BLG 337E- Principles of Computer Communications

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16/09/ 2014

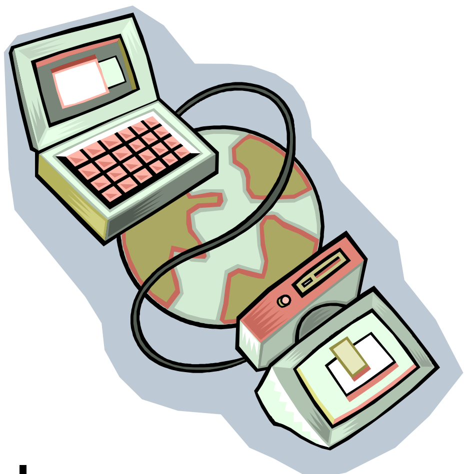
-Physical Layer-

References:

Data and Computer Communications, William Stallings, Pearson-Prentice Hall, 9th Edition, 2010.

-*Computer Networking, A Top-Down Approach Featuring the Internet*, James F.Kurose, Keith W.Ross, Pearson-Addison Wesley, 6th Edition, 2012.

Data Transmission



The successful transmission of data depends on two factors:

- quality of the signal being transmitted
- characteristics of the transmission medium

Transmission Terminology

Data transmission occurs between transmitter and receiver over some transmission medium.

Communication is in the form of electromagnetic waves.

Guided media

- twisted pair, coaxial cable, optical fiber

Unguided media (wireless)

- air, vacuum, seawater

Transmission Terminology

Direct link

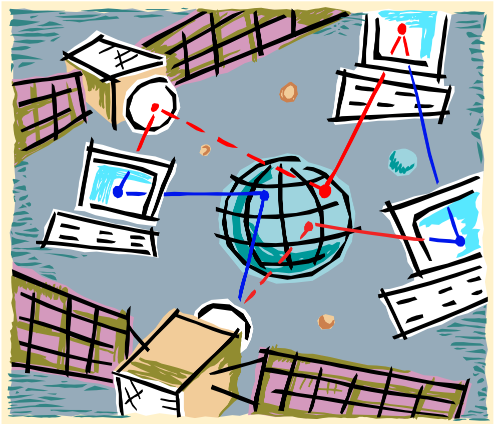
- no intermediate devices

Point-to-point

- direct link
- only 2 devices share link

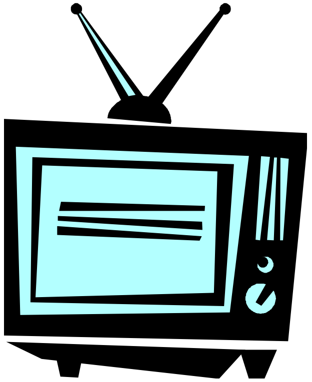
Multi-point

- more than two devices share the link

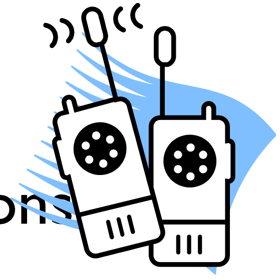


Transmission Terminology

- **Simplex**
  - signals transmitted in one direction
    - eg. Television



- **Half duplex**
  - both stations transmit, but only one at a time
    - eg. police radio



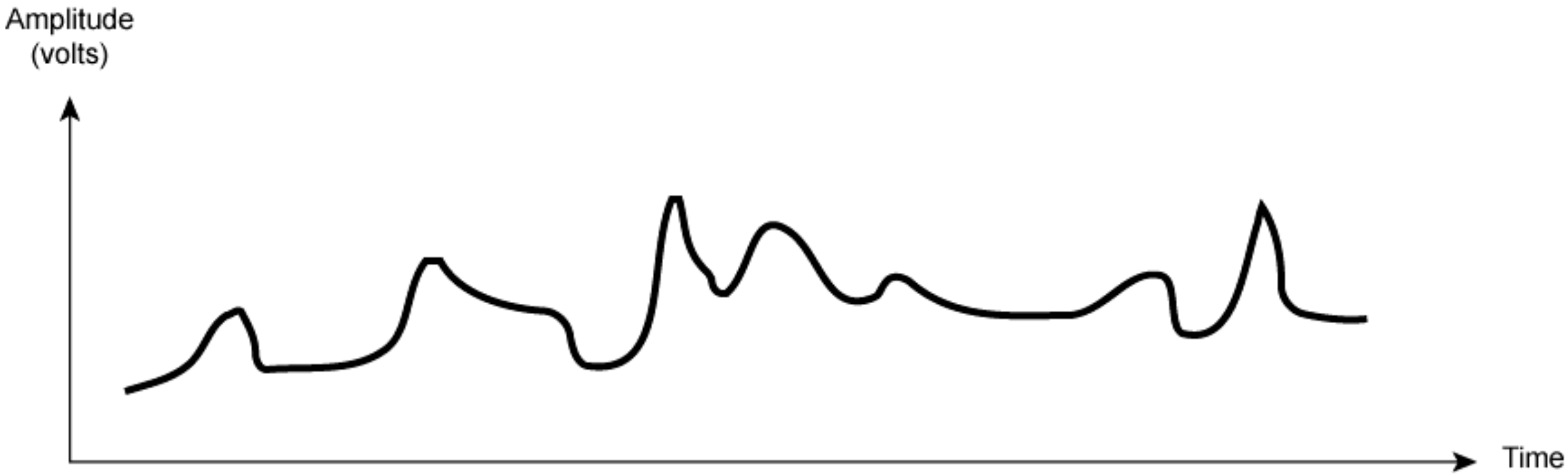
- **Full duplex**
  - simultaneous transmissions
    - eg. telephone

Frequency, Spectrum and Bandwidth

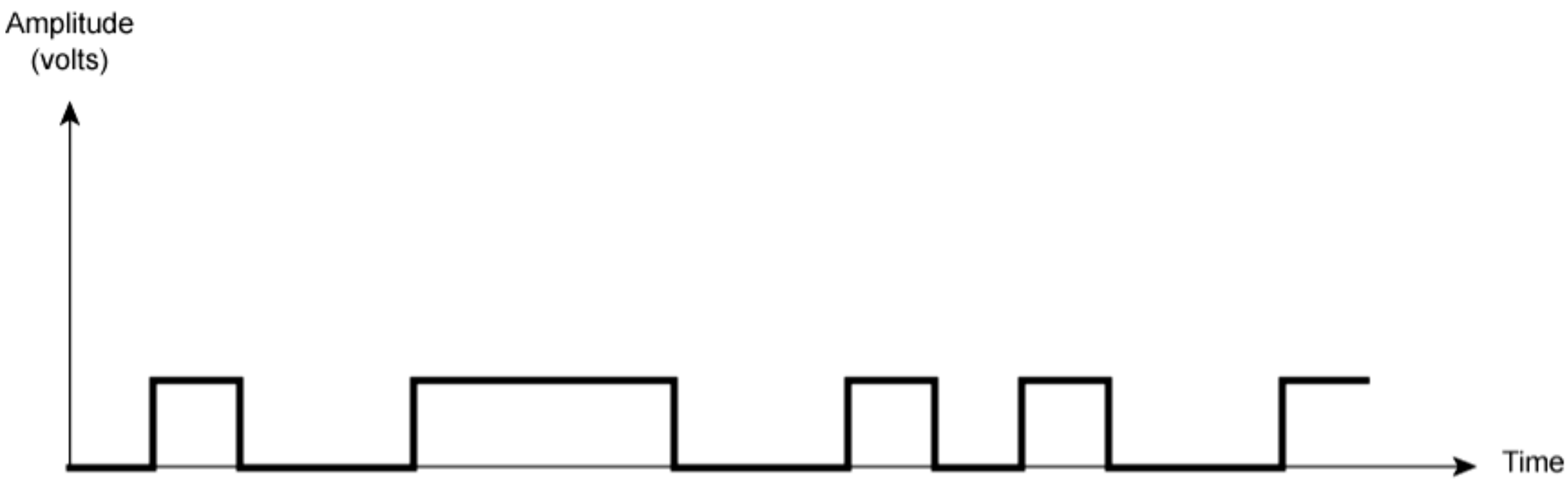
Time Domain Concepts

- **analog signal**
  - signal intensity varies smoothly with no breaks
- **digital signal**
  - signal intensity maintains a constant level and then abruptly changes to another level
- **periodic signal**
  - signal pattern repeats over time
- **aperiodic signal**
  - pattern not repeated over time

