EECS, University of Ottawa

ELG5374 –Fall 2021
Computer Communication Networrk
Physical Layer

Note: some material in the slides has been taken from various other sources 1-1

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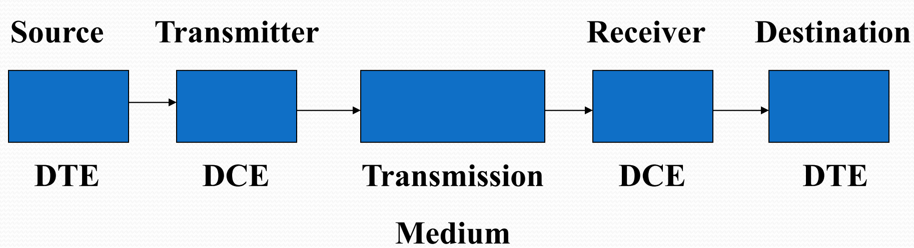
Elements of Physical Layer



- •Data Terminating Equipment (DTE)
- •Data Circuit Terminating Equipment (DCE)

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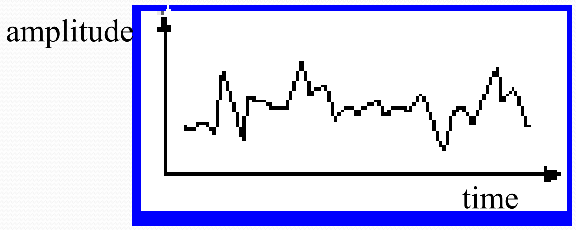
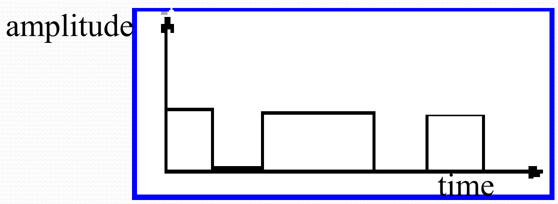
Continuous signal vs discrete signal



Continuous signal (e.g. speech) => Analog signal



Discrete signal (e.g. binary 1s and 0s) => Digital signal

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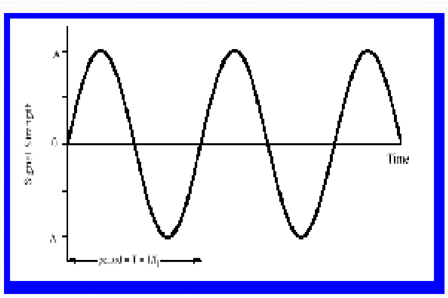
Periodic signal

- A signal s(t) is periodic if and only if s(t+T)=s(t) for all t where T is the period of the signal
- Example: sine wave s(t)



- $s(t) = A\sin(2\pi ft + \phi)$
- Parameters:
  Amplitude: A
  Frequency: f
  Phase : ϕ

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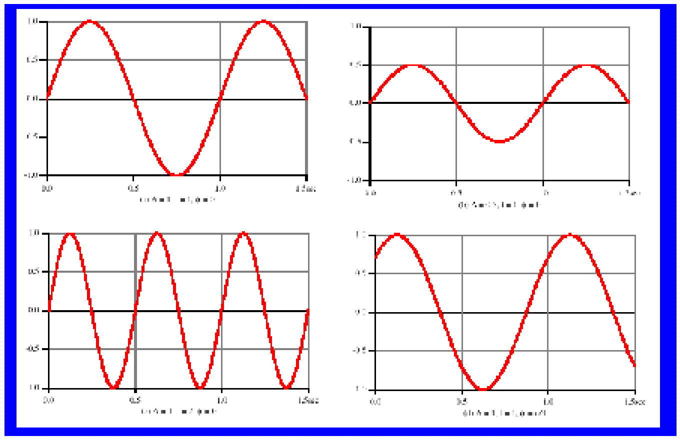
Varying the sine wave parameters



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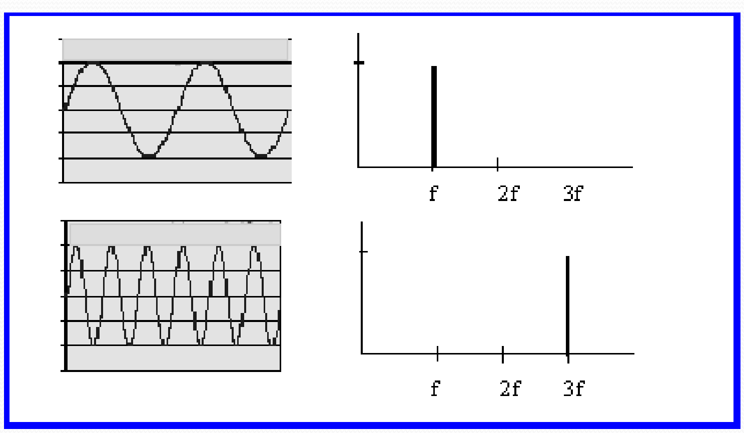
Time domain vs frequency domain



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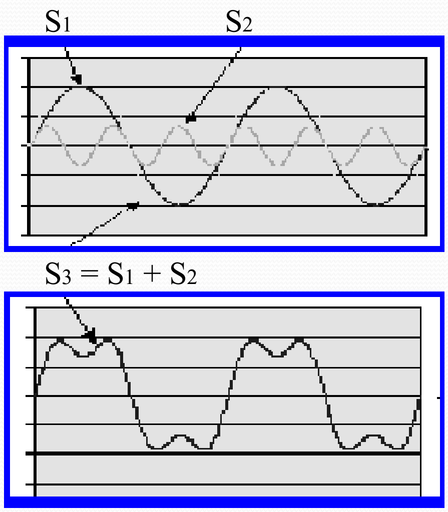
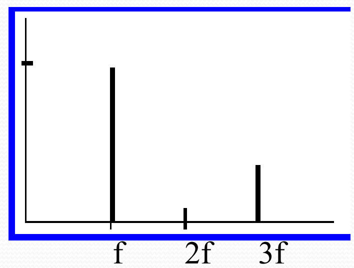
Frequency components





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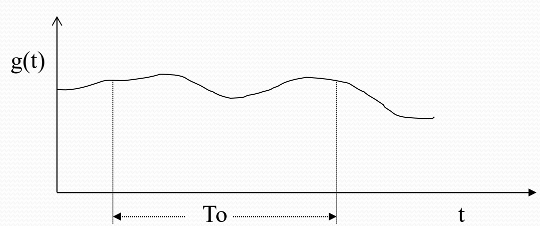
Fourier Series



$$g(t) = a_0 + \sum_{n=1}^{\infty} a_n \cos(n\omega_0 t + \phi_n)$$

$$\omega_0 = \frac{2\pi}{T_0}$$

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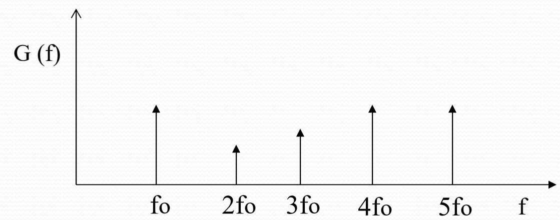
Discrete Spectrum



$f_o = 1 / T_o$

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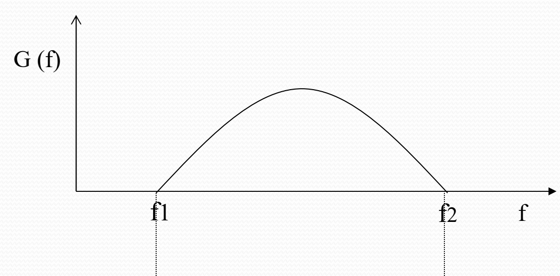
Spectrum of Signal (1)



Spectrum of Signal: Range of frequencies it has energy/power content

Absolute Bandwidth: Width of its spectrum ($= f_2 - f_1$)

1-10

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Spectrum of Signal (2)

- **Band-limited Signal**: A signal with finite Absolute Bandwidth
- All band-limited signals expand from - infinity to + infinity in time domain --> No real signal can be band-limited
- **Effective Bandwidth:** Area of spectrum where MOST of the signal bandwidth is contained

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Channel capacity (without noise)

Nyquist Formula

$C = 2W\log_2 M$

where

W = bandwidth in hertz

M = number of discrete signal levels

C = theoretical maximum capacity in bits per second

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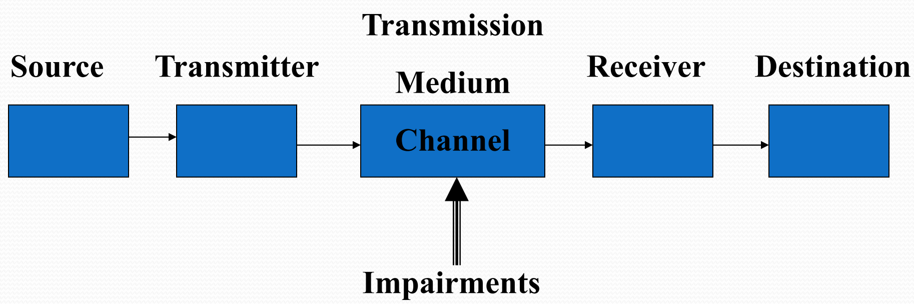
Elements of Physical Layer



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Signal Impairments

Impact:
- degrade the signal quality for analog signals
- introduce errors in digital signals (i.e. 0 may be changed to 1 and vice-versa)

Types:
- signal attenuation
- delay distortion
- noise

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Attenuation

The amplitude of signal decreases with distance over any transmission medium

repeaters and amplifiers are used to restore the signal to its original level

Attenuation is an increasing function of frequency

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Signal impairments

- Fact:
  - As a signal propagates along a transmission path there is loss, attenuation of signal strength.

- Solution:
  - To compensate the attenuation, we can use devices inserted at various points to "boost" signal's strength (amplifiers).

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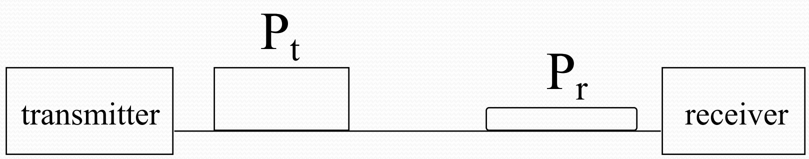
Signal impairments



Attenuation is measured in dB

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Decibel (1)

- Gains and losses are expressed in decibels (dB)
- Definition:

$$N_{dB} = 10 \log_{10} \frac{P_r}{P_t}$$

where: N_{dB} = number of decibels

P_r = power at destination

P_t = power at source

$\log_{10}$ = logarithm base 10 (also noted log)

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Decibel (2)

- Important: the decibel is a measure of relative, not absolute difference.
- For example:
  - a loss from 1000 W to 500 W is a loss of 3 dB.
  - a loss from 10 mW to 5 mW is also a loss of 3 dB.
- In other words, a loss of 3 dB halves the strength; similarly, a gain of 3 dB doubles the strength.

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Amplifiers and Repeaters

- **Amplifiers**: Amplify the received signals (this includes useful signal plus noise).
- **Repeaters:** Recover the digital information, and retransmit it.

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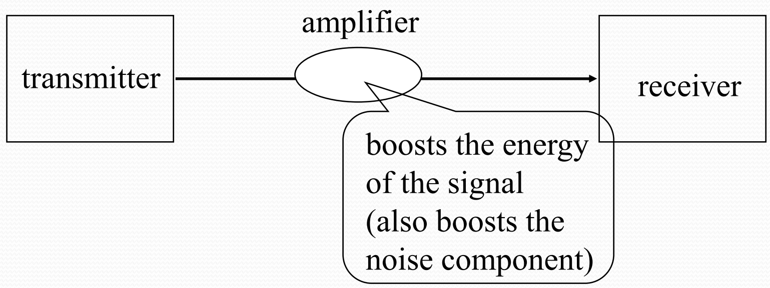
Amplifiers

- Can be used with Analog and Digital Communication Systems



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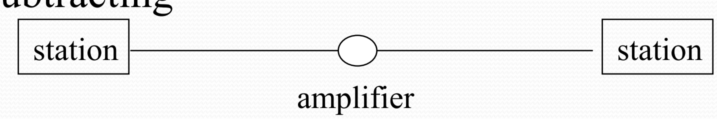
Decibel (3)

- Useful to determine overall gain or loss in a system. This is done simply by adding or subtracting



if

- loss on first portion of line is 13 dB
- gain of the amplifier is 30 dB
- loss of second portion of line is 40 dB
- the overall loss is 23 dB (i.e. -13 + 30 - 40 = -23 dB)

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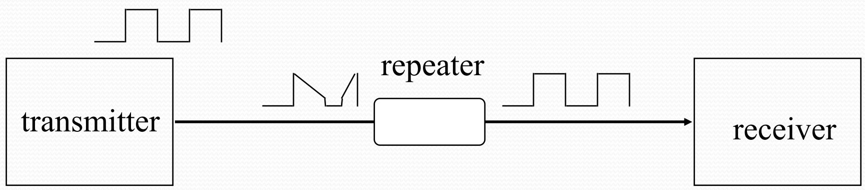
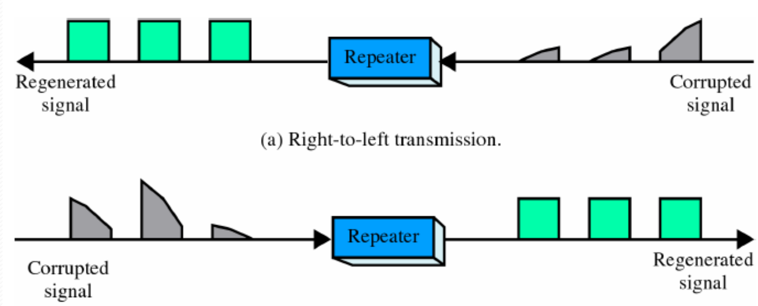
Repeaters

- Can be used with Digital Communication Systems



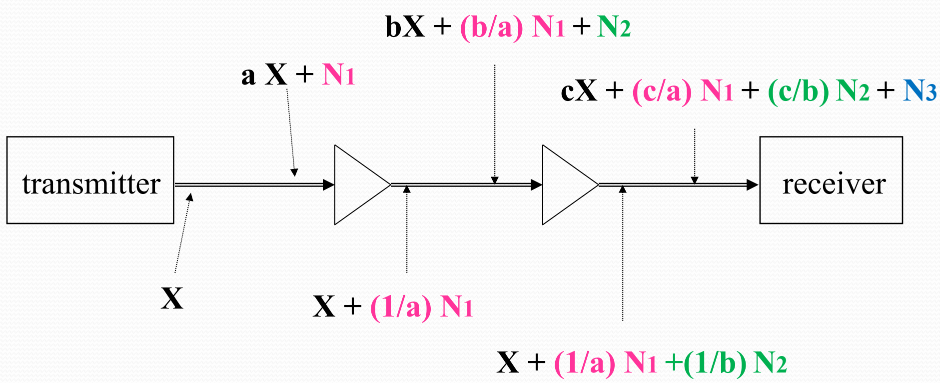
Function of Repeater



(a) Right-to-left transmission.

