Propagation – It's Not Always Free Space

I can talk to the International Space Station with my handie-talkie – why can't I talk to friends across town?

Kai, KE4PT, 2015 Oct 27

Gold Coast ARA

How Far Can a Pair of 2-meter Handie-Talkies Talk?

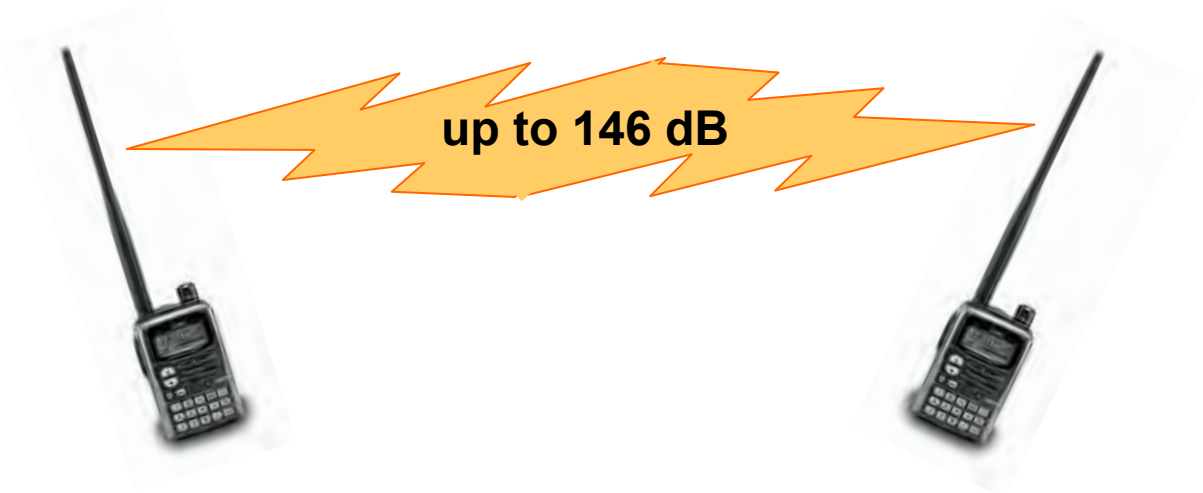
They can…

- burn up to **160 dB attenuation** between the handie-talkie antenna connectors

A Better Way to Eat up 160 dB

Or we can…

- include two **–7 dBi** "rubber duckie" antennas, leaving 146 dB for the path



