

18CSS202J- COMPUTER COMMUNICATION

UNIT 3

Course Objective:

The purpose of learning this course is to

- Understand the basic services and concepts related to Internetwork
- Understand the layered network architecture
- Acquire knowledge in IP addressing
- Exploring the services and techniques in physical layer
- Understand the functions of Data Link layer
- Implement and analyze the different Routing Protocols

Course Outcomes (CO):

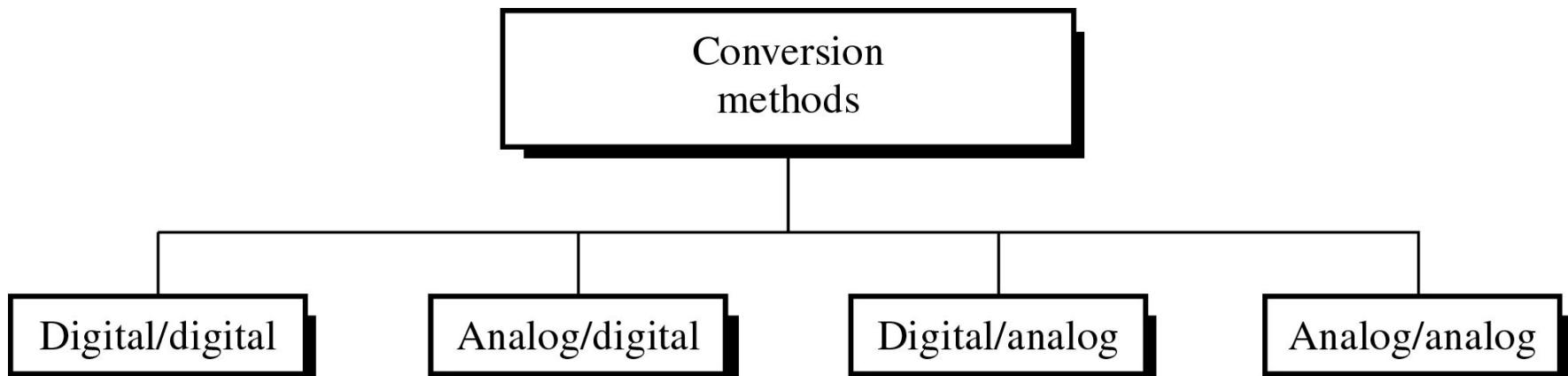
At the end of this course, learners will be able to

1. Apply the knowledge of communication
2. Identify and design the network topologies
3. Design the network using addressing schemes
4. Identify and correct the errors in transmission
5. Identify the guided and unguided transmission media
6. Implement the various Routing Protocols

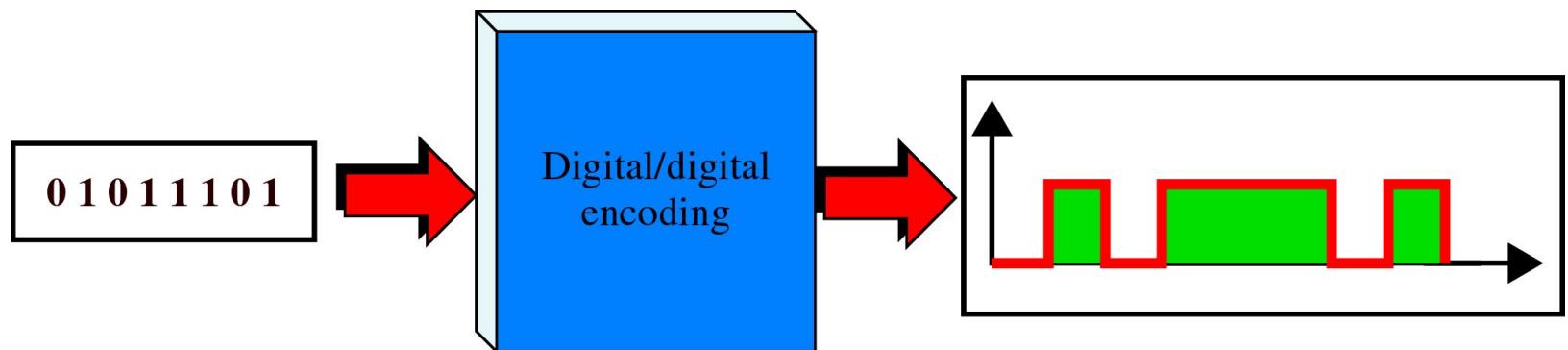
TOPICS TO BE LEARNED:

- **Session 1:** Line Coding Schemes: Unipolar, Polar and Bipolar.
- **Session 2:** Amplitude Shift Keying Technique, Frequency Shift Keying Technique and Phase Shift Keying Technique, Pulse Code Modulation, Delta Modulation
- **Session 5:** Multiplexing: Frequency Division Multiplexing(FDM)
- **Session 6:** Time Division Multiplexing(TDM), Wavelength Division Multiplexing(WDM)
- **Session 9 :** Guided Media: Twisted pair, coaxial and Fiber optic cables, Unguided Media: Radio waves.
- **Session 10:** Microwaves and Infrared.

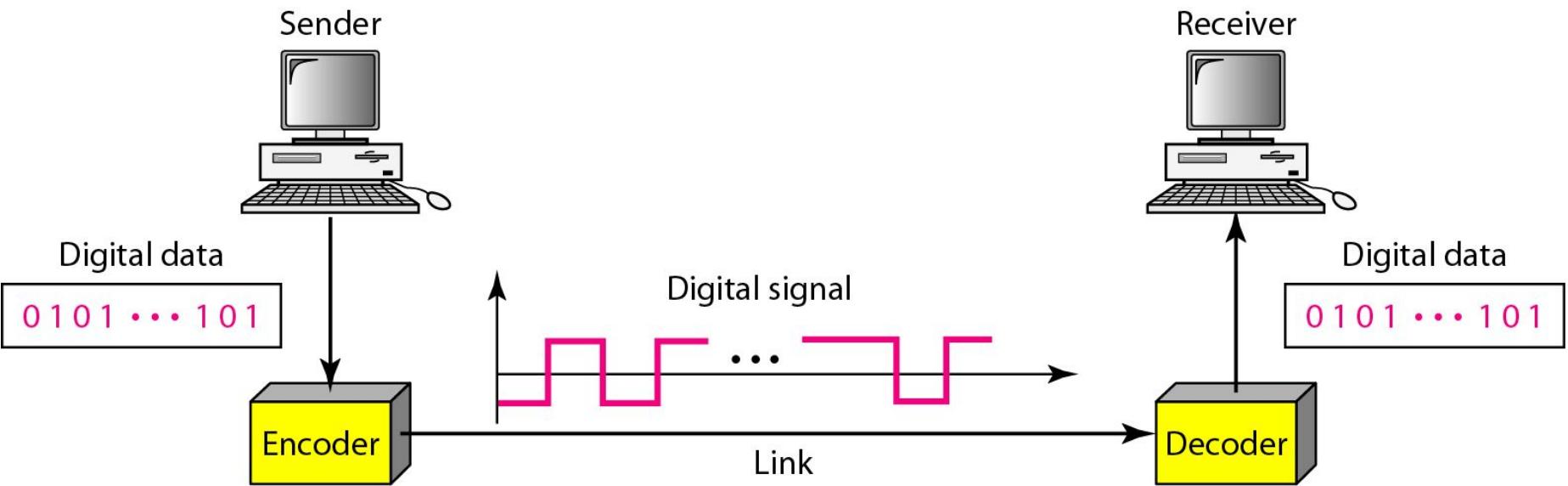
Different Conversion Schemes



Digital to Digital Encoding



Line coding and decoding



DIGITAL-TO-DIGITAL CONVERSION -LINE CODING

Data can be either digital or analog. Signals that represent data can also be digital or analog. In this section, we see how we can represent digital data by using digital signals.

The conversion involves three techniques:

- LINE CODING**
- BLOCK CODING**
- SCRAMBLING.**

Line coding is always needed; block coding and scrambling may or may not be needed.

Line coding is used to convert digital data to a digital signal.

Line Coding

- **Line coding** is the process of converting digital data to digital signals
- Converting a string of 1's and 0's (digital data) into a sequence of signals that denote the 1's and 0's.
- For example a high voltage level (+V) could represent a “1” and a low voltage level (0 or -V) could represent a “0”.

Characteristics of different line coding schemes

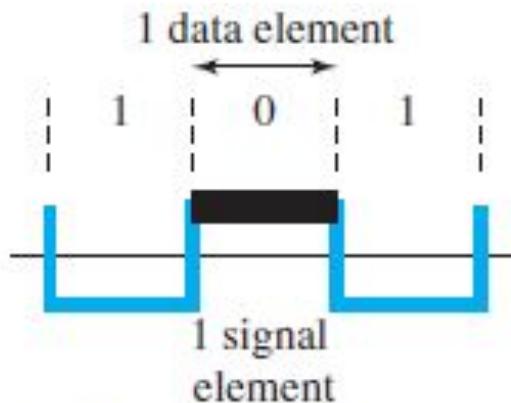
1. *Signal Element Versus Data Element*

A data element is the smallest entity that can represent a piece of information: this is the bit. In digital data communications, a signal element carries data elements.

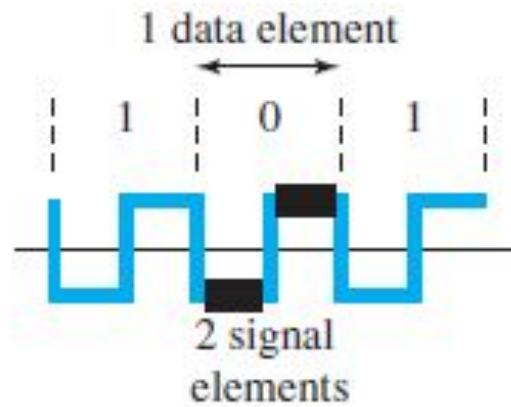
Data elements ☐ what we need to send
Signal elements ☐ what we can send.

Data elements are being carried; signal elements are the carriers.

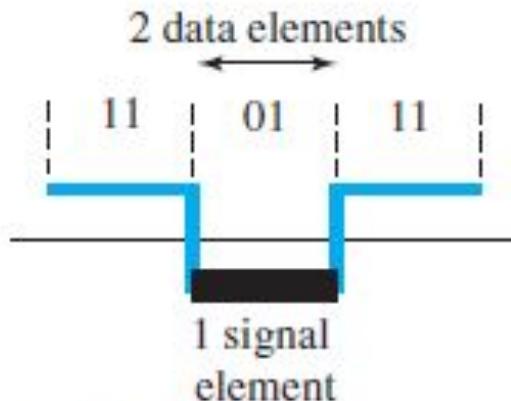
The ratio represented by r is defined as the number of data elements carried by each signal element



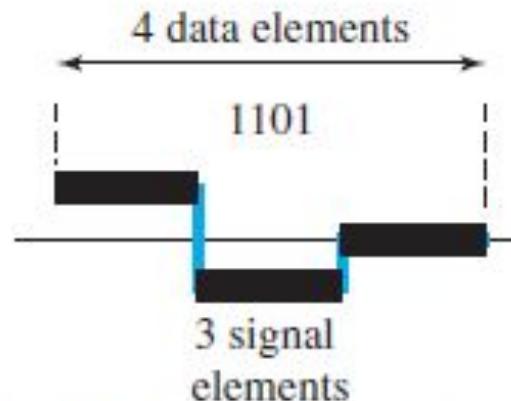
a. One data element per one signal element ($r = 1$)



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



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



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

Data Rate Versus Signal Rate

- The **data rate** defines the number of data elements (bits) sent in 1s. The unit is bits per second (bps).
- The **signal rate** is the number of signal elements sent in 1s. The unit is the baud.
- The data rate is sometimes called the **bit rate**; the signal rate is sometimes called the **pulse rate**, the **modulation rate**, or the **baud rate**.

Data Rate Versus Signal Rate (Contd....)

- One goal in data communications is to increase the data rate while decreasing the signal rate.
- Increasing the data rate increases the speed of transmission; decreasing the signal rate decreases the bandwidth requirement.
- the relationship between data rate (N) and signal rate (S)

$$S = N/r$$

the average signal rate is defined as

$$\text{Save} = c \times N \times (1/r) \text{ baud}$$

C - case factor

Mapping Data symbols onto Signal levels

- A data symbol (or element) can consist of a number of data bits:
 - 1 , 0 or
 - 11, 10, 01,
- A data symbol can be coded into a single signal element or multiple signal elements
 - 1 -> +V, 0 -> -V
 - 1 -> +V and -V, 0 -> -V and +V
- The ratio ‘r’ is the number of data elements carried by a signal element.

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

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

Example

The maximum data rate of a channel (see Chapter 3) is $N_{max} = 2 \times B \times \log_2 L$ (defined by the Nyquist formula). Does this agree with the previous formula for N_{max} ?

Solution:

A signal with L levels actually can carry $\log_2 L$ bits per level. If each level corresponds to one signal element and we assume the average case ($c = 1/2$), then we have

$$N_{max} = \frac{1}{c} \times B \times r = 2 \times B \times \log_2 L$$

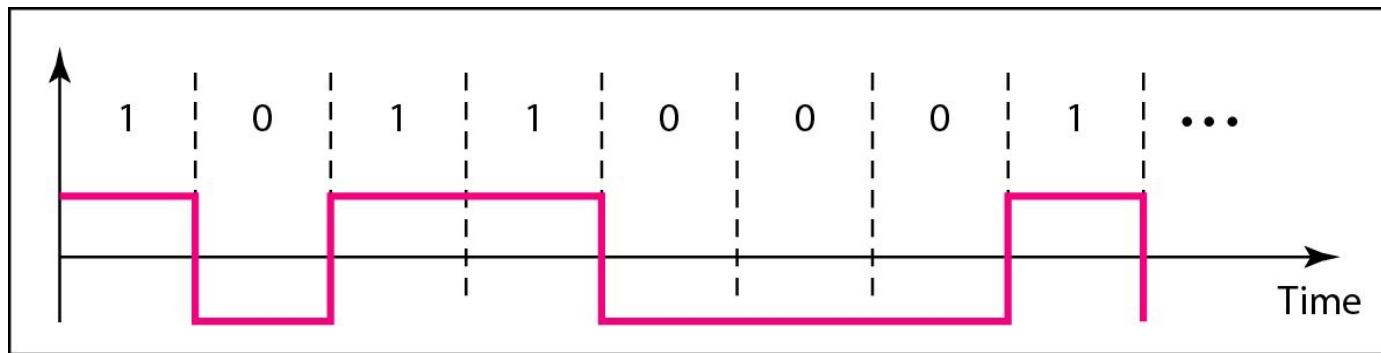
Considerations for choosing a good signal element referred to as line encoding

- **Baseline wandering** - a receiver will evaluate the average power of the received signal (called the baseline) and use that to determine the value of the incoming data elements. If the incoming signal does not vary over a long period of time, the baseline will drift and thus cause errors in detection of incoming data elements.
- A good line encoding scheme will prevent long runs of fixed amplitude.

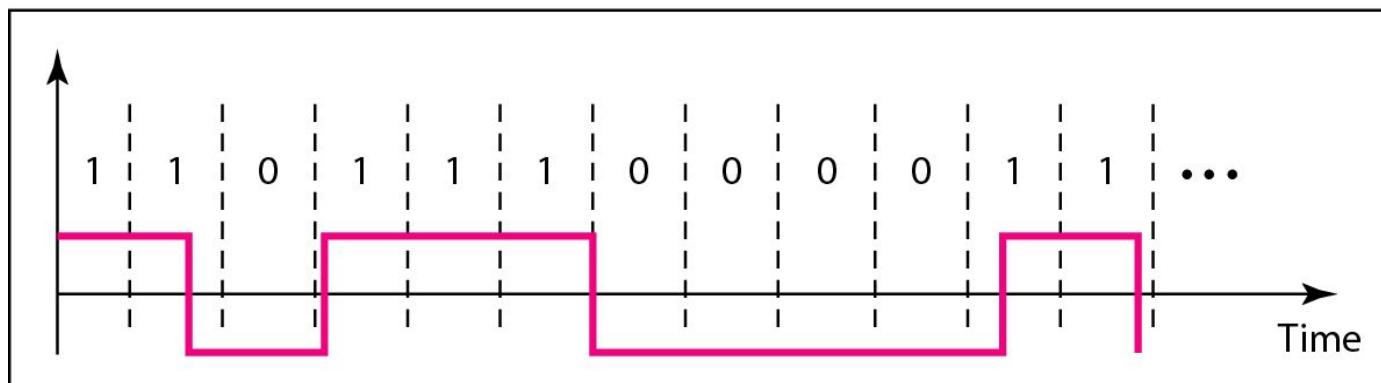
Line encoding characteristics

- **DC components** - when the voltage level remains constant for long periods of time, there is an increase in the low frequencies of the signal. Most channels are bandpass and may not support the low frequencies.
 - This will require the removal of the dc component of a transmitted signal.
- **Self synchronization** - the clocks at the sender and the receiver must have the same bit interval.
- If the receiver clock is faster or slower it will misinterpret the incoming bit stream.

Figure 4.3 Effect of lack of synchronization



a. Sent



b. Received

Example 4.3

In a digital transmission, the receiver clock is 0.1 percent faster than the sender clock. How many extra bits per second does the receiver receive if the data rate is 1 kbps? How many if the data rate is 1 Mbps?

At 1 kbps, the receiver receives 1001 bps instead of 1000 bps.

1000 bits sent

1001 bits received

1 extra bps

At 1 Mbps, the receiver receives 1,001,000 bps instead of 1,000,000 bps.

1,000,000 bits sent

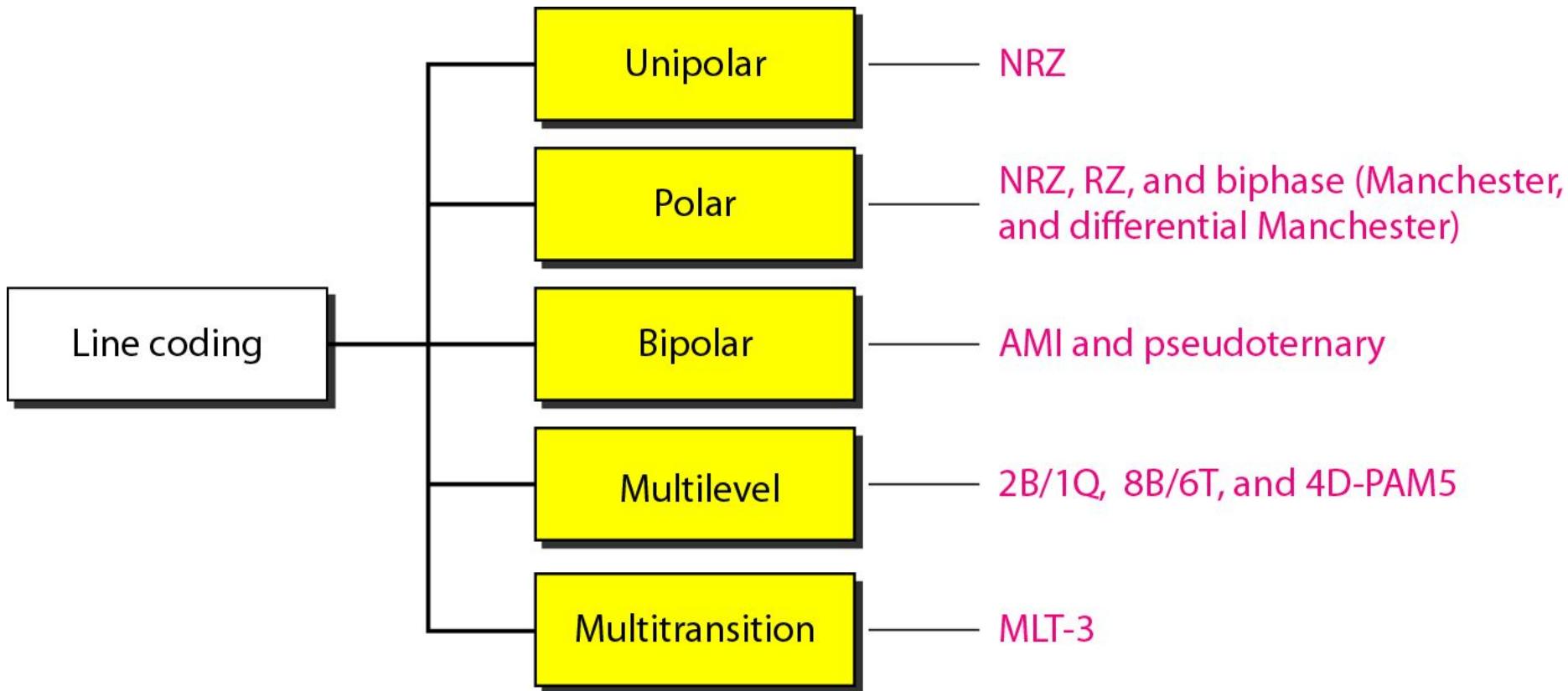
1,001,000 bits received

1000 extra bps

Line encoding characteristics

- **Error detection** - errors occur during transmission due to line impairments.
 - Some codes are constructed such that when an error occurs it can be detected.
- **Noise and interference** - there are line encoding techniques that make the transmitted signal “immune” to noise and interference.
 - This means that the signal cannot be corrupted, it is stronger than error detection.

Figure *Line coding schemes*

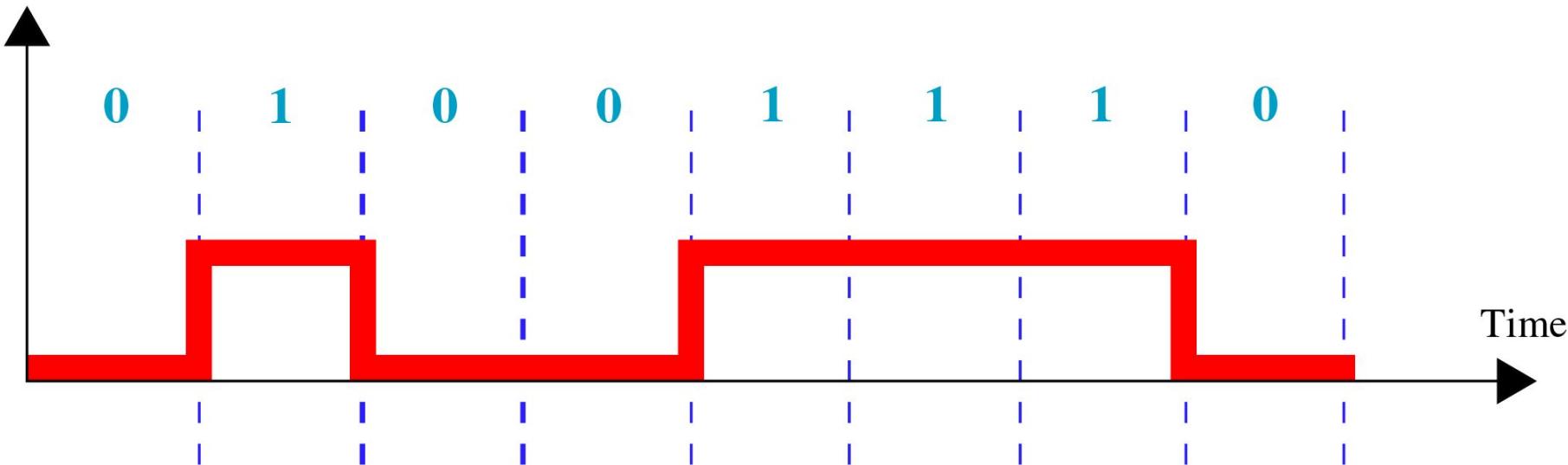


Unipolar

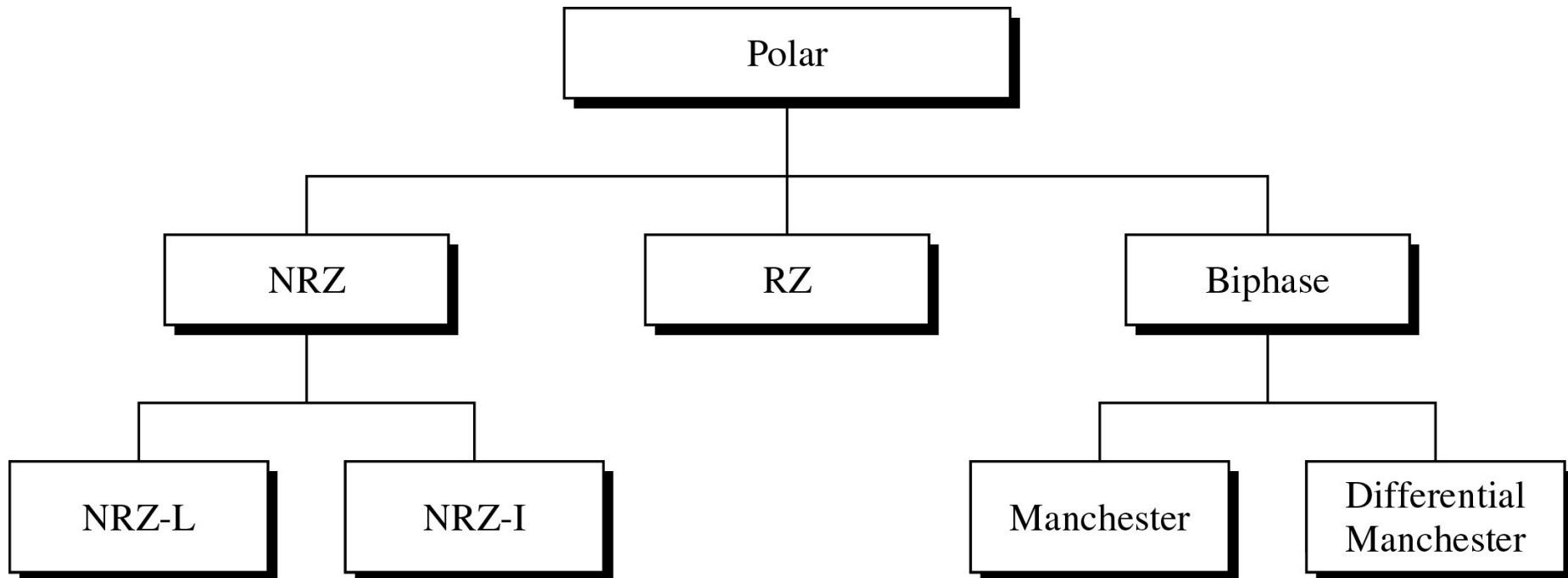
- All signal levels are on one side of the time axis , either above or below.
- +v define 1 and –v define 0.
- NRZ - Non Return to Zero scheme is an example of this code. The signal level does not return to zero at a middle of the bit.
- Scheme is prone to baseline wandering and DC components. It has no synchronization or any error detection. It is simple but costly in power consumption.

Unipolar Encoding

Amplitude



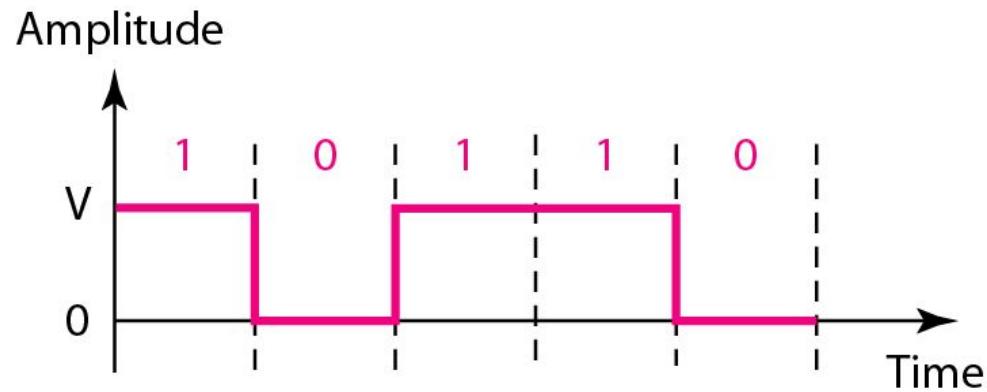
Types of Polar Encoding



Polar - NRZ

- The voltages are on both sides of the time axis.
- Polar NRZ scheme can be implemented with two voltages.
E.g. +V for 0 and -V for 1.
- There are two versions:
 - NZR - Level (NRZ-L) - positive voltage for one symbol and negative for the other
 - NRZ - Inversion (NRZ-I) - the change or lack of change in polarity determines the value of a symbol. E.g. a “1” symbol inverts the polarity a “0” does not.

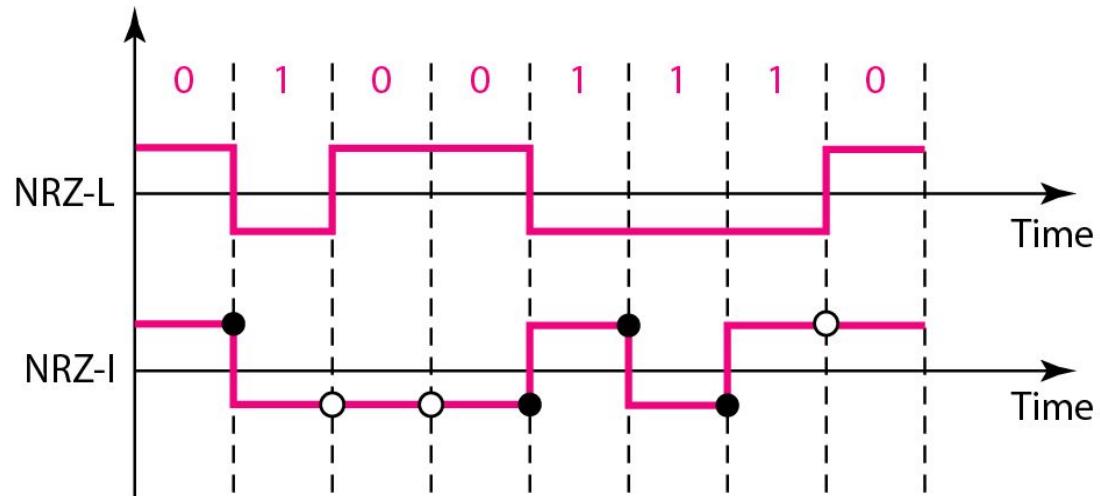
Unipolar NRZ scheme



$$\frac{1}{2}V^2 + \frac{1}{2}(0)^2 = \frac{1}{2}V^2$$

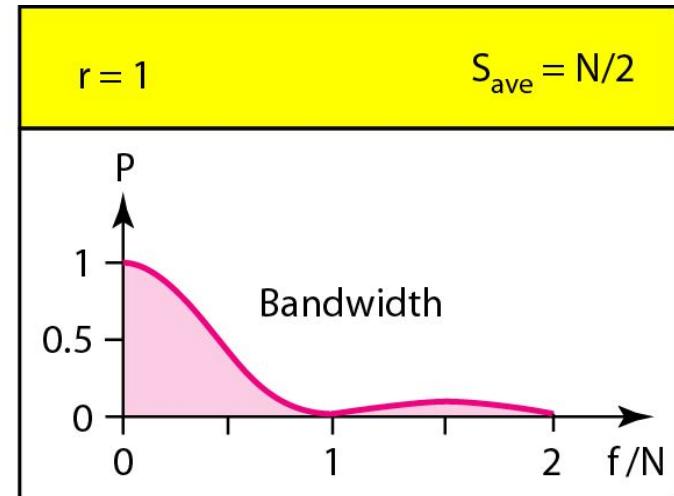
Normalized power

Polar NRZ-L and NRZ-I schemes



○ No inversion: Next bit is 0

● Inversion: Next bit is 1



Not e

In NRZ-L the level of the voltage determines the value of the bit.

In NRZ-I the inversion or the lack of inversion determines the value of the bit.

NRZ-L and NRZ-I both have an average signal rate of $N/2$ Bd.

Not

e

NRZ-L and NRZ-I both have a DC component problem and baseline wandering, it is worse for NRZ-L. Both have no self synchronization & no error detection. Both are relatively simple to implement.

Example

A system is using NRZ-I to transfer 10-Mbps data. What are the average signal rate and minimum bandwidth?

Solution

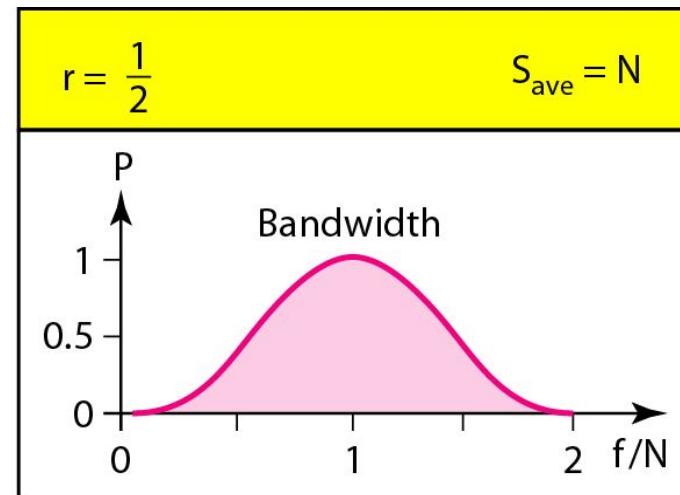
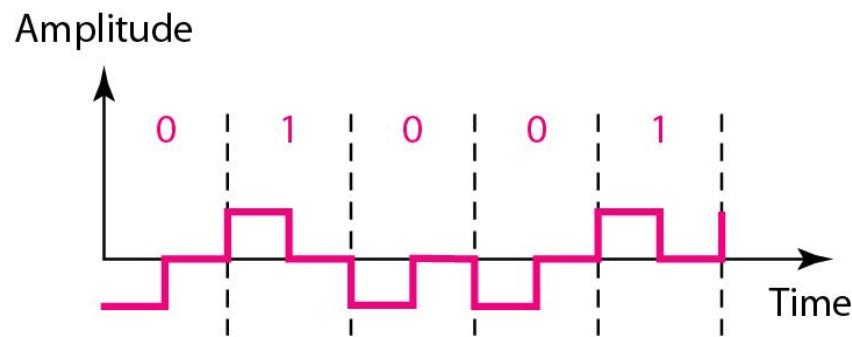
The average signal rate is $S = N / 2 = 500$ baud. The minimum bandwidth for this average baud rate is $B_{min} = S = 500$ kHz.

Note $c = 1/2$ for the avg. case as worst case is 1 and best case is 0

Polar - RZ

- The Return to Zero (RZ) scheme uses three voltage values. +, 0, -.
- Each symbol has a transition in the middle. Either from high to zero or from low to zero.
- This scheme has more signal transitions (two per symbol) and therefore requires a wider bandwidth.
- No DC components or baseline wandering.
- Not synchronized.
- More complex as it uses three voltage level. It has no error detection capability.

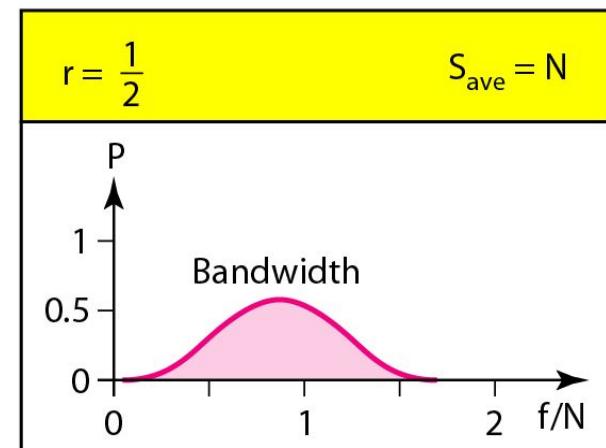
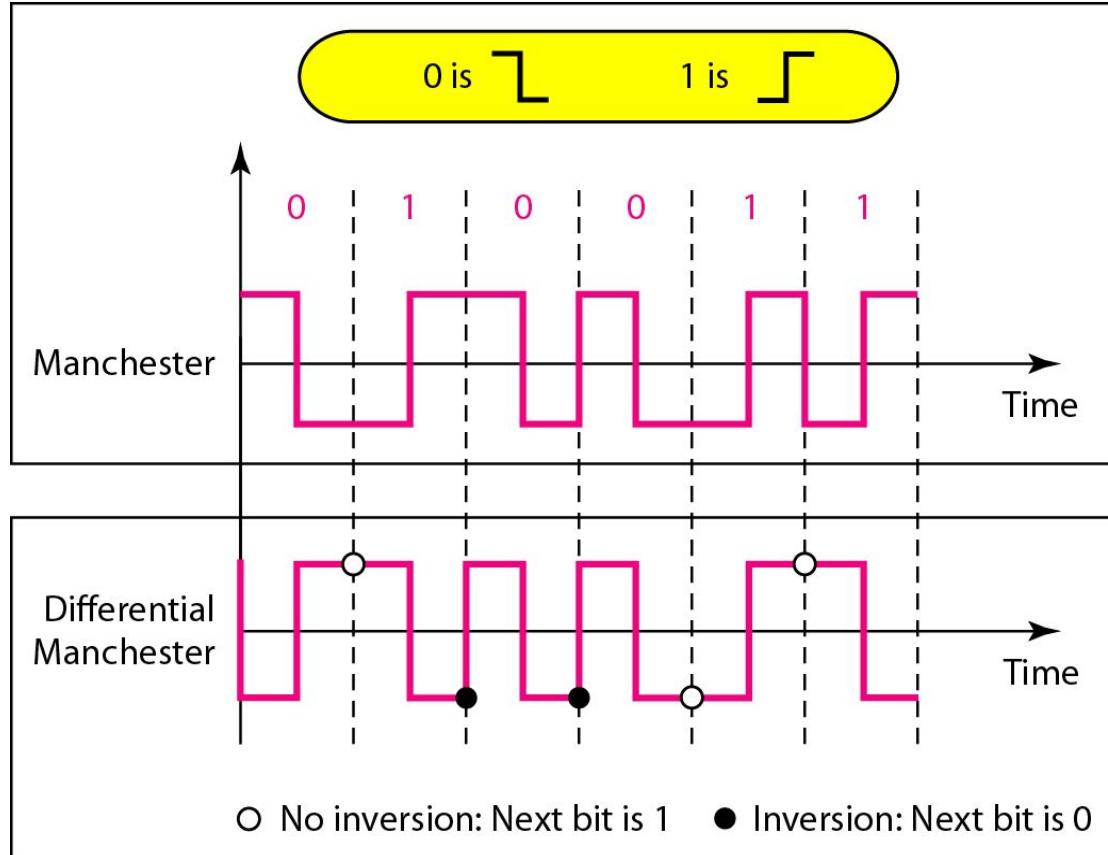
Polar RZ scheme



Polar - Biphase: Manchester and Differential Manchester

- **Manchester** coding consists of combining the NRZ-L and RZ schemes.
 - Every symbol has a level transition in the middle: from high to low or low to high. Uses only two voltage levels.
- **Differential Manchester** coding consists of combining the NRZ-I and RZ schemes.
 - Every symbol has a level transition in the middle. But the level at the beginning of the symbol is determined by the symbol value. One symbol causes a level change the other does not.