Analog and Digital Signals



(a) Analog



(b) Digital

Spectrum & Bandwidth

spectrum

- *range of frequencies contained in signal*

absolute bandwidth

- *width of spectrum*

effective bandwidth

- *often just bandwidth*
- *narrow band of frequencies containing most energy*

dc component

- *component of zero frequency*

Data Rate and Bandwidth

any transmission system has a limited band of frequencies

this limits the data rate that can be carried on the transmission medium

square waves have infinite components and hence an infinite bandwidth

most energy in first few components

limiting bandwidth creates distortions

There is a direct relationship between data rate and bandwidth.

Analog and Digital Data Transmission

- data
  - entities that convey information
- signals
  - electric or electromagnetic representations of data
- signaling
  - physically propagates along a medium
- transmission
  - communication of data by propagation and processing of signals

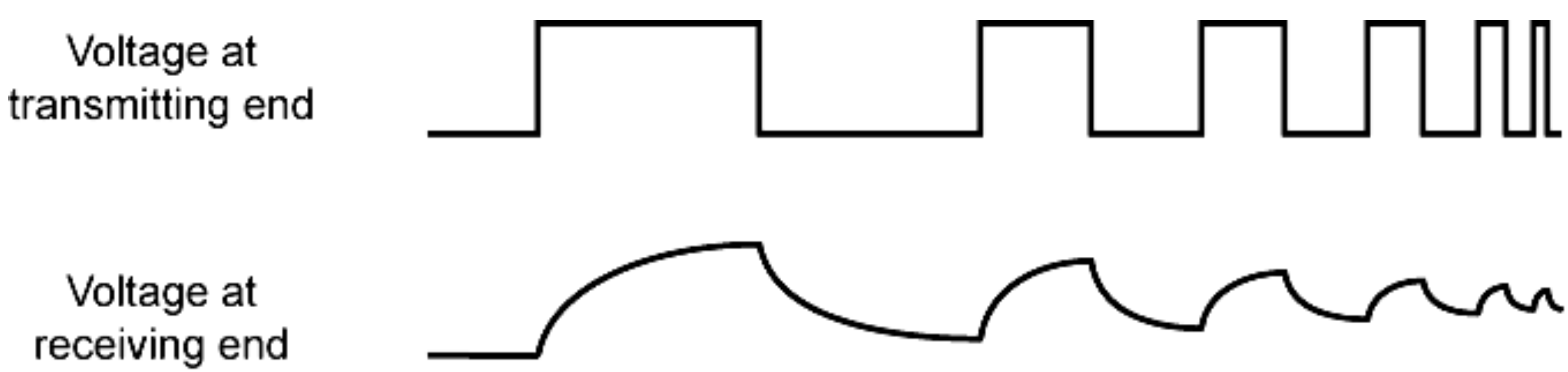
Advantages & Disadvantages of Digital Signals

cheaper

less susceptible to noise interference

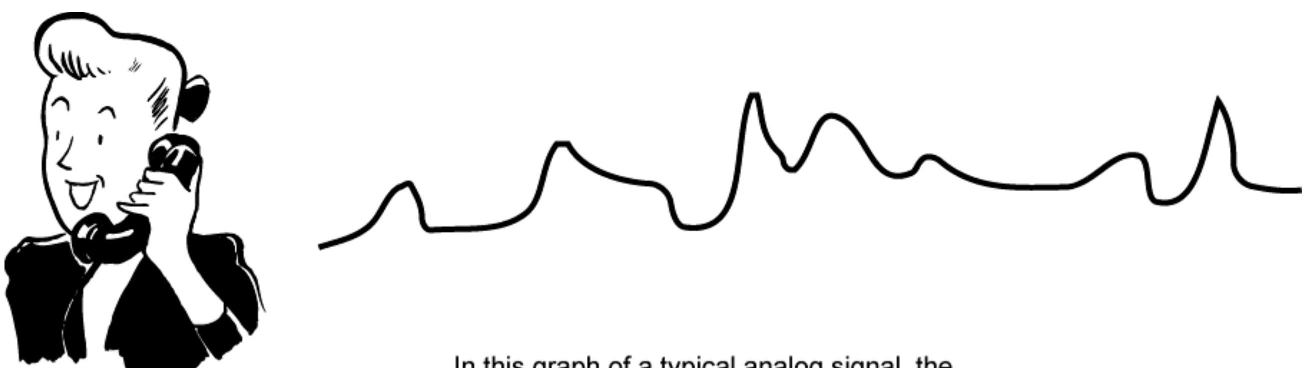
suffer more from attenuation

digital now preferred choice



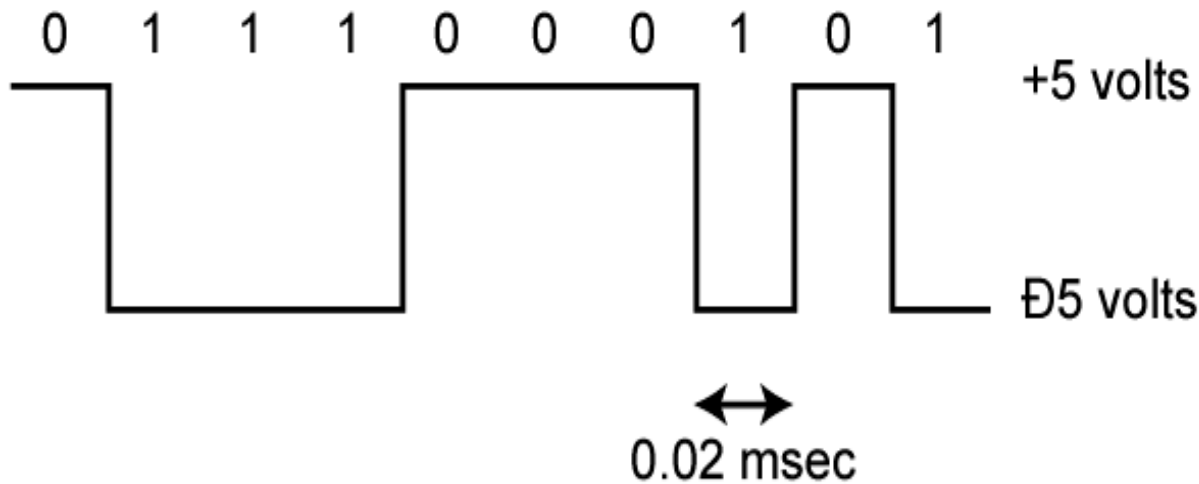
Audio Signals

- frequency range of typical speech is 100Hz-7kHz
- easily converted into electromagnetic signals
- varying volume converted to varying voltage
- can limit frequency range for voice channel to 300-3400Hz



