Propagation Measurement Workshop

ITS 3.5 GHz Propagation Measurement System

July 14, 2016

1:00 p.m. to 2:00 p.m.

Institute for Telecommunication Sciences

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Rationale for Measurement System

- We want a system to provide accurate mobile channel measurements
- Capture high-fidelity data that permits flexible post-processing and statistical analysis
- Measure selected propagation effects:
  - Path Loss
  - Fast-fading
  - Examine the local scattering environment
  - Determine the amount of signal power that arrives directly from the transmitter compared to the amount of power that comes from scattering

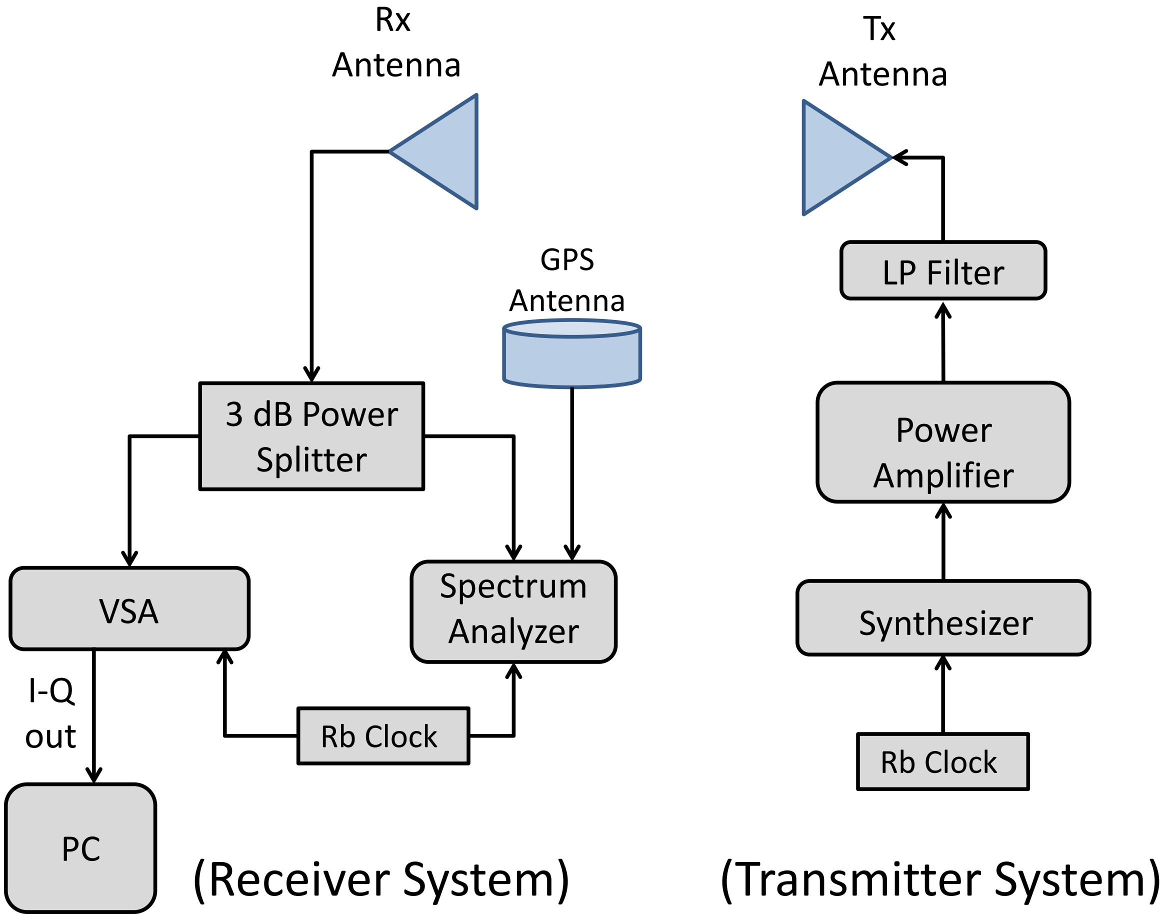
Development of a Suitable System

- Wanted to benchmark an ITS broadband propagation measurement system using a CW measurement system
- Used a portable spectrum analyzer but wanted to do better
- Sound card/receiver…time base issues
- Spectrum analyzer…data latency issues, envelope only

Vector Signal Analyzer

- Baseband complex I-Q data acquisition
- Laboratory grade, self-calibrating
- Continuous I-Q data stream without gaps
- The VSA we used did not permit real-time monitoring of signals
- The VSA we used had no GPS
- We added a portable spectrum analyzer with built-in GPS for signal monitoring and to GPS discipline the VSA data

The ITS Mobile-Channel Measurement System



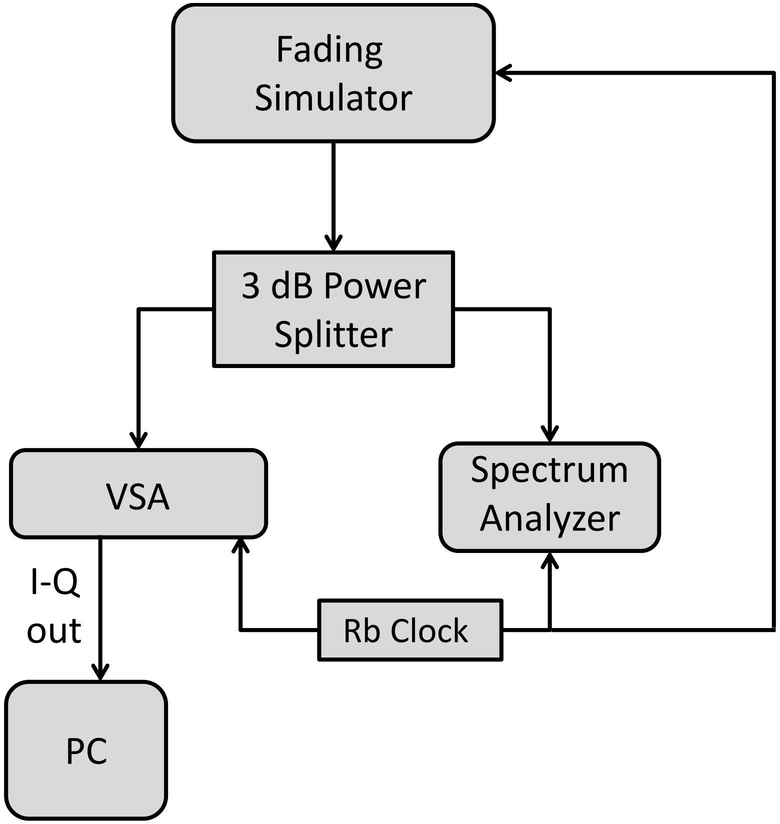
Mobile Channel Measurement System

- Simple fixed-to-mobile transmitter/receiver architecture
- Single-frequency (CW) transmitter at a fixed location
- Receiver located on a mobile platform that moves around on a prescribed route
- Implemented by ITS engineers for both outdoor mobile and indoor building environments

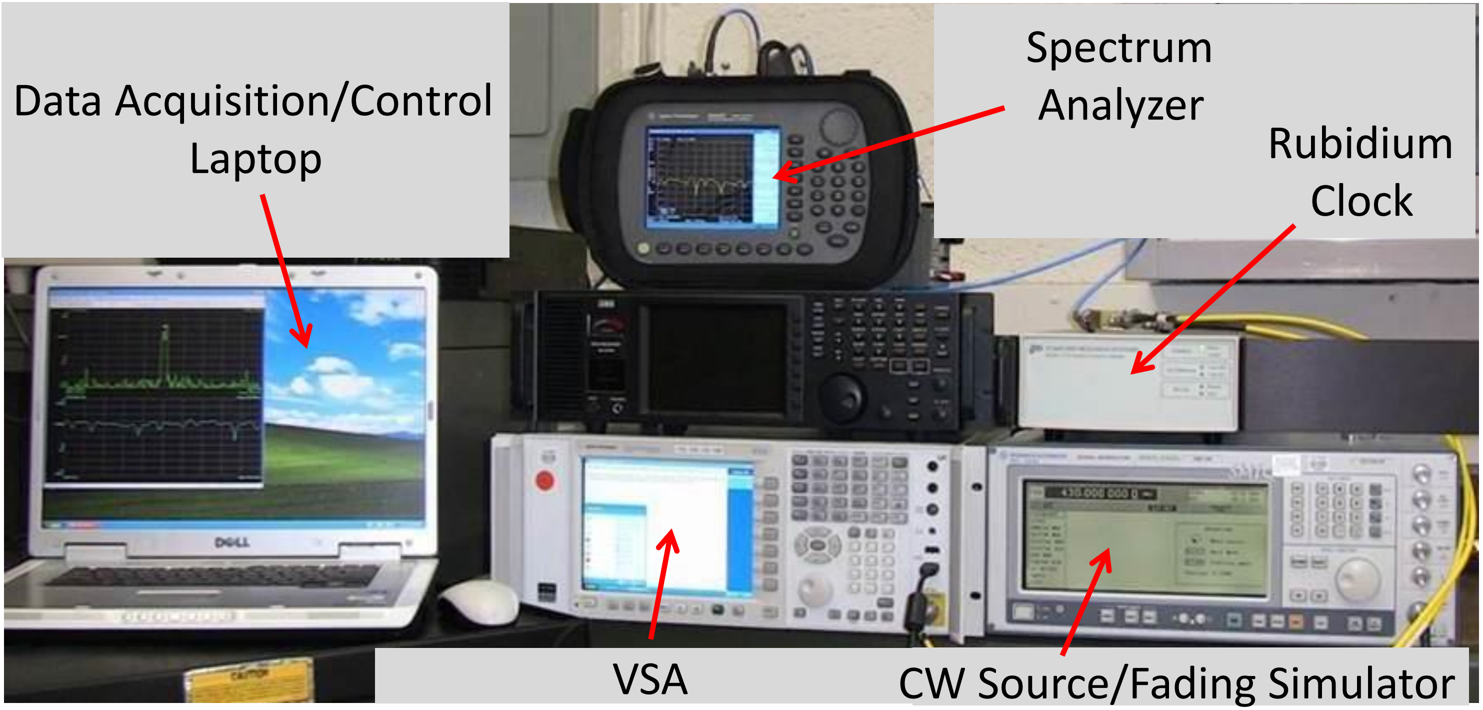
Benchtop Fading Simulation System

- Tool for simulating mobile measurements
- Simulates fast-fading and shadowing effects
- Simulates Rayleigh, Rician, and other channel profiles
- Adjustable velocity, Doppler, shadowing parameters
- We use this system to validate data acquisition parameters and signal processing algorithms
- Deeper understanding of our measurement system

