Data Communication & Networking
UNIT - I

 U1.1

Learning Objectives

In this Unit we will discuss :

- Introduction and The Physical Layer: Uses of Computer Networks, Network Hardware,
- Network Software, Reference Model (OSI, TCP/IP Overview), The Physical Layer,
- Theoretical Basis for Data Communication, Guided Transmission Media, Wireless
- Transmission, Communication Satellites,
- Digital Signal Encoding Formats
- Digital Modulation
- Analog Modulation –The Public Switched Telephone Network, The Mobile Telephone System

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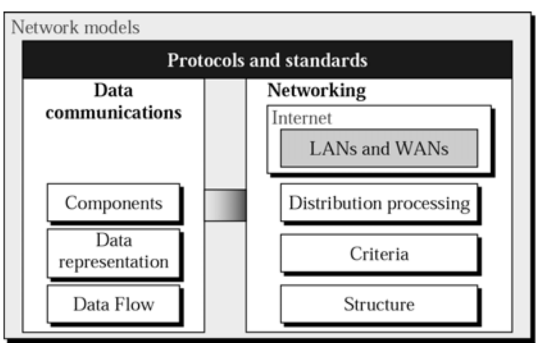
Introduction



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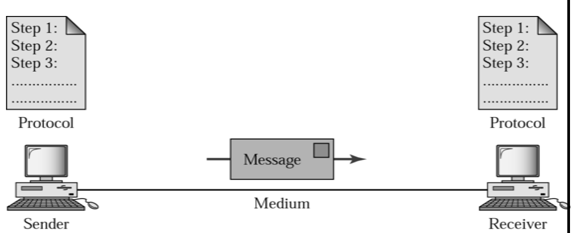
Introduction

BASICS OF DATA COMMUNICATION

- Components
- Data Representation
- Direction of Data Flow

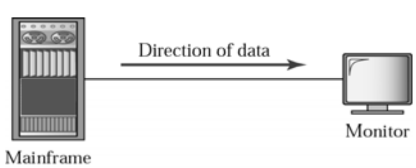
Introduction

Five components of data communication



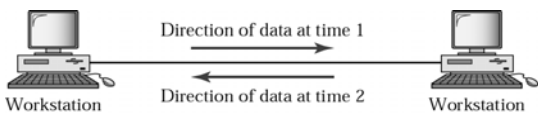
Data Flow

Simplex



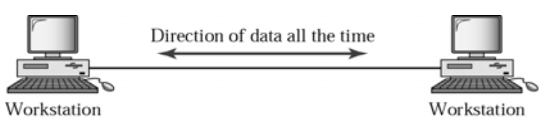
Data Flow

Half-Duplex



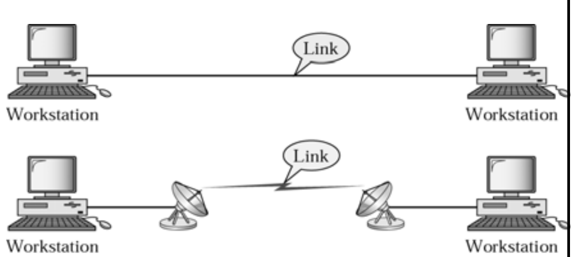
Data Flow

Full-Duplex



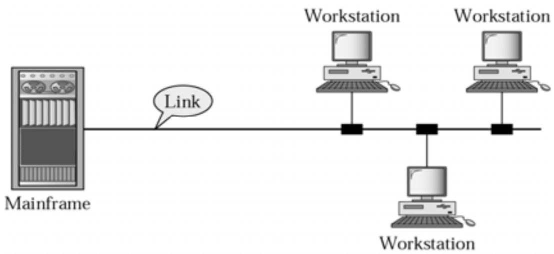
Types of Connection

Point-to-point connection



Types of Connection

Multi Point Connection



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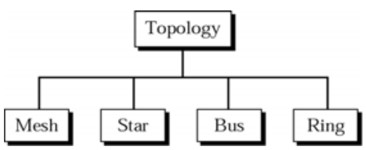
Introduction

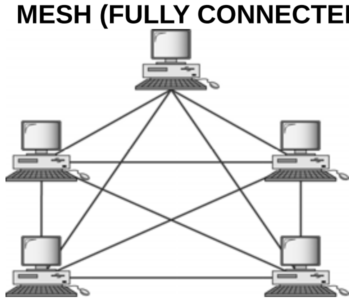
Categories of Topology



 U1.11

Introduction

MESH (FULLY CONNECTED)



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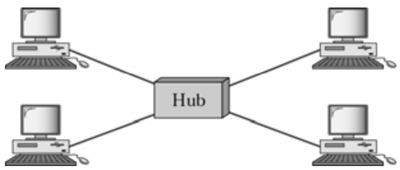
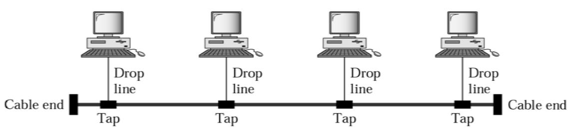
Introduction

STAR



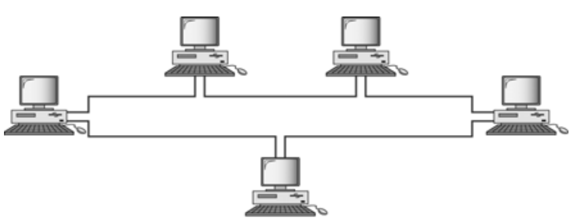
Introduction

BUS



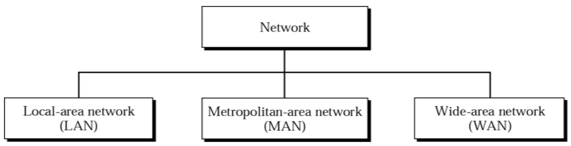
Introduction

RING



Introduction

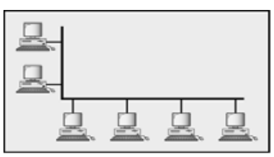
Categories of Networks



 U1.16

Introduction

LAN

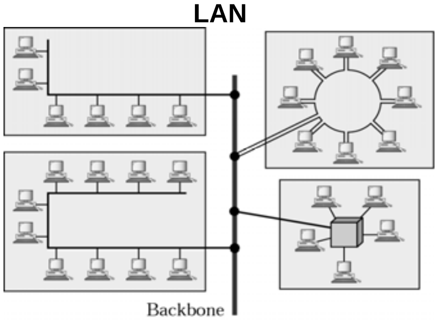


a. Single-building LAN

 U1.17

Introduction

LAN

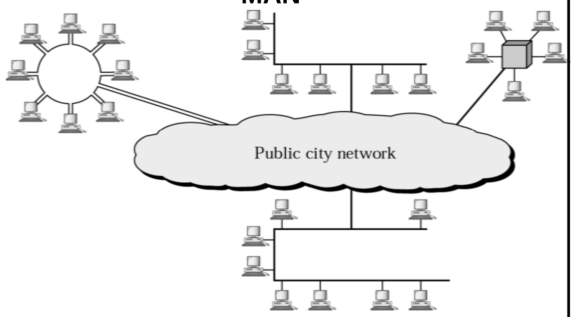


b. Multiple-building LAN

 U1.18

Introduction

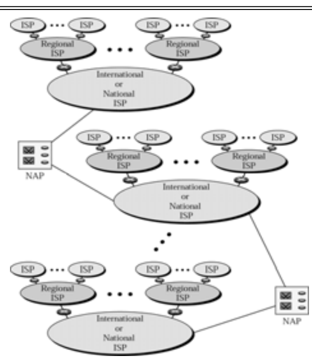
MAN



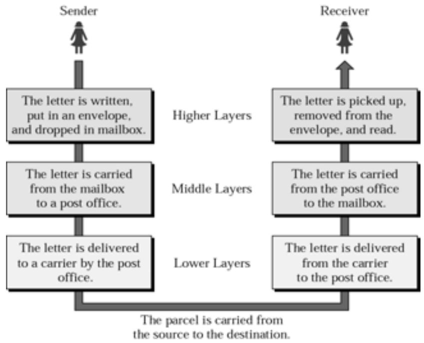
Introduction

WAN

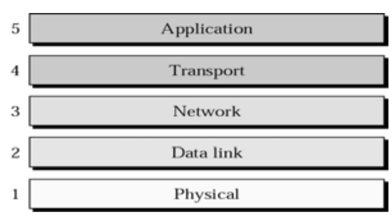
Internet Today



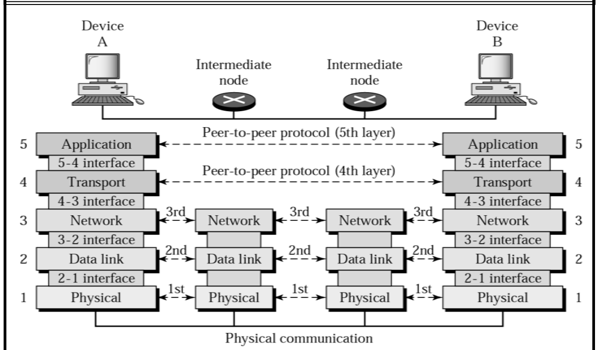
Network Models



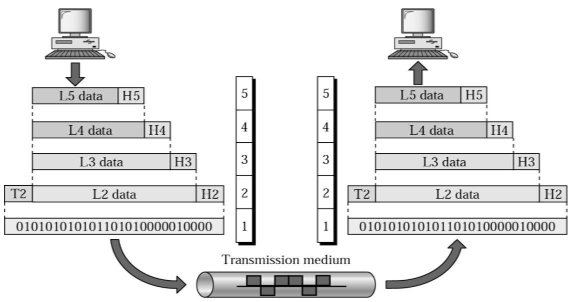
Internet Layers



Internet Layers



Internet Layers

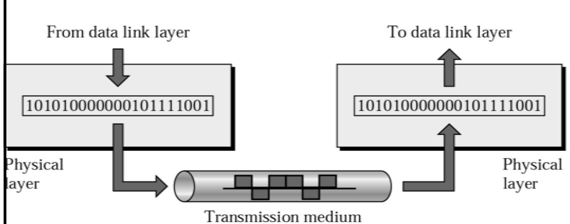


OSI Model

7. Application
6. Presentation
5. Session
4. Transport
3. Network
2. Data link
1. Physical

Physical Layer

The physical layer is responsible for transmitting individual bits from one node to the next.



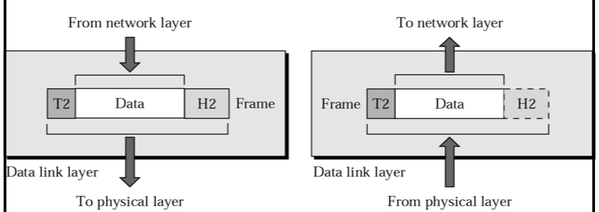
Physical Layer

Responsibilities of Physical Layer :-

- Physical Characteristics of interfaces and medium
- Representation of bits
- Data rate
- Synchronization of bits
- Line configuration
- Physical topology
- Transmission mode

Data Link Layer

The data link layer is responsible for transmitting frames from one node to the next.

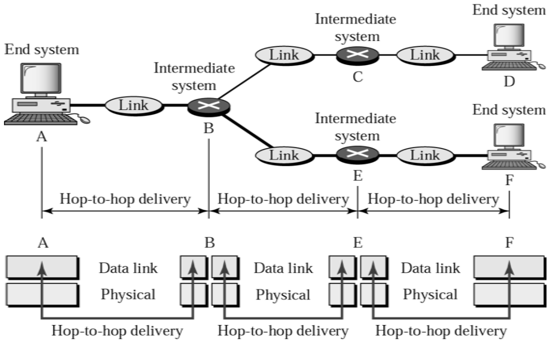


Data Link Layer

Responsibilities of Data Link Layer :-

- Framing
- Physical Addressing
- Flow Control
- Error Control
- Access Control

Node to Node Delivery



 U1.31

Node to Node Delivery

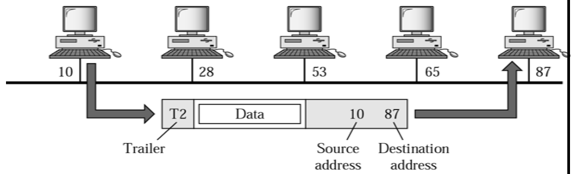
Example

- In Figure, a node with physical address 10 sends a frame to a node with physical address 87.
- The two nodes are connected by a link. At the data link level this frame contains physical addresses in the header. These are the only addresses needed.
- The rest of the header contains other information needed at this level. The trailer usually contains extra bits needed for error detection

 U1.32

Node to Node Delivery

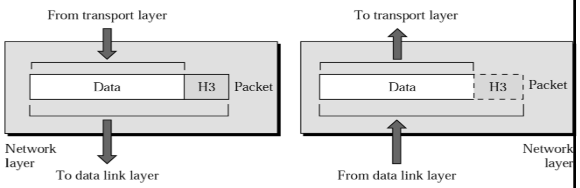
Example



 U1.33

Network Layer

The network layer is responsible for the delivery of packets from the original source to the final destination.

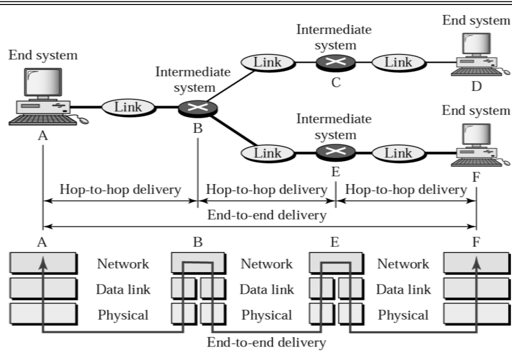


Network Layer

Responsibilities of Network Layer :-

- Logical Addressing
- Routing

Source – to - Destination



Source – to - Destination

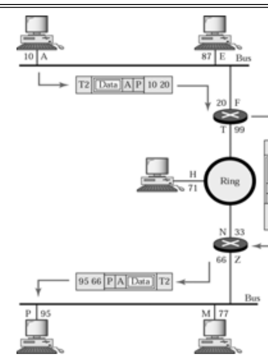
Example

- In Figure, we want to send data from a node with network address A and physical address 10, located on one LAN, to a node with a network address P and physical address 95, located on another LAN.
- Because the two devices are located on different networks, we cannot use physical addresses only; the physical addresses only have local jurisdiction.
- What we need here are universal addresses that can pass through the LAN boundaries. The network (logical) addresses have this characteristic.

