

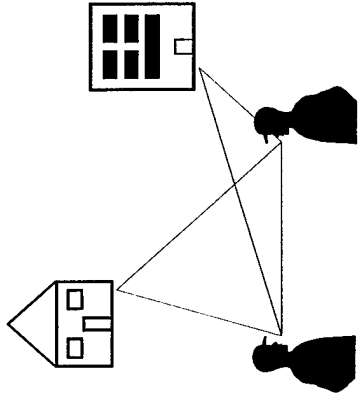
# REPORT DOCUMENTATION PAGE

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# Wireless Propagation Measurements, Analysis, and Modeling



SSC-SD D855

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# Outline

- Measurement Goals and Capabilities
- Multipath Tutorial
- Sample Results
  - Urban Channel
    - HMMWV Motion
    - Human Mount w/Motion
    - Various Antenna Heights
  - Many Channels
    - Path Loss vs. Delay Spread
- Model Comparisons

# SSC-SD Measurement Goals

- **Measure Channel Responses**
  - **Urban/Suburban, Hills/Trees, Airfield**
  - **Antennas close to buildings**
  - **Antennas mounted on humans in motion**
  - **Low antenna heights**
  - **VHF, UHF, ISM, LBand**
- **Compare w/existing Propagation Models**

# Measurement System Capabilities

- Long Duration (25s)
- High Resolution (12m)
- Long Range (10km)
- Frequency Versatile (30MHz-2GHz)
- Severe Environments (Heavy Urban)
- Arbitrary Waveform Capability

# Data Applications

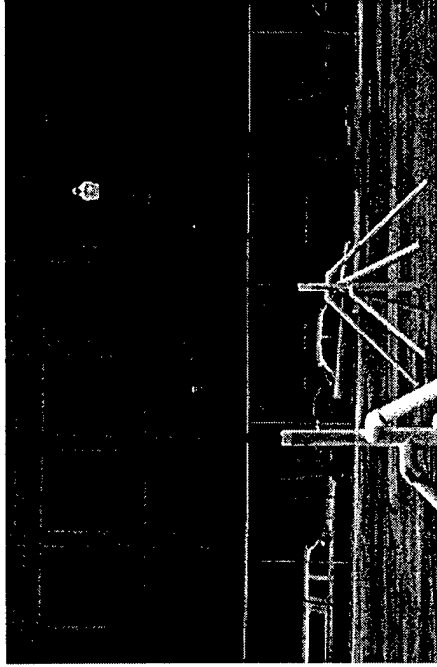
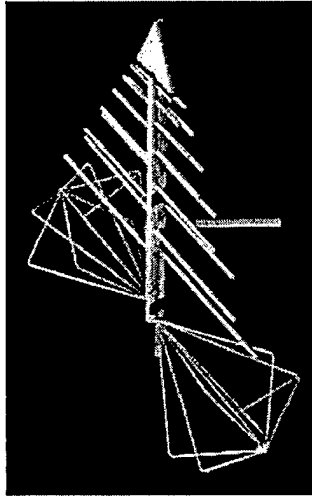
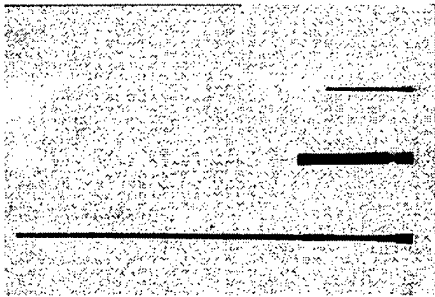


- **Propagation Science**
- **Radio Design**
  - **Algorithm development/testing**
  - **Waveform development/testing**
  - **Antenna development/testing**
  - **Transmit power selection/power control design**
  - **Frequency and BW selection**
  - **Computation update requirements**
- **Network Modeling**
- **Network Design**

# Transmitter/Receiver

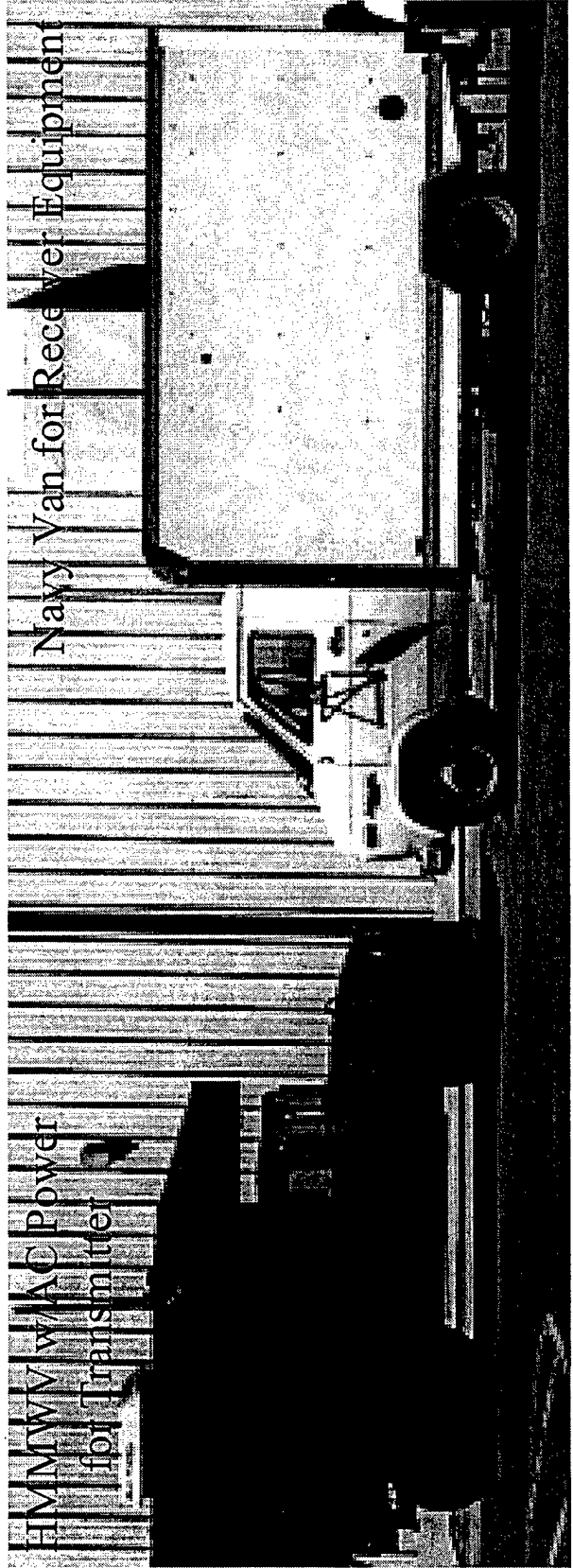
Receiver Antennas

Transmitter Antennas



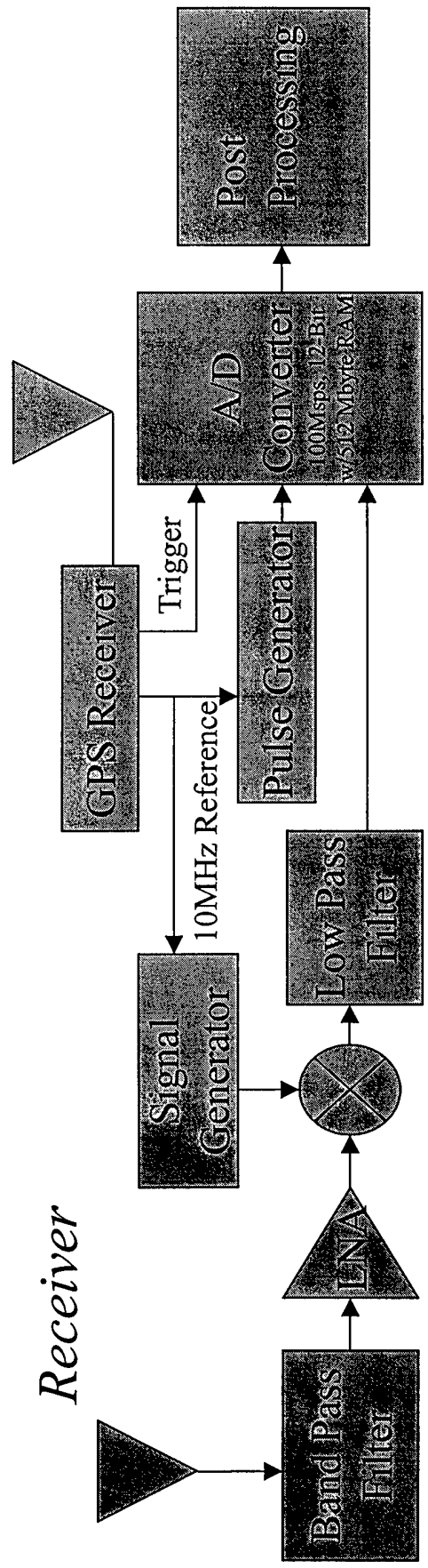
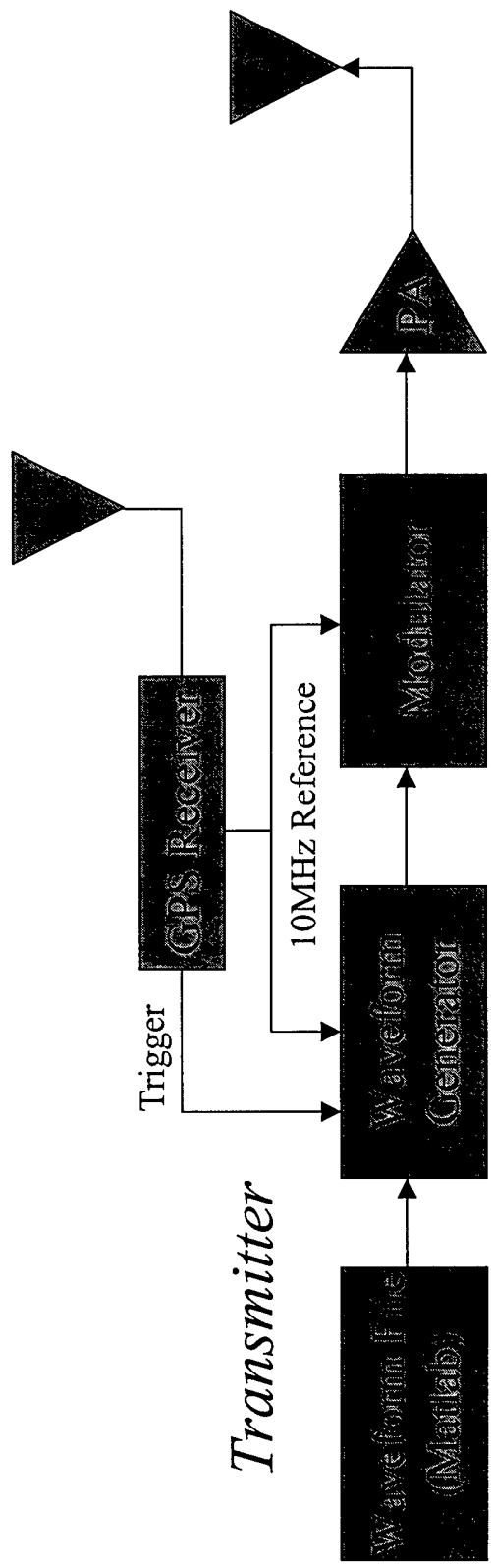
110 MW AC Power  
for Transmitter

Navy Van for Receiver Equipment



# Propagation Testbed

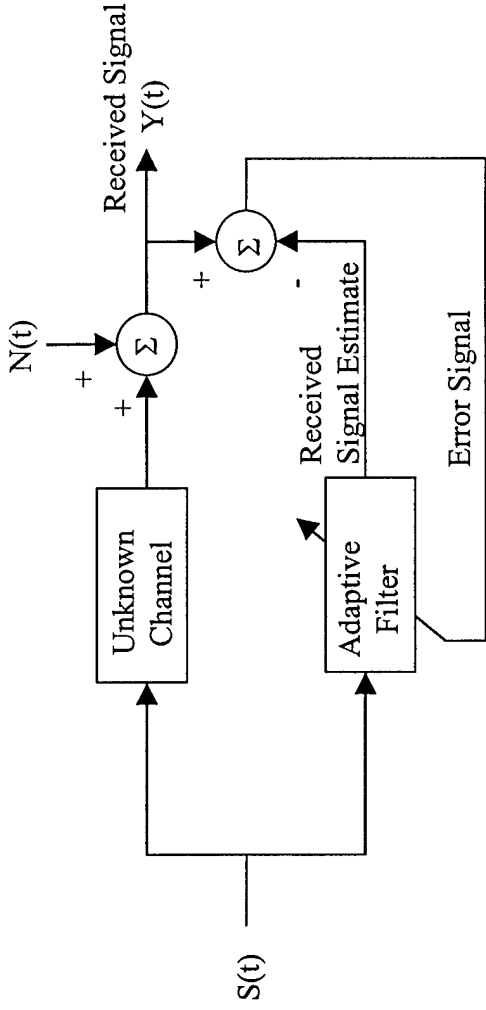
30MHz-2GHz





# Adaptive Channel Estimation

- Channel Modeling Algorithm:

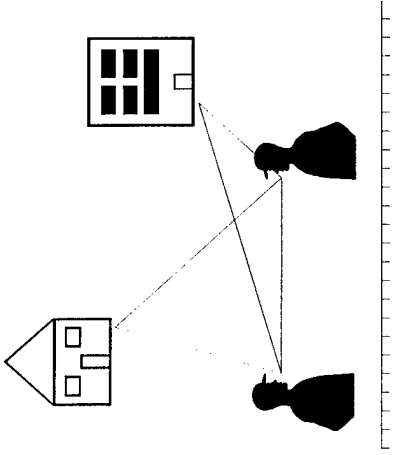


- Adaptive FIR Channel Estimation Filter:
  - 3 Phases:
    - Acquisition - Recursive Least Squares (RLS)
    - Training - Normalized Gradient Decent (NLMS)
    - Tracking - Normalized Gradient Decent (NLMS)
  - Filter Tap Length - 240 Taps

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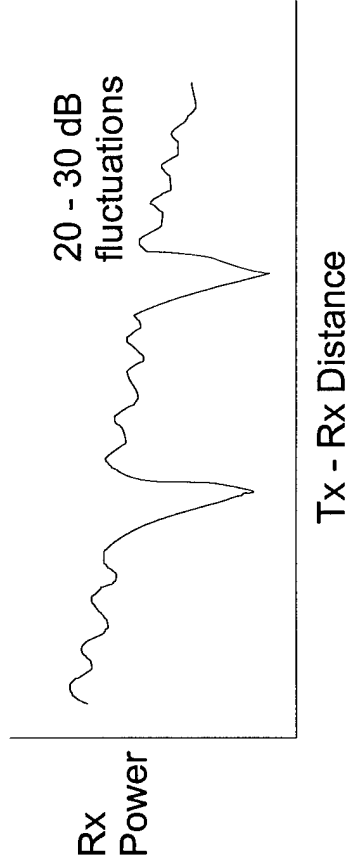
# Multipath



- Exact solution: Maxwell's equations and Boundary Conditions
- Approximate solution: Trace rays using geometric optic rules
- Better: Add edge diffraction and transmission through wall
- But: Need a good geometrical description of the environment
- Alternative: STATISTICAL DESCRIPTION

# Narrowband Signals

$$p_{\tau} = p_o \left| \sum_{i=1}^L \frac{a_i}{d_i} e^{j\phi_i} \right|^2$$



# Wideband Signal

$$h(\tau, t) = \sum_{i=1}^L \beta_i e^{j\varphi_i} \delta(t - \tau_i)$$

$$y(t) = \int x(t - \tau') h(\tau, \tau') d\tau'$$

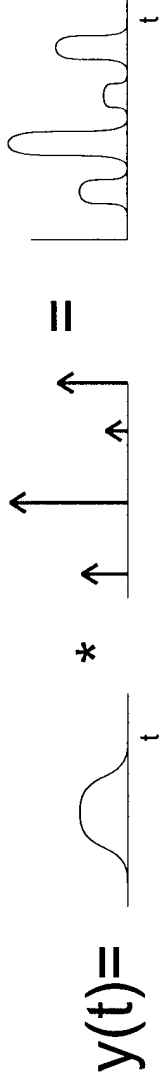
$$= \int x(t - \tau') \sum_{i=1}^L \beta_i e^{j\varphi_i} \delta(\tau' - \tau_i) d\tau'$$

$$= \sum_{i=1}^L \beta_i e^{j\varphi_i} x(t - \tau_i)$$

# Ideal Case (Infinite BW)

$$\begin{aligned}
 \text{Let } x(t) &= \delta(t) \\
 \Rightarrow y(t) &= h(\tau, t) \\
 |y(t)|^2 &= y(t)y^*(t) \\
 &= \sum_{i=1}^L \sum_{k=1}^L \beta_i \beta_k^* e^{j(\varphi - \varphi_k)} \int \delta(t - \tau_i) \delta(t - \tau_k) dt \\
 p &= \int |y(t)|^2 dt = \\
 &= \sum_{i=1}^L \sum_{k=1}^L \beta_i \beta_k^* e^{j(\varphi - \varphi_k)} \int \delta(t - \tau_i) \delta(t - \tau_k) dt \\
 &= \sum_{i=1}^L |\beta_i|^2
 \end{aligned}$$

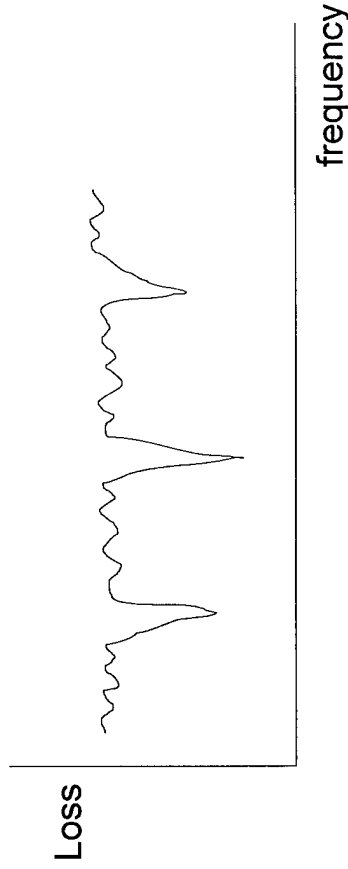
# Power Delay Profile (Practical Case)



$\sigma =$  delay spread

Smearing due to convolution.