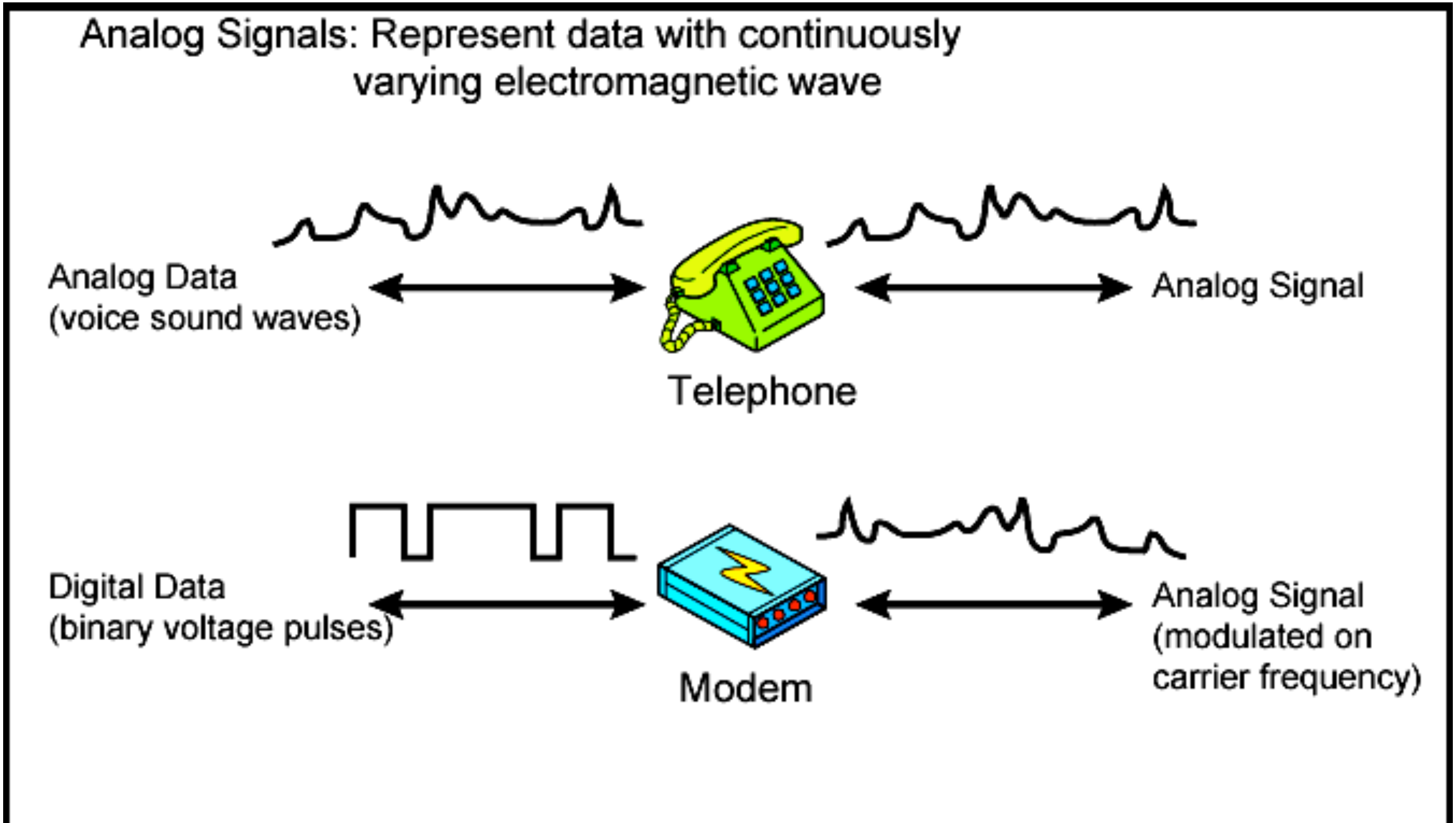
In this graph of a typical analog signal, the variations in amplitude and frequency convey the gradations of loudness and pitch in speech or music. Similar signals are used to transmit television pictures, but at much higher frequencies.

Conversion of PC Input to Digital Signal

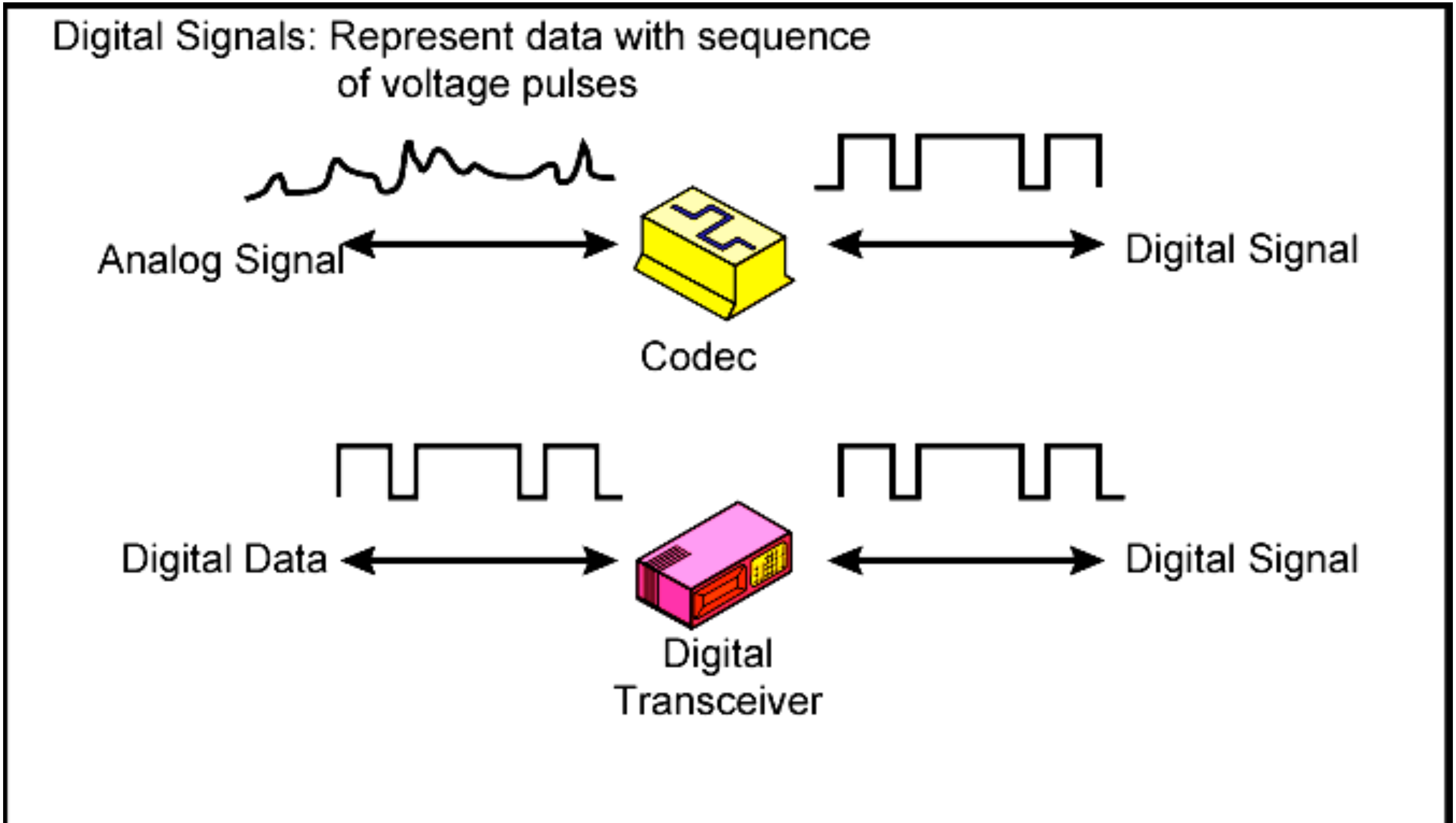


User input at a PC is converted into a stream of binary digits (1s and 0s). In this graph of a typical digital signal, binary one is represented by Ð5 volts and binary zero is represented by +5 volts. The signal for each bit has a duration of 0.02 msec, giving a data rate of 50,000 bits per second (50 kbps).

