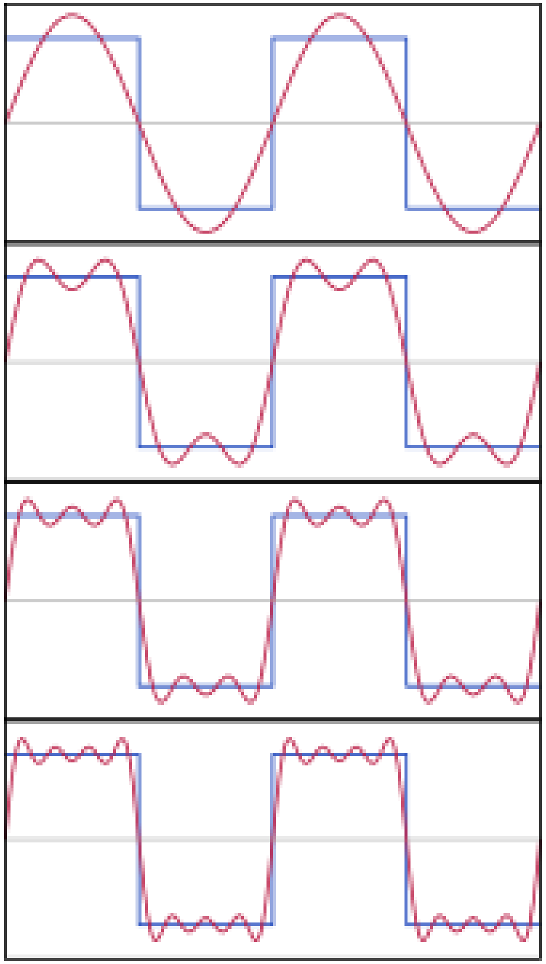
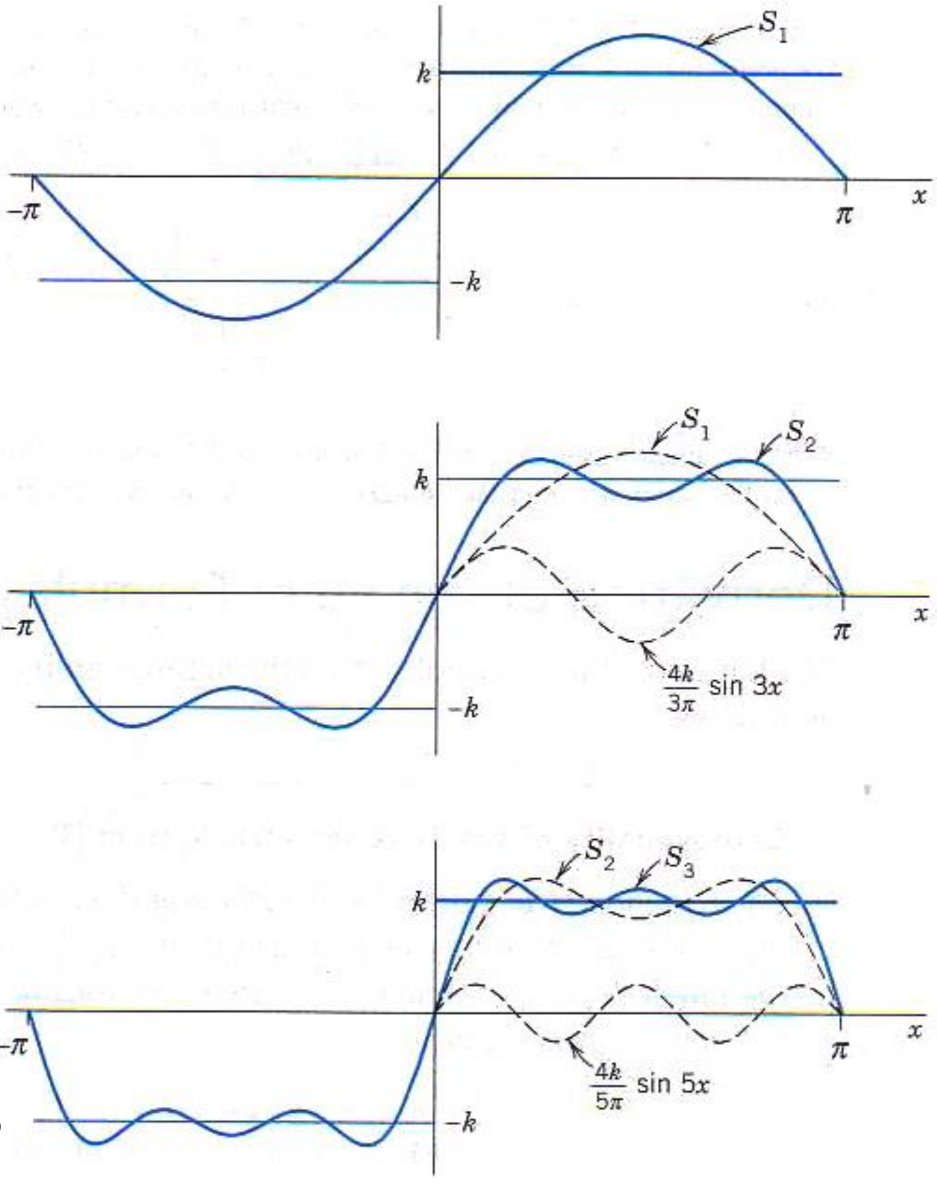
Antennas, RF Power, and Sectorization

Last Class

- Transmission Fundamentals
- Important Concepts
  - Frequency domain expression
  - Channel Capacity

Frequency-Domain Concepts





What is the bandwidth of the signal?

Shannon Capacity Formula

- Equation:

$$C = B\log_2\left(1 + \mathrm{SNR}\right)$$

- Represents *theoretical, error-free* maximum that can be achieved
- In practice, only much lower rates achieved
  – Formula assumes white noise (thermal noise)
  – Impulse noise is not accounted for
  – Attenuation distortion or delay distortion not accounted for

Today

- Finish remaining part of Part I
- CH 5: Antennas and propagation from William Stallings

Classifications of Transmission Media

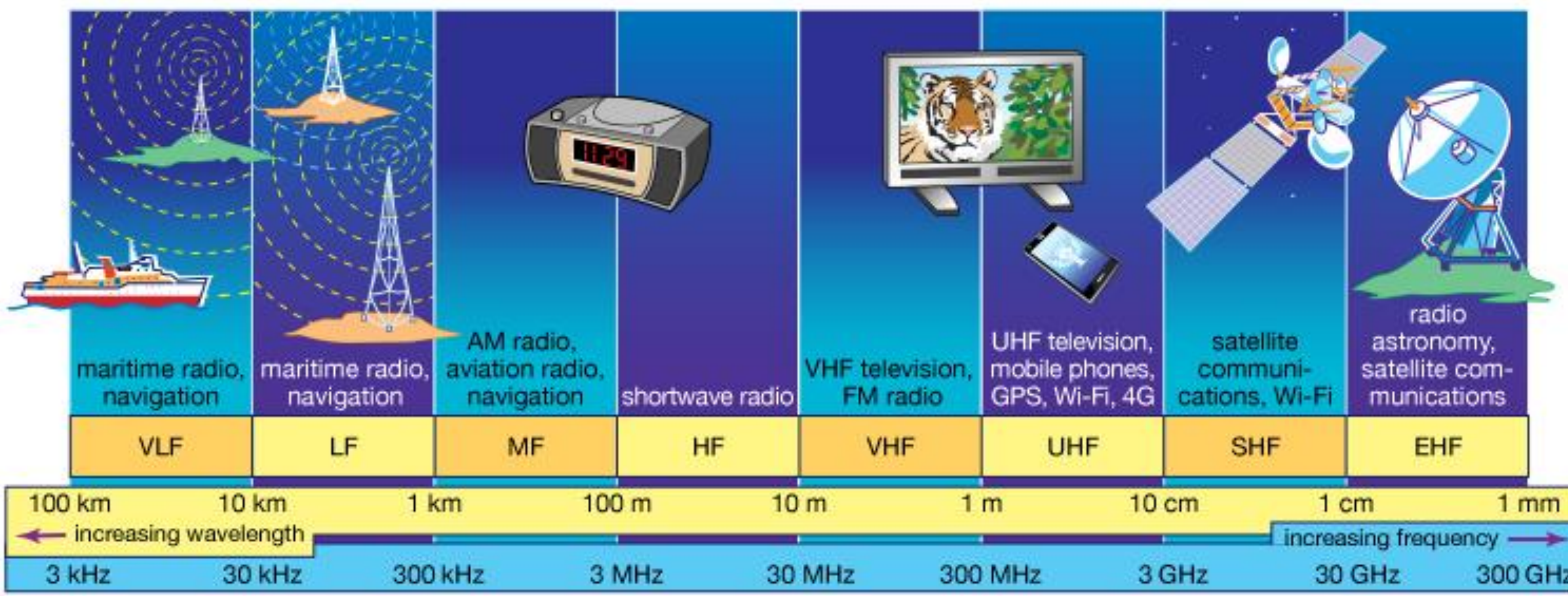
- Transmission Medium
  - Physical path between transmitter and receiver
- Guided Media
  - Waves are guided along a solid medium
  - e.g., hollow wave guide, copper coaxial cable, optical fiber
- Unguided Media
  - Does not guide signals
  - Usually referred to as wireless transmission
  - e.g., atmosphere, outer space