Polar biphasic: Manchester and differential Manchester schemes



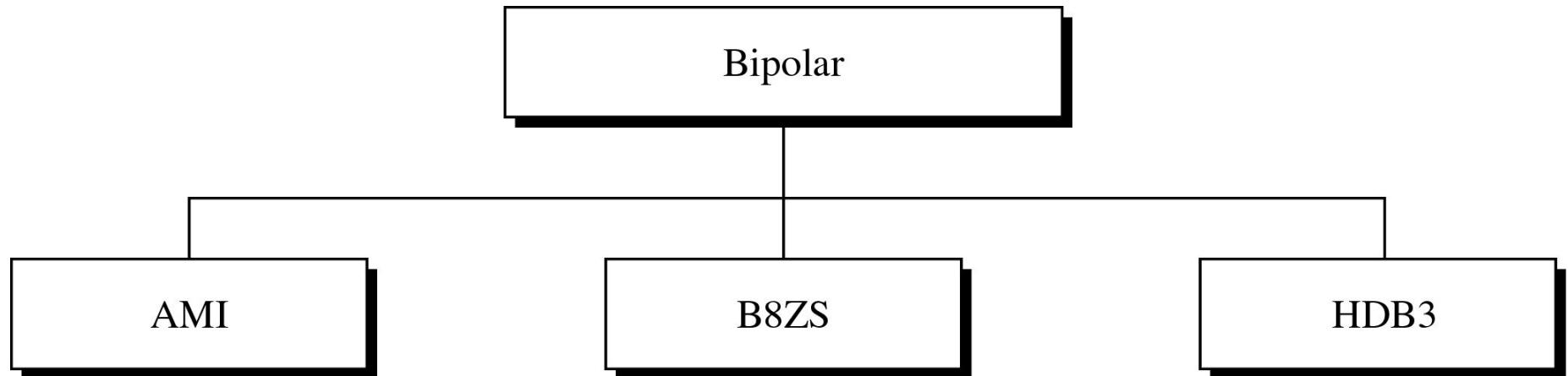
Not

e

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. There is no DC component and no baseline wandering. None of these codes has error detection.

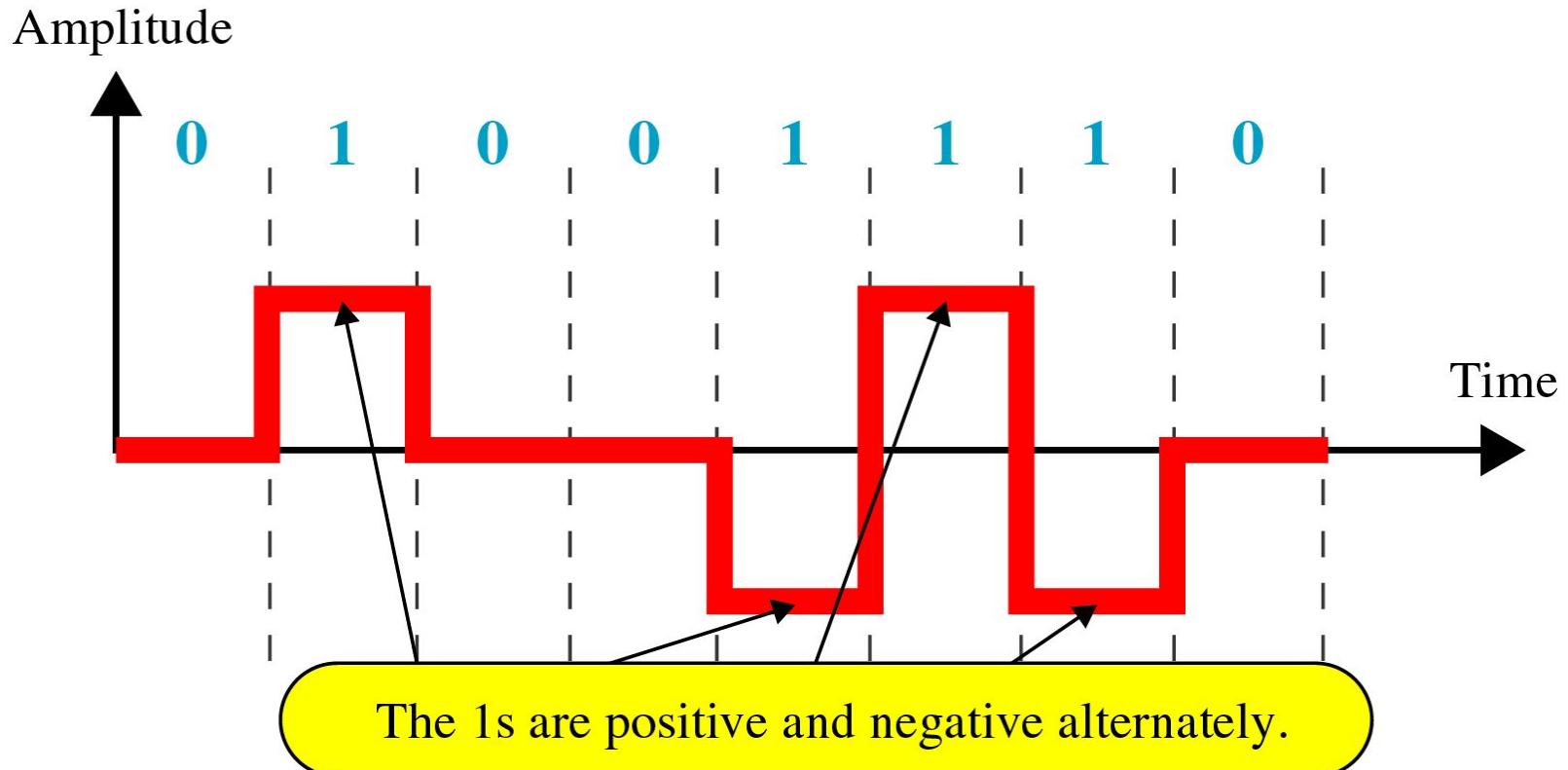
Types of Bipolar Encoding



Bipolar schemes

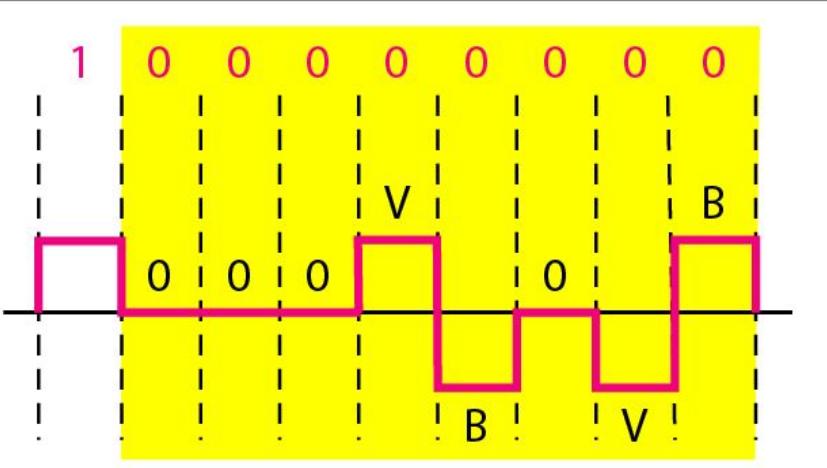
- In this scheme there are three voltage levels **positive, negative, and zero**. The voltage level for one data element is at zero, while the voltage level for the other element alternates between positive and negative.
- The bipolar scheme is an alternative to NRZ. This scheme has the same signal rate as NRZ, but there is no DC component as one bit is represented by voltage zero and other alternates every time.

Bipolar AMI Encoding

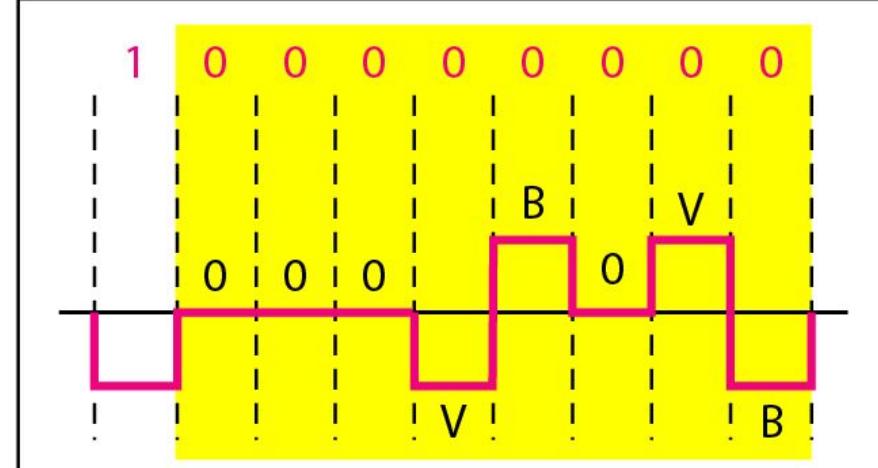


For example: B8ZS substitutes eight consecutive zeros with 000VB0VB.
The V stands for violation, it violates the line encoding rule
B stands for bipolar, it implements the bipolar line encoding rule

Figure 4.19 Two cases of B8ZS scrambling technique

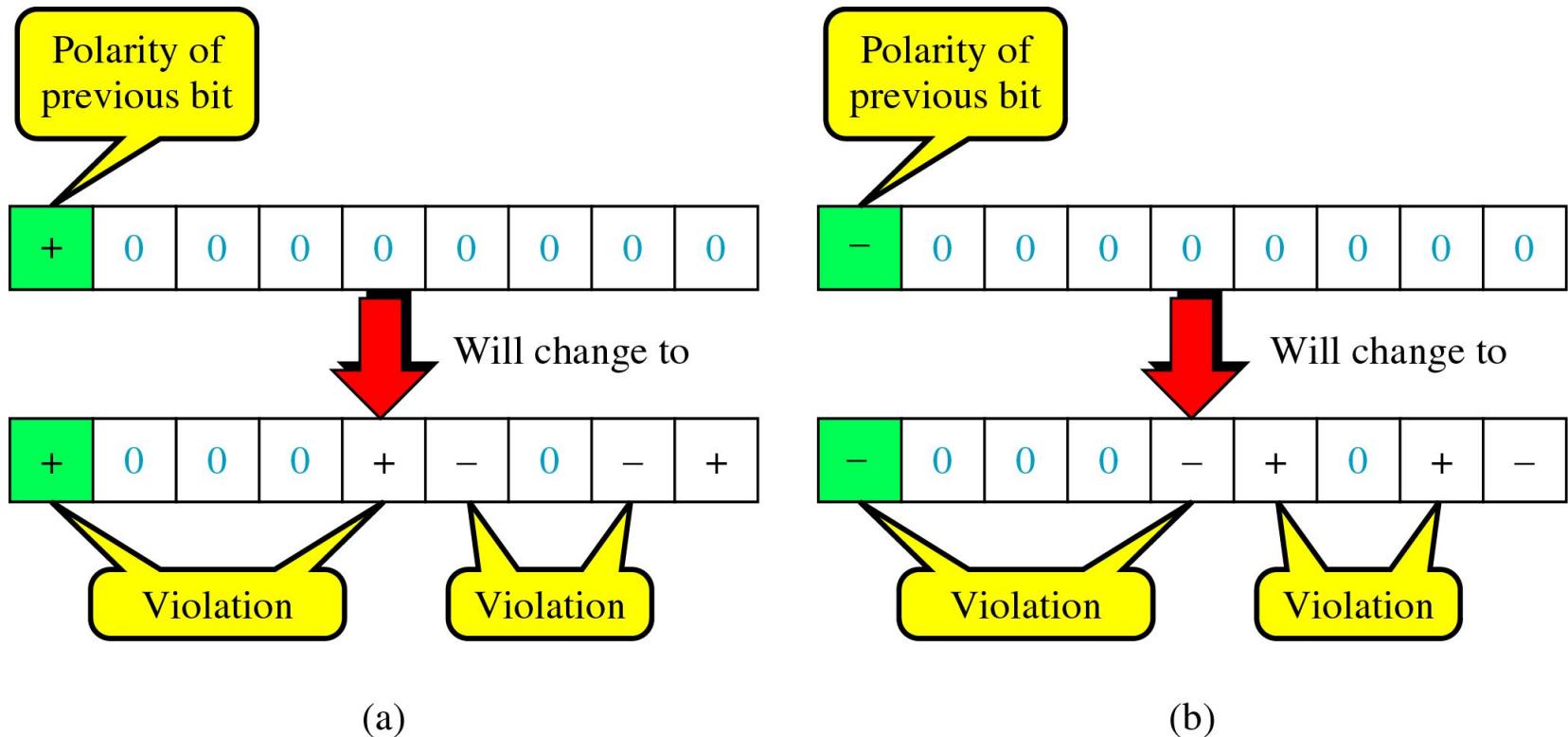


a. Previous level is positive.



b. Previous level is negative.

B8ZS Encoding

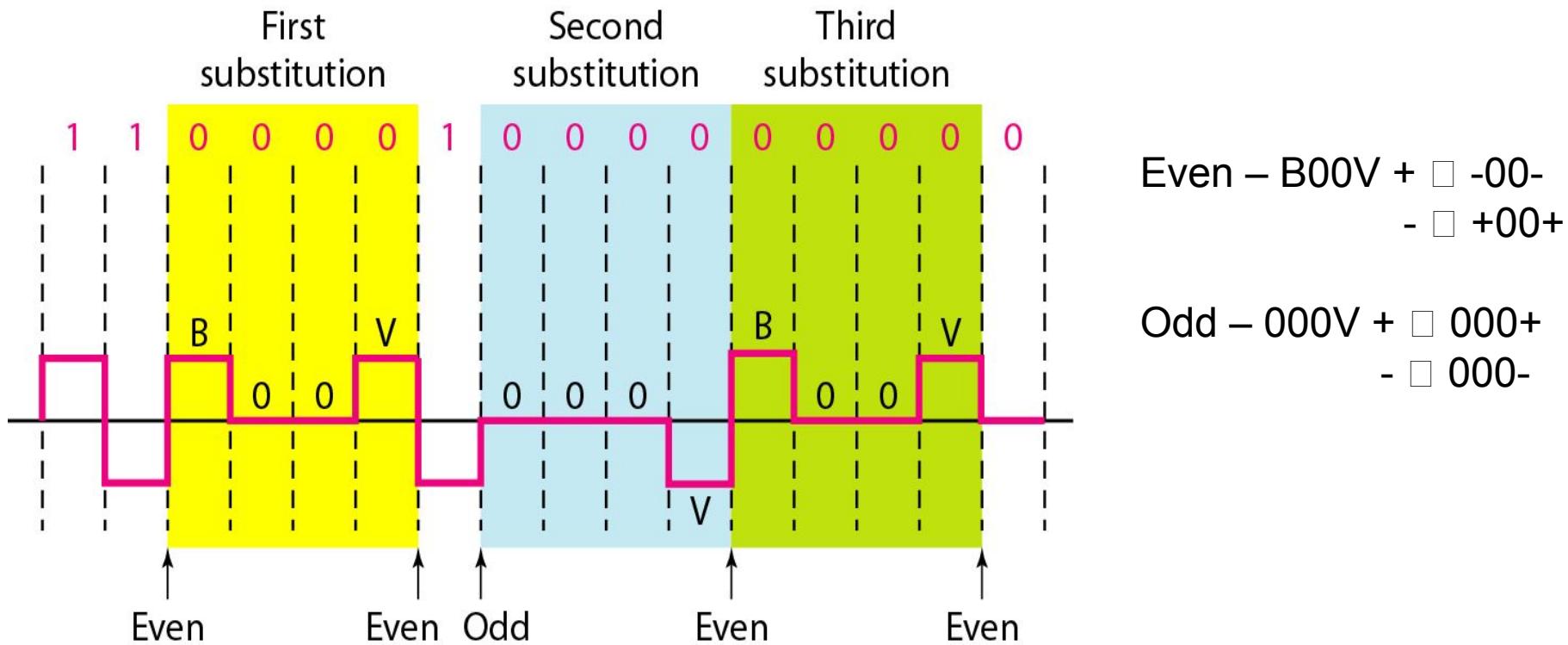


HDB3 substitutes four consecutive zeros with 000V or B00V depending on the number of nonzero pulses after the last substitution.

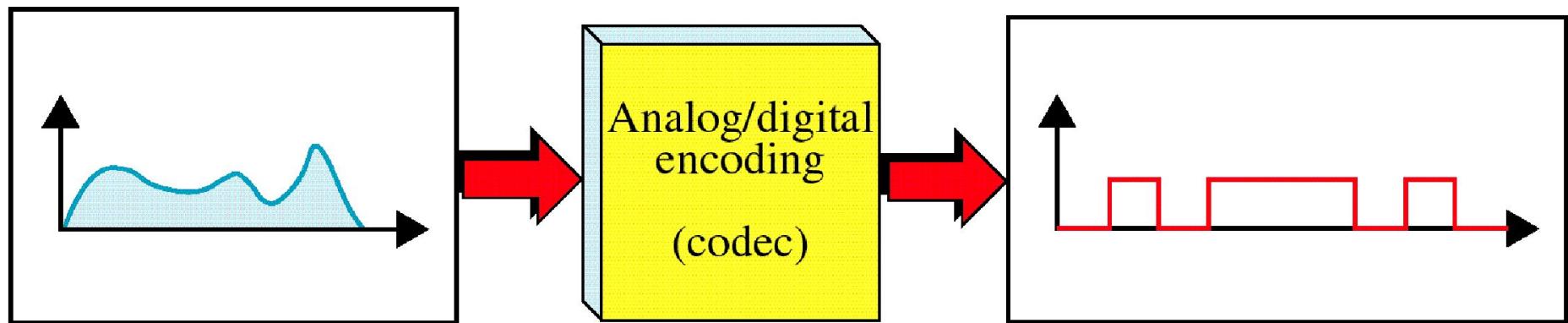
If # of non zero pulses is even the substitution is B00V to make total # of non zero pulse even.

If # of non zero pulses is odd the substitution is 000V to make total # of non zero pulses even.

Figure 4.20 *Different situations in HDB3 scrambling technique*



ANALOG TO DIGITAL CONVERSION



ANALOG-TO-DIGITAL CONVERSION

- *A digital signal is superior to an analog signal because it is more robust to noise and can easily be recovered, corrected and amplified. For this reason, the tendency today is to change an analog signal to digital data. In this section we describe two techniques, **pulse code modulation** and **delta modulation**.*

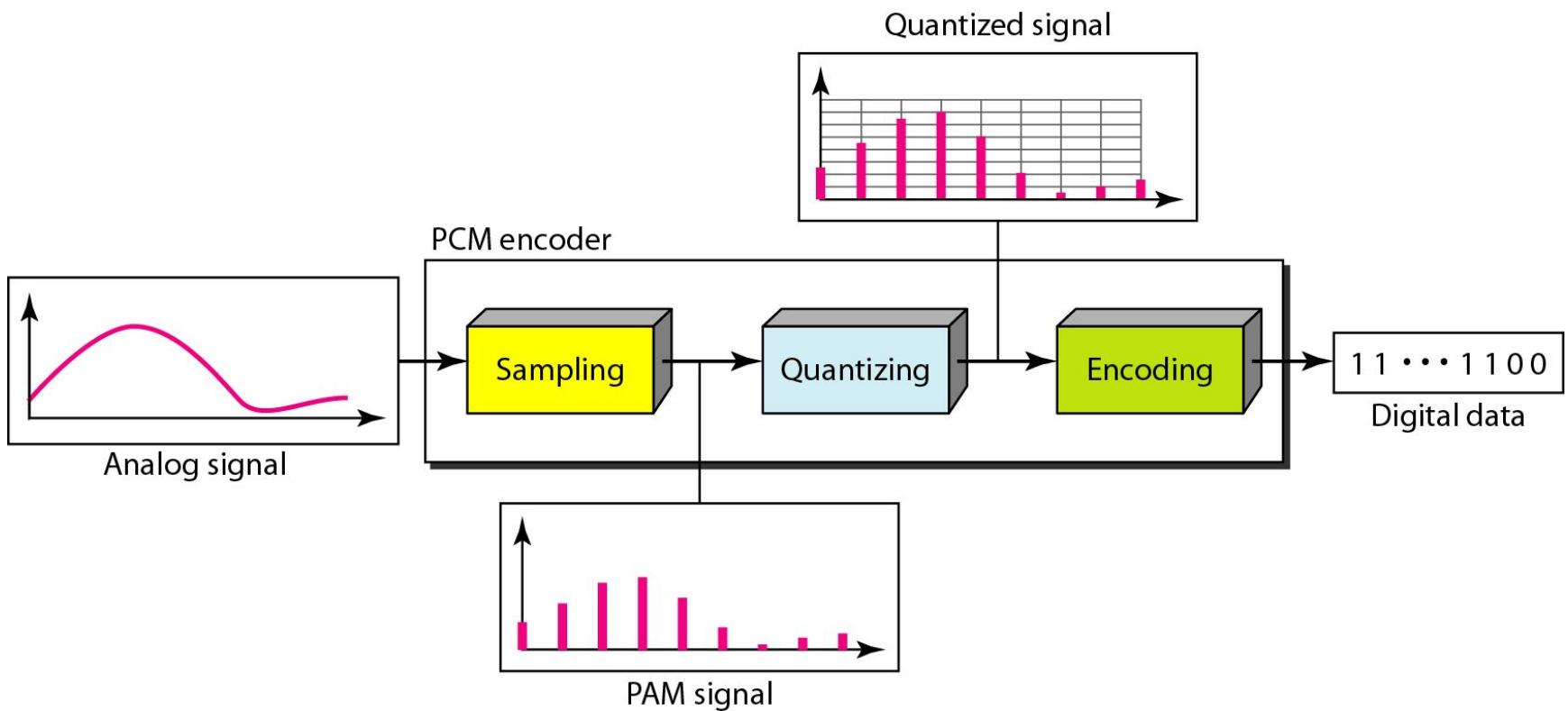
Topics discussed in this section:

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

PCM- Pulse Code Modulation

- PCM consists of three steps to digitize an analog signal:
 - 1. Sampling**
 - 2. Quantization**
 - 3. Binary encoding**
- Before we sample, we have to filter the signal to limit the maximum frequency of the signal as it affects the sampling rate.
- Filtering should ensure that we do not distort the signal, i.e. remove high frequency components that affect the signal shape.

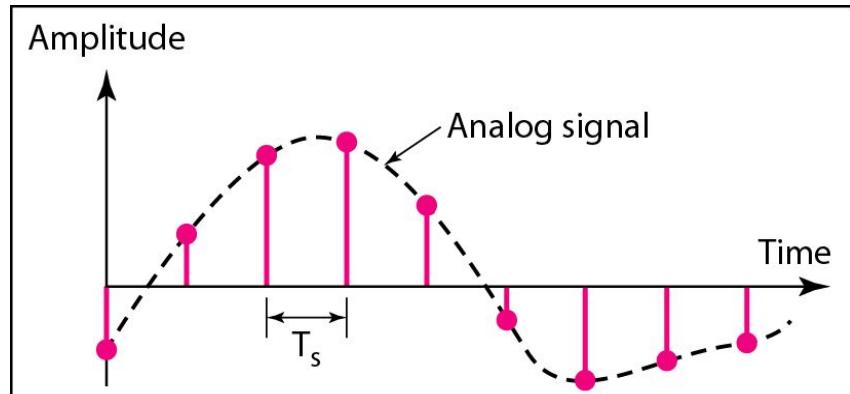
Components of PCM encoder



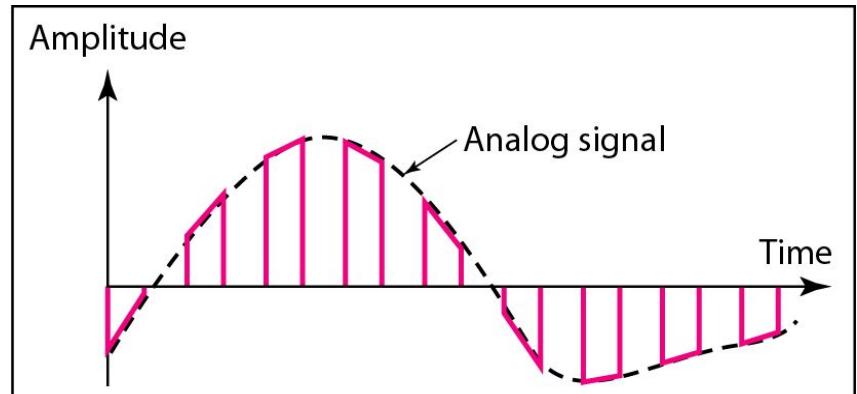
Sampling

- Analog signal is sampled every T_s secs.
- T_s is referred to as the sampling interval.
- $f_s = 1/T_s$ is called the sampling rate or sampling frequency.
- There are 3 sampling methods:
 - Ideal - an impulse at each sampling instant
 - Natural - a pulse of short width with varying amplitude
 - Flattop - sample and hold, like natural but with single amplitude value
- The process is referred to as pulse amplitude modulation PAM and the outcome is a signal with analog (non integer) values

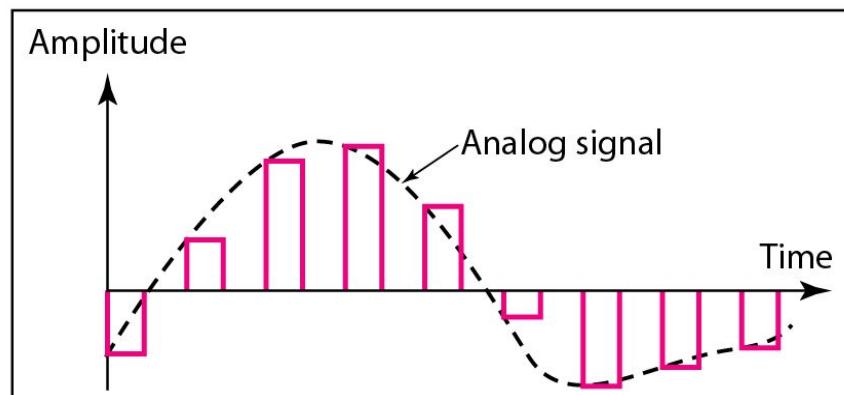
Three different sampling methods for PCM



a. Ideal sampling



b. Natural sampling



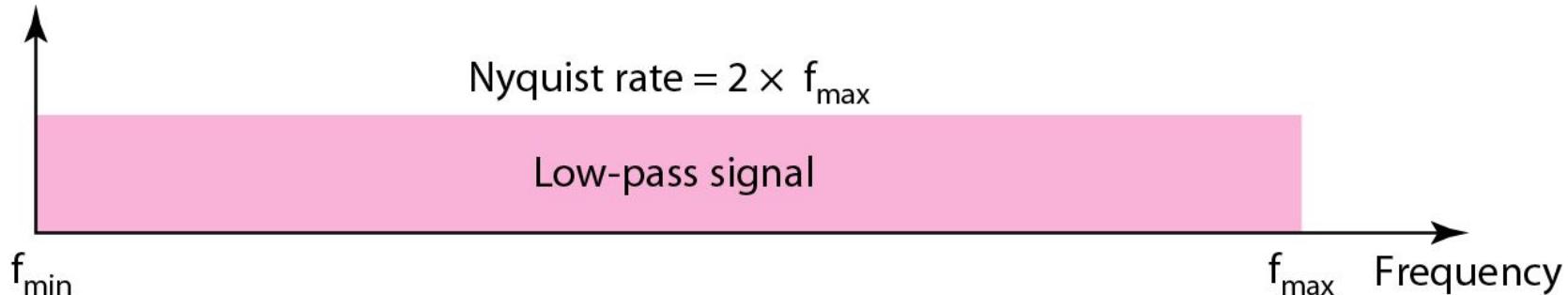
c. Flat-top sampling

Note

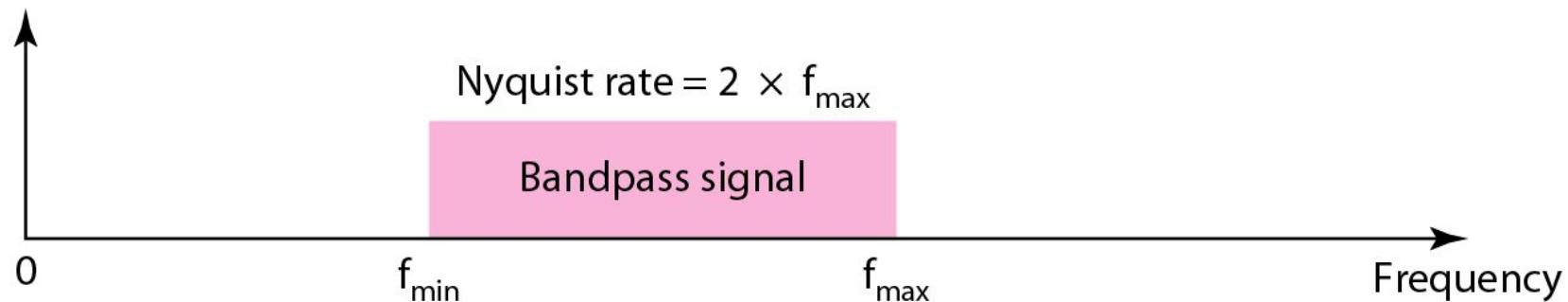
- According to the Nyquist theorem, the sampling rate must be
- at least 2 times the highest frequency contained in the signal.

Nyquist sampling rate for low-pass and bandpass signals

Amplitude



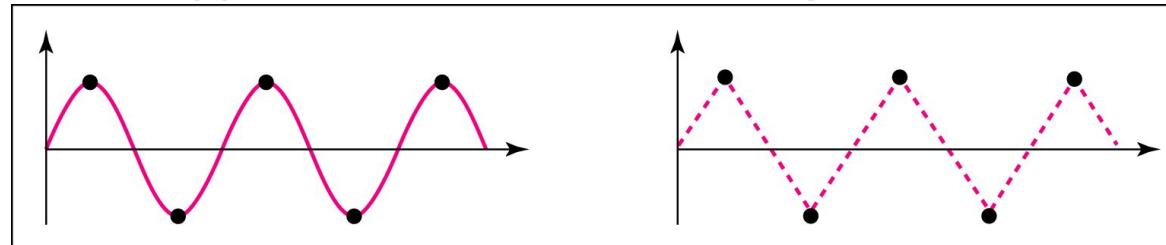
Amplitude



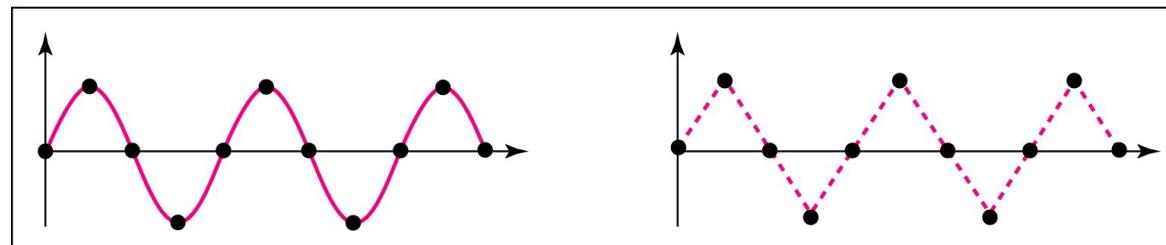
Example 1

- For an intuitive example of the Nyquist theorem, let us sample a simple sine wave at three sampling rates: $f_s = 4f$ (2 times the Nyquist rate), $f_s = 2f$ (Nyquist rate), and $f_s = f$ (one-half the Nyquist rate). Figure 4.24 shows the sampling and the subsequent recovery of the signal.
- It can be seen that sampling at the Nyquist rate can create a good approximation of the original sine wave (part a). Oversampling in part b can also create the same approximation, but it is redundant and unnecessary. Sampling below the Nyquist rate (part c) does not produce a signal that looks like the original sine wave.

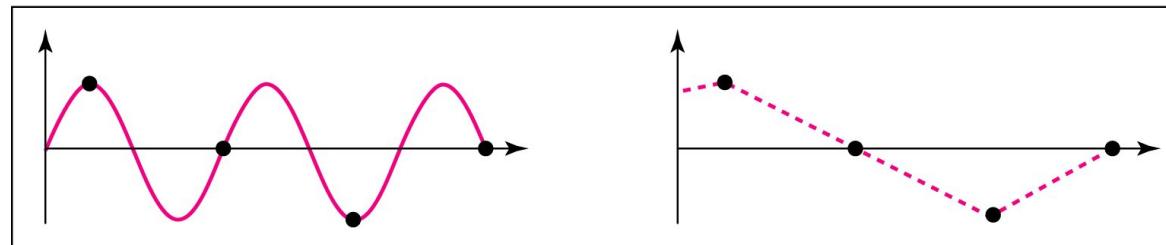
Recovery of a sampled sine wave for different sampling rates



a. Nyquist rate sampling: $f_s = 2f$



b. Oversampling: $f_s = 4f$



c. Undersampling: $f_s = f$

Quantization

- Sampling results in a series of pulses of varying amplitude values ranging between two limits: a min and a max.
- The amplitude values are infinite between the two limits.
- We need to map the *infinite* amplitude values onto a finite set of known values.
- This is achieved by dividing the distance between min and max into **L zones**, each of **height Δ** .

$$\Delta = (\max - \min)/L$$

Quantization Levels

- The midpoint of each zone is assigned a value from 0 to $L-1$ (resulting in L values)
- Each sample falling in a zone is then approximated to the value of the midpoint

Quantization Zones

- Assume we have a voltage signal with amplitudes $V_{\min} = -20V$ and $V_{\max} = +20V$.
- We want to use $L=8$ quantization levels.
- Zone width $\Delta = (20 - -20)/8 = 5$
- The 8 zones are: -20 to -15, -15 to -10, -10 to -5, -5 to 0, 0 to +5, +5 to +10, +10 to +15, +15 to +20
- The midpoints are: -17.5, -12.5, -7.5, -2.5, 2.5, 7.5, 12.5, 17.5

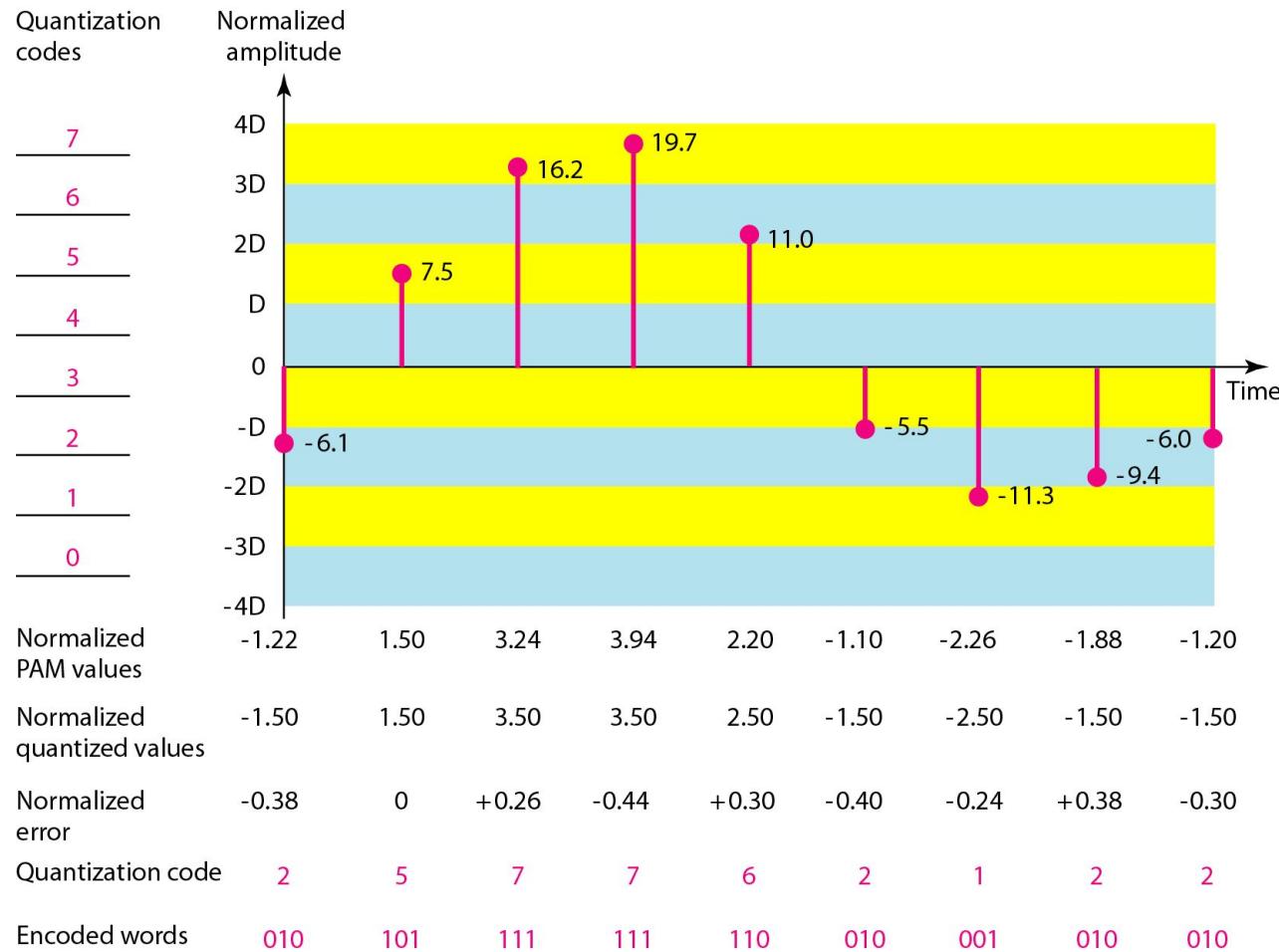
Assigning Codes to Zones

- Each zone is then assigned a binary code.
- The number of bits required to encode the zones, or the number of bits per sample as it is commonly referred to, is obtained as follows:

$$n_b = \log_2 L$$

- Given our example, $n_b = 3$
- The 8 zone (or level) codes are therefore: 000, 001, 010, 011, 100, 101, 110, and 111
- Assigning codes to zones:
 - 000 will refer to zone -20 to -15
 - 001 to zone -15 to -10, etc.

