  

Effects of Trees on Slant Propagation Paths

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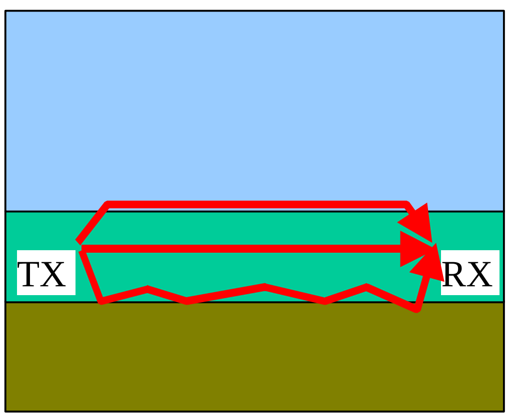
Content

- Terrestrial vs. Satellite Tree Attenuation
- VHF, UHF, L-Band, S-Band and K-Band Measurements and Model Comparison
- Foliage Effects Scaling
- Spatial, Frequency, Elevation Variations
- Conclusions

Paths and Models

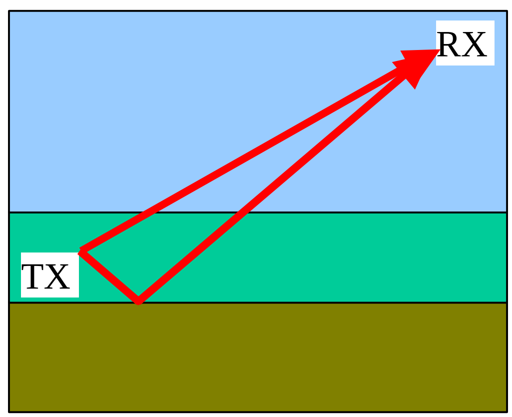
Horizontal: long

SLAB Model

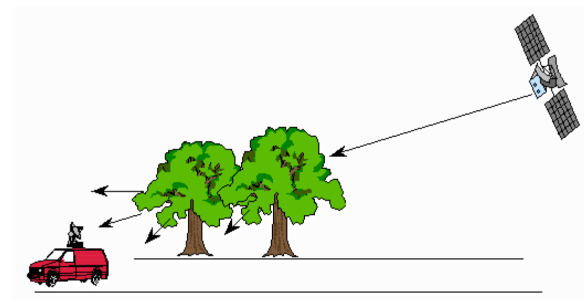


Slant: med.

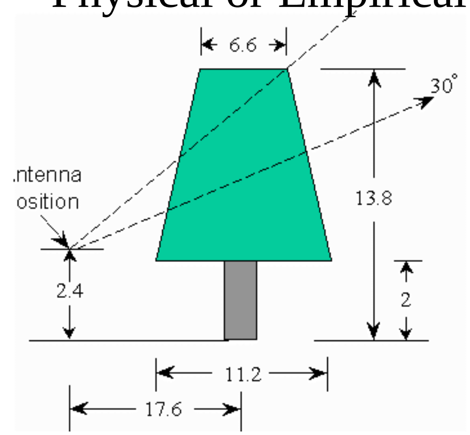
SLAB Model



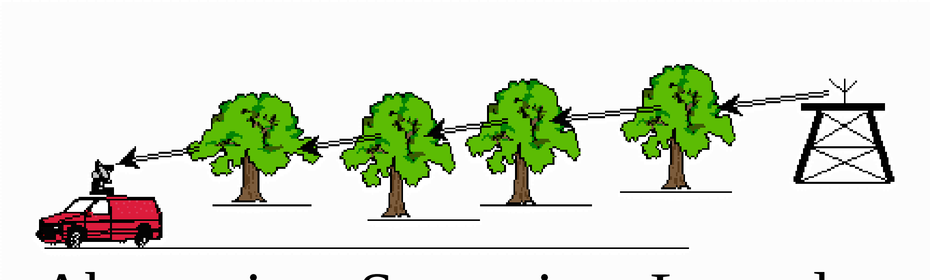
Roadside: short



Physical or Empirical



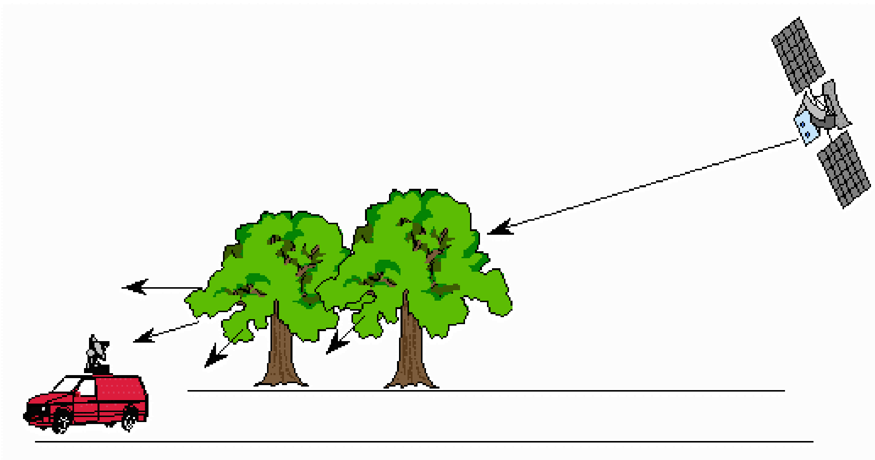
Horizontal Path Tree Attenuation



- Absorption, Scattering, Lateral wave over tree boundary layer, Slab model for layers, e.g., undergrowth, trunks, crowns
- Long propagation path through many trees
- Below 3° in elevation
- High initial specific attenuation, ***R***
  - 2-10 dB/m
- **Fade, *A* = increase diminishes with range, *d***

$$A = A_{max}(1 - \exp(-\frac{R \cdot d}{A_{max}}))$$

Slant Path Tree Attenuation



- Short propagation path through 1 or 2 trees
- Absorption, Scattering, Ground reflection
- Usually above 10° in elevation
- **Fade = attenuation constant * path length**