Unguided Media

- Transmission and reception are achieved by means of an antenna
- Configurations for wireless transmission
  - Directional
  - Omnidirectional

General Frequency Ranges

- Microwave frequency range
  - 1 GHz to 40 GHz
  - Directional beams possible
  - Suitable for point-to-point transmission
  - Used for satellite communications
- Radio frequency range
  - 30 MHz to 1 GHz
  - Suitable for omnidirectional communications

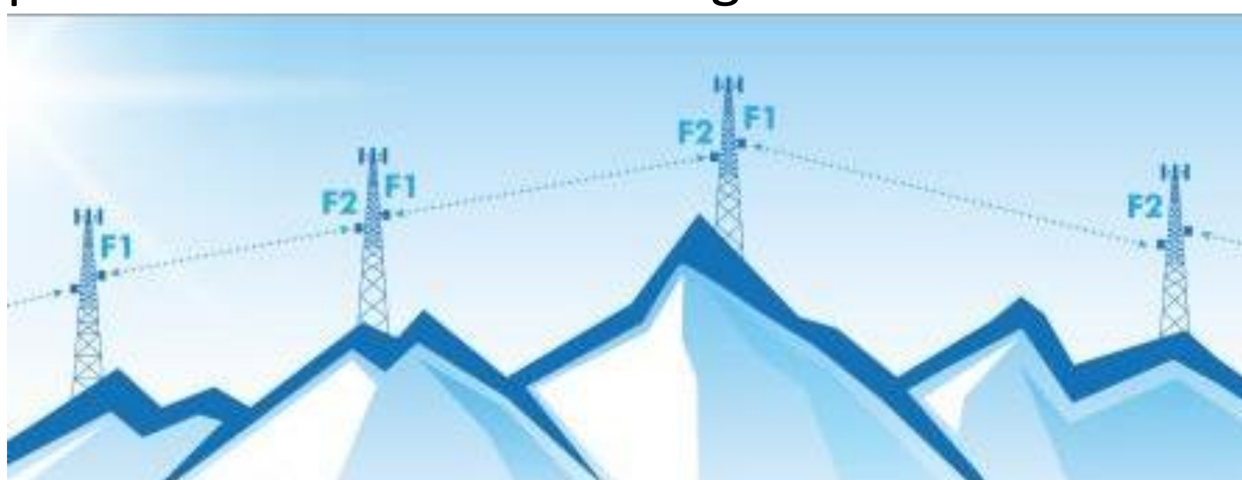


General Frequency Ranges (contd.)

- Infrared frequency range
  - Roughly, $3x10^{11}$ to $2x10^{14}$ Hz
  - Useful in local point-to-point multipoint applications within confined areas

Terrestrial Microwave

- Description of common microwave antenna
  - Parabolic "dish", 3 m in diameter
  - Fixed rigidly and focuses a narrow beam
  - Achieves line-of-sight transmission to receiving antenna
  - Located at substantial heights above ground level
- Applications
  - Long haul telecommunication service
  - Short point-to-point links between buildings



Ref: http://www.commscope.com/Blog/Back-to-Basics-in-Microwave-Systems--Front-to-Back-Ratio-and-Antenna-Beamwidth/

Satellite Microwave

- Description of communication satellite
  - Microwave relay station
  - Used to link two or more ground-based microwave transmitter/receivers
  - Receives transmissions on one frequency band (uplink), amplifies or repeats the signal, and transmits it on another frequency (downlink)
- Applications
  - Television distribution
  - Long-distance telephone transmission
  - Private business networks

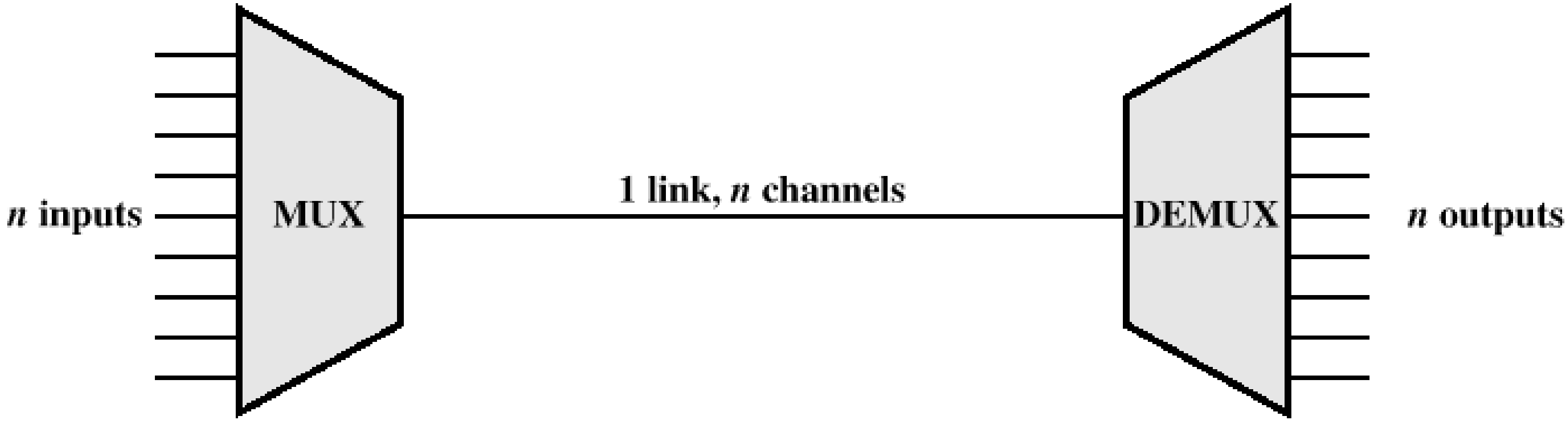
Broadcast Radio

- Description of broadcast radio antennas
  - Omnidirectional
  - Antennas not required to be dish-shaped
  - Antennas need not be rigidly mounted to a precise alignment
- Applications
  - Broadcast radio
    - VHF and part of the UHF band; 30 MHZ to 1GHz
    - Covers FM radio and UHF and VHF television

Multiplexing

- Capacity of transmission medium usually exceeds capacity required for transmission of a single signal
- Multiplexing - carrying multiple signals on a single medium
  – More efficient use of transmission medium

