Basic Radio Physics

Network Startup Resource Center
www.nsrc.org

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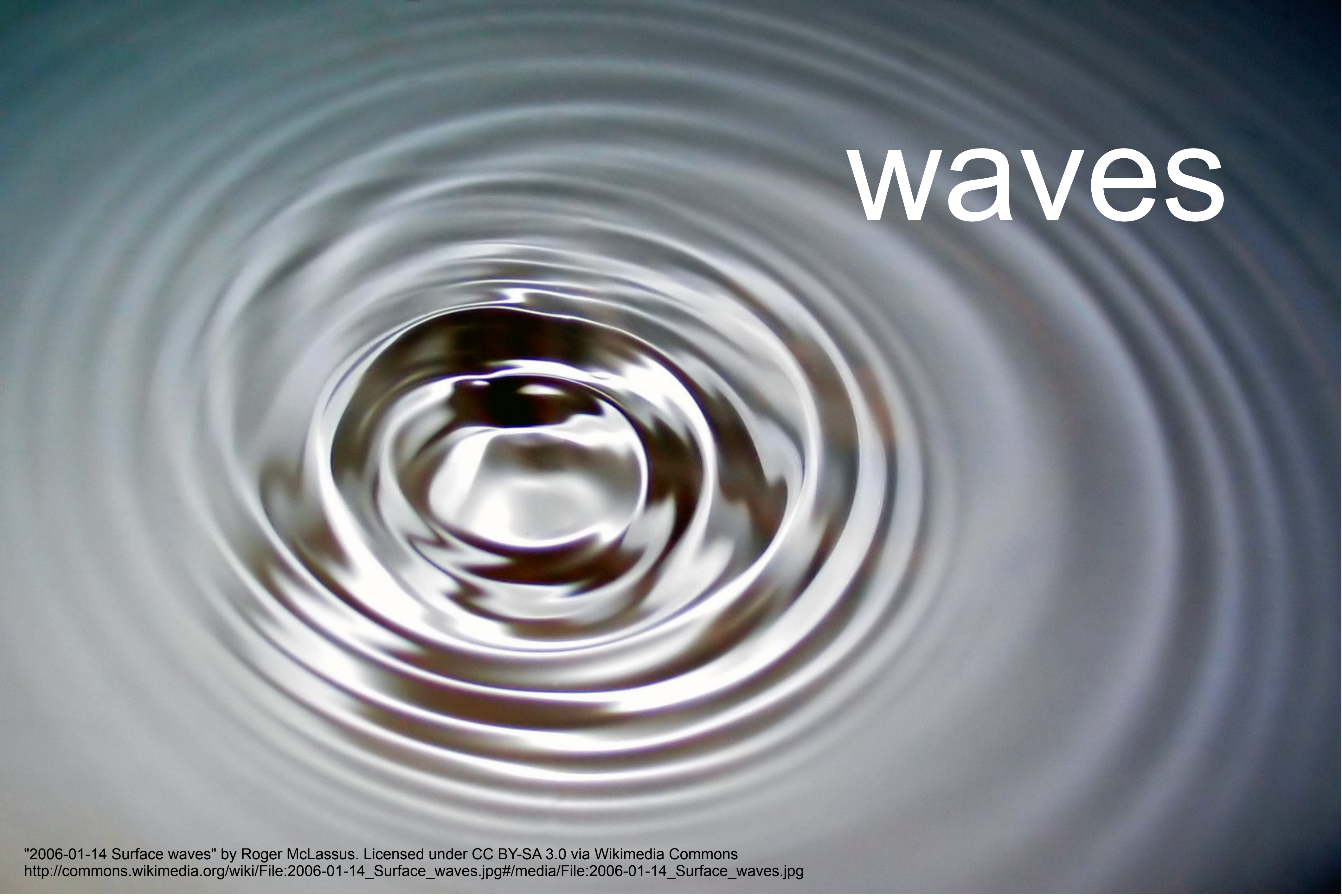
UNIVERSITY OF OREGON

Electromagnetic Fields

- Electromagnetic forces act between electric charges and electric currents
- **E** Electric Field, **H** Magnetic Field
- **Electromagnetic waves** are fields traveling in space