- **So how far will 146 dB take us?**

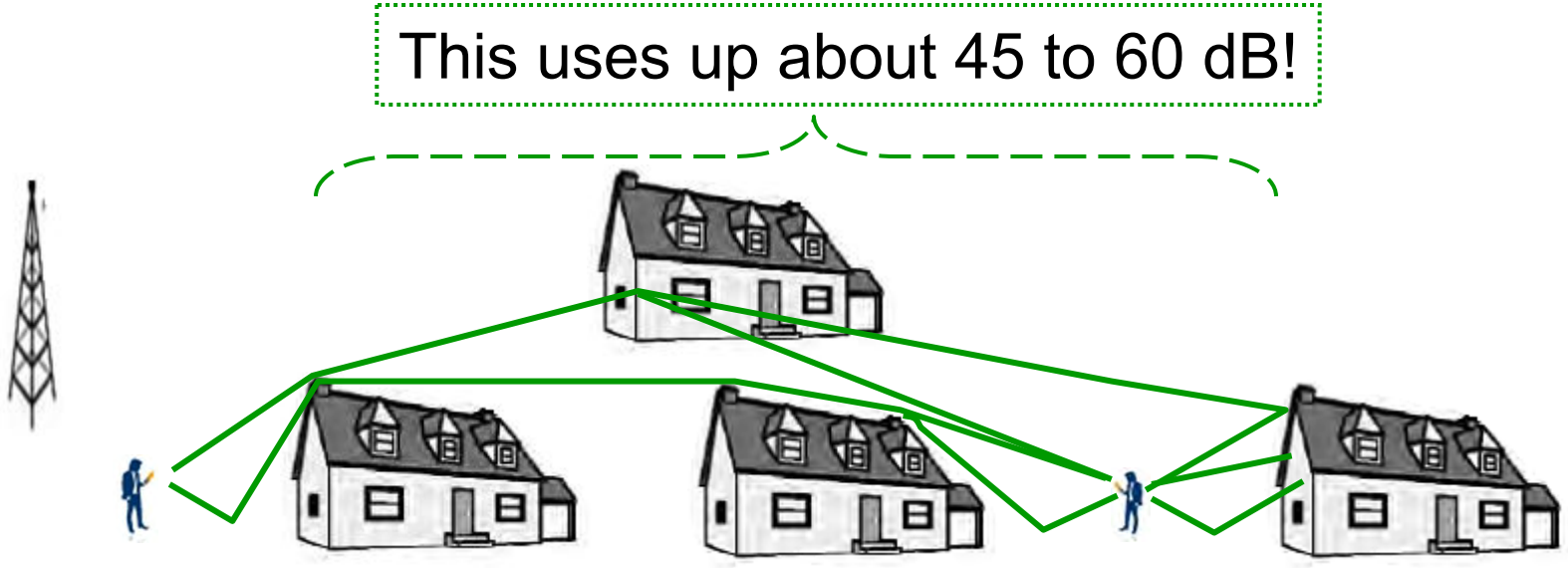
Unobstructed Path to ISS Uses up 143 dB

NASA image

Distance to ISS varies from 400 km (249 mi) straight up, to 2,300 km (1430 mi) on the horizon.

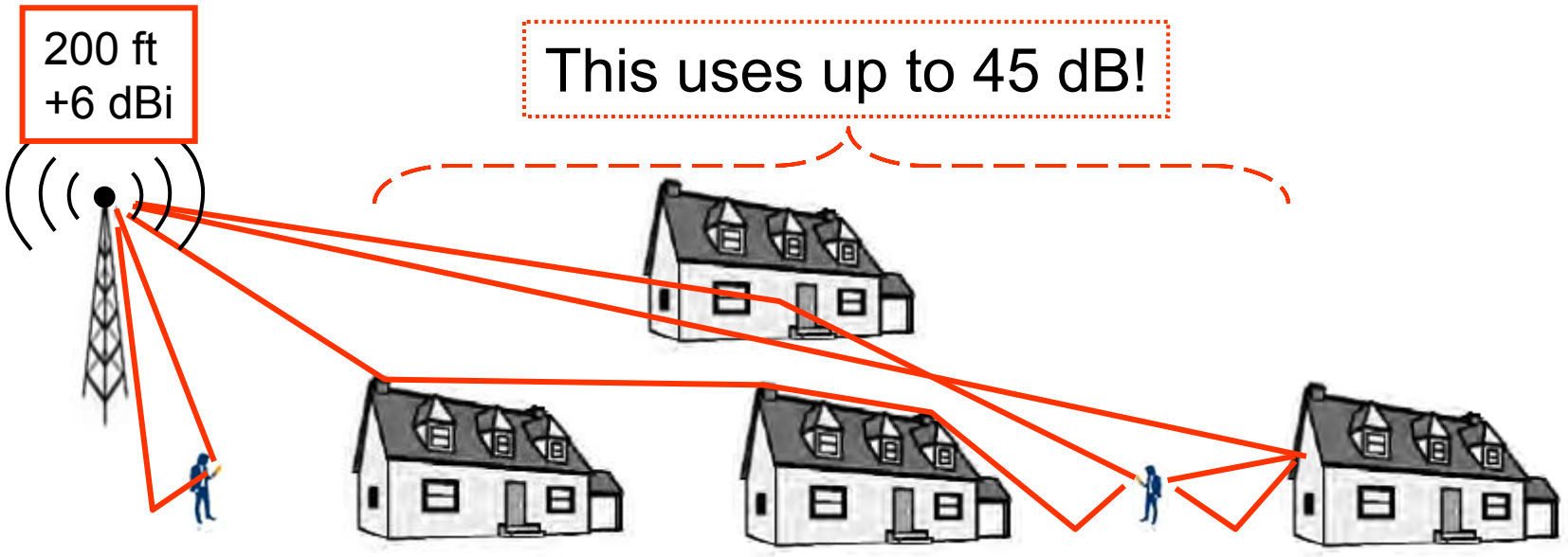
Free Space Path attenuation is 143 dB at the horizon … we have 3 dB to spare!

The Cross-town Path Includes Diffractions, Shadows, Reflections



Path attenuation is 146 dB at a distance of just 2.7 km!

