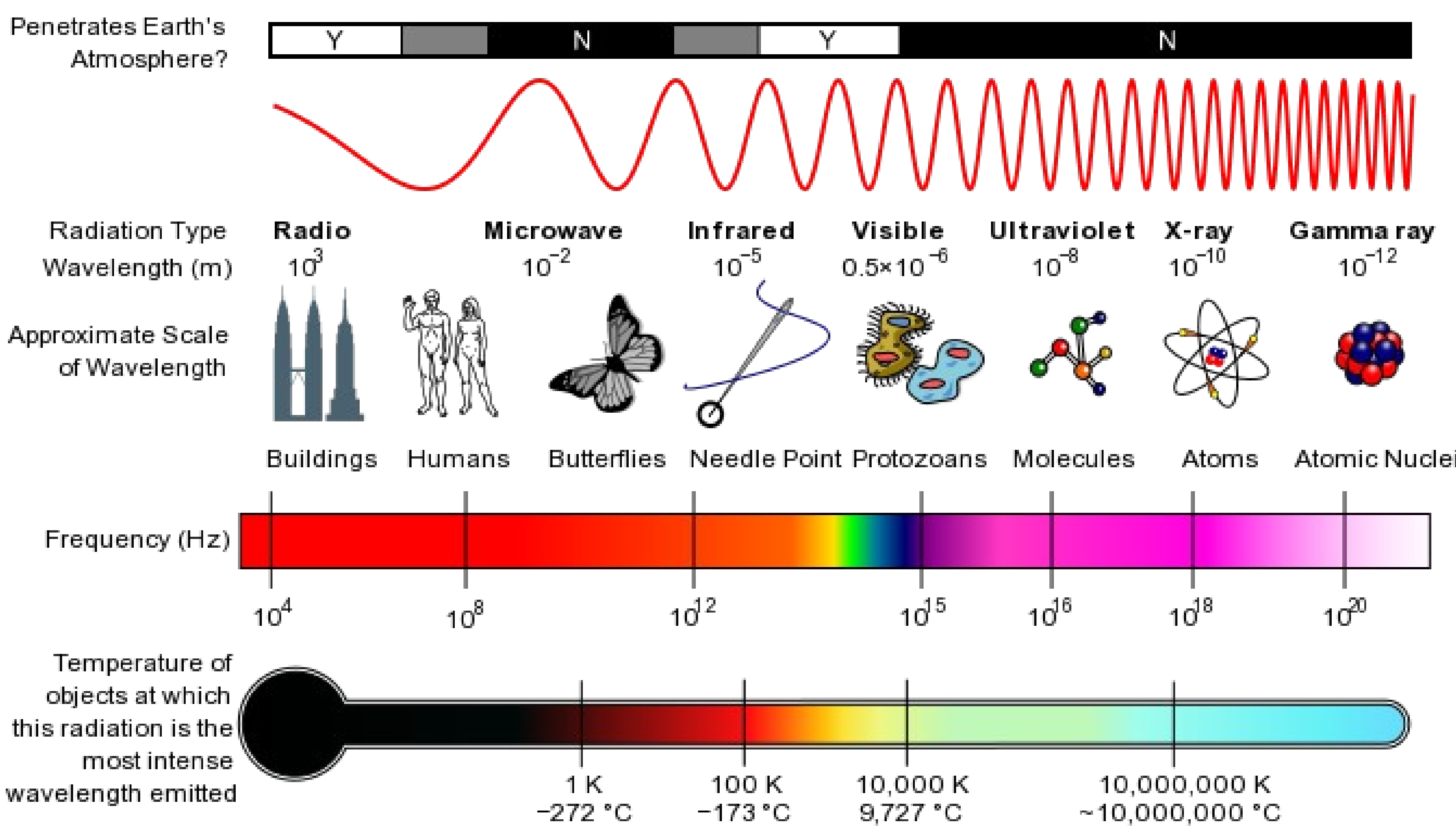
Intro to Wireless

Joel Jaeggli
For
AIT Wireless and Security Workshop

Wireless Workshop

- We're concerned with technologies utilizing a small portion of the electromagnetic spectrum...
- First installment is a little background on radio frequency terminology, implementation, etc.
- It's a testament to how far the technology has come that you can get rather far in the industry with only a superficial grasp of the fundamentals (I don't view this as a bad thing).
- That said when you're building a business around it, it's a good idea to have a deeper grasp of the physics and engineering principles at work.