waves



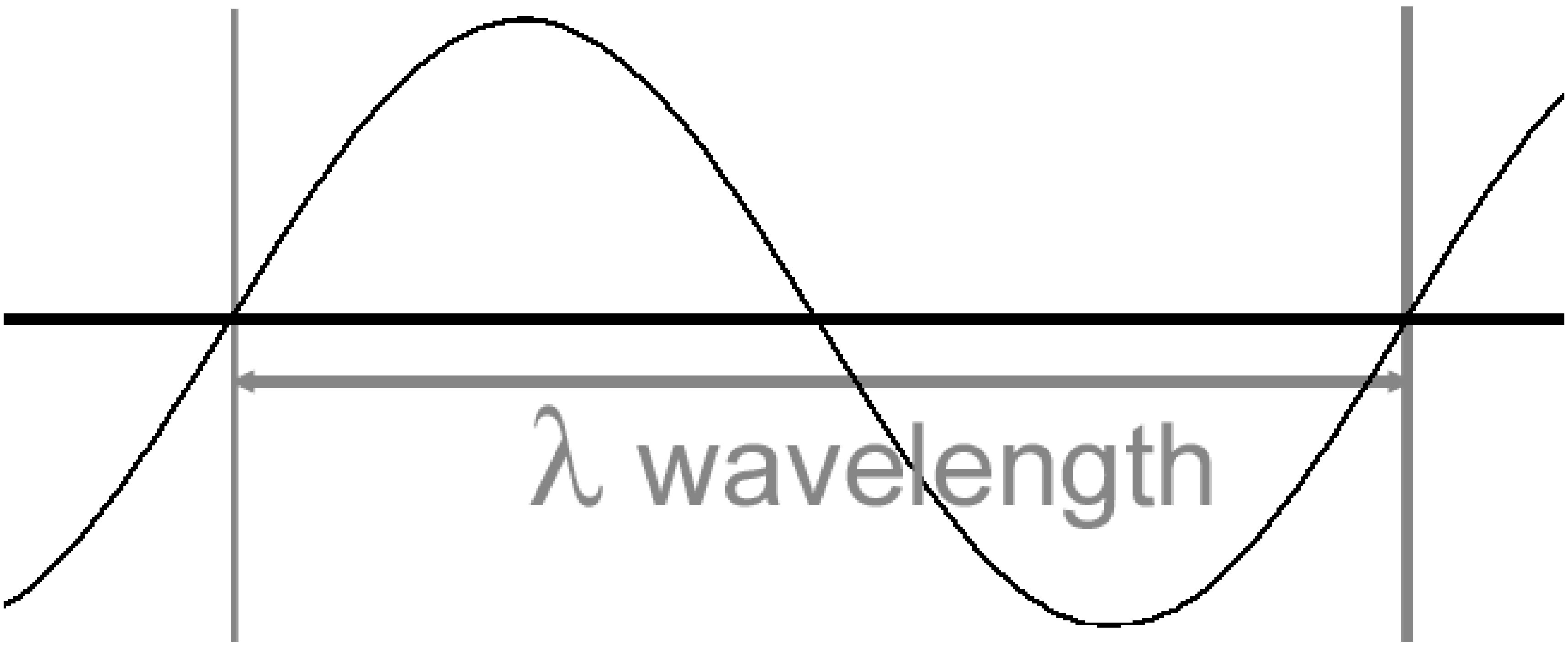
Waves

- 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

Electromagnetic Waves

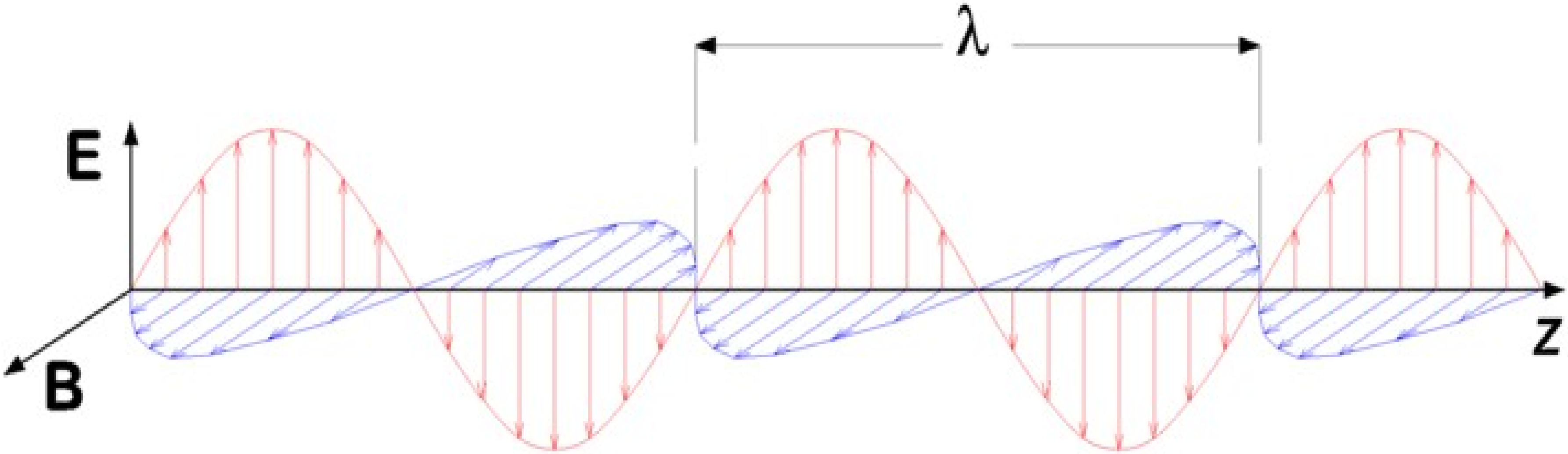
- $c = \lambda * \nu$
- c is the speed of light (3×10^8 m/s)
- λ Lambda is the wavelength [m]
- ν Nu is the frequency [1/s = Hz]
- Light needs 1.3 seconds from the moon to earth, and 8 minutes from the sun … and how long for 100 km? ...

A Wave

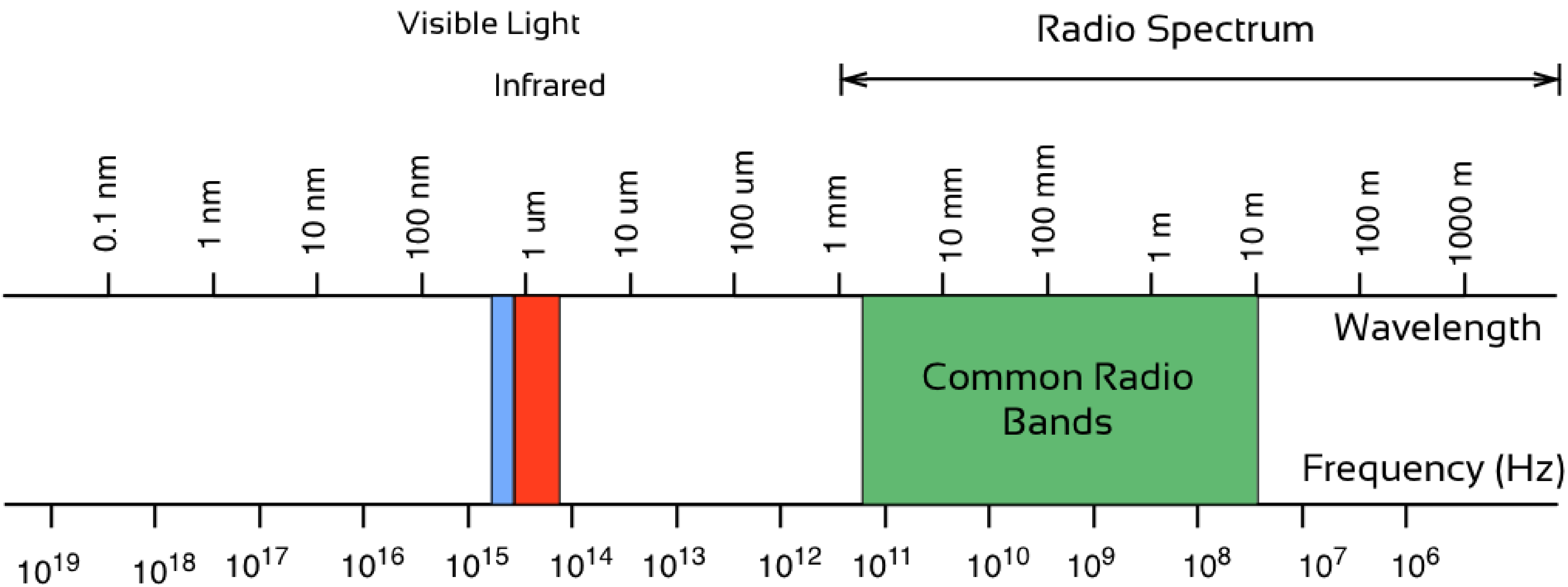


EM Wave Polarization

- Direction of the electric field vector
- **Linear**, elliptic, circular polarization



Electromagnetic spectrum



Wavelength Calculations

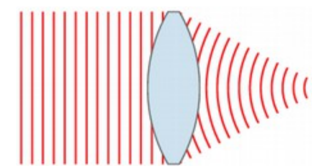
- Speed of Light = Wavelength * Frequency
- Frequency = Speed of Light / Wavelength
- Wavelength = Speed of Light / Frequency
- What's the frequency of 3.5mm waves?
- What's the wavelength at 91.5 MHz?

Wireless Networking Frequencies

- Focus on the ISM (license exempt) bands at
  - 2.4 GHz – 802.11b/g – 12 cm
  - 5.x GHz – 802.11a – 5...6 cm
- Other bands interesting to us
  - 915 MHz
  - 3.5 GHz
  - 24 GHz
  - 60-80 GHz

