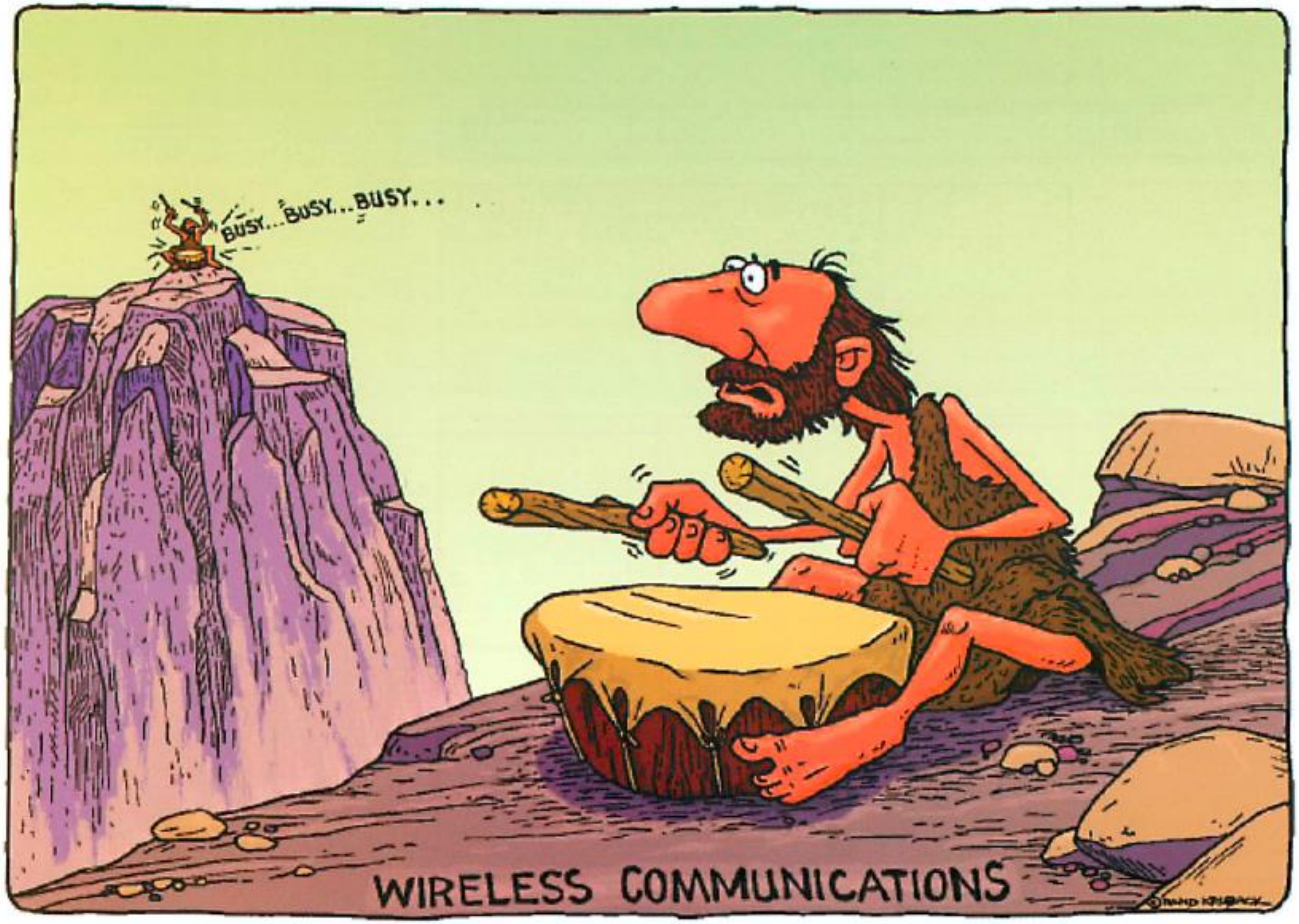
CWNA Guide to Wireless LANs, Third Edition

Chapter 4: Antennas


BUSY...BUSY...BUSY...
WIRELESS COMMUNICATIONS

Objectives

- Explain the different concepts that relate to antennas
- List the types of antennas
- Describe the antenna coverage patterns
- Explain MIMO
- List the different antenna measurements

Antenna Concepts

- Basic concepts important to understand about antennas:
  - What an antenna is
  - What it does
  - The measurements for determining an antenna's performance

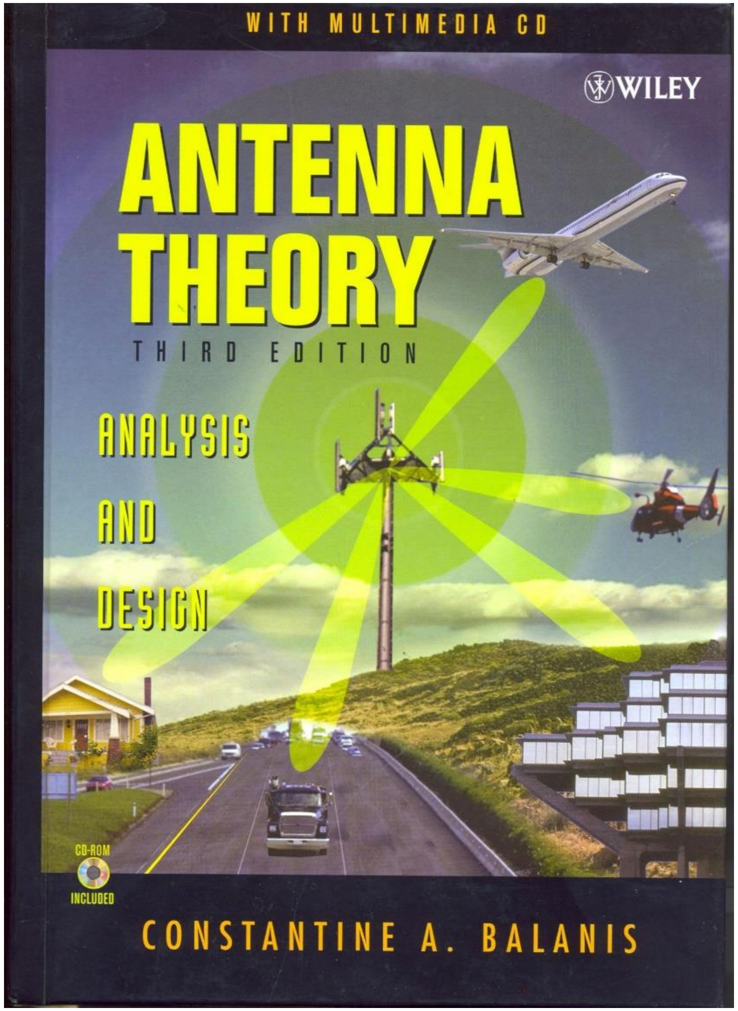
What is an Antenna?

- Conductor: a material that allows electrical current to flow through it

- Antenna: conductor used to transmit/receive electromagnetic waves through space

  - Relies on the power source to which it is attached
  - Located at the transition point between the device that creates the AC and the air through which the waves are transmitted

What is an Antenna?



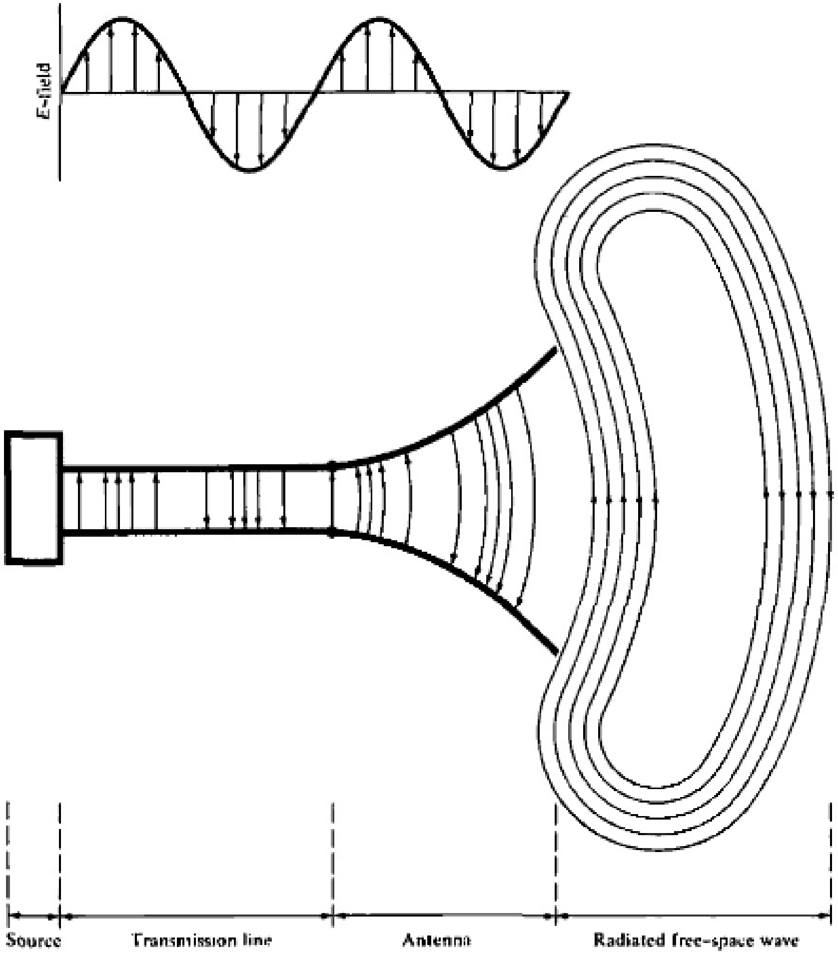
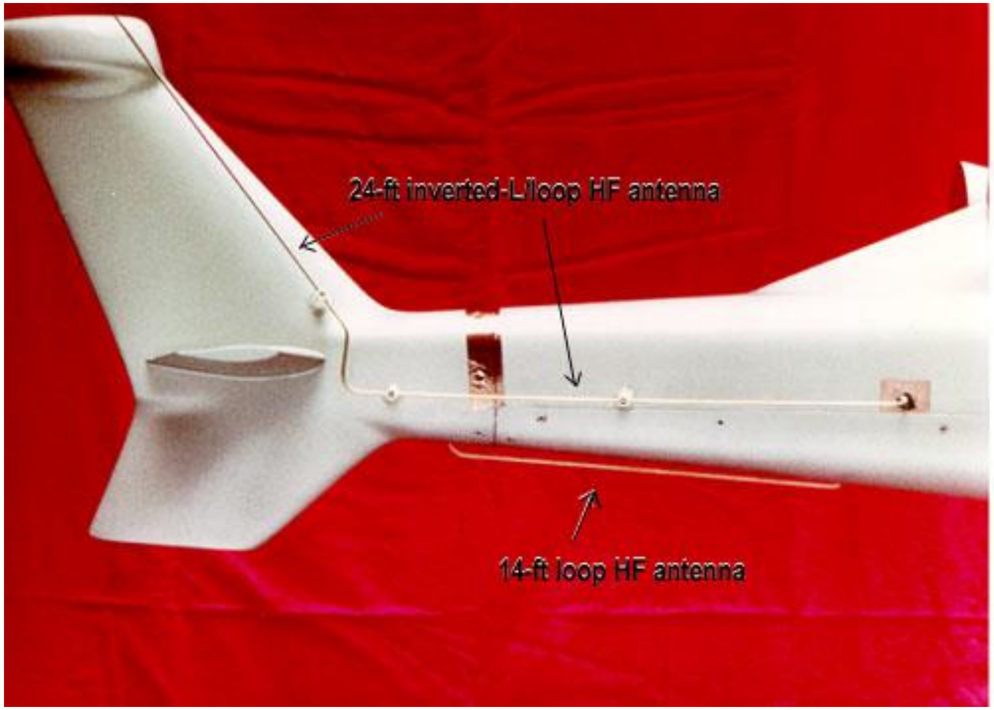


Figure 1.1 Antenna as a transition device.

What is an Antenna?



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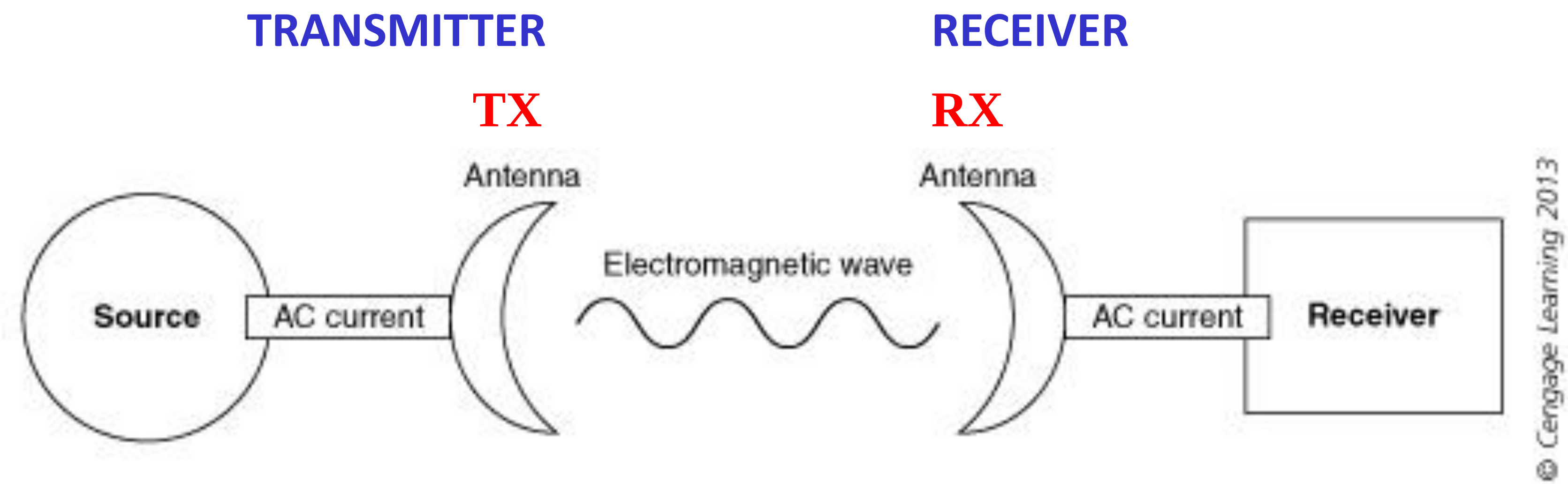
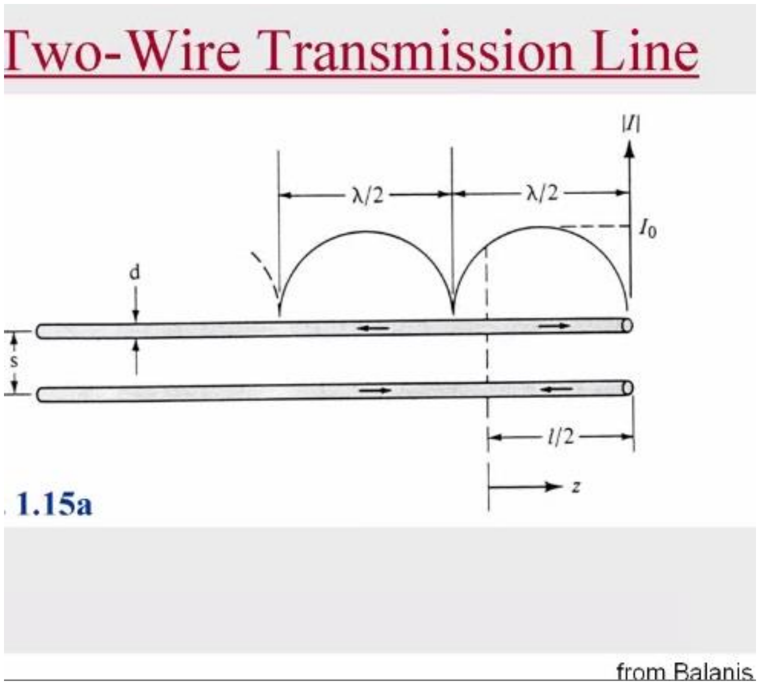
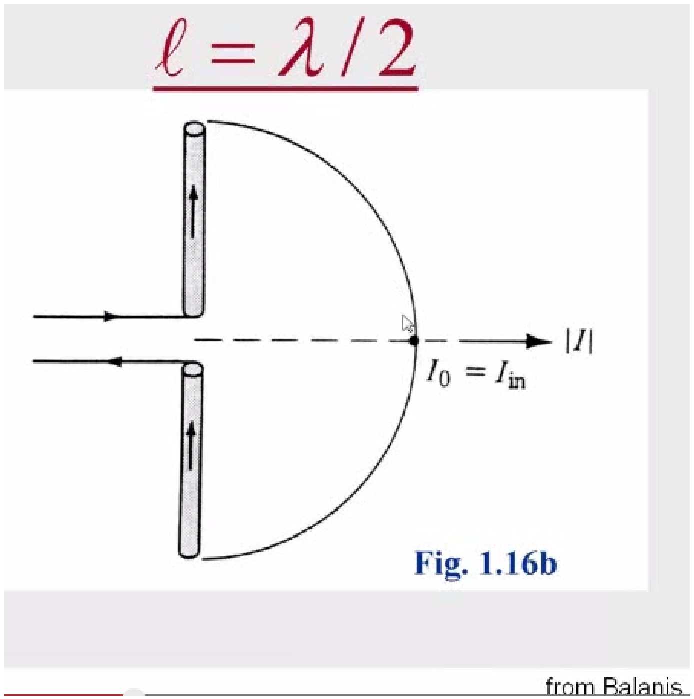