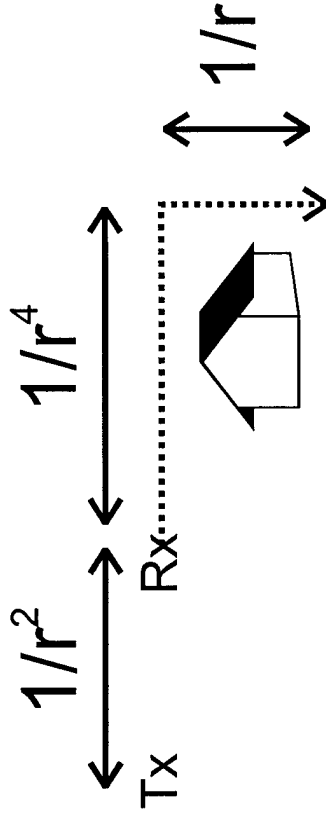
# Channel Frequency Response





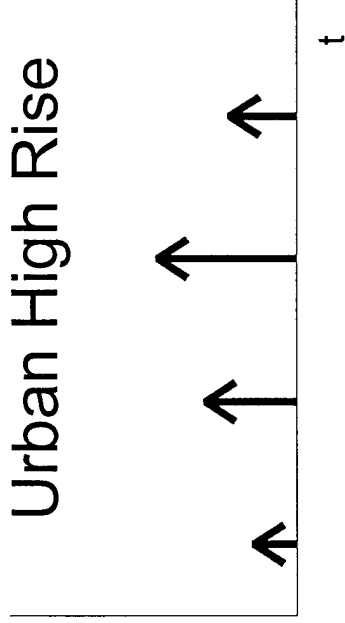
# Modeling

- Path Loss (JTC)

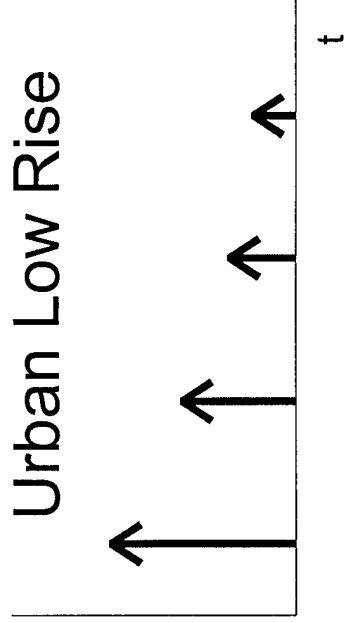


# Canonical Tapped Delay Line Model

Urban High Rise

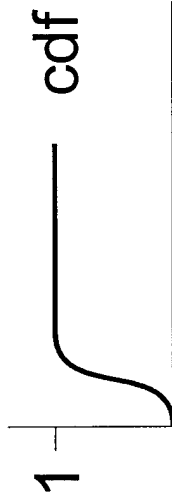
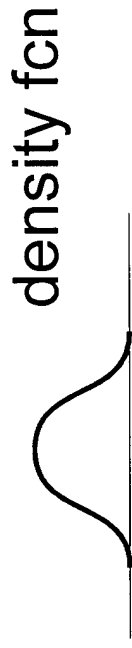


Urban Low Rise



# Motion Measurements (8 Sec)

- A collection of channel realization in a single measurement



Loss on Delay Sprea

# Motion Measurements (8 Sec)

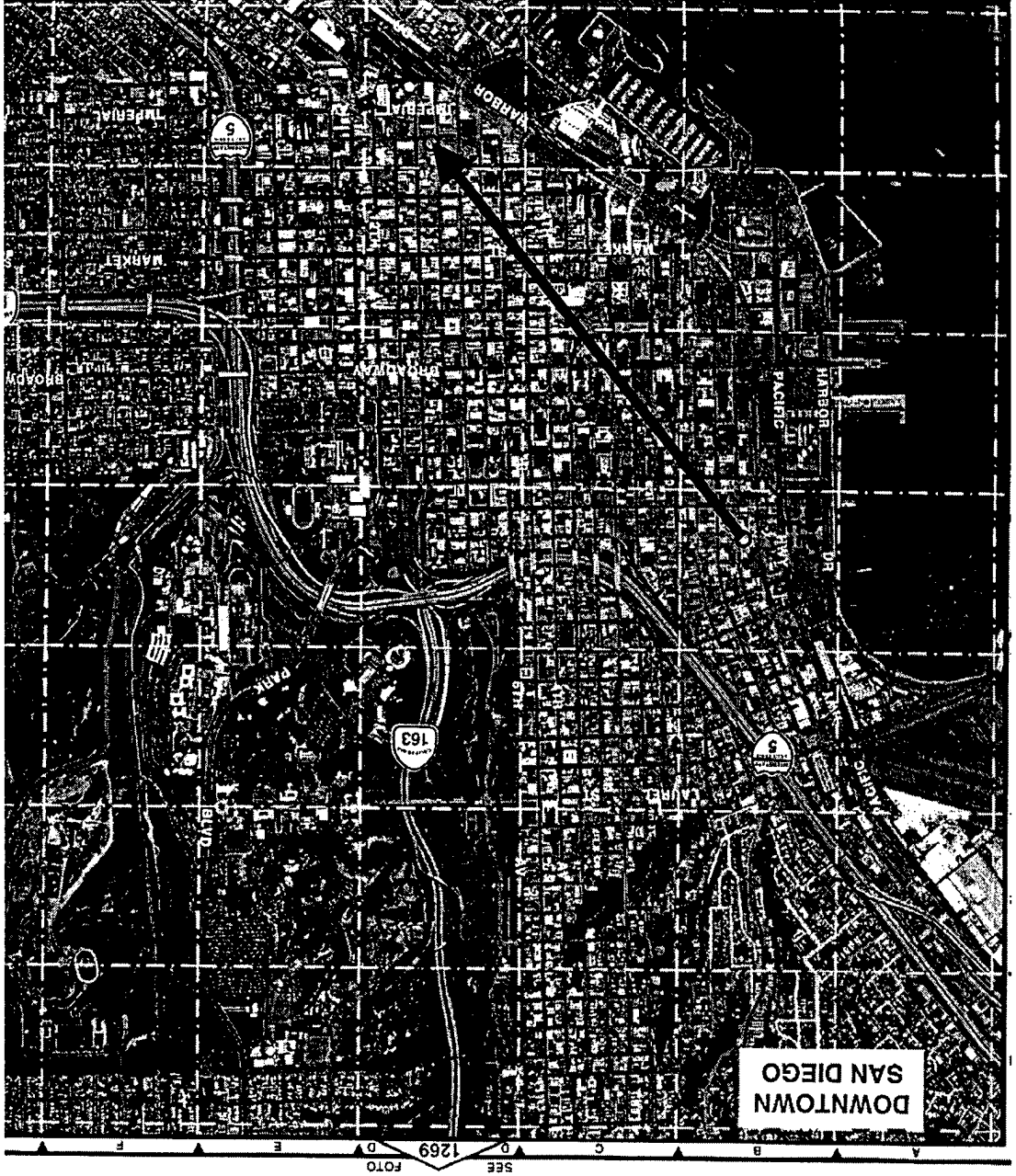
- Compute means and
  - 1) Compare to each other
    - different carrier freqs
    - different environments
  - 2) Compare to Models
    - JTC
    - Hata
    - TIREM

# Outline

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    - HMMWV Motion
    - Human Mount w/Motion
    - Various Antenna Heights
  - Many Channels
    - Path Loss vs. Delay Spread
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# Urban San Diego

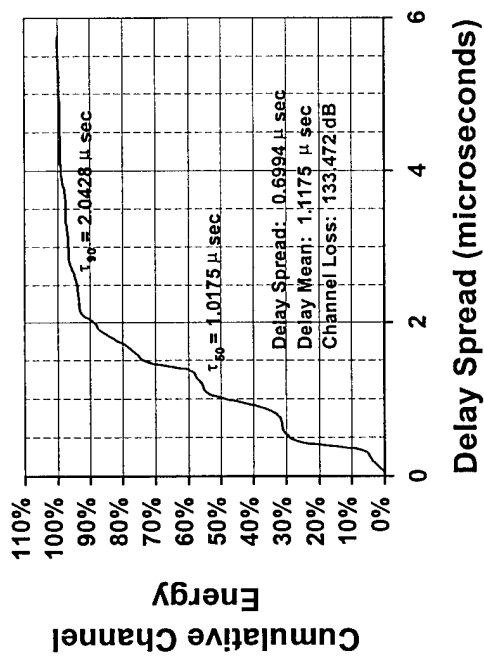
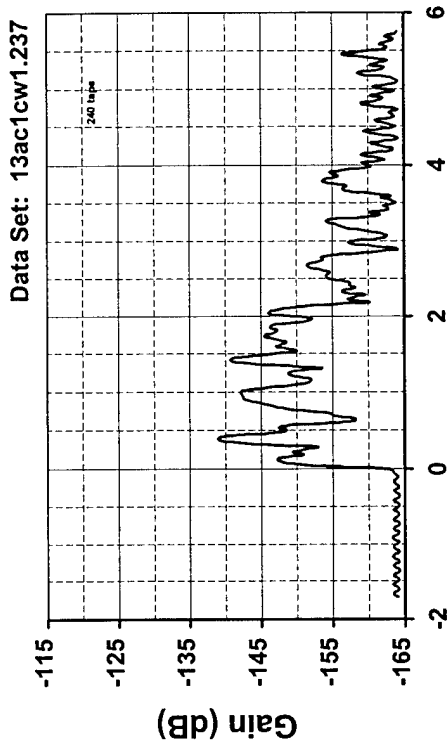
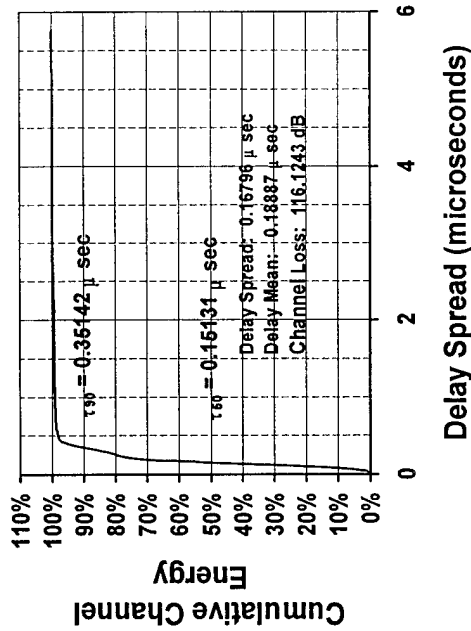
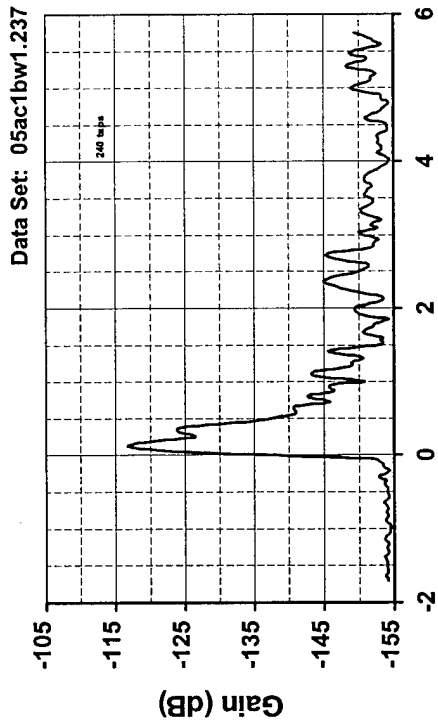