 U1.37

Source – to - Destination

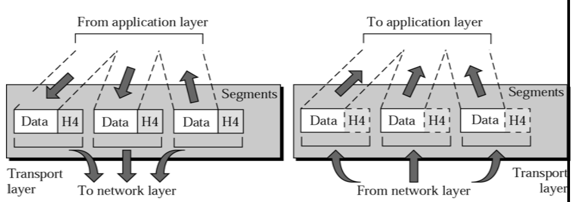
Example



 U1.38

Transport Layer

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



 U1.39

Transport Layer

Responsibilities of Transport Layer :-

•Service-point addressing

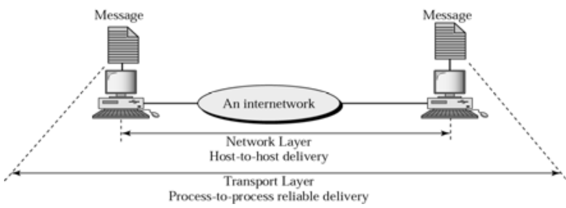
•Segmentation and reassembly

•Connection control

•Flow control

•Error Control

Process to Process



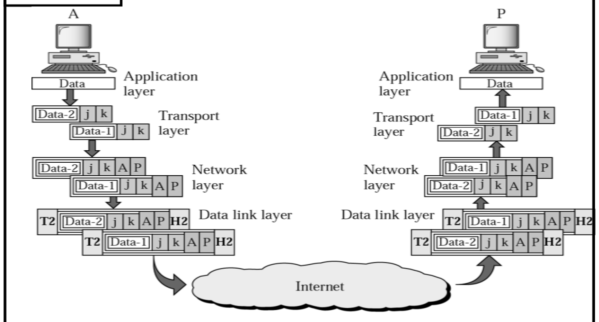
Process to Process

Example

- Figure, shows an example of transport layer communication. Data coming from the upper layers have port addresses j and k (j is the address of the sending process, and k is the address of the receiving process).
- Since the data size is larger than the network layer can handle, the data are split into two packets, each packet retaining the port addresses (j and k). Then in the network layer, network addresses (A and P) are added to each packet.

Process to Process

Example



 U1.43

Session Layer

The session layer is responsible for dialog control and synchronization.

 U1.44

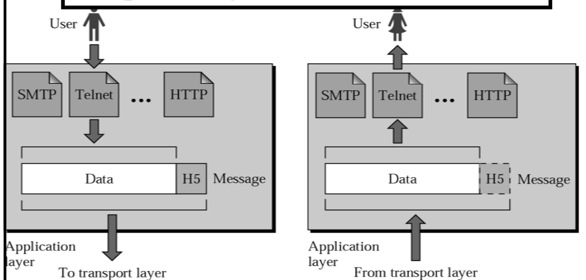
Presentation Layer

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

 U1.45

Application Layer

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

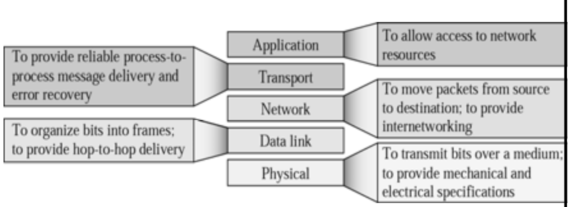


Application Layer

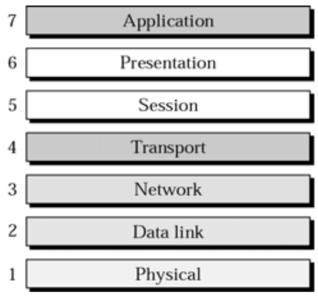
Services provided by the Application Layer :-

- Network virtual terminal
- File transfer, access and management
- Mail services
- Directory services

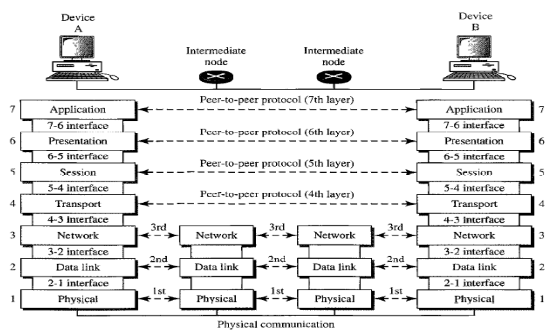
Summary of Layers



OSI Model



OSI Model



OSI Model

Physical layer	Deals with the mechanical and electrical specification of the interface and transmission media.
Data Link Layer	Transforms the physical layer, to a reliable link and is responsible for node-to-node delivery.
Network Layer	Responsible for the source-to-destination delivery of a packet across multiple links.

OSI Model

Transport Layer	Responsible for the source-to-destination (end-to-end) delivery of the entire message.
Session Layer	It establishes, maintains and synchronizes the interaction between communicating systems.
Presentation Layer	It concerns with the syntax and semantics of the information between two systems.

 U1.52

OSI Model

Application Layer	It provides user interfaces and support for services such as E-Mail, Remote Login and other types of Distributed Information Services.

 U1.53

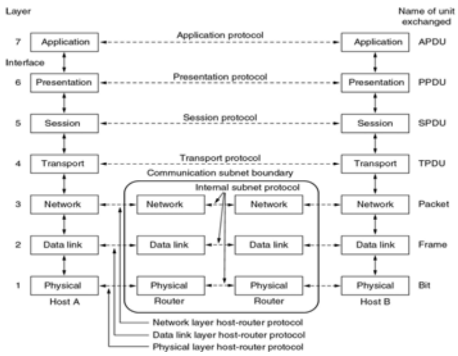
Reference Models

- The OSI Reference Model
- The TCP/IP Reference Model
- A Comparison of OSI and TCP/IP
- A Critique of the OSI Model and Protocols
- A Critique of the TCP/IP Reference Model

 U1.54

Reference Models

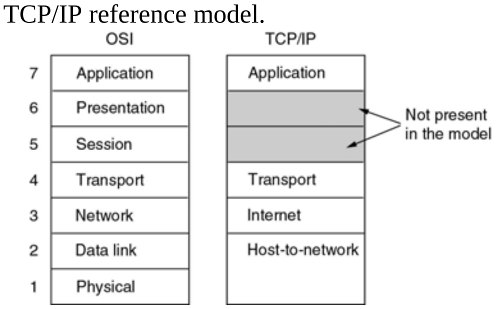
The OSI reference model.



 U1.55

Reference Models (2)

The TCP/IP reference model.



 U1.56

Comparing OSI and TCP/IP Models

Concepts central to the OSI model

- Services
- Interfaces
- Protocols

 U1.57

A Critique of the OSI Model and Protocols

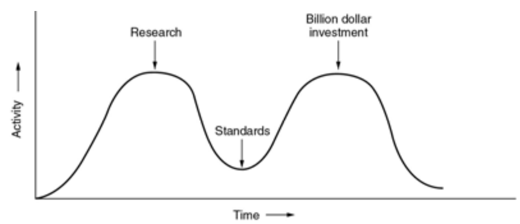
Why OSI did not take over the world

- Bad timing
- Bad technology
- Bad implementations
- Bad politics

 U1.58

Bad Timing

The apocalypse of the two elephants.



 U1.59

A Critique of the TCP/IP Reference Model

Problems:

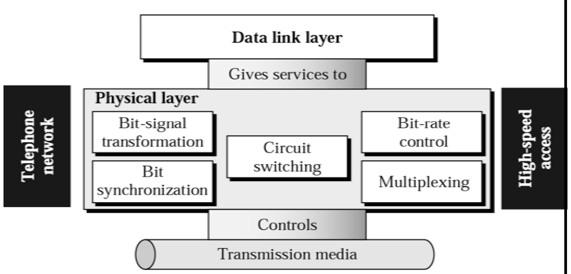
- Service, interface, and protocol not distinguished
- Not a general model
- Host-to-network "layer" not really a layer
- No mention of physical and data link layers
- Minor protocols deeply entrenched, hard to replace

 U1.60

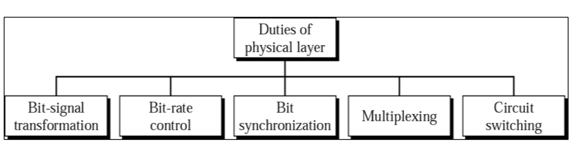
Computer Networks

Physical Layer

Position of Physical Layer



Physical Layer

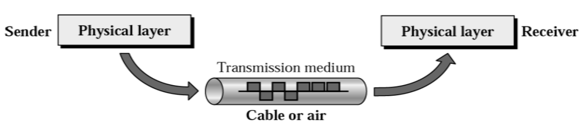


Physical Layer

Transmission Media

 U1.64

Transmission medium and physical layer



 U1.65

Guided: Transmission capacity depends critically on the medium, the length, and whether the medium is point-to-point or multipoint (e.g. LAN). Examples are co-axial cable, twisted pair, and optical fiber.

Unguided: provides a means for transmitting electro-magnetic signals but do not guide them. Example wireless transmission.

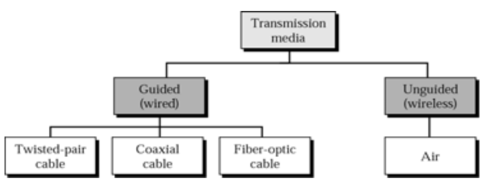
 U1.66

•For guided media, the medium is more important in determining the limitations of transmission.

•While in case of unguided media, the bandwidth of the signal produced by the transmitting antenna and the size of the antenna is more important than the medium.

 U1.67

Classes of transmission media



 U1.68

Physical Layer

Guided Media

Twisted-Pair Cable

Coaxial Cable

Fiber-Optic Cable

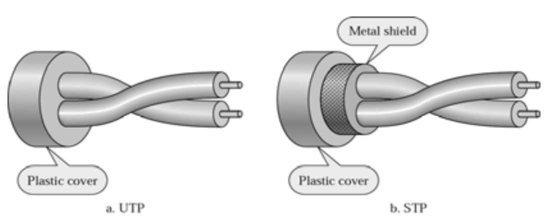
 U1.69

Physical Layer

- A twisted pair consists of two conductors (normally copper), each with its own plastic insulation, twister together
- One of the wires is use 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.
- 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.

Twisted-pair cable

UTP and STP

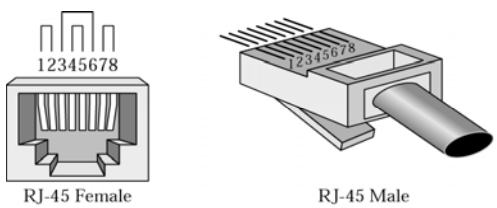


STP cable has a metal foil covering that encases each pair of insulated conductors.

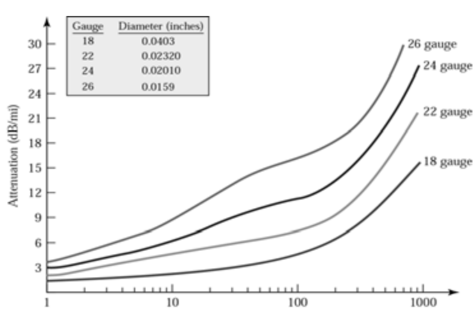
Categories of unshielded twisted-pair cables

Category	Bandwidth	Data Rate	Digital/Analog	Use
1	very low	< 100 kbps	Analog	Telephone
2	< 2 MHz	2 Mbps	Analog/digital	T-1 lines
3	16 MHz	10 Mbps	Digital	LANs
4	20 MHz	20 Mbps	Digital	LANs
5	100 MHz	100 Mbps	Digital	LANs
6 (draft)	200 MHz	200 Mbps	Digital	LANs
7 (draft)	600 MHz	600 Mbps	Digital	LANs

UTP connector



UTP performance



•One way to measure the performance of twisted-pair is to compare attenuation versus frequency and distance.

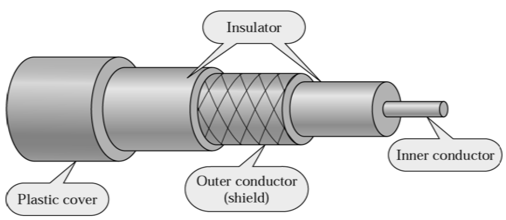
•A twisted pair cable can pass a wide range of frequencies.

•In figure, increasing frequency, the attenuation, sharply increases with frequency above 100 kHz.

•Attenuation measures in decibels per kilometer (dB/Km)

•Gauge is a measure of the thickness of the wire.

Coaxial cable



•Coaxial cable carries signals of higher frequency ranges than those in twisted pair cable, in part because the two media are constructed 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.

•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.

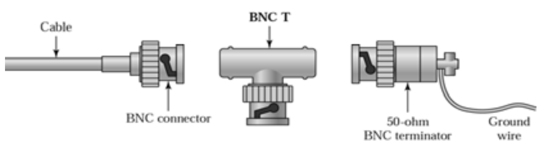
Categories of coaxial cables

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

RG-Radio Government (ratings)

 U1.79

BNC connectors



BNC – Bayone-Neill-Concelman

 U1.80

•The BNC connector is used to connect the end of the cable to a device, such as a TV set

•BNC T connector is used in ETHERNET

•BNC terminator is used at the end of the cable to prevent the reflection of the signal.

 U1.81

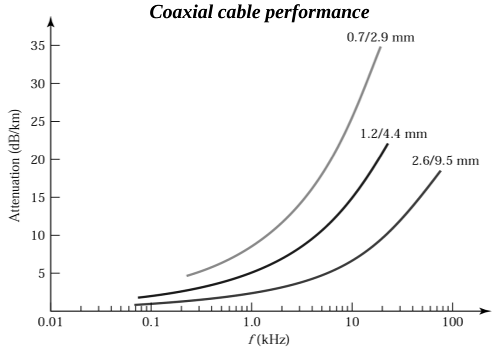
•We can measure the performance of a coaxial cable, as shown in figure (on next slide).

•The attenuation is much higher in coaxial cable that in twister pair.

•In other words, although coaxial cable has a much higher bandwidth, the signal weakens rapidly and requires the frequent use of repeaters.

 U1.82

Coaxial cable performance



 U1.83

Optical Fiber

•Optical Fiber is made of glass or plastic and transmit signals in the form of light.

