
Vehicle to Vehicle RF Propagation Measurements

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Outline of Talk

- Brief Description of Intelligent Vehicle Highway Systems
- Short Review of RF Propagation
- Measurement Setup
- Results

Intelligent Vehicle Highway Systems (IVHS)



- Cars Will Travel In Platoons
- Cars Must Communicate To Other Platoon Members
- Communication Must Be *Extremely* Reliable!

Distortion in Wireless Channels

Primary Causes of Distortion:

- Path Loss Attenuation
- Small Scale Attenuation
 - Multipath Transmission
 - Time Variation

Multipath Transmission Leads To:

- Signal Variation Over the Frequency Domain
- Fading in the Time Domain at any given time instant
- Spreading of signal

Time Variation Leads To:

- Signal Variation Over the Time Domain

Path Loss Attenuation

Causes of Path Loss Attenuation:

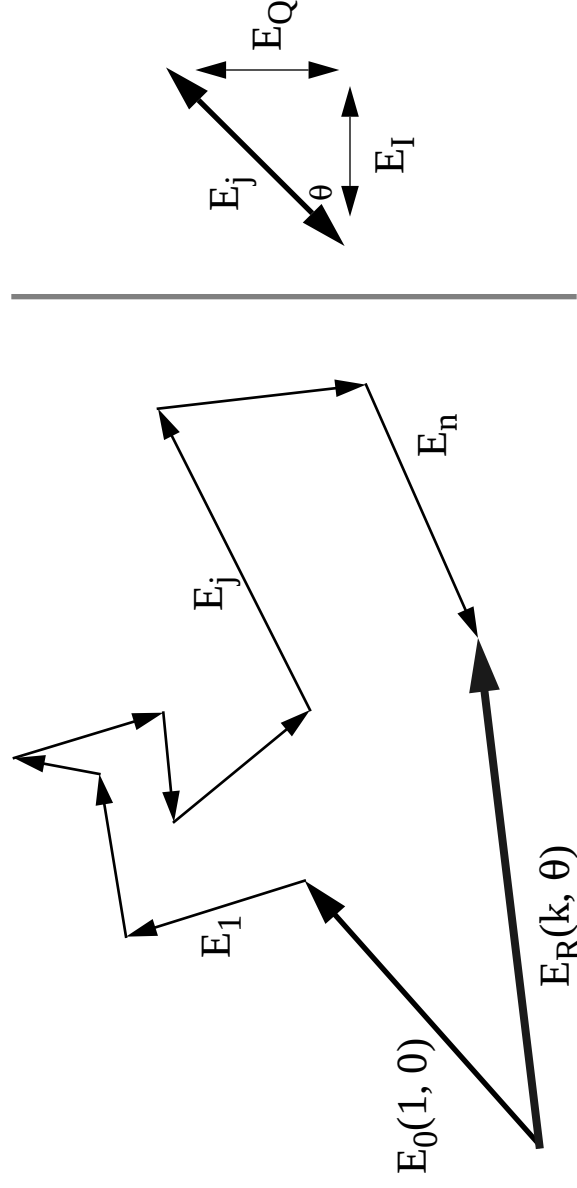
- Free Space Loss
- Received power decreases at rate d^{-2}

Measurements of Path Loss from Other Researchers:

- Attenuation at Rate: $\sim d^{-n}$

d - *distance*

General Statistical Model



- E_0 - Constant vector representing amplitude of strongest path.
- E_j ($j \neq 0$) - Smaller path components with I/Q Gaussian ($0, \sigma^2$) distribution.
- $E_R(1 + k^2, \theta)$ - Resultant received signal
- $\sum_{j=1}^n E_j^2 = k^2$

