Vehicle to Vehicle RF Propagation Measurements

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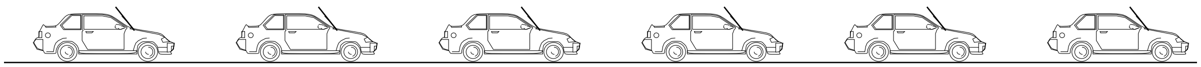
Outline of Talk

- Brief Description of Intelligent Vehicle Highway Systemsl
- 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:

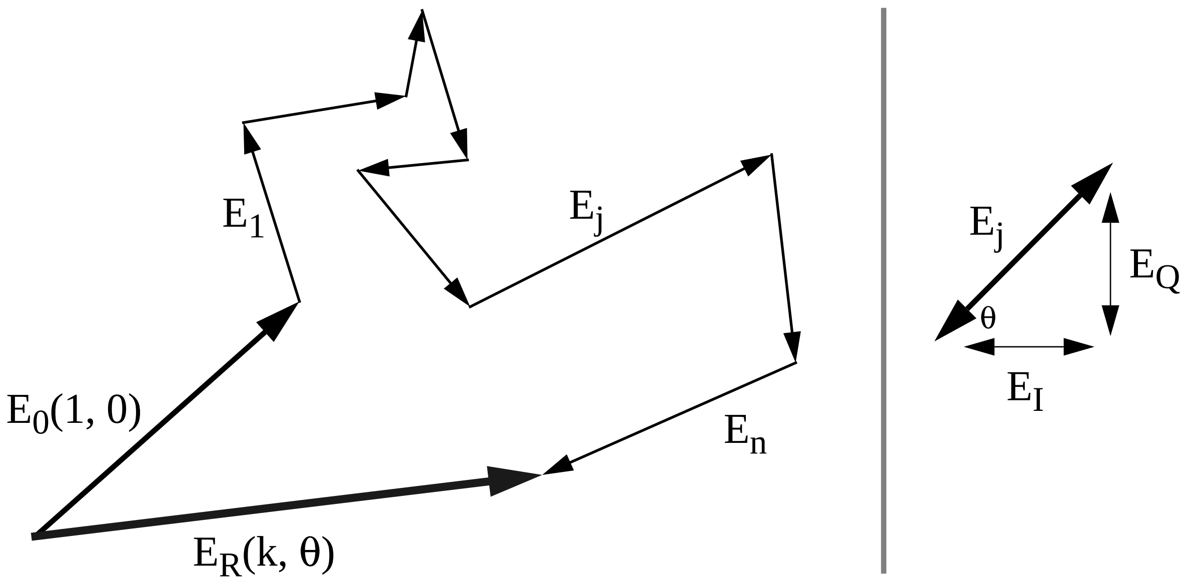
- Free Space Loss
  - Received power decreases at rate d^{-2}

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

$k^2 >> 1$

- *Rayleigh* Received Amplitude - y, $f(y|\, \sigma^2) \;=\; \frac{y}{\sigma^2} \cdot e^{\frac{y^2}{2\sigma^2}}$

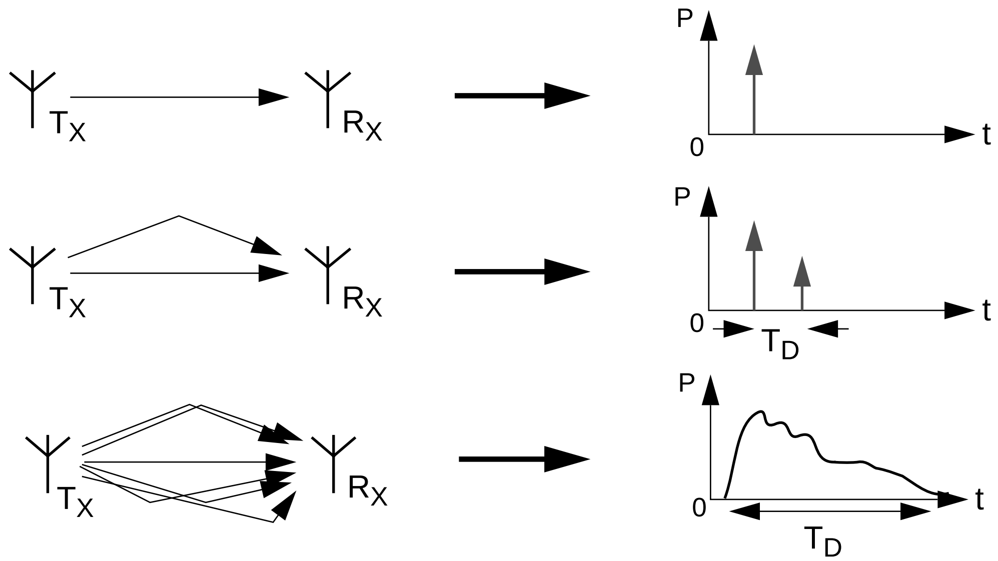
- Parameters
  - Rician K-factor, $k \;=\; \frac{\frac{1}{2}b^2}{\sigma^2}$
  - Zeroth Order Bessel Function, $I_0(x) \;=\; \frac{1}{\pi}\int_0^{\pi} \exp(x\cos\phi)\,d\phi$
  - $0.5(b)^2$ - Power of strongest path
  - σ^2 - Power of other reflections

