ITSC 301: Wireless Security

Module 2 – Basic RF Theory

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Review Module 1 Lecture & Lab

Review Module 1

- RF terminology
- Radio spectrum
- Regulatory bodies
  - Canada (DIESC)
  - US (FCC)
- Standards bodies
  - IEEE
- Lab/Assignment

RF Terminology

Introduction

This module will examine RF measurements and characteristics.

Learning Outcome:

- Analyze radio frequency characteristics and behaviour to solve wireless application problems.

RF Terminology

- Wavelength: Length from crest to crest (or trough to trough). Unit in meters with typical values in the nano-meter range.
- Frequency: 1/Wavelength. Unit in hertz (Hz) with typical values being in the KHz-GHz range.

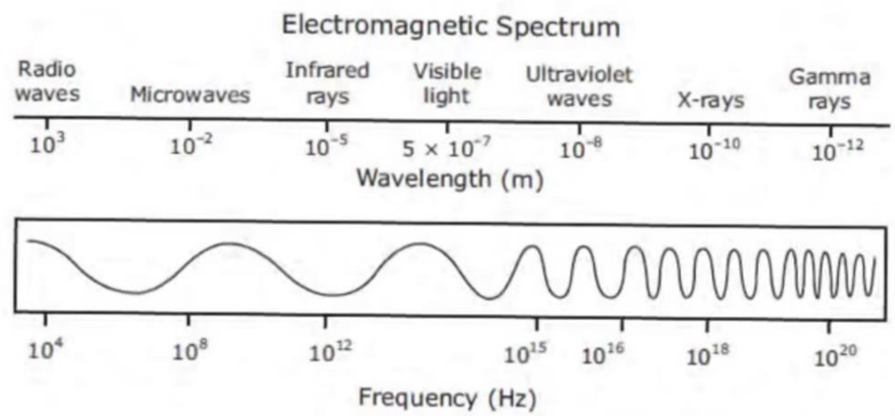

Figure 1: Electromagnetic Spectrum
Source?

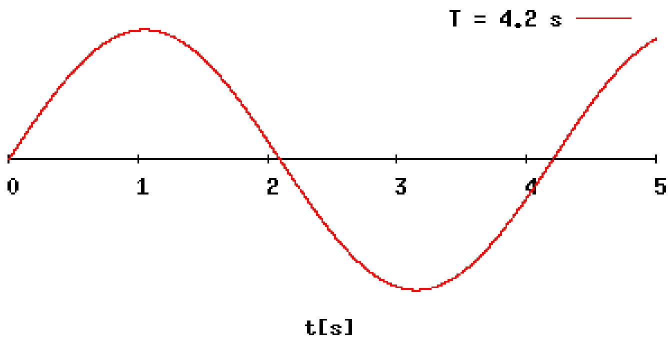

Figure 2: Wave Change Due to Increase of Period
© Superborsuk, 2006, https://commons.wikimedia.org/wiki/File:Wave_period.gif (CC-BY-SA 3.0)

RF Terminology

- Modulation: Process of varying one or more properties of a periodic waveform, called the *carrier signal*, with a modulating signal that typically contains information to be transmitted.
  - Used in most 802.11 WiFi: orthogonal frequency-division multiple access (OFDM), frequency-hopping spread spectrum (FHSS), direct-sequence spread spectrum (DSSS)

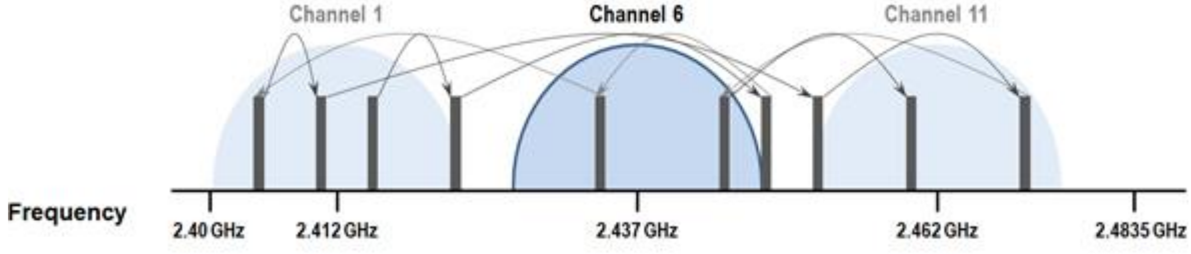

Figure 3: Title

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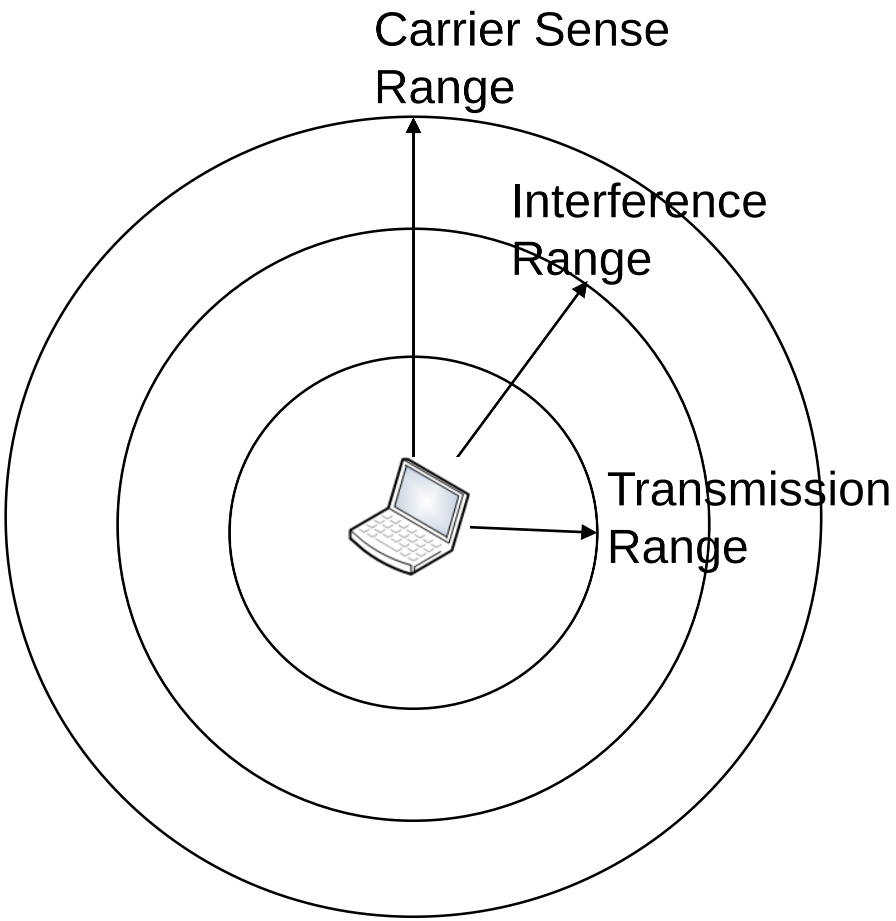
RF Terminology

- Transmission Range: The range within which the receiver of a packet can receive and decode the packet correctly
- Interference Range: The range within which the transmission cannot be decoded correctly by the receiver but is of sufficient power/energy to disrupt the correct reception of other packets that the receiver could also be receiving
- Carrier Sense Range: The range where the transmission does not necessarily interfere with other packets being received by the receiver

Ranges


Carrier Sense
Range
Interference
Range
Transmission
Range

RF Terminology

- RF interference: The suppression of communication between two nodes due to simultaneous communication by two or more other nodes.
  - Detecting the existence of RF interference can be extremely difficult because of its variability
- Non-uniform coverage area: An irregular coverage area results from inaccurate prediction of signal coverage for a wireless network, creating dead spots. One solution is to deploy additional access points to guarantee coverage.
- Dynamic coverage area: As well as being irregular, coverage areas are also dynamic. Changes can occur due to furniture movement (e.g., metal cabinet) or the opening/closing of a door.

RF Terminology

- Radio spectrum: The electromagnetic spectrum with frequencies from 3 Hz to 3,000 GHz (3 THz). Electromagnetic waves in this frequency range called radio waves.

- Frequency allocation: The allocation and regulation of the electromagnetic spectrum into radio frequency bands, performed by governments in most countries.

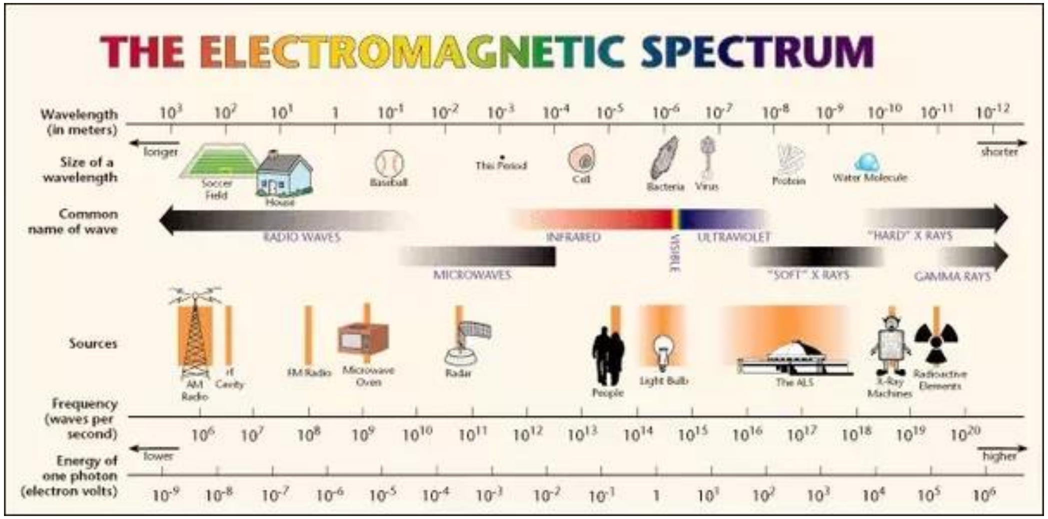


Figure 5: The Electromagnetic Spectrum
Source: NASA, 2010. https://commons.wikimedia.org/wiki/File:Cont_emspec2.jpg (CC0)

RF Basics & History

Learning Objectives

- Outline RF signal characteristics.
- Describe the basic concepts of RF behaviour.
- Explain decibel (dB) as it is used in RF measurements and calculations.
- Perform calculations on frequency and wavelength conversions by employing the basic components of RF mathematics.
- Configure autonomous environments.

