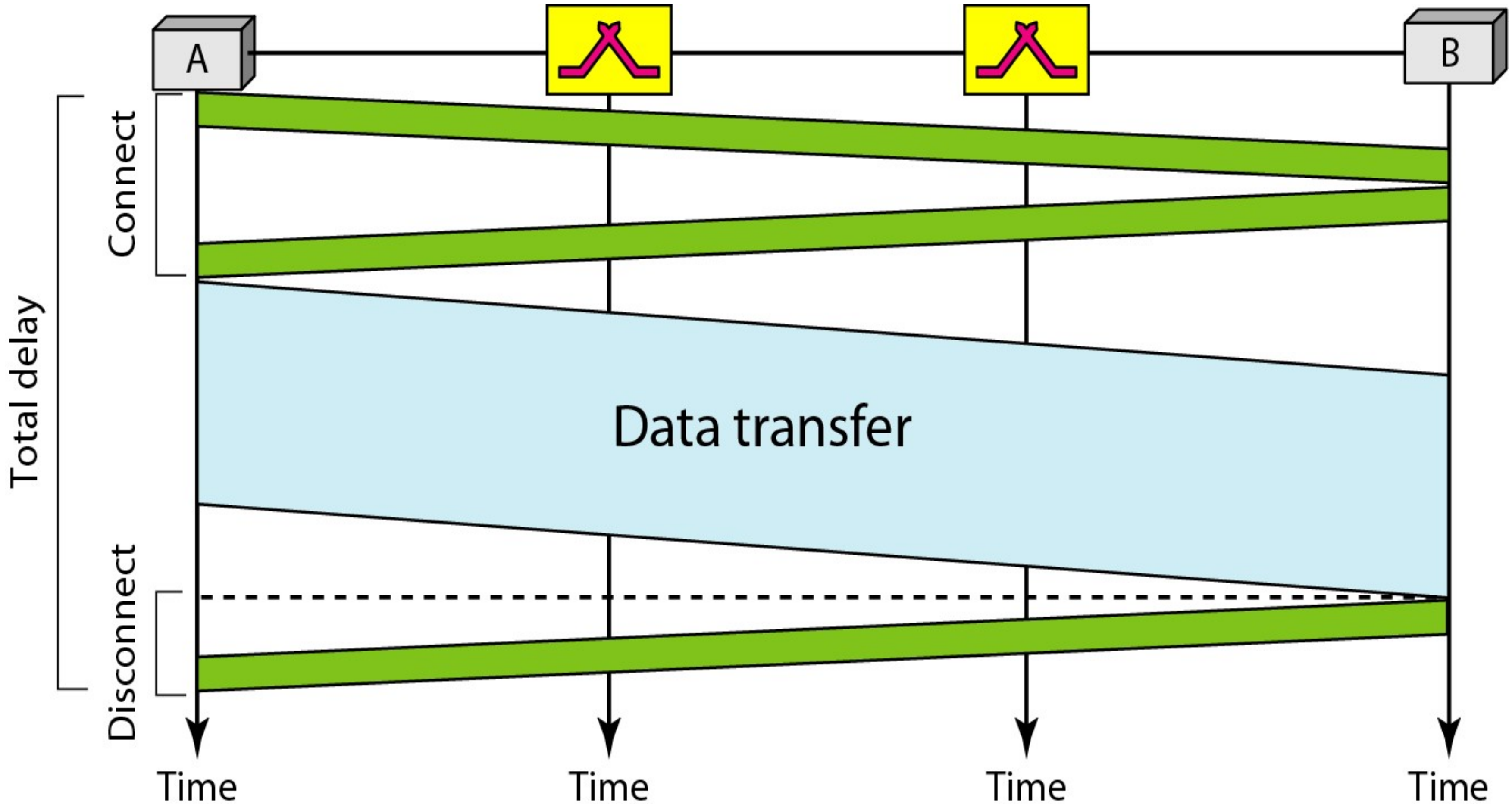
Efficiency

- ✓ Uses dedicated resource until teardown phase.
- ✓ So resources are unavailable to other connections.
- ✓ Allowing resources to be dedicated means that other connections are deprived.

Delay

During data transfer the data are not delayed at each switch as the resources are allocated for the duration of the connection.
So delay of circuit switched network is minimal.

Module 1: *Switching:*



Delay in a circuit-switched network

Total delay = Connect time + Data transfer time+ Disconnect time

Switching at the physical layer in the traditional telephone network uses the circuit-switching approach.