Penetrates Earth's Atmosphere?
Y
N
Y
N
Radiation Type
Wavelength (m)
Radio
10^3
Microwave
10^-2
Infrared
10^-5
Visible
0.5×10^-6
Ultraviolet
10^-8
X-ray
10^-10
Gamma ray
10^-12
Approximate Scale of Wavelength
Buildings
Humans
Butterflies
Needle Point
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^4
10^8
10^12
10^15
10^16
10^18
10^20
Temperature of objects at which this radiation is the most intense wavelength emitted
1 K
−272 °C
100 K
−173 °C
10,000 K
9,727 °C
10,000,000 K
~10,000,000 °C

NOT ALLOCATED
RADIONAVIGATION
FIXED
MARITIME MOBILE
FIXED
MARITIME MOBILE
FIXED
MARITIME MOBILE
FIXED
MARITIME MOBILE
FIXED
MARITIME MOBILE
Radiolocation
FIXED
RADIONAVIGATION
FIXED
Radiolocation
MARITIME MOBILE
FIXED
MARITIME MOBILE
MARITIME MOBILE
FIXED
AERONAUTICAL RADIONAVIGATION
Aeronautical Mobile
AERONAUTICAL RADIONAVIGATION
3 kHz
300 kHz
BROADCASTING (AM RADIO)
300 kHz
3 MHz
AMATEUR
MARITIME MOBILE
BROADCASTING
3 MHz
30 MHz
BROADCASTING (TV CHANNELS 2-4)
BROADCASTING (TV CHANNELS 5-6)
BROADCASTING (FM RADIO)
AERONAUTICAL RADIONAVIGATION
BROADCASTING (TV CHANNELS 7-13)
MOBILE
MOBILE SATELLITE
FIXED
30 MHz
300 MHz
BROADCASTING (TV CHANNELS 14-20)
TV BROADCASTING
AERONAUTICAL RADIONAVIGATION
300 MHz
3 GHz
3 GHz
30 GHz
30 GHz
300 GHz

ISM Bands

- Industrial Scientific and Measurement bands
- Defined internationally by ITU-R
- Actual allocation at the discretion of individual country member.
- Radio frequency applications other than communications (microwaves, flourescent lights, radar etc).
- ISM communications equipment must accept interference from other applications.