Basic Wireless Elements

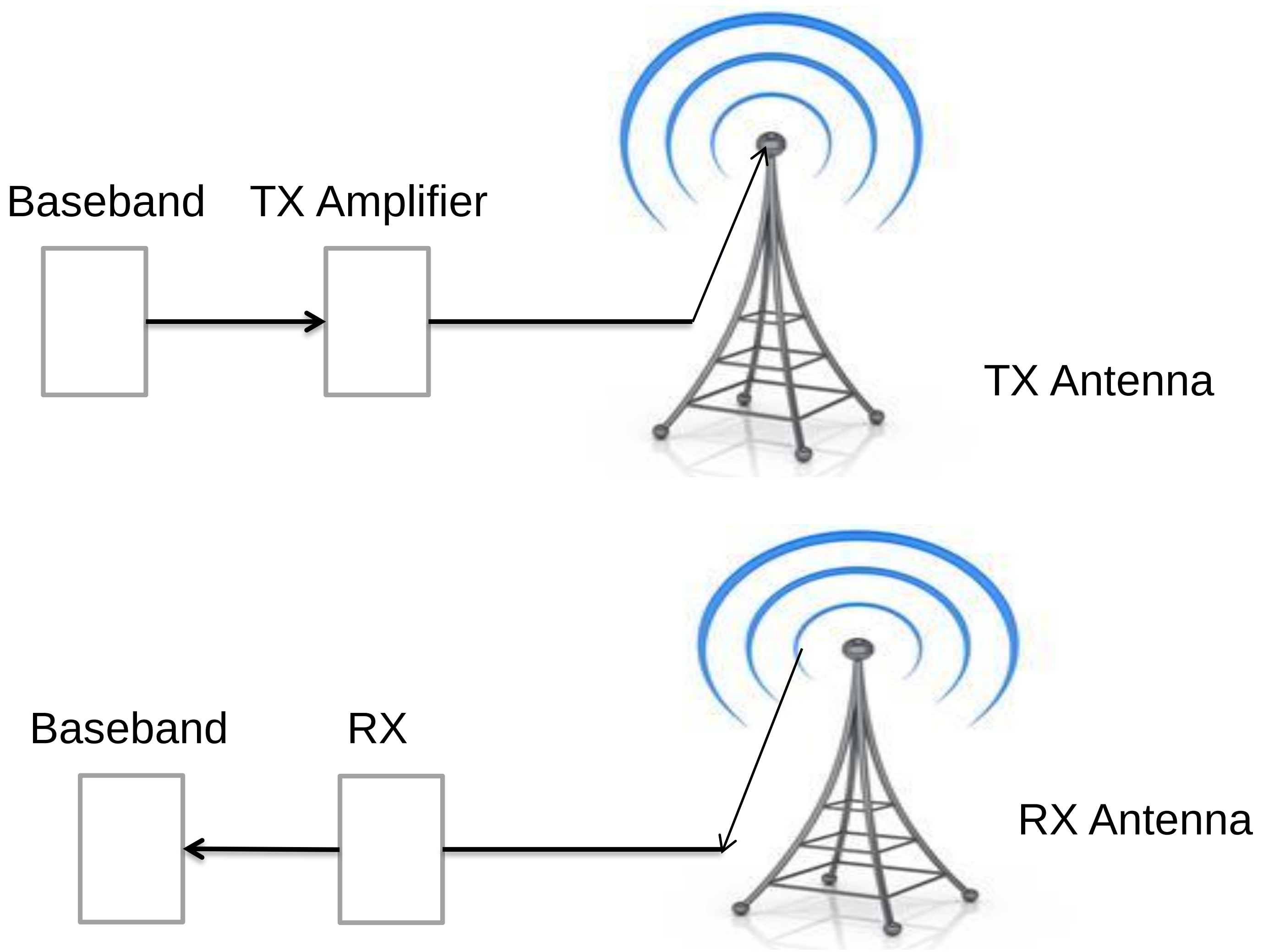


Figure 6: Title
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Basic Wireless Elements

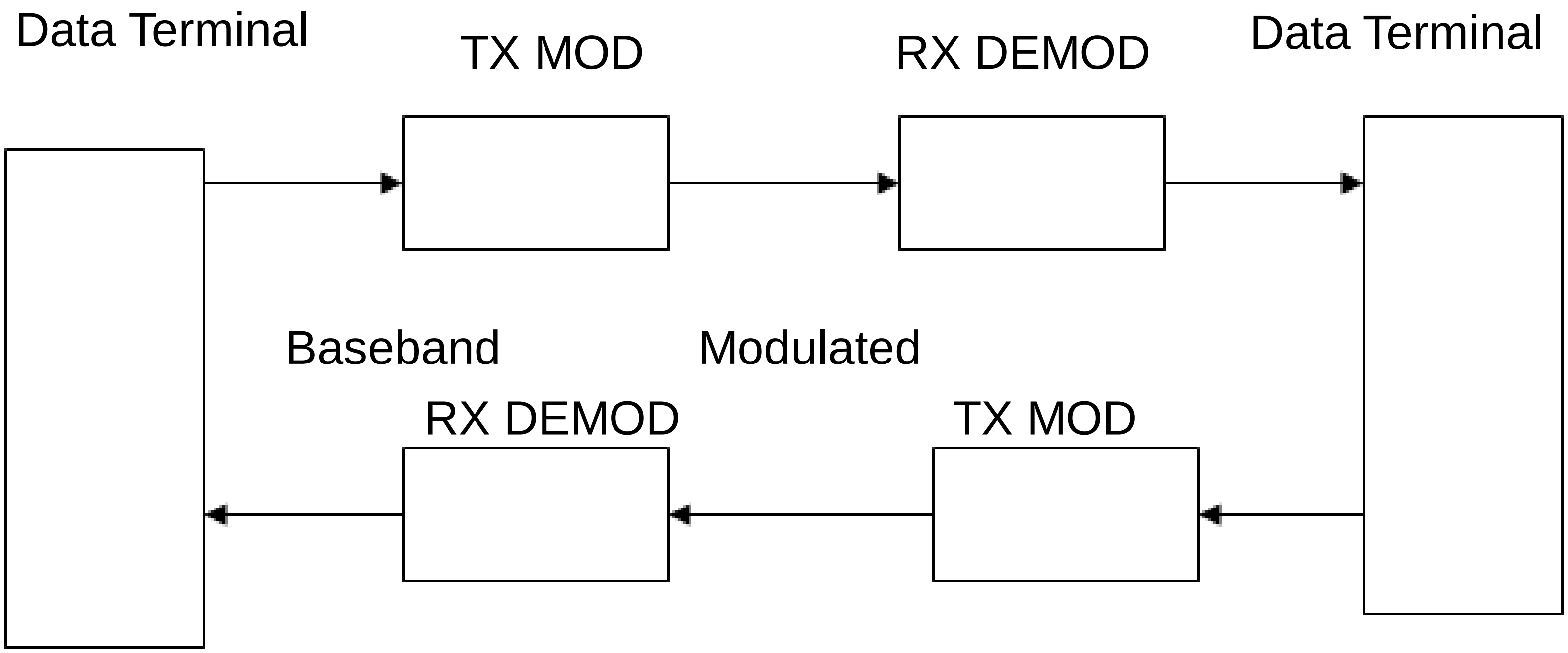

Figure 7: Title

Frequency and Wavelength

- Frequency: number of complete cycles per unit of time.
- One complete cycle of a sine wave = one hertz
- One wavelength = One complete wave's distance as measured units of meters.