Quantization and encoding of a sampled signal



Quantization Error

- When a signal is quantized, we introduce an error - the coded signal is an approximation of the actual amplitude value.
- The difference between actual and coded value (midpoint) is referred to as the quantization error.
- The more zones, the smaller Δ which results in smaller errors.
- BUT, the more zones the more bits required to encode the samples -> higher bit rate

Quantization Error and $SN_Q R$

- Signals with lower amplitude values will suffer more from quantization error as the error range: $\Delta/2$, is fixed for all signal levels.
- Non linear quantization is used to alleviate this problem. Goal is to keep $SN_Q R$ **fixed** for all sample values.
- **Two approaches:**
 - The quantization levels follow a logarithmic curve. Smaller Δ 's at lower amplitudes and larger Δ 's at higher amplitudes.
 - **Companding:** The sample values are compressed at the sender into logarithmic zones, and then expanded at the receiver. The zones are fixed in height.

Bit rate and bandwidth requirements of PCM

- The bit rate of a PCM signal can be calculated from the number of bits per sample x the sampling rate

$$\text{Bit rate} = n_b \times f_s$$

- The bandwidth required to transmit this signal depends on the type of line encoding used. Refer to previous section for discussion and formulas.
- A digitized signal will always need more bandwidth than the original analog signal. Price we pay for robustness and other features of digital transmission.

Example

- *We want to digitize the human voice. What is the bit rate, assuming 8 bits per sample?*

Solution

- *The human voice normally contains frequencies from 0 to 4000 Hz. So the sampling rate and bit rate are calculated as follows:*

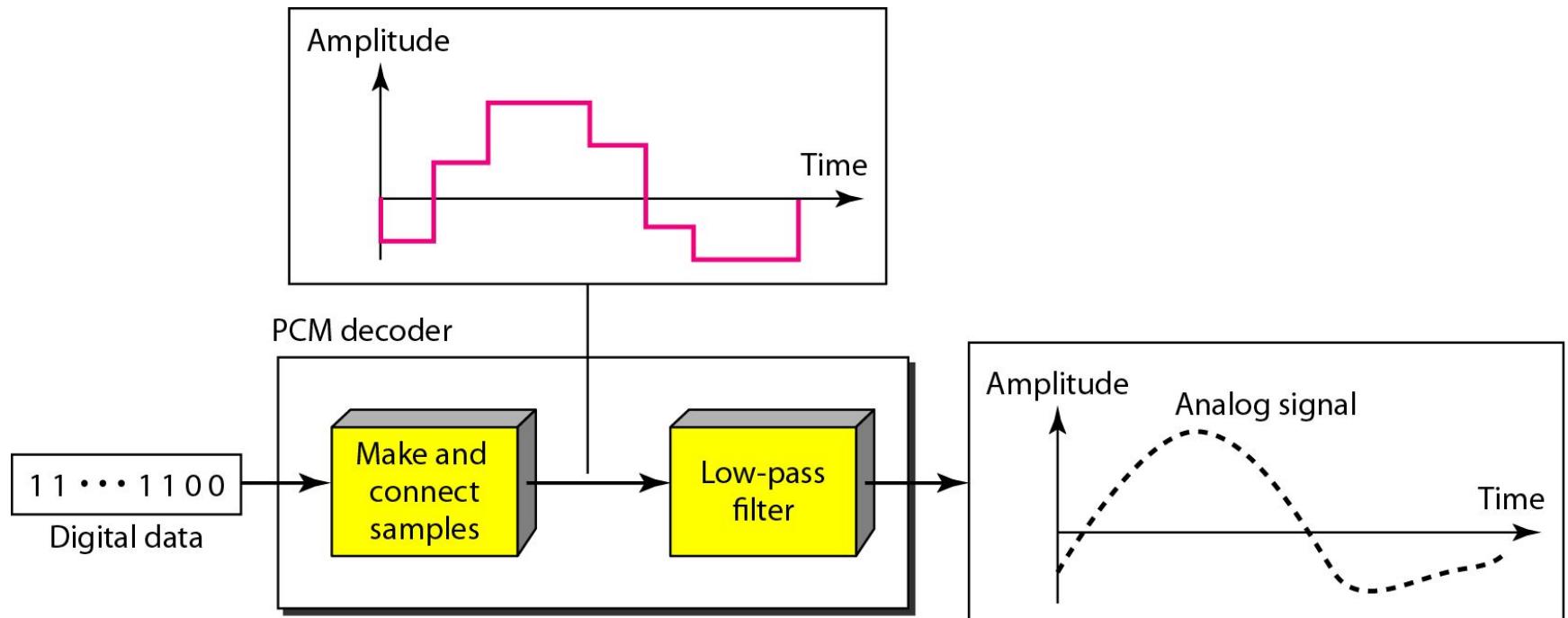
$$\text{Sampling rate} = 4000 \times 2 = 8000 \text{ samples/s}$$

$$\text{Bit rate} = 8000 \times 8 = 64,000 \text{ bps} = 64 \text{ kbps}$$

PCM Decoder

- To recover an analog signal from a digitized signal we follow the following steps:
 - We use a hold circuit that holds the amplitude value of a pulse till the next pulse arrives.
 - We pass this signal through a low pass filter with a cutoff frequency that is equal to the highest frequency in the pre-sampled signal.
- The higher the value of L, the less distorted a signal is recovered.

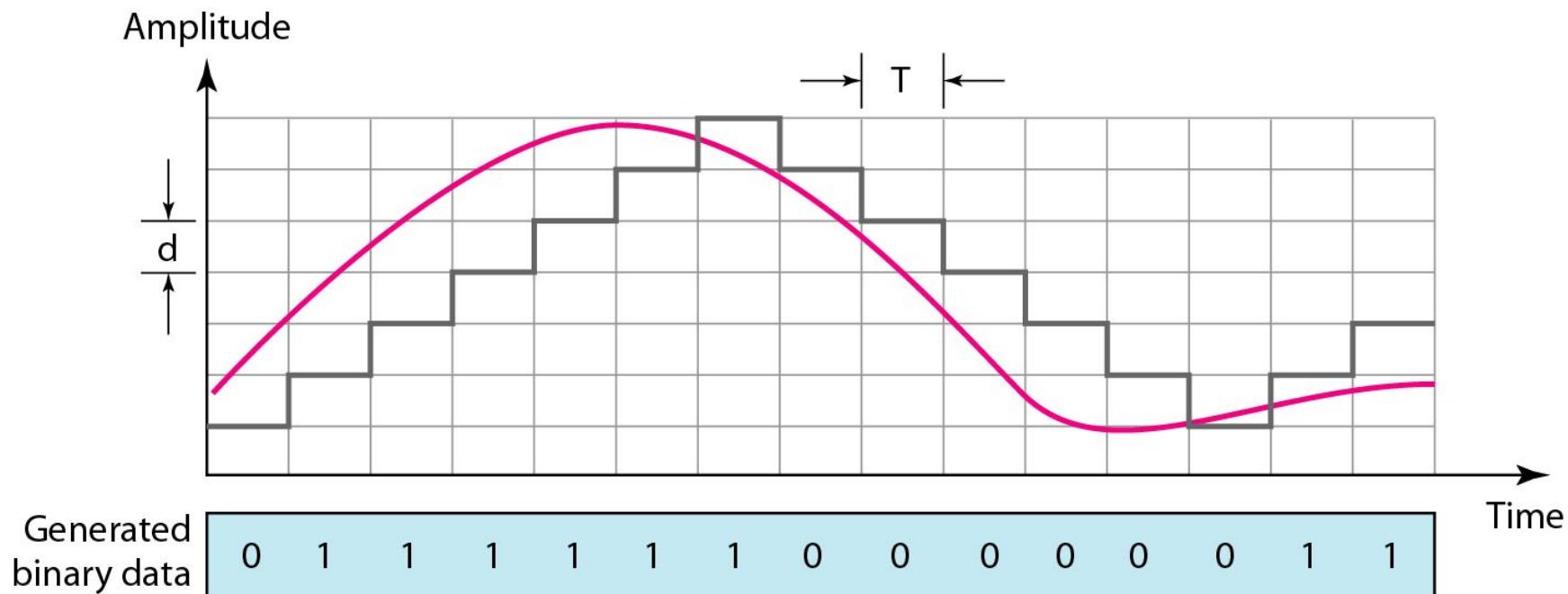
Components of a PCM decoder



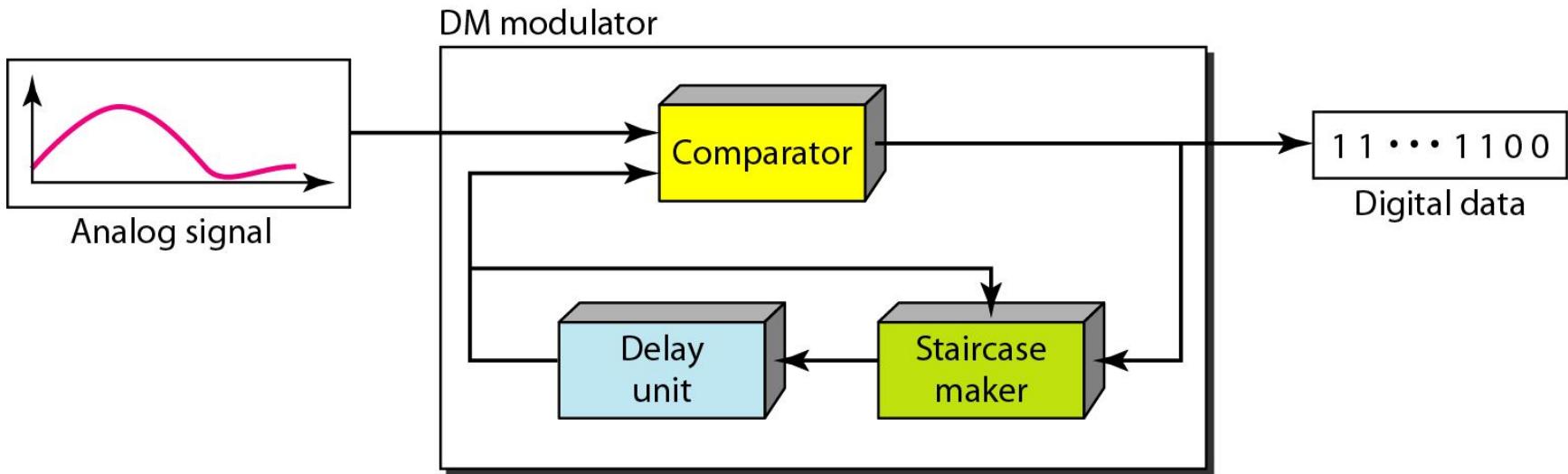
Delta Modulation

- This scheme sends only the difference between pulses, if the pulse at time t_{n+1} is higher in amplitude value than the pulse at time t_n , then a single bit, say a “1”, is used to indicate the positive value.
- If the pulse is lower in value, resulting in a negative value, a “0” is used.
- This scheme works well for small changes in signal values between samples.
- If changes in amplitude are large, this will result in large errors.

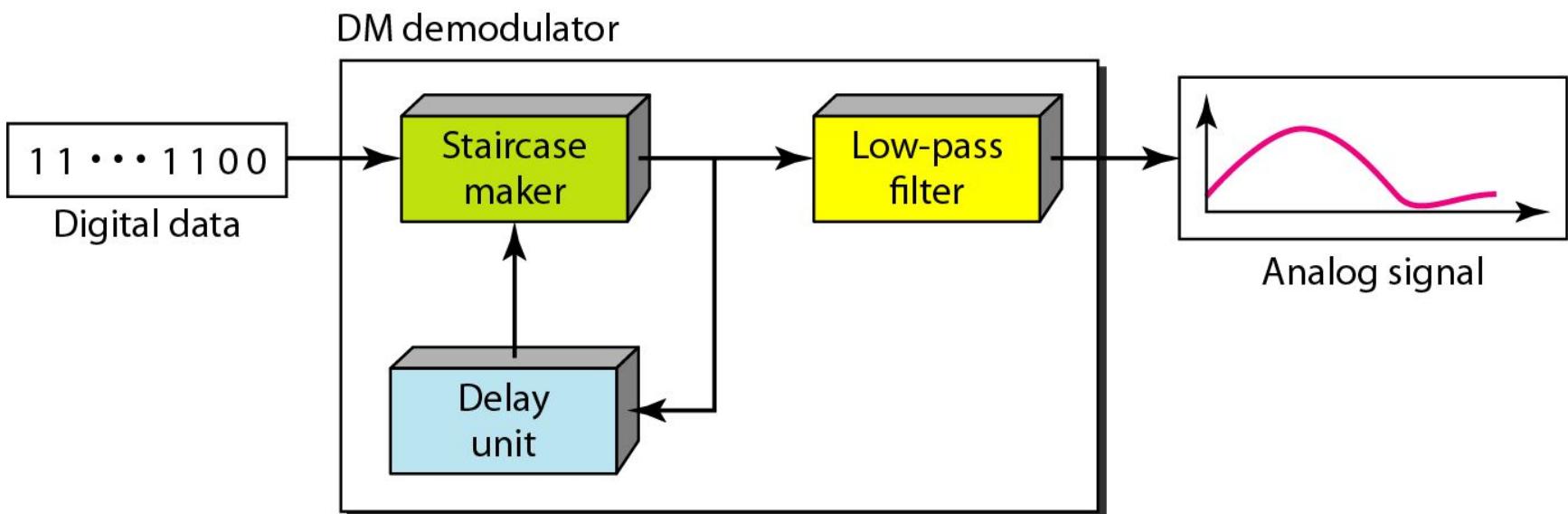
The process of delta modulation



Delta modulation components



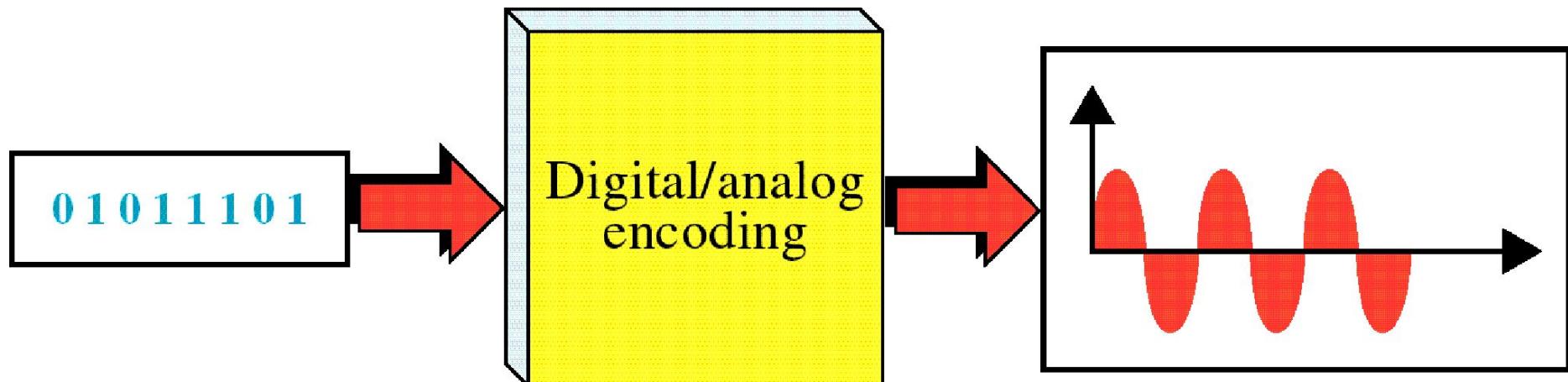
Delta demodulation components



Delta PCM (DPCM)

- Instead of using one bit to indicate positive and negative differences, we can use more bits -> quantization of the difference.
- Each bit code is used to represent the value of the difference.
- The more bits the more levels -> the higher the accuracy.

DIGITAL-TO-ANALOG CONVERSION



Digital to Analog Conversion

- Converting digital data to a bandpass analog signal is traditionally called 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.*
- Digital data needs to be carried on an analog signal.
- A **carrier** signal (frequency f_c) performs the function of transporting the digital data in an analog waveform.
- The analog carrier signal is manipulated to uniquely identify the digital data being carried.

Digital-to-analog conversion

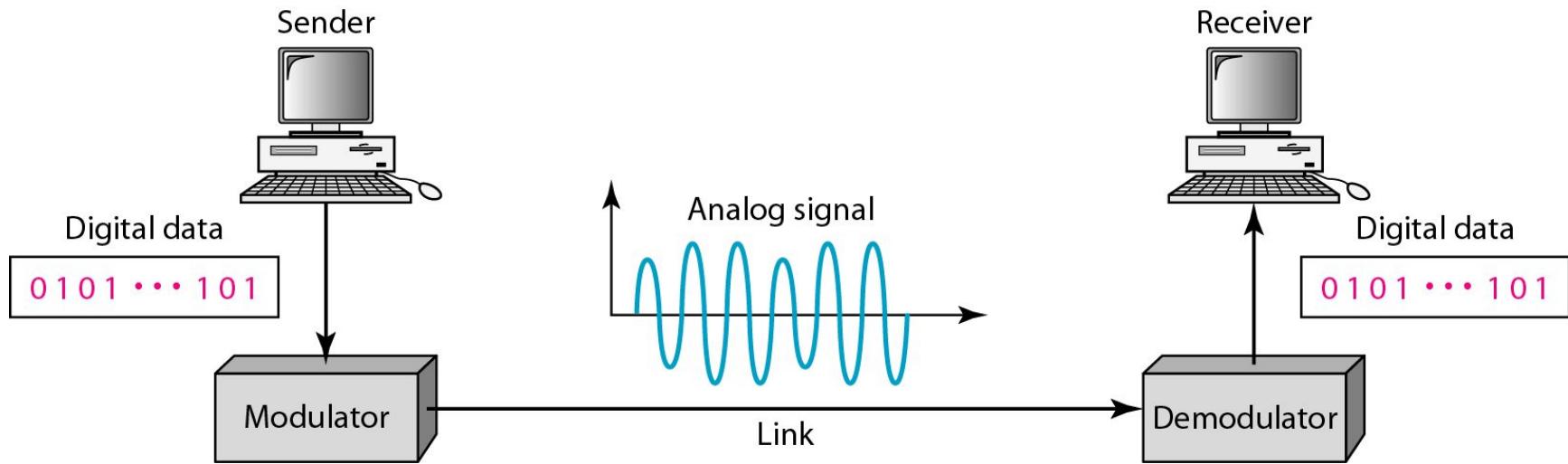


Figure 1 shows the relationship between the digital information, the digital-to-analog modulating process, and the resultant analog signal.

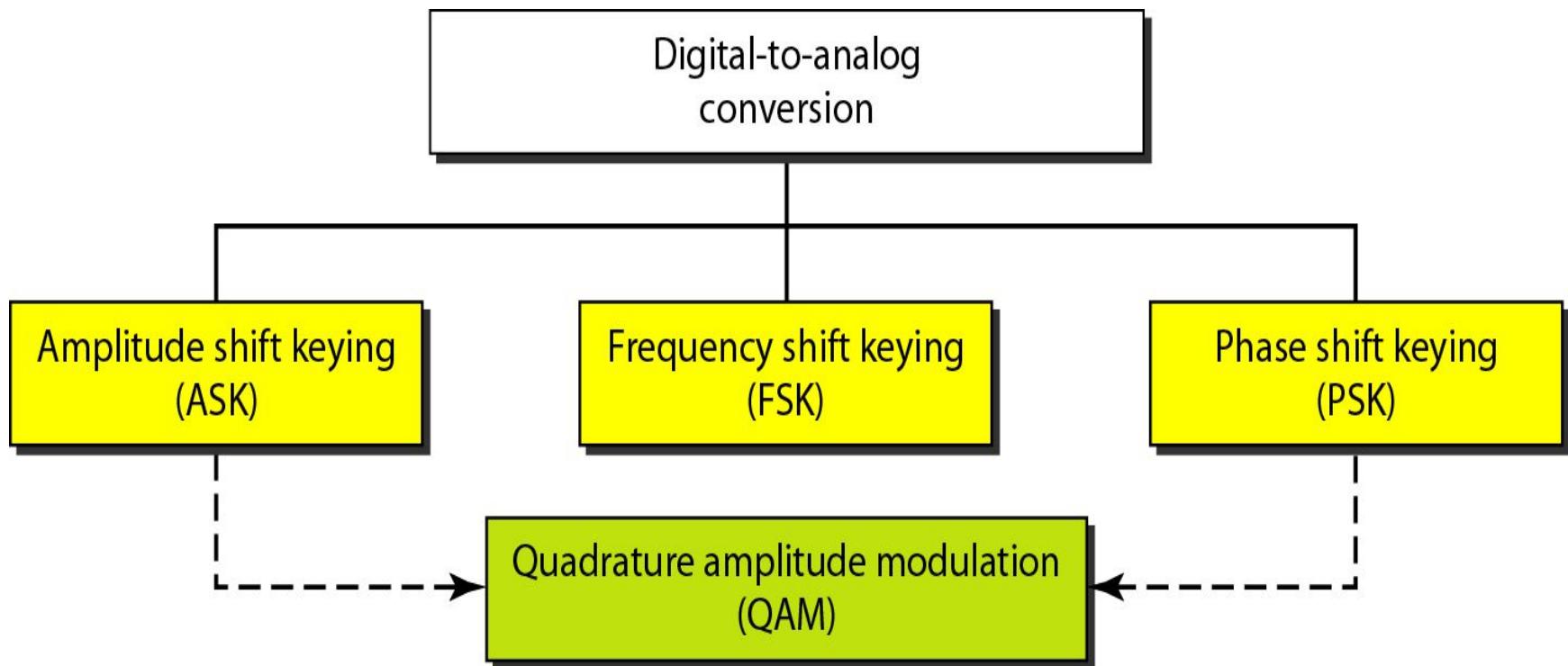
Types of digital-to-analog conversion

Four mechanisms are used for modulating digital data into an analog signal

- *Amplitude shift keying (ASK)*
- *Frequency shift keying (FSK)*
- *Phase shift keying(PSK)*
- *Quadrature amplitude modulation (QAM – combines ASK & PSK)*

QAM is the most efficient and commonly used today

Types of digital-to-analog conversion



Bit and Baud rates and the carrier signal

- **Bit rate, N**, is the number of bits per second (bps). Also called as *Data Rate*
- **Baud rate, S** is the number of signal elements per second (bauds). Also called as *Signal Rate*

Cond..

- The relationship between them is

$$\mathbf{S=Nx1/r \text{ bauds}}$$

Where

S - Signal rate

N - *data rate*

r - number of data bits per signal element.

- In the analog transmission of digital data, the signal or baud rate is less than or equal to the bit rate.

Bit Rate and Baud Rate

Bit

Baud rate = N

0	0	1	0	1	0	0	0	1	0	1	0	1	0	1	0	0
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Dibit

Baud rate = N

Bit rate = $2N$

0	0	1	0	1	0	0	0	1	0	1	0	1	1	1	1	0
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Bit Rate and Baud Rate - Continued

Tribit

Baud rate = N

Bit rate = $3N$

0	0	1	0	1	0	0	0	1	0	1	1	1	1	0
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Quadbit

Baud rate = N

Bit rate = $4N$

0	0	1	0	1	0	0	0	1	0	1	0	1	1	1	0
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Example 1

- 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

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

Example 2

- An analog signal has a bit rate of 8000 bps and a baud rate of 1000 baud. How many data elements are carried by each signal element? How many signal elements do we need?

Solution

- In this example, $S = 1000$, $N = 8000$, and r and L are unknown. We find first the value of r and then the value of L .

$$S = N \times \frac{1}{r} \quad \rightarrow \quad r = \frac{N}{S} = \frac{8000}{1000} = 8 \text{ bits/baud}$$

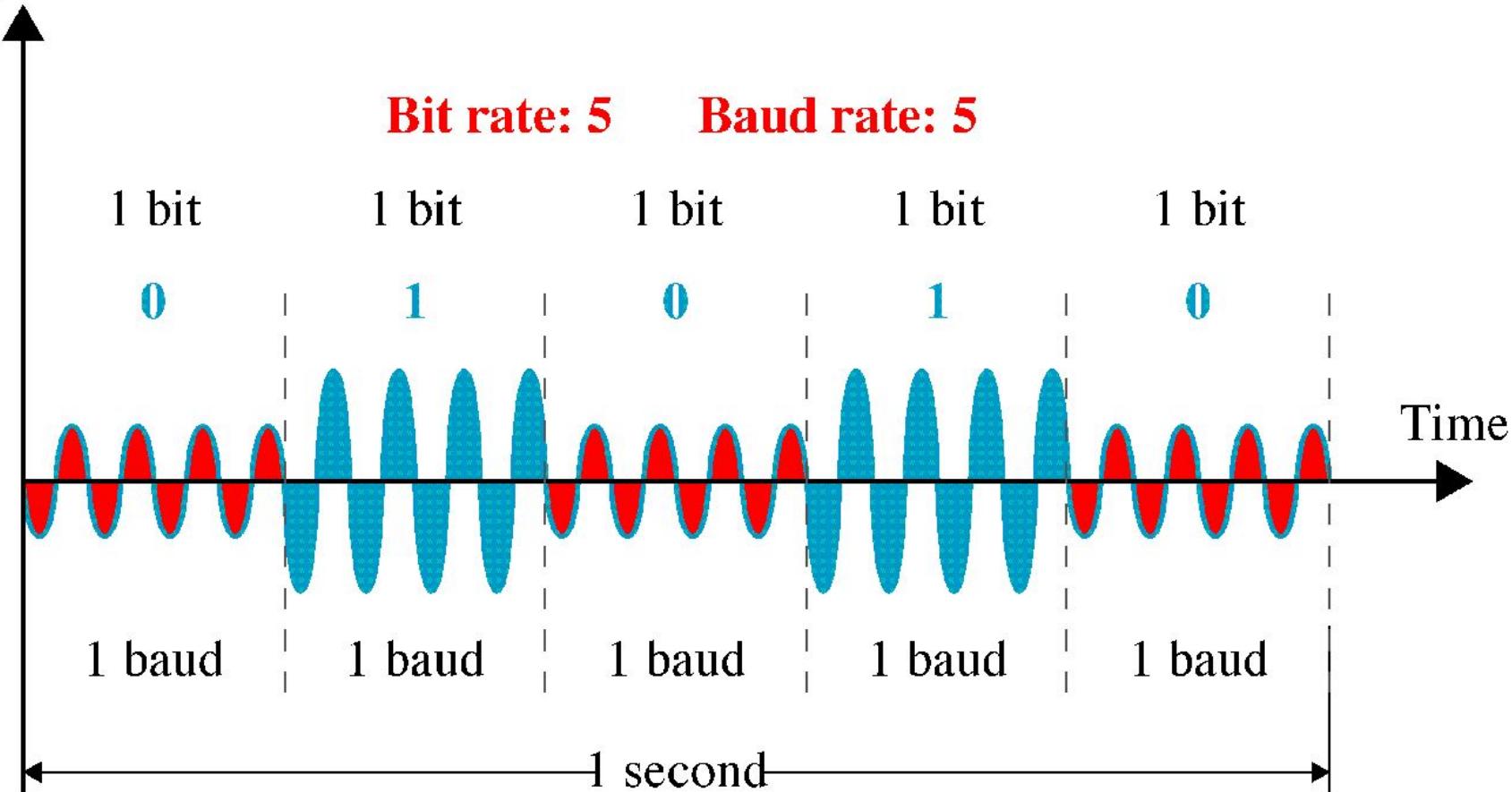
$$r = \log_2 L \quad \rightarrow \quad L = 2^r = 2^8 = 256$$

Amplitude Shift Keying (ASK)

- In ASK, the amplitude of the carrier signal is varied to create signal elements. Both frequency and phase remain constant while the amplitude changes.
- ASK is implemented by changing the amplitude of a carrier signal to reflect amplitude levels in the digital signal.
- For example: a digital “1” could not affect the signal, whereas a digital “0” would, by making it zero.
- The line encoding will determine the values of the analog waveform to reflect the digital data being carried.

ASK

Amplitude



Bandwidth of ASK

- The bandwidth B of ASK is proportional to the signal rate S .

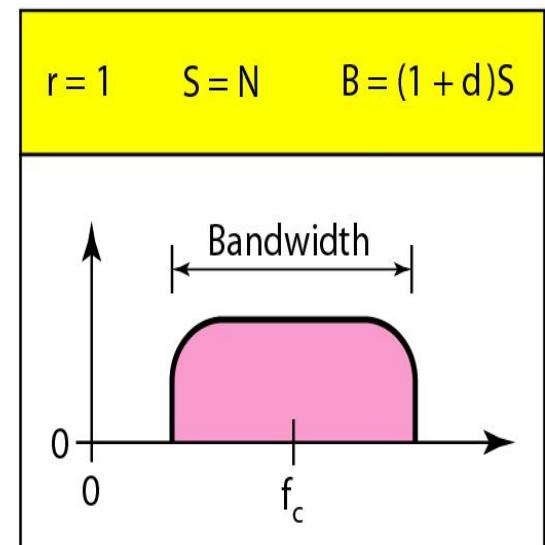
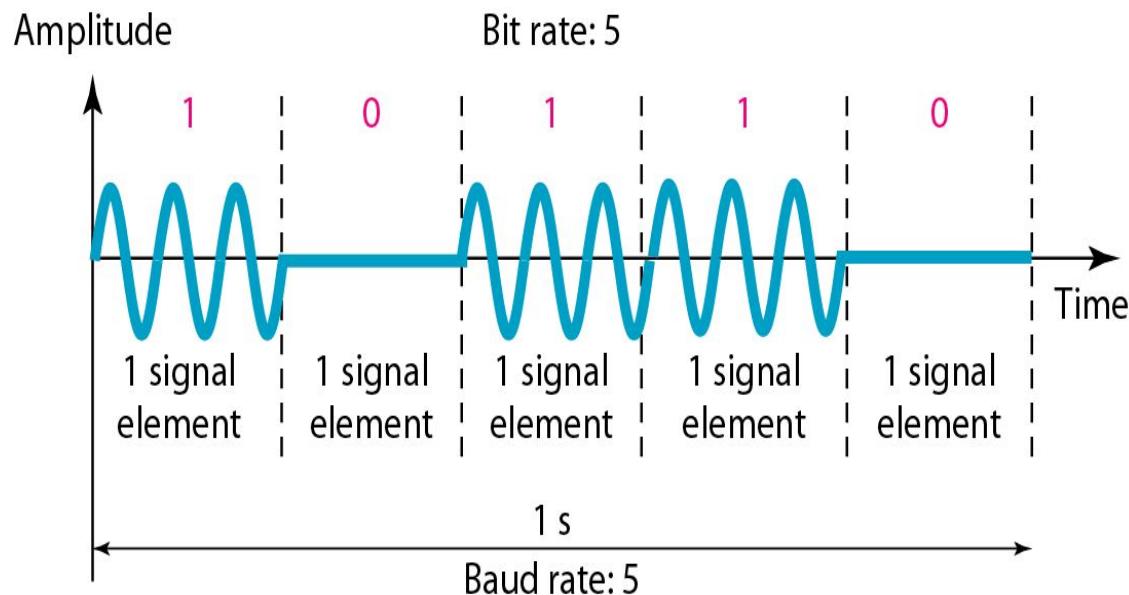
$$\mathbf{B = (1+d)S}$$

- “d” is depends on modulation and filtering process
- “d” value lies between 0 and 1.

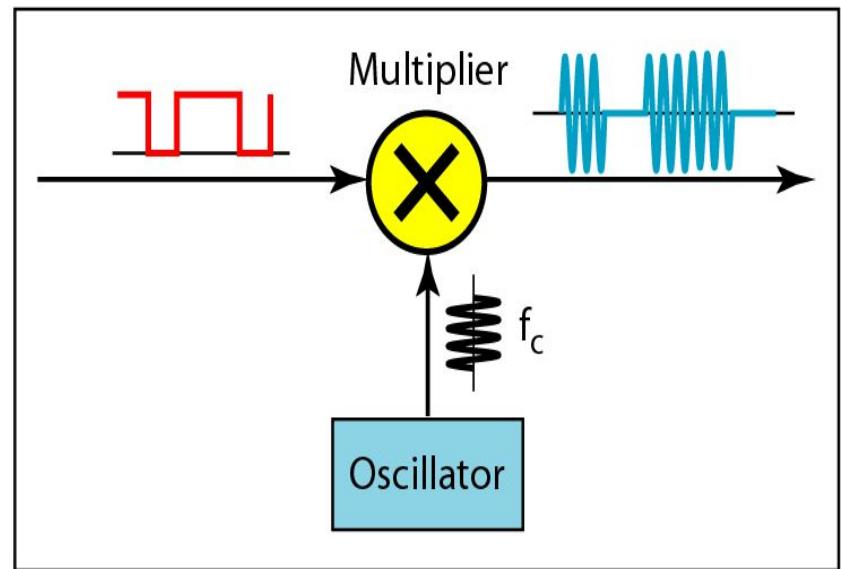
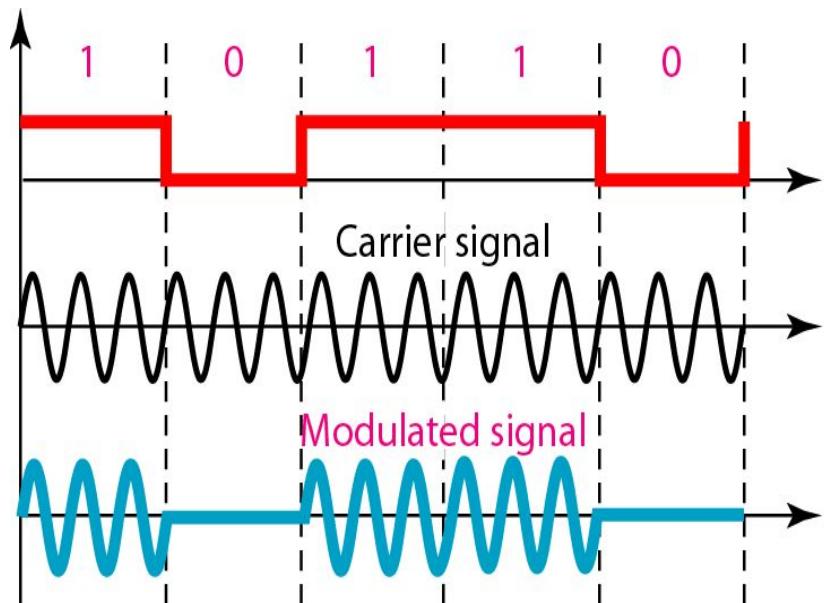
Binary ASK (BASK)

- ASK is normally implemented using only two levels.
- This is referred to as binary amplitude shift keying or ***on-off keying (OOK)***.
- ***The peak amplitude of one signal level is 0***
- the other is the same as the amplitude of the carrier frequency

Binary amplitude shift keying



Implementation of binary ASK



- If digital data are presented as a unipolar NRZ digital signal with a high voltage of 1 V and a low voltage of 0 V
- Implementation can be achieved by multiplying the NRZ digital signal by the carrier signal coming from an oscillator.
- When the amplitude of the NRZ signal is 1, the amplitude of the carrier frequency is held;
- when the amplitude of the NRZ signal is 0, the amplitude of the carrier frequency is zero.

Example 3

We have an available bandwidth of 100 kHz which spans from 200 to 300 kHz. What are the carrier frequency and the bit rate if we modulated our data by using ASK with $d = I$?