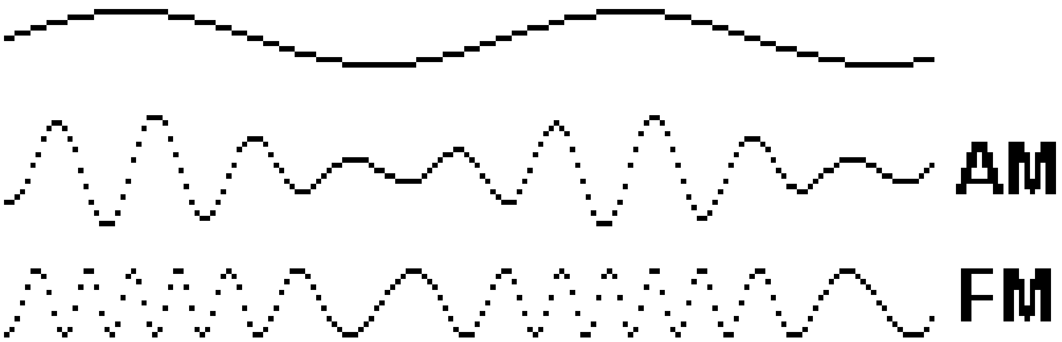
Usable for our application

- 6.765–6.795 MHz (centre frequency 6.780 MHz)
- 13.553–13.567 MHz (centre frequency 13.560 MHz)
- 26.957–27.283 MHz (centre frequency 27.120 MHz)
- 40.66–40.70 MHz (centre frequency 40.68 MHz)
- 433.05–434.79 MHz (centre frequency 433.92 MHz) in Region 1
- 902–928 MHz (centre frequency 915 MHz) in Region 2 **(Conflicts with GSM 900)**
- 2.400–2.500 GHz (centre frequency 2.450 GHz)
- 5.725–5.875 GHz (centre frequency 5.800 GHz)
- 24–24.25 GHz (centre frequency 24.125 GHz)
- 61–61.5 GHz (centre frequency 61.25 GHz)
- 122–123 GHz (centre frequency 122.5 GHz)
- 244–246 GHz (centre frequency 245 GHz)

Liscensed Spectrum

- ITFS (2.5Ghz) North America
- MMDS 2-3Ghz
- Liscensed fixed microwave in:
- 3.7-4.2Ghz
- 4.5Ghz
- 6-7Ghz
- 10.7-11.7Ghz
- 22-25Ghz
- Various between 30-60Ghz
- 70-79Ghz

Modulation



Modulation

- Traditional (analog FM and AM)
- QAM
- PSK
- DSS
- OFDM

Old school

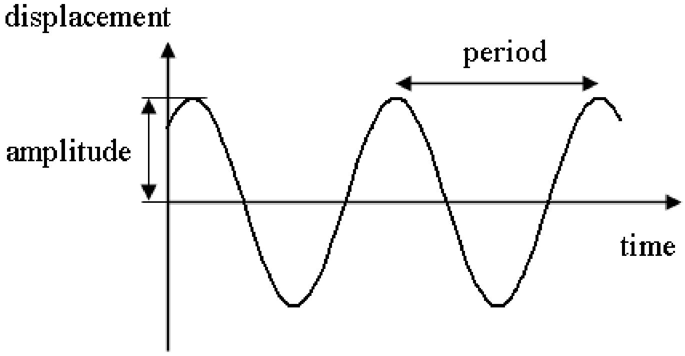
- AM Radio - State of the art 1870s technology!
  - Modulate the intensity of the energy transmitted on a constant frequency carrier.
- FM Radio – State of the art 1930s technology...
  - Modulate the frequency of a carrier proportionally to the input signal. High quality due to the dynamic range being tied to the bandwidth used. First used to carry digital data using frequency shift keying.