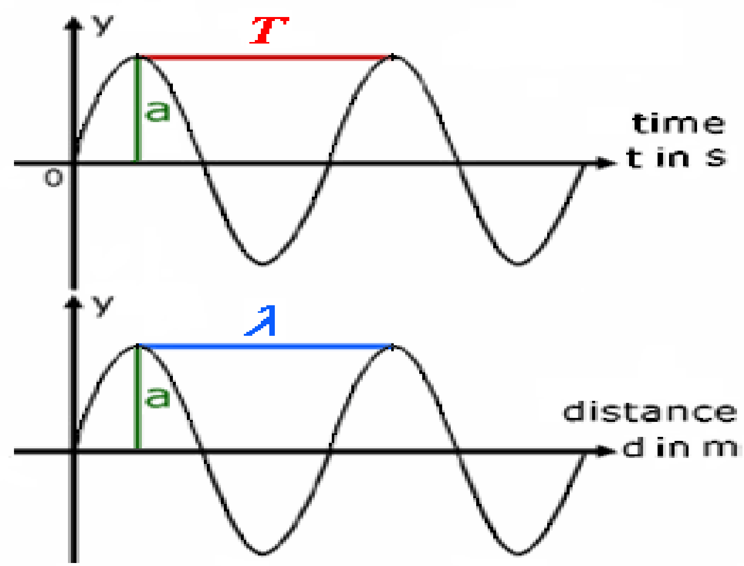

Figure 8: Title
© 2016, A-level Physics Tutor, http://www.a-levelphysicstutor.com/wav-wave-props.php# (CC-BY-NC-ND 4.0)

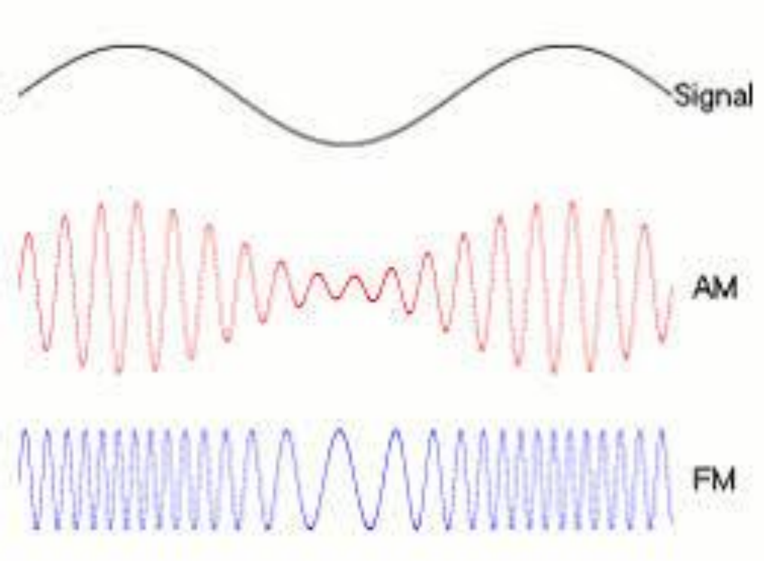

Figure 9: A low-frequency message signal (top) may be carried by an AM or FM radio wave
© 2008, Berserkerus, https://commons.wikimedia.org/wiki/File:Amfm3-en-de.gif (CC-BY-SA 2.5)

Time Domain vs. Frequency Domain

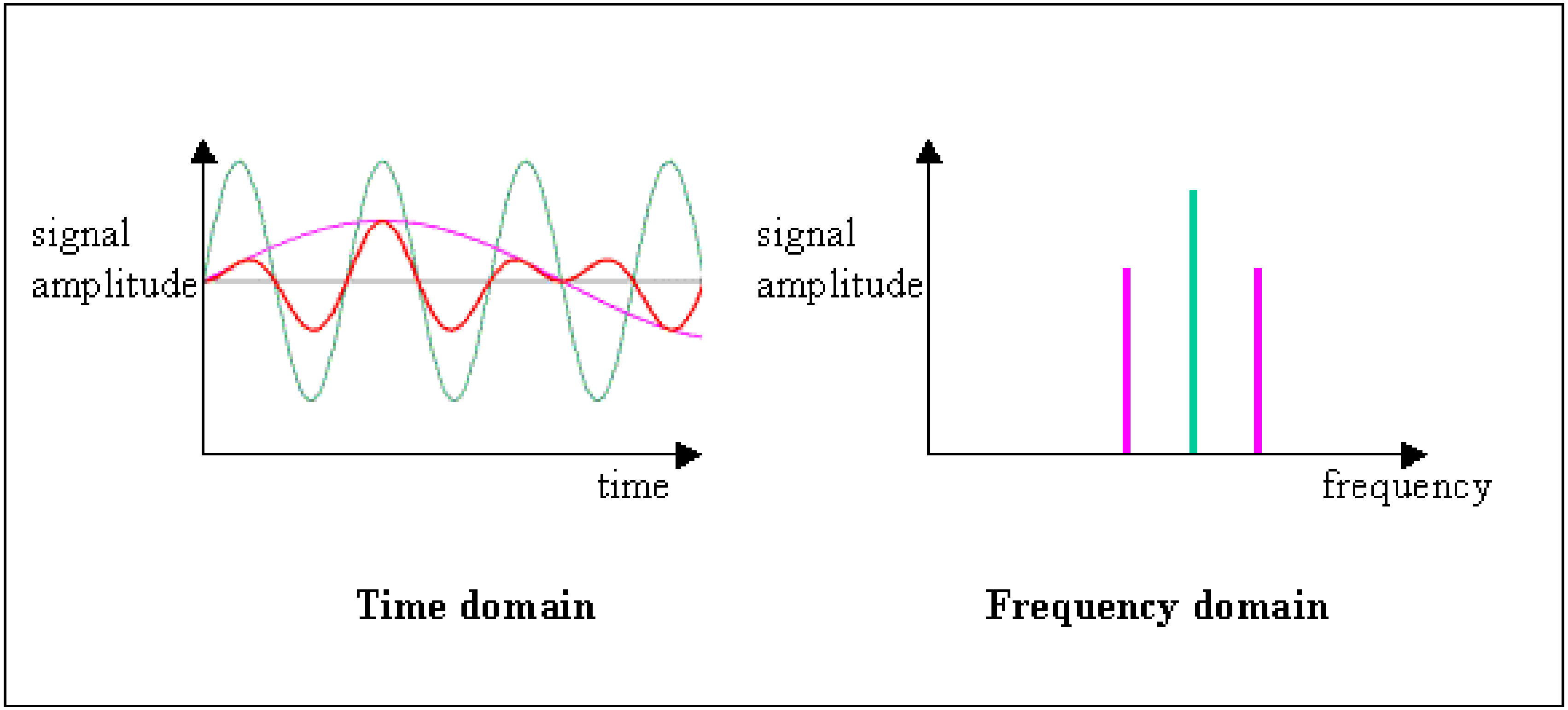

Figure 10: Time Domain vs. Frequency Domain

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Frequency vs. Wavelength

Wavelength is the length of a cycle at its propagation rate.

$$\lambda = \frac{C}{f}$$

Where:
λ = wavelength (meters)
C = rate of travel (meters/second) [in this case the speed of light]
f = frequency

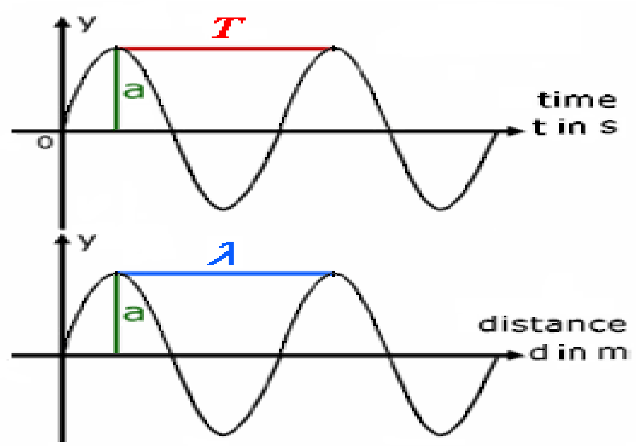

Figure 10: Title

If the frequency were 300,000,000 Hz,
at the speed of light (approx. 300,000,000 m/s), the wavelength would be
1 meter.

Frequency to Wavelength Conversion

- Frequency identifies a particular path through spectrum
- Wavelength describes the particular path through spectrum
- Frequency and wavelength are inversely proportional
  - C = Velocity (c in a vacuum = 300,000 km/s)
  - F = Frequency
  - λ = Wavelength

$$\lambda = \frac{C}{f}$$

Radio Wave Propagation

- As the signal leaves the antenna it propagates, or disperses, into space. The antenna selection determines how much propagation occurs.
- At 2.4 GHz, it is extremely important to ensure a that a path (or tunnel) between the two antennas is clear of any obstructions. Should the propagating signal encounter any obstructions in the path, signal degradation occurs.

Radio Wave Propagation: Dispersion

- Behaves as an expanding sphere equally in all directions.