(b) Left-to-right transmission.

Amplifiers



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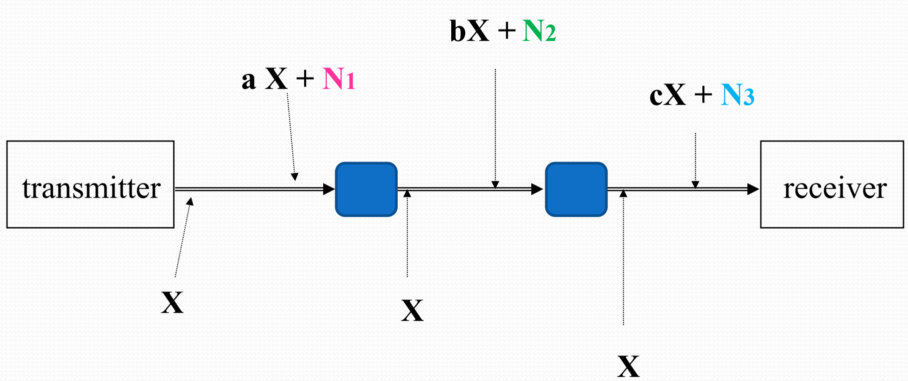
Repeaters



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Noise

- 4 categories
  - thermal noise
  - intermodulation noise
  - crosstalk
  - impulsive noise

Thermal Noise

- Due to the thermal agitation of electrons in a conductor (uniformly distributed across the frequency spectrum)
- The amount of thermal noise power in a BW of 1 Hz is given by:

$$N_0 = kT$$

where:

- N_0 = noise power density
- k = Boltzmann' s constant = 1.3803 x E-23 J/ºK
- T = temperature (ºK)

Inter-modulation Noise (1)

- It is produced when different frequencies are passed through the same non-linear device (e.g. non-linear amplifier)

Effect:

produces signals at frequencies that are the multiple, sum or difference of the frequencies the original signal contains.

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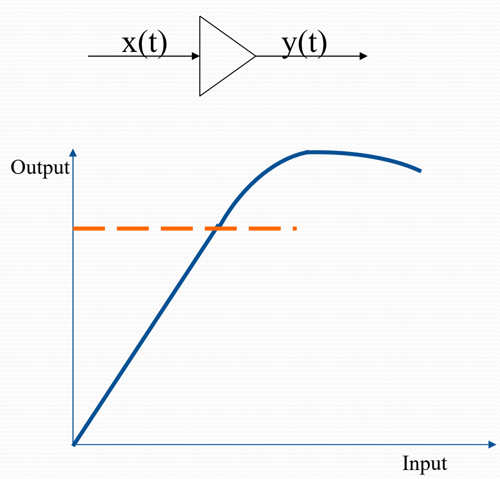

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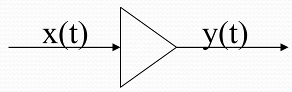
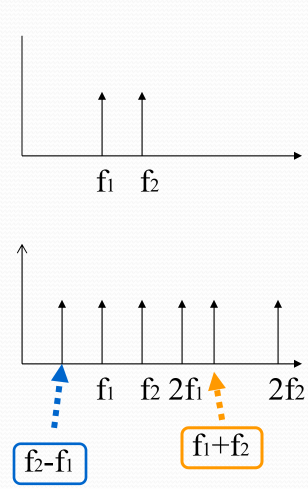
Inter-modulation Noise: Example



$y(t) = x(t) + a\,\{x(t)\}^2$

$x(t) = \cos(2\pi f_1 t) + \cos(2\pi f_2 t)$

$$\boxed{\begin{aligned} y(t) = \; & \cos(2\pi f_1 t) + \cos(2\pi f_2 t) + (a/2) + \\ & (a/2)\,\{\cos(2\pi 2 f_1 t) + \cos(2\pi 2 f_2 t)\} + \\ & a\,\{\cos(2\pi\,[f_1+f_2]\,t) + \cos(2\pi\,[f_1-f_2]\,t)\} \end{aligned}}$$



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Crosstalk

- Unwanted coupling between signal paths
- Example: more than one conversation can be heard.

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Impulsive Noise

- Non-continuous noise consisting of irregular pulses or noise spikes of short duration and of relatively high amplitude.

Causes:

- external electromagnetic disturbances and faults in the communication system

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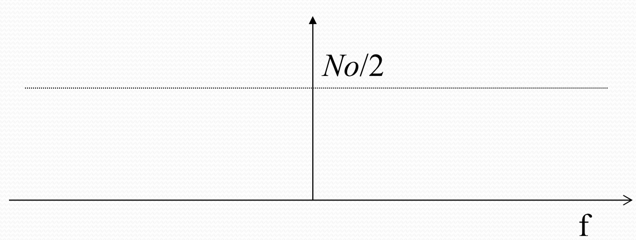
Power Spectral Density of Additive White Gaussian Noise (AWGN)



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Delay distortion

- The speed of propagation of a sinusoidal signal along a transmission line varies with the frequency
  - For a signal composed of more than one frequencies, the signal frequency components arrive at the receiver with different delays from each other
- This distorts the signal
- The effect of delay distortion tends to increase with the size of the signal bandwidth (=> it increases with an increase in transmission rate)
  - the pulses become distorted, spread in time and can spill over to neighboring pulses, making their detection difficult
  - (Intersymbol Interference) => incorrect interpretation of the received signal

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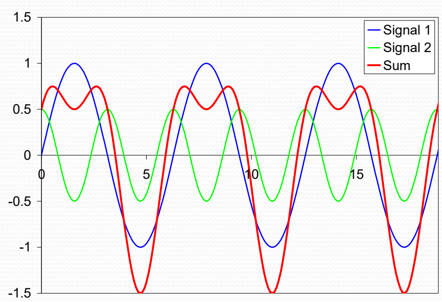
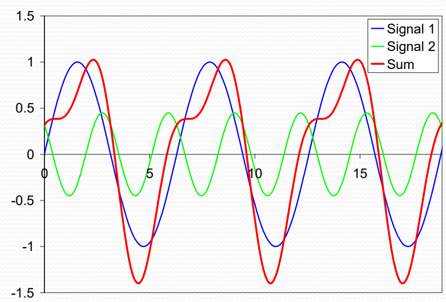
Atmospheric absorption

- Strength of signal falls off because the atmosphere absorbs some of its energy
- Attenuation and delay are greater at higher frequencies, causing distortion





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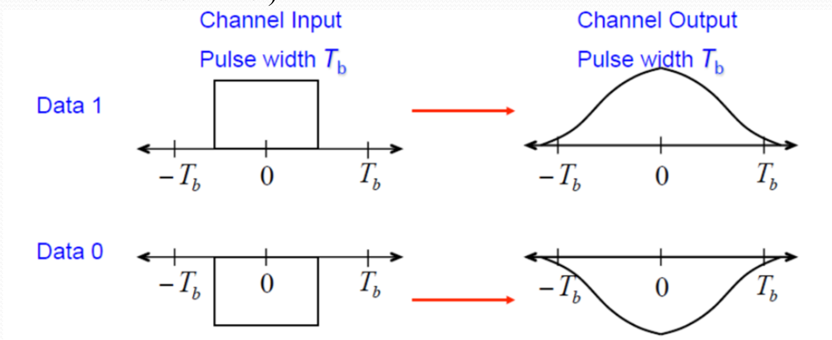
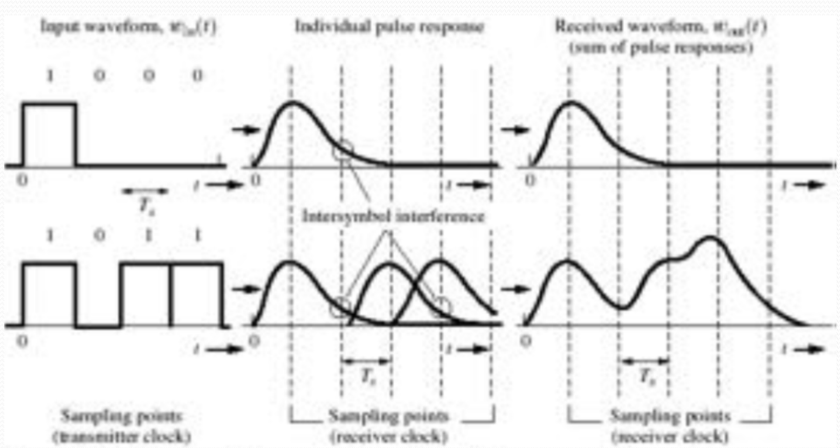
Intersymbol Interference (1)

- **Intersymbol interference (ISI)** occurs when a pulse spreads out in such a way that it interferes with adjacent at the sample instant.
- Example: assume polar NRZ line code. The channel outputs are shown as "smeared" (width T_b becomes $2T_b$) pulses (spreading due to bandlimited channel)



Intersymbol Interference (2)



Impact of ISI on received signal of binary communication system

Causes of Impairments

- **Reflection** - occurs when signal encounters a surface that is large relative to the wavelength of the signal.
- **Diffraction** - occurs at the edge of an impenetrable body that is large compared to wavelength of radio wave.
- **Scattering** – occurs when incoming signal hits an object whose size is in the order of the wavelength of the signal or less.

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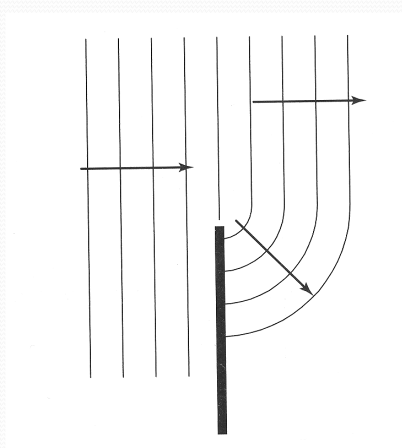
Illustration of knife-edge diffraction



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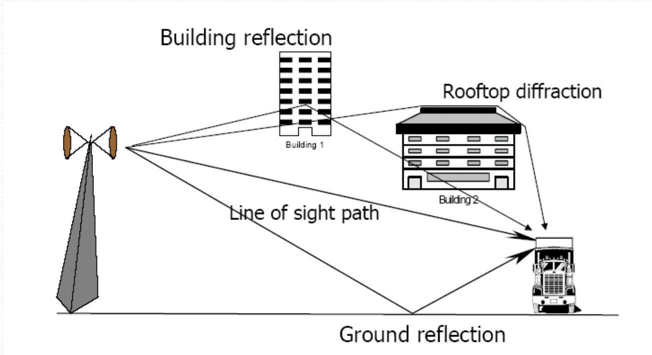
Multipath Propagation

- Obstacles reflect signals so that multiple copies of a signal may arrive at the receiver at different times, and therefore with different phases.



- If phases add destructively the signal level declines, and vice versa.
- When the transmitter or the receiver moves even short distances (of the order of λ, which is a few centimeters for the frequencies used) the signal amplitude can vary greatly.
- Also produces ISI.

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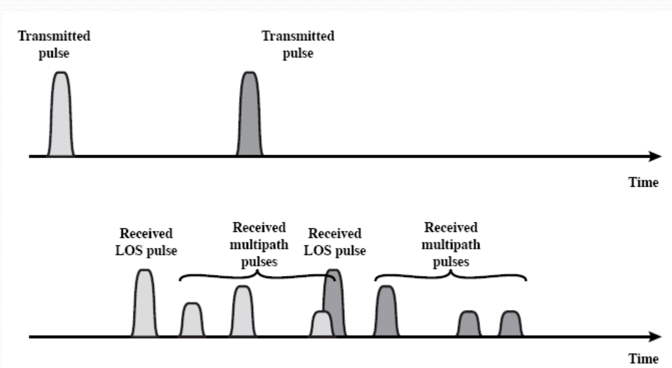
ISI due to Multipath



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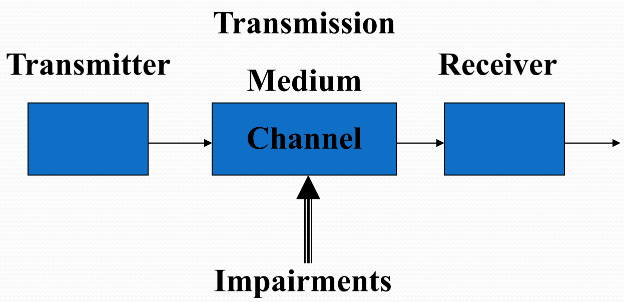
Communication System



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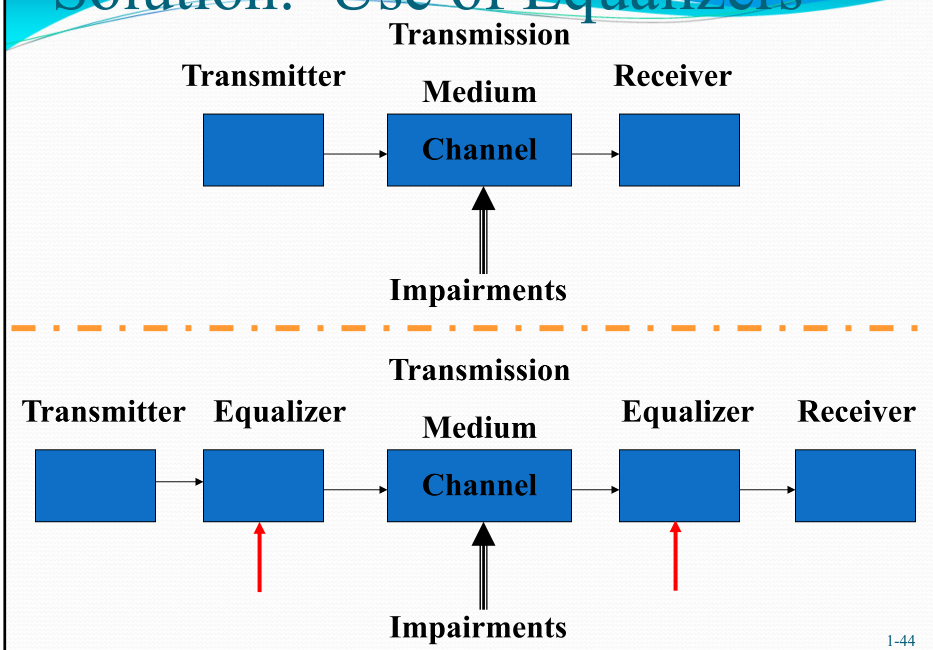
Solution: Use of Equalizers