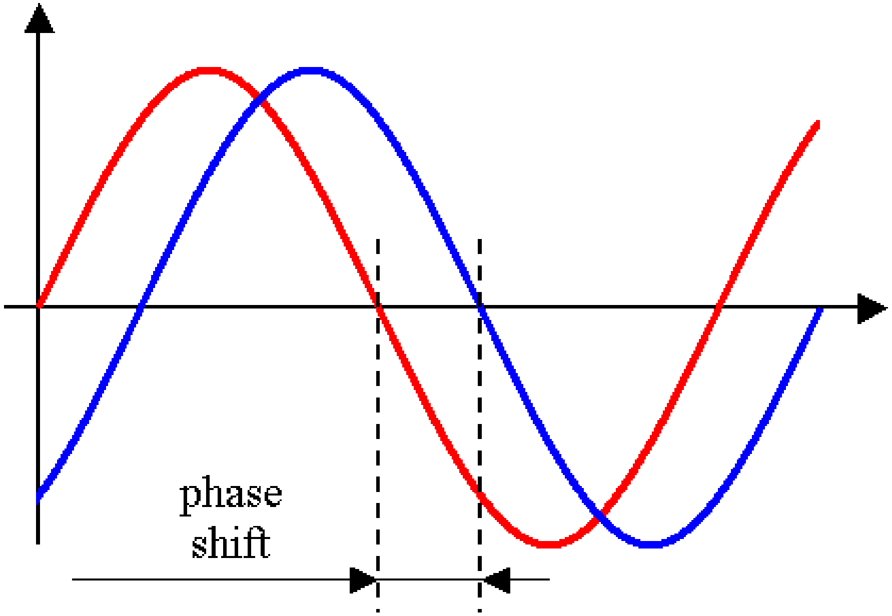
QAM

- Quadrature Amplitude Modulation
- Two AM carriers are modulated 90 degrees out of phase to each other.
- The result is bandwidth efficient, like other AM carriers (relative to FM) to but better defined than a single AM carrier. you're measuring the difference between the two carriers.
- A common (analog) use of QAM is for the RF transmission of video in the NTSC and PAL systems.

What is Phase?

- Phase is the fraction of a cycle that the wave is offset from a reference point.