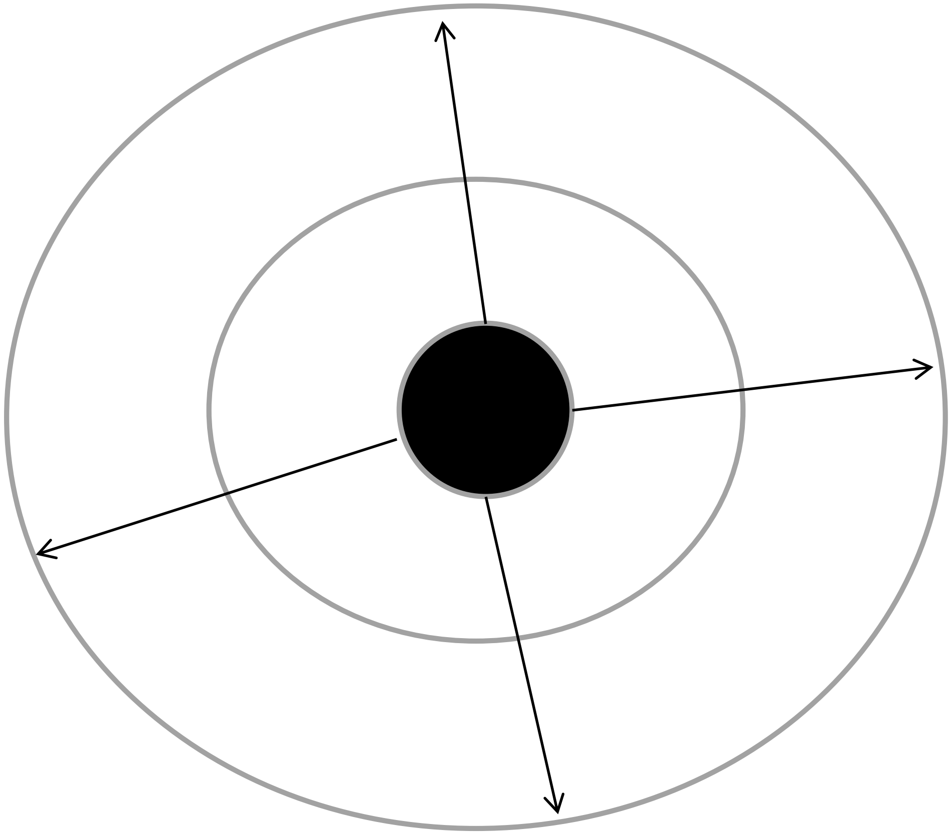

Figure 11: Dispersion
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Radio Wave Propagation

The greatest amount of loss in your wireless system is from *free space propagation*. The *free space loss* is predictable and given by the formula:

$$FSL(dB) = 32.45 + 20Log10F(MHz) + 20Log10D(km)$$

The free space loss at 1 km using a 2.4 GHz system is:

$$FSL(dB) = 32.45 + 20Log10(2400) + 20Log10(1)$$

$$= 32.45 + 67.6 + 0$$

$$= 100.05 \text{ dB}$$

Radio Wave Propagation

- Attaining Line of Sight (LOS) between the sending and receiving antenna is essential in both point-to-point and point-to-multipoint installations.
- Generally, there are two types of LOS that are used during installations:
  - Optical LOS: the ability to see one site from the other
  - Radio LOS: the ability of the receiver to ‘see’ the transmitted signal. 1/3 greater distance than optical.

Radio Wave Propagation

The distance between the transmitter and receiver over average terrain is a factor of frequency, K factor, the height of the tower, temperature, barometric pressure and humidity.

d = sqrt17ht + sqrt17hr

- d: distance in km
- sqrt: square root
- ht: height of transmitting antenna in meters
- hr: height of receiving antenna in meters

Radio Wave Propagation: Refraction

- The bending of waves as they change speed through differing mediums.

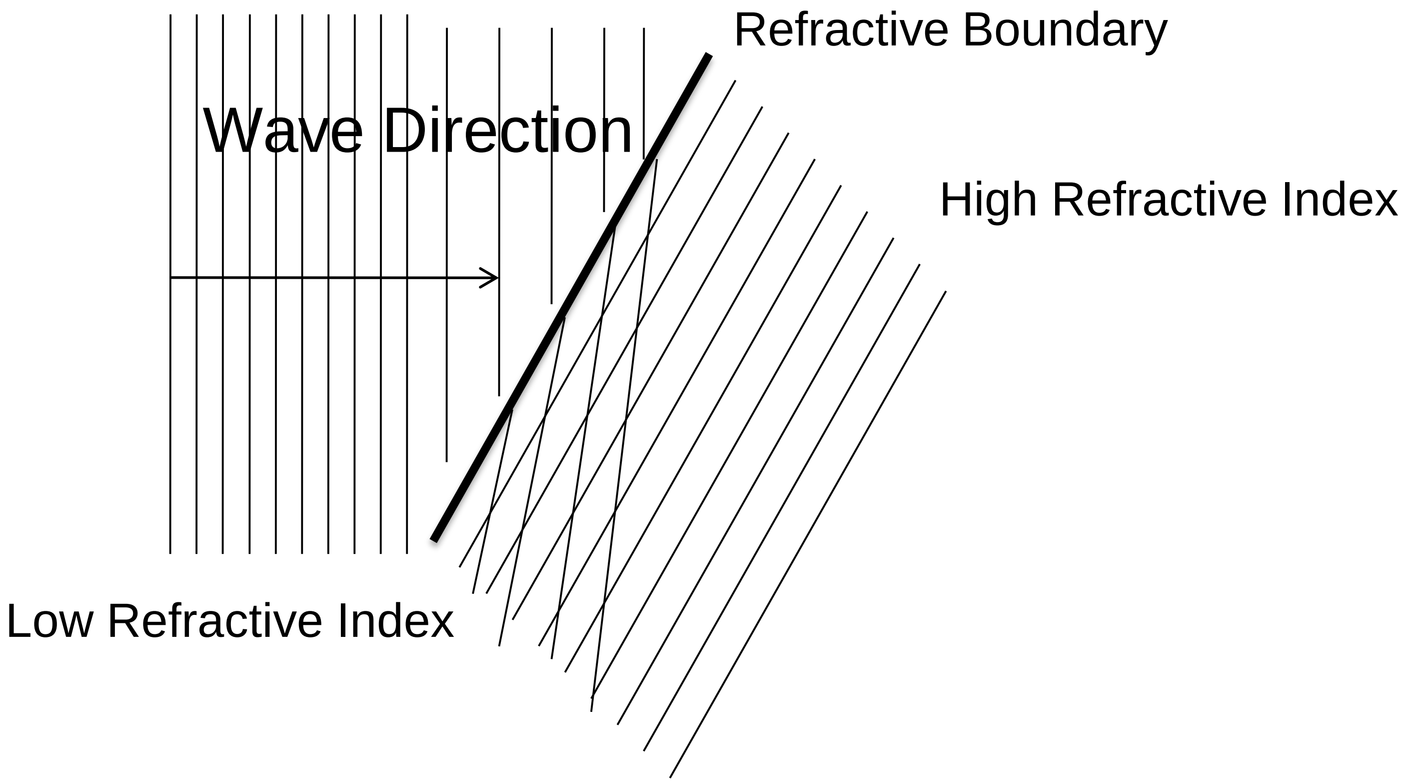

Figure 12: Refraction
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Radio Wave Propagation: Reflection

- The bending of waves back towards their source.