1st Moment of the Rician Distribution

$$E\rho_{m,i} = e^{-K/2}\sqrt{\frac{\pi}{2(K+1)}\overline{p_{0,i}}}\left[(1+K)I_0\left(\frac{K}{2}\right)+KI_1\left(\frac{K}{2}\right)\right]$$

Delay Spread, T_d

Delay Spread is due to transmission times of different paths:

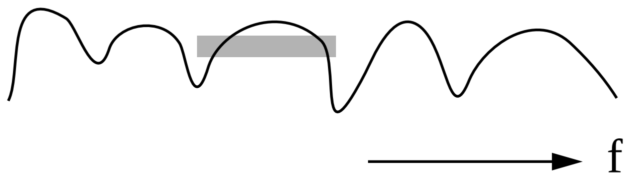


Narrowband vs. Wideband Fading

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

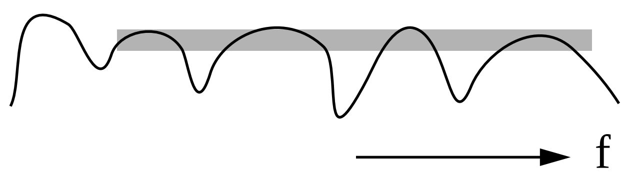
Narrowband (Frequency Non-Selective) Fading

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



Wideband (Frequency Selective) Fading

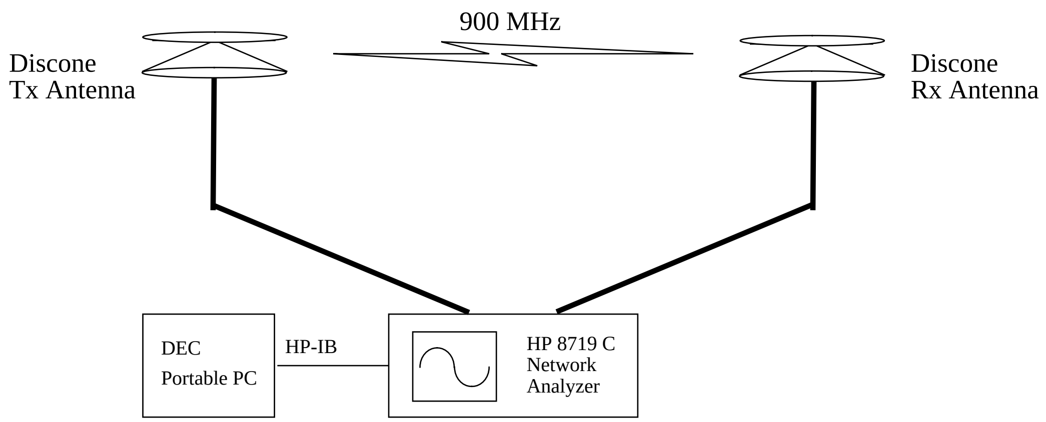
- $B_W \geq (\Delta f)_c \approx \frac{1}{T_D}$
- Intersymbol Interference