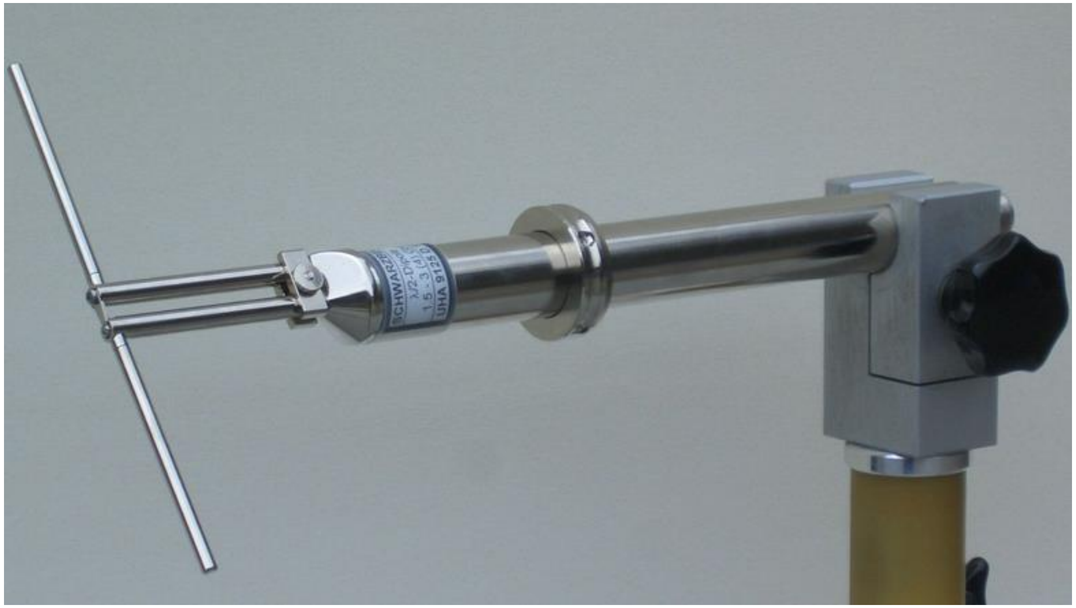
Figure 4-1 Conceptual antenna

What is a Dipole Antenna?





What is a Dipole Antenna?



What is an Antenna?

- Simplest antenna is a bare metal wire called "whip antenna"
  - Found on older automobiles and cellular phones
  - The length of the antenna should be at least one-quarter of the wavelength of the electromagnetic wave that is sending or re

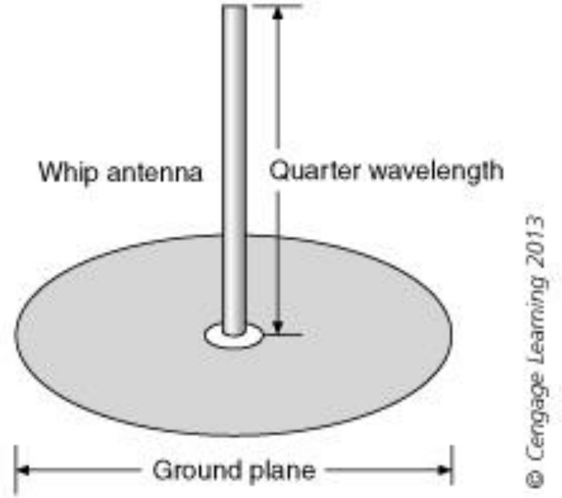
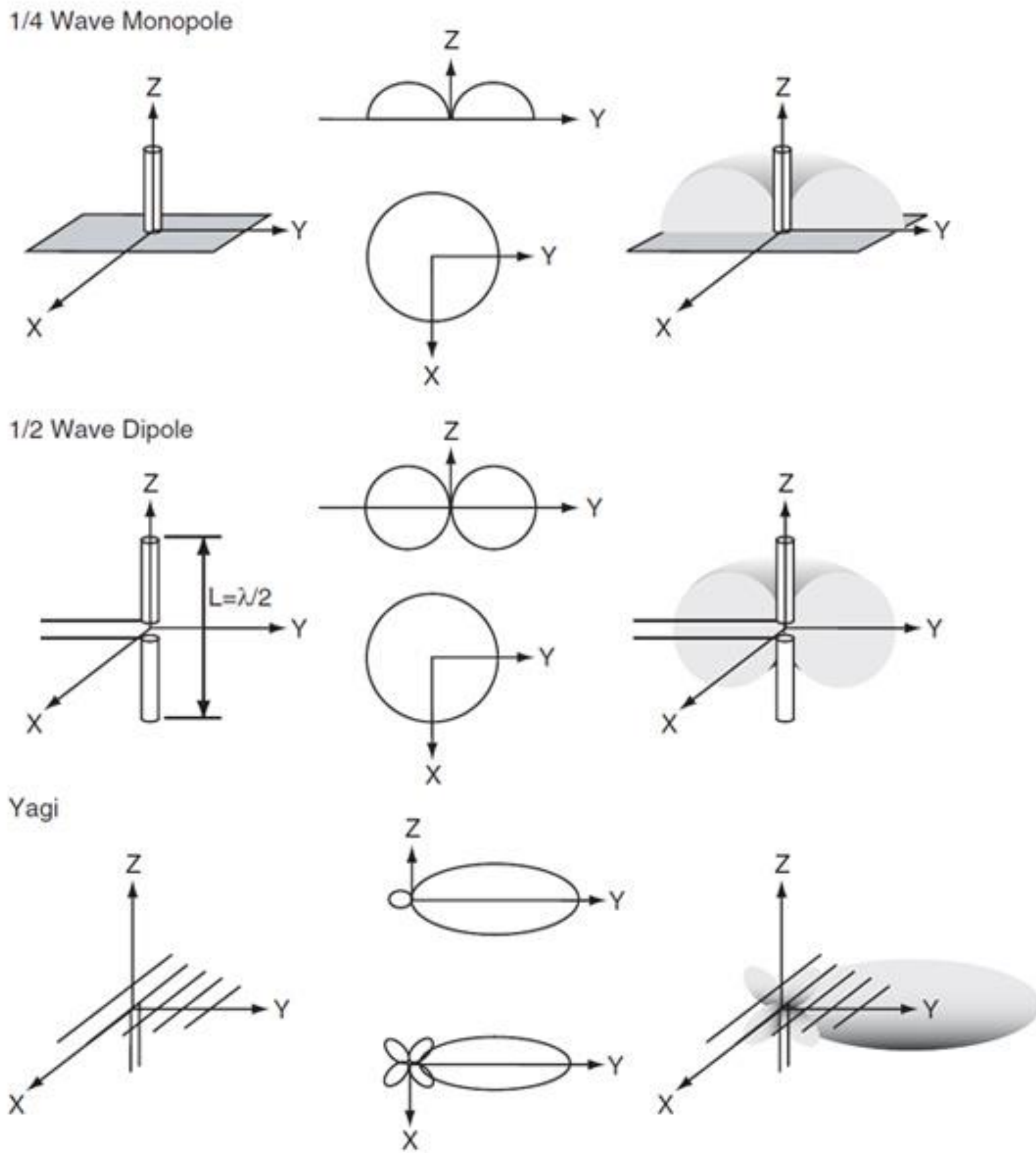


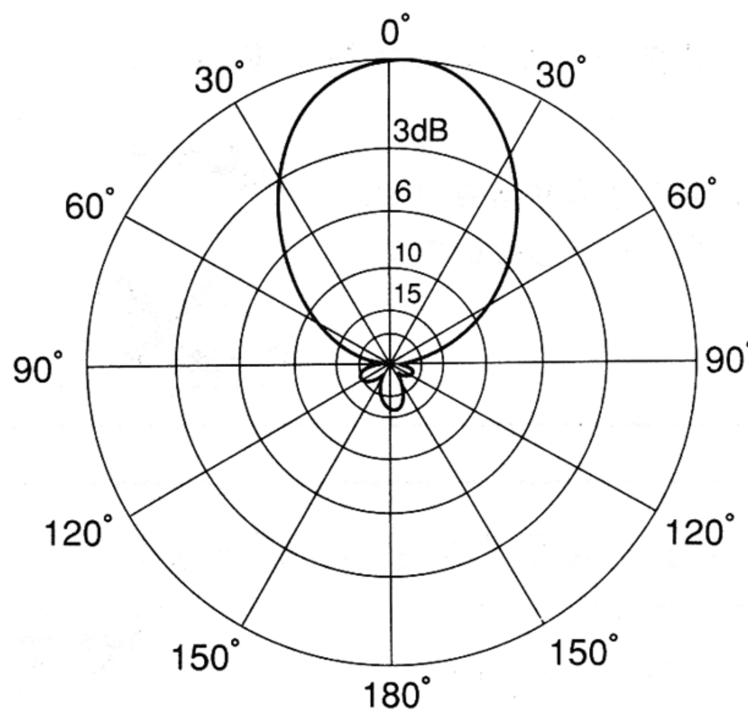
Figure 4-2 Whip antenna


1/4 Wave Monopole
Z
Y
X
1/2 Wave Dipole
L=λ/2
Yagi

Antenna Radiation (Coverage) Patterns

- Precision is needed to determine the best type of antenna and antenna location for the optimum coverage area

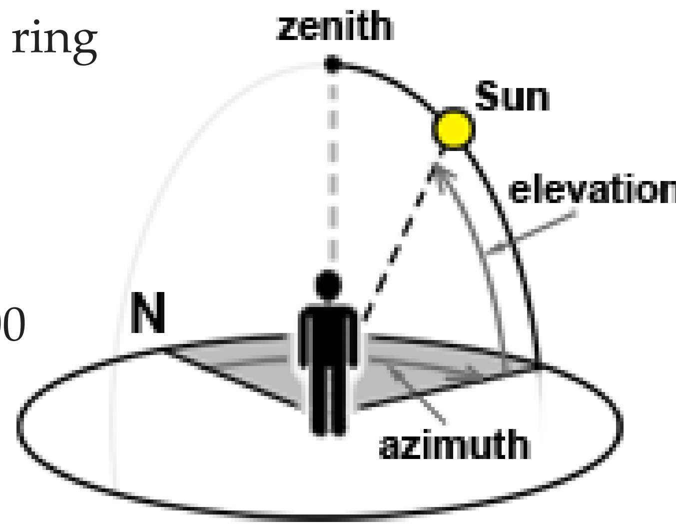
- Antenna coverage patterns involve:
  - Azimuth and elevation
  - Beamwidth
  - Fresnel zone



Azimuth and Elevation

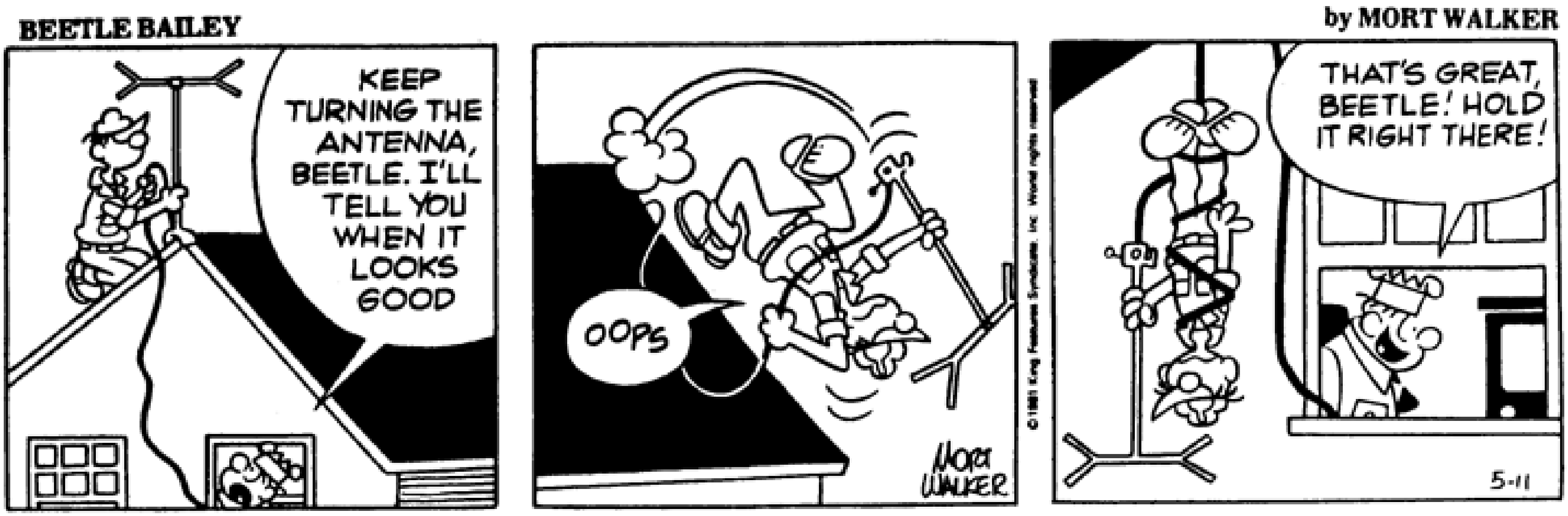
- **Antenna radiation pattern (chart)**: used to illustrate an antenna's radiation pattern

- How to interpret these charts:
  - Antenna location: center of the chart is the location
  - Degrees: degree symbols (0-360) along the outer ring indicate the coverage pattern
  - Outer circle: represents a 100-percent gain
  - Inner circles: represent a gain that is less than 100 percent

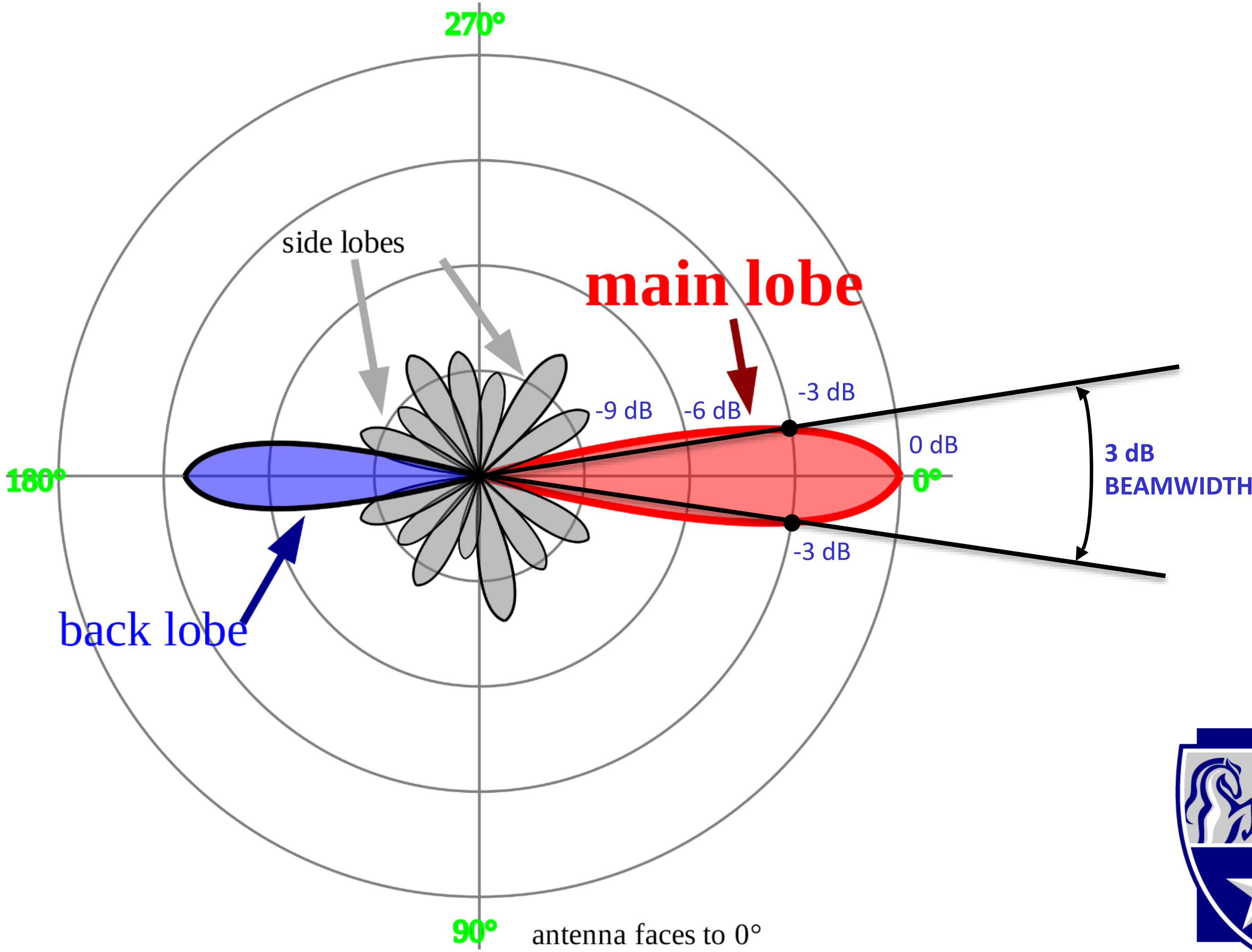


- Antenna radiation charts:
  - **Azimuth chart**: represents the horizontal coverage
  - **Elevation chart**: used to show the vertical coverage