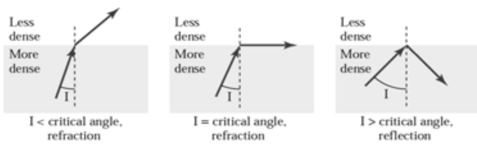
•Light travels in a straight line as long as it is moving through a single medium substance.

•If a ray of light traveling through one instance suddenly enters another substance (of a different density), the ray changes direction. .

•In next slide, you can see how a ray of light changes direction when going form a more dense to less dense substance.

 U1.84

Bending of light ray



Optical Fiber

•If the angle of incidence I (the angle the ray makes with the line perpendicular to the interface between the two substance) is less that 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 surface.

•If the angle I greater than the critical angle, the ray reflects (makes a turn) and travels again in the denser substance.

•Note that the critical angle is property of the substance, and its value differs from one substance to another.

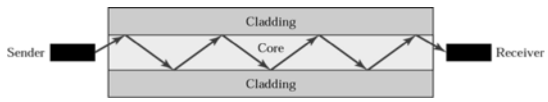
Optical Fiber

•Optical fibers use reflection to guide light through a channel.

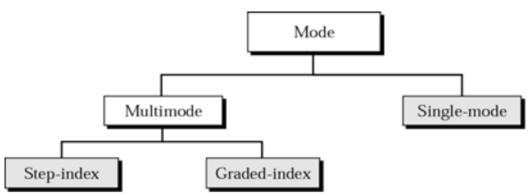
•A glass or plastic is surrounded by a cladding of less dense glass or plastic.

•The difference in density of the two materials must be such that a beam of light moving through the core is reflected of the cladding instead of being refracted into it.

Optical fiber



Propagation modes



Optical Fiber

•**Multimode** is so named because multiple beams from a light source move through the core in different paths.

•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.

Optical Fiber

•Multimode step index fibers are similar to the single mode step index fibers except the center core is much larger with multimode configuration.

•With this large core diameter there are many paths through which light can travel.

•This type of fiber has a large light to fiber aperture and allows more light to enter the fiber.

•The light rays that strike the core/cladding interface at an angle greater than the critical angle are propagated down the core in a zigzag fashion.

Optical Fiber

•Light rays that strike the core/cladding interface at an angle less than the critical angle enter the cladding and are lost.

•Light rays take different paths down the fiber, which results in large difference in propagation times.

•Due to this light rays travelling down fiber have a tendency to spread out.

Optical Fiber

•**Multimode graded-index fiber,** decreases this distortion of the signal through the cable.

•The word index here refers to the index of refraction.

•Refraction is related to the 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.

Optical Fiber

•The multimode graded index fiber is an improvement on the multimode step index fiber.

•Multimode graded index fibers have non-uniform refractive index.

•This fiber has maximum density at the center which gradually decreases towards the outer edge.

•Light rays propagate down this type of fiber through refraction rather than reflection.

 U1.94

Optical Fiber

•As the light rays propagate down the fiber, the rays travelling in the outer most area of the fiber travel a greater distance than the rays travelling near the center.

•Because the refractive index decreases with distance from the center, the light rays travelling farthest from the center propagate at a higher velocity.

•Therefore all light rays take approximately the same time to travel the length of the fiber.

 U1.95

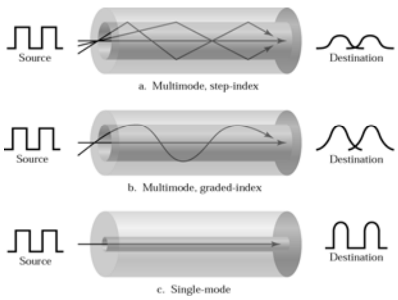
Optical Fiber

•**Single-mode** uses step-index fiber and a highly focused source of light that limits beams to a small range of angles, all close to horizontal.

•The single mode fiber itself is manufactures with a much smaller diameter than that of multimode fiber, and with substantially lower density (index of refraction).

 U1.96

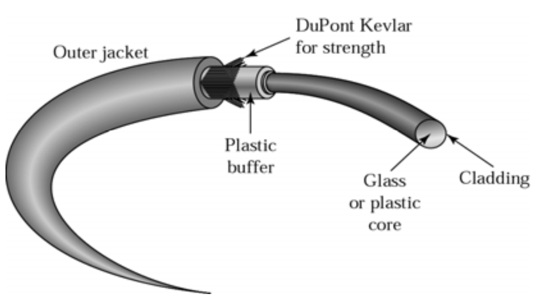
Modes



Fiber types

Type	Core	Cladding	Mode
50/125	50	125	Multimode, graded-index
62.5/125	62.5	125	Multimode, graded-index
100/125	100	125	Multimode, graded-index
7/125	7	125	Single-mode

Fiber construction



Optical Fiber

•The outer jacket is made of either PVC or Teflon.

•Inside the jacket are KEVLAR strands to strengthen the cable.

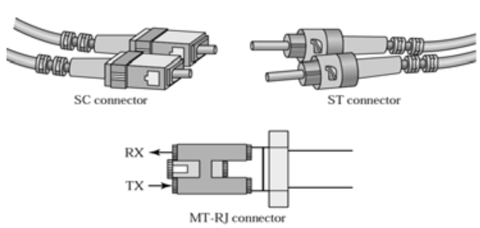
•KEVLAR is a strong material used in the fabrication of bulletproof vests.

•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.

 U1.100

Fiber-optic cable connectors



 U1.101

Optical Fiber

•Subscriber Channel (SC) connector is used for cable TV. It used push/pull locking system.

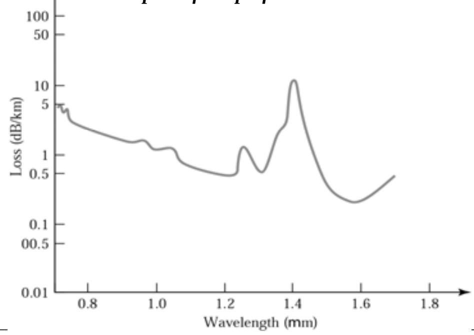
•Straight Tip (ST) connector is used for connecting cable to networking devices.

•It uses a bayonet locking system and is more reliable than SC.

•MT-RJ is a connector that is the same size as RJ45.

 U1.102

Optical fiber performance



 U1.103

Unguided Media: Wireless

- **Radio Waves**
- **Microwaves**
- **Infrared**

 U1.104

Unguided Media: Wireless

Unguided transmission is used when running a physical cable (either fiber or copper) between two end points is not possible.
For example, running wires between buildings is probably not legal if the building is separated by a public street.
Infrared signals typically used for short distances (across the street or within same room),
Microwave signals commonly used for longer distances (10's of km). Sender and receiver use some sort of dish antenna

 U1.105

Unguided Media: Wireless

Difficulties:

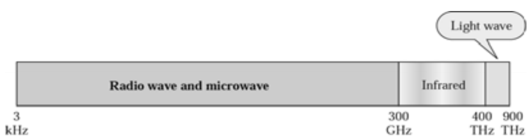
1. Weather interferes with signals. For instance, clouds, rain, lightning, etc. may adversely affect communication.

2. Radio transmissions easy to tap. A big concern for companies worried about competitors stealing plans.

3. Signals bouncing off of structures may lead to out-of-phase signals that the receiver must filter out.

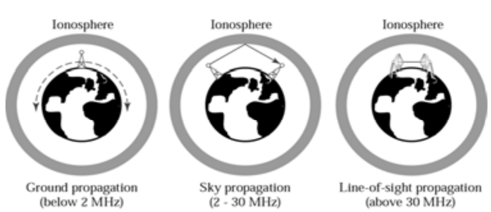
 U1.106

Electromagnetic spectrum for wireless communication



 U1.107

Propagation methods



 U1.108

WIRELESS

•**Ground propagation** – radio waves travel through the lowest portion of the atmosphere.

•These low-frequency signals emanate in all directions form the transmitting antenna and follow the curvature of the planet.

•Distance depends on the amount of power of the signal : The greater the power, the greater the distance.

 U1.109

WIRELESS

•**Sky propagation-** higher-frequency radio waves radiate upward into the ionosphere (the layer of atmosphere where particles exists as ions) where they are reflected back to the earth.

•This type of transmission allows for greater distances with lower output power.

 U1.110

WIRELESS

•**Line –of-Sight propagation -** very high-frequency signals are transmitted in straight lines directly from antenna to antenna.

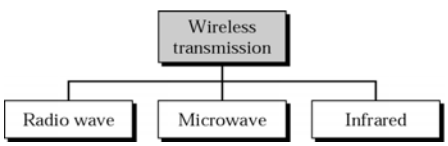
•Antennas must be directions, facing each other, and either tall enough or close enough together not to be affected by the curvature of the earth.

 U1.111

Bands

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

Wireless transmission waves



RADIO WAVE

•Ranges in frequencies between 3 Khz and 1 Ghz.

•Radio waves use omnidirectional antenna.

•When an antenna transmits radio waves, they are propagated in all directions.

•This means that the sending and receiving antenna do not have to be aligned.

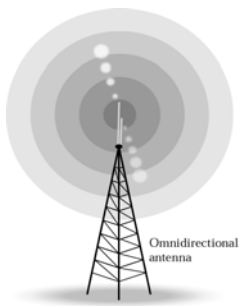
•A sending antenna send waves that can be received by any receiving antenna.

•It has a disadvantage , that radio waves transmitted by one antennas are susceptible to interference by another antenna that may send signals using the same frequency or band.

RADIO WAVE

- Omnidirectional antenna of radio waves make them useful for multicasting, in which there is one sender but many receivers
- AM, FM, Television, Cordless Phone and paging

Omnidirectional antennas



Note:

Radio waves are used for multicast communications, such as radio and television, and paging systems.

Microwave

•Electromagnetic waves having frequencies between 1 and 300 GHz are called micro-waves.

•It uses uni-directional antenna

•When an antenna transmits microwave waves, they can be narrowly focused.

•This means that the sending and receiving antennas need to be aligned.

•It has an advantage, a pair of antennas can be aligned without interfering with another pair of aligned antennas.

Microwave

•Unidirectional antenna can be **parabolic dish** antenna and **the horn**

•A **parabolic antenna** is based on the geometry of a parabola : Every line parallel to the line of symmetry reflects off the curve at angles such that all the lines intersect in a common point called the focus.

•The parabolic dish works as a 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.

Microwave

•Outgoing transmission are broadcast through a horn aimed at the dish.

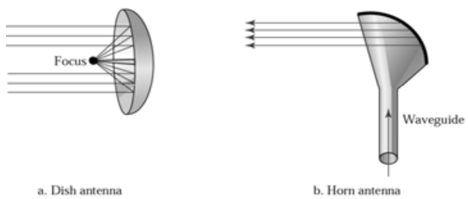
•The microwaves hit the dish and are deflected outward in a reversal of the receipt path

•Outgoing transmission are broadcast up a stem (resembling a handle) and deflected outward in a series of narrow parallel beams of a curved head.

•Received transmissions are collected by the scooped shape of the horn, in a manner similar to the parabolic dish, and deflected down into the stem.

•USED IN CELLULAR PHONES, SATELLITE NETWORKS, WIRELESS LANs

Unidirectional antennas



 U1.121

Note:

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

 U1.122

Note:

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

 U1.123

Satellite Networks

Three Categories of Satellites

- GEO Satellites
- MEO Satellites
- LEO Satellites

 U1.124

Satellite Networks

Microwave frequencies, which travel in straight lines, are commonly used for wideband communication.

The curvature of the earth results in obstruction of the signal between two *earth stations* and the signal also gets attenuated with the distance it traverses.

To overcome both the problems, it is necessary to use a *repeater*, which can receive a signal from one earth station, amplify it, and retransmit it to another earth station.

Larger the height of a repeater from the surface of the earth, longer is the distance of line-of-sight communication.

 U1.125

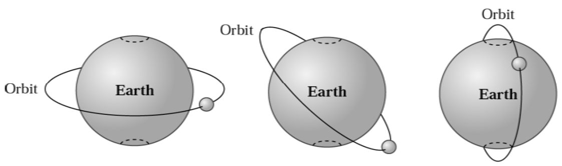
Satellite Networks

Satellite networks were originally developed to provide long-distance telephone service.

So, for communication over long distances, satellites are a natural choice for use as *repeaters in the sky*. In this lesson, we shall discuss different aspects of satellite networks.

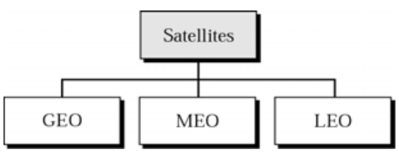
 U1.126

Satellite Networks



a. Equatorial-orbit satellite b. Inclined-orbit satellite c. Polar-orbit satellite

Satellite Networks



Satellite Networks

The satellites can be categorized into three different types , based on the location of the orbit.

These orbits are chosen such that the satellites are not destroyed by the high-energy charged particles present in the two *Van Allen belts*, as shown in Fig..

The Low Earth Orbit (LEO) is below the lower Van Allen belt in the altitude of 500 to 2000 Km. T

he Medium Earth Orbit (MEO) is in between the lower Van Allen belt and upper Van Allen belt in the altitude of 5000 to 15000 Km.

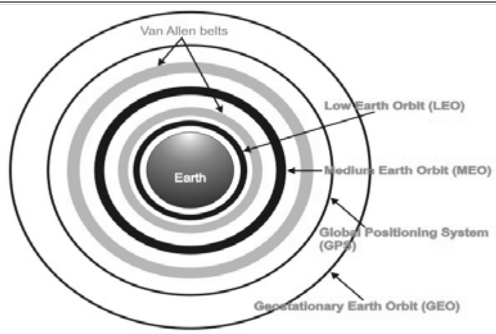
Satellite Networks

The Medium Earth Orbit (MEO) is in between the lower Van Allen belt and upper Van Allen belt in the altitude of 5000 to 15000 Km.

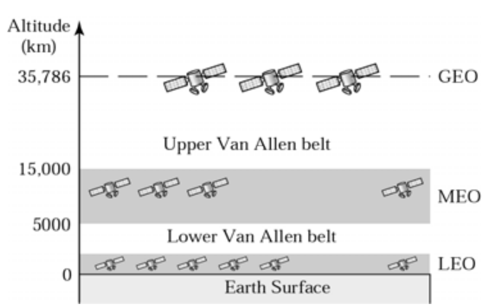
Above the upper Van Allen belt is the Geostationary Earth Orbit (GEO) at the altitude of about 36,000 Km.