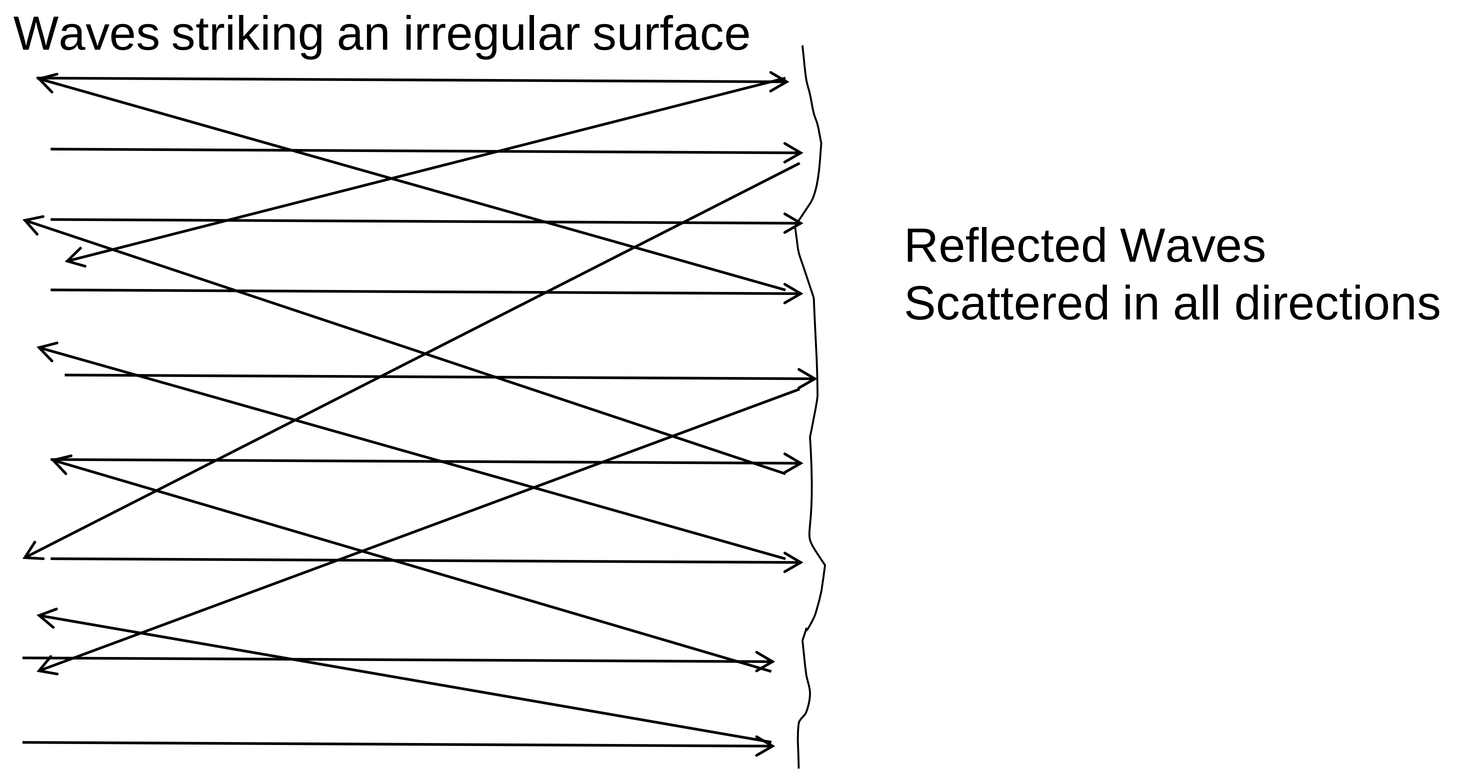

Figure 13: Reflection
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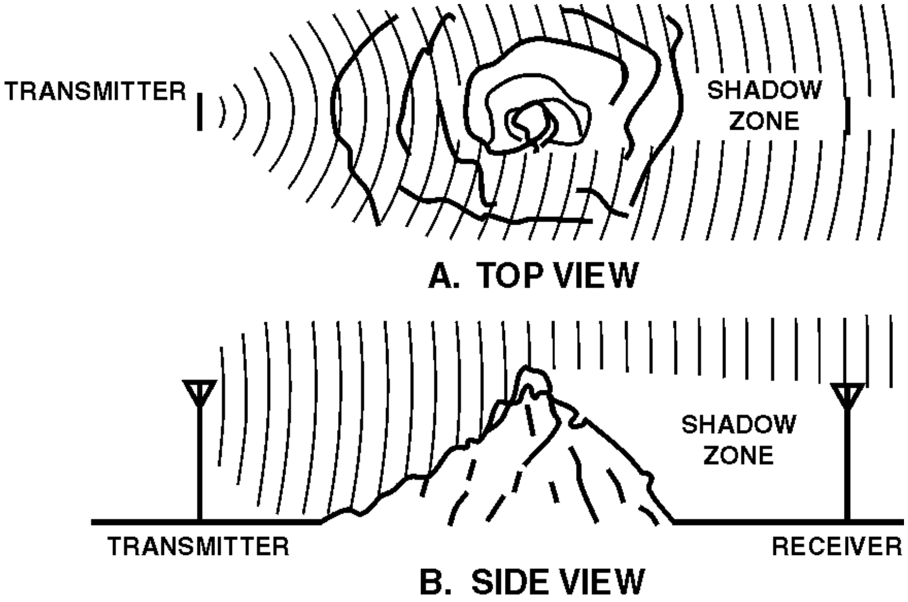
Radio Wave Propagation: Diffraction

- Interference caused when two waves of differing frequency or phase interact.



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http://radiomobile.pe1mew.nl/?Calculations:Propagation_calculation:Radio_propagation&q=diffraction (CC BY-SA 3.0 NL)

Radio Wave Propagation: Absorption

- Energy that becomes part of another entity.

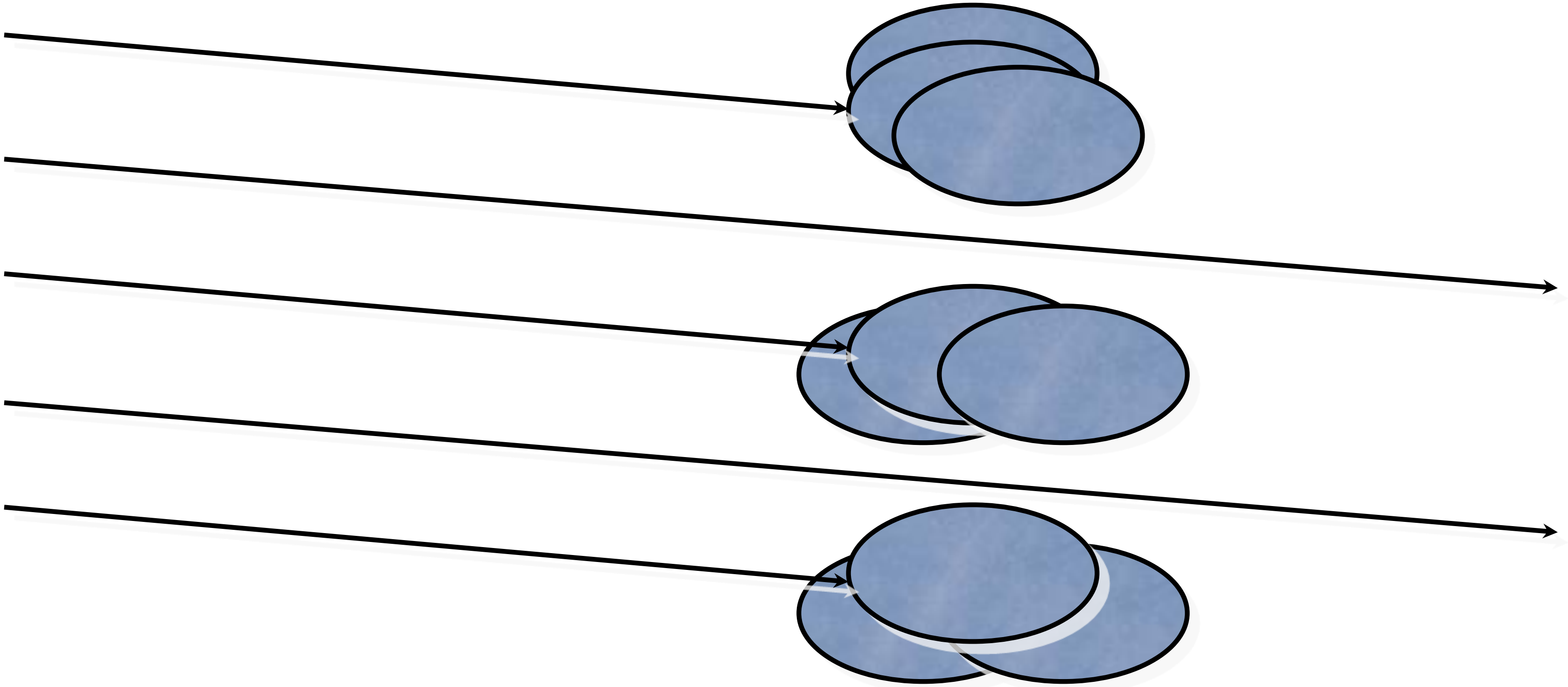

Figure 16: Absorption

Radio Wave Propagation: Scatter

- Non-uniform changes in an electromagnetic wave’s trajectory.

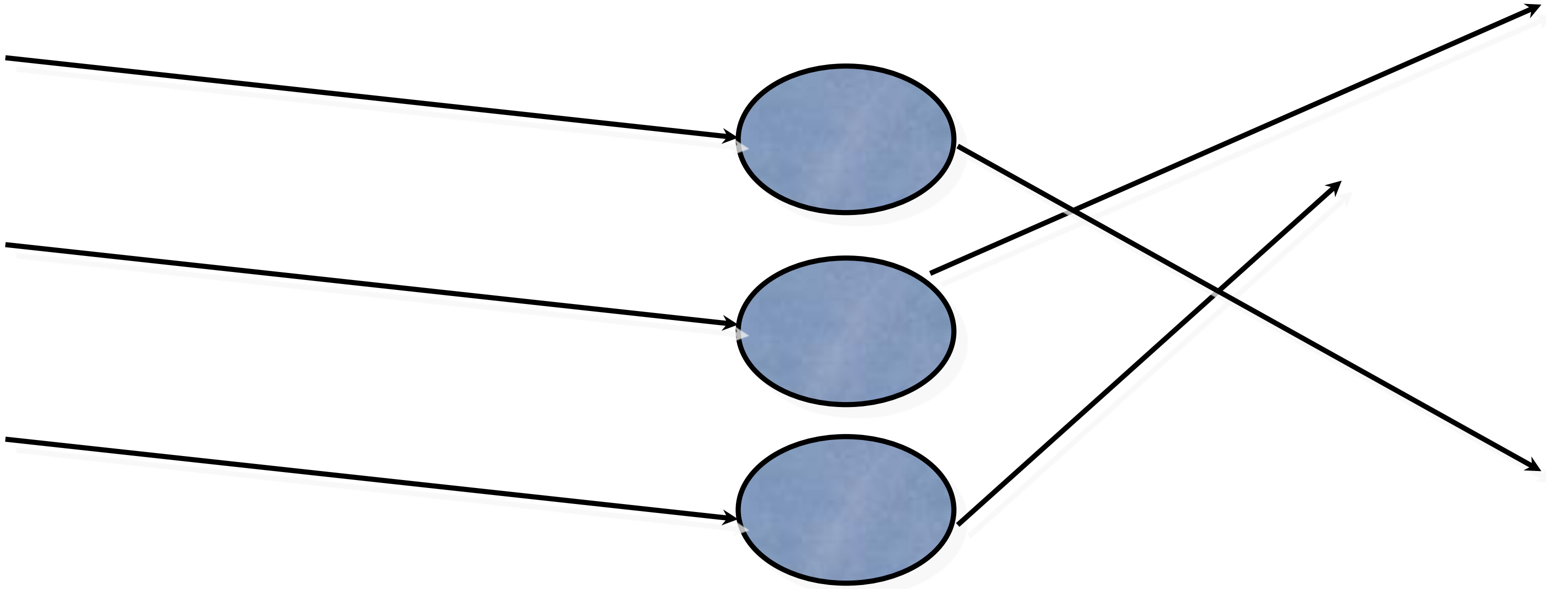

Figure 17: Scatter

Radio Wave Propagation

- To quantify radio line of sight, the *Fresnel Zone theory* is applied.
- Think of the Fresnel Zone as a football-shaped tunnel between the two sites that provides a path for RF signals.
- Obstructions in the Fresnel Zone are generally undesirable.