Antenna Measurement

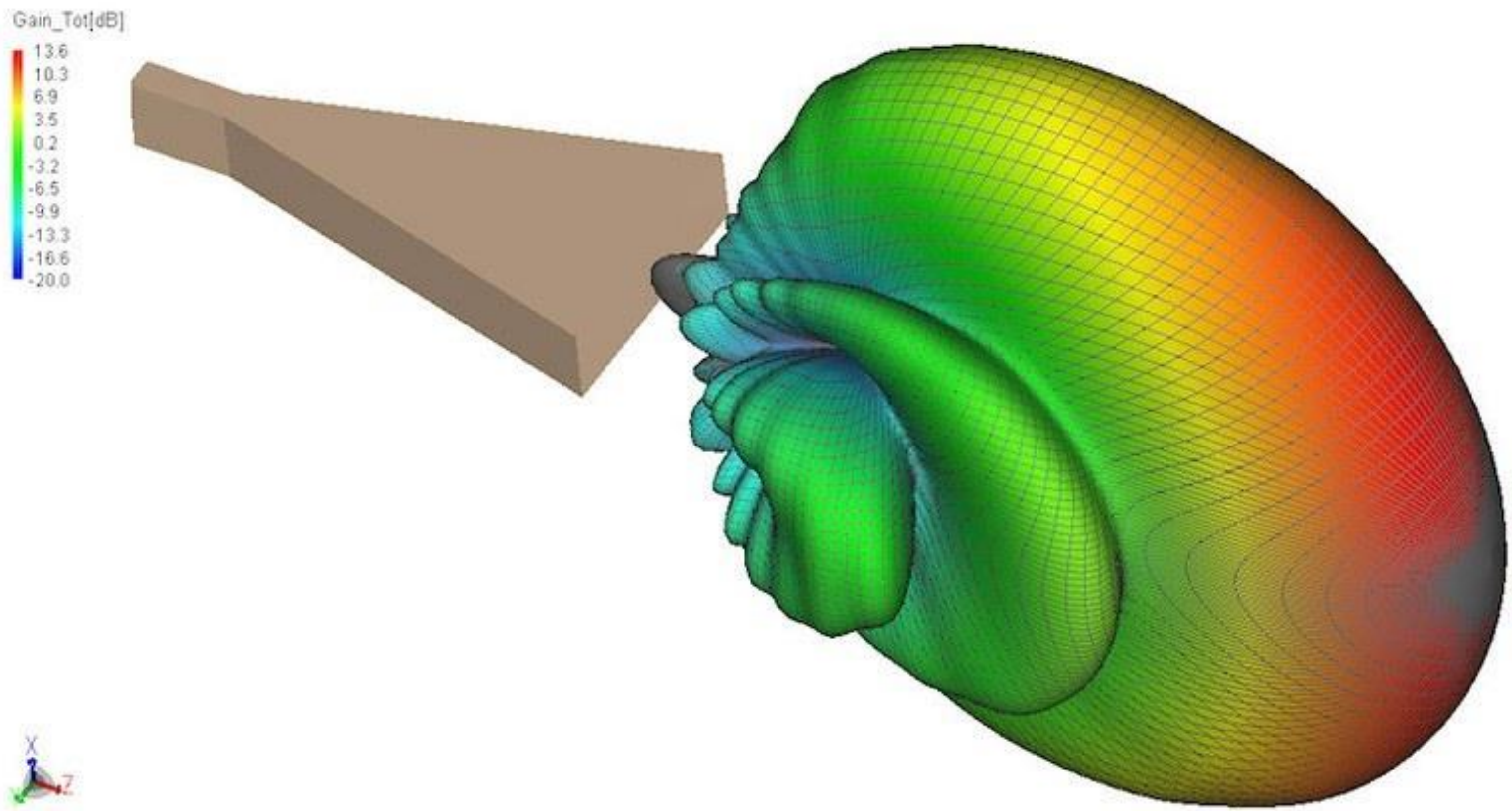


Antenna Measurements “Radiation Pattern”



antenna faces to 0°

3-D Radiation Pattern



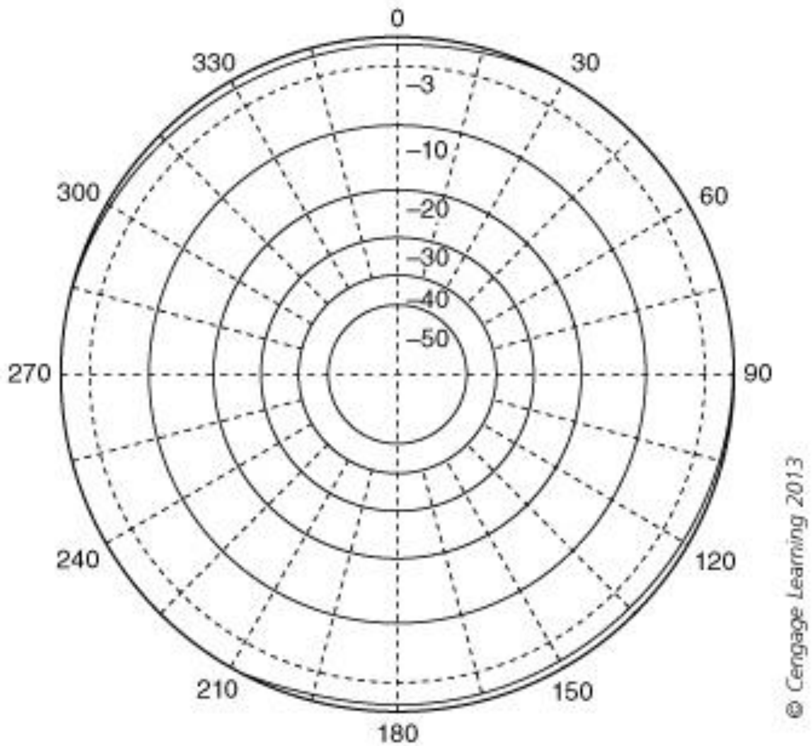


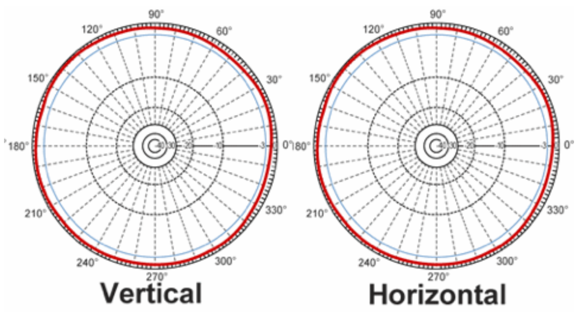
Figure 4-10 Antenna radiation chart

Radiation Patterns

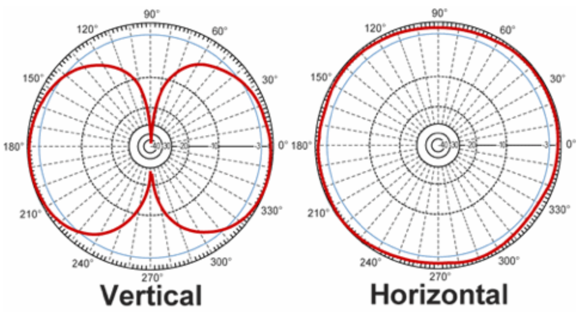
The toothpick represents the axis at which the antenna is placed at the middle of.

The antenna is in the middle of the sphere

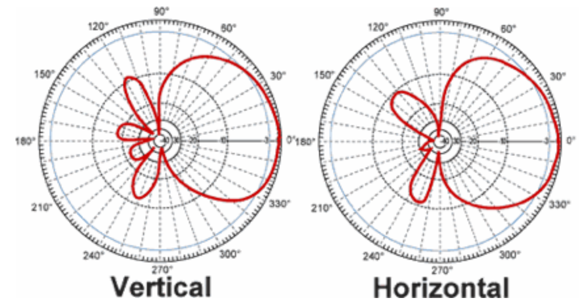
0 dBi Isotropic Antenna

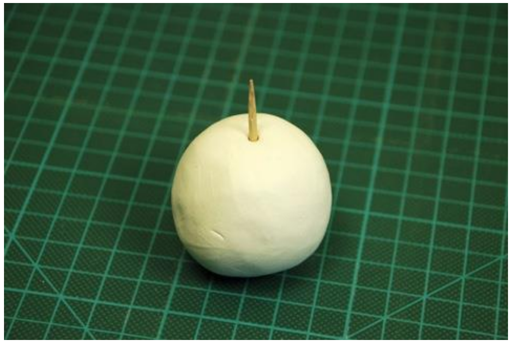


3 dBi Patch Antenna

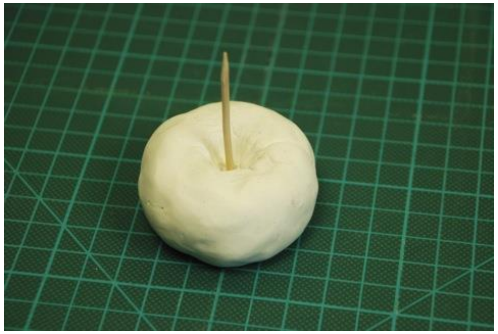


8 dBi Patch Antenna





Isotropic

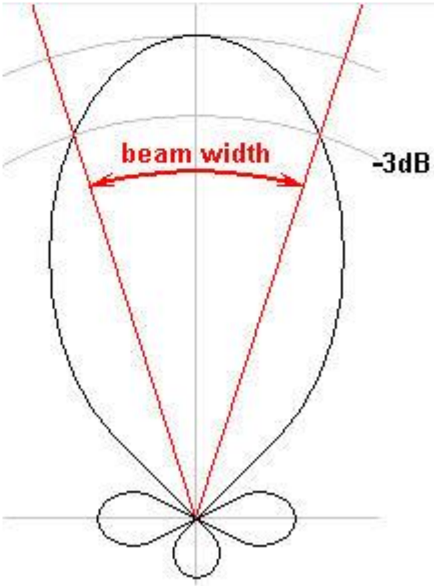


Omni-directional

Directional

Beamwidth

- Beamwidth: a measurement of a transmission's width
  - Determined by locating the peak radiation intensity then locating the points on the other side of the peak that represent half the power (-3 dB) of the peak intensity



Beamwidth

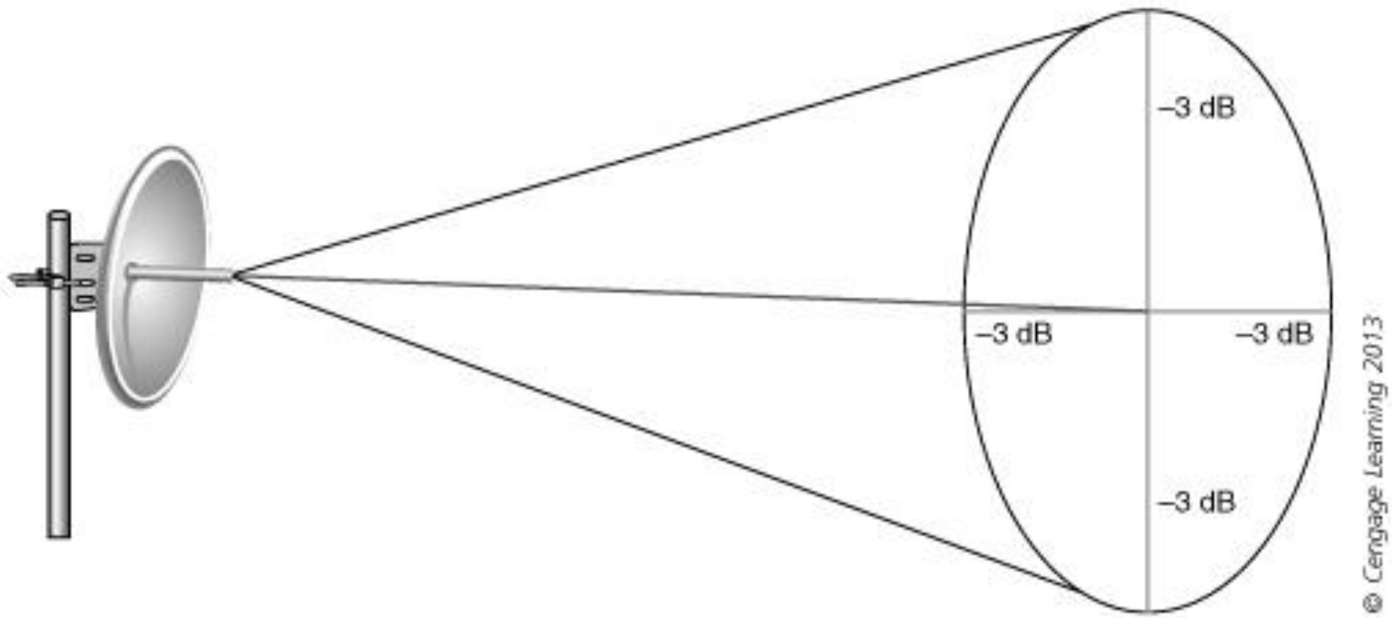


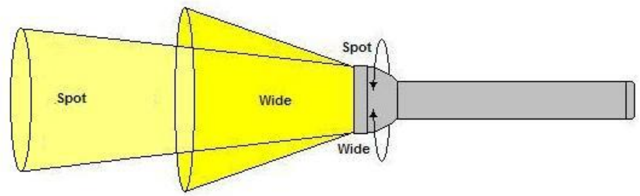
Figure 4-13 Beamwidth

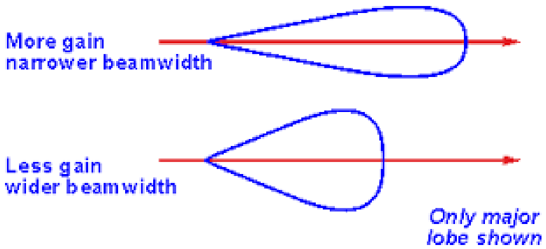
Antenna Gain

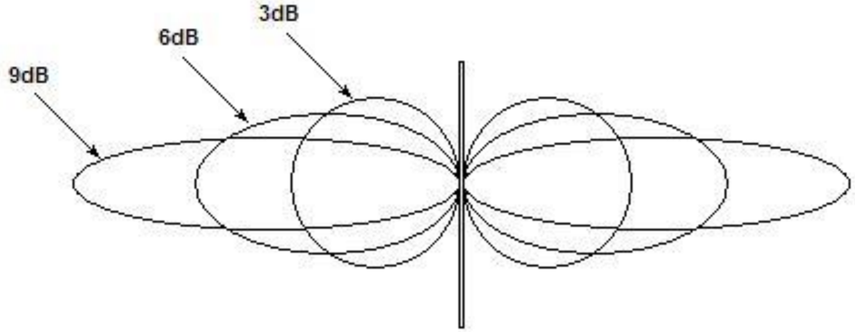
- **Antenna Gain:** A relative measure of an **antenna's** ability to direct or concentrate radio frequency energy in a particular direction or pattern.