Benchtop Implementation with Fading Simulator



Benchtop Receiver Deployment



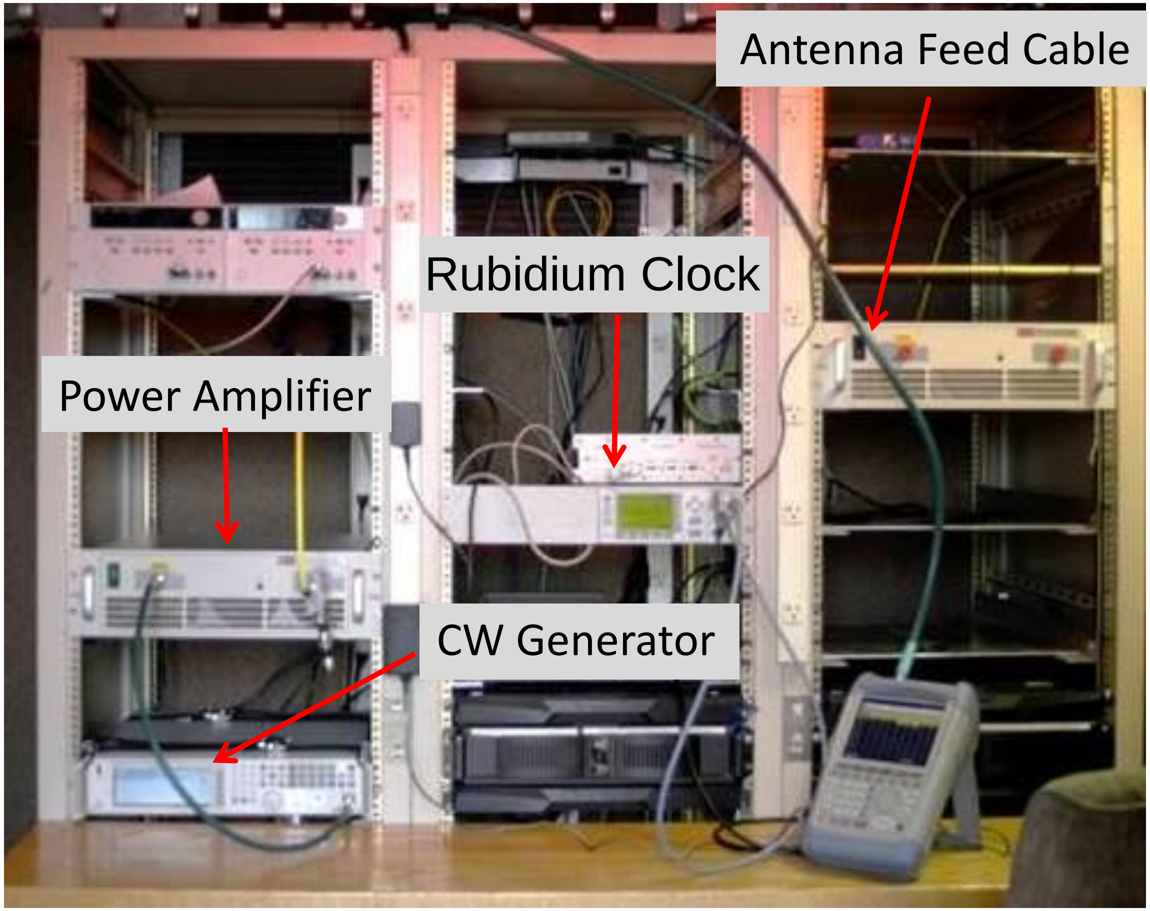
Outdoor Mobile Channel Measurements-1

Fixed Transmitter

Receiving Van

Transmitting System at Fixed Field Location on ITS RSMS Vehicle

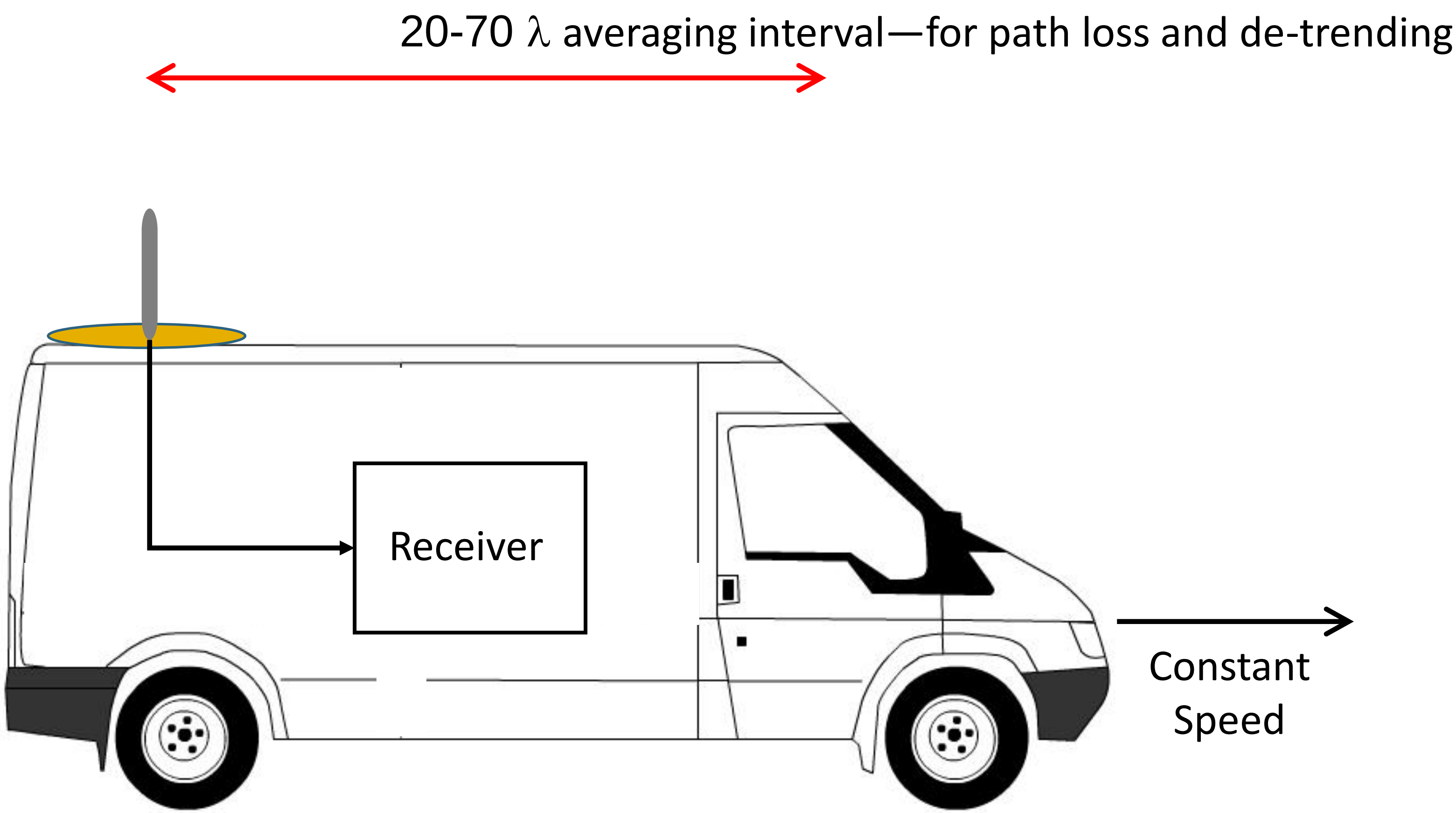
Transmitting System



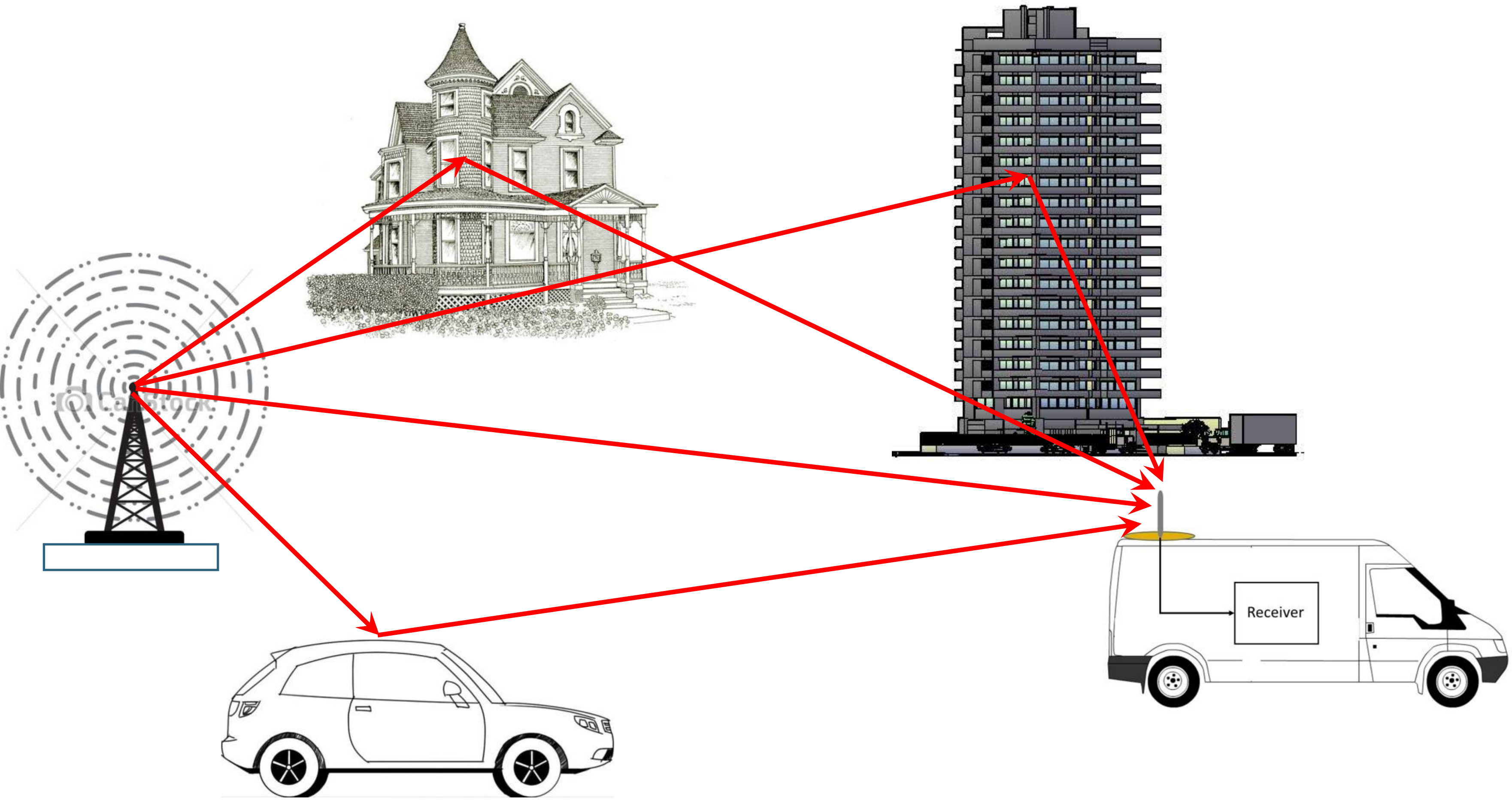
Scanning-Probe Measurement System

- Our measurement system is designed as a scanned probe
- This is our receiving antenna moving through the radio channel on the van
- Ideally we like to do this at a constant velocity—not always possible due to road conditions
- Movement enables us to resolve scatterers
- Movement is needed to estimate a local mean signal level—mandatory for path loss estimation
- Static measurements can be done but difficult to interpret with CW single-frequency source—tuning effects due to both static and moving scatterers

Scanning-probe measurement system



Complex Scattering



Nature of the Received Signal

- We transmit a pure CW signal into the environment
- The signal travels from the transmitter to the receiver over a number of paths:
  - Direct path (if available)
  - Diffracted paths due to blockage of terrain, vegetation, and structures
  - Scattering from nearby buildings, cars, etc.
  - The components constructively and destructively interfere as a function of the motion of the receiver
- This results in a modulated received signal—no longer CW!

What does the received signal look like at 3.5 GHz?