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Adaptive Equalization

- Used to compensate the distortion introduced by the channel
- It basically tries to reverse the unequal response of the channel, both in amplitude and phase, to the frequency components of the transmitted signal
- It is commonly adaptive in the sense that the channel response is periodically estimated and the equalizer adapts accordingly
- It is useful to combat intersymbol interference
- It involves sophisticated digital signal processing algorithms

1-45

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Channel capacity without noise

- Nyquist Formula

  - $C = 2W\log_2 M$

  where

  - W = bandwidth in hertz
  - M = number of discrete signal levels
  - C = capacity in bits per second

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Channel capacity with noise

- Shannon-Hartley formula
  - $C = W \log_2(1+S/N)$

    where
  - W = bandwidth in hertz
  - S/N = signal-to-noise ratio
  - C = maximum theoretical capacity in bits per second

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Digital vs. Analog Transmission (1)

- Digital technology
  - VLSI product became "low cost"
- Data integrity
  - Example: the use of repeaters guarantees the integrity of the data being transmitted

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Digital vs. Analog Transmission (2)

- Capacity utilization
  - links can be shared (multiplexed)effectively
- Security and privacy
  - encryption techniques can be applied easily to digital data

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Bit rate and baud rate

- Bit rate:
  - number of bits transmitted per second
- Baud rate:
  - number of signal changes per second
- Relation

bit rate = baud rate * n

where

n = number of bits per change

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Transmission media

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Transmission media

Guided Transmission media

- twisted pair
- coaxial Cable
- optical Fiber

Wireless transmission

- microwave
- radio
- infrared and millimeter waves
- light-wave transmission

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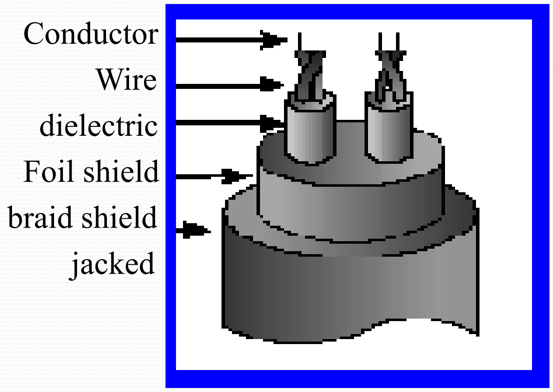
Twisted pair (1)



- Widely used in the telephone network
- Used for either analog and digital transmission

1-53

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Twisted pair (2)

- Attenuation very strong with frequency
  - analog: amplifiers every 5-6 km
  - digital: repeaters every 2-3 km
- Low noise immunity
  - crosstalk is a problem
  - poor channel characteristics
- Easy to install, repair, ..
- Low cost

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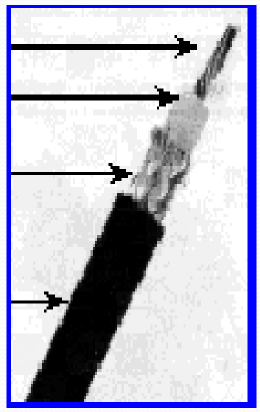
Coaxial cable (1)



- Baseband coaxial cable commonly used for digital transmission
- one channel

- Broadband coaxial cable commonly used for analog transmission
- multiple channels, e.g. analog TV, CD-quality audio.
- two types:
  - dual cable system
  - single cable system

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Coaxial cable (2)

- Attenuation linear with frequency
- Better noise immunity
- Error rate:
  - baseband: 10^{-7}
  - broadband:10^{-9}
- ~ 1 Km Baseband Cable =?-2 Gbps
- ~100 km Broadband cable => 300-450 MHz
- Moderate cost

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Optical Fiber

- Physical Description
  - an optical fiber is a thin (2 to 125 µm), flexible medium capable of conducting an optical ray
  - an optical fiber cable has a cylindrical shape and consists of three concentric sections: the core, the cladding and the jacket.

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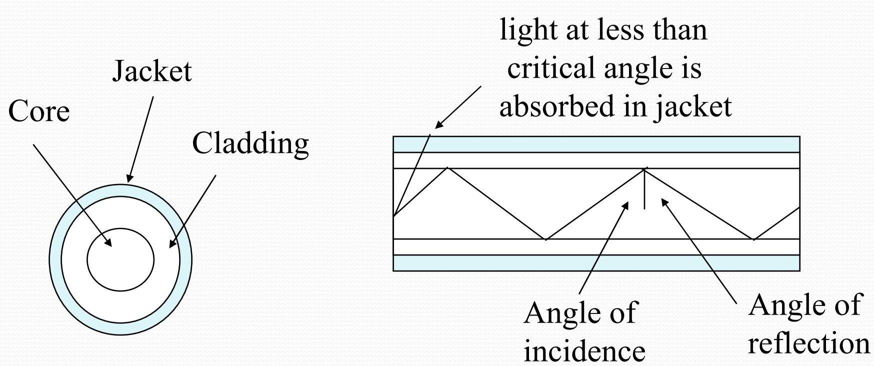
Optical Fibers (cont'd)



- Idea: refraction principle
- Utilization: light trapped by total internal reflection when…

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Fiber optics (2)

Three components:

- light source (LED or laser diode)
- transmission medium (fiber)
- detector (photodiode)

Two major types of fiber

- multimode fiber (largely used)
- single mode fiber (expensive but can be used for long distances)

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Fiber optics(3)

- Attenuation very low
- High noise immunity
- Error rate: 10^{-15}
- ~100 km of fiber => ~2 Gbps
- Unfamiliar technology: high skills required
- Lightweight
- Expensive

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Optical Fiber (cont'd)

- Applications
  - Long-Haul trunks
    - average length 900 miles
    - 20,000 to 60,000 voice channels
  - Metropolitan networks
    - average length 7.8 miles
    - 100,000 voice channels
  - Rural-exchange trunks
    - 25 to 100 miles
    - less than 5,000 voice channels

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Optical Fiber (cont'd)

- Applications (cont'd)
  - Subscriber loop
    - fibers running from the central exchange to the subscriber
  - Local Area Networks
    - networks linking 100's and even 1000's of workstations
    - Ethernet, ATM-LAN,...

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Optical Fiber (cont'd)

- Wavelength Division Multiplexing (WDM)
  - Send more than one wavelengths through the same fiber
  - Allows re-use of fiber

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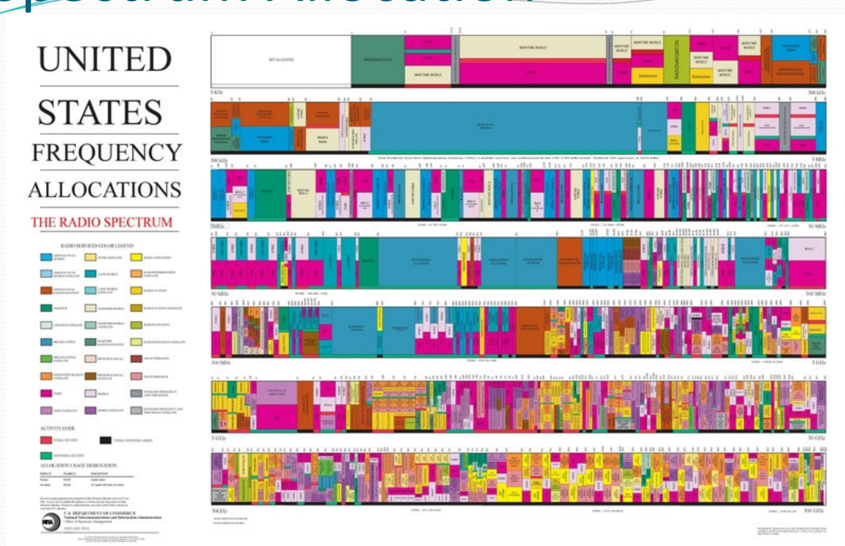
Spectrum Allocation



Spectrum is valuable commodity; needs to be shared

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Spectrum Allocation

Band name	Abbreviation	ITU band number	Frequency and Wavelength	Example Uses
Extremely low frequency	ELF	1	3–30 Hz 100,000–10,000 km	Communication with submarines
Super low frequency	SLF	2	30–300 Hz 10,000–1,000 km	Communication with submarines
Ultra low frequency	ULF	3	300–3,000 Hz 1,000–100 km	Submarine communication, communication within mines
Very low frequency	VLF	4	3–30 kHz 100–10 km	Navigation, time signals, submarine communication, wireless heart rate monitors, geophysics
Low frequency	LF	5	30–300 kHz 10–1 km	Navigation, time signals, AM longwave broadcasting (Europe and parts of Asia), RFID, amateur radio
Medium frequency	MF	6	300–3,000 kHz 1,000–100 m	AM (medium-wave) broadcasts, amateur radio, avalanche beacons
High frequency	HF	7	3–30 MHz 100–10 m	Shortwave broadcasts, citizens band radio, amateur radio and over-the-horizon aviation communications, RFID, over-the-horizon radar, automatic link establishment (ALE) / near-vertical incidence skywave (NVIS) radio communications, marine and mobile radio telephony
Very high frequency	VHF	8	30–300 MHz 10–1 m	FM, television broadcasts, line-of-sight ground-to-aircraft and aircraft-to-aircraft communications, land mobile and maritime mobile communications, amateur radio, weather radio
Ultra high frequency	UHF	9	300–3,000 MHz 1–0.1 m	Television broadcasts, microwave oven, microwave devices/communications, radio astronomy, mobile phones, wireless LAN, Bluetooth, ZigBee, GPS and two-way radios such as land mobile, FRS and GMRS radios, amateur radio, satellite radio, Remote control Systems, ADSB
Super high frequency	SHF	10	3–30 GHz 100–10 mm	Radio astronomy, microwave devices/communications, wireless LAN, DSRC, most modern radars, communications satellites, cable and satellite television broadcasting, DBS, amateur radio, satellite radio
Extremely high frequency	EHF	11	30–300 GHz 10–1 mm	Radio astronomy, high-frequency microwave radio relay, microwave remote sensing, amateur radio, directed-energy weapon, millimeter wave scanner, wireless LAN (802.11ad)
Terahertz or Tremendously high frequency	THz or THF	12	300–3,000 GHz 1–0.1 mm	Experimental medical imaging to replace X-rays, ultrafast molecular dynamics, condensed-matter physics, terahertz time-domain spectroscopy, terahertz computing/communications, remote sensing

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Spectrum Allocation

Band name	Abbreviation	ITU band number	Frequency and Wavelength	Example Uses
Extremely low frequency	ELF	1	3–30 Hz 100,000–10,000 km	Communication with submarines
Super low frequency	SLF	2	30–300 Hz 10,000–1,000 km	Communication with submarines
Ultra low frequency	ULF	3	300–3,000 Hz 1,000–100 km	Submarine communication, communication within mines
Very low frequency	VLF	4	3–30 kHz 100–10 km	Navigation, time signals, submarine communication, wireless heart rate monitors, geophysics
Low frequency	LF	5	30–300 kHz 10–1 km	Navigation, time signals, AM longwave broadcasting (Europe and parts of Asia), RFID, amateur radio
Medium frequency	MF	6	300–3,000 kHz 1,000–100 m	AM (medium-wave) broadcasts, amateur radio, avalanche beacons
High frequency	HF	7	3–30 MHz 100–10 m	Shortwave broadcasts, citizens band radio, amateur radio and over-the-horizon aviation communications, RFID, over-the-horizon radar, automatic link establishment (ALE) / near-vertical incidence skywave (NVIS) radio communications, marine and mobile radio telephony

1-66

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Spectrum Allocation

Band name	Abbreviation	ITU band number	Frequency and Wavelength	Example Uses
Ultra high frequency	UHF	9	300–3,000 MHz 1–0.1 m	Television broadcasts, microwave oven, microwave devices/communications, radio astronomy, mobile phones, wireless LAN, Bluetooth, ZigBee, GPS and two-way radios such as land mobile, FRS and GMRS radios, amateur radio, satellite radio, Remote control Systems, ADSB
Super high frequency	SHF	10	3–30 GHz 100–10 mm	Radio astronomy, microwave devices/communications, wireless LAN, DSRC, most modern radars, communications satellites, cable and satellite television broadcasting, DBS, amateur radio, satellite radio
Extremely high frequency	EHF	11	30–300 GHz 10–1 mm	Radio astronomy, high-frequency microwave radio relay, microwave remote sensing, amateur radio, directed-energy weapon, millimeter wave scanner, wireless LAN (802.11ad)
Terahertz or Tremendously high frequency	THz or THF	12	300–3,000 GHz 1–0.1 mm	Experimental medical imaging to replace X-rays, ultrafast molecular dynamics, condensed-matter physics, terahertz time-domain spectroscopy, terahertz computing/communications, remote sensing

Microwave frequencies: range between 10^9 Hz (1 GHz) to 1000 GHz. Respective wavelengths: 30cm to 0.03 cm.