# Airfield and Urban Delay

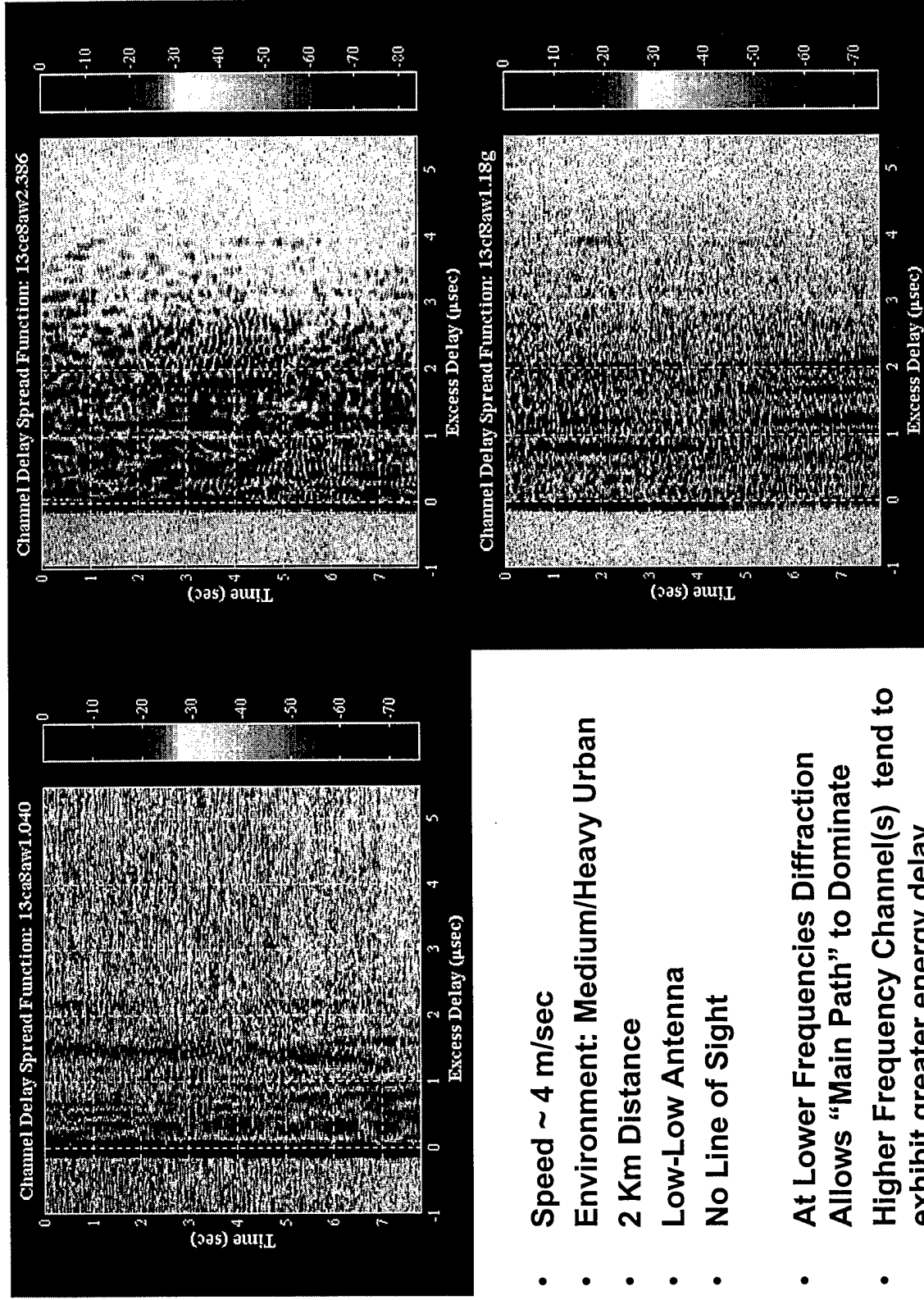
## Profiles

**Airfield**  
(3.48 km; 237 MHz)

**Urban**  
(2.15 km; 237 MHz)



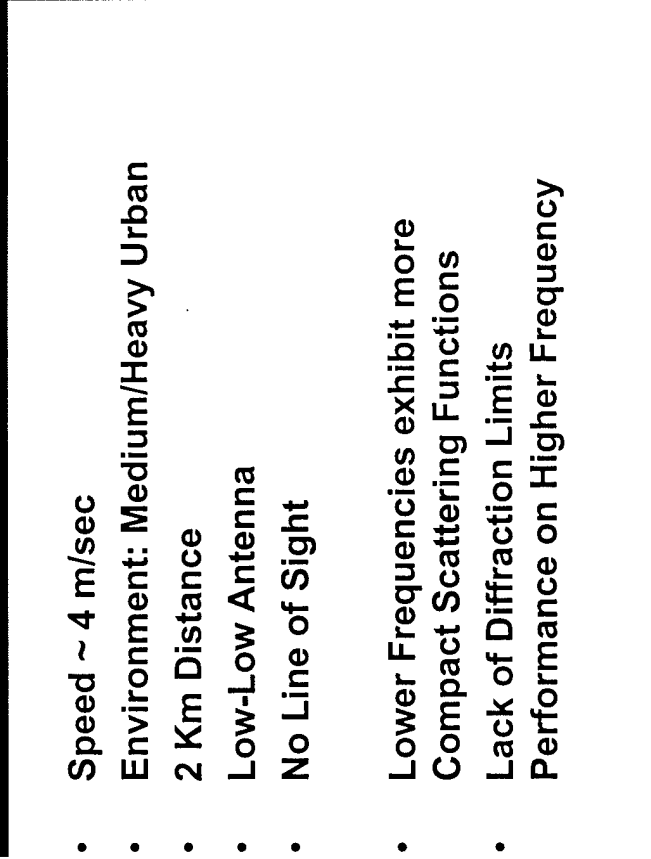
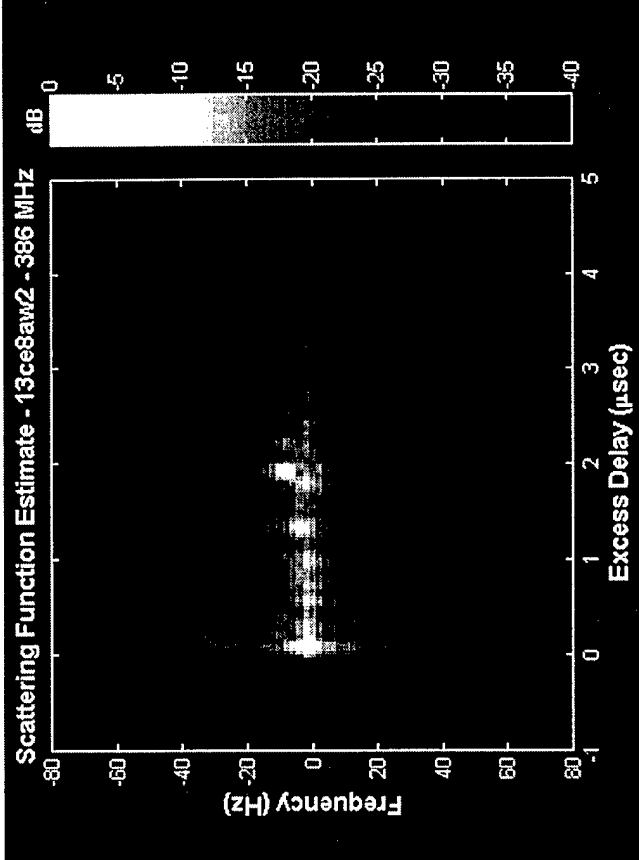
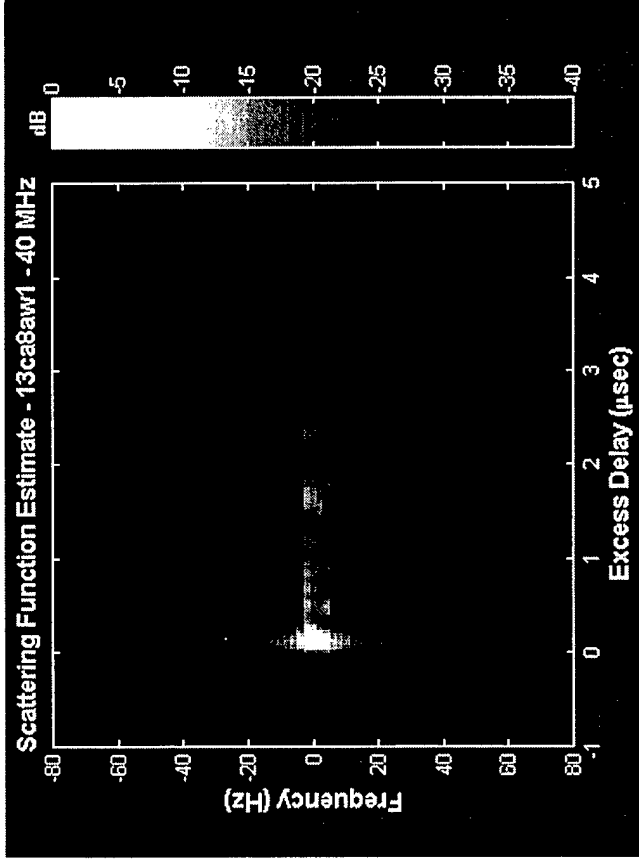
# Channel Estimates - Motion



- Speed ~ 4 m/sec
- Environment: Medium/Heavy Urban
- 2 Km Distance
- Low-Low Antenna
- No Line of Sight
- At Lower Frequencies Diffraction Allows "Main Path" to Dominate
- Higher Frequency Channel(s) tend to exhibit greater energy delay

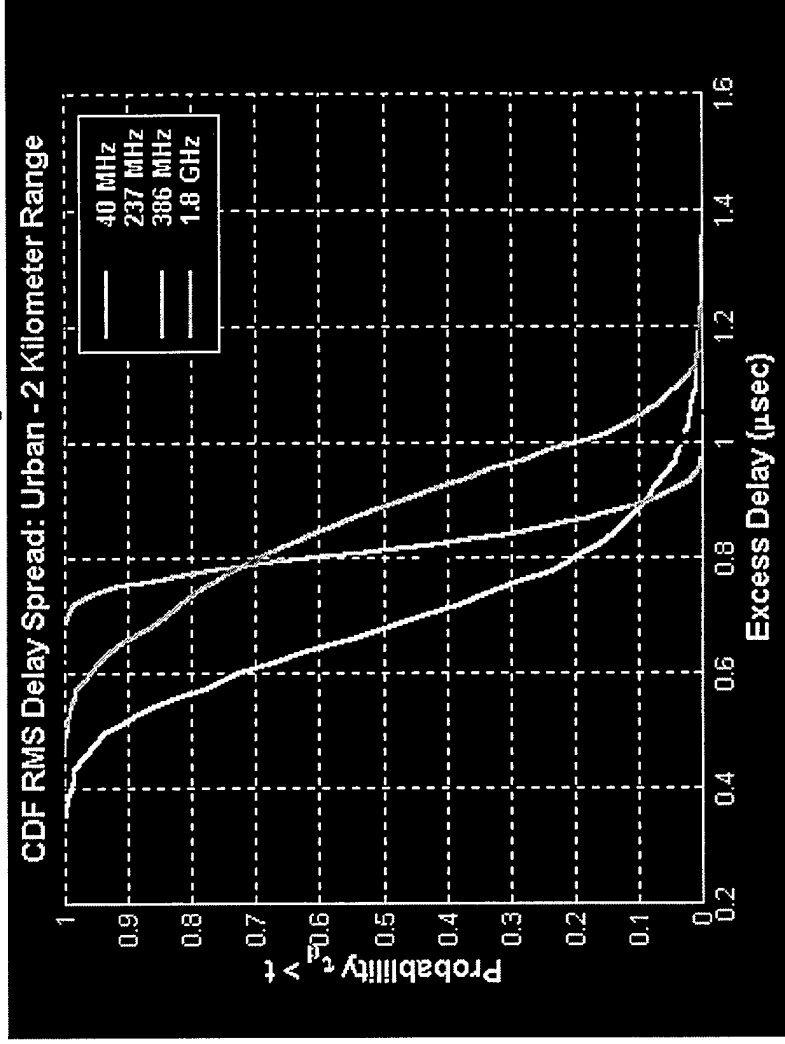


# Scattering Functions - Motion



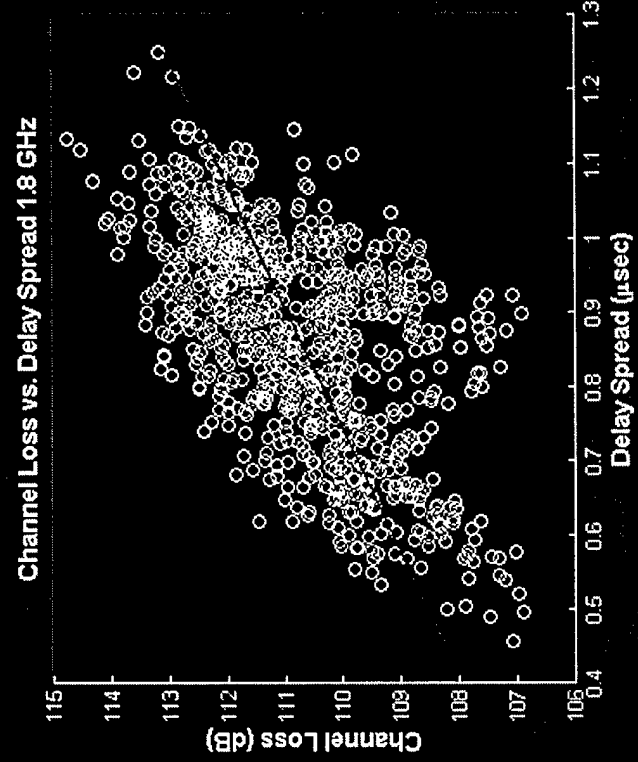
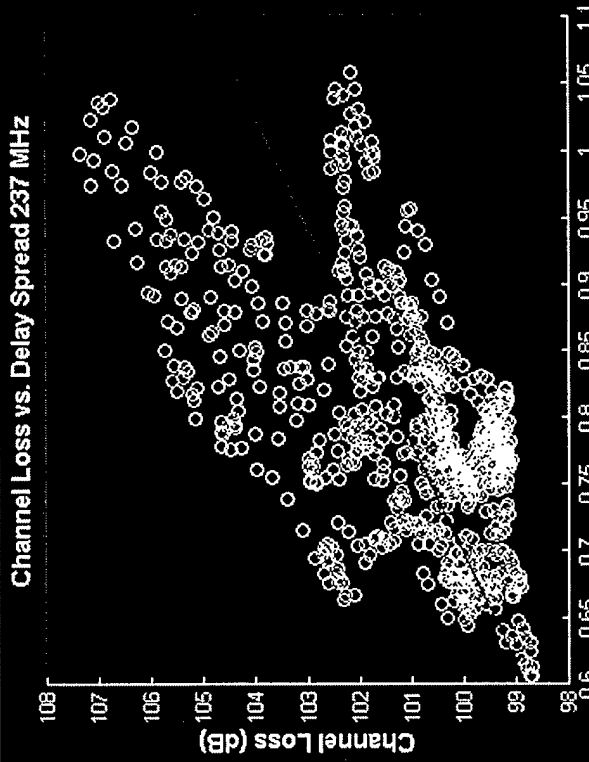
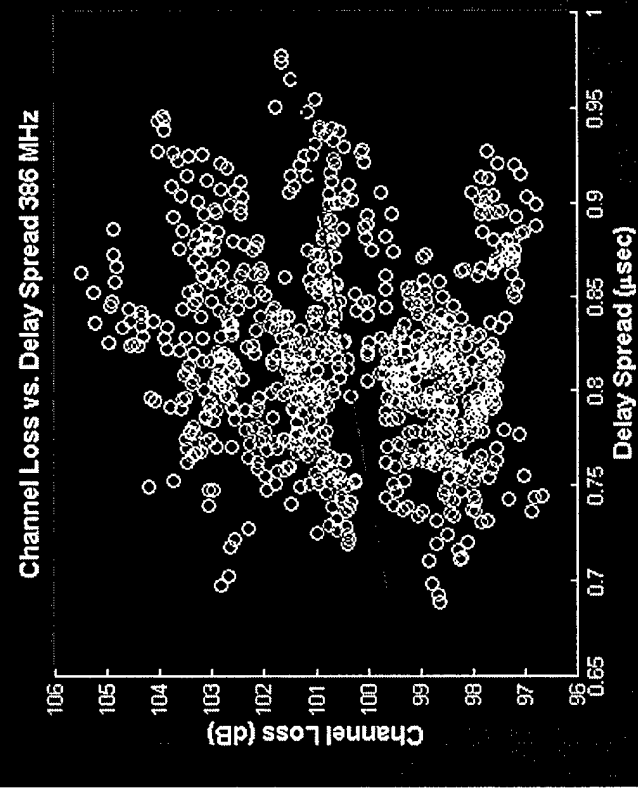
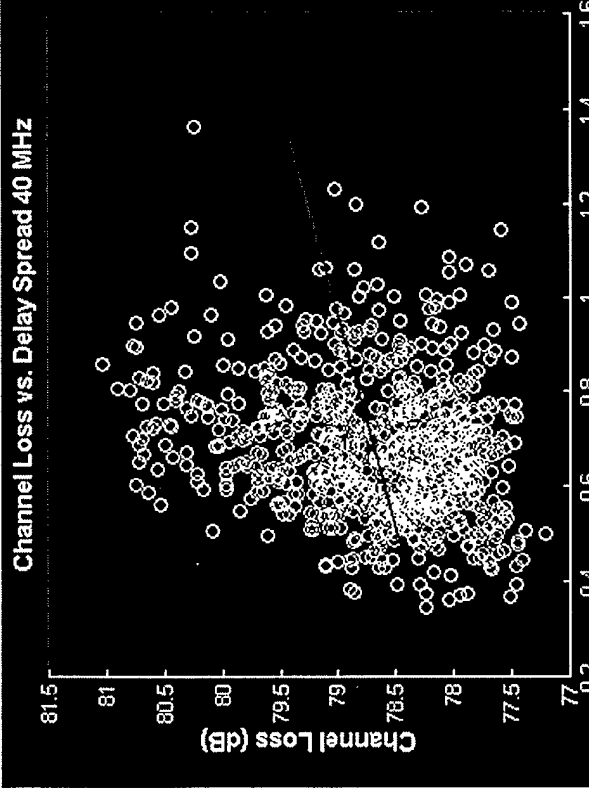
- Speed ~ 4 m/sec
- Environment: Medium/Heavy Urban
- 2 Km Distance
- Low-Low Antenna
- No Line of Sight
- Lower Frequencies exhibit more Compact Scattering Functions
- Lack of Diffraction Limits Performance on Higher Frequency

## Channel Response

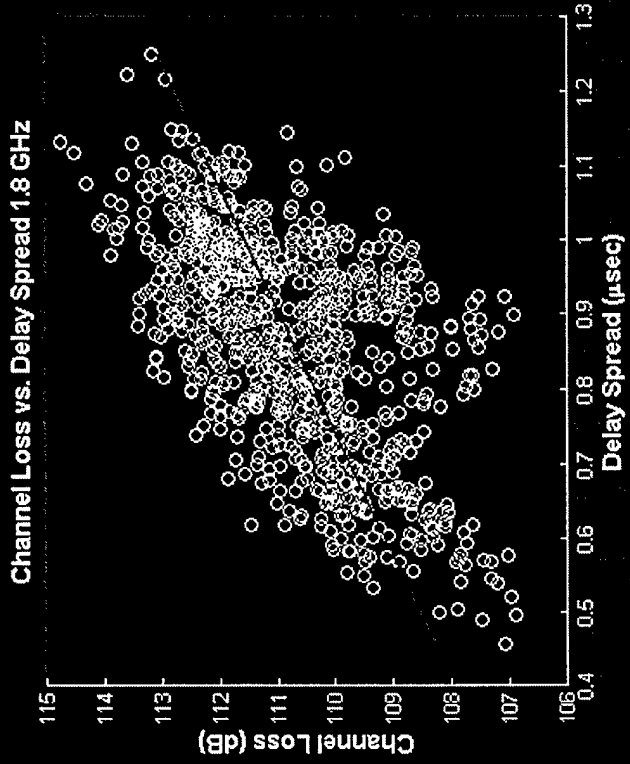
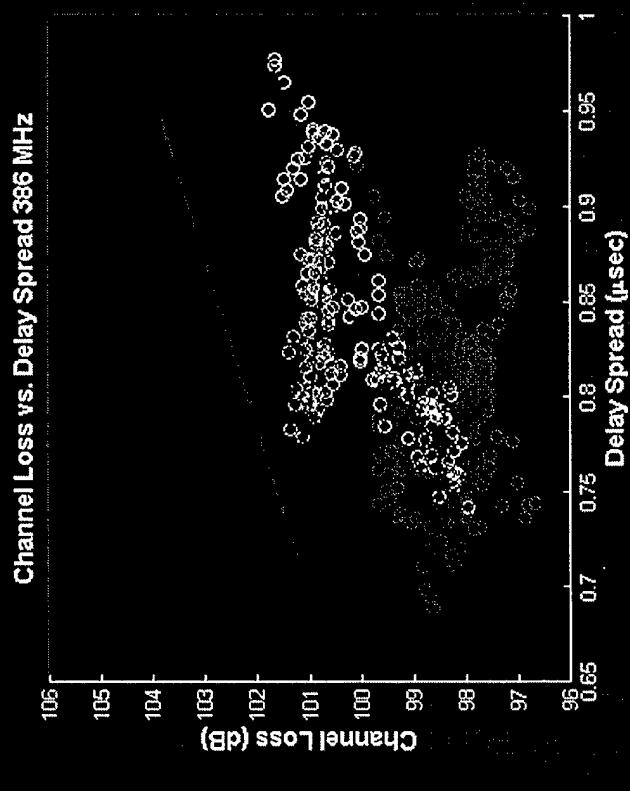
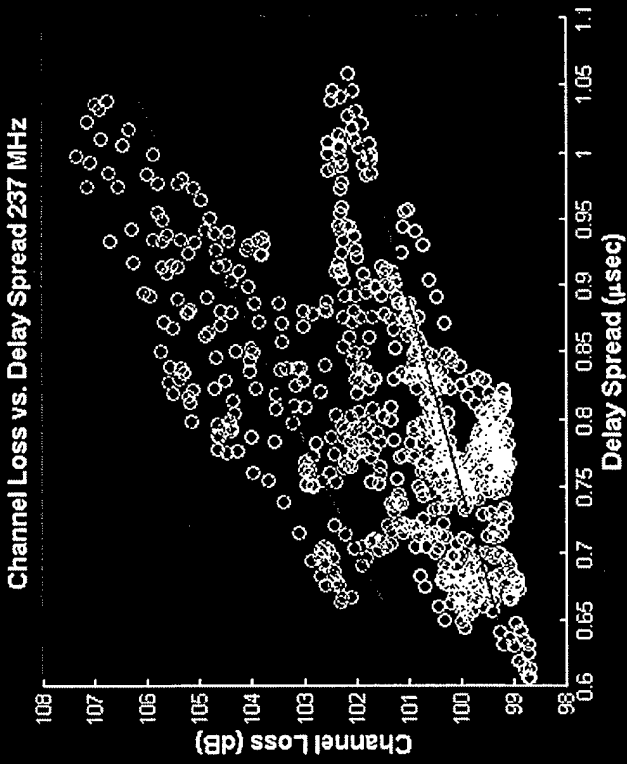
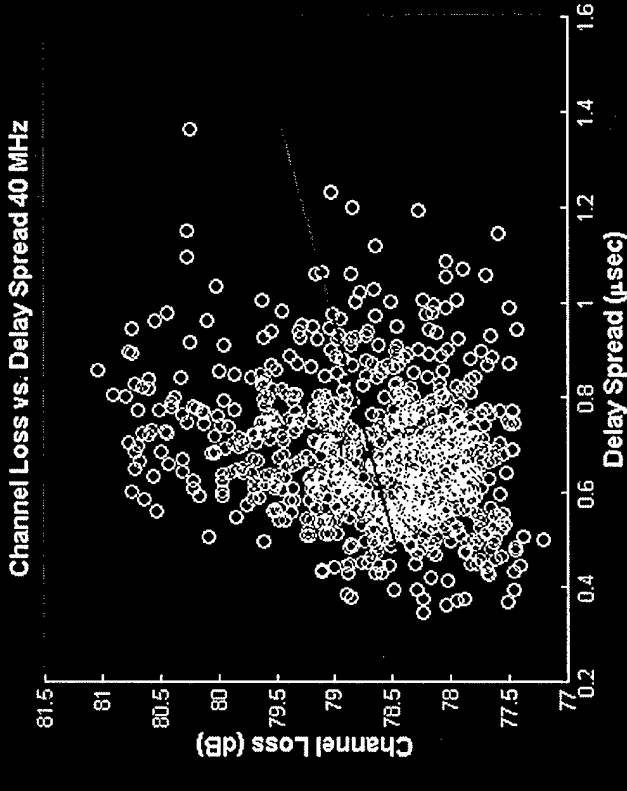