Received Signal Distribution

$$k^2 \leq 1$$

- *Rician* Received Amplitude - y ,

$$f(y|b, \sigma^2) = \frac{y}{\sigma^2} \cdot e^{\frac{y^2+b^2}{2\sigma^2}} \cdot I_0\left(\frac{by}{\sigma^2}\right)$$

$$k^2 \gg 1$$

- *Rayleigh* Received Amplitude - y ,

$$f(y|\sigma^2) = \frac{y}{\sigma^2} \cdot e^{\frac{y^2}{2\sigma^2}}$$
- Parameters
 - Rician K-factor,

$$k = \frac{\frac{1}{2}b^2}{\sigma^2}$$
 - Zeroth Order Bessel Function,

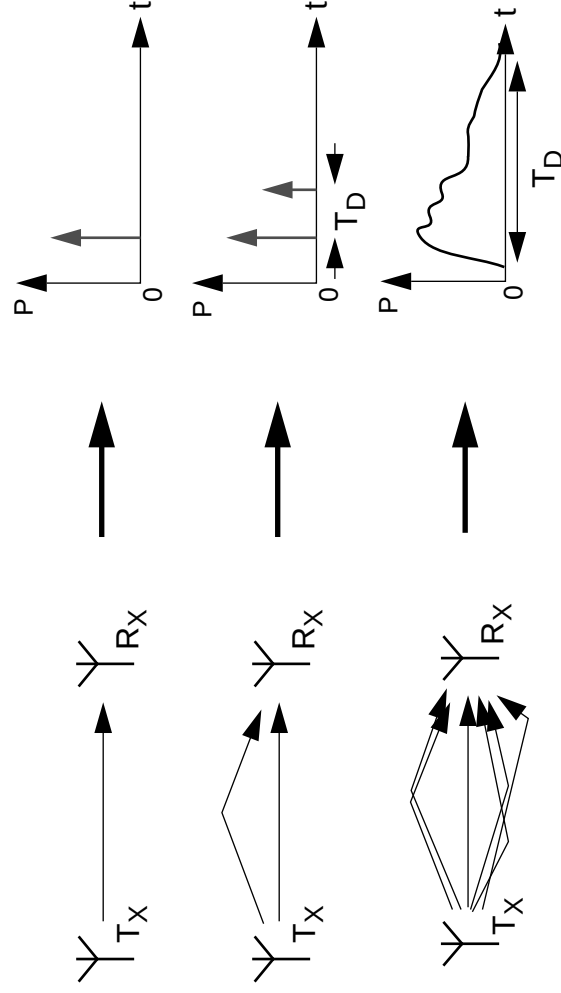
$$I_0(x) = \frac{1}{\pi} \int_0^\pi \exp(x \cos \phi) d\phi$$
 - $0.5(b)^2$ - Power of strongest path
 - σ^2 - Power of other reflections

1st Moment of the Rician Distribution

$$E\rho_{m,i} = e^{-K/2} \sqrt{\frac{\pi}{2(K+1)}} p_{0,i} \left[(1+K) I_0\left(\frac{K}{2}\right) + K I_1\left(\frac{K}{2}\right) \right]$$

Delay Spread, T_d

Delay Spread is due to transmission times of different paths:

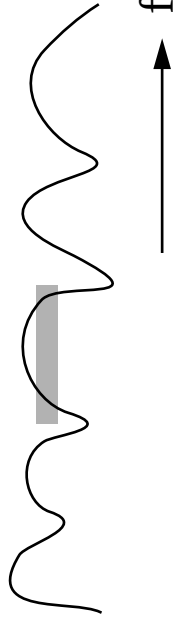


Narrowband vs. Wideband Fading

Coherence Bandwidth, $(\Delta f)_c \approx \frac{1}{T_D}$

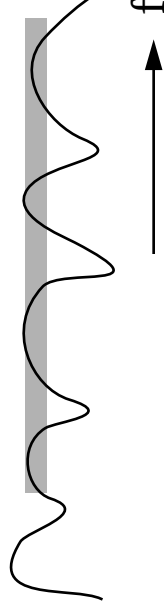
Narrowband (Frequency Non-Selective) Fading