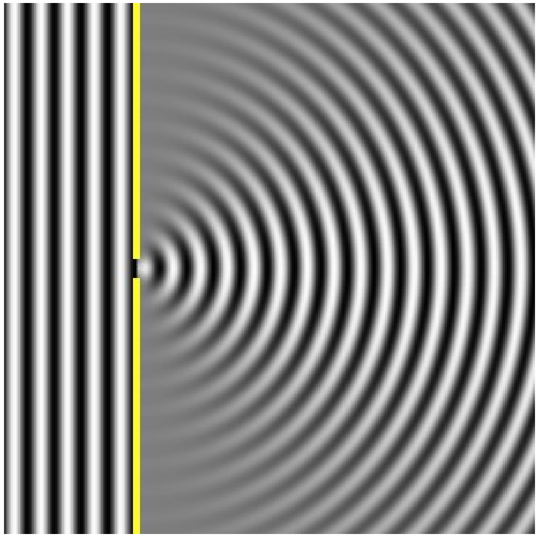
Propagation of Radio waves

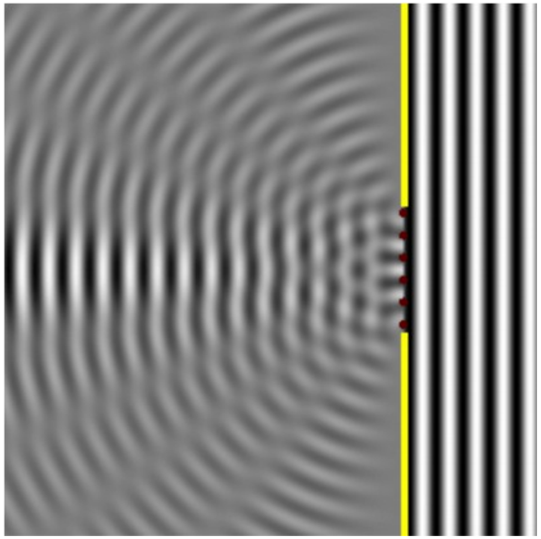
- Wavefronts: plane & spherical



- Huygens principle: at any disturbance, spherical waves start
- Radio waves (like light) do not propagate as a straight line .. not even light does that
- Behavior scales with wavelength

Huygens principle





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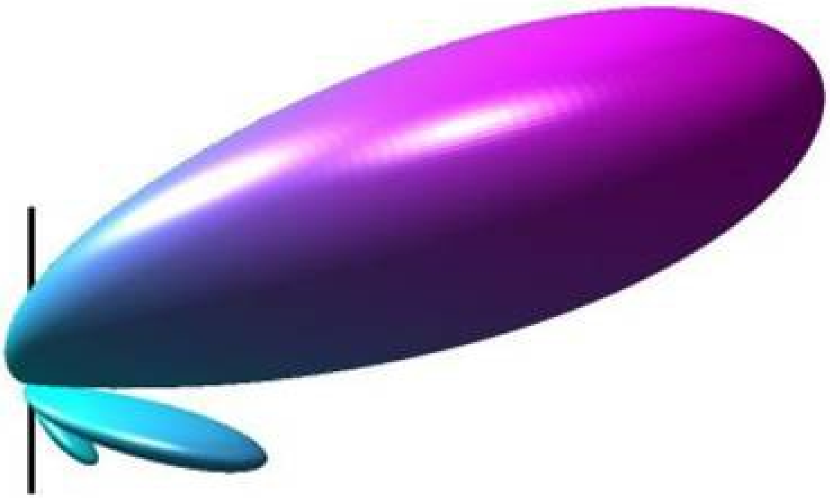
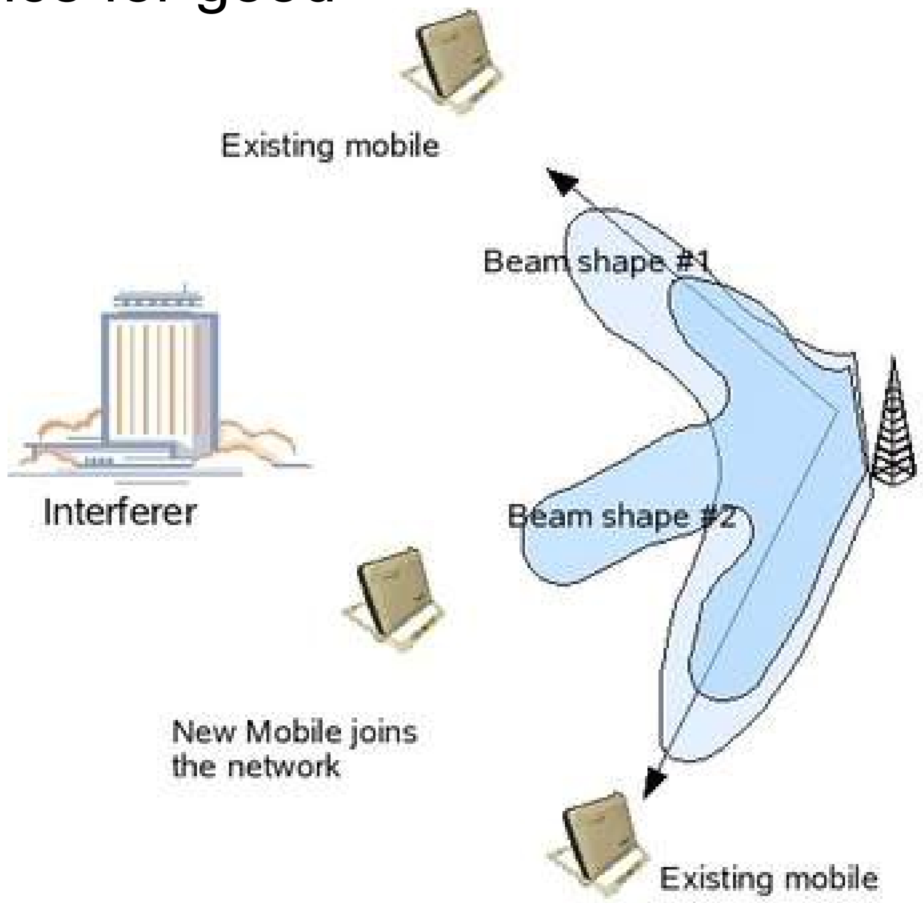
MU-MIMO, Dynamic Beam Shaping

