Basic Radio Physics

Network Startup Resource Center
www.nsrc.org

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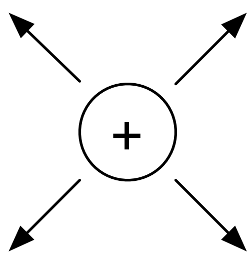
UNIVERSITY OF OREGON

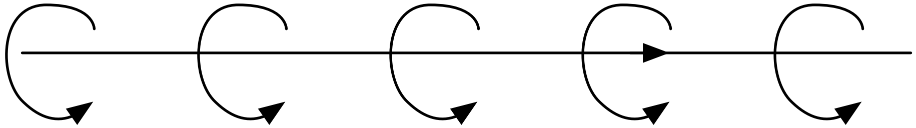
NSRC Network Startup Resource Center

Electromagnetism

A Positive Charge in Space Creates an Electric Field (E)

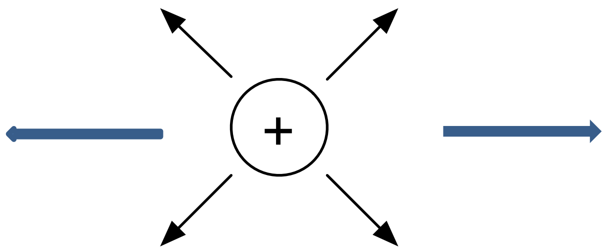


Current in Wires Creates a Magnetic Field (B)

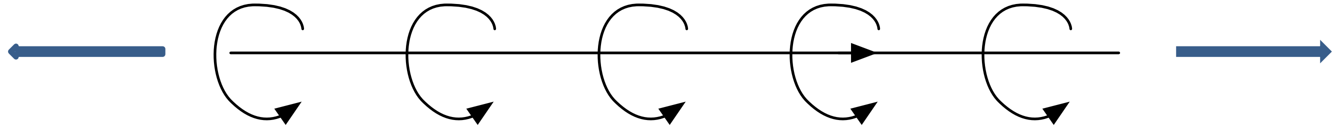


Electromagnetism

Change an Electric Field, you create a Magnetic Field (B)

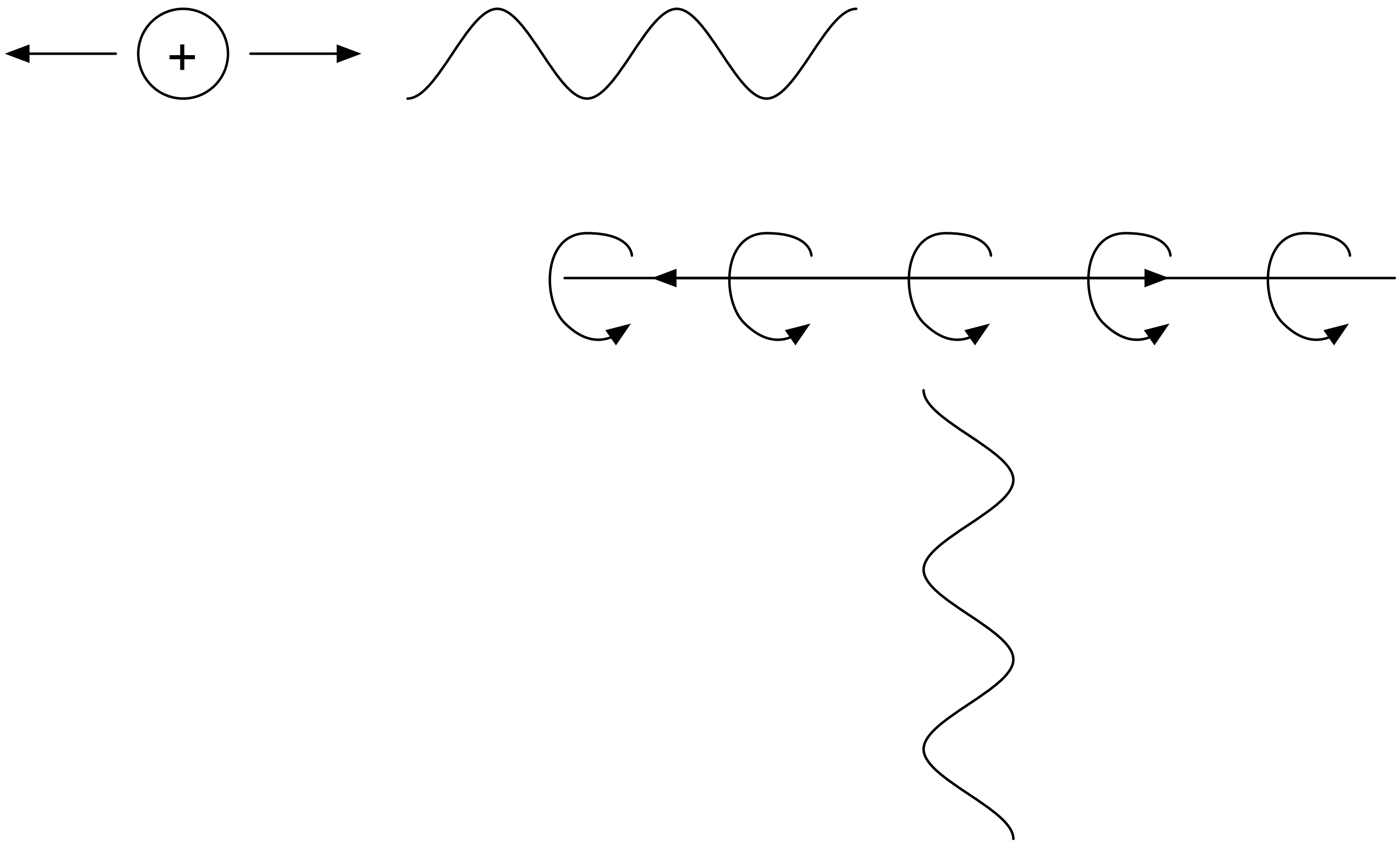


Change a Magnetic Field, you create an Electric Field (E)



Electromagnetic Waves

Changing Electromagnetic Fields propagate outwards in waves.



waves

Waves

- Oscillation + Transfer of Energy
- Mechanical Waves:
  - Sound, Water
  - Require a physical medium
- Electromagnetic Waves:
  - Light, Radio Microwave, Infrared, X-Ray, Gamma Ray
  - No Physical Medium Required
  - Radio can propagate through metal
  - Light can propagate through glass