VHF Measurements

- Vegetation
  - Eucalyptus Forest (California)
  - Tropical Rain Forest (Asia)
- Frequencies - 50, 75, 100, 250, 400 MHz
- Polarization – linear, V and H
- Platforms - aircraft towed & balloon borne
- Elevation Angles – 8° to 29°
- Calibration - Relative, by (1) differential path lengths at forest edge, (2) measured or (3) calculated clear path comparison

VHF Results

Freq.	Pol.	Median Attenuation Constant (dB/m)		
(MHz)	(V/H)	Jungle A	Jungle B	Eucalyptus
50	H	0.031 - 0.060	0.040 - 0.100	0.012 – 0.030
50	V	0.045 - 0.090	0.070 – 0.120	0.060 – 0.100
75	H	0.038 - 0.075		0.075 – 0.110
75	V	0.043 - 0.090		0.075 – 0.125
100	H	0.048 - 0.100	0.030 – 0.070	0.061 – 0.133
100	V	0.043 - 0.120	0.075 – 0.140	0.145 – 0.151
250	H		0.040 – 0.075	
250	V		0.054 – 0.108	
400	H		0.076 – 0.146	
400	V		0.075 – 0.200	

Comparison to Frequency Scaling Model

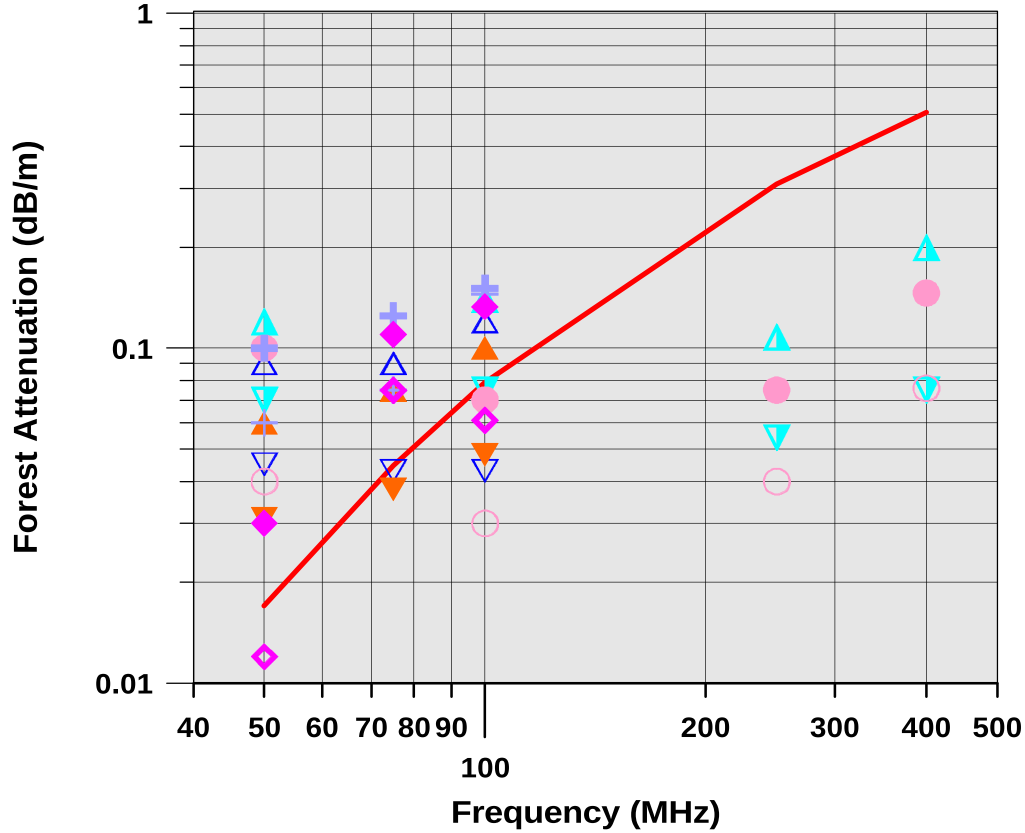
$$A(f_2) = A(f_1)\exp\left\{b\cdot\left[\left(\frac{1}{f_1}\right)^{0.5} - \left(\frac{1}{f_2}\right)^{0.5}\right]\right\}$$

b =1.173 for median fade level

Solid line: Model with 1dB/m at 1 GHz

Red symbols: H Pol.

Blue symbols: V Pol.