1-67

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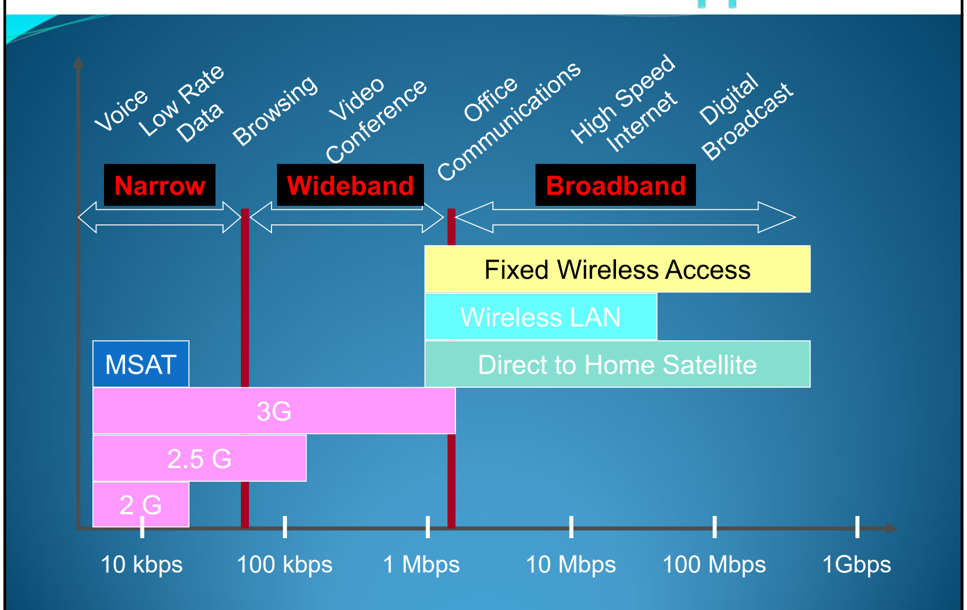
Wireless Rates and Applications



1-68

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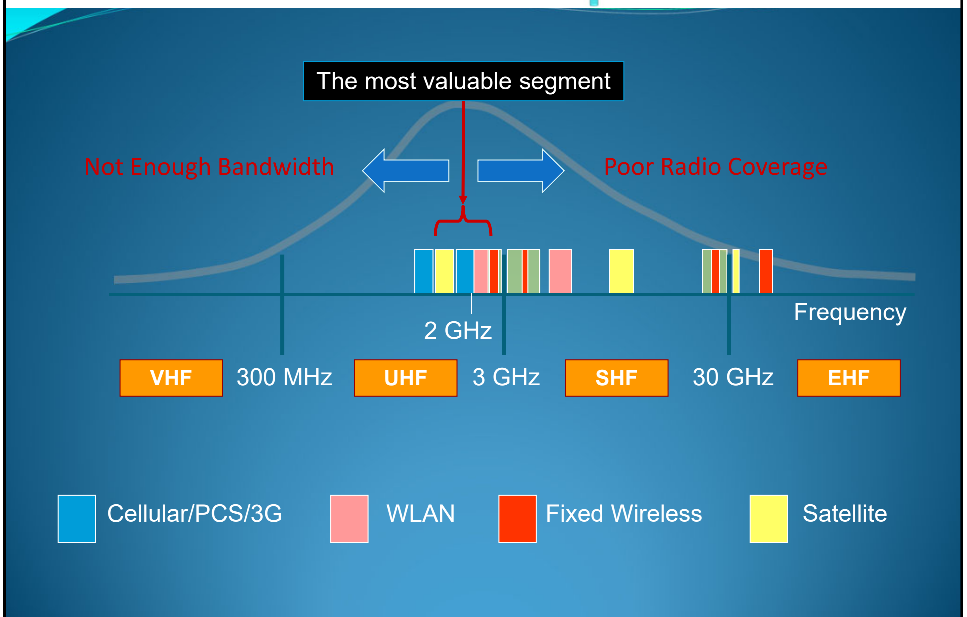
Spectrum Cost



1-69

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Licensed & Unlicensed Bands

Licensed

- 800-900 MHz
- 1800-1900 GHz
- 2 GHz
- 5 GHz
- 28 GHz

Cellular/PCS
3G/4G
WiMax

Unlicensed

- 915 MHz
- 2.4 GHz
- 5 GHz
- 60 GHz ??

Wireless LAN
ITS
IMS Applications

1-70

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Licensed and Unlicensed Bands

Licensed

TACS/NMT/AMPS/TDMA 400 MHz

AMPS/CDMA/TDMA 800 MHz

GSM/TACS/NMT 850 MHz

Subscriber Radio 1.4 GHz

GSM/DECT 1.8 GHz

PCS/PHS/3G 1.9 GHz

MMDS 2.5 GHz

Point to multi-point 10.5 GHz

LMDS 24/26/28/32/40 GHz

Unlicensed

900 MHz General Application

2.4 GHz IMS (802.11b/g/n, Bluetooth)

5 GHz UNII (802.11a), DSRC (802.11p)

60 GHz ??? New

1-71

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Employed Frequencies

- Wireless channel's behaviour is dependent on the frequency band of the signal.
- Frequency band of operation depends on the availability of spectrum, antenna characteristics, propagation behavior, and technological preferences.
- Licensed wireless systems operate at 150 MHz, 450 MHz, 800 MHz, 2 GHz, 28 GHz.
- Unlicensed systems at 900 MHz, 2.4 GHz, 5 GHz, [3.1 GHz to 10.3 GHz: UWB], 57 GHz to 64 GHz, optical frequencies.

1-72

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Radio transmission

- Radio waves
  - easy to generate, can travel long distances, penetrate buildings at lower part of spectrum, omnidirectional (all directions from the source)
  - widely used for indoor and outdoor communication
- Low noise immunity
  - interference from electrical equipment
  - multipath interference
  - Co/adjacent-channel interference
- Attenuation increases with distance “fast”

1-73

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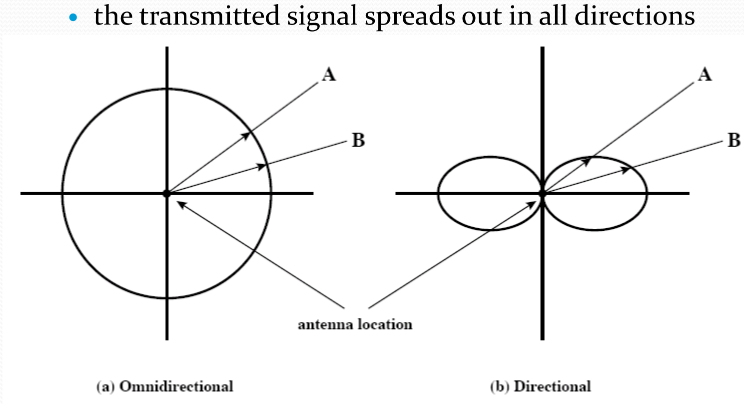
Wireless transmission patterns

- directional -
  - the transmitting antenna puts out a focused electromagnetic beam

    example: terrestrial microwave, satellite
- omnidirectional
  - the transmitted signal spreads out in all directions



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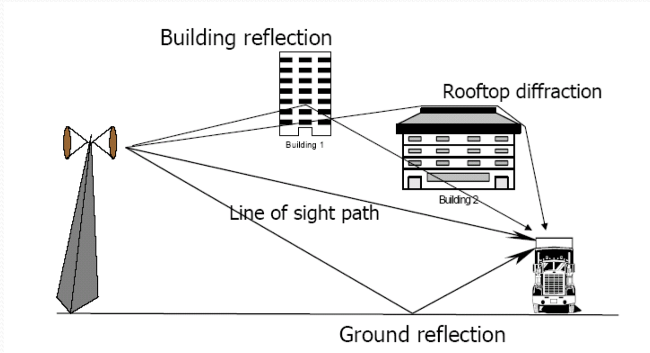
Multipath Propagation

- Obstacles reflect signals so that multiple copies of a signal may arrive at the receiver at different times, and therefore with different phases.



- If phases add destructively the signal level declines, and vice versa.
- When the transmitter or the receiver moves even short distances (of the order of λ, which is a few centimeters for the frequencies used) the signal amplitude can vary greatly.
- Also produces ISI.

1-75

75

Microwave transmission

- Microwave transmission is widely used
  - long-distance communication, cellular phones, TV distribution, etc.
- Microwave transmissions can be made easier directional
  - repeaters are needed (for 100-m high towers, repeaters can be spaced 80 km apart)
- Higher signal to noise ratio
- They do not penetrate deep into buildings
- Multipath fading effect can occur

1-76

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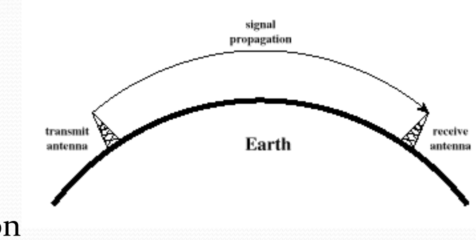
Terrestrial Microwave



- Physical Description
  - parabolic dish
  - ~ 10 feet in diameter
  - line-of-sight transmission
  - maximum distance between 2 antennas (in km):

$$d = 3.57\left(\sqrt{\mathrm{K}h_1} + \sqrt{\mathrm{K}h_2}\right)$$

where

- h_1 = height of antenna one
- h_2 = height of antenna two
- K = 4/3 (adjustment factor)

1-77

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Terrestrial Microwave (cont'd)

- Applications
  - long-haul communications
  - TV and voice communications
  - transmission in small regions (radius < 10 km)

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Terrestrial Microwave (cont'd)

- Transmission Characteristics
  - attenuation is the major source of loss

$$L = 10\log\left(\frac{4\pi d}{\lambda}\right)^2 dB$$

  - where d is the distance and λ is the wavelength, expressed in the same units.

IMPORTANT:

loss varies as the square of the distance

1-79

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Satellite Microwave

- Physical Description
  - a satellite is a **microwave relay station** used to link 2 or more ground-based microwave transmitters/receivers.
  - a single orbiting satellite will operate on a number of frequency bands, called **transponder** channels.
  - **Geostationary** - a satellite is required to remain stationary with respect to its position over the earth. This match occurs at ~36,000 km
  - Low Earth Orbit (LEO), Medium Earth Orbit (MEO) systems (satellite phones)

1-80

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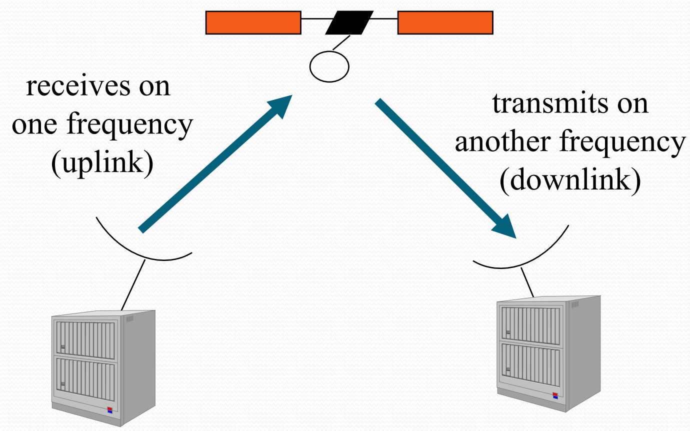
Satellite Microwave (cont'd)



1-81

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Satellite Microwave (cont'd)

- Applications:
  - television distribution (broadcast)
  - long-distance telephone
  - private business networks (VSAT/USAT networks)

1-82

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Satellite Microwave (cont'd)

- Transmission characteristics
  - 4GHz / 6GHz , 12 GHz / 14 GHz, 15 GHz / 17 GHz
    - below 1 GHz there is significant noise from natural sources, including galactic solar and atmospheric noise.
  - 20 GHz to 30 GHz
    - Personal Satellite Communication Systems
    - High-Definition TV (around 23 GHz)

1-83

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Infrared, Optical and millimeter waves

- They are widely used for short-range communication
  - remote control on TV, VCRs, etc.
  - indoor wireless LANs
- Characteristics
  - relatively directional, cheap, easy to build
  - do not pass-through solid object (e.g. wall)
  - mmWave and Visual Optical proposed for use in 5G Access networks

1-84

84

Free Space Lightwave transmission

- An application: connect two LANs in two buildings via lasers
  - high bandwidth, very low cost and easy to install
- Characteristics
  - laser beams cannot penetrate rain or thick fog
  - laser beams work well on sunny days, but ….

1-85

85

Digital Data/Digital Signals

- Modulation rate is the rate at which signal level is changed (rate at which signal elements are generated)
- Digital signaling rate or just data rate of a signal is the rate, in bits per seconds, that data are transmitted.
- Duration of length of a bit is the amount of time it takes for the transmitter to emit a bit. For a data date R, the bit duration, t_B, is 1/R.

1-86

86

Data Rate vs. Modulation Rate

- data rate:

$$R = 1/t_B$$

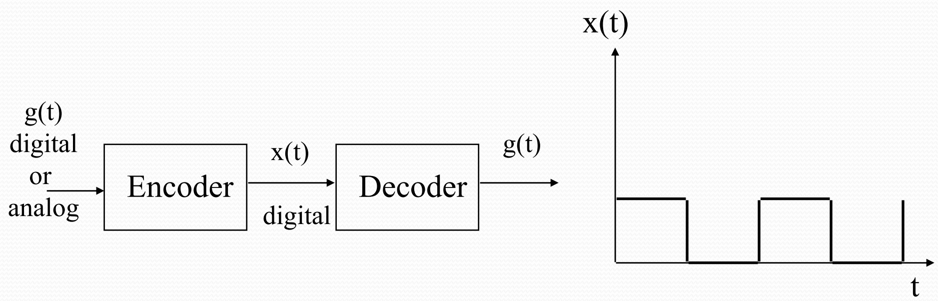
where t_B is the bit duration

example: In the case of code Manchester, the maximum modulation rate, D_{max}, is 2 R

Data Encoding

Data Encoding - Baseband Transmission

- Encoding onto a digital signal located at baseband



1-89

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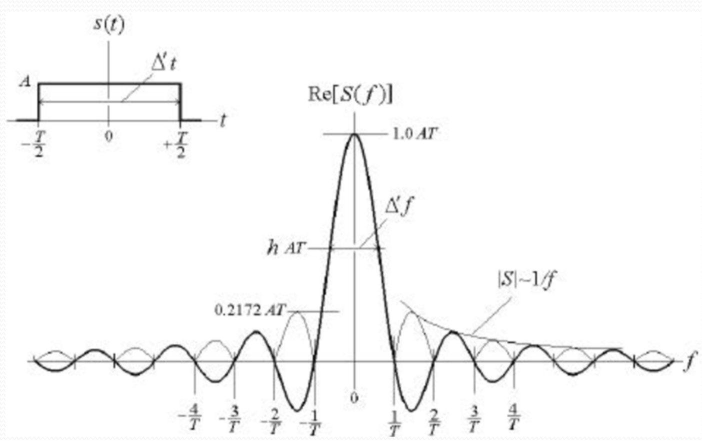
Square Pulse



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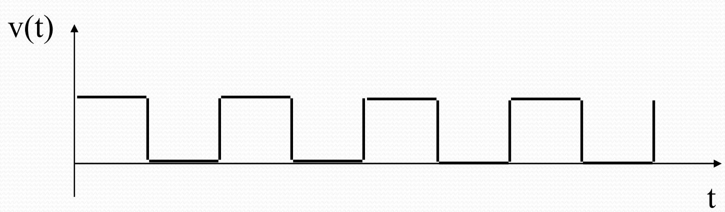
Digital Data/Digital Signals

- Definition
  - Unipolar signal: all the signal elements have the same algebraic sign, all positive or all negative



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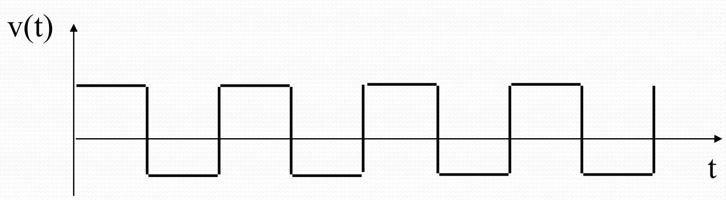
Digital Data/Digital Signals

- Definition
  - Bipolar signalling: one logic state is represented by a positive voltage level an the other by a negative voltage level



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Digital Signal Encoding Schemes