Electromagnetic Waves

$c = \lambda * \nu$

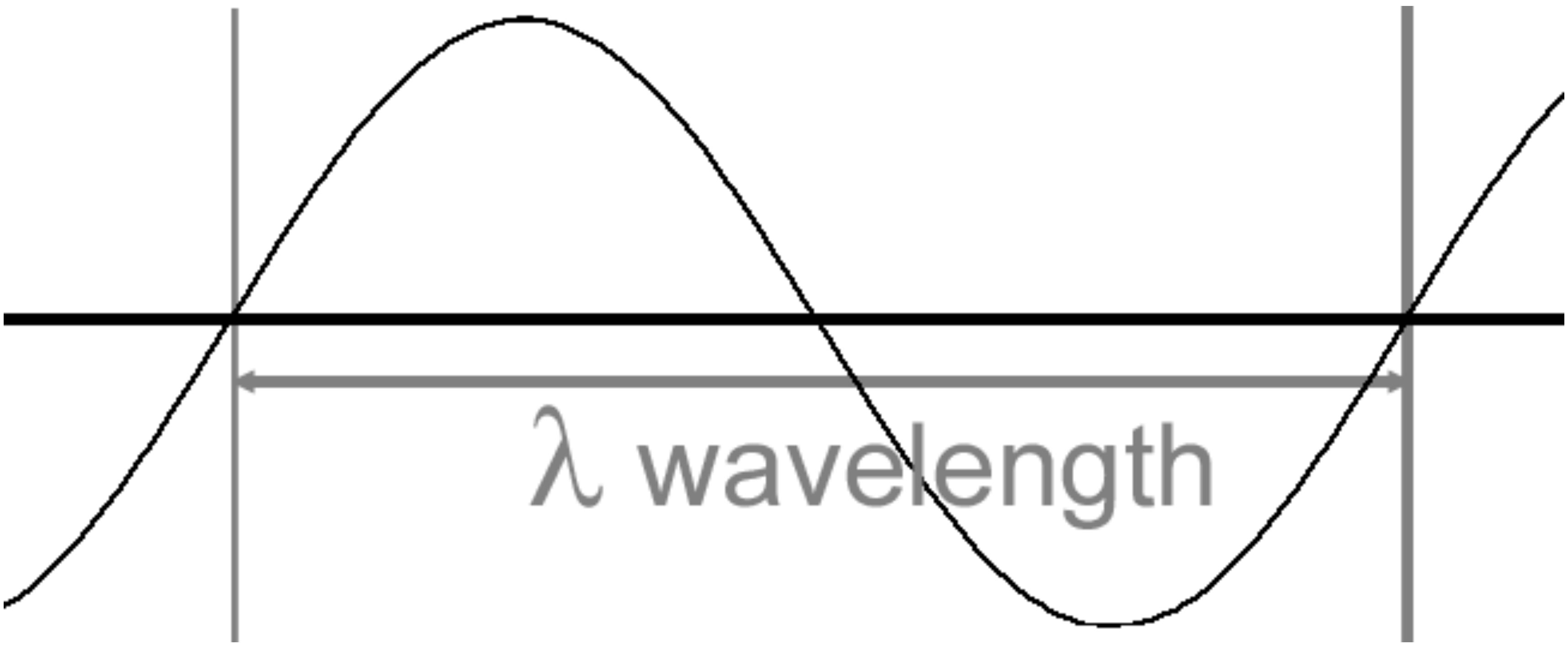
c is the speed of light (in vacuum) 3×10^8 m/s

λ Lambda is the wavelength [m]

ν Nu is the frequency [1/s = Hz]

- Light takes 8 minutes from Sun to Earth
- How long does it take to go 100km?
- Does it go as fast in a cable?

A Wave



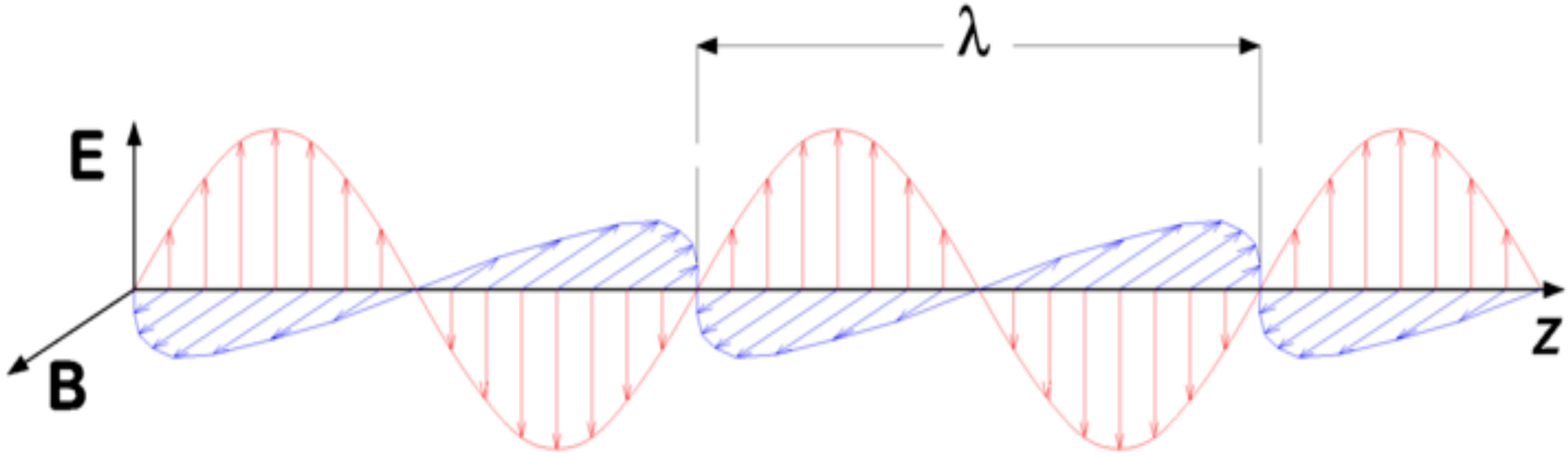
Wavelength Calculations

- Speed of Light = Wavelength * Frequency
- Frequency = Speed of Light / Wavelength
- Wavelength = Speed of Light / Frequency
- What's the frequency of 3.5 mm waves?
- What's the wavelength at 2400 MHz?