- $B_w \ll (\Delta f)_c \approx \frac{1}{T_D}$



Wideband (Frequency Selective) Fading

- $B_w \geq (\Delta f)_c \approx \frac{1}{T_D}$

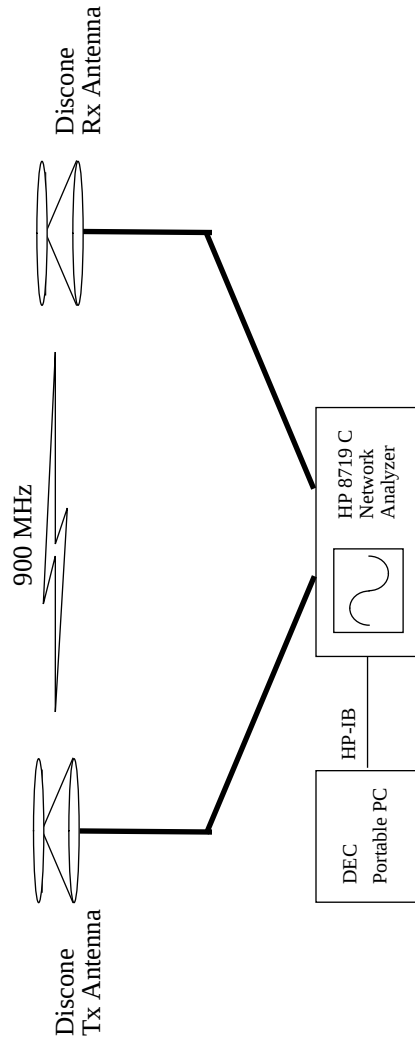


- Intersymbol Interference

What Was Measured:

- Delay Spread
 - RMS Delay Spread
- Path Loss
- Rician K Factor

Measurement Setup



- 2 Omnidirectional Discone Antennas
- HP Network Analyzer
- Coaxial Cable
- DEC Portable PC with HP-IB Card

Transmission Parameters

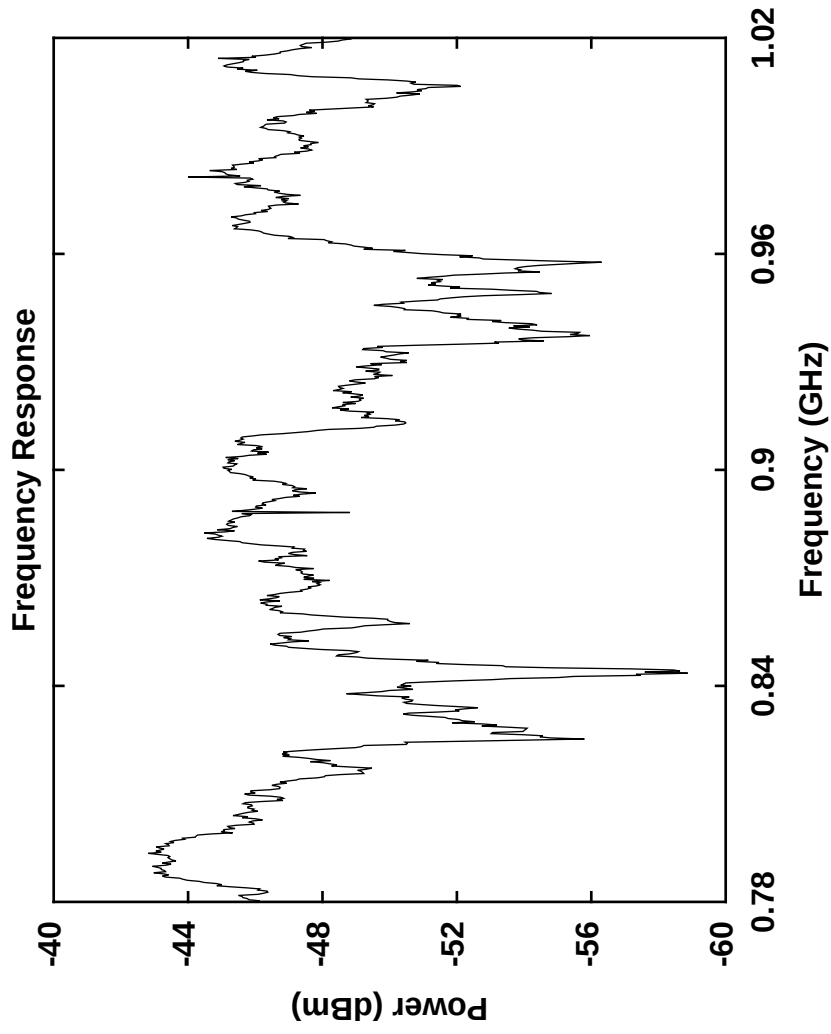
- Transmit Power +10 dBm
- Center Frequency 900 MHz
- Bandwidth 240 MHz

