



# **Mobile-to-Mobile Wireless Propagation Measurement Systems**

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**Institute for Telecommunication Sciences**

**Boulder, Colorado**



# Overview

- Project Background/Overview
- Measurement System Description
- Measurement Locations
- Selected Measurement Results
- Alternative Measurement Approaches
- Summary and Conclusions



# Short Range (Mobile-to-Mobile) Project Background

- Measure Radio Propagation Between (Mobile) Terminals Immersed in Clutter at Short Range
- $d \leq 2\text{-}3 \text{ km}$
- Low Terminal Heights (Typically  $h_{t,r} \leq 3 \text{ m}$ )
- Frequency Range:  $\sim 150 \text{ MHz} - 6000 \text{ MHz}$
- Although All Land-Use/Land-Clutter Categories are of Interest, Urban Category has Highest Priority



# Short Range (Mobile-to-Mobile) Project Background

- Pseudo Mobile Realization (Fixed Tx, Mobile Rx )

## Locations so far

- Downtown Denver High-Rise Environment—deep urban canyon
- Large Parking Lot, Empty & Full, Downtown Denver, CO
- Low-Rise Urban Downtown Boulder, CO
- Rural—Country road NW of Boulder, CO
- Mixed—Residential & open Boulder, CO



# The System

- Transmitter Truck-stationary
- Receiver Van-driven in prescribed patterns



Transmitter Truck



Receiver Truck



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# General Features

- Measure over large frequency range: 183-5750 MHz
- Seven Channels: 183, 430, 915, 1360, 1602, 2260, and 5750 MHz
- 511 bit PN codes transmitted into the environment via binary PSK
- Transmitter/Receiver Phase synchronization maintained using Rubidium clocks
- Variable chip rates: 2, 5, 10 Mb/sec—avoid interference with other services
- Transmitted power levels 1-8 W



# Measurement Frequencies and Bandwidths

Configuration	Channel Number	Frequency (MHz)	Bit Rate (MHz)	Processing Bandwidth's		
				Max (MHz)	3dB (MHz)	Min (kHz)
<b>Tx/Rx 1</b>	1	430	10	20	10	19.6
	2	1350	10	20	10	19.6
	3	2260	10	20	10	19.6
	4	5750	10	20	10	19.6
<b>Tx/Rx 2</b>	1	183	2	4	2	3.9
	2	915	10	20	10	19.6
	3	1602.5	5	10	5	9.8
	4	5750	10	20	10	19.6



## General Features cont'd

- Power-delay profiles generated using cross-correlation of transmitted and received P/N sequences
- High-fidelity time-domain information
- RMS delay spread, range, multipath effects
- We obtain frequency-domain information as well
- excess path loss, basic path loss, fading
- We can examine both broadband and narrowband fading



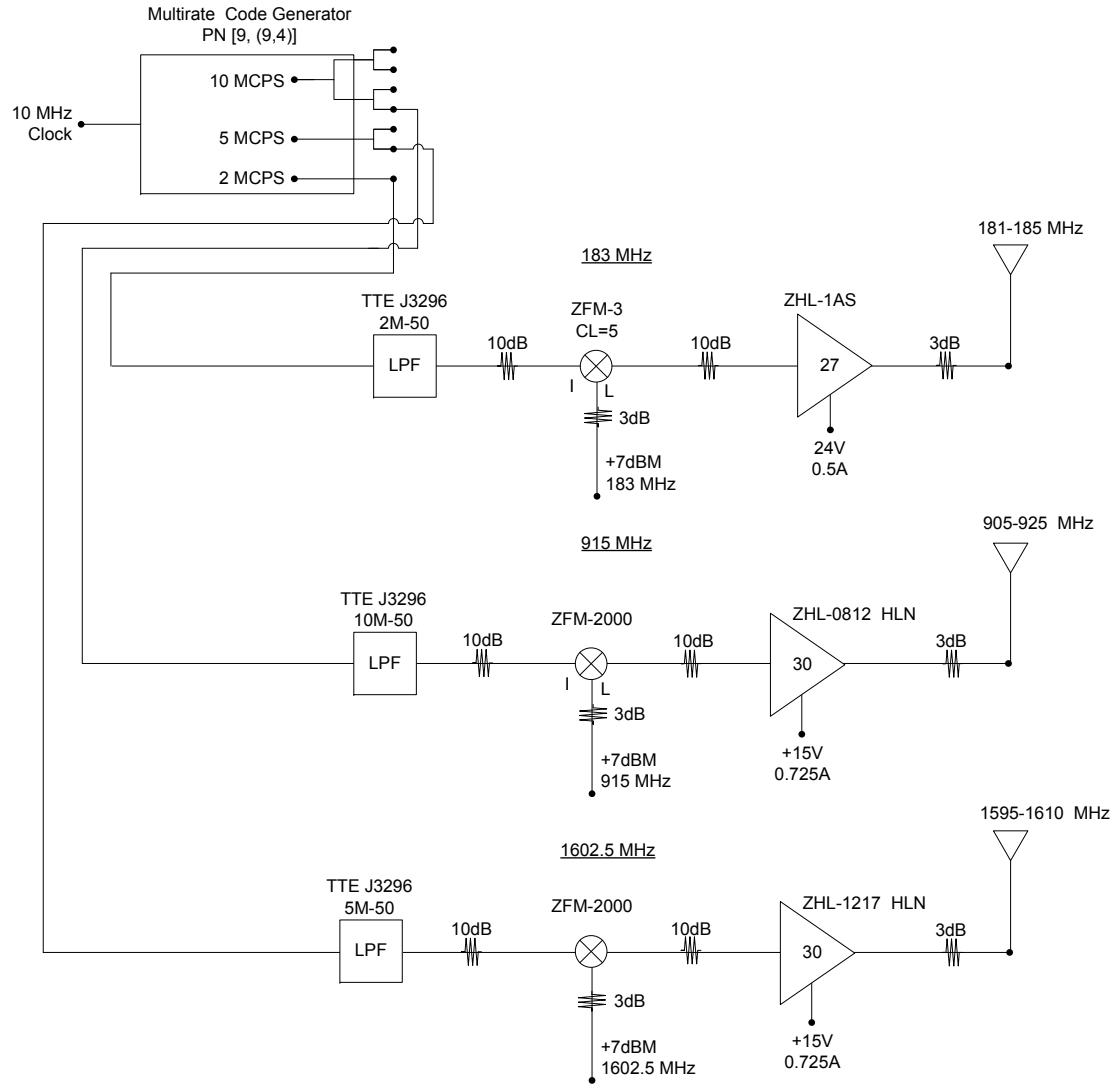


# System Architecture-Transmitter

- Baseband variable chip rate codes generated by programmable COTS generator
- RF signals generated using commercial signal generators and ITS designed & fabricated boxes
- High-quality hardware used to achieve precise spectral control
- Two transmit setups, 4 channels each (5750 MHz covered twice)
- High- & low-power modes available



OSM Transmitter 2





# Transmitter Truck Interior



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# Transmit Antenna Configuration-2

183, 915, 1602.5, 5750 MHz



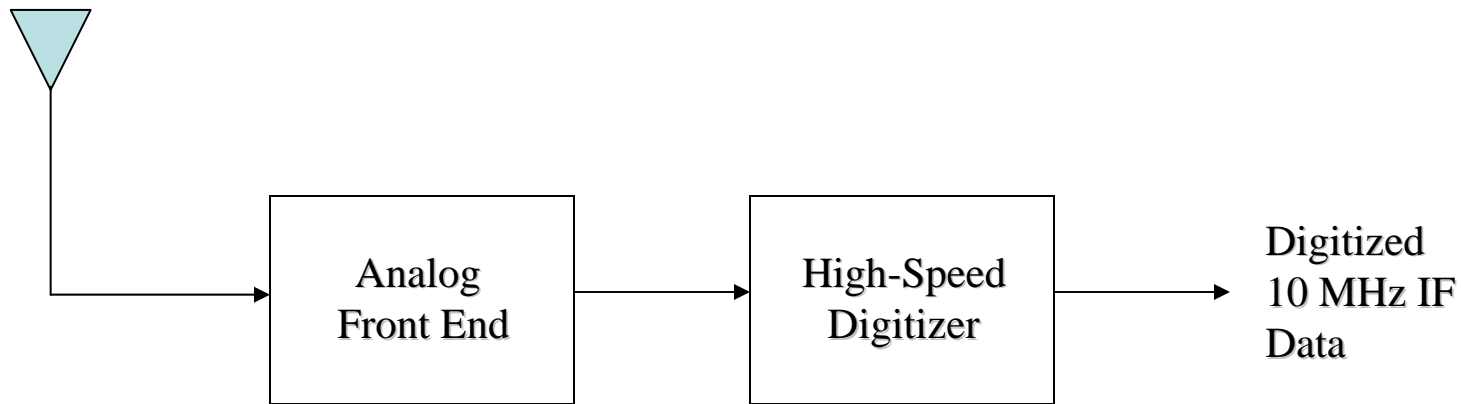


# Receiver Architecture

- Dual-Conversion—150 MHz & 10 MHz IF frequencies
- Analog front end custom-built and fabricated by ITS engineers
- High-quality components (mixers, filters, amplifiers, cables)
- Designed to maximize linearity & dynamic range
- Fixed gain design to capture rapidly-changing propagation effects encountered in complex propagation environments
- High-speed 40 Ms/sec digitizer to capture 4 channels simultaneously



# Receiver Architecture

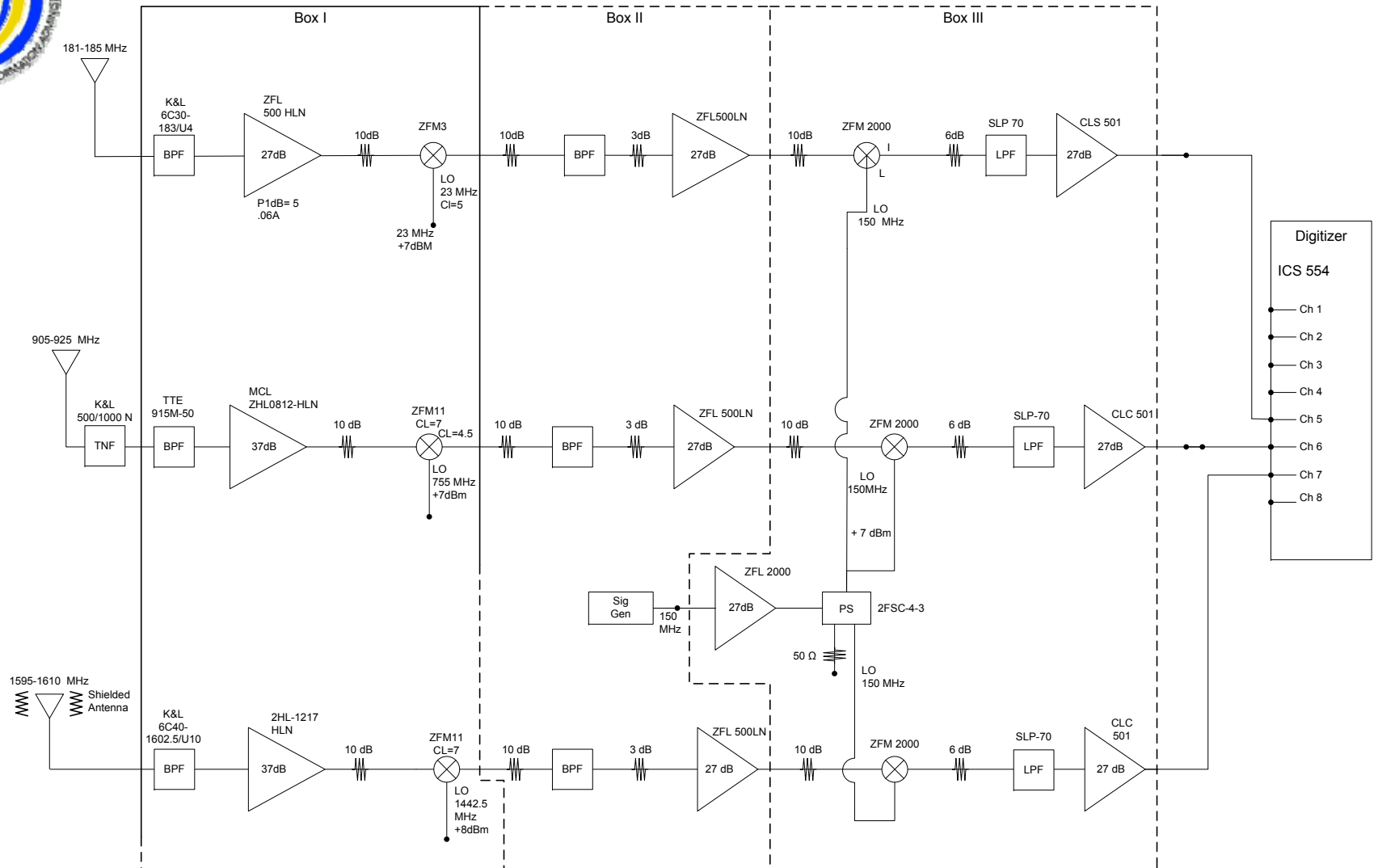


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OSM Receiver 2



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# Receiver Truck Interior



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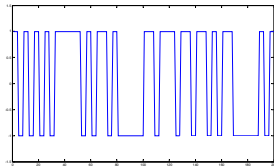