- ~320,000 Channel Estimates taken at 44 kHz
- Averaged to 100 Hz for Power Delay Profiles to Estimate Delay Spread (and Loss)

# Channel Loss

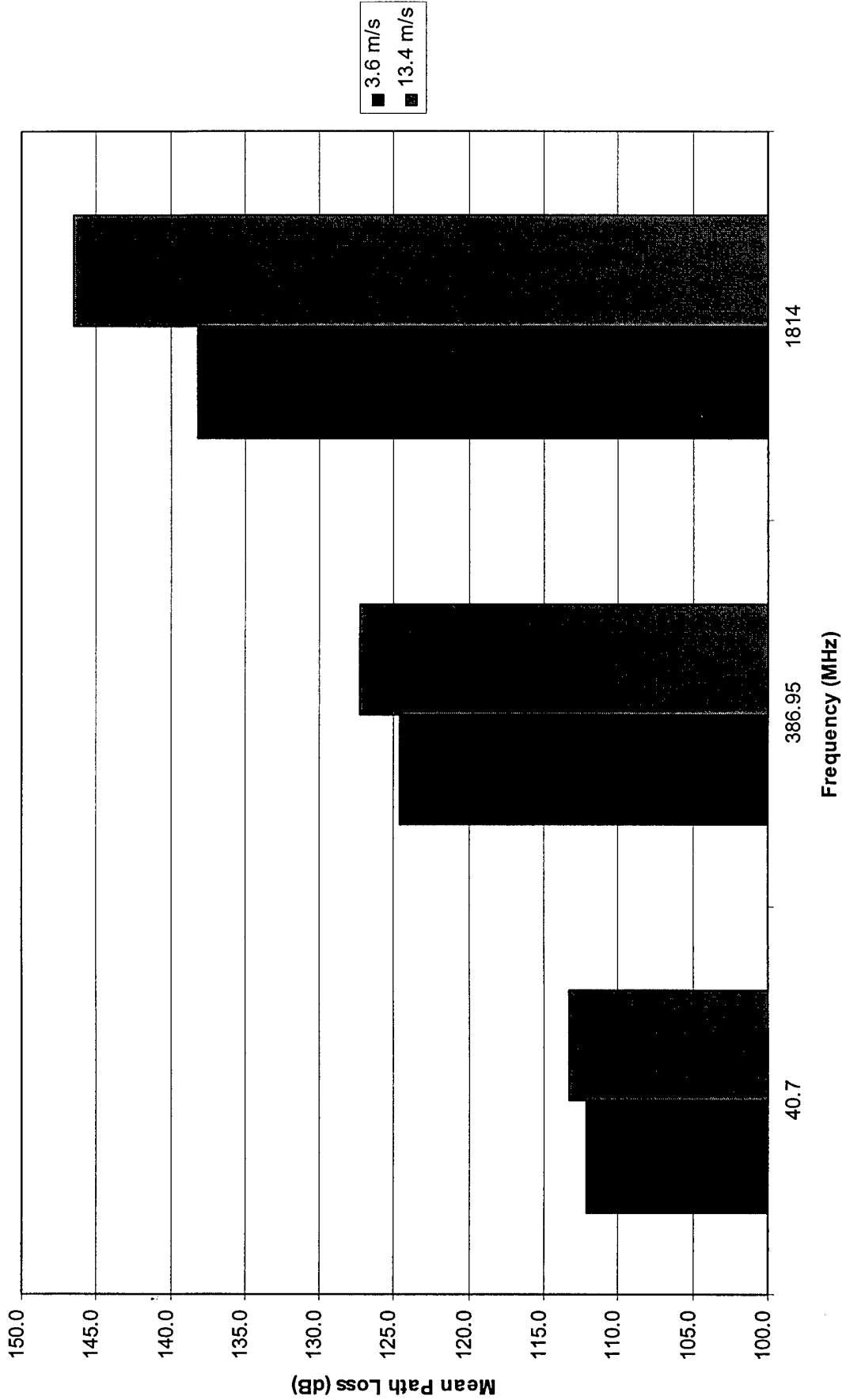


# Channel Loss



# Urban Path Loss

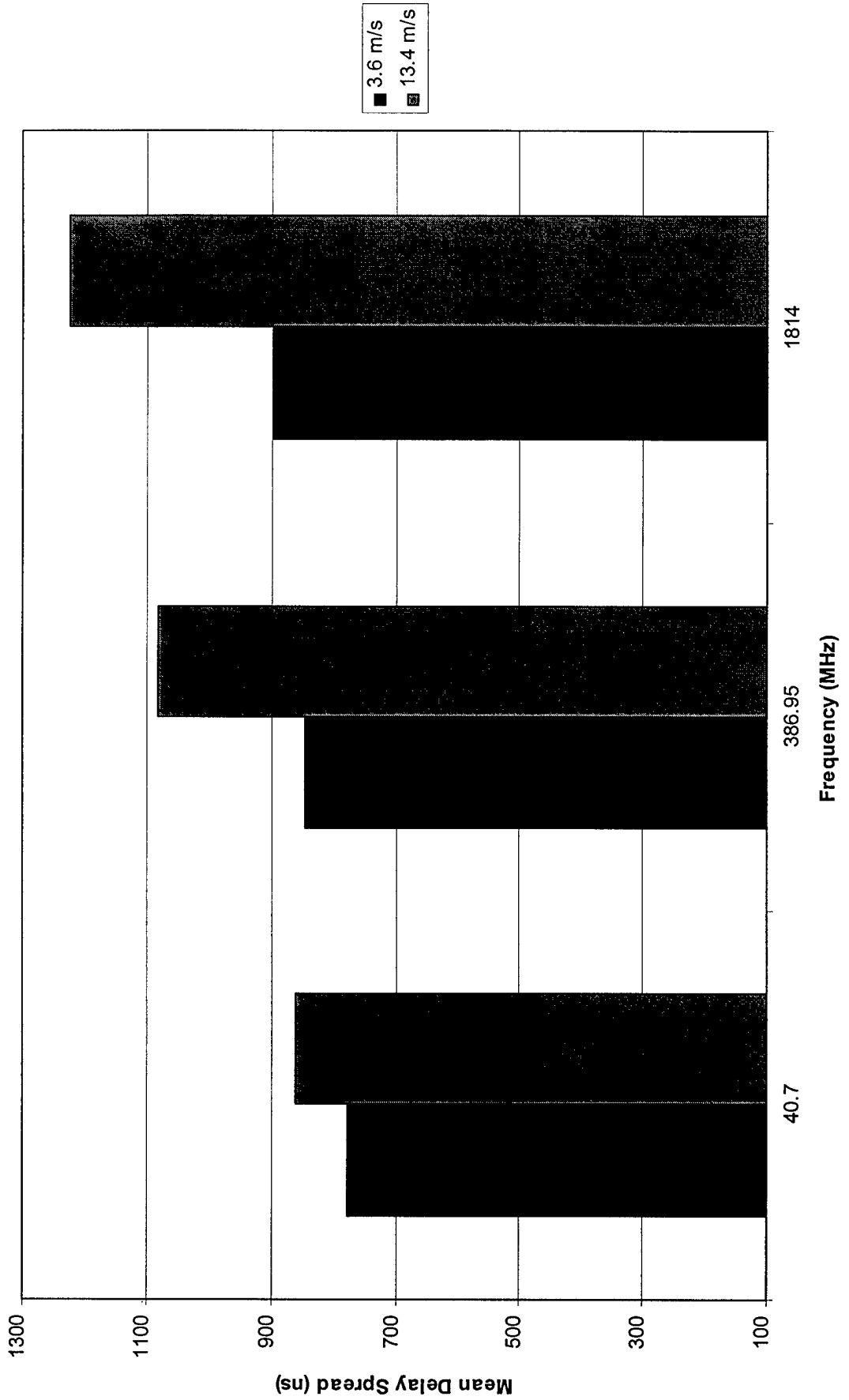
Urban Environment, (Ch. 13; HMMVV Motion)



# Urban Delay Spread

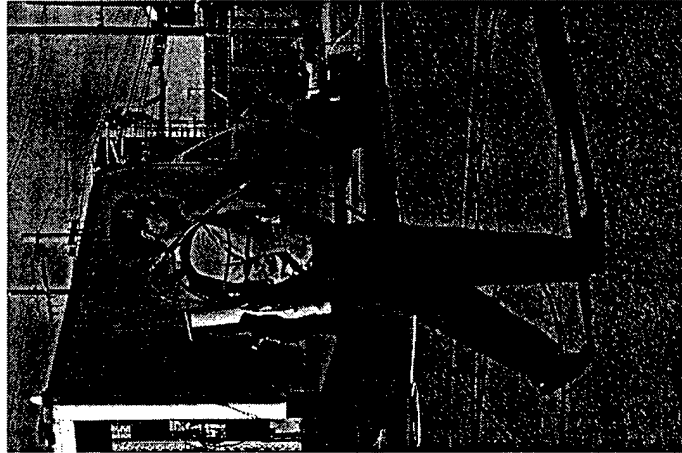


Urban Environment, (Ch. 13; HMMWV Motion)



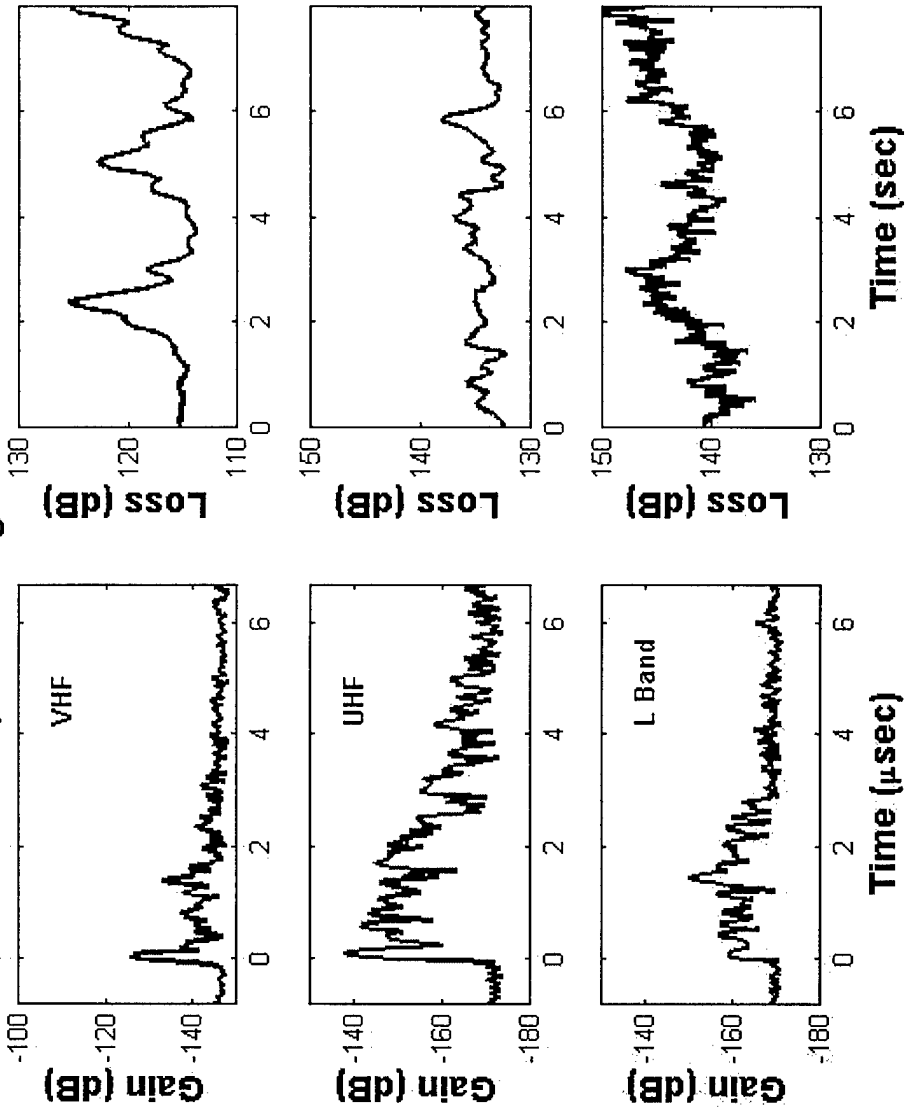


# Soldier Mount



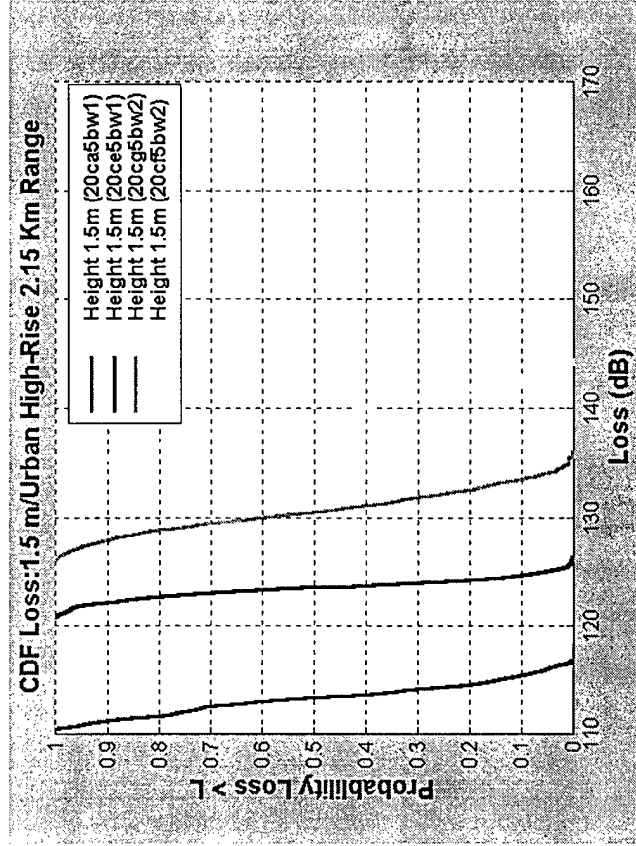
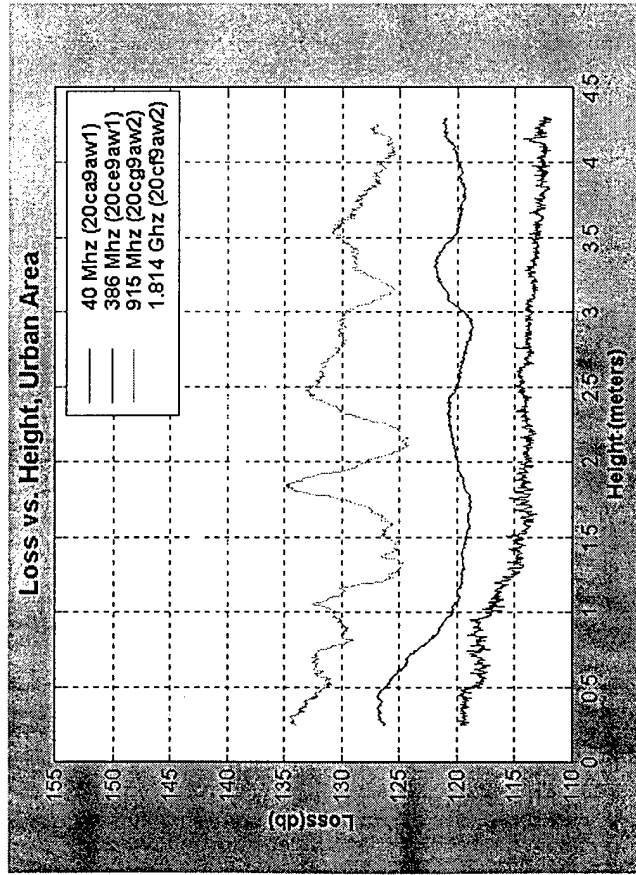
# Soldier Mount