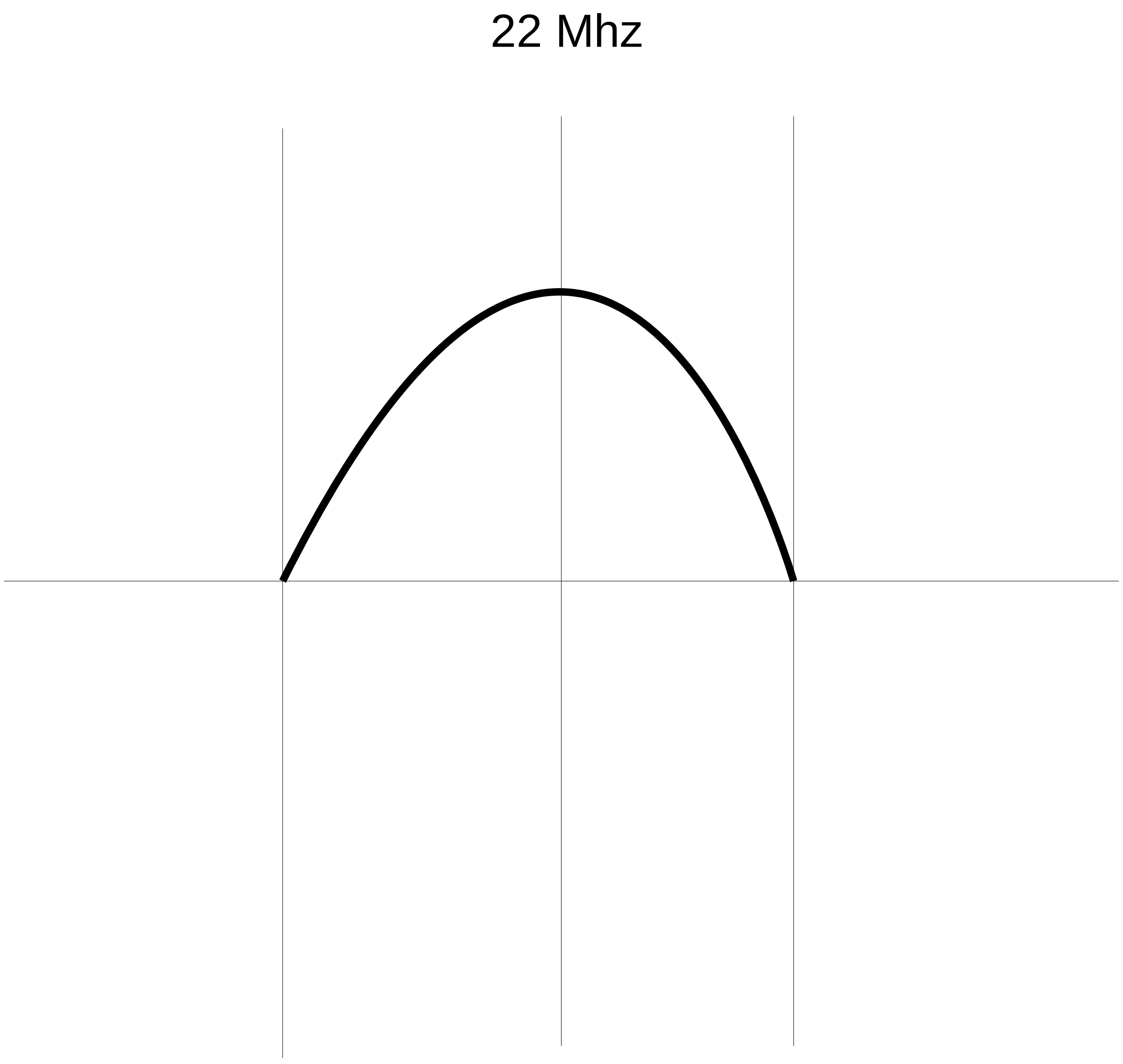
PSK

- Phase Shift Keying is essentially a variation of QAM where the amplitude remains constant but that the separation of phase is shifted between the two carriers.
- Each step in the phase adjustment is assigned a pattern of bits and data is modulated onto the two carriers by selecting the proper phase for a given bit pattern. The receiver then compares the phase of the two signals to a reference source in order to derive their current setting.

Somewhat less old school

- Direct Sequence Spread Spectrum
  - Used in state of the art mid-to-late 90s wireless lan technology (e.g. 802.11b)
  - The information being modulated is multiplied together with a pseudo-random bit pattern and is sprayed across the entire-frequency range used by the carrier.
  - Looks a lot like FM except the edges are much more heavily used.
  - In the case of 802.11 the channel is 22Mhz wide.

DSS Continued



ODFM

- OFDM takes the same channel and divides it up into multiple adjacent smaller bands which can be modulated at a lower symbol rate using another modulation such a QAM or PSK
- Adjacent frequencies are orthogonal to each other eliminating crosstalk interference.

RF Propagation/Attenuation

- Radio Waves propagate through a medium, be it vacuum, earth's atmosphere water, copper wire etc. in a deterministic fashion.
- This is fortunate because it means that we can:
  - model wireless deployments before spending money on equipment.
  - Monitor deployed equipment for changes in the physical characteristics of the link.