Below the Geostationary Earth Orbit and above the upper Van Allen belt is Global Positioning System (GPS) satellites at the altitude of 20,000 Km.

Satellite Networks



Satellite Networks



Satellite Networks

Frequency Bands

Two frequencies are necessary for communication between a ground station and a satellite; one for communication from the ground station on the earth to the satellite called *uplink frequency* and another frequency for communication from the satellite to a station on the earth, called *downlink frequency*.

These frequencies, reserved for satellite communication, are divided in several bands such as L, S, Ku, etc are in the gigahertz (microwave) frequency range as shown in Table . Higher the frequency, higher is the available bandwidth.

 U1.133

Satellite Networks

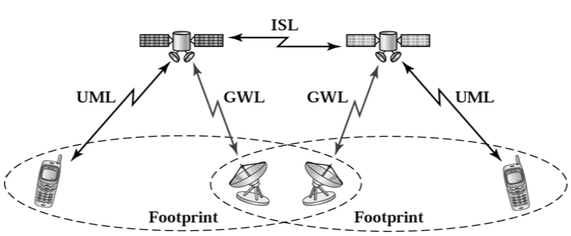
Satellite frequency band

Band	Downlink, GHz	Uplink, GHz	Bandwidth, MHz
L	1.5	1.6	15
S	1.9	2.2	70
C	4	6	500
Ku	11	14	500
Ka	20	30	3500

 U1.134

Satellite Networks

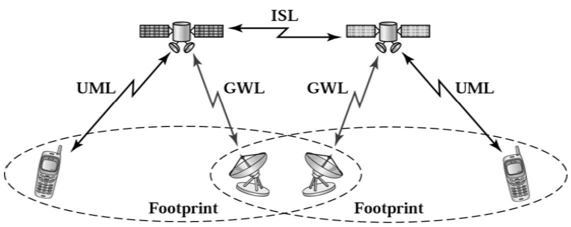
LEO satellite system



 U1.135

Satellite Networks

LEO satellite system



Satellite Networks

LEO satellite system

Iridium System

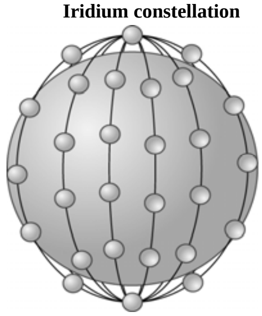
The Iridium system was a project started by Motorola in 1990 with the objective of providing worldwide voice and data communication service using handheld devices.

It took 8 years to materialize using 66 satellites.

The 66 satellites are divided in 6 polar orbits at an altitude of 750 Km. Each satellite has 48 spot beams (total 3168 beams). The number of active spot beams is about 2000. Each spot beam covers a cell

Satellite Networks

Iridium constellation



Satellite Networks

The Iridium system has 66 satellites in six LEO orbits, each at an altitude of 750 km.

 U1.139

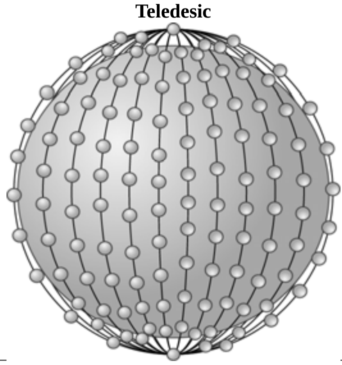
Satellite Networks

Iridium is designed to provide direct worldwide voice and data communication using handheld terminals, a service similar to cellular telephony but on a global scale.

 U1.140

Satellite Networks

Teledesic



 U1.141

Satellite Networks

Teledesic

The Teledesic System

The Teledesic project started in 1990 by Craig McCaw and Bill Gates in 1990 with the objective of providing fiber-optic like communication (Internet-in-the-sky).

It has 288 satellites in 12 polar orbits, each orbit having 24 satellites at an altitude of 1350 Km.

Satellite Networks

Teledesic

Three types of communications that are allowed in Teledasic are as follows;

ISL: Intersatellite communication allows eight neighbouring satellites to communicate with each other

GWL: Communication between a satellite and a gateway

UML: Between an user and a satellite

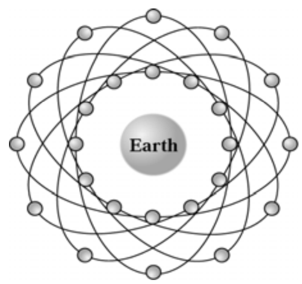
The surface of the earth is divided into thousands of cells and each satellite focuses it beams to a cell during dwell time. It uses Ka band communication with data rates of 155Mbps uplink and 1.2Gbps downlink.

Satellite Networks

Teledesic has 288 satellites in 12 LEO orbits, each at an altitude of 1350 km.

Satellite Networks

Medium Earth Orbit



 U1.145

Satellite Networks

Medium Earth Orbit Satellites

MEO satellites are positioned between two Van Allen Belts at an height of about 10,000 Km with a rotation period of 6 hours. One important example of the MEO satellites is the Global Positioning System (GPS)

 U1.146

Satellite Networks

GPS

The Global Positioning System (GPS) is a satellite-based navigation system. It comprises a network of 24 satellites at an altitude of 20,000 Km (Period 12 Hrs) and an inclination of 55° as shown in Fig.

Although it was originally intended for military applications and deployed by the Department of Defence, the system is available for civilian use since 1980.

It allows land, sea and airborne users to measure their position, velocity and time.

 U1.147

Satellite Networks

It works in any weather conditions, 24 hrs a day.
Positioning is accurate to within 15 meters.
It is used for land and sea navigation using the principle of triangulation as shown in Fig. .
It requires that at any time at least 4 satellites to be visible from any point of earth. A GPS receiver can find out the location on a map.

Figure shows a GPS receiver is shown in the caption’s cabin of a ship. GPS was widely used in Persian Gulf war.

Satellite Networks

Satellite Networks

GEO Satellites

Back in 1945, the famous science fiction writer Arthur C. Clarke suggested that a radio relay satellite in an equatorial orbit with a period of 24 h would remain stationary with respect to the earth’s surface and that can provide radio links for long distance communication.

Although the rocket technology was not matured enough to place satellites at that height in those days, later it became the basis of Geostationary (GEO) satellites.

To facilitate constant communication, the satellite must move at the same speed as earth, which are known as Geosynchronous. GEO satellites are placed on equatorial plane at an Altitude of 35786Km.

Satellite Networks

The radius is 42000Km with the period of 24 Hrs.

With the existing technology, it is possible to have 180 GEO satellites in the equatorial plane. But, only three satellites are required to provide full global coverage as shown in figure

Long round-trip propagation delay is about 270 msec between two ground stations. Key features of the GEO satellites are mentioned below:

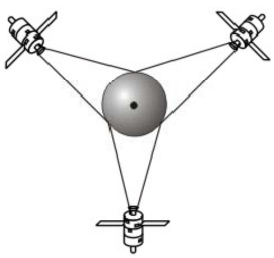
Inherently broadcast media: It does not cost much to send to a large number of stations

Lower privacy and security: Encryption is essential to ensure privacy and security

Cost of communication is independent of distance

 U1.151

Satellite Networks



Three satellites providing full global coverage in GEO system Version

 U1.152

Physical Layer

Signals

 U1.153

Physical Layer

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

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Physical Layer

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

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Physical Layer

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

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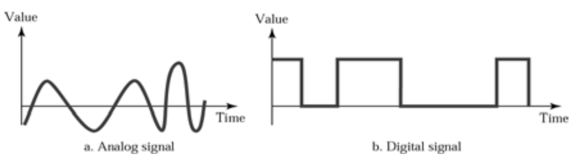
Physical Layer

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

 U1.157

Physical Layer

Comparison of analog and digital signals



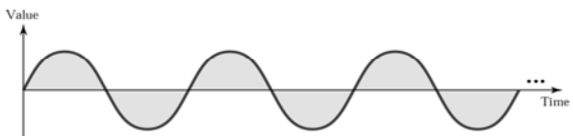
 U1.158

Analog Signals

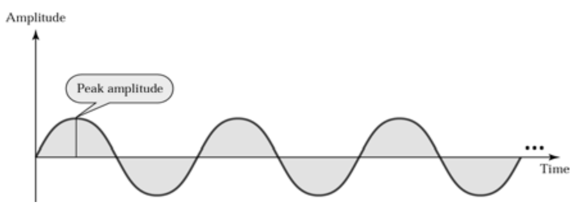
- ***Sine Wave***
- ***Phase***
- ***Examples of Sine Waves***
- ***Time and Frequency Domains***
- ***Composite Signals***
- ***Bandwidth***

 U1.159

Sine Wave



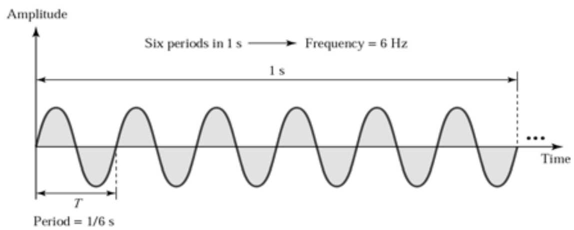
Amplitude



Amplitude

Frequency and period are inverses of each other.

Period and Frequency



Period and Frequency

Units of periods and frequencies

Unit	Equivalent	Unit	Equivalent
Seconds (s)	1 s	hertz (Hz)	1 Hz
Milliseconds (ms)	10^{-3} s	kilohertz (KHz)	10^{3} Hz
Microseconds (ms)	10^{-6} s	megahertz (MHz)	10^{6} Hz
Nanoseconds (ns)	10^{-9} s	gigahertz (GHz)	10^{9} Hz
Picoseconds (ps)	10^{-12} s	terahertz (THz)	10^{12} Hz

Period and Frequency

Units of periods and frequencies

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Nanoseconds (ns)	10^{-9} s	gigahertz (GHz)	10^{9} Hz
Picoseconds (ps)	10^{-12} s	terahertz (THz)	10^{12} Hz

Example

Express a period of 100 ms in microseconds, and express the corresponding frequency in kilohertz.

Solution

From Table we find the equivalent of 1 ms.We make the following substitutions:

$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 100 \times 10^{-3} \times 10^{6} \ \mu\text{s} = 10^{5} \ \mu\text{s}$

Now we use the inverse relationship to find the frequency, changing hertz to kilohertz

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

$f = 1/10^{-1} \text{ Hz} = 10 \times 10^{-3} \text{ KHz} = 10^{-2} \text{ KHz}$

 U1.166

Signals

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

 U1.167

Signals

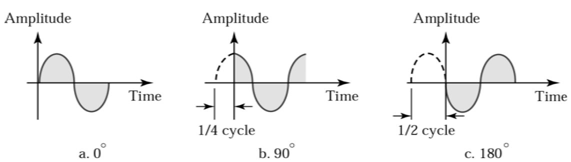
If a signal does not change at all, its frequency is zero. If a signal changes instantaneously, its frequency is infinite.

 U1.168

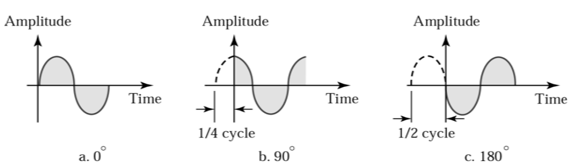
Signals

Phase describes the position of the waveform relative to time zero.

Different Phases



Different Phases



Example

A sine wave is offset one-sixth of a cycle with respect to time zero. What is its phase in degrees and radians?

Solution

We know that one complete cycle is 360 degrees.

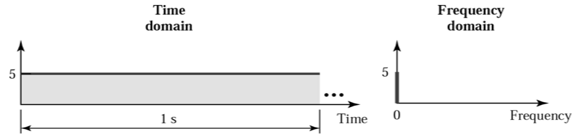
Therefore, 1/6 cycle is

$(1/6)\ 360 = 60$ degrees $= 60 \times 2\pi/360$ rad $= 1.046$ rad

Signals

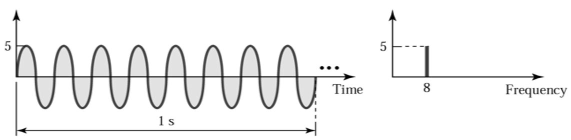
An analog signal is best represented in the frequency domain.

Time and Frequency Domain



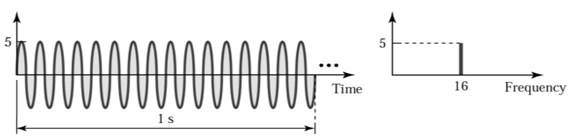
a. A signal with frequency 0

Time and Frequency Domain



b. A signal with frequency 8

Time and Frequency Domain



c. A signal with frequency 16

Signals

A single-frequency sine wave is not useful in data communications; we need to change one or more of its characteristics to make it useful.

Signals

When we change one or more characteristics of a single-frequency signal, it becomes a composite signal made of many frequencies.

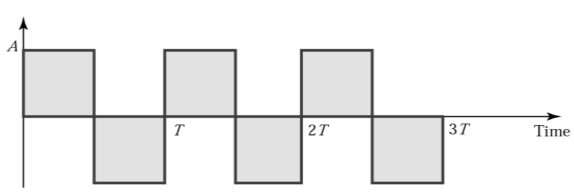
 U1.178

Signals

According to Fourier analysis, any composite signal can be represented as a combination of simple sine waves with different frequencies, phases, and amplitudes.