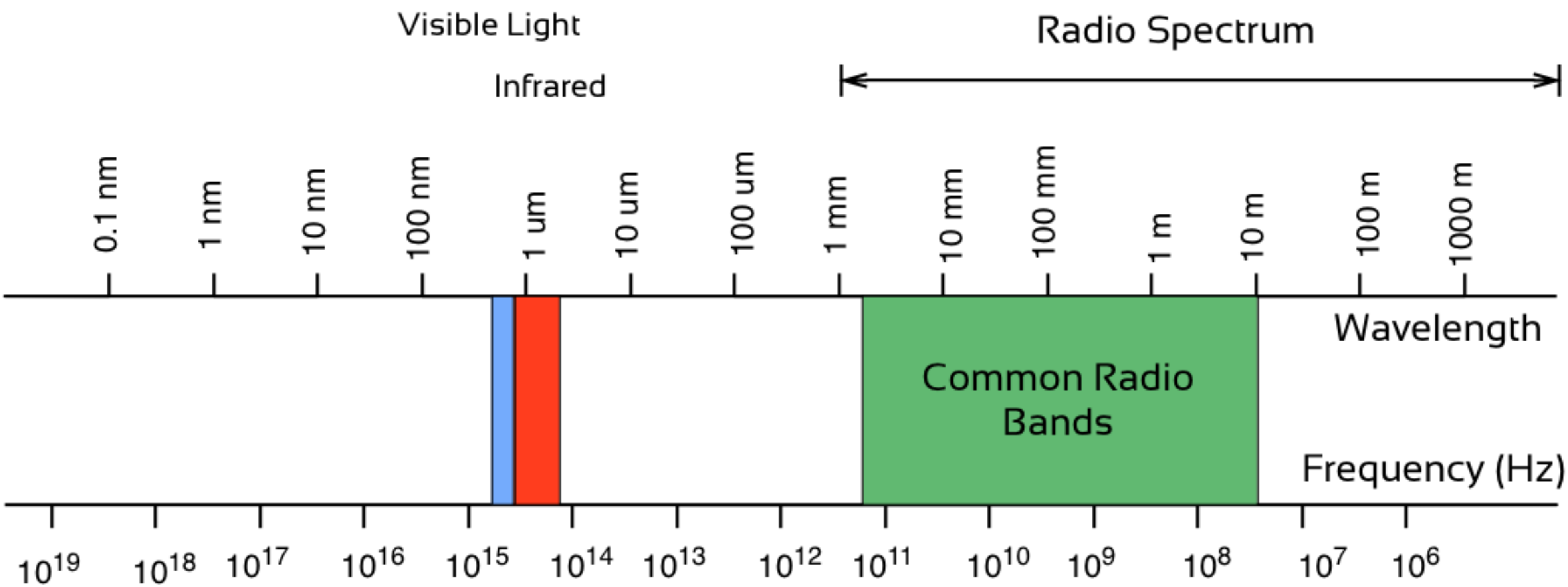
EM Wave Polarization

Direction of the electric field vector

Linear, elliptic, circular polarization



Electromagnetic spectrum

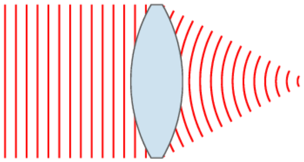


Wireless Networking Frequencies

- Wi-Fi is typically used in:
  - 2.4 GHz – 802.11b/g/n
  - 5.x GHz – 802.11a/n
- Other bands interesting to us
  - 415/433 MHz
  - 868 MHz
  - 915 MHz
  - 3.5 GHz
  - 24 GHz
  - 60-80 GHz

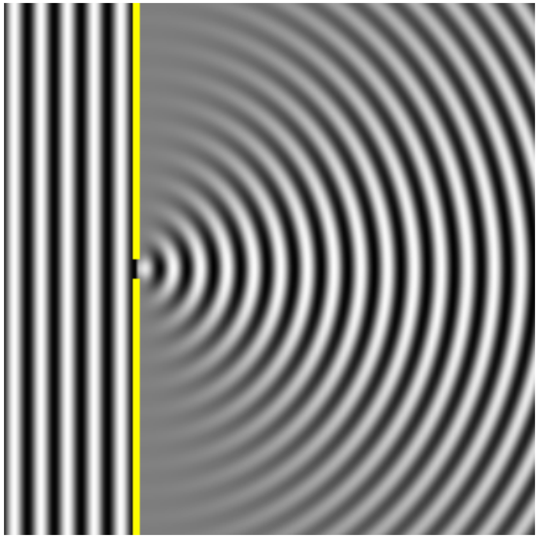
Propagation of Radio waves

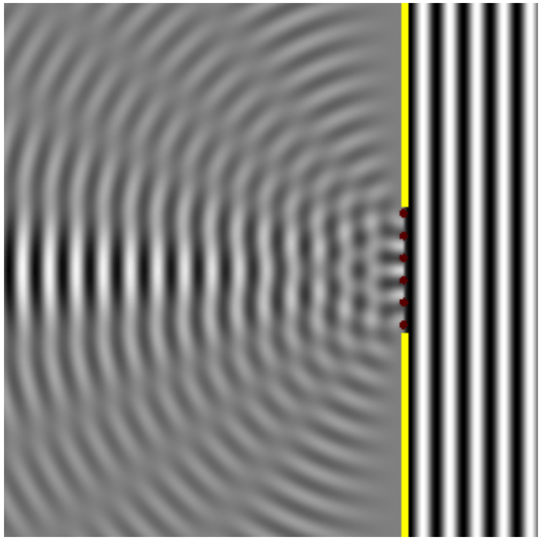
- Wave Fronts: planar & spherical



- Huygens principle:
  - Spherical waves start at any disturbance
- Waves do not propagate as a straight line
  - Not even light!
- Behavior scales with wavelength

Huygens principle





Animated images thanks to Fu-Kwun Hwang and author of Easy Java Simulation = Francisco Esquembre

http://commons.wikimedia.org/wiki/File:Wavelength%3Dslitwidth.gif#/media/File:Wavelength%3Dslitwidth.gif

Radio Waves are Affected By

- Absorption
- Reflection
- Diffraction
- Interference

Radio waves: Absorption

- Converts energy into heat
- Decreases power exponentially
    - this is a linear decrease in dB
- Water, Metal, Oxygen
- Stones, Bricks, Concrete
- Wood, Trees

Radio waves: Absorption

- Plasterboard / Drywall Wall: 3-5dB
- Metal Door: 6-10dB
- Window: 3dB
- Concrete Wall: 6-15dB
- Block Wall: 4-6dB