Analog Signals



Digital Signals



Overview of Transmission Media

- Guided - wire
- Unguided - wireless
- Characteristics and quality determined by medium and signal
  - For guided, the medium is more important
  - For unguided, the bandwidth produced by the antenna is more important
- Key concerns are data rate and distance

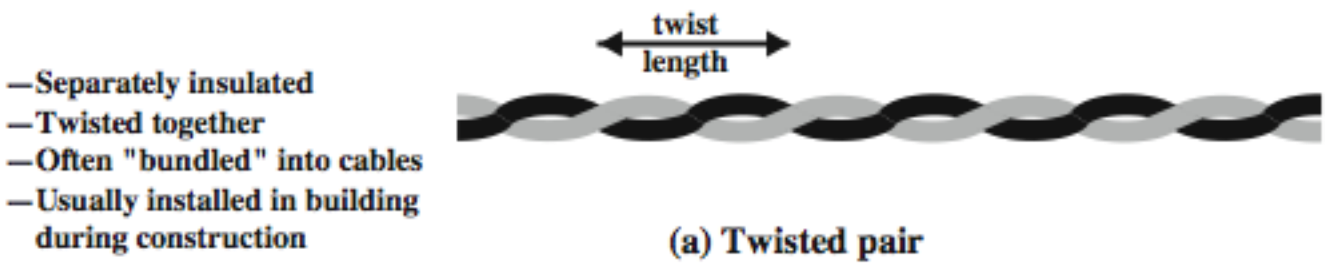
Design Factors

- Bandwidth
  - Higher bandwidth gives higher data rate
- Transmission impairments
  - Attenuation
- Interference
- Number of receivers
  - In guided media
  - More receivers (multi-point) introduce more attenuation

Transmission Characteristics of Guided Media

	Frequency Range	Typical Attenuation	Typical Delay	Repeater Spacing
Twisted pair (with loading)	0 to 3.5 kHz	0.2 dB/km @ 1 kHz	50 µs/km	2 km
Twisted pairs (multi-pair cables)	0 to 1 MHz	0.7 dB/km @ 1 kHz	5 µs/km	2 km
Coaxial cable	0 to 500 MHz	7 dB/km @ 10 MHz	4 µs/km	1 to 9 km
Optical fiber	186 to 370 THz	0.2 to 0.5 dB/km	5 µs/km	40 km

Twisted Pair



(a) Twisted pair

Twisted pair is the least expensive and most widely used guided transmission medium.

- consists of two insulated copper wires arranged in a regular spiral pattern
- a wire pair acts as a single communication link
- pairs are bundled together into a cable
- most commonly used in the telephone network and for communications within buildings

Unshielded vs. Shielded Twisted Pair

Unshielded Twisted Pair (UTP)

- **ordinary telephone wire**
- **cheapest**
- **easiest to install**
- **suffers from external electromagnetic interference**

Shielded Twisted Pair (STP)

- **has metal braid or sheathing that reduces interference**
- **provides better performance at higher data rates**
- **more expensive**
- **harder to handle (thick, heavy)**

Signal Power Relationships

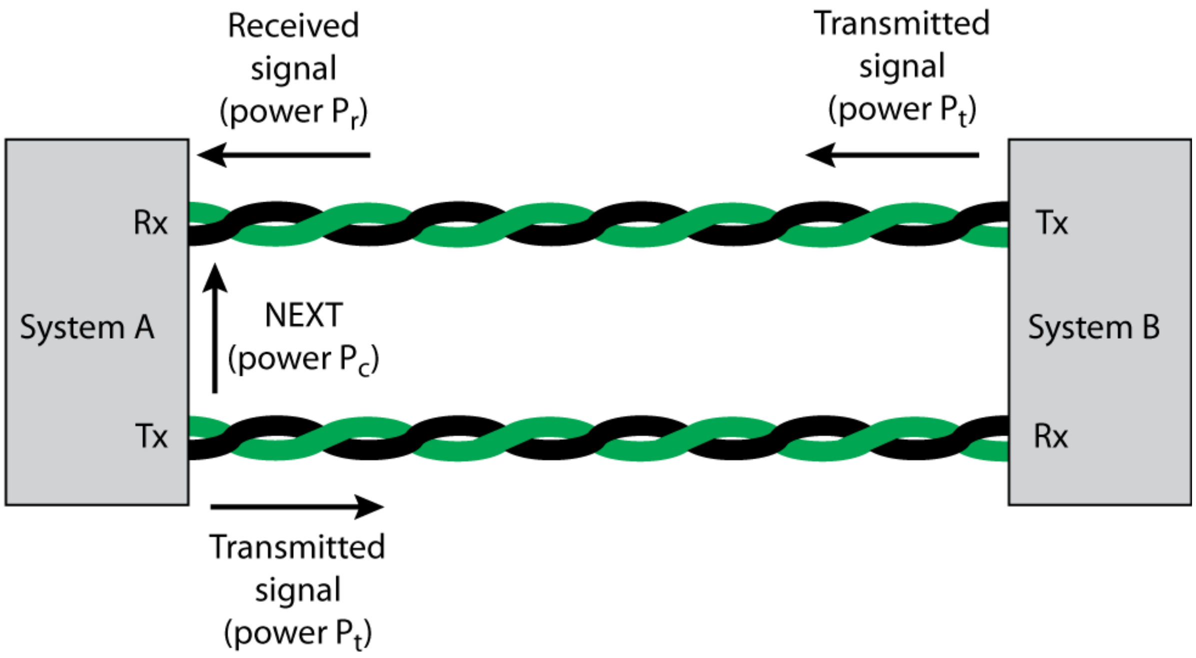
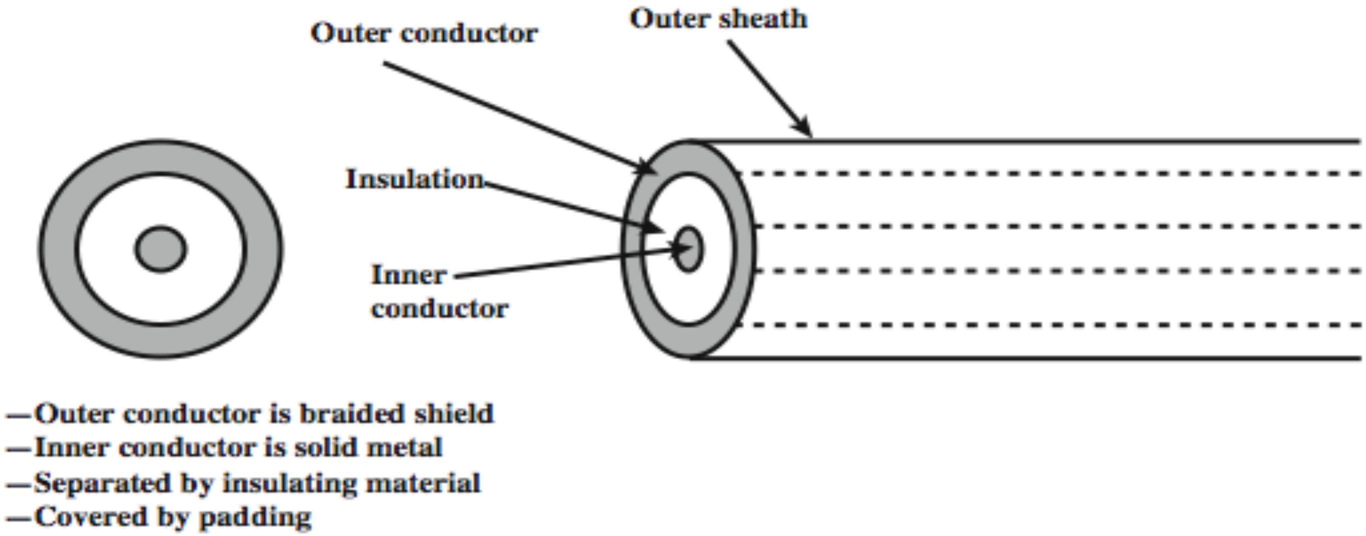