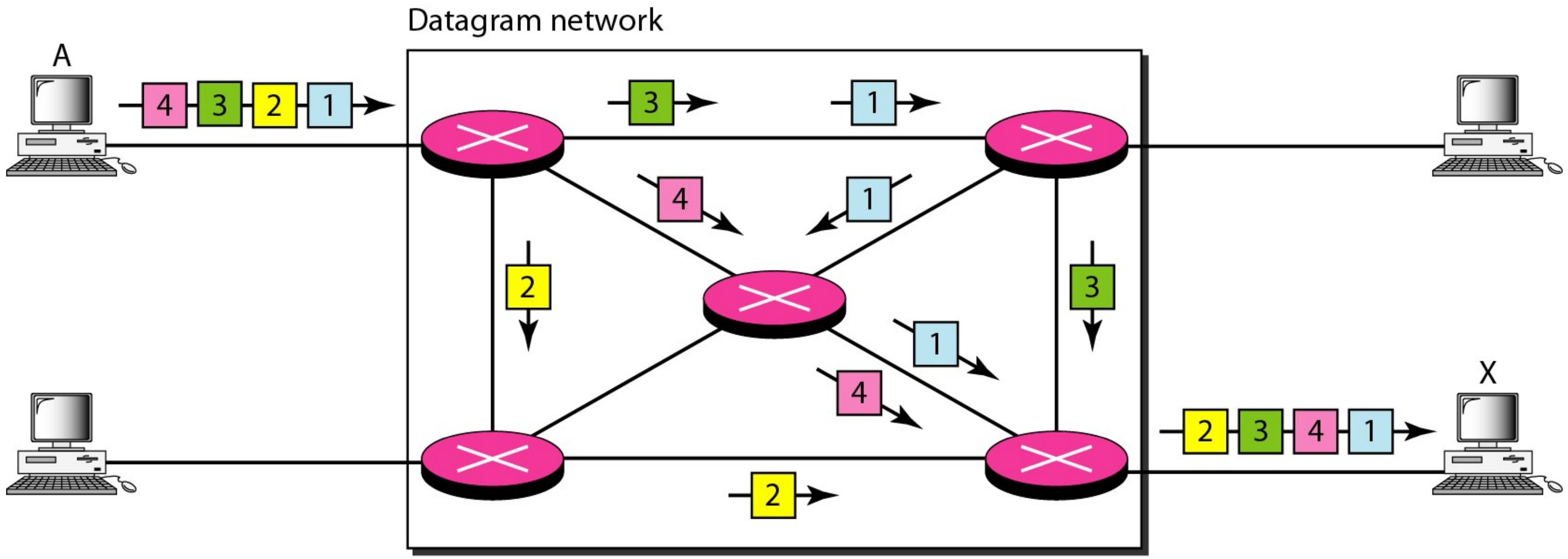
Datagram Network

- ✓ If the message is going to pass through a packet-switched network, it needs to be divided into packets of fixed or variable size.
- ✓ The size of the packet is determined by the network and the governing protocol.
- ✓ In a packet-switched network, there is no resource reservation , resources are allocated on demand.

Module 1: *Switching:*

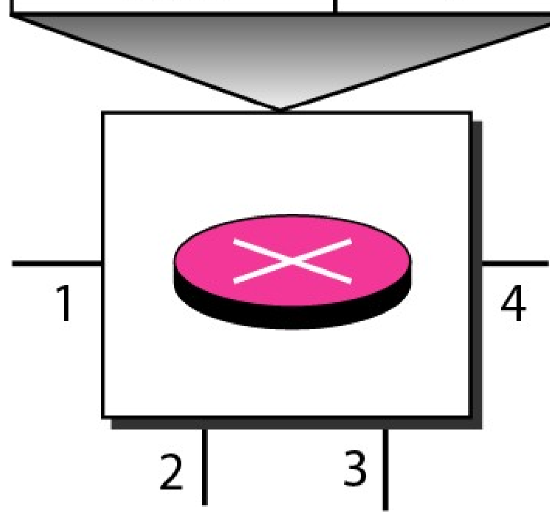
- ✓ The resource allocation is done on a first come, first-served basis.
- ✓ When a switch receives a packet, no matter what is the source or destination, the packet must wait if there are other packets being processed.
- ✓ In a datagram network, each packet is treated independently of all others.
- ✓ Even if a packet is part of a multi packet transmission, the network treats it as though it existed alone.
- ✓ Packets in this approach are referred to as datagram.

Module 1: *Switching:*



A datagram network with four switches (routers)