Multiplexing



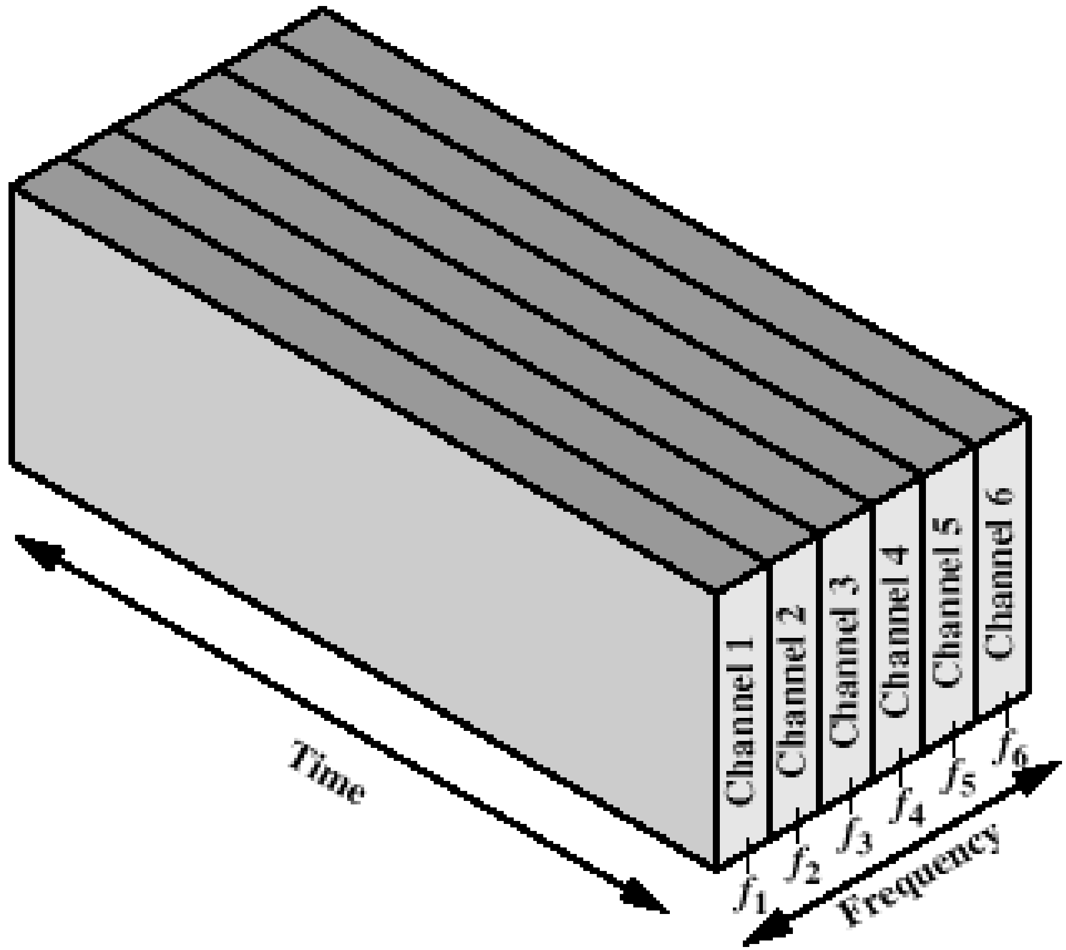
Reasons for Widespread Use of Multiplexing

- Cost per kbps of transmission facility declines with an increase in the data rate
- Cost of transmission and receiving equipment declines with increased data rate
- Currently most individual data communicating devices can work at relatively high data rate support

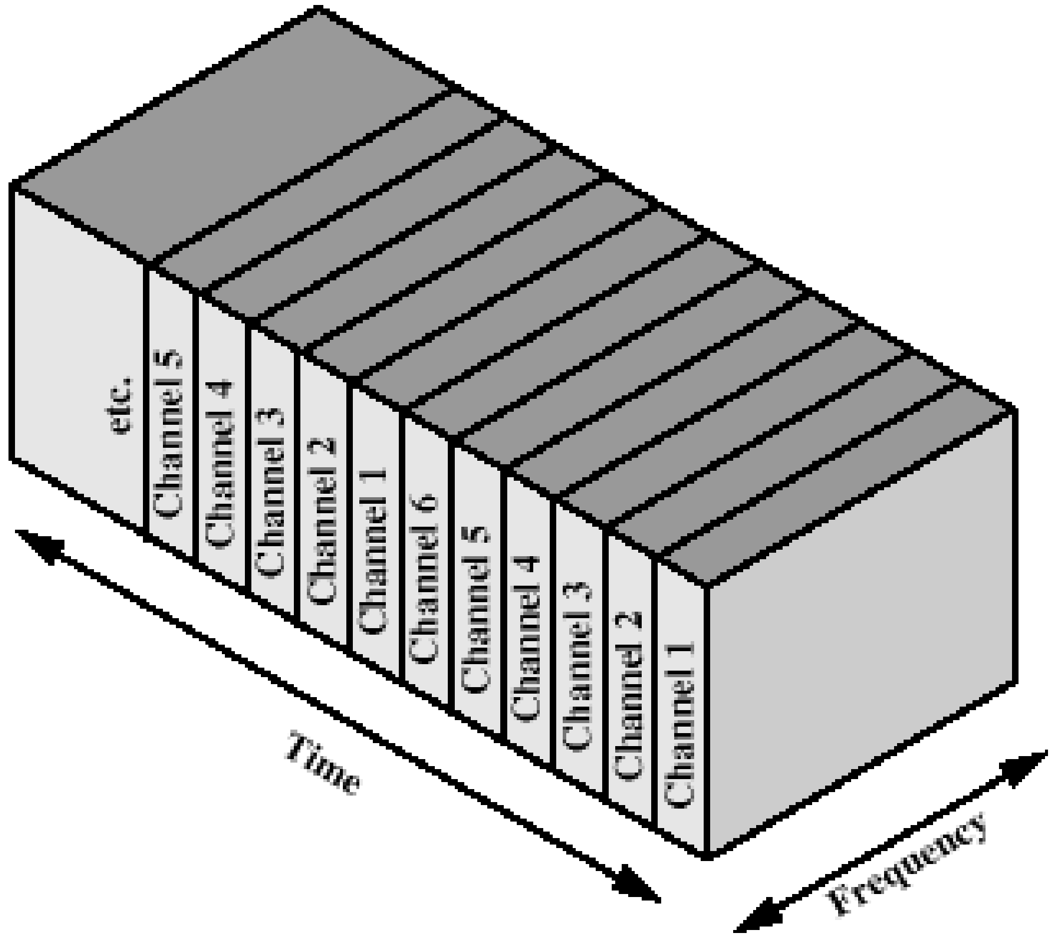
Multiplexing Techniques

- Frequency-division multiplexing (FDM)
  - Takes advantage of the fact that the useful bandwidth of the medium exceeds the required bandwidth of a given signal
- Time-division multiplexing (TDM)
  - Takes advantage of the fact that the achievable bit rate of the medium exceeds the required data rate of a digital signal

Frequency-division Multiplexing



Time-division Multiplexing



Chapter 5: Antennas and Propagation

Introduction

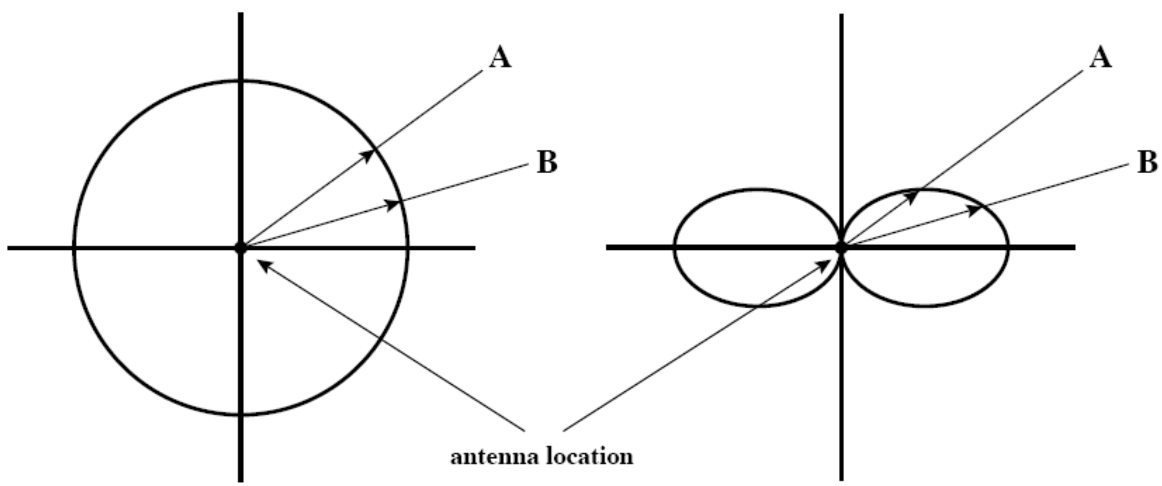
- An antenna is an electrical conductor or system of conductors
  - Transmission - radiates electromagnetic energy into space
  - Reception - collects electromagnetic energy from space
- In two-way communication, the same antenna can be used for transmission and reception