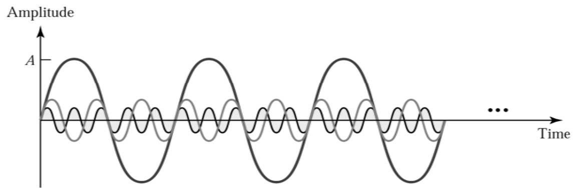
 U1.179

Square Wave



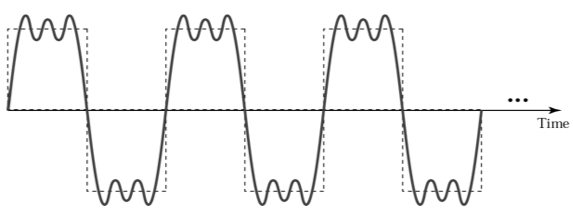
 U1.180

Three Harmonics



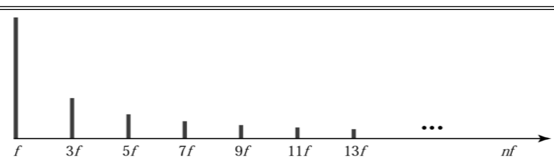
 U1.181

Adding first three Harmonics

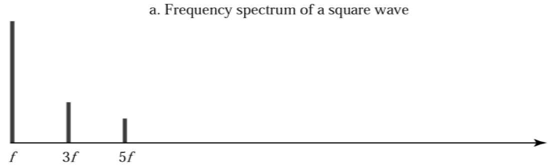


 U1.182

Frequency Spectrum



a. Frequency spectrum of a square wave



b. Frequency spectrum of an approximation with only three harmonics

 U1.183

Signals

Signals

Signals

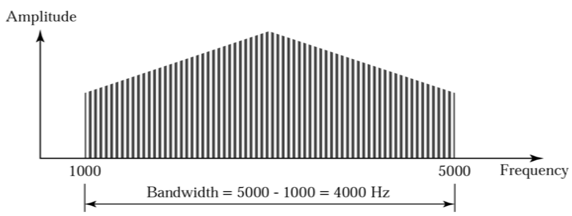
The bandwidth is a property of a medium: It is the difference between the highest and the lowest frequencies that the medium can satisfactorily pass.

Signals

Here, we use the term bandwidth to refer to the property of a medium or the width of a single spectrum.

 U1.187

Bandwidth



 U1.188

Example

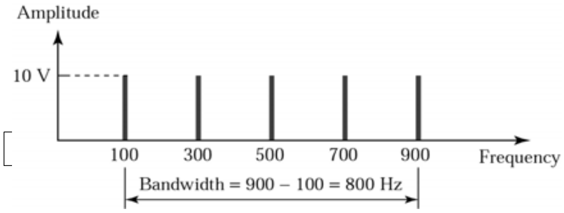
If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is the bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V.

Solution

$B = f_h - f_l = 900 - 100 = 800$ Hz
The spectrum has only five spikes, at 100, 300, 500, 700, and 900 (see Figure)

 U1.189

Example



Example

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

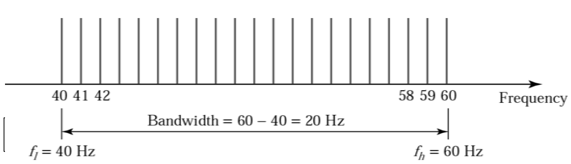
Solution

$B = f_h - f_l$

$20 = 60 - f_l$

$f_l = 60 - 20 = 40$ Hz

Example



Example

A signal has a spectrum with frequencies between 1000 and 2000 Hz (bandwidth of 1000 Hz). A medium can pass frequencies from 3000 to 4000 Hz (a bandwidth of 1000 Hz). Can this signal faithfully pass through this medium?

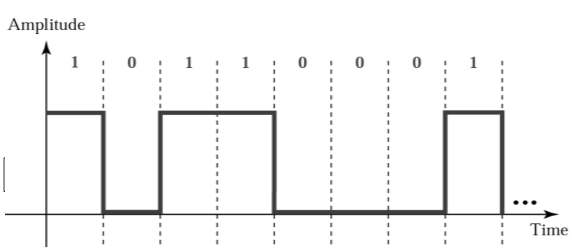
Solution

The answer is definitely no. Although the signal can have the same bandwidth (1000 Hz), the range does not overlap. The medium can only pass the frequencies between 3000 and 4000 Hz; the signal is totally lost.

Digital Signals

- ***Bit Interval and Bit Rate***
- ***As a Composite Analog Signal***
- ***Through Wide-Bandwidth Medium***
- ***Through Band-Limited Medium***
- ***Versus Analog Bandwidth***
- ***Higher Bit Rate***

Digital Signals



Example

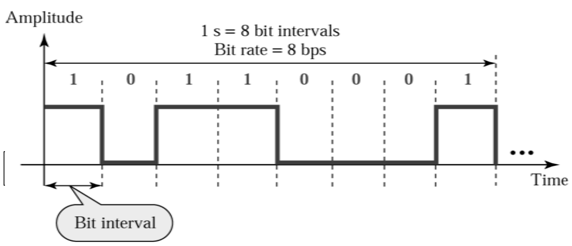
A digital signal has a bit rate of 2000 bps. What is the duration of each bit (bit interval)

Solution

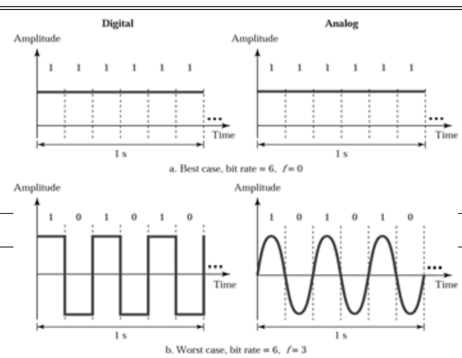
The bit interval is the inverse of the bit rate.

Bit interval = 1/ 2000 s = 0.000500 s
= 0.000500 x 10^6 μs = 500 μs

Bit Rate and Bit Interval



Digital Versus Analog



Digital Versus Analog

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

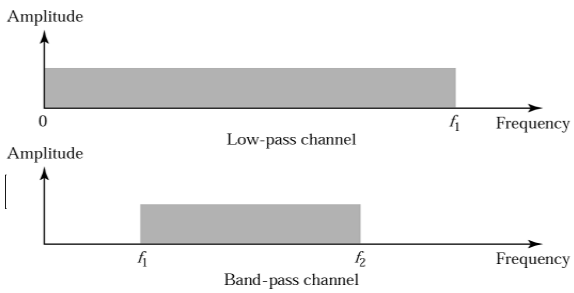
Digital Versus Analog

The bit rate and the bandwidth are proportional to each other.

Digital Versus Analog

- ***Low-pass versus Band-pass***
- ***Digital Transmission***
- ***Analog Transmission***

Low Pass and Band Pass Channel



 U1.202

Low Pass and Band Pass Channel

The analog bandwidth of a medium is expressed in hertz; the digital bandwidth, in bits per second.

 U1.203

Low Pass and Band Pass Channel

Digital transmission needs a low-pass channel.

 U1.204

Low Pass and Band Pass Channel

Analog transmission can use a band-pass channel.

 U1.205

Data Rates

- ***Noiseless Channel: Nyquist Bit Rate***
- ***Noisy Channel: Shannon Capacity***
- ***Using Both Limits***

 U1.206

Example

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

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

 U1.207

Example

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

$$\text{Bit Rate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}$$

 U1.208

Example

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

$$C = B \log_2 (1 + SNR) = B \log_2 (1 + 0)$$

$$= B \log_2 (1) = B \times 0 = 0$$

 U1.209

Example

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

$$C = B \log_2 (1 + SNR) = B \log_2 (1 + 0)$$

$$= B \log_2 (1) = B \times 0 = 0$$

 U1.210

Example

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

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

 U1.211

Example

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

Solution

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

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

Then we use the Nyquist formula to find the number of signal levels.

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

 U1.212

Transmission Impairment

A transmission impairment is a property of a transmission medium which causes the signal to be degraded, reduced in amplitude, distorted or contaminated.

Impairment can introduce errors into digital signals.

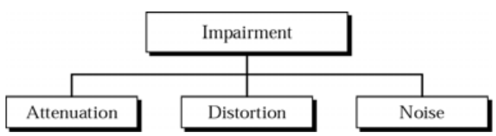
Examples of transmission impairments are attenuation, delay distortion, and several sources of noise including, thermal noise, impulse noise, and inter-modulation noise.

 U1.213

Transmission Impairment

- ***Attenuation***
- ***Distortion***
- ***Noise***

Transmission Impairment



Transmission Impairment

•It is important to understand transmission impairments for several reasons.

•Understanding the source of a transmission impairment like attenuation or dispersion will enable the user to partially correct for (equalize the signal) these effects.

•Understanding the source of transmission impairments (dispersion, attenuation, impulse noise, thermal noise) can also help the user understand some of the constraints placed on the transmission of data as a result of these effects.

Transmission Impairment

•Such constraints include the maximum length of network links, the choice of physical transmission media, the choice of encoding methods, and the data rate supported by the medium.

Transmission Impairment

•Attenuation is a property of the transmission medium.

•It measures how much energy is absorbed and/or radiated from the traveling signal due to it's interaction with the transmission medium.

•Attenuation is measured as a function of the distance traveled through the transmission medium.

Transmission Impairment

•The transmission medium absorbs energy because the signal is influenced by small impurities within it.

•Such impurities have different sizes and distributions depending on the type of medium. Impurities of different sizes effect different frequencies in the signal.

•The effect of attenuation is, therefore, a function of frequency.

Transmission Impairment

- The frequency variation of attenuation can be partially corrected, or equalized, by applying corrections based on a physical model.
- When a signal is attenuated it's amplitude is reduced.
- The interpretation of a received signal depends on being able to tell the difference between different signal levels.
- If the amplitude is reduced too much by attenuation it becomes impossible to accurately tell the difference between the different signal levels, and the information in the signal is lost.

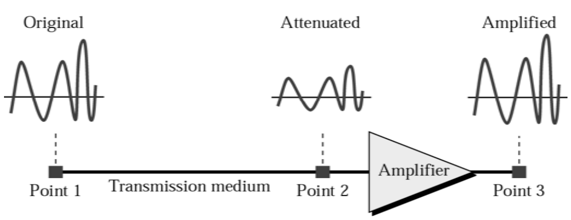
 U1.220

Transmission Impairment

- To prevent this from happening repeaters (digital) or amplifiers (analog) are used.
- These devices increase the amplitude of the signal by decoding and retransmitting the signal or increasing the received amplitudes respectively.
- By inserting amplifiers or repeaters in the transmission media, the maximum signal propagation distance (a property of the attenuation of the medium) is increased.

 U1.221

Attenuation



 U1.222

Example

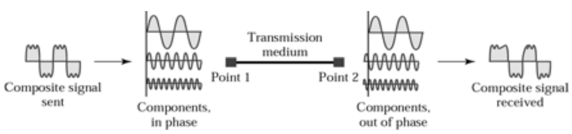
Imagine a signal travels through a transmission medium and its power is reduced to half. This means that P2 = 1/2 P1. In this case, the attenuation (loss of power) can be calculated as

Solution

$10 \log_{10} (P2/P1) = 10 \log_{10} (0.5P1/P1) = 10 \log_{10} (0.5)$
$= 10(-0.3) = -3$ dB

 U1.223

Distortion



 U1.224

Distortion

- **Dispersion** is also a property of the transmission medium.
- Signals with different frequencies will travel through a transmission medium with slightly different velocities.
-
- Therefore, the signal will be smeared or distorted when it reaches the destination.
- The longer the transmission medium the larger the time difference in the arrival times of the parts of the signal with different frequencies and the more severe the smearing or distortion of the signal.

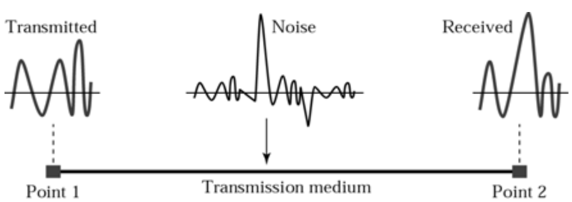
 U1.225

Distortion

- Like attenuation, the physical properties of dispersion can be modeled.
- Thus it is also possible to develop an equalization model to partially compensate for dispersion.

 U1.226

Noise



 U1.227

Noise

- Noise of different types will affect a transmitting signal.
- Thermal noise, low amplitude random noise at predictable low amplitude (amplitude related to the temperature of the transmission medium), is caused by the thermal vibration of the molecules within the transmission medium.
- The difference between signal levels in a transmitted signal will generally be much larger than the amplitude of the thermal noise.

 U1.228

Noise

•Thermal noise sets a limit of how close different signal levels can be at the receiver (larger than the 2X amplitude of the thermal noise).

•Thermal noise will not usually be of high enough amplitude to cause the introduction of bit errors in an encoded signal (unless attenuation has been excessive).

• However, impulse noise picked up from the environment can have high amplitude for significant lengths of time

Noise

•Such impulse noise can be caused by interference from other signals in the environment including other transmitted signals, or electrical fields natural (lightning, aurora) or manmade (signals emitted by other electrical equipment).

•The amplitude of impulse noise may reach or exceed the magnitude of the signal.

Noise

•The duration of a pulse of impulse noise may be several time the duration of a single signal.

•Because of the large amplitude of the impulse noise pulse it is possible that, when added to the real signal, the resultant received signal may appear to have been transmitted at a different level that it actually was.

Noise

For example,

•for a signal with three levels (1 , 0, -1) and impulse noise has an amplitude of 1 added to a signal, the resulting received signal will have a level of (0, 1, 2).

•During the noise pulse a signal transmitted at level 0 will arrive at the receiver with an amplitude of 1,.

•Similarly a signal transmitted at level -1 will arrive at the receiver with an amplitude of 0. In both cases the level of the received signal will be different from the signal that was sent.

•When the signal is decoded the resulting value of the data bit will have changed in transmission. A bit error has been introduced into the received signal.

 U1.232

Signals

•***Throughput***

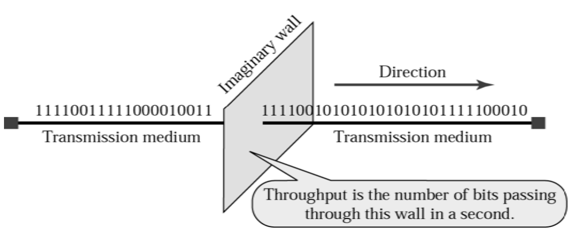
•***Propagation Speed***

•***Propagation Time***

•***Wavelength***

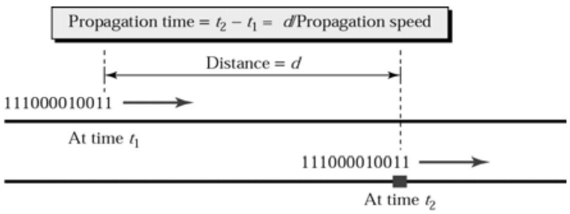
 U1.233

Throughput

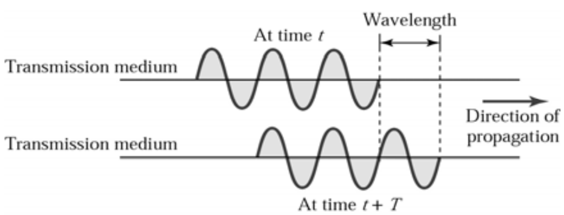


 U1.234

Propagation Time



Wave Length



Signals

Digital Transmission

Characterstics

Some Characteristics

Line Coding Schemes

Some Other Schemes

 U1.238

Characterstics

- A computer network is used for communication of data from one station to another station in the network.
- We have seen that analog or digital data traverses through a communication media in the form of a signal from the source to the destination.
- The channel bridging the transmitter and the receiver may be a guided transmission medium such as a wire or a wave-guide or it can be an unguided atmospheric or space channel.
- But, irrespective of the medium, the signal traversing the channel becomes attenuated and distorted with increasing distance.