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





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

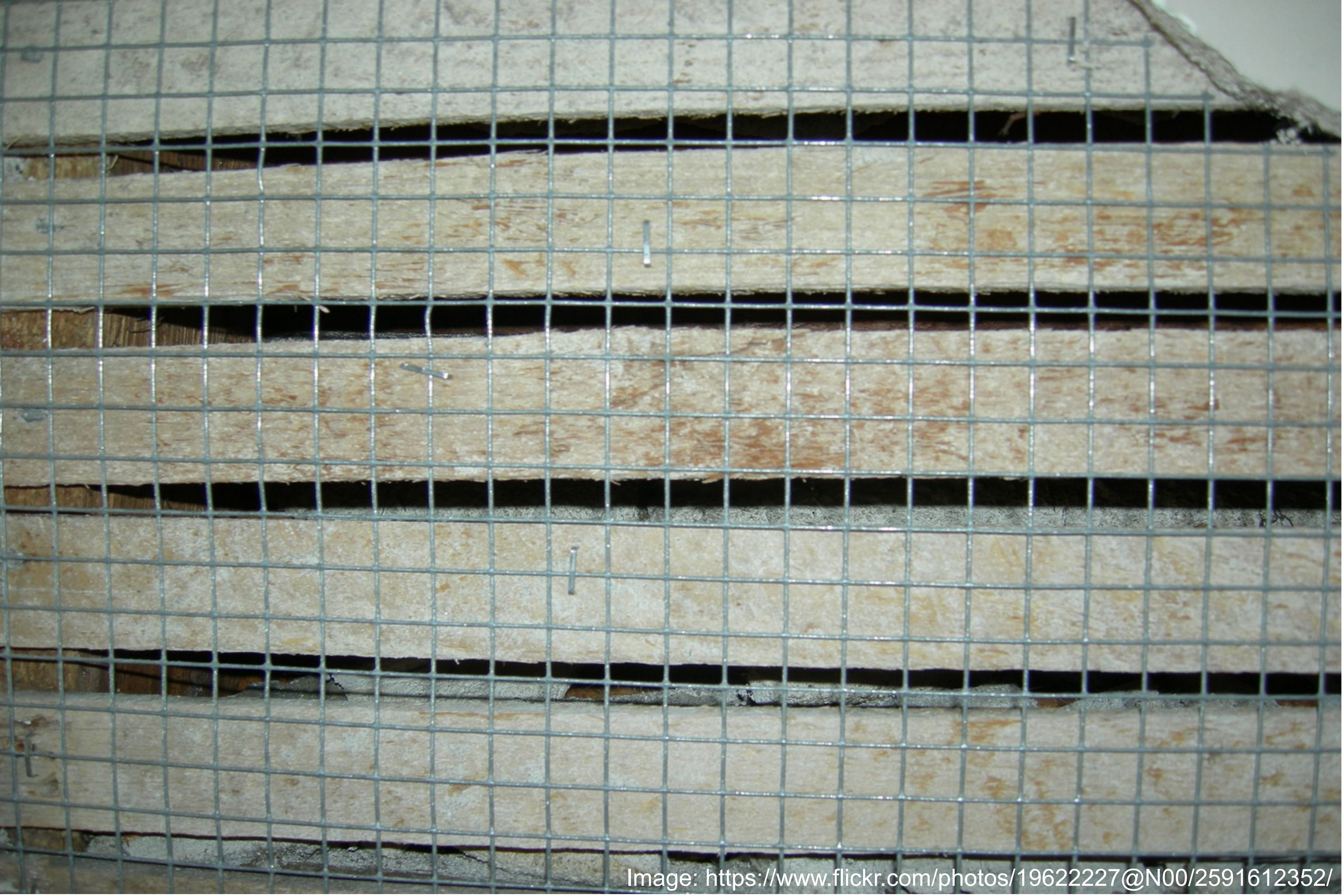
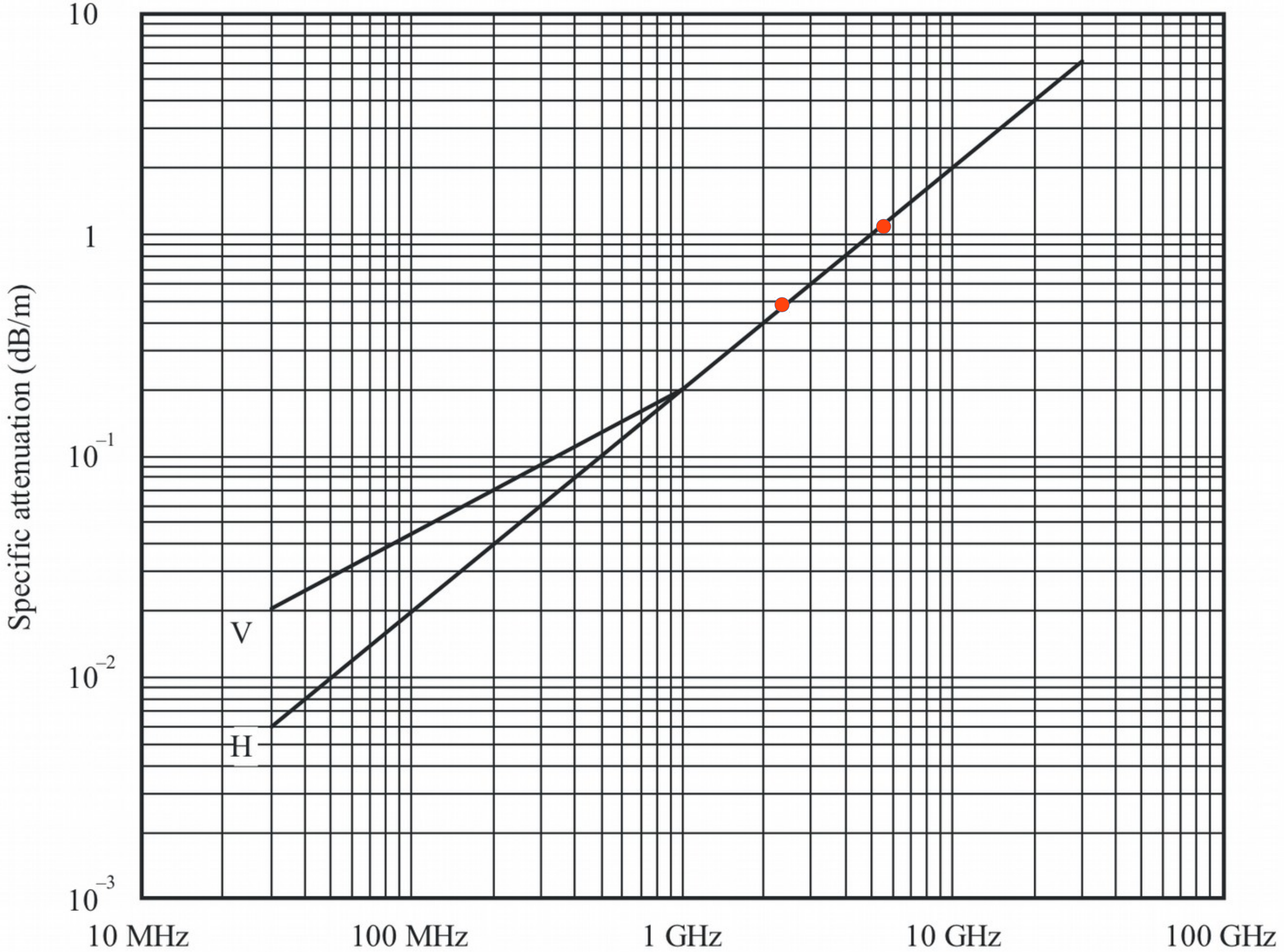


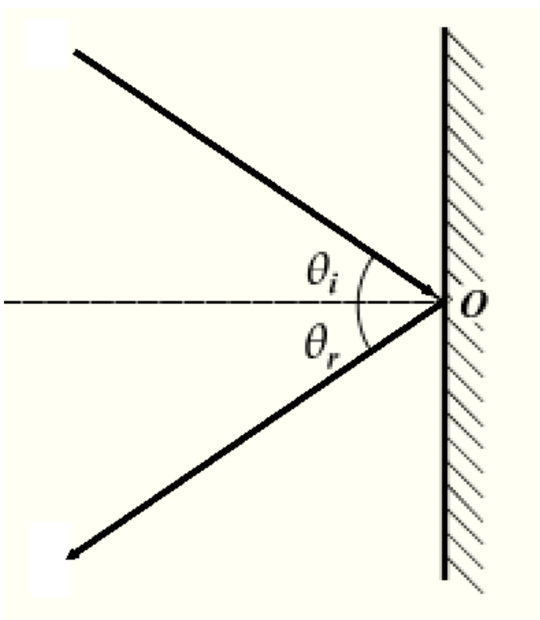
Image: https://www.flickr.com/photos/19622227@N00/2591612352/

