ICA0008
Fundamentals of Wireless LANS

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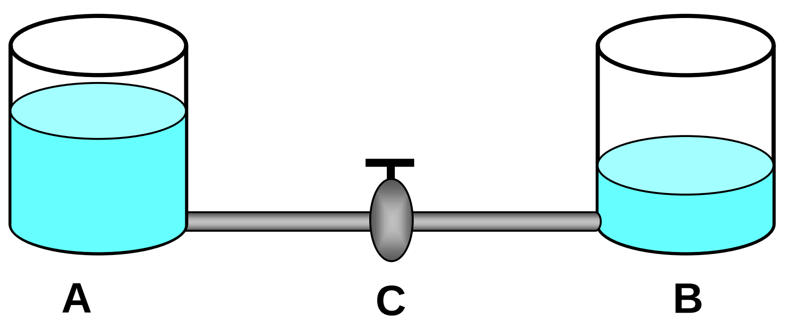
Radio Frequency
and
Antenna Fundamentals

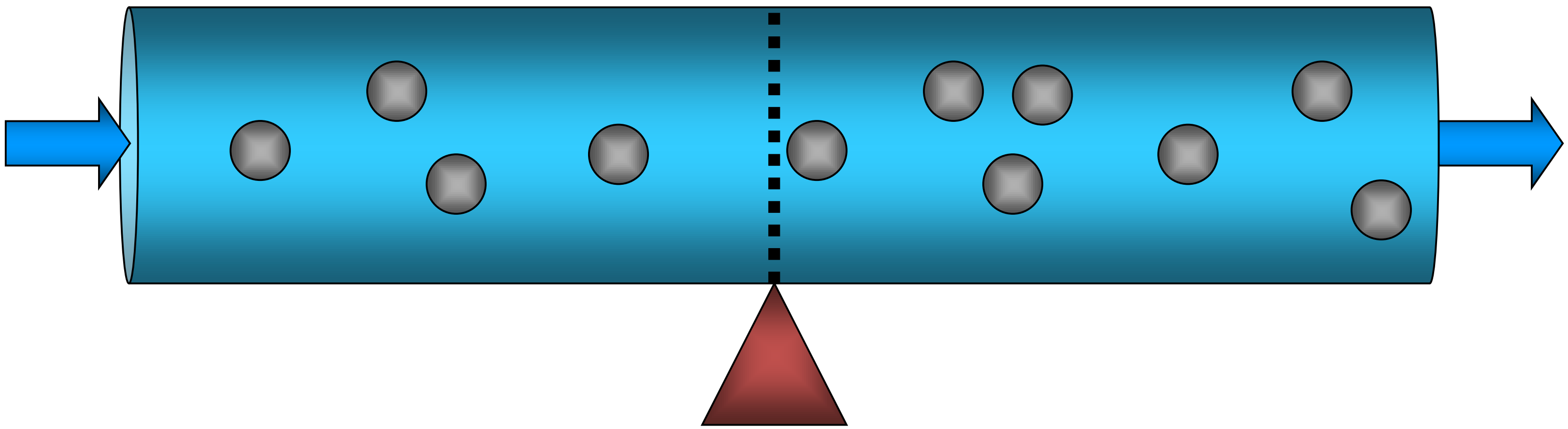
Parameters & Units of Measure

- Voltage
  - electric potential or potential difference expressed in volts.
- Volt –
  - a unit of potential equal to the potential difference between two points on a conductor carrying a current of 1 ampere when the power dissipated between the two points is 1 watt.



Parameters & Units of Measure

- Current
  - a flow of electric charge (electrons); The amount of electric charge flowing past a specified circuit point per unit time.
  - Ampere



Parameters & Units of Measure

- Power –
  - The rate at which work is done, expressed as the amount of work per unit time.
  - Watt
    - An International System unit of power equal to one joule per second. The power dissipated by a current of 1 ampere flowing between 1 volt of differential.

$$P = I \times E$$
$$P = 1A \times 1V = 1W$$

Metric SI Prefixes

- SI prefixes combine with any unit name to give subdivisions and multiples.

Prefix	Symbol	Magnitude	Multiply by
femto-	f	10^{-15}	0.000 000 000 000 001
micro-	μ(mu)	10^{-6}	0.000 001
milli-	m	10^{-3}	0.001
kilo-	k	10^{+3}	1000
Mega	M	10^{+6}	1 000 000
Giga	G	10^{+9}	1 000 000 000

Power, Watts and milli-watts

1 W = 1000 mW, $1000 \times 10^{-3} = 1 \times 10^{+3} \times 10^{-3} = 1W$

30 mW = 0.030 W

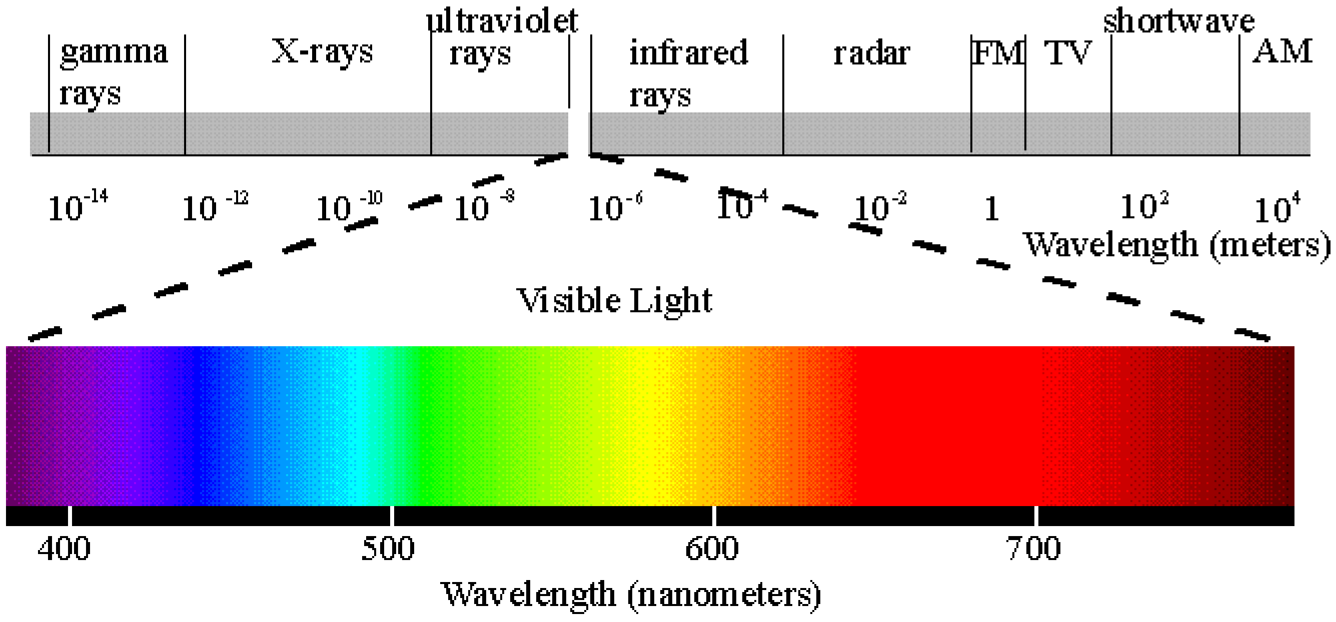
300 mW = 0.3 W

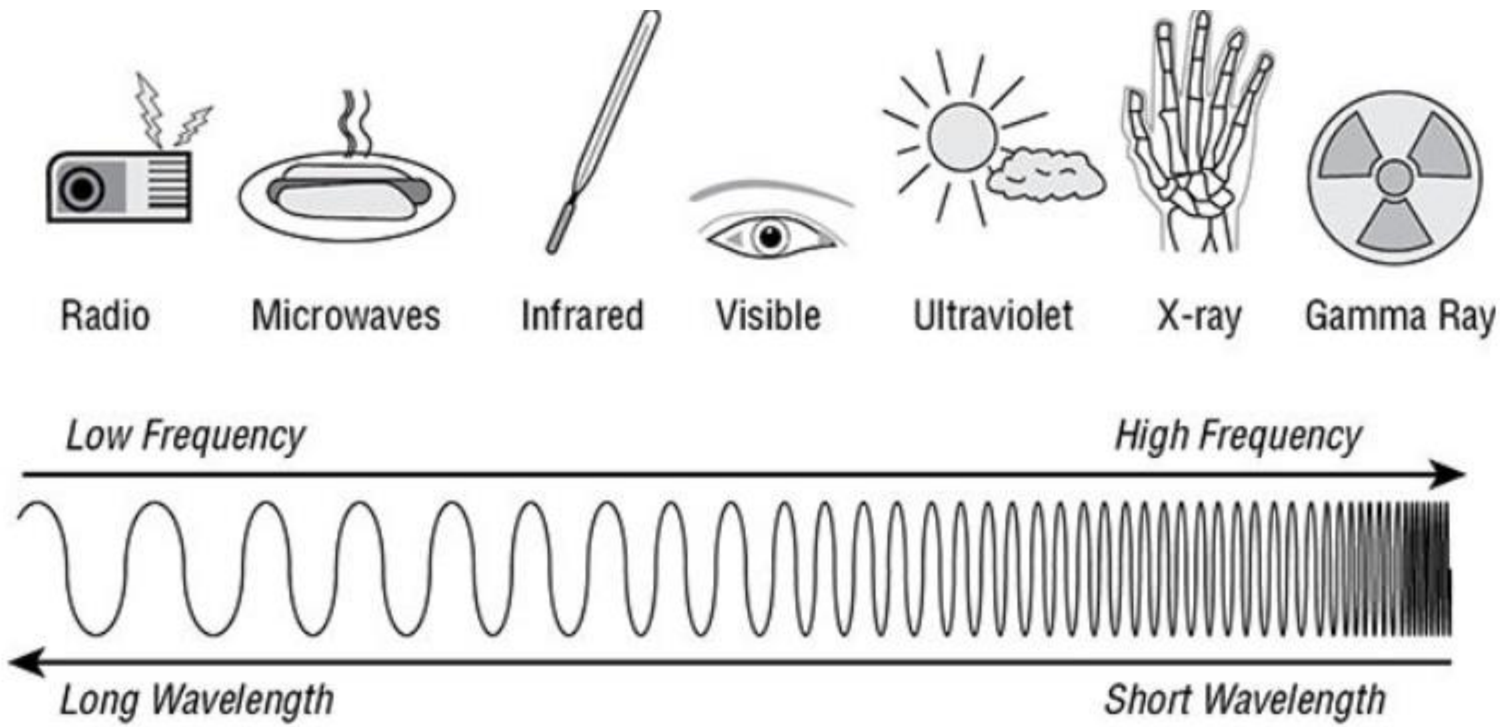
4 W = 4000 mW

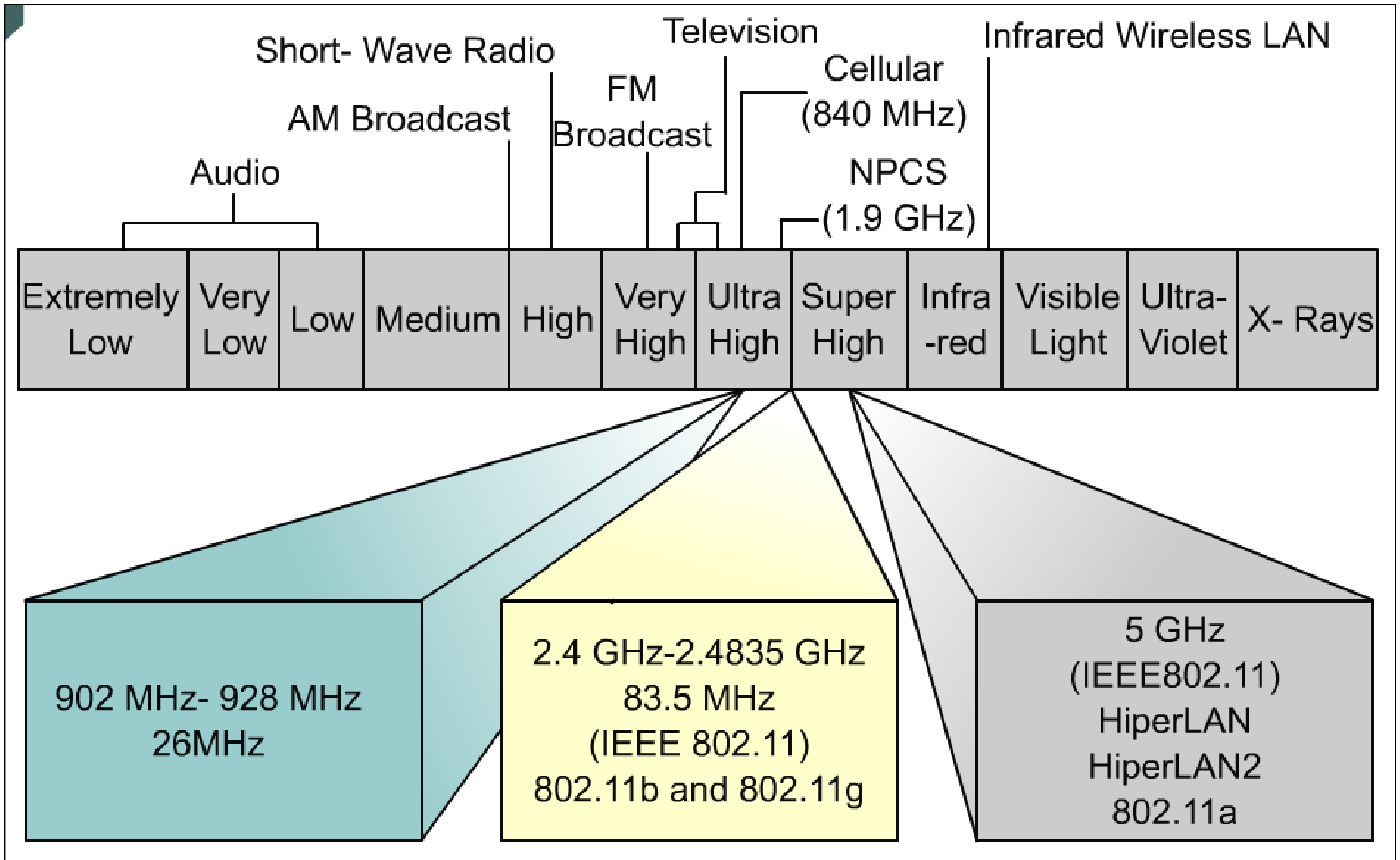
4 mW = 0.004 W

Radio and the Electromagnetic Spectrum

- Radio frequencies are part of the electromagnetic spectrum




Radio
Microwaves
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
Low Frequency
High Frequency
Long Wavelength
Short Wavelength


Short- Wave Radio
Television
Infrared Wireless LAN
Cellular
(840 MHz)
FM
Broadcast
AM Broadcast
Audio
NPCS
(1.9 GHz)
Extremely Low
Very Low
Low
Medium
High
Very High
Ultra High
Super High
Infra -red
Visible Light
Ultra- Violet
X- Rays
902 MHz- 928 MHz
26MHz
2.4 GHz-2.4835 GHz
83.5 MHz
(IEEE 802.11)
802.11b and 802.11g
5 GHz
(IEEE802.11)
HiperLAN
HiperLAN2
802.11a

Early Radio

Marconi at his Instrument in the station on Signal Hill, St John's, Newfoundland, from *Scientific American*

- 1895 Marconi was not the first
- 1906 Reginald Fessenden , 11 miles land to sea
- 1927 First transatlantic telephone
- 1924 Bell Labs two-way voice carrying radio
- Radio first used for voice and broadcast
- Then used by military

SPARK

1895 by Marconi

AM

1906 by Fessenden

SHORTWAVE

1921 by Conrad

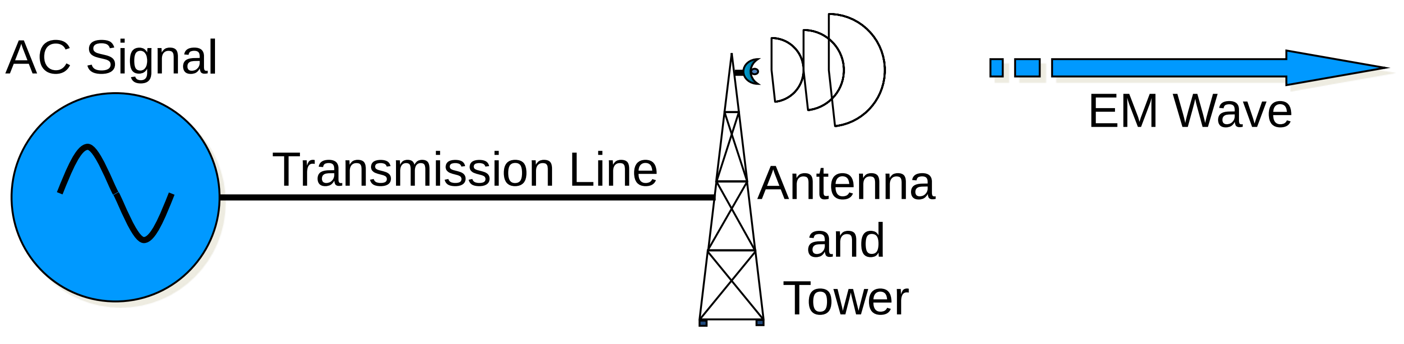
FM

1931 by Armstrong

crystal radio receiver 1921 from GEC Archives

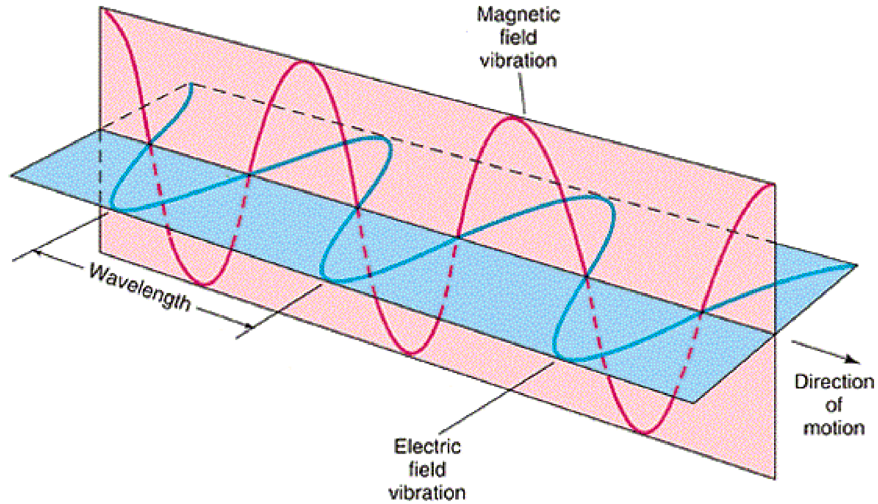
Radio Frequency

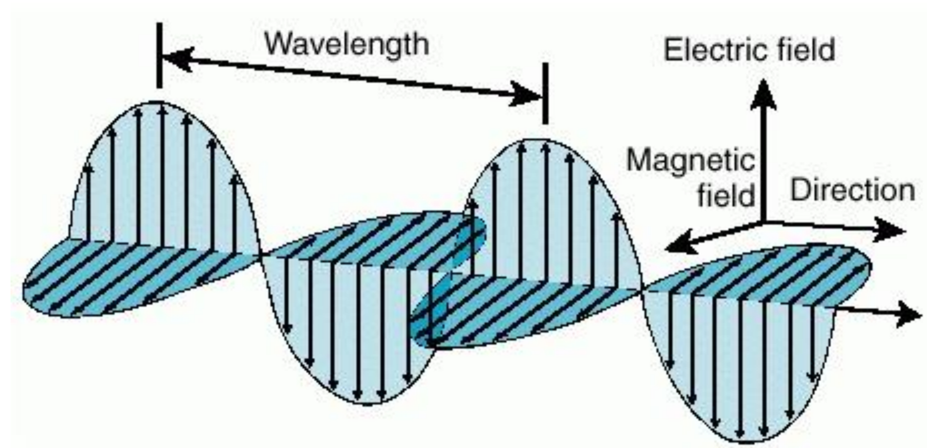
- Radio frequency, (RF)
  - is a term that refers to alternating current, (AC) having characteristics such that, if the current is input to an antenna, an electromagnetic (EM) field/wave is generated suitable for wireless communications.
  - Frequency (f - Hz)
    - Frequency is the number of occurrences of a repeating event per unit time.