Radio Wave Propagation

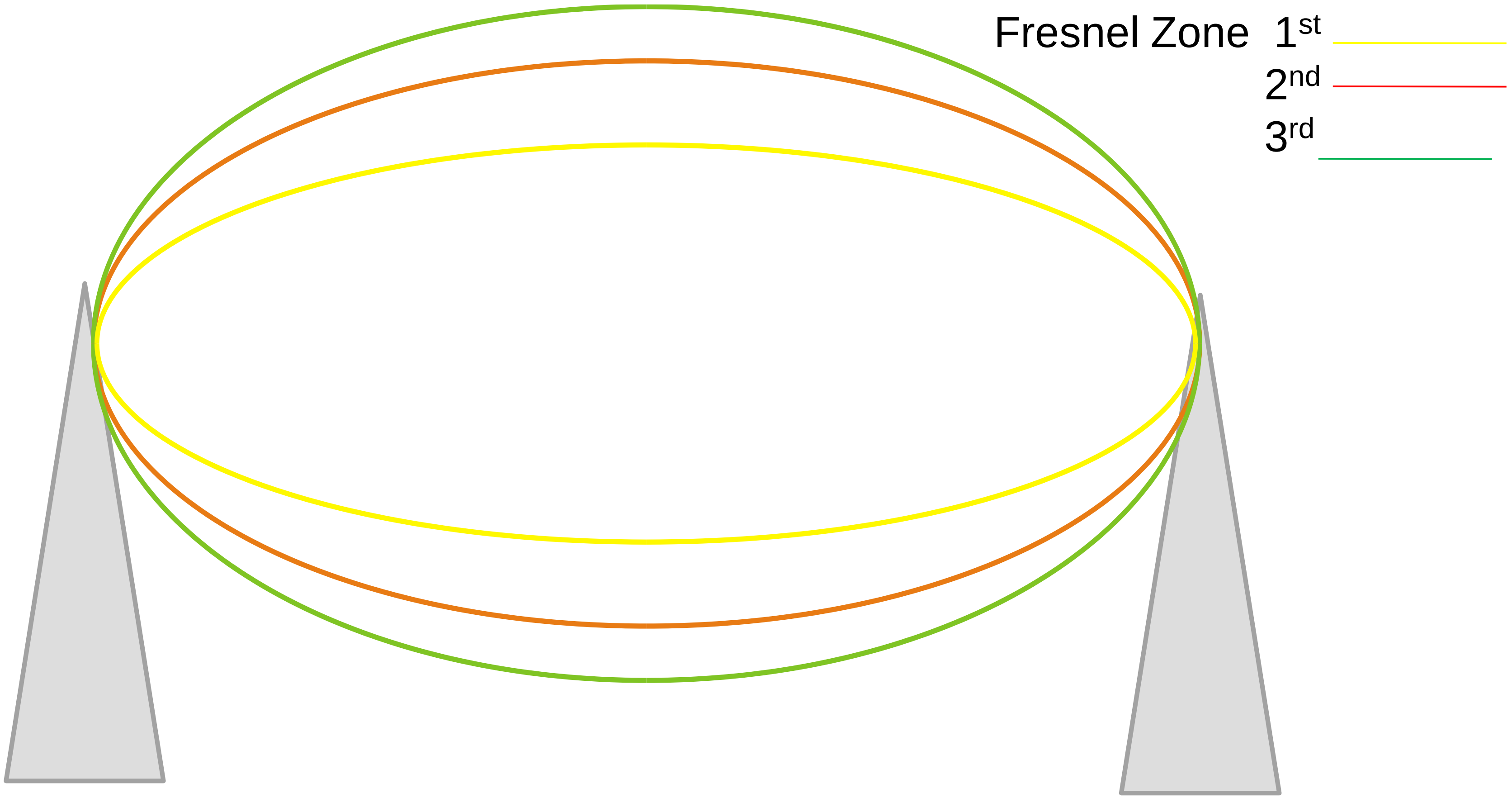

Figure 18: Fresnel Zone
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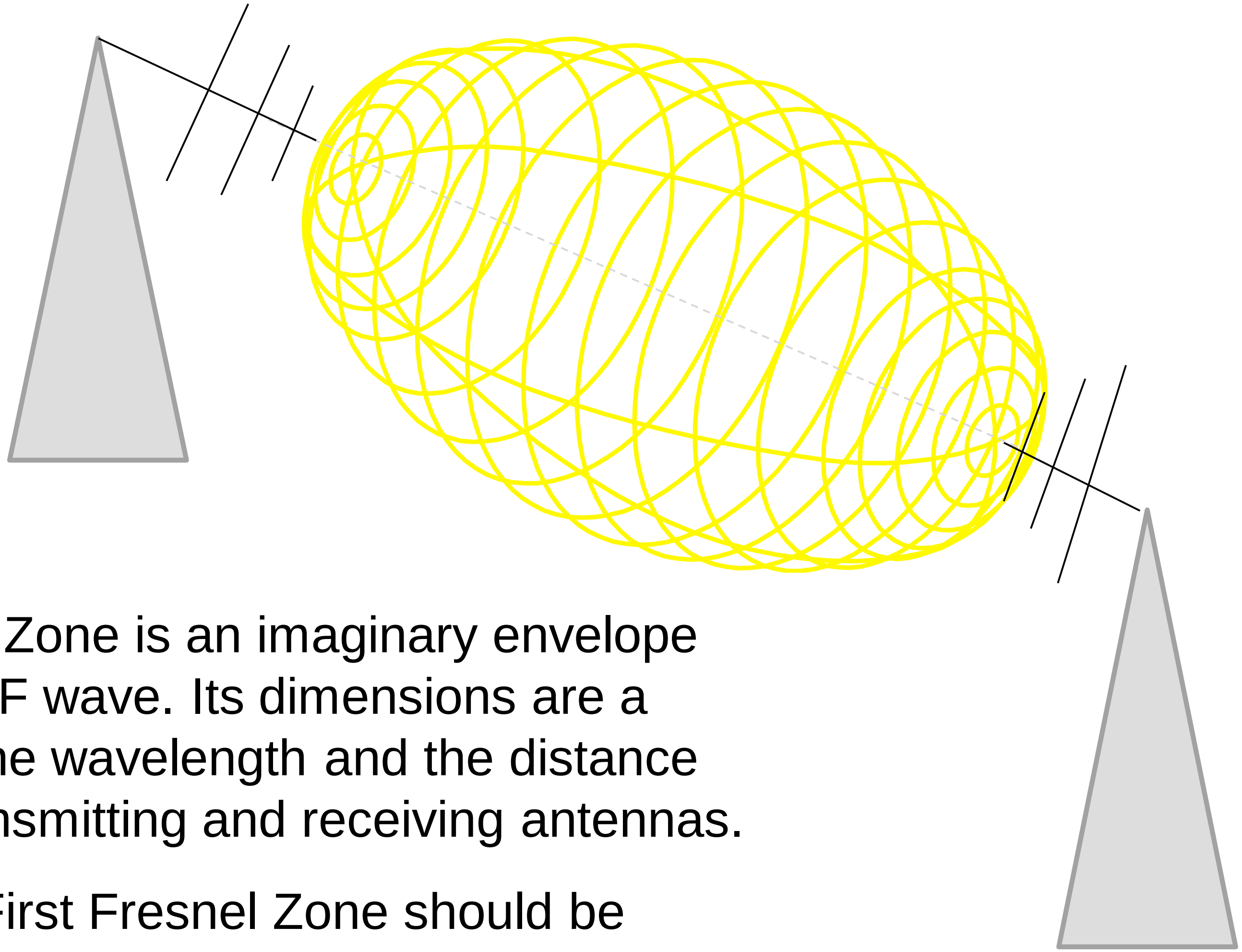
The First Fresnel Zone



- The Fresnel Zone is an imaginary envelope around an RF wave. Its dimensions are a function of the wavelength and the distance between transmitting and receiving antennas.
- 60% of the First Fresnel Zone should be obstruction free