# Digitizer

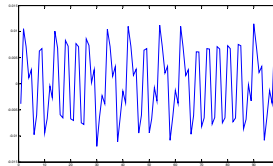
- High-speed 14-bit ADC
- ITS designed & fabricated FPGA timing board
- Windows-controlled PC & 300 GB raid array
- Custom Labview program for data acquisition
- Acquires data on the fly
- 4 channels



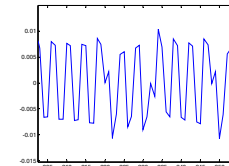
# The Process



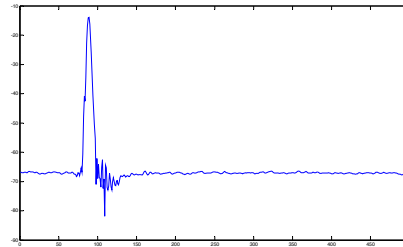
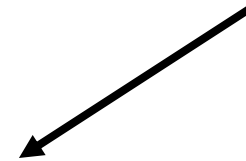
PN sequence input



Digitized 10MHz IF



Baseband PN Sequence



Channel Impulse Response



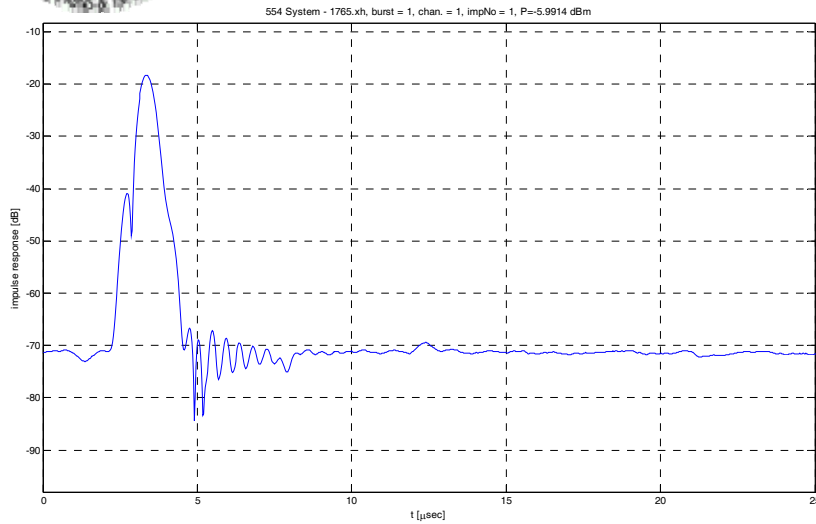
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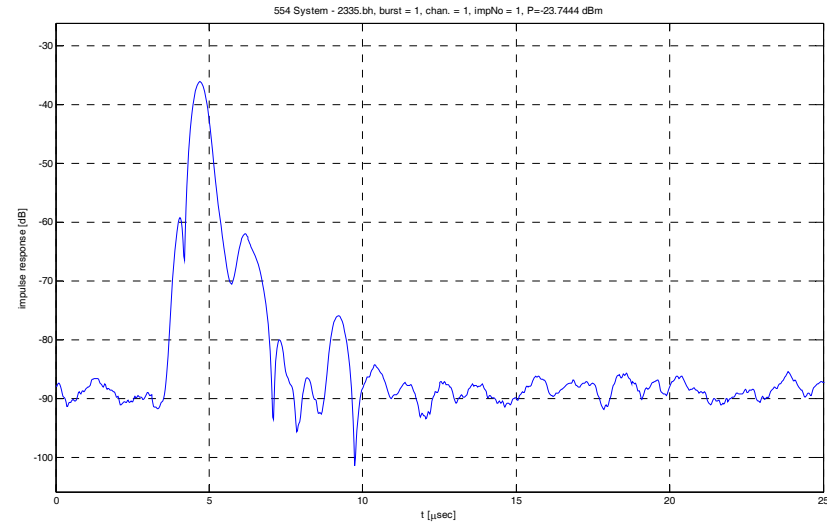