Urban Soldier Mount, 2 Km Range



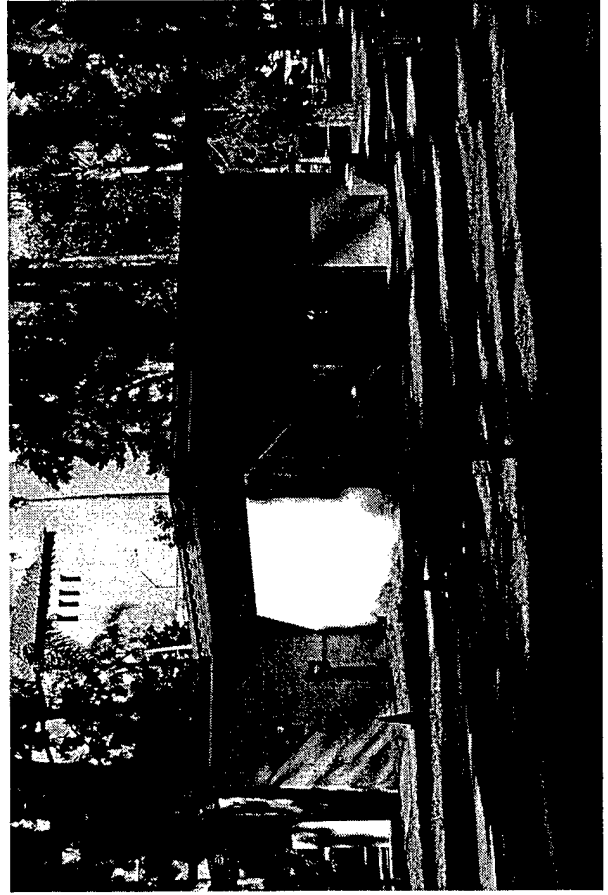
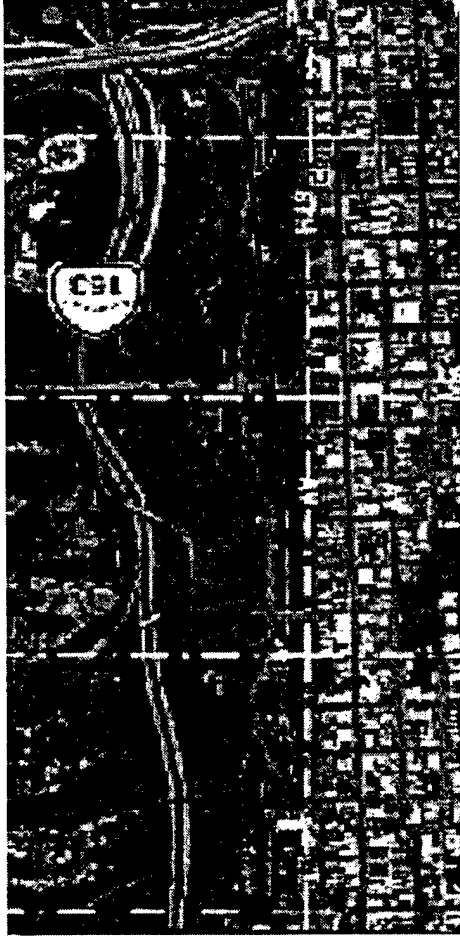


# Urban Path Loss vs. Height

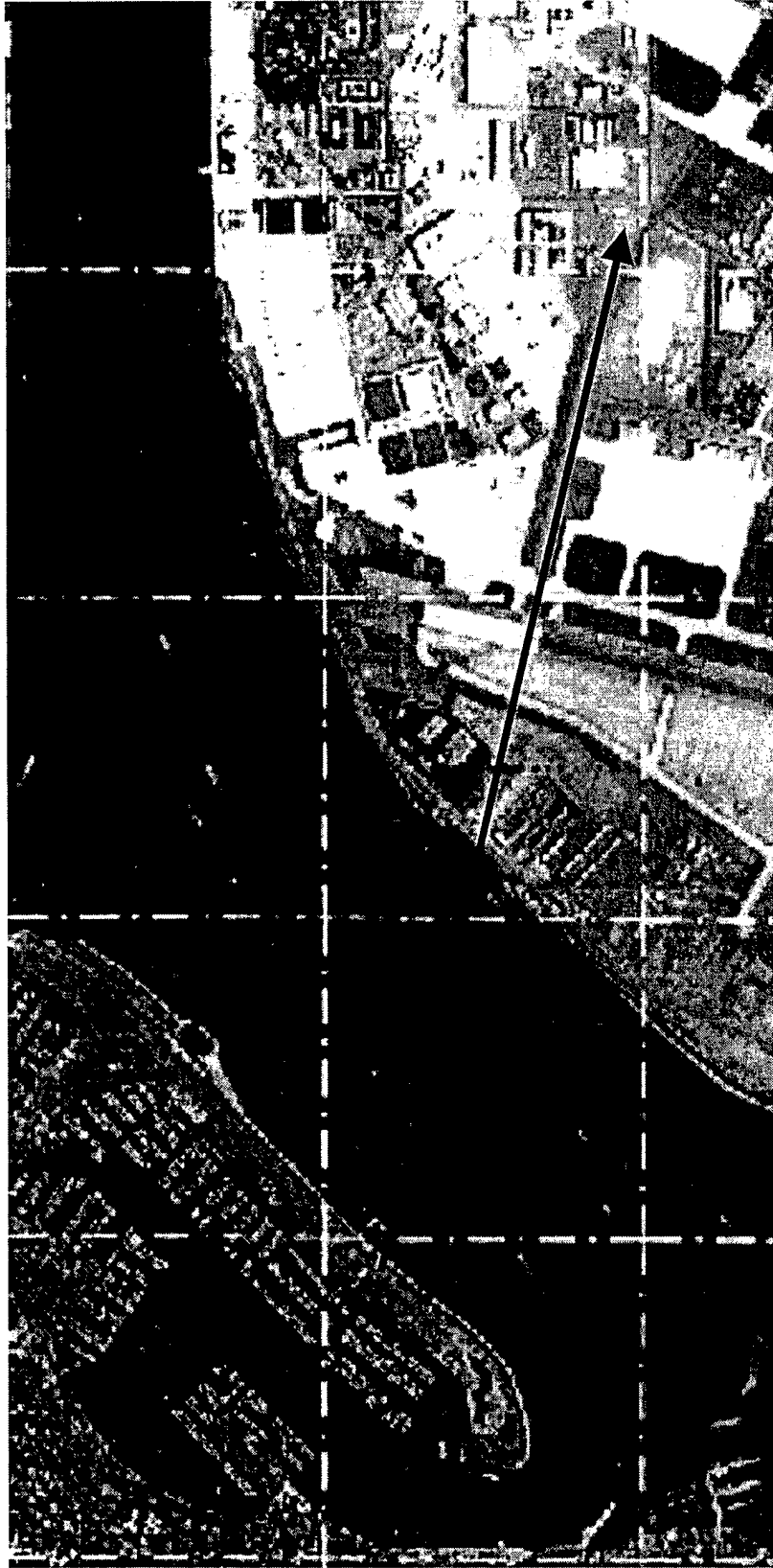


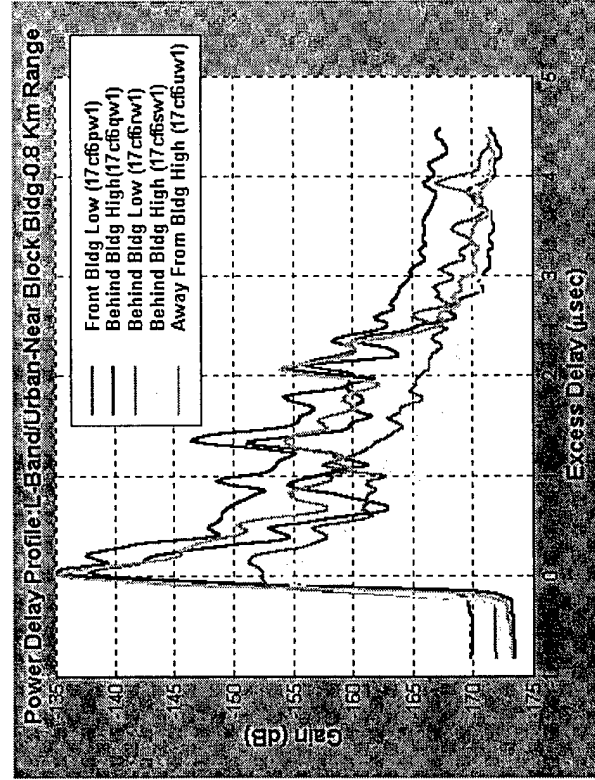
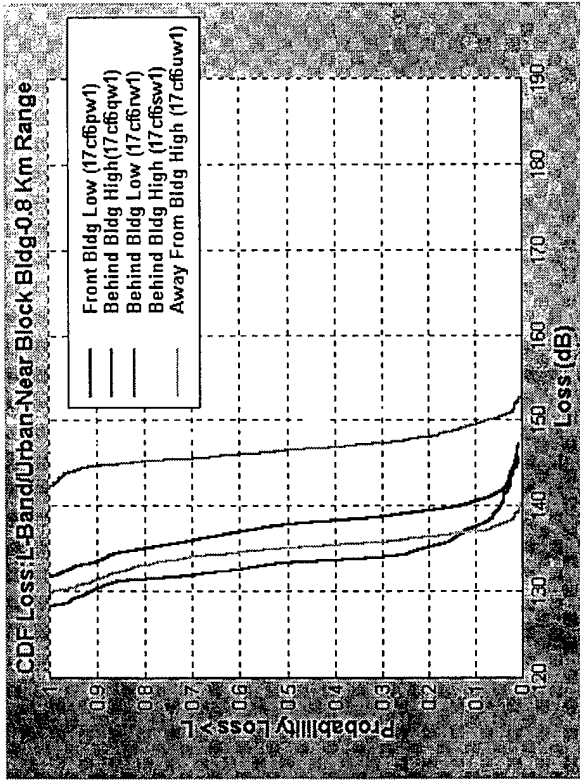
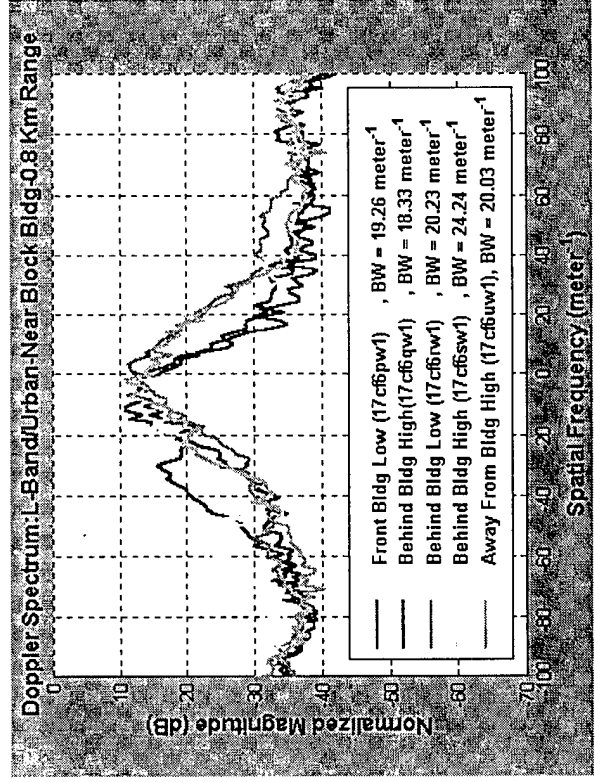
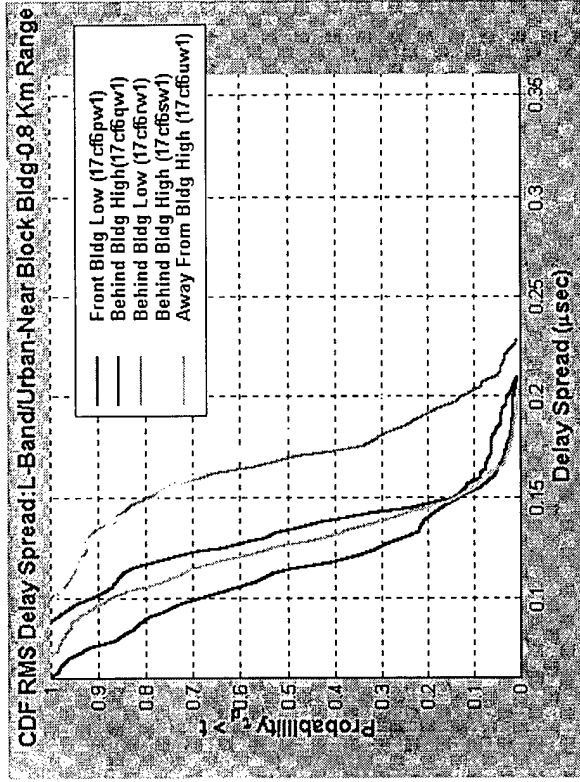


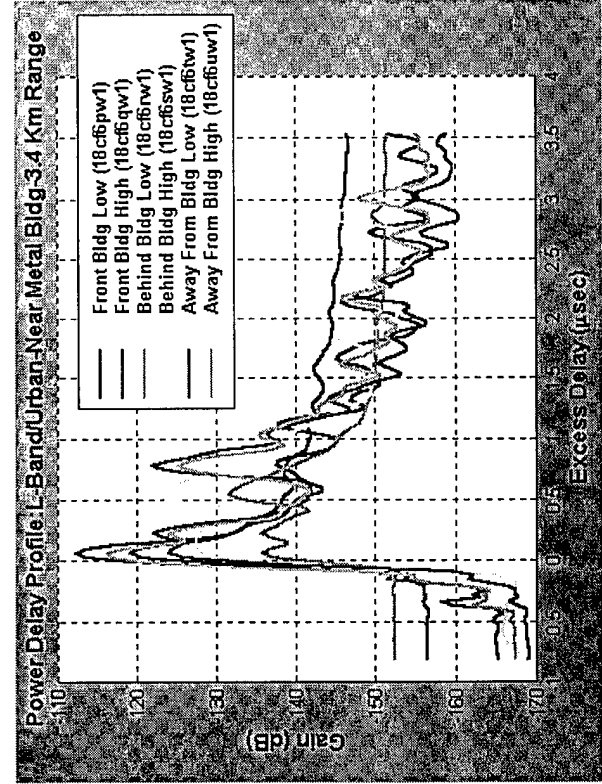
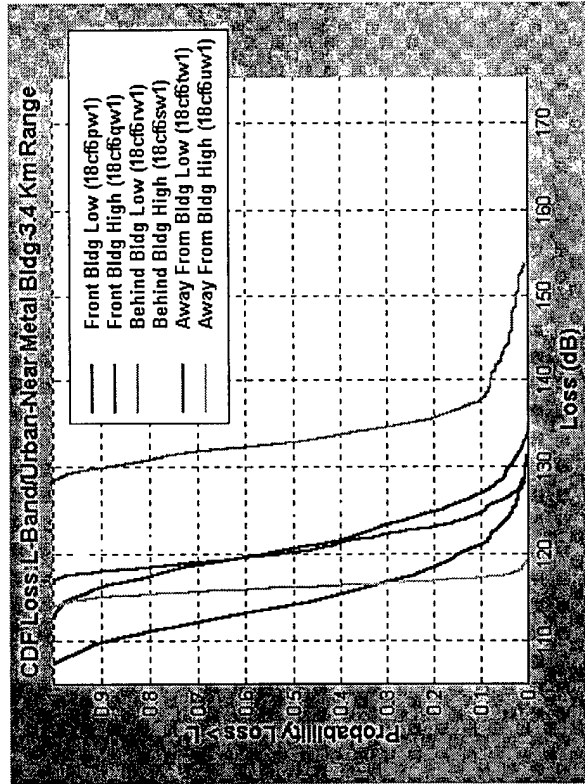
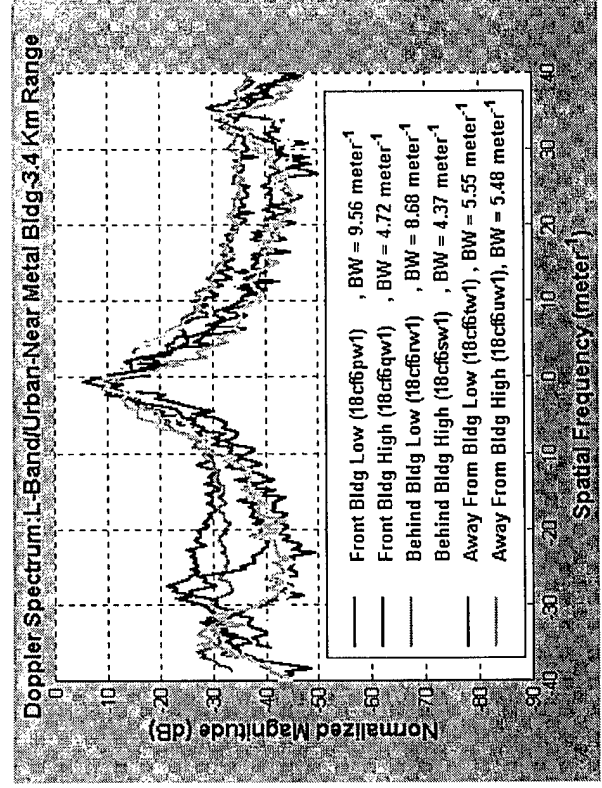
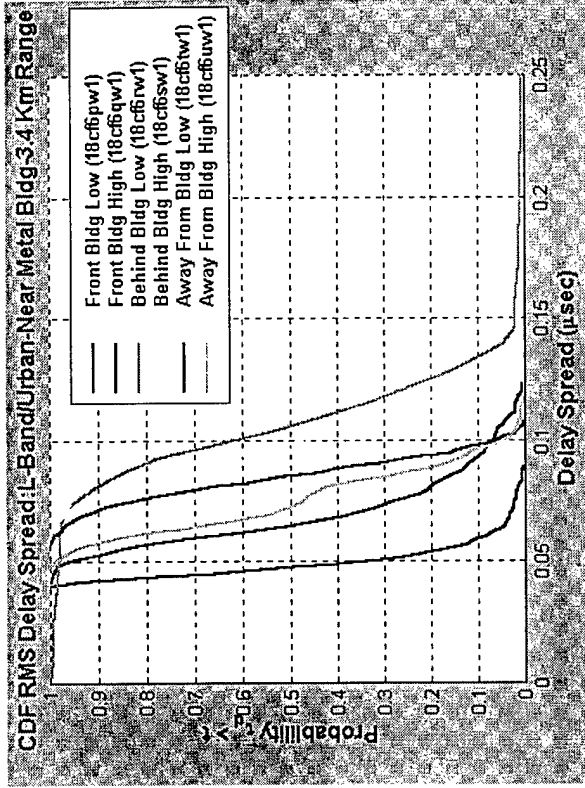
# Balboa Park, Block Building