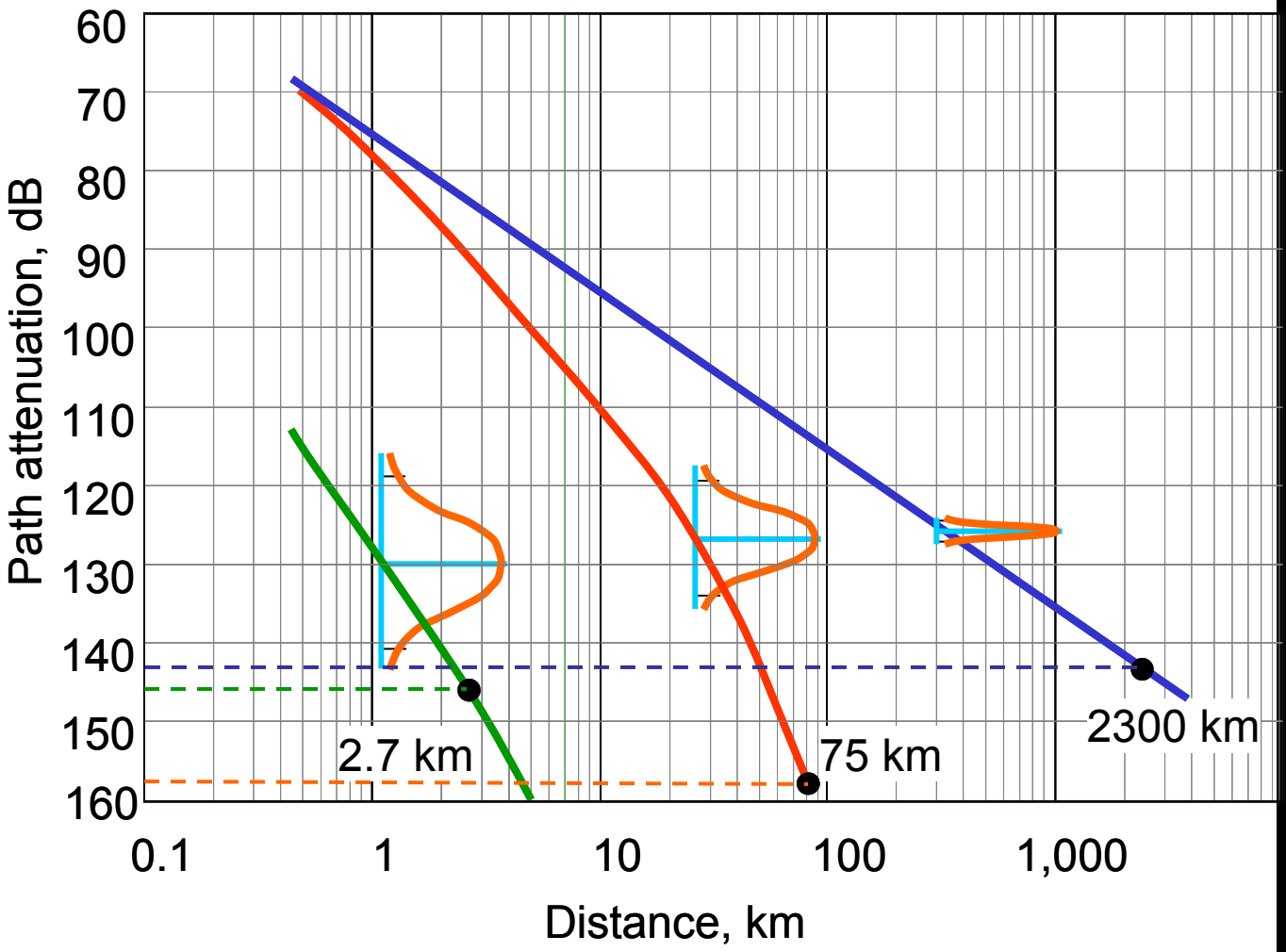
Everyone Benefits from the High Repeater Antenna



Path attenuation to a high repeater antenna is 160 –7+6 dB = 159 dB at a distance of 75 km!

Alan Bloom, N1AL, “VHF/UHF Mobile Propagation”, QST, Aug 2006, pp 35-37.

2-meter 5 W Handie-Talkie Range



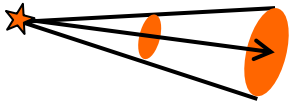
The green and red curves are median values,

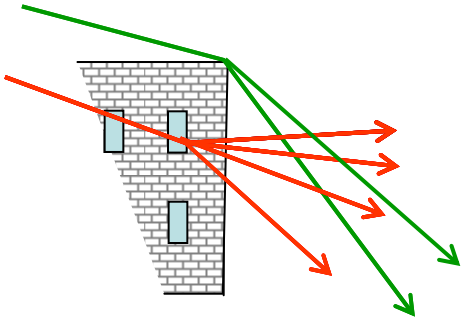
there is a large standard deviation, σ = 6 to 10 dB, and tends to increase with distance

What Causes Path Attenuation?