Specific attenuation due to woodland



Radio waves: Reflection

- e.g. on Metal
- angle in = angle out



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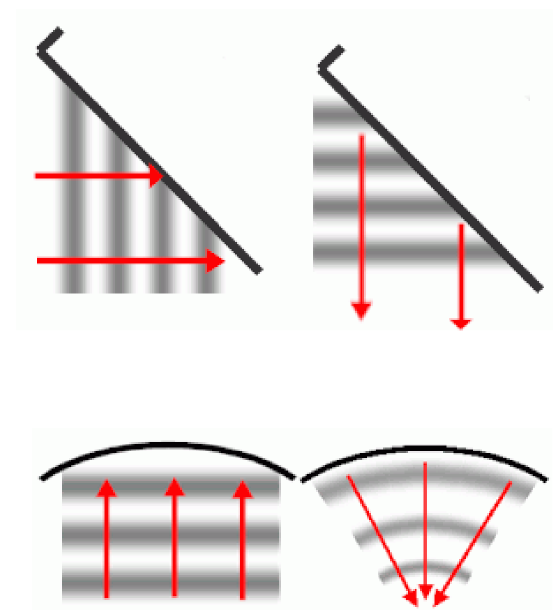
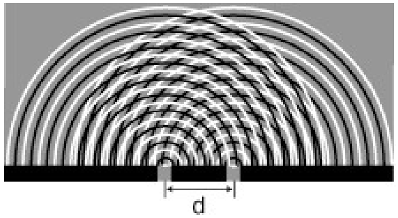
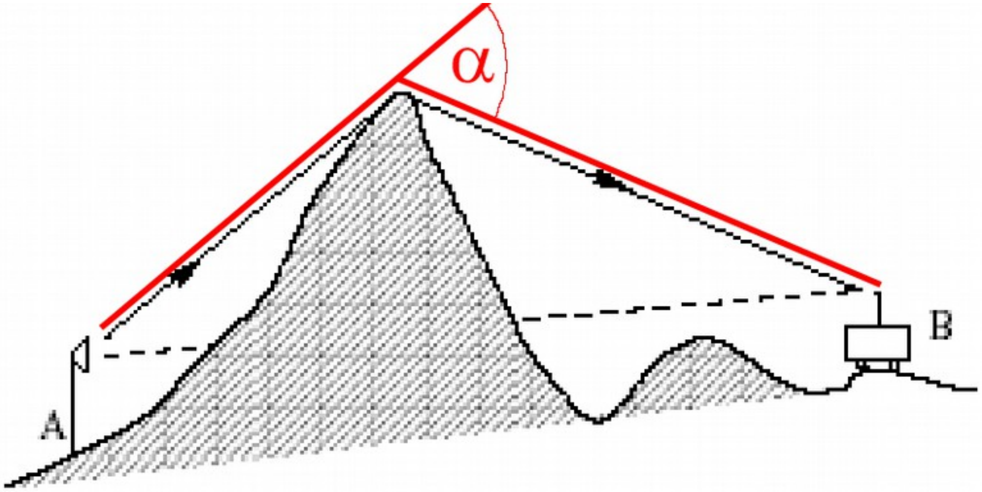


Radio waves: Diffraction

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





Radio waves: Interference

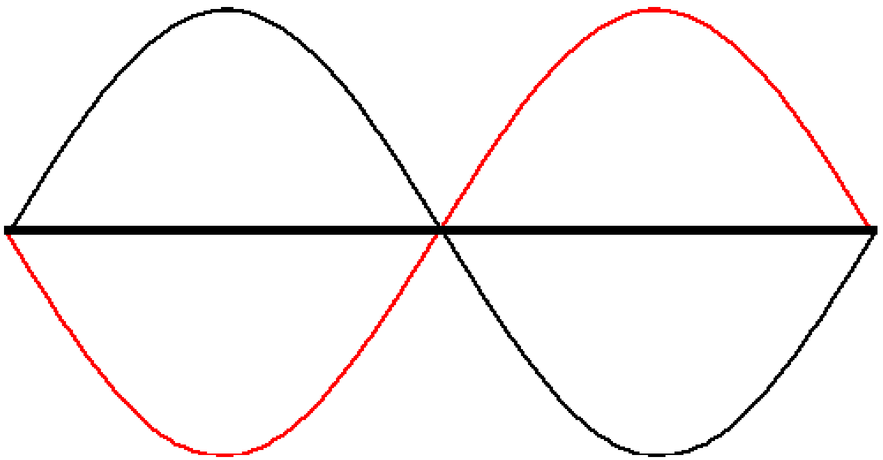
- Interference is **misunderstood**
- Is it really interference?
- Or are too lazy to find the real problem?
- Maybe we don't care!

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

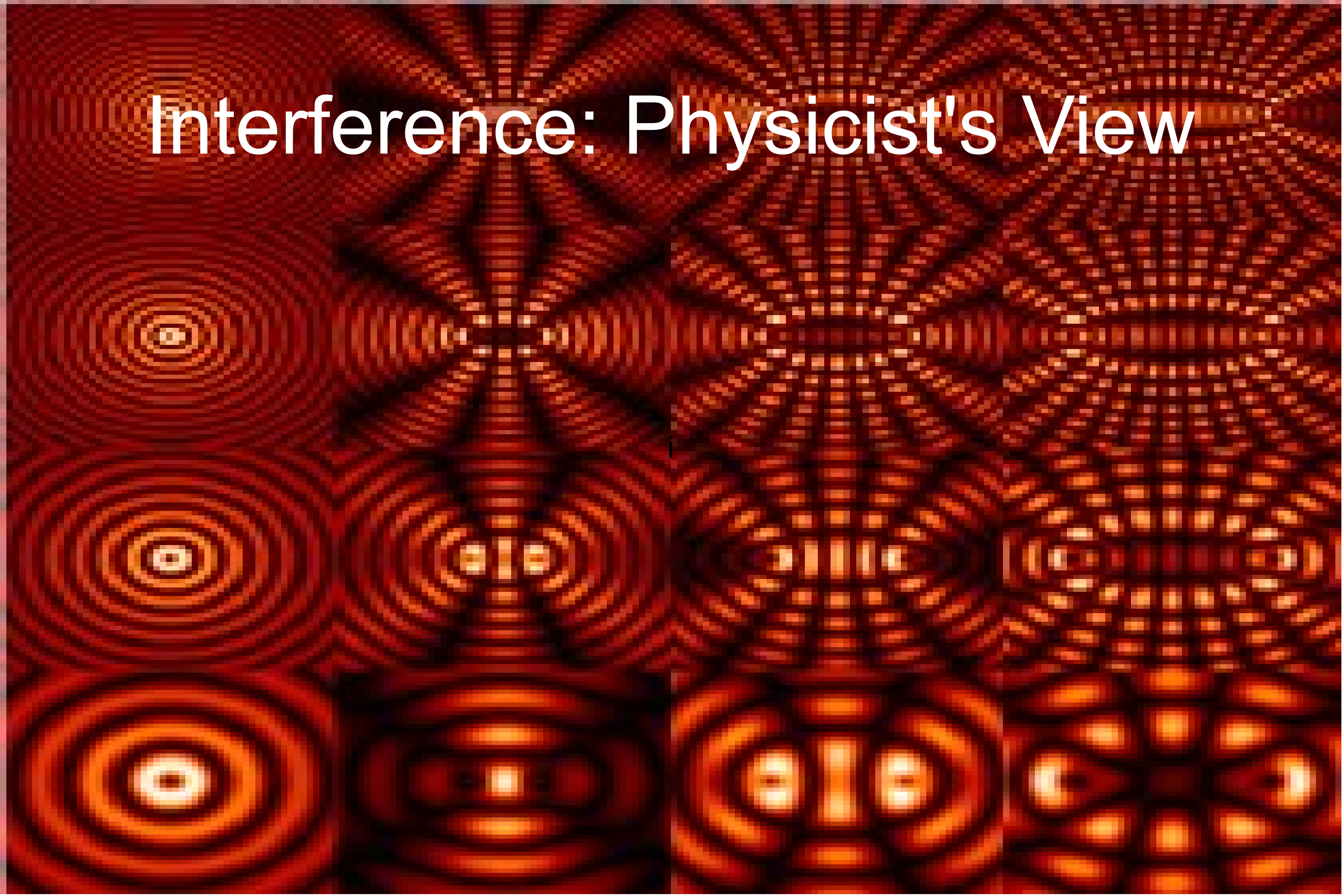


- ...when they have fixed **frequency and phase relation**
- Waves can also enhance each other