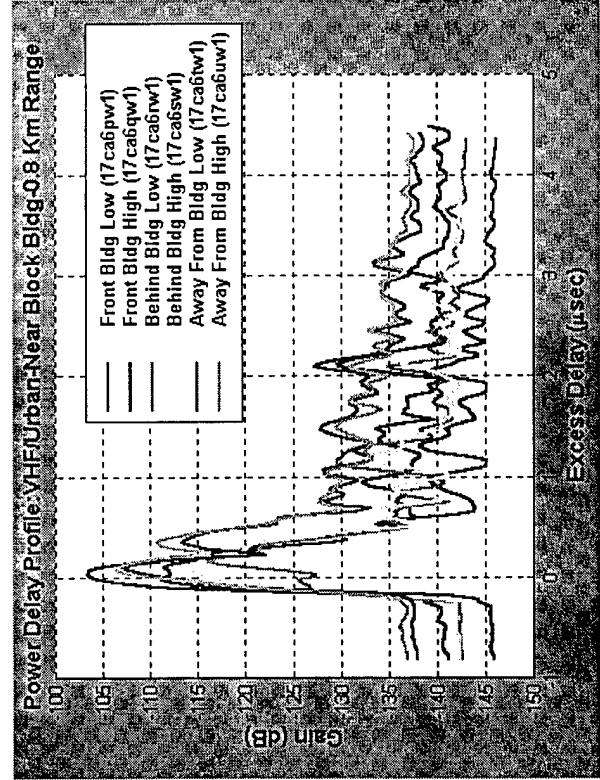
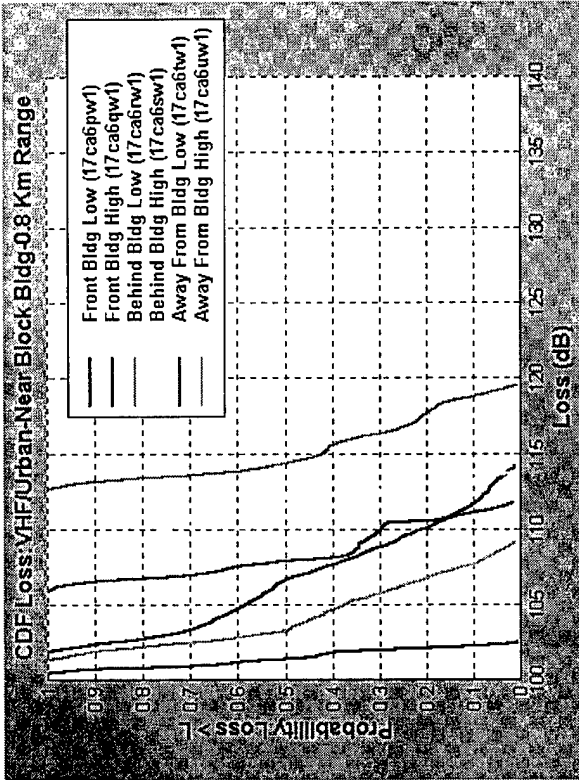
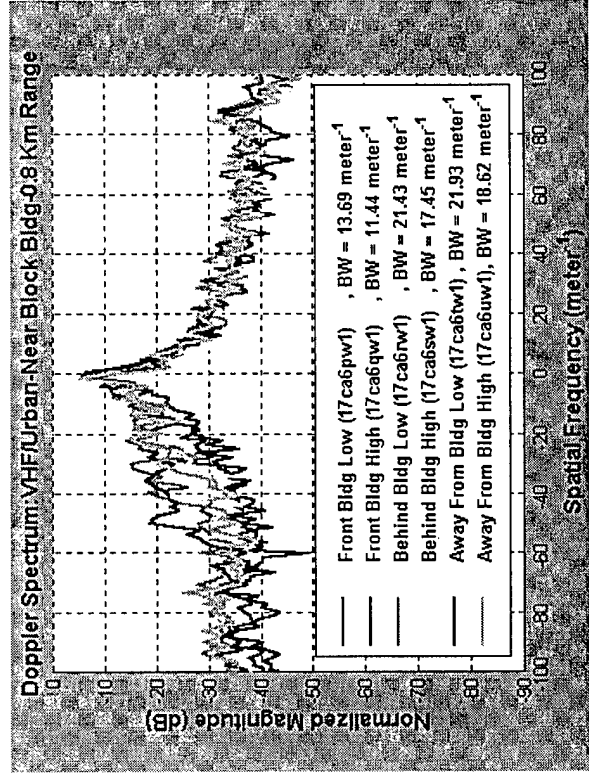
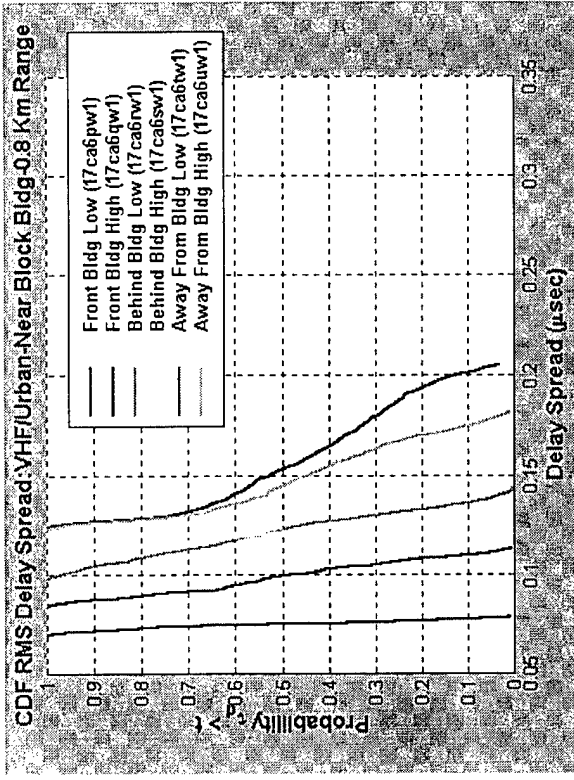


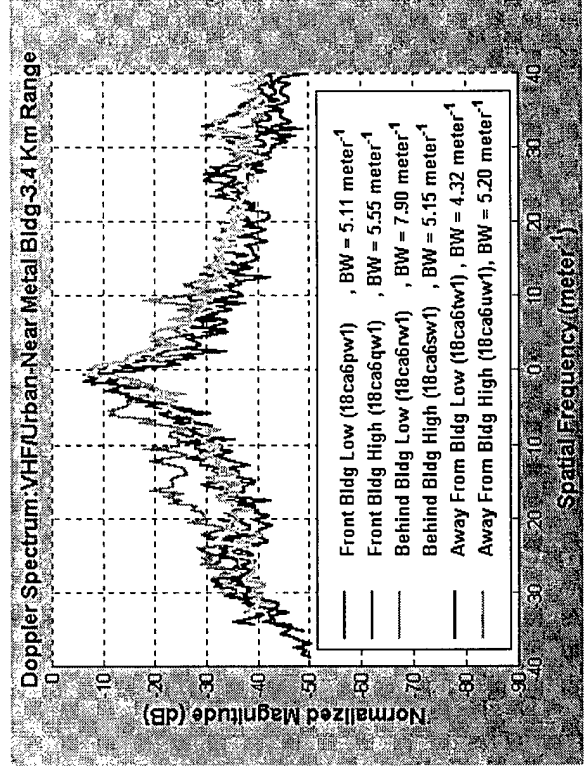
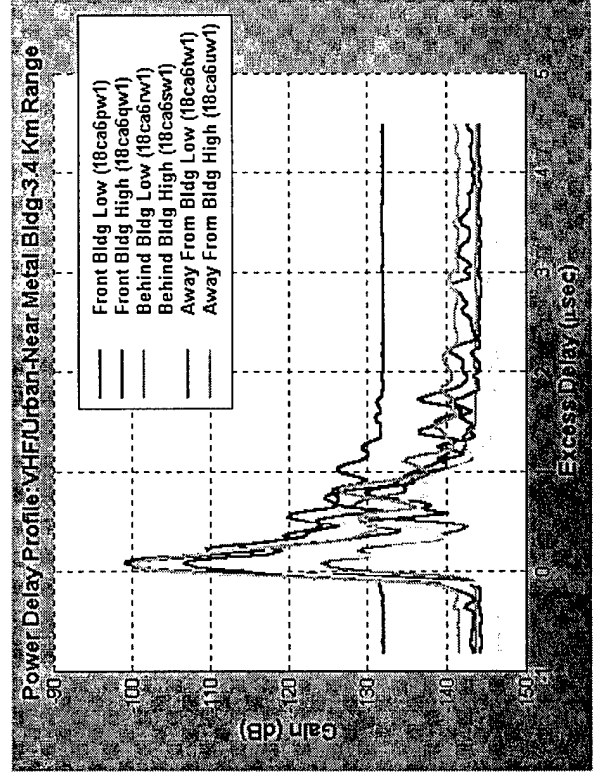
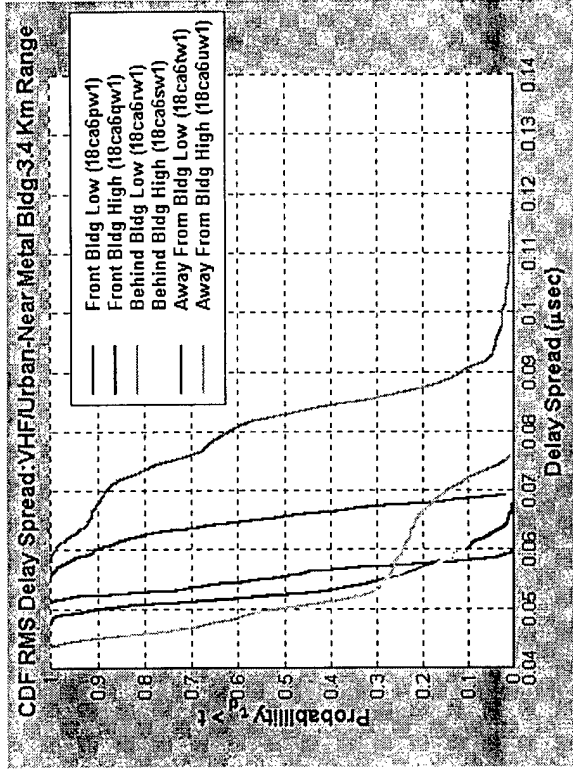
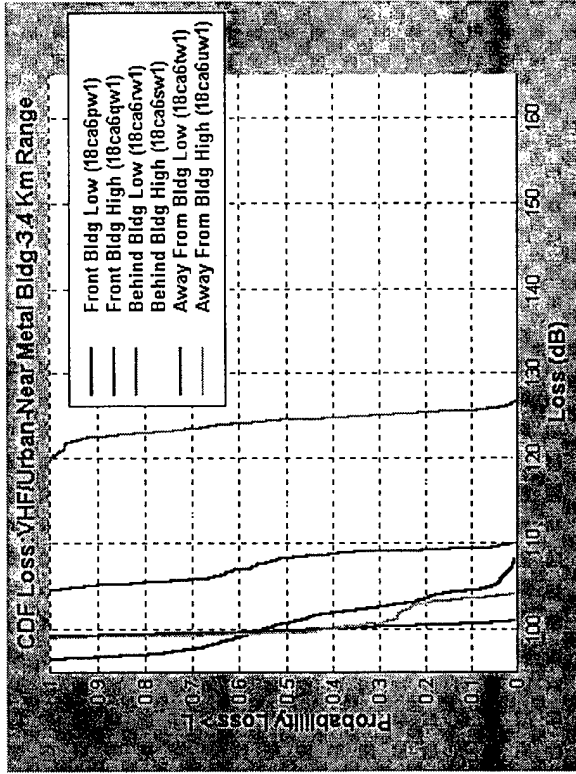
# North Island - Metal Building









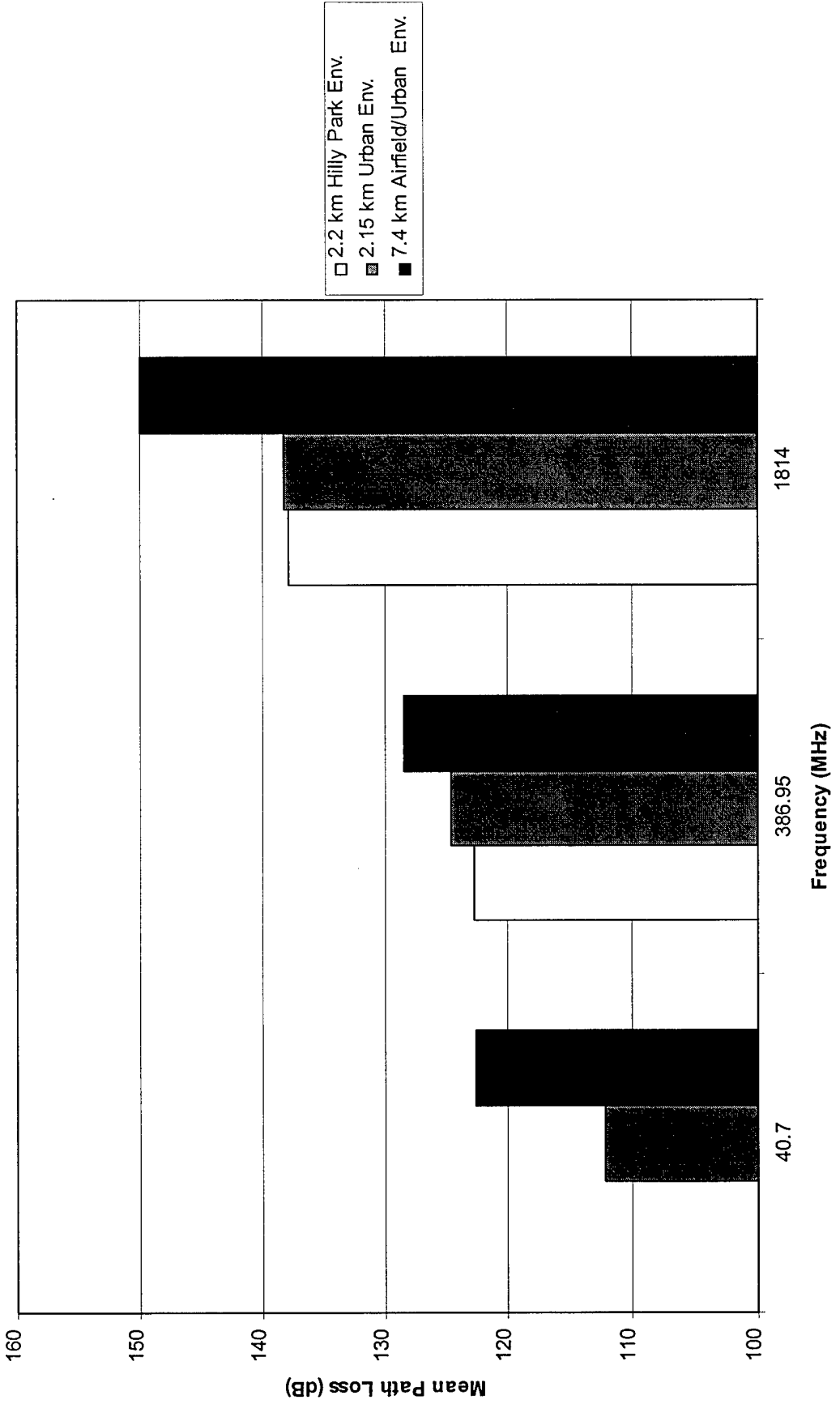


# Path Loss vs.



# Frequency & Environment

Various Environments (Ch 16, 13, 19; 3.6 m/s HMMWV Motion)