Solution:

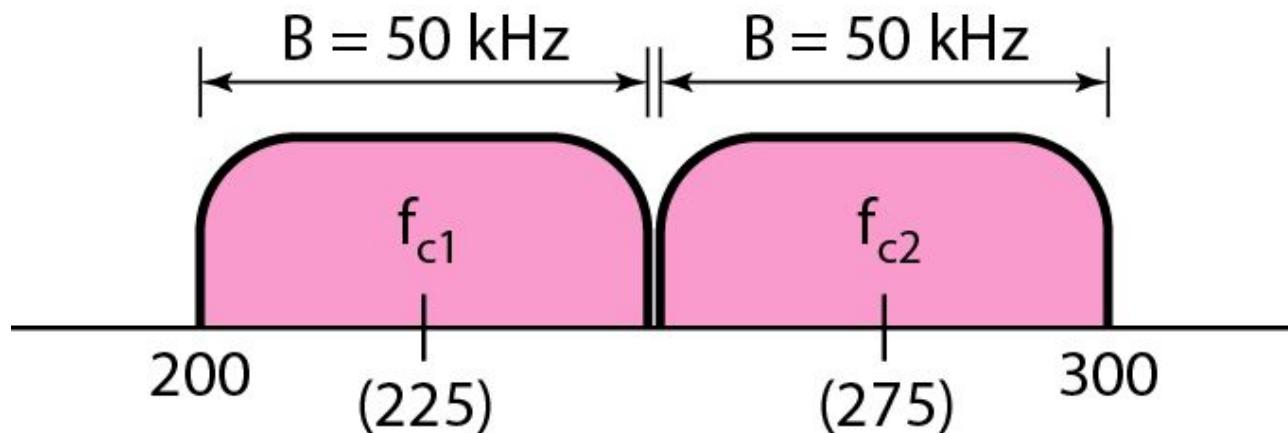
- The middle of the bandwidth is located at 250 kHz. This means that our carrier frequency can be $at fe = 250 \text{ kHz}$. *We can use the formula for bandwidth to find the bit rate (with $d = 1$ and $r = 1$).*

$$B = (1 + d) \times S = 2 \times N \times \frac{1}{r} = 2 \times N = 100 \text{ kHz} \quad \rightarrow \quad N = 50 \text{ kbps}$$

Example 4

- *In data communications, we normally use full-duplex links with communication in both directions. We need to divide the bandwidth into two with two carrier frequencies, as shown in Figure 5. The figure shows the positions of two carrier frequencies and the bandwidths. The available bandwidth for each direction is now 50 kHz, which leaves us with a data rate of 25 kbps in each direction.*

Figure 5 Bandwidth of full-duplex ASK used in Example 4



Frequency Shift Keying

- In frequency shift keying, the frequency of the carrier signal is varied to represent data.
- The frequency of the modulated signal is constant for the duration of one signal element, but changes for the next signal element if the data element changes.
- Both peak amplitude and phase remain constant for all signal elements.
- The digital data stream changes the frequency of the carrier signal, f_c .
- For example,
 - a “1” could be represented by $f_1 = f_c + \Delta f$,
 - a “0” could be represented by $f_2 = f_c - \Delta f$.

FSK

Amplitude

Bit rate: 5 Baud rate: 5

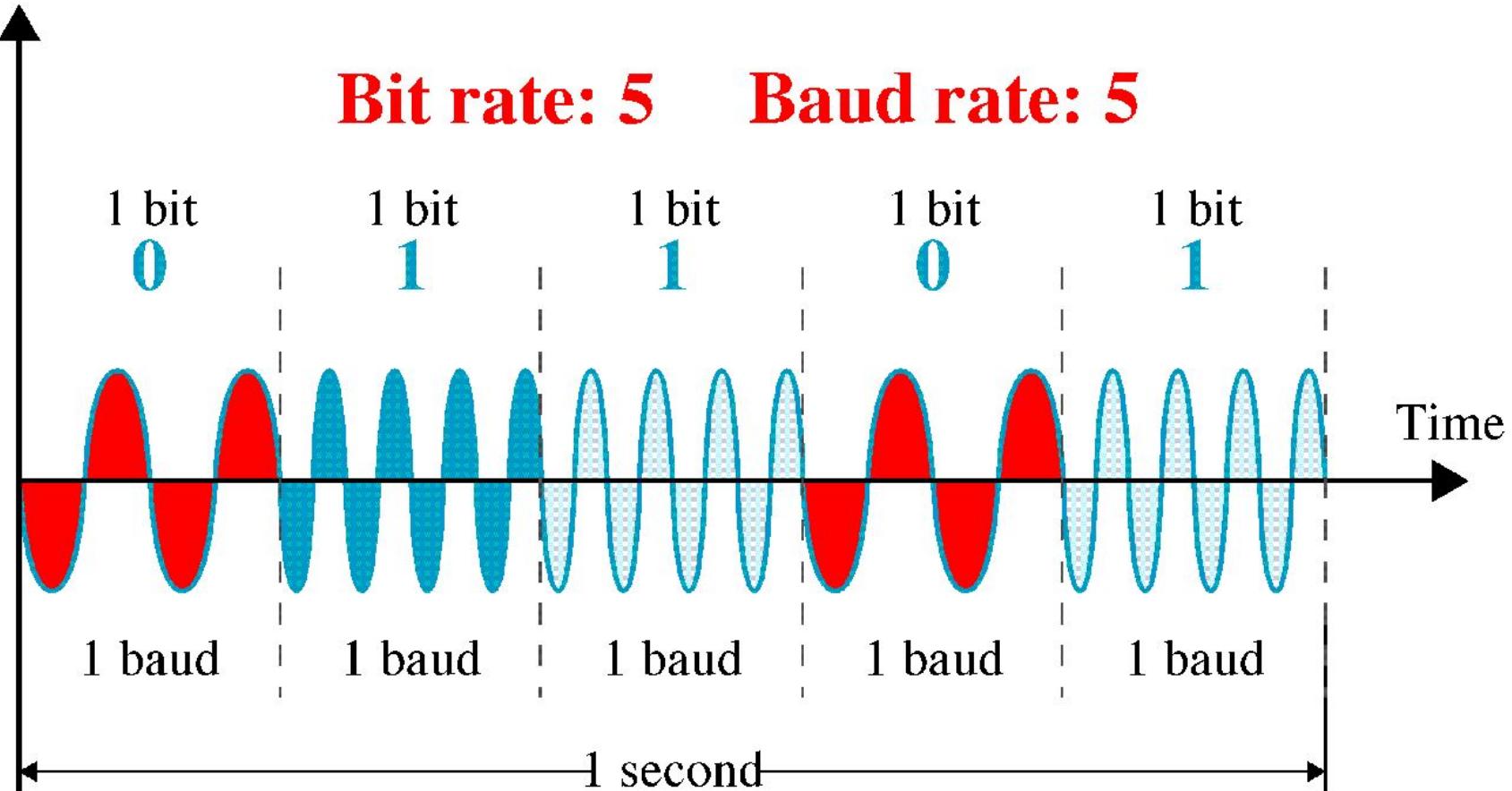
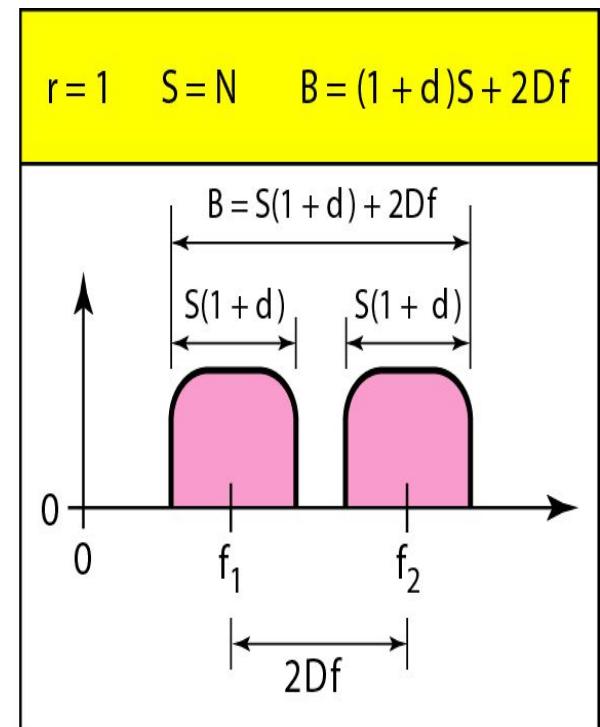
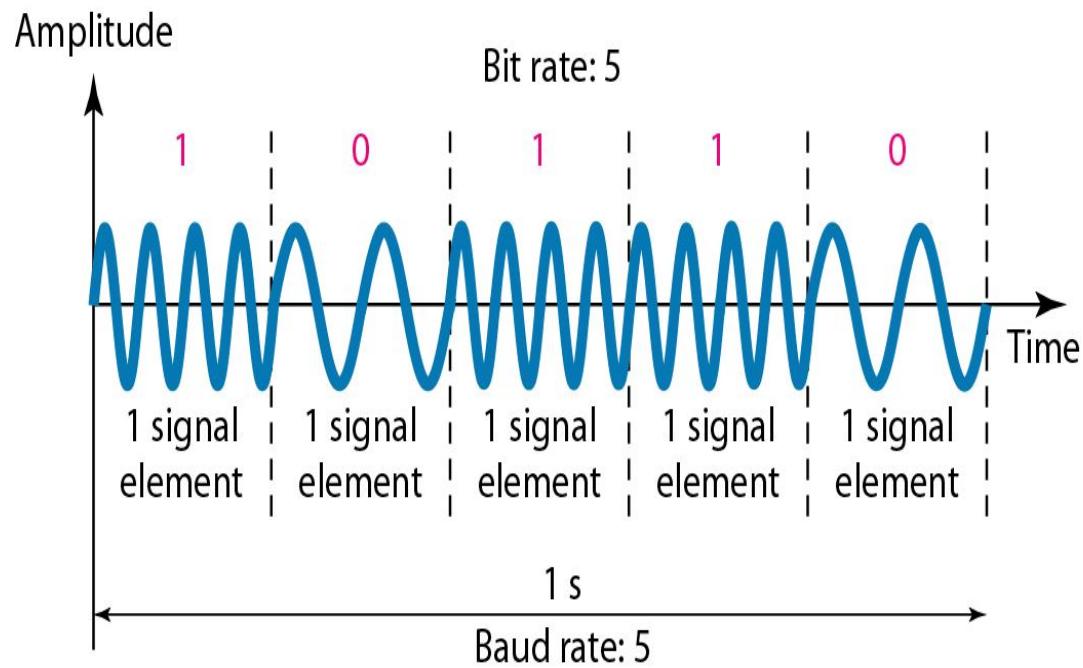


Figure 6 *Binary frequency shift keying (BFSK)*



Bandwidth of FSK

- If the difference between the two frequencies (f_1 and f_2) is $2\Delta f$, then the required BW B will be:

$$\mathbf{B = (1+d) \times S + 2\Delta f}$$

Example 5

- *We have an available bandwidth of 100 kHz which spans from 200 to 300 kHz. What should be the carrier frequency and the bit rate if we modulated our data by using FSK with $d = 1$?*

Solution

- *This problem is similar to Example 5.3, but we are modulating by using FSK. The midpoint of the band is at 250 kHz. We choose $2\Delta f$ to be 50 kHz; this means*

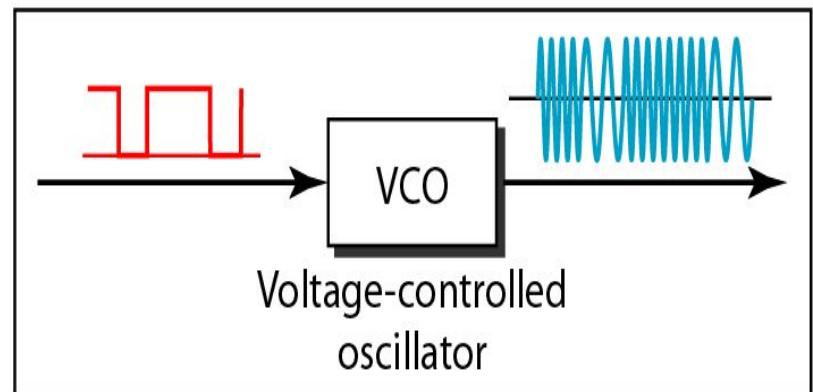
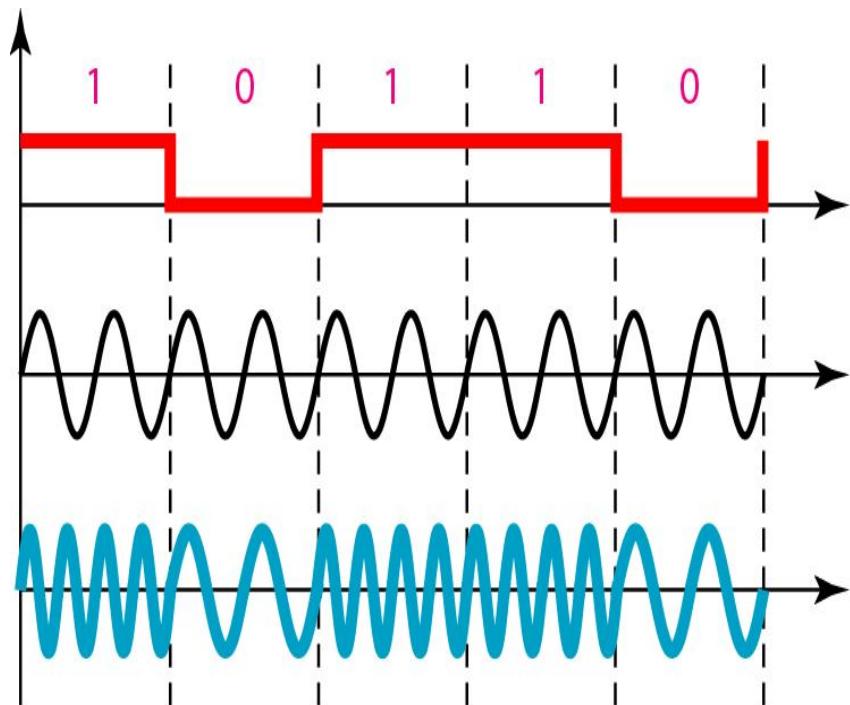
$$B = (1 + d) \times S + 2\Delta f = 100 \quad \rightarrow \quad 2S = 50 \text{ kHz} \quad S = 25 \text{ baud} \quad N = 25 \text{ kbps}$$

Coherent and Non Coherent

- Two implementations of BFSK:
 - *Non-coherent*
 - *Coherent.*
- In a non-coherent FSK scheme, when we change from one frequency to the other, we do not adhere to the current phase of the signal.
- In coherent FSK, the switch from one frequency signal to the other only occurs at the same phase in the signal.

- Non-coherent BFSK can be implemented by treating BFSK as two ASK modulations and using two carrier frequencies.
- Coherent BFSK can be implemented by using one *voltage-controlled oscillator (VeO) that changes its frequency* according to the input voltage.
- Figure 7 shows the implementation.
- The input to the oscillator is the unipolar NRZ signal. When the amplitude of NRZ is zero, the oscillator keeps its regular frequency; when the amplitude is positive, the frequency is increased.

Figure 7 Implementation of BFSK



Multi level FSK

- Similarly to ASK, FSK can use multiple bits per signal element.
- That means we need to provision for multiple frequencies, each one to represent a group of data bits.
- The bandwidth for FSK can be higher

$$B = (1+d)xS + (L-1)/2\Delta f = LxS$$

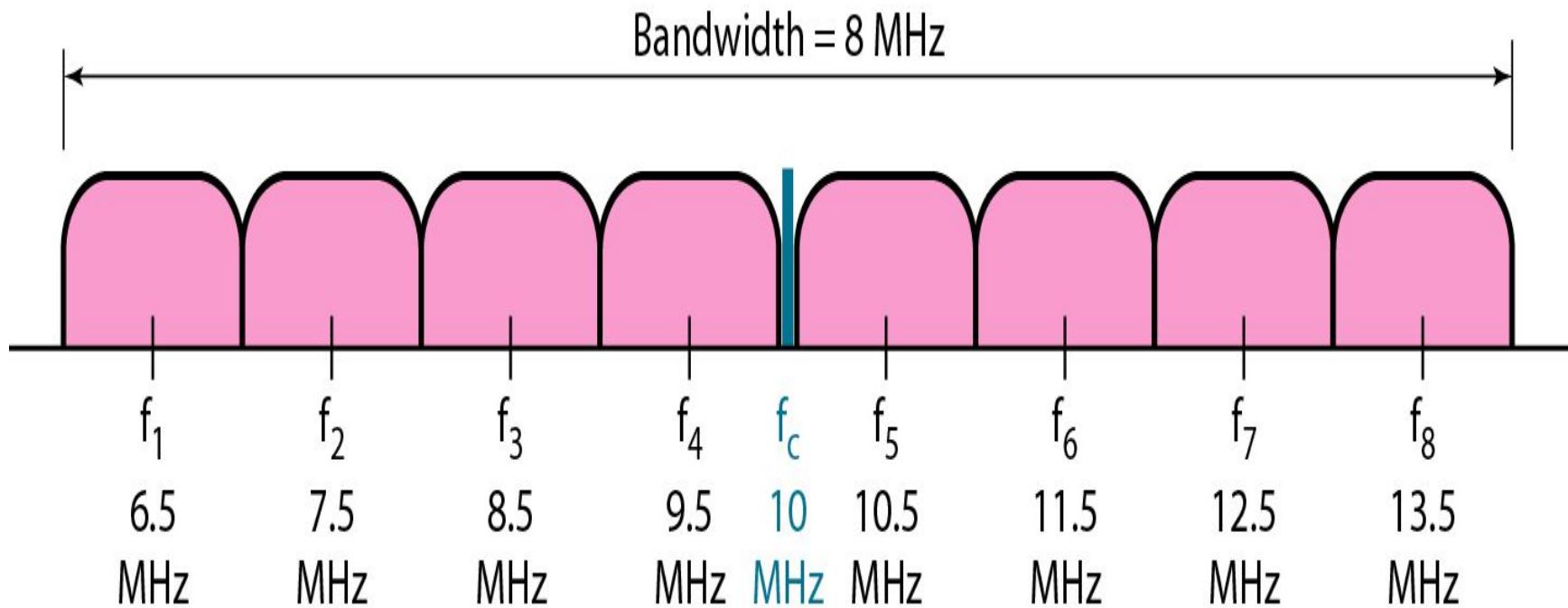
Example 6

- *We need to send data 3 bits at a time at a bit rate of 3 Mbps. The carrier frequency is 10 MHz. Calculate the number of levels (different frequencies), the baud rate, and the bandwidth.*

Solution

- *We can have $L = 2^3 = 8$. The baud rate is $S = 3 \text{ Mbps}/3 = 1 \text{ Mbaud}$. This means that the carrier frequencies must be 1 MHz apart ($2\Delta f = 1 \text{ MHz}$). The bandwidth is $B = 8 \times 1M = 8M$. Figure 8 shows the allocation of frequencies and bandwidth.*

Figure 8 Bandwidth of MFSK used in Example 6



Phase Shift Keying

- In PSK, the phase of the carrier is varied to represent two or more different signal elements. Both peak amplitude and frequency remain constant as the phase changes.
- Today, PSK is more common than ASK or FSK
- We vary the phase shift of the carrier signal to represent digital data.
- The bandwidth requirement, B is:

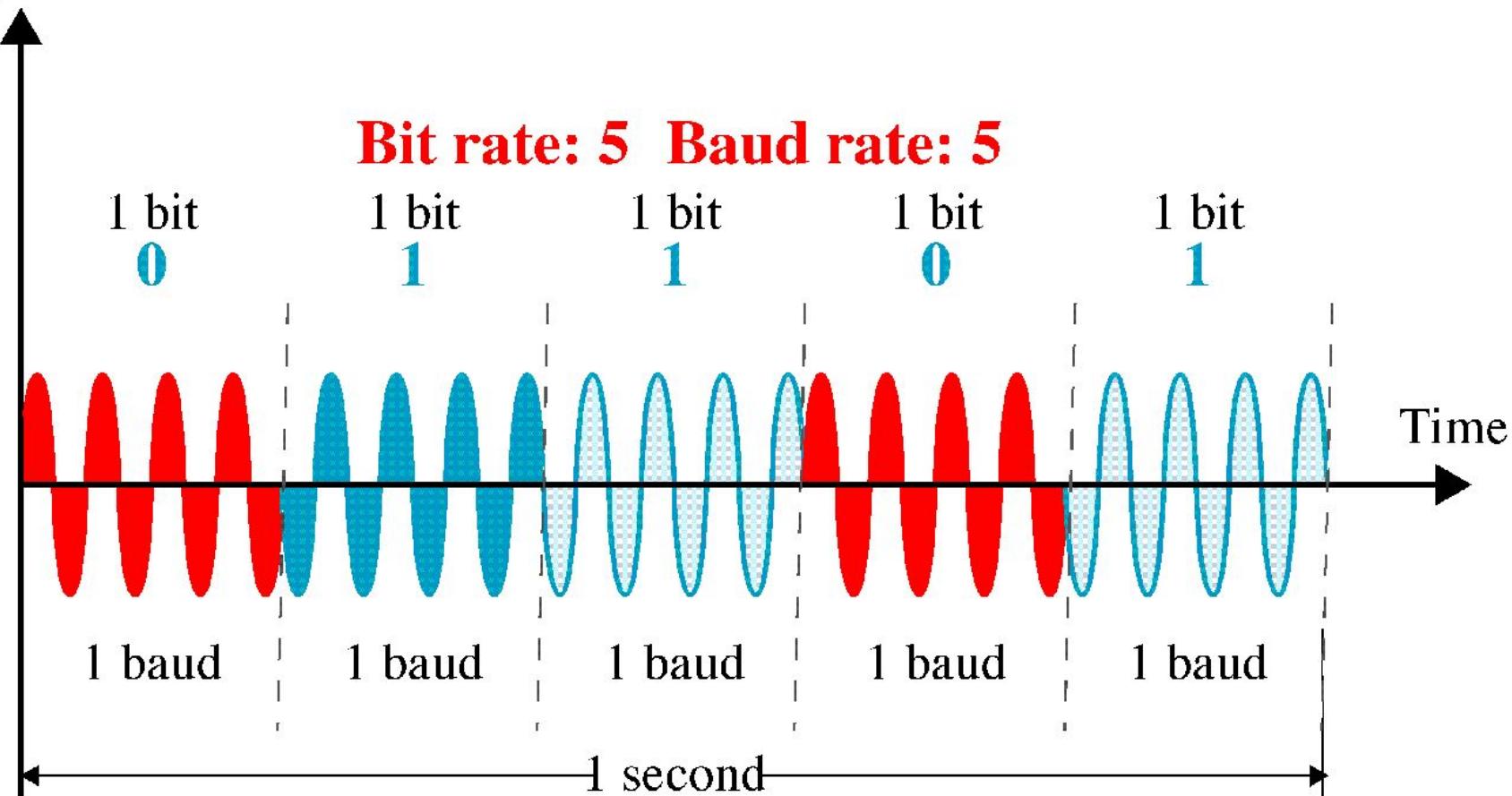
$$B = (1+d) \times S$$

- PSK is much more robust than ASK as it is not that vulnerable to noise, which changes amplitude of the signal.

PS K

Amplitude

Bit rate: 5 Baud rate: 5



Binary phase shift keying (BPSK)

- The simplest PSK is binary PSK, in which we have only two signal elements, one with a phase of 0° , and the other with a phase of 180° .
- Binary PSK is as simple as binary ASK
- PSK is less susceptible to noise than ASK.
- PSK is superior to FSK because we do not need two carrier signals.

Figure 9 *Binary phase shift keying*

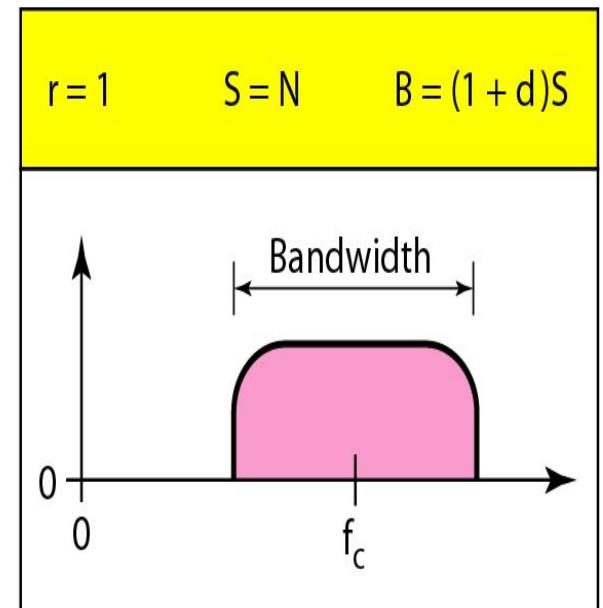
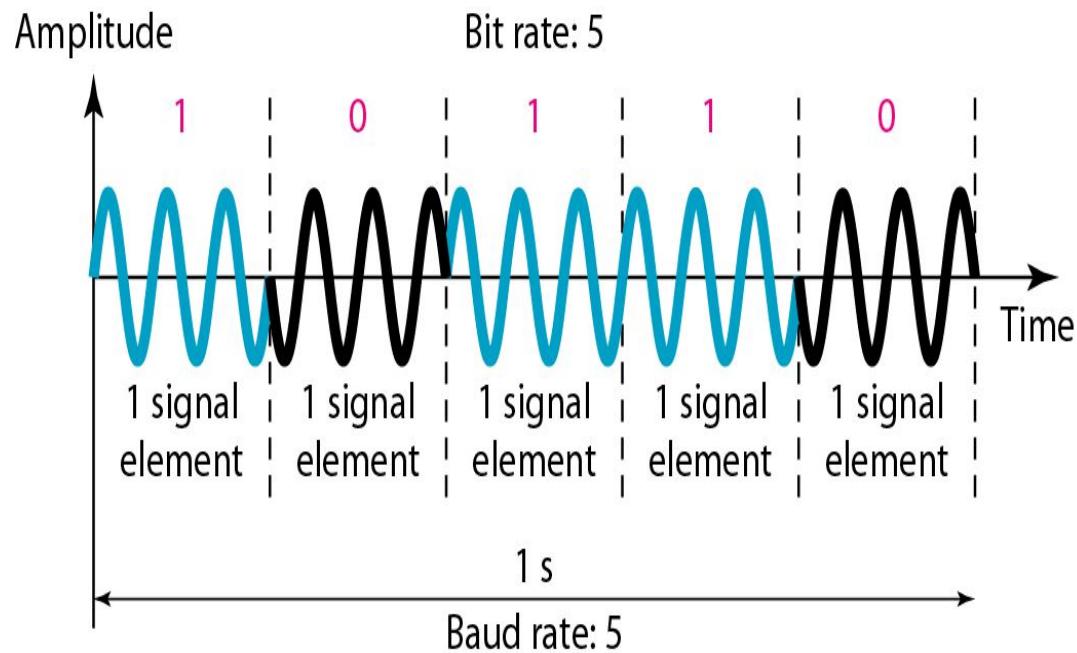
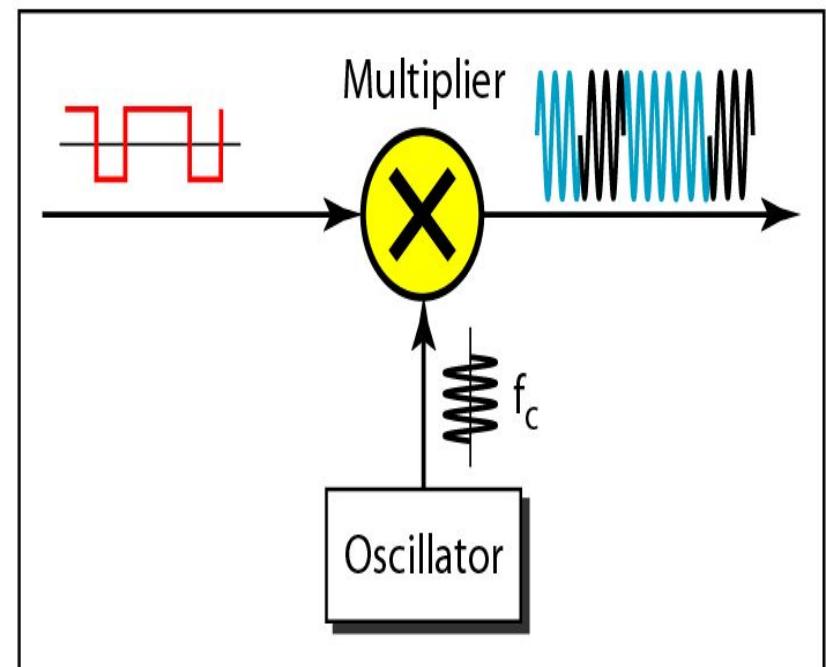
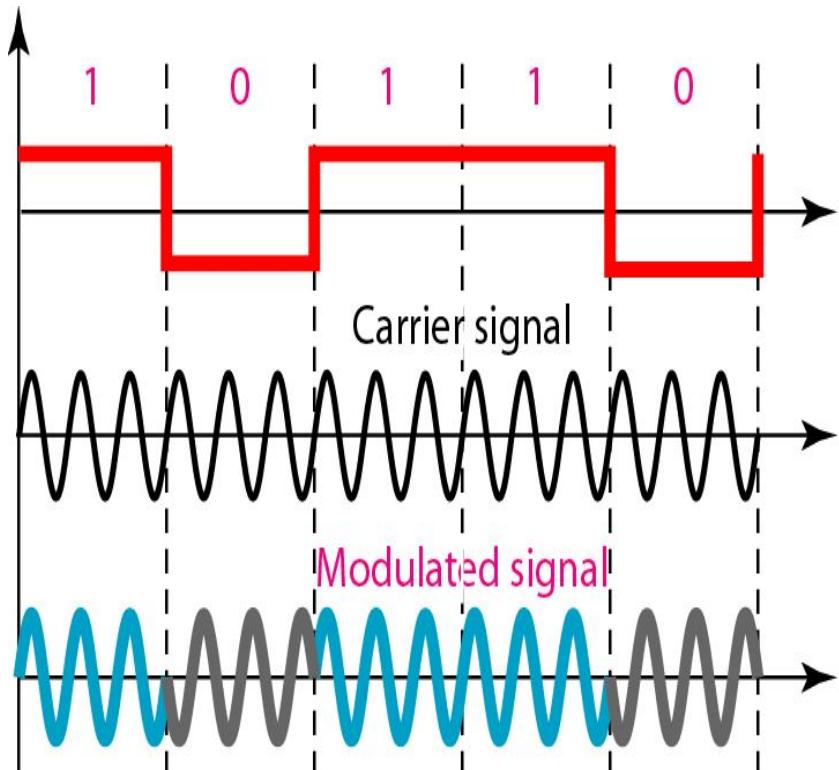


Figure 10 *Implementation of BASK*

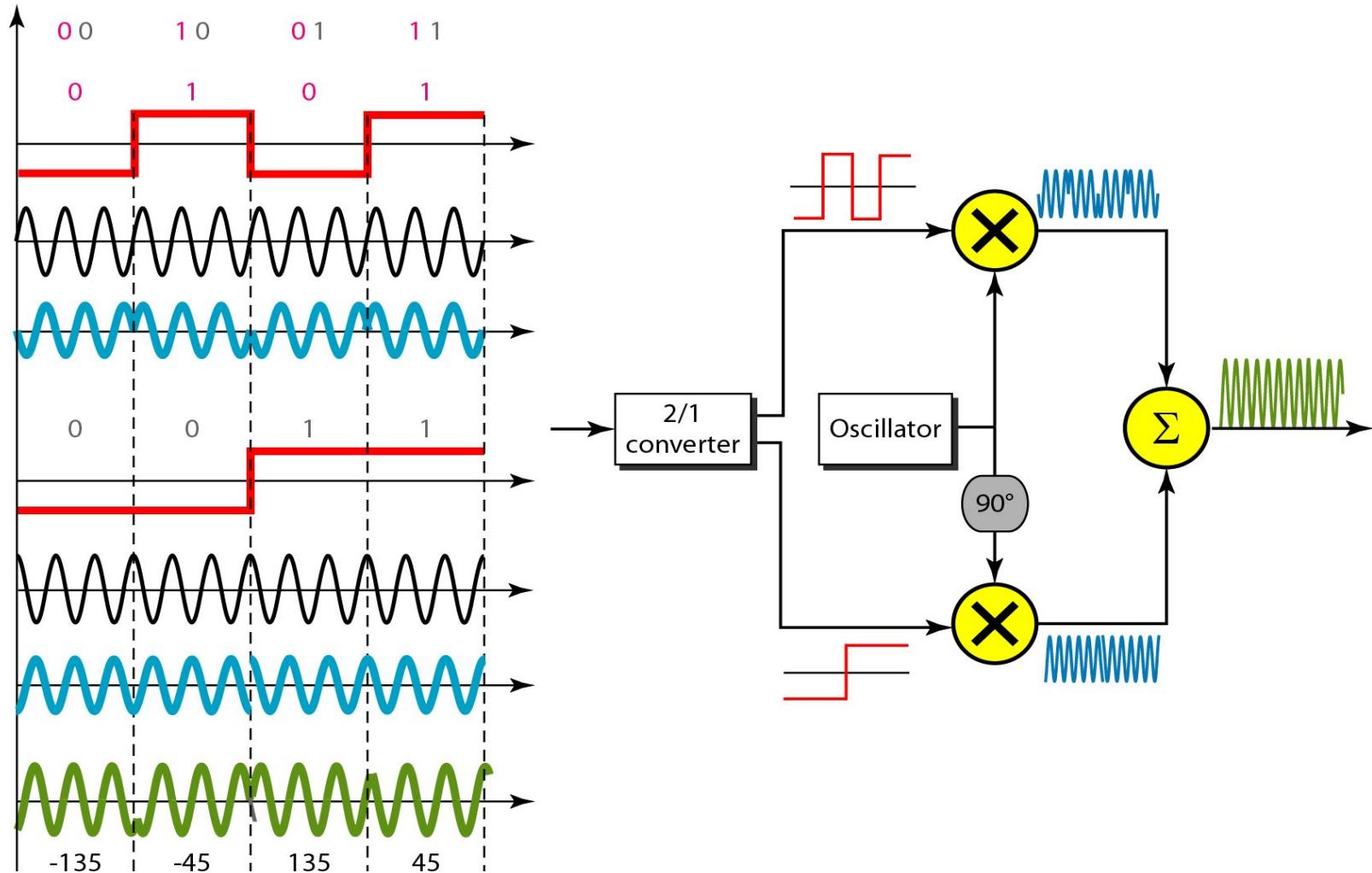


- The implementation of BPSK is as simple as that for ASK
- The reason is that the signal element with phase 180° can be seen as the complement of the signal element with phase 0°
- The polar NRZ signal is multiplied by the carrier frequency;
- the 1 bit (positive voltage) is represented by a phase starting at 0° ;
- the 0 bit (negative voltage) is represented by a phase starting at 180° .

Quadrature PSK

- To increase the bit rate, we can code 2 or more bits onto one signal element.
- In QPSK, we parallelize the bit stream so that every two incoming bits are split up and PSK a carrier frequency. One carrier frequency is phase shifted 90° from the other - in quadrature.
- The two PSKed signals are then added to produce one of 4 signal elements. $L = 4$ here.

Figure 11 *QPSK and its implementation*



Example 7

- Find the bandwidth for a signal transmitting at 12 Mbps for QPSK. The value of $d = 0$.

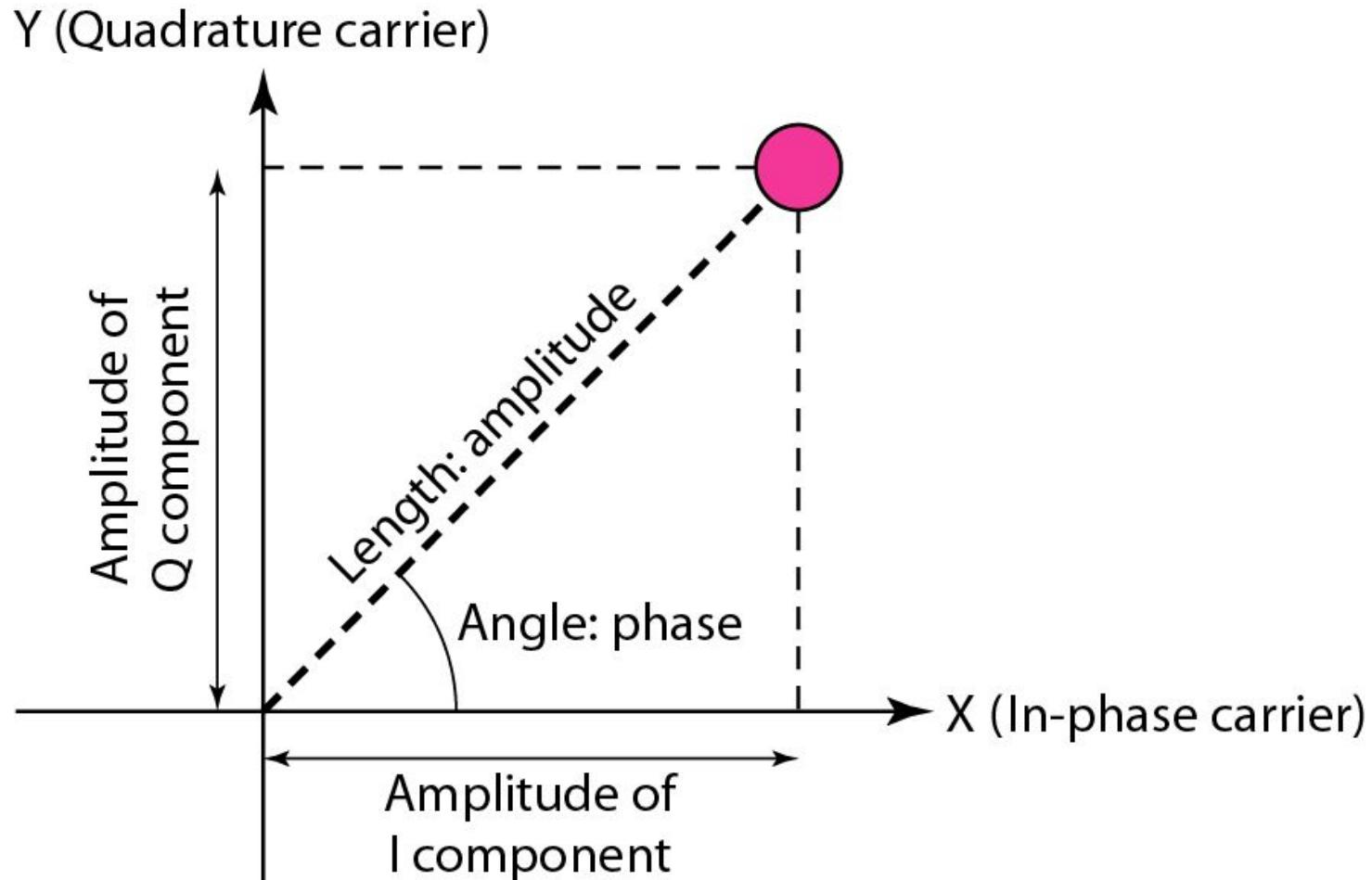
Solution

- For QPSK, 2 bits is carried by one signal element. This means that $r = 2$. So the signal rate (baud rate) is $S = N \times (1/r) = 6 \text{ Mbaud}$. With a value of $d = 0$, we have $B = S = 6 \text{ MHz}$.