Comments to VHF Results

- Due to tree morphology, vertical polarization fades more than horizontal polarization
- Model under-predicts attenuation to 100 MHz
  - Model is based on UHF to K-Band measurements
- Model over-predicts attenuation at 250 and 400 MHz
  - Paths were longer than 5 – 10 m, above which the effective specific attenuation decreases
- Model could be tuned to reflect VHF measurements

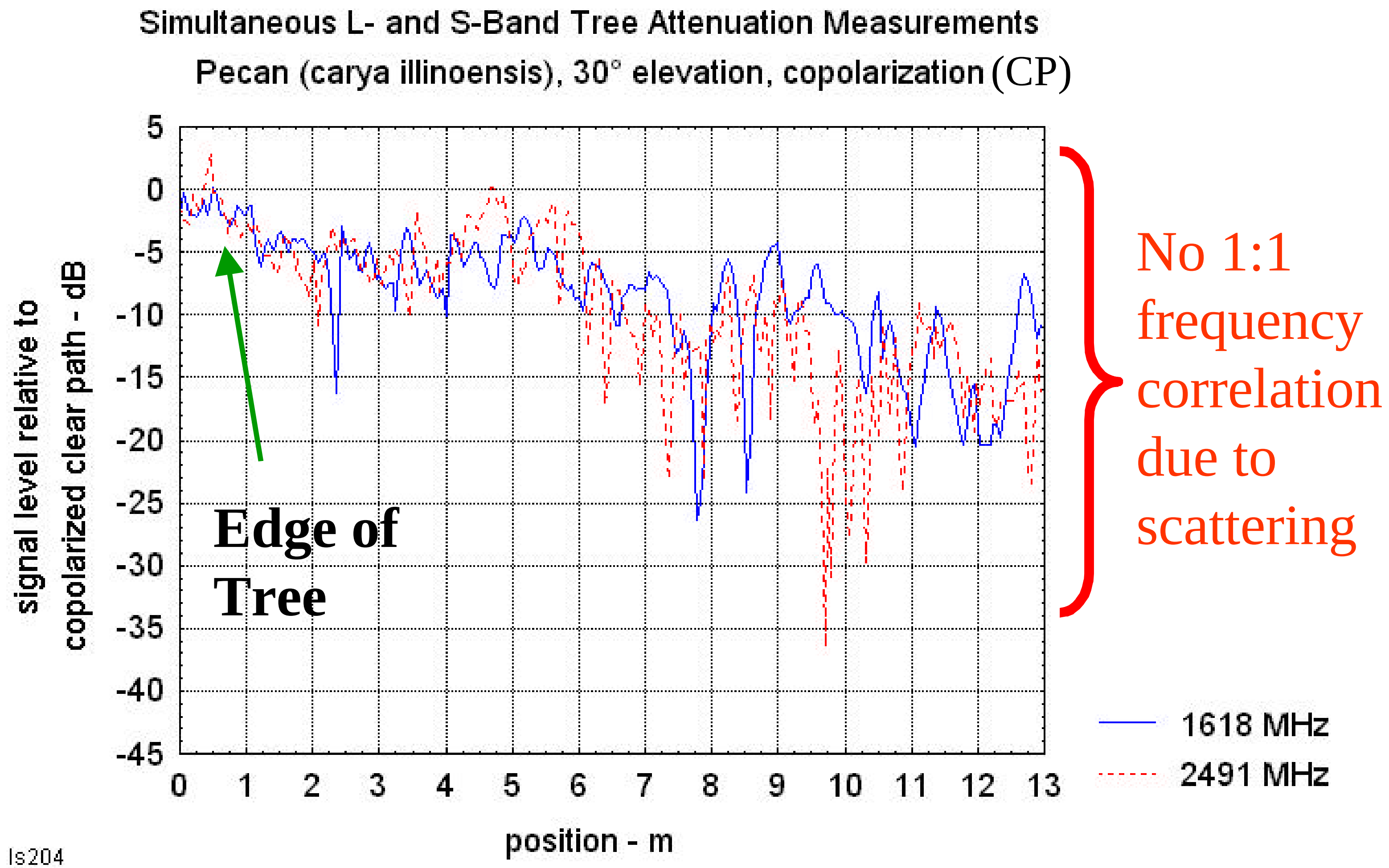
UHF (870 MHz, CP) Measurements of Single Trees

Tree Type	Attenuation (dB)		Attenuation Coefficient (dB/m)	
	Largest	Average	Largest	Average
Burr Oak*	13.9	11.1	1.0	0.8
Callery Pear	18.4	10.6	1.7	1.0
Holly*	19.9	12.1	2.3	1.2
Norway Maple	10.8	10.0	3.5	3.2
Pin Oak	8.4	6.3	0.85	0.6
Pin Oak*	18.4	13.1	1.85	1.3
Pine Grove	17.2	15.4	1.3	1.1
Sassafras	16.1	9.8	3.2	1.9
Scotch Pine	7.7	6.6	0.9	0.7
White Pine*	12.1	10.6	1.5	1.2
Average	14.3	10.6	1.8	1.3
RMS	4.15	2.6	0.9	0.7