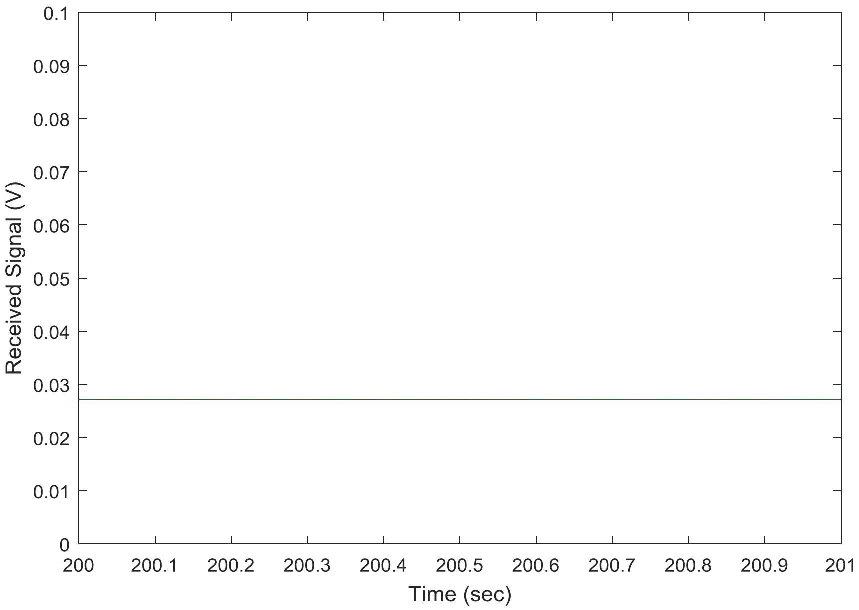
- Benchtop testing with a synthesizer with fading simulator

1) Examine a pure CW signal with no fading
2) Fading simulator
   - Rayleigh fading (non line-of-sight conditions, a rich distribution of local scatterers)
   - At 3.5 GHz, $\lambda = 8.6$ cm
   - Assume a speed of 20 mph (8.9 m/s or 104 λ/s)
   - Maximum Doppler spread=208 Hz
   - VSA captures 3,840 samples/sec

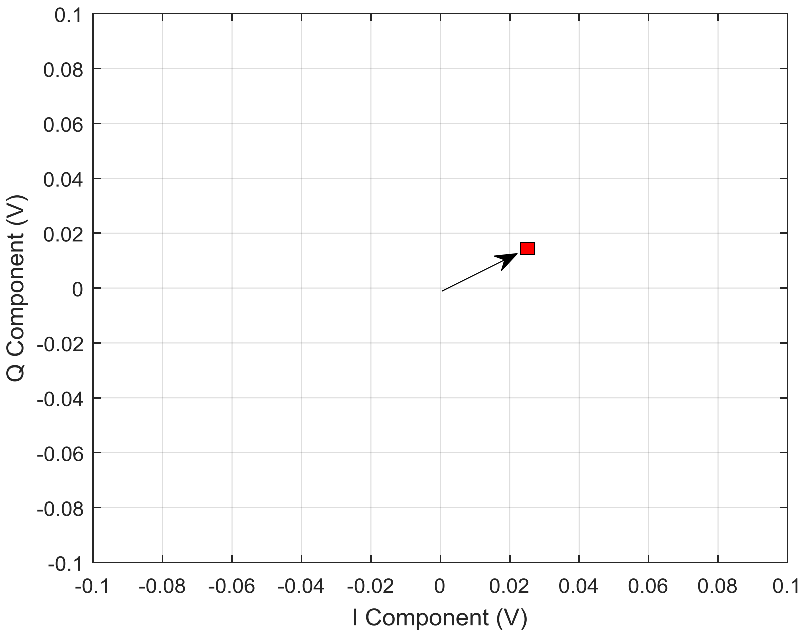
CW Signal Envelope and I-Q

- Single-tone sinusoidal CW signal, no channel variations, 1s record

Envelope



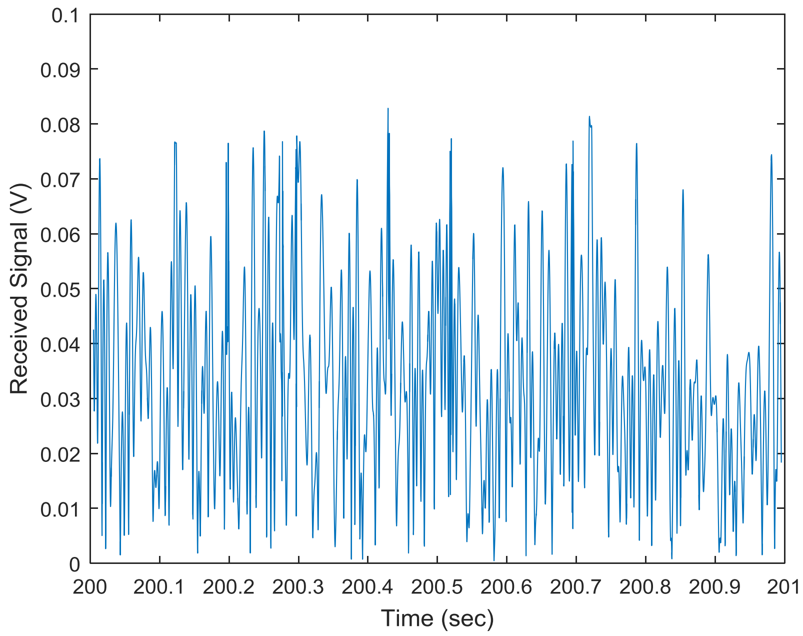
I-Q Components



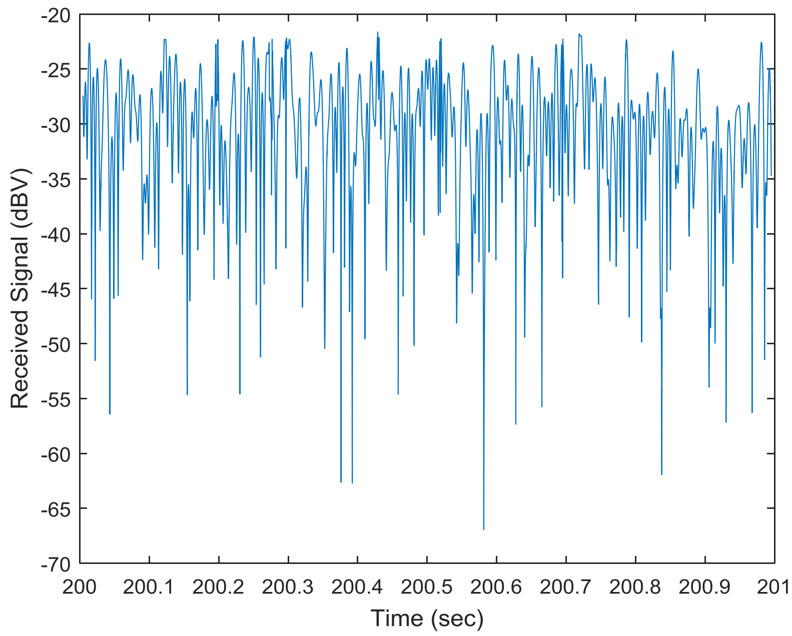
Turn on the Fading Simulator

- Select Rayleigh fading, set speed at 20 mph

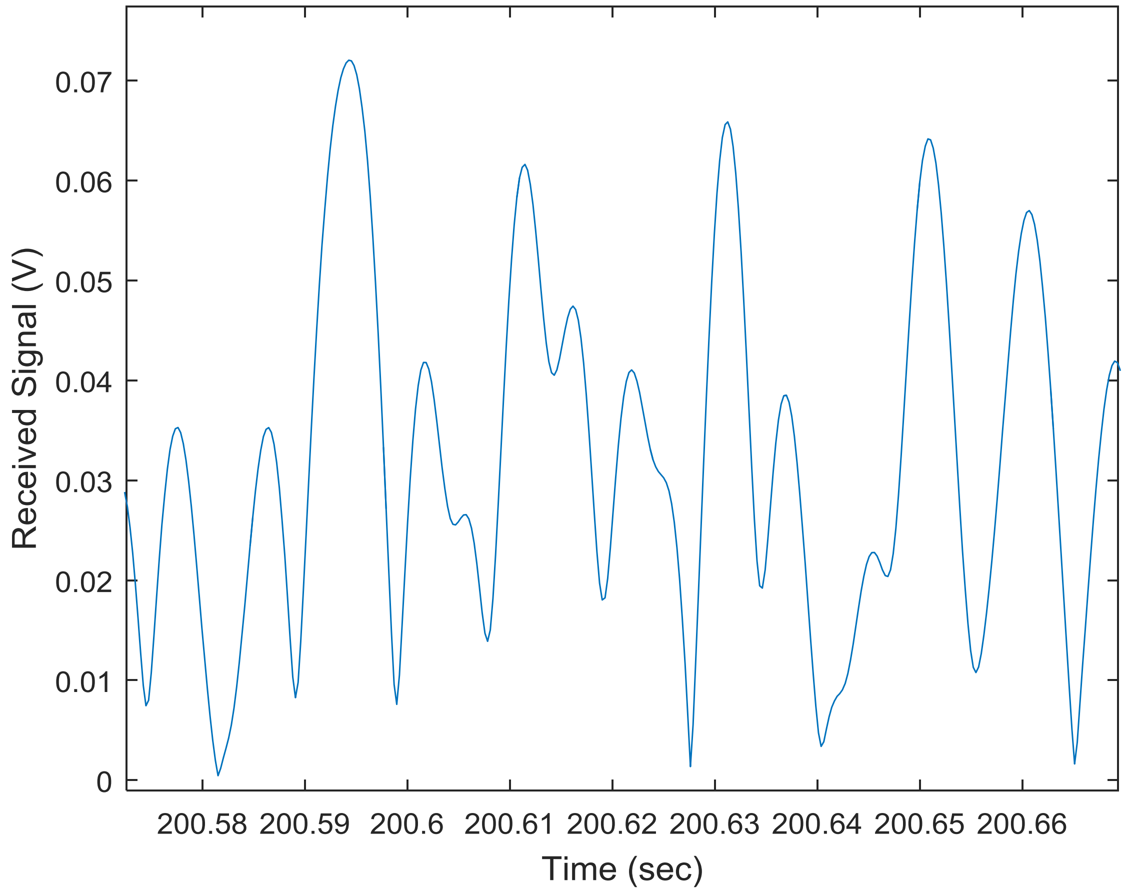
Envelope (V)



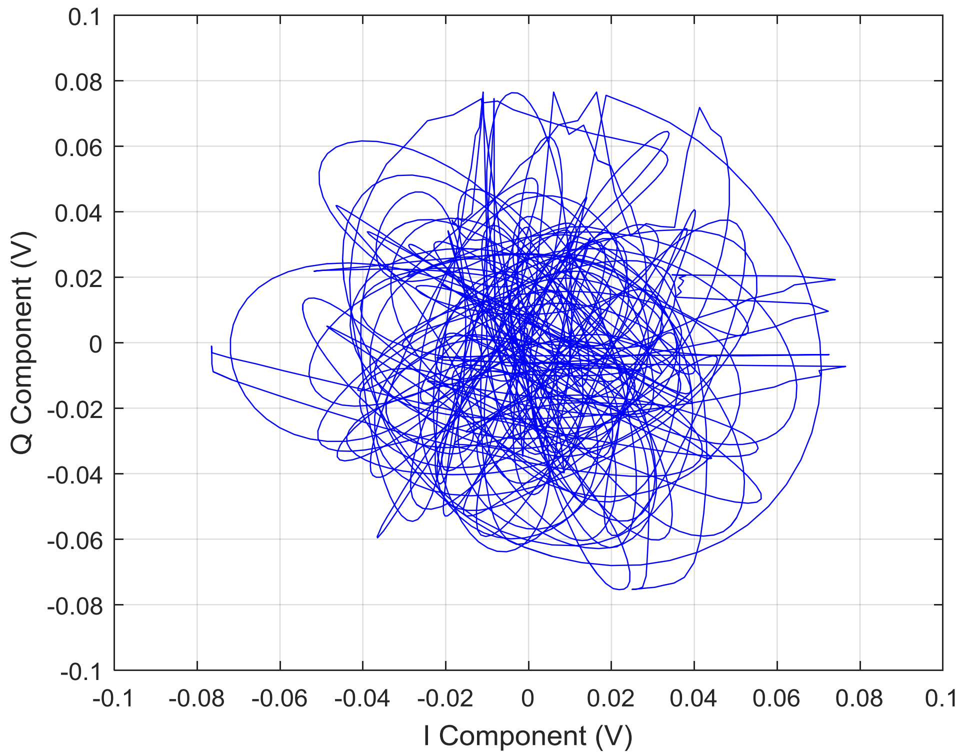
Envelope (dBV)