Figure 4.4 Signal Power Relationships (from System A viewpoint)

Coaxial Cable

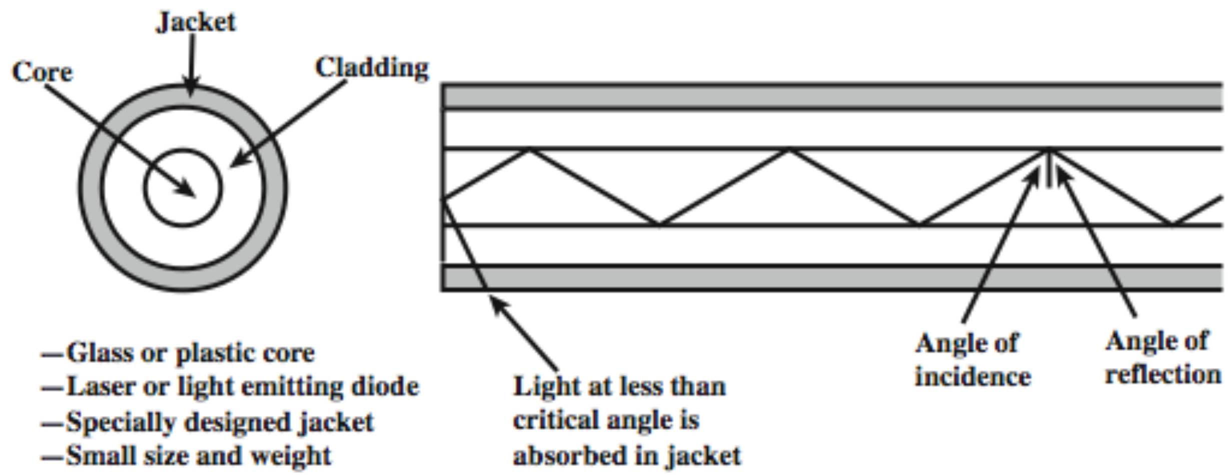


(b) Coaxial cable

Coaxial cable can be used over longer distances and support more stations on a shared line than twisted pair.

- consists of a hollow outer cylindrical conductor that surrounds a single inner wire conductor
- is a versatile transmission medium used in a wide variety of applications
- used for TV distribution, long distance telephone transmission and LANs

Optical Fiber



(c) Optical fiber

Optical fiber is a thin flexible medium capable of guiding an optical ray.

- various glasses and plastics can be used to make optical fibers
- has a cylindrical shape with three sections – core, cladding, jacket
- widely used in long distance telecommunications
- performance, price and advantages have made it popular to use

Wireless Transmission Frequencies

1GHz to 40GHz

- referred to as microwave frequencies
- highly directional beams are possible
- suitable for point to point transmissions
- also used for satellite

30MHz to 1GHz

- suitable for omnidirectional applications
- referred to as the radio range

3×10^{11} to 2×10^{14}

- infrared portion of the spectrum
- useful to local point-to-point and multipoint applications within confined areas

Terrestrial Microwave

most common type is a parabolic dish with an antenna focusing a narrow beam onto a receiving antenna

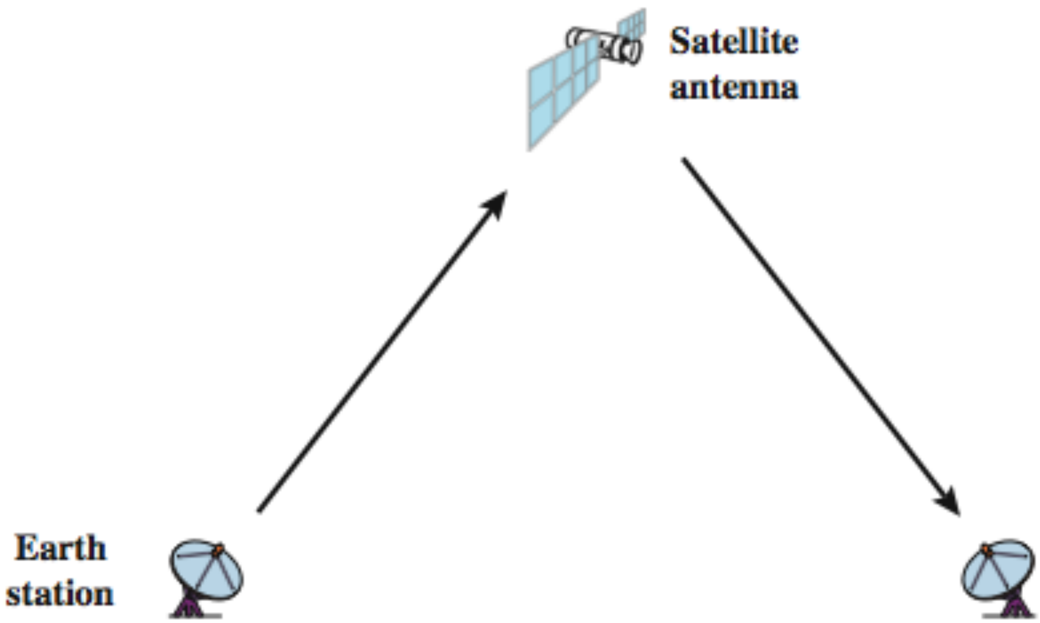
located at substantial heights above ground to extend range and transmit over obstacles

uses a series of microwave relay towers with point-to-point microwave links to achieve long distance transmission

Satellite Microwave

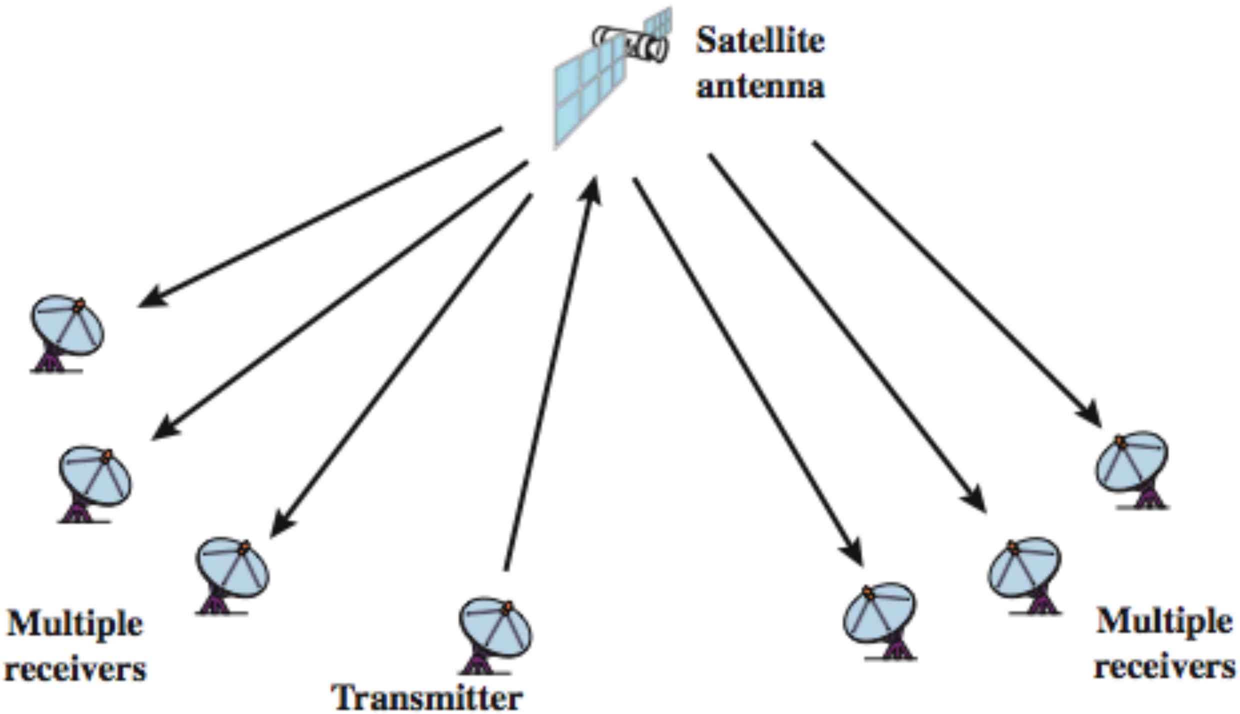
- a communication satellite is in effect a microwave relay station
- used to link two or more ground stations
- receives on one frequency, amplifies or repeats signal and transmits on another frequency
  - frequency bands are called transponder channels
- requires geo-stationary orbit
  - rotation match occurs at a height of 35,863km at the equator
  - need to be spaced at least 3° - 4° apart to avoid interfering with each other
  - spacing limits the number of possible satellites