Radiation Patterns

- Radiation pattern
  - Graphical representation of radiation properties of an antenna
  - Depicted as two-dimensional cross section
- Beam width (or half-power beam width)
  - Measure of directivity of antenna
- Reception pattern
  - Receiving antenna’s equivalent to radiation pattern

Types of Antennas

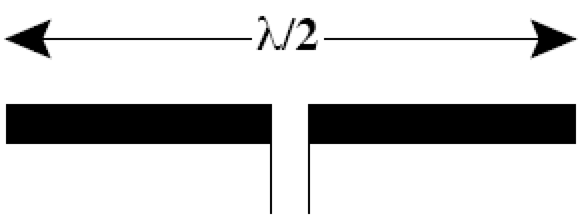
- Isotropic antenna (idealized)
  - Radiates power equally in all directions
- Directional antenna
  - Radiates in certain direction(s)



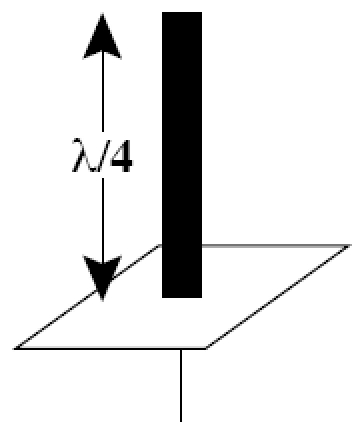
(a) Omnidirectional (b) Directional

Types of Antennas

- Dipole antennas
  - Half-wave dipole antenna (or Hertz antenna)
  - Quarter-wave vertical antenna (or Marconi antenna)



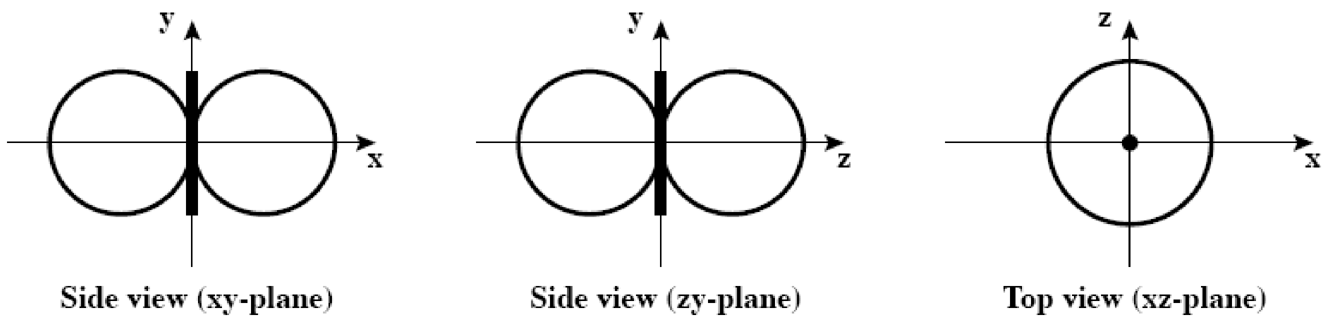
(a) Half-wave dipole



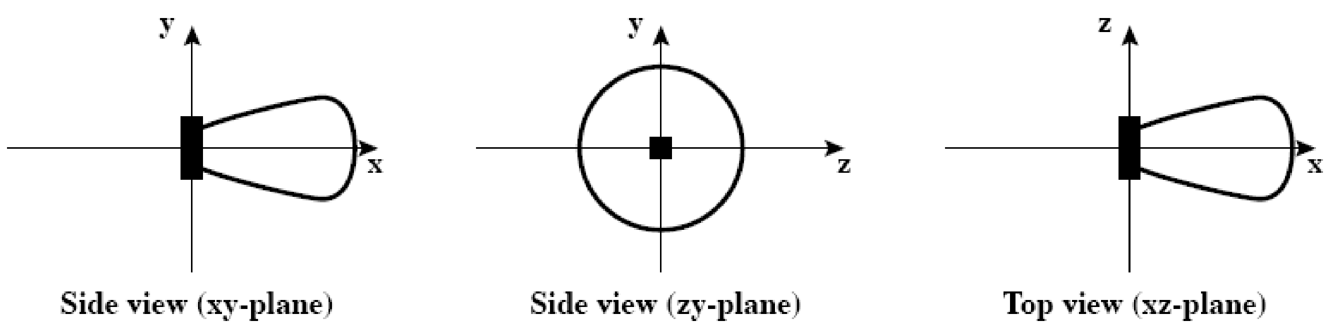
(b) Quarter-wave antenna

Types of Antennas

- Dipole antennas



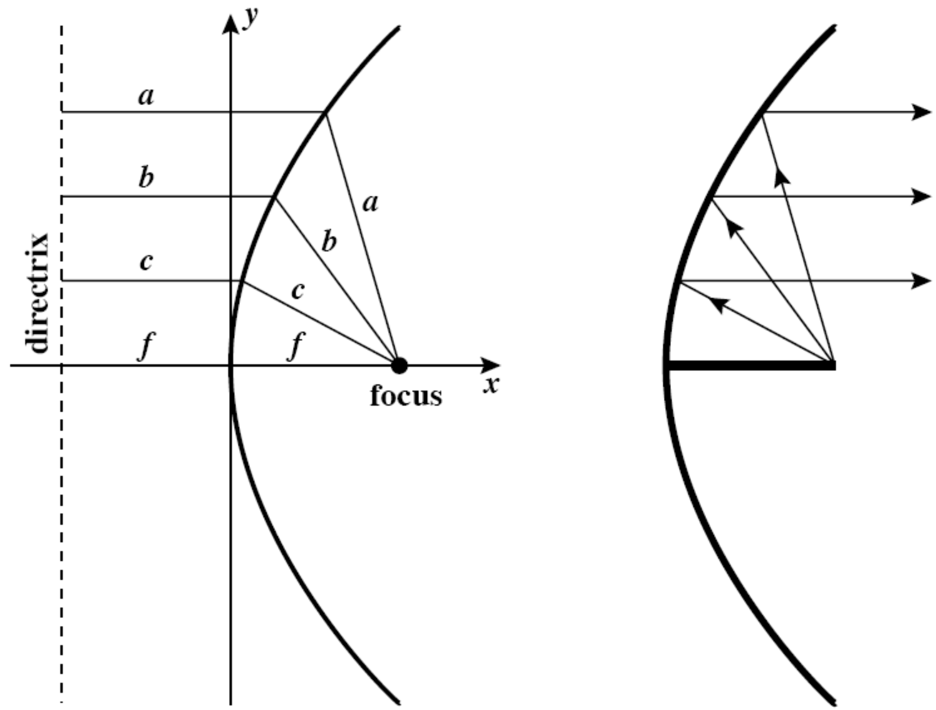
(a) Simple dipole



(b) Directed antenna

Types of Antennas

- Parabolic Reflective Antenna



(a) Parabola

(b) Cross-section of parabolic antenna showing reflective property

Antenna Gain

- Antenna gain
  - Power output, in a particular direction, compared to that produced in any direction by a perfect omnidirectional antenna (isotropic antenna)
- Effective area
  - Related to physical size and shape of antenna

$$P_r = W_t A_e \qquad A_e = \text{Gain} \times \text{efficiency} \times \left(\frac{\lambda^2}{4\pi} \right)$$

Antenna Gain

- Relationship between antenna gain and effective area

$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi f^2 A_e}{c^2}$$

  - G = antenna gain
  - A_e = effective area
  - f = carrier frequency
  - c = speed of light ($\approx 3 \times 10^8$ m/s)
  - λ = carrier wavelength