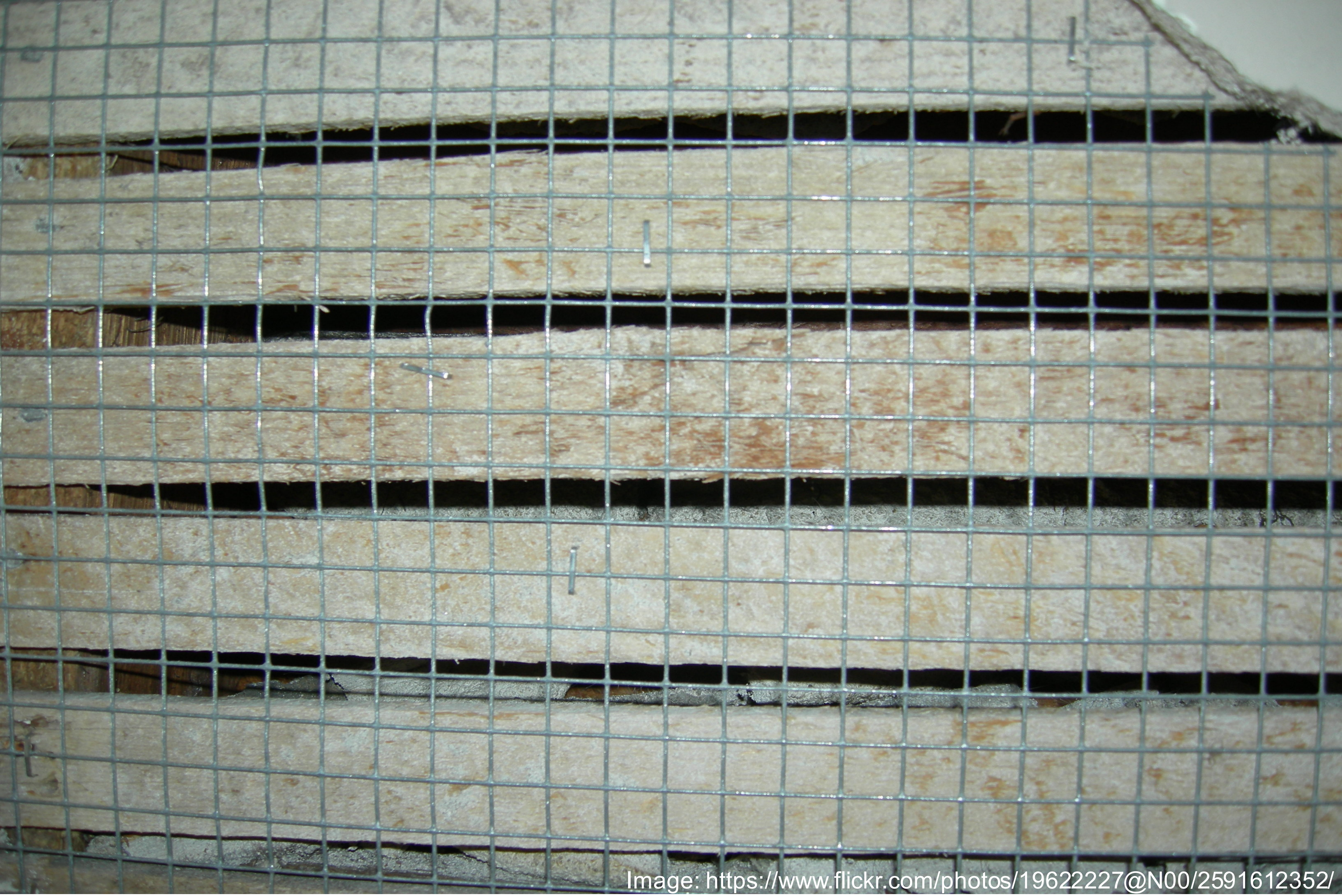
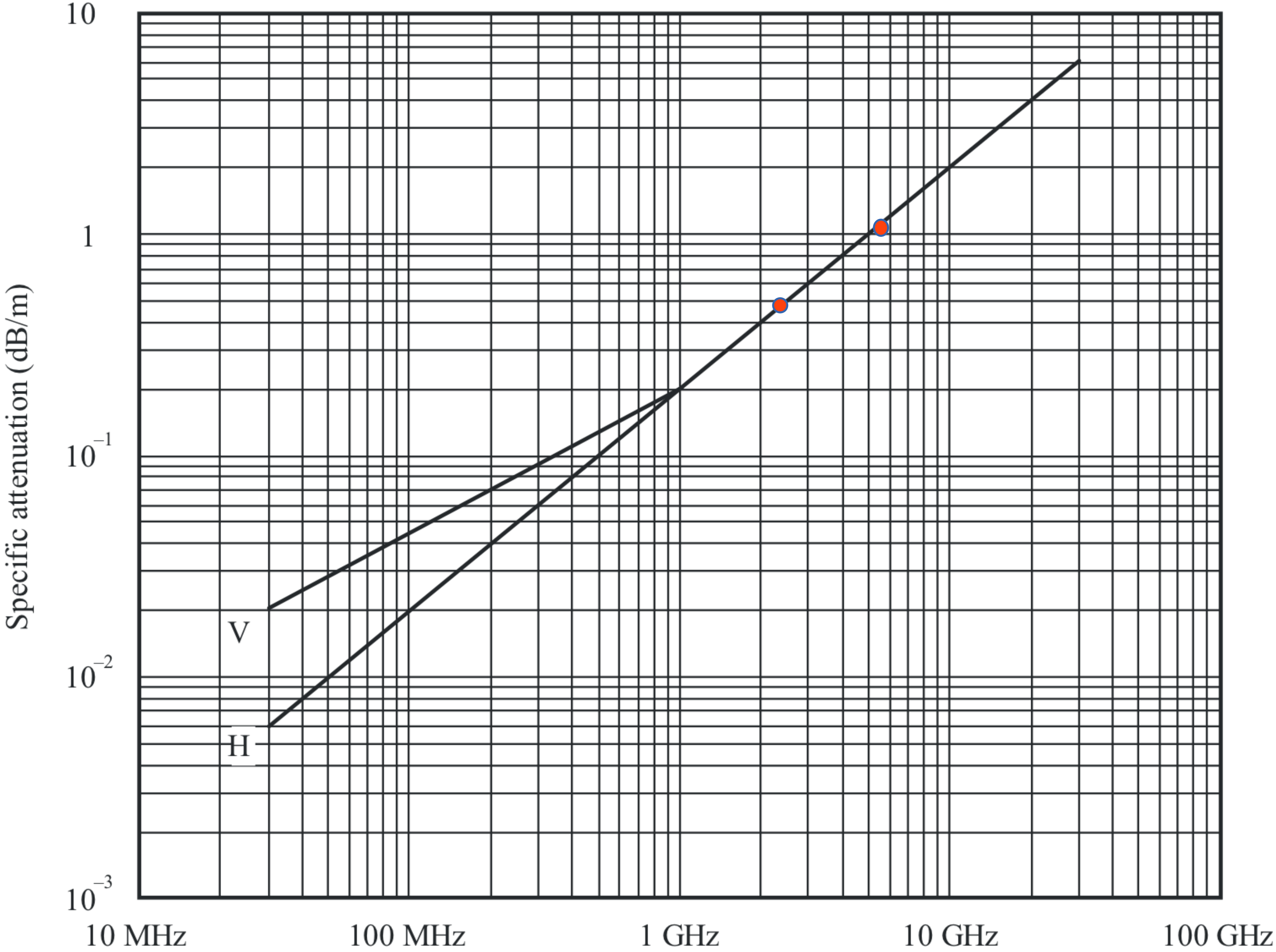


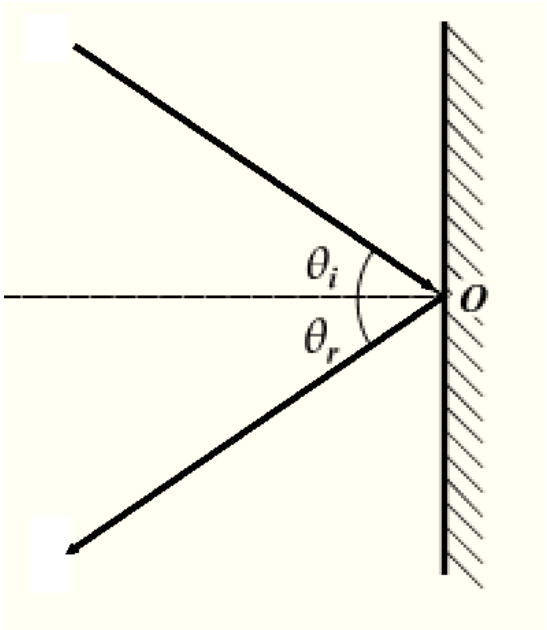
Image: https://www.flickr.com/photos/19622227@N00/2591612352/