- The measurement is typically measured in dBi (Decibels relative to an isotropic radiator) or

- in dBd (Decibels relative to a dipole radiator).







Antenna Measurements

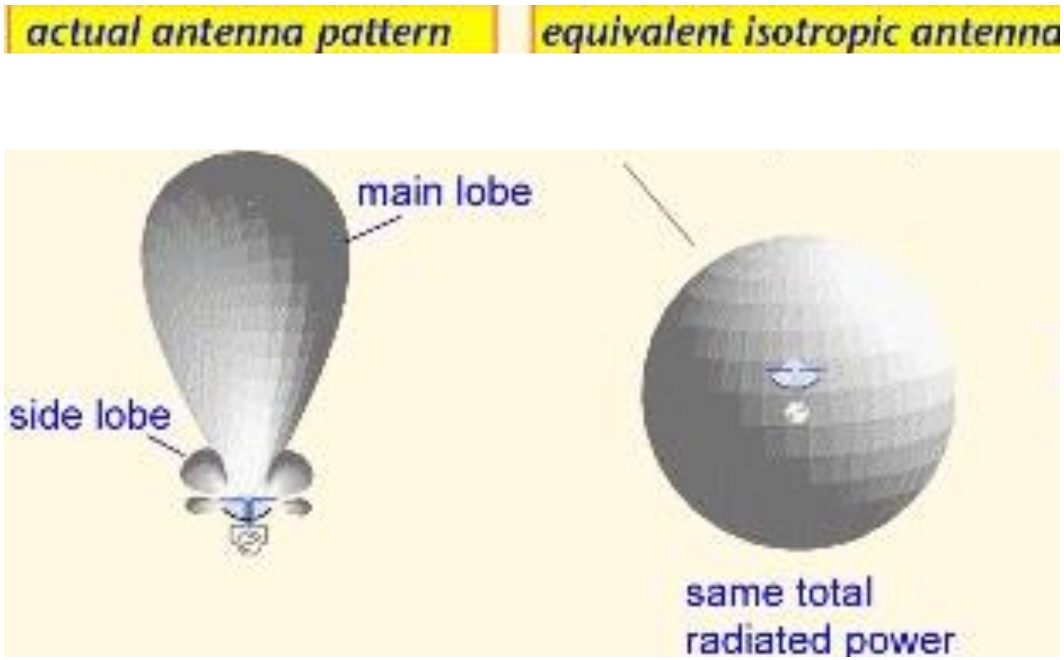
- Several measurements used with antennas:
  - Intentional Radiator (IR)
  - Equivalent Isotropically Radiated Power (EIRP)
  - Decibels Isotropic (dBi)
  - Decibels Dipole (dBd)

Intentional Radiator (IR)

- Intentional Radiator: a system used to create and transmit RF signals
  - Labeled by the FCC
  - Specifically designed to send out electromagnetic waves (*intentional*)
  - Also designed to radiate out, or send, a signal (*radiator*)
- FCC limits the amount of power that can be generated by an IR

Equivalent Isotropically Radiated Power (EIRP)

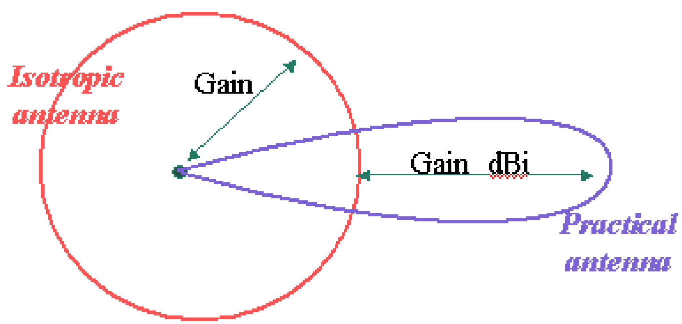
- **Isotropic radiator (antenna)**: source of RF waves that have the same magnitude or properties in all directions
  - No preference in the direction of radiation

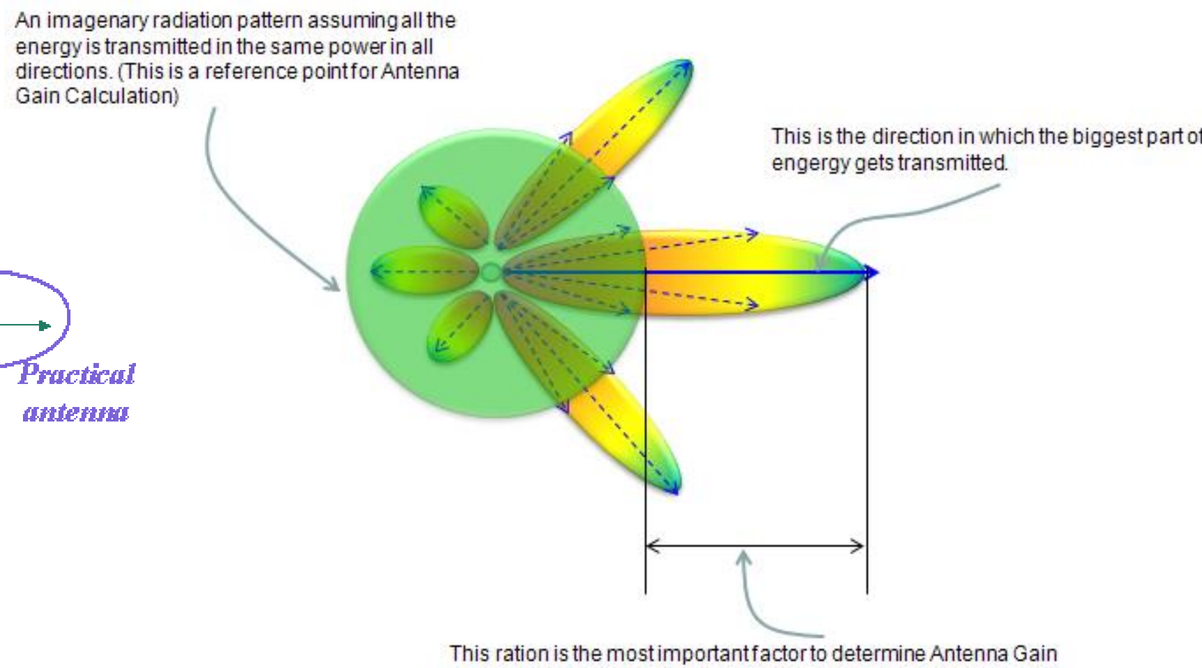


- **Equivalent isotropically radiated power (EIRP)** is the amount of power that a theoretical isotropic antenna (which evenly distributes power in all directions) would emit to produce the peak power density observed in the direction of maximum antenna gain.
- FCC also limits the amount of EIRP that can radiate from an antenna.
- Maximum EIRP for IEEE 802.11b WLAN is 100 mW (20 dBm)

Decibels Isotropic (dBi)

- **Decibels isotropic (dBi):** passive gain of power that is funneled from an antenna compared to that of an isotropic radiator sent in all directions
  - Focusing the signal in a specific direction is known as a passive gain (no additional power is added)





- Focusing the signal can also be accomplished through the type of antenna
  - **High-gain antennas**: have longer ranges and higher signal quality, but aim must be precise
  - **Low-gain antennas**: have a shorter range but aim does not have to be as precise

Decibels Dipole (dBd)

- Dipole: most basic type of antenna
- Decibels dipole (dBd): compares the antenna gain against that of a dipole antenna
- WLAN equipment is rarely measured in dBd

Name	Abbreviation	Description	Comments
Intentional radiator	IR	Power directed to the antenna	Includes all components except the antenna
Equivalent isotropically radiated power	EIRP	Power directed from the antenna	Amount of power that theoretical isotropic radiator can generate
Decibels isotropic	dBi	Antenna gain	Gain compared to theoretical isotropic radiator
Decibels dipole	dBd	Antenna gain compared to dipole antenna	Rarely used in WLANs

Table 4-2 Antenna measurements

Types of Antennas

- Three basic categories of antennas:
  - Omnidirectional
  - Semidirectional
  - Highly directional

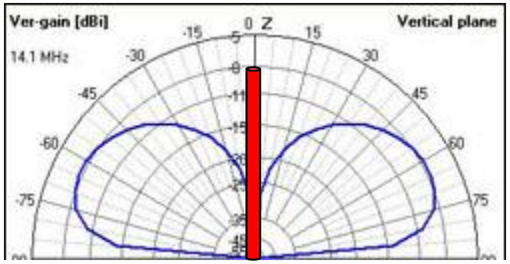
- Each category includes multiple types, each with different characteristics

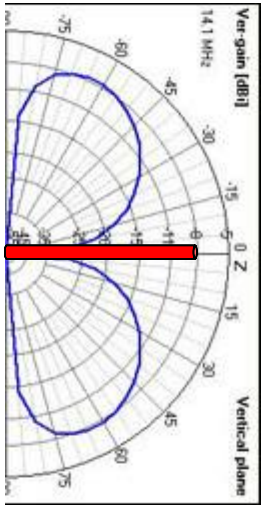
Omnidirectional Antennas

- Omnidirectional antennas: most common type of antenna for a WLAN
  - Radiates its signal out horizontally in all directions equally
- Dipole antennas are an example of an omnidirectional antenna and are frequently used with WLANs
- Three factors to consider with dipole omnidirectional antennas: horizontal vs. vertical coverage; polarization; and antenna diversity

Omnidirectional Antennas

- **Horizontal vs. Vertical Coverage:**
  - If antenna is in upright vertical position, most of the signal goes out “sideways” rooms



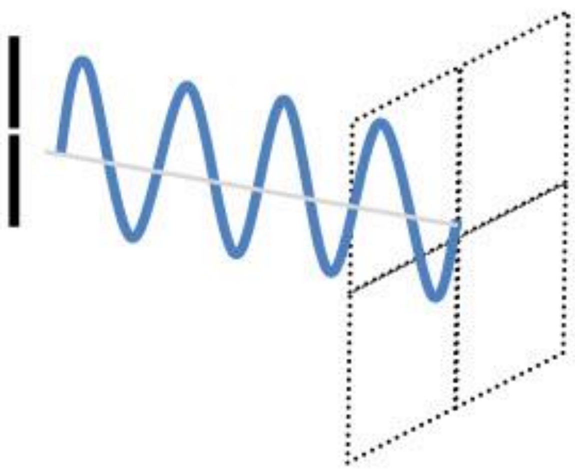


  - If antenna is in a horizontal position, most of the signal goes up to the ceiling and down to the floor

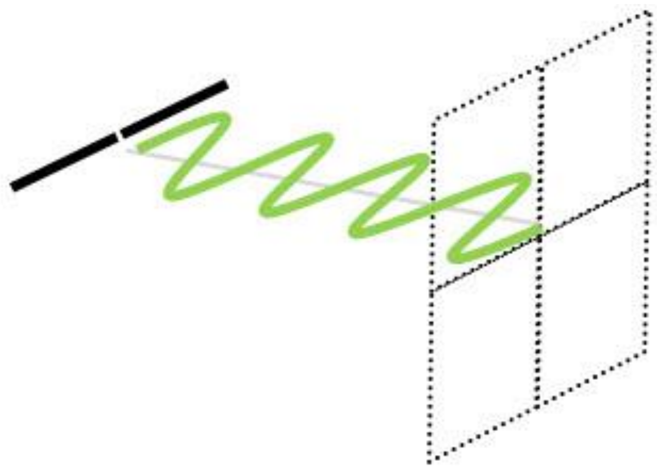
- **Polarization**: orientation of radio waves as they leave an antenna
  - Antennas must be polarized alike to be efficient
  - Antennas in a horizontal position will not communicate well with an antenna in a vertical position

Polarization

- **Polarization**: orientation of radio waves as they leave an antenna
  - Antennas must be polarized alike to be efficient
  - Antennas in a horizontal position will not communicate well with an antenna in a vertical position



VERTICAL POLARIZATION



HORIZONTAL POLARIZATION

Polarization

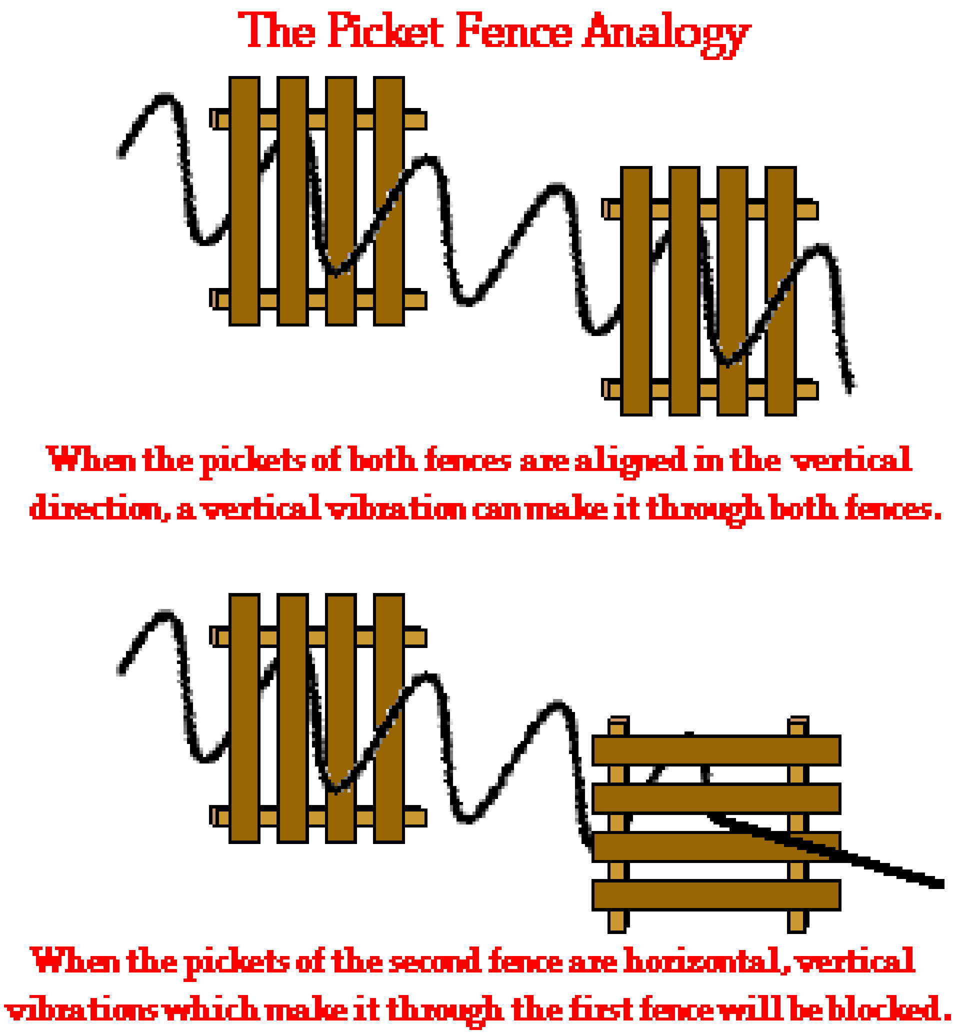


Figure 4-5 Monopole Antenna

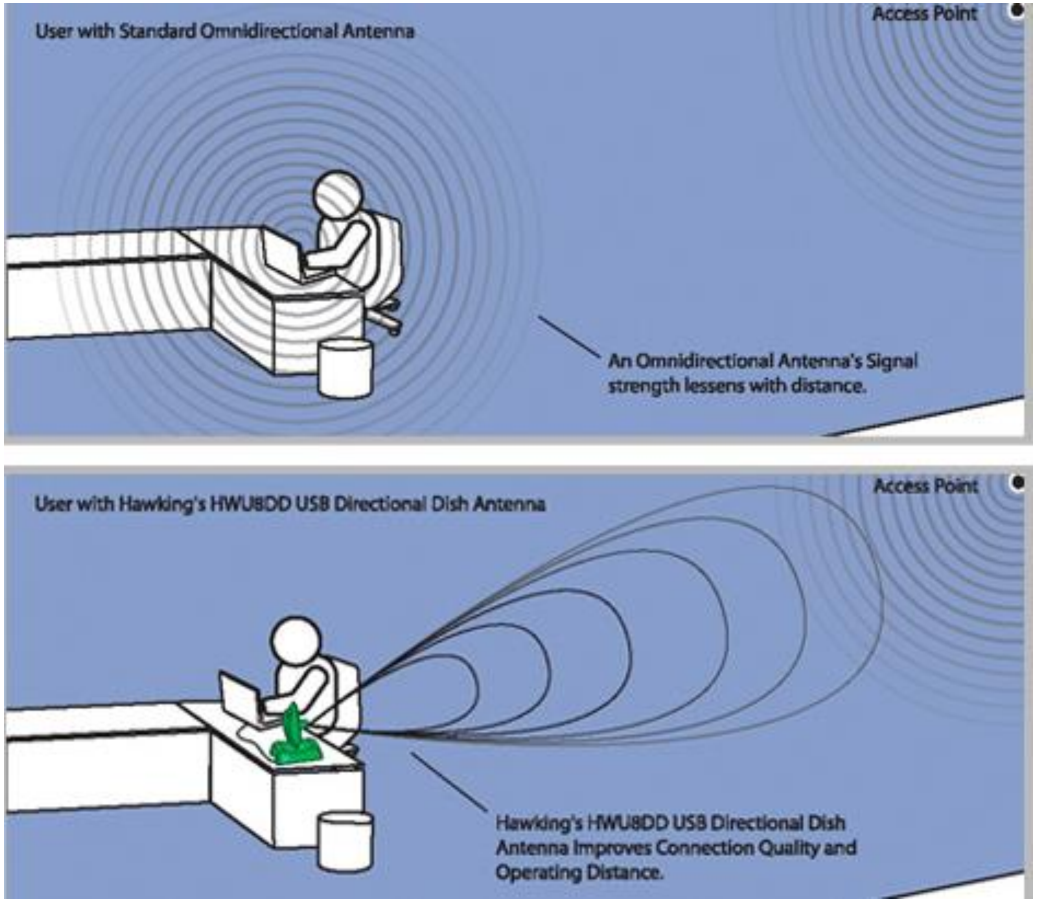
Figure 4-6 WLAN vertical polarization

Antenna Diversity

- **Antenna Diversity**: Ability of an access point to examine multiple copies of a received transmission and then select the best signal
  - Selecting the best signal is known as switching
- Antenna diversity can also be used in transmitting
  - **Transmit diversity**: the AP can transmit on the antenna that most recently received the strongest incoming signal