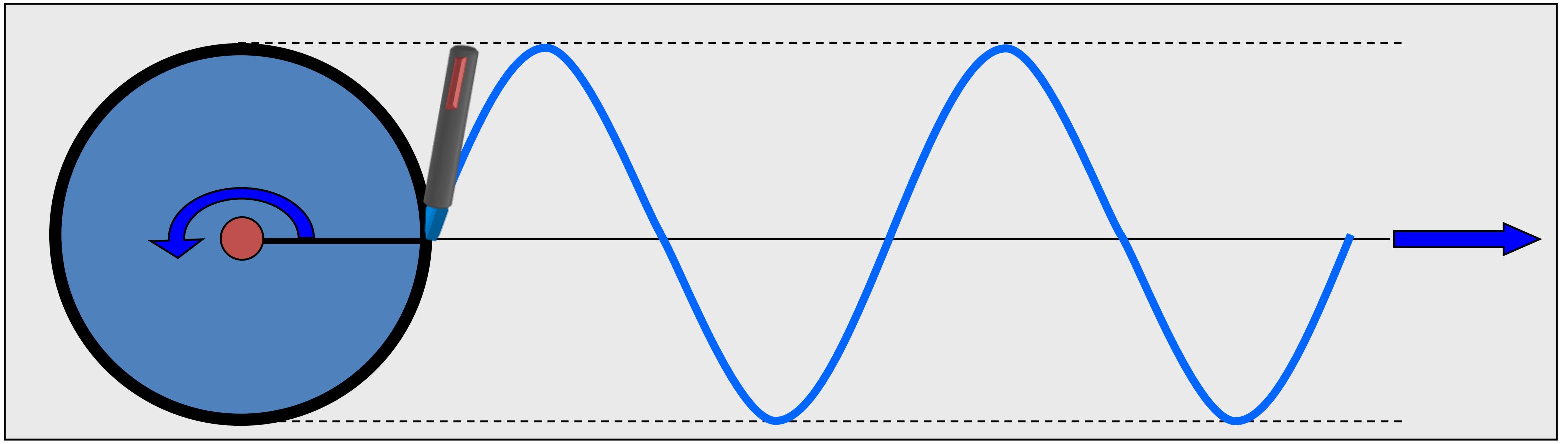
Electromagnatic Waves

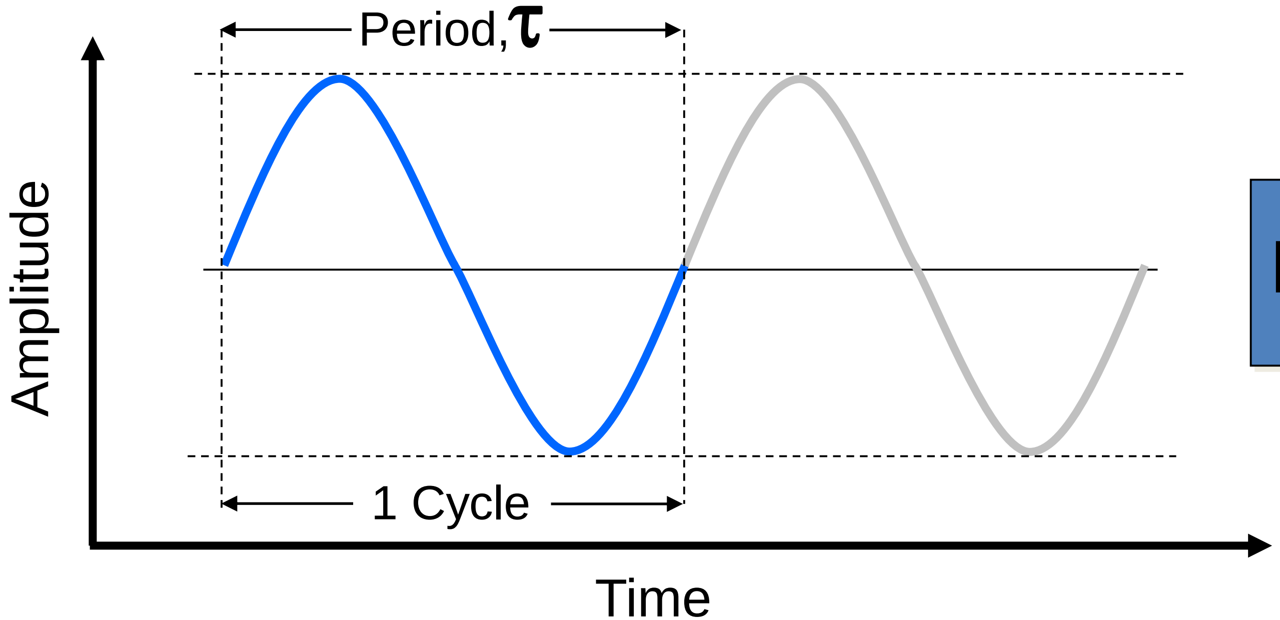
- Electromagnetic waves are made up of electric wave and magnetic waves at right angles
- The wave moves at right angle to the electric and magnetic waves
- In a vacuum the wave moves at the speed of light (3×10^8 meter/sec)
- Electric field is the force on an electric charge
- A moving electric field will produce a moving magnetic field, which produces a moving electric field, ad infinitum





Sine Wave Cycle

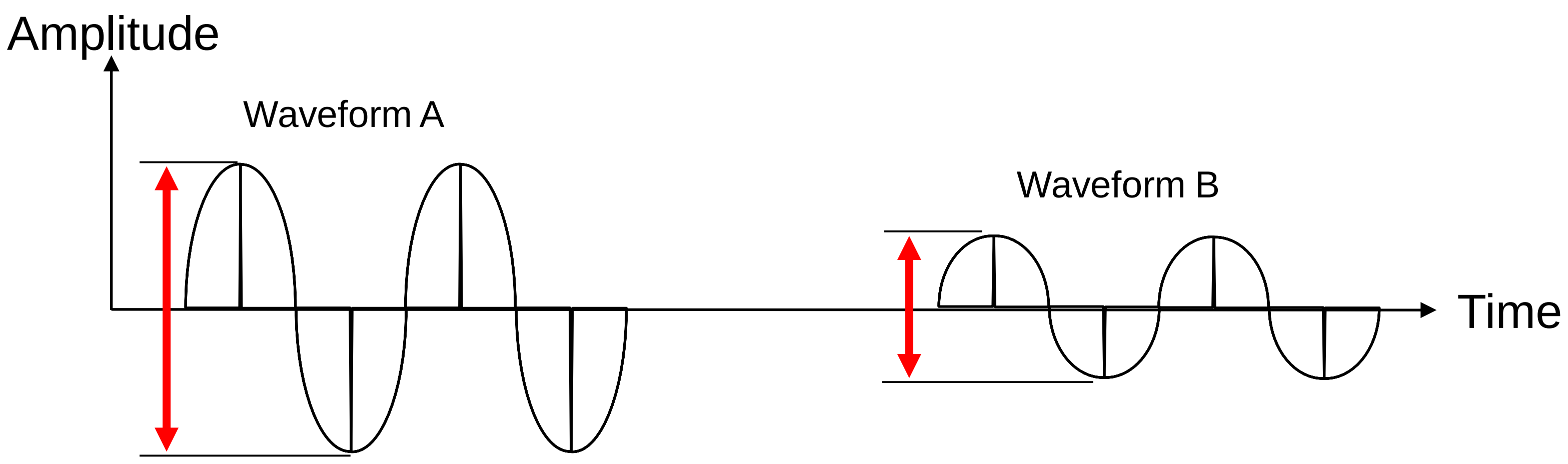




$$F = \frac{1}{\tau}$$

RF Properties

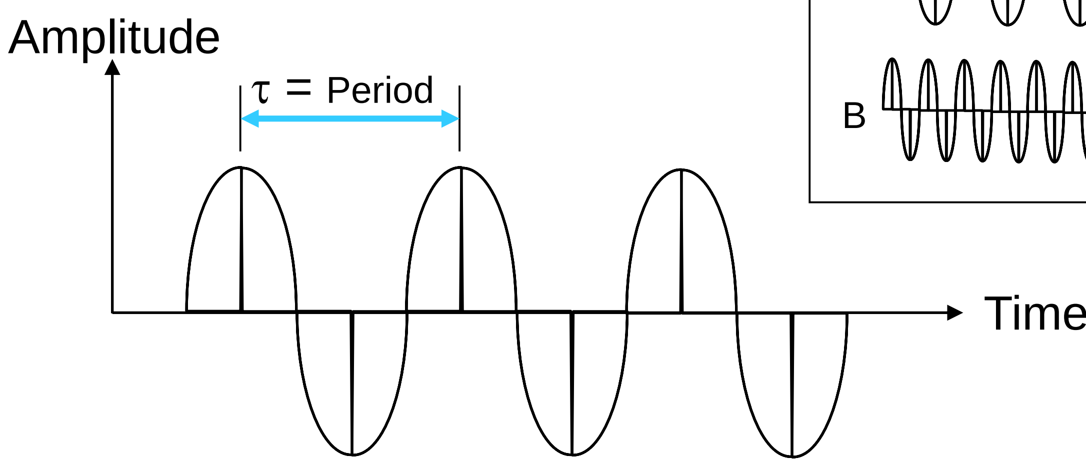
- Amplitude
  - The amount of a signal. Amplitude is measured by determining the amount of fluctuation in air pressure for sound or the voltage of an electrical signal.

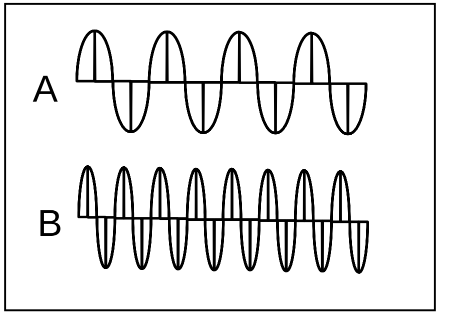


RF Properties

- Frequency
  - The number of repetitions per unit time of a complete waveform, measured in Hertz. The number of complete oscillations per second of electromagnetic radiation.

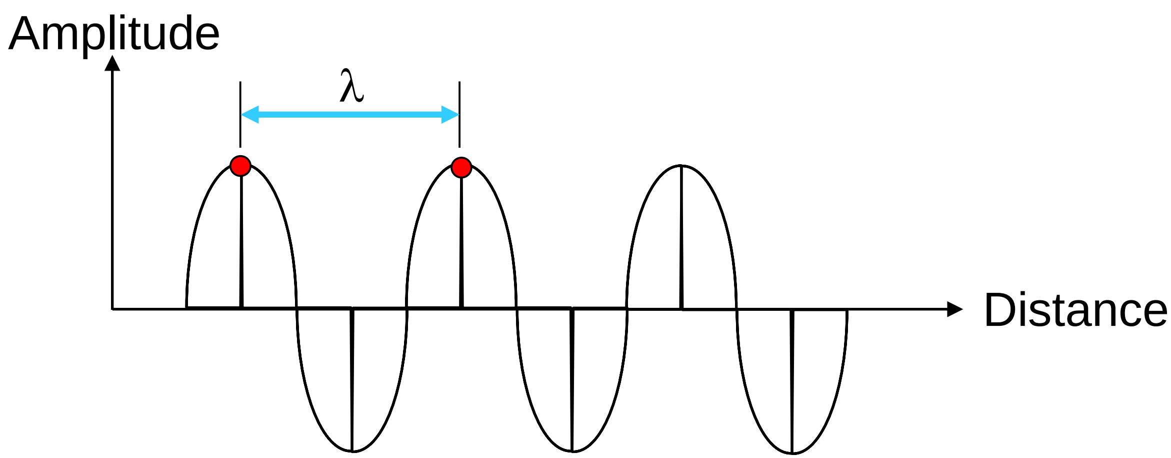
$F = 1/\tau$



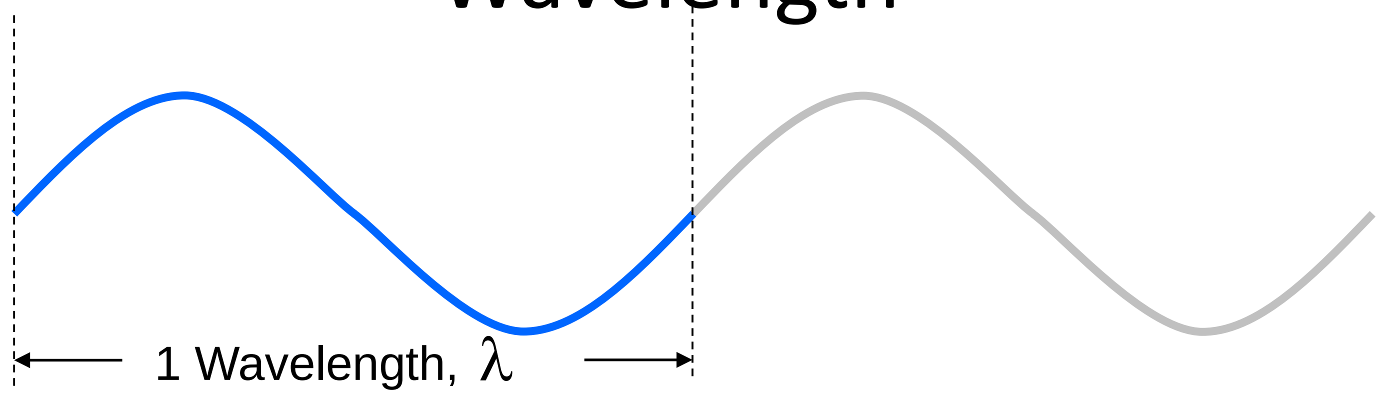


RF Properties

- Wavelength, λ
  - The distance that a wave travels in the time it takes to go through one full 360 degree phase change, or one cycle.



Wavelength



$$\lambda = \frac{300{,}000{,}000 \text{ m/s}}{2.45 \text{ GHz}}$$

$$\lambda = 0.122 \text{ m} = 12.2 \text{ cm}$$

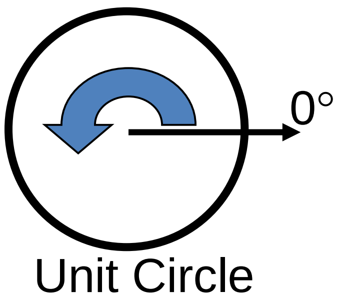
$$\lambda = \frac{300{,}000{,}000 \text{ m/s}}{\text{Frequency (Hz)}}$$

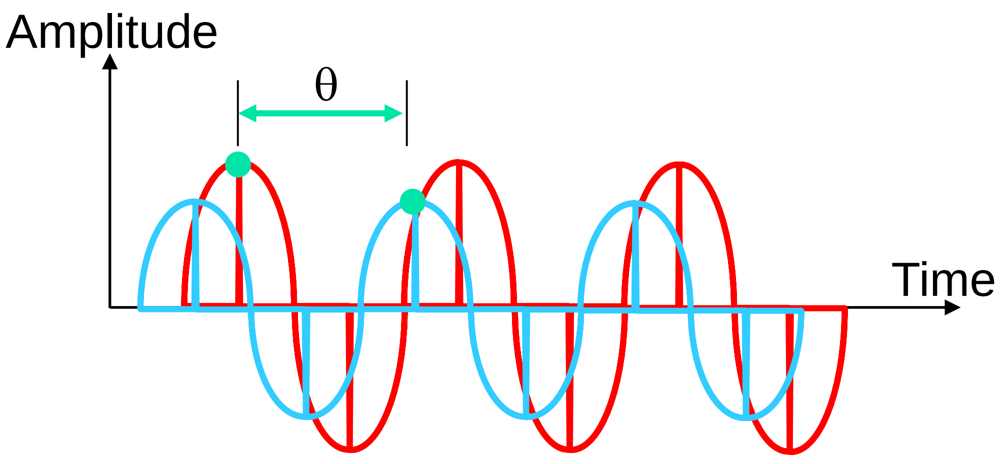
$$\lambda = \frac{984{,}000{,}000 \text{ f/s}}{\text{Frequency (Hz)}}$$

In a Vacuum

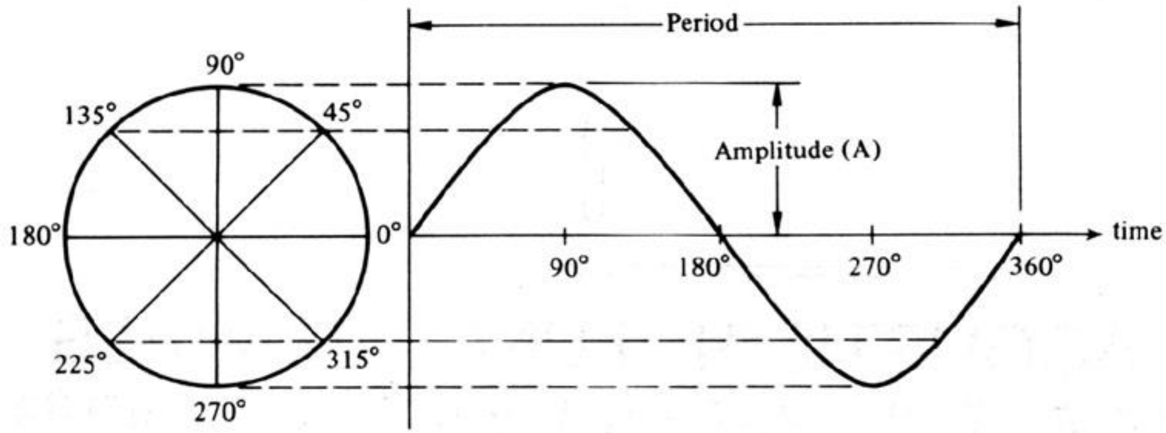
RF Properties

- Phase, θ
  - Time based relationship between a periodic function and a reference. In electricity, it is expressed in angular degrees to describe the voltage or current relationship of two alternating waveforms.