Interference: an Experiment

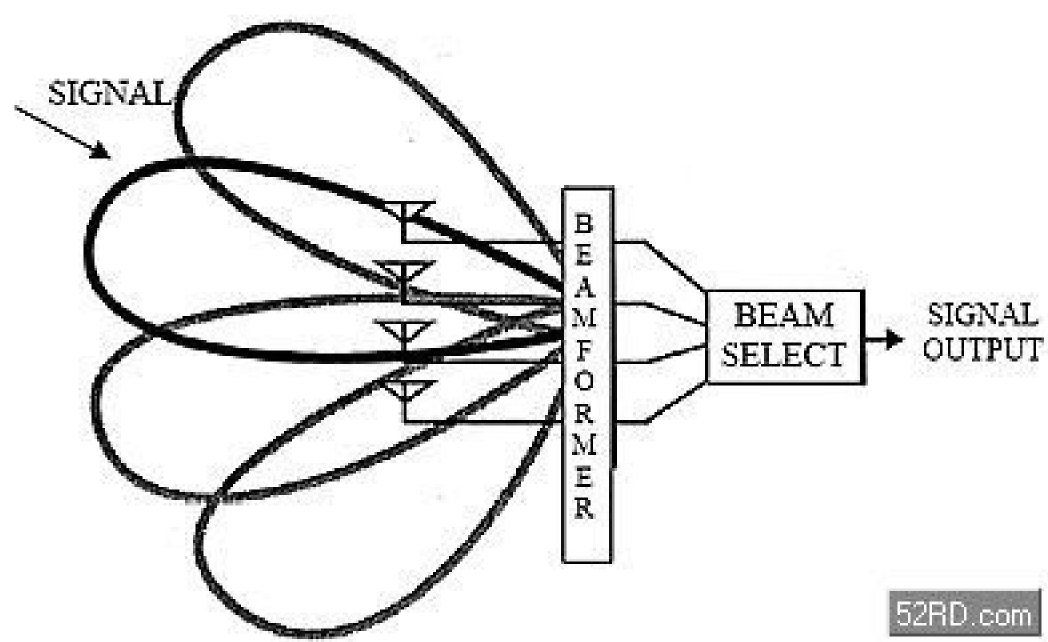
- Take two laser pointers – one green, one red
- Cross the beams – will one change the other?
- Point them in the same direction, will one change the other?
- If you give signals with them, both in the same direction, would you be able to read them?
- Now use two lasers of the same color – what happens?

Interference: Physicist's View



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

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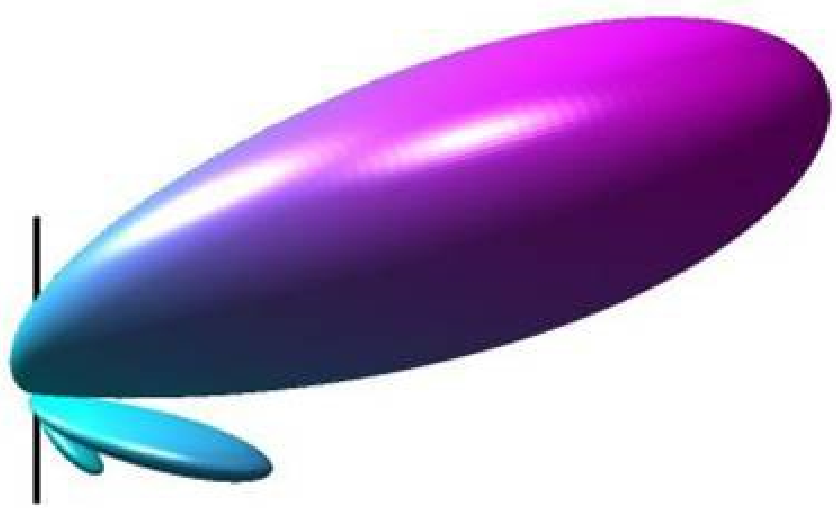