Semidirectional Antennas

- **Semidirectional antennas**: focuses energy in one direction
  - Primarily used for short and medium range remote wireless bridge networks
- **Sectorized antenna**: divides the coverage area into different sectors and gives each sector its own antenna
- **Antenna array**: multiple antennas that can be customized to send an optimal signal
  - Each antenna does not have to have the same power



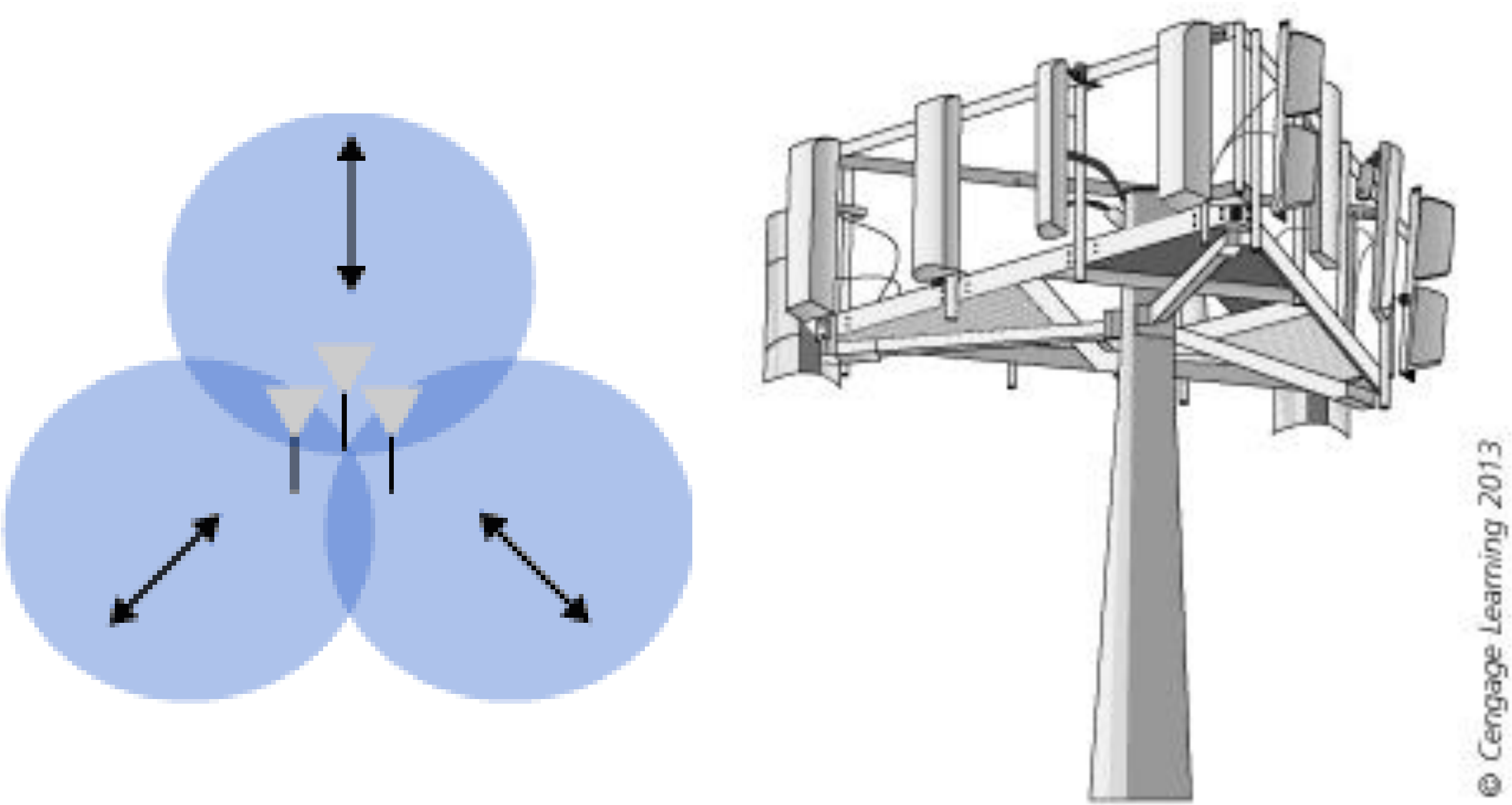
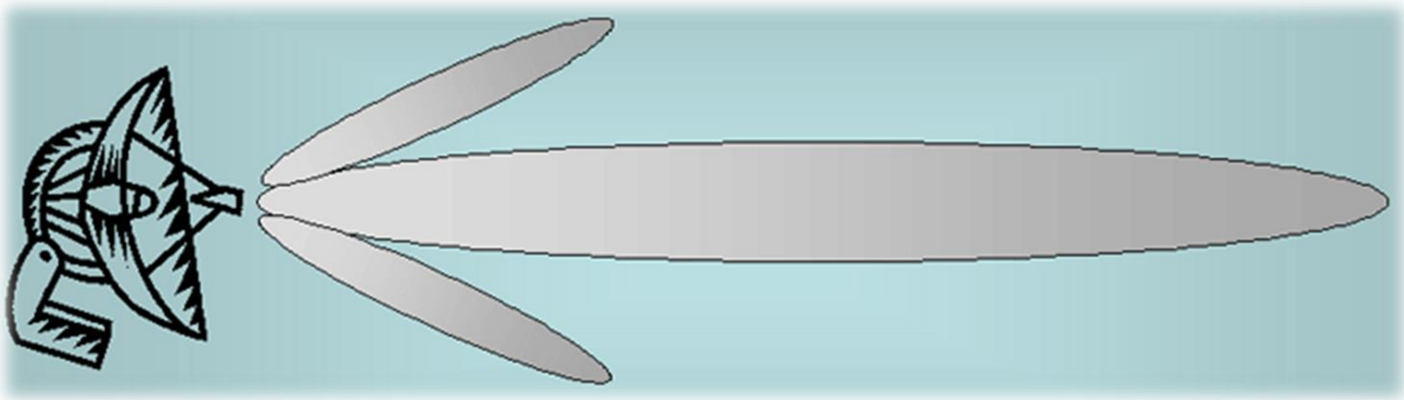


Figure 4-8 Sectorized antenna

Highly-Directional Antenna

- **Highly-Directional Antennas:** sends a narrowly focused signal beam long distances
  - Generally reflective devices that are shaped like a concave dish
  - Used for outdoor long-distance point-to-point wireless links, such as connecting buildings that are up to 25 miles apart
  - Not used for indoor WLANs



Highly-Directional Antenna

Figure 4-9 Highly-directional antenna

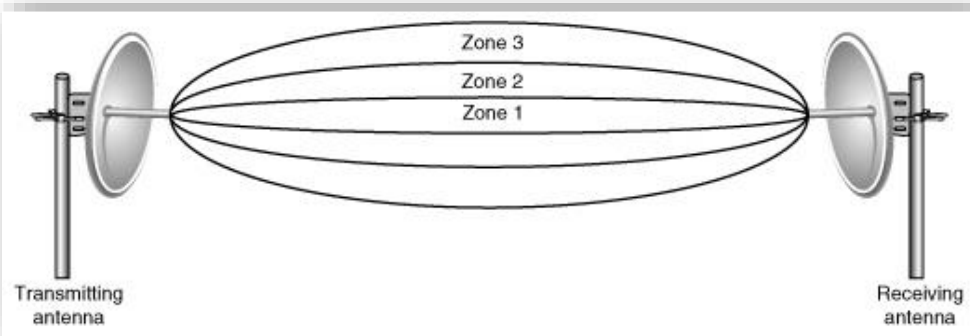
Highly-Directional Antenna

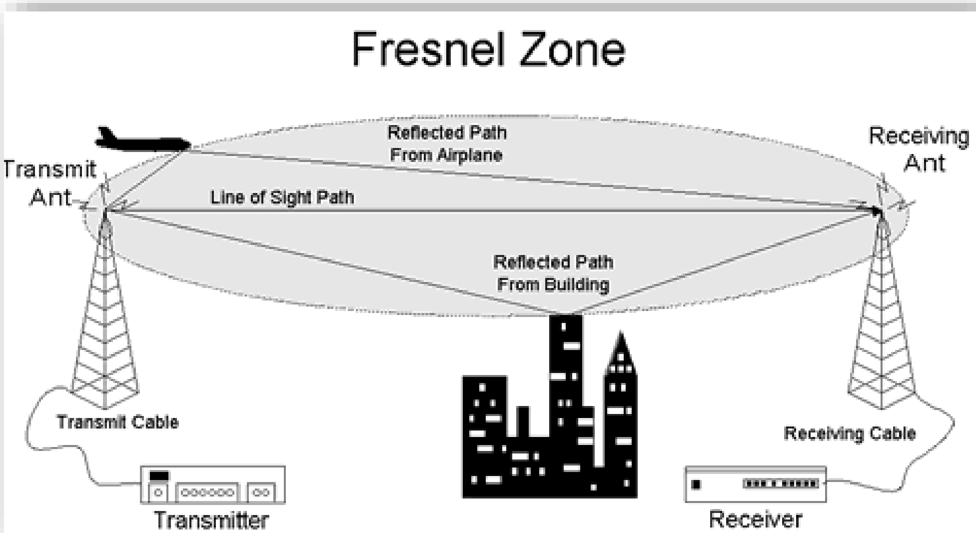
Homemade directional wi-fi antenna!

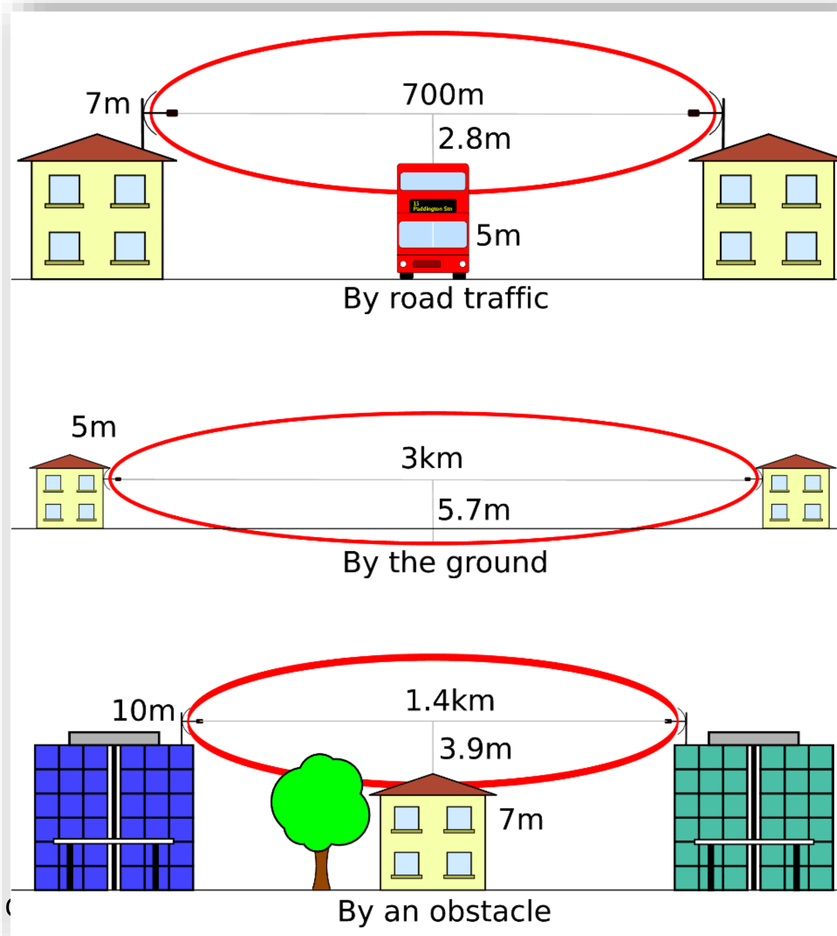
Fresnel Zone

- RF line of sight: theoretical straight line between a transmitter and the receiver
  - An object that is close to the path of the RF transmission can impact the signal
- Fresnel zone: elliptical area immediately surrounding the visual line of sight for RF transmissions
- General rule: 60% of the first Fresnel zone must be clear of obstacles

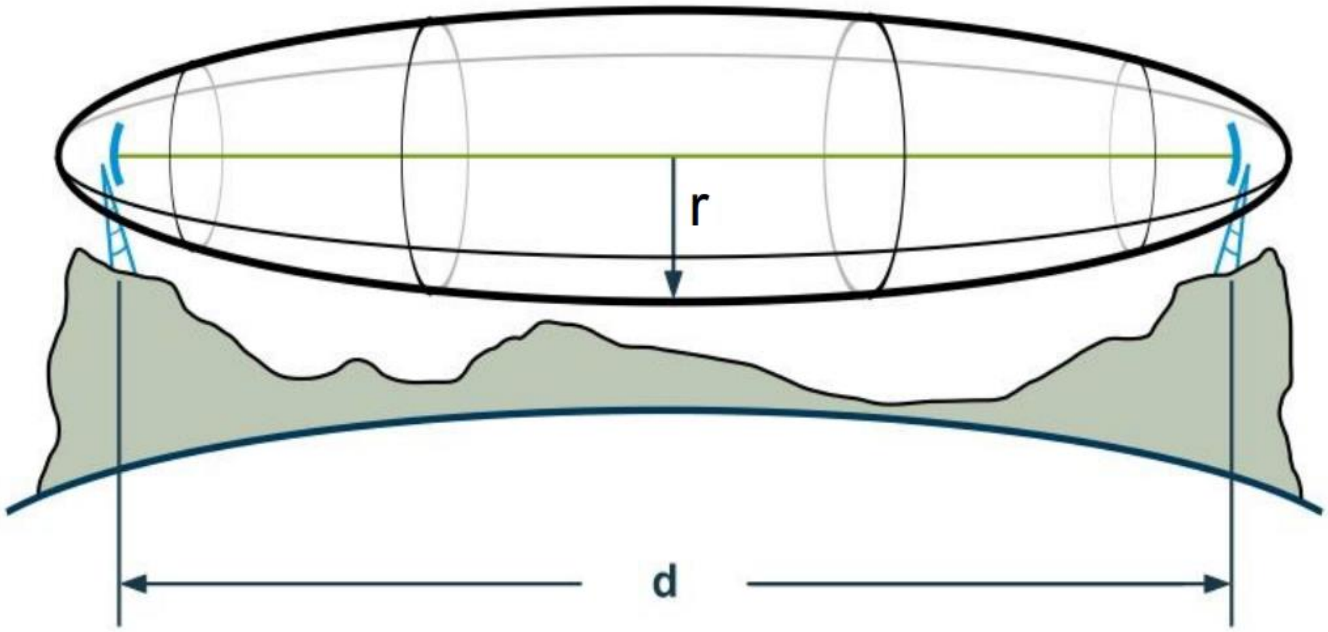
Fresnel Zone







Fresnel Zone



a free line-of-sight **IS NOT EQUAL TO** a free Fresnel Zone

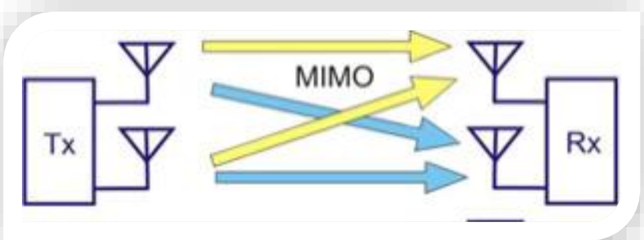
Fresnel Zone

- Steps for mitigating obstructions in the Fresnel zone include:
  - Raising the antenna mounting point on the existing structure
  - Increasing the height of an existing power
  - Building a new structure that is tall enough to mount the antenna
  - Locating a different mounting point on another building or tower for the antenna
  - Cutting down trees

Multiple-Input Multiple-Output (MIMO)

- A wireless device with multiple receive (Rx) antennas can improve transmissions by either:
  - Selecting the stronger incoming signal
  - Combining the individual signals at the receiver

- IEEE 802.11a/b/g devices can only use a single antenna
  - Wireless system that uses a single antenna is called a **single-input single-output (SISO)** system
  - Has only one **radio chain** (radio with supporting infrastructure such as devices to amplify the signal or convert an analog signal to a digital signal)



What is MIMO?