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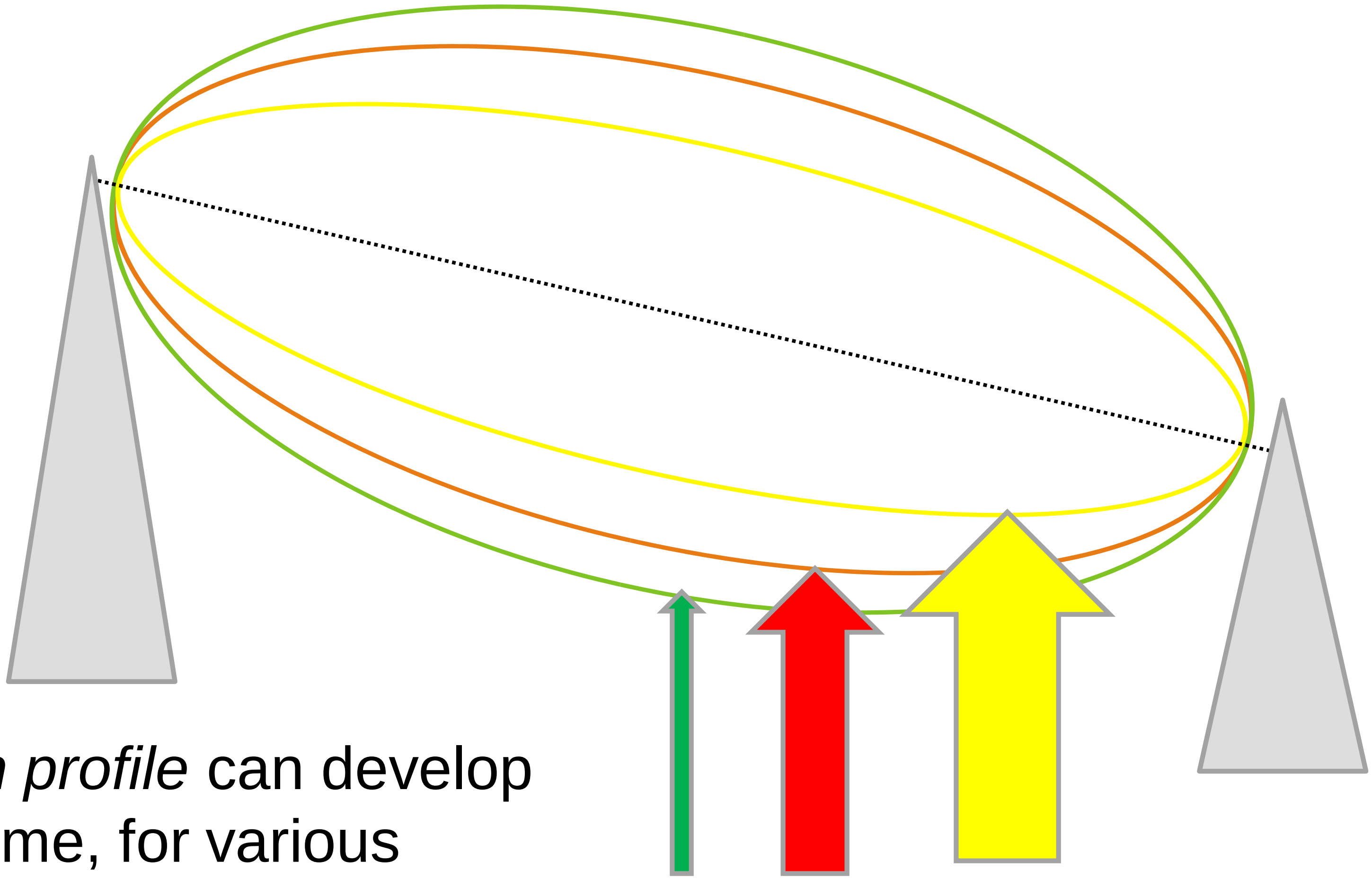
The Path Profile



A *path profile* can develop over time, for various reasons (e.g., vegetation, buildings).

Figure 20: Title
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Ground Waves

- Frequencies up to 3 MHz follow the curvature of earth.
- Ground waves attenuate quickly.
- Ground waves are effective in achieving over-the-horizon applications, but only LF or VLF bands.
- See: http://www.radio-electronics.com/info/propagation/ground_wave/ground_wave.php

Space Waves

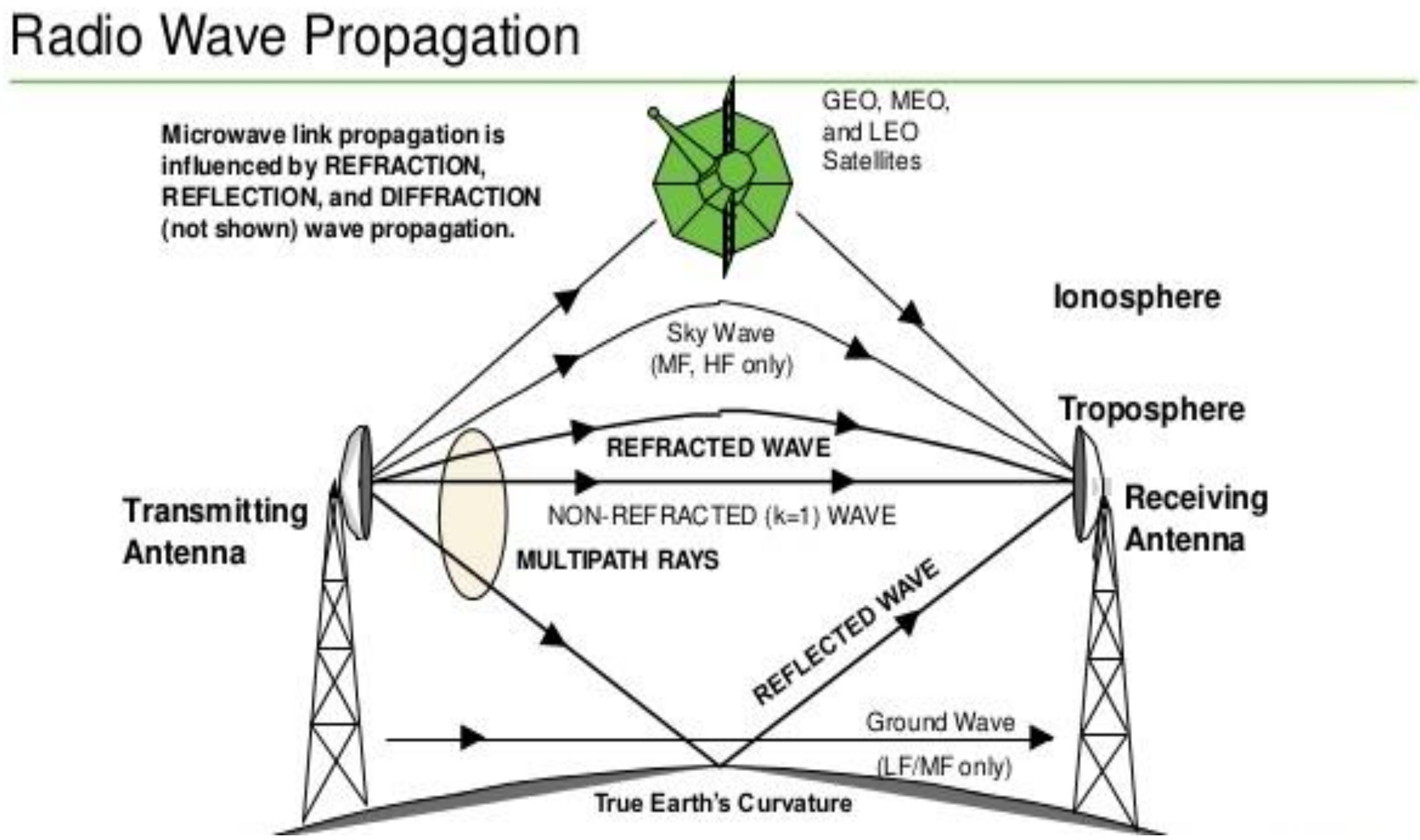
- Space waves are also referred to as *direct waves*.

- Tx to RX Line of Sight LOS is required.

Sky Waves

- Sky waves are refracted back to earth by the ionosphere.
- Sky waves are high frequency HF band signals.
- Sky waves must contact the ionosphere at the perfect angle to skip back to earth.