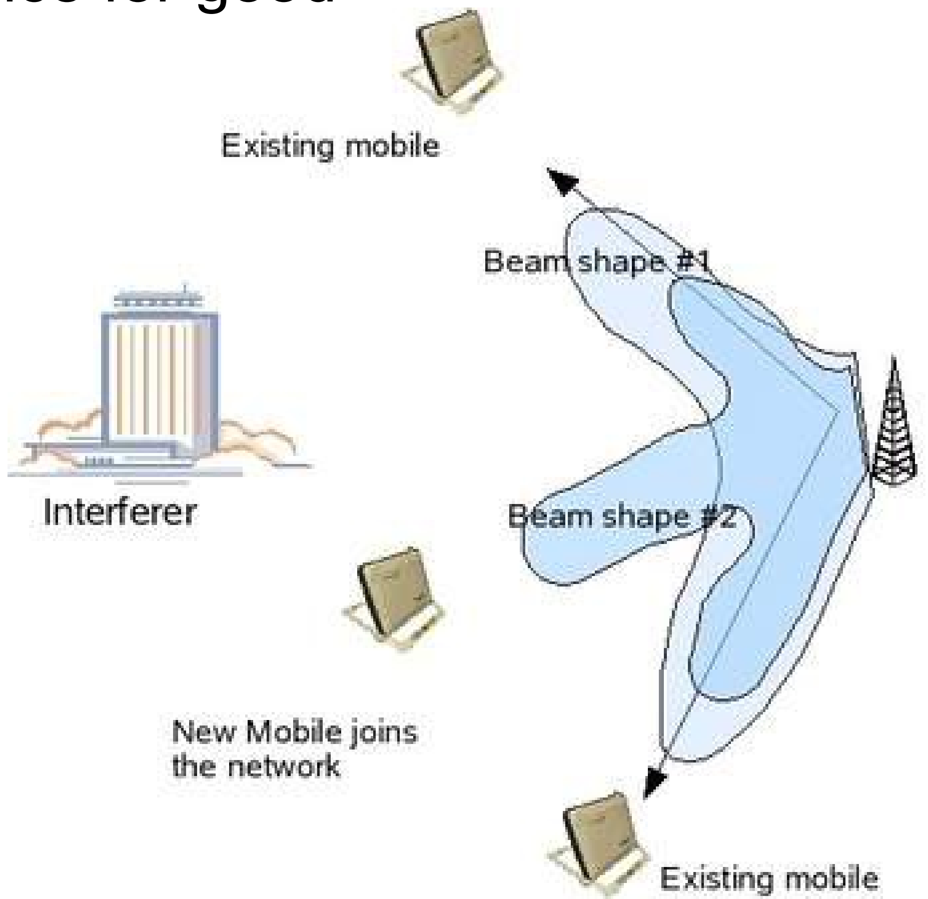

Interference

- 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

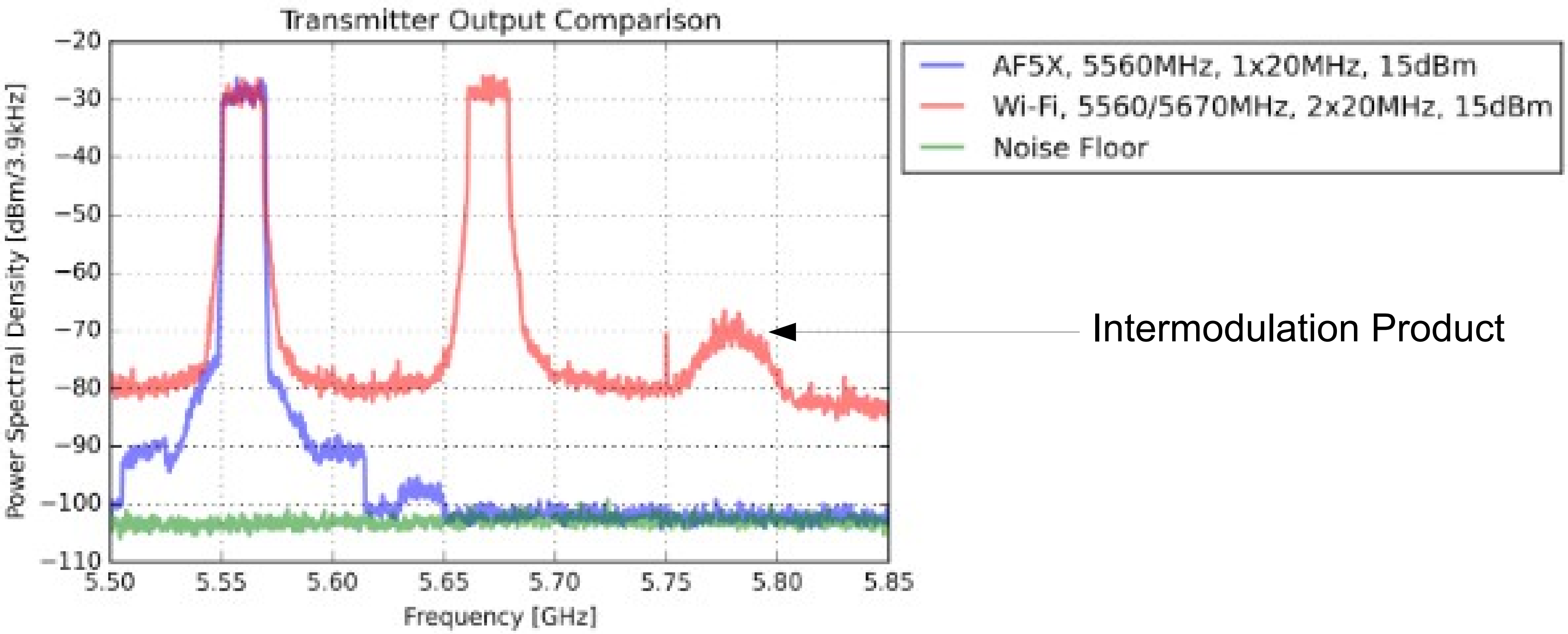

Image: http://community.ubnt.com/t5/airFiber-Stories/AF5X-Why-you-owe-it-to-yourself-to-use-these-radios-for-backhaul/cns-p/1239600

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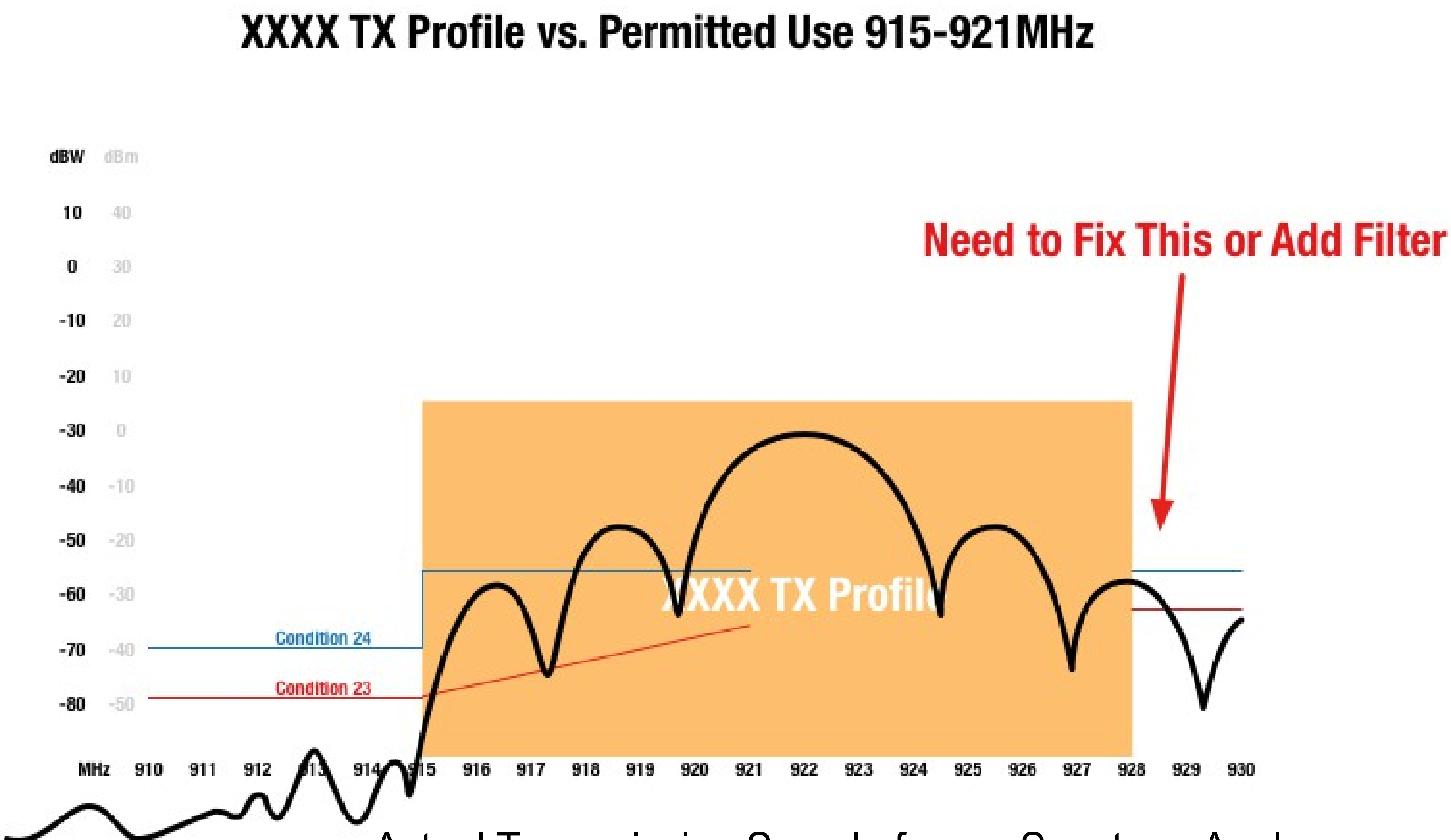


Actual Transmission Sample from a Spectrum Analyzer
Compared to New Zealand 921MHz License Conditions