SOME SLIDES FROM PAUL BEDELL'S BOOK

Antenna Basics and Gain

- An antenna's function is two fold: Transmit and Receive RF electromagnetic energy
- A *passive device* which does not add any power to a radio signal; simply redirects
- Antennas can be classified as omnidirectional and directional
- *Gain* is the amount of increase in energy that an antenna adds to a RF signal in a given direction
- Wireless antennas are arrays of small antenna elements covered with a "*radome*"
- *Collinear array*:
  Antenna created by stacking
  multiple antenna elements
  together

Antenna Basics and Gain II

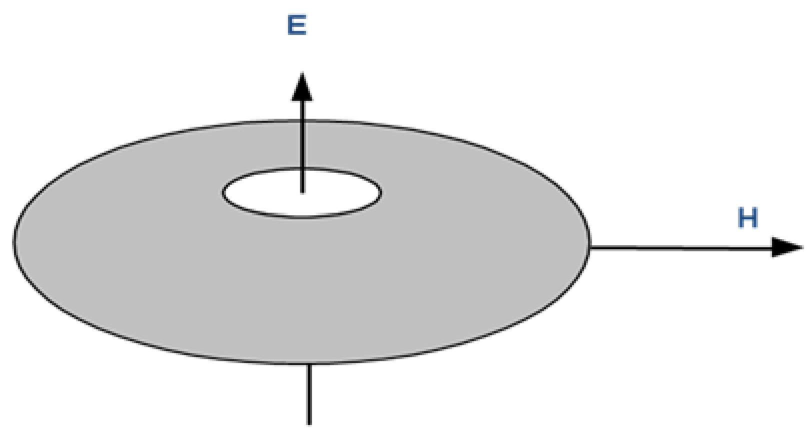
- Antenna gain is measure in dBi or dBd
  - dBi → Gain of an antenna with respect to an isotropic radiator
  - dBd → Gain of an antenna compared to the gain of a reference dipole
  - Gain in dBi - Gain in dBd = 2.15 dB
- *Polarization*: direction of the electrical field of an antenna with reference to earth's surface

Effective Radiated Power

- *ERP* – Antenna gain x RF power delivered
- Example: 8-watt power amplifier with a 15-dB-gain antenna and 3 dB of line loss
  - Net antenna gain = 15-3 = 12 dB
  - Antenna ERP = 8 Watts if its net gain is 0 dB---{8x1}
  - Antenna ERP = 16 Watts if its net gain is 3 dB---{8x2}
  - Antenna ERP = 32 Watts if its net gain is 6 dB---{8x2x2}
  - Antenna ERP = 64 Watts if its net gain is 9 dB---{8x2x2x2}
  - Antenna ERP = 128 Watts if its net gain is 12 dB---{8x2x2x2x2}

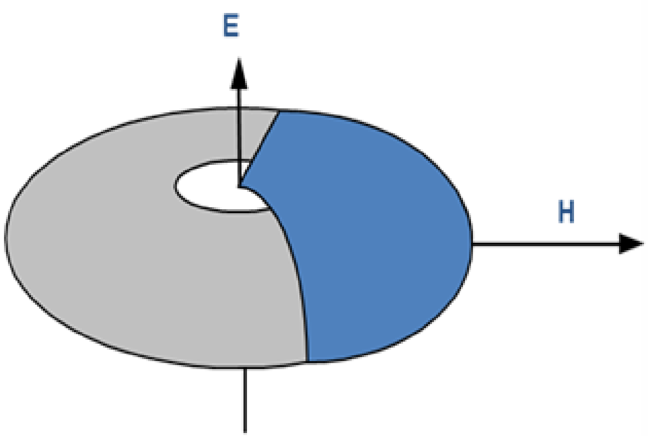
Omnidirectional Antennas

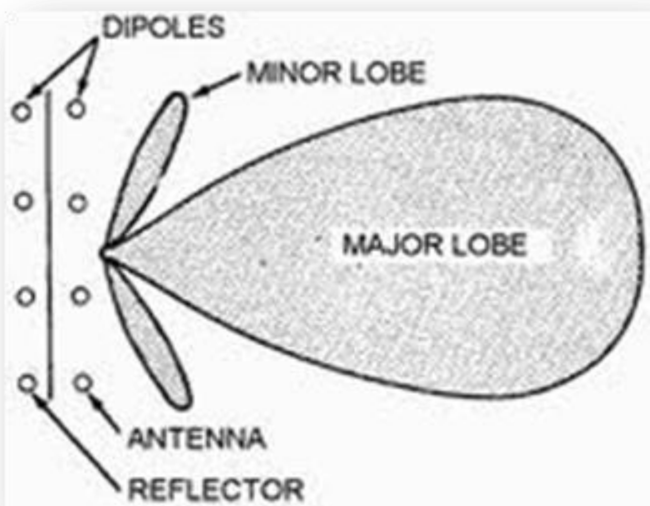
- Propagates radio power uniformly in all directions in one plane
- A pattern resembling a dough nut
- Cell base stations using omnidirectional antennas are known as *omni*, or *single-sectored*---suitable for indoor coverage
- No coverage below or above the antenna



Directional Antennas

- Radiates greater power in one direction allowing for increased performance and reduced interference from unwanted sources
- Directs or focuses the RF signal energy over a specified *beamwidth*
- Analogous to flashlight
- Helpful with sectorization or providing coverage in long hallways/tunnels
- Different types of directional antennas: log periodic, Yagi-Uda, phased-array, and panel antennas





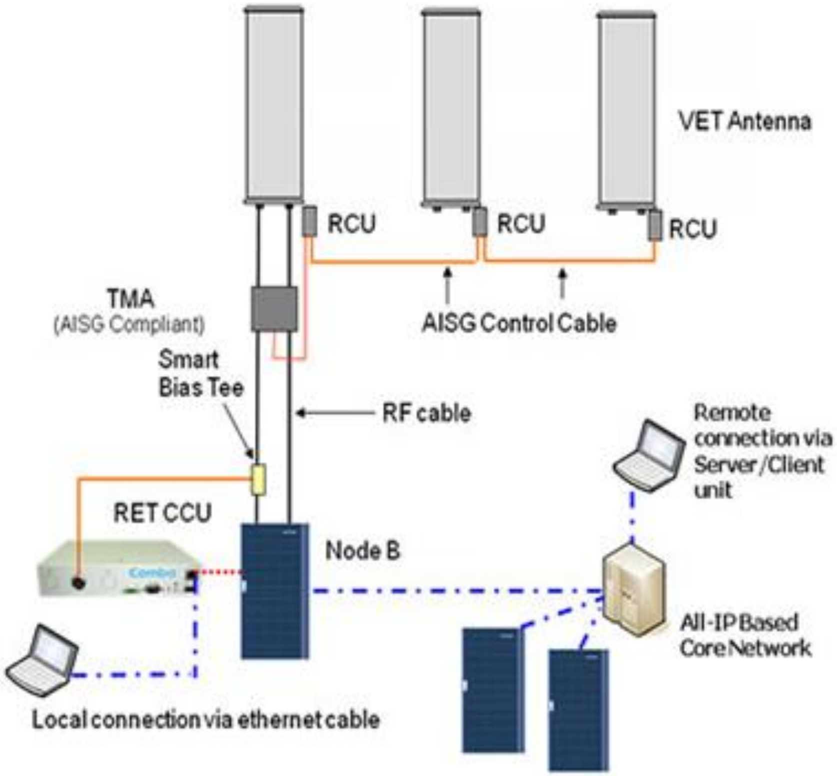
Downtilt Antennas and Remote Electrical Tilt (RET)

- Mechanically or electrical adjustment of antenna's horizontal propagation
- Purpose of tilting: Optimize coverage and/or reduce interference
  That is, best signal level only where needed; also, to fill shadows near site
- Reduces the *far-field effect*: radio coverage projected from a given site completely and unintentionally overshoots
- *Mechanical downtilting* is accomplished by manipulating a tilt bracket that's on the back mount