Satellite Point-to-Point Link



(a) Point-to-point link

Satellite Broadcast Link



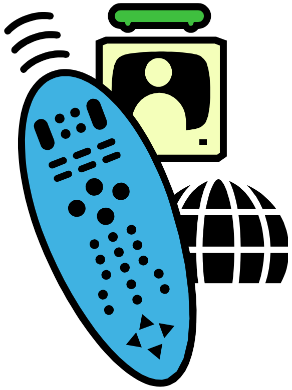
(b) Broadcast link

Broadcast Radio

- **radio** is the term used to encompass frequencies in the range of 3kHz to 300GHz
- **broadcast radio** (30MHz - 1GHz) covers
    - FM radio
    - UHF and VHF television
    - data networking applications
- **omnidirectional**
- limited to **line of sight**
- suffers from **multipath interference**
    - reflections from land, water, man-made objects

Infrared

- achieved using transceivers that modulate noncoherent infrared light
- transceivers must be within line of sight of each other directly or via reflection
- does not penetrate walls
- no licenses required
- no frequency allocation issues
- typical uses:
    - TV remote control



Frequency Bands

Band	Frequency Range	Free-Space Wavelength Range	Propagation Characteristics	Typical Use
ELF (extremely low frequency)	30 to 300 Hz	10,000 to 1000 km	GW	Power line frequencies; used by some home control systems.
VF (voice frequency)	300 to 3000 Hz	1000 to 100 km	GW	Used by the telephone system for analog subscriber lines.
VLF (very low frequency)	3 to 30 kHz	100 to 10 km	GW; low attenuation day and night; high atmospheric noise level	Long-range navigation; submarine communication
LF (low frequency)	30 to 300 kHz	10 to 1 km	GW; slightly less reliable than VLF; absorption in daytime	Long-range navigation; marine communication radio beacons
MF (medium frequency)	300 to 3000 kHz	1,000 to 100 m	GW and night SW; attenuation low at night, high in day; atmospheric noise	Maritime radio; direction finding; AM broadcasting.
HF (high frequency)	3 to 30 MHz	100 to 10 m	SW; quality varies with time of day, season, and frequency.	Amateur radio; military communication
VHF (very high frequency)	30 to 300 MHz	10 to 1 m	LOS; scattering because of temperature inversion; cosmic noise	VHF television; FM broadcast and two-way radio, AM aircraft communication; aircraft navigational aids
UHF (ultra high frequency)	300 to 3000 MHz	100 to 10 cm	LOS; cosmic noise	UHF television; cellular telephone; radar; microwave links; personal communications systems
SHF (super high frequency)	3 to 30 GHz	10 to 1 cm	LOS; rainfall attenuation above 10 GHz; atmospheric attenuation due to oxygen and water vapor	Satellite communication; radar; terrestrial microwave links; wireless local loop
EHF (extremely high frequency)	30 to 300 GHz	10 to 1 mm	LOS; atmospheric attenuation due to oxygen and water vapor	Experimental; wireless local loop; radio astronomy
Infrared	300 GHz to 400 THz	1 mm to 770 nm	LOS	Infrared LANs; consumer electronic applications
Visible light	400 THz to 900 THz	770 nm to 330 nm	LOS	Optical communication