A Closer Look



I-Q with Rayleigh Fading



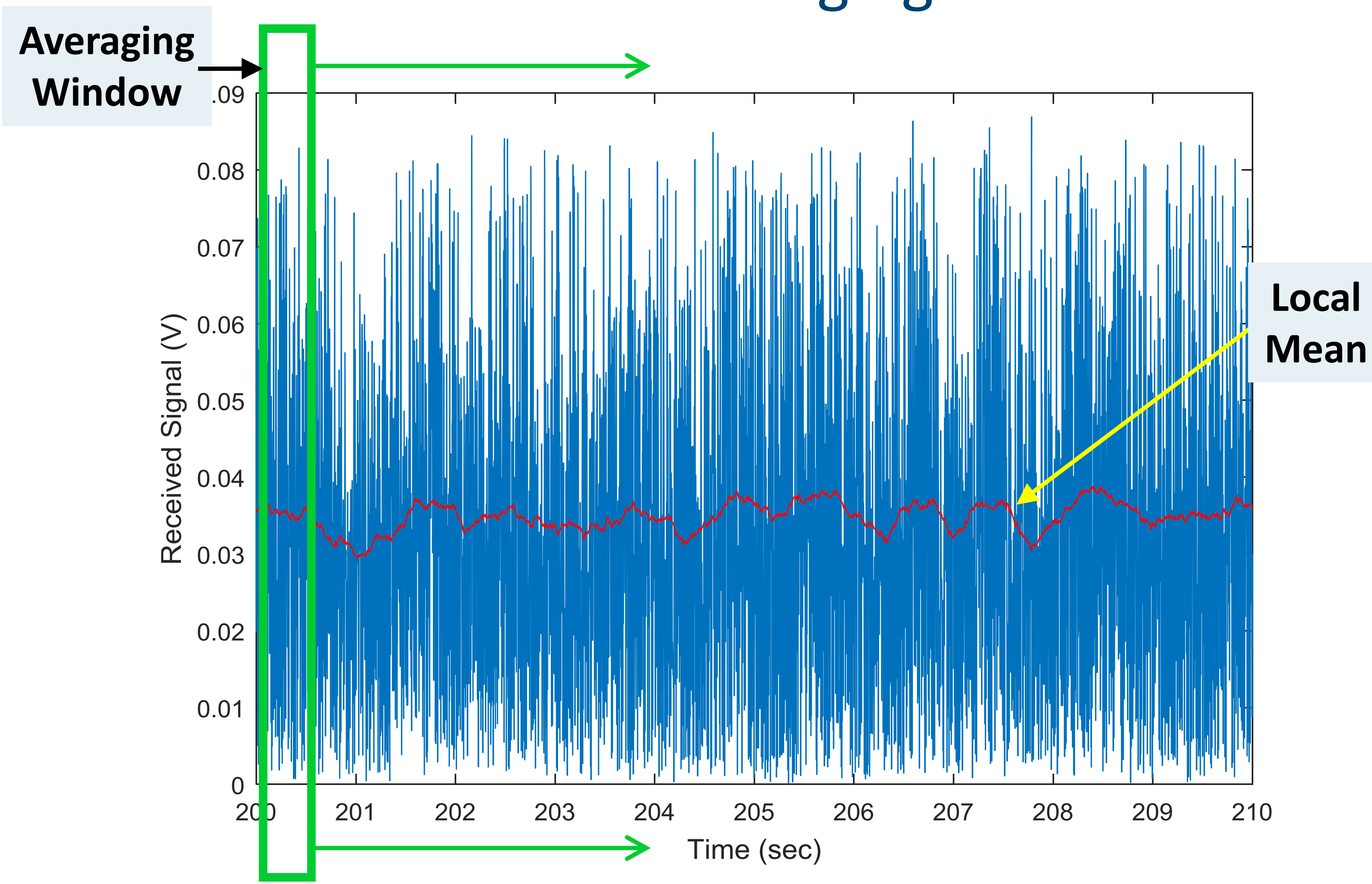
Some Observations

- Envelope and I-Q variations are caused by motion through the channel, channel path variations, and nearby moving objects (cars, people, etc.)
- How do we extract useful information from this data?
- One critical thing to do is to compute a local mean

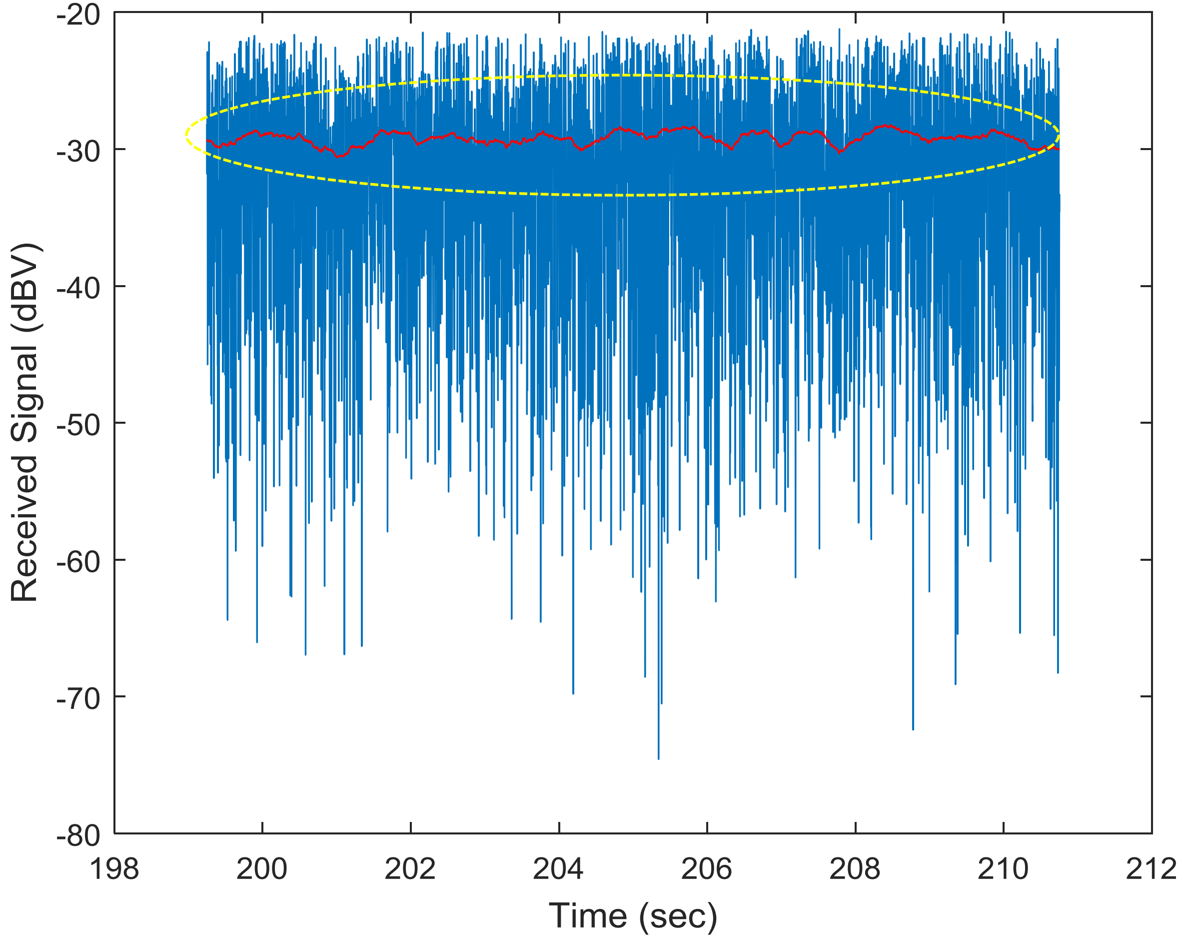
Local Mean

- The local mean is needed to compute path loss and to de-trend data for fast-fading and power spectral analysis
- We compute a local mean by applying a moving average window to our received I-Q voltage envelope
- The averaging window width sets the scanning interval (20λ–70λ)
- This averaging window width also sets minimum spatial resolution for path loss computation—this is a key point!

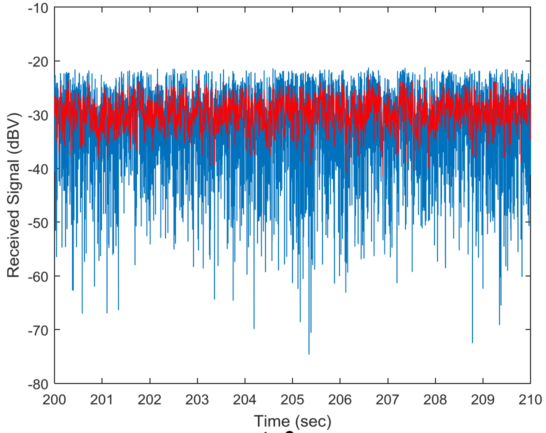
Windowed Averaging 0.5s=52λ interval



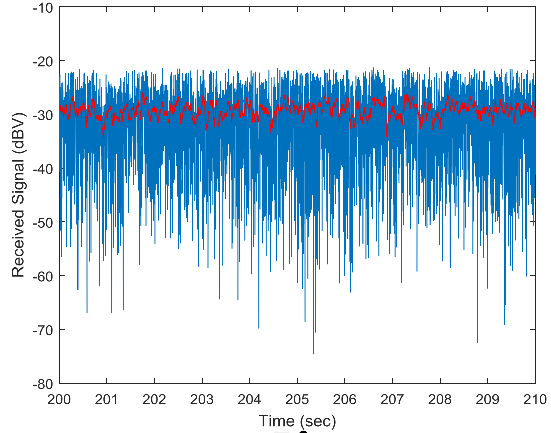
In Decibels—note the variations are roughly 1 dB after averaging



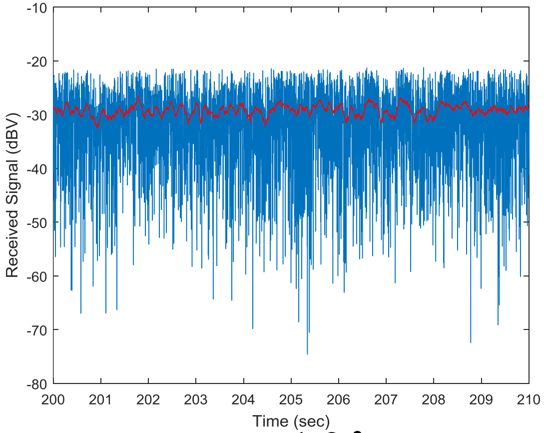
Impact of Averaging Window Width (Rayleigh Fading) raw data (blue) and averaged data (red)