 U1.239

Characterstics

- Hence a process is adopted to match the properties of the transmitted signal to the channel characteristics so as to efficiently communicate over the transmission media.
- There are two alternatives; the data can be either converted to digital or analog signal.
- Both the approaches have pros and cons.
- What to be used depends on the situation and the available bandwidth.

 U1.240

Characterstics

•Now, either form of data can be encoded into either form of signal.

•For digital signaling, the data source can be either analog or digital, which is encoded into digital signal, using different encoding techniques.

Characterstics

•The basis of analog signaling is a constant frequency signal known as a ***carrier signal***, which is chosen to be compatible with the transmission media being used, so that it can traverse a long distance with minimum of attenuation and distortion.

•Data can be transmitted using these carrier signals by a process called ***modulation***, where one or more fundamental parameters of the carrier wave, i.e. amplitude, frequency and phase are being modulated by the source data.

•The resulting signal, called ***modulated signal*** traverses the media, which is ***demodulated*** at the receiving end and the original signal is extracted.

Characterstics

•**No of signal levels**: This refers to the number values allowed in a signal, known as s**ignal levels**, to represent data.

•**<u>Bit rate versus Baud rate</u>**:

•The **bit rate** represents the number of bits sent per second, whereas the **baud rate** defines the number of signal elements per second in the signal.

•Depending on the encoding technique used, baud rate may be more than or less than the data rate.

Characterstics

DC components:

•After line coding, the signal may have zero frequency component in the spectrum of the signal, which is known as the direct-current **(DC) component**.

•DC component in a signal is not desirable because the DC component does not pass through some components of a communication system such as a transformer.

•This leads to distortion of the signal and may create error at the output. The DC component also results in unwanted energy loss on the line.

 U1.244

Characterstics

Signal Spectrum:

•Different encoding of data leads to different spectrum of the signal.

•It is necessary to use suitable encoding technique to match with the medium so that the signal suffers minimum attenuation and distortion as it is transmitted through a medium.

 U1.245

Characterstics

Synchronization:
•To interpret the received signal correctly, the bit interval of the receiver should be exactly same or within certain limit of that of the transmitter.

•Any mismatch between the two may lead wrong interpretation of the received signal.

•Usually, clock is generated and synchronized from the received signal with the help of a special hardware known as Phase Lock Loop (PLL).

•However, this can be achieved if the received signal is self-synchronizing having frequent transitions (preferably, a minimum of one transition per bit interval) in the signal.

 U1.246

Characterstics

Cost of Implementation: It is desirable to keep the encoding technique simple enough such that it does not incur high cost of implementation.

 U1.247

Characteristics

Signal Element Vs 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 Element being carried; Signal elements are the carriers.

 U1.248

Characteristics

Data Rate Vs 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 baud.

•The data rate sometimes called the bit rate; the signal rate is sometimes called the **pulse rate**, **modulation rate**, or the **baud rate**.

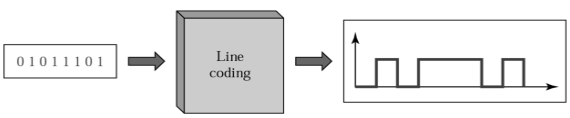
 U1.249

Characteristics

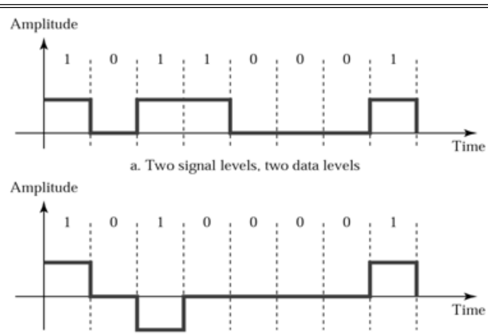
•Our goal in data communications is to increase the data rate while decreasing the signal rate.

•Increasing the data rate increases the speed of transmission; decreasing the signal rate decreases the bandwidth requirement.

Line Coding



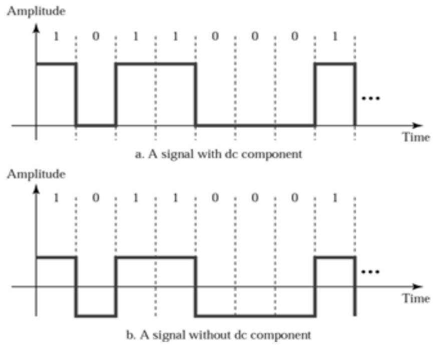
Signal Levels Vs Data level



a. Two signal levels, two data levels

b. Three signal levels, three data levels

DC Component



a. A signal with dc component

b. A signal without dc component

 U1.253

DC Component

- When the voltage level in digital signal is constant for a while, spectrum creates very low frequencies.
- These frequencies around Zero, called DC components.
- It presents problem for a system that can not pass low frequencies or a system that uses electrical coupling.

 U1.254

DC Component

- For example,

A telephone line cannot pass frequencies below 200 Hz. Also a long-distance link may use one or more transformers to isolate different parts of the line electrically.

 U1.255

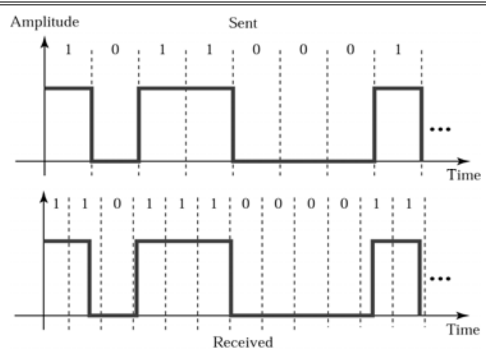
DC Component

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

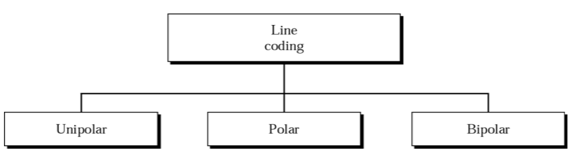
Pulse Rate = $1/10^{-3}$ = 1000 pulses/s

Bit Rate = Pulse Rate x $\log_2 L$ = 1000 x $\log_2 2$ = 1000 bps

Lack of Synchronization



Digital Transmission

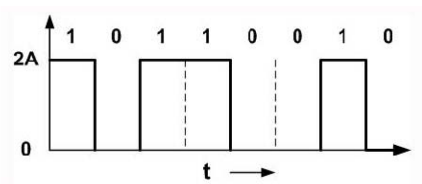


Digital Transmission

- In unipolar encoding technique, only one voltage levels are used.
- It uses only one polarity of voltage level as shown in Fig..
- In this encoding approach, the bit rate same as data rate.
- Unfortunately, DC component present in the encoded signal and there is loss of synchronization for long sequences of 0's and 1's.
- It is simple but obsolete.

 U1.259

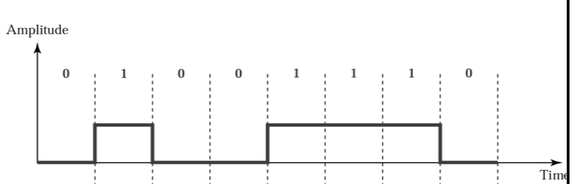
Digital Transmission



 U1.260

Digital Transmission

Unipolar encoding uses only one voltage level.



 U1.261

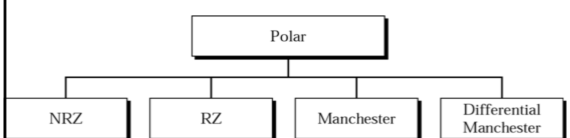
Digital Transmission

•This scheme is very costly.

•Unipolar scheme is normally not used in data communications today.

Digital Transmission

Polar encoding uses two voltage levels (positive and negative).



Digital Transmission

Non Return to zero (NRZ):

•The most common and easiest way to transmit digital signals is to use two different voltage levels for the two binary digits.

•Usually a negative voltage is used to represent one binary value and a positive voltage to represent the other.

•The data is encoded as the presence or absence of a signal transition at the beginning of the bit time.

•As shown in the figure below, in NRZ encoding, the signal level remains same throughout the bit-period.

•There are two encoding schemes in NRZ: NRZ-L and NRZ-I, as shown in Fig.

Digital Transmission

The **advantages** of NRZ coding are:

- Detecting a transition in presence of noise is more reliable than to compare a value to a threshold.
- NRZ codes are easy to engineer and it makes efficient use of bandwidth.
- The spectrum of the NRZ-L and NRZ-I signals are shown in Fig. It may be noted that most of the energy is concentrated between 0 and half the bit rate.
- The main limitations are the presence of a dc component and the lack of synchronization capability.
- When there is long sequence of 0's or 1's, the receiving side will fail to regenerate the clock and synchronization between the transmitter and receiver clocks will fail.

 U1.265

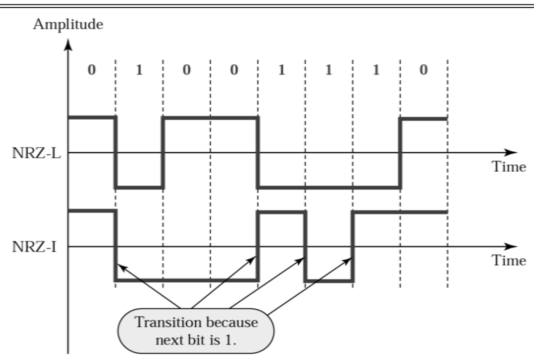
Digital Transmission

In NRZ-L the level of the signal is dependent upon the state of the bit.

In NRZ-I the signal is inverted if a 1 is encountered.

 U1.266

Digital Transmission



 U1.267

Digital Transmission

•NRZ-Level, the level of the voltage determines the value of the bit

•NRZ-Invert, the change or lack of change in the level of the voltage determines the value of the bit. If there is no change, the bit is 0, if there is a change, the bit is 1.

•If there is a long sequence of 0s or 1s in NRZ-L, the average signal power becomes skewed. The receiver might have difficulty discerning the bit value.

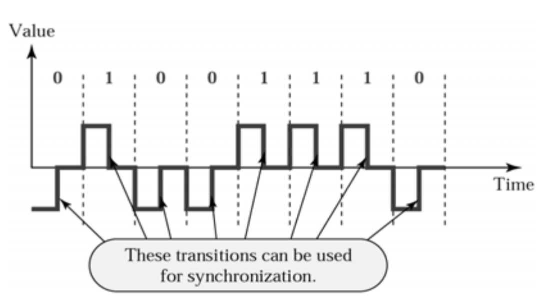
•IN NRZ-I this problem occurs only for a long sequence of 0s.

Digital Transmission

•The main problem with NRZ encoding occurs when the sender and receiver clocks are not synchronized. The receiver does not know when one bit has ended and the next bit is starting.

•One solution is the RZ (return-to-zero) scheme, which uses three voltage levels.

RZ Encoding



RZ Encoding

Return to Zero RZ: To ensure synchronization, there must be a signal transition in each bit as shown in Fig. 2.4.9. Key characteristics of the RZ coding are:

- Three levels
- Good synchronization
- Main limitation is the increase in bandwidth

RZ Encoding

- The main disadvantage of RZ encoding is that it requires two signal changes to encode a bit and therefore occupies greater bandwidth.

RZ Encoding

A good encoded digital signal must contain a provision for synchronization.

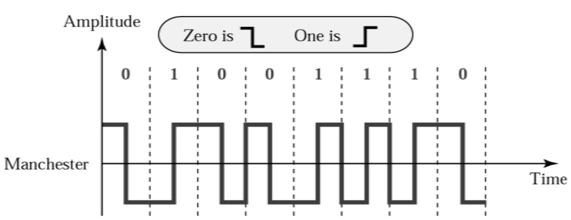
Manchaster

Biphase:

•To overcome the limitations of NRZ encoding, biphase encoding techniques can be adopted.
•*Manchester* and *differential Manchester Coding* are the two common Biphase techniques in use, as shown in Fig. .
•In Manchester coding the mid-bit transition serves as a clocking mechanism and also as data.

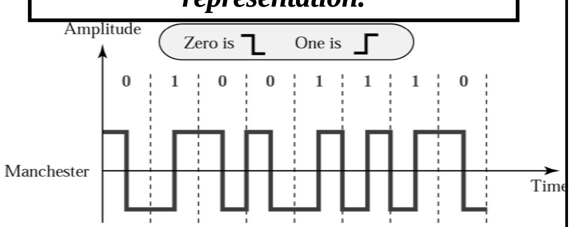
•In the standard Manchester coding there is a transition at the middle of each bit period.
•A binary 1 corresponds to a *low-to-high transition* and a binary 0 to a *high-to-low transition* in the middle.

Manchaster



Manchester

In Manchester encoding, the transition at the middle of the bit is used for both synchronization and bit representation.



Differential Manchester

- **In Differential Manchester**, inversion in the middle of each bit is used for synchronization.
- The encoding of a 0 is represented by the presence of a transition both at the beginning and at the middle and 1 is represented by a transition only in the middle of the bit period.

Key characteristics are:

- Two levels
- No DC component
- Good synchronization
- Higher bandwidth due to doubling of bit rate with respect to data rate

 U1.277

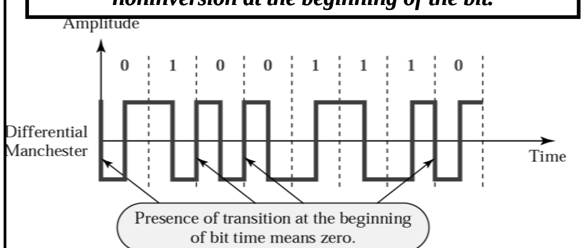
Differential Manchester

- The bandwidth required for biphase techniques are greater than that of NRZ techniques, but due to the predictable transition during each bit time, the receiver can synchronize properly on that transition.
- Biphase encoded signals have no DC components as shown in Fig..
- A Manchester code is now very popular and has been specified for the IEEE 802.3 standard for base band coaxial cables and twisted pair CSMA/CD bus LANs.