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

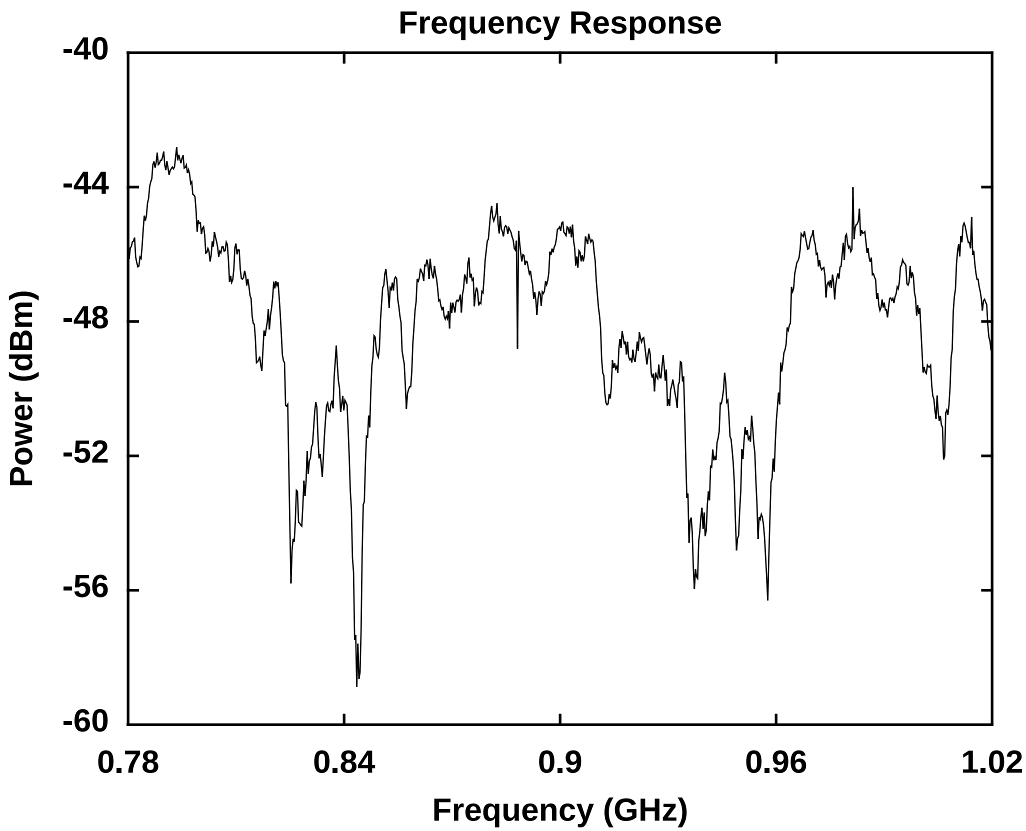
Derivation of Transmitted Bandwidth

Based On Time/Frequency Duality (DFT):

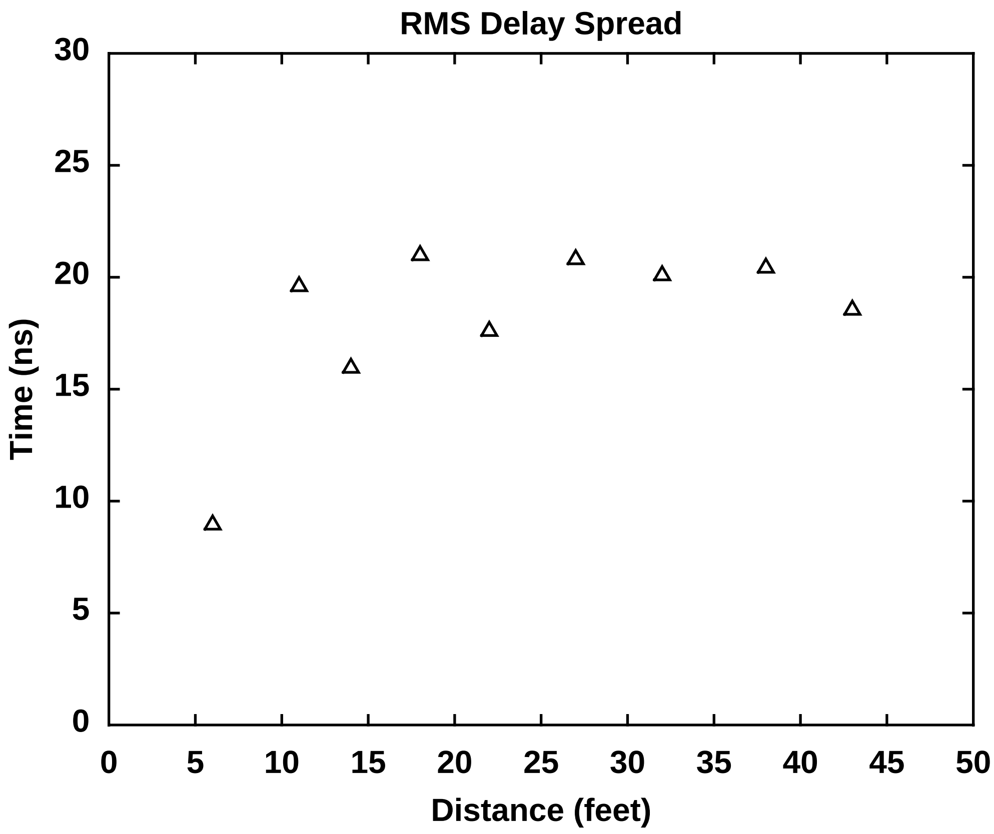
- Time Resolution = T_R = 4.17 ns
- Frequency Window = $F_W = (T_R)^{-1}$ = 240 MHz
- Frequency Resolution = $F_R = (801 \cdot T_R)^{-1}$ = 299 KHz
- Time Window = $T_W = (F_R)^{-1}$ = 3.34 μs