- Five evaluation factors:
  1) signal spectrum
     - lack of high-frequency components means that less bandwidth is required for transmission

  2) clocking
     - every bit being received needs to be identified

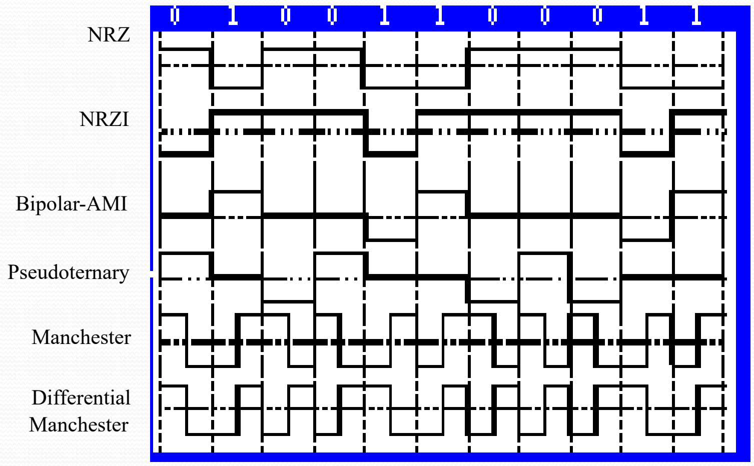
Digital Signal Encoding Schemes

3) error detection
   - useful to be able to detect errors at the physical level

4) signal interference and noise immunity

5) cost and complexity

Some encoding techniques



Digital Signal Encoding Schemes

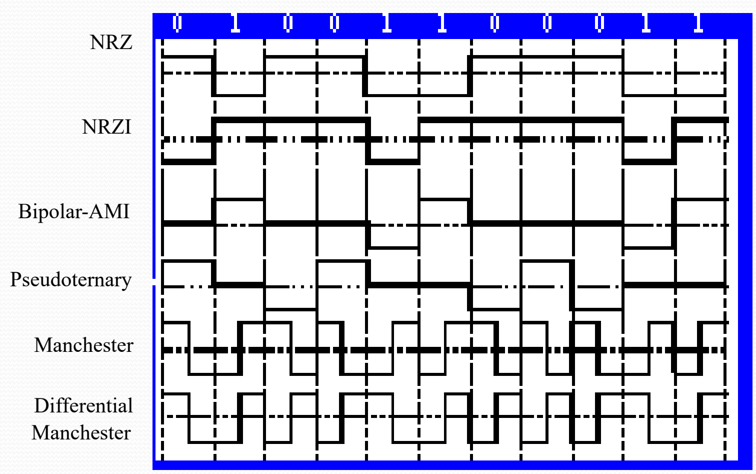
- 3 main techniques:
  - Nonreturn to Zero (NRZ)
  - Multilevel Binary
  - Biphase

Digital Signal Encoding Schemes

- Non-return to zero (NRZ)
  - maintains a constant value for the duration of a bit time.

  example 1: NRZ-L (nonreturn-to-zero-level)
    - during a bit interval there is no transition
    - two different levels for the two binary digits
      - binary 0 - negative voltage
      - binary 1 - positive voltage

Some encoding techniques



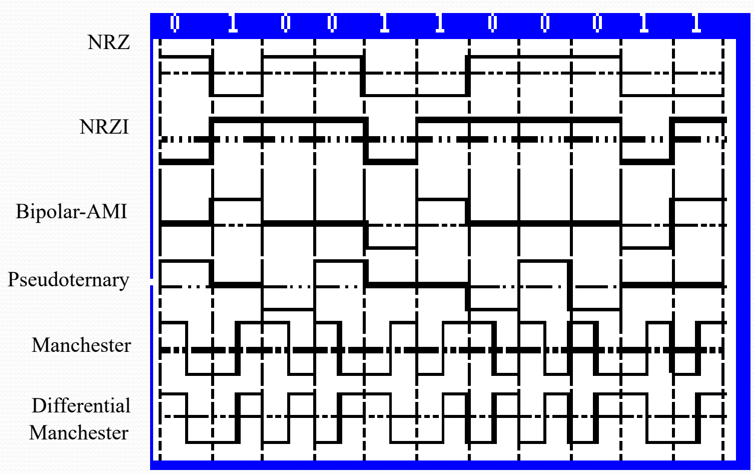
Digital Signal Encoding Schemes

- Non-return to zero (NRZ)
  - example 2: NRZI (non-return to zero, invert on ones)
    - the data is encoded as the presence or absence of a signal transition at the beginning of the bit time.
    - this type is called differential encoding (the signal is decoded by comparing the polarity of adjacent signal elements)

1-99

99

Some encoding techniques



1-100

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Digital Signal Encoding Schemes

- Non-return to zero (NRZ)
  - Advantage:
    - make efficient use of bandwidth
  - Drawback:
    - presence of a dc component and lack of synchronization (used in digital magnetic recording)

1-101

101

Digital Signal Encoding Schemes

- Multilevel Binary
  - uses more than 2 signal levels

  example 1:

  bipolar AMI - the binary 1 pulses alternate in polarity

  example 2:

  Pseudo-ternary - the binary 0 pulses alternate in polarity

1-102

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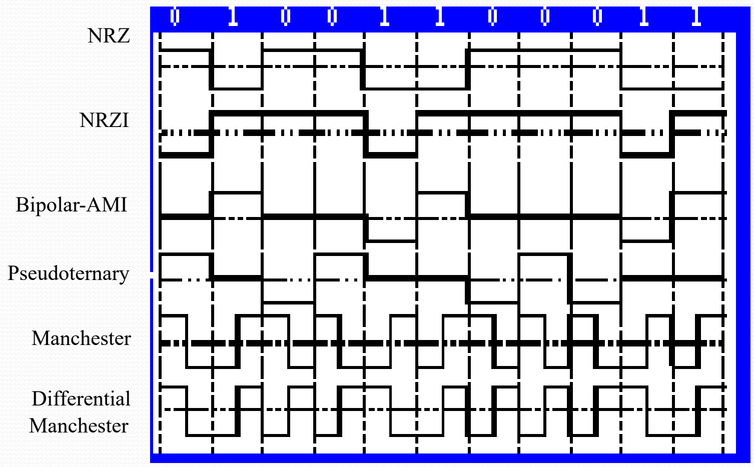
Some encoding techniques



Digital Signal Encoding Schemes

- Multilevel Binary
  - advantages:

    1) since signal alternate in voltage, there is no net DC component

    2) pulse alternation property provides a simple means of error detection
  - drawback:

    1) loss of synchronization

    bipolar AMI - if a long string of 0's occurs

    pseudoternary - if a long string of 1's occurs

Digital Signal Encoding Schemes

- Biphase:
  - there is a transition at the middle of each bit period

  Example 1:

  Manchester - the mid-bit transition serves as a clocking mechanism and also for transporting data.
- Biphase:

  example 2:

  Differential Manchester - mid-bit transition provides clocking

  binary 0 - transition at the beginning of a bit

  binary 1 - no transition at the beginning of a bit

1-105

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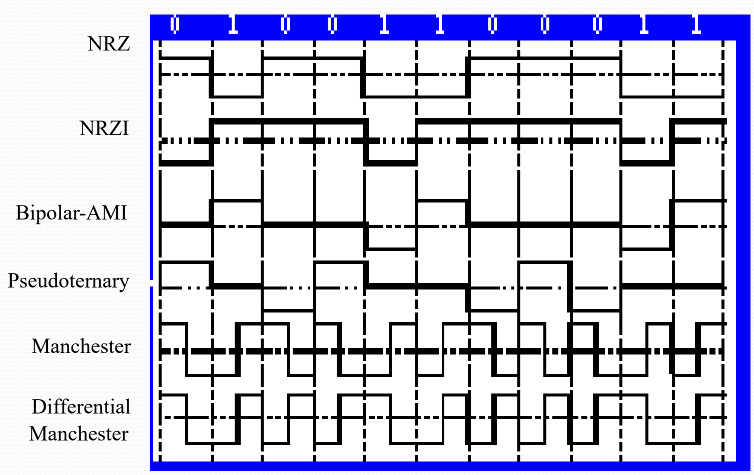
Some encoding techniques



1-106

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Digital Signal Encoding Scheme

- Biphase
  - advantages:
    - a) synchronization - predictable transition permit to the receiver to resynchronize.
    - b) absence of expected transition can be used to detect errors
    - c) no DC component
  - drawback
    - a) higher modulation rate than NRZ => higher BW

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Digital Signal Encoding Schemes

Normalized Signal Transition Rate of Various Digital Signal Encoding Schemes

	Minimum	101010...	Maximum
NRZ-L	0 (all o's or 1's)	1.0	1.0
NRZI	0 (all 0's)	0.5	1.0 (all 1's)
Binary-AMI	0 (all 0's)	1.0	1.0
Pseudoternary	0 (all 1's)	1.0	1.0
Manchester	1.0 (1010...)	1.0	2.0 (all o's or 1's)
Differential Manchester	1.0 (all 1's)	1.5	2.0 (all 0's)

1-108

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Evaluation

- NRZ
  - lack of synchronization capability; widely used for digital magnetic recording but not for signal transmission
- Multilevel binary
  - long string of **0**s (Bipolar-AMI) and **1**s (pseudoternary) cause synchronization problems (scrambling techniques are used to address this deficiency);
  - it is easy to detect isolated errors; it is not as efficient as NRZ (three signal levels are used instead of 2 levels used in NRZ)
- Biphase
  - no synchronization problems; good error detection; more bandwidth is needed (as many as two transitions per bit time)

1-109

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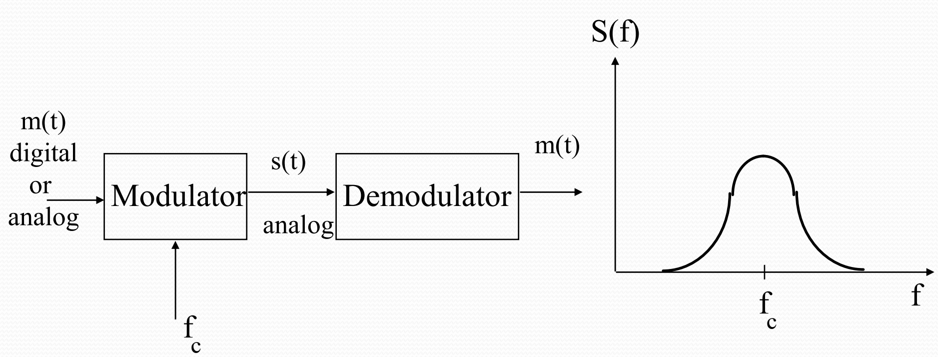
Data Encoding

- Modulation onto an analog signal



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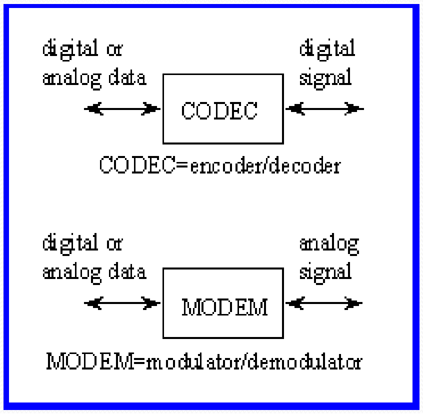
Encoding and modulation



- Digital data, digital signal: improve the capacity of the receiver to interpret the incoming signal
- Analog data, digital signal: use of modern digital and switching equipment
- Digital data, analog signal: some transmission media will only propagate analog signals
- Analog data, analog signal: frequency-division multiplexing

1-111

111

Modulation Techniques

- Amplitude modulation
  - $S(t)=[1+n_a X(t)]\cos 2\pi f_c t$, where $\cos 2\pi f_c t$ is the carrier and $x(t)$ is the input signal, n_a is the modulation index (ratio of the amplitude of $x(t)$ to the carrier)
  - simplest form of modulation
- Angle modulation
  - $S(t)=A\cos[2\pi f_c t + \phi(t)]$
  - phase modulation : $\phi(t)=n_p m(t)$ where n_p is the phase modulation index
  - frequency modulation: $\phi(t)=n_f m(t)$ where n_f is the frequency modulation index

1-112

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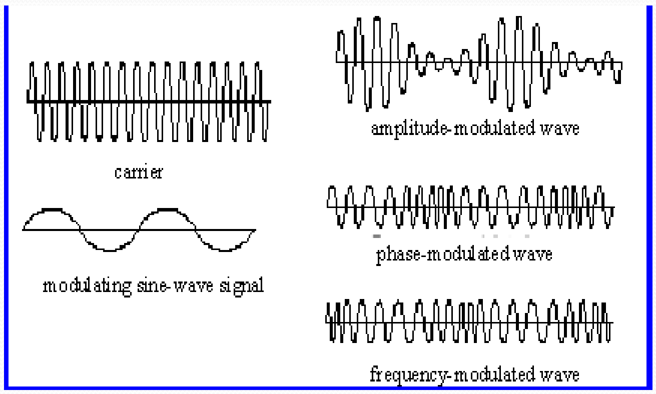
Modulation of a sine-wave carrier by a sine-wave signal



1-113

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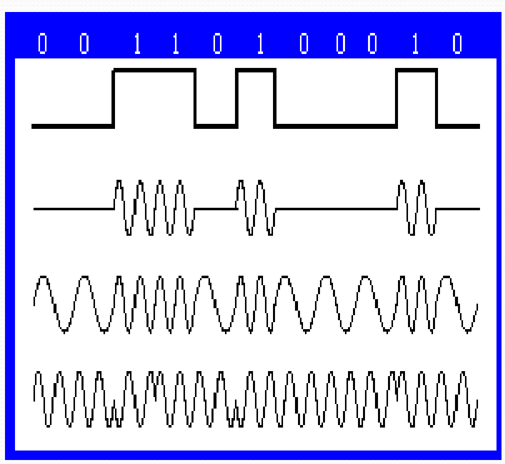
Modulation of digital signal

Amplitude-shift keying

Frequency-shift keying

Phase-shift keying



1-114

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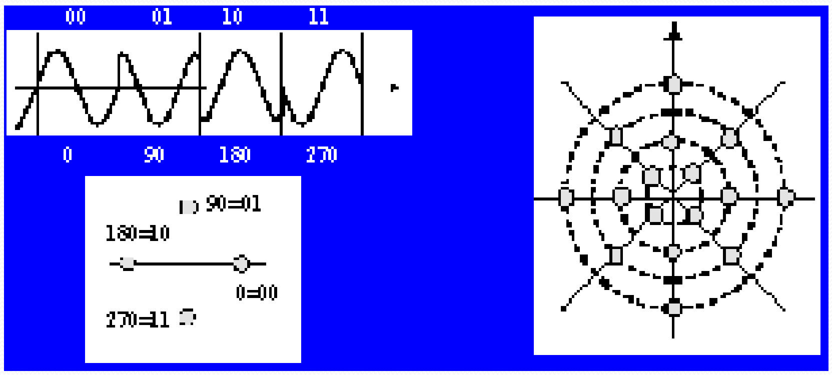
Multilevel modulation