Constellation Diagrams

- A constellation diagram helps us to define the amplitude and phase of a signal when we are using two carriers, one in quadrature of the other.
- The X-axis represents the in-phase carrier and the Y-axis represents quadrature carrier.

Figure 12 *Concept of a constellation diagram*



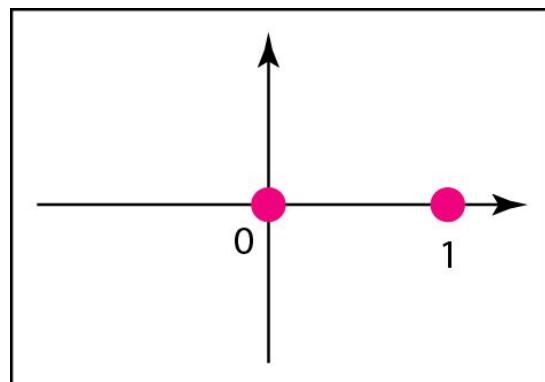
Example 8

- Show the constellation diagrams for an ASK (OOK), BPSK, and QPSK signals.

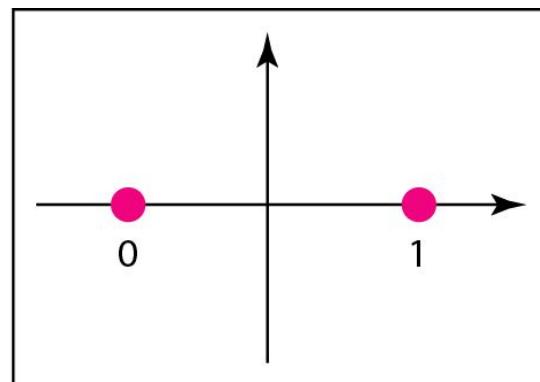
Solution

- Figure 5.13 shows the three constellation diagrams.

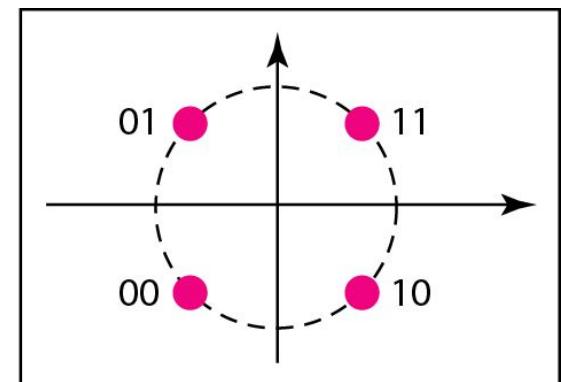
Figure 13 Three constellation diagrams



a. ASK (OOK)



b. BPSK



c. QPSK

Quadrature amplitude modulation (QAM)

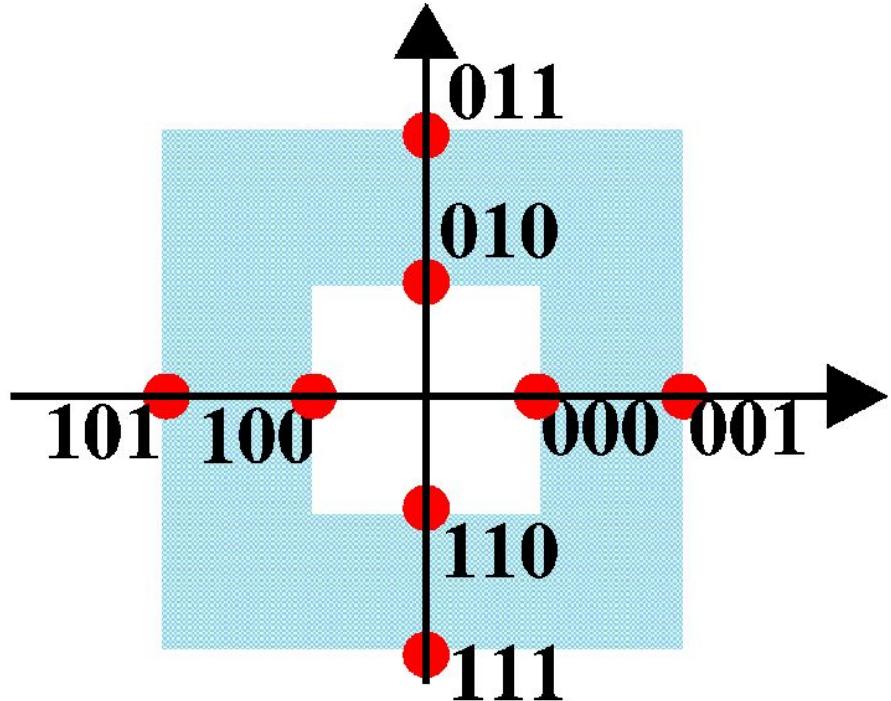
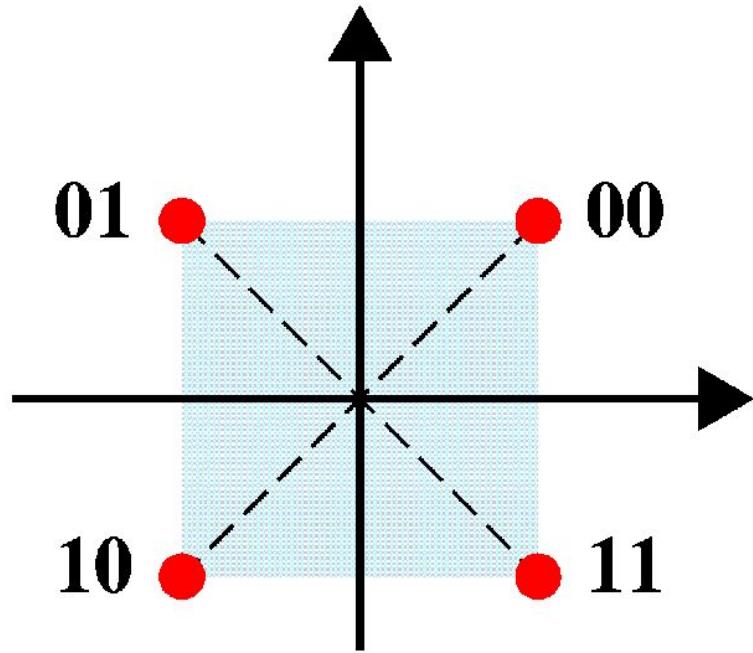
QAM is a combination of ASK and PSK.

Bandwidth for QAM

The minimum bandwidth required for QAM transmission is the same as that required for ASK and PSK transmission.

QAM has the same advantages as PSK over ASK.

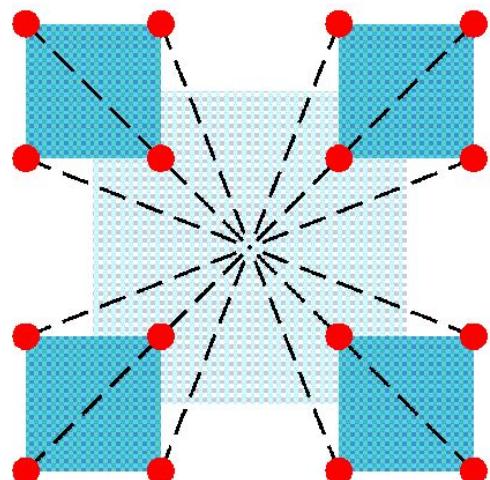
4-QAM and 8-QAM Constellations



4-QAM
1 amplitude, 4 phases **8-QAM**
2 amplitudes, 4 phases

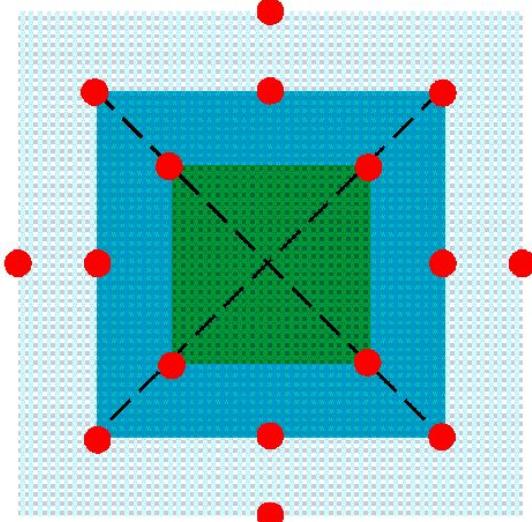
16-QAM Constellati on

3 amplitudes,
12 phases



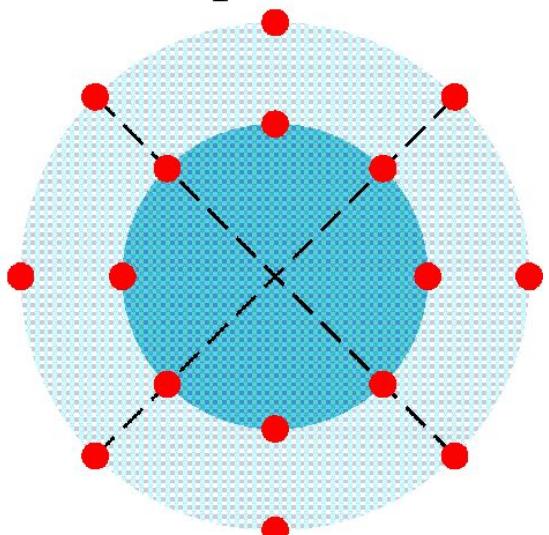
16-QAM

4 amplitudes,
8 phases



16-QAM

2 amplitudes,
8 phases



16-QAM

Multiplexing : Sharing a Medium

Introduction

Introduction-multiplexing and De-multiplexing

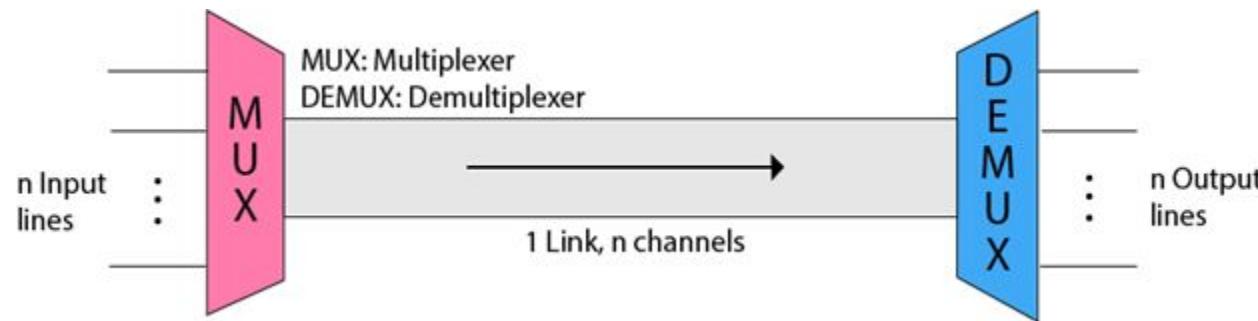
What is Multiplexing?

-Multiplexing is a technique used to combine and send the multiple data streams over a single medium. The process of combining the data streams is known as **multiplexing** and hardware used for multiplexing is known as a **multiplexer**.

-Multiplexing is achieved by using a device called Multiplexer (**MUX**) that combines n input lines to generate a single output line. Multiplexing follows many-to-one, i.e., n input lines and one output line.

Demultiplexing

- **Demultiplexing** is achieved by using a device called Demultiplexer (**DEMUX**) available at the receiving end. DEMUX separates a signal into its component signals (one input and n outputs). Therefore, we can say that demultiplexing follows the one-to-many approach.



- The 'n' input lines are transmitted through a multiplexer and multiplexer combines the signals to form a composite signal.
- The composite signal is passed through a Demultiplexer and demultiplexer separates a signal to component signals and transfers them to their respective destinations

Why Multiplexing?

- The transmission medium is used to send the signal from sender to receiver. The medium can only have one signal at a time.
- If there are multiple signals to share one medium, then the medium must be divided in such a way that each signal is given some portion of the available bandwidth. For example: If there are 10 signals and bandwidth of medium is 100 units, then the 10 unit is shared by each signal.
- When multiple signals share the common medium, there is a possibility of collision. Multiplexing concept is used to avoid such collision.
- Transmission services are very expensive.

Advantages of Multiplexing:

- More than one signal can be sent over a single medium.
- The bandwidth of a medium can be utilized effectively.

Multiplexing Techniques

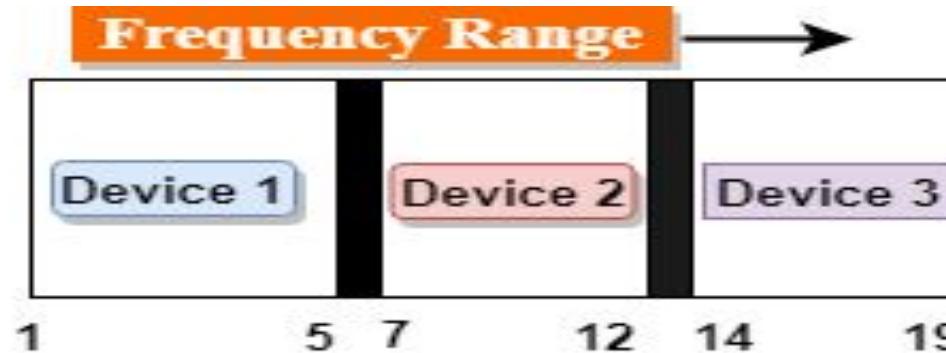
1. Frequency division multiplexing (FDM)
2. Time division multiplexing (TDM)
3. Wavelength division multiplexing (WDM)
4. Code division multiplexing (CDM)

Frequency Division Multiplexing

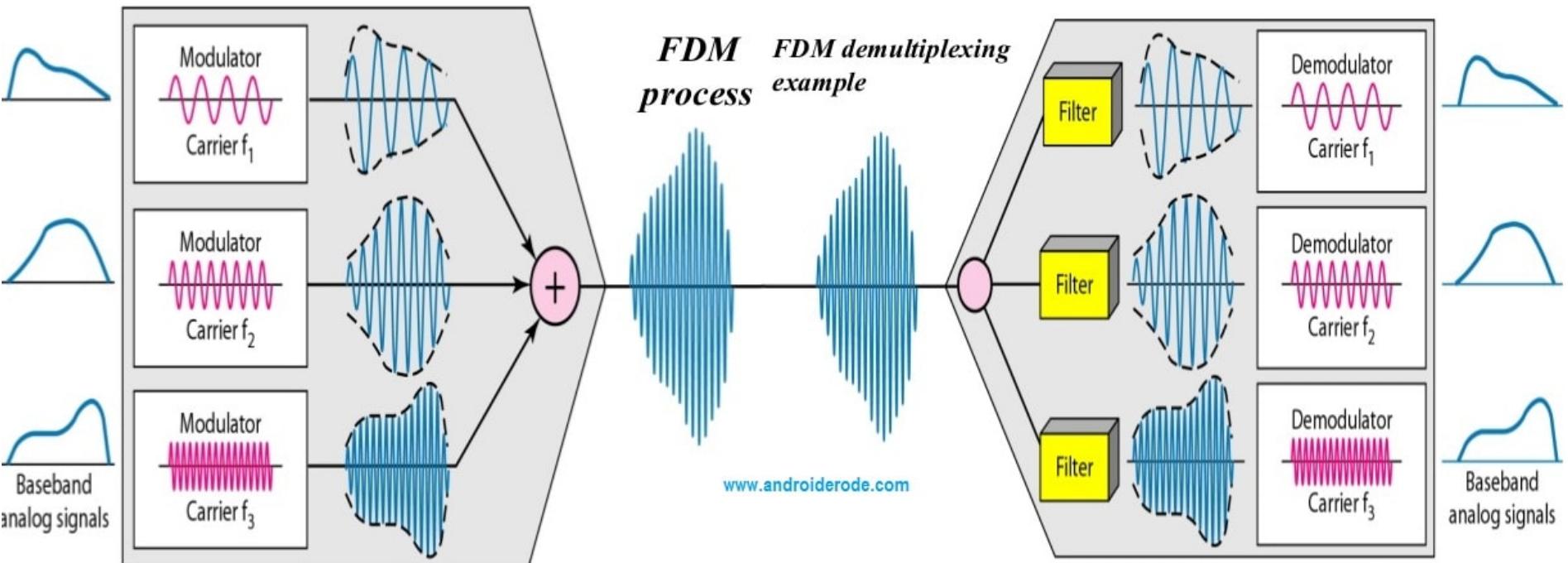
- Frequency Division Multiplexing (FDM) is a networking technique in which multiple data signals are combined for simultaneous transmission via a shared communication medium.
- FDM uses a carrier signal at a discrete frequency for each data stream and then combines many modulated signals.
- When FDM is used to allow multiple users to share a single physical communications medium (i.e. not broadcast through the air), the technology is called frequency-division multiple access (FDMA).

Frequency Division Multiplexing

- It is an analog technique.



- In the above diagram, a single transmission medium is subdivided into several frequency channels, and each frequency channel is given to different devices. Device 1 has a frequency channel of range from 1 to 5.
- The input signals are translated into frequency bands by using modulation techniques, and they are combined by a multiplexer to form a composite signal.
- The main aim of the FDM is to subdivide the available bandwidth into different frequency channels and allocate them to different devices.
- Using the modulation technique, the input signals are transmitted into frequency bands and then combined to form a composite signal.
- The carriers which are used for modulating the signals are known as **sub-carriers**. They are represented as f_1, f_2, \dots, f_n .
- **FDM** is mainly used in radio broadcasts and TV networks.



Assignment of frequencies for cable television channels

	Channel	Frequency in MHz
Low-Band VHF and Cable	2	54-60
	3	60-66
	4	66-72
	5	76-82
	6	82-88
Mid-Band Cable	95	90-96
	96	96-102
	97	102-108
	98	108-114
	99	114-120
	14	120-126
	15	126-132
	16	132-138
	17	138-144
	18	144-150
	19	150-156
	20	156-162
	21	162-168
	22	168-174
High-Band VHF and Cable	7	174-180
	8	180-186
	9	186-192
	10	192-198
	11	198-204
	12	204-210
	13	210-216

- Analog signaling is used to transmits the signals.
- Broadcast radio and television, cable television, and the AMPS cellular phone systems use frequency division multiplexing.
- This technique is the oldest multiplexing technique.
- Since it involves analog signaling, it is more susceptible to noise.

Advantages Of FDM:

- FDM is used for analog signals.
- FDM process is very simple and easy modulation.
- A Large number of signals can be sent through an FDM simultaneously.
- It does not require any synchronization between sender and receiver.

Disadvantages Of FDM:

- FDM technique is used only when low-speed channels are required.
- It suffers the problem of crosstalk.
- A Large number of modulators are required.
- It requires a high bandwidth channel.

Applications Of FDM:

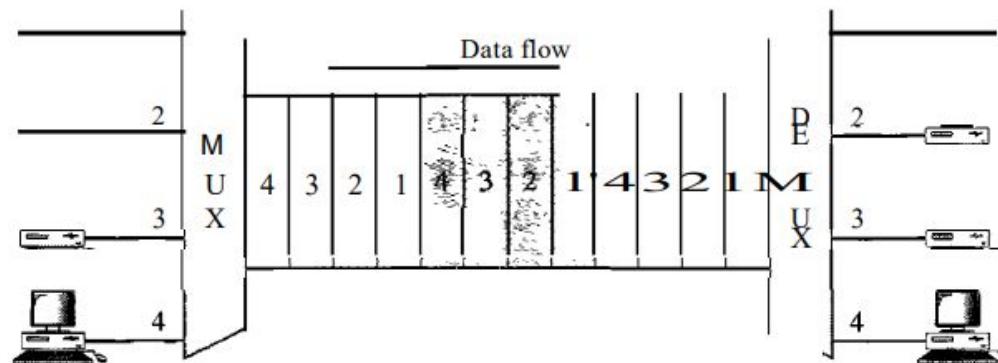
- FDM is commonly used in TV networks.
- It is used in FM and AM broadcasting. Each FM radio station has different frequencies, and they are multiplexed to form a composite signal. The multiplexed signal is transmitted in the air.

Time Division Multiplexing

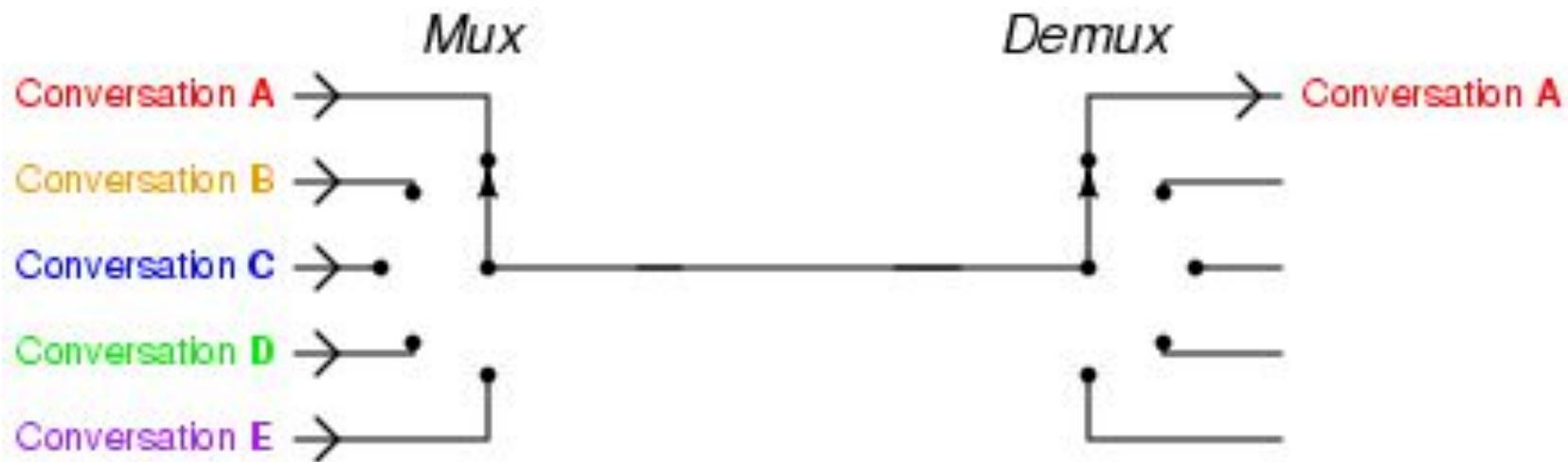
- Time-division multiplexing (TDM) is a digital process that allows several connections to share the high bandwidth of a line Instead of sharing a portion of the bandwidth as in FDM, time is shared.
- Each connection occupies a portion of time in the link.

Time Division Multiplexing

- Note that the same link is used as in FDM; here, however, the link is shown sectioned by time rather than by frequency. In the figure, portions of signals 1,2,3, and 4 occupy the link sequentially.



- Types : synchronous and statistical.**



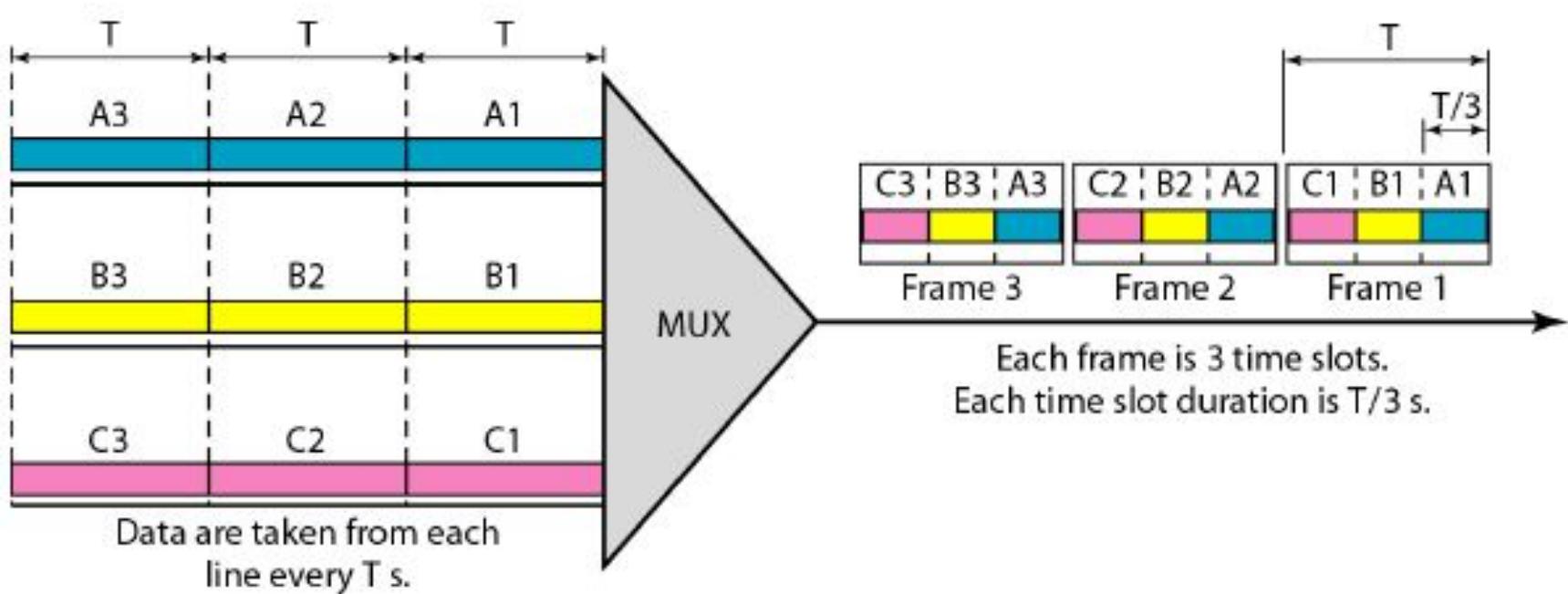
Synchronous Time Division Multiplexing

- The original time division multiplexing.
- The multiplexor accepts input from attached devices in a round-robin fashion and transmit the data in a never ending pattern.
- T-1 and ISDN telephone lines are common examples of synchronous time division multiplexing.

Synchronous TDM

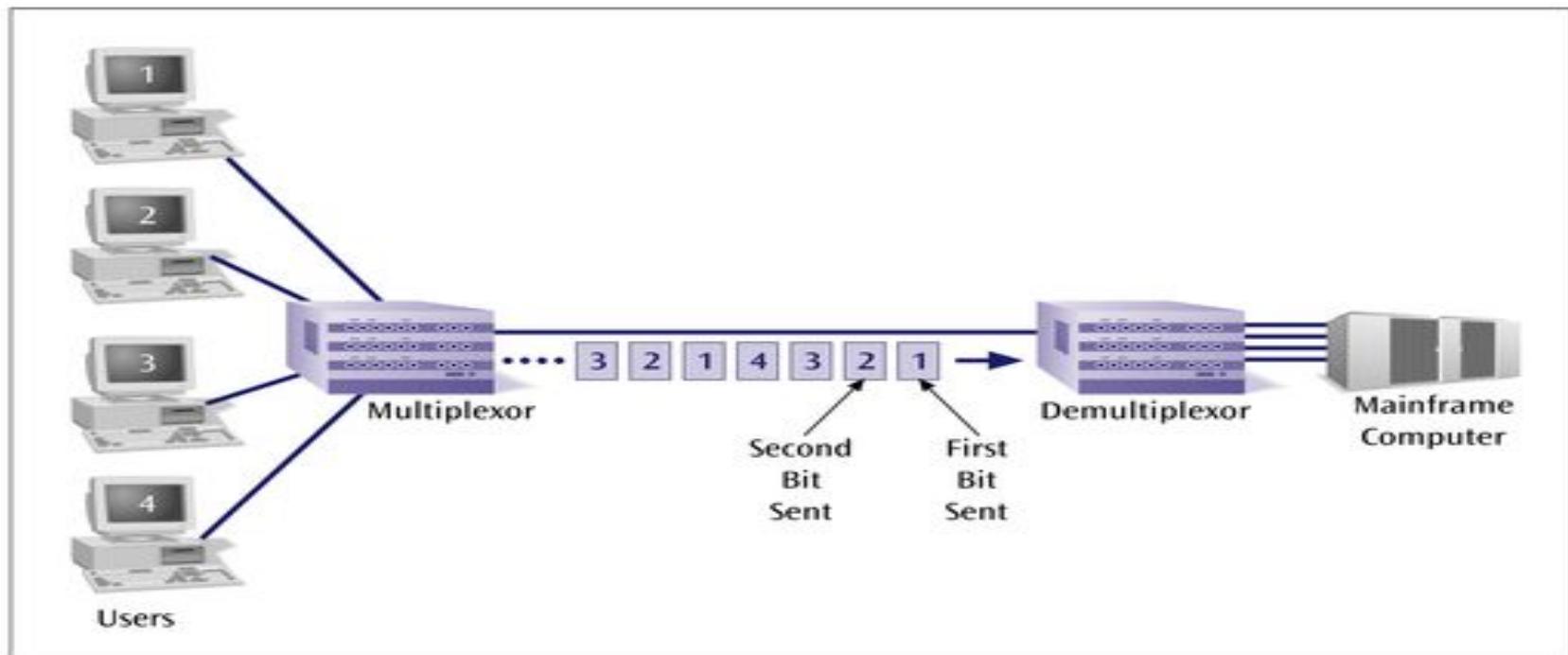
- In synchronous TDM, the data flow of each input connection is divided into units, where each input occupies one input time slot.
- A unit can be 1 bit, one character, or one block of data. Each input unit becomes one output unit and occupies one output time slot.
- However, the duration of an output time slot is n times shorter than the duration of an input time slot. If an input time slot is T s, the output time slot is T/n s, where n is the number of connections.
- In other words, a unit in the output connection has a shorter duration; it travels faster.

Synchronous TDM



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

Sample Output Stream generated by a Synchronous Time Division Multiplexing



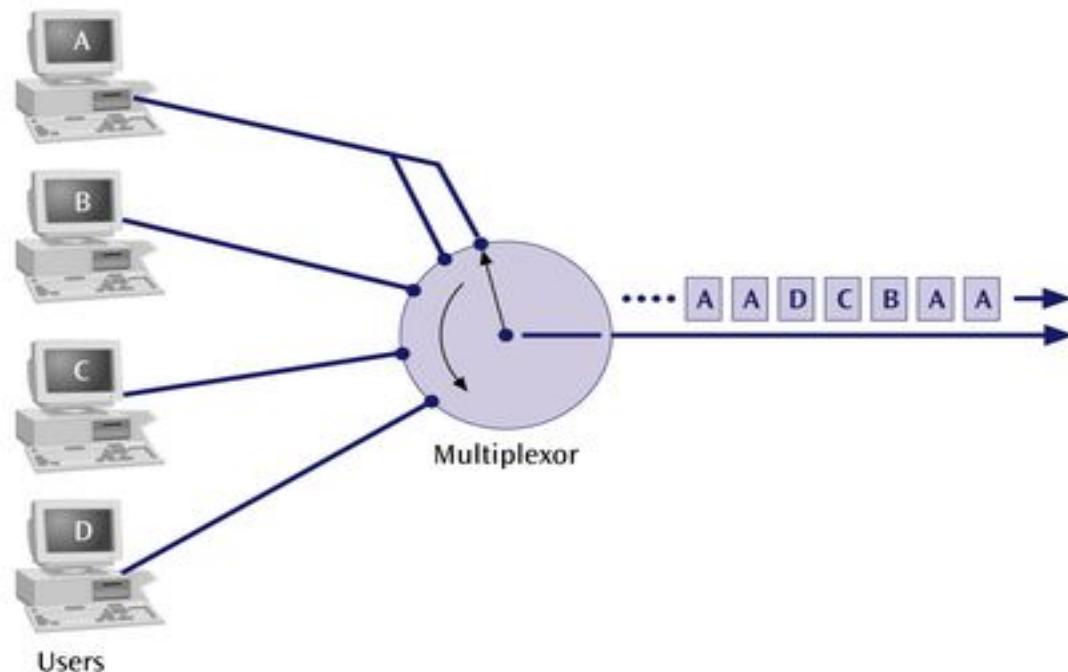
Synchronous Time Division Multiplexing

If one device generates data at a faster rate than other devices, then the multiplexor must either sample the incoming data stream from that device more often than it samples the other devices, or buffer the faster incoming stream.

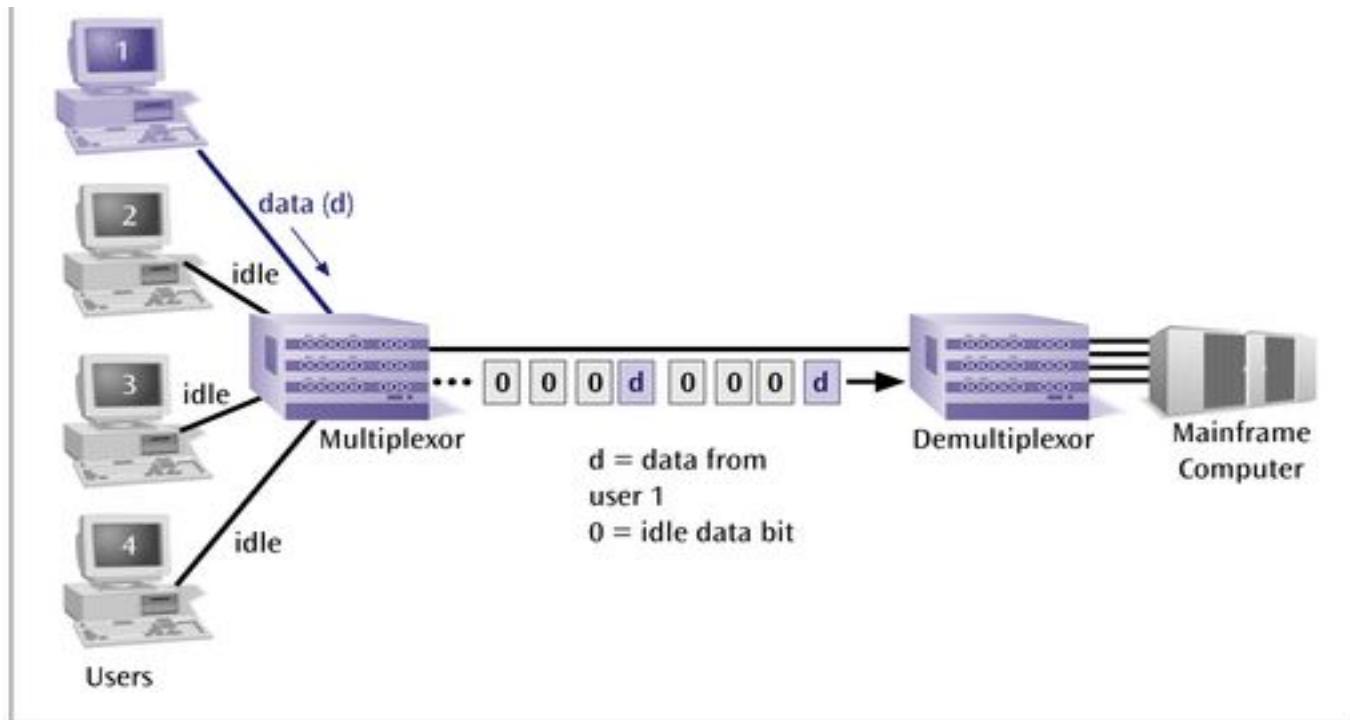
If a device has nothing to transmit, the multiplexor must still insert a piece of data from that device into the multiplexed stream.

Example

A synchronous time division multiplexor system which samples device A twice as fast as the other devices

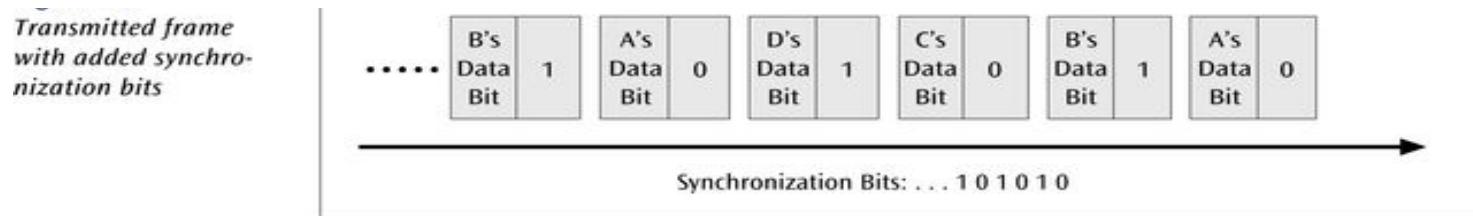


Multiplexor transmission stream with only one input device transmitting data



Synchronous time division multiplexing

So that the receiver may stay synchronized with the incoming data stream, the transmitting multiplexor can insert alternating 1s and 0s into the data stream.



Synchronous Time Division Multiplexing

Three types popular today:

- T-1 multiplexing (the classic)
- ISDN multiplexing
- SONET (**S**ynchronous **O**ptical **N**ETwork)

Statistical Time Division Multiplexing

A statistical multiplexor does not require a line over as high a speed line as synchronous time division multiplexing since STDM does not assume all sources will transmit all of the time!