Specific attenuation due to woodland

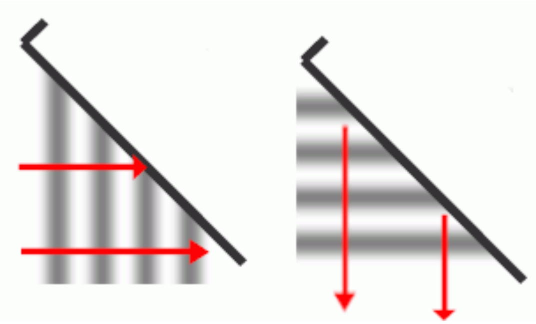


Radio waves: Reflection

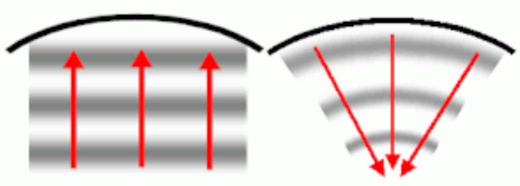
e.g. on Metal
angle in = angle out



plane

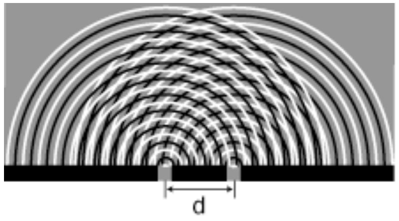


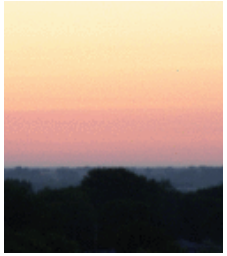
parabole

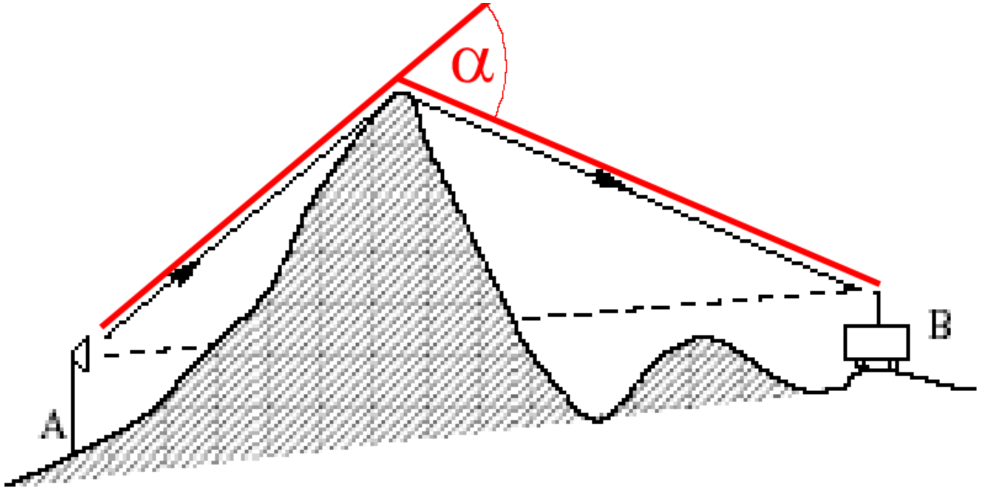


Radio waves: Diffraction

Diffraction is the apparent bending and spreading of waves when they meet an obstruction. Scales roughly with wavelength.







Radio waves: Interference

Interference is **misunderstood**
Is it really interference?
Or are too lazy to find the real problem?
Maybe we don't care!

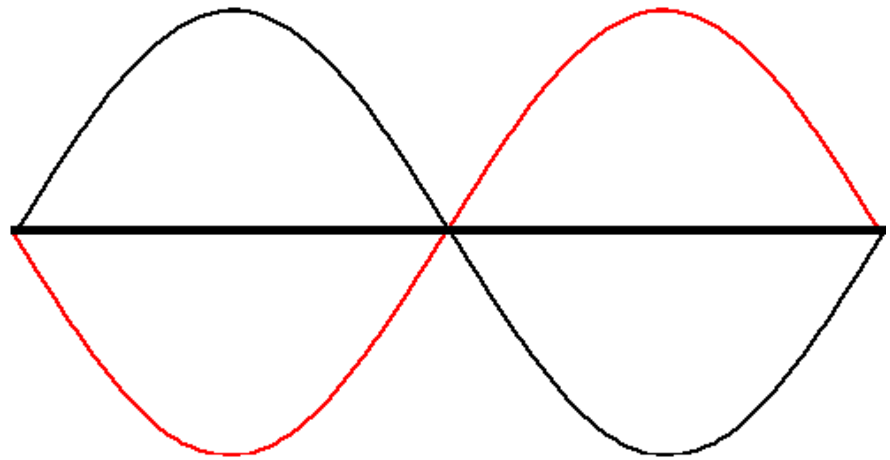
Two Meanings of Interference

- Physicists View:
  - The behavior of waves
- Engineer's View:
  - Noise that causes problems
- Both are important for Wireless
  - In different ways!

Interference: Physicist's View

Waves can annihilate each other

1 + 1 = 0



...when they have fixed **frequency and phase relation**

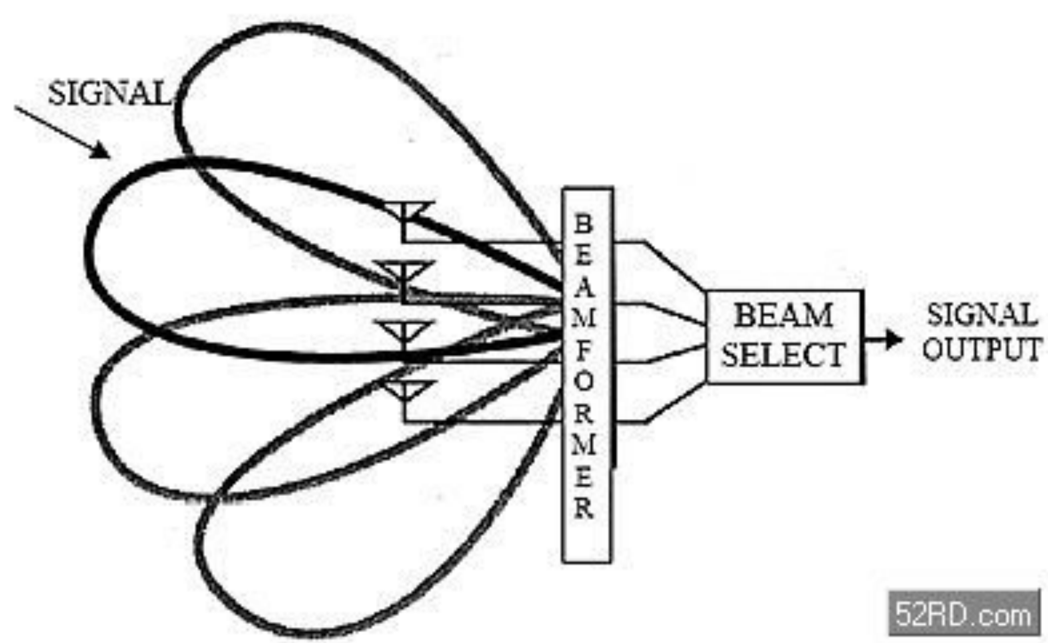
Waves can also enhance each other

Interference: an Experiment

- Take two laser pointers – one green, one red
- Cross the beams – will one change the other?
- Point them in the same direction, will one change the other?
- If you give signals with them, both in the same direction, would you be able to read them?
- Now use two lasers of the same color – what happens?