- **Multiple-Input Multiple Output (MIMO):** system that uses <u>one radio chain for each antenna</u>
  - that each antenna can simultaneously transmit and receive signals
  - IEEE made MIMO the heart of 802.11n
  - Estimated the MIMO alone contributes 40% to the increase in speed
  - 802.11n standard is sometimes called HT (MIMO) for *High Throughput Multiple-Input Multiple-Output*

SISO (Single Input Single Output)

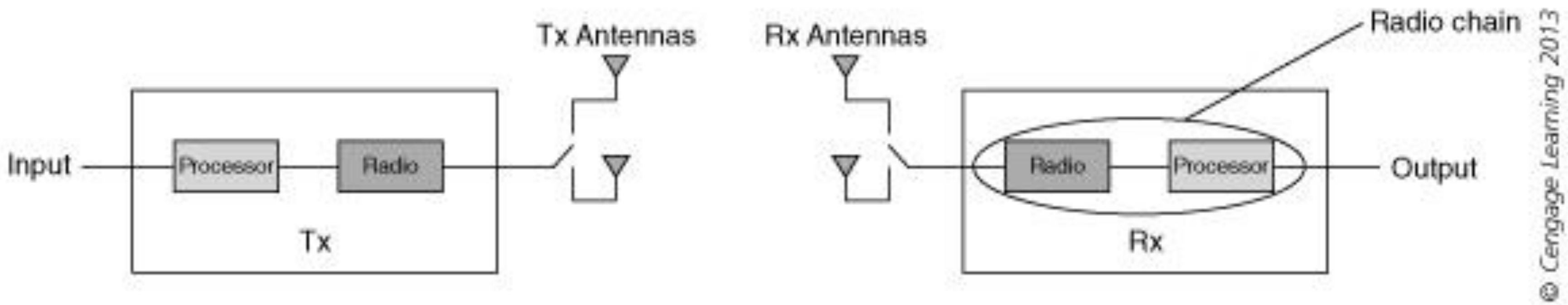


Figure 4-15 SISO radio chain

MIMO (Multiple Input Multiple Output)

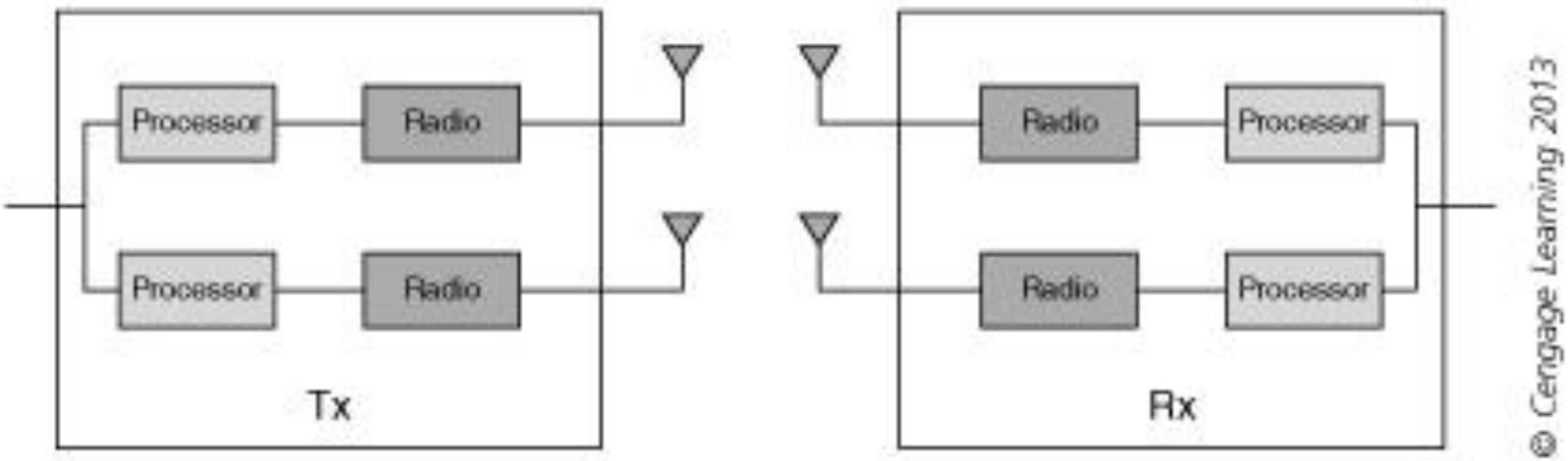


Figure 4-16 MIMO radio chain

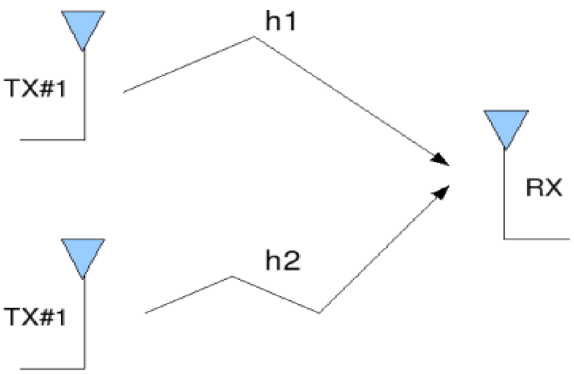
MIMO Signal Processing Techniques

- Signaling process techniques:
  - Spatial diversity
  - Spatial multiplexing
  - Maximal ratio combining
  - Transmit beam forming

- MIMO can take advantage of these signaling process techniques to create high throughput

Spatial Diversity

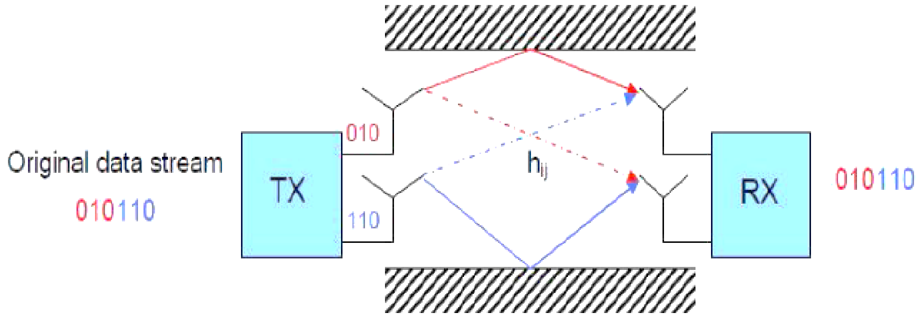
- **Spatial diversity**: a MIMO technique of sending the same transmission out from different antennas that will take different paths
- Can increase reliability of an RF signal
  - Each transmission will take different paths (called spatial paths)
  - It is unlikely all paths will degrade the signal in the same way



- **Cyclic Shift Diversity (CSD)**: sends a normal version of the signal along with a shifted version of the same signal

Spatial Multiplexing

- Spatial diversity improves reliability and range but it does not increase speed
- Instead of sending the same data out through multiple antennas, **spatial multiplexing** first splits up the data and sends it out over multiple antennas
  - Receiving antenna merges data back together
  - Increases speed without the need for any additional power or bandwidth



- **Space Time Block Coding (STBC)**: sends a redundant copy of part or all of the transmitted signal on any unused antennas

Spatial Multiplexing

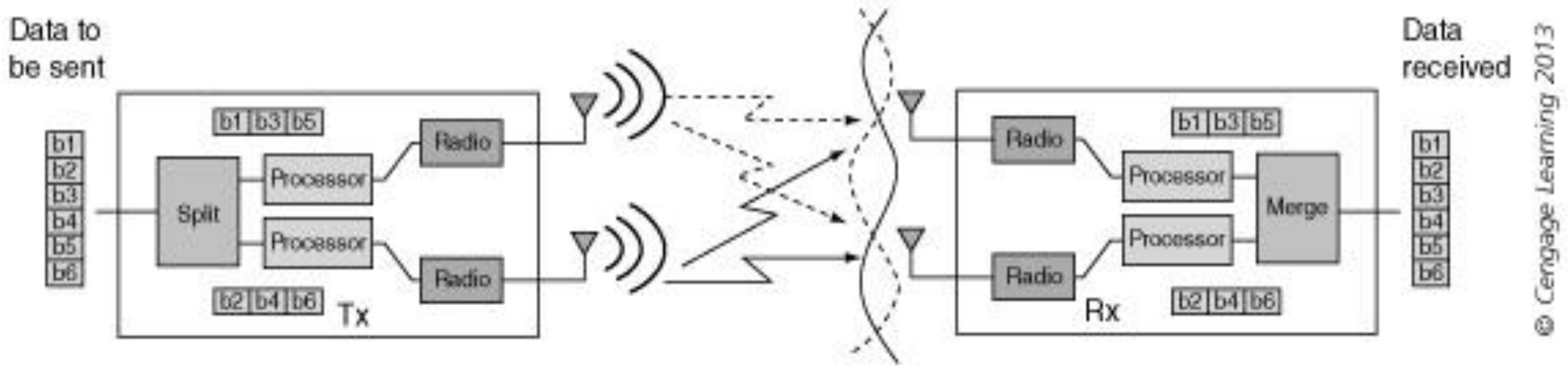
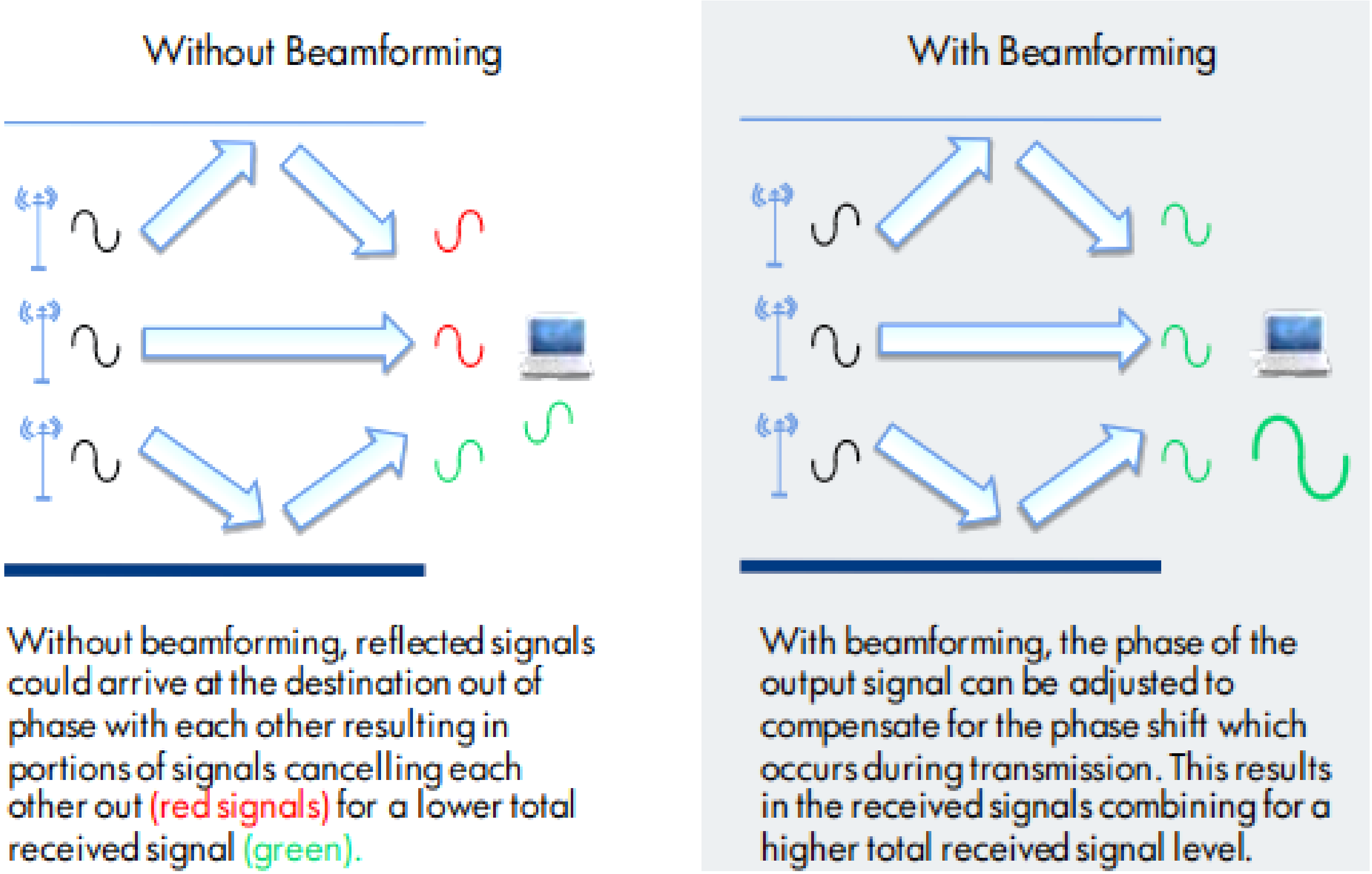


Figure 4-17 Spatial multiplexing

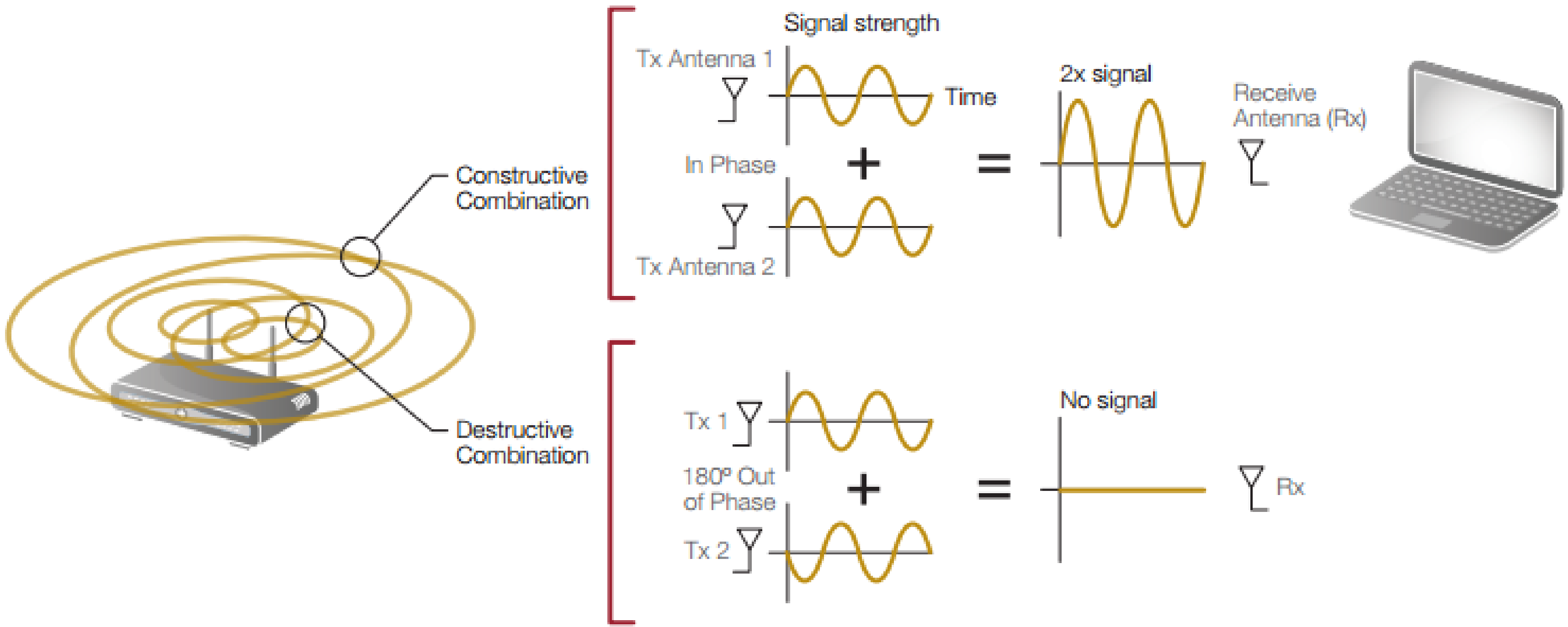
Maximal Ratio Combining

- Maximal ratio combining (MRC):
  - The algorithm a MIMO AP uses when it receives multiple copies of a signal from a non-MIMO device
  - The AP will receive multiple copies of the multipath signal on each of its Rx antennas
  - MRC multiplies each received signal by a weight factor that is proportional to the signal amplitude
    - A strong signal is further amplified while weaker signals are not used