Good for low bandwidth lines (used for LANs)

Much more efficient use of bandwidth!

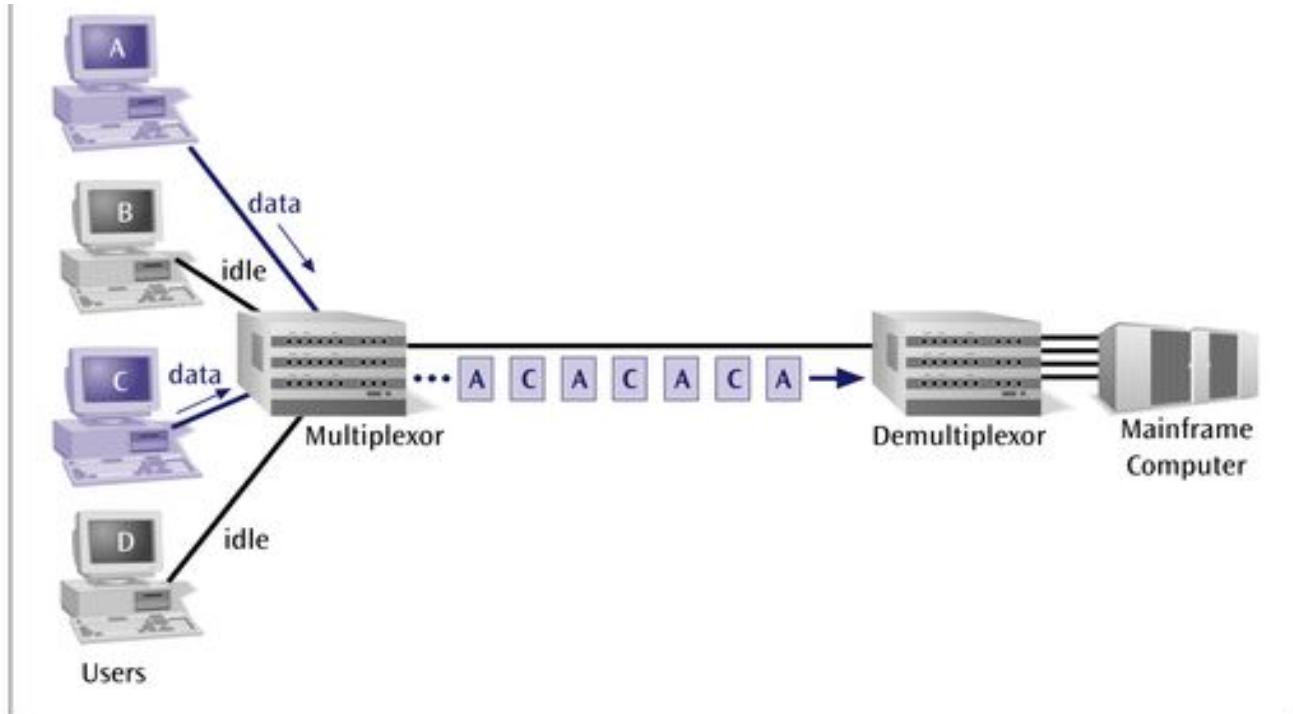
Statistical Time Division Multiplexing

A statistical multiplexor transmits only the data from active workstations (*or why work when you don't have to*).

If a workstation is not active, no space is wasted on the multiplexed stream.

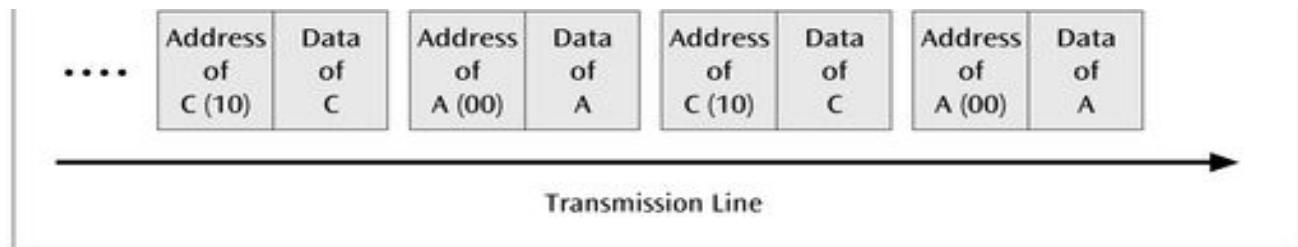
A statistical multiplexor accepts the incoming data streams and creates a frame containing only the data to be transmitted.

Two stations out of four transmitting via a statistical multiplexor



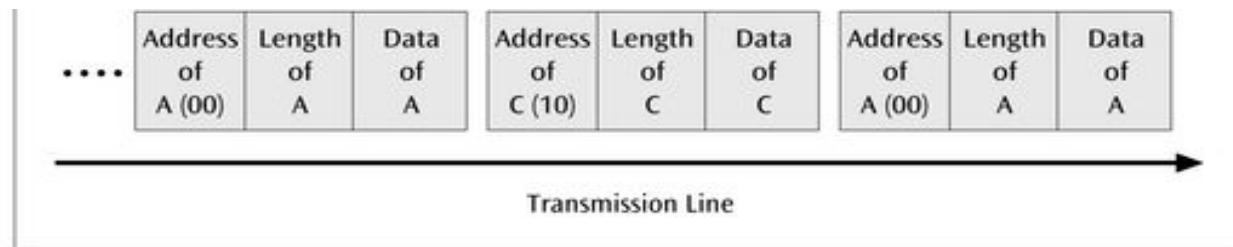
To identify each piece of data, an address is included.

Sample address and data in a statistical multiplexor output stream



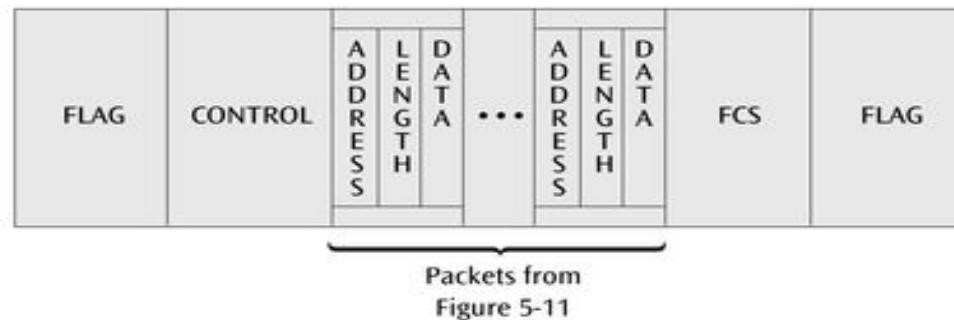
If the data is of variable size, a length is also included.

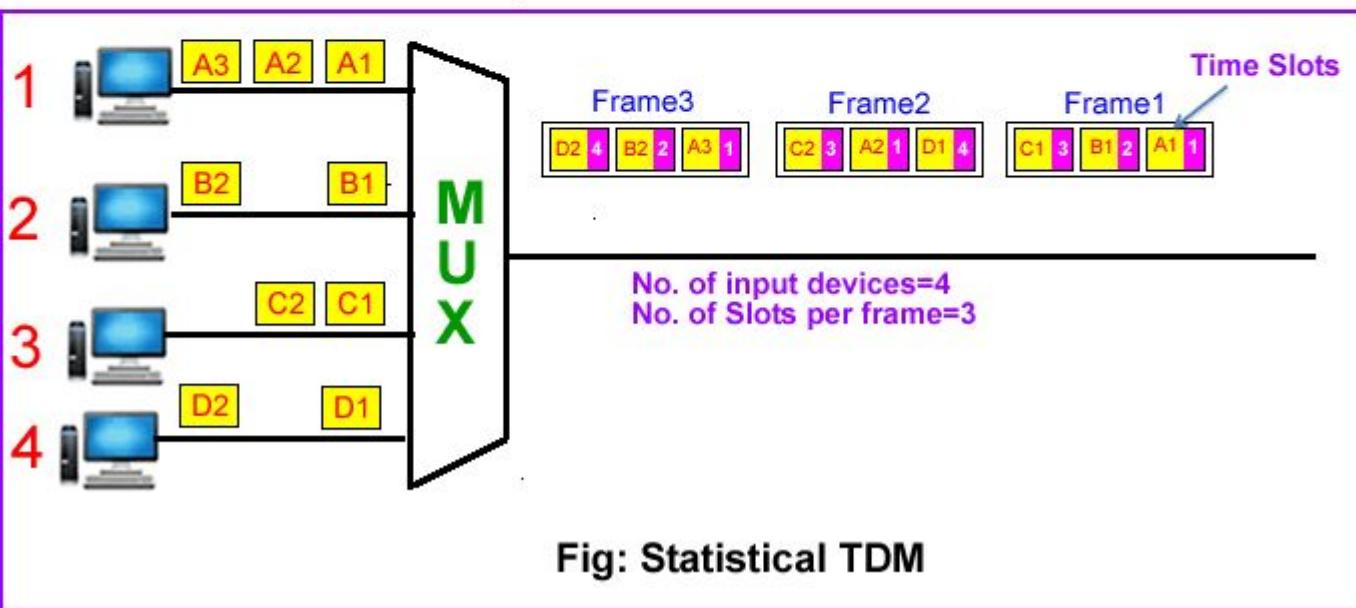
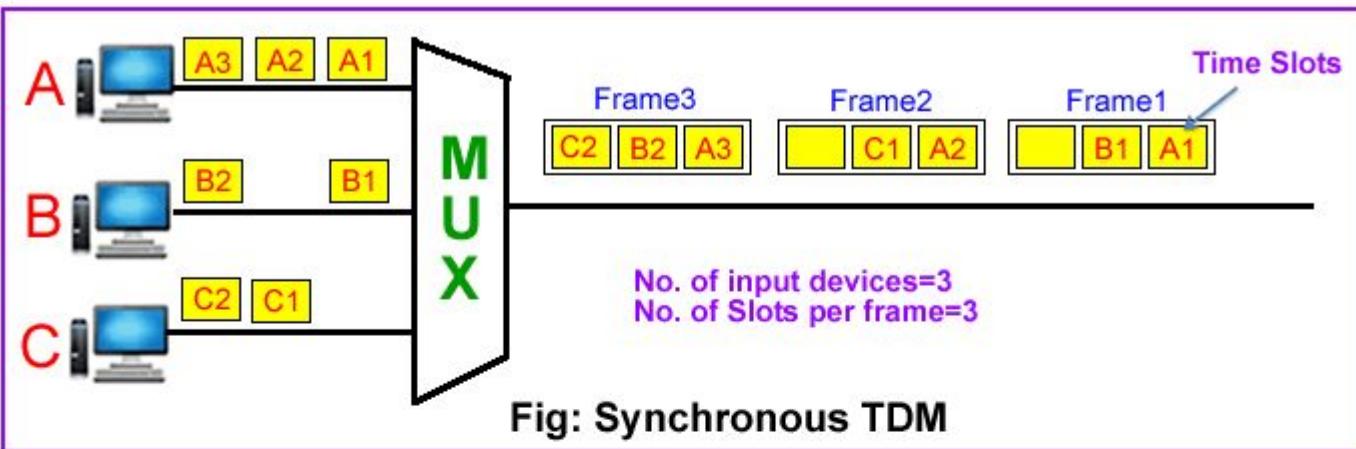
Packets of address and data fields in a statistical multiplexor output stream



More precisely, the transmitted frame contains a collection of data groups.

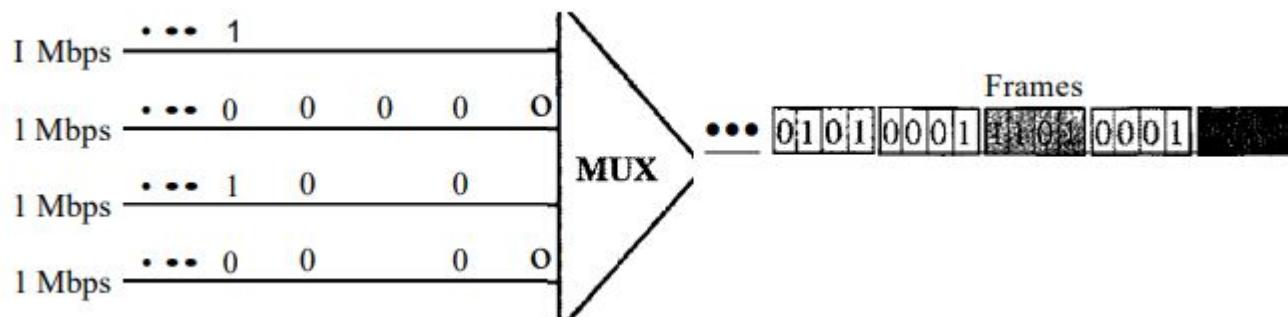
Frame layout for the information packet transferred between statistical multiplexors





Problems

- Synchronous TDM with a data stream for each input and one data stream for the output. The unit of data is 1 bit. Find (a) the input bit duration, (b) the output bit duration, (c) the output bit rate, and (d) the output frame rate.

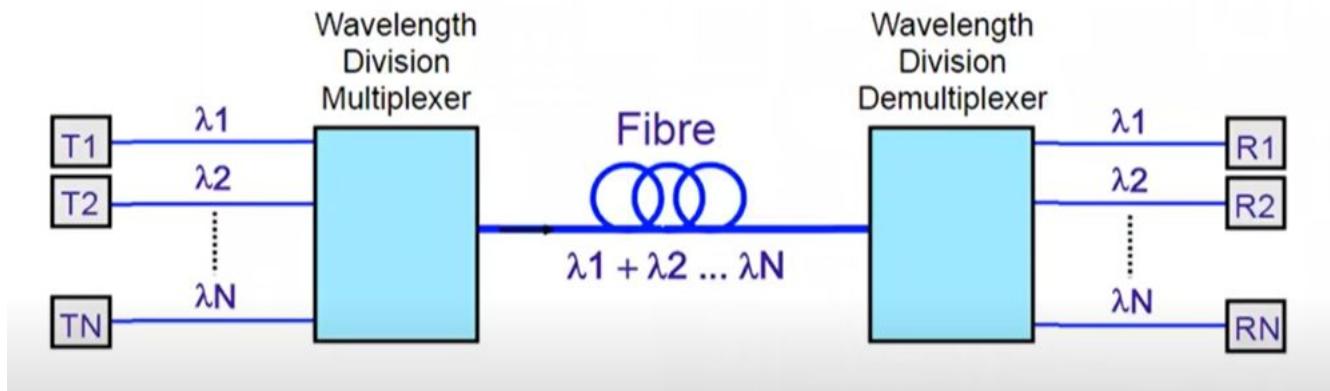


Solution

- A. The input bit duration is the inverse of the bit rate: $1/1 \text{ Mbps} = 1 \text{ lls}$.
- b. The output bit duration is one-fourth of the input bit duration, or $1/411\text{s}$.
- c. The output bit rate is the inverse of the output bit duration or $1/4 \text{ lls}$, or 4 Mbps . This can also be deduced from the fact that the output rate is 4 times as fast as any input rate; so the output rate $= 4 \times 1 \text{ Mbps} = 4 \text{ Mbps}$.
- d. The frame rate is always the same as any input rate. So the frame rate is 1,000,000 frames per second. Because we are sending 4 bits in each frame, we can verify the result of the previous question by multiplying the frame rate by the number of bits per frame.

Wavelength Division Multiplexing (WDM)

- Give each message a different wavelength (frequency).
- Easy to do with fiber optics and optical sources



Categories of WDM

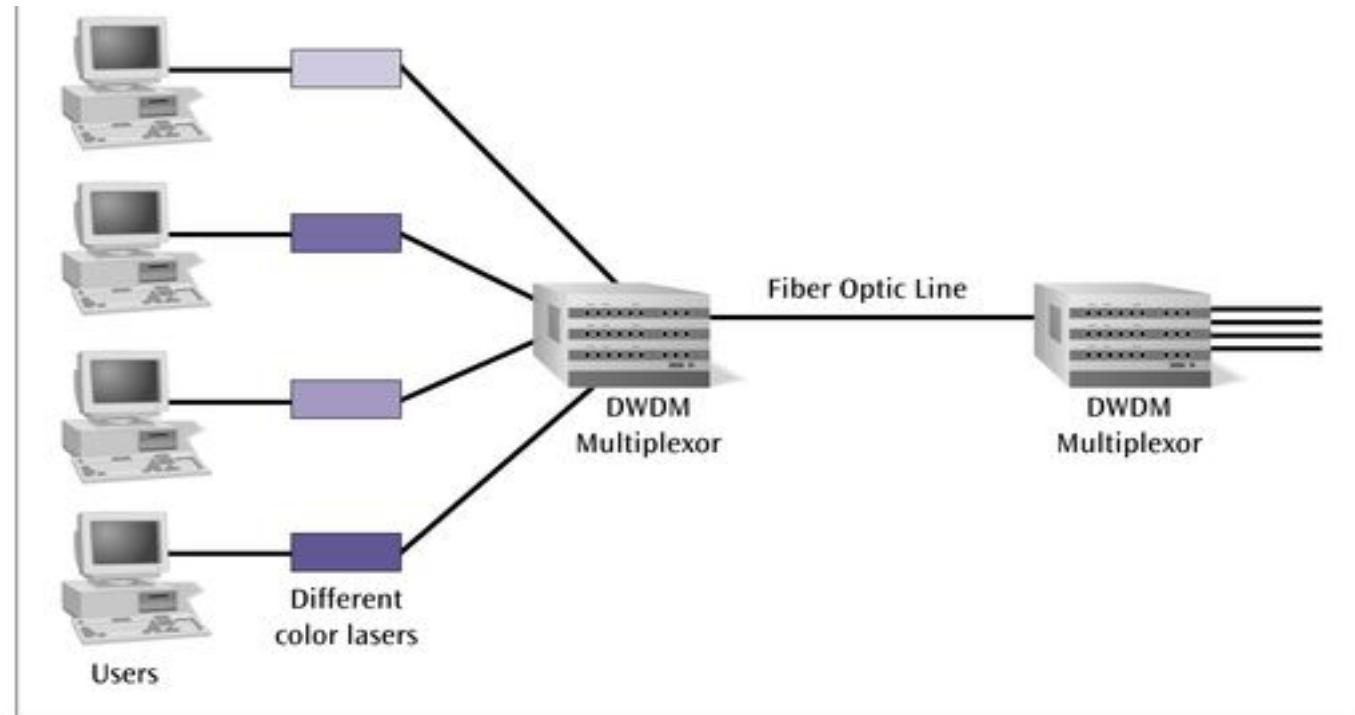
- **Course WDM (CWDM)** : CWDM generally operates with 8 channels where the spacing between the channels is 20 nm (nanometers) apart. It consumes less energy than DWDM and is less expensive. However, the capacity of the links, as well as the distance supported, is lesser.
- **Dense WDM (DWDM)** : In DWDM, the number of multiplexed channels much larger than CWDM. It is either 40 at 100GHz spacing or 80 with 50GHz spacing. Due to this, they can transmit the huge quantity of data through a single fiber link. DWDM is generally applied in core networks of telecommunications and cable networks. It is also used in cloud data centers for their IaaS services.

Dense Wavelength Division Multiplexing (DWDM)

- Dense wavelength division multiplexing is often called just wavelength division multiplexing
- Dense wavelength division multiplexing multiplexes multiple data streams onto a single fiber optic line.
- Different wavelength lasers (called lambdas) transmit the multiple signals.
- Each signal carried on the fiber can be transmitted at a different rate from the other signals.
- Dense wavelength division multiplexing combines many (30, 40, 50, 60, more?) onto one fiber.

Data Signals Transmitted

Multiple lasers transmitting data signals down a single fiber optic line



Advantages and disadvantages of multiplexing techniques

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

Business Multiplexing In Action

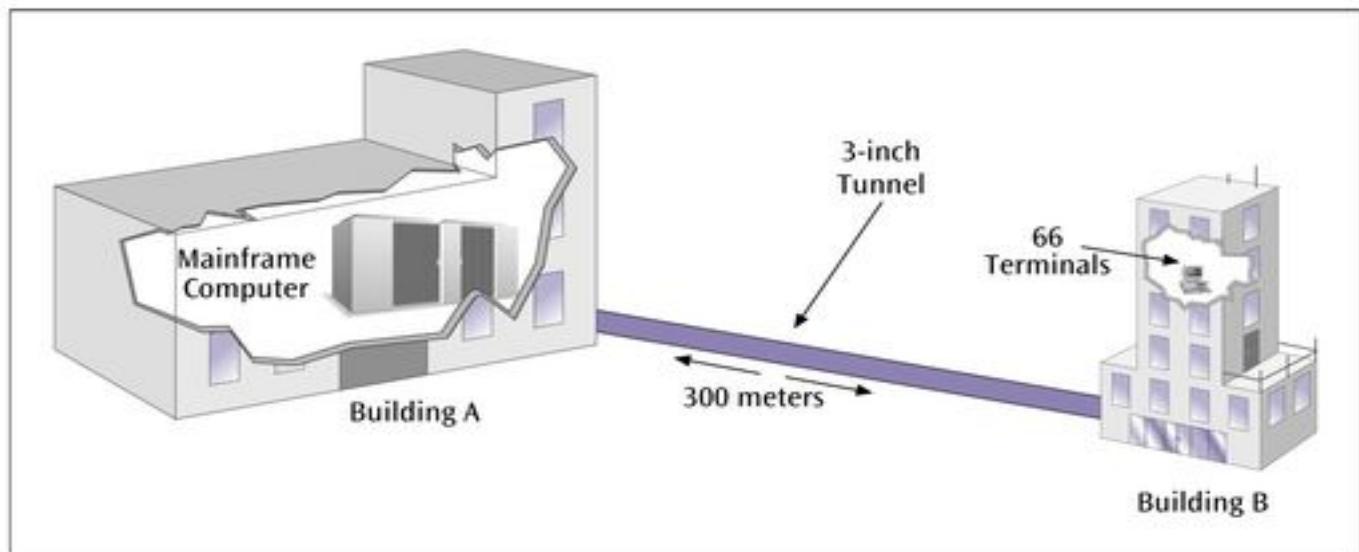
XYZ Corporation has two buildings separated by a distance of 300 meters.

A 3-inch diameter tunnel extends underground between the two buildings.

Building A has a mainframe computer and Building B has 66 terminals.

List some efficient techniques to link the two buildings.

Figure 5-15
Buildings A and B and the 3-inch tunnel connecting the buildings



Transmission Media

Transmission Media

- The physical path between transmitter and receiver is called transmission medium. It is a pathway that carries information from sender to receiver.
- In One type of transmission medium , transmission occurs through a solid medium, such as copper twisted pair, copper coaxial cable, and optical fiber
- For second type of transmission medium , transmission occurs wireless through the atmosphere, outer space, or water.
- It is located below the physical layer and are directly controlled by the physical layer.
- Data is transmitted normally in electrical or electromagnetic signals.
- Signals are transmitted in the form of electromagnetic energy.

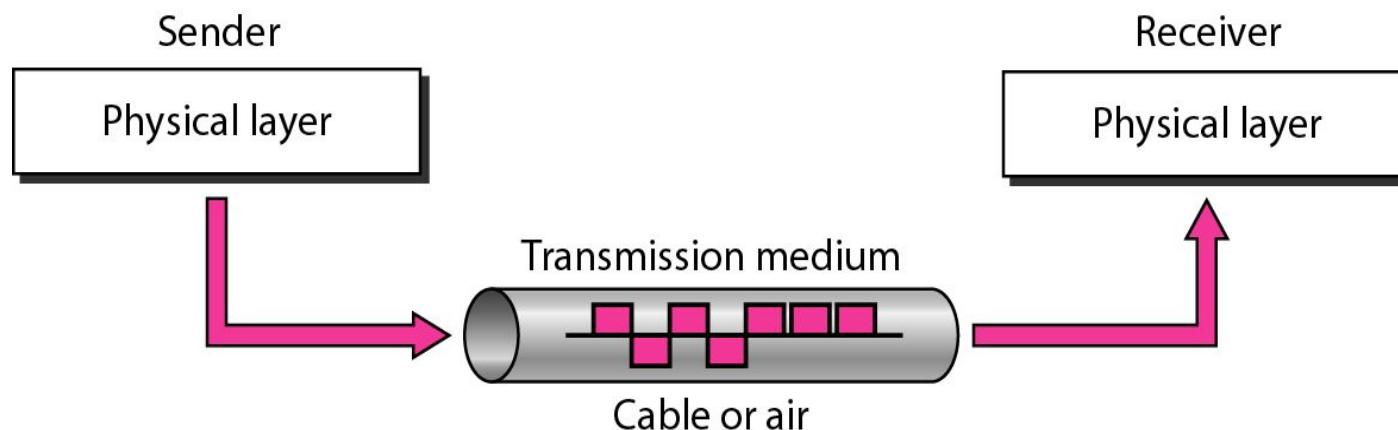


Figure 7.1 *Transmission medium and physical layer*

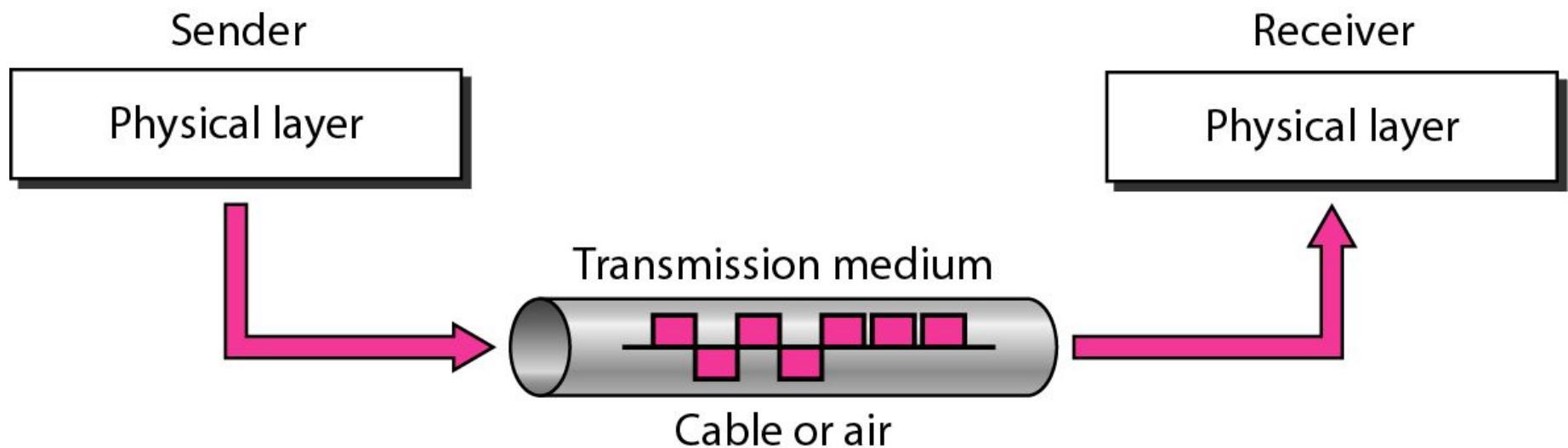
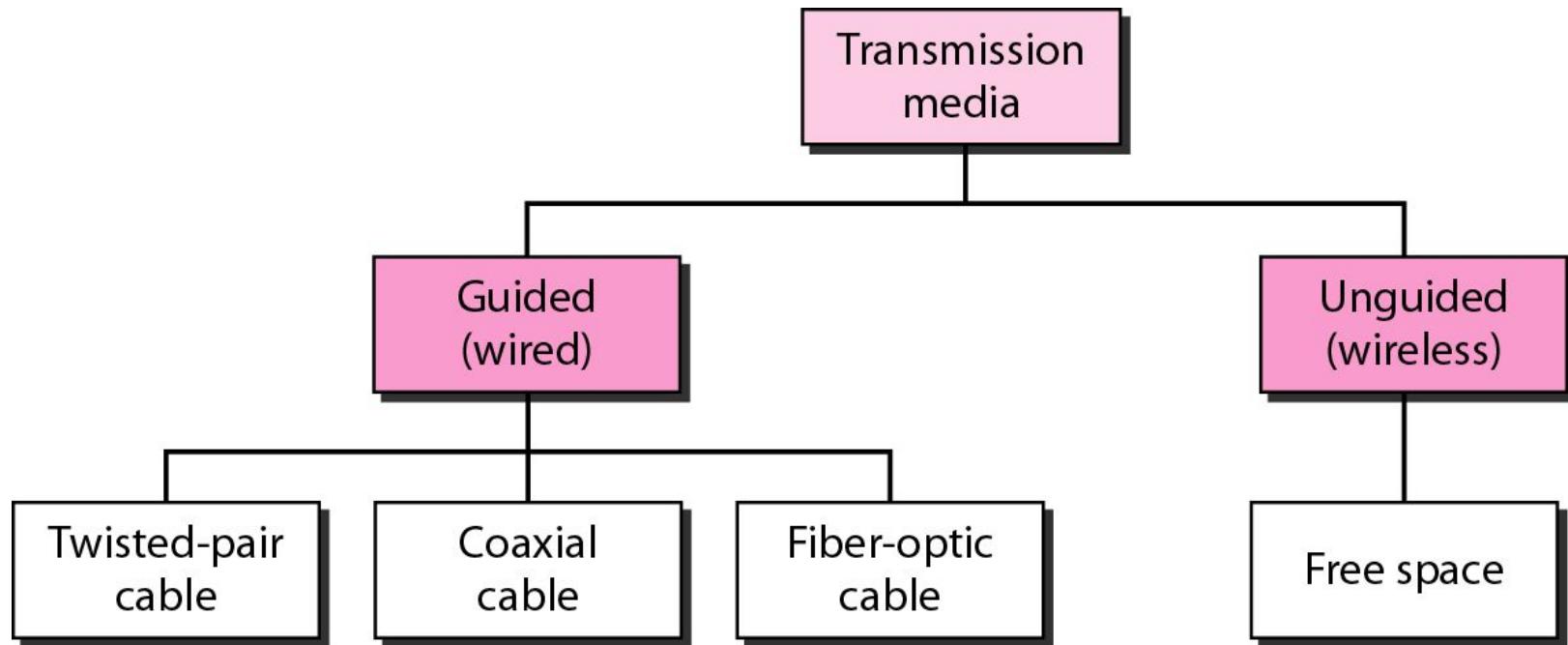


Figure 7.2 *Classes of transmission media*



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.

Topics discussed in this section:

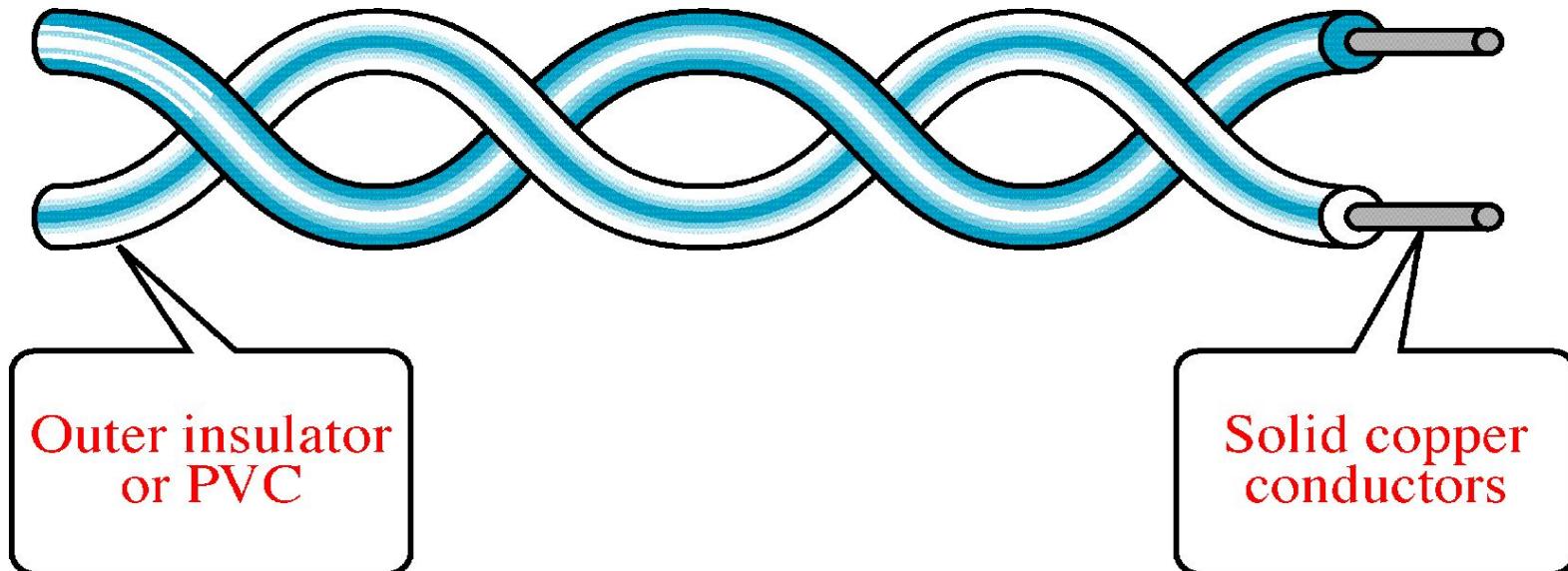
Twisted-Pair Cable

Coaxial Cable

Fiber-Optic Cable

- ❖ Twisted-pair and coaxial cable use metallic (copper) conductors that accept and transport signals in the form of electric current.
- ❖ Optical fiber is a cable that accepts and transports signals in the form of light.

Figure 7.3 Twisted-pair cable



Twisted-pair cable

- A twisted pair consists of two conductors (normally copper), each with its own plastic insulation, twisted together.
- One of the wires is used to carry **signals** to the receiver, and the other is used only as a **ground reference**.
- The receiver uses the difference between the two.
- In addition to the signal sent by the sender on one of the wires, **interference (noise) and crosstalk** may affect both wires and create unwanted signals.

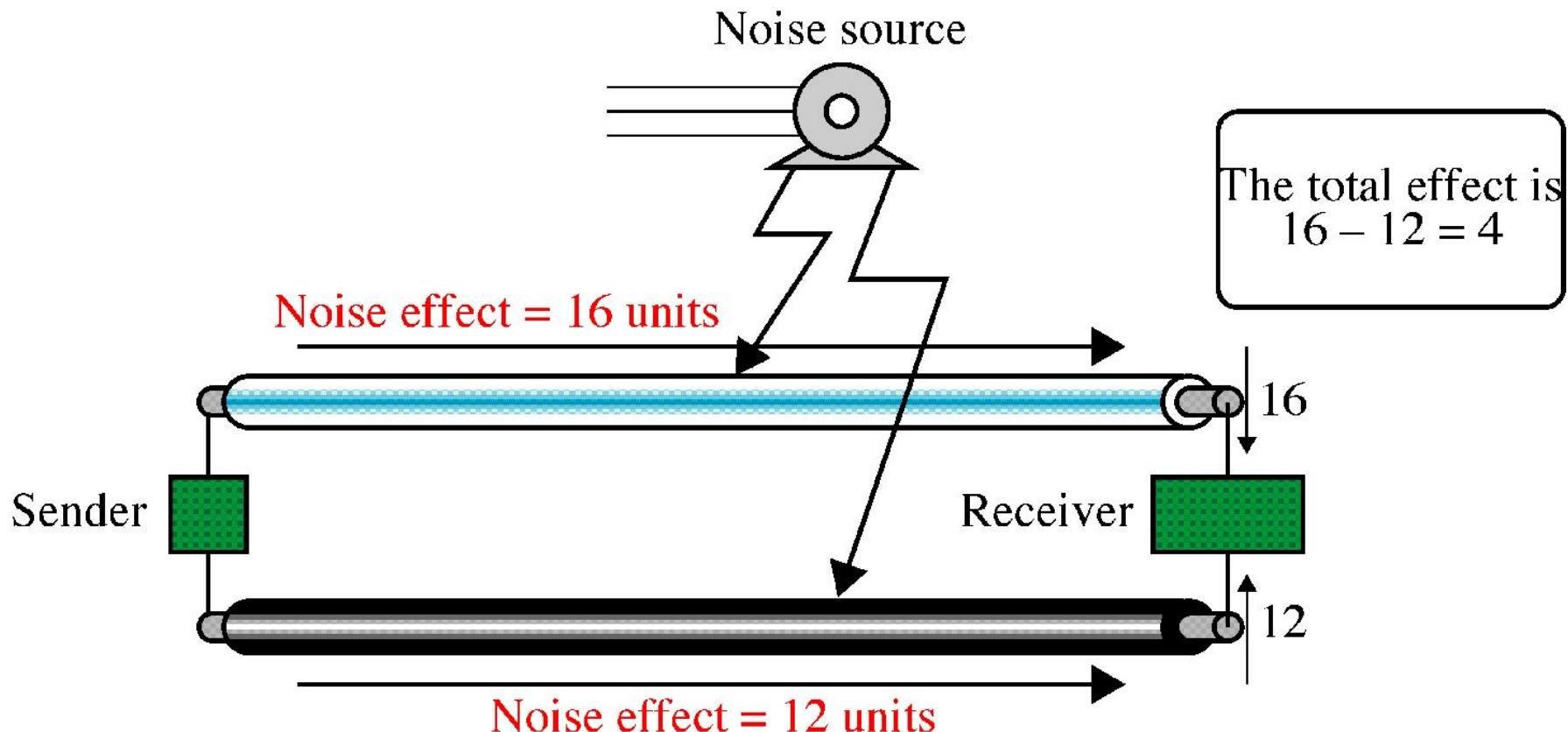
Twisted-pair cable

- **If the two wires are parallel,** the effect of these unwanted signals is not the same in both wires because they are at different locations relative to the noise or crosstalk sources
- (e.g., one is closer and the other is farther). This results in a difference at the receiver.
- **By twisting the pairs,** a balance is maintained.
- For example, suppose in one twist, one wire is closer to the noise source and the other is farther; in the next twist, the reverse is true.