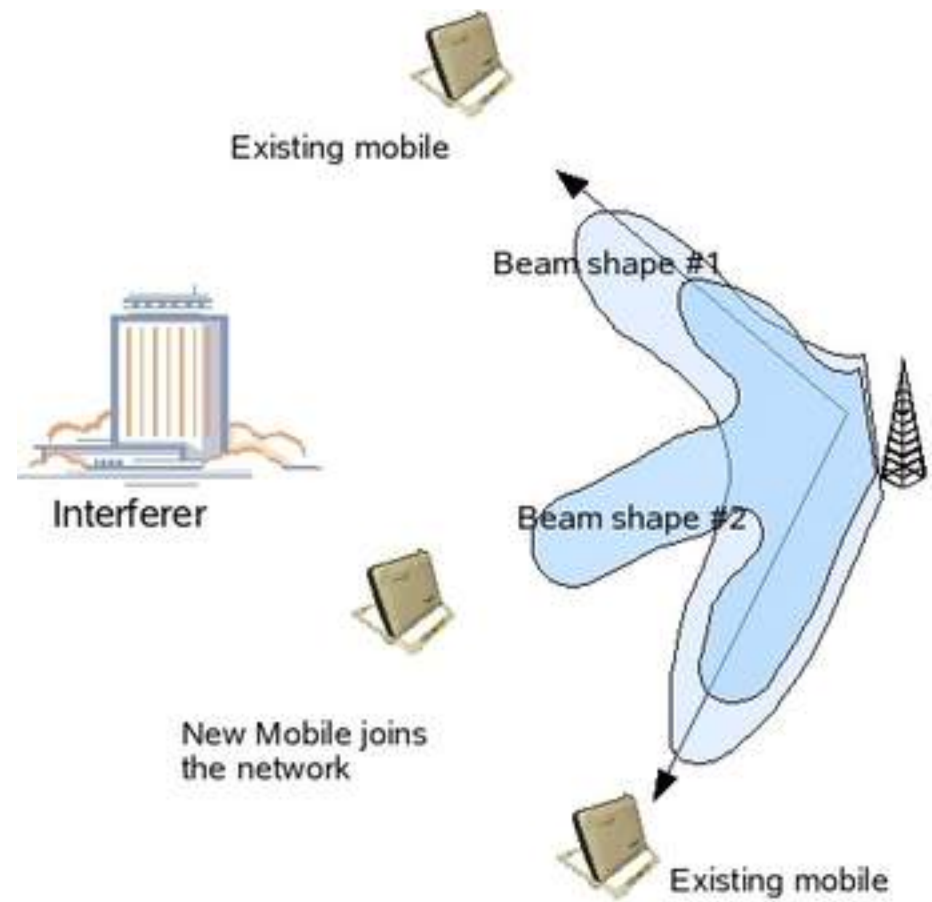
Interference: MIMO, Beam Shaping

- Interference is used for good in:
  beam-shaping, smart antennas, MIMO
  Modern MIMO techniques use interference to optimize antennas, allow for full multiplexing on same frequency



MU-MIMO, Dynamic Beam Shaping

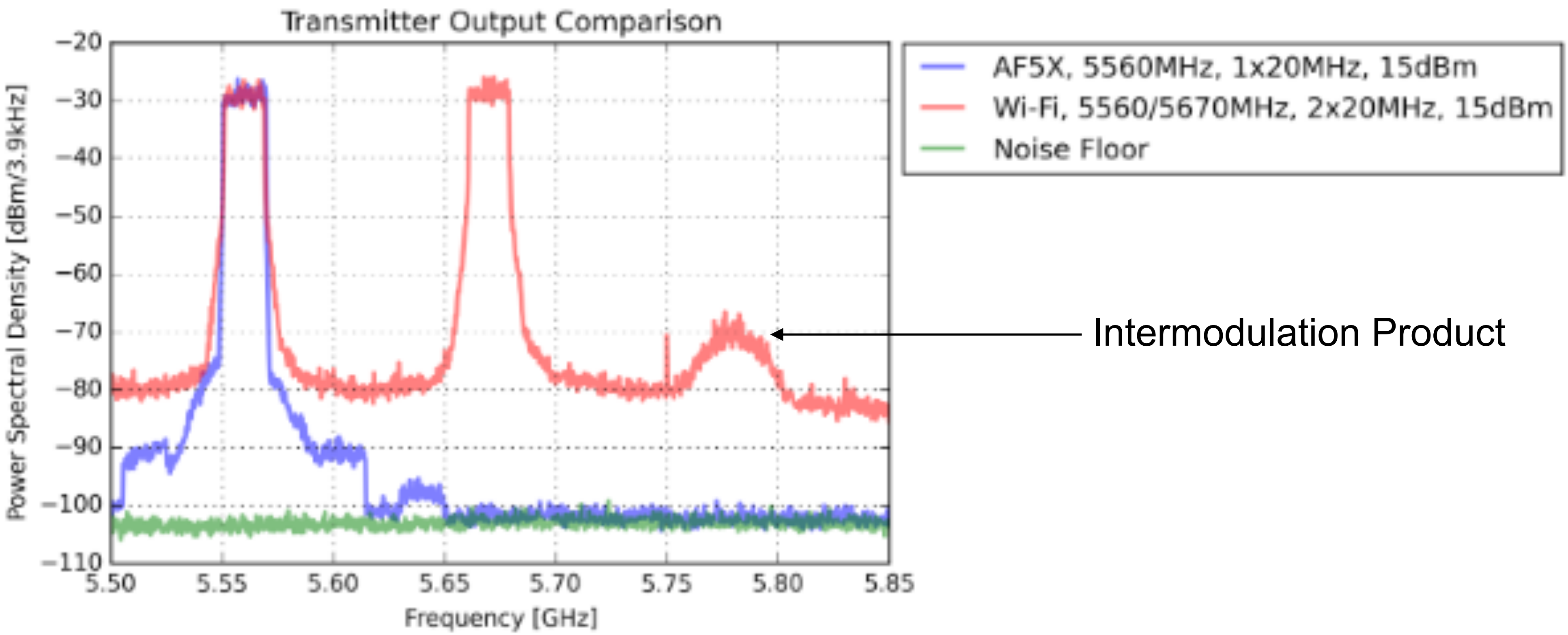
- In multi-antenna arrays, possibilities are virtually unlimited
- Fast processors use interference for good



Interference

- The Engineering View:
  - “any noise that gets in the way”
- High Noise Floor From Busy Spectrum
- Co-Channel Interference
- Adjacent-Channel Interference
  - Next frequency, overloading your receiver
    - Use a better receiver!
  - Next frequency, leaking into your channel
    - Time to talk to the interferer