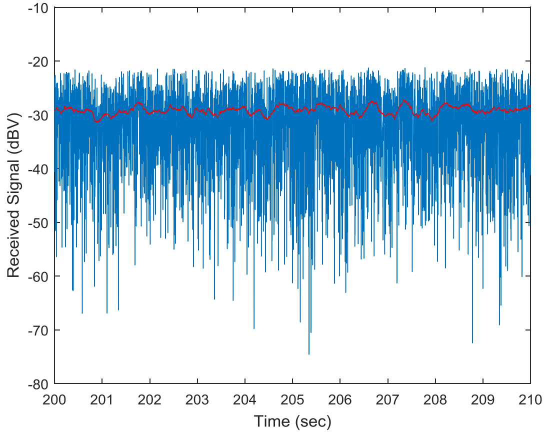
1λ



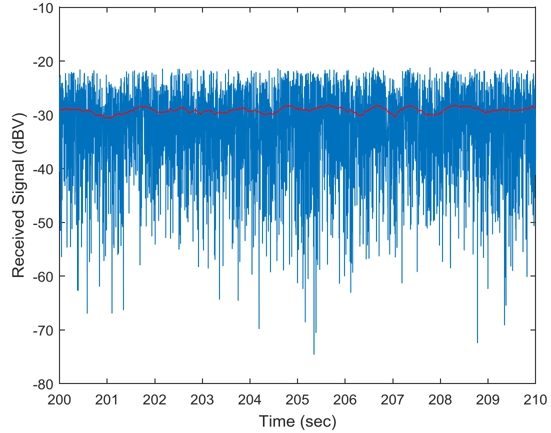
5λ



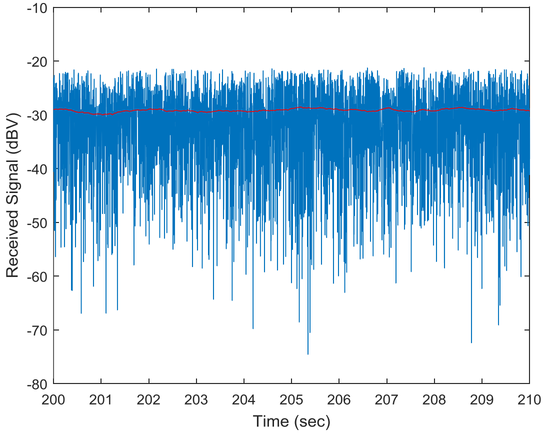
10λ



20λ



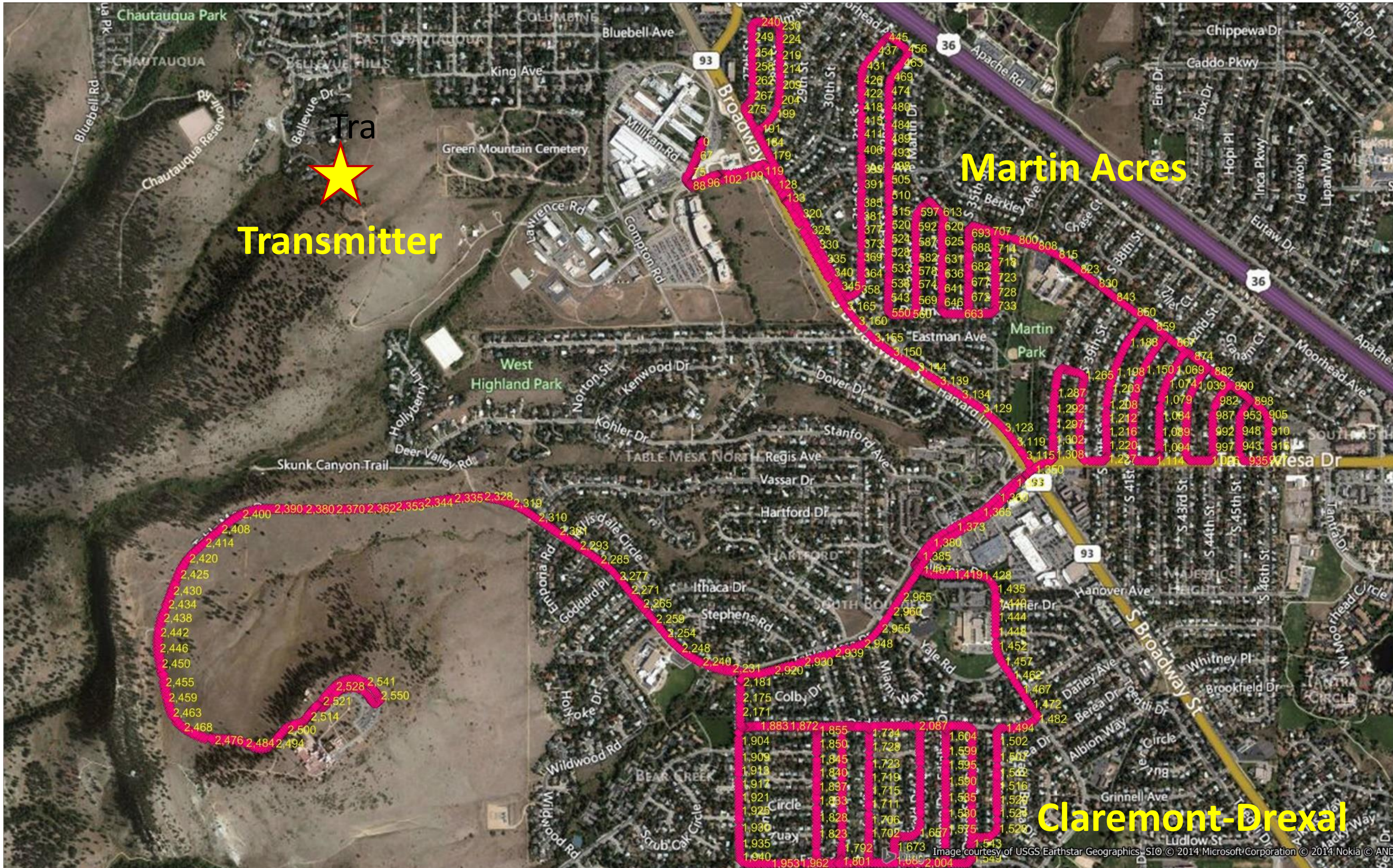
40λ



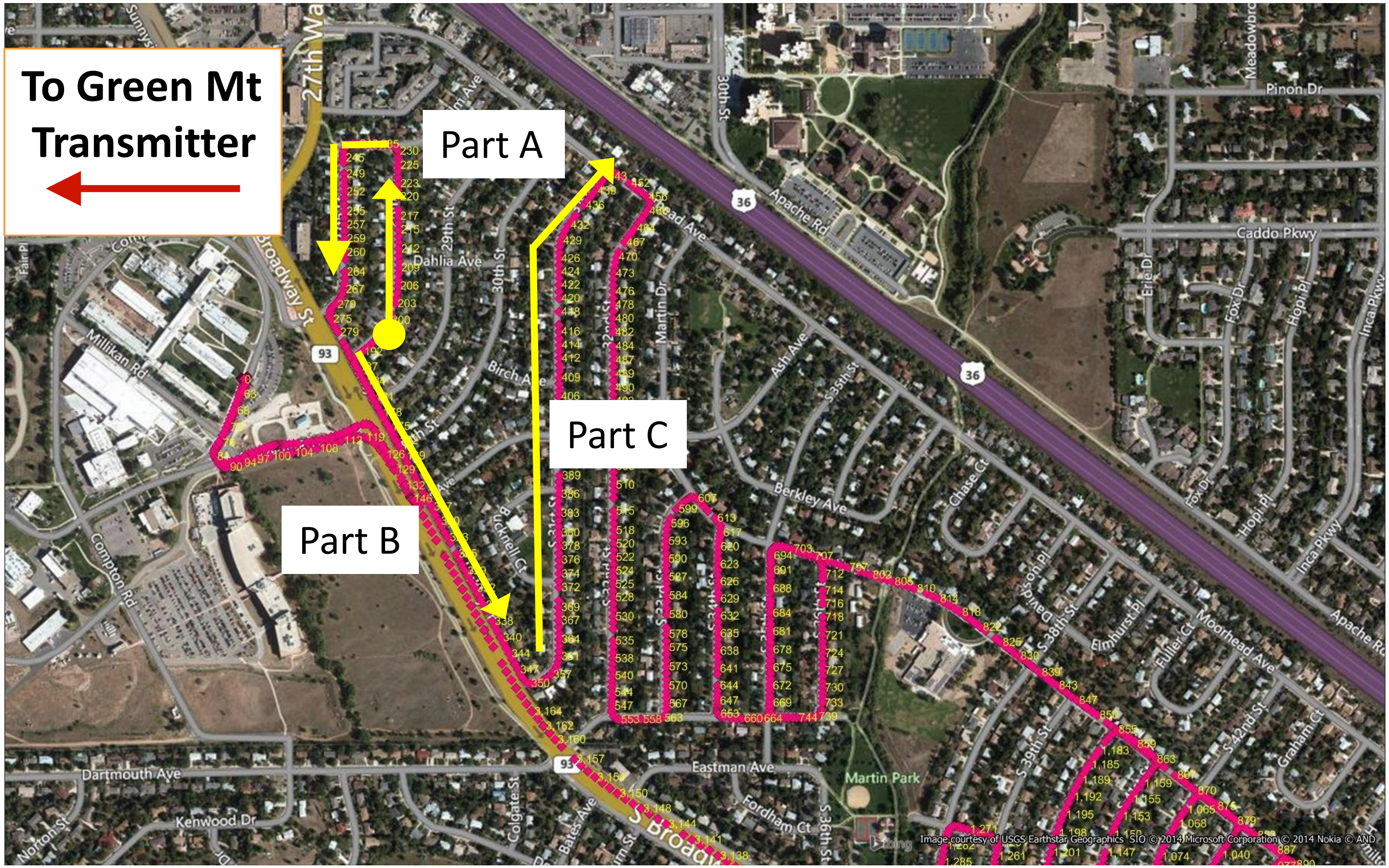
100λ

ITS

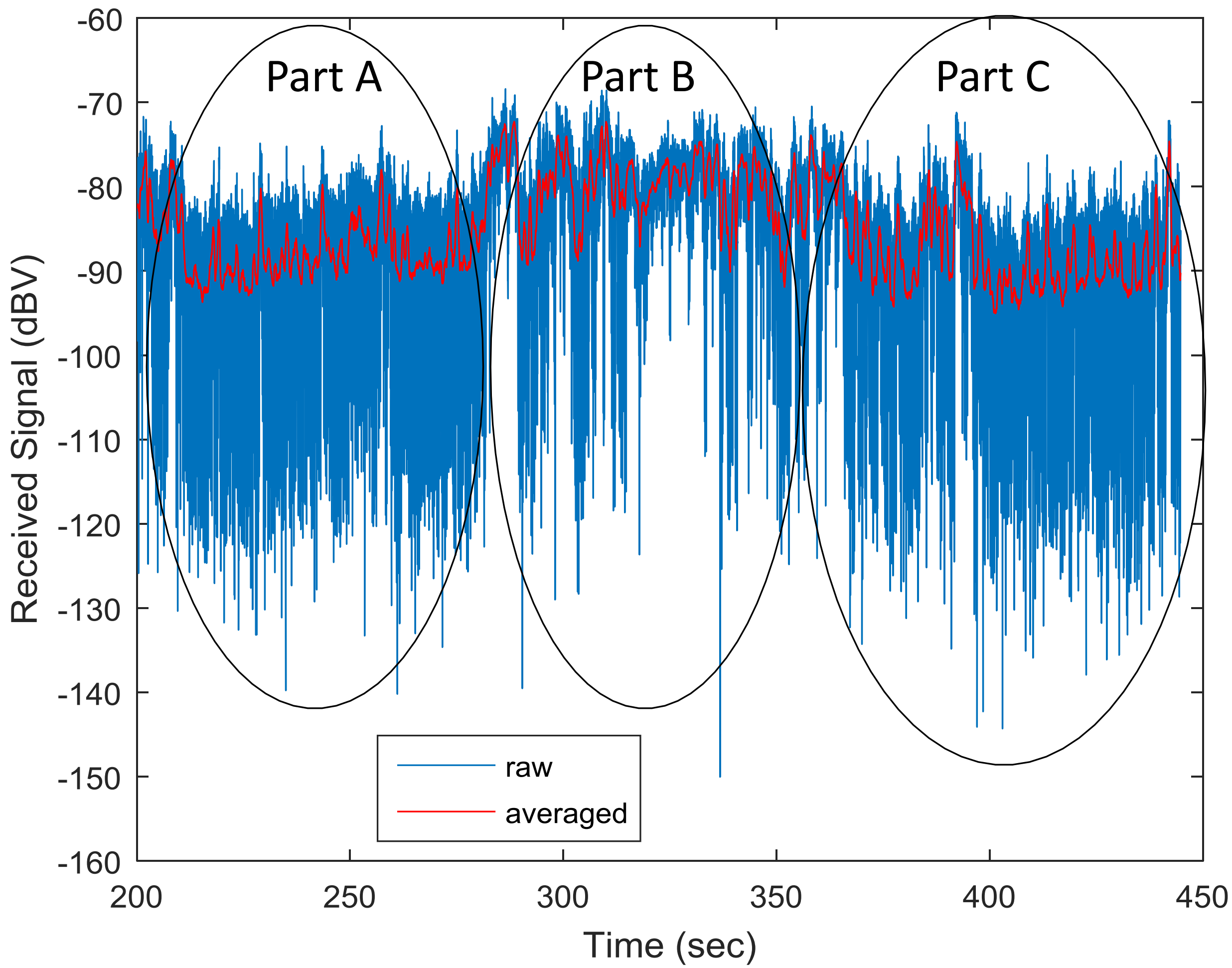
Let’s Look at Some Field Data



West Martin Acres



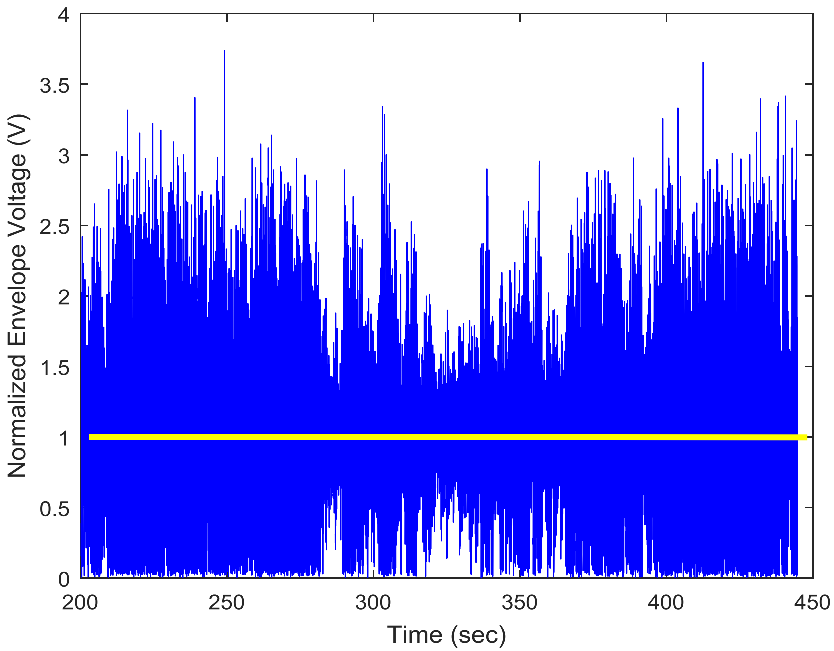
Raw Received Signal

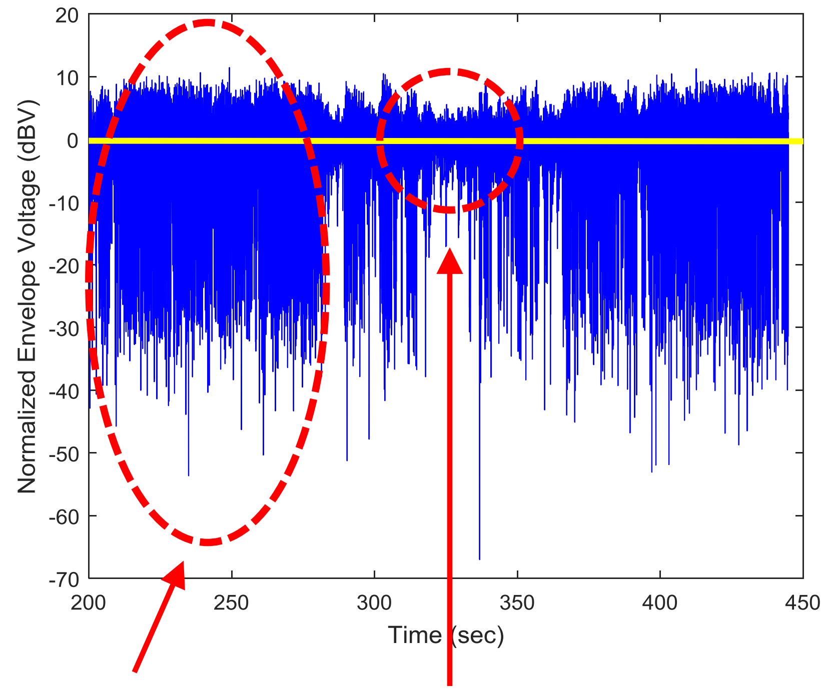


Next Processing Steps

- We want to isolate the fast-fading
- Suppress the effects of path loss and shadowing
- We divide (in linear voltage) the received I-Q time series by the smoothed envelope
- This results in a normalized time series that emphasizes the fast fading and suppresses other effects
- Let’s see what happens…

De-Trended Martin Acres Received Envelope