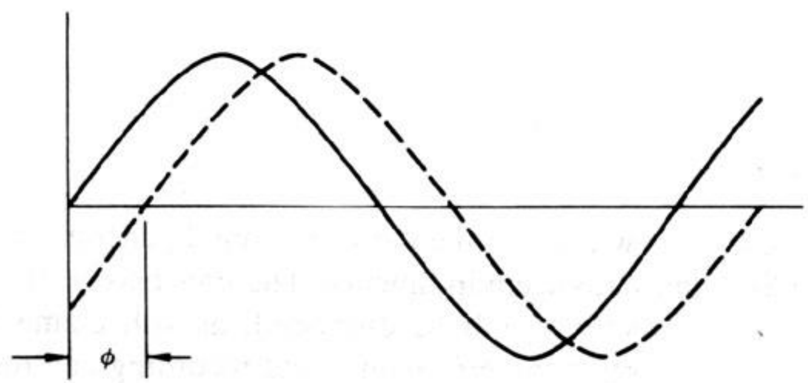




Frequency – Amplitude – Period – Phase



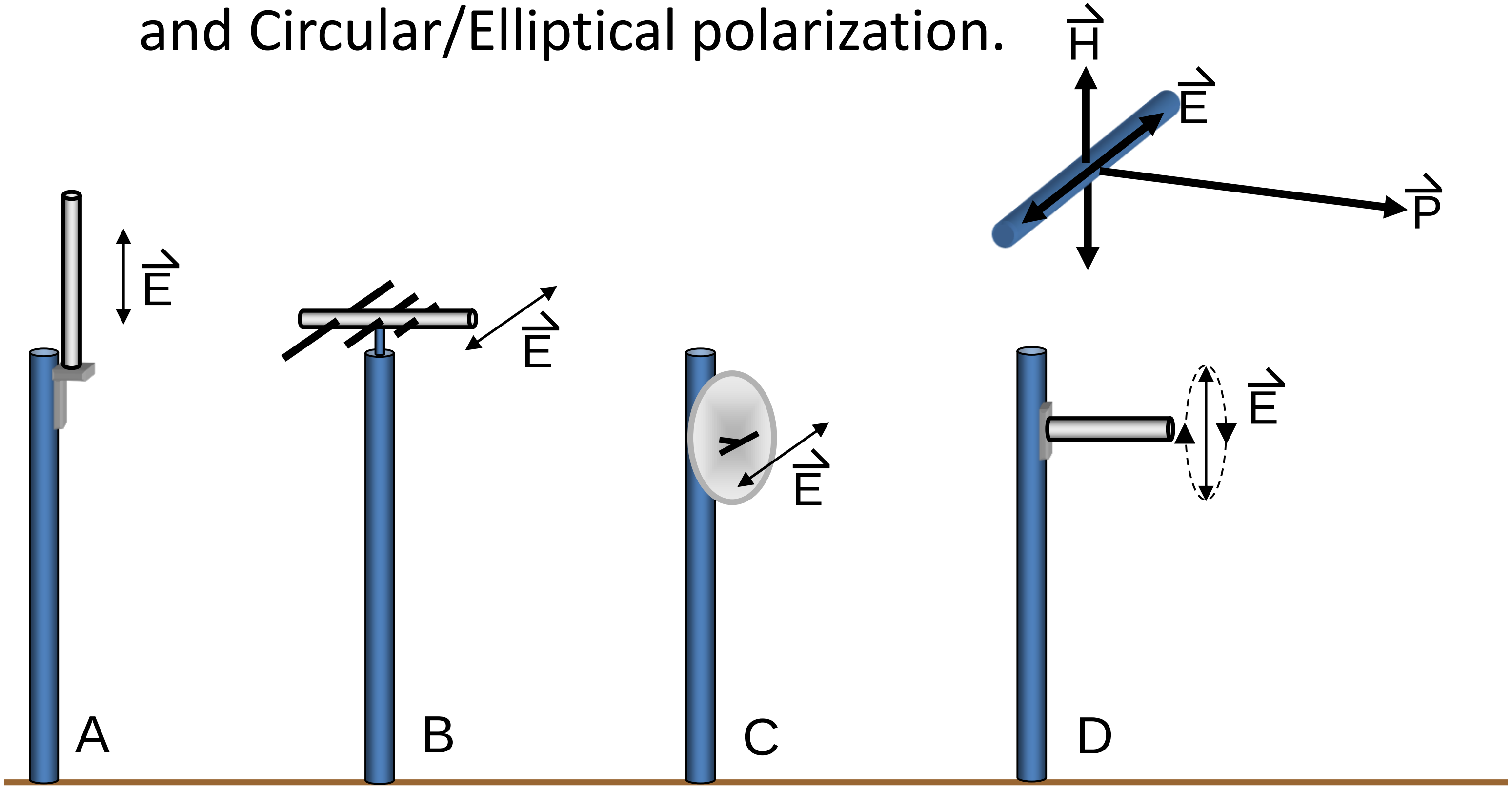
(a)



(b)

RF Properties

- Polarization
  - By convention the orientation of the electric field, (E) with respect to the earth's surface. Vertical, Horizontal, and Circular/Elliptical polarization.



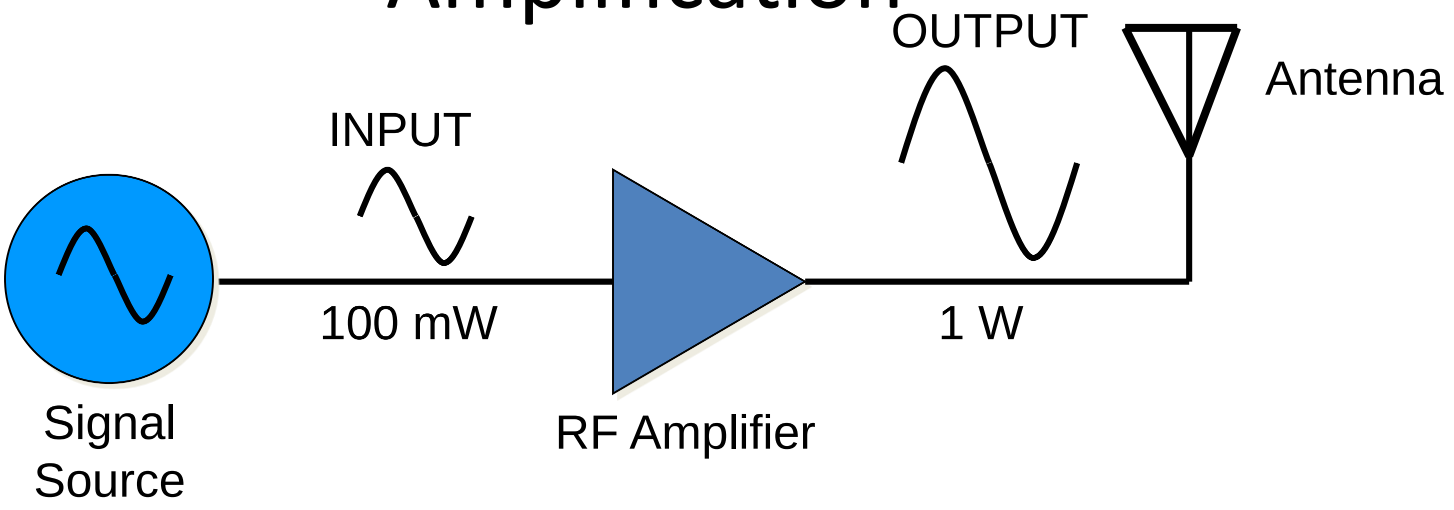
RF Spectrum

Designation	Abbreviation	Frequencies
Ultra High Frequency	UHF	300 MHz - 3 GHz
Super High Frequency	SHF	3 GHz - 30 GHz
Very Low Frequency - Extremely High Frequency	VLF - EHF	9 kHz – 300 GHz

Amplification and Attenuation

- Amplification/Gain –
  - An increase in signal level, amplitude or magnitude of a signal. A device that does this is called an amplifier.
- Attenuation/Loss –
  - A decrease in signal level, amplitude, or magnitude of a signal. A device that does this is called an attenuator.

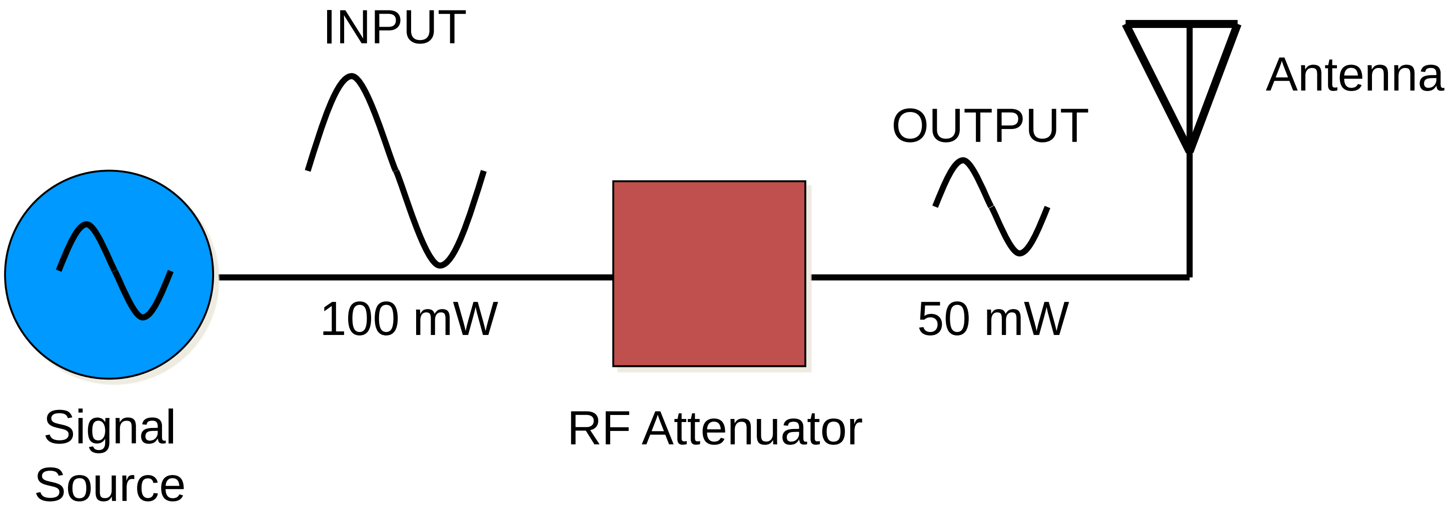
Amplification



The power gain of the RF amplifier is a power ratio.

$$\text{Power Gain} = \frac{\text{Power Output}}{\text{Power Input}} = \frac{1\ \text{W}}{100\ \text{mW}} = 10 \text{ no units}$$

Attenuation



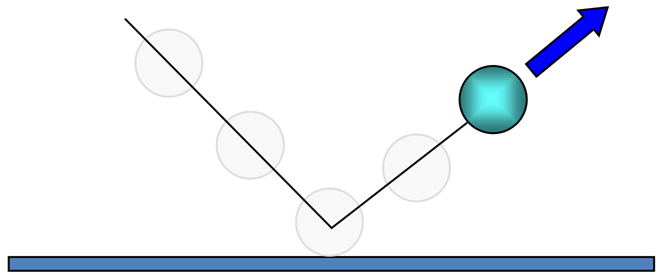
The power loss of the RF attenuator is a power ratio.

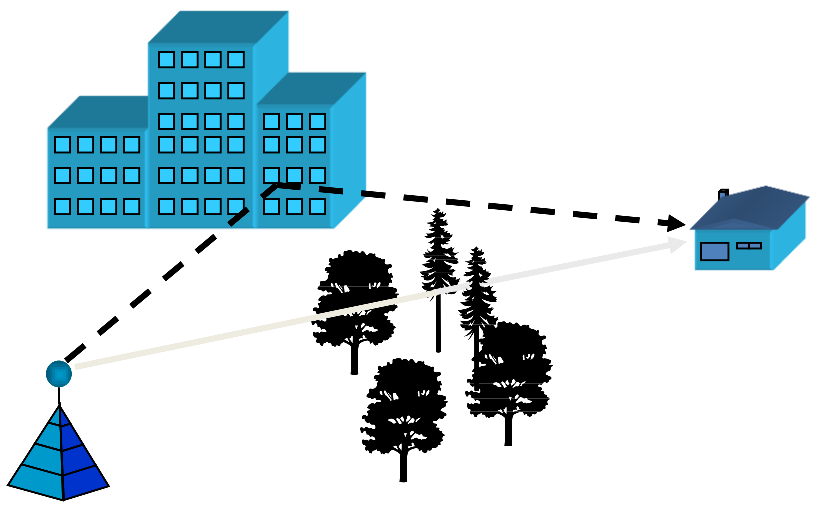
$$\text{Power Loss} = \frac{\text{Power Output}}{\text{Power Input}} = \frac{50\text{ mW}}{100\text{ mW}} = 0.5 \text{ no units}$$

- **Loss:** Negative difference in amplitude between signals
  - **Attenuation**
  - Can be intentional or unintentional
  - Intentional loss may be necessary to decrease signal strength to comply with standards or to prevent interference
  - Unintentional loss can be cause by many factors

Reflection

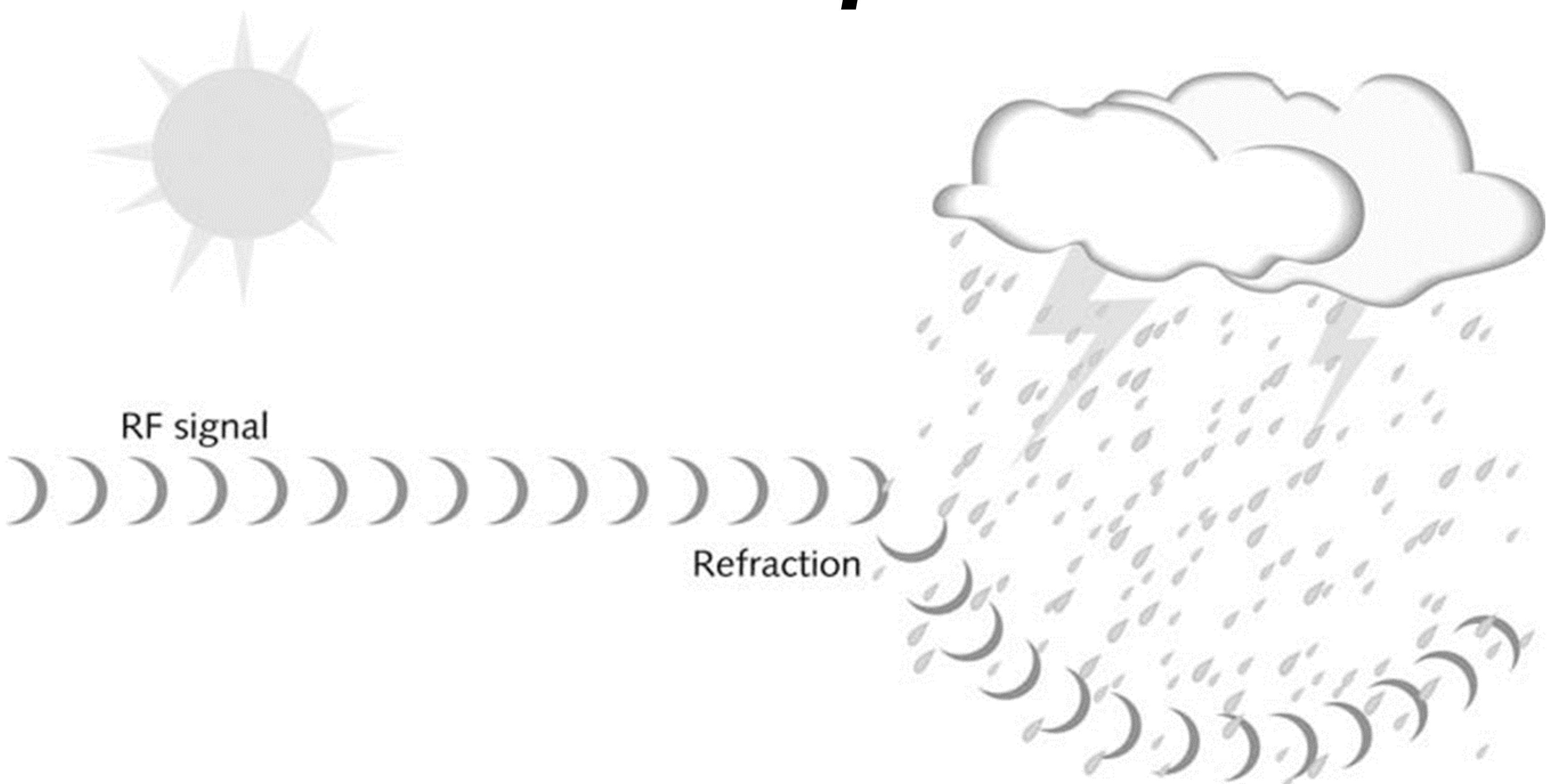
- cast off or turn back, (bouncing).