Electrical DT

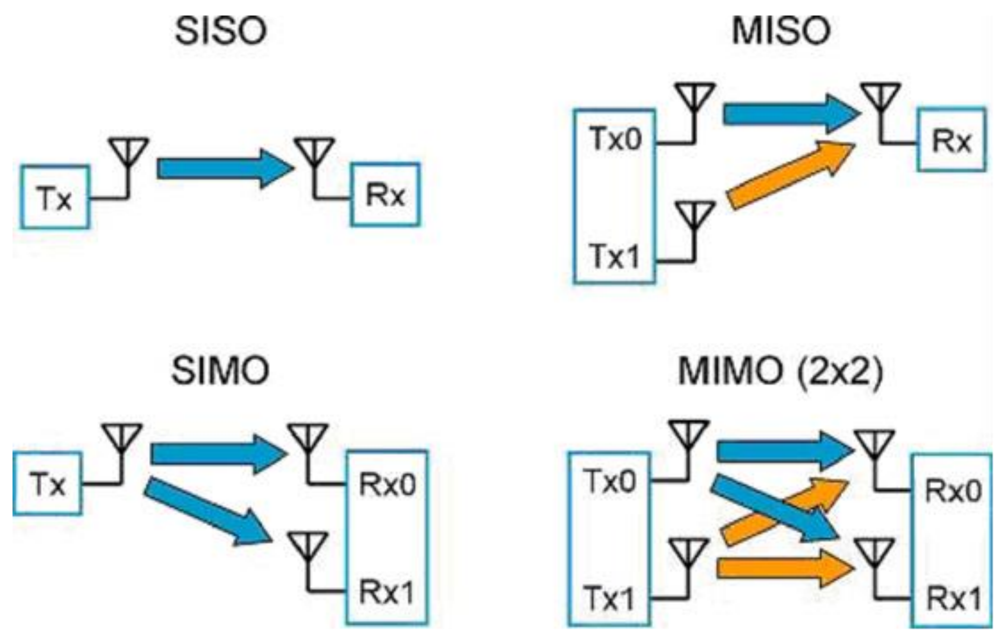
- RET systems use a compact and light weight actuator that mechanically connects to the electrical phase shifter of the site antenna(s) for remote adjustment of electrical down-tilt
- Today RET systems can be accessed remotely from a wireless carrier’s network operation center (NOC) or via the Internet using a laptop

AISG – Antenna Interface Standards Group
Bias-T – Current injector
RCU= remote control unit
CCU= common control unit



Multiple In/Multiple Out (MIMO) Antennas

- Multiple antennas are used at both transmitter and receiver
  - Increasing the robustness of data transmission – transmit diversity
  - Increasing the data rate – spatial multiplexing
- Commonly used with Wi-Fi and LTE
- *Spatial diversity*: Antennas located in different positions, take advantage of the different radio paths. It is used as the basis for MIMO
- *Spatial multiplexing*: Provides additional data capacity by utilizing the different paths to carry additional traffic
- *Beam-forming*:
  - Phased array systems
  - Adaptive array systems



MIMO Transmission Modes

Downlink Transmission modes in LTE Release 12			
Transmission modes	**Description**	**DCI** (Main)	**Comment**
1	Single transmit antenna	1/1A	single antenna port port 0
2	Transmit diversity	1/1A	2 or 4 antennas ports 0,1 (...3)
3	Open loop spatial multiplexing with cyclic delay diversity (CDD)	2A	2 or 4 antennas ports 0,1 (...3)
4	Closed loop spatial multiplexing	2	2 or 4 antennas ports 0,1 (...3)
5	Multi-user MIMO	1D	2 or 4 antennas ports 0,1 (...3)
6	Closed loop spatial multiplexing using a single transmission layer	1B	1 layer (rank 1), 2 or 4 antennas ports 0,1 (...3)
7	Beamforming	1	single antenna port, port 5 (virtual antenna port, actual antenna configuration depends on implementation)
8	Dual-layer beamforming	2B	dual-layer transmission, antenna ports 7 and 8
9	8 layer transmission	2C	Up to 8 layers, antenna ports 7 - 14
10	8 layer transmission	2D	Up to 8 layers, antenna ports 7 - 14

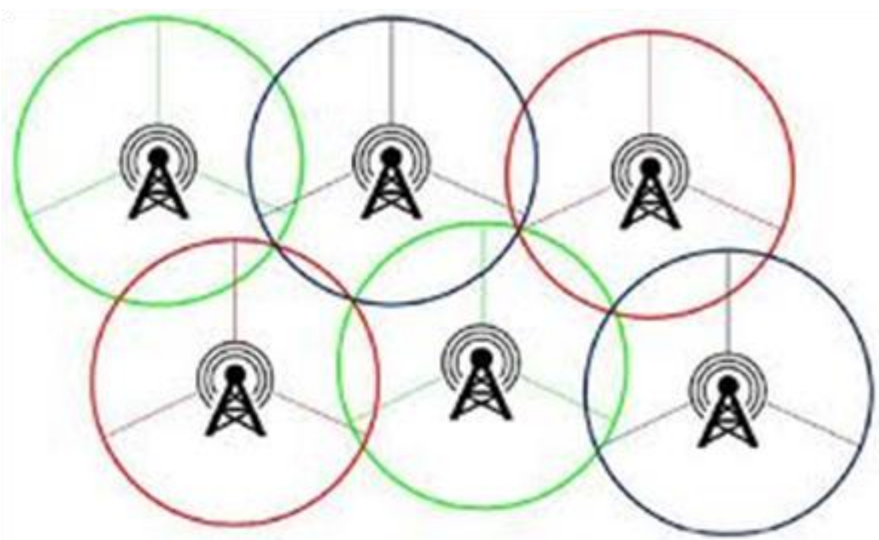
Ref: https://cdn.rohde-schwarz.com/pws/dl_downloads/dl_application/application_notes/1ma186/1MA186_2e_LTE_TMs_

Smart Antenna Systems

- *Beam Forming*: Can locate users, track them, and provide optimal RF signals as they move
- *Switched-Beam Systems*: Use a finite number of fixed, predefined patterns and choose the setting that gives the best performance
- *Adaptive-Array Smart Antenna Systems*: Use a variety of signal-processing algorithms to effectively locate and track various signals to dynamically minimize interference and maximize intended signal transmission/reception
  - Focus on intended users and direct intentional nulls towards potential interference regions
- More complex and expensive ($4,500 compared to $500 for a regular panel)

Sectorization

- One way to increase to the capacity of a cellular network is replace the omnidirectional antenna at base stations with three (or six) directional (i.e. sector) antennas of 120 (or 60) degrees beamwidths
- Each sector is viewed as a new cell, with its own (set of) frequencies/channels
- Directional antennas have better gain than omnis so more coverage possible



Space Diversity and Antenna Mounting

- Scheme that uses two or more antennas to improve the quality and reliability of a wireless signal (typically) for the uplink
- With no clear LOS, the uplink signal is reflected along multiple paths (Rayleigh fading), before received at the cell site
- For example, if one antenna is experiencing extensive fading (attenuation), it’s likely that another has a sufficient signal. A device in the base station radio receivers known as a “comparator” constantly selects and re-selects the better of the two (diverse) received signals

Front-to-Back Ratio

- Ratio of power gain between the front and rear of a directional antenna
- Another way to think of F-B ratio: The ratio of signal strength transmitted/received at the front to that transmitted/received at the back of an antenna
- High F-B ratio ratings are desirable