Transmit Beam Forming (TxBF)



Transmit Beam Forming (TxBF)



https://www.youtube.com/watch?v=8rMtqRObvvU

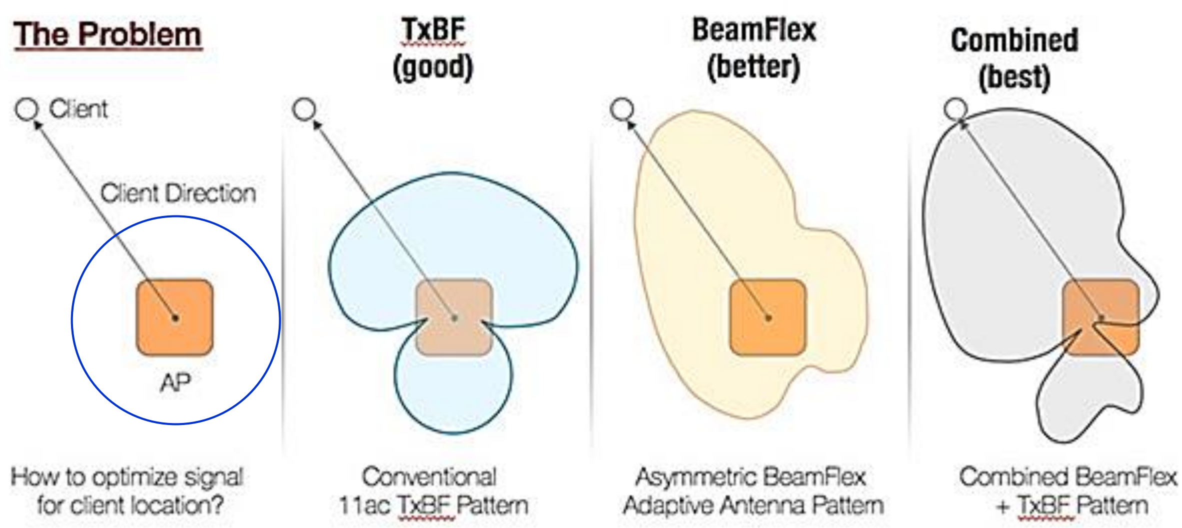
https://www.youtube.com/watch?v=UJlwWzEJug0

Transmit Beam Forming (TxBF)

- **Transmit Beam Forming (TxBF)**:
  An option for reducing outside signal interference by using complex antenna systems to allow for different directions and bandwidths

- **Explicit feedback**: a TxBF technique in which the receiver makes a series of computations and sends them to the transmitter, which then uses them to configure how to make the best transmissions

- **Implicit feedback**: information that is computed by the receiver and sent back to the transmitter for use in antenna configuration



Antenna Installation

- Some enterprise-grade APs allow for attaching an external antenna

- Installing an external antenna involves:
  - Positioning it at the best location
  - Using the correct installation accessories
  - Measuring antenna performance

Antenna (AP) Location

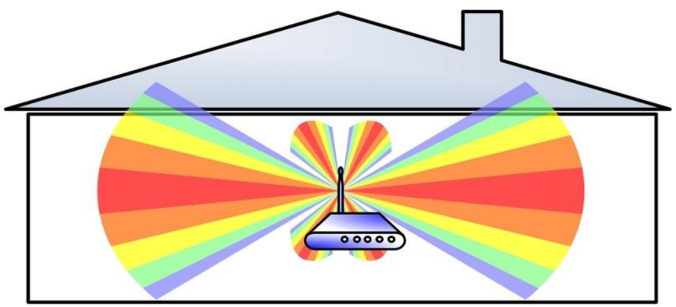
- Because WLAN systems use omnidirectional antennas to provide broadest area of coverage, APs should be located near middle of coverage area

- Antenna should be positioned as high as possible
  - To avoid obstructions for the RF signal
  - To deter thieves from stealing the device ☺

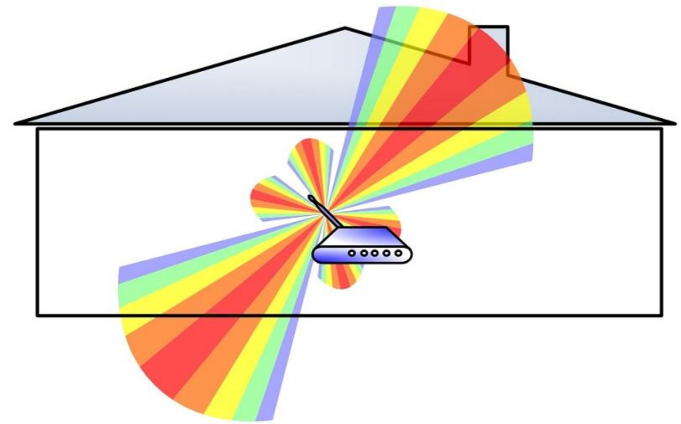
- Outdoor antennas are usually affixed to a pole or mast
  - Antenna-mounting systems should be used

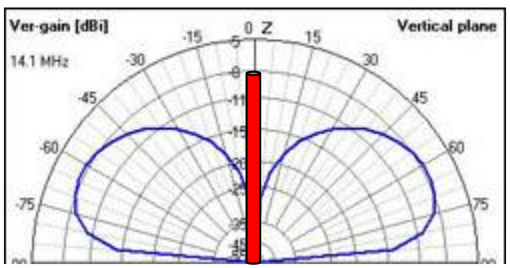
Antenna (AP) Location

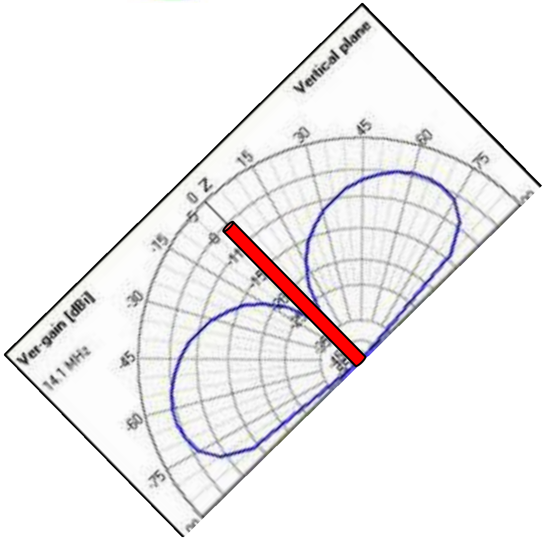
Beam Pattern with Wifi Antenna at 90° Angle



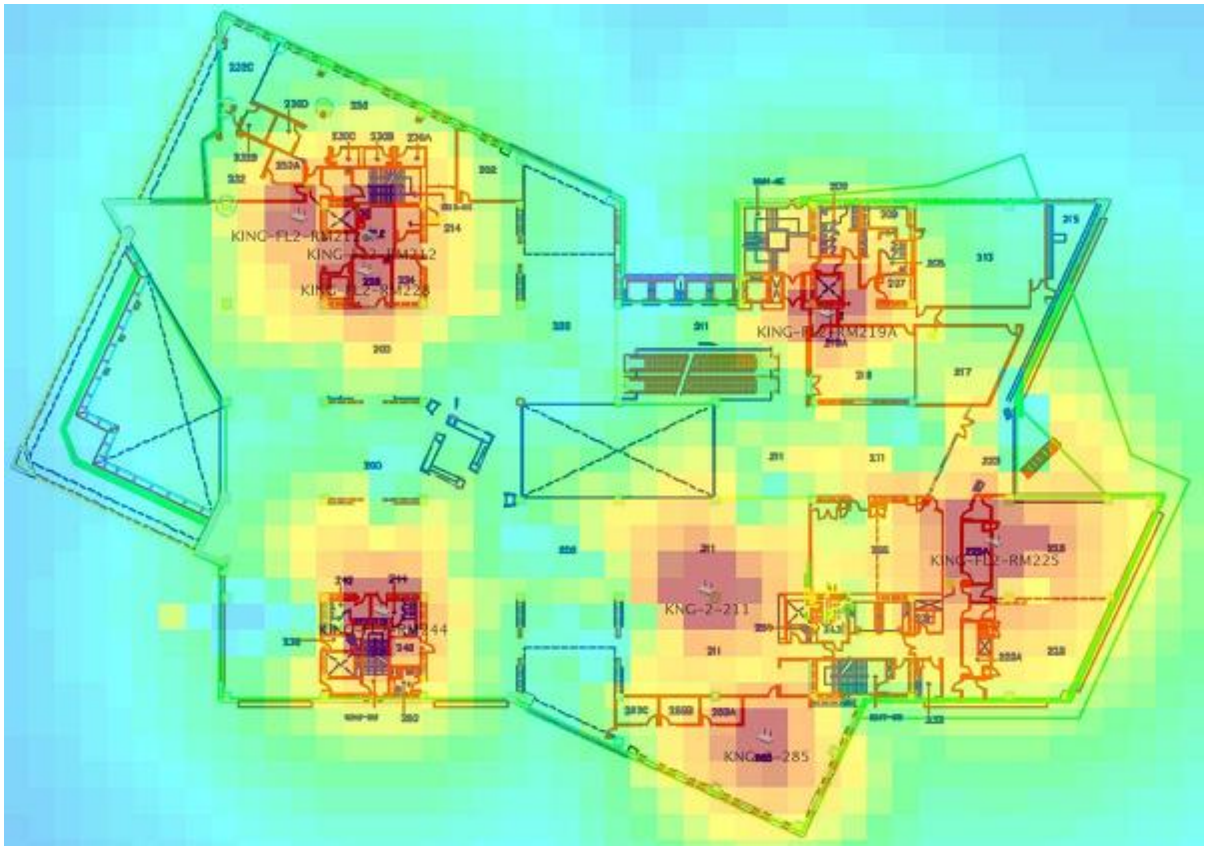
Beam Pattern with Wifi Antenna at 45° Angle







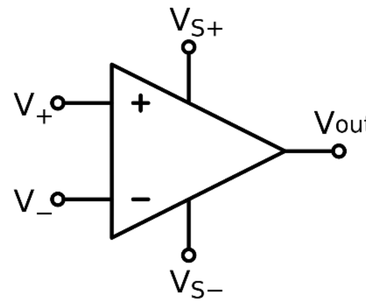
Antenna (AP) Location



Antenna Accessories

- Antenna accessories provide additional functionality and safety
- Antenna accessories include:
  - Amplifiers
  - Attenuators
  - RF cable and connectors
  - Lightning arrestors

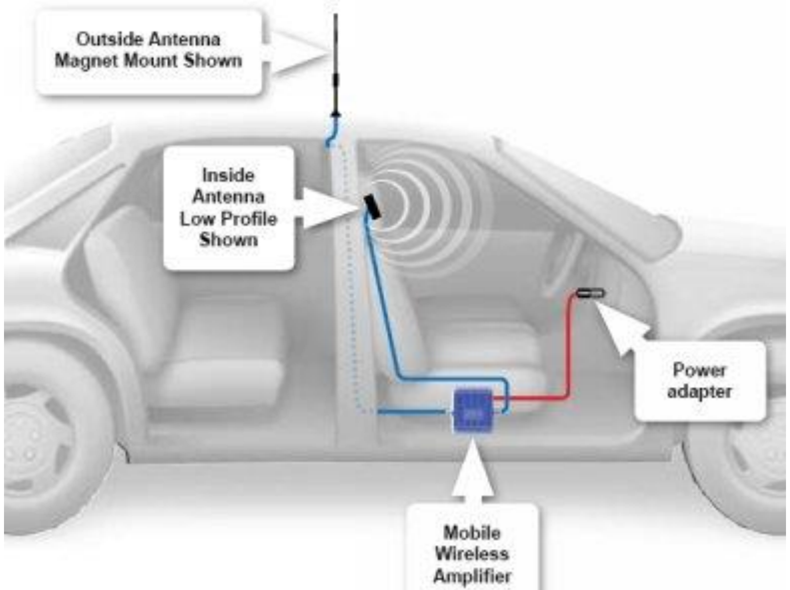
Amplifier



- **Amplifier**: device that increases the amplitude of an RF signal
  Often necessary to "boost" the strength of a signal to compensate for its loss of power

- **Unidirectional amplifier**: increases the RF signal level before it is injected into the transmitting antenna

- **Bidirectional amplifier**: boosts the RF signal before it is injected into the device that contains or is directly connected to the antenna
  - Most amplifiers for WLANs are bidirectional

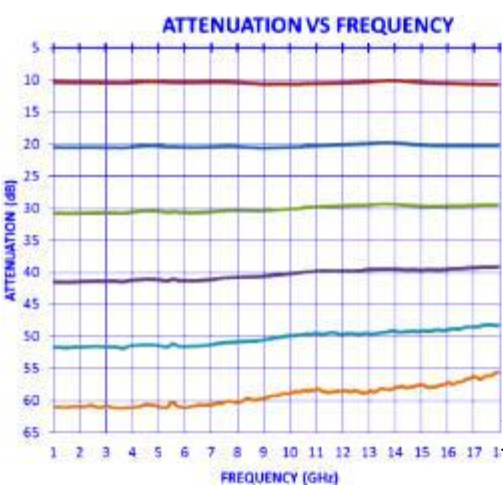


Attenuators

- **RF attenuator**: decreases the RF signal and is used when the gain of an antenna did not match the power output of an AP

- **Fixed-loss attenuators**: limit the RF power by a set amount
  - The only type permitted by the FCC for WLAN systems

- **Variable-loss attenuators**: allow the user to set the amount of loss



RF Cables and Connectors

- Basic rules for selecting cables & connectors:
  - Connector should match the electrical capacity of the cable and device to which it is connected
  - Use only high-quality from well-known suppliers
  - Cable lengths should be as short as possible
  - Low loss cables should be preferred
  - Cables should match electrical capacity of the connectors
  - Purchase pre-manufactured cables

  - Use RF signal splitters sparingly
    - **RF signal splitter**: device with one input and two or more outputs

Lightning Arrestor

- Antennas can pick up high electrical discharges from a nearby lightning strike
- Lightning arrestor: limits the amplitude and disturbing interference voltage by channeling them to the ground
  - Installed between the antenna cable and the wireless device

Figure 4-18 Lightning arrestor

Measuring Antenna Performance

- Measurements that relate to the performance of RF transmissions from antennas:
  - Link budget
  - System operating margin (SOM)
  - Voltage standing wave ratio (VSWR)

Link Budget

- Link budget: rough calculation of all known elements of a link to determine if a signal will have the proper strength when it reaches its destination

- Needed to make an accurate link budget:
  - Antenna gain
  - Free space path loss
  - Frequency of the link
  - Loss of each connector at the specified frequency
  - Number of connectors used
  - Path length
  - Power of the transmitter
  - Total length of transmission cable