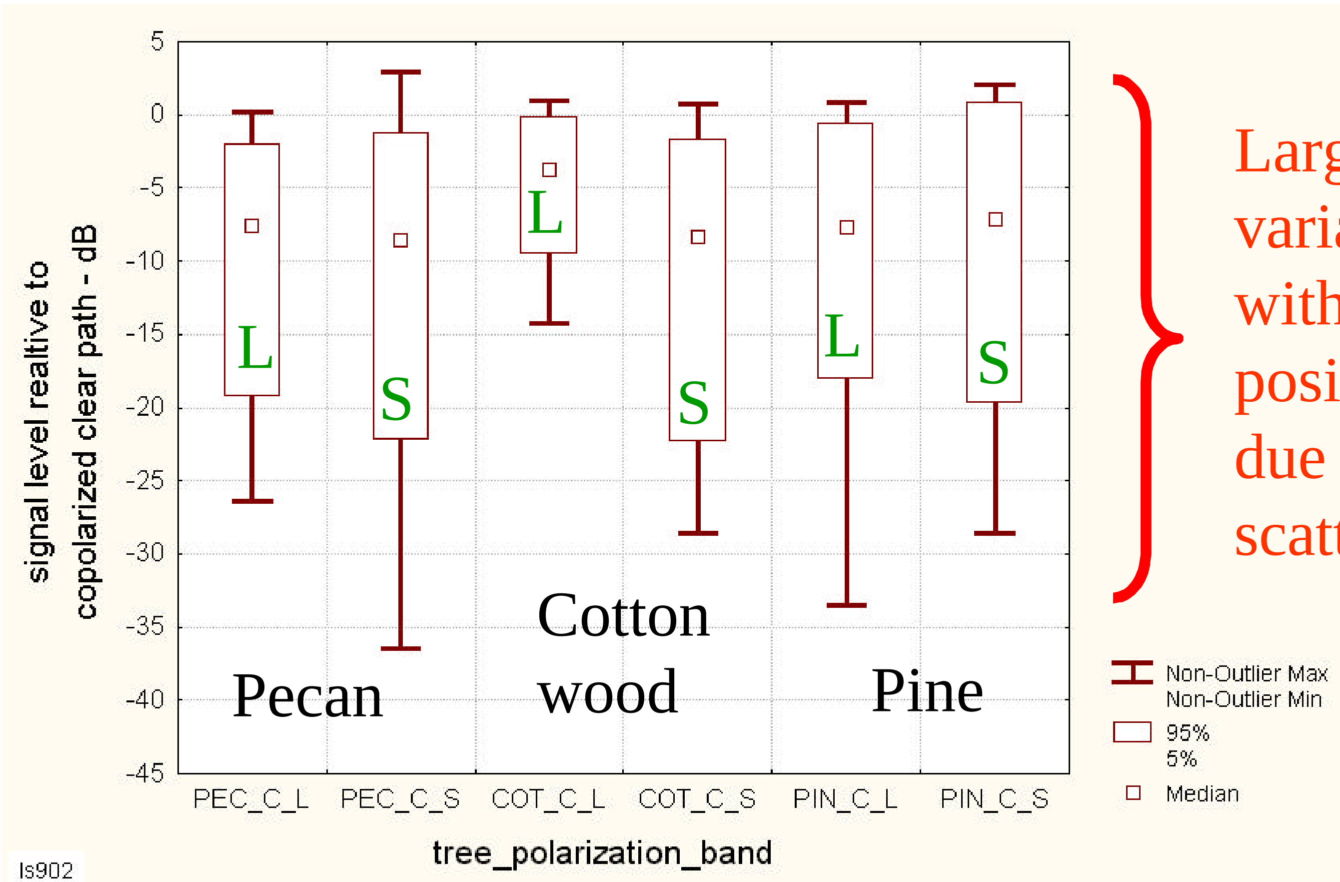
L-Band (1.6 GHz, CP) Measurements of Single Trees

Tree Type	Average Attenuation (dB)	Attenuation Coefficient (dB/m)
Willow	10.45	1.1
Pine	18.0	1.8
Linden	9.1	1.4
European Alder	7.0	1.0
Acacia	6.75	0.9
Poplar	3.5	0.7
Elm	9.0	1.2
Hazelnut	2.75	1.1
Maple	16.25	1.25
White Spruce	20.1	1.75
Laurel Cherry	12.0	2.0
Plane	16.9	1.35
Fir	12.75	1.5
Fruit	9.6	1.2
Average	11.0	1.3
RMS	5.1	0.35