Destination address	Output port
1232	1
4150	2
⋮	⋮
9130	3



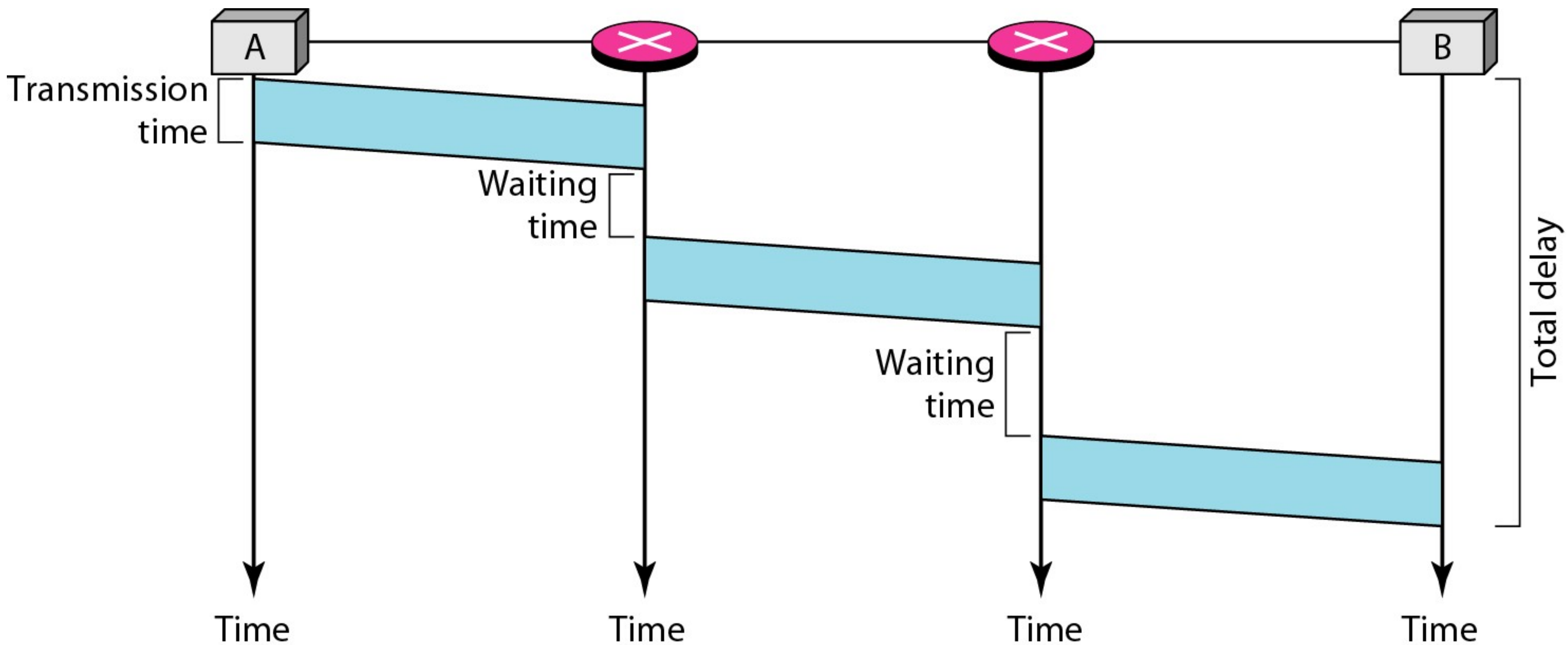
Routing table in a datagram network

Module 1: *Switching:*

- ✓ A switch in a datagram network uses a routing table that is based on the destination address.
- ✓ The destination address in the header of a packet in a datagram network remains the same during the entire journey of the packet.

Delay

Although there are no setup and teardown phases, each packet may experience a wait at a switch before it is forwarded.



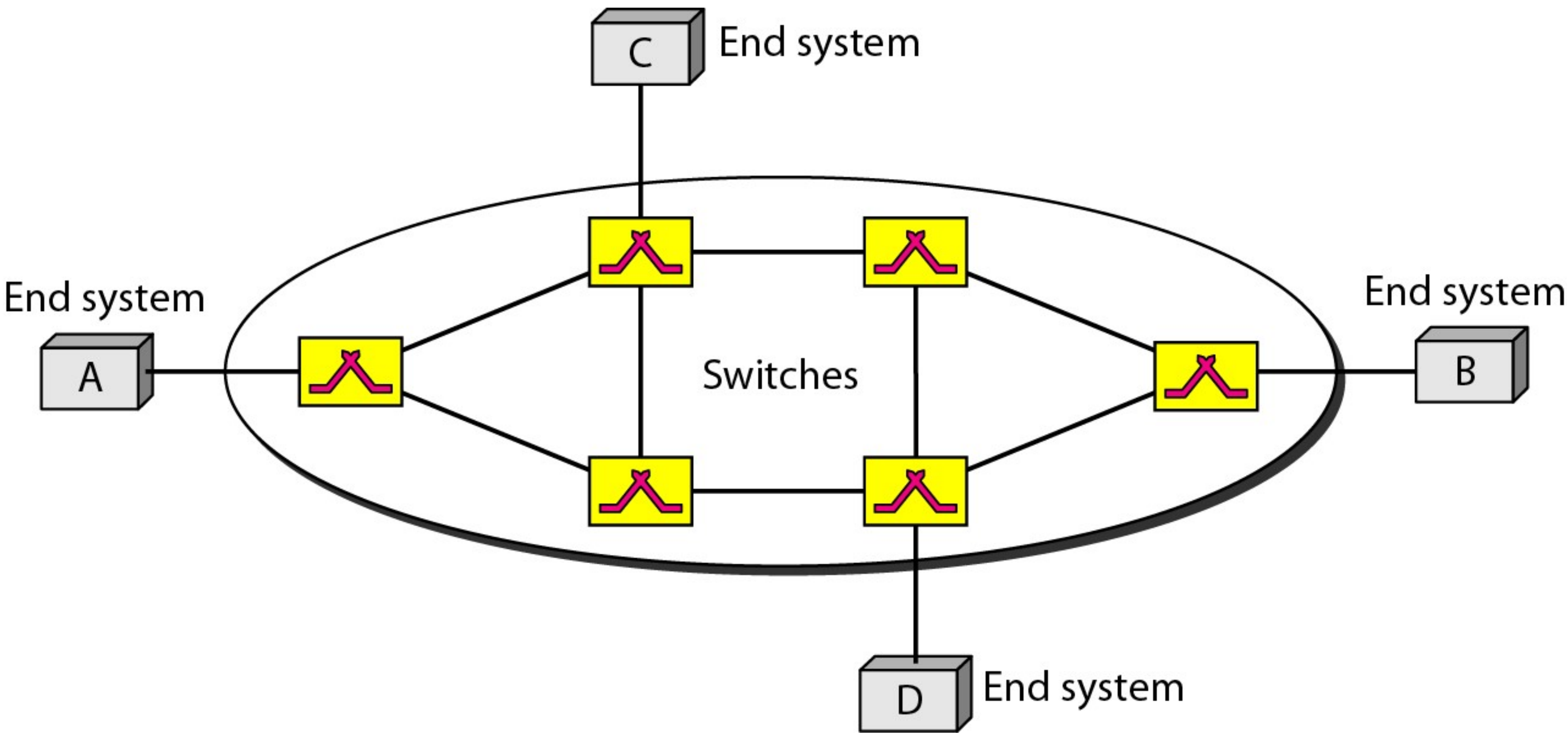
Switching in the Internet is done by using the datagram approach to packet switching at the network layer.