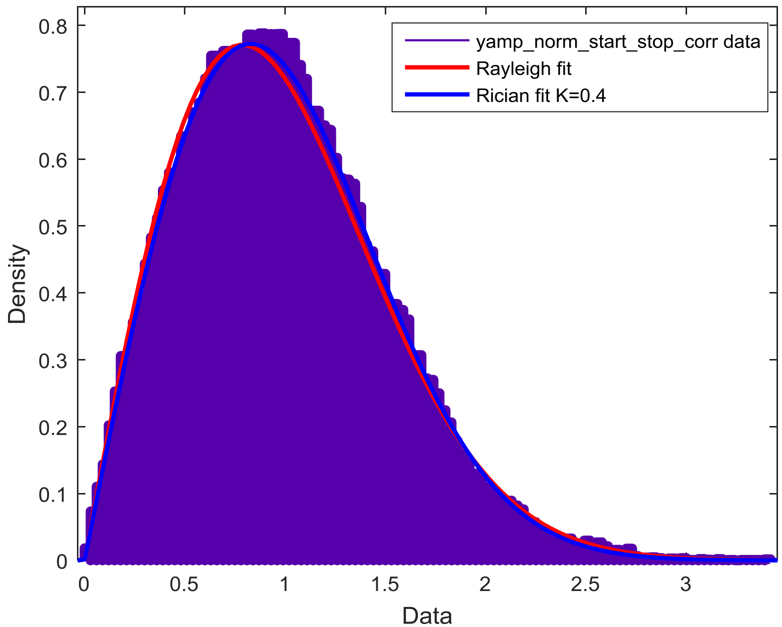


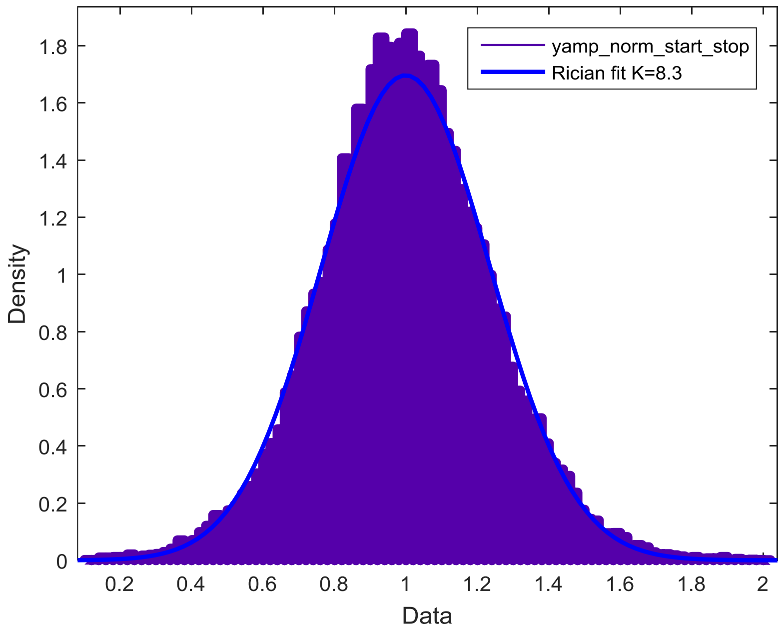


Strong Non Line Of Sight Behavior (NLOS)

Strong Line Of Sight Behavior (LOS)

Examine the Fast-Fading envelope distributions for the NLOS and LOS intervals of the time series





225-245 sec
K-Factor = 0.4
Weak LOS component!

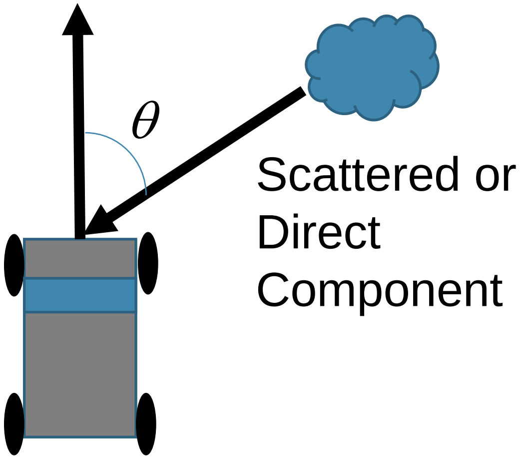
318-332 sec
K-Factor = 8.3
Strong LOS Component!

Power Spectral Analysis

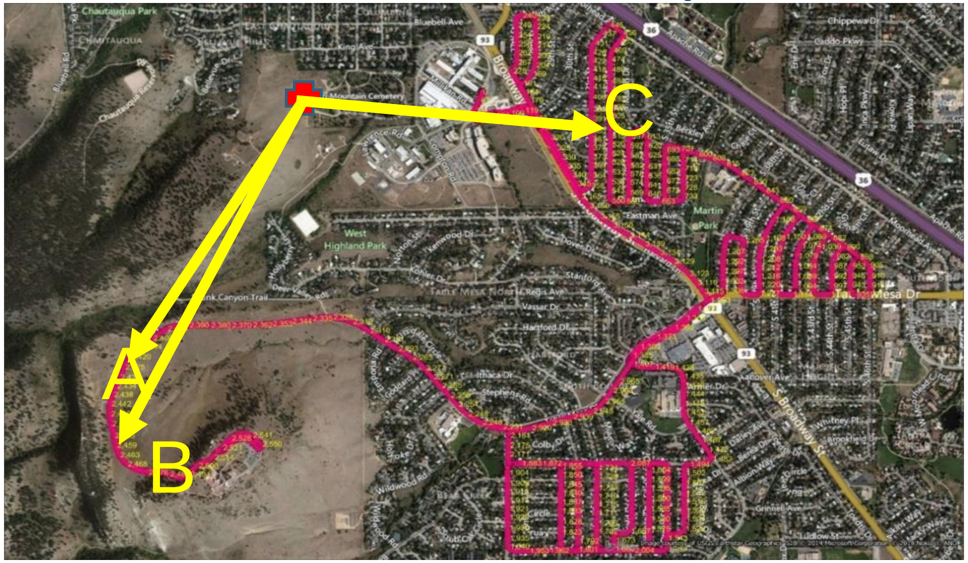
- Requires precise frequency references on both transmitter and receiver
- De-trend received complex baseband I-Q signal to isolate the fast-fading
- Perform power spectral analysis in complex I-Q time series series to yield a baseband Doppler Spectrum
- We used a periodogram and Welch's method
- Requires a stationary time series—can be challenging in field measurements!