Signal Variation with Position



Simultaneous L- and S-Band Measurements of Single Trees VS Position

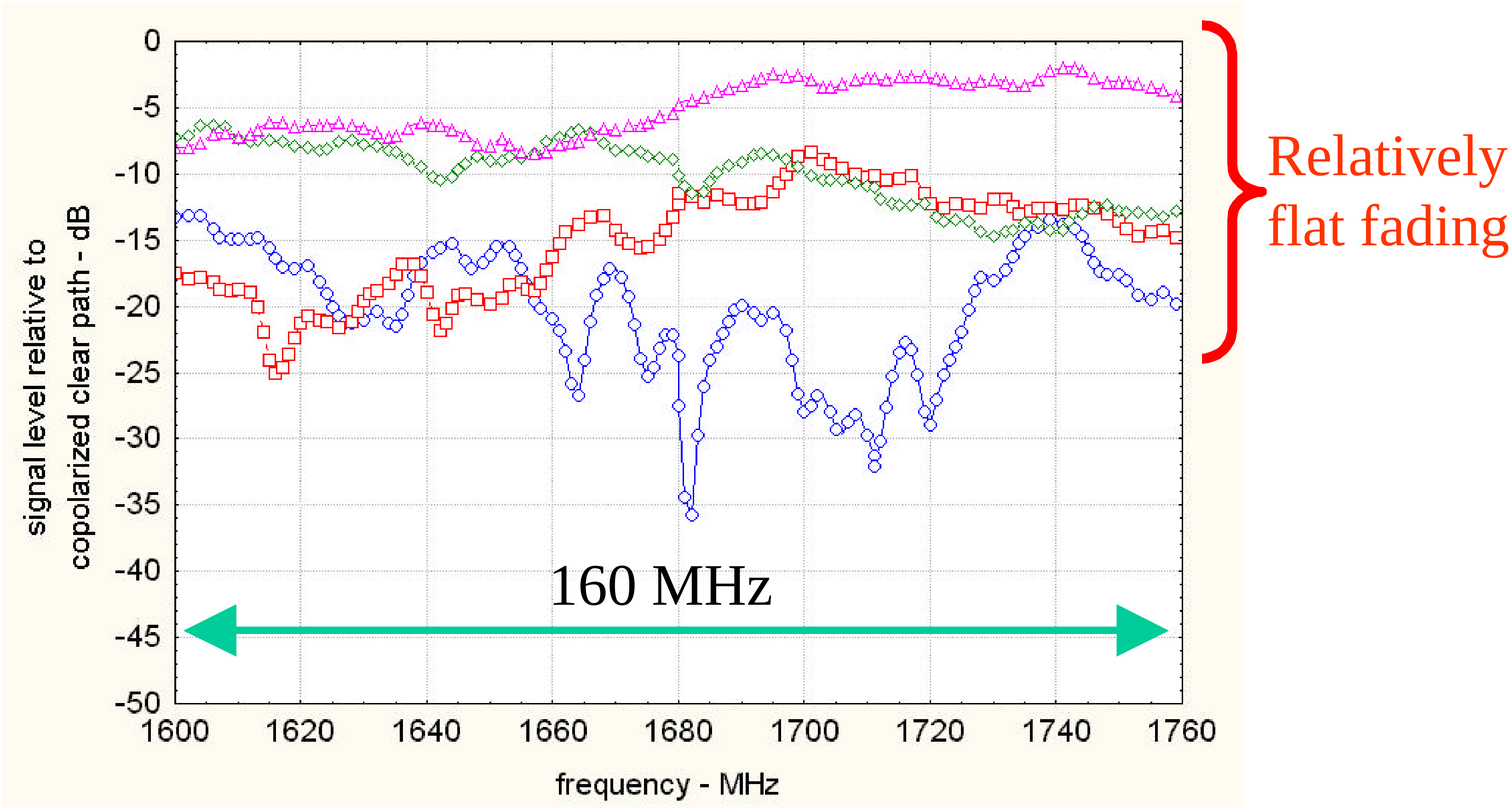


Large variations with position due to scattering

weak frequency dependence

Signal Variation with Frequency

Pine Tree; 5, 10, 15, 20 dB average fade



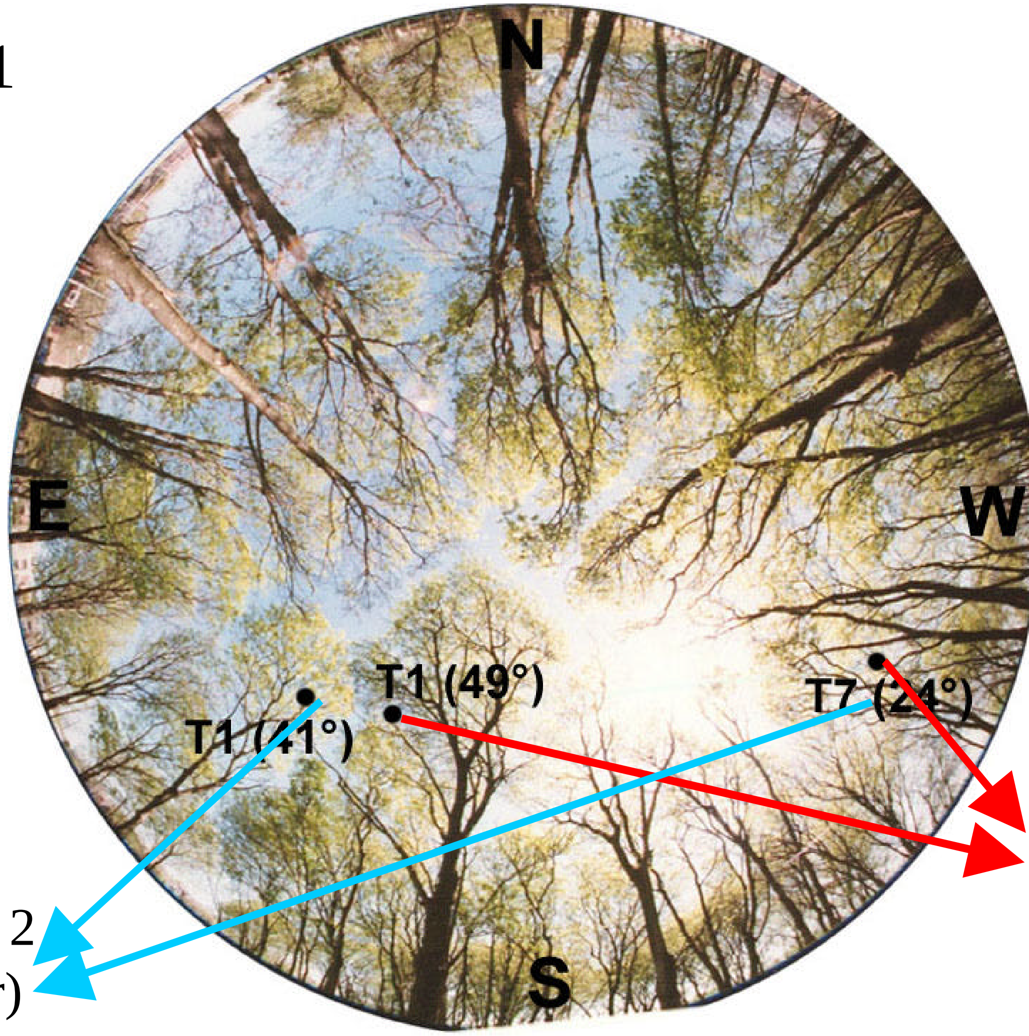
Short delay times of mostly forward scattered waves