Efficiency

The efficiency of a datagram network is better than that of a circuit-switched network.
Resources are allocated only when there are packets to be transferred.

virtual-circuit network

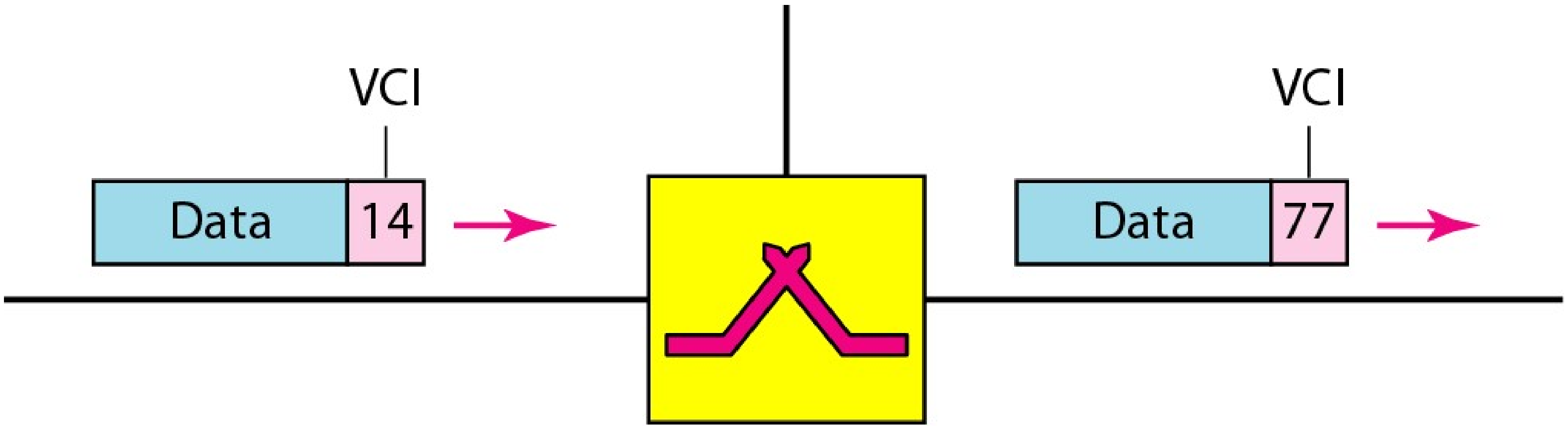
- ✓ A virtual-circuit network is a cross between a circuit-switched network and a datagram network.



Addressing

- ✓ Two types of addressing are involved in VCN: **global** and **local**(virtual-circuit identifier).
- ✓ ***Global Addressing***: *A source or a destination needs to have a global address(an address with network scope)*
- ✓ ***Virtual-Circuit Identifier(VCI):*** Identifier that is actually used for data transfer. It has local scope.
- ✓ When a frame arrives at a switch, it has a VCI; when it leaves, it has a different VCl.