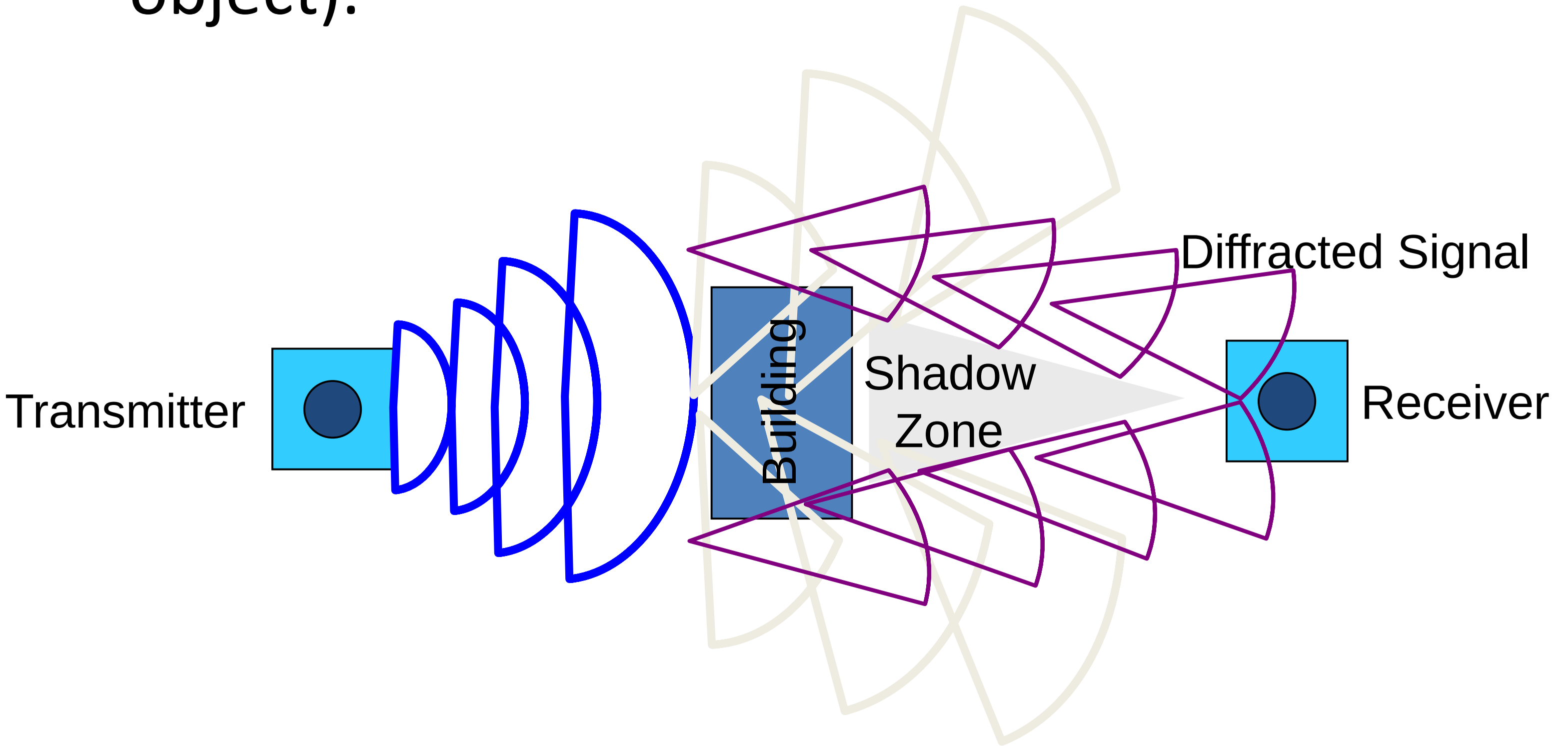
Refraction

- deflection from a straight path, (bending through a medium).



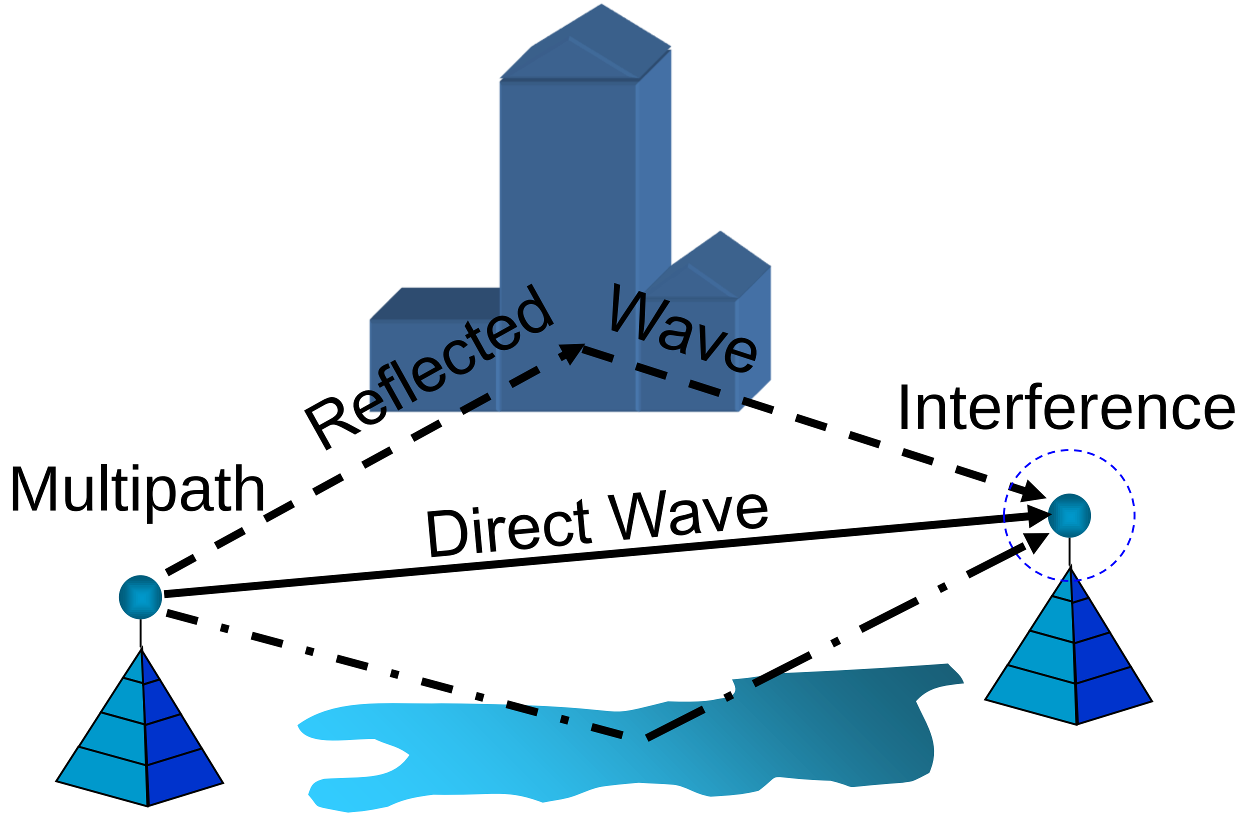
Diffraction

- Change in the directions and intensities of a group of waves when they pass near the edge of an EM *opaque* object (at sharp edges), (bending around object).



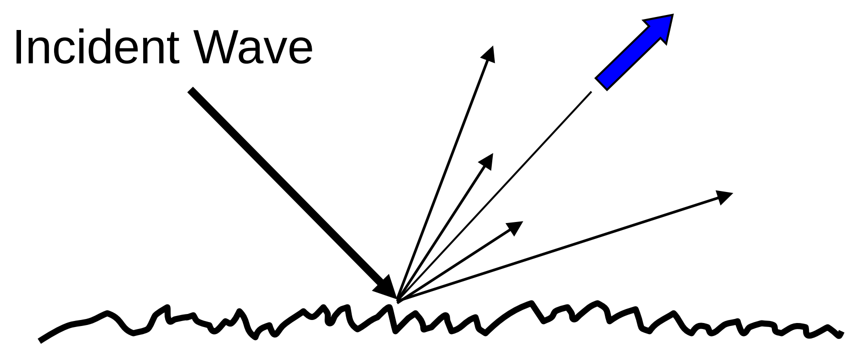
Interference

- hinders, obstructs, or impedes. When two or more wave fronts meet, (colliding).



Scattering

- A specification of the angular distribution of the electromagnetic energy scattered by a particle or a scattering medium, (dispersion).



Decibels

- The decibel is defined as one tenth of a bel where one bel is a unit of a logarithmic power scale and represents a difference between two power levels.

P_x and P_{ref} or P_{out} and P_{in}

The definition of a dB is:

$$dB = 10 \log_{10}(P_x / P_{ref})$$

Relative and Absolute dB

- Relative dB is selecting any value for P_{Ref}

dB

- Absolute dB is selecting a *standard* value for P_{Ref} and identifying the *standard* value with one or more letter following the dB variable.

dBm dBW dBV dBspl

What are log's ?

- log's or logarithms are way of representing a large range of numeric values. http://en.wikipedia.org/wiki/Logarithm http://www.math.utah.edu/~pa/math/log.html
  - Very small numbers and very large numbers
- The logarithm of a number *y* with respect to a base *b* is the exponent to which we have to raise *b* to obtain *y.*
- We can write this definition as
- $x = \log_b y$ <---> $b^x = y$ and we say that *x* is the logarithm of *y* with base *b* if and only if *b* to the power *x* equals *y*.

  Ex. b=10, Y=100, x=2, b=10, Y=100,000, b=5

  Ex. b=10, Y=.01, x=-2, b=10, Y=1/100,000, b=-5

Free Space Path Loss

- Free space path loss, sometimes called free space loss (FSL) or just path loss, is a weakening of the RF signal due to a broadening of the wave front.
  - This broadening of the wave front is known as signal dispersion.

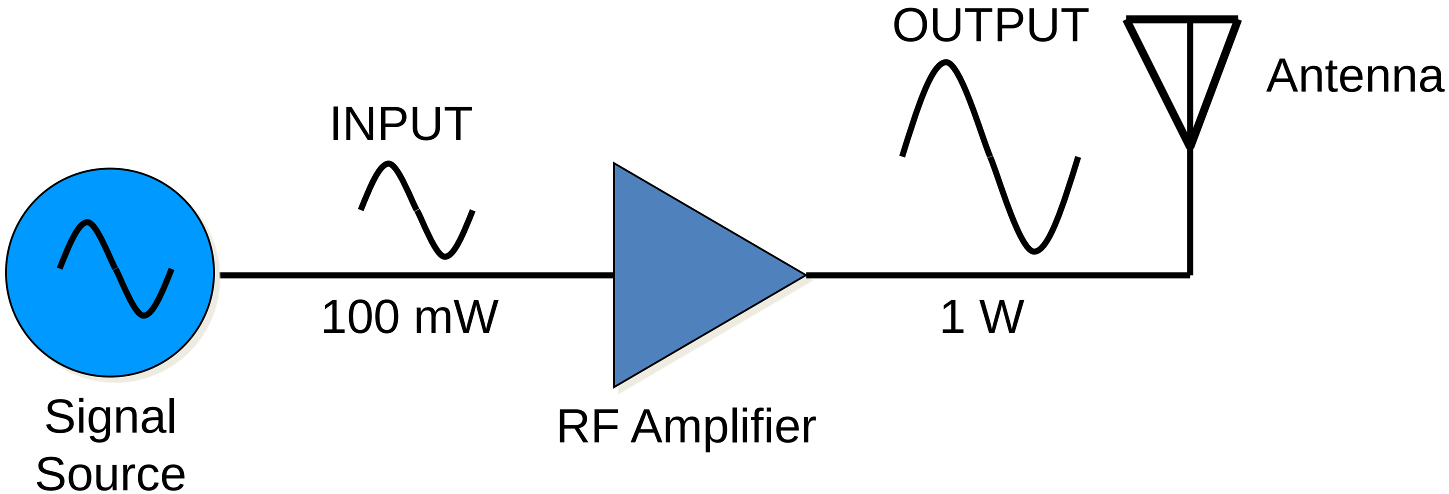
$$\mathbf{LP = 36.6 + (20 \times \log_{10}(F)) + (20 \times \log_{10}(D))}$$

  - where LP is the free space path loss in dB, F is the frequency in MHz, and D is the path length in miles

$$\mathbf{LP = 32.4 + (20 \times \log_{10}(F)) + (20 \times \log_{10}(D))}$$

  - where LP is the free space path loss in dB, F is the frequency in MHz, and D is the path length in km

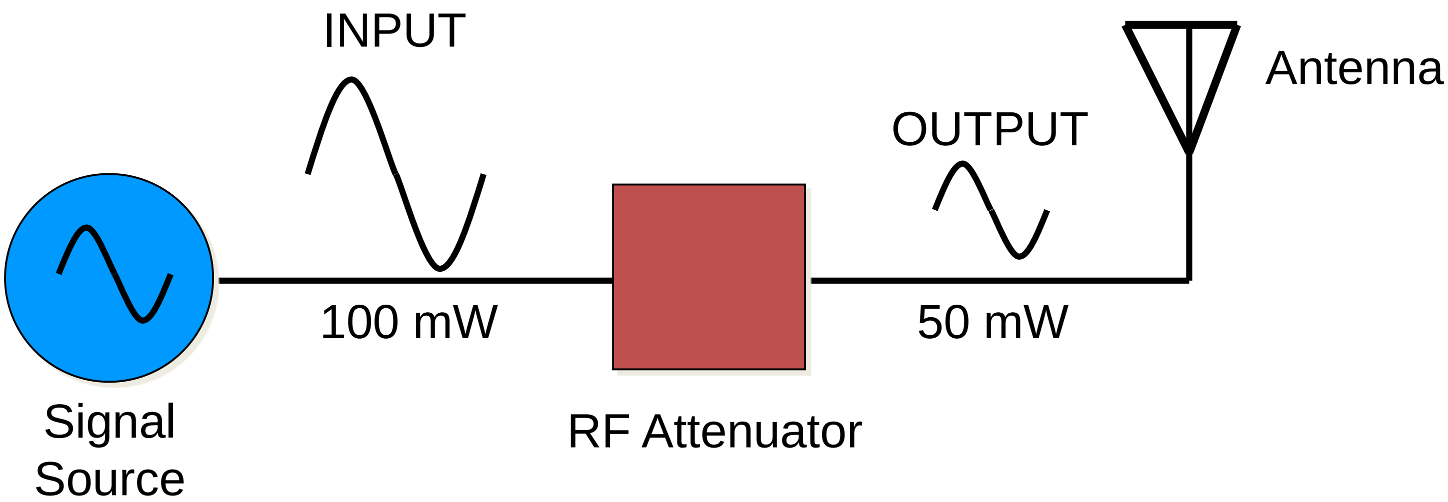
dB gain Sample Problem



Compute the relative power gain of the RF Amplifier in dB.

$$dB = 10 \log_{10} (\ 1W / \underset{\substack{\uparrow \\ P_{Ref}}}{100\ mW}) \ = \ 10 \log_{10} (\ 10\ ) \ = \ 10\ (\ 1\ ) \ = \ 10\ dB$$

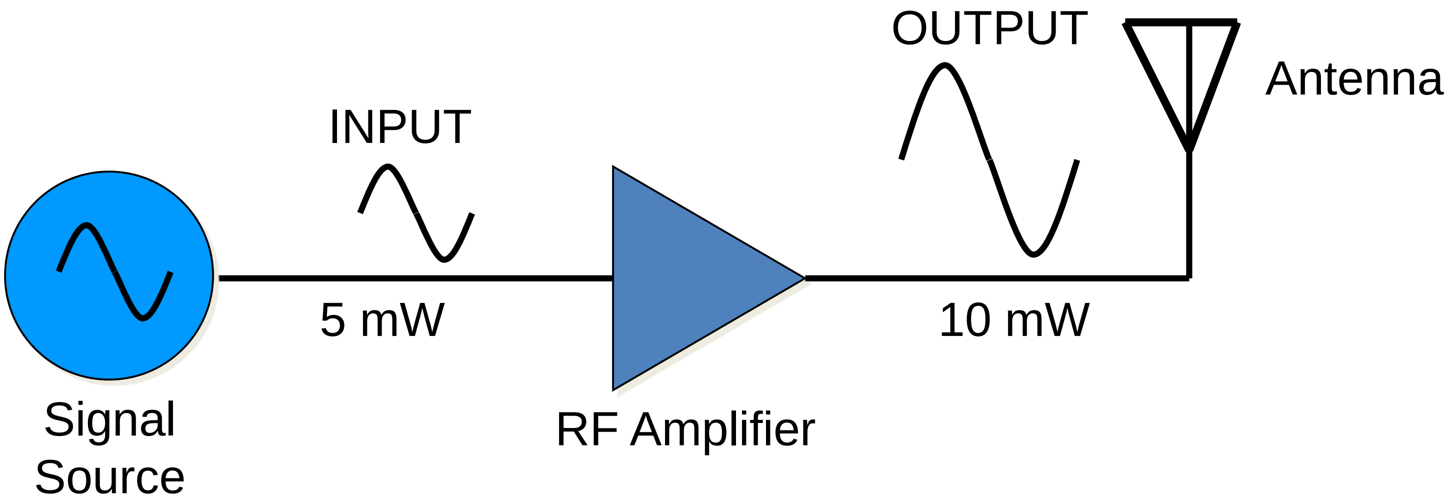
dB loss Sample Problem



Compute the relative power loss of the RF Amplifier in dB.

