VHF vs. 800 MHz Performance In Colorado Mountains

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Purpose

- Many Rural Systems Still VHF Today
- Most New Systems are 700/800 MHz
  - More channels available
  - Interoperability with State of CO
  - Interoperability with urban systems
- Does VHF Have Advantages Over 700/800?
- Which Band Wins in the Real World?

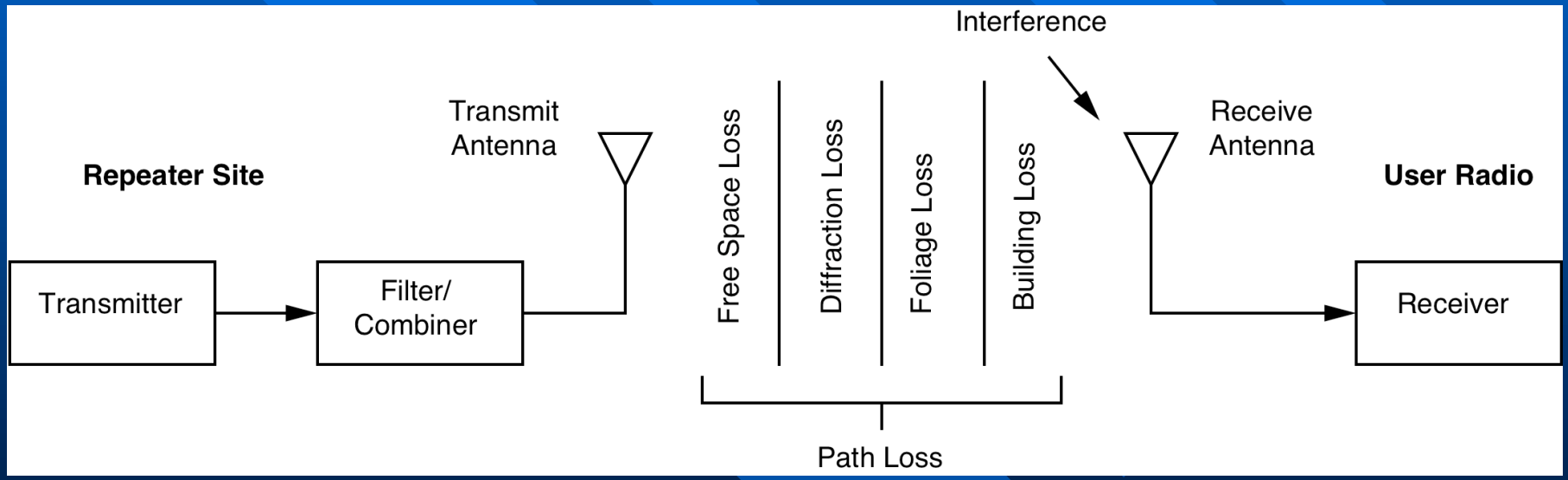
Topics

- Radio Propagation Refresher
- System Components – VHF vs. 700/800
  - Transmitters
  - Receivers
  - Transmission line, filters, combiners
  - Antennas
- Interference
- Case Studies