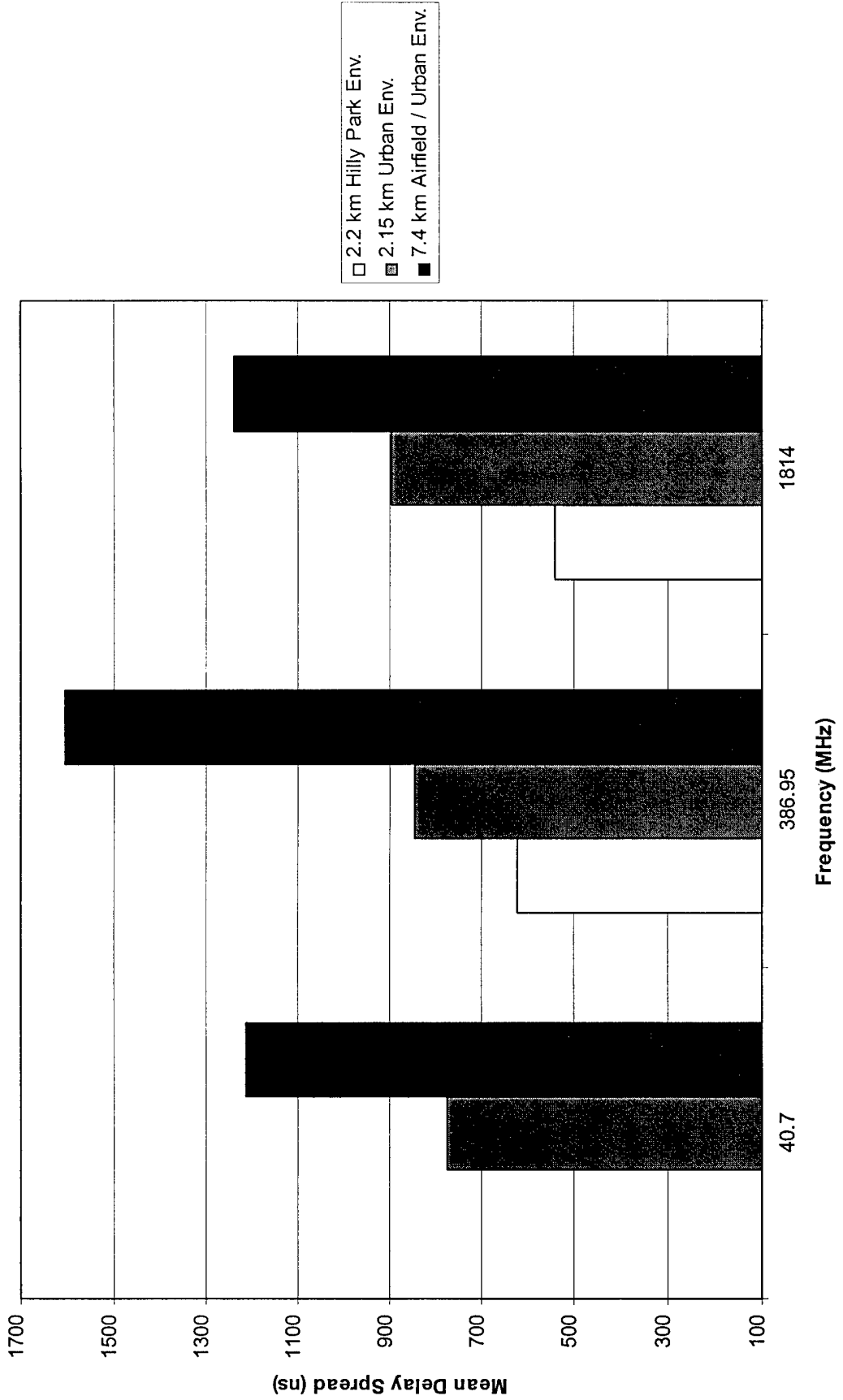




# Delay Spread vs.

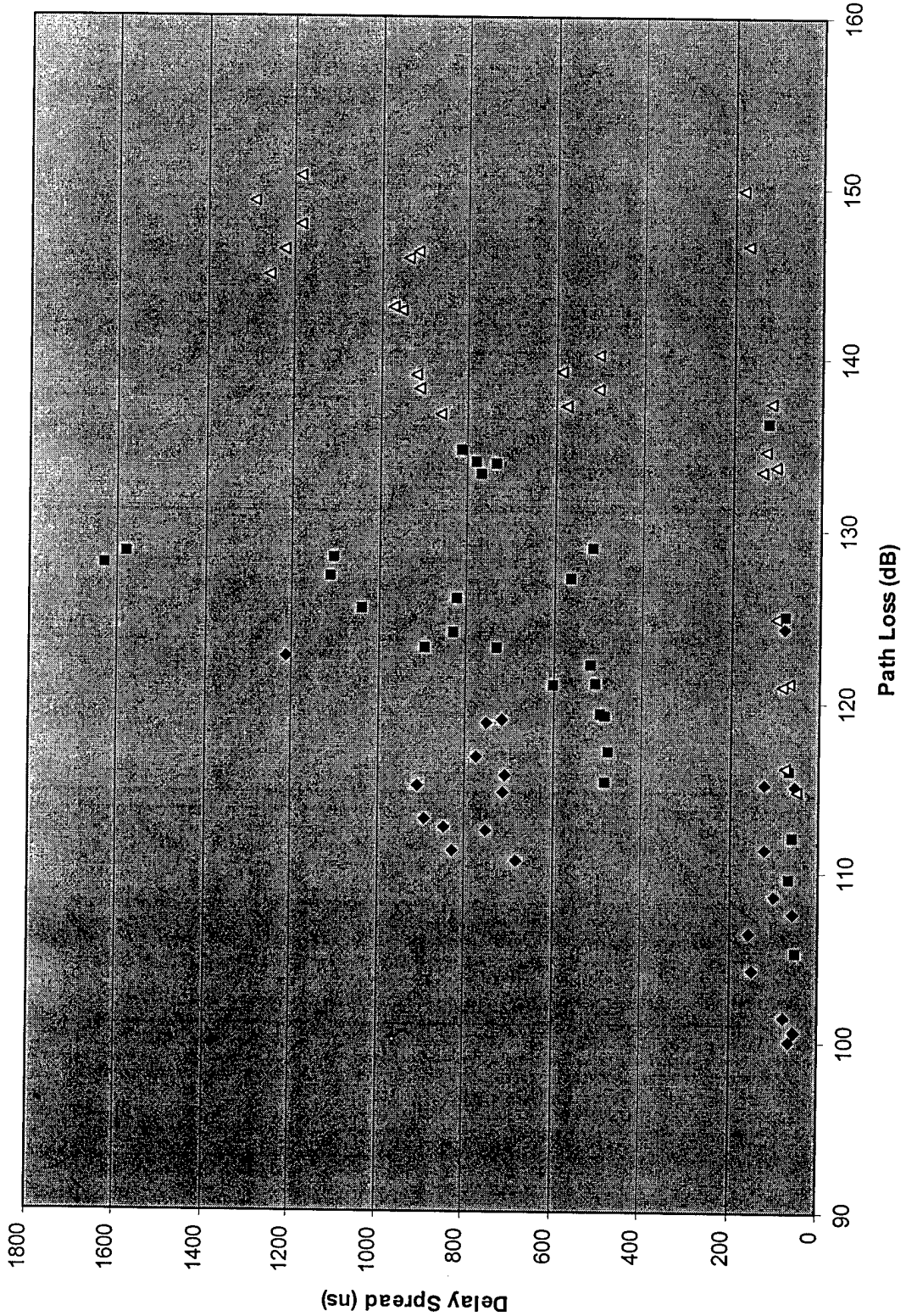
# Frequency & Environment

Various Environments (Ch 16, 13, 19; 3.6 m/s HMMWV Motion)



# PL-DS Scatter Plot

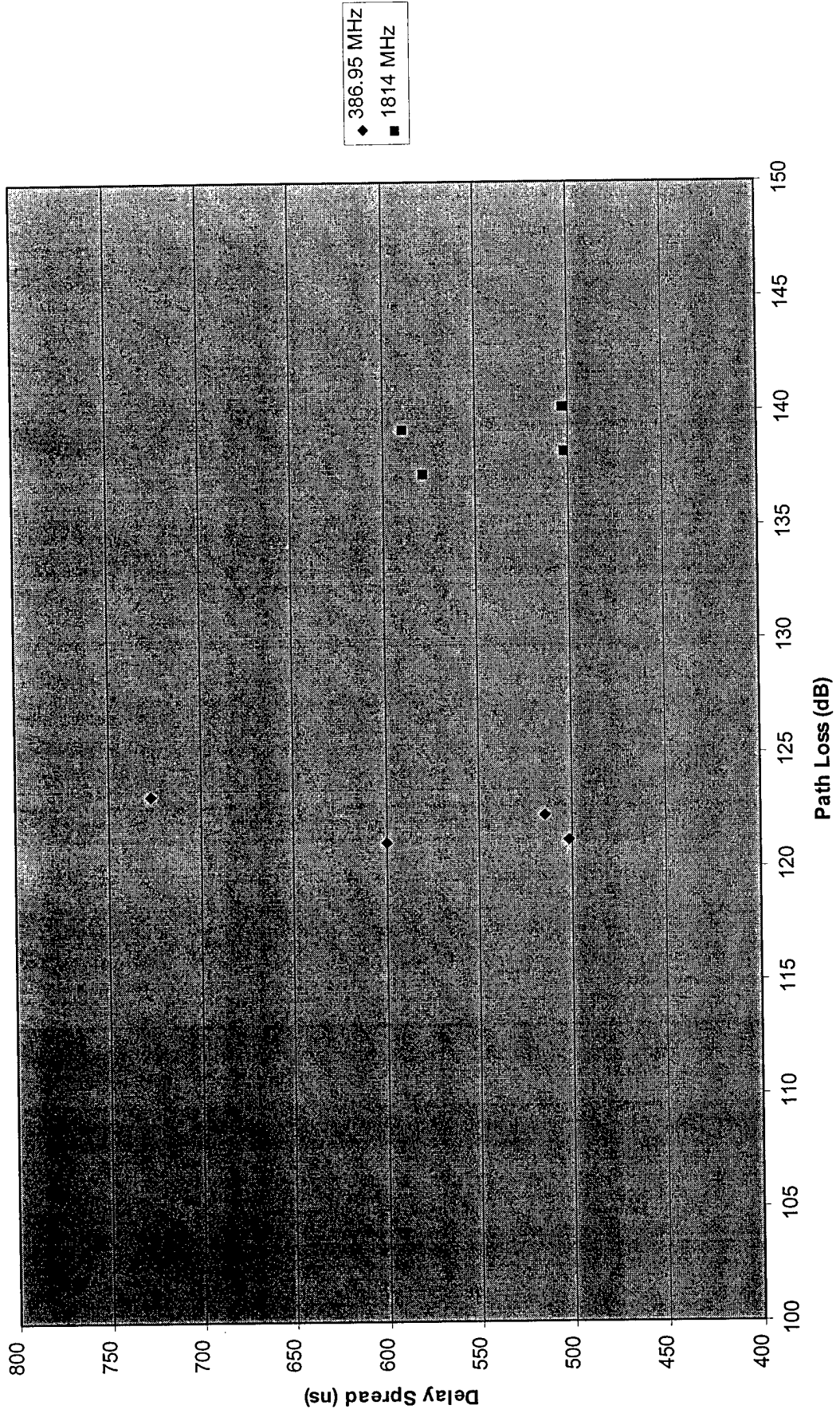
(All Cases Combined)



◆ 40.7 MHz  
■ 386.95 MHz  
△ 1814 MHz

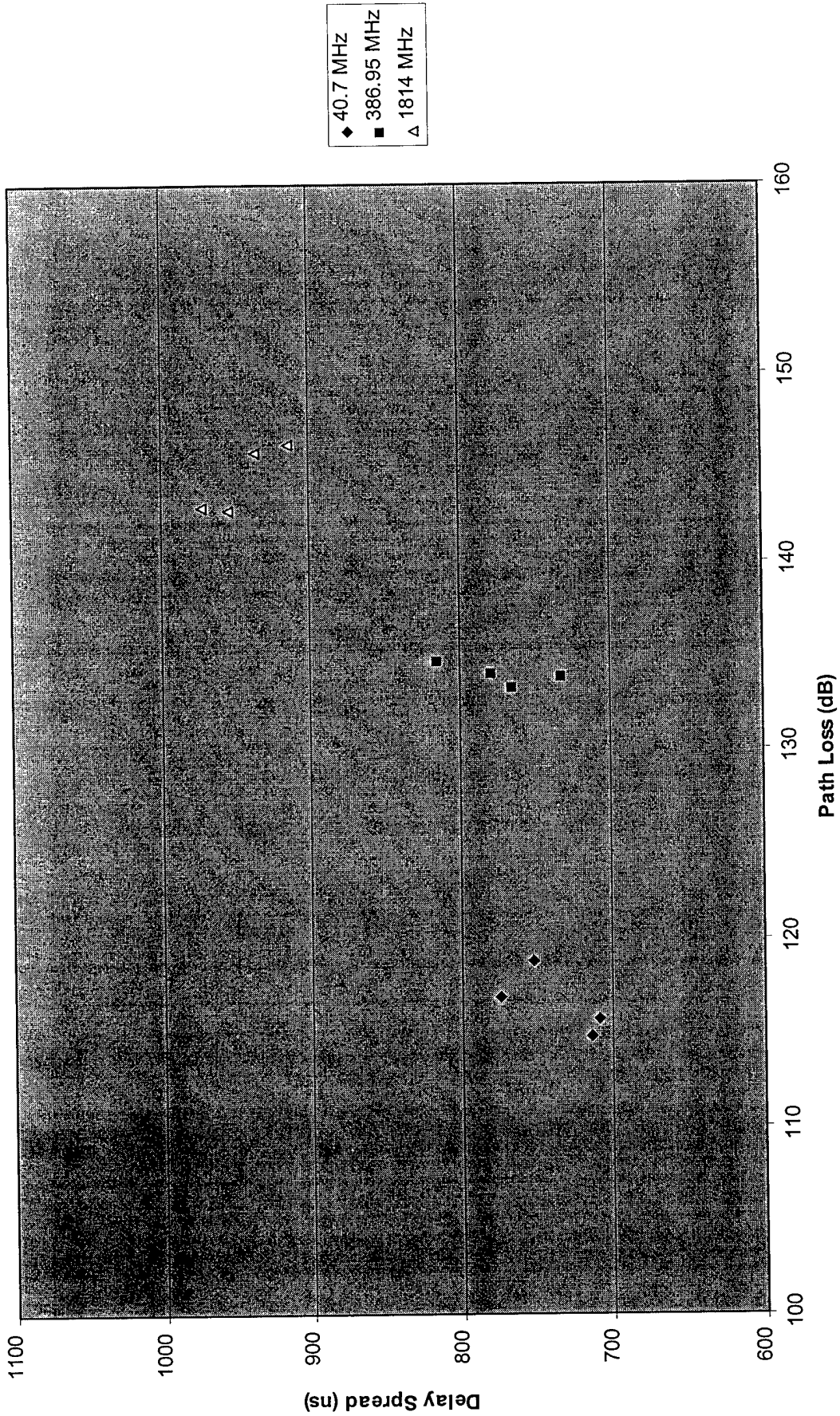
# Balboa Park Hills/Trees (2.2 Km)

PL-DS Scatter Plot (Hilly Balboa Park, Ch.16)



# Urban Soldier Mount (2.1 Km)

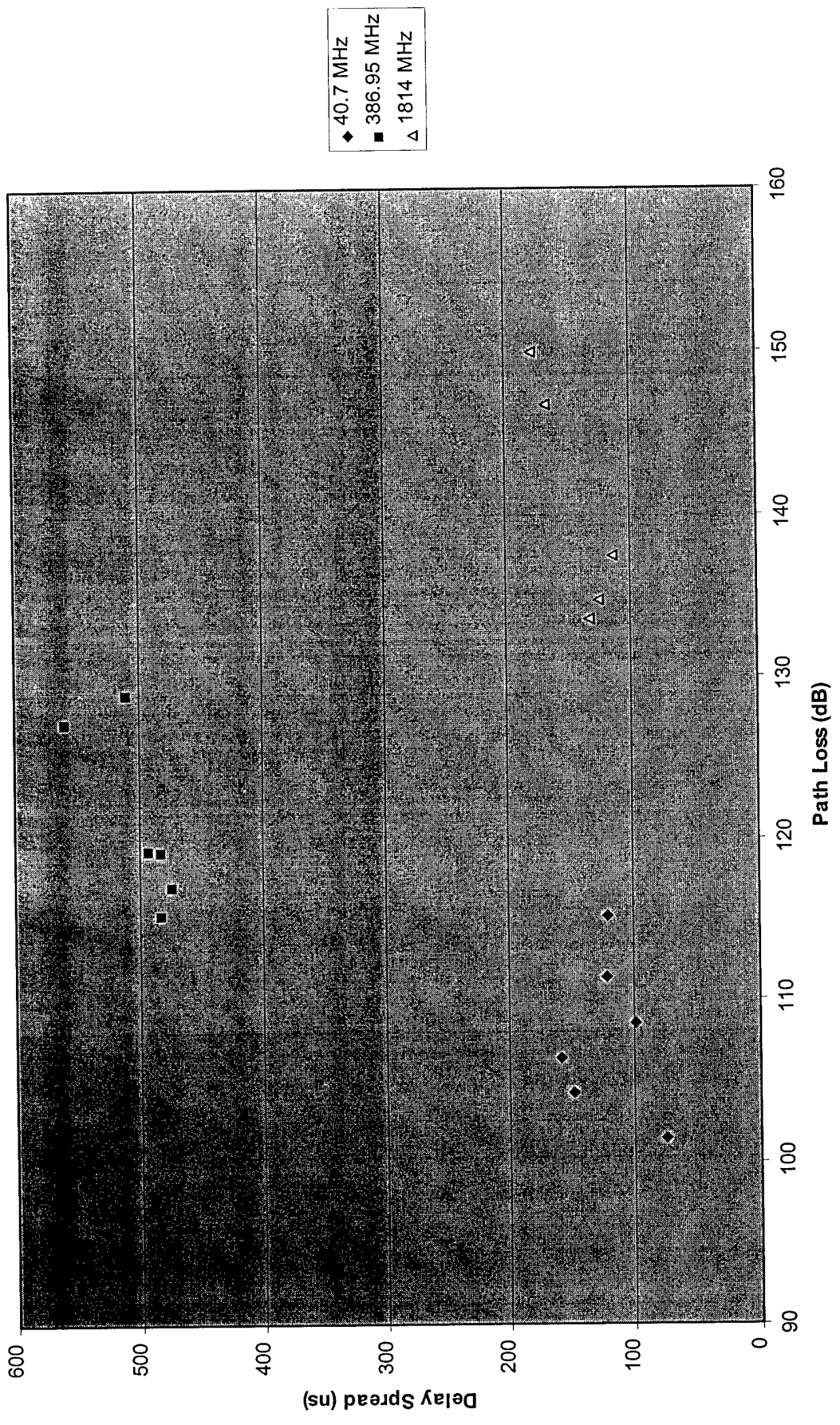
PL - DS Scatter Plot (Soldier Motion, Ch. 13 & 20)