$$dB = 10 \log_{10} (50 \text{ mW} / \underset{\substack{\uparrow \\ P_{Ref}}}{100 \text{ mW}}) = 10 \log_{10} (.5) = 10 (-0.3) = -3.0 \text{ dB}$$

dB Gain Sample Problem



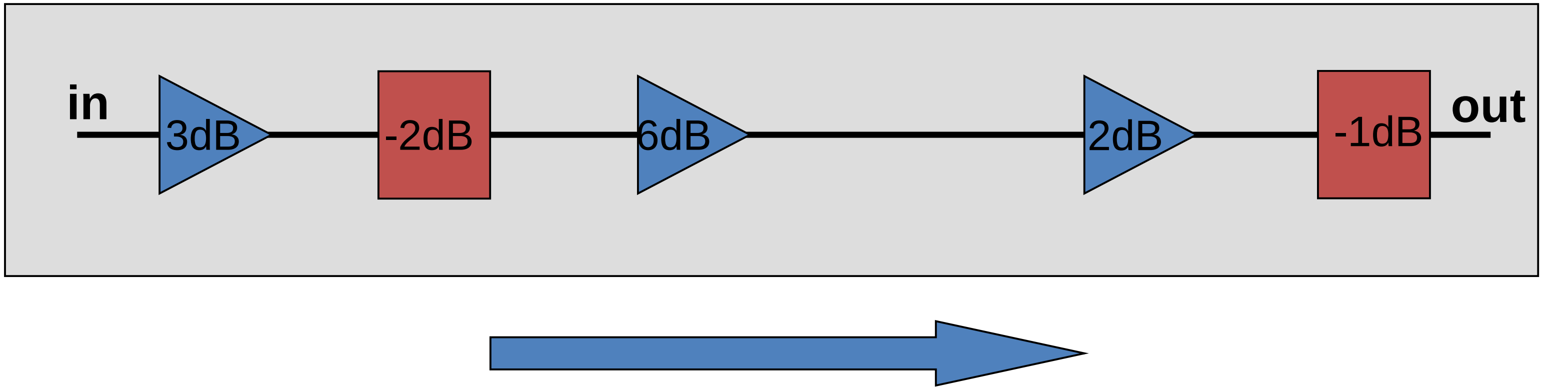
Compute the absolute dBm power level at the output of the RF Amplifier.

$$\text{dBm} = 10 \log_{10} (\underbrace{10 \text{ mW} / 1 \text{ mW}}_{1 \text{ mW} = P_{Ref}}) = 10 \log_{10} (10) = 10 (1) = 10 \text{ dBm}$$

$$\text{dB} = 10 \log_{10} (\underbrace{10 \text{ mW} / 5 \text{ mW}}_{5 \text{ mW} = P_{Ref}}) = 10 \log_{10} (2) = 10 (0.3) = 3 \text{ dB}$$

Helpful Hints

- dB's are additive
- loss = -dB
- gain = +dB
- For Power
  - A doubling or halving is 3 dB
  - A ten times or one-tenth is 10 dB



Rules of 10 and 3's

Table 1

n	Log(n)
1/1000	-3
1/100	-2
1/10	-1
1	0
10	1
100	2
1000	3

Table 2

Power Ratio	dB
Half the power ½ or 0.5	-3
Double the power X 2	+3
One-tenth the power 1/10 or 0.1	-10
Ten times the power X 10	+10

Using rules of 10's and 3's

How do you estimate dB gain when the values are not multiples of 2 and 10? Given a value of dB, come up with a series of 10's and 3's that when added equals the given dB.

Gain in dB	Expression in 10s and 3s
1	+ 10 – 3 – 3 – 3
2	+ 3 + 3 + 3 + 3 – 10
3	+ 3
4	+ 10 – 3 – 3
5	+ 3 + 3 + 3 + 3 + 3 – 10
6	+ 3 + 3
7	+ 10 – 3
8	+ 10 + 10 – 3 – 3 – 3 – 3
9	+ 3 + 3 + 3
10	+ 10

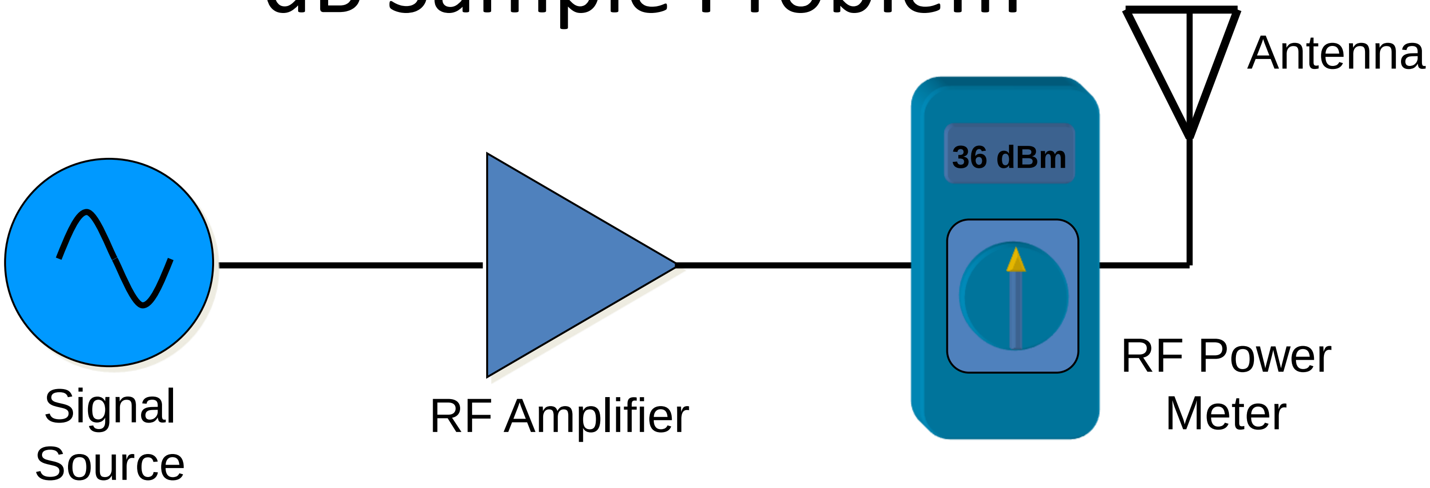
10x1/2x1/2x1/2 =1.25

2x2x2x2x1/10 = 1.60

2

10x10x1/2x1/2x1/2x1/2 = 6.25

dB Sample Problem



Compute the power level in watts at the output of the RF Amplifier.

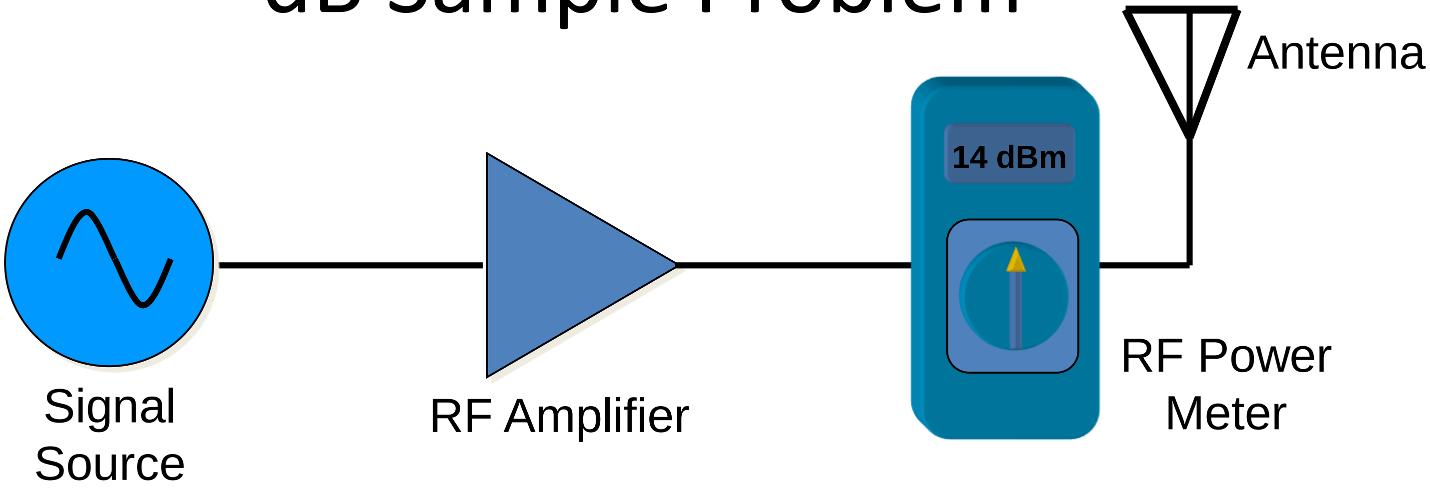
$36\text{ dBm} = 10 \log_{10} (P_X / 1\text{ mW})$ ⇨ $3.6 = \log_{10} (P_X / 1\text{ mW})$

$\text{antilog } (3.6) = \text{antilog } \log_{10}(P_X / 1\text{ mW})$ ⇨ $3{,}980 = (P_X / 1\text{ mW})$

$3{,}980 \times 1\text{ mW} = P_X$ ⇨ $P_X = 3.98\text{ W} \cong 4\text{ W}$

36 dBm = (10 + 10 + 10 + 3 +3)dB, 1 mW x 10 x 10 x 10 = 1W x 2 x 2 = 4 W

dB Sample Problem



Compute the power level in watts at the output of the RF Amplifier.

14 dBm = (10 + 3 +1)dB 1mW x 10 = 10mW x 2 = 20mW > 20mW

Actual Value = 25.1 mW

1 dB = (10 – 9)dB

1 dB = 10 x 0.5 x 0.5 x 0.5 = 1.25

1 mW x 10 x 2 x 1.25 = 25 mW

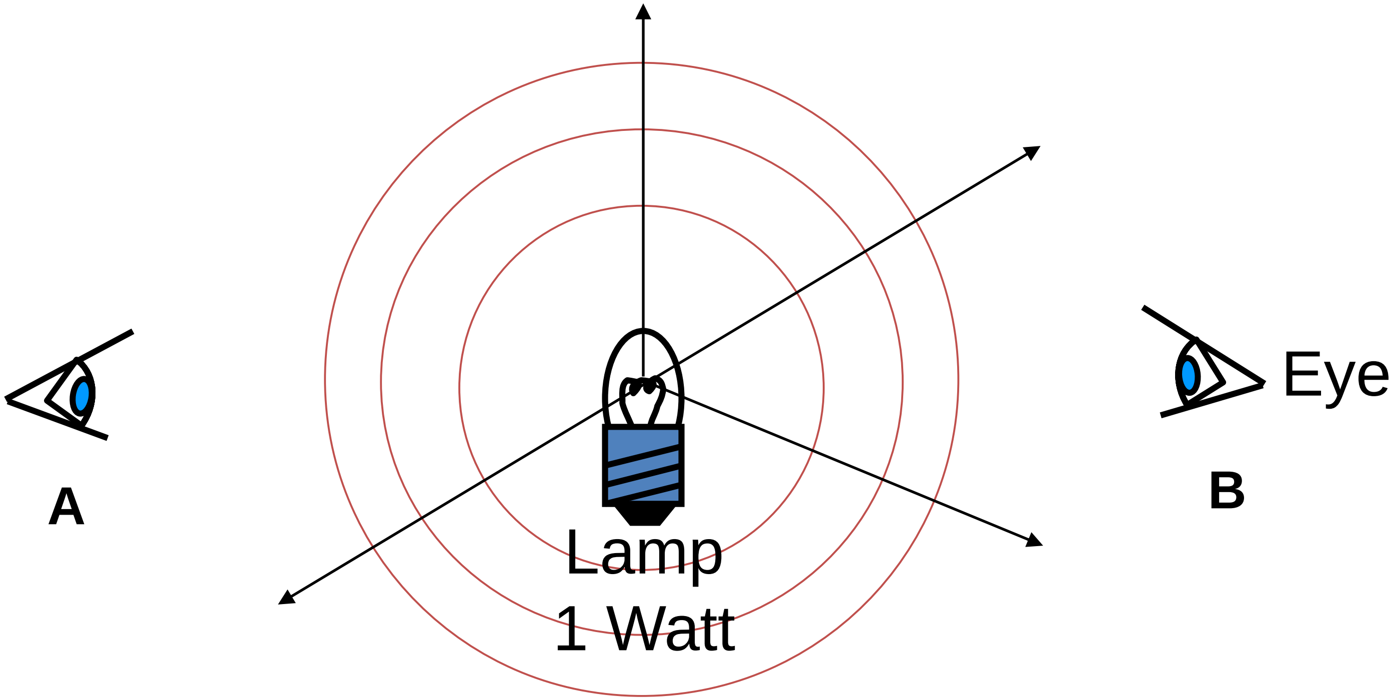
a. 10 mW
b. 25 mW
c. 50 mW
d. 100 mW

Antenna Gain

- Measure of the ability of the antenna to **focus** radio waves in a particular direction. It is the ratio of the power required at the input of a **reference antenna** to the power supplied to the input of the given antenna to produce the same **field strength** at the same location.

Antenna Gain

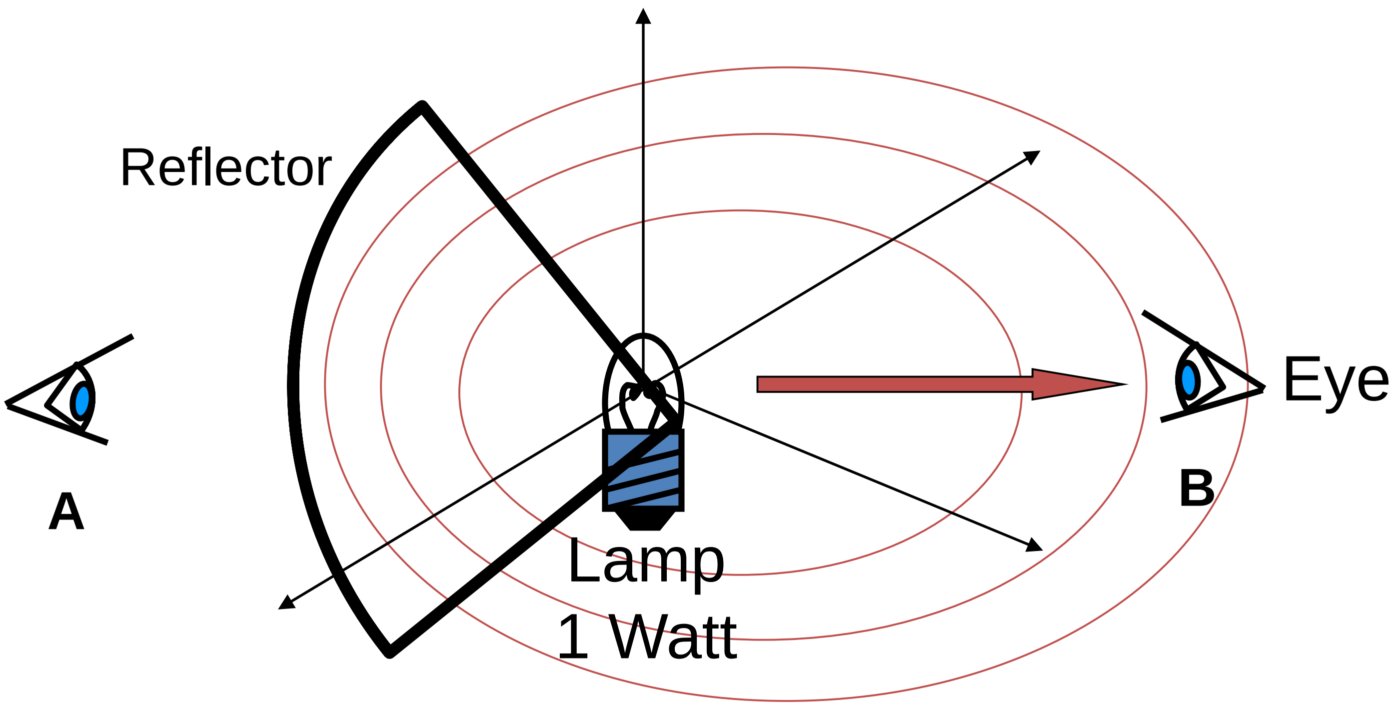
The light analogy. **Reference device**



Omni-directional
Radiation Pattern

Antenna Gain

The light analogy. **Focus/Field Strength**

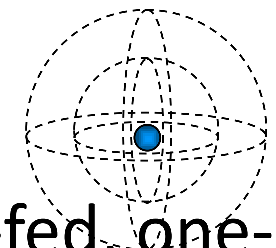


Directional
Radiation Pattern

Two reference Antennas

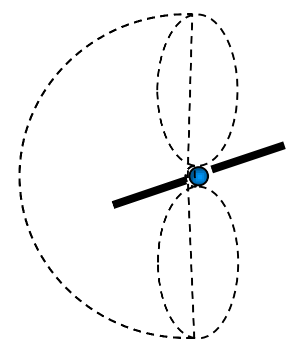
- Isotropic Antenna - A hypothetical antenna that radiates or receives energy equally in all directions.

dBi or G_i



- Dipole Antenna - a straight, center-fed, one-half wavelength antenna.

dBd or G_d

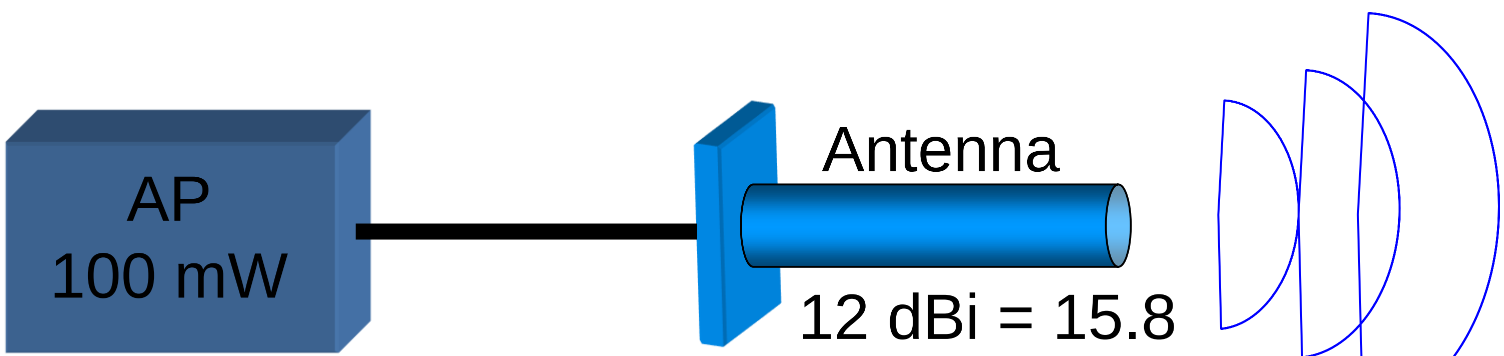


EIRP

- EIRP - Effective Isotropic Radiated Powe
- The product of the power supplied to the antenna and the antenna gain in a given direction relative to a reference isotropic antenna.