Land Mobile Radio Bands

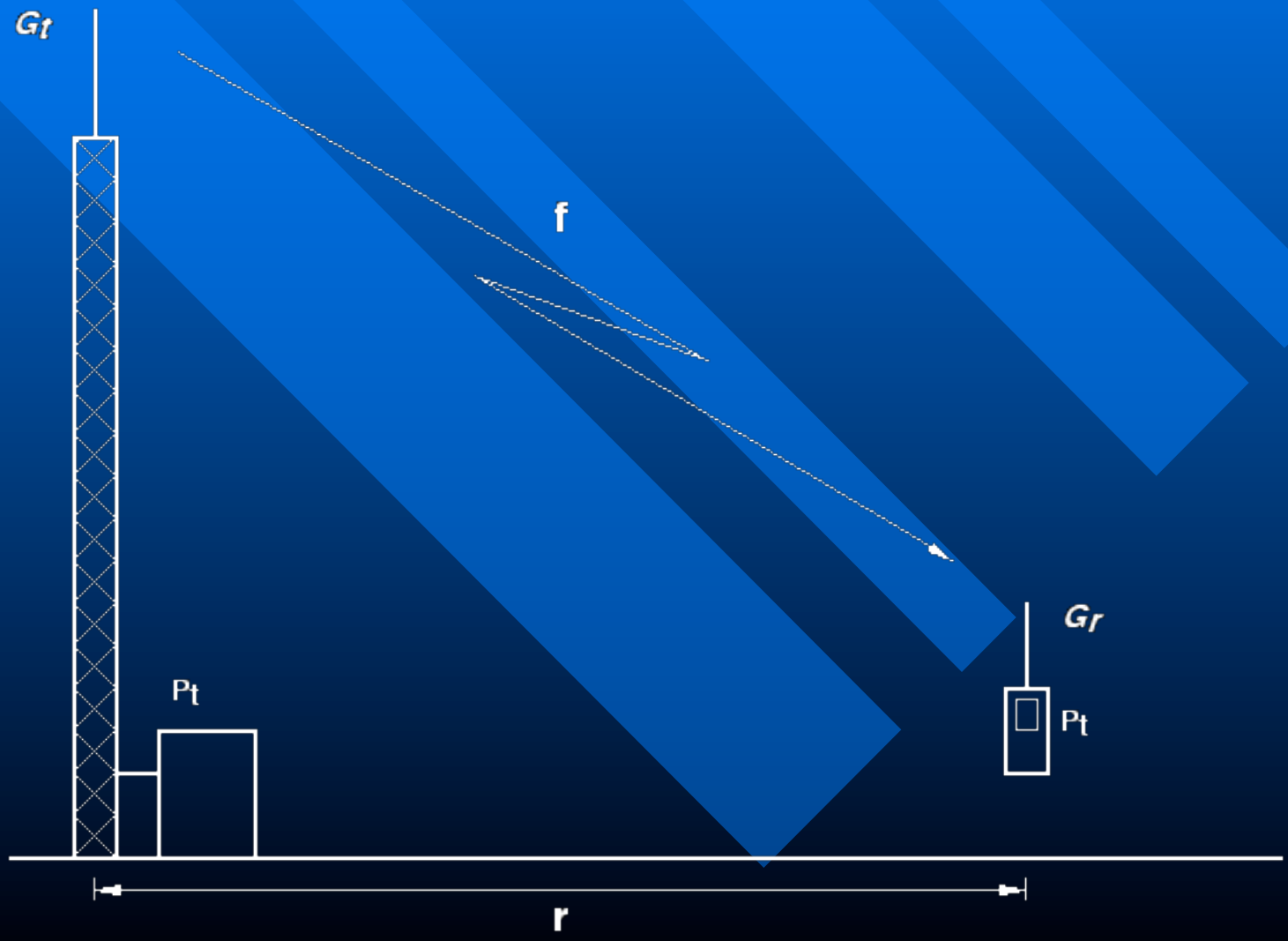
- **Frequencies**
  - 35 - 54 MHz (Low Band VHF)
  - 150 - 174 MHz (High Band VHF)
  - 450 - 512 MHz (UHF)
  - 746 - 806 MHz (700 MHz)
  - 806 - 869 MHz (800 MHz)
  - 4.9 GHz
- **Airlink Standards**
  - FM = the standard since 1940
  - Digital P25 = present and future

The LMR Link


Interference
Transmit Antenna
Repeater Site
Free Space Loss
Diffraction Loss
Foliage Loss
Building Loss
Receive Antenna
User Radio
Transmitter
Filter/ Combiner
Receiver
Path Loss

Radio Propagation

The Radio Link



Path Losses

- Free Space Loss
- Shadow Loss
  - Diffraction
  - Reflection
  - Foliage Attenuation
- Material Attenuation
  - Walls
  - Windows
  - Body loss (for portable radios)
  - Other man-made objects

Free Space Equation

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi r)^2}$$

where

$P_t = Transmitter\ \ power$

$G_t = Transmit\ antenna\ gain$

$G_r = Receiver\ antenna\ gain$

$\lambda = Radio\ carrier\ wavelength$

$r = Path\ distance$

Free Space Loss

$$FSL = \frac{(4\pi r)^2}{\lambda^2}$$

Free Space Loss (dB)