 U1.278

Differential Manchester

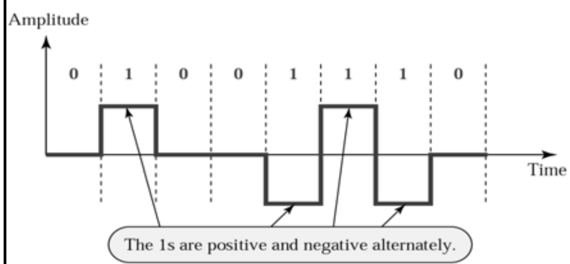
In differential Manchester encoding, the transition at the middle of the bit is used only for synchronization. The bit representation is defined by the inversion or noninversion at the beginning of the bit.



 U1.279

Bipolar Encoding

In bipolar encoding, we use three levels: positive, zero, and negative.



Sampling

- ***Pulse Amplitude Modulation***
- ***Pulse Code Modulation***
- ***Sampling Rate: Nyquist Theorem***
- ***How Many Bits per Sample?***
- ***Bit Rate***

Sampling

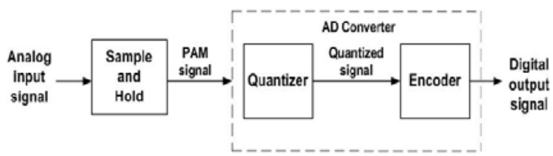
Analog data such as voice, video and music can be converted into digital signal communication through transmission media. This allows the use of modern digital transmission and switching equipment's. The device used for conversion of analog data to digital signal and vice versa is called a *coder* (coder-decoder). There are two basic approaches:

Pulse Code Modulation (PCM)
Delta Modulation (DM)

Sampling

Pulse Code Modulation involves the following three basic steps as shown in Fig. :
- Sampling – PAM
- Quantization
- Line coding

Sampling



Sampling

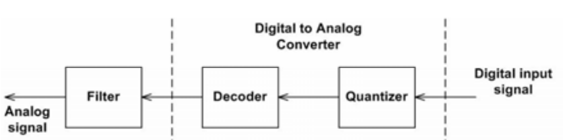
Sampling: This process is based on Shannon's sampling theorem. Numbers of samples of the signal are taken at regular intervals, at a rate higher than twice the highest significant signal frequency. This basic step is known as Pulse Amplitude Modulation (PAM) as shown in Fig. . For example, during the sampling of voice data, in the frequency range 300 to 4000 Hz, 8000 samples per second are sufficient for the coding

Sampling

Sampling

Quantization: The PAM samples are quantized and approximated to n-bit integer by using analog-to-digital converter. For example, if n = 4, then there are 16 (=24) levels available for approximating the PAM signals. This process introduces an error are known as ***quantization* error**. Quantization error depends on step size. Use of uniform step size leads to poorer S/N ratio for small amplitude signals. With the constraint of a fixed number of levels, the situation can be improved using variable step size. The effect of quantization error can be minimized by using a technique known as **companding**. In this case, instead of using uniform stage sizes, the steps are close together at low signal amplitude and further apart at high signal amplitude as shown in Fig. 2.4.18. It uses a compressor before encoding and expander after decoding. This helps to improve the S/N ratio of the signal.

Sampling



Sampling

Limitations: The PCM signal has high bandwidth. For example, let us consider voice signal as input with bandwidth of 4 kHz. Based on Nyquist theorem, the Sampling frequency should be 8 kHz. If an 8-bit ADC is used for conversion to digital data, it generates data rate of 64 Kbps.

Therefore, to send voice signal a data rate of 64 Kbps is required. To overcome this problem a technique known as

Differential PCM (DPCM) can be used. It is based on the observation that voice signal changes slowly. So, the difference between two consecutive sample values may be sent. Since the signal changes slowly, the difference between two consecutive sample values will be small and fewer number of bits can be used with consequent reduction in data rates.

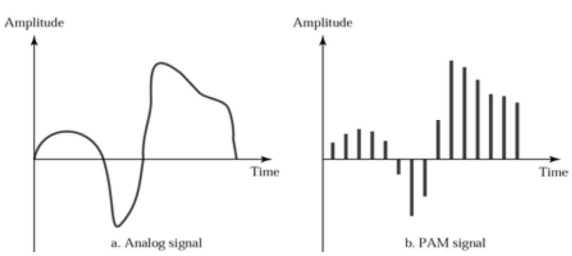
 U1.289

PAM

Pulse amplitude modulation has some applications, but it is not used by itself in data communication. However, it is the first step in another very popular conversion method called pulse code modulation.

 U1.290

PAM

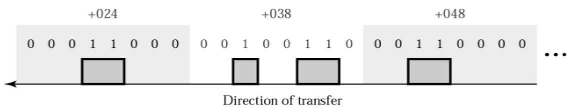


a. Analog signal

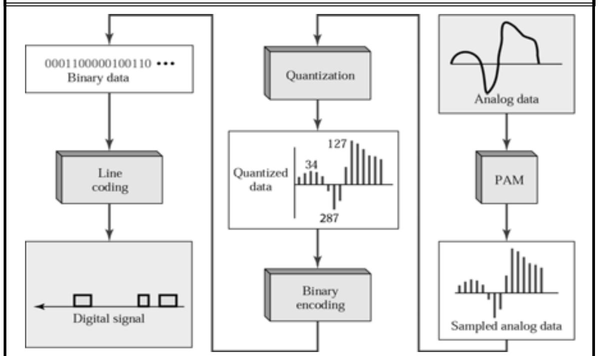
b. PAM signal

 U1.291

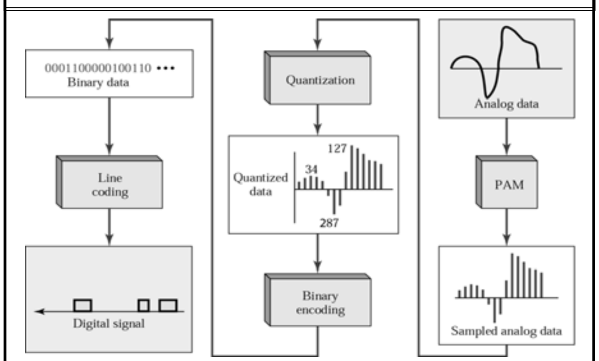
PCM



Analog to PCM Digital code



Analog to PCM Digital code



Sampling

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

 U1.295

Example

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

Solution

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

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

 U1.296

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.
Sampling rate = 4000 x 2 = 8000 samples/s

Bit rate = sampling rate x number of bits per sample
= 8000 x 8 = 64,000 bps = 64 Kbps

 U1.297

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.
Sampling rate = 4000 x 2 = 8000 samples/s

Bit rate = sampling rate x number of bits per sample
= 8000 x 8 = 64,000 bps = 64 Kbps

Sampling

Note that we can always change a band-pass signal to a low-pass signal before sampling. In this case, the sampling rate is twice the bandwidth.

Sampling

Delta Modulation (DM)

•Delta Modulation is a very popular alternative of PCM with much reduced complexity.

•Here the analog input is approximated by a staircase function, which moves up or down by one quantization level (a constant amount) at each sampling interval.

•Each sample delta modulation process can be represented by a single binary digit, which makes it more efficient than the PCM technique.

Sampling

In this modulation technique, instead of sending the entire encoding of each and every sample, we just send the change from previous sample.

If the difference between analog input and the feedback signal is positive, then encoded output is 1, otherwise it is 0. So, only one bit is to be sent per sample.

 U1.301

Sampling

What are the four possible encoding techniques? Give examples.
Ans: The four possible encoding techniques are

- Digital Data to Digital Signal; Example - Transmitter
- Analog Data to Digital Signal; Example - Codec (Coder-Decoder)
- Digital Data to Analog Signal; Example - Modem
- Analog Data to Digital Signal; Example - Telephone

 U1.302

Sampling

Between RZ and NRZ encoding techniques, which requires higher bandwidth and why?
Ans: RZ encoding requires more bandwidth, as it requires two signal changes to encode one bit**.**

 U1.303

Sampling

Why do you need encoding of data before sending over a medium?

Ans: Suitable encoding of data is required in order to transmit signal with minimum attenuation and optimize the use of transmission media in terms of data rate and error rate.

Sampling

How does Manchester encoding differ from differential Manchester encoding?

Ans: In the Manchester encoding, a low-to-high transition represents a 1, and a high-to-low transition represents a 0. There is a transition at the middle of each bit period, which serves the purpose of synchronization and encoding of data.

In Differential Manchester, the encoding of a 0 is represented by the presence of a transition at the beginning of a bit period, and a 1 is represented by the absence of a transition at the beginning of a bit period. In this case, the midbit transition is only used for synchronization. .

Sampling

How Manchester encoding helps in achieving better synchronization?

Ans: In Manchester encoding, there is a transition in the middle of each bit period and the receiver can synchronize on that transition. Hence better synchronization is achieved.

Sampling

Distinguish between PAM and PCM signals?

Ans: In order to convert Analog data to Digital signal, initially sampling is done on the analog data by using Sample & Hold (S/H) circuit. The output of the S/H circuit is known as PAM (Pulse Amplitude Modulated) signal. The PAM signal is then converted to PCM

 U1.307

Modulation of Digital Data

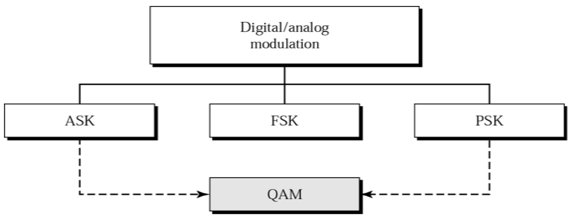
- ***Digital-to-Analog Conversion***
- ***Amplitude Shift Keying (ASK)***
- ***Frequency Shift Keying (FSK)***
- ***Phase Shift Keying (PSK)***
- ***Quadrature Amplitude Modulation***
- ***Bit/Baud Comparison***

 U1.308

Digital to Analog

 U1.309

Digital to Analog



Digital to Analog

Bit rate is the number of bits per second. Baud rate is the number of signal units per second. Baud rate is less than or equal to the bit rate.

Digital to Analog

An analog signal carries 4 bits in each signal unit. If 1000 signal units are sent per second, find the baud rate and the bit rate

Solution

Baud rate = 1000 bauds per second (baud/s)
Bit rate = 1000 x 4 = 4000 bps

Digital to Analog

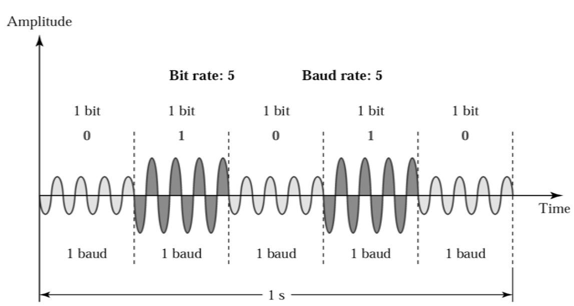
The bit rate of a signal is 3000. If each signal unit carries 6 bits, what is the baud rate?

Solution

Baud rate = 3000 / 6 = 500 baud/s

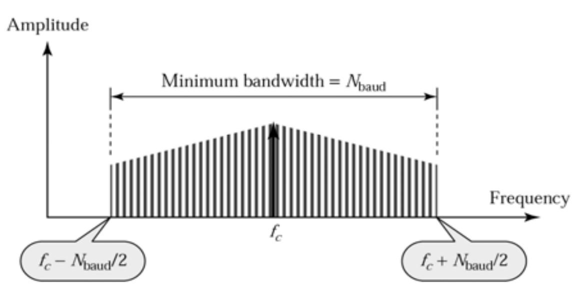
 U1.313

ASK



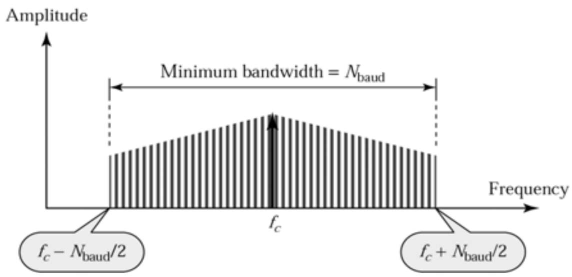
 U1.314

Bit rate and Baud rate in ASK



 U1.315

Bit rate and Baud rate in ASK



 U1.316

Example

Find the minimum bandwidth for an ASK signal transmitting at 2000 bps. The transmission mode is half-duplex.

Solution

In ASK the baud rate and bit rate are the same. The baud rate is therefore 2000. An ASK signal requires a minimum bandwidth equal to its baud rate. Therefore, the minimum bandwidth is 2000 Hz.

 U1.317

Example

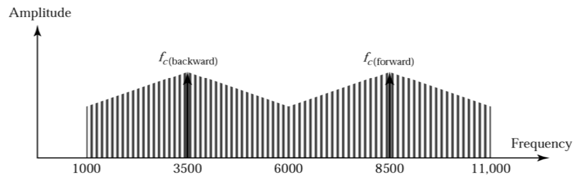
Given a bandwidth of 10,000 Hz (1000 to 11,000 Hz), draw the full-duplex ASK diagram of the system. Find the carriers and the bandwidths in each direction. Assume there is no gap between the bands in the two directions.

Solution

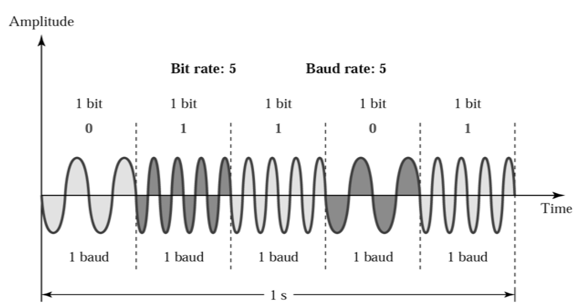
For full-duplex ASK, the bandwidth for each direction is
BW = 10000 / 2 = 5000 Hz
The carrier frequencies can be chosen at the middle of each band (see Fig. 5.5).
fc (forward) = 1000 + 5000/2 = 3500 Hz
fc (backward) = 11000 – 5000/2 = 8500 Hz

 U1.318

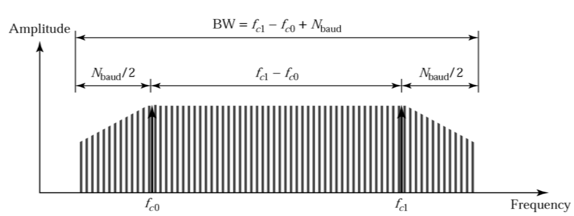
Last Example Solution



FSK



Bid rate and Baud rate in FSK



Example

Find the minimum bandwidth for an FSK signal transmitting at 2000 bps. Transmission is in half-duplex mode, and the carriers are separated by 3000 Hz.