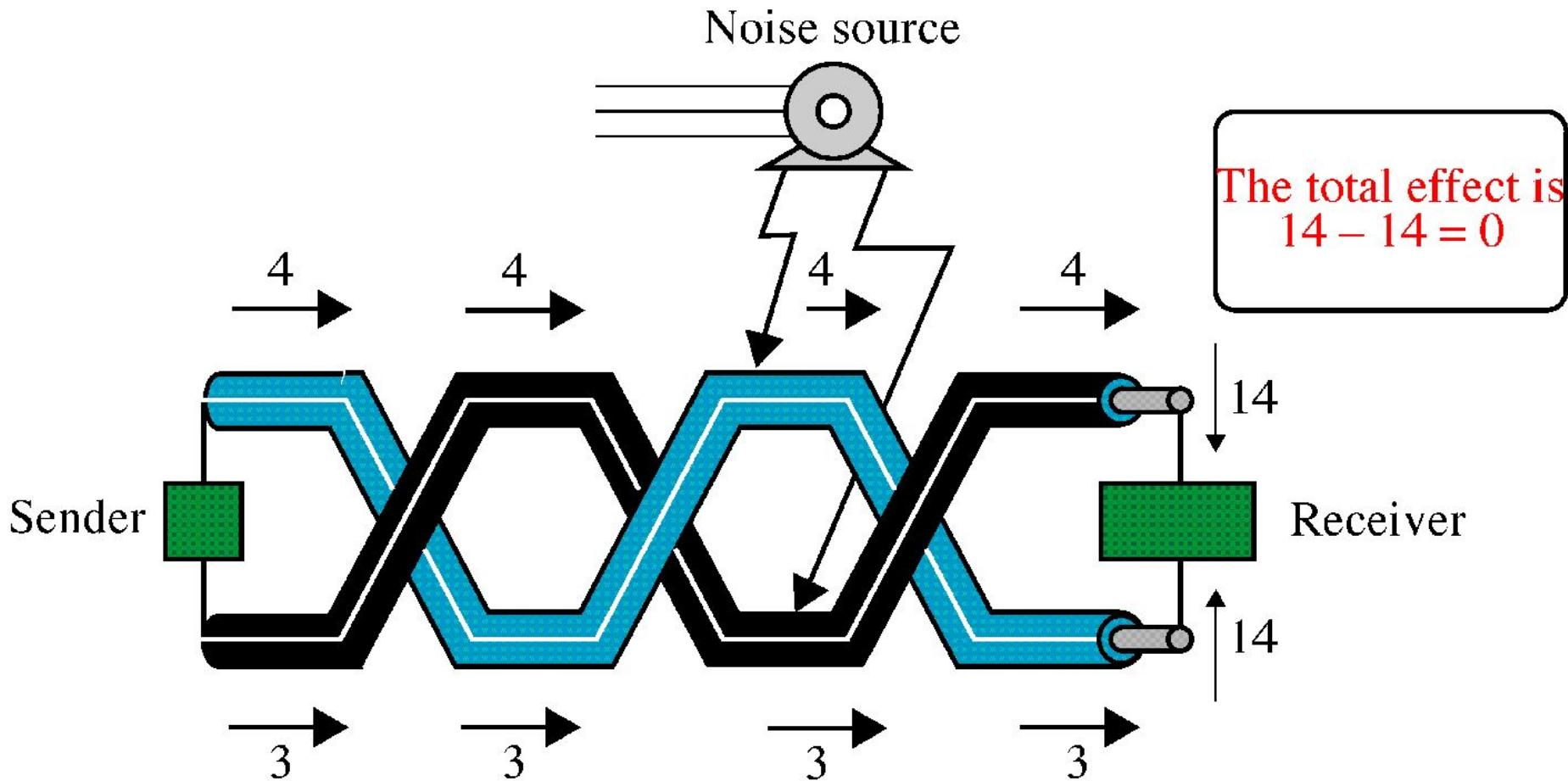
Twisted-pair cable

- Twisting makes it probable that both wires are equally affected by external influences (noise or crosstalk).
- This means that the receiver, which calculates the difference between the two, receives no unwanted signals. The unwanted signals are mostly canceled out.
- From the above discussion, it is clear that the number of twists per unit of length (e.g., inch) has some effect on the quality of the cable.

Effect of Noise on Parallel Lines



Noise on Twisted-Pair Lines



Unshielded Twisted Pair (UTP)

- Ordinary telephone wire
- Cheapest
- Easiest to install
- Suffers from external EM interference

Advantages of UTP:

- Affordable
- Most compatible cabling
- Major networking system

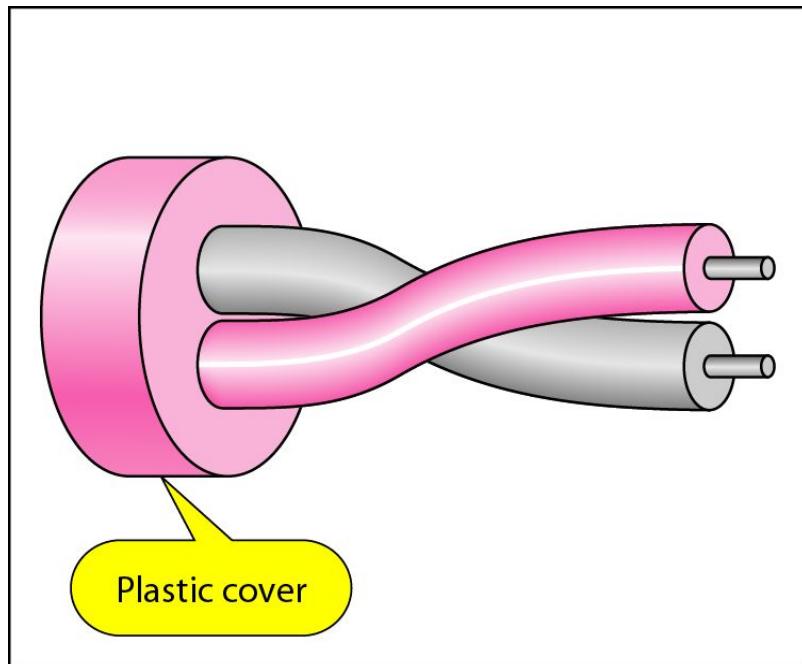
Disadvantages of UTP:

- Suffers from external Electromagnetic interference

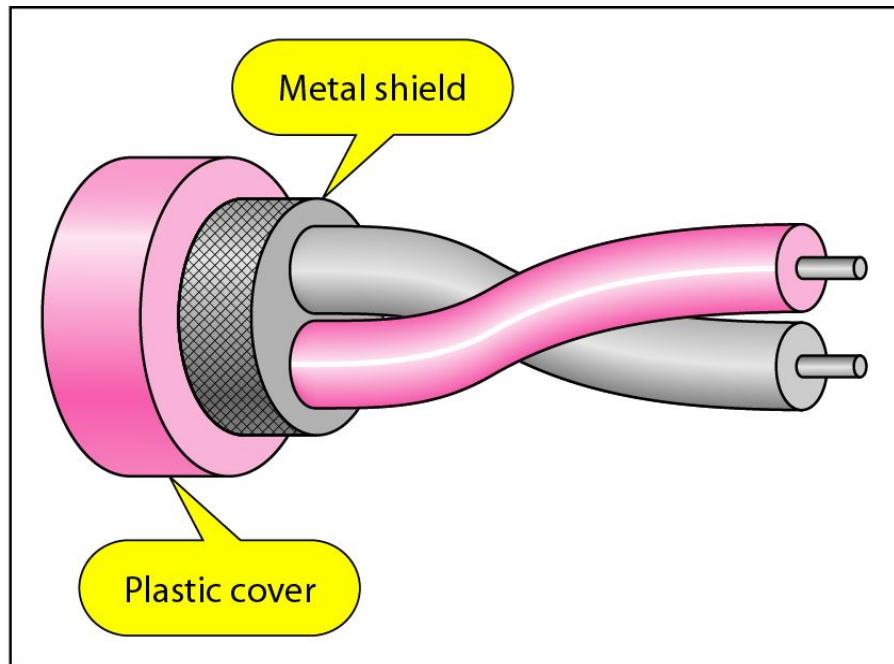
Applications:

- Telephone lines connecting subscribers to the central office
- DSL lines
- LAN – 10Base-T and 100Base-T

Figure 7.4 *UTP and STP cables*



a. UTP



b. STP

Unshielded Versus Shielded Twisted-Pair Cable

- The most common twisted-pair cable used in communications is referred to as unshielded twisted-pair (UTP).
- IBM has also produced a version of twisted-pair cable for its use called shielded twisted-pair (STP).
- STP cable has a **metal foil or braided mesh** covering that encases each pair of insulated conductors.
- Although metal casing **improves the quality of cable** by preventing the penetration of noise or crosstalk, it is **bulkier and more expensive**.
- Our discussion focuses primarily on UTP because STP is seldom used outside of IBM.

Table 7.1 Categories of unshielded twisted-pair cables

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

Performance

- One way to measure the performance of twisted-pair cable is to compare **attenuation versus frequency and distance.**
- A twisted-pair cable can pass a wide range of frequencies.
- However, Figure 7.6 shows that with increasing frequency, the attenuation, measured in decibels per kilometer (dB/km), sharply increases with frequencies above 100 kHz.
- Note that *gauge is a measure of the thickness of the wire.*

Figure 7.6 UTP performance

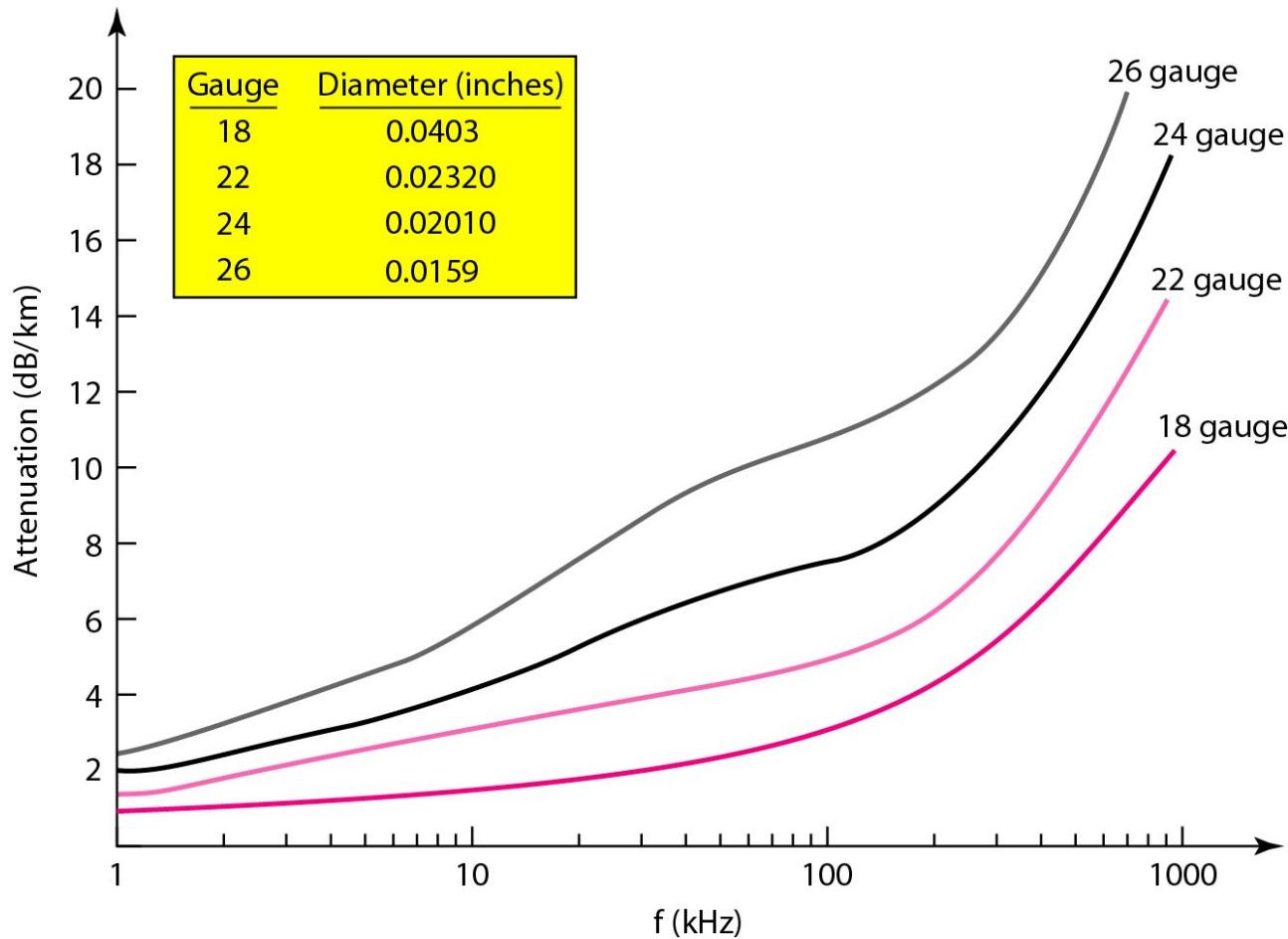
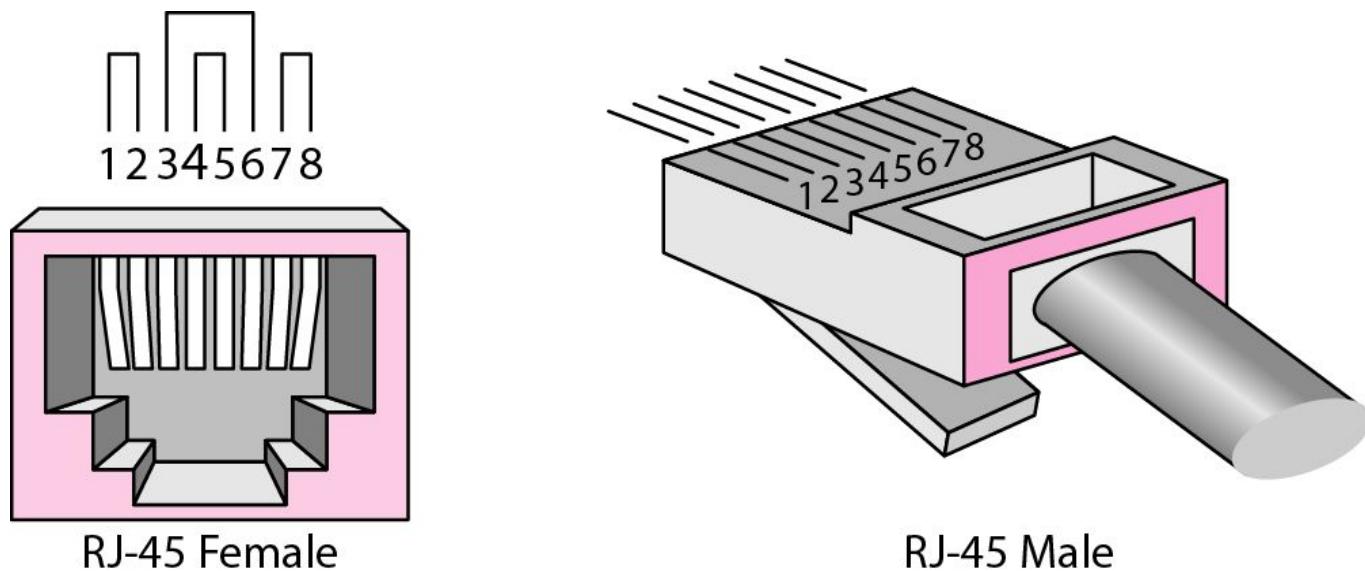


Figure 7.5 UTP connector



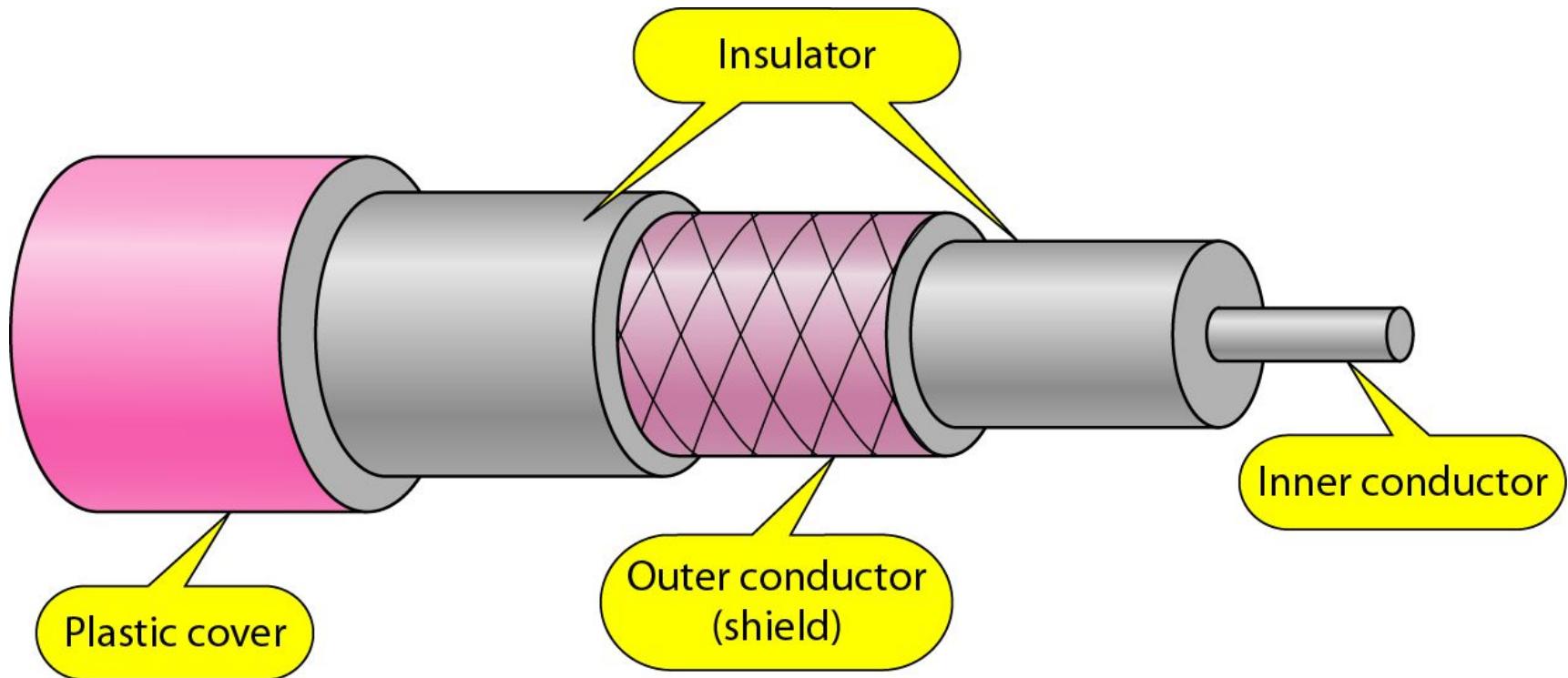
Applications

- Twisted-pair cables are used in telephone lines to provide voice and data channels.
- The **local loop**-the line that connects subscribers to the central telephone office---commonly consists of unshielded twisted-pair cables.
- The **DSL lines** that are used by the telephone companies to provide high-data-rate connections also use the high-bandwidth capability of unshielded twisted-pair cables.

Coaxial Cable

- Coaxial cable (or *coax*) *carries signals of higher frequency ranges than those in twistedpair cable*, in part because the two media are constructed quite differently.
- Instead of having two wires, coax has a central core conductor of solid or stranded wire (usually copper) enclosed in an insulating sheath, which is, in turn, encased in an outer conductor of metal foil, braid, or a combination of the two.
- The outer metallic wrapping serves both as a shield against noise and as the second conductor, which completes the circuit.
- This outer conductor is also enclosed in an insulating sheath, and the whole cable is protected by a plastic cover

Figure 7.7 Coaxial cable



Coaxial Cable Standards

- Coaxial cables are categorized by their radio government (RG) ratings.
- Each RG number denotes a unique set of physical specifications, including the *wire gauge of the inner conductor, the thickness and type of the inner insulator, the construction of the shield, and the size and type of the outer casing*.
- Each cable defined by an RG rating is adapted for a specialized function, as shown in following Table

Table 7.2 Categories of coaxial cables

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

Coaxial Cable Connectors

- To connect coaxial cable to devices, we need coaxial connectors.
- The most common type of connector used today is the **Bayone-Neill-Concelman (BNC) connector**.
- The BNC connector is used to connect the **end of the cable to a device, such as a TV set**.
- The BNC T connector is used in Ethernet networks to branch out to a connection to a computer or other device.
- The **BNC terminator** is used at the end of the cable to prevent the reflection of the signal.

Figure 7.8 BNC connectors

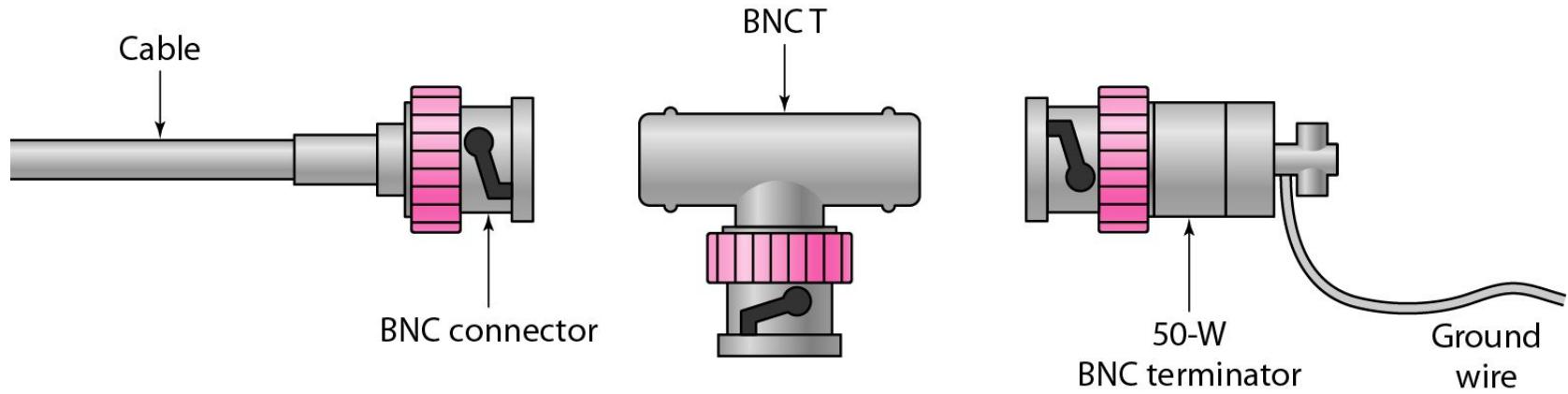
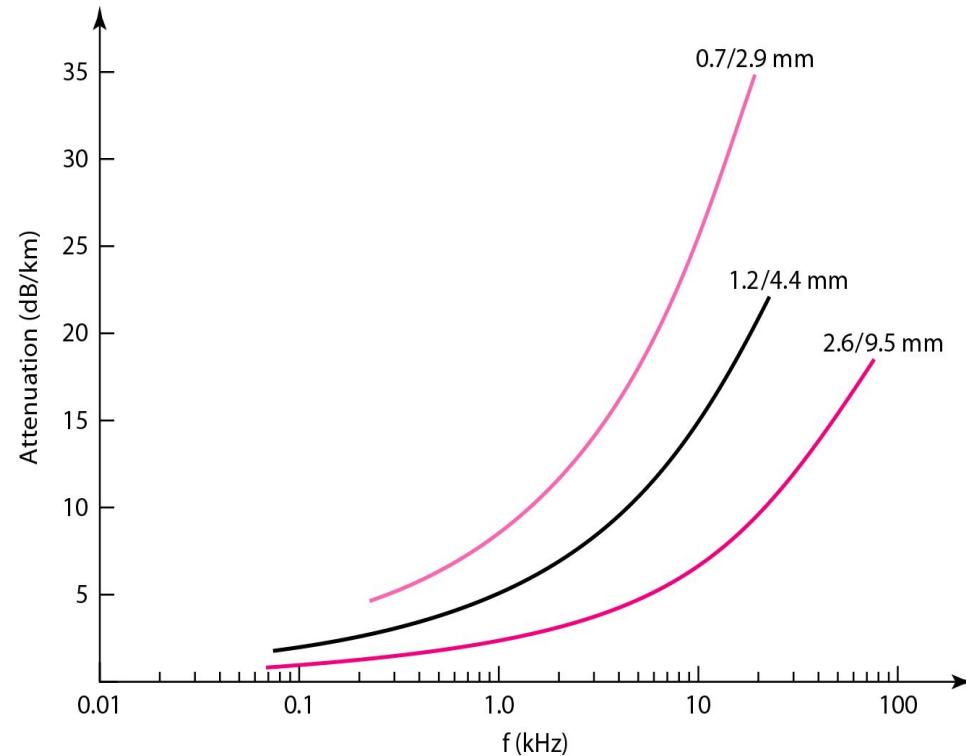


Figure 7.9 *Coaxial cable performance*

- As we did with twisted-pair cables, we can measure the performance of a coaxial cable.
- We notice in Figure 7.9 that the attenuation is much higher in coaxial cables than in twisted-pair cable.
- In other words, although coaxial cable has a much higher bandwidth, the signal weakens rapidly and requires the frequent use of repeaters.



Applications

- Coaxial cable was widely used in **analog telephone networks** where a single coaxial network could carry **10,000 voice signals**.
- Later it was used in digital telephone networks where a single coaxial cable could carry digital data up to **600 Mbps**.
- However, coaxial cable in telephone networks has largely been **replaced** today with fiber-optic cable.
- Cable TV networks also use coaxial cables. In the traditional cable TV network, the entire network used coaxial cable.
- Later, however, cable TV providers replaced most of the media with fiber-optic cable;
- Hybrid networks use coaxial cable only at the network boundaries, near the consumer premises.
- Cable TV uses RG-59 coaxial cable.

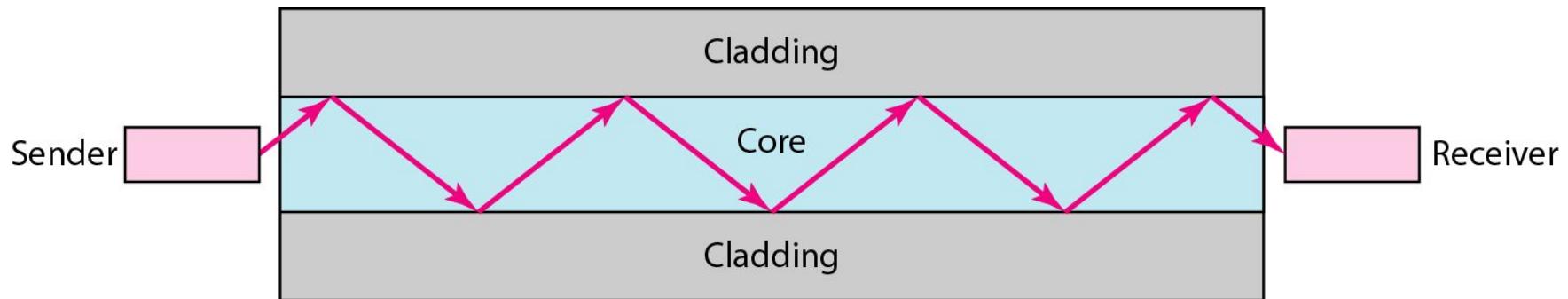
Applications

- Another common application of coaxial cable is in traditional Ethernet LANs. Because of its high bandwidth, and consequently high data rate, coaxial
- cable was chosen for digital transmission in early Ethernet LANs.
- The 10Base-2, or Thin Ethernet, uses RG-58 coaxial cable with BNC connectors to transmit data at 10 Mbps with a range of 185 m.
- The 10Base5, or Thick Ethernet, uses RG-11 (thick coaxial cable) to transmit 10 Mbps with a range of 5000 m.
- Thick Ethernet has specialized connectors.

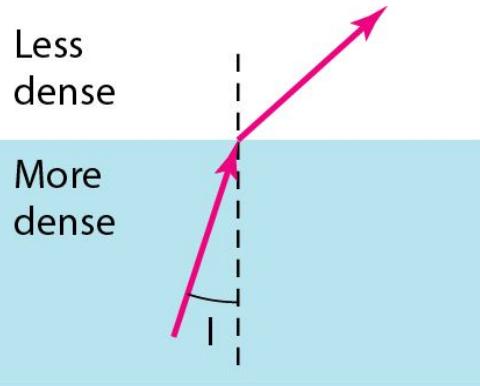
Fiber-Optic Cable

- A fiber-optic cable is made of glass or plastic and transmits signals in the form of light.
- To understand optical fiber, we first need to explore several aspects of the nature of light.
- Light travels in a straight line as long as it is moving through a single uniform substance.
- If a ray of light traveling through one substance suddenly enters another substance (of a different density), the ray changes direction.
- The following figure shows how a ray of light changes direction when going from a more dense to a less dense substance.

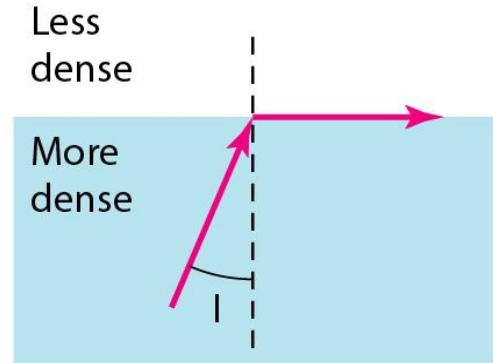
Optical fiber



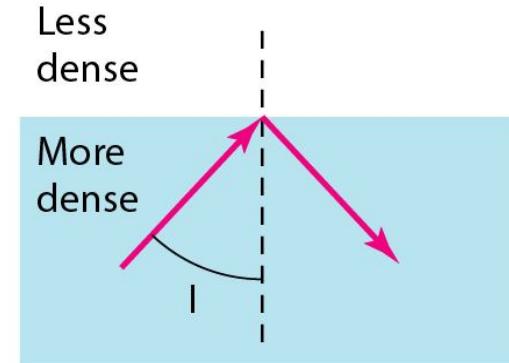
Fiber optics: *Bending of light ray*



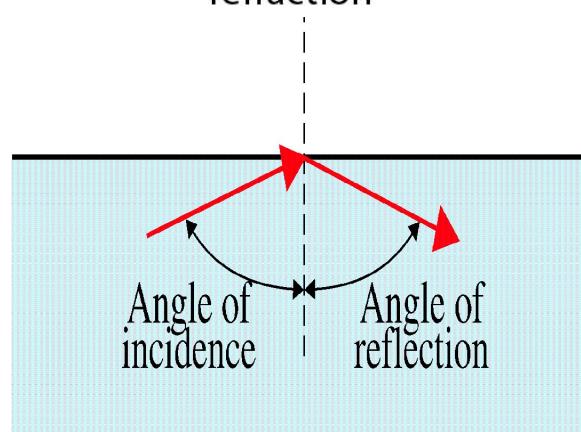
$I <$ critical angle,
refraction



$I =$ critical angle,
refraction



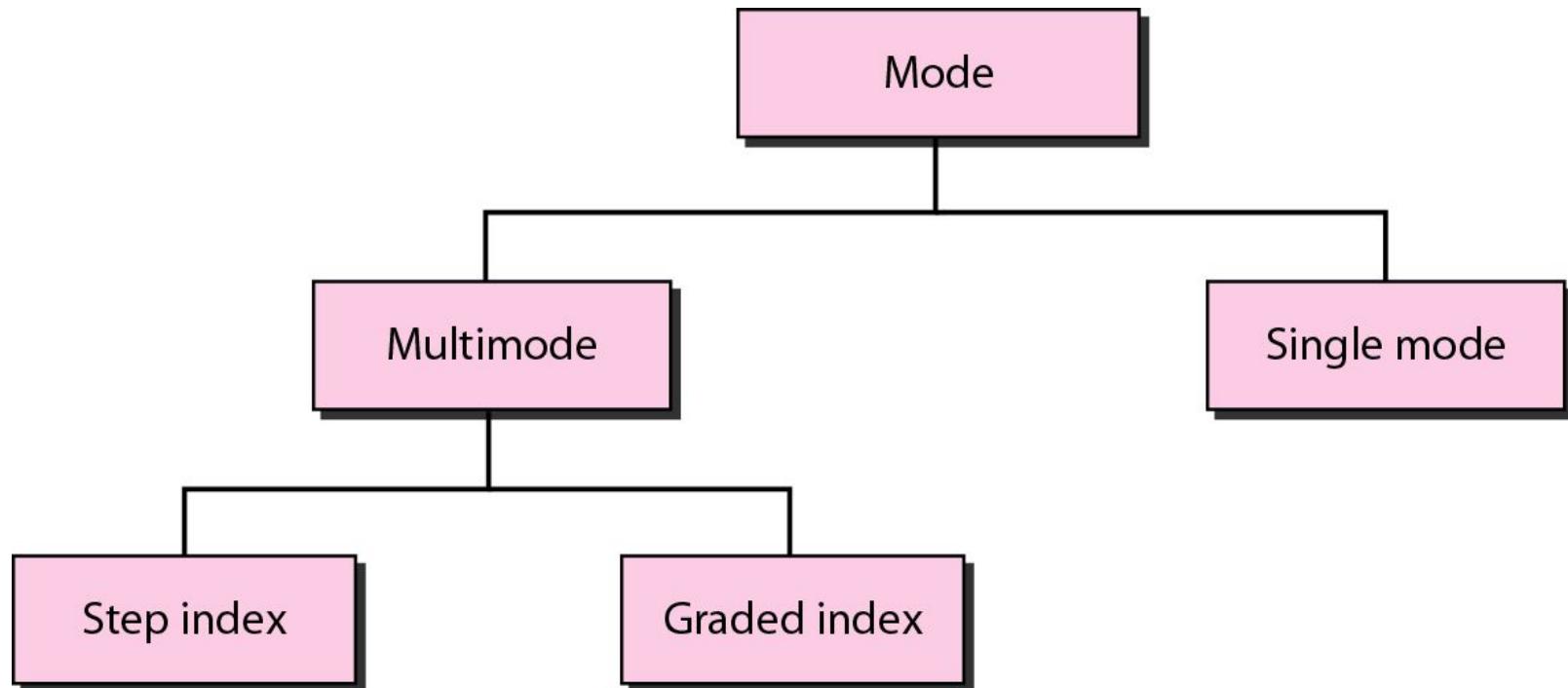
$I >$ critical angle,
reflection



Fiber-Optic Cable

- If the angle of incidence I (the angle the ray makes with the line perpendicular to the interface between the two substances) is less than the critical angle, the ray refracts and moves closer to the surface.
- If the angle of incidence is equal to the critical angle, the light bends along the interface.
- If the angle is greater than the critical angle, the ray reflects (makes a turn) and travels again in the denser substance.
- Note that the critical angle is a property of the substance, and its value differs from one substance to another.
- Optical fibers use **reflection** to guide light through a channel.
- A glass or plastic core is surrounded by a cladding of less dense glass or plastic. The difference in density of the two materials must be such that a beam of light moving through the core is reflected off the cladding instead of being refracted into it.