Derivation of Transmitted Bandwidth

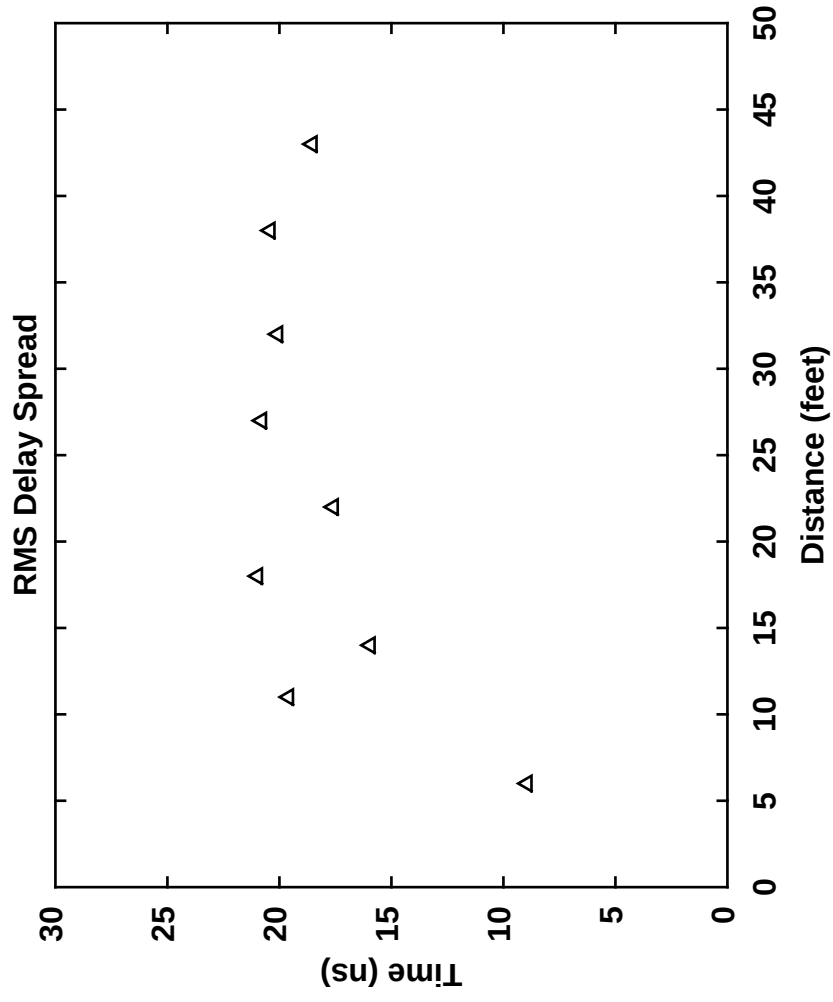
Based On Time/Frequency Duality (DFT):

- Time Resolution = $T_R = 4.17 \text{ ns}$
- Frequency Window = $F_W = (T_R)^{-1} = 240 \text{ MHz}$
- Frequency Resolution = $F_R = (801 \cdot T_R)^{-1} = 299 \text{ KHz}$
- Time Window = $T_W = (F_R)^{-1} = 3.34 \text{ } \mu\text{s}$
- $T_W \gg \max(T_D) = 4.17 \text{ ns}$