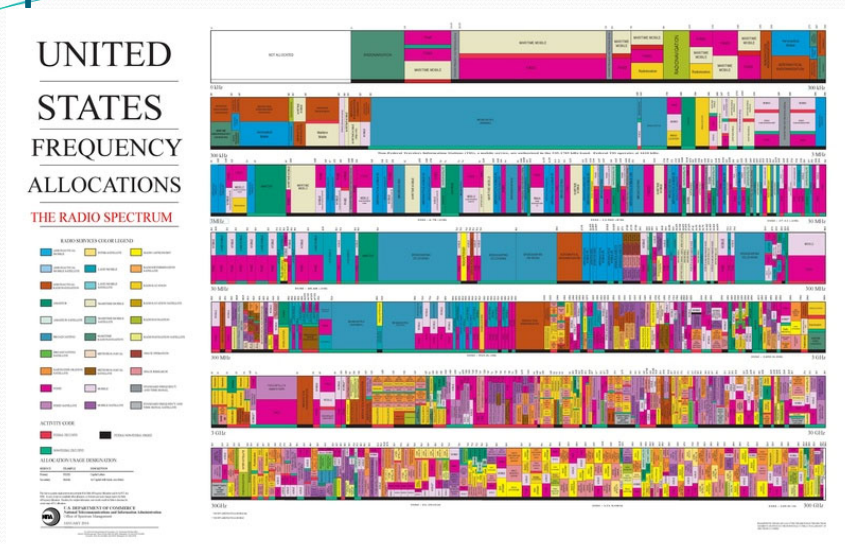
Quadrature phase-shift keying
(R=2*D)

Quadrature amplitude modulation
(R=4*D)



Multiplexing

Spectrum Allocation



Spectrum is valuable commodity; needs to be shared

1-117

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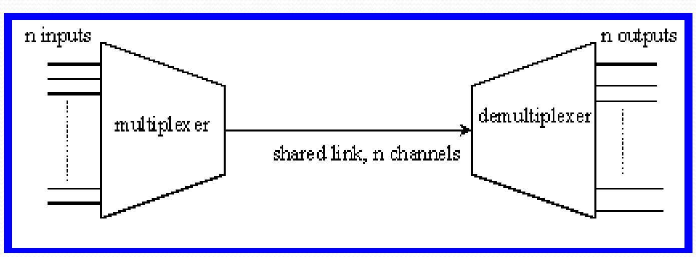
Multiplexing



- Objective: share a link between several users (i.e., telephone companies transmit many conversations over a single physical trunk)

- Two basic techniques: FDM (Frequency Division Multiplexing) and TDM (Time Division Multiplexing)

1-118

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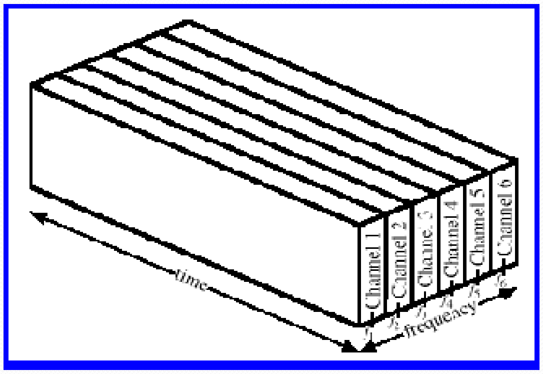
Frequency-division multiplexing



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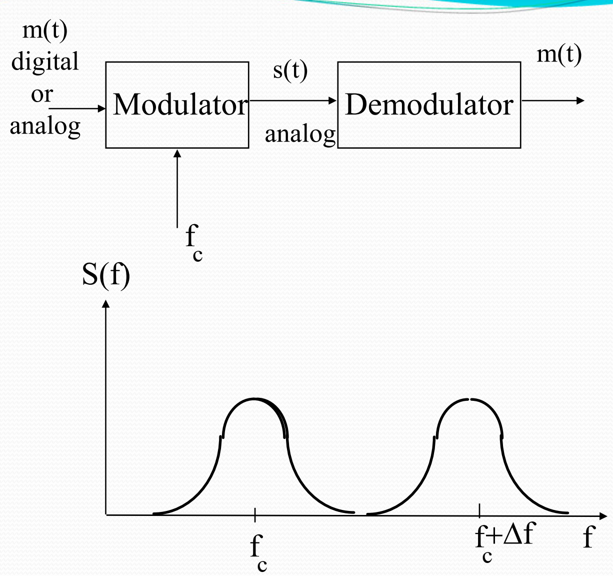
FDM



1-120

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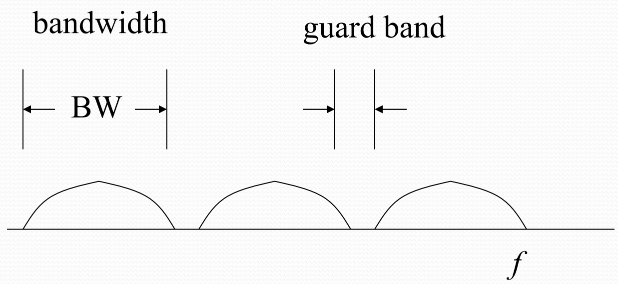
Frequency Division Multiple Access FDMA



1-121

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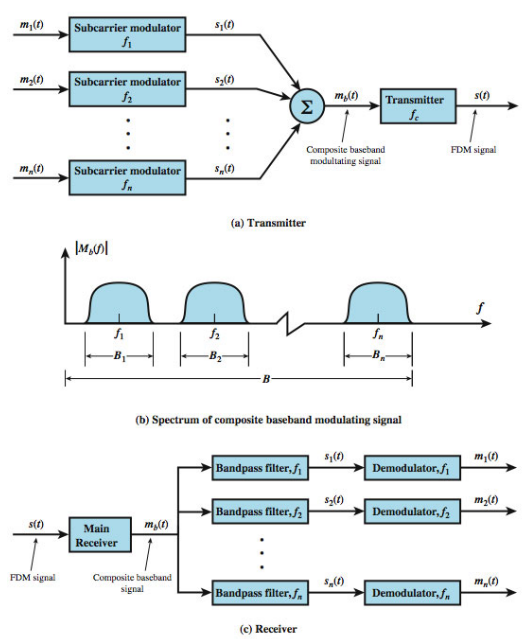
FDM System Overview



1-122

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Frequency-division multiplexing: problems

- Crosstalk
  - guard bands (separating two "adjacent" channels) should be carefully chosen
  - a voice signal has an effective bandwidth of 3.1 kHz; a channel of 4 kHz is adequate to avoid crosstalk in analog voice transmissions
- Intermodulation noise
  - nonlinear effects of amplifiers on a signal in one channel can produce undesirable frequency components in other
  - Channels
- More challenging and expensive RF technology (narrow filters; large)
- Inefficiency
  - Channels might be allocated to sources that are not using them all the time

1-123

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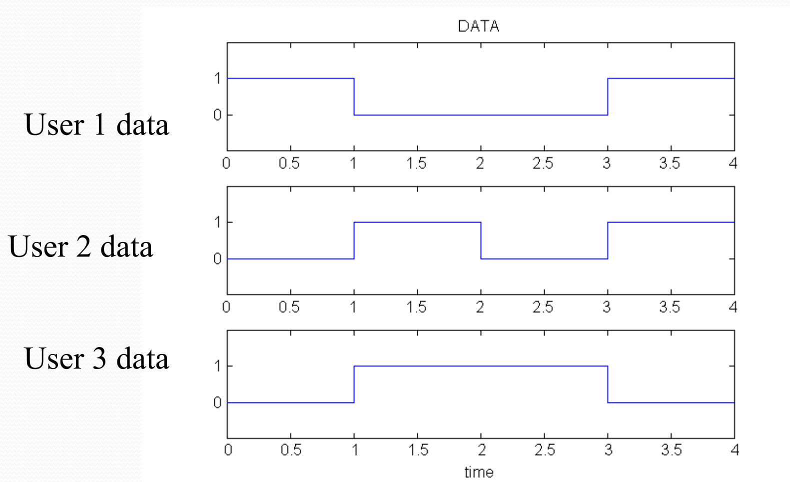
Consider the following samples of 3 users' data to be multiple accessed



1-124

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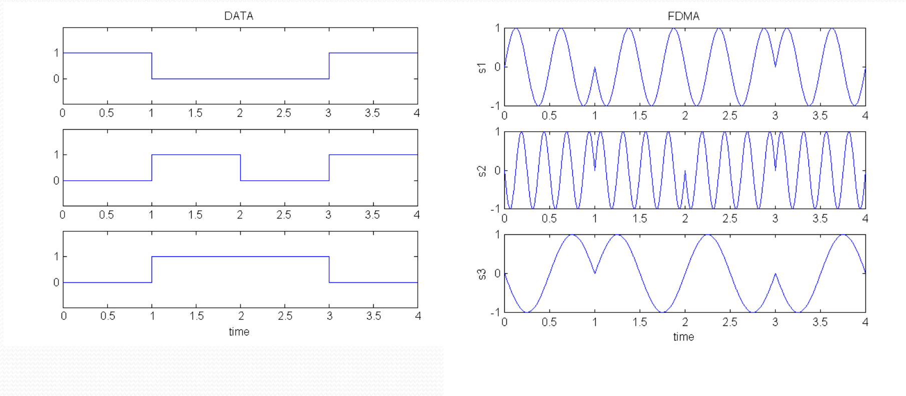
Waveforms of Users 1,2 & 3 after FDM



1-125

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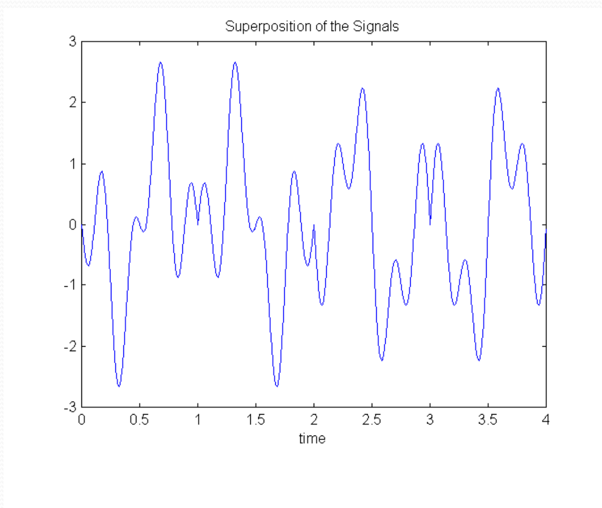
Input to the amplifier after 3 FDM signals are added



1-126

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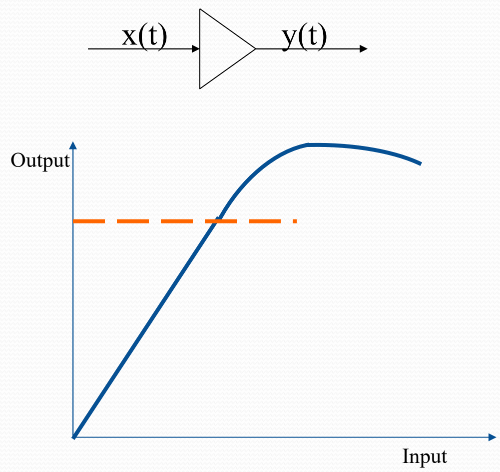

1-127

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Nonlinear Effects in FDM

- Received signal is <u>sum of multiple carriers</u>.
- Receiver power amplifiers are operated <u>nonlinearly</u> (near saturation) for <u>maximum efficiency</u>.
- The nonlinearities cause intermodulation (IM) frequencies to appear in the amplifier output.
- IM components can <u>interfere with other channels</u> in the FDMA system.

1-128

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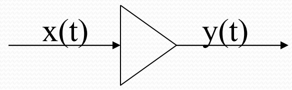
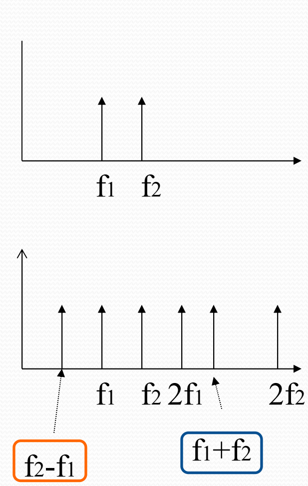
Inter-modulation Noise



$y(t) = x(t) + a\ \{x(t)\}^2$

$x(t) = \cos(2\pi f_1 t) + \cos(2\pi f_2 t)$

$$\boxed{\begin{aligned} &y(t) = \cos(2\pi f_1 t) + \cos(2\pi f_2 t) \\ &a + (a/2)\ \{\cos(2\pi 2 f_1 t) + \cos(2\pi 2 f_2 t) + \\ &a\ \{\cos(2\pi\ [f_1+f_2]\ t)\ + \cos(2\pi\ [f_1-f_2]\ t) \end{aligned}}$$



1-129

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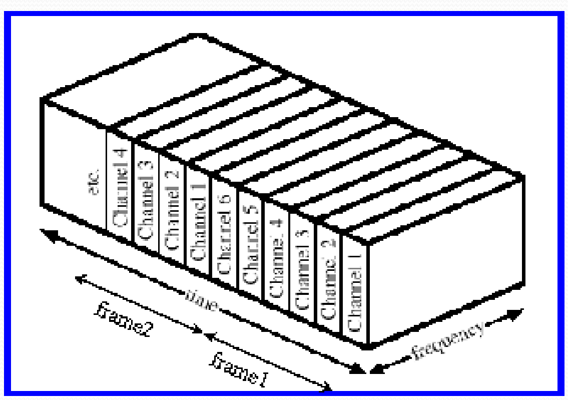
Time-division multiplexing (TDM)



1-130

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Time Division Multiple Access

- TDMA systems divide the radio spectrum into time slots.
- Only one user can transmit or receive during one time slot.
- Usually, each user may occupy the channel once during a time frame, where one frame comprises *N* time slots.