# Sample Waveforms—Time Domain

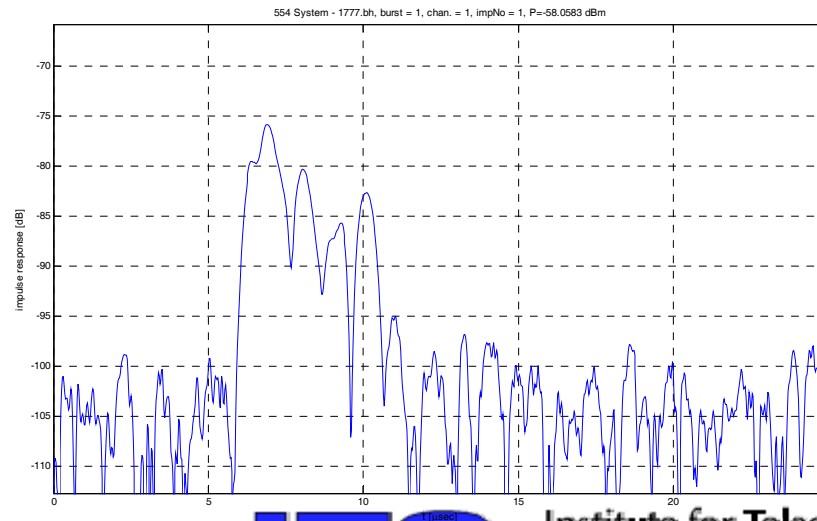
## Thru Calibration-183 MHz



## Rural-183 MHz



## Downtown Denver-183 MHz

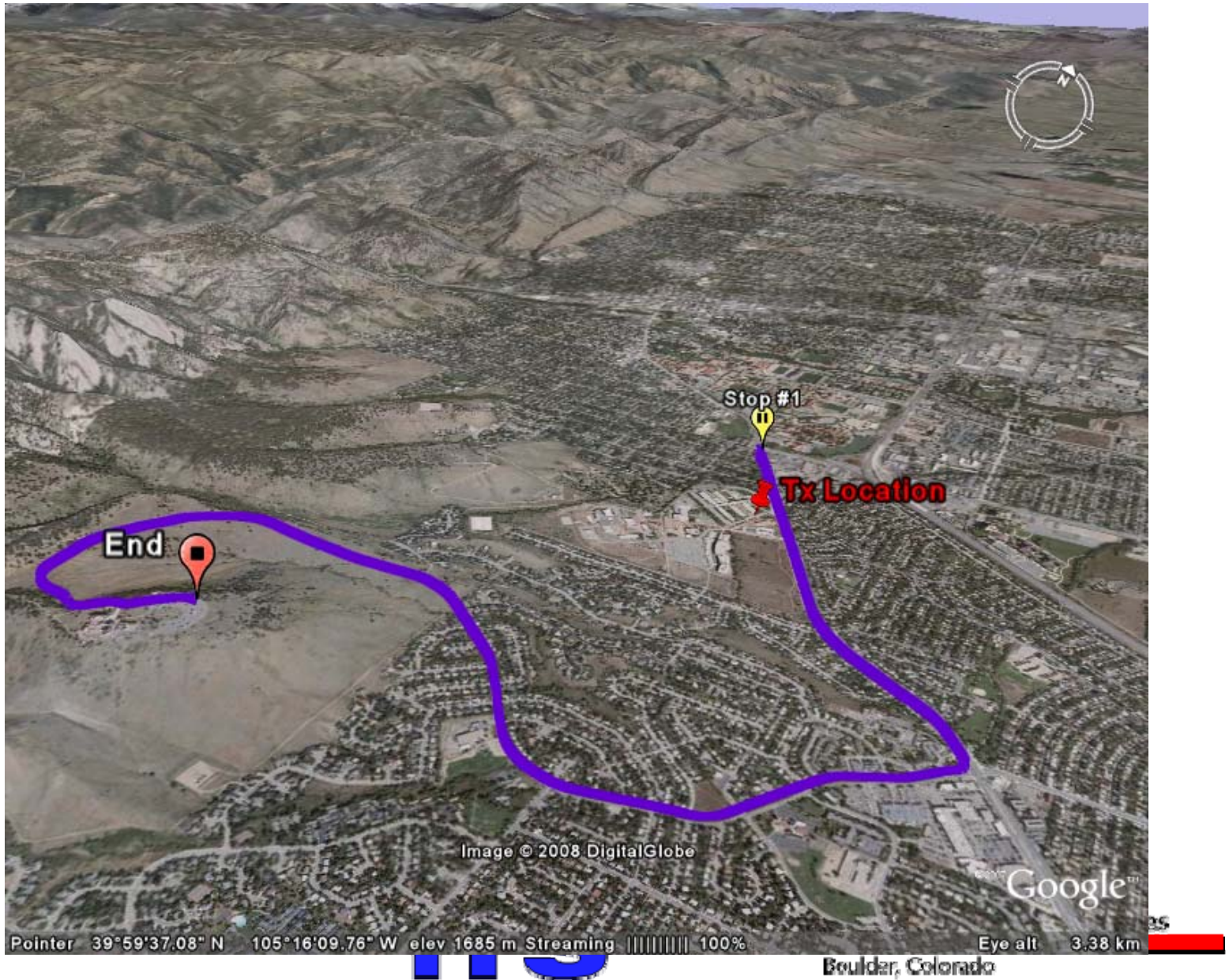


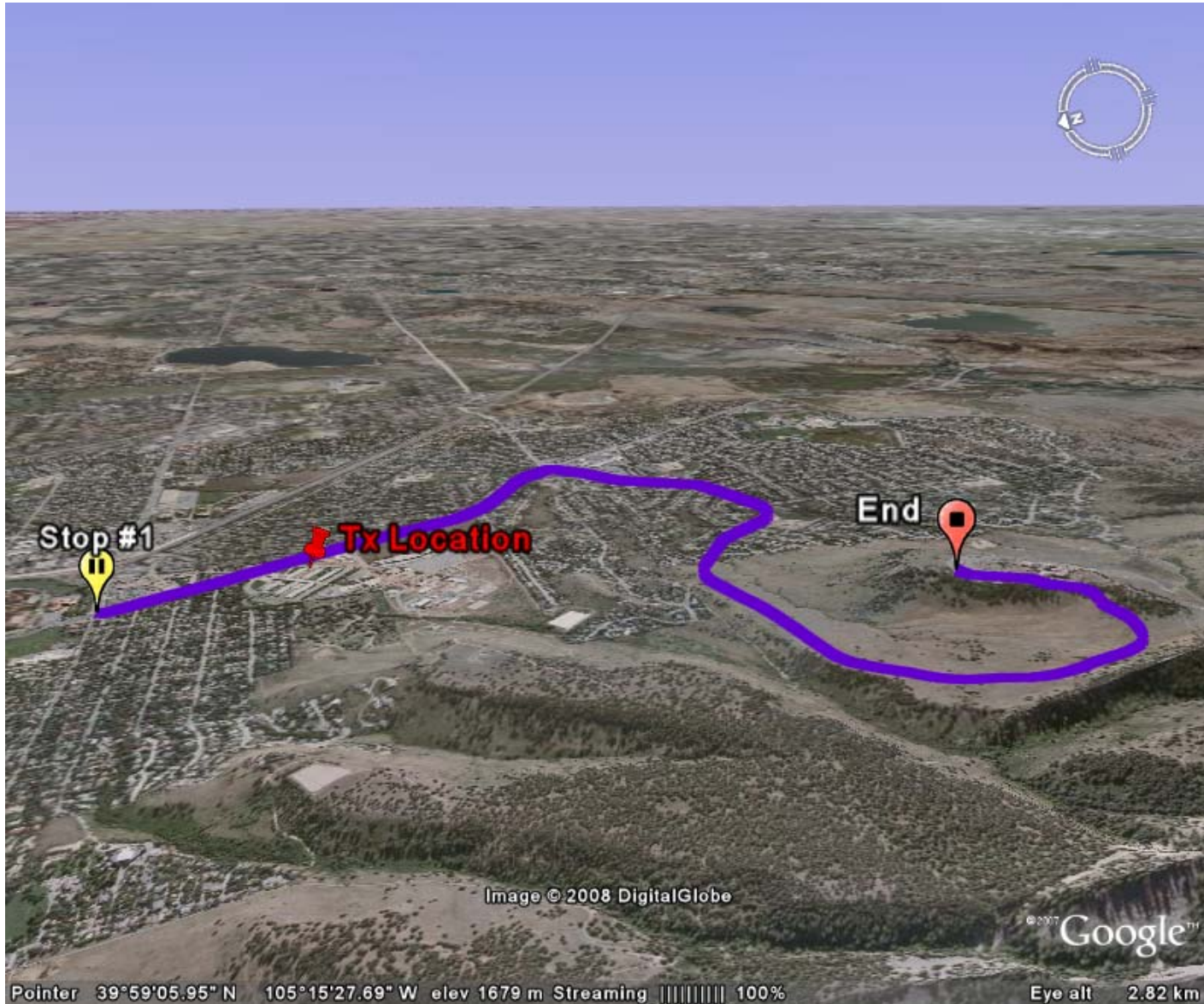
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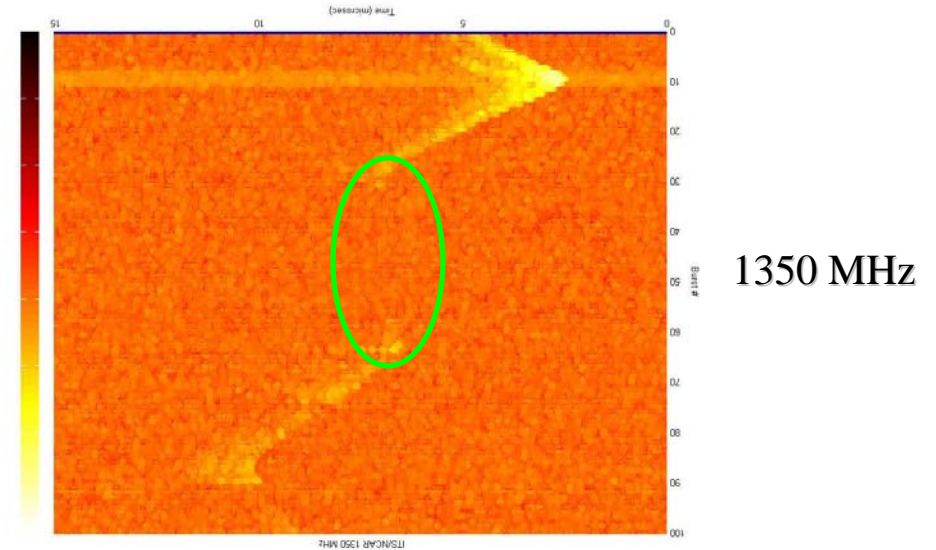
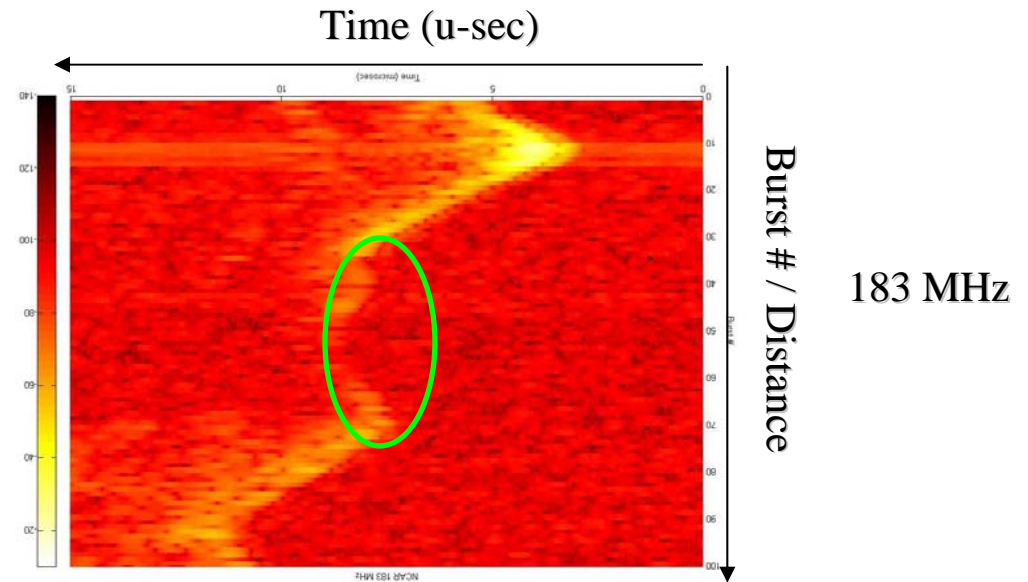
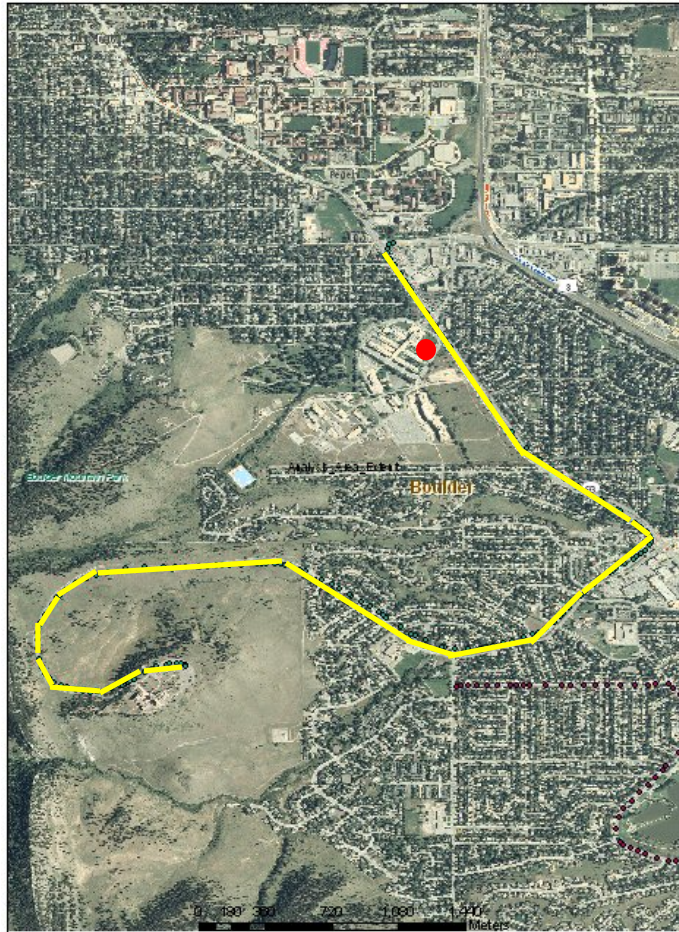


# A Drive to NCAR



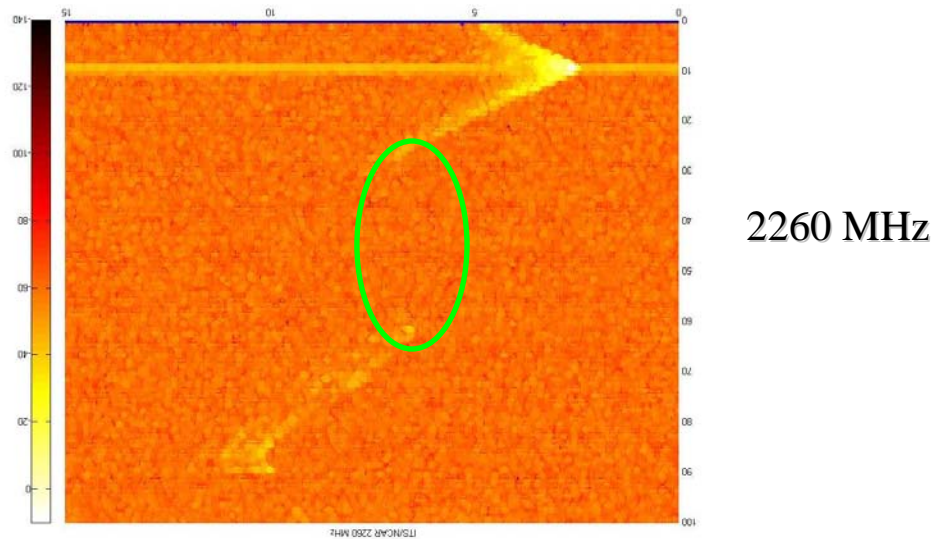
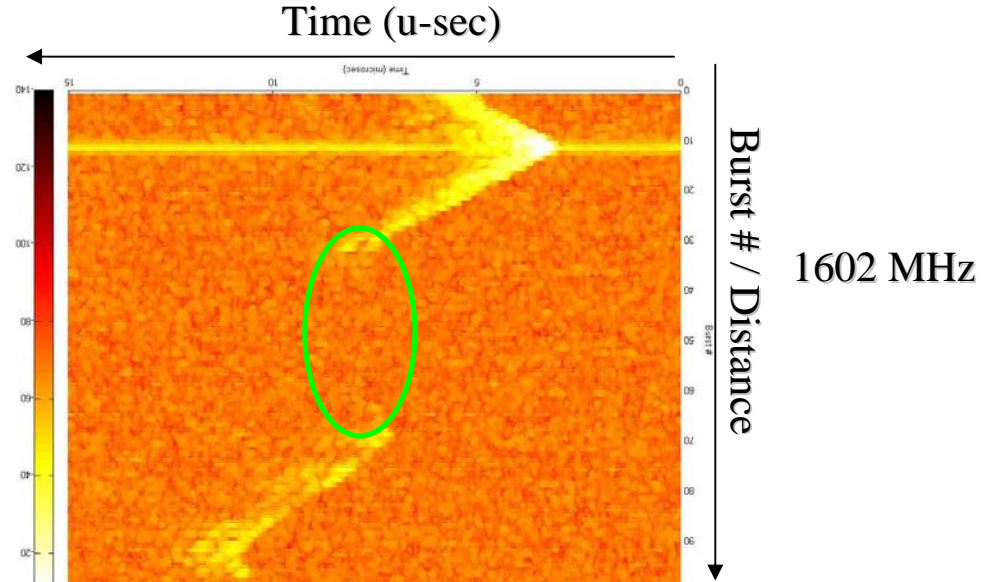
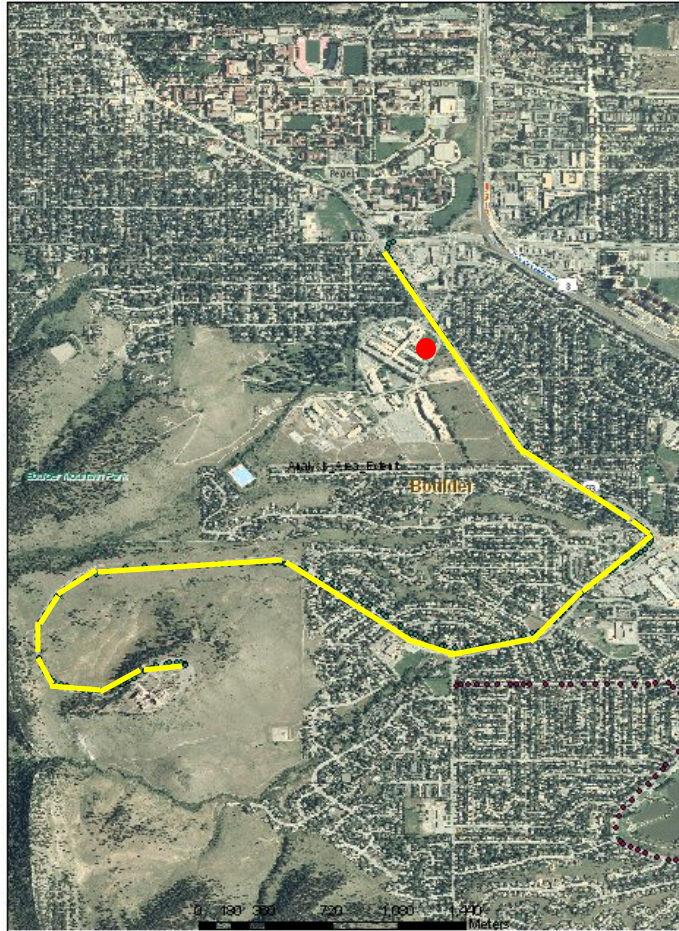