Signals weaken because of

- Spherical Wave Expansion
- Diffraction and Shadowing
- Scattering
- Fading





and

- Ohmic losses (we will ignore)

electronics.stackexchange.com

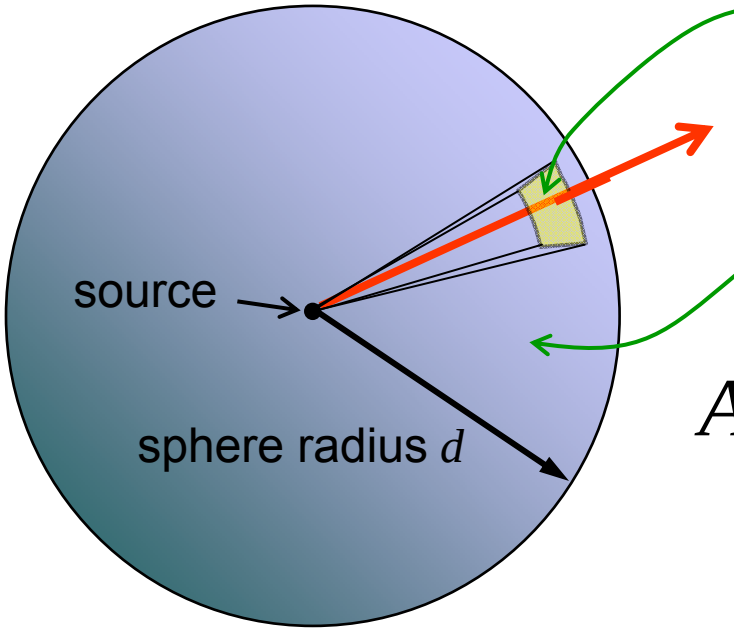
Understanding Propagation

- We first, **"assemble"** the components of propagation one path at a time
- Then, we build up an "exact" **Eye-Glazing Formula** from the components and paths
- Last, radically simplify the **Eye-Glazer** because of how Ham FM receivers work

We'll omit many explanations and physical details

K. Siwiak, H. L. Bertoni, and S. Yano, "Relation between multipath and wave propagation attenuation", Electronic Letters, 9 Jan 2003, Vol. 39 Num 1, pp. 142-143.