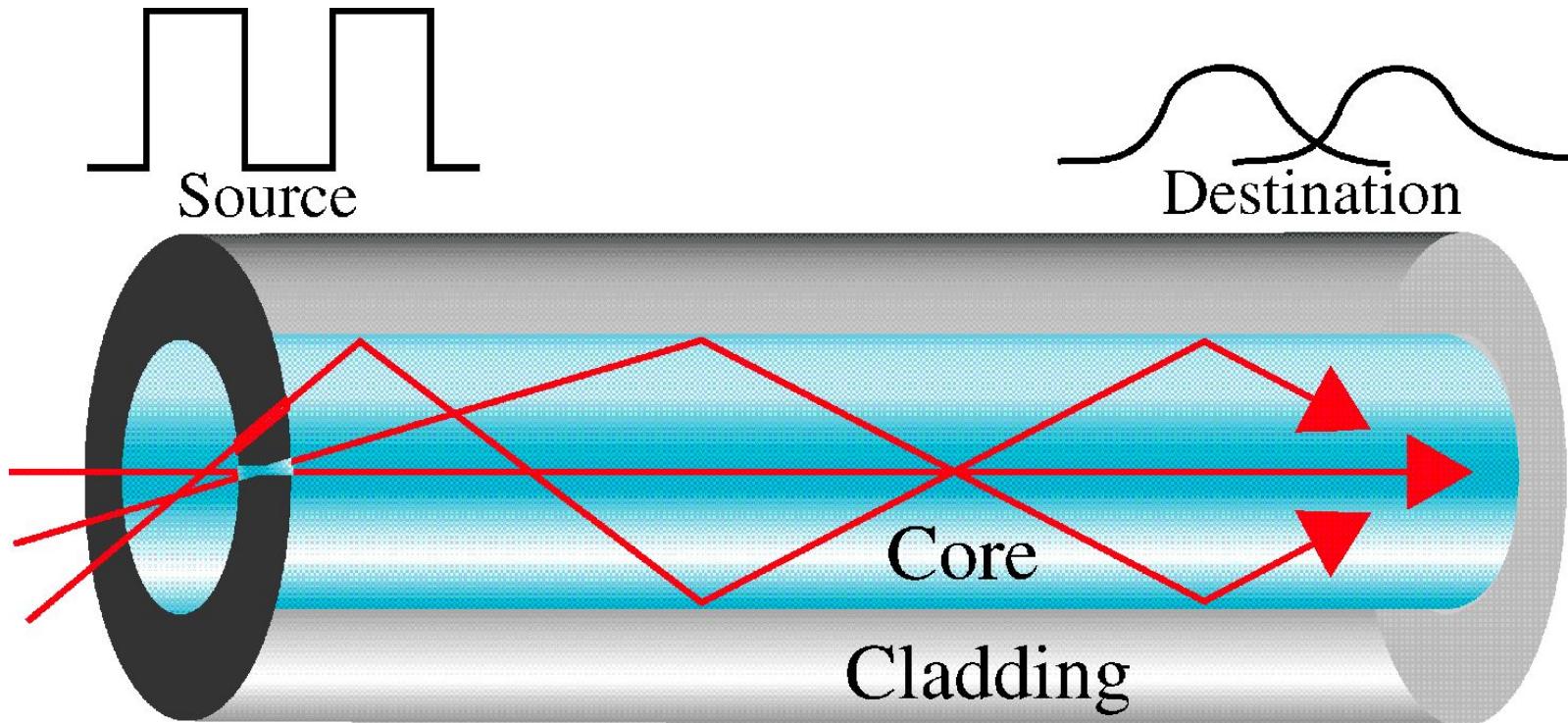
Figure 7.12 Propagation modes



Multimode – Step index

- Multimode is so named because multiple beams from a light source move through the core in different paths. How these beams move within the cable depends on the structure of the core, as shown in Figure 7.13.
- In multimode step-index fiber, **the density of the core remains constant from the center to the edges**. A beam of light moves through this constant density in a straight line until it reaches the interface of the core and the cladding. At the interface, there is an abrupt change due to a lower density; this alters the angle of the beam's motion.
- The **term step index refers to the suddenness of this change**, which contributes to the distortion of the signal as it passes through the fiber

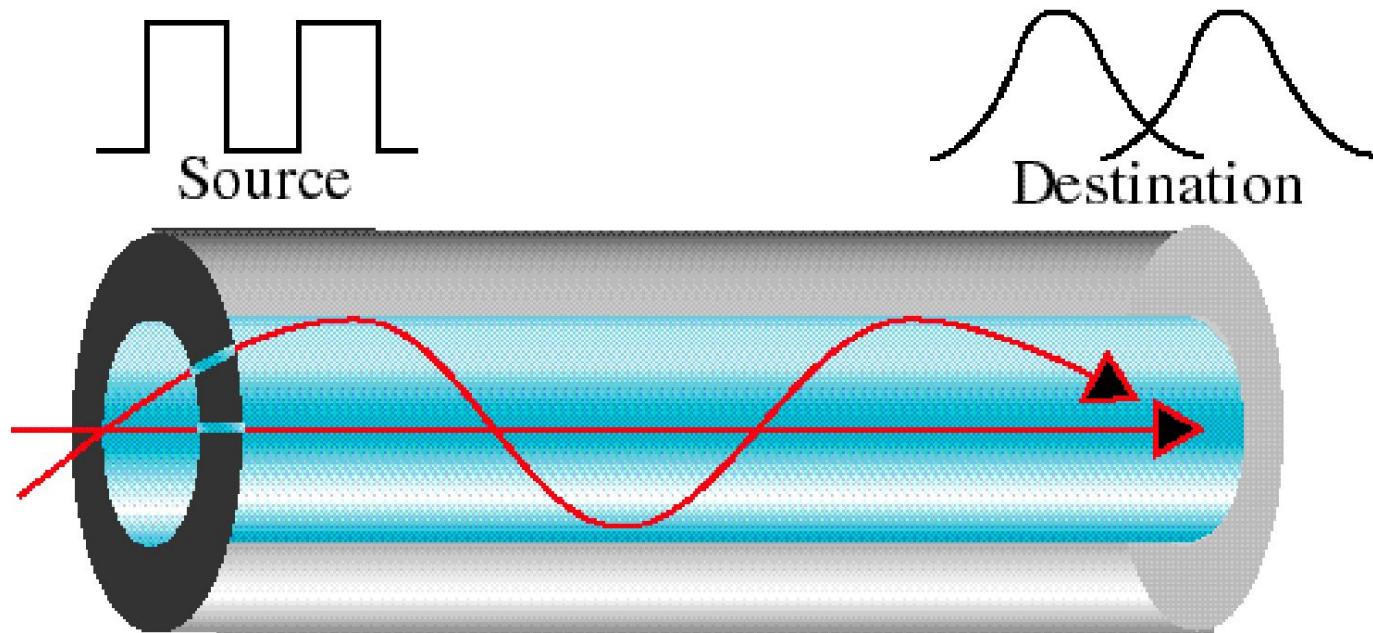
Multimode Step-Index



Multimode – Graded Index

- A second type of fiber, called **multimode graded-index fiber**, decreases this distortion of the signal through the cable. The word index here refers to the index of refraction.
- As we saw above, the index of refraction is related to density. A graded-index fiber, therefore, is one with varying densities. Density is highest at the center of the core and decreases gradually to its lowest at the edge.

Multimode Graded-Index



Single-Mode

- Single-mode uses step-index fiber and a highly focused source of light that limits beams to a small range of angles, all close to the horizontal.
- The singlemode fiber itself is manufactured with a much smaller diameter than that of multimode fiber, and with substantially lower density (index of refraction).
- The decrease in density results in a critical angle that is **close enough to 90° to make the propagation of beams almost horizontal**.
- In this case, propagation of different beams is almost identical, and delays are negligible. All the beams arrive at the **destination "together" and can be recombined with little distortion to the signal**

Single Mode

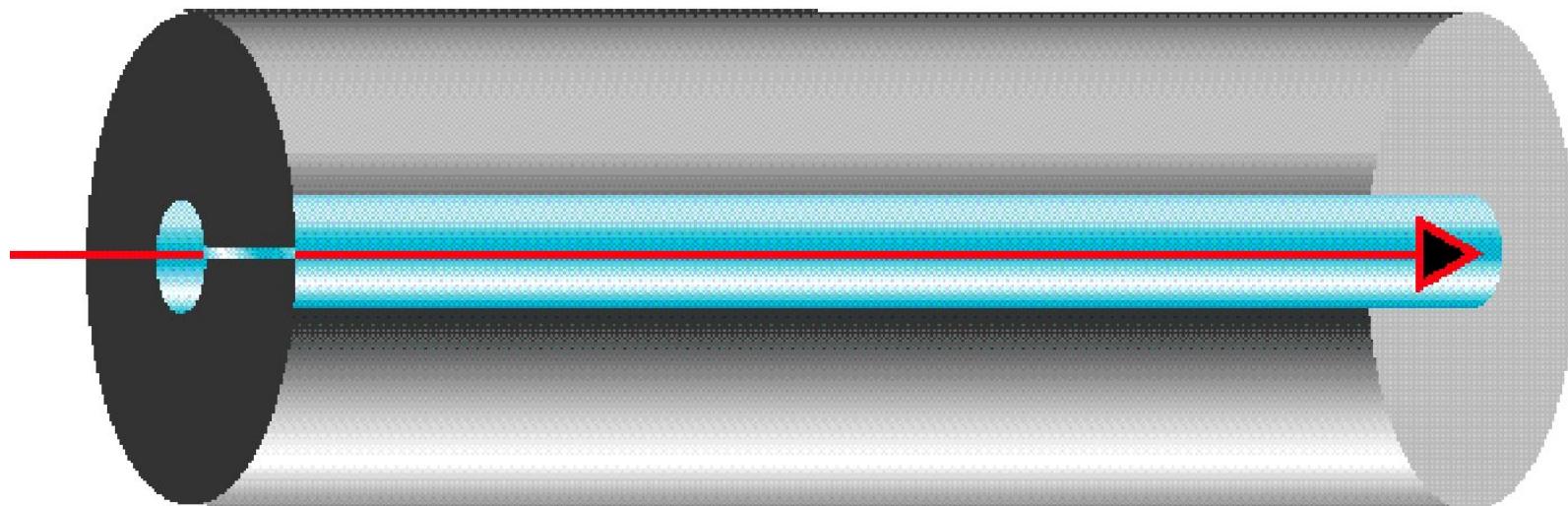
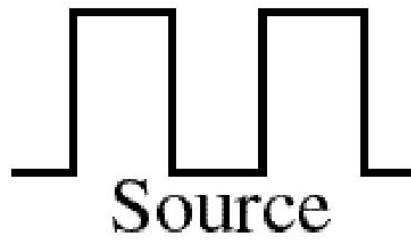


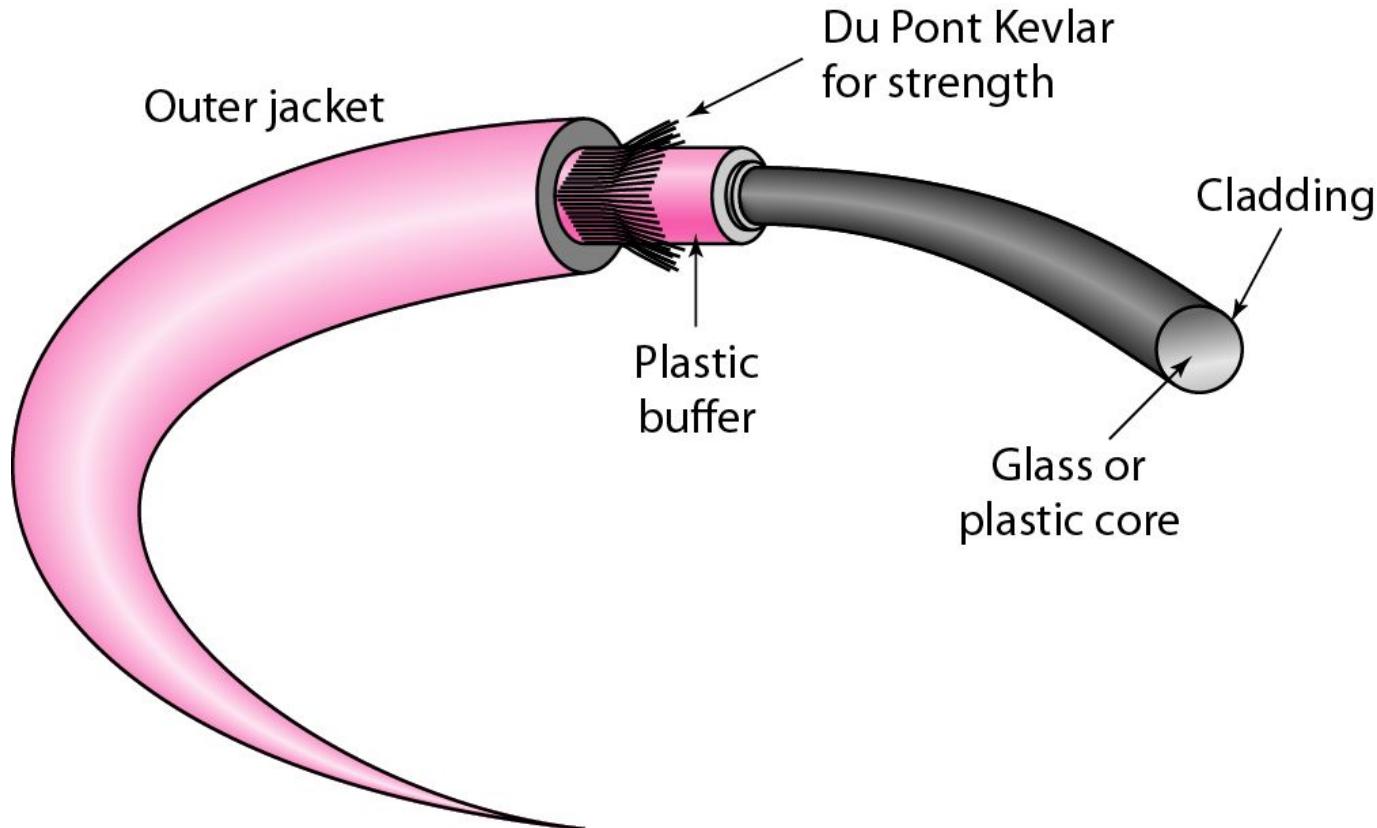
Table 7.3 *Fiber types*

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

Cable Composition

- Figure 7.14 shows the composition of a typical fiber-optic cable.
- The outer jacket is made of either **PVC or Teflon**. Inside the jacket are Kevlar strands to strengthen the cable.
- **Kevlar** is a strong material used in the fabrication of **bulletproof vests**.
- Below the Kevlar is another plastic coating to **cushion the fiber**. The fiber is at the center of the cable, and it consists of cladding and core.

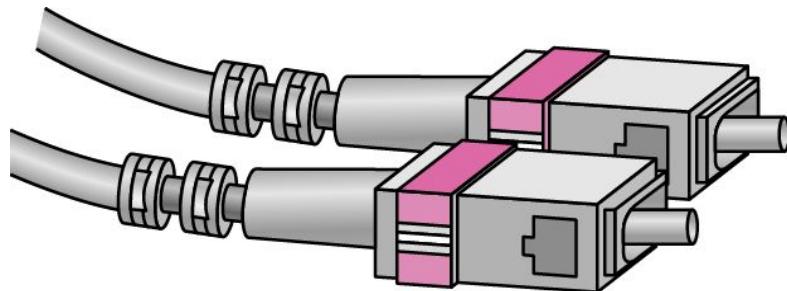
Figure 7.14 Fiber construction



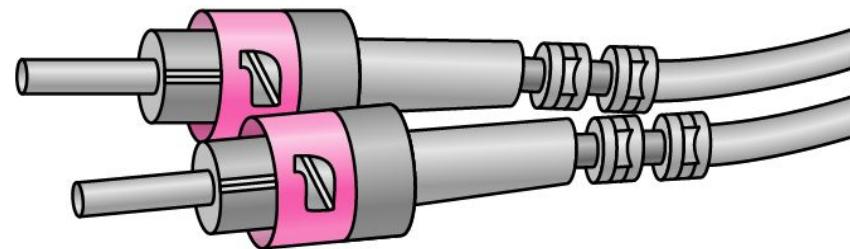
Fiber-optic cable connectors

- The **subscriber channel (SC) connector** is used for cable TV.
 - It uses a push/pull locking system.
- The **straight-tip (ST) connector** is used for connecting cable to networking devices.
 - It uses a bayonet locking system and is more reliable than SC.
- MT-RJ is a connector that is the same size as RJ45.

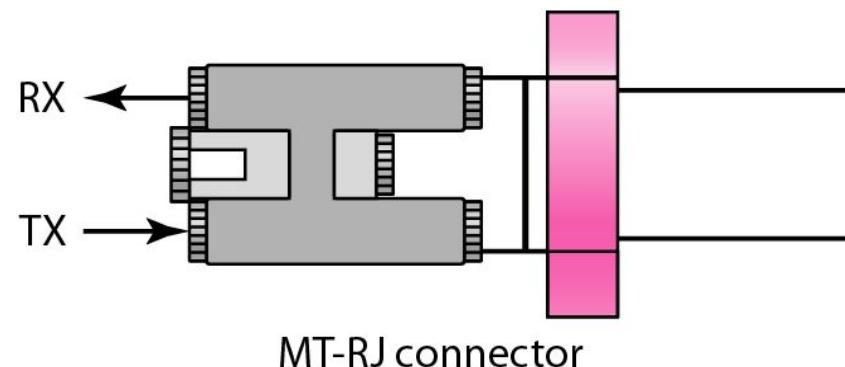
Figure 7.15 *Fiber-optic cable connectors*



SC connector



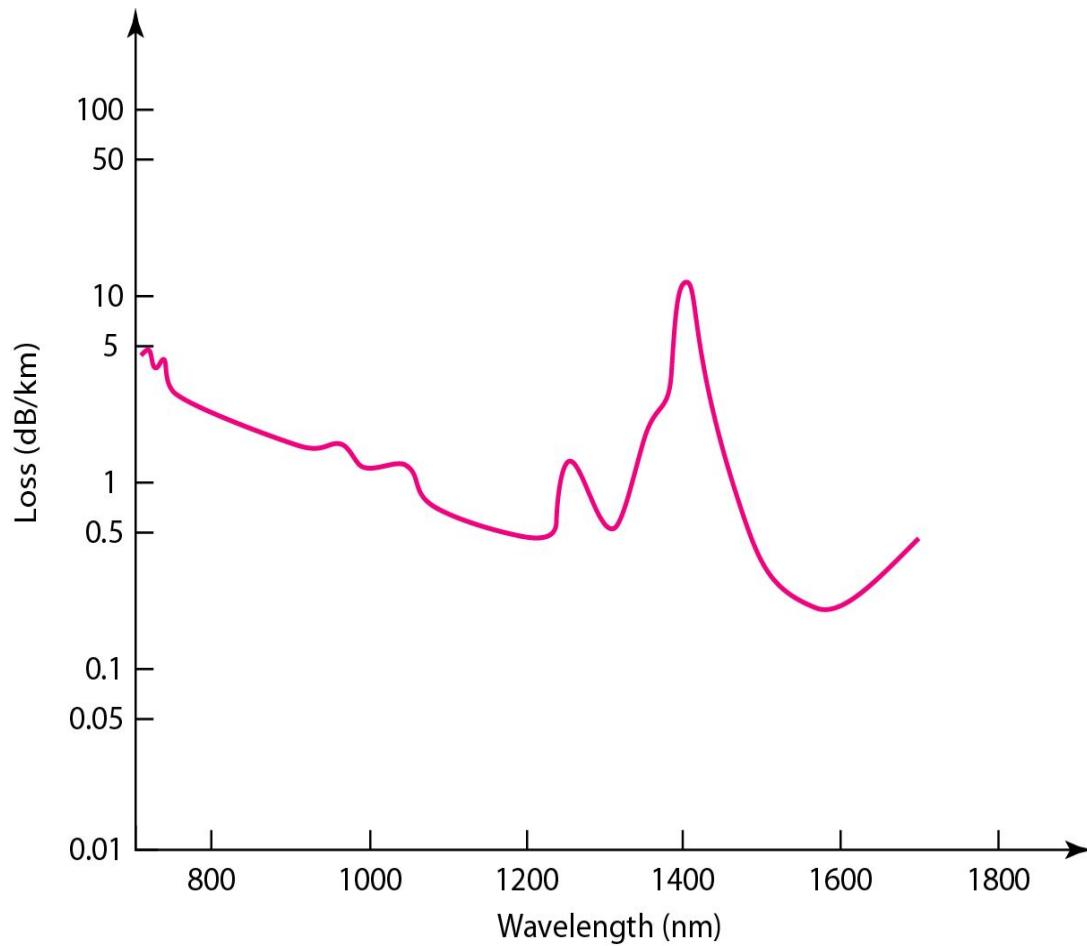
ST connector



MT-RJ connector

Figure 7.16 Optical fiber performance

- The plot of attenuation versus wavelength in Figure 7.16 shows a very interesting phenomenon in fiber-optic cable.
- Attenuation is flatter than in the case of twisted-pair cable and coaxial cable.
- The performance is such that we need fewer (actually 10 times less) repeaters when we use fiber-optic cable.



Applications

- Fiber-optic cable is often found in **backbone networks** because its wide bandwidth is cost-effective.
- Some **cable TV companies** use a combination of optical fiber and coaxial cable, thus creating a hybrid network.
- Optical fiber provides the backbone structure while coaxial cable provides the connection to the user premises. This is a cost-effective configuration since the narrow bandwidth requirement at the user end does not justify the use of optical fiber.
- Local-area networks such as **100Base-FX network (Fast Ethernet)** and **1000Base-X** also use fiber-optic cable.

Advantages of Optical Fiber

- **Higher bandwidth.** Fiber-optic cable can support dramatically higher bandwidths (and hence data rates) than either twisted-pair or coaxial cable. Currently, data rates and bandwidth utilization over fiber-optic cable are limited not by the medium but by the signal generation and reception technology available.
- **Less signal attenuation.** Fiber-optic transmission distance is significantly greater than that of other guided media. A signal can run for 50 km without requiring regeneration. We need repeaters every 5 km for coaxial or twisted-pair cable.

Advantages of Optical Fiber

- **Immunity** to electromagnetic interference. Electromagnetic noise cannot affect fiber-optic cables.
- **Resistance** to corrosive materials. Glass is more resistant to corrosive materials than copper.
- **Light weight**. Fiber-optic cables are much lighter than copper cables.
- **Greater immunity to tapping**. Fiber-optic cables are more immune to tapping than copper cables. Copper cables create antenna effects that can easily be tapped.

Disadvantages

- **Installation and maintenance.** Fiber-optic cable is a relatively new technology. Its installation and maintenance require expertise that is not yet available everywhere.
- **Unidirectional light propagation.** Propagation of light is unidirectional. If we need **bidirectional communication**, two fibers are needed.
- **Cost.** The cable and the interfaces are relatively more expensive than those of other guided media. If the demand for bandwidth is not high, often the use of optical fiber cannot be justified.

7-2 UNGUIDED MEDIA: WIRELESS

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

Topics discussed in this section:

Radio Waves

Microwaves

Infrared

Figure 7.17 *Electromagnetic spectrum for wireless communication*

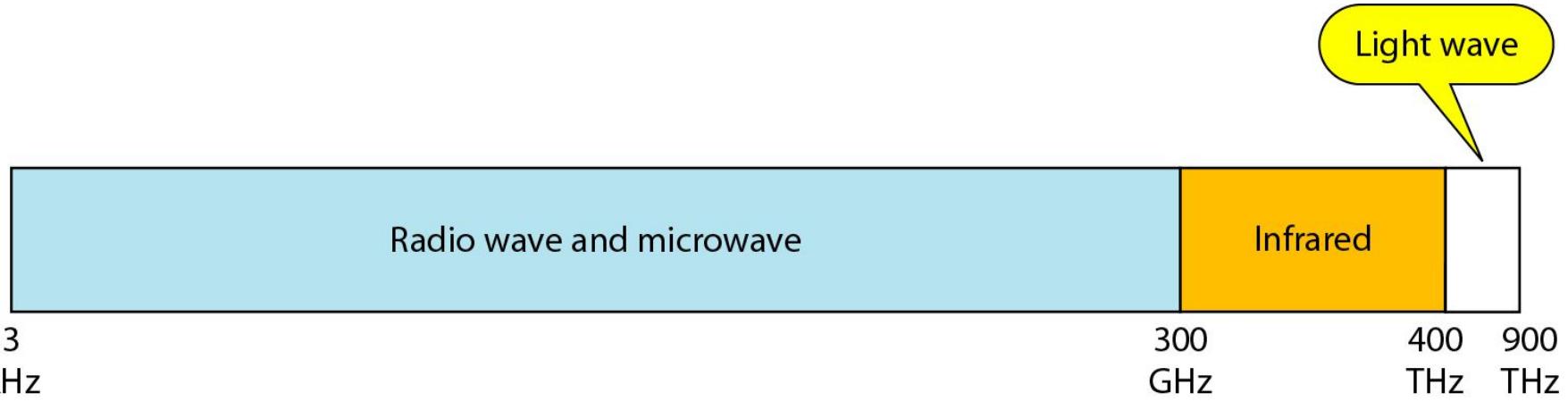
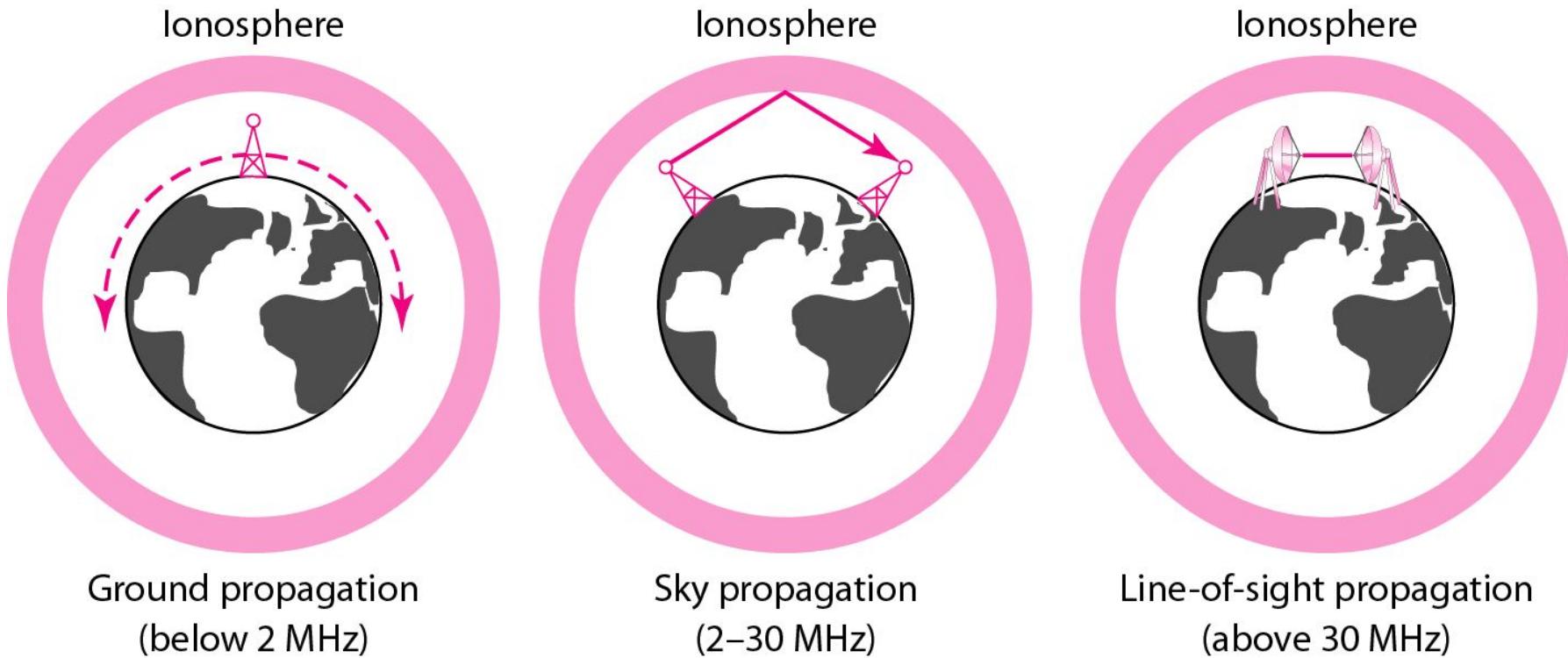


Figure 7.18 Propagation methods



Unguided signals can travel from the source to destination in several ways: ground propagation, sky propagation, and line-of-sight propagation

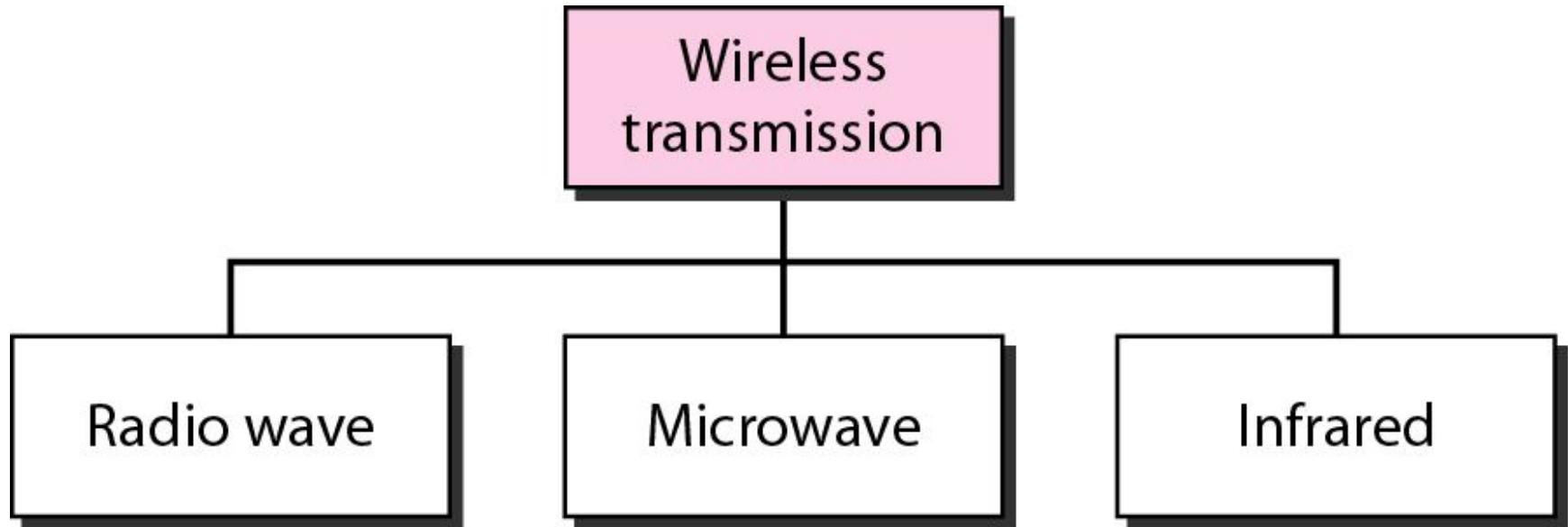
- In ground propagation, radio waves travel through the **lowest portion of the atmosphere**, hugging the earth. These low-frequency signals **emanate in all directions** from the transmitting antenna and follow the curvature of the planet. Distance depends on the amount of power in the signal: **The greater the power, the greater the distance.**
- In sky propagation, **higher-frequency radio waves radiate upward into the ionosphere** (the layer of atmosphere where particles exist as ions) where they are reflected back to earth. This type of transmission allows for greater distances with lower output power.
- In line-or-sight propagation, **very high-frequency signals are transmitted in straight lines directly from antenna to antenna**. Antennas must be **directional, facing each other, and either tall enough or close enough together** not to be affected by the curvature of the earth. Line-of-sight propagation is tricky because radio transmissions cannot be completely focused.

- The section of the electromagnetic spectrum defined as radio waves and microwaves is divided into eight ranges, called **BANDS**, each regulated by government authorities.
- These bands are rated from very low frequency (VLF) to extremely highfrequency (EHF).

Table 7.4 *Bands*

<i>Band</i>	<i>Range</i>	<i>Propagation</i>	<i>Application</i>
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

Figure 7.19 *Wireless transmission waves*



Radio Vs Micro Waves

- Electromagnetic waves ranging in frequencies between 3 kHz and 1 GHz are normally called radio waves;
- Waves ranging in frequencies between 1 and 300 GHz are called microwaves.
- However, the behavior of the waves, rather than the frequencies, is a better criterion for classification.

Note

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

RADIO WAVES

- Radio waves, for the most part, are **omnidirectional**.
- When an antenna transmits radio waves, they are propagated in all directions.
- This means that the **sending and receiving antennas do not have to be aligned**.
- A sending antenna sends waves that can be received by any receiving antenna.

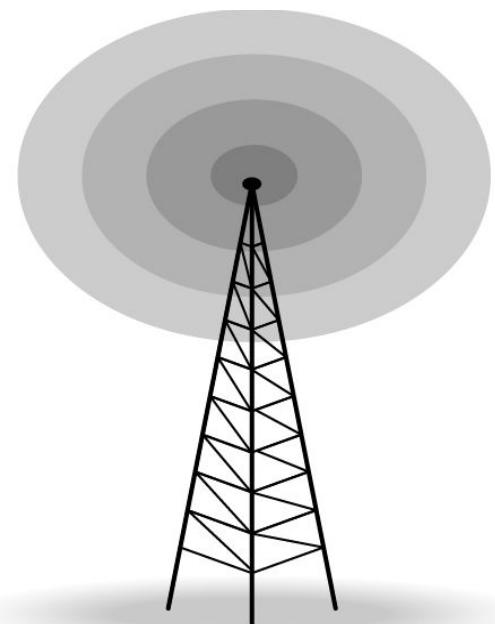
Disadvantage:

The radio waves transmitted by one antenna are susceptible to interference by another antenna that may send signals using the same frequency or band.

- Radio waves, particularly those waves that propagate in the sky mode, can travel long distances.
- Radio waves, particularly those of low and medium frequencies, can penetrate walls.
- This characteristic can be both an advantage and a disadvantage.
 - Advantage: An AM radio can receive signals inside a building.
 - Disadvantage : We cannot isolate a communication to just inside or outside a building.
- The radio wave band is relatively narrow, just under **1 GHz**, compared to the microwave band.
- When this band is divided into **subbands**, the subbands are also narrow, leading to a low data rate for digital communications.
- Almost the entire band is regulated by authorities (e.g., the FCC in the United States). **Using any part of the band requires permission from the authorities.**

Applications

- The omnidirectional characteristics of radio waves make them useful for **multicasting, in which there is one sender but many receivers.**
- AM and FM radio, television, maritime radio, cordless phones, and paging are examples of multicasting.



- Electromagnetic waves having frequencies between 1 and 300 GHz are called microwaves.
- Microwaves are unidirectional. When an antenna transmits microwave waves, they can be narrowly focused. This means that the sending and receiving antennas need to be aligned.
- The unidirectional property has an obvious advantage. A pair of antennas can be aligned without interfering with another pair of aligned antennas.

CHARACTERISTICS OF MICROWAVE PROPAGATION:

- **Microwave propagation is line-of-sight.** Since the towers with the mounted antennas need to be in direct sight of each other, towers that are far apart need to be very tall. The curvature of the earth as well as other blocking obstacles do not allow two short towers to communicate by using microwaves. Repeaters are often needed for longdistance communication.
- **Very high-frequency microwaves cannot penetrate walls.** This characteristic can be a disadvantage if receivers are inside buildings.
- **The microwave band is relatively wide, almost 299 GHz.** Therefore wider subbands can be assigned, and a high data rate is possible.
- **Use of certain portions of the band requires permission from authorities.**

Note

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

Higher frequency ranges cannot penetrate walls.

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

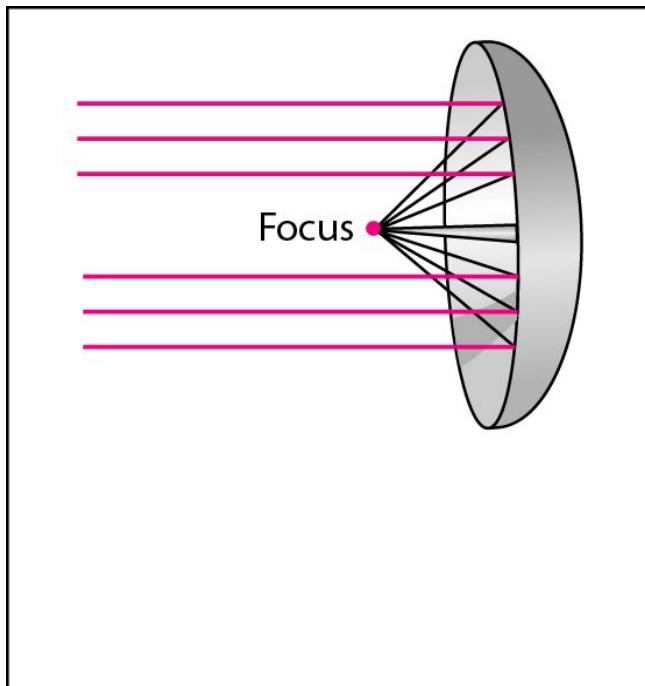
Unidirectional Antenna

- Microwaves need unidirectional antennas that send out signals in one direction.
- Two types of antennas are used for microwave communications: **the parabolic dish and the horn.**
- A parabolic dish antenna is based on the geometry of a parabola: Every line parallel to the line of symmetry (line of sight) reflects off the curve at angles such that all the lines intersect in a common point called the focus. The parabolic dish works as funnel, catching a wide range of waves and directing them to a common point.
- In this way, more of the signal is recovered than would be possible with a single-point receiver.

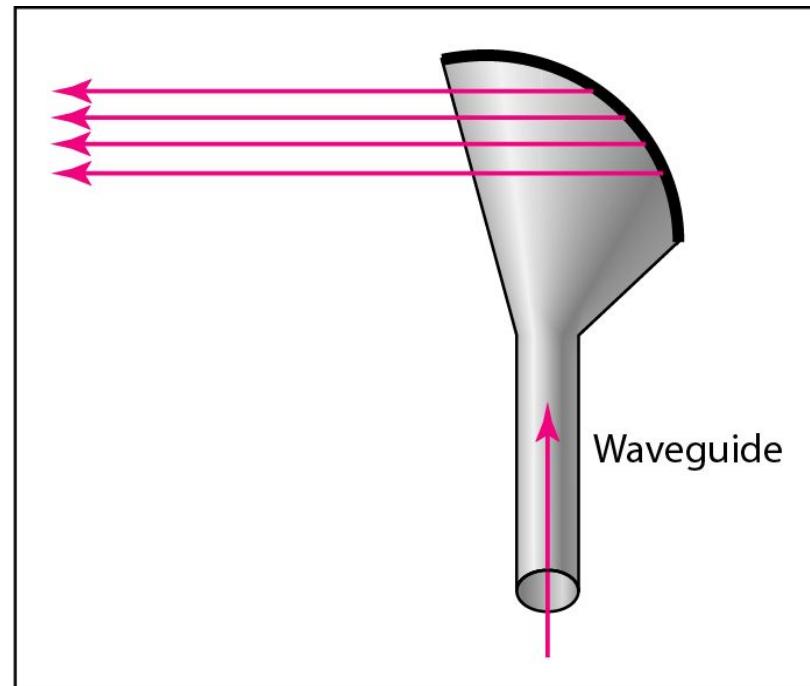
Horn antenna

- A horn antenna looks like a gigantic scoop.
- Outgoing transmissions are broadcast up a stem (resembling a handle) and deflected outward in a series of narrow parallel beams by the curved head.
- Received transmissions are collected by the scooped shape of the horn, in a manner similar to the parabolic dish, and are deflected down into the stem.

Figure 7.21 Unidirectional antennas



a. Dish antenna



b. Horn antenna

Applications

- Microwaves, due to their unidirectional properties, are very useful when unicast (one-to-one) communication is needed between the sender and the receiver.
- They are used in cellular phones, satellite networks and wireless LANs.

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.