# A drive to NCAR—Impulse Signal Levels

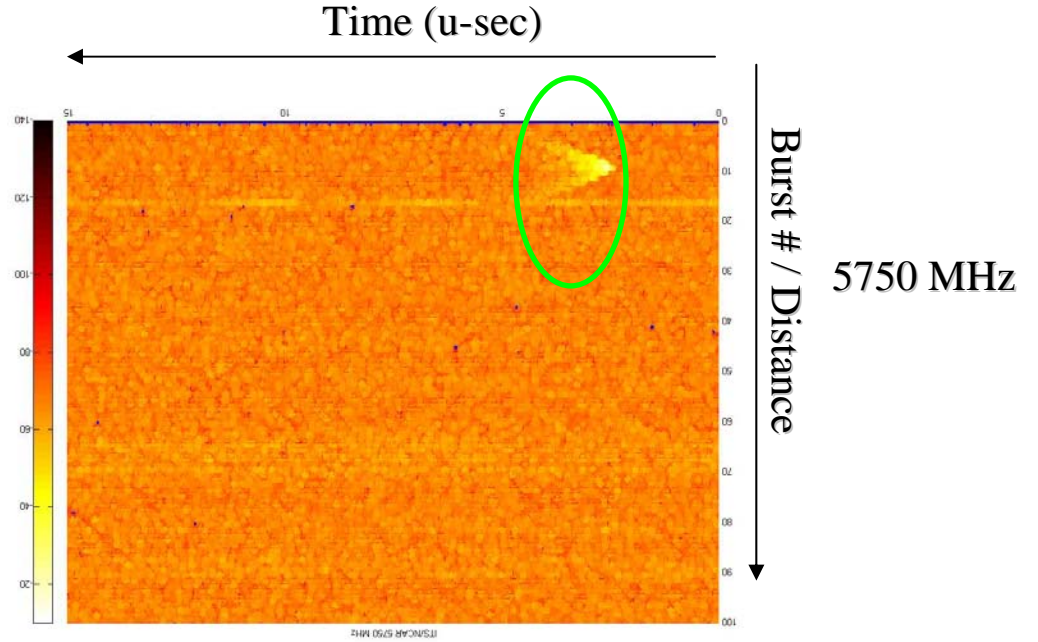
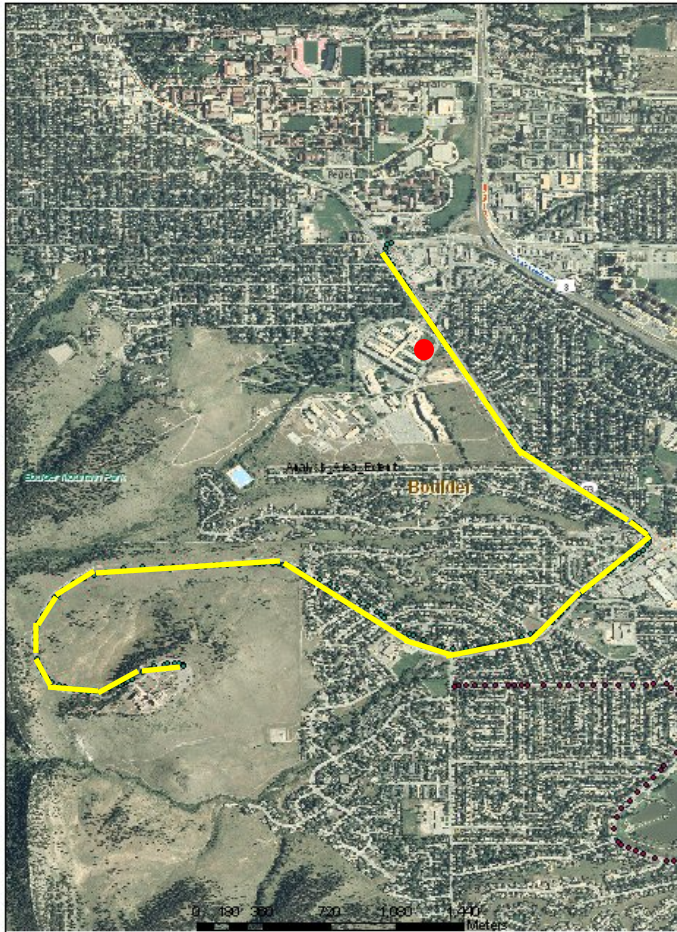




# A drive to NCAR—Impulse Signal Levels—cont'd



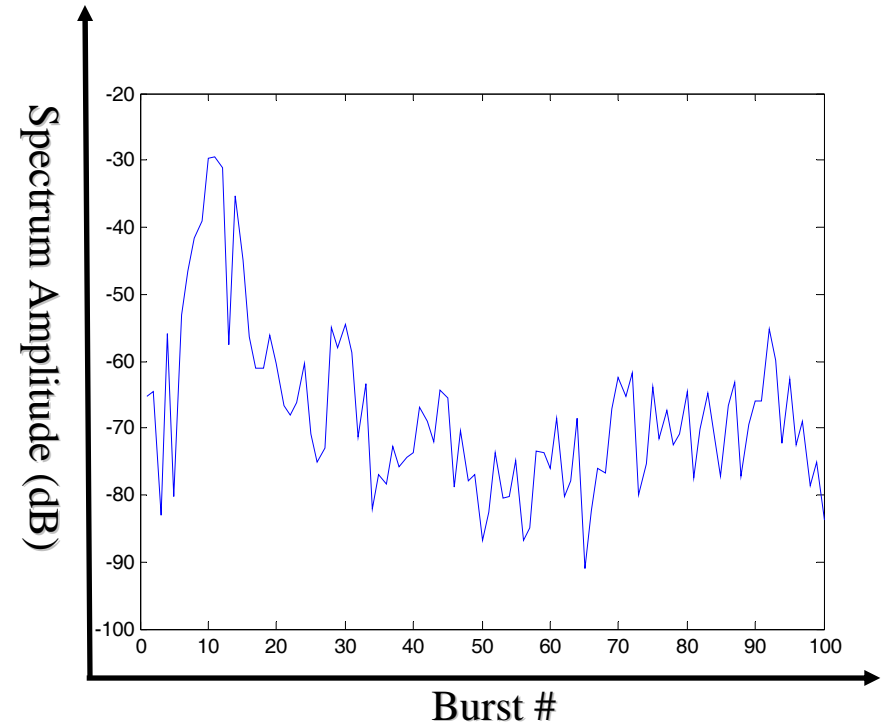
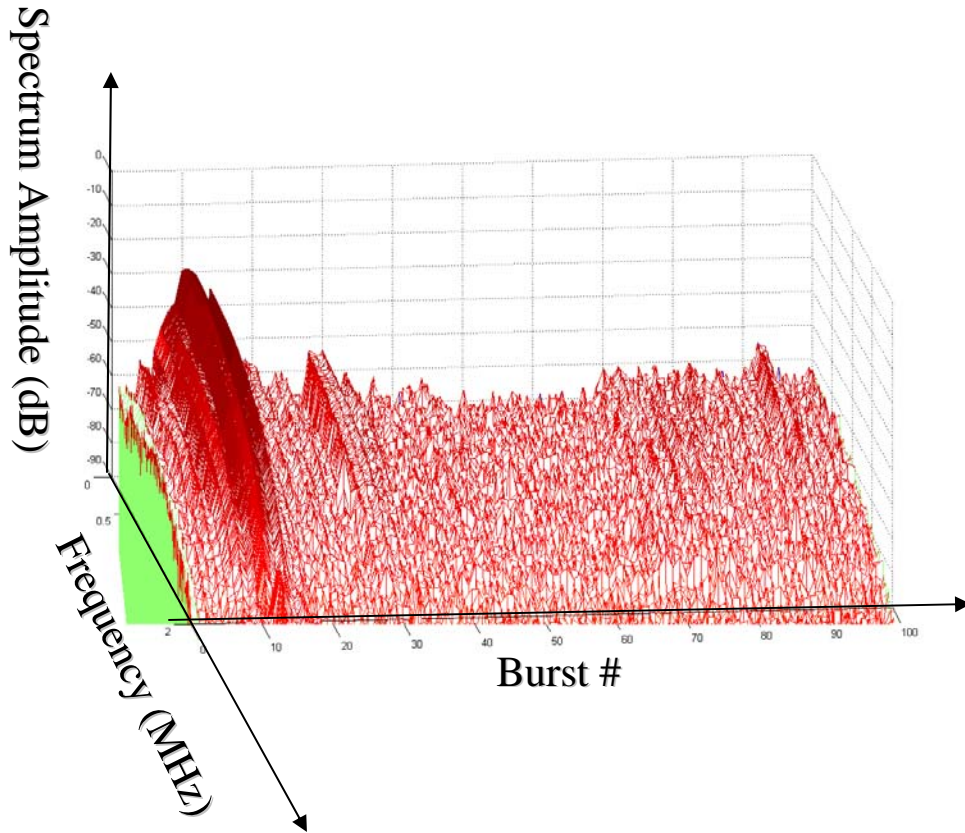
# A drive to NCAR—Impulse Signal Levels—cont'd







# NCAR Run 183 MHz—Narrowband Response





# Downtown Denver



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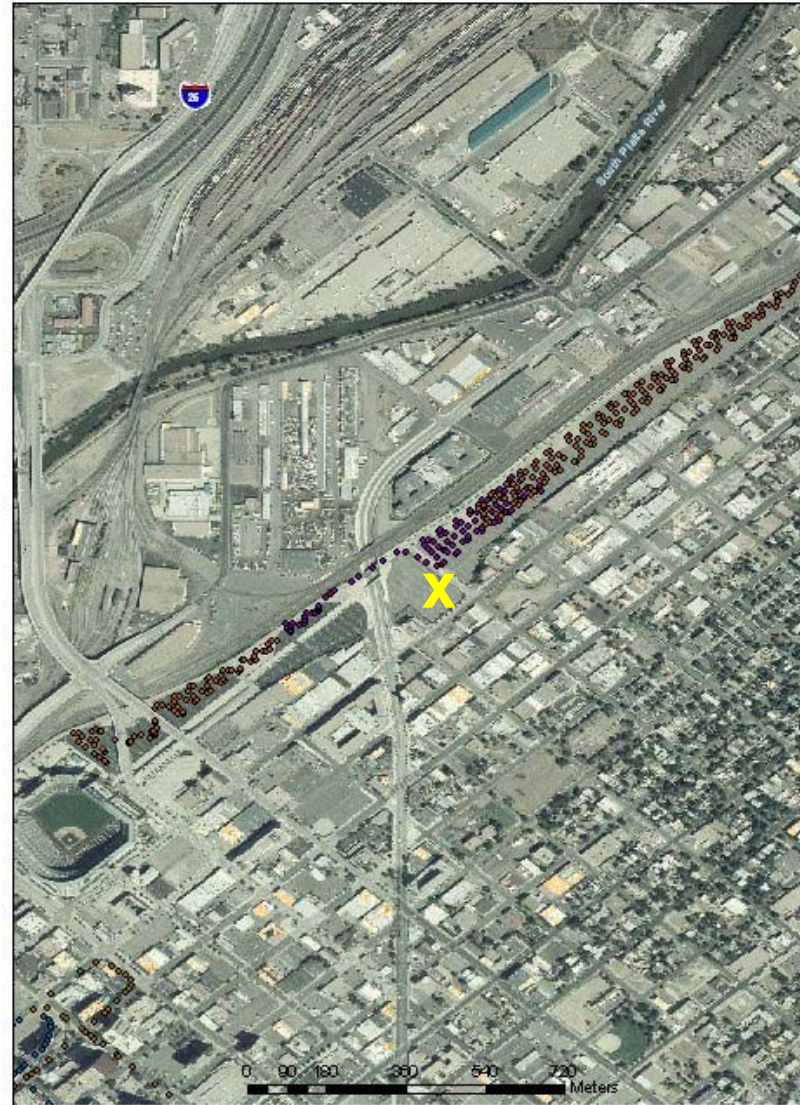