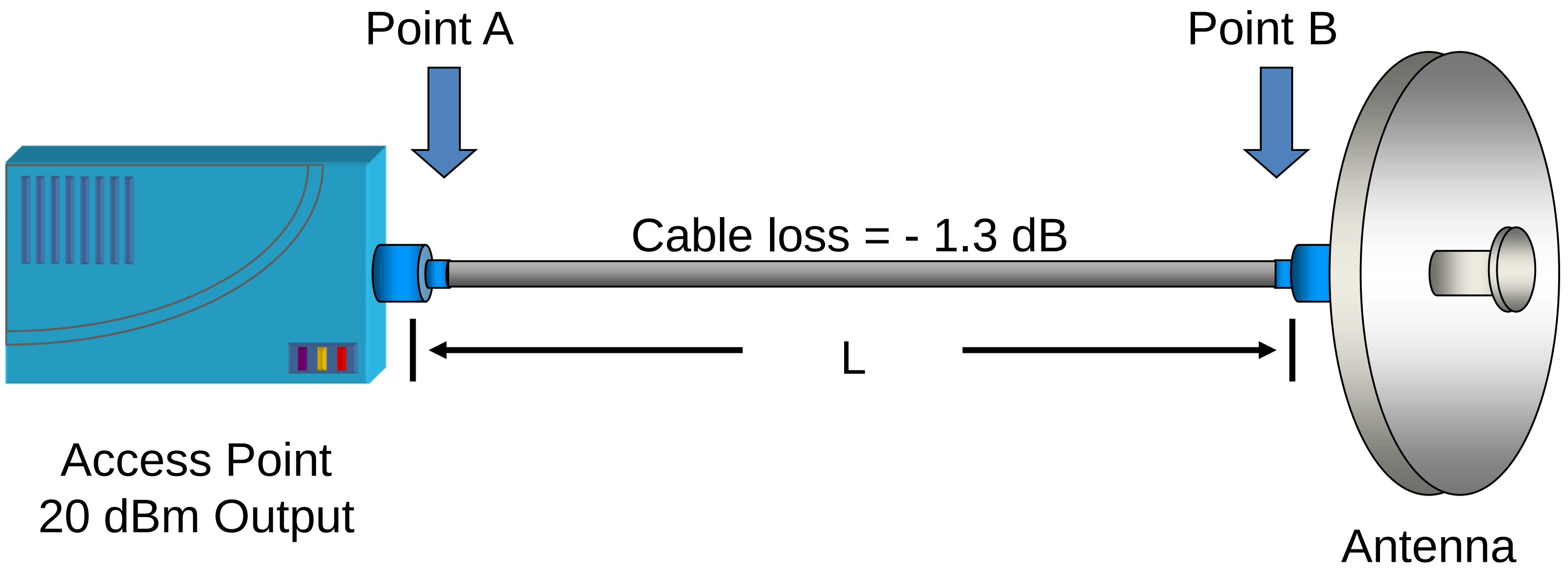
$$\text{EIRP} = P_{in} \ \text{X} \ G_i$$

$$1.58 \text{ W} = 100 \text{ mW} \times 15.8$$



12 dBi = (3 + 3 + 3 + 3) dBi, 2 x 2 x 2 x 2 = 16

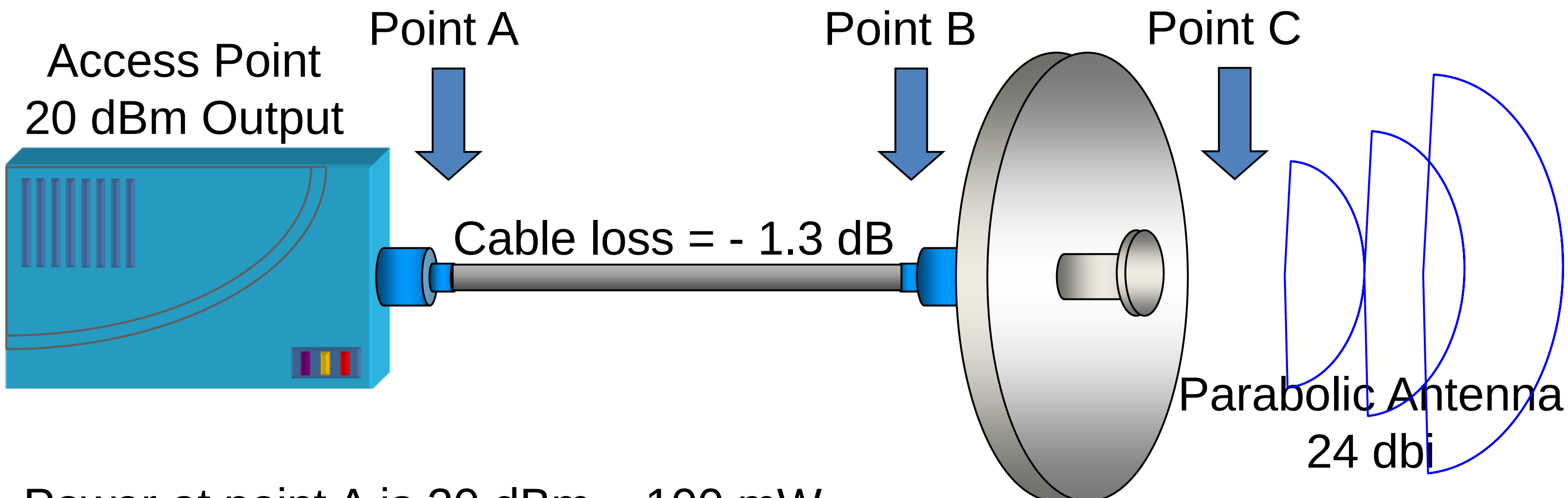
dB Sample Problem



Power at point A is 20 dBm = 100 mW

Power at point B is 20 dBm – 1.3 dB = 18.7 dBm = 74.1 mW

EIRP Example



Power at point A is 20 dBm = 100 mW

Power at point B is 20 dBm – 1.3 dB = 18.7 dBm = 74.1 mW

EIRP at point C is 74.1 mW x 251 = 18.6 W

Another method:
0dBm +20db-1.3dB+24dB = 42.7 dBm= 40 dB + 3dB
Approximately = 1mw x 10,000 x 2 =20 mw

dBd and dBi

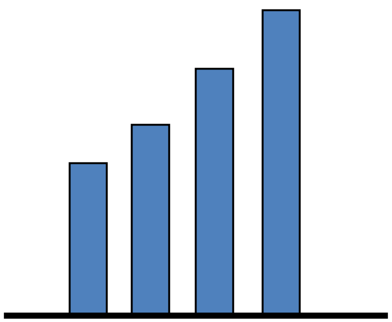
- dBi is the gain of an ideal antenna – isotropic radiator
  - Isotropic antenna radiates equally in all directions (think sphere)
- dBd is the calculation of directional gain compared to a dipole antenna (d =dipole)
- A dipole gain = 2.14 dBi
- To convert: 0 dBd = 2.14 dBi
- Ex: an antenna with 7 dBd = 9.14 dBi (7+2.14=9.14)

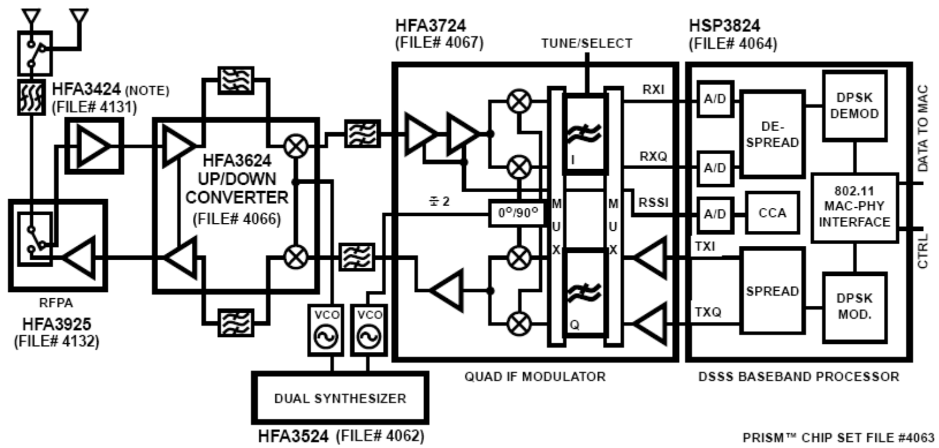
SNR and RSSI

- SNR is Signal to Noise Ratio
- The RF signal power relative the background noise level –expressed in dB's
- Important measure of signal strength and the reliability of the connection
- RSSI is Received Signal Strength Indicator
- An arbitrary measurement of received signal strength defined by IEEE 802.11
- Not all vendors use the range of values

RSSI

- Received Signal Strength Indication. RSSI is a measurement of the strength (not necessarily the quality) of the received signal strength in a wireless environment, in arbitrary units.





Note: Cisco Systems RSSI range is 0 to 100. An Atheros based card’s range is 0 to 60. RSSI may be one byte values for 256 levels.

Link Budget and System Operating Margin

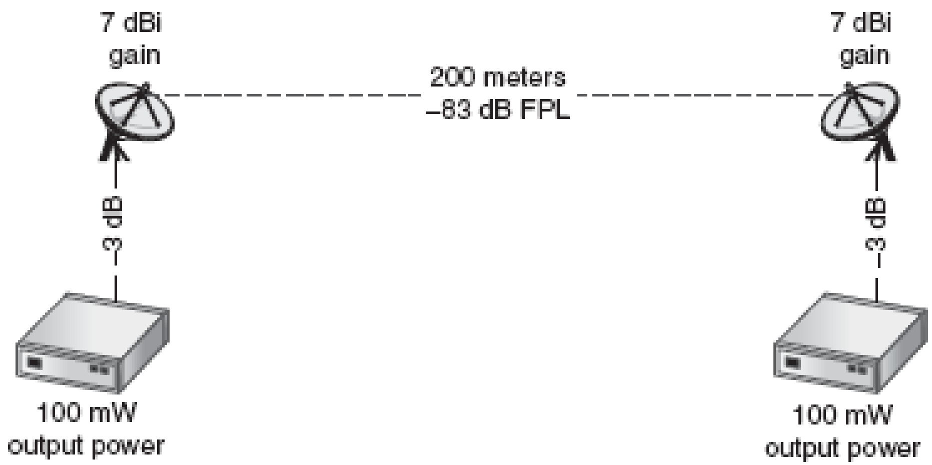
- Link budget is an accounting of gains and losses of all RF components. Includes:
  - Gain, loss, receiver sensitivity, fade margin, cable loss, connectors, antenna gain and free space loss
  - Fade Margin –signal loss due to weather, trees other variables
- System Operating Margin (SOM) is the amount of received signal strength (S) relative to the client device's receiver sensitivity (RS)

$$SOM = RS - S$$

Ex: RS= -94 dBm, S= -65 dBm SOM = (-94) –(-65) =-29dBm
This means the signal (S) can in theory weaken by 29 dB and the system will work

Link Budget Calculation

Link budget calculation



Let's consider an actual example of a link budget calculation. Figure 2.18 shows a site-to-site link being created across a distance of 200 meters with IEEE 802.11 bridges. Based on the output power of the bridge, the attenuation of the cables, the gain of the antennas, and the free space path loss, we can calculate the link budget, since the receive sensitivity of both bridges is –94 dBm. The calculations are as follows:

Link budget calculation 1: 100 mW = 20 dBm

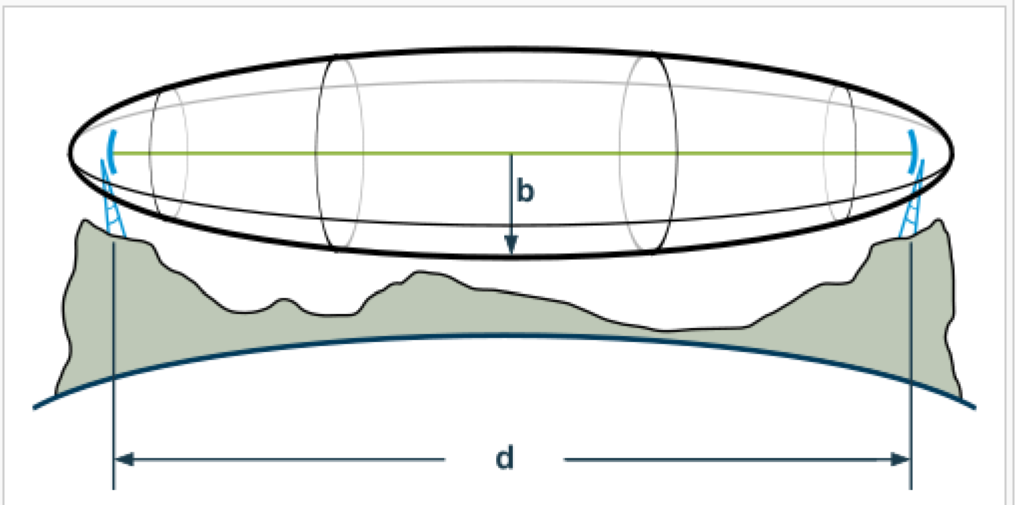
Link budget calculation 2: 20 dBm – 3 dB + 7 dBi – 83 dB = –59 dBm

Link budget calculation 3: (–94 dBm) – (–59 dBm) = 35 dBm

SOM = 35 dBm

Antenna Concepts

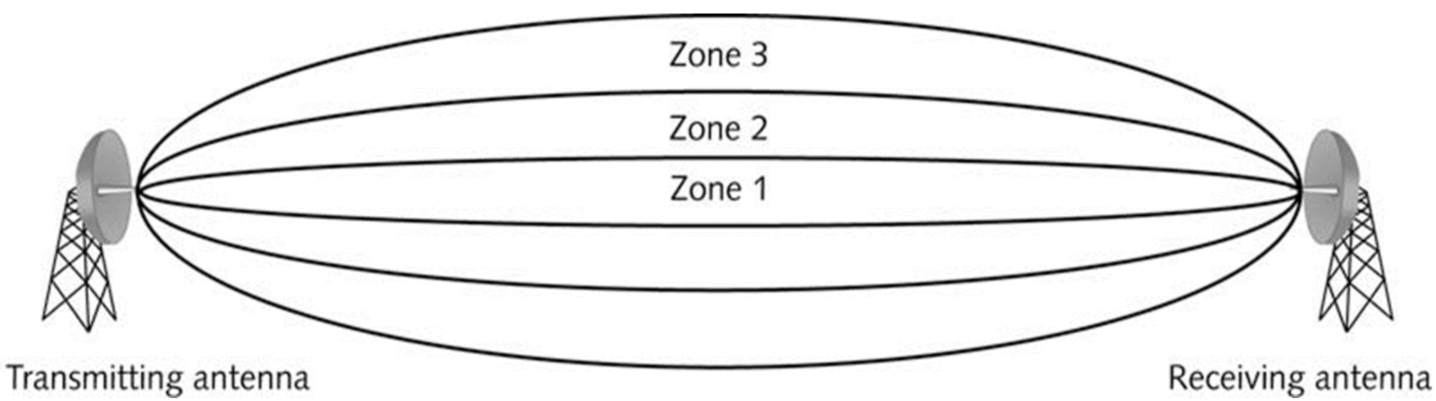
- Visual Line of Site (visual LOS) – straight line site
- RF LOS is a more sensitive measure of LOS which takes in to account the Fresnel Zone
- Fresnel Zone is the ellipsoidal shape necessary to support RF transmission



Fresnel zone. d is the distance between the transmitter and the receiver, b is the radius of the Fresnel zone.