- $T_W >> \max(T_D)$ = 4.17 ns

Frequency Response



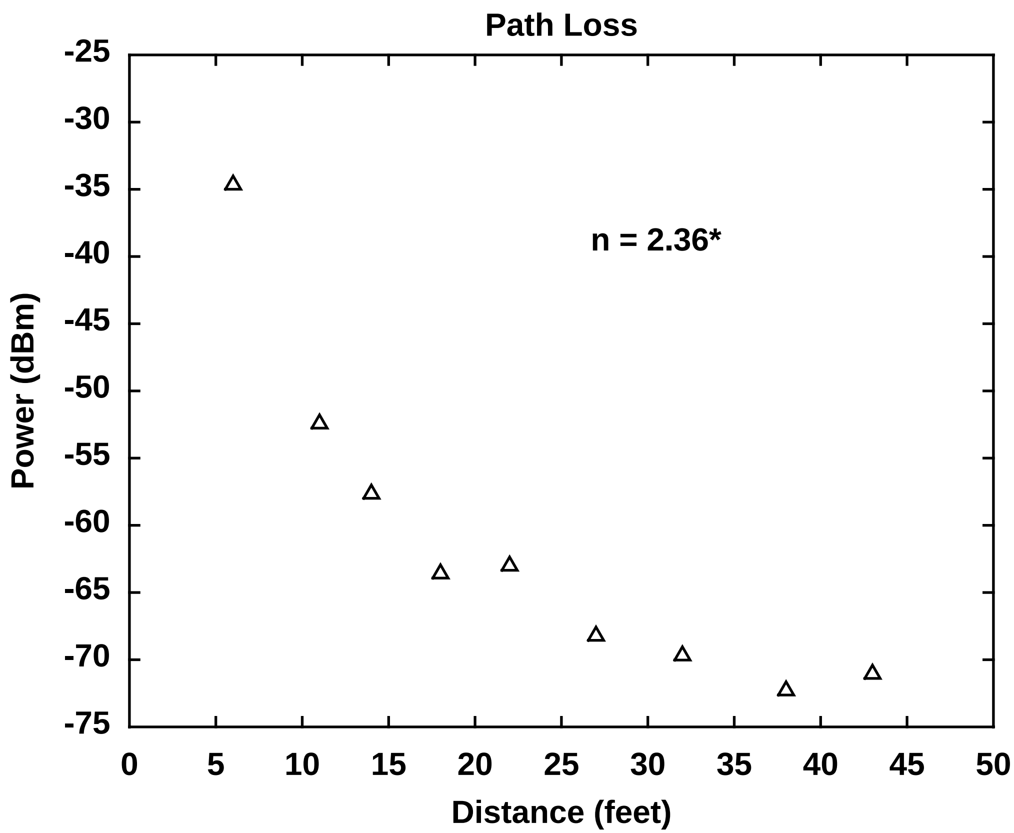
RMS Delay Spread vs. Distance



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 • 17.6, 1.38	5.0 - 11.0

References

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[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.

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