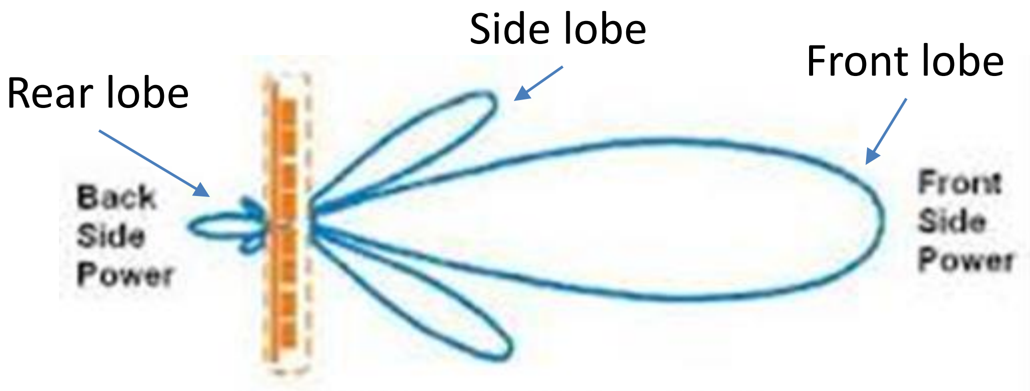
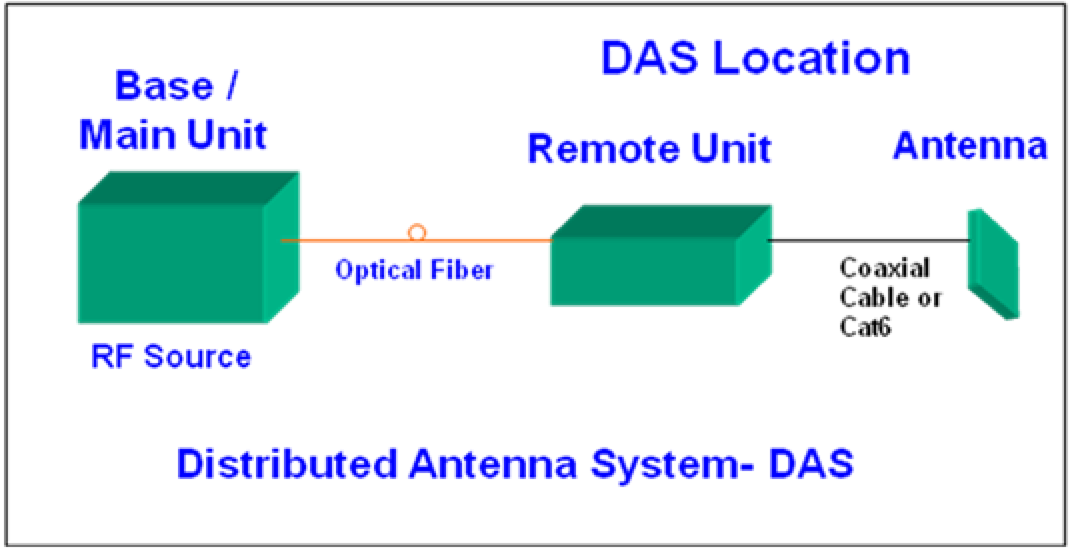


Figure 3.5 Front to Back Ratio

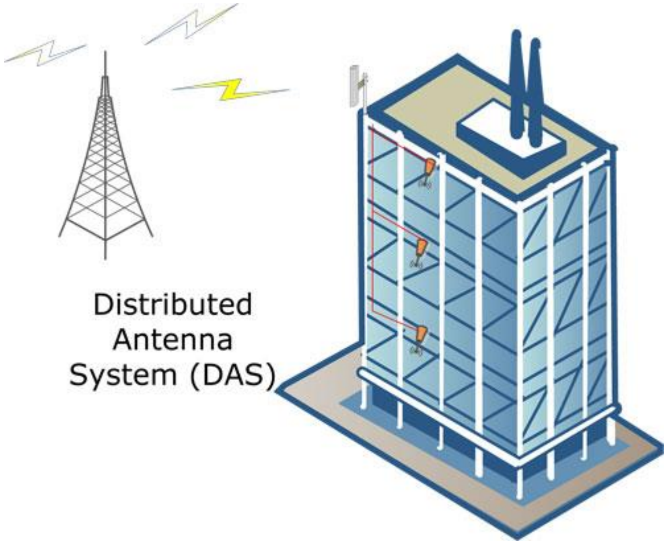
Distributed Antenna Systems (DAS)

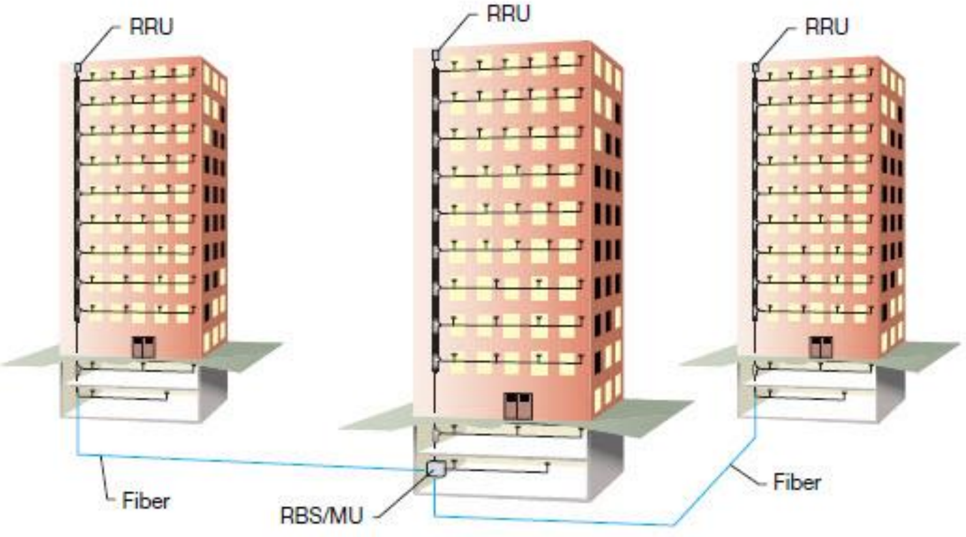
- “a network of spatially separated antenna nodes connected to a common source via a transport medium that provides wireless service within a geographical area or structure”, DAS Forum
  - Less RF power required as most users at LOS
  - Data capacity is off-loaded from the macro network



Different DAS

- Active vs Passive DAS
- Indoor DAS (iDAS)
- Outdoor DAS (oDAS)





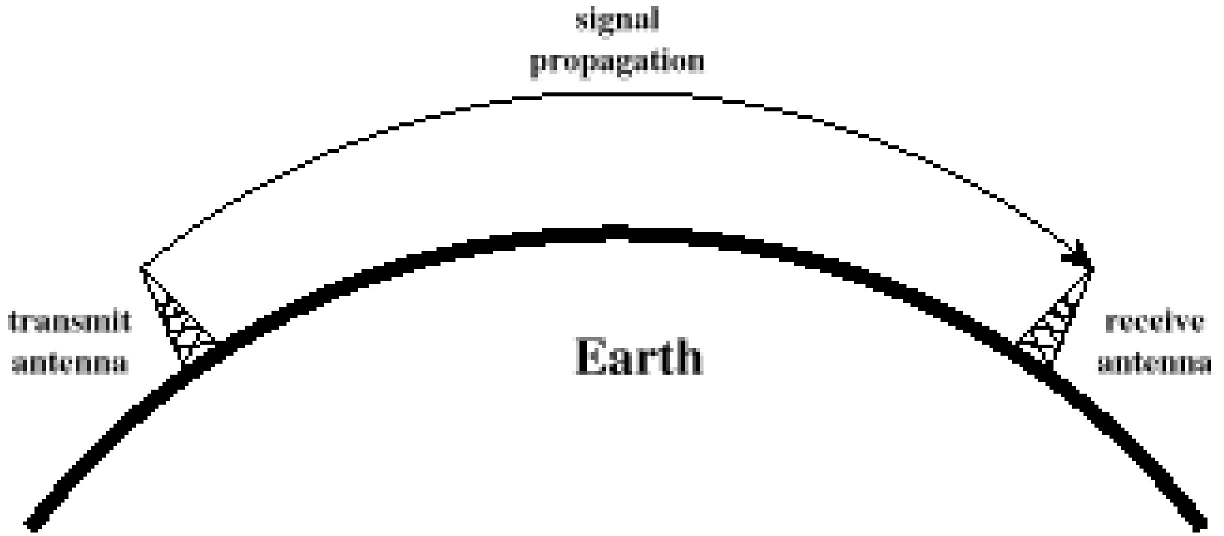
Micro-Trenching

- Special new trenching technology used for oDAS deployments
- Trench depths achieved: 6”- 18”
- Avoids excessive damage to the roadway, curb lines or sidewalks