Link Budget


Tx antenna gain (+)
Rx antenna gain (+)
Free space path loss (−)
Tx cable (−)
Rx cable (−)
Connector (−)
Connector (−)
Transmitter
Receiver
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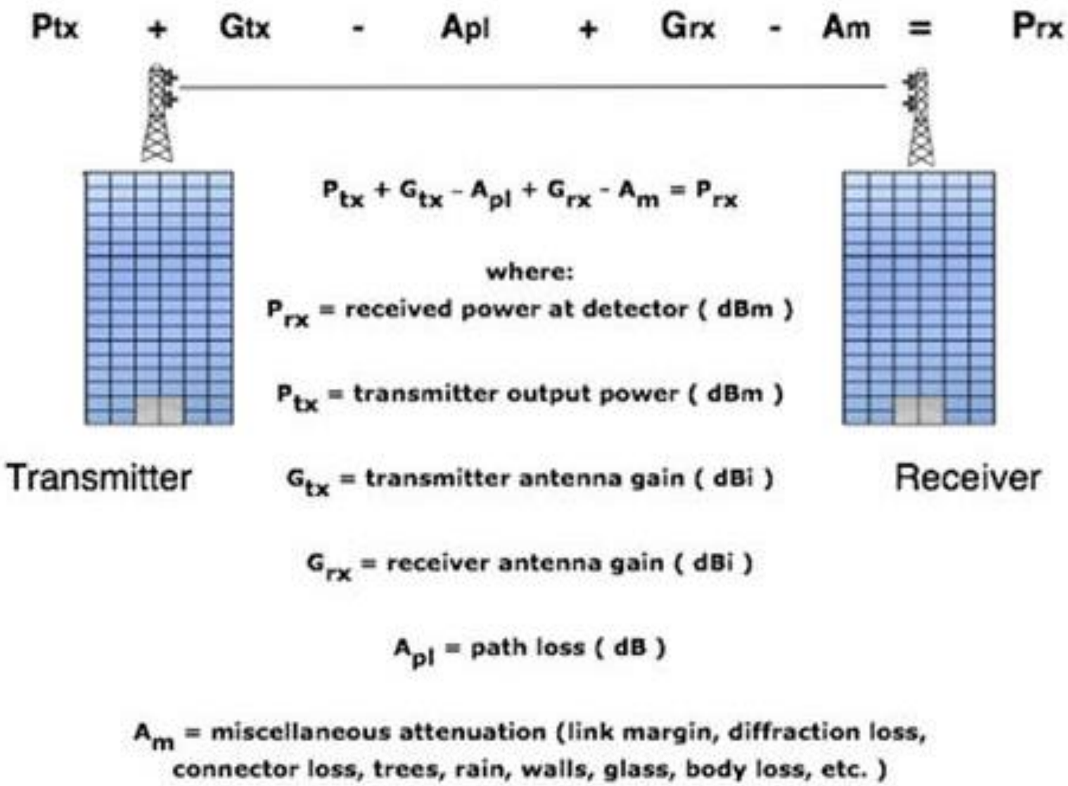
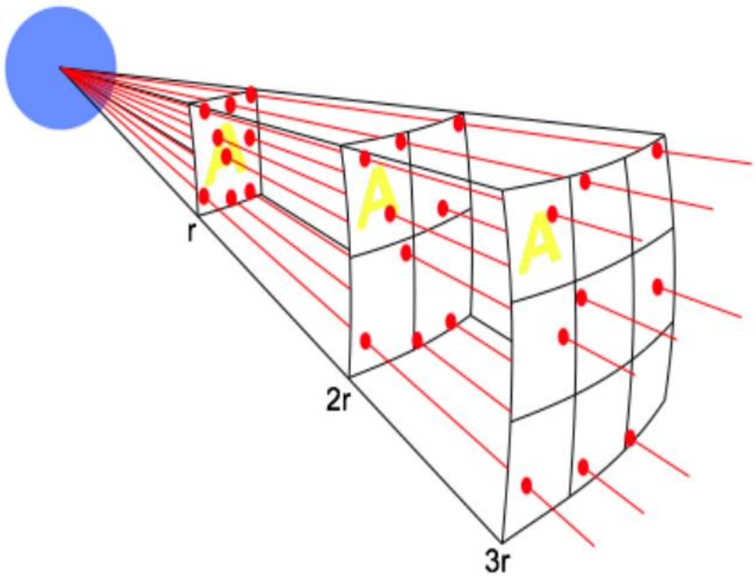
Link Budget


Ptx + Gtx - Apl + Grx - Am = Prx
Transmitter
Receiver
$P_{tx} + G_{tx} - A_{pl} + G_{rx} - A_m = P_{rx}$
where:
P_{rx} = received power at detector (dBm)
P_{tx} = transmitter output power (dBm)
G_{tx} = transmitter antenna gain (dBi)
G_{rx} = receiver antenna gain (dBi)
A_{pl} = path loss (dB)
A_m = miscellaneous attenuation (link margin, diffraction loss, connector loss, trees, rain, walls, glass, body loss, etc.)

Free space loss

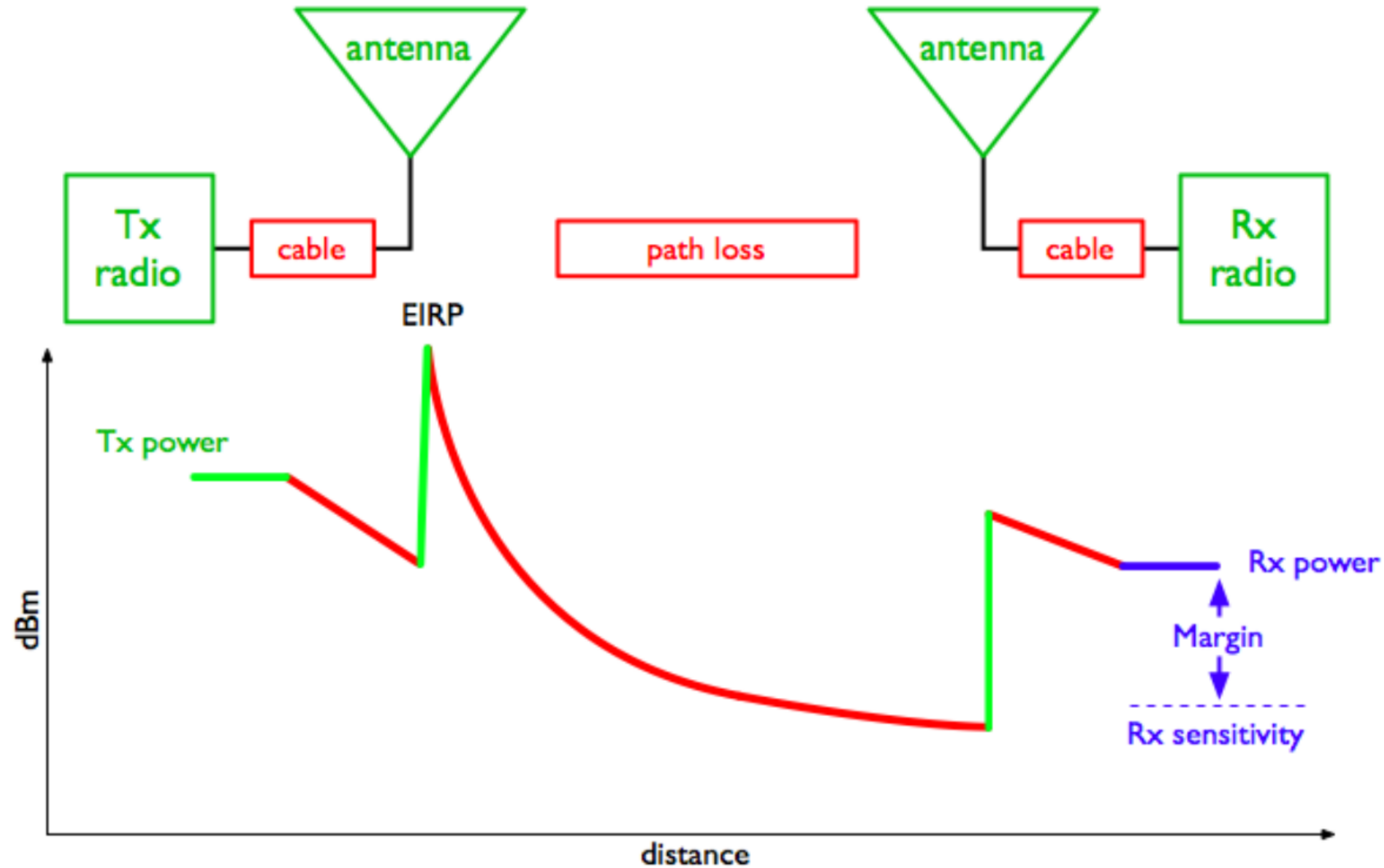
- Signal power is diminished by geometric spreading of the wavefront, commonly known as ***Free Space Loss***.
- The power of the signal is spread over a wave front, the area of which increases as the distance from the transmitter increases. Therefore, the power density diminishes.



	FSPL (dB)		
Distance	900MHz	2.4GHz	5.8GHz
1km	91.53	100.05	107.72
2km	97.56	106.07	113.74
3km	101.08	109.60	117.26
4km	103.58	112.10	119.76
5km	105.51	114.03	121.70
10km	111.53	120.05	127.72
20km	117.56	126.07	133.74
30km	121.08	129.60	137.26
40km	123.58	132.10	139.76
50km	125.51	134.03	141.70

$$FSPL(dB) = 10\log_{10}\left(\frac{4\pi d f}{c}\right)^2$$

Power in a wireless system



Example link budget calculation

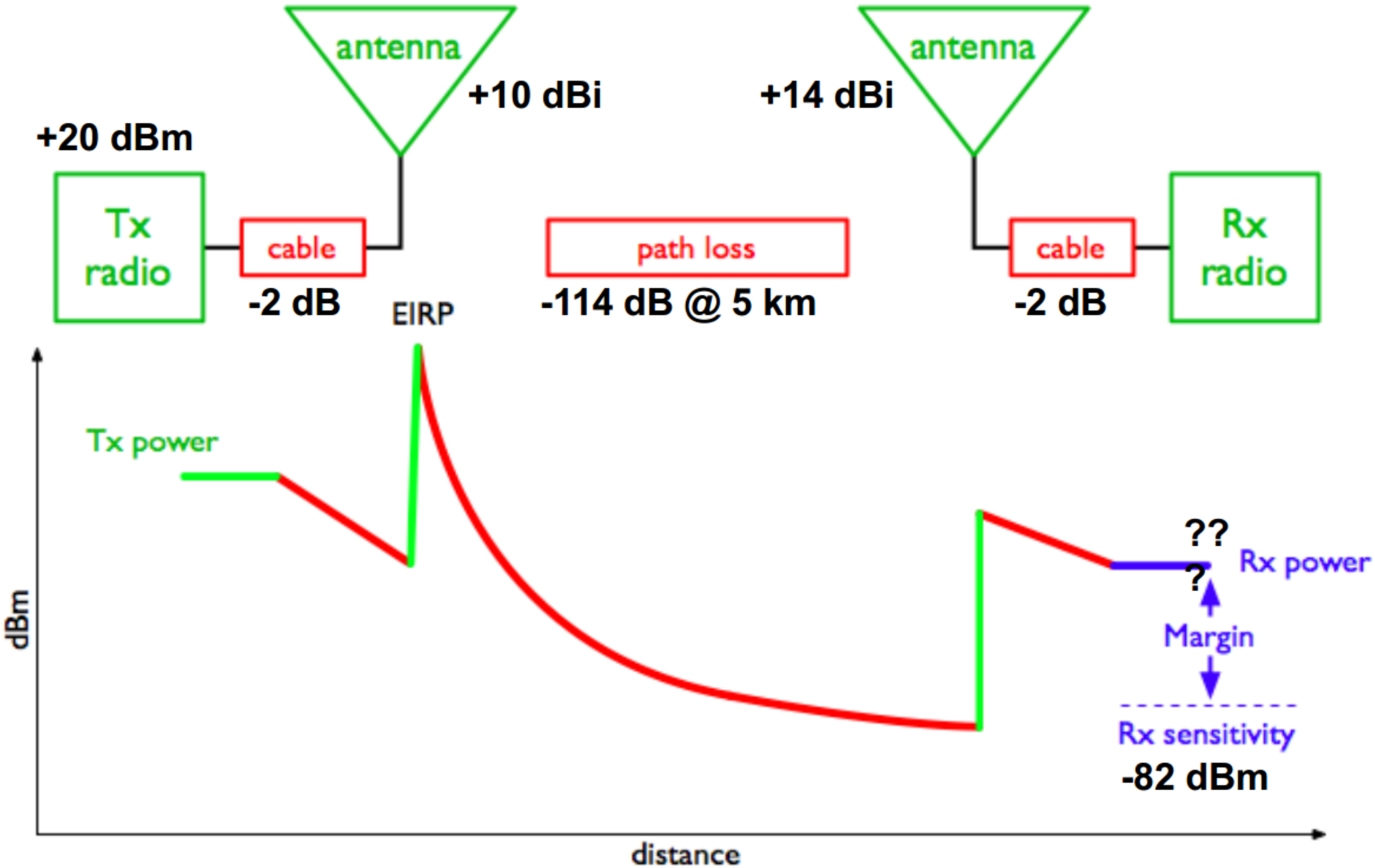
Let’s estimate the feasibility of a **5 km** link, with one access point and one client radio.

The access point is connected to an antenna with **10 dBi** gain, with a transmitting power of **20 dBm** and a receive sensitivity of **-89 dBm**.

The client is connected to an antenna with **14 dBi** gain, with a transmitting power of **15 dBm** and a receive sensitivity of **-82 dBm**.

The cables in both systems are short, with a loss of **2dB** at each side at the 2.4 GHz frequency of operation.

AP to Client link



Link budget: AP to Client link

20 dBm (TX Power AP)
+ 10 dBi (Antenna Gain AP)
- 2 dB (Cable Losses AP)
+ 14 dBi (Antenna Gain Client)
- 2 dB (Cable Losses Client)

---

40 dB Total Gain
-114 dB (free space loss @5 km)

-74 dBm (expected received signal level)
--82 dBm (sensitivity of Client)

---

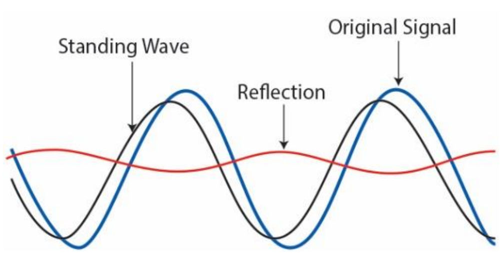
8 dB (link margin)

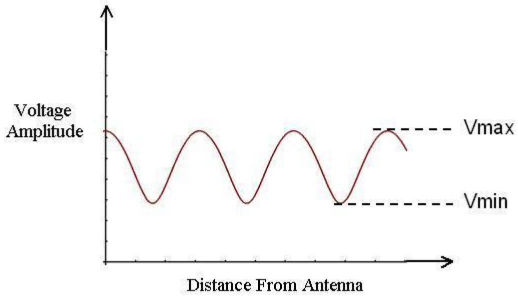
System Operating Margin (SOM)

- **System operating margin (SOM)**: difference between the received signal level and the signal level that is required by that radio to assure that the transmission can be decoded without errors
  - Also referred to as the **fade margin**
- **Sensitivity**: signal strength needed for a good reception

Voltage Standing Wave Ratio (VSWR)

- Voltage standing wave ratio (VSWR): measure of how well an electrical load is impedance-matched to its source
  - Impedance: term applied to any electrical entity that hinders the flow of current
  - Value of VSWR is expressed as a ratio (2:1, 3.1)
  - Perfect impedance match of the maximum power transferred from the source corresponds to a VSWR of 1:1





$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|}$$

$$\text{VSWR} = \frac{V_{max}}{V_{min}}$$

Summary

- An antenna is used to send electromagnetic waves to a receiving device
- Four measurements are used with antennas: intentional radiator, Equivalent Isotropically Radiated Power, decibels isotropic (dBi), and decibels dipole (dBd)
- There are three categories of antennas: omnidirectional antenna, semidirectional antenna, highly-directional antenna
- A chart used to illustrate the radiation pattern of an antenna is called an antenna radiation chart

Summary

- Multiple-input multiple-output (MIMO) systems have separate radio chains connected to each antenna
- MIMO can take advantage of different signaling processing techniques in order to create high throughput
- Four signaling processing techniques: spatial diversity, spatial multiplexing, maximal ratio combining, and transmit beam forming
- Installing an external antenna involves positioning it at the best location, using correct installation accessories, and measuring antenna performance

Summary

- Antenna accessories that can provide improved functionality include: amplifiers, attenuators, RF cable and connectors, and lightning arrestors

- Several measurements relate to the performance of RF transmissions from antennas: link budget, system operating margin (SOM), and voltage standing wave ratio (VSWR)