# Downtown Denver Measurement Locations



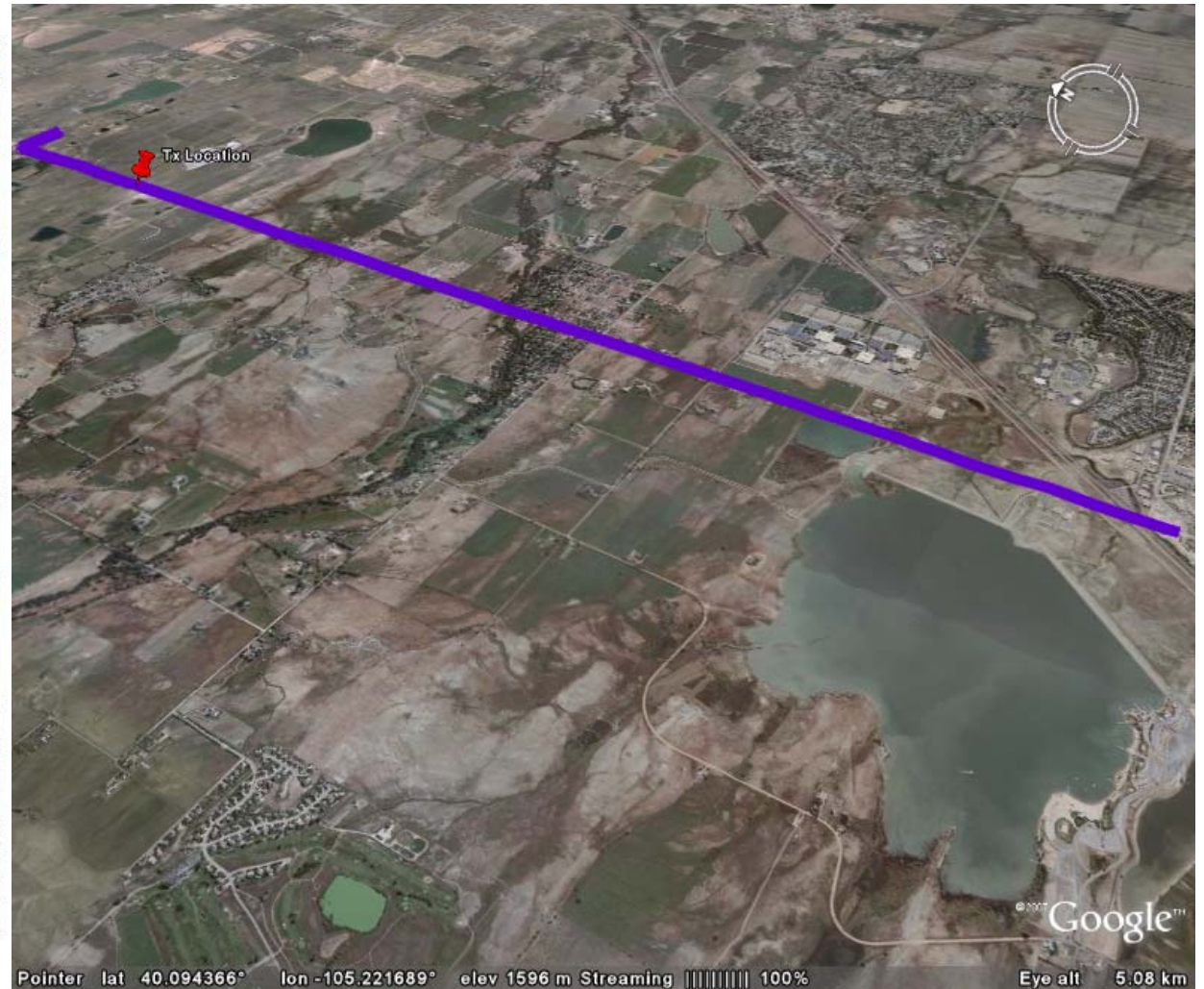
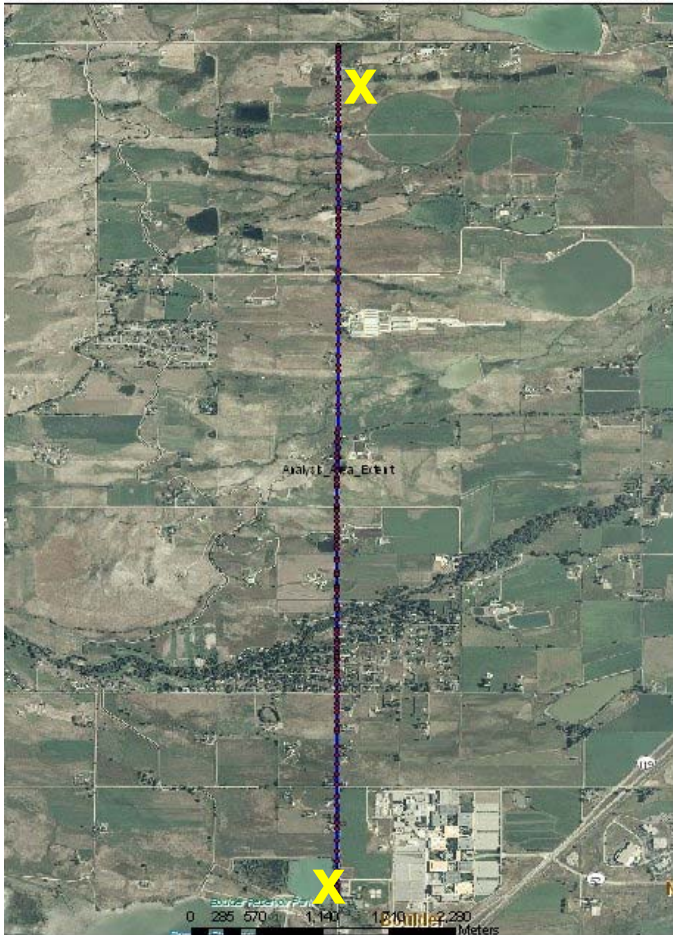


# Parking Lot Measurement Locations Coors Field Downtown Denver





# Rural Country Road Boulder County

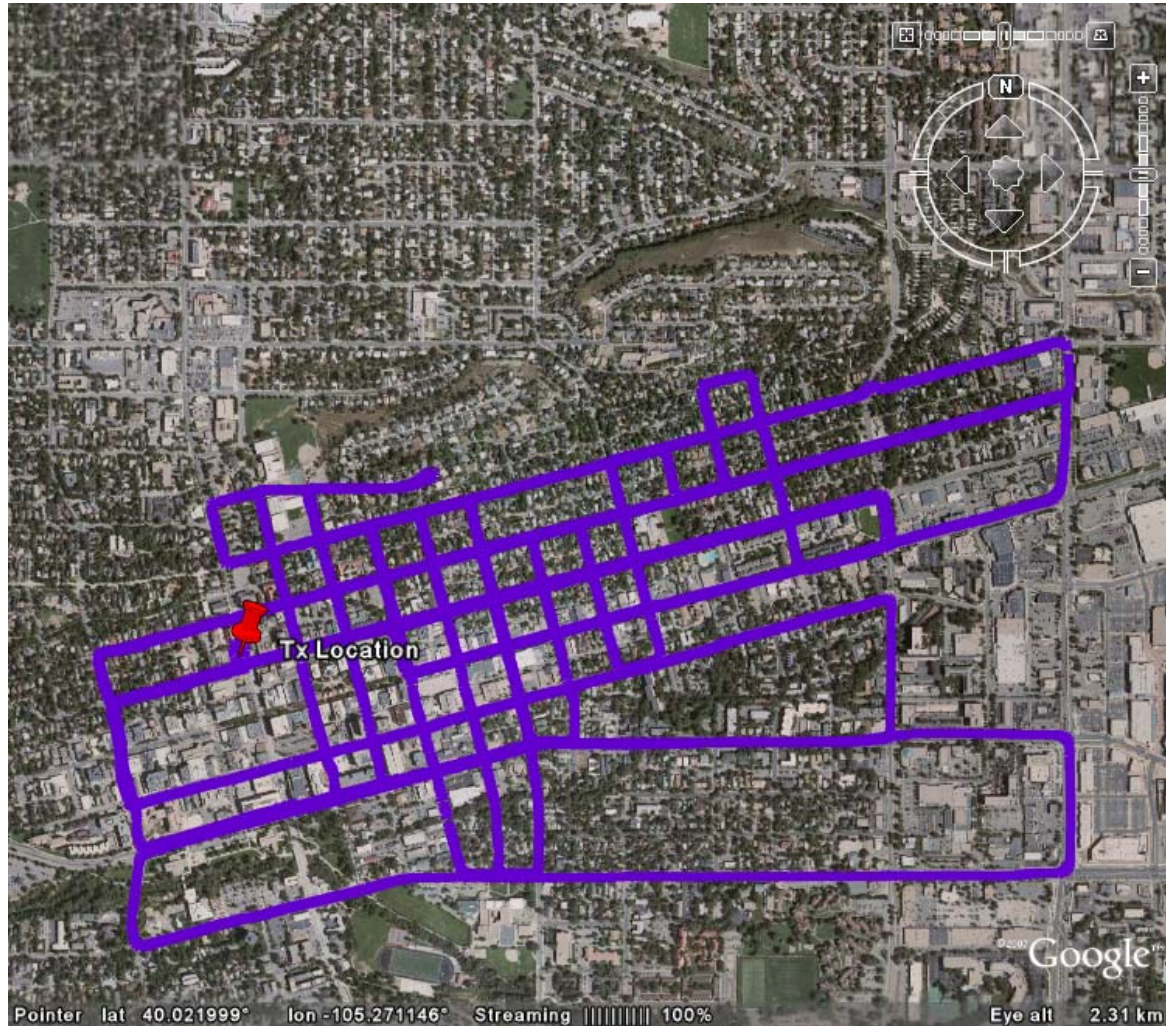


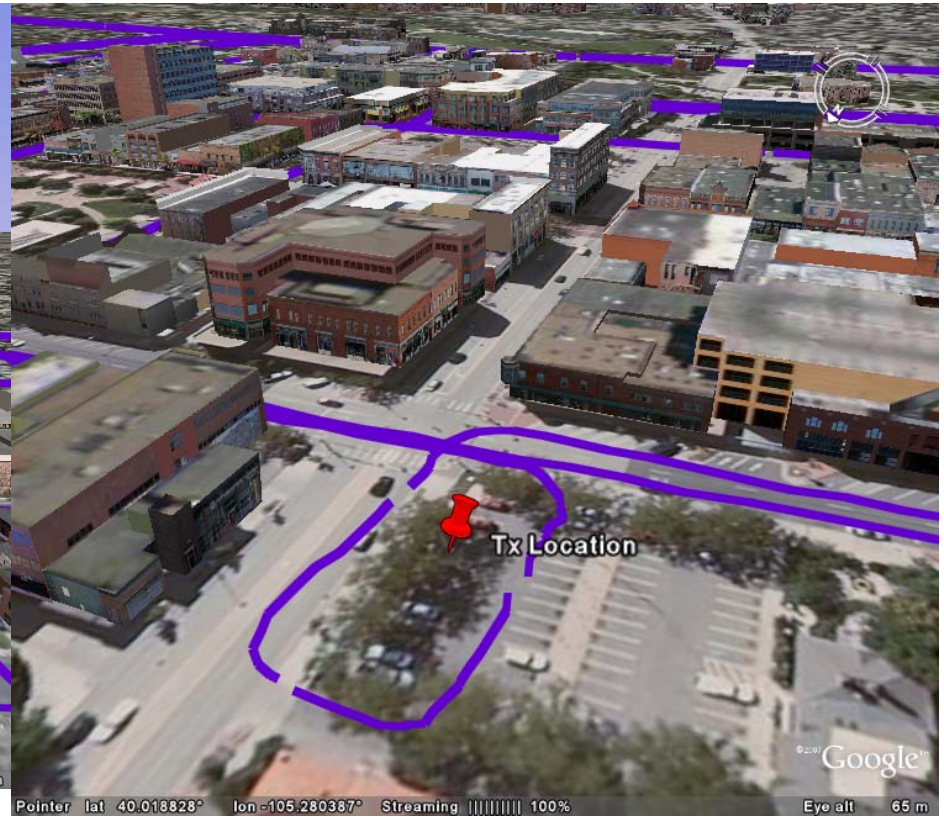
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# Low-Rise Urban Downtown Boulder, CO