Module 1: *Switching:*



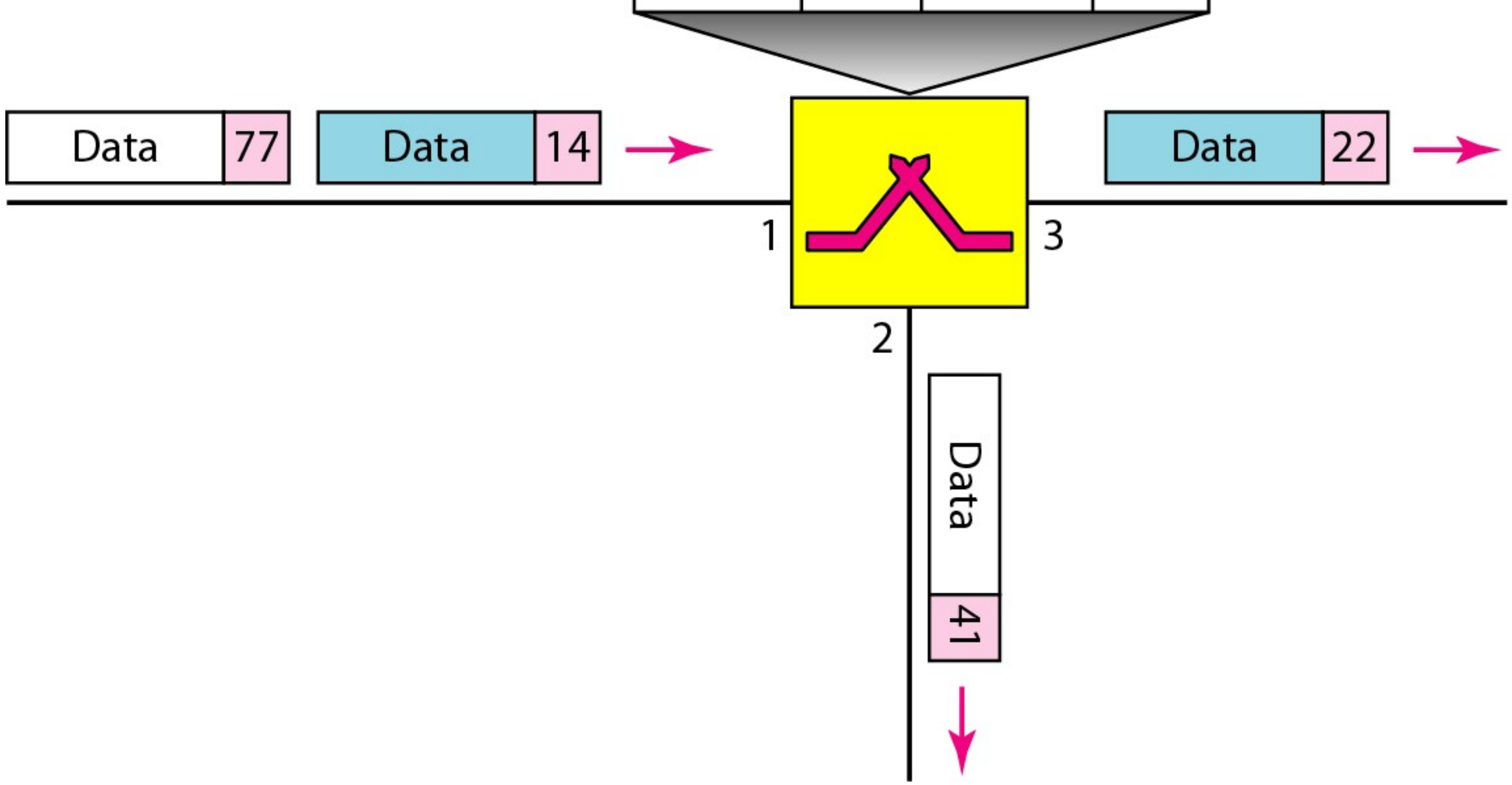
Virtual-circuit identifier

Phases

- ✓ **Setup phase** : In the setup phase, the source and destination use their global addresses to help switches make table entries for the connection.
- ✓ **Data transfer phase**: transfer data
- ✓ **Teardown phase**: In the teardown phase, the source and destination inform the switches to delete the corresponding entry