Frequency Response



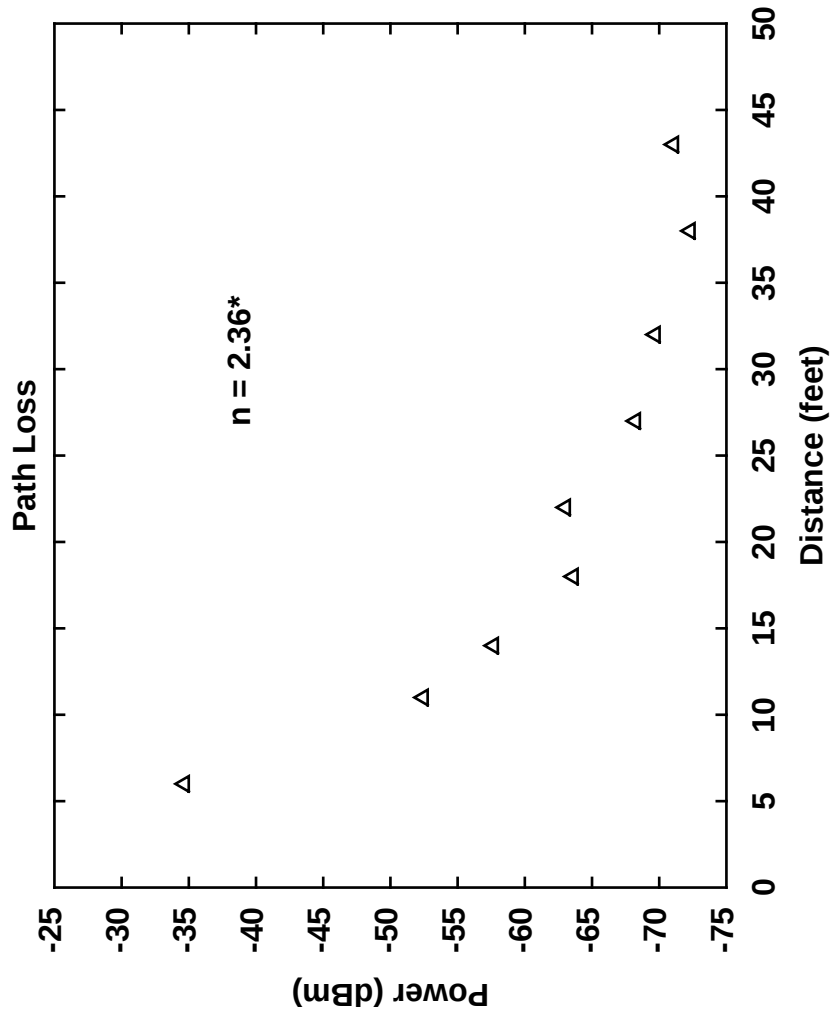
RMS Delay Spread vs. Distance



Rician K Factors

- Typical Values in Range { 5.0 , 11.0 }
- Extreme Values (high) { 17.6 }
- Extreme Values (low) { 1.38 }

Path Loss



* - Note that n is based on log-log data although graph shown is log-linear

Conclusions

- | | |
|--------------------|---------------|
| • Path Loss | n = 2.36 |
| • RMS Delay Spread | 7.0 - 22.0 ns |
| • Rician K Factor | 5.0 - 11.0 |
| • 17.6, 1.38 | |

References

- [1] Bultitude, Robert J.C., "Measurement, Characterization and Modeling of Indoor 800/900 MHz Radio Channels for Digital Communications", **IEEE Communications Magazine**, Vol. 25, No. 6, June 1987, pp. 5 - 12.
- [2] Ganesh, R., Pahlavan, K., "Effects of Traffic and Local Movements on Multipath Characteristics of an Indoor Radio Channel", **Electronics Letters**, Vol. 26, No. 12, June 7, 1990, pp. 810 - 812.
- [3] Hashemi, Homaoun, "The Indoor Radio Propagation Channel", **Proceedings of the IEEE**, Vol. 81, No. 7, July 1993, pp. 941 - 968.
- [4] Howard, S. & Pahlavan, K., "Doppler Spread Measurements of the Indoor Radio Channel", **Electronics Letters**, Vol. 26, No. 2, 1990, pp. 107-109.
- [5] Rappaport, Theodore S., "Characterization of UHF Multipath Radio Channels in Factory Buildings", **IEEE Transactions on Antennas and Propagation**, Vol. 37, No. 8, August 1989, pp. 1058 - 1069.
- [6] Saleh, A., Valenzuela, R., "A Statistical Model for Indoor Multipath Propagation", **IEEE Journal on Selected Areas in Communications**, Vol. SAC-5, No. 2, February 1987, pp. 128 - 137.