## Broadway and Spruce Streets--Boulder







## Wells Fargo Bank Downtown Boulder Transmitter Location With 2-3 Story Urban Corridor





## Ryssby Church 63<sup>rd</sup> Street Transmitter Location With Rural Environment Showing Measurement Path





## Measurement Vans at Ryssby Church 63<sup>rd</sup> Street Transmitter Location With Rural Environment





## Measurement Vans at Coors Field Parking Lot





## Auraria Campus Transmitter Site Next to Downtown Denver Medium-Rise Urban Environment



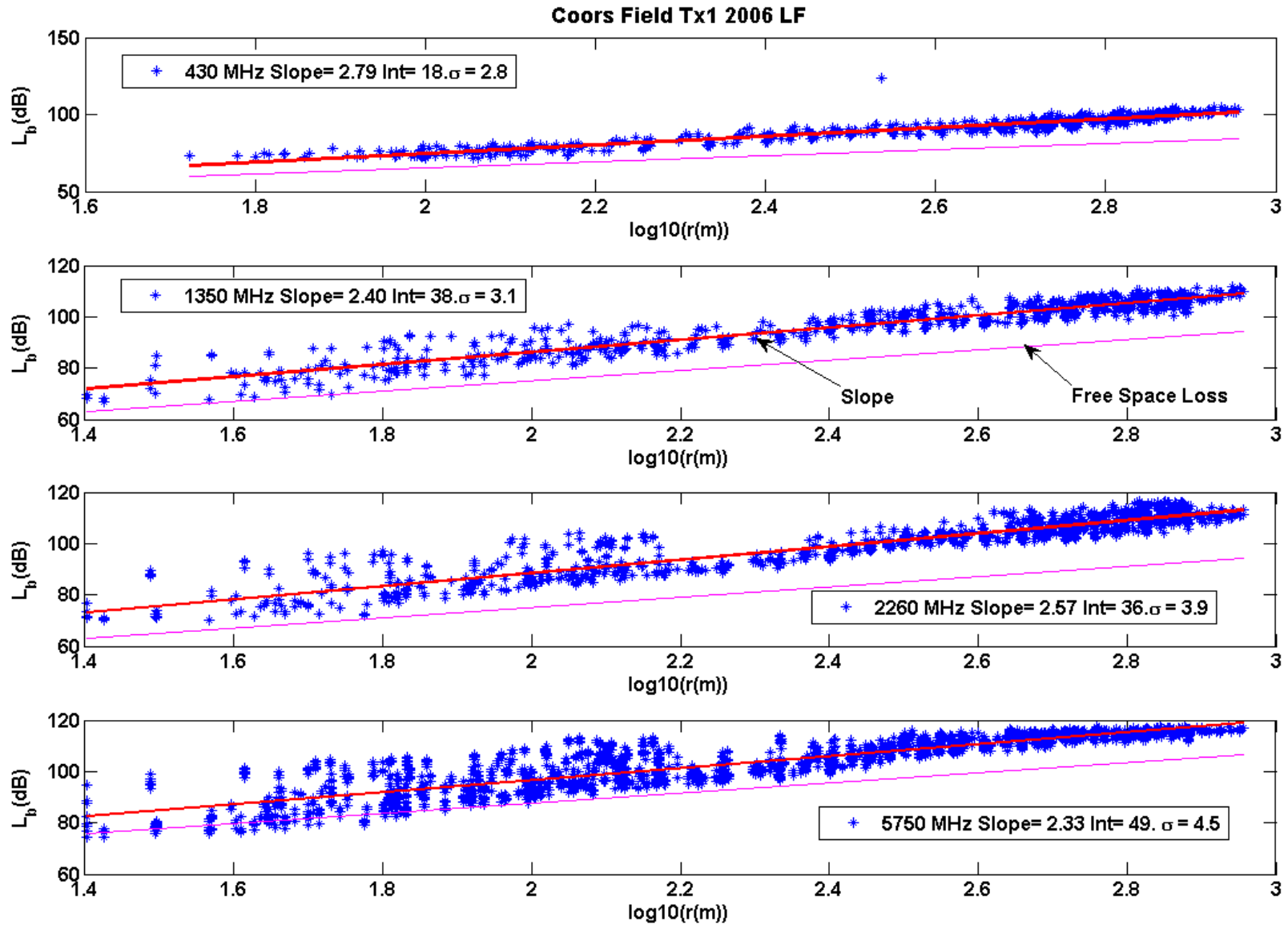


# Sample Data Run – Coors Field, Transmitter 1



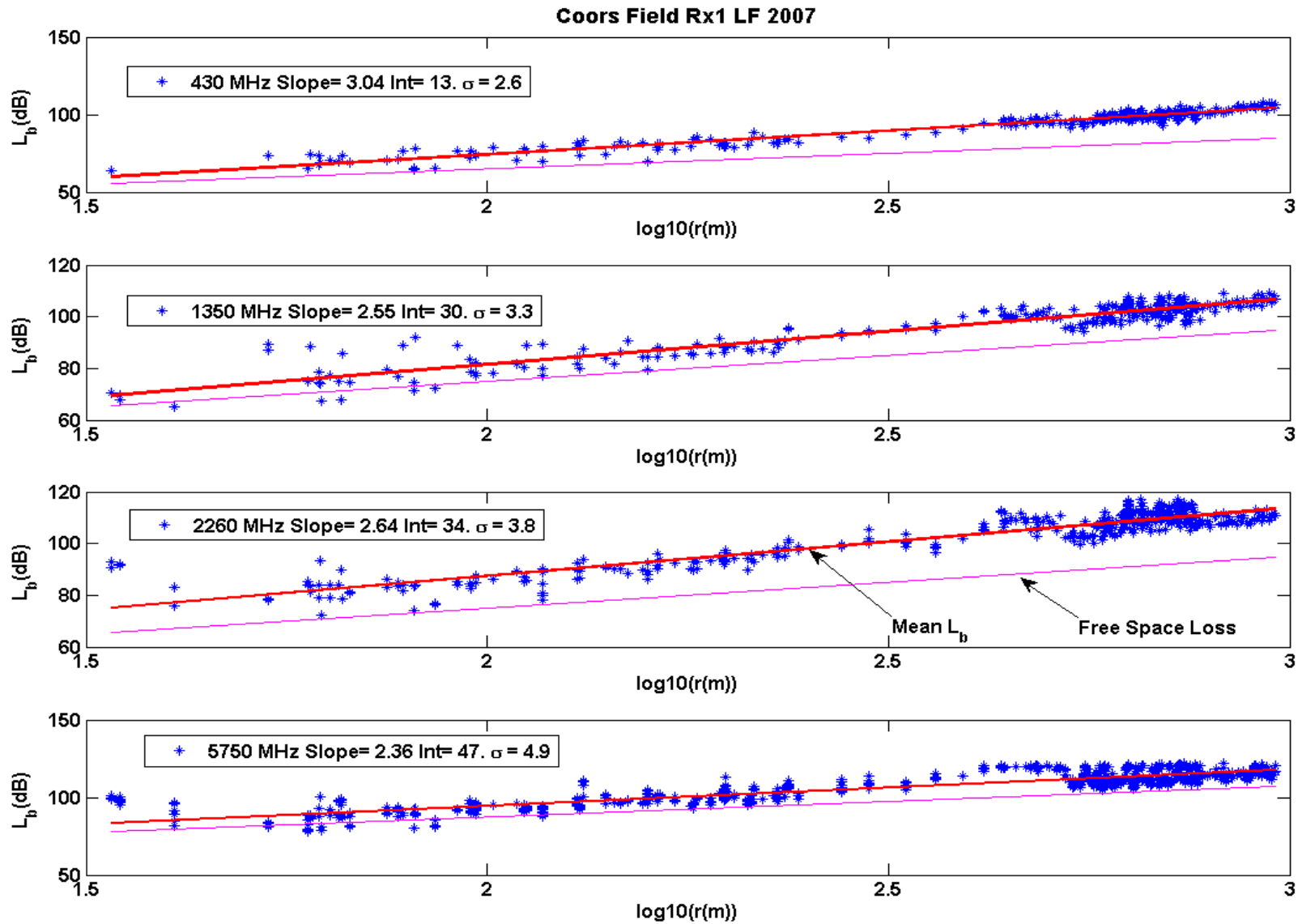


# Basic Transmission Loss Coors Field Lot Full 2006





# Basic Transmission Loss, Coors Field, Lot Full 2007

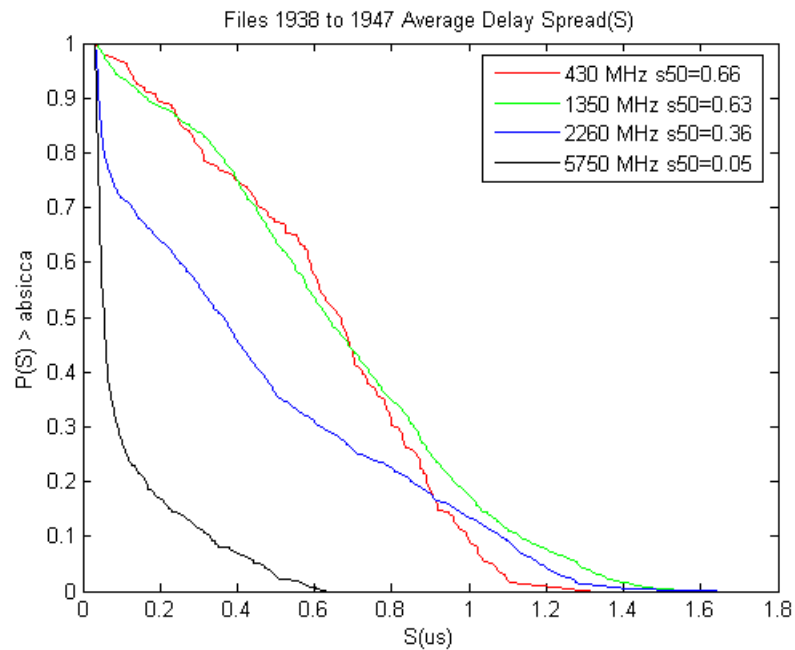