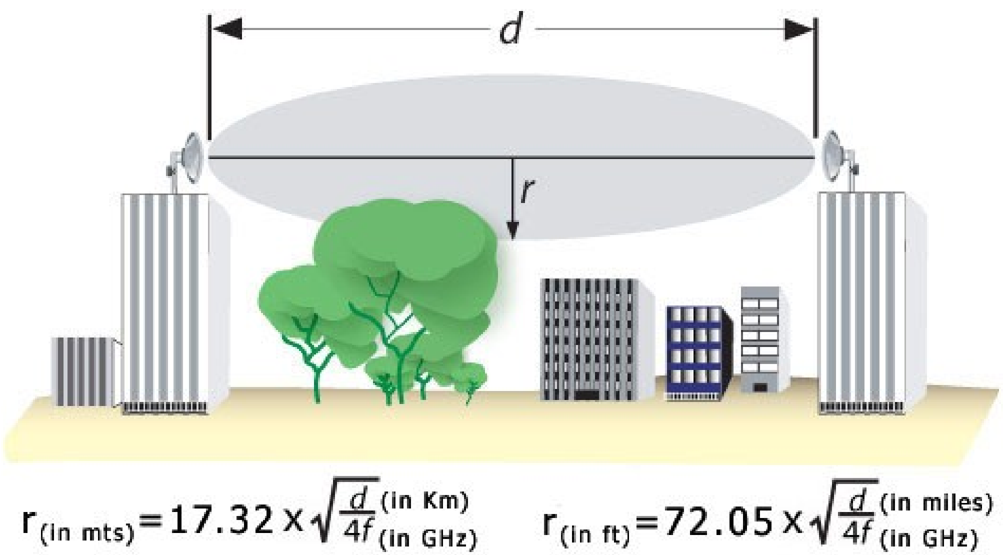
Free-space loss

- The equation we're looking for is:
  - Lp (dB) =92.45 + 20 * (10log F) + 20 *(10log d)
  - Where D is distance in KM and F is the Frequency in Ghz
  - So plug in some numbers:
    - d = 6 (6Km) F=2.45 (2.45Ghz)
    - 116dB = 92.45 + (20 * log 6) + (20 * log 2.45)
  - So the free space loss on our 6Km link is 116dB

dBm vs Milliwatts

- Deci-Bell relative to 1-milliwatt (dBm) is a measure of absolute power, it's a convenient unit to use because path and link calculations typically work with dB and dBm calculations can be seamless folded into that calculation.
- dBm= 10*(10logP)
- 20dBm= 10*(10log100mW)
- 30dBm = 1 Watt

Fresnel Zone



- The Fresnel zone is the region between the antennas that needs to remain unobstructed in order to avoid additional path loss due to obstruction.
- R = 17.32 * square root of (d/4f)
- Where d is kilometers and f is frequency in ghz. R is the radius in meters of the region that needs to be unobstructed

Other Considerations

- Receive Sensitivity - the minimum received energy before a receiver can process the signal at a given rate, a typical number might be -80dBm to -89dBm (-80dBm is .00000001 Watt)
- Noise Floor - The level of background noise and interference from other sources in the same or adjacent frequency ranges.
- SNR – Signal to Noise Ratio. Typically this comes into play when you measure the difference between the received signal and the noise floor. If the Noise floor is below the minimum receive sensitivity the SNR is not a significant concern. SNR is normally expressed as the difference between the received signal and the noise floor in dB rather than as a fraction since it's easier to use in link budge calculations.

Other Considerations 2

- Link margin – amount of signal between the minimum amount you need and the amount you have. Designing systems with link margin in them leaves room for unforeseen path losses, changing noise conditions etc.