2 GHz Measurements

Deciduous tree grove, TDRSS, CP

TDRS-1 was drifting East

TDRS-7 was fixed



East

West

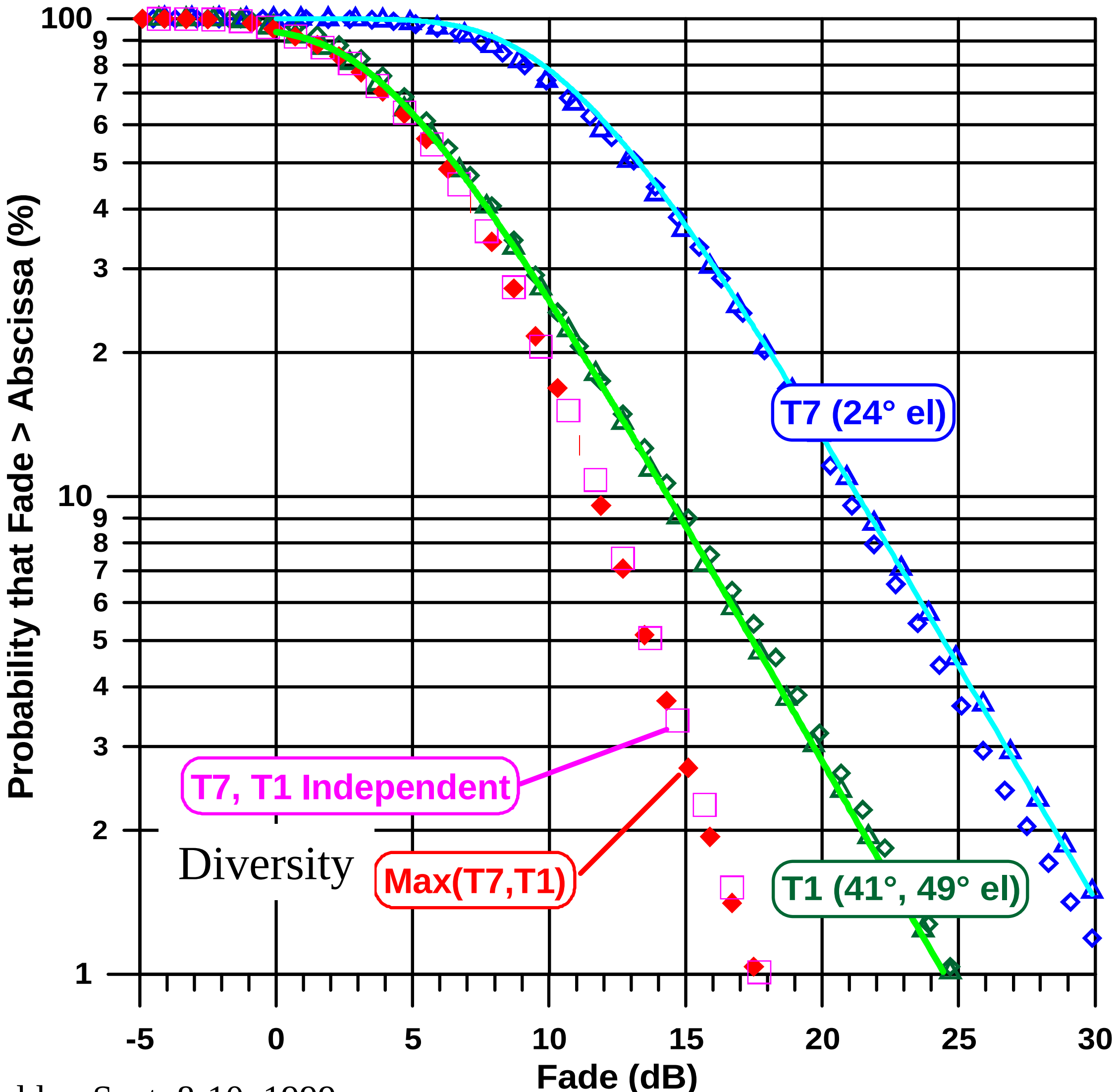
Measurement 1

Measurement 2
(2 weeks later)

South

Tree Grove Fading at 2 GHz (TDRSS)

Elevation Angle Dependence, 24° vs 41° and 49°



Comments to 2 GHz TDRSS Data

- CDFs for T7 at 24° repeated to within 0.5 dB rms
- CDFs for T1 at 49° and later at 41° are almost identical
  - for a layer of uniform-height vegetation
  - if attenuation proportional to path length in the medium
  - fading at 41° should be 87% of fading at 49°
- Loo Model for tree shadowing

$$p_{Loo}(x) = \frac{8.686\sqrt{2}Kx}{s\sqrt{p}} \int_0^\infty \frac{1}{z} \exp[\frac{(20\log z - m)^2}{2s^2}$$