$$FSL = 21.98 + 20\log_{10}\left(\frac{r}{\lambda}\right)$$

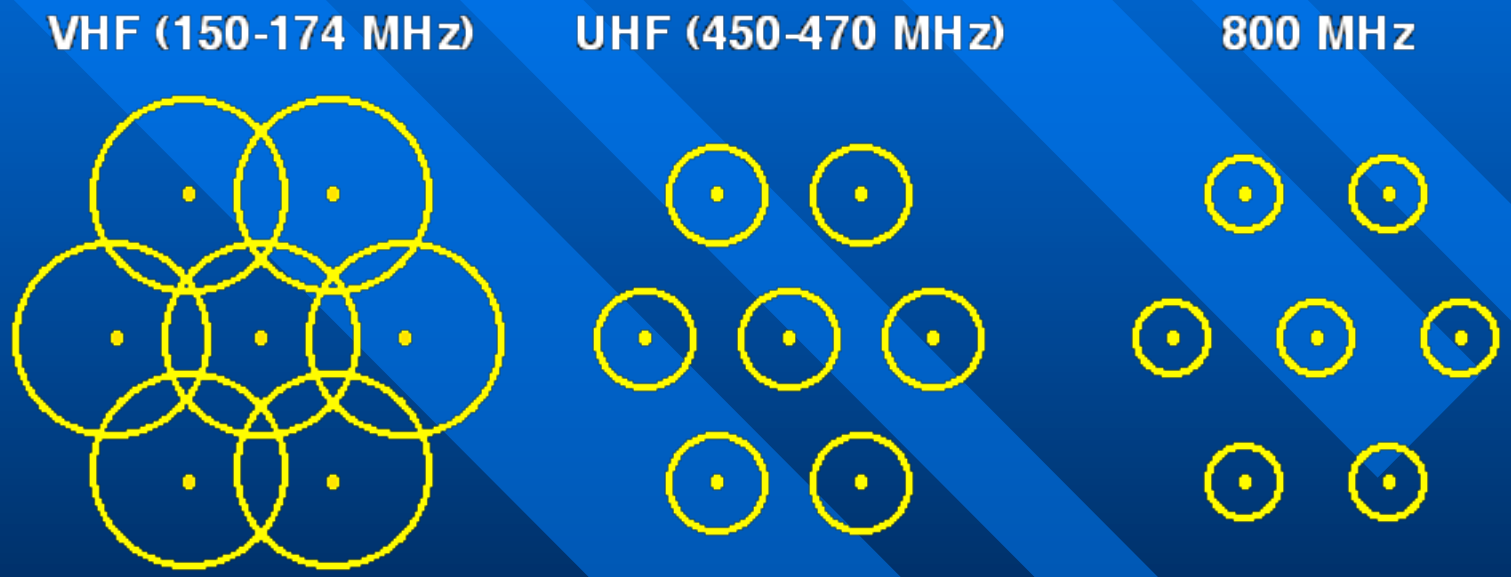
r, λ *in the same units*

$$\lambda = \frac{c}{f} = \frac{300}{f_{MHz}}$$

Free Space Loss vs. Frequency

- FSL is Proportional to Freq. Squared
- I.e., Additional Loss = $20\log_{10}(f_2/f_1)$
- Examples
  - Double frequency = 6 dB more loss
  - 800 MHz vs. 150 MHz = 14.5 dB more loss
    - » Or reduced range of factor of 5.3

Effect on Coverage



Notes:

1. Simplified representation assuming only free space loss.
2. Actual coverage boundaries are irregular due to terrain effects.
3. Repeater site antenna gain is 3 dBd for 150 MHz, 6 dBd for 450 MHz, 9 dBd for 800 MHz.
4. Transmitter power and receiver sensitivity is the same for all.
5. Portable radio antenna gain is the same for all.

Path Loss Summary

- Free Space Loss
  - VHF wins by 14.5 dB
- Diffraction Losses Favor VHF
  - Abundance of theory and measurements support it
  - VHF wins
- Attenuation Losses Also Favor VHF
  - I.e., construction materials, foliage
  - VHF wins
- Exceptions
  - Fresnel zone loss on line-of-sight paths
  - Apertures (windows) small relative to VHF wavelength