Receiving Capture Area



$$A_R = receiving\ area$$

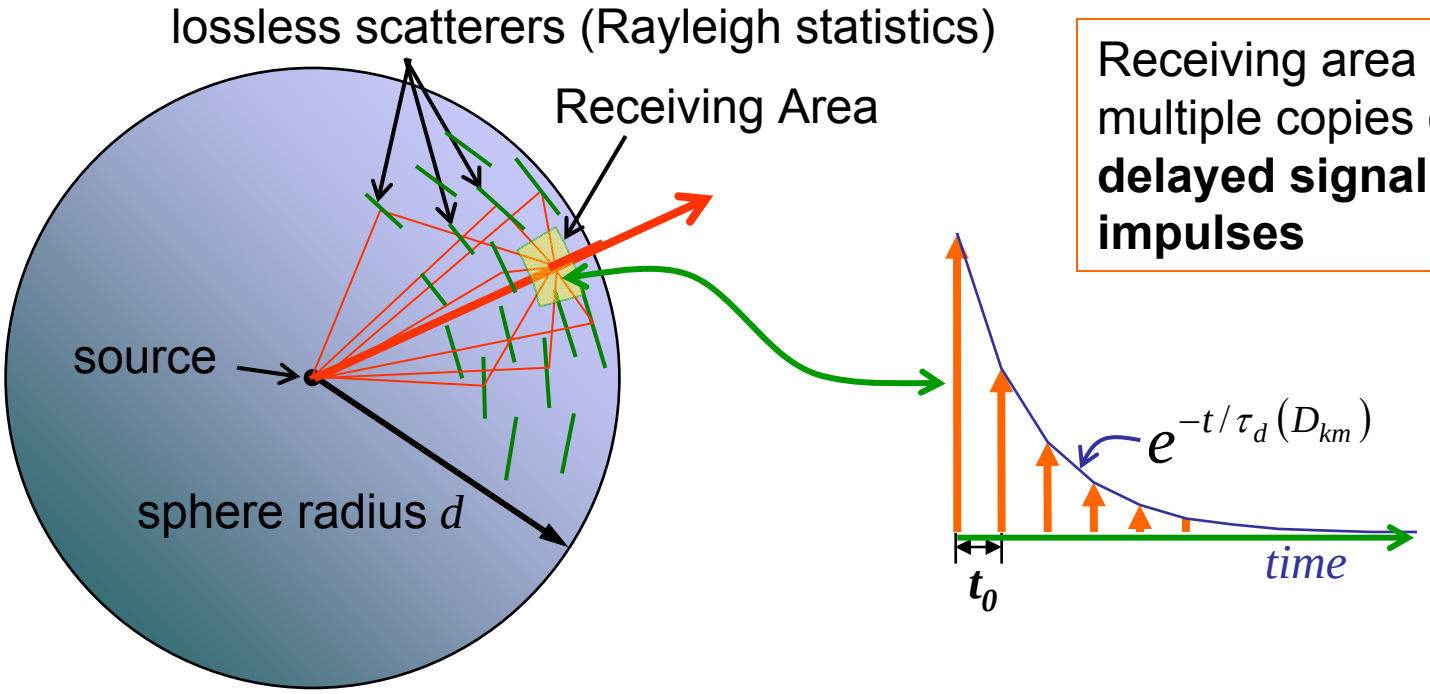
$$A_{SPHERE} = 4\pi d^2$$

$$Atten. = \frac{A_R}{A_{SPHERE}} = \frac{A_R}{4\pi d^2}$$

1st component is Free Space Propagation, or, inverse square law, 20 dB for every decade of distance

J. Hallas, W1ZR, "Antenna Gain, Part III: How Much Signal Gets Received?" QST, Jan 2016, [scheduled].

Propagation with Many Scatterers



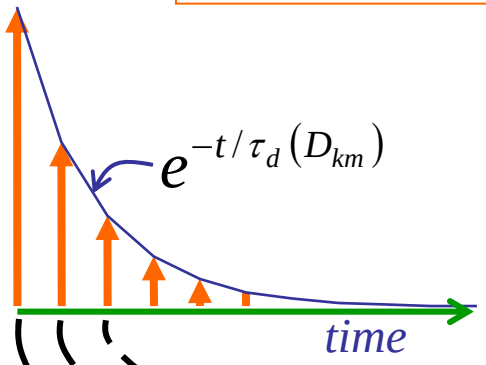
Receiving area captures multiple copies of **time-delayed signal energy impulses**

(a) Attenuation by expanding spherical wave
(b) Energy bleeding into 4th dimension: *time!*

Build Up the Eye-Glazing Equation

Add up one impulse "echo" after another

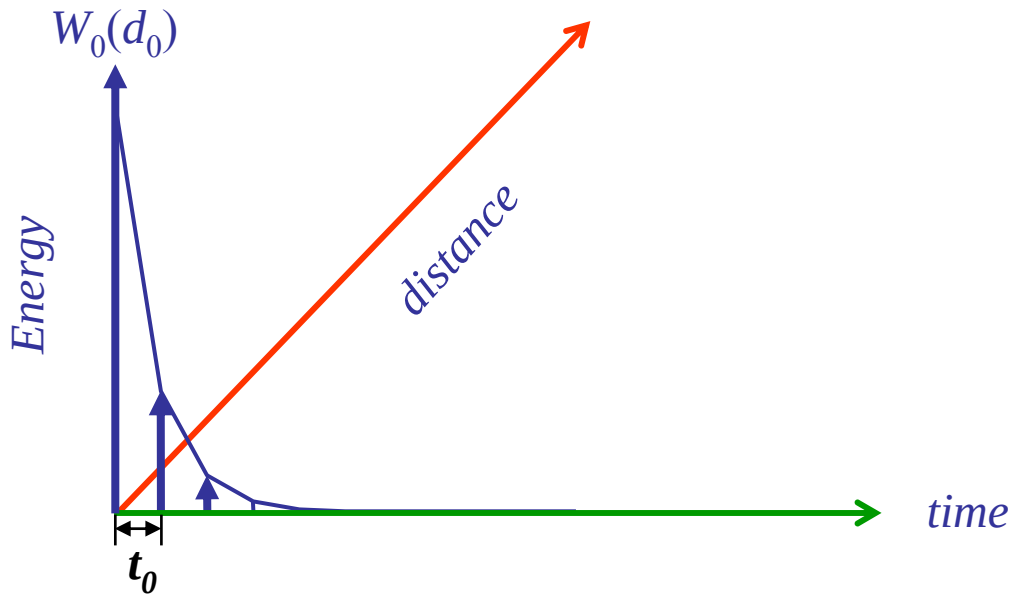
Three parts to the propagation equation



$$W(D_{km}) = [FreeSpace \quad term] \times (Scaling \quad factor) \times (1^{st} + 2^{nd} + 3^{rd} + 4^{th} + \cdots)$$