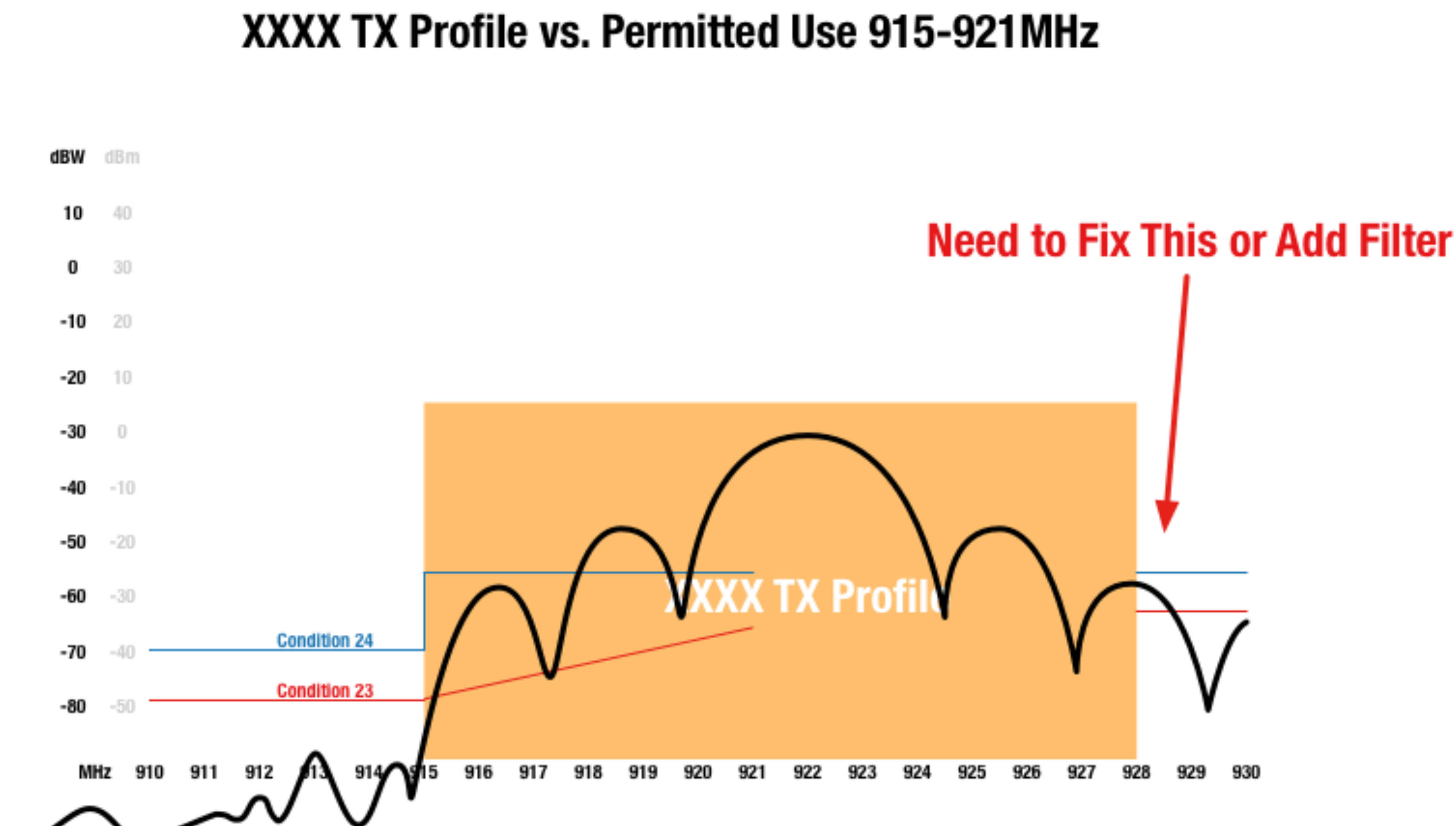
Some Transmitters Interfere



Intermodulation Product

Image: http://community.ubnt.com/t5/airFiber-Stories/AF5X-Why-you-owe-it-to-yourself-to-use-these-radios-for-backhaul/cns-p/1239600

Some Transmitters Interfere



Actual Transmission Sample from a Spectrum Analyzer
Compared to New Zealand 921MHz License Conditions

Frequency Dependent Behavior

- Longer wavelengths
  - Go further
  - Travel through obstacles
  - Bend around obstacles
  - Need bigger antennas
- Shorter wavelengths
  - Can transport more data
  - Need smaller antennas

Not All Spectrum is Created Equal

Capacity →

5GHz Wi-Fi
2.4GHz: Wi-Fi
2.1GHz: 3G
1.8GHz: 2G & LTE
900MHz: 3G
700MHz: LTE
500-700MHz: UHF Television
100MHz: Radio

Antenna Size ↓

Better Propagation ↓

Radio Propagation in Free Space

Free space loss
Fresnel zones
Line of Sight

Free Space Loss

Proportional to square of the distance

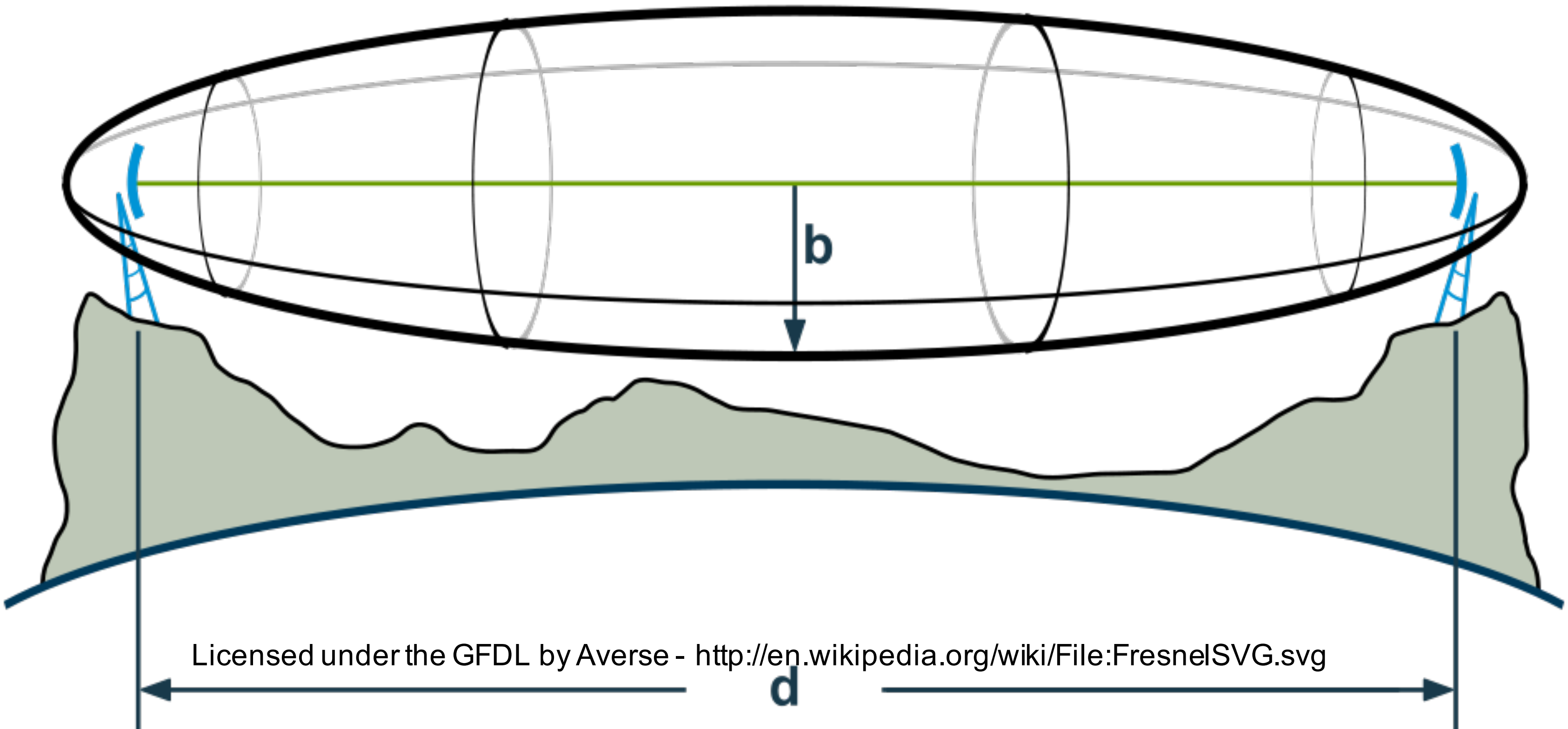
Proportional to square of the radio frequency