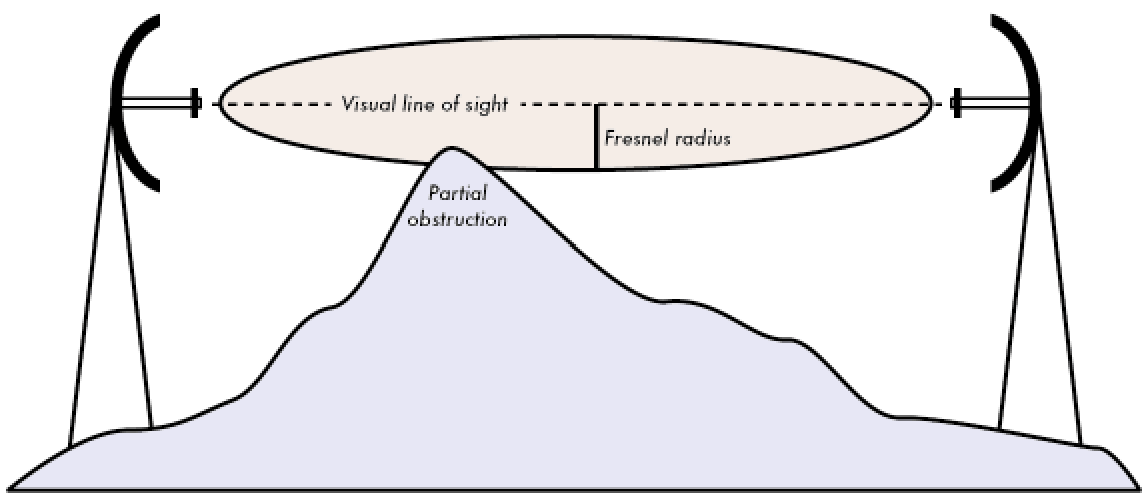
Fresnel Zones

- Theoretically, infinite number of ellipsoidal areas around the LOS in an RF link
- Many engineers refer to the Fresnel zone when it is more proper to refer to the first Fresnel zone, 1FZ
- First Fresnel zone is the zone with the greatest impact on a RF link



Fresnel Equation

- Good link is:
  - http://www.vias.org/wirelessnetw/wndw_04_08b.html
  - Radius = 72.2 x SQRT (D/(4xF))
  - Where D is the distance of the link(miles) and F is transmission frequency (GHz). Radius will be in feet



Fresnel Equation

- Important: blockage of the 1FZ of more than 40 percent can cause the link to become nonfunctional.
- Minimum the 60 percent radius should be clear, to ensure the RF LOS, use the following formula:

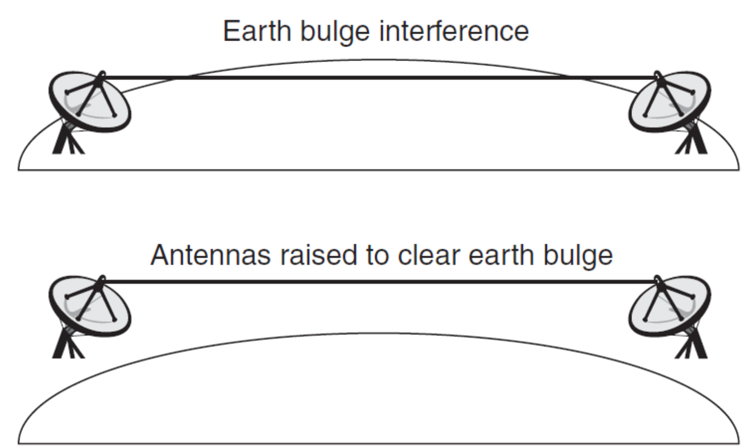
$$\text{Radius} = 43.3 \ * \ \sqrt{\frac{D}{4*F}}$$

- To be on safe side, engineers choose to a 20 percent blockage or 80 percent clearance:

$$\text{Radius} = 57.8 \ * \ \sqrt{\frac{D}{4*F}}$$

Earth Bulge and the Fresnel Zone

- Another factor that should be considered in 1FZ blockage is the Earth itself.
- If the wireless link is over distances greater than 7 miles using WLAN technologies, the Earth bulge must be considered in antenna-positioning formulas.
- The formula to calculate the extra height of the antennas will need to compensate for Earth bulge is:
  - Height = $D^2 / 8$
  - where height is the height of Earth bulge (feet) and D is the distance between antennas (miles).



Minimum Antenna Height

- To bring all the discussion of Fresnel zones together, it is important that to deal with 1FZ obstructions and the Earth bulge all together in a single formula.
- To calculate the height of antenna (in feet)
- Minimum Antenna Height = $57.9 * \sqrt{\frac{D}{4*F}} + \frac{D^2}{8}$

Antennas

Sample semi-directional antennas

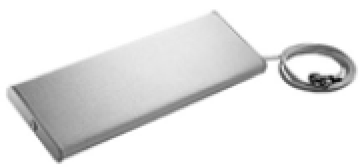
Yagi Antenna

Patch Antenna

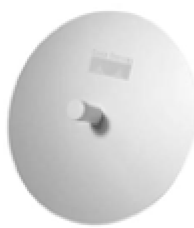
Panel Antenna

Sample of a highly-directional parabolic dish antenna

Sample omni-directional antennas



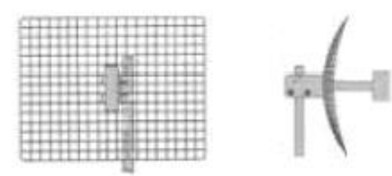
Omni Pillar
Mount Antenna



Omni Ground
Plane Antenna

Omni Ceiling
Mount Antenna

Sample of a highly-directional grid antenna



Antenna Concepts

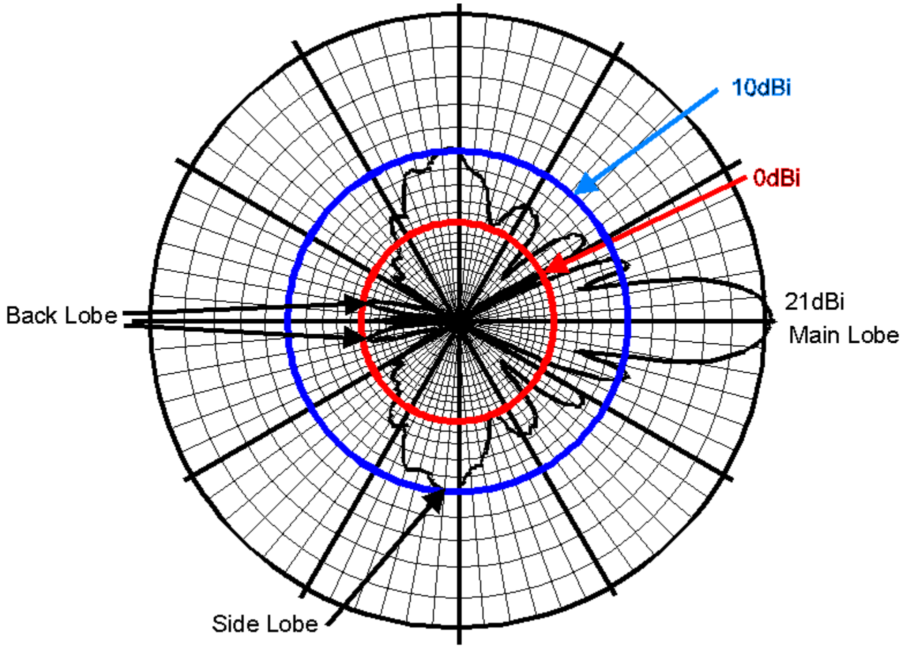
- Directionality
  - Omni (360º coverage) directional
  - Directional (limited range of coverage)
- Gain
  - Measured in dBi and dBd (0 dBd = 2.14 dBi)
  - More gain means more coverage - in certain directions
- Polarization
  - Vertical (Elevation)
  - Horizontal (Azimuth)

Antenna Concepts

- **Main beam** is the region around the direction of maximum radiation The main beam is centered at 90 degrees
- **Sidelobes** are smaller beams that are away from the main beam. Radiate in directions other than the main beam and can never be completely eliminated.
- **Half Power Beamwidth (HPBW)** is the angular separation in which the magnitude of the radiation pattern decrease by 50% (or -3 dB) from the peak of the main beam.
- **Null to Null Beamwidth**. the angular separation from which the magnitude of the radiation pattern decreases to zero (negative infinity dB) away from the main beam.

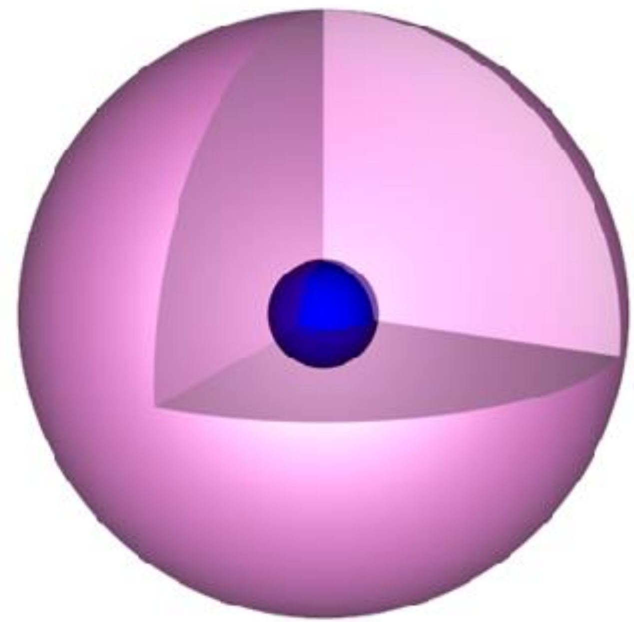
Antenna Issues

- Antennas have gain in particular directions
- Direction other than the main intended radiation pattern, are typically related to the main lobe gain



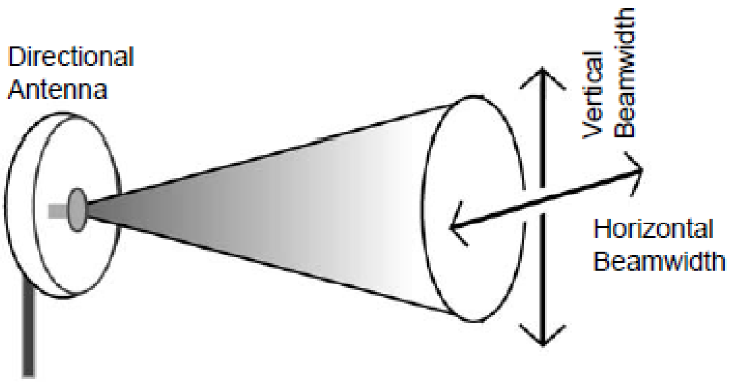
Isotropic Radiator

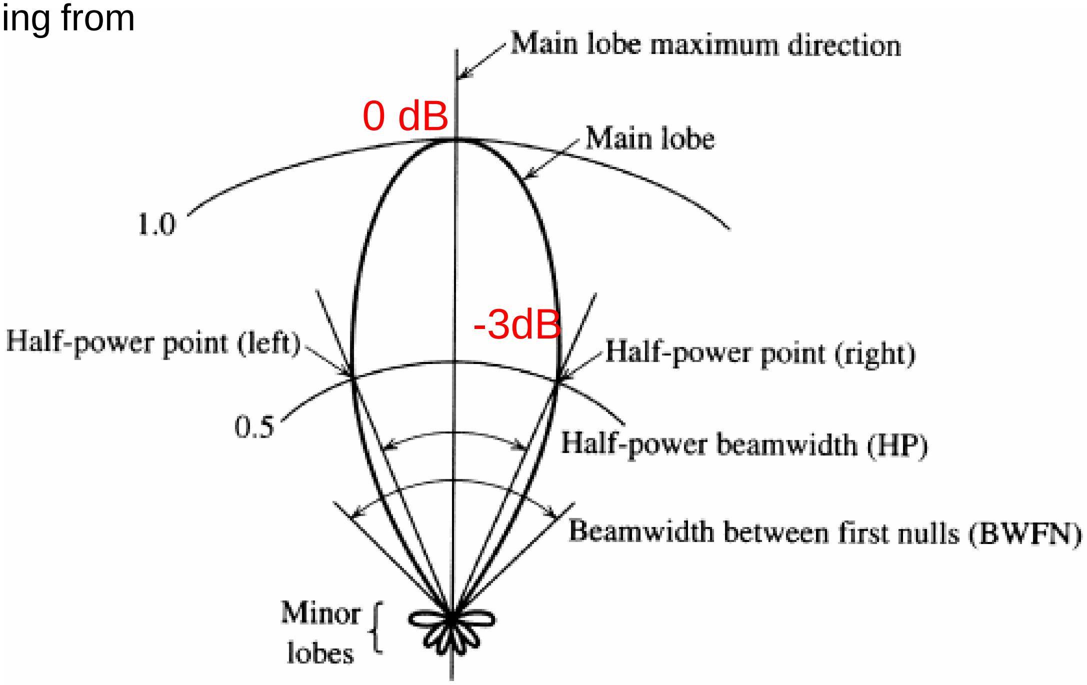
- A theoretical isotropic antenna has a perfect 360º vertical and horizontal beamwidth
- This is a reference for ALL antennas
- This is a fictional antenna
- The Isotropic antenna is the a reference for all antennas (dBi)



Beamwidths

- measurement of how broad or narrow the focus of the RF energy is as it propagates from the antenna along the main lobe.
- The *main lobe* is the primary RF energy coming from the antenna.
- Beamwidth is measured both vertically and horizontally in angles

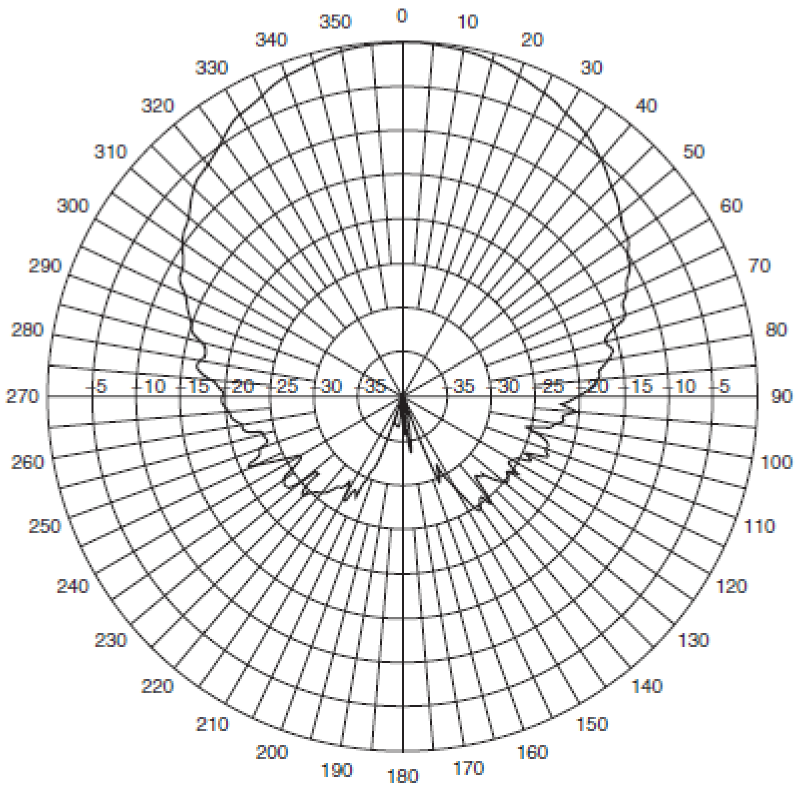




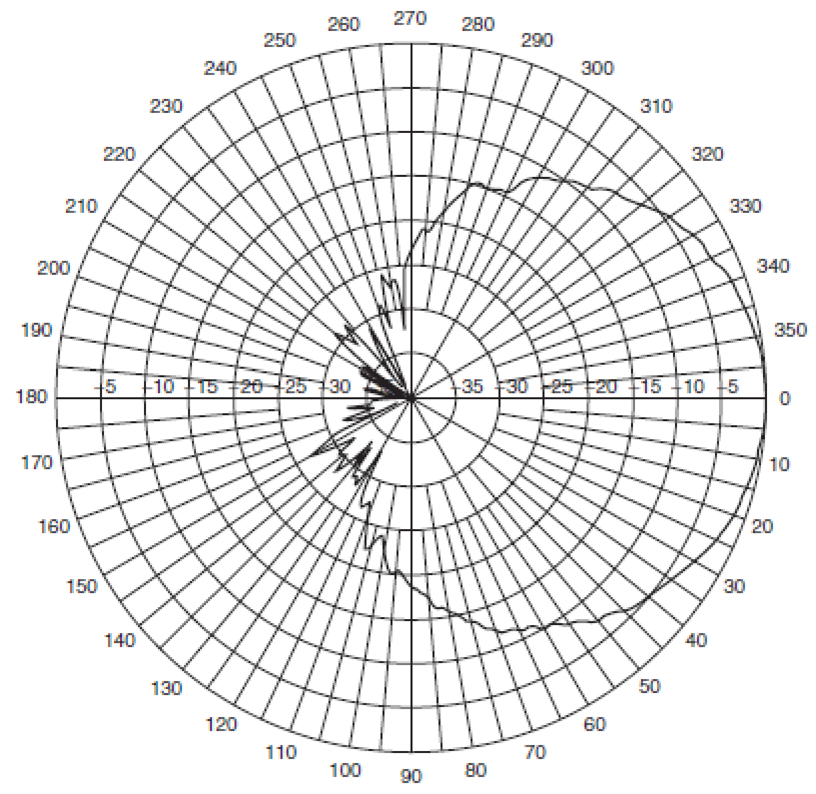
Antenna Type	Horizontal Beamwidth (in degrees)	Vertical Beamwidth (in degrees)
Omni-directional	360	Ranges from 7-80
Patch/Panel	Ranges from 30-180	Ranges from 6-90
Yagi	Ranges from 30-78	Ranges from 14-64
Parabolic Dish	Ranges from 4-25	Ranges from 4-21

Azimuth and Elevation

Azimuth chart



Elevation chart



Azimuth chart shows a top-down view of the propagation path (to the left, in front, to the right, and behind the antenna)

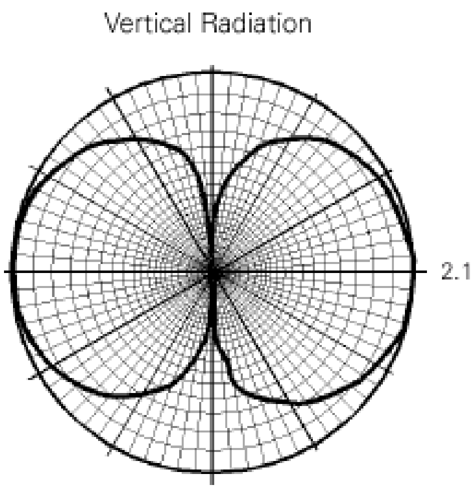
Elevation chart shows a side view of the propagation path (above, in front, below, and behind the antenna)

Polarization

- A factor that greatly impacts the performance of RF antennas is the polarization of the antennas.
- *Antenna polarization* refers to the physical orientation of the antenna in a horizontal or vertical position.
- The electromagnetic wave is made up of electric and magnetic fields. The electric field forms what is known as the E-plane, and the magnetic field forms what is known as the H-plane.
- The E-plane is parallel to the radiating antenna element, and the H-plane is perpendicular to it.
- The E-plane, or electric field, determines the polarization of the antenna, since it is parallel to the antenna. Therefore,
  - If the antenna is in a vertical position, it is said to be vertically polarized.
  - If the antenna is in a horizontal position, it is said to be horizontally polarized.
- Vertical polarization means that most of the signal is being propagated horizontally
- horizontal polarization means most of the signal is being propagated vertically.

2.4 GHz Omni-Directional Antennas

- 2 dBi Dipole "Standard Rubber Duck"

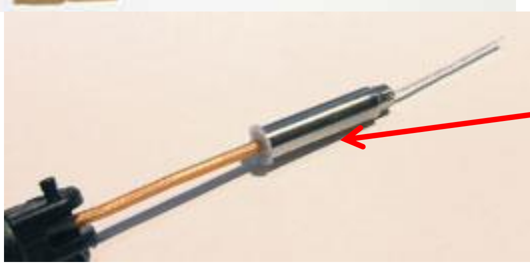


Rubber Ducky Antenna Construction

Each half of the dipole is a 1/4 wavelength, with the length corrected based on the velocity of the coax being used. Assuming a centre frequency for 802.11b of 2.441GHz, a 1/4 wavelength in free space is 30.7mm.