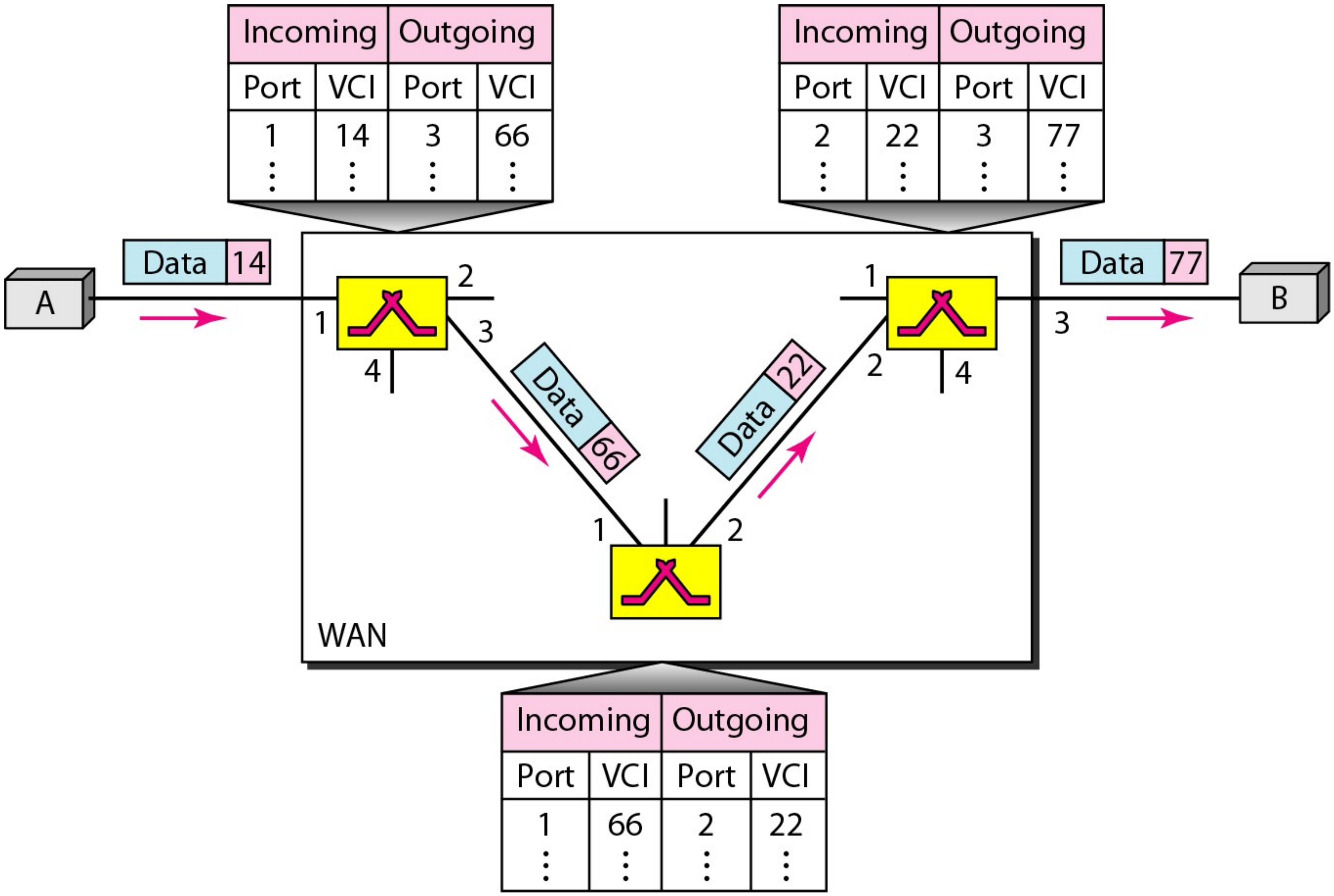
Module 1: *Switching:*

Incoming		Outgoing	
Port	VCI	Port	VCI
1	14	3	22
1	77	2	41



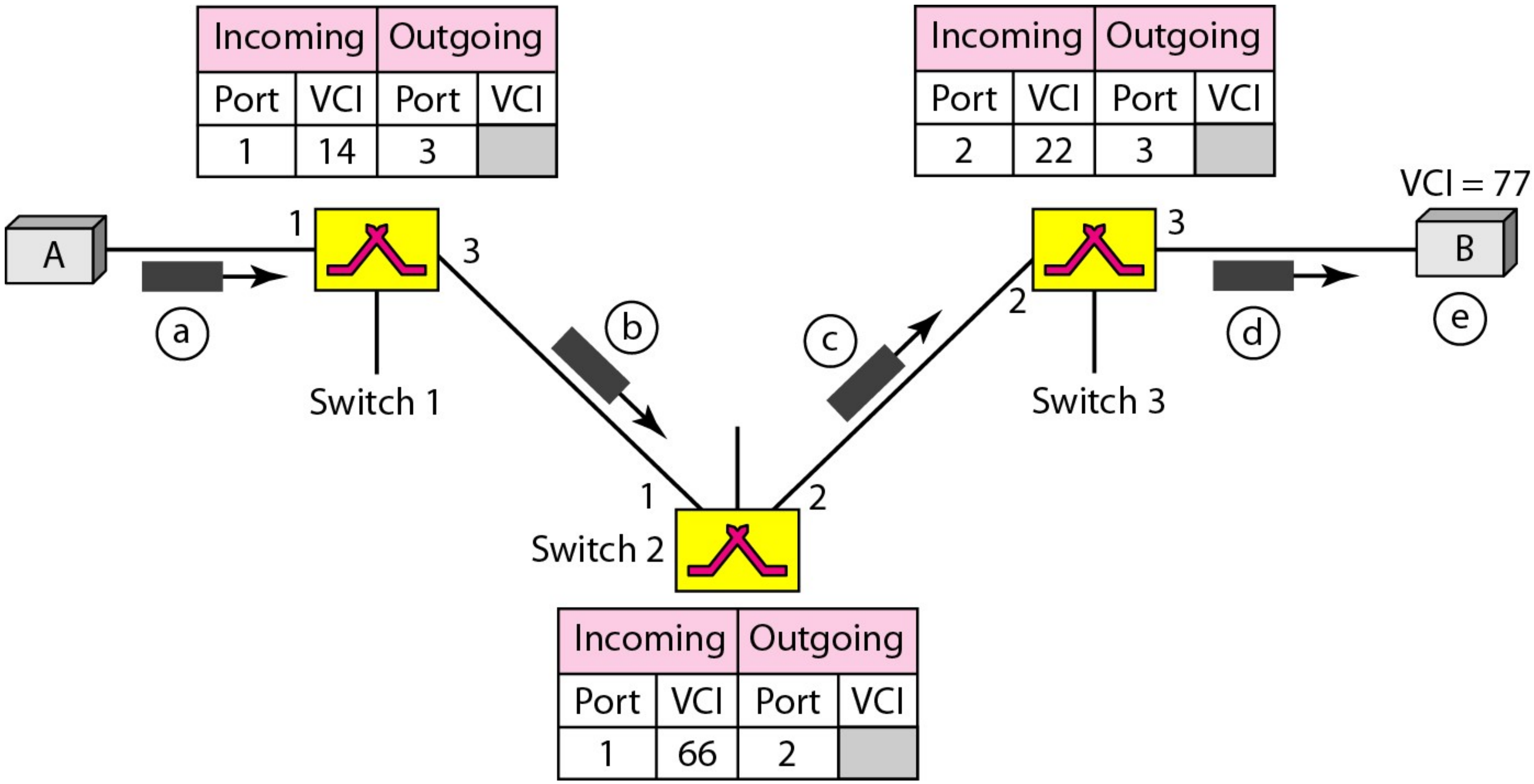
Switch and tables in a virtual-circuit network