# Balboa Park (0.8 Km)

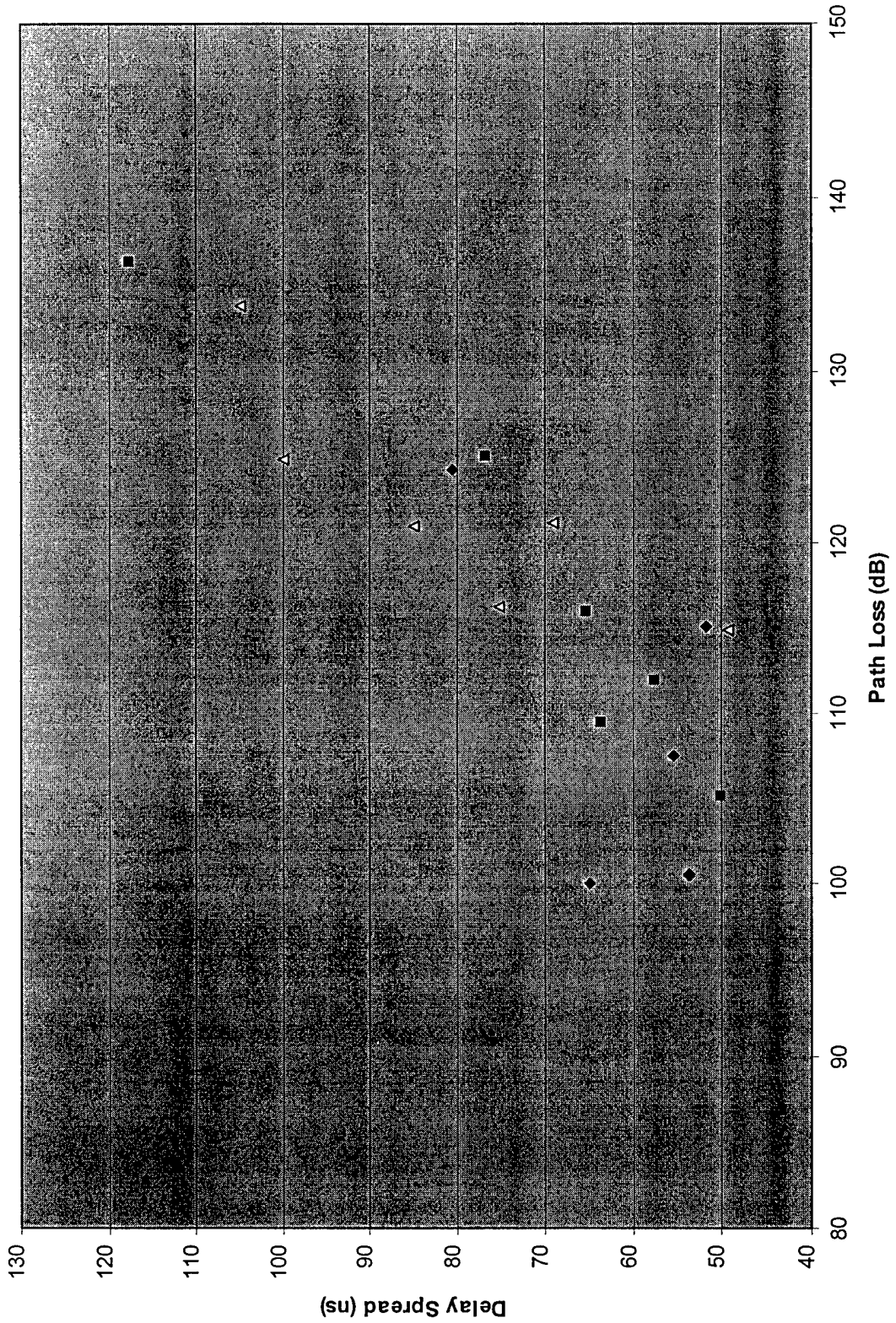
PL - DS Scatter Plot (Block Bldg, Ch. 17)



# Airfield (3.4 Km)



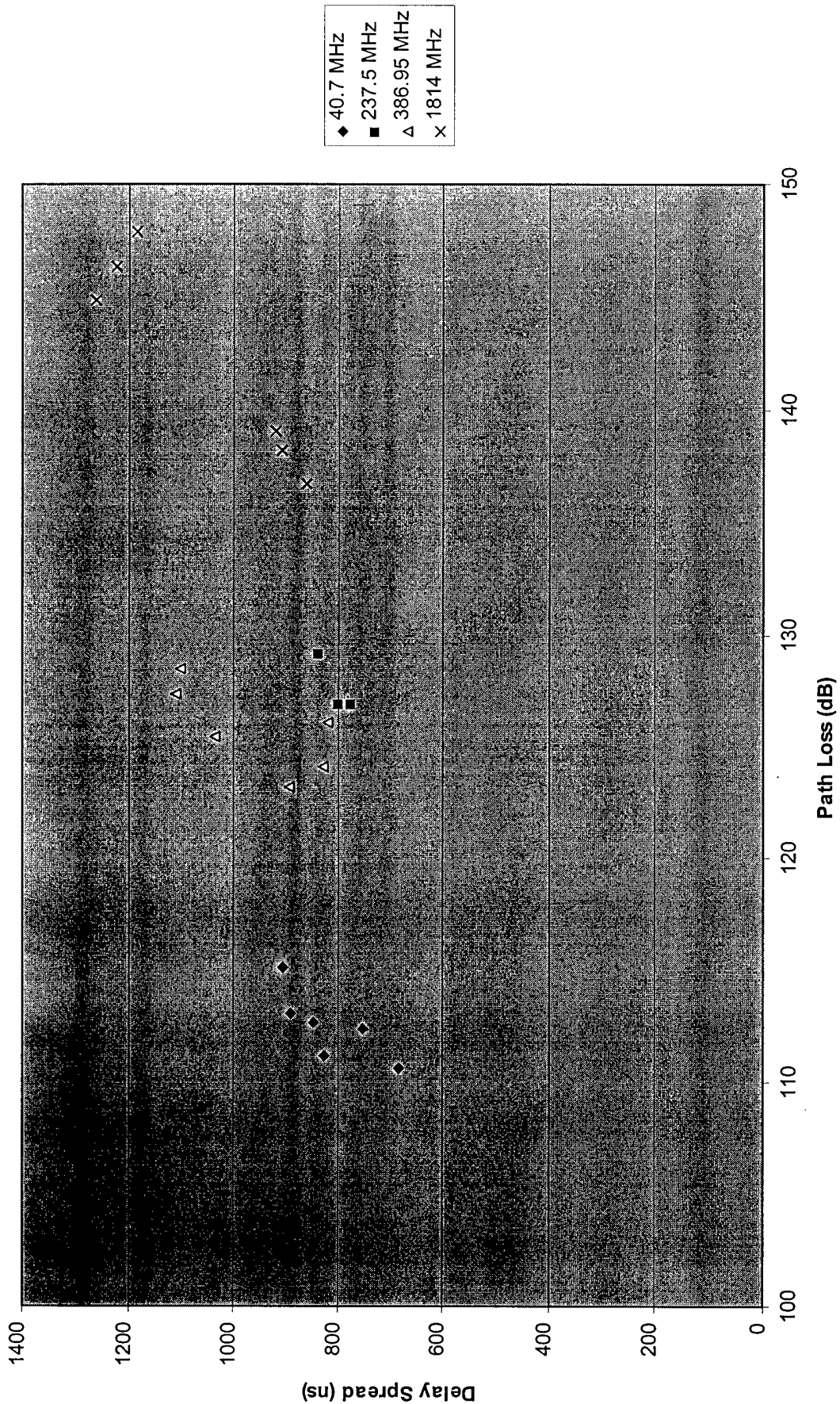
PL - DS Scatter Plot (Near Metal Bldg, Ch. 18)



◆ 40.7 MHz  
■ 386.95 MHz  
△ 1814 MHz

# Urban HMMWV Mount (2.1 Km)

PL - DS Scatter Plot (Urban, Ch. 13)

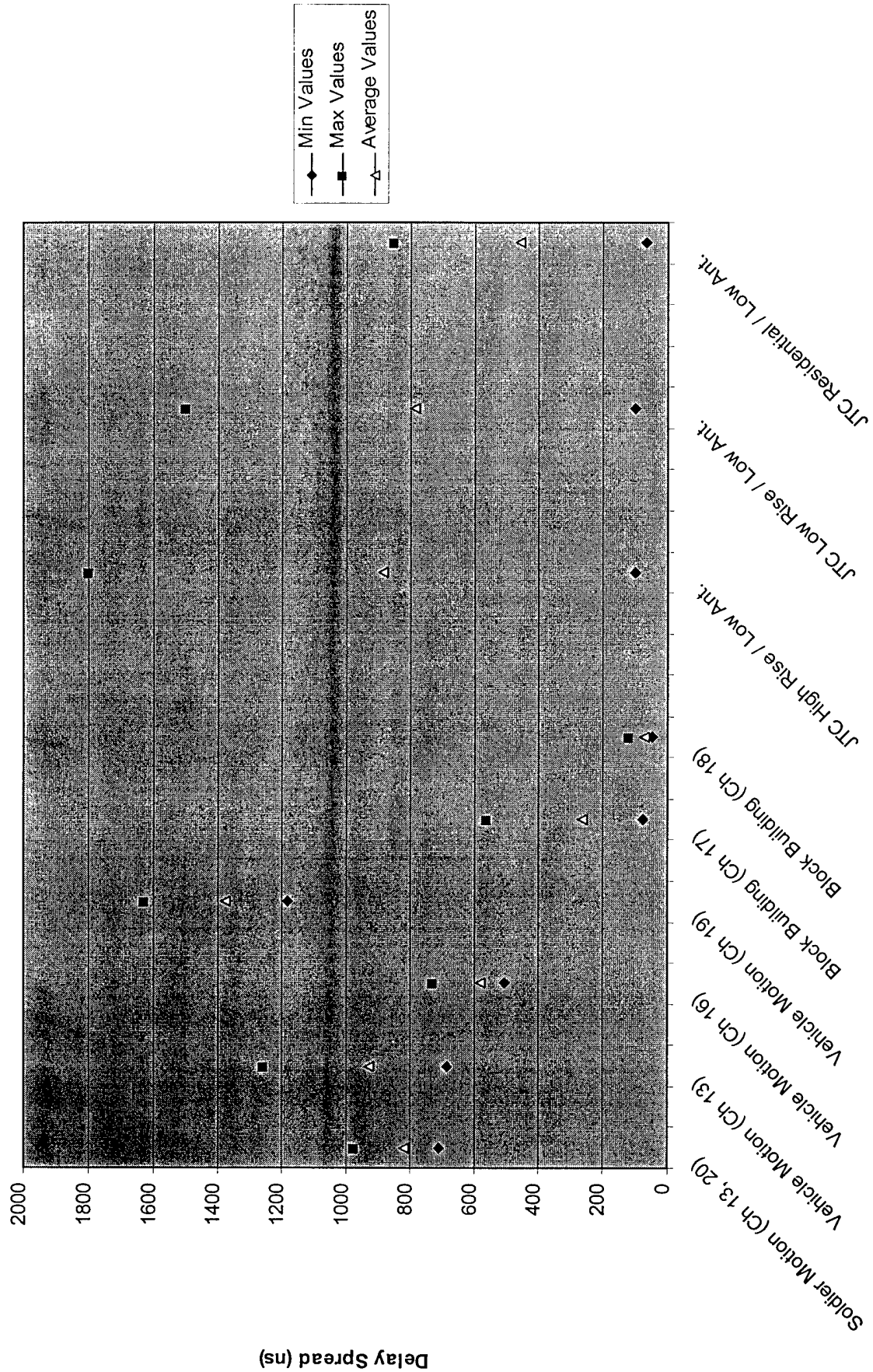


# Outline

- Measurement Goals and Capabilities
- Multipath Tutorial
- Sample Results
  - Urban Channel
    - HMMWV Motion
    - Human Mount w/Motion
    - Various Antenna Heights
  - Many Channels
    - Path Loss vs. Delay Spread
- » Model Comparisons

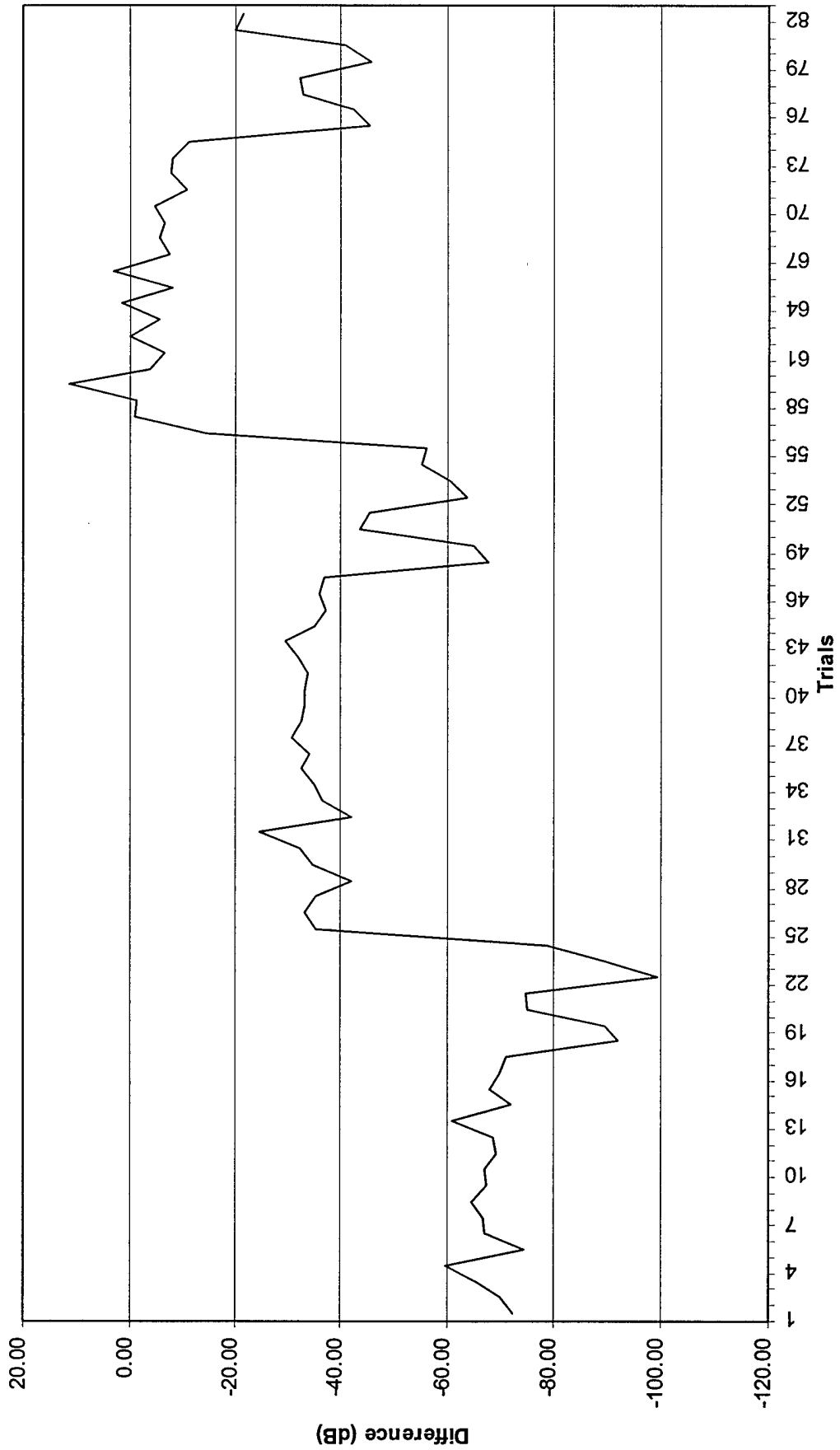


# JTC Model Comparison



# JTC Model Comparison

Measured - JTC (dB)  
Sorted by Frequency/Distance/Channel



# Hata Model Comparison

Measured - HATA (dB)  
Sorted by Frequency/Distance/Channel