System Components

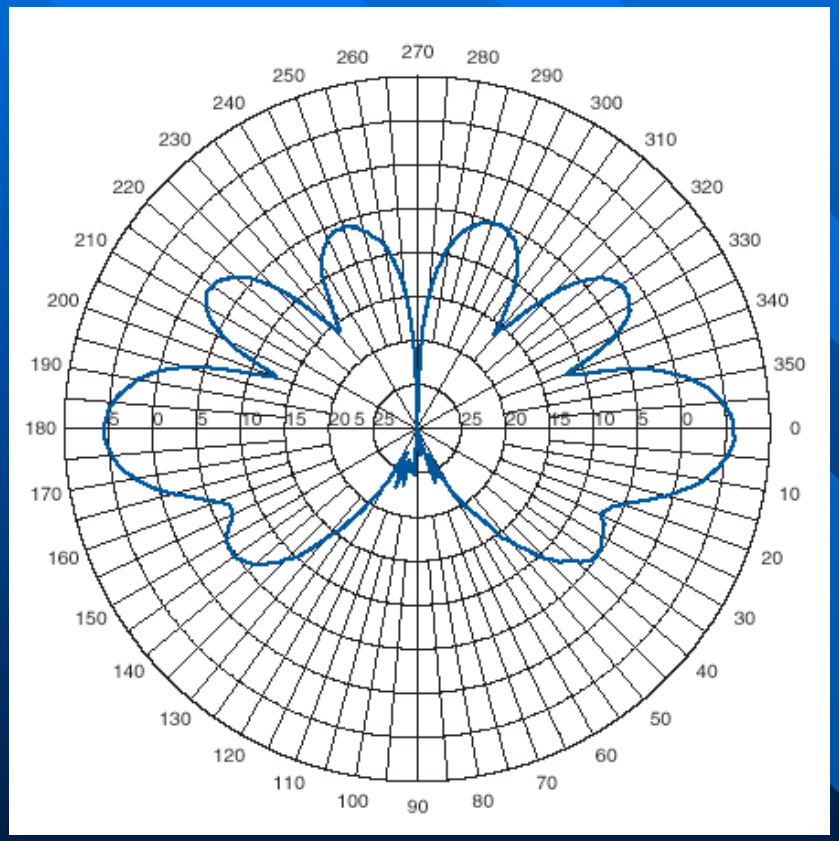
System Components

- **Transmitter**
  - VHF & 800 MHz transmit power is comparable (100 W) - TIE
- **Receiver Sensitivity**
  - VHF & 800 MHz receiver sensitivity is comparable (-118 dBm) - TIE
- **Transmission Line**
  - Line loss less for VHF, but not dramatic difference - TIE
- **Filters & Combiners**
  - System dependent, sometimes less for VHF - TIE
- **Antennas**
  - Can be significant differences, see next slide
  - Short answer: 700/800 wins