1-131

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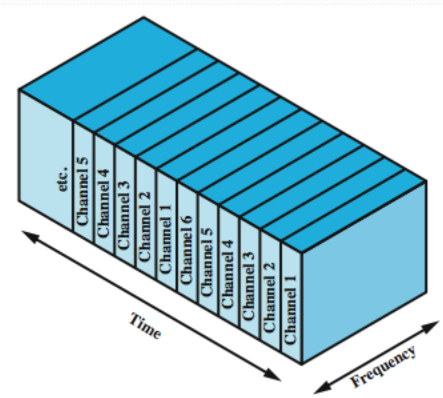
Synchronous Time Division Multiplexing



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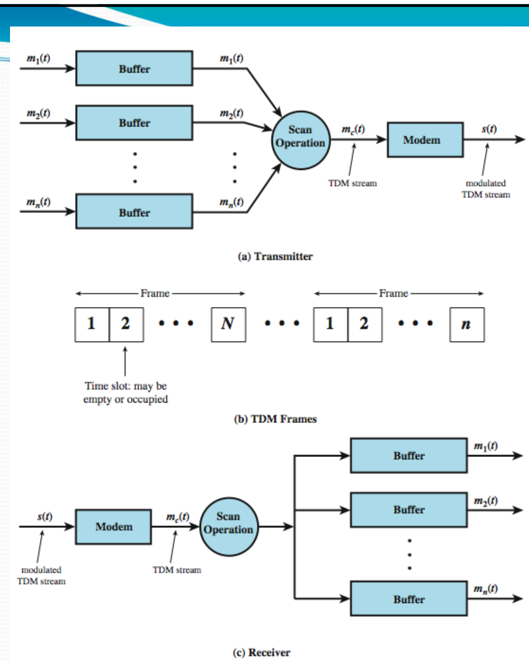
TDM System Overview



1-133

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Time-division multiplexing: problems

- Frame synchronization
  - use an identifiable pattern of bits at the beginning of each frame
- Pulse stuffing
  - If user does not have data, the assigned slot needs to be staffed with dummy bit
- Inefficiency
  - many of the time slots are wasted; slots are allocated to inputs even these input are not sending any data
- High Pick Transmission power

1-134

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Statistical TDM

- in Synch TDM many slots are wasted
- Statistical TDM allocates time slots dynamically based on demand
- multiplexer scans input lines and collects data until frame full
- line data rate lower than aggregate input line rates
- may have problems during peak periods
  - must buffer inputs

1-135

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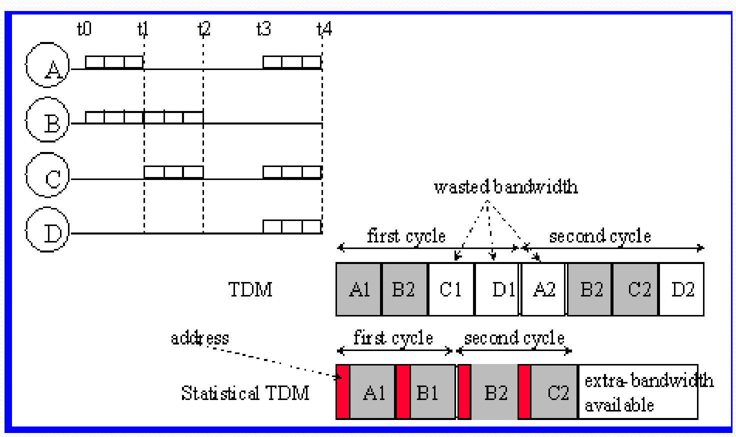
Statistical time-division multiplexing



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TDMA Systems

- TDMA systems transmit data in a buffer and burst method.
- The transmission is non-continuous.
- Unlike FDMA systems which can transmit analog signals, TDMA must transmit data and digital modulation must be used.

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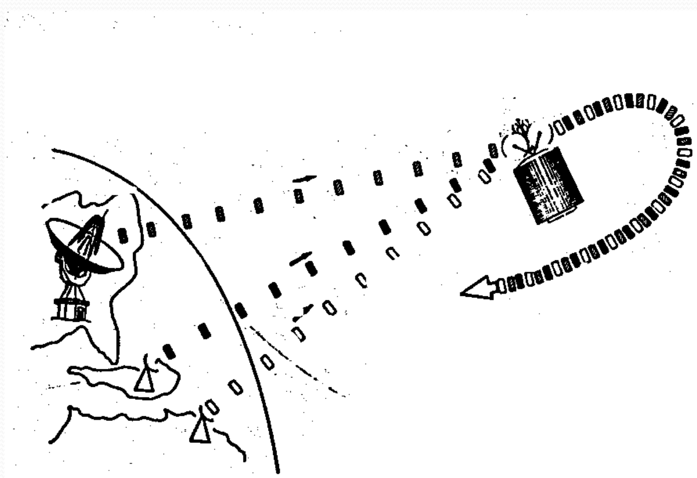
TDMA



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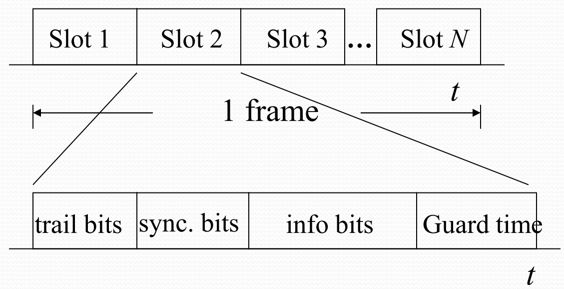
TDMA



Each slot requires overhead bits.
More overhead reduces efficiency.

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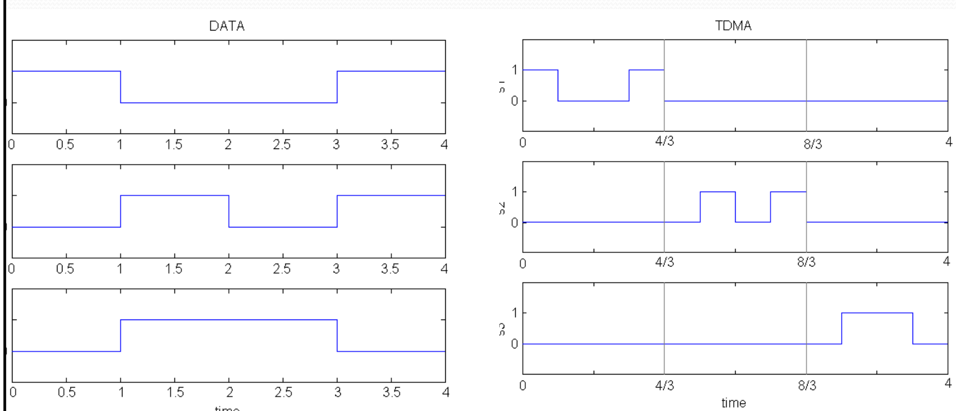
User 1,2&3 data before and after TDMA



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TDMA Features

- Only one carrier. No intermodulation.
- Number of time slots per frame depends on bandwidth, desired date rate, modulation technique.
- Receiver must synchronize to each time slot, thus more synchronization bits are required in TDMA compared to FDMA.
- It is possible to allocate more than one time slot per frame – bandwidth on demand.

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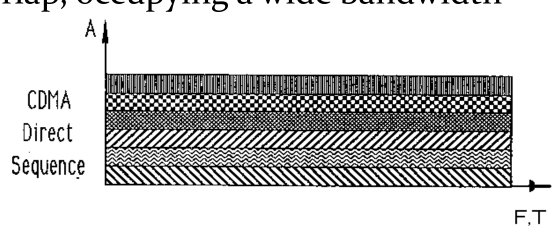
Spread Spectrum

- Also known as Code Division Multiple Access (CDMA)
- Important encoding method for wireless communications
- Can be used with analog & digital signal formats
- Users share both time & frequency domains; their signals overlap, occupying a wide bandwidth



- The separation is achieved by assigning different codes to each user.

1-142

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Spread Spectrum

- Makes jamming and interception harder
- Initially used for military communications
- Two approaches, both in use:
  - Frequency Hopping (FH)
  - Direct Sequence (DS-SS)
- Cellular radio (IS-95, CDMA2000,WCDMA)
- Wireless LANs (IEEE 802.11 b, g)

1-143

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Spread Spectrum: Advantages/Disadvantages

- Resistive to interference, multipath fading
- Easy Encryption
- Easy traffic multiplexing of discontinuous sources
- Allows "soft" hand-offs
- Synchronization imposes a challenge

1-144

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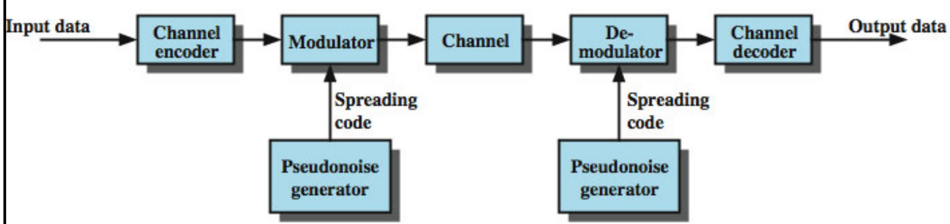
General Model of Spread Spectrum System



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Pseudorandom Numbers

- generated by a deterministic algorithm
  - not actually random
  - but if algorithm good, results pass reasonable tests of randomness
- starting from an initial seed
- need to know algorithm and seed to construct the sequence
- hence only receiver can decode signal

1-146

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Frequency Hopping Spread Spectrum (FHSS)

- signal is broadcast over seemingly random series of frequencies
- receiver hops between frequencies in sync with transmitter
- eavesdroppers hear unintelligible blips
- jamming on one frequency affects only a few bits

1-147

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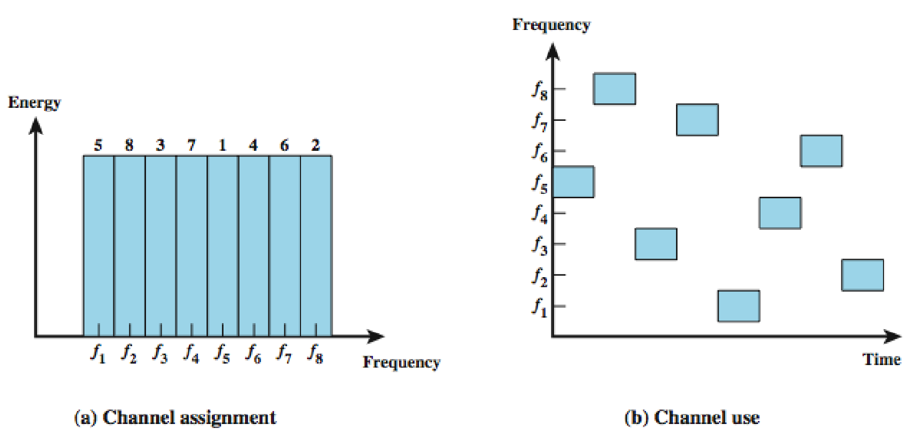
Frequency Hopping Example



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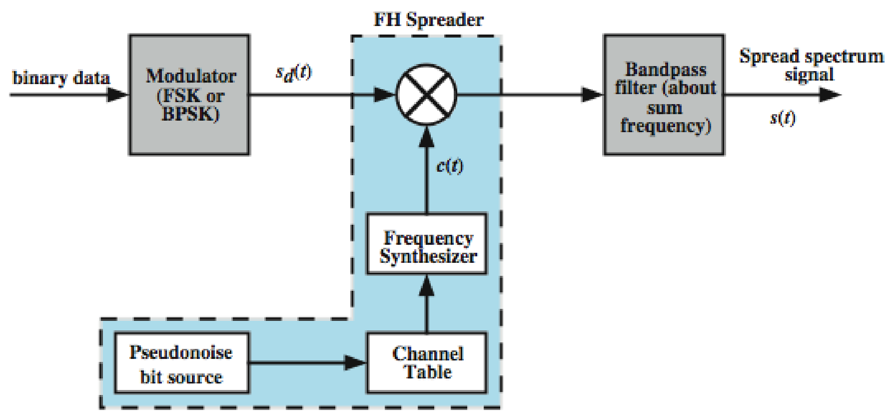
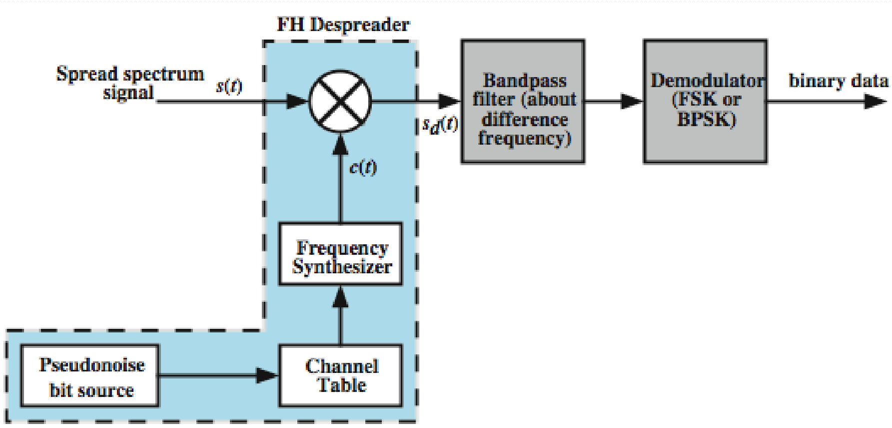
FHSS (Transmitter)



(a) Transmitter

Frequency Hopping Spread Spectrum System (Receiver)



(b) Receiver

Slow and Fast FHSS

- commonly use multiple FSK (MFSK)
- have frequency shifted every T_c seconds
- duration of signal element is T_s seconds
- Slow FHSS has $T_c \geq T_s$
- Fast FHSS has $T_c < T_s$
- FHSS quite resistant to noise or jamming
  - fast FHSS is giving better performance

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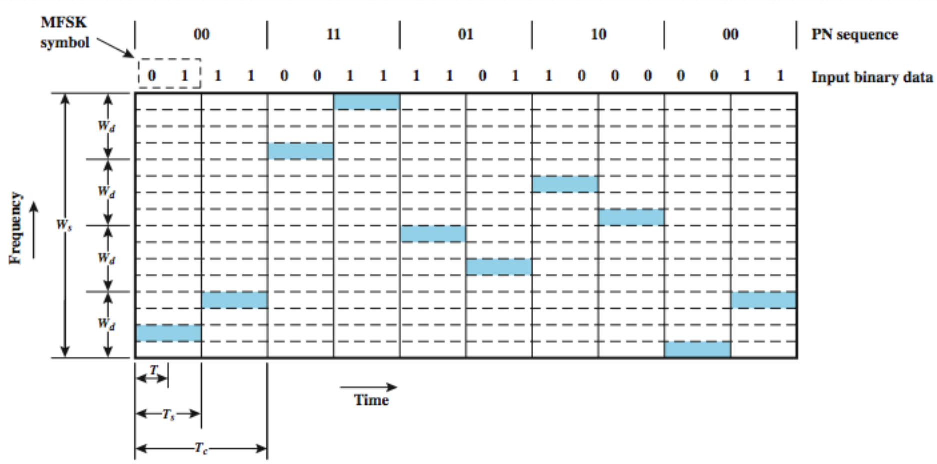
Slow MFSK FHSS