Length of the metal casing is approx 24mm, with a total length of 50mm.

Thin wire whip protruding from the top of the metal casing is approx 26mm

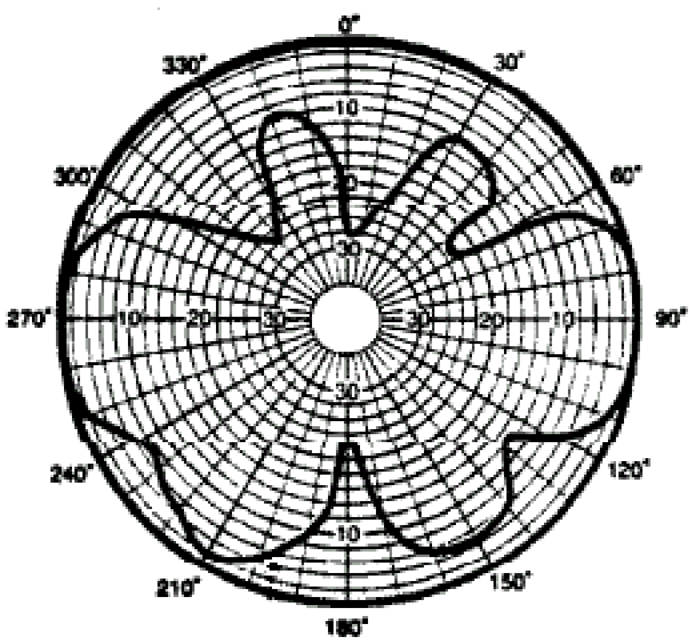


Metal casing is a "decoupler", and is typically used to tune the antenna, by moving the decoupler up and down to vary the VSWR

.

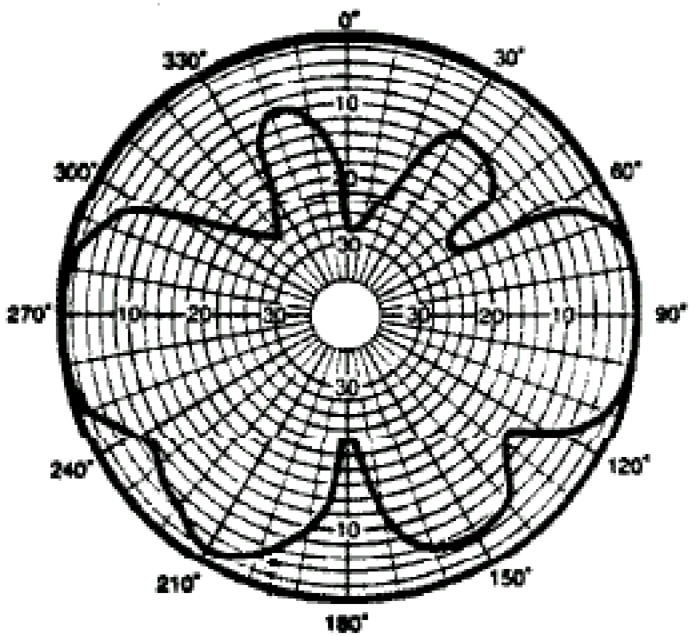
2.4 GHz Omni-Directional Antennas

- 5.2 dBi Mast Mount Vertical



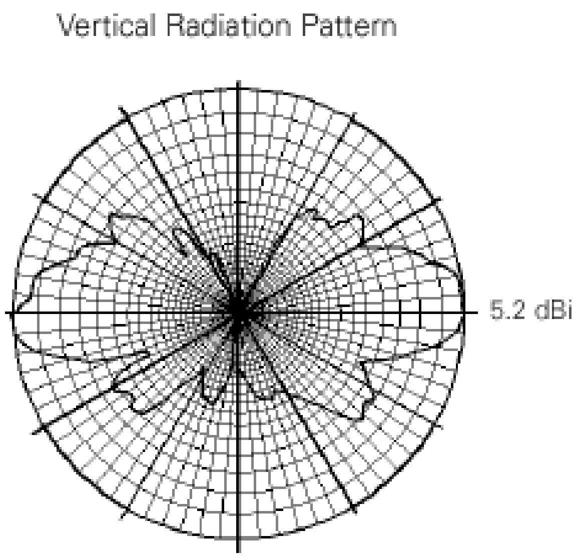
2.4 GHz Omni-Directional Antennas

- 5.2 dBi Ceiling Mount



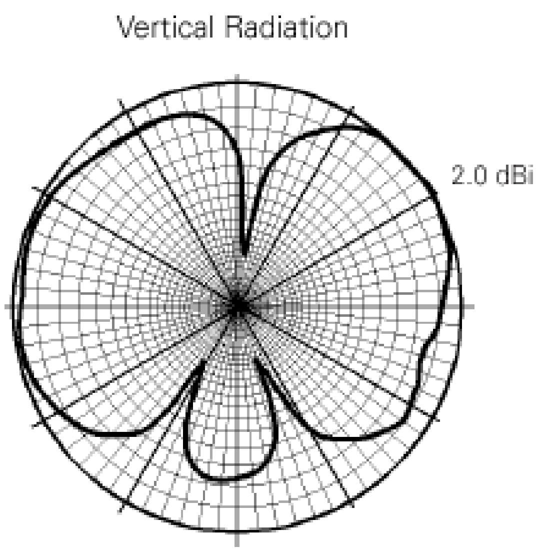
2.4 GHz Omni-Directional Antennas

- 5.2 dBi Pillar Mount Diversity



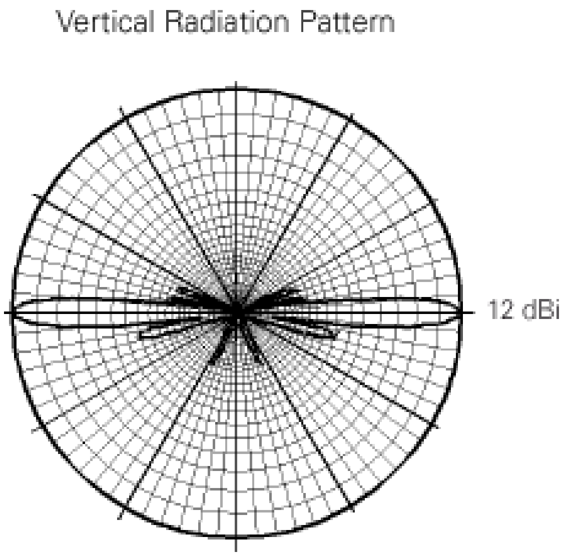
2.4 GHz Diversity
Omni-Directional Antennas

- 2 dBi Diversity Omni-Directional Ceiling Mount



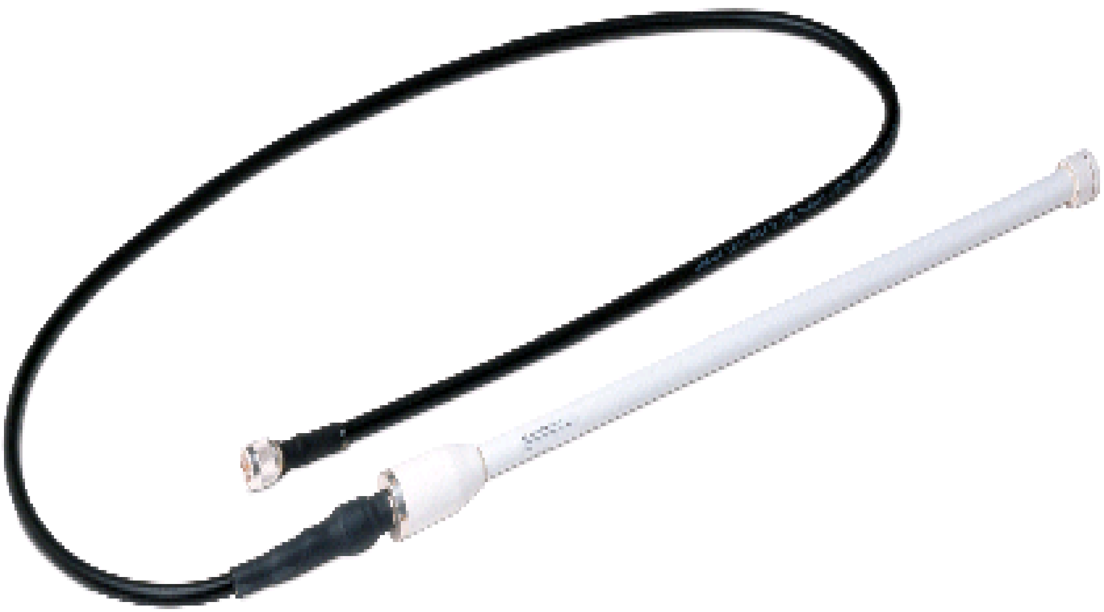
2.4 GHz Omni-Directional Antennas

- 12 dBi Omni-Directional (Outdoor only)



5 GHz Omni-Directional Antennas

- 9 dBi omni (Vertical polarization)

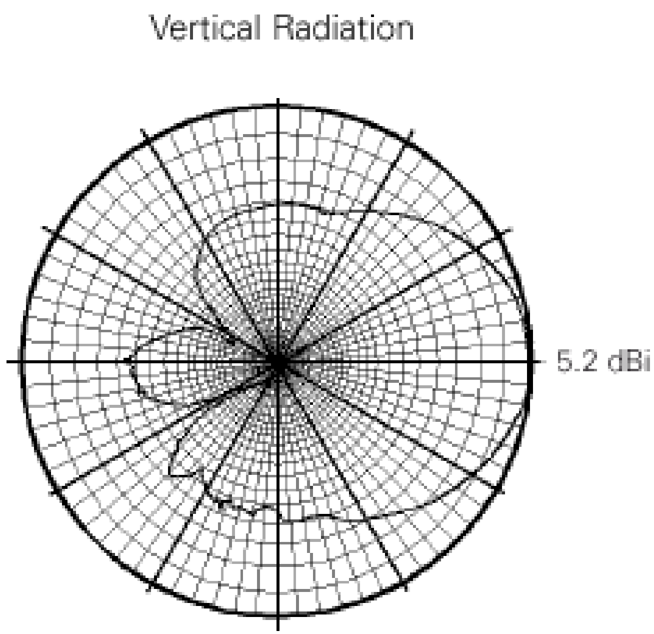


5 GHz Omni-Directional Antennas

– 9.5 dBi sector (H or V polarization)

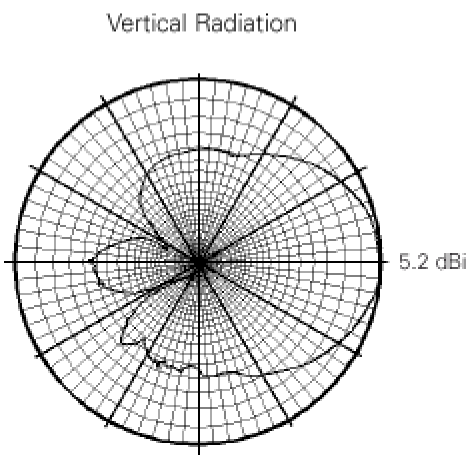
2.4 GHz Diversity Antennas

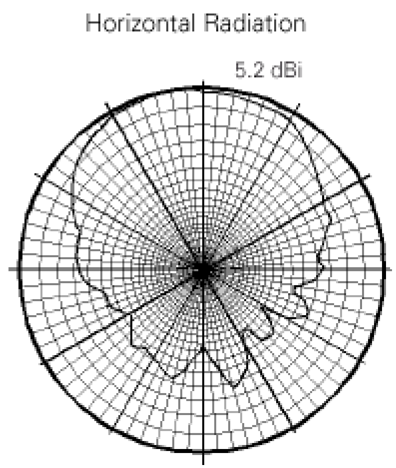
- 6.5 dBi Diversity Patch Wall Mount – 55 degree



2.4 GHz Directional Antennas (cont.)

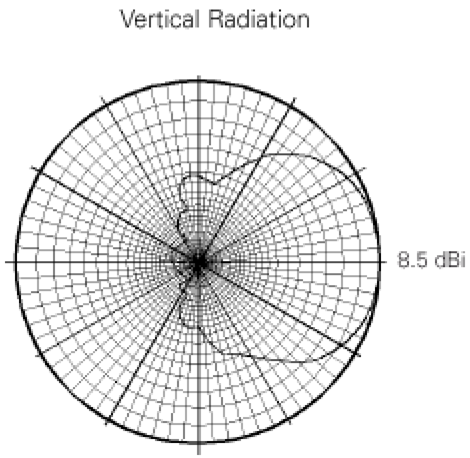
- 6 dBi Patch Antenna – 65 degree

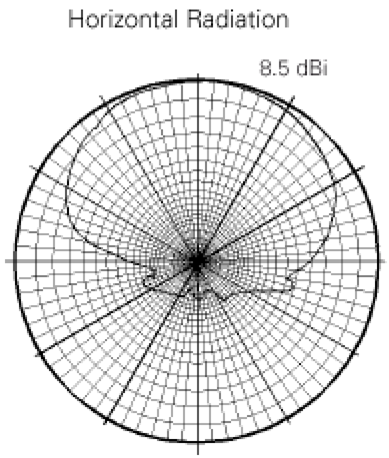




2.4 GHz Directional Antennas (cont.)

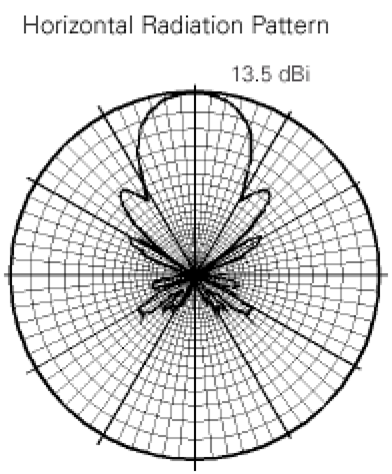
- 8.5 dBi Patch Antenna – 60 degree

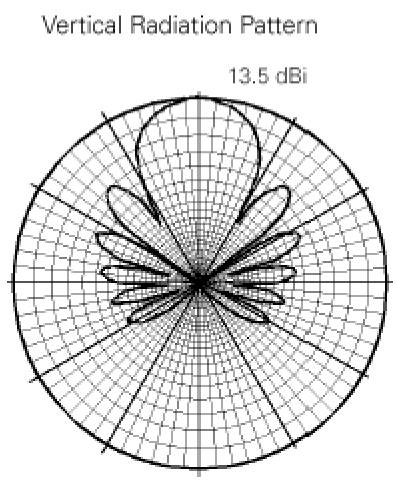




2.4 GHz Directional Antennas (cont.)

- 13.5 dBi Yagi Antenna – 25 degree

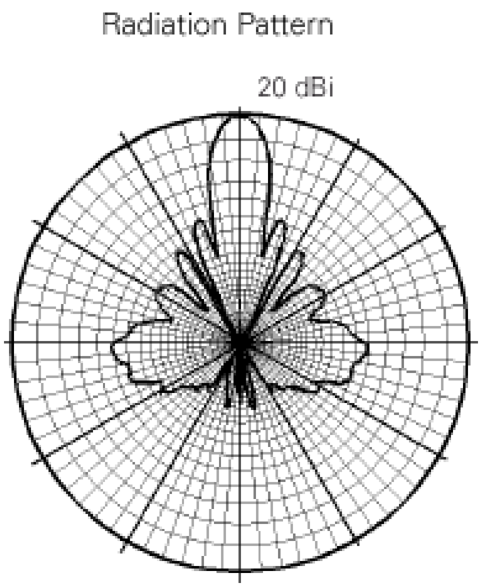


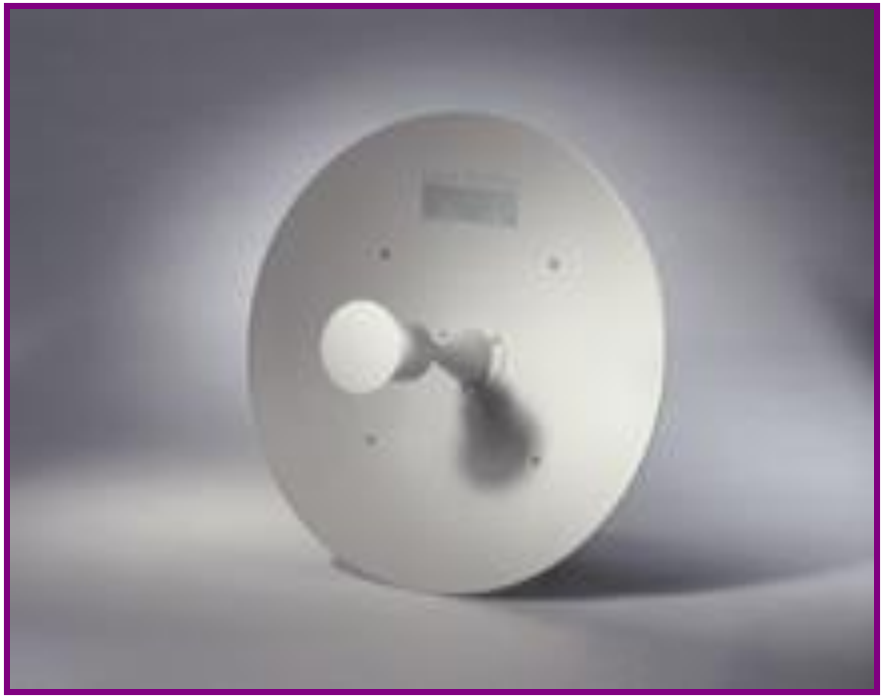


13.5 dBi Yagi Antenna—Inside view

2.4 GHz Directional Antennas (cont.)

- 21 dBi Parabolic Dish Antenna – 12 degree





5 GHz Omni-Directional Antennas

– 28 dBi dish (H or V polarization)

Antenna Connectors

"RP-TNC" connector is used on most Cisco APs.

"RP-SMA" connector is used on some Linksys products.

"N" connector is used on the 1500 Mesh and 1400 Bridge.

"SMA" connector is used on "pig-tail" type cable assemblies.