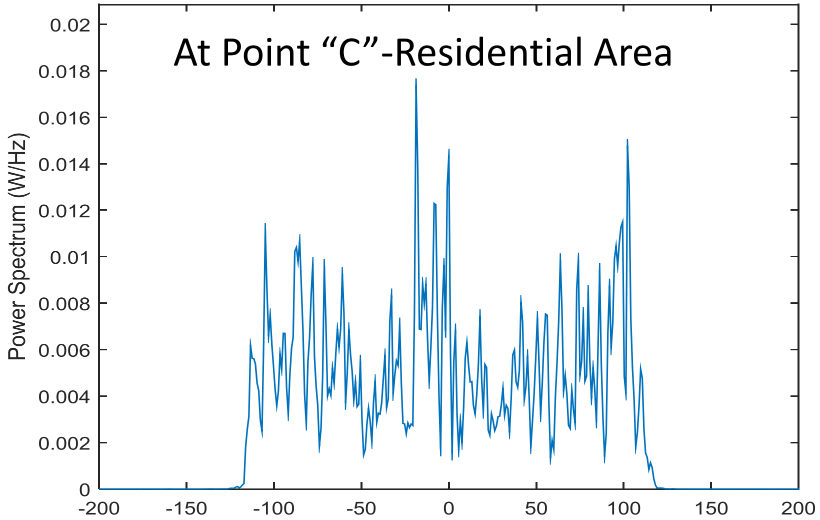
Doppler Shift

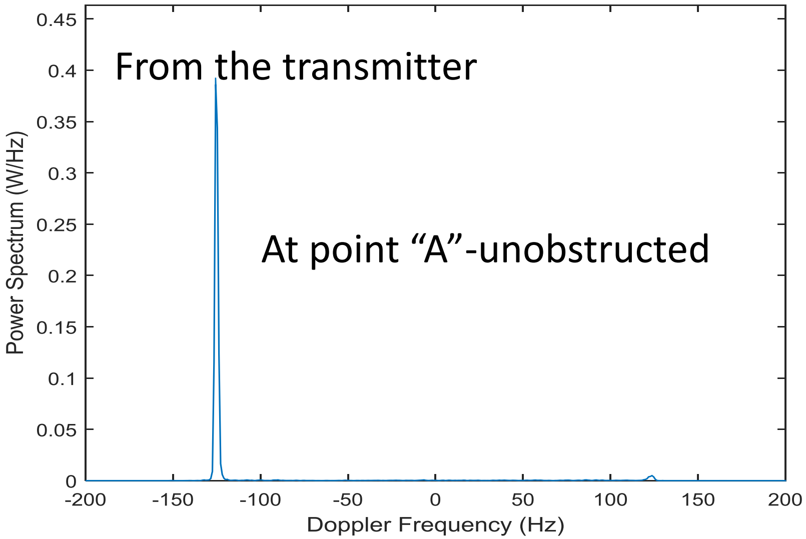
- Doppler shift: $f_d = \frac{Carrier\ Freq * velocity}{3.0 * 10^8} * \cos(\theta)$
- The Doppler frequency is related to the direction of a radio wave relative to the direction of travel of the mobile measurement system
- The “radio wave” could either be directly from the transmitter or a scattered component
- Insight into the scattering environment
- Powerful enhancement!

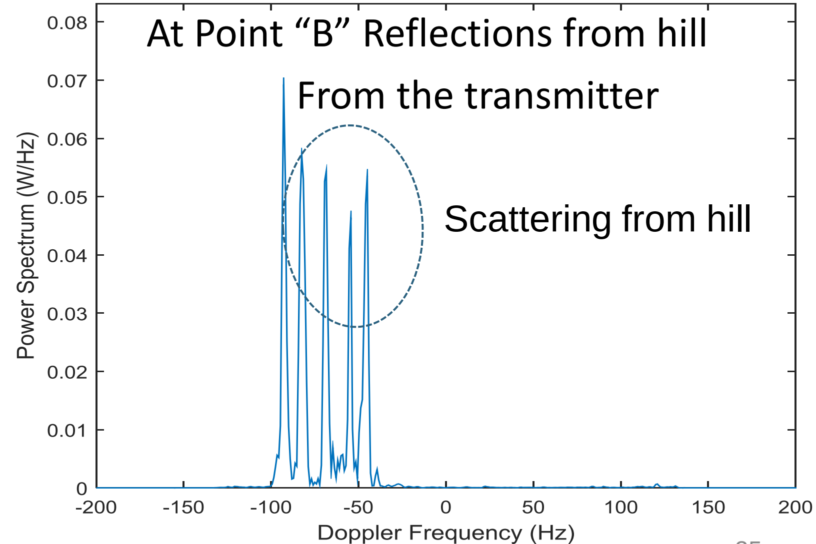


Power Spectra on a Drive Test

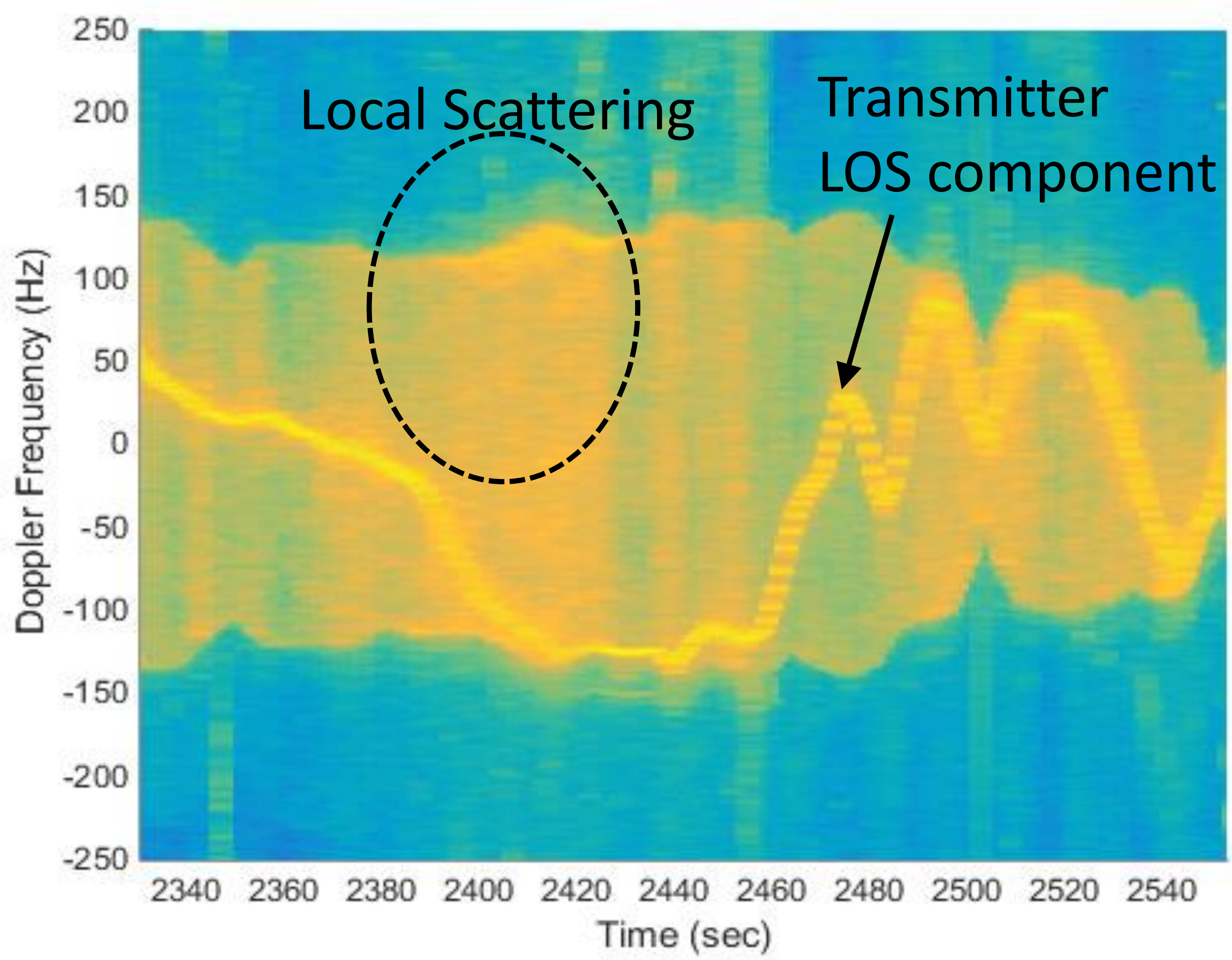








Joint Time Power Spectrum Plot



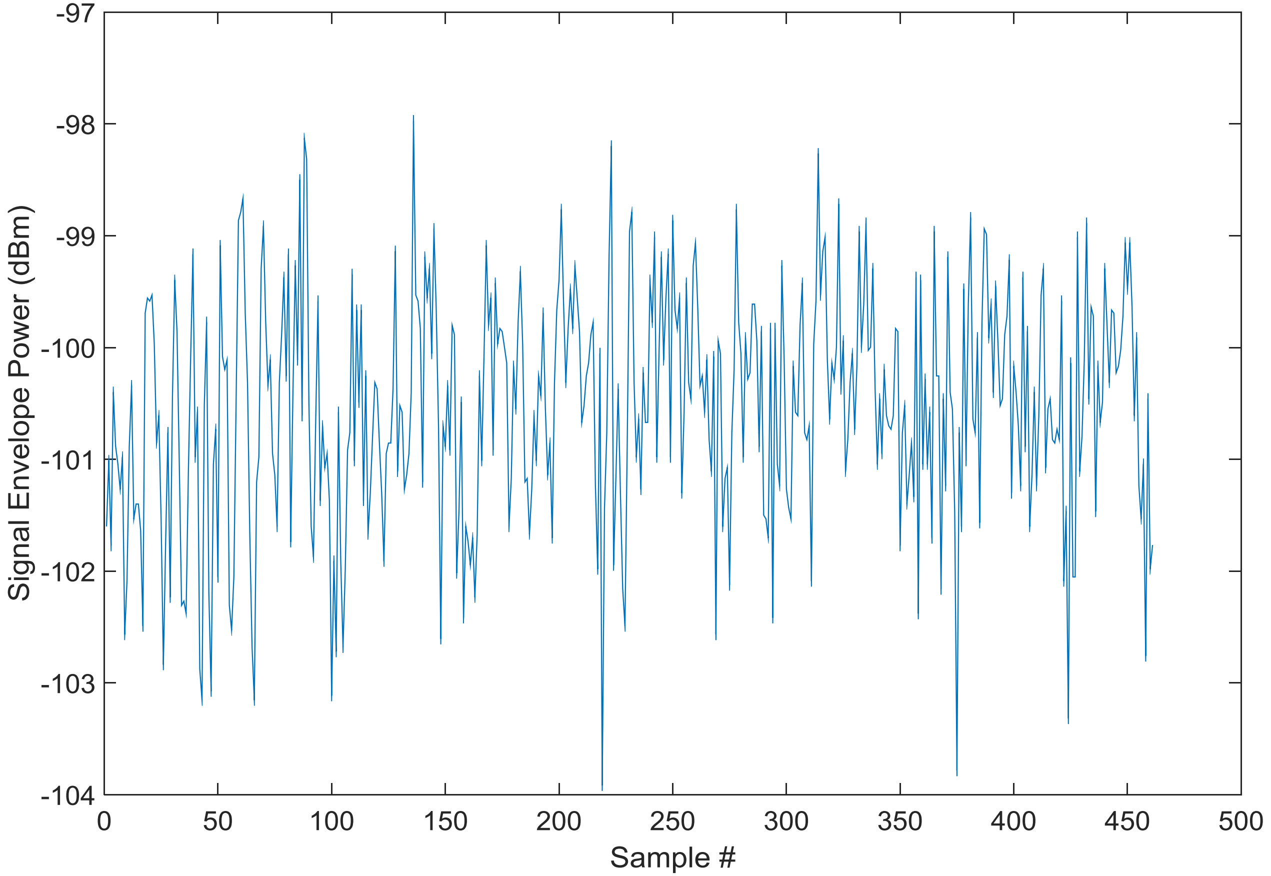
How Do We Geolocate Data in Mobile Outdoor Measurements?