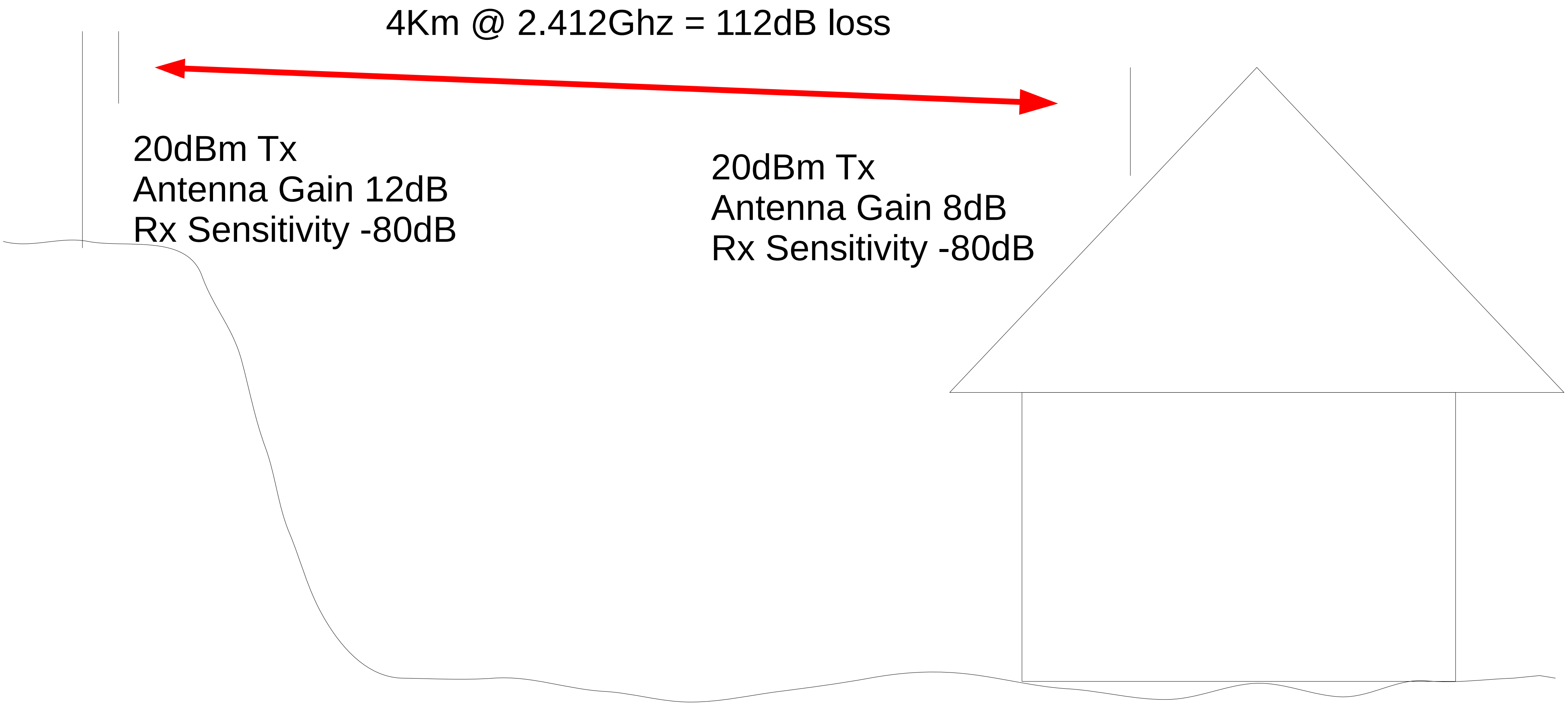
Other Considerations - 3

- Sources of loss
  - Obstructions or partial obstructions (objects in the Fresnel zone)
  - Connectors (can vary radically based on size and quality .1-.5dB is common for 2.4Ghz)
  - Cables (lm400 runs are for example rated at ~.7dB loss per meter)
  - Polarization
  - Multipath

Other Considerations - 4

- Sources of Gain in calculations
  - Input Radio energy
  - Antennas
  - Amplifiers (Tx or Rx)

A Scenario


4Km @ 2.412Ghz = 112dB loss
20dBm Tx
Antenna Gain 12dB
Rx Sensitivity -80dB
20dBm Tx
Antenna Gain 8dB
Rx Sensitivity -80dB

A Scenario - part 2

- From the tower on top of the hill to the house in the valley, our system has the following properties:
  - EIRP (Equivalent isotropically radiated power) 32dBm = 20dBm Tx + 12dB gain
  - Received at the house 32dB – 112dB + 8dB = -72dB
  - Rx sensitivity = -80dB
  - Link Budget = 8dB
  - Note, that path is symmetrical from the house, 20 + 8 – 112 + 12 = -72
  - For an 802.11b link this might be kind of marginal especially as their might be unaccounted for loss elements in our model, for some other technologies 8dB might be more than enough.

Bibliography

- Wlan link planner - http://huizen.deds.nl/~pa0hoo/helix_wifi/linkbudgetcalc/wlan_budgetcalc.html
- Terabeam calculators - http://www.terabeam.com/support/calculations/fresnel-zone.php
- ISM Bands - http://en.wikipedia.org/wiki/ISM_band
- OFDM - http://en.wikipedia.org/wiki/Orthogonal_frequency-division_multiplexing
- DSS - http://en.wikipedia.org/wiki/Direct-sequence_spread_spectrum