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

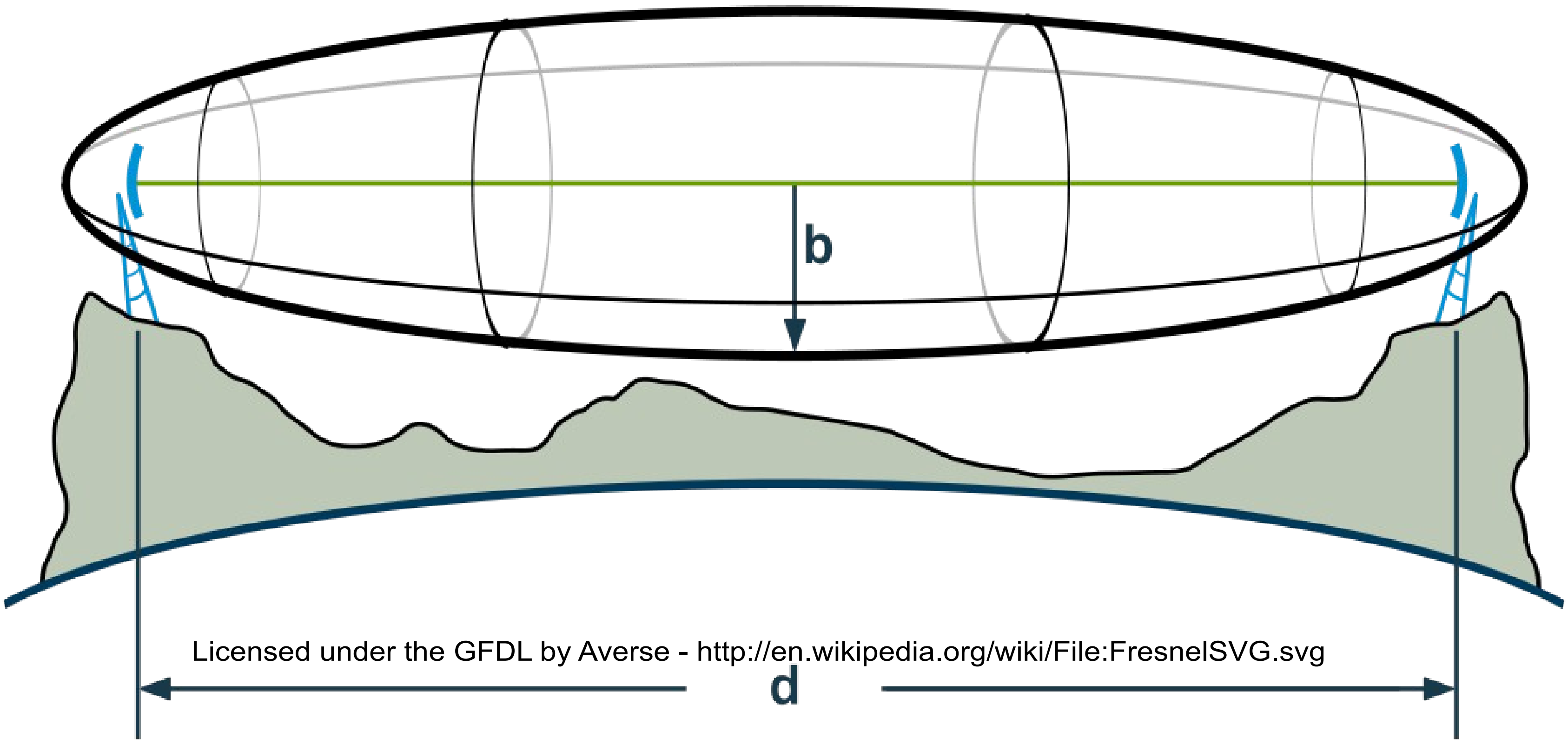
- Free space loss
- Fresnel zones
- *Line of Sight*

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*

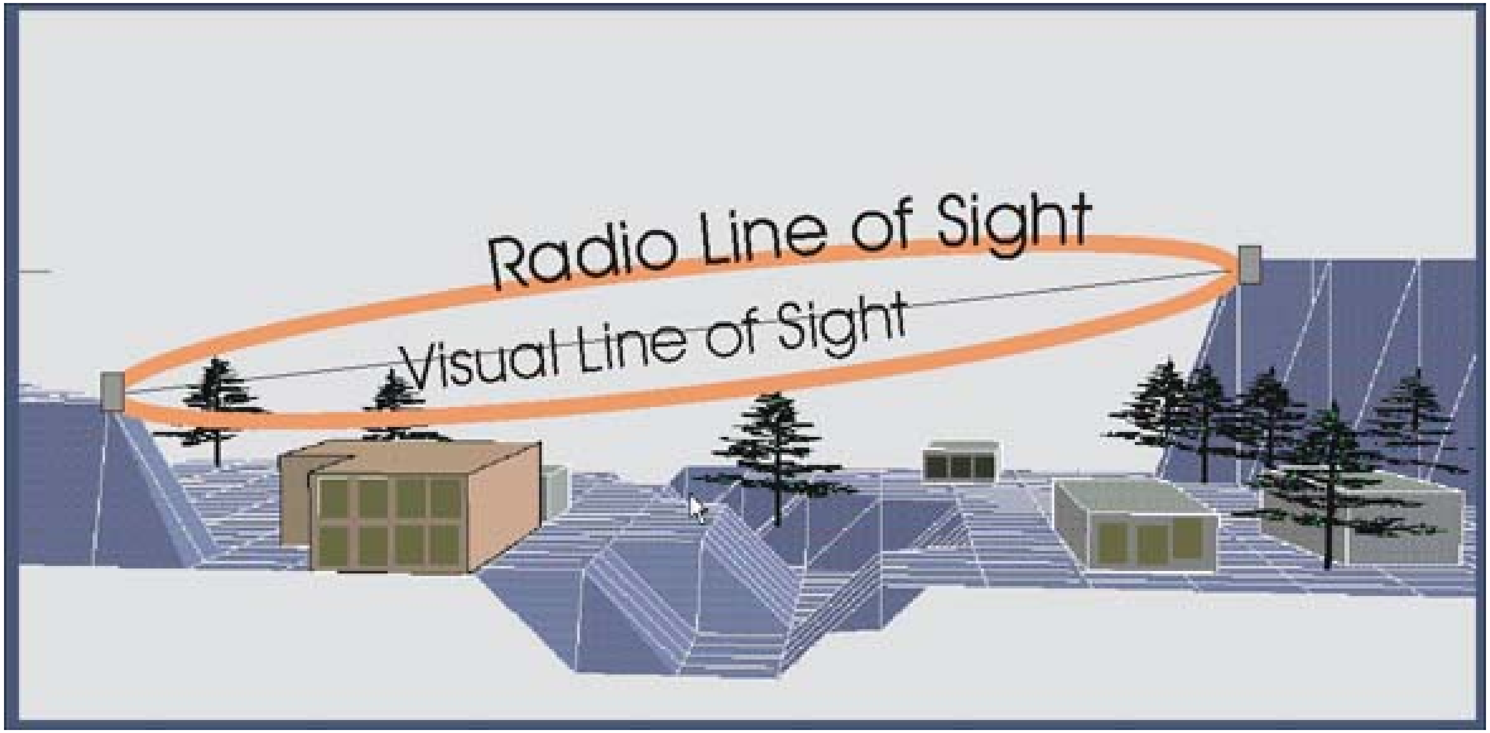
Fresnel zones

- 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