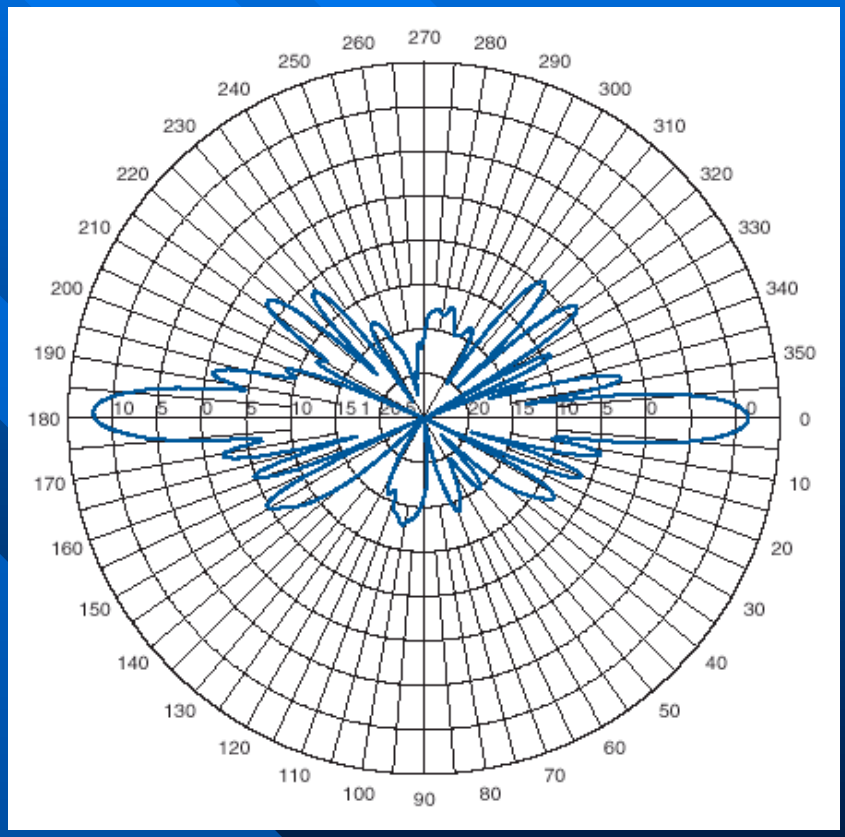
Antennas

- Efficient Antennas Have Lengths Close to Wavelength
  - 150 MHz: Lamda/4 = 0.5 meters (1.6 feet)
  - 860 MHz: Lamda/4 = 0.1 meters (3.4 inches)
- Mobile (Vehicle) Radio
  - Quarter wavelength antennas are practical at 150 and 860 MHz
- Portable (Handheld) Radios
  - Quarter wavelength antennas not practical at 150 MHz
  - VHF gain will be typically be less than 700/800 MHz radio
- Repeater Site Antennas
  - Space limitations typically limit 150 MHz antennas to 6 dBd (omni)
  - Typical 700/800 MHz antennas gain = 9 dBd (omni)
  - Higher gain at 700/800 MHz , though possible, is not necessarily good at high sites

Antenna Patterns



G = 4 dBd



G = 10 dBd

Interference

Radio Frequency Interference
(Repeater Sites)

- VHF
  - Co-channel: Somewhat variable, FCC specifies minimum separation
  - Co-site: Highly variable, depends on quality of site and protections installed at repeater
  - No duplex band, so difficult to isolate transmit and receive
  - Lots of interference sources at VHF

- 700/800 MHz
  - Co-channel: Somewhat variable, FCC specifies minimum separation
  - Co-site: Highly variable, depends on quality of site and protections installed at repeater

- Bottom Line:
  - No theoretical difference, but VHF sites tend to be older and poorly maintained, resulting in greater vulnerability to interference
  - 700/800 MHz wins

Case Studies

Case Studies

- Three Cases
  - Larimer County, Middle Bald Mountain
  - Larimer County, South Bald Mountain
  - Gilpin County, Dakota Site
- Drive Measurements, Not Computer Models

Case Study Results

Table 2 - Measured Signal Levels (Mobile Outbound, Rural Forested Area)		
Site	**Location**	**Mean Difference VHF - 800 MHz**
Middle Bald Mountain	Larimer County, CO	20.8 dB
South Bald Mountain	Larimer County, CO	22.2 dB
Dakota Site	Gilpin County, CO	18.6 dB

Gilpin County Statistics

- From Drive Test Data,
  - Mean difference favors VHF by 18.6 dB (mobile)
  - Mean difference favors VHF by 8.6 dB (portable)
- Coverage Comparison
  - Dakota site: 93% coverage above -99 dBm over drive test route
  - 800 MHz: Combination of Thorodin, Lookout, Dakota, Squaw, Black Hawk, and Mines = 92.6% above -105 dBm
- Mitigating Factor
  - If starting with clean slate, one would not necessarily choose these six sites to cover area of interest

Conclusions

- Path Losses in Rural Areas Favor VHF
  - E.g., in Gilpin County, mean difference > 18 dB
- Portable Antenna Favors 700/800 MHz
  - By roughly 10 dB
- Site Interference Could be Deciding Factor
  - But it might be correctable
- Replicating VHF Coverage with 800 MHz:
  - Can be expensive
  - But often other factors come into play
  - Frequency availability being the most important
- VHF vs. 800 MHz Decision Must Be Case by Case

Questions?

Backup Slides

Decibel Refresher

Decibel Refresher

- **A logarithmic representation of a power ratio:**

  $Decibels = 10 \log_{10}(Pout/Pin)$ dB

- **Properties:**

  log (xy) = log(x) + log(y)
  log(x/y) = log(x) - log(y)
  log(x^b) = b log (x)

- **The ratio of two voltages in decibels:**

  $Decibels = 20 \log_{10}(Vout/Vin)$ dB

- **Negative Decibels Means Ratio is Less Than 1**

- **Positive Decibels Means Ratio is Greater Than 1**

Decibel Refresher

- **Decibels Are Unitless**
- **Decibels Relative to a Power Level are Useful, Too**
  dBm = Decibels relative to 1 milliwatt
  dBW = Decibels relative to 1 Watt
- **Other Decibels**
  dBc = Decibels relative to power in the radio carrier
  dBi = Antenna gain relative to isotropic antenna
  dBd = Antenna gain relative to 1/2 wave dipole
- **Why Use Decibels?**
  - Engineers are lazy
  - Addition and subtraction easier than multiplication and division

Decibel Refresher

- Some Useful Ratios to Remember

Ratio	Decibels
1	0 dB
2	3 dB
4	6 dB
5	7 dB
10	10 dB
20	13 dB
50	17 dB
100	20 dB
1,000	30 dB
10,000	40 dB
100,000	50 dB
1 million	60 dB

Gilpin County Dakota Site