- Operate in the "zero-span" mode, sample detection, RBW=3 kHz, VBW=3 kHz—this mimics the VSA
- Sweep time=500 ms…50% efficiency in terms of data acquisition—limited by data acquisition latency and sweep "flyback"
- Observe fast fading envelope during a sweep interval
- GPS active
- Assigns a GPS time stamp and coordinates to each sweep
- The 500 ms sweep time matches the smoothing window width of the VSA

Benefits

- Time and location reference
- Back up path loss measurement and cross check
- Simple path loss calculation for each 500 ms trace
- Now some details…

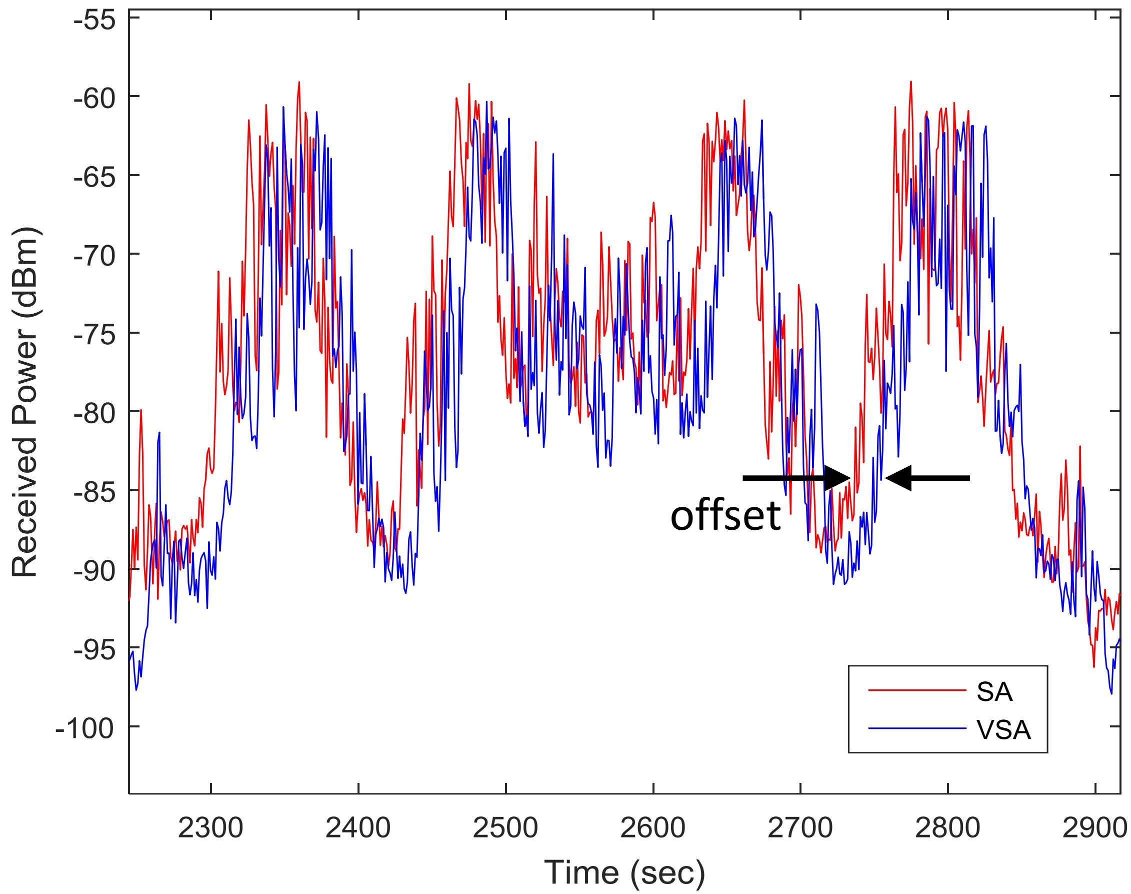
Sample Spectrum Analyzer Trace



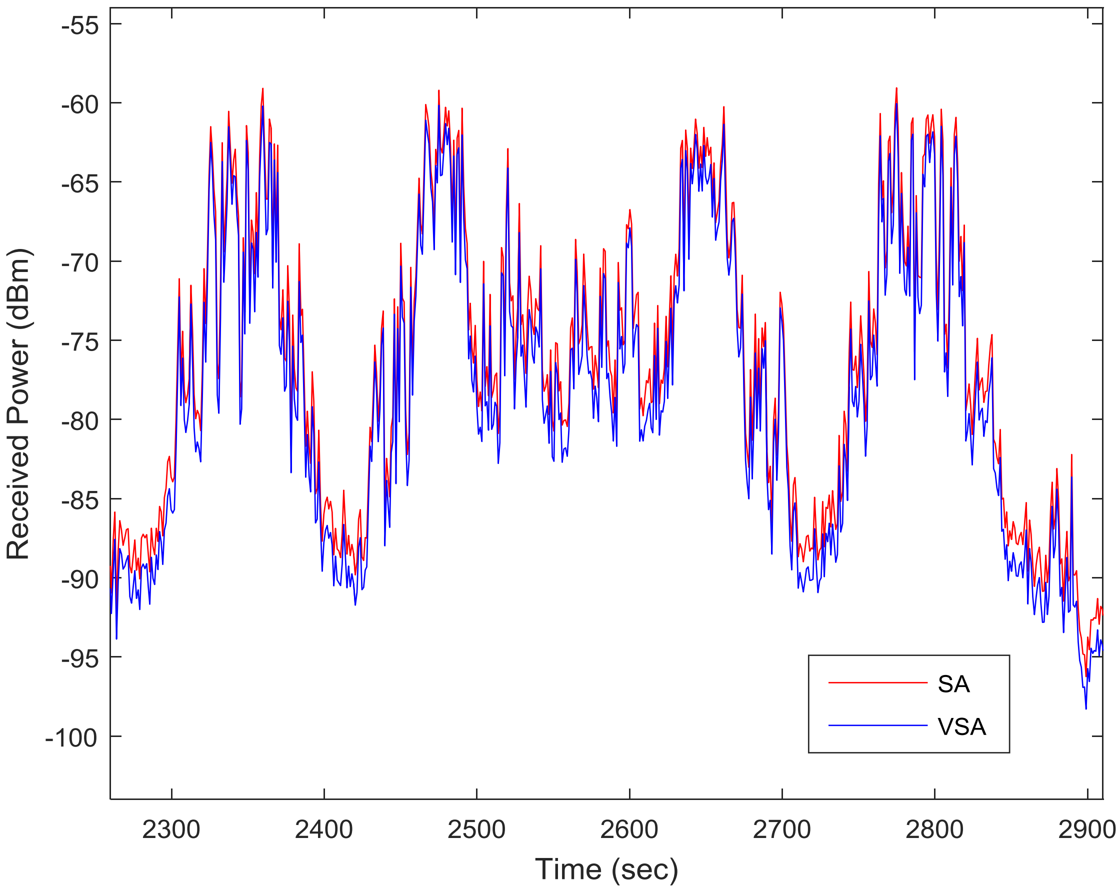
What do we do with the traces?

- Convert to the linear domain (w) and average the entire trace
- Average received power in a trace
- Compare this SA averaged data to VSA windowed-averaged data at the GPS time stamp locations
- Data acquisition initiation times for the VSA and spectrum analyzer differ by 1-10 seconds
- We shift the VSA data to harmonize the sample times

Offset Between VSA and SA before correction



After Shifting the VSA Signal



So how do we get Path loss?

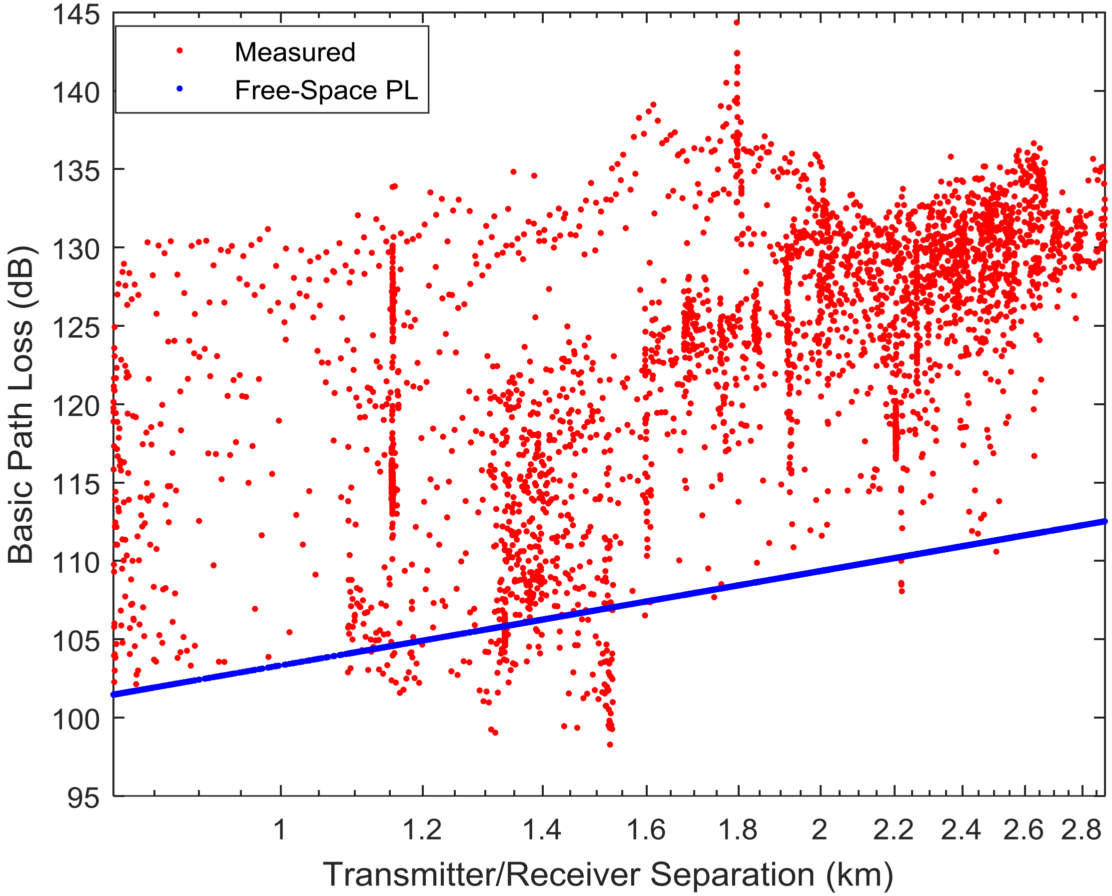
For mobile measurements we calculate basic path loss (dB):

$$BPL(dB)=P_t - P_{\text{windowed VSA}} + (G_t - L_{\text{cables+coupler}}) + (G_r - L_{\text{cables+splitter}})$$

- P_t: transmit power (dBm)
- $P_{\text{windowed VSA}}$: received power (dBm)
- $G_t - L_{\text{cables+coupler}}$: transmit antenna gain and feed network losses (dB)
- $G_r - L_{\text{cables+splitter}}$: receive antenna gain and feed network losses (dB)

- We measure the transmit power with a power meter
- Characterize cables, coupler, and splitter using a precision network analyzer and store resulting S-parameter data
- Use either our own measured antenna patterns or manufacturers' data to compute transmit and receive antenna gains

Path Loss Results



Conclusions

- We have developed a powerful and versatile propagation measurement tool
- We are collaborating with the University of Colorado and NIST CTL to improve geolocation accuracy for our outdoor mobile measurements as well as in-building measurements
- Working on joint ITS/NIST CTL project to intercompare channel Sounders and assess measurement uncertainties
- Goal: develop best measurement practices
- Thanks!

Questions?

Contact info for questions

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ITS Website: http://its.bldrdoc.gov

Look forward to discussions and answering questions ☺

References

[1] R.T. Johnk, C.A. Hammerschmidt, M.A. McFarland, J.J. Lemmon, “A Fast-Fading Mobile Channel Measurement System,” *IEEE International Symposium on EMC,* August 2012, pp. 584-589.

[2] R. Vaughan and J. B. Andersen, *Channels Propagation and Antennas for Mobile Communications,* The Institution of Electrical Engineers, London, U.K, 2003.

[3] J.D. Parsons, *The Mobile Radio Propagation Channel,* New York, NY, John Wiley & Sons, 1992.

[4] S. M. Kay, *Modern Spectral Estimation,* Upper Saddle River, N.J., Prentice-Hall, 1987.

[5] P.D. Welch, “The use of the Fast Fourier Transform for the estimation of power spectra: A method of time-averaging over short, modified periodograms”, *IEEE Transactions on Audio and Electroacoustics, AU-15(2), pp. 70-73, 1967.*