Solution

For FSK

BW = baud rate + $f_{c1} - f_{c0}$

BW = bit rate + fc1 – fc0 = 2000 + 3000 = 5000 Hz

Example

Find the maximum bit rates for an FSK signal if the bandwidth of the medium is 12,000 Hz and the difference between the two carriers is 2000 Hz. Transmission is in full-duplex mode.

Solution

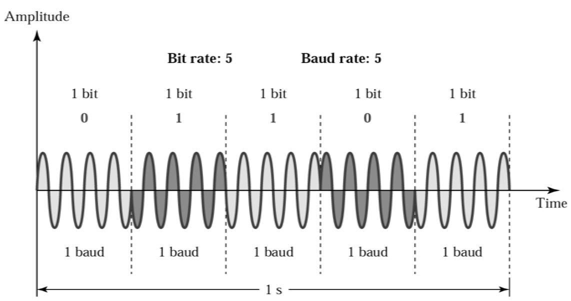
Because the transmission is full duplex, only 6000 Hz is allocated for each direction.

BW = baud rate + fc1 – fc0

Baud rate = BW – (fc1 – fc0) = 6000 – 2000 = 4000

But because the baud rate is the same as the bit rate, the bit rate is 4000 bps.

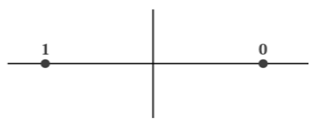
PSK



PSK Constellation

Bit	Phase
0	0
1	180

Bits

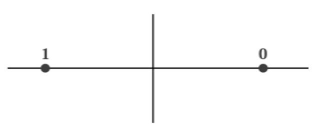


Constellation diagram

PSK Constellation

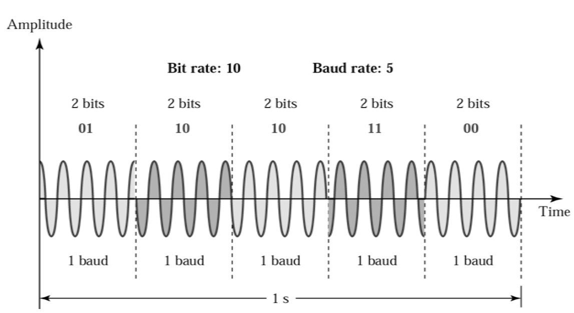
Bit	Phase
0	0
1	180

Bits



Constellation diagram

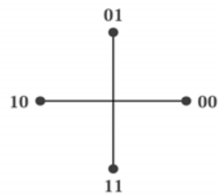
4-PSK



4-PSK

Dibit	Phase
00	0
01	90
10	180
11	270

Dibit
(2 bits)



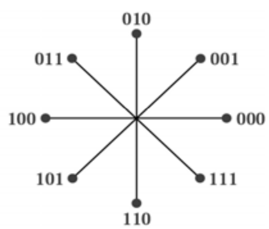
Constellation diagram

 U1.328

8-PSK

Tribit	Phase
000	0
001	45
010	90
011	135
100	180
101	225
110	270
111	315

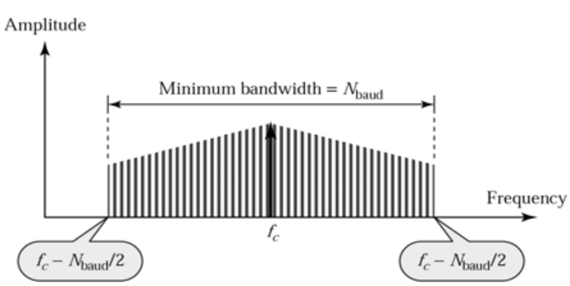
Tribits
(3 bits)



Constellation diagram

 U1.329

Bit rate and Baud rate in PSK



 U1.330

Example

Find the bandwidth for a 4-PSK signal transmitting at 2000 bps. Transmission is in half-duplex mode.

Solution

For PSK the baud rate is the same as the bandwidth, which means the baud rate is 5000. But in 8-PSK the bit rate is 3 times the baud rate, so the bit rate is 15,000 bps.

Example

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

Solution

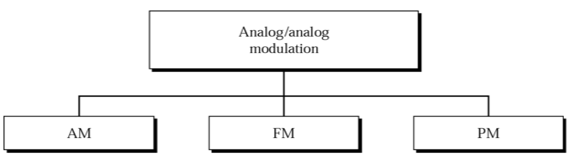
For PSK the baud rate is the same as the bandwidth, which means the baud rate is 5000. But in 8-PSK the bit rate is 3 times the baud rate, so the bit rate is 15,000 bps.

Analog Modulation

- ***Amplitude Modulation (AM)***
- ***Frequency Modulation (FM)***
- ***Phase Modulation (PM)***

Analog Modulation

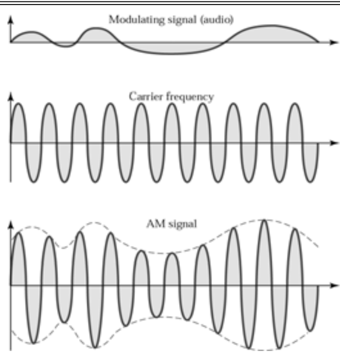
Analog Modulation



AM

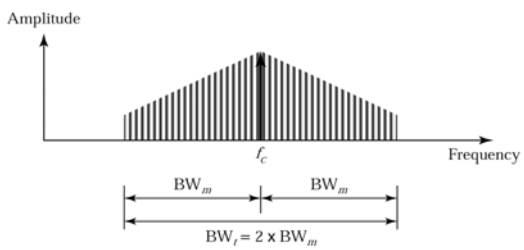
The total bandwidth required for AM can be determined from the bandwidth of the audio signal:
BWt = 2 x BWm.

AM



AM Bandwidth

BW_m = bandwidth of the modulating signal (audio)
BW_t = total bandwidth (radio)
f_c = frequency of the carrier



Example

We have an audio signal with a bandwidth of 4 KHz. What is the bandwidth needed if we modulate the signal using AM? Ignore FCC regulations.

Solution

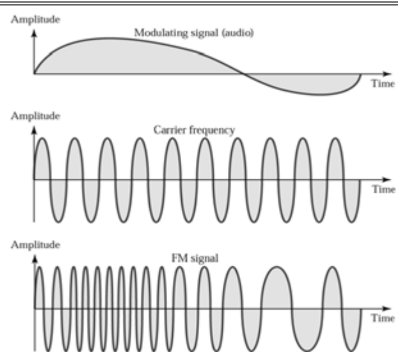
An AM signal requires twice the bandwidth of the original signal:

BW = 2 x 4 KHz = 8 KHz

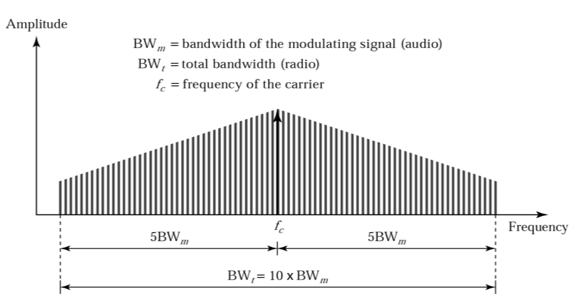
Frequency Modulation

The total bandwidth required for FM can be determined from the bandwidth of the audio signal:
BWt = 10 x BWm.

Frequency Modulation



FM Bandwidth



FM Bandwidth

The bandwidth of a stereo audio signal is usually 15 KHz. Therefore, an FM station needs at least a bandwidth of 150 KHz. The FCC requires the minimum bandwidth to be at least 200 KHz (0.2 MHz).

 U1.343

FM Bandwidth

We have an audio signal with a bandwidth of 4 MHz. What is the bandwidth needed if we modulate the signal using FM? Ignore FCC regulations.

Solution

An FM signal requires 10 times the bandwidth of the original signal:

BW = 10 x 4 MHz = 40 MHz

 U1.344

FM Bandwidth

We have an audio signal with a bandwidth of 4 MHz. What is the bandwidth needed if we modulate the signal using FM? Ignore FCC regulations.

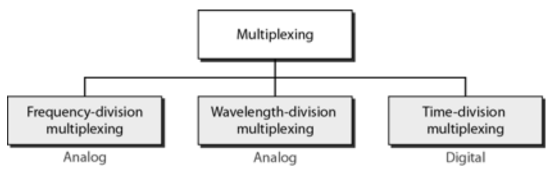
Solution

An FM signal requires 10 times the bandwidth of the original signal:

BW = 10 x 4 MHz = 40 MHz

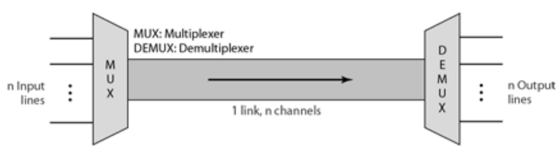
 U1.345

Multiplexing



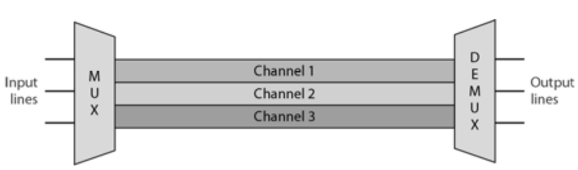
 U1.346

Dividing a link into channels



 U1.347

Frequency-division multiplexing

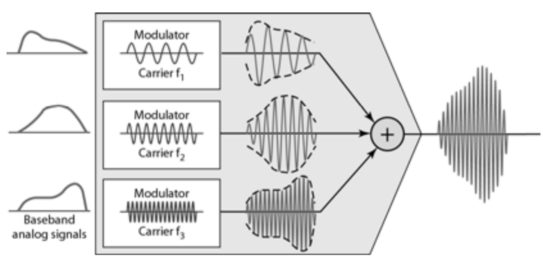


 U1.348

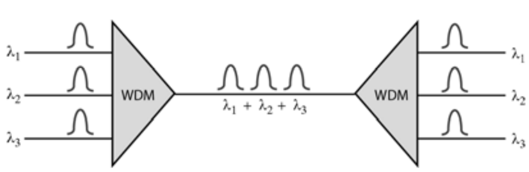
Note

FDM is an analog multiplexing technique that combines analog signals.

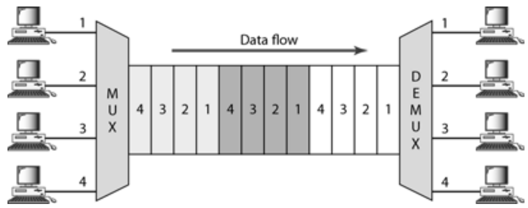
FDM process



Wavelength-division multiplexing



TDM



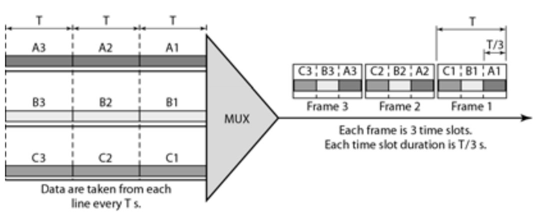
 U1.352

Note

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

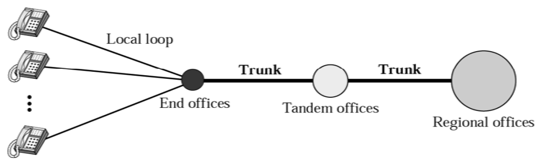
 U1.353

Synchronous Time-Division Multiplexing



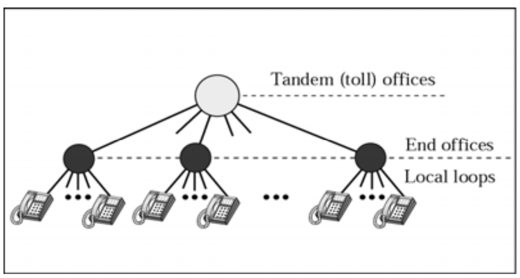
 U1.354

Telephone System



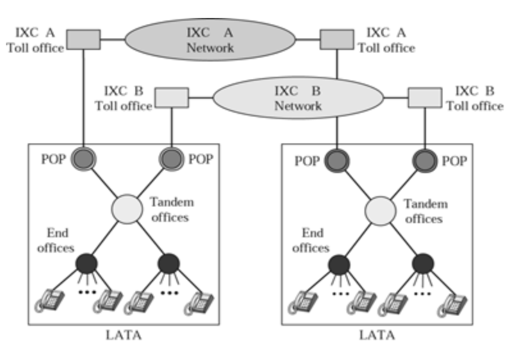
 U1.355

Telephone System



 U1.356

Telephone System



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Review Questions (Short)

1. What is computer networking? Discuss the various types of it.
2. Give the names of various layers in OSI model. State the role of network layer in it.
3. What do you mean by wireless transmission? Briefly describe the various media that support wireless transmission.
4. Distinguish between FSK, PSK and ASK? Discuss Pulse code modulation.

Review Questions (Long)

1. An analog signal has a bandwidth of 40 KHz. If we sample this signal and send it through a 50Kbps channel. What is the SNR?
2. Which of the four digital-to-analog conversion techniques (ASK, FSK, PSK or QAM) is the most susceptible to noise? Defend your answer.
3. Explain Mobile Telephone System.
4. Difference between guided and unguided media with the help of an example.
5. Explain Pulse Code Modulation.
6. What does the Shannon capacity and Nyquist theorem have to do with communication?

Recommended Reading

1. Behrouz Forouzun, “Data Communication and Networking”:TMH
2. Tanenbaum , “A computer Networks”: Prentice Hall
3. Stallings , “High speed Networks” :Prentice Hall
4. Comer D. “Computer Networks”: Prentice hall
5. Kurose, J and Ross , “Computer Networking : Addison Wesley