(1) Free Space spherical expansion component
(2) Scaling factor component
(3) Each impulse "echo" component

Scatterers Create Time-delayed Impulses (copies of the signal)



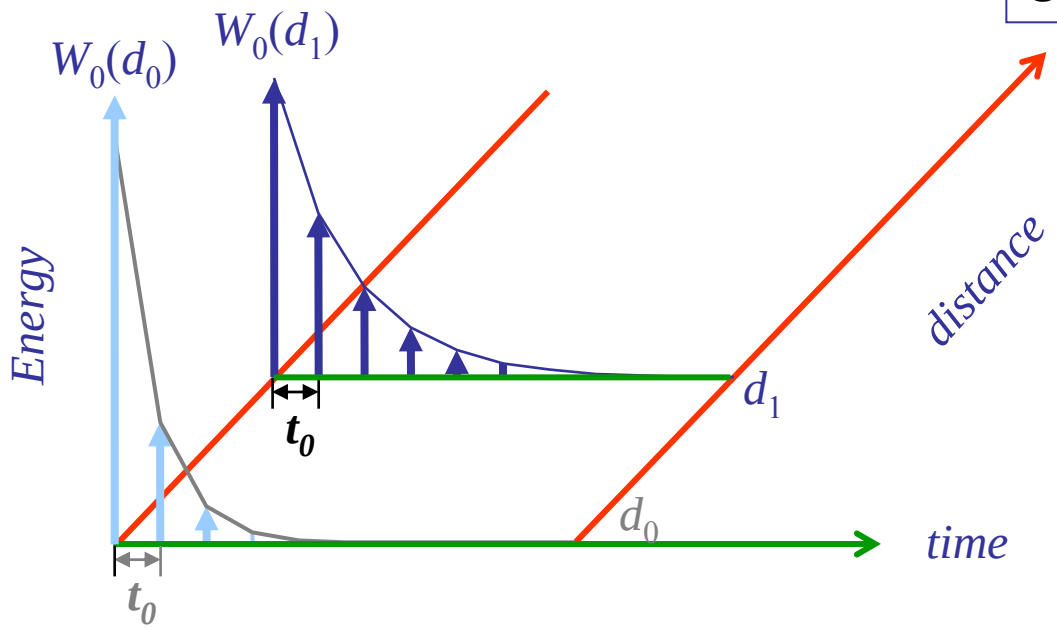
Spherical expansion Free Space term

$$W(D_{km}) = \left[\frac{1}{(42F_{MHz}D_{km})^2}\right] \times (Scaling\ \ factor) \times (a\ \ few\ impulses)$$