- ratio of means agrees with layer model

$$m_{49^\circ}/m_{24^\circ} = 0.54 = \sin 24^\circ / \sin 49^\circ$$

K-Band Measurements

Roadside Trees in Maryland

<u>Foliage scaling of fading in dB:</u>

UHF

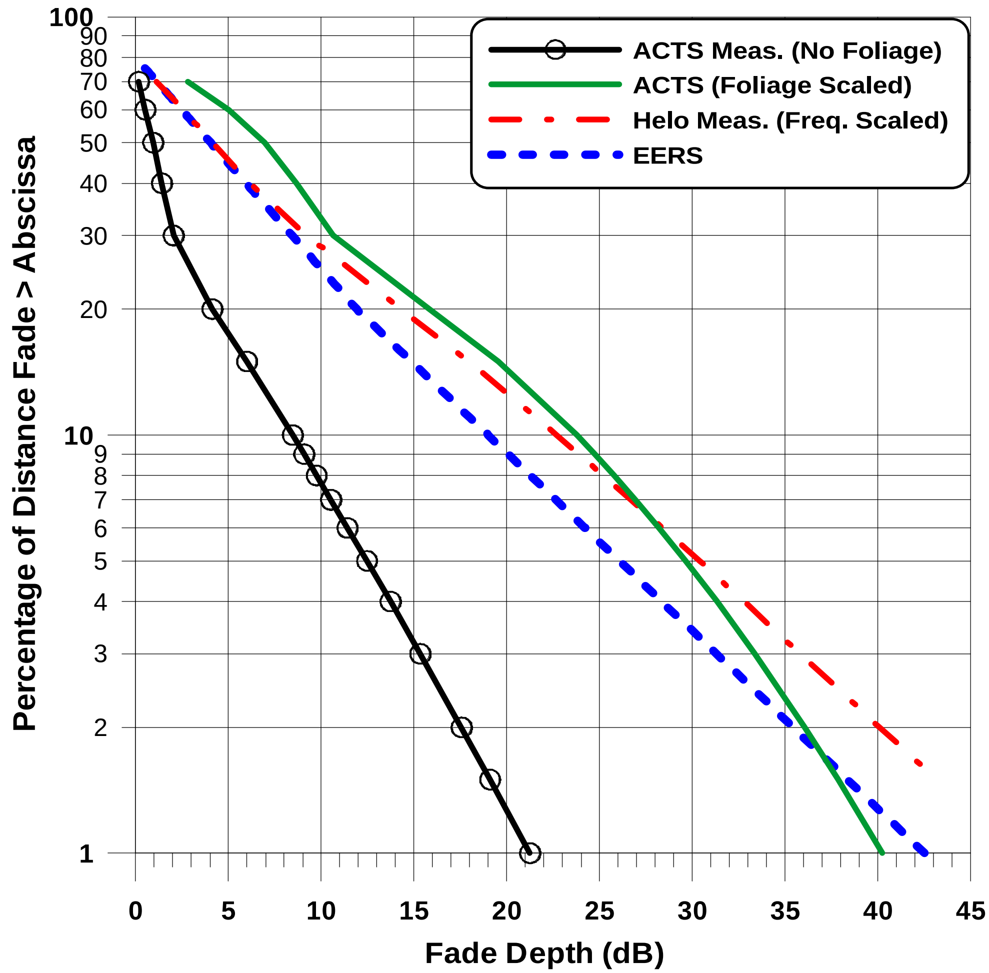
$A_F = 1.35 * A_{NF}$

L-Band

$A_F = 2.33 + 0.9 * A_{NF}$

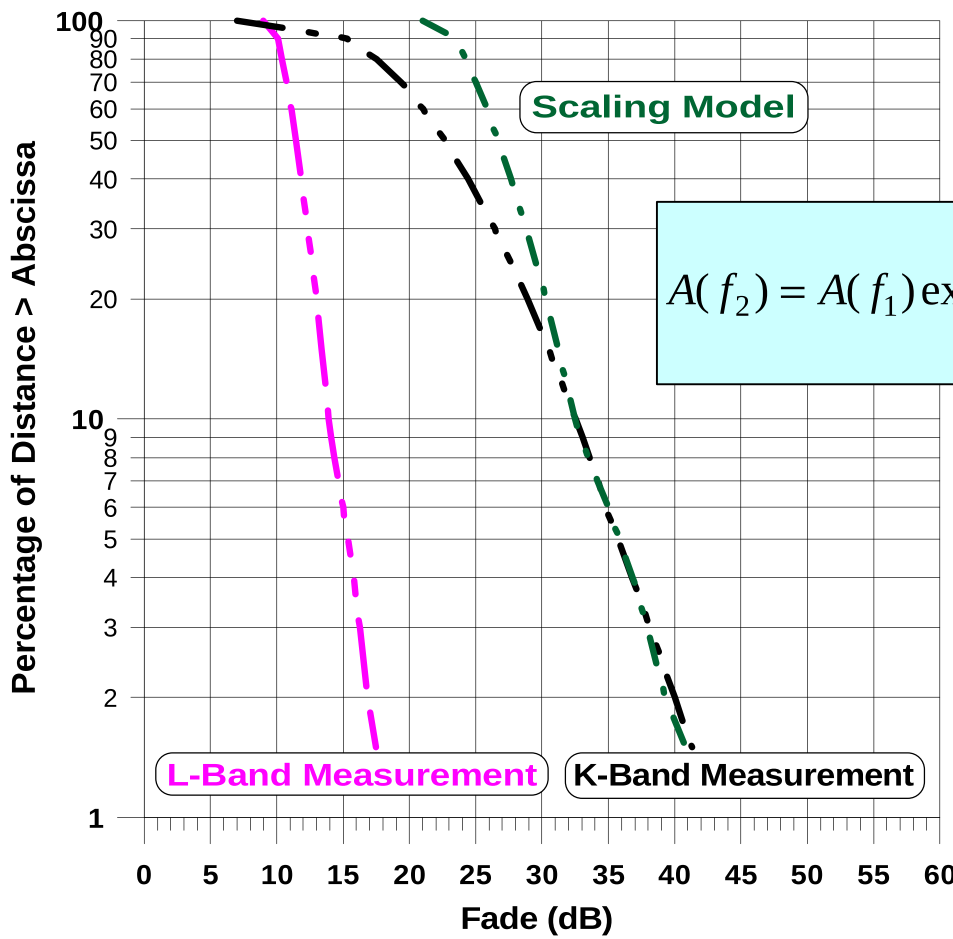
K-Band

$$A_F = 0.35 + 6.8 A_{NF}^{0.58}$$



Frequency Scaling of Fade Distribution

Single Tree: Pecan in Leaf

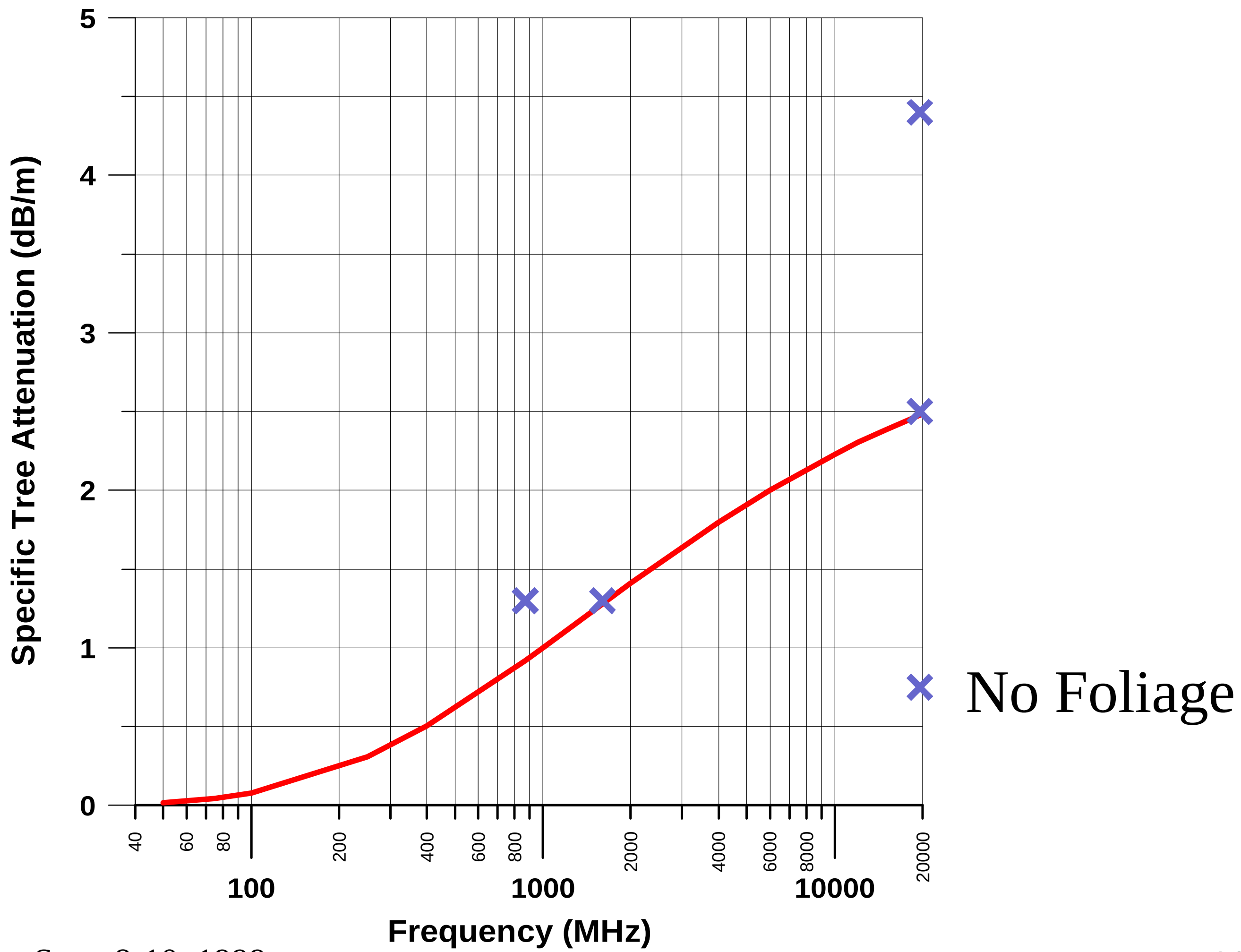


$$A(f_2) = A(f_1)\exp\left\{b\cdot\left[\left(\frac{1}{f_1}\right)^{0.5} - \left(\frac{1}{f_2}\right)^{0.5}\right]\right\}$$

With b =1.5 scales best below ~30%

Frequency Scaling for Median Fade

Valid for Trees with Foliage, b=1.173



Conclusions - 1

- Average short path multi-tree attenuation at
  - VHF (100 MHz) is 0.03 to 0.15 dB/m
  - VHF (400 MHz) is 0.075 to 0.2 dB/m
- Average single tree attenuation at
  - UHF (870 MHz) is 10.6 dB (2.6 dB RMS)
  - L-Band (1.6 GHz) is 11 dB (5.1 dB RMS)
  - K-Band (20 GHz) is 23 dB
- The frequency scaling formulation pertaining to trees in full foliage at frequencies between VHF (25 MHz) and K-Band (20 GHz) is given by

$$A(f_2) = A(f_1)\exp\left\{b\cdot\left[\left(\frac{1}{f_1}\right)^{0.5} - \left(\frac{1}{f_2}\right)^{0.5}\right]\right\}$$

where A(f1), A(f2) are the respective equal probability attenuations (dB) at frequencies f1, f2 (in GHz), with b=1.173 for median, b=1.5 for 1% to 30% of distribution.

Conclusions - 2

- The dominant contributor to attenuation is the wood part of the tree at frequencies between VHF (50 MHz) and S-Band (4 GHz). For example, foliage has been found to introduce approximately 35% additional attenuation at UHF and 15% at L-Band
- At K-Band (20 GHz), the wood and leaf parts of the tree are both important showing increases due to foliage ranging from 2 to 3 times the attenuation
- As most signal variations in the shadow of a tree are due to forward scattering effects, the delays associated with the multipath are short and the fading is flat.