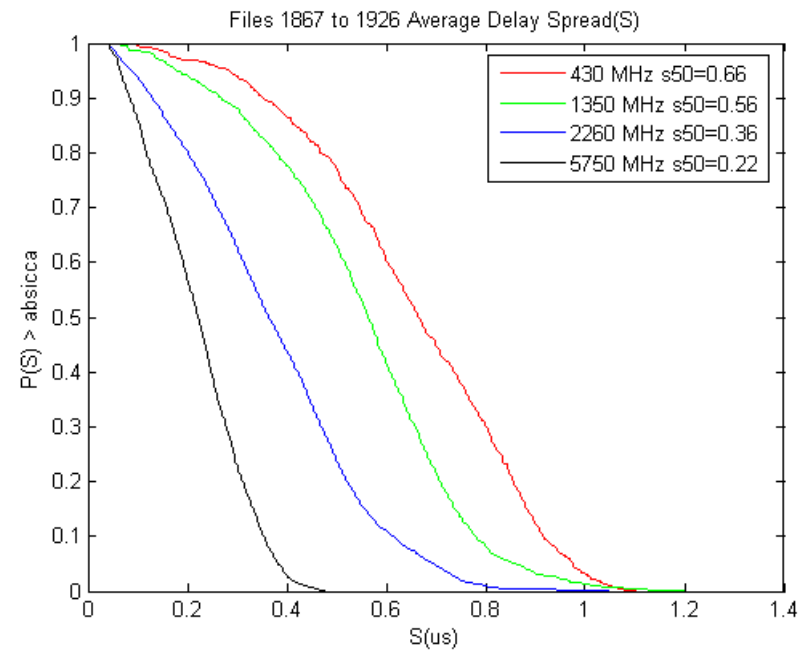


# Downtown Denver: Auraria Campus (Tx Site), Speer Blvd. and High Rise Routes, Delay Spreads

## Speer Blvd.



## High Rise





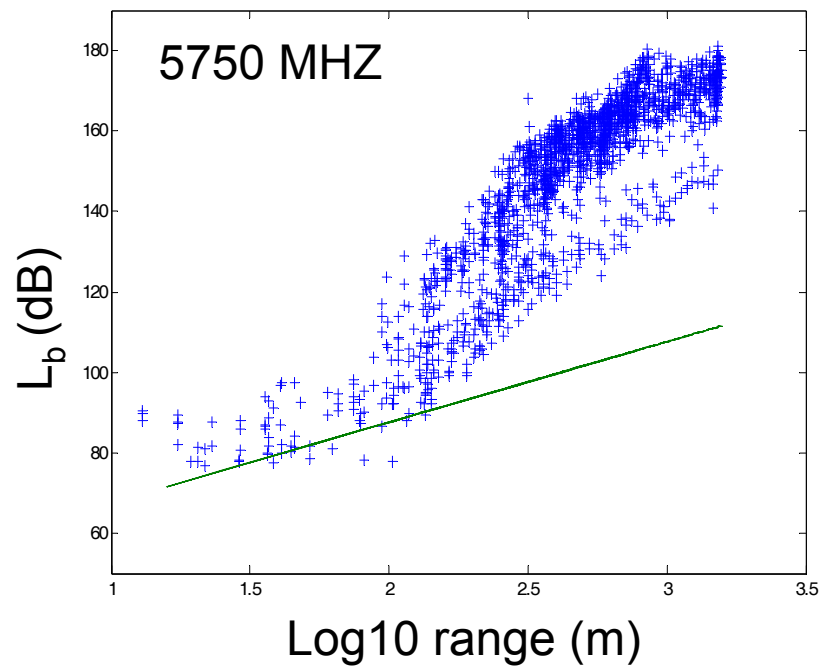
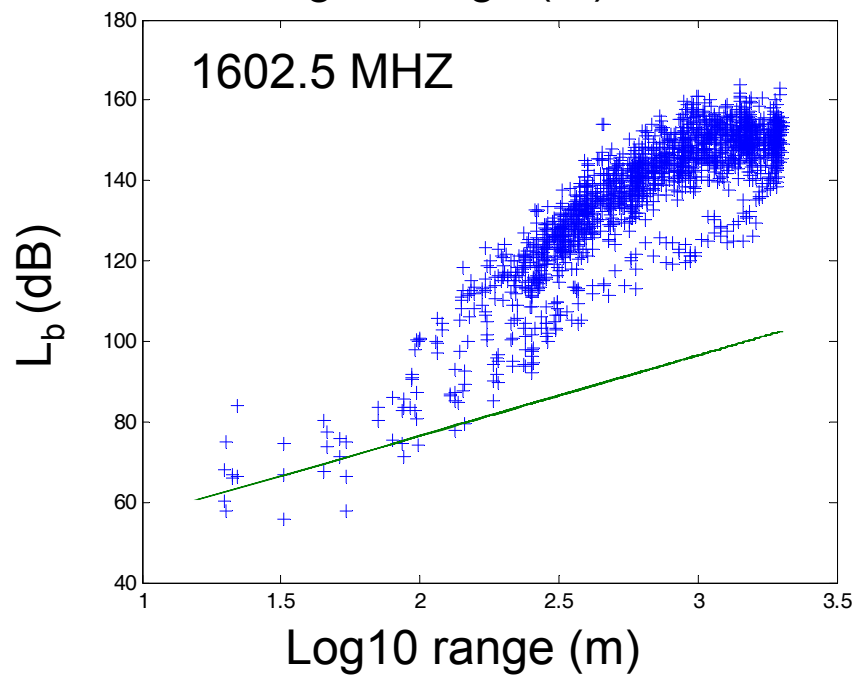
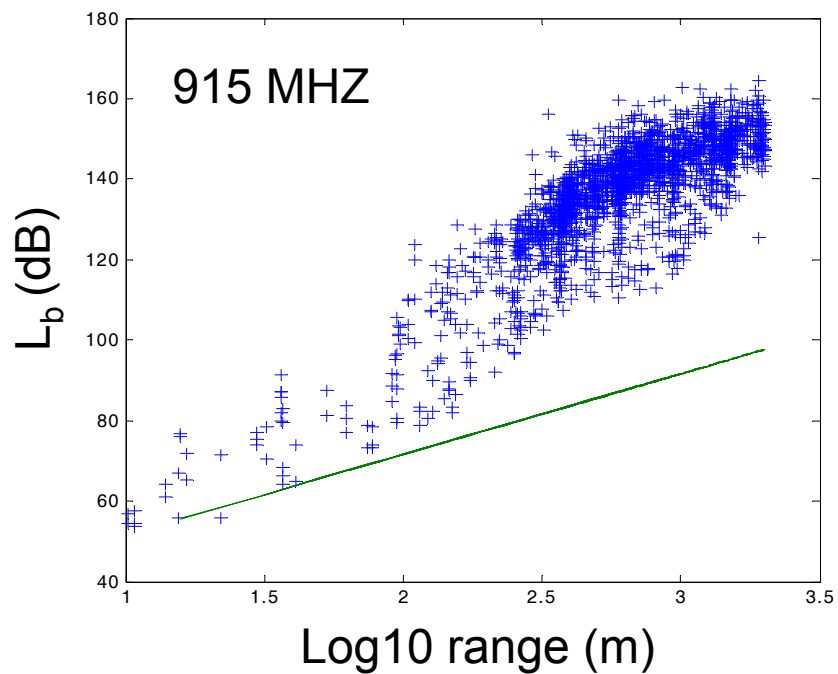
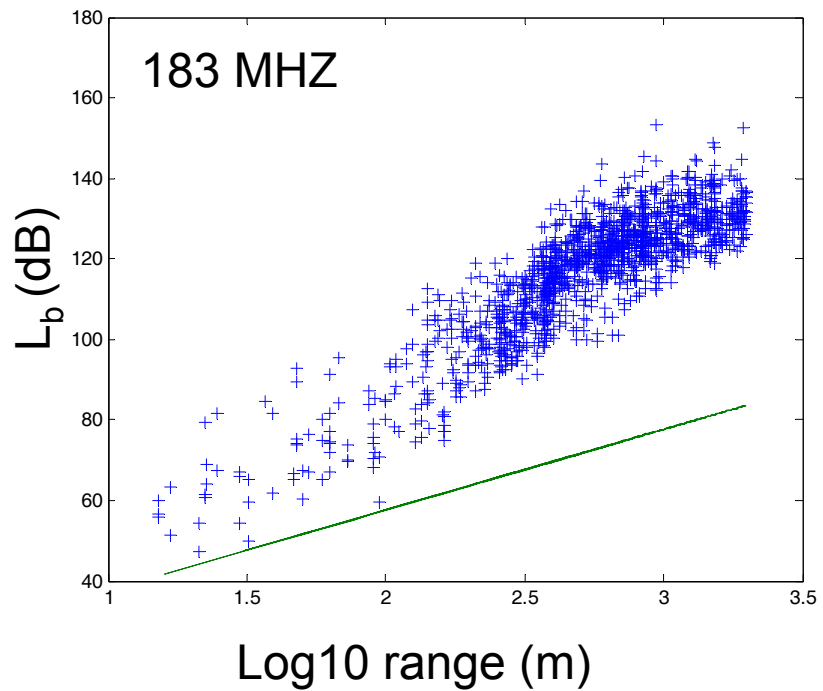
# Alternative Measurement Methods

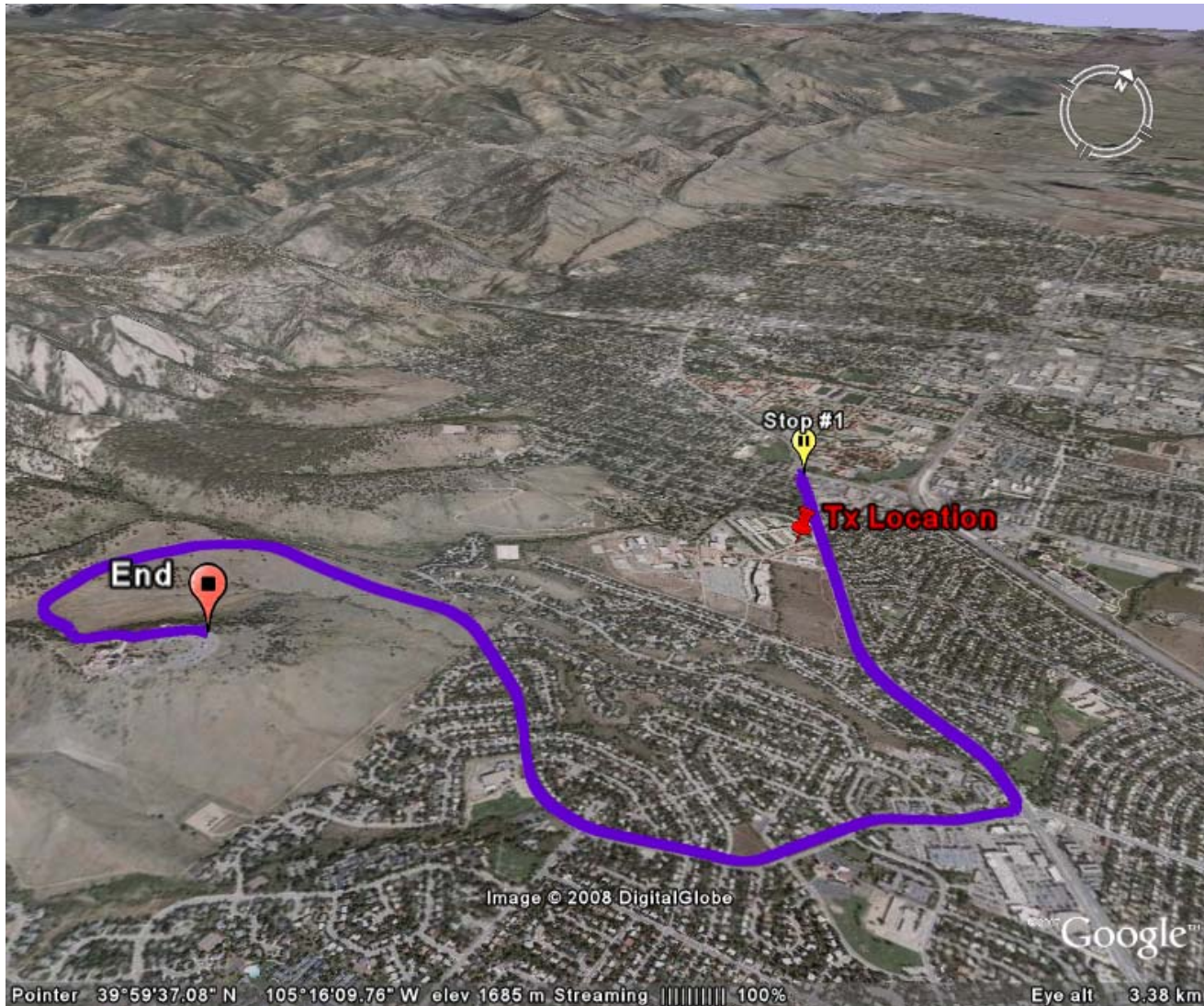
- Interference Immunity—problems with the wideband system at certain frequencies
  - Improved Sensitivity/Dynamic Range
  - Fast Fading & Doppler Spreading
  - Provide Traceable Measurement
- 
- Spectrum Analyzer & GPS logger
  - Sound Card/Receiver Method

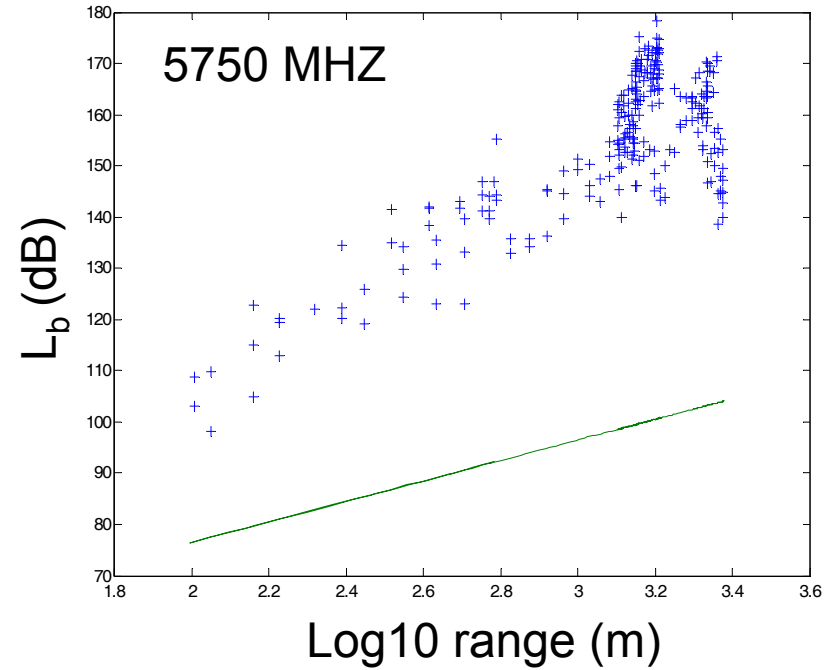
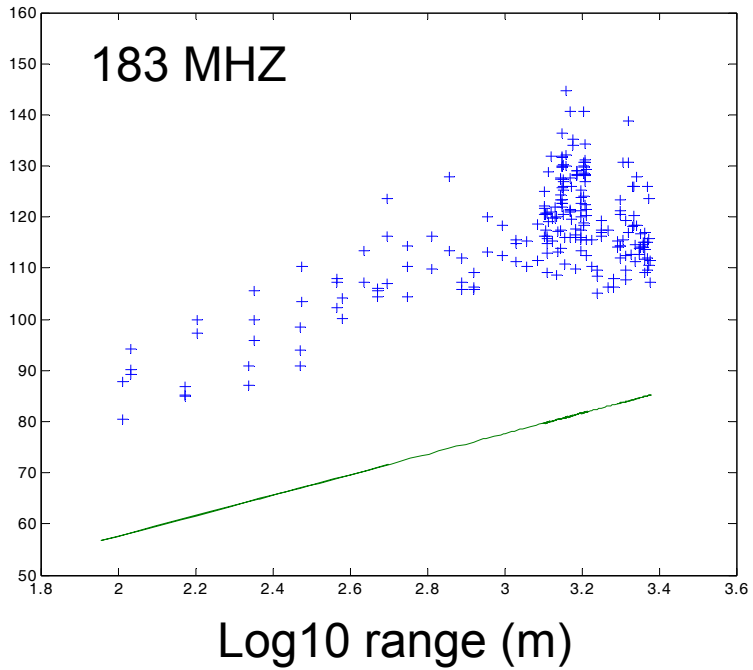