Scaled Time delayed echoes

Free Space attenuation modifies the impulse echoes

The Number of Scatterers, and Impulses, Increase with Range



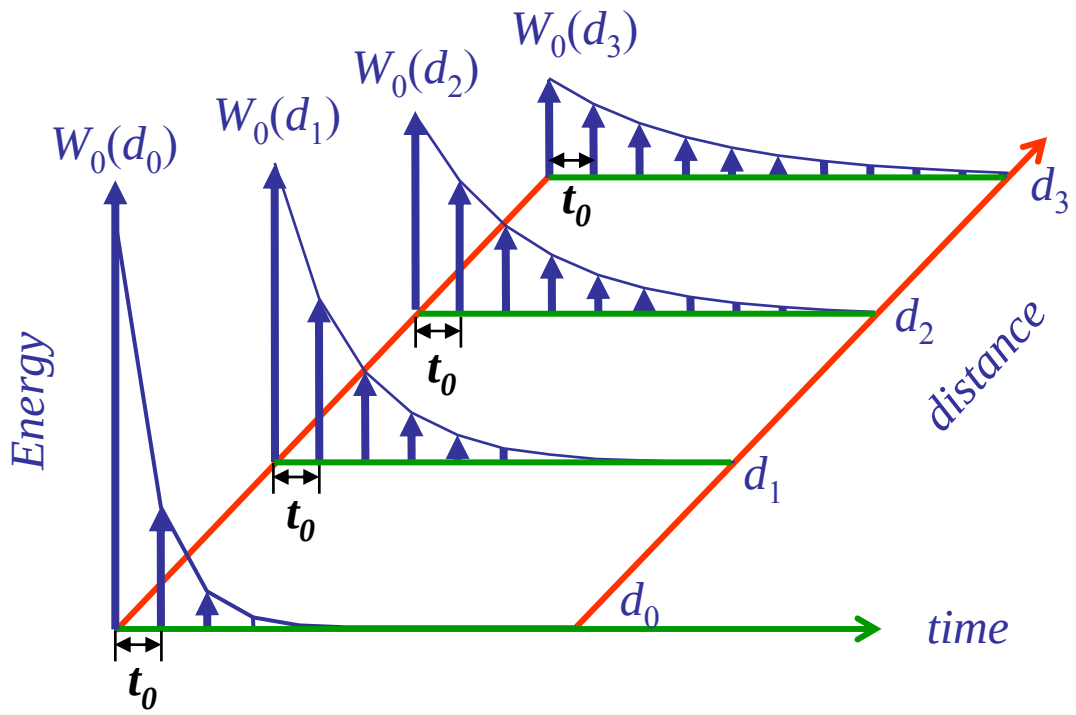
Spherical expansion Free Space term

$$W(D_{km}) = \left[\frac{1}{(42 F_{MHz} D_{km})^2}\right] \times (Scaling \quad factor) \times (further\ delayed\ impulses)$$

Scaled Time delayed echoes

More time-delayed impulses are involved as distance from the transmitter increases

The Eye-Glazing Finale …



Free Space term

$$W(D_{km}) = \left[\frac{1}{(42F_{MHz}D_{km})^2}\right] \times \left(1 - e^{\left[\frac{-t_0}{\tau_d(D_{km})}\right]}\right) \sum_{n=0}^{\infty} e^{\left[\frac{-nt_0}{\tau_d(D_{km})}\right]}$$

Scaled | **time-delayed impulses**

Free Space attenuation modifies time delayed impulse echoes, a rake diversity receiver can capture this energy

K. Siwiak, H. L. Bertoni, and S. Yano, "Relation between multipath and wave propagation attenuation", Electronic Letters, 9 Jan 2003, Vol. 39 Num 1, pp. 142-143.

Now, It All Depends on Your Antenna and Receiver!

- So far, we've described the **raw energy components** at the receiving location
- What happens next depends on the
  - Antenna **(we'll assume a typical linearly polarized ham antenna)**
  - The type of receiver **(we'll assume a typical Ham FM receiver)**

Yes! the receiving system impacts the system propagation law!

Ham FM Receivers Lock Onto Just *ONE* Impulse

$$W(D_{km}) = \left[\frac{1}{(42F_{MHz}D_{km})^2}\right] \times \left(1 - e^{\left[\frac{-t_0}{\tau_d(D_{km})}\right]}\right) \sum_{n=0}^{\infty} e^{\left[\frac{-nt_0}{\tau_d(D_{km})}\right]}$$

"1"

Just the scaling factor survives

This Eye-Glazer simplifies because Ham FM receivers "see" just one (usually *n*=0) impulse

The rest of the impulse energy shifts into the 4th dimension (time) and contributes to fading!

The Eye-Glazer ***busted!***

$$W(D_{km}) \approx \left[\frac{1}{(42F_{MHz}D_{km})^2}\right] \times \left(1 - e^{\left[\frac{-t_0}{\tau_d(D_{km})}\right]}\right)$$

$$\frac{t_0}{\tau_d(D_{km})} = \left(\frac{D_B}{D_{km}}\right)^M$$

$$W_0(D_{km}) \approx \frac{\left(\frac{D_B}{D_{km}}\right)^M}{(42F_{MHz}D_{km})^2}$$

Receiver locks to *only* the strongest impulse (*n*=0)

- **D_B is roughly the distance to the first scatterer**
- ***M* is between 0.5 and 2.5 depending on how delay spread τ_d increases**

Multipath creates a 2+*M* inverse power attenuation, rest of the energy shifts into time and contributes to fading!