Radio Wave Propagation



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Radio Wave Propagation

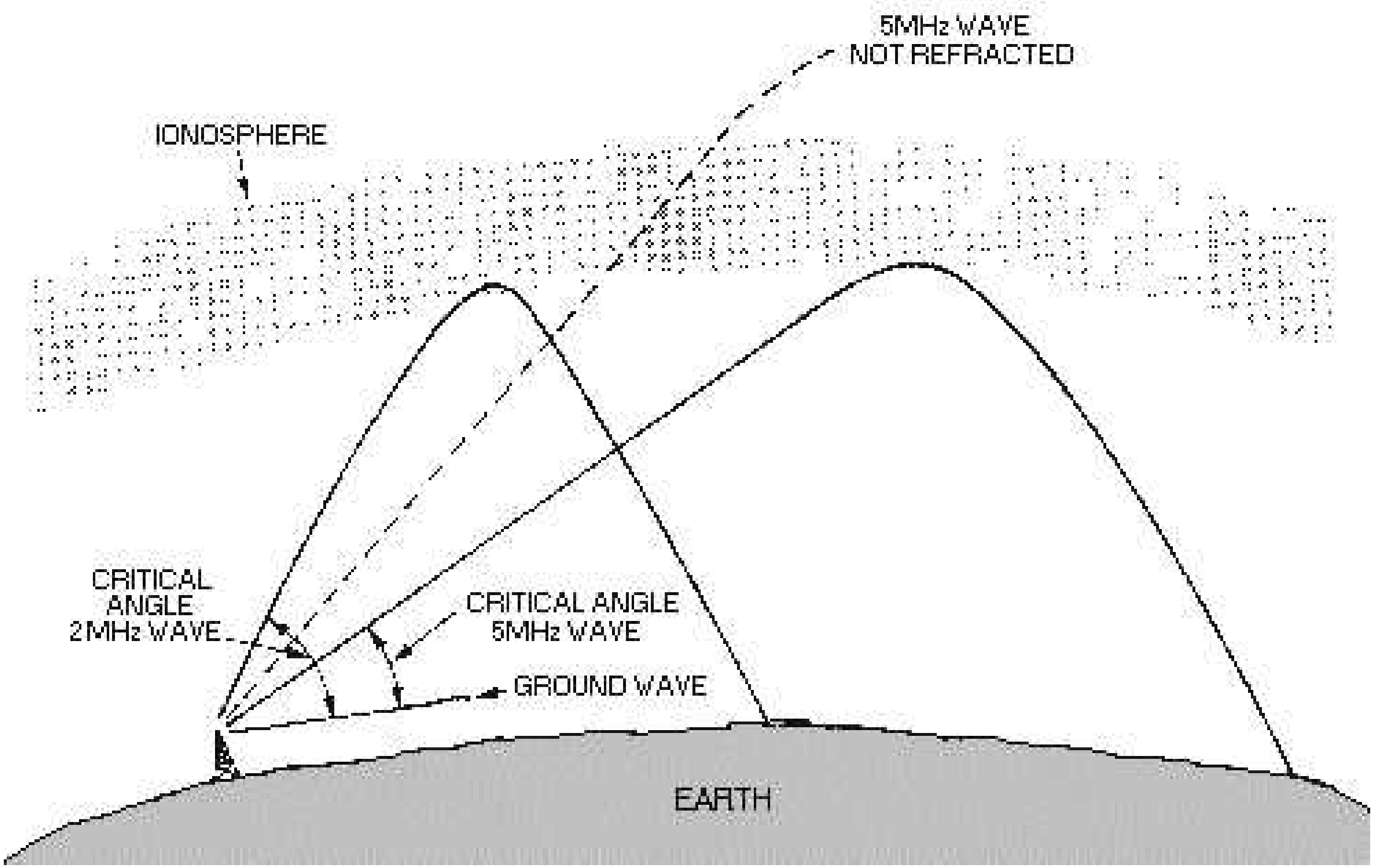

Figure 22: Effects of Frequency on the Critical Angle

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Radio Wave Propagation

- Fixed environment versus mobile environment
- Mobile environment path is dynamic
- Mobile environment can be very cluttered
- Mobile environment attenuation increases more rapidly with distance

Free Space Loss Lfs(dB) = 32.45 + 20Log f (MHz) + 20Log d(km)

Mobile Propagation loss Lp(db) = 68.75 + 26.16 Log f – 13.82 log h + (44.9-6,55 log h) log d

Units & Conversion

Units of Measure

- Watt (W)
- Milliwatt (mW)
- Decibel (dB)
- Decibel milliwatt (dBm)
- Decibel isotropic (dBi)

Milliwatts & Watts

Milliwatts

- 802.11 devices use between 1 and 100 mW
- 1 mW used for small areas
- 15–30 mW for PCMCIA
- 30–100 mW for APs (some companies use up to 250 mW)
- > 250 mW for outdoor use

Watts

- CSA allows up to four watts radiated antenna power on PTMP unlicensed 2.5GHz

Decibels

- RF signal has logarithmic drop-off during propagation
- Signal weakens quickly
- Measures the relative strength between two signals

Power difference (dB) = 10 × log(power A ÷ power B)

Gain & Loss

- Measures in dB
- 10s & 3s RF shortcut

  -3 dB = 1/2 power mW = ÷ 2

  +3 dB = double power mW = × 2

  -10 dB = 1/10 power mW = ÷ 10

  +10 dB = 10 times power mW = × 10

10s and 3s

- 25 mW signal has 3 dB loss:

  25 mW – 3 dB = 25 mW ÷ 2 = 12.5 mW

- 200 mW signal has a 10 dB gain:

  200 mW + 10 dB = 200mW × 10 = 2000 mW = 2W

10s and 3s Combining

- 15 mW signal has a 13 dB gain:

  15 mW + 13 dB

  = 15 mW + 10 dB + 3 dB

  = 15 mW × 10 × 2

  = 300 mW

10s and 3s Table

Gain dB	10s and 3s
1 dB	+ 10 - 9 (+ 10 - 3 - 3 - 3)
2 dB	- 10 + 12 (- 10 + 3 +3 + 3 + 3)
3 dB	+ 3
4 dB	+ 10 - 6 (+10 - 3 - 3)
5 dB	+ 20 - 15 (+ 10 + 10 - 3 - 3 - 3 - 3 - 3)
6 dB	+ 6 (+ 3 + 3)
7 dB	+ 10 - 3
8 dB	+ 20 - 12 (+ 10 + 10 - 3 - 3 - 3 - 3)
9 dB	+ 9 (+ 3 + 3 + 3)
10 dB	+ 10

Gain & Loss

- Remember: it's additive
- Add and subtract all gain or loss for a link, and then calculate the resulting dB from the original signal

dBm

- Normalizing the decibel (using an arbitrary reference point)
- dBm uses 1 mW as the reference point

100mW transmit power

$= 1 \text{ mW} \times 10 \times 10$

$= 1 \text{ mW} + 10 \text{ dB} + 10 \text{ dB}$

$= 1 \text{ mW} + 20 \text{ dB}$

Cumulative dBm

- Add gains and subtract losses
- Calculate total dB gain or loss as normal
- Use 1mW as reference to find total power in mW

45 mW transmitter has a cable loss of 6 dB, then is amplified with a gain of 10 dB

= 45 mW - 6 dB + 10 dB

= 45 mW - 3 dB - 3 dB +10 dB

= 45 mW ÷ 2 ÷ 2 × 10

= 112.5 mW

Or

= 45 mW - 6 dB + 10 dB

= 45 mW + 4 dB

= 45 mW + 10 dB - 3 dB - 3 db

= 45 mW × 10 ÷ 2 ÷ 2

= 112.5 mW

Convert dBm to mW

Convert to dBm first:

1 mW × 9 × 5 = 45 mW

1 mW + 9dB + 5dB = 45 mW

1 mW +14dB = 45 mW

14 dBm = 45 mW

= 14 - 6 + 10 = 18 dBm

Convert back to mW:

1 mW + 10 dB + 8 dB

= 1 mW × 10 × 10 × 10 ÷ 2 ÷ 2 ÷ 2 ÷ 2

= 62.5 mW

Not accurate (other method = 112.5 mW)

Accurate dBm

(wireless calculator)

$$dBm = (10\text{Log}_{10}(\text{milliWatts})) + 30$$

$$10\text{Log}_{10}(45\text{mW}) + 30$$

$$16.5 \text{ dBm}$$

$$16.5 \text{ dBm} - 6 \text{ dB} + 10 \text{ dB} = 20.5 \text{ dBm}$$

$$\text{milliWatts} = 10^{(\text{dBm}/10)}$$

$$10^{(20.5\text{dBm}/10)}$$

$$112.2 \text{ mW}$$

Power Level Chart

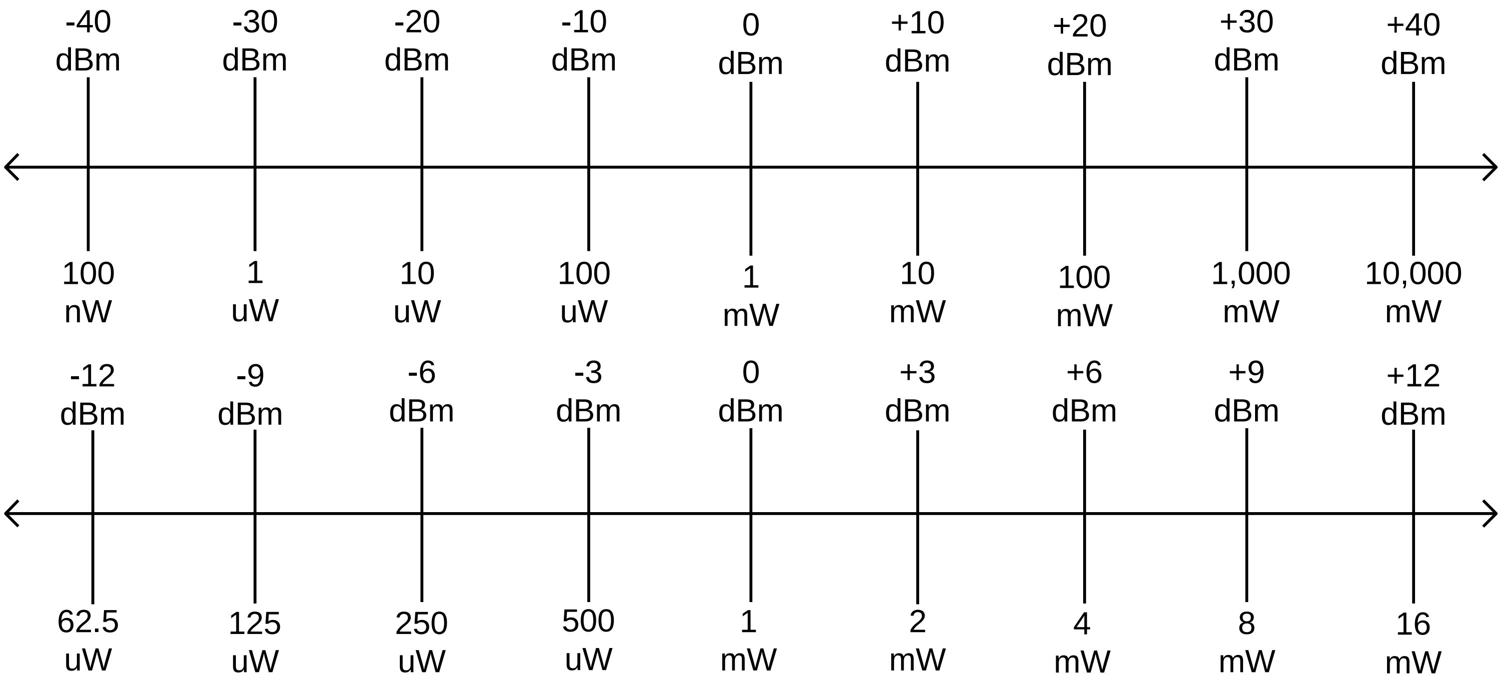

Figure 23: Power Level Chart
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