# Spectrum Analyzer Results Downtown Boulder







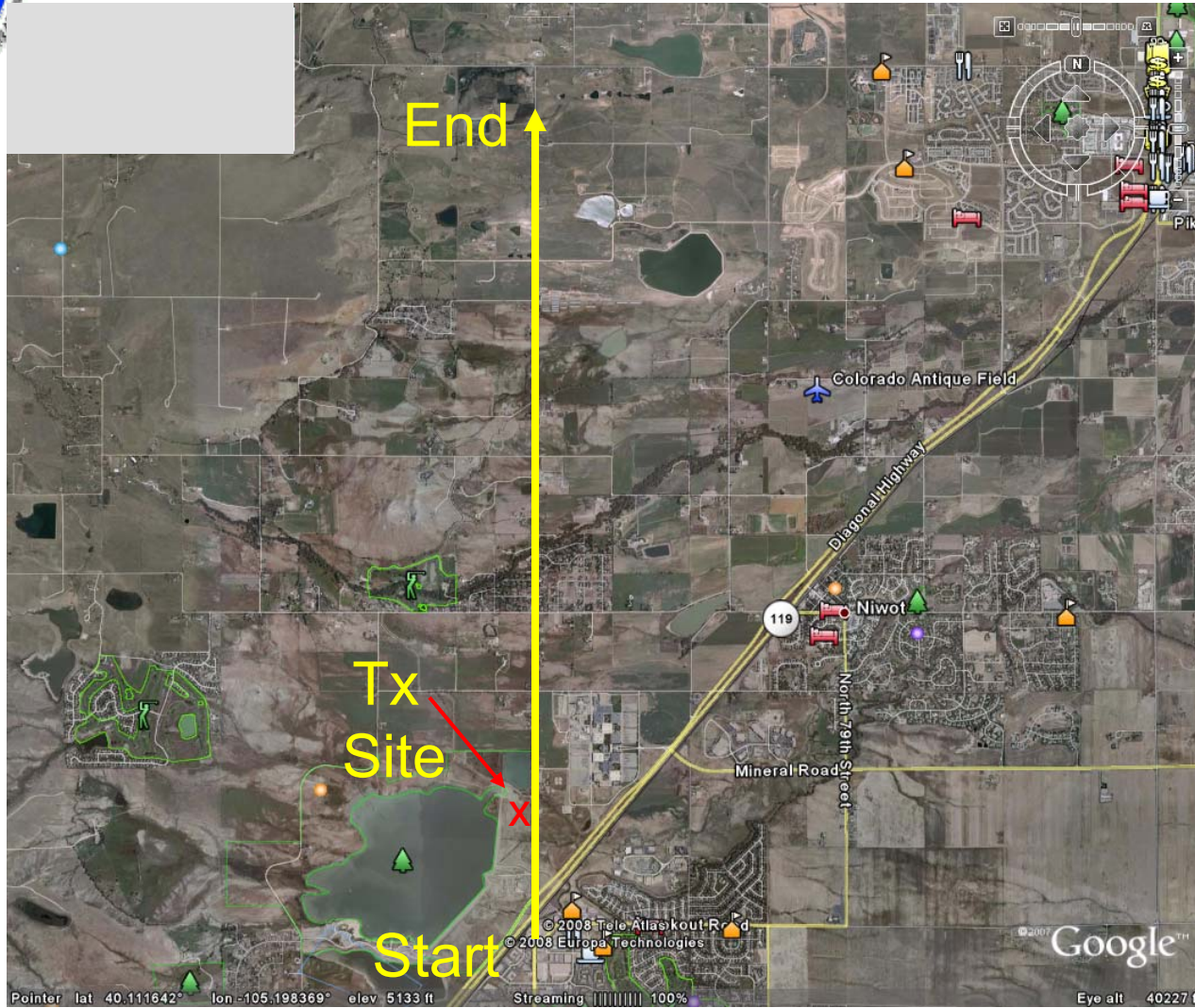






# Coot Lake N. 63rd St., Boulder County

Length of run approx. 4.5 mi



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# Coot Lake Signal Profile

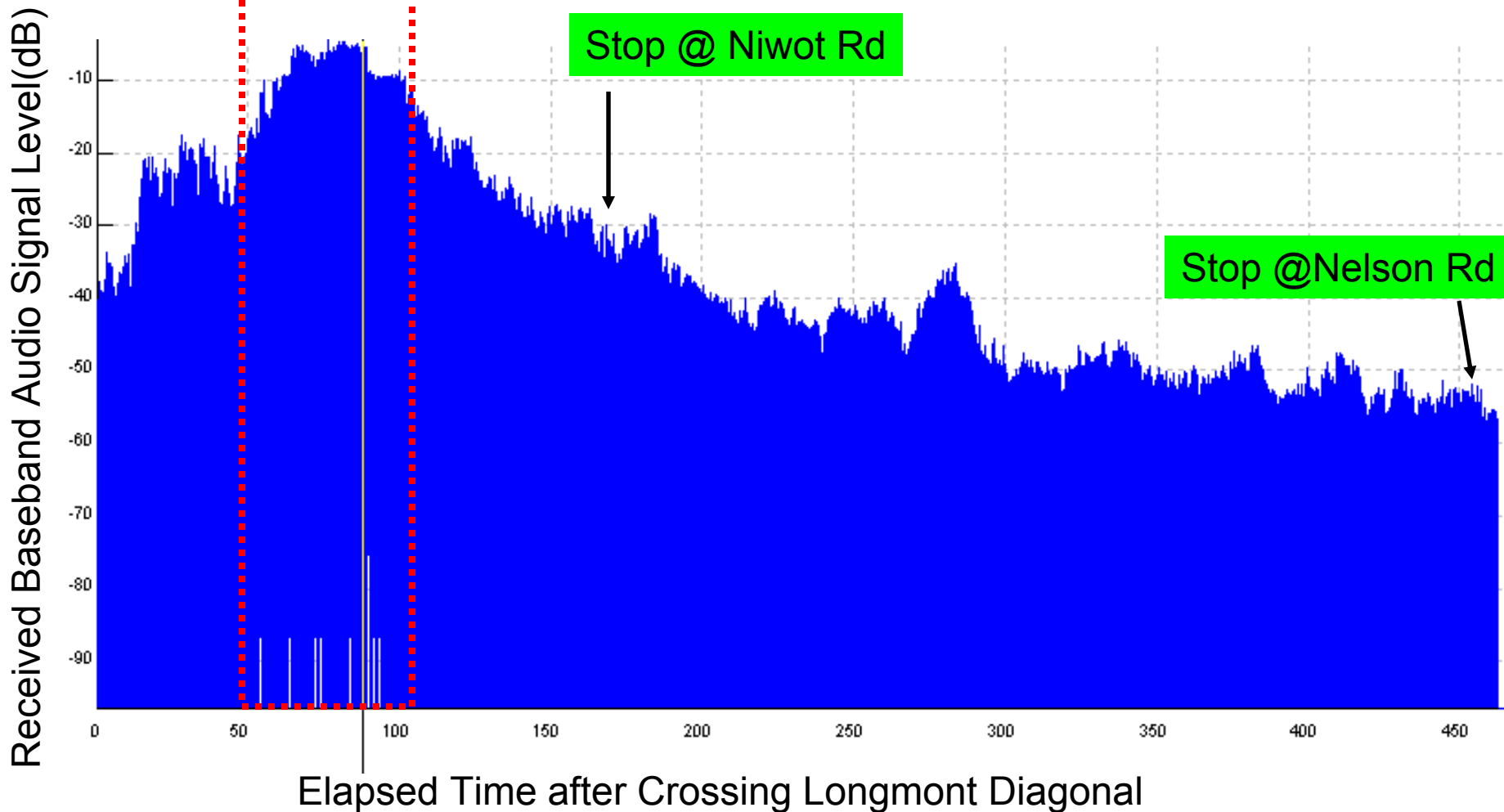
$20 \cdot \log_{10}(|V_r|)$  (dB)



Receiver Saturation  
Tx Site too close!

Stop @ Niwot Rd

Stop @ Nelson Rd





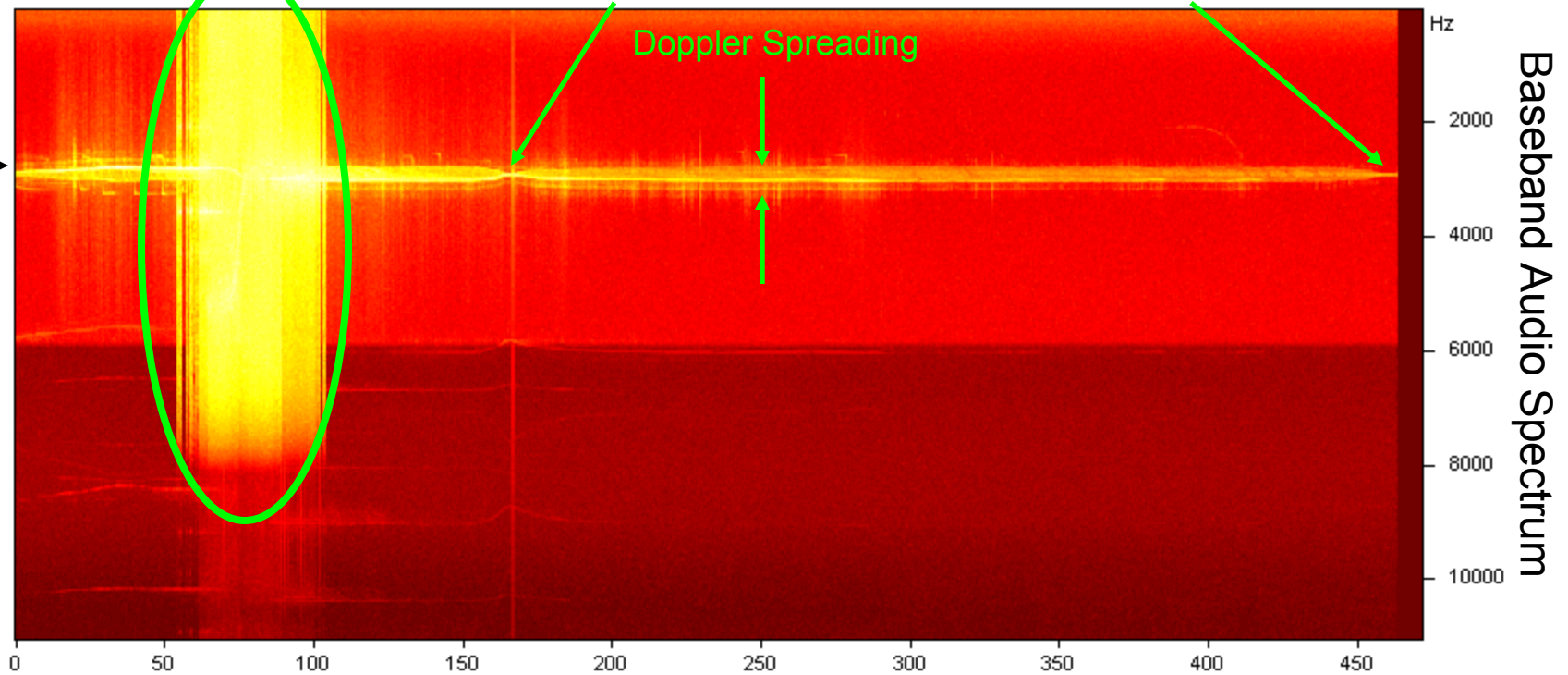
# Coot Lake Spectrogram 11,000+ FFT's 2048 Pts

Receiver Saturation  
Tx Site too close!

Stop @ Niwot Rd

Stop @ Nelson Rd

Longmont  
Diagonal



Elapsed Time after Crossing Longmont Diagonal



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## Future Directions

- More measurements in selected environments
- Model Development
- Enhanced signal processing
- Doppler spreading measurements
- Additional Narrowband Propagation measurements
- Final Report