K. Siwiak, "Radio Wave Propagation: How Waves Attenuate with Distance", *QST*, Feb 2016, [scheduled].

The Bottom Line

$$W_0(D_{km}) \approx \frac{\left(\frac{D_B}{D_{km}}\right)^M}{(42F_{MHz}D_{km})^2}$$

- **D_B is roughly the distance to the first scatterer**
- **M is between 0.5 and 2.5 depending on how delay spread τ_d increases**

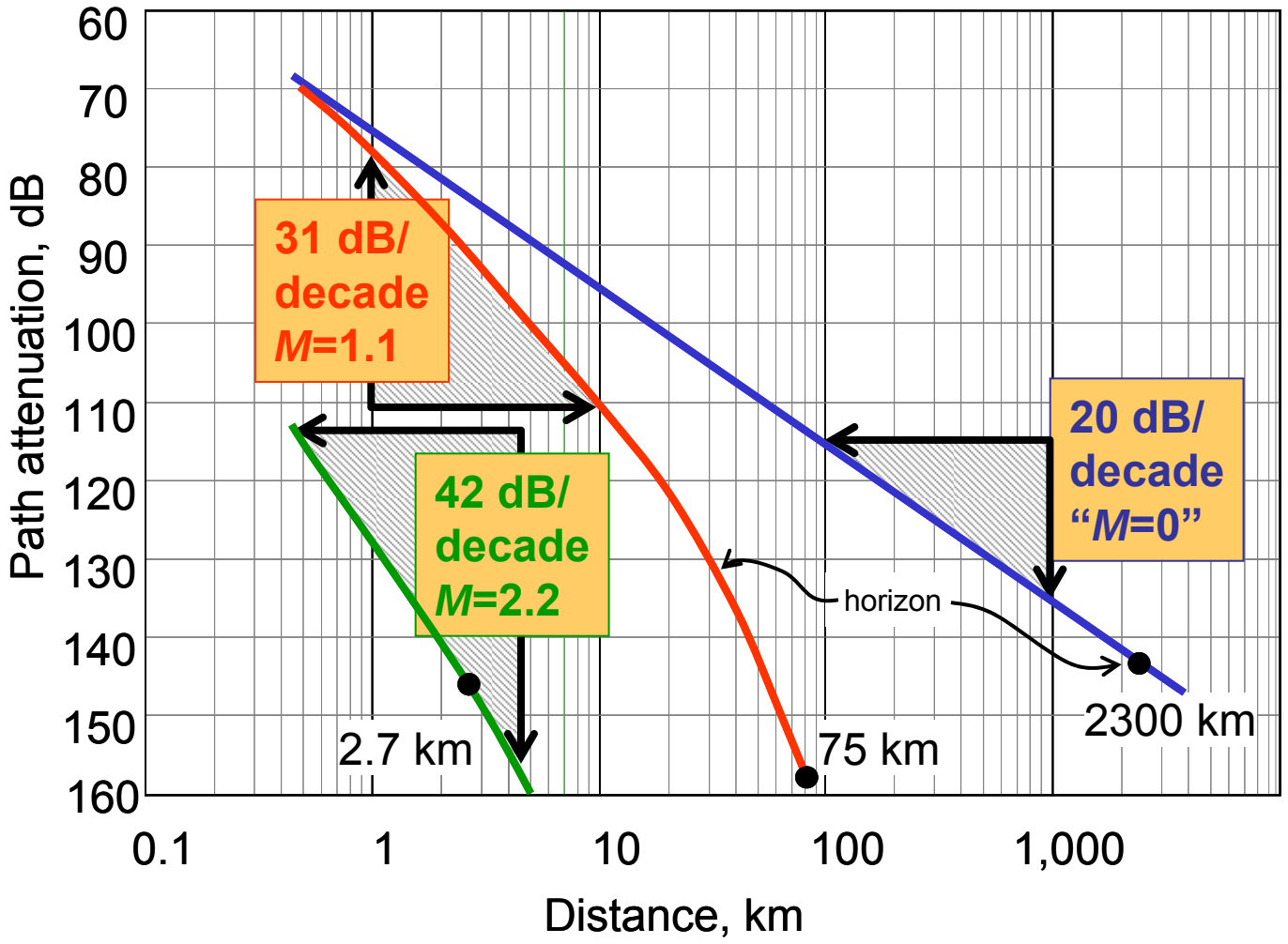
… can be written as decibels of loss:

$$W_{dB} = 20\log(42F_{MHz}D_{km}) - 10M\log\left(\frac{D_B}{D_{km}}\right)$$

Free space loss

Additional multipath loss

Different Propagation Laws



Summary

- Radio waves expand spherically
- Additional energy can be lost to
  - Diffraction
  - Reflection
  - Scattering and Cross Polarization
  - The 4^{th} dimension
  - Heating up the environment
- The path determines the details

Thanks for your Attention