Module 1: *Switching:*

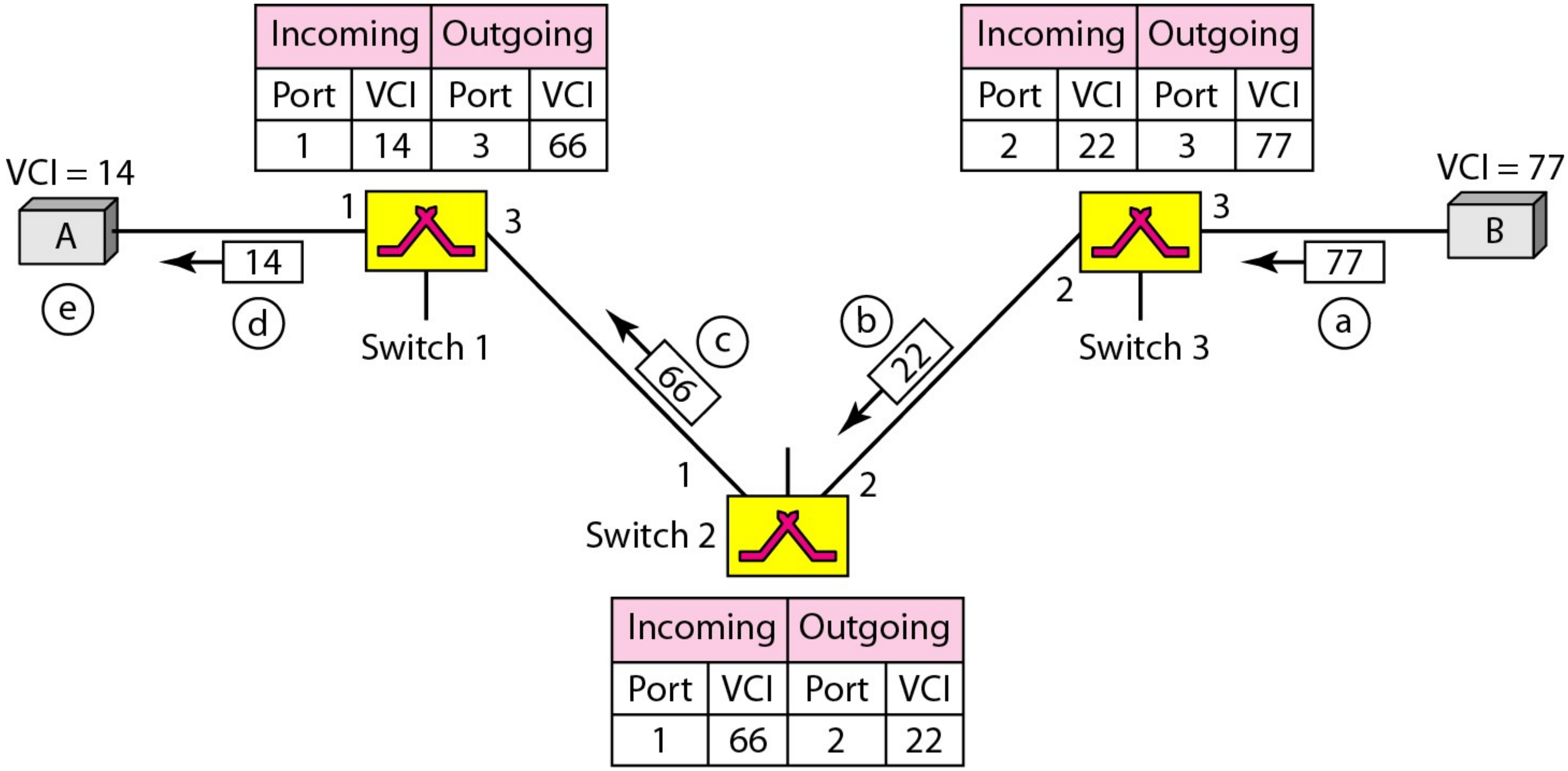


Source-to-destination data transfer in a virtual-circuit network

Module 1: *Switching:*



Setup request in a virtual-circuit network



Switch 1:

Incoming		Outgoing	
Port	VCI	Port	VCI
1	14	3	66

Switch 3:

Incoming		Outgoing	
Port	VCI	Port	VCI
2	22	3	77

Switch 2:

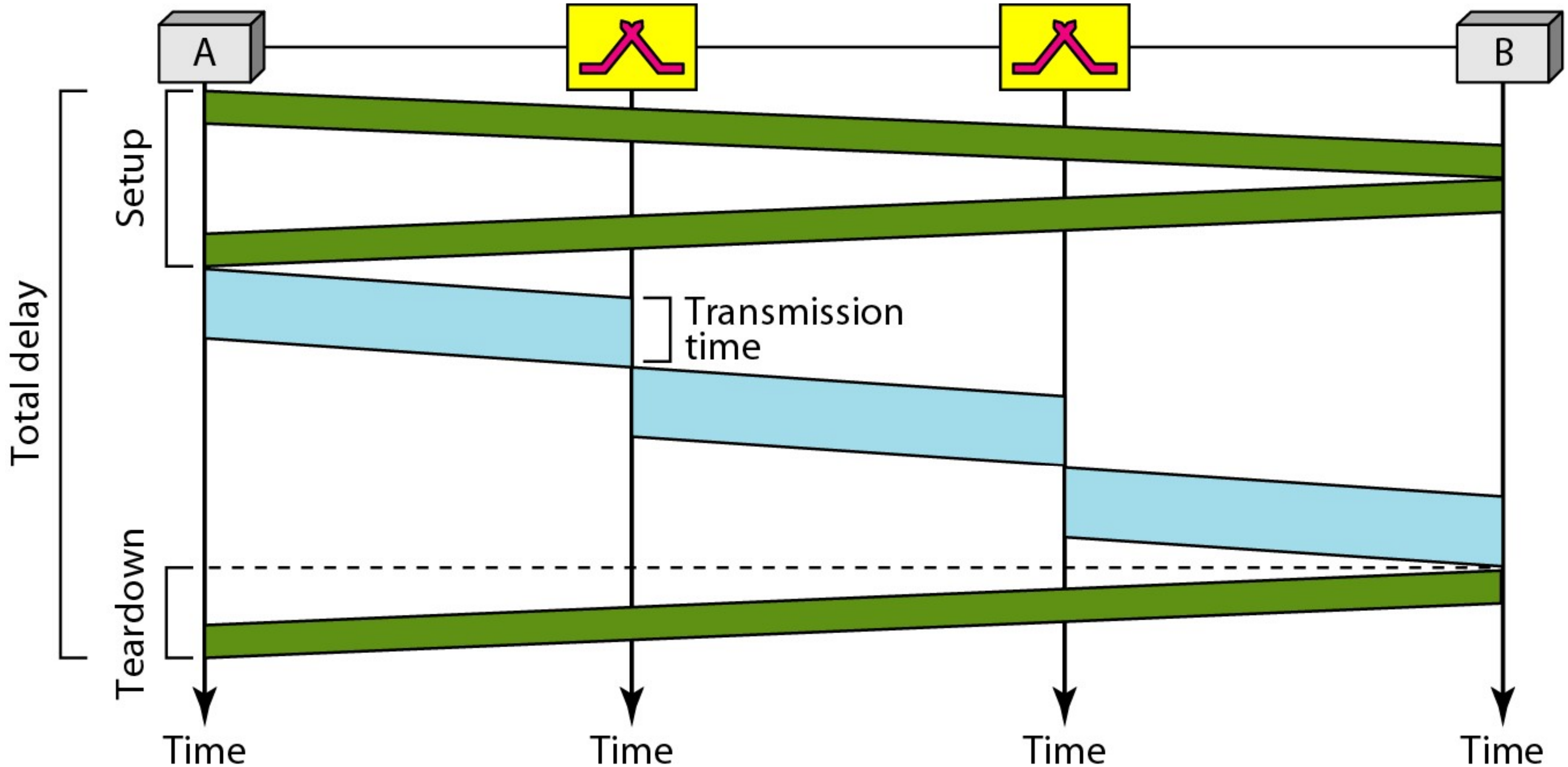
Incoming		Outgoing	
Port	VCI	Port	VCI
1	66	2	22

Setup acknowledgment in a virtual-circuit network

Module 1: *Switching:*

In virtual-circuit switching, all packets belonging to the same source and destination travel the same path; but the packets may arrive at the destination with different delays if resource allocation is on demand.

Module 1: *Switching:*



Delay in a virtual-circuit network

Module 1: *Switching:*

Switching at the data link layer in a switched WAN is normally implemented by using virtual-circuit techniques.