Line of Sight Transmission

Free space loss

- loss of signal with distance

Atmospheric Absorption

- from water vapor and oxygen absorption

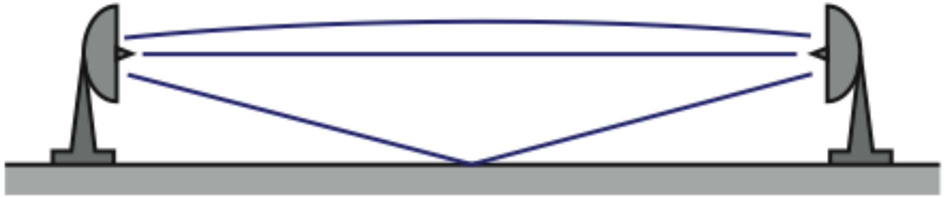
Multipath

- multiple interfering signals from reflections

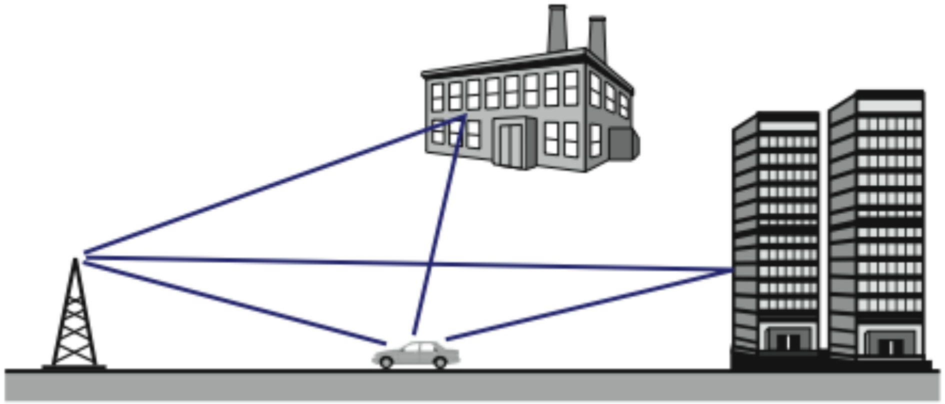
Refraction

- bending signal away from receiver

Multipath Interference



(a) Microwave line of sight



(b) Mobile radio

Signal Encoding Techniques

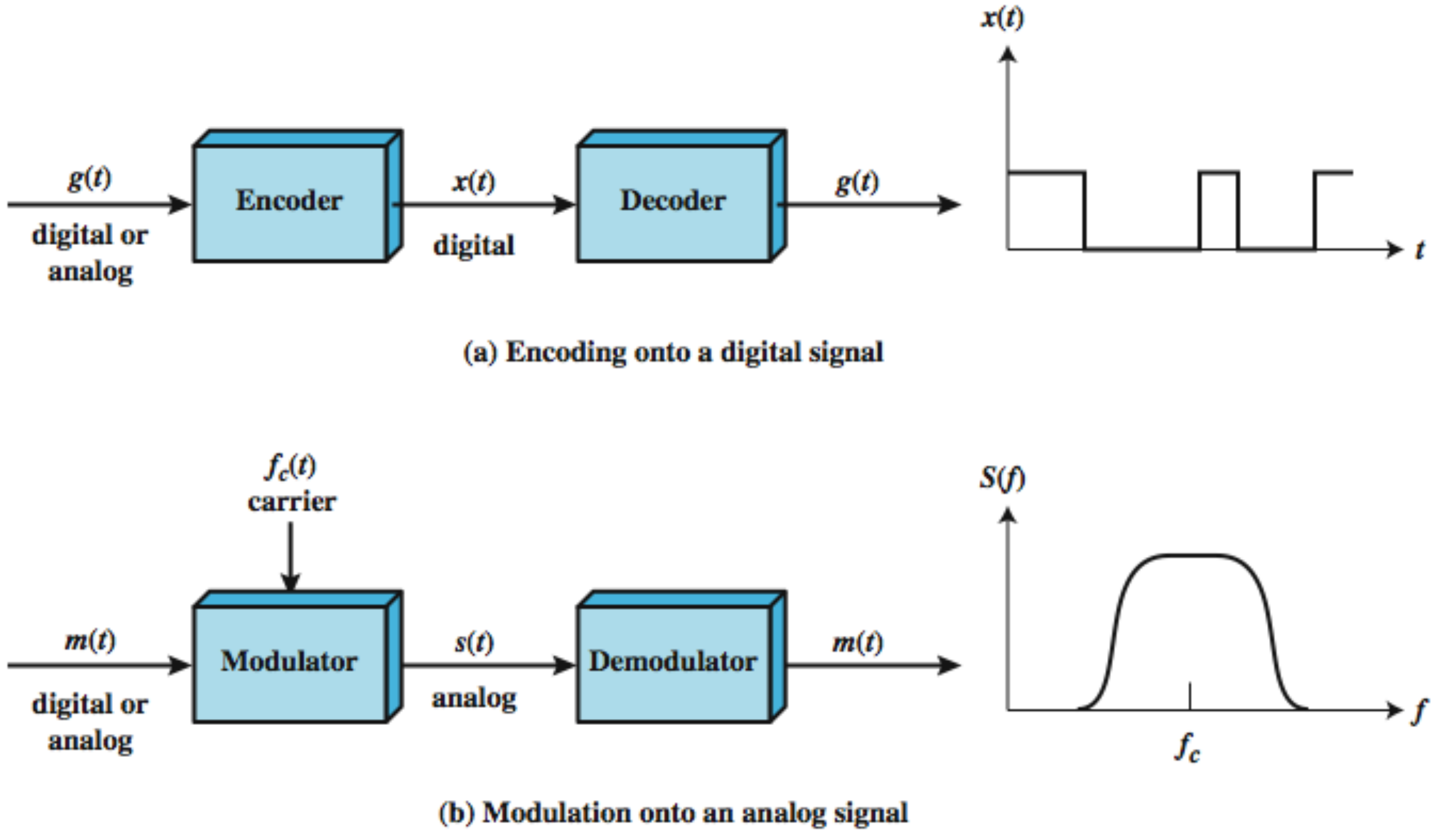
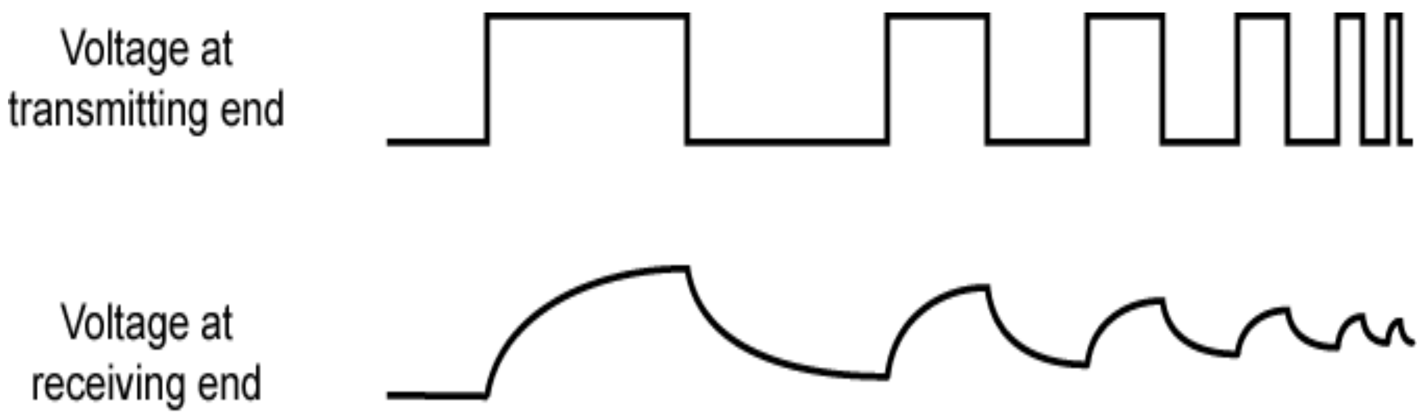


Figure 5.1 Encoding and Modulation Techniques

Transmission Impairments

- Signal received may differ from signal transmitted
- Analog - degradation of signal quality
- Digital - bit errors
- Mostly caused by
  - Attenuation and attenuation distortion
  - Noise

Attenuation



- Signal strength falls off with distance
- Depends on medium
- Received signal strength:
  - must be enough to be detected
  - must be sufficiently higher than noise to be received without error
- Attenuation is an increasing function of frequency

Noise

- Additional signals inserted between transmitter and receiver
- Thermal
  - Due to thermal agitation of electrons
  - Uniformly distributed
  - White noise
- Intermodulation
  - Signals that are the sum and difference of original frequencies sharing a medium
- Crosstalk
  - A signal from one line is picked up by another
- Impulse
  - Irregular pulses or spikes
  - e.g. External electromagnetic interference
  - Short duration
  - High amplitude

Noise

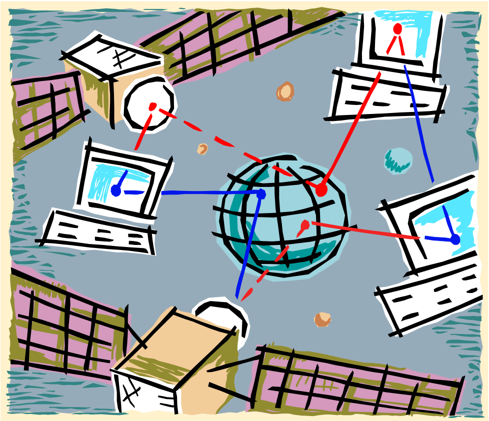
unwanted signals inserted between transmitter and receiver

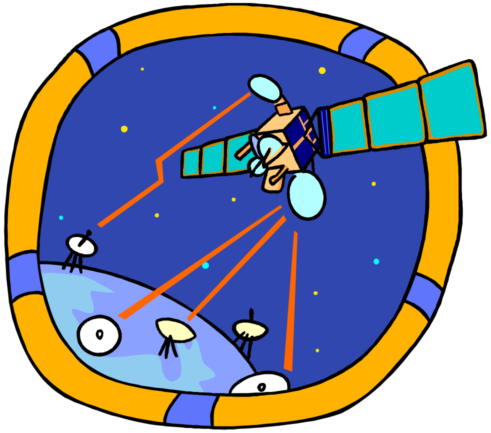
is the major limiting factor in communications system performance

Categories of Noise

Thermal noise

- due to thermal agitation of electrons
- uniformly distributed across bandwidths
- referred to as white noise





Intermodulation noise

- produced by nonlinearities in the transmitter, receiver, and/or intervening transmission medium
- effect is to produce signals at a frequency that is the sum or difference of the two original frequencies