Propagation Modes

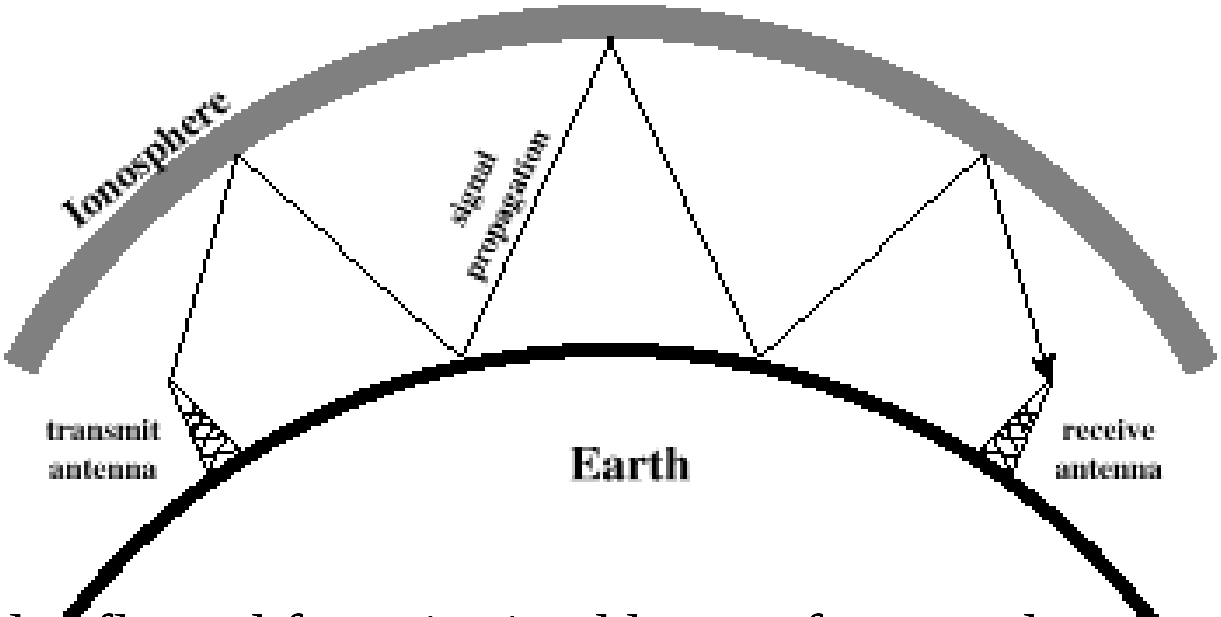
- Ground-wave propagation
- Sky-wave propagation
- Line-of-sight propagation

Ground Wave Propagation



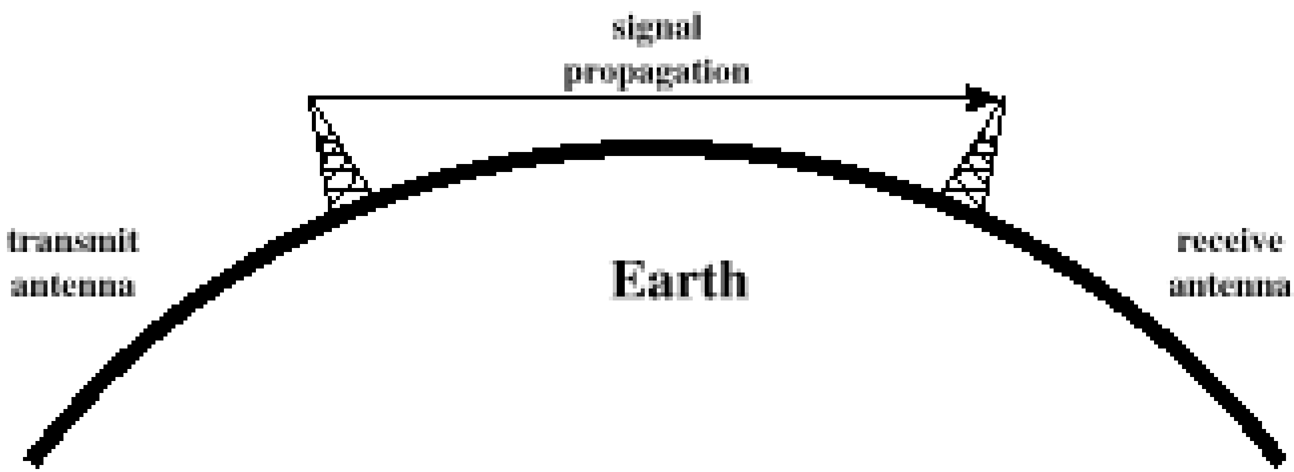
- Follows contour of the earth
- Can Propagate considerable distances
- Frequencies up to 2 MHz
- Example
  - AM radio

Sky Wave Propagation



- Signal reflected from ionized layer of atmosphere back down to earth
- Signal can travel a number of hops, back and forth between ionosphere and earth's surface
- Reflection effect caused by refraction
- Example: Amateur radio

Line-of-Sight Propagation



Line-of-Sight Propagation

- Transmitting and receiving antennas must be within line of sight
  - Satellite communication – signal above 30 MHz not reflected by ionosphere
  - Ground communication – antennas within *effective* line of sight due to refraction
- Refraction – bending of microwaves by the atmosphere
  - Velocity of electromagnetic wave is a function of the density of the medium
  - When wave changes medium, speed changes
  - Wave bends at the boundary between mediums

Line-of-Sight Equations

- Optical line of sight

$$d = 3.57\sqrt{h}$$

- Effective, or radio, line of sight

$$d = 3.57\sqrt{\mathrm{K}h}$$

  - *d* = distance between antenna and horizon (km)
  - *h* = antenna height (m)
  - K = adjustment factor to account for refraction, rule of thumb K = 4/3

Line-of-Sight Equations

- Maximum distance between two antennas for LOS propagation:

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

  - h_1 = height of antenna one
  - h_2 = height of antenna two

LOS Wireless Transmission Impairments

- Attenuation and free space loss
- Noise
- Multipath
- Refraction
- Thermal noise

Attenuation

- Strength of signal falls off with distance over transmission medium
- Attenuation factors for unguided media:
  - Received signal must have sufficient strength so that circuitry in the receiver can interpret the signal (*sensitivity*)
  - Signal must maintain a level sufficiently higher than noise to be received without error
  - Attenuation is greater at higher frequencies, causing distortion

Free Space Loss

- Free space loss, ideal isotropic antenna

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

  - P_t = signal power at transmitting antenna
  - P_r = signal power at receiving antenna
  - λ = carrier wavelength
  - d = propagation distance between antennas
  - c = speed of light ($\approx 3 \times 10$ 8 m/s)

  where d and λ are in the same units (e.g., meters)

Free Space Loss

- Free space loss equation can be recast:

$$L_{dB} = 10\log\frac{P_t}{P_r} = 20\log\left(\frac{4\pi d}{\lambda}\right)$$

$$= -20\log(\lambda) + 20\log(d) + 21.98\,\mathrm{dB}$$

$$= 20\log\left(\frac{4\pi f d}{c}\right) = 20\log(f) + 20\log(d) - 147.56\,\mathrm{dB}$$

Free Space Loss

- Free space loss accounting for gain of other antennas

$$\frac{P_t}{P_r} = \frac{(4\pi)^2 (d)^2}{G_r G_t \lambda^2} = \frac{(\lambda d)^2}{A_r A_t} = \frac{(cd)^2}{f^2 A_r A_t}$$

  - G_t = gain of transmitting antenna
  - G_r = gain of receiving antenna
  - A_t = effective area of transmitting antenna
  - A_r = effective area of receiving antenna

Free Space Loss

- Free space loss accounting for gain of other antennas can be recast as

$$L_{dB} = 20\log(\lambda) + 20\log(d) - 10\log(A_t A_r)$$

$$= -20\log(f) + 20\log(d) - 10\log(A_t A_r) + 169.54\mathrm{dB}$$

Q & A