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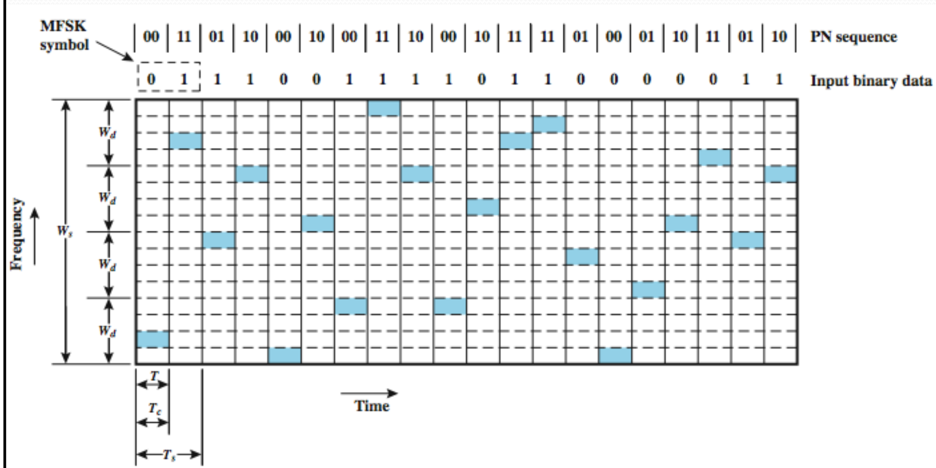
Fast MFSK FHSS



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Direct Sequence Spread Spectrum (DSSS)

- each bit is represented by multiple bits using a spreading code
- this spreads signal across a wider frequency band
- has performance similar to FHSS

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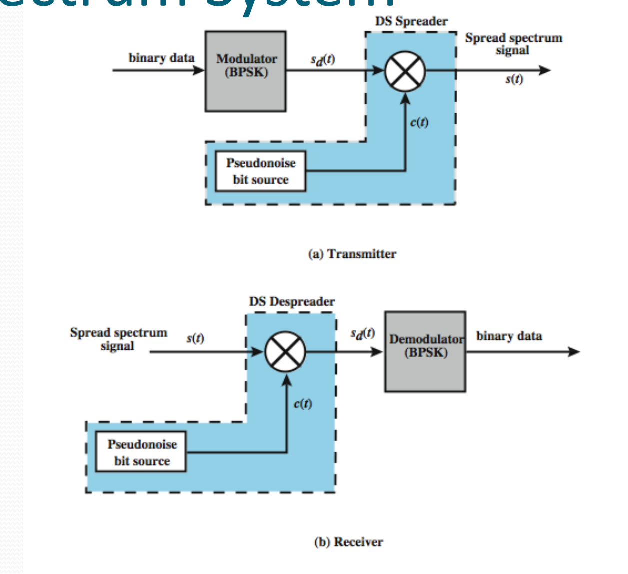
Direct Sequence Spread Spectrum System



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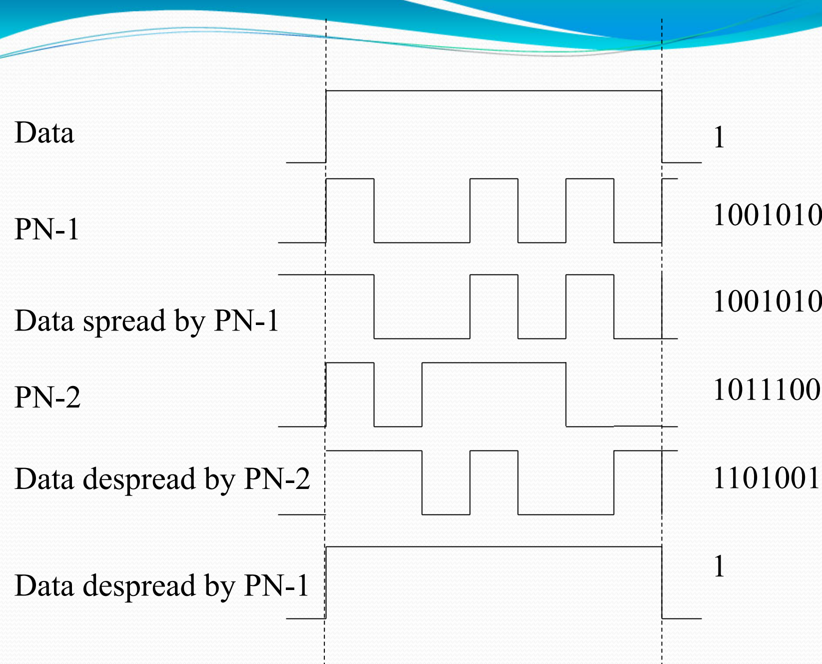

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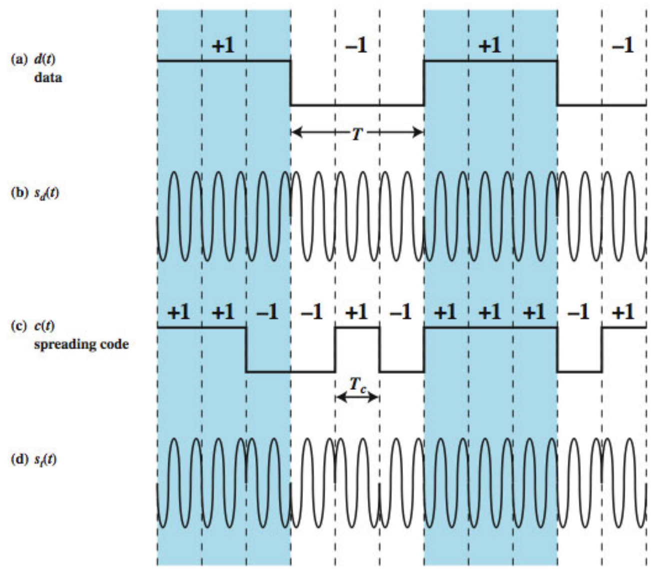
DSSS Example Using BPSK



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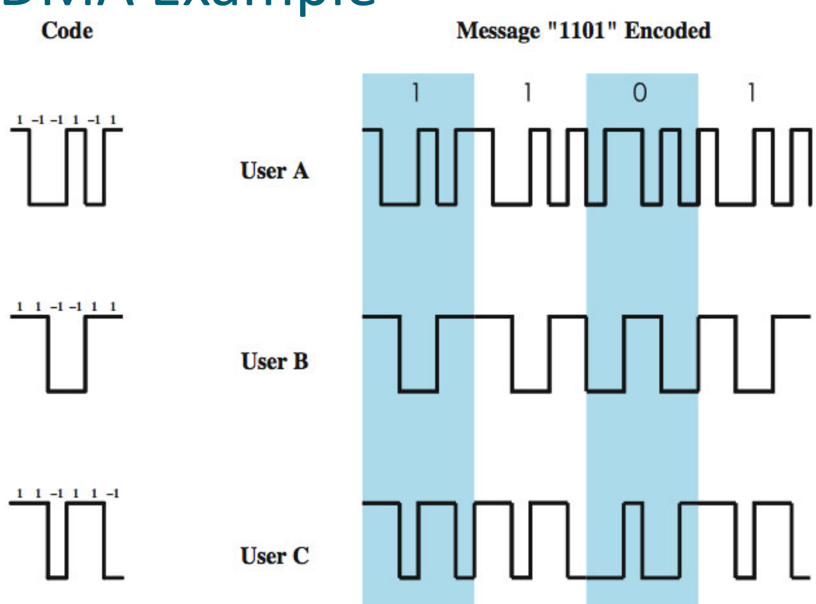
CDMA Example



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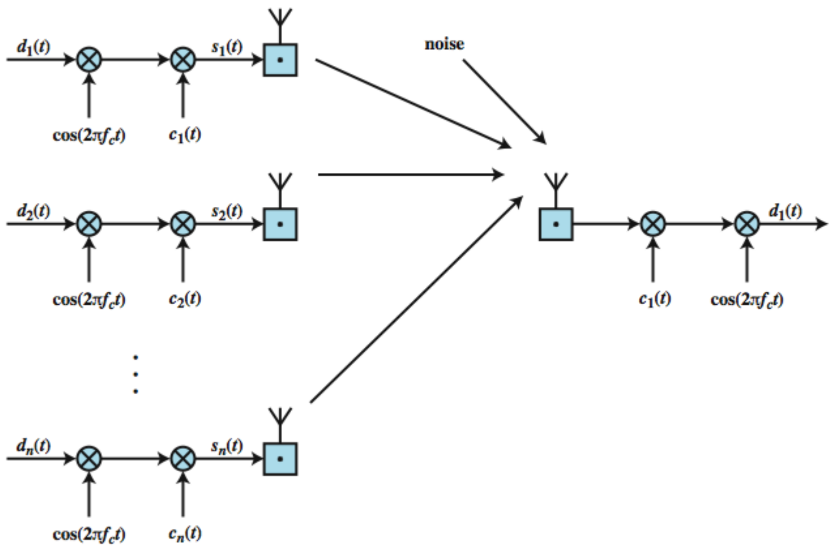
CDMA for DSSS



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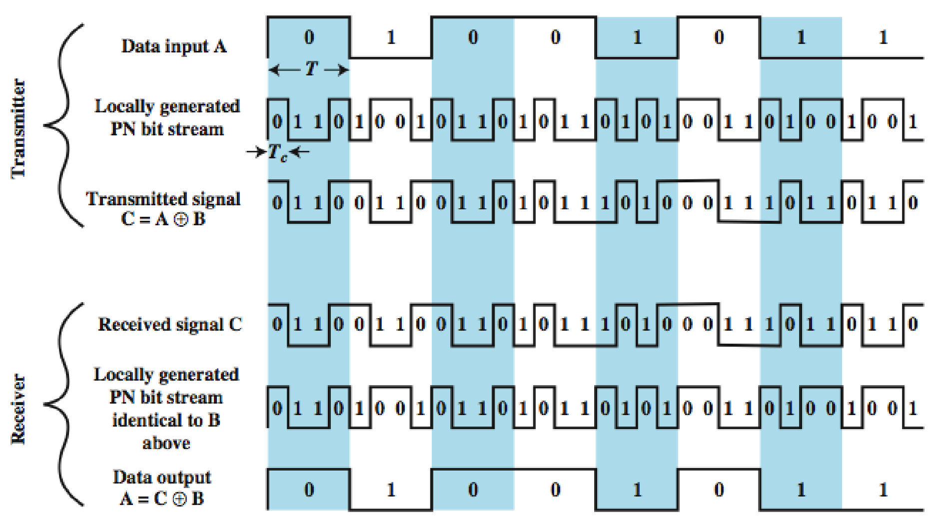
Direct Sequence Spread Spectrum Example



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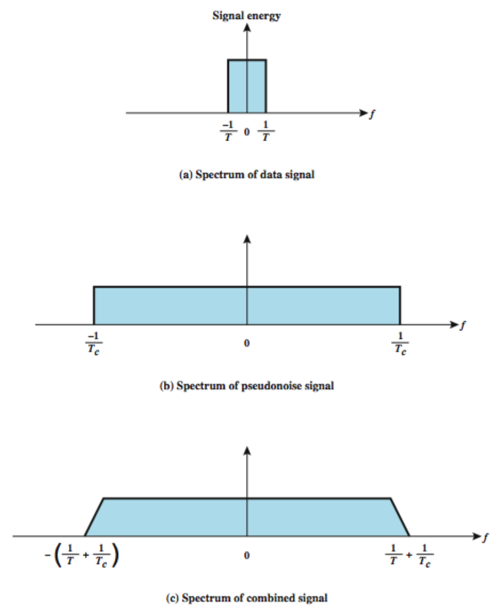
Approximate Spectrum of DSSS Signal



1-161

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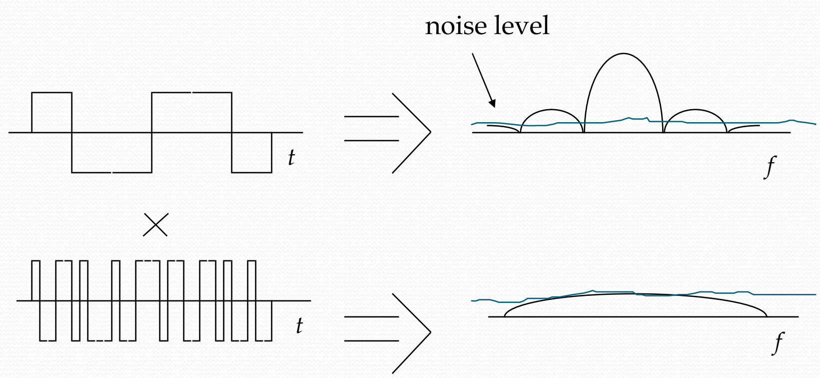
Power of DS-SS Signals at Tx when square pulses are used



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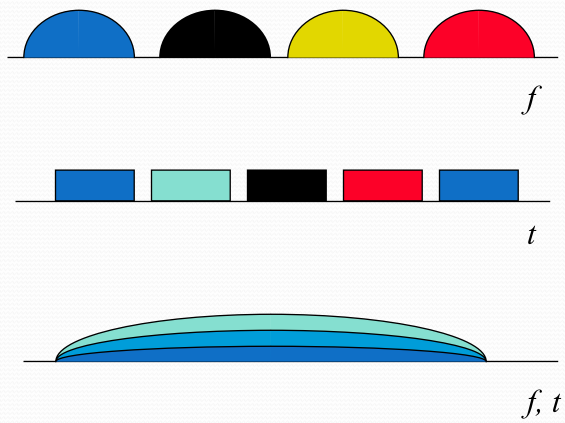
Do all systems fall into only one of 3 categories?



Answer: In practice NO.

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Examples of their use in wireless mobile communications systems

- **FDM/FDMA**
  - 1st generation: analog cellular, AMPS (each channel was occupying 60 KHz bandwidth)
  - 2nd generation North American digital cellular radio; IS-41
  - 2nd generation North American digital cellular radio (improved); IS-136.
    - Hybrid architecture. TDMA multiplexing 4 users in each 60 KHz AMPS channel.
- **TDM/TDMA**
  - 2nd and 2.5 generation European cellular radio, GSM/GPRS/EDGE
- **CDMA**
  - 2nd generation: IS-95 based North American cellular radio (DS-SS).
  - 3rd generation CDMA2000 and WCDMA (DS-SS)
  - IEEE 802.11 WLAN (FH & DS-SS)
  - Bluetooth (FH-SS), ZigBee (DS-SS), Home RF (FH & DS-SS)

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END

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