Categories of Noise

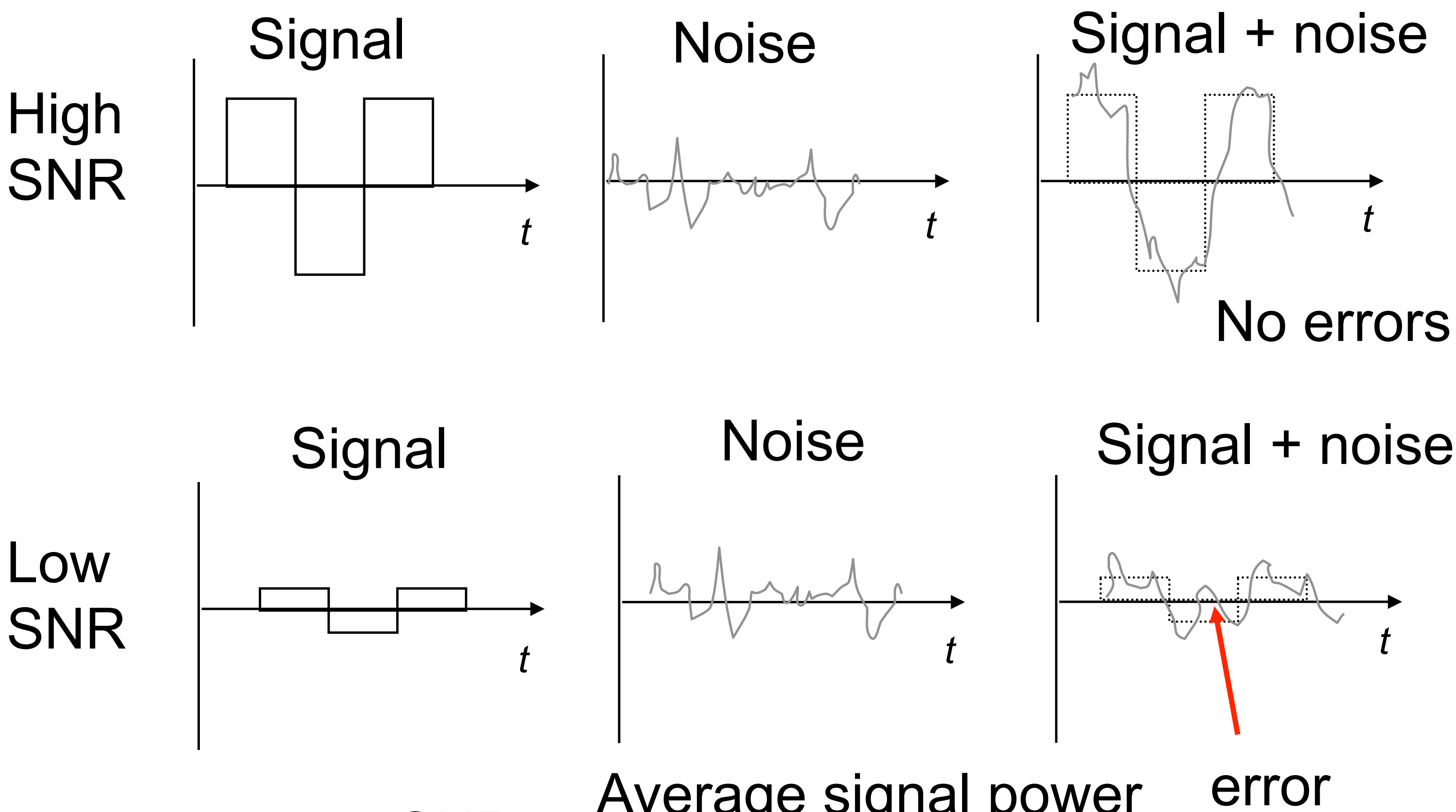
Crosstalk:

- a signal from one line is picked up by another
- can occur by electrical coupling between nearby twisted pairs or when microwave antennas pick up unwanted signals

Impulse Noise:

- caused by external electromagnetic interferences
- noncontinuous, consisting of irregular pulses or spikes
- short duration and high amplitude
- minor annoyance for analog signals but a major source of error in digital data

Signal-to-Noise Ratio



$$\text{SNR} = \frac{\text{Average signal power}}{\text{Average noise power}}$$

$$\text{SNR (dB)} = 10 \log_{10} \text{SNR}$$

Channel Capacity

- Data rate
  - In bits per second
  - Rate at which data can be communicated
- Bandwidth
  - In cycles per second of Hertz
  - Constrained by transmitter and medium

Shannon Capacity

- Consider data rate, noise and error rate
- Faster data rate shortens each bit so burst of noise affects more bits
  - At a given noise level, high data rate means higher error rate
- Signal to noise ratio (in decibels)
- SNR_{db}=10 $\log_{10}$ (signal/noise)
- Capacity C=B $\log_2$(1+SNR) (B: bandwidth)
- This is error free capacity

Examples of Channels

Channel	***Bandwidth***	***Bit Rates***
Telephone voice channel	3 kHz	33 kbps
Copper pair	1 MHz	1-6 Mbps
Coaxial cable	500 MHz (6 MHz channels)	30 Mbps/ channel
5 GHz radio (IEEE 802.11)	300 MHz (11 channels)	54 Mbps / channel
Optical fiber	Many TeraHertz	40 Gbps / wavelength

DATA RATE LIMITS

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

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

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

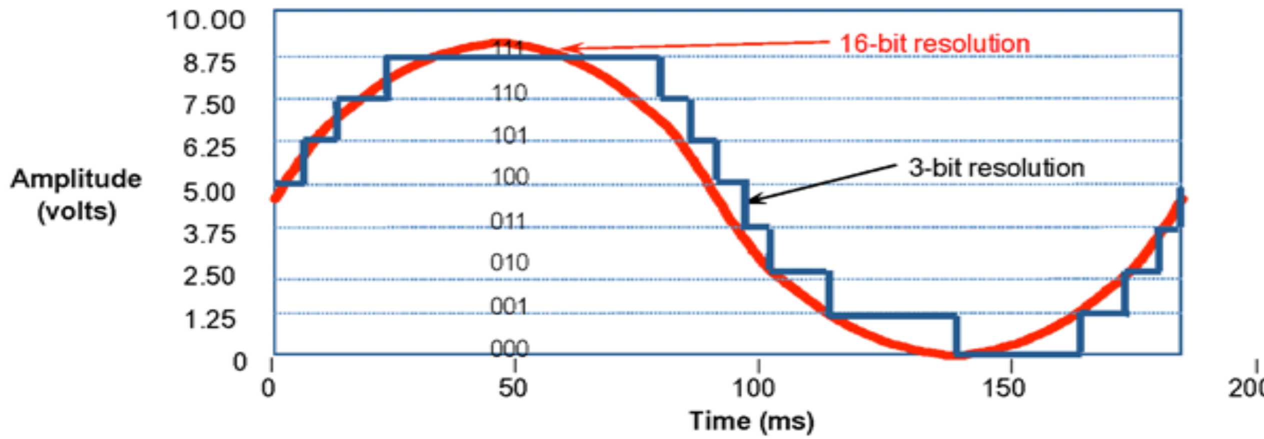


Figure 2. 16-Bit resolution versus 3-Bit resolution chart of a sine wave

Capacity of a System

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

Nyquist Theorem

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

$$C = 2\ B\ \log_2 2^n$$

C= capacity in bps

B = bandwidth in Hz

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

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

Example

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

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

Example

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

Solution

We can use the Nyquist formula as shown:

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

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

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

Shannon's Theorem

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

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

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 C is calculated as

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

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

Example

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

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

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

Example

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

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

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

Example

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

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

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

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

Example

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

Solution

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

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

Example

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

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

Note

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