L_{FS} *(dB) = 20*log[4*π*distance/wavelength]*

where distance and wavelength are in the same units

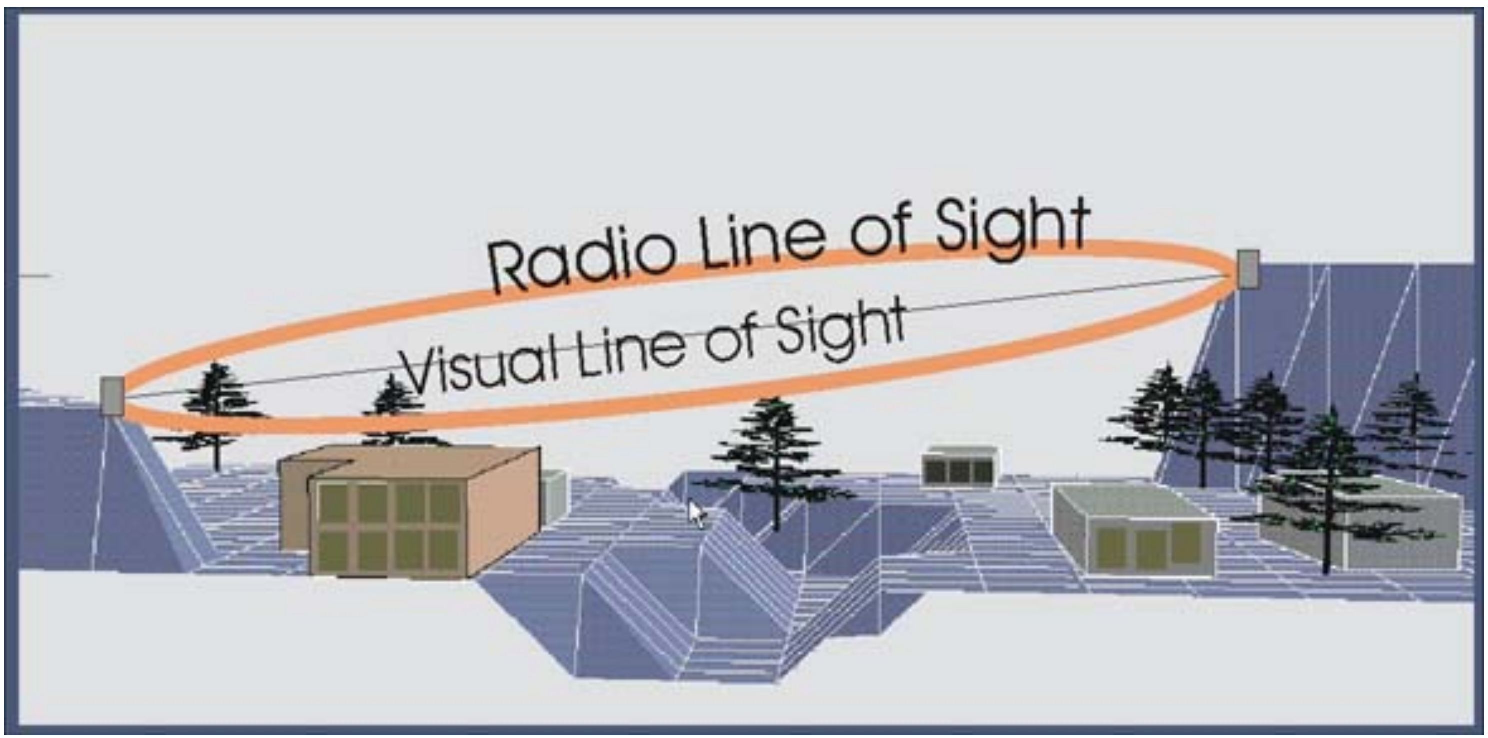
Fresnel zones

Zone where reflections are bad
Reflected waves = (good/bad) interference



Line of sight

Required for Higher Frequencies (> 1GHz)
Less Absorption / Reflection = Better Links



The dB

Definition: $10 * \text{Log} (P_1 / P_0)$

3 dB = double power

10 dB = order of magnitude = x 10

Calculating in dBs

Relative dBs

- dBm = relative to 1 mW
- dBi = relative to ideal isotropic antenna

The dB: Examples

1 mW = 0 dBm
100 mW = 20 dBm
1 W = 30 dBm
An omni antenna with 6 dBi gain
A parabolic dish with 29dBi gain
A cable (RG213) with 0.5 dB/m loss

dB to measure Transmit Power

Example from a 802.11a/b card:

Output Power:

802.11b: 18 dBm (65 mW) peak power
802.11a: 20 dBm (100 mW) peak power

dB to Measure Receive Sensitivity

Example from a Senao 802.11b card

Receive Sensitivity:

1 Mbps:	-95 dBm;
2 Mbps:	-93 dBm;
5.5 Mbps:	-91 dBm
11 Mbps:	-89 dBm

Radio Physics Matter

Always! ... and especially ...
when an AP or 3G modem is under a desk
or in a metal cabinet.
when winter turns to springtime
when it is rush hour in the city
with long distance links (speed of light!)

Examples: Office network

Offices typically have massive multi-path conditions cause by reflections
Reflections: metal infrastructure (computers, radiators, desks, even CDs!)
Absorbtion: from People, Plants, Books
Choice of locations and antennas essential

Changing Seasons: Absorption

Vegetation, humidity, rain and change with the seasons!

Dry trees might be radio transparent

Wet green trees are not radio transparent

Rush Hour: Reflection/Diffraction

- Urban conditions change with the day
- They change with the hour
  - People, Vans, Cars
  - Electromagnetic Interference (Noise Floor)
- Test Monday what you measure Sunday
- In the Afternoon.... In the Morning

The Speed of Light

Some 802.11_ standards set time-out windows: PCF, DIFS, SIFS
For long links, travel time of the signal might lead to timeout and performance losses
We have to hack the MAC layer to go long distance … see e.g. TIER group, Berkeley