

# Electromagnetic Penetration Measurements of an Apartment Building using an Ultra-Wideband Measurement System

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# NIST Building Penetration Measurements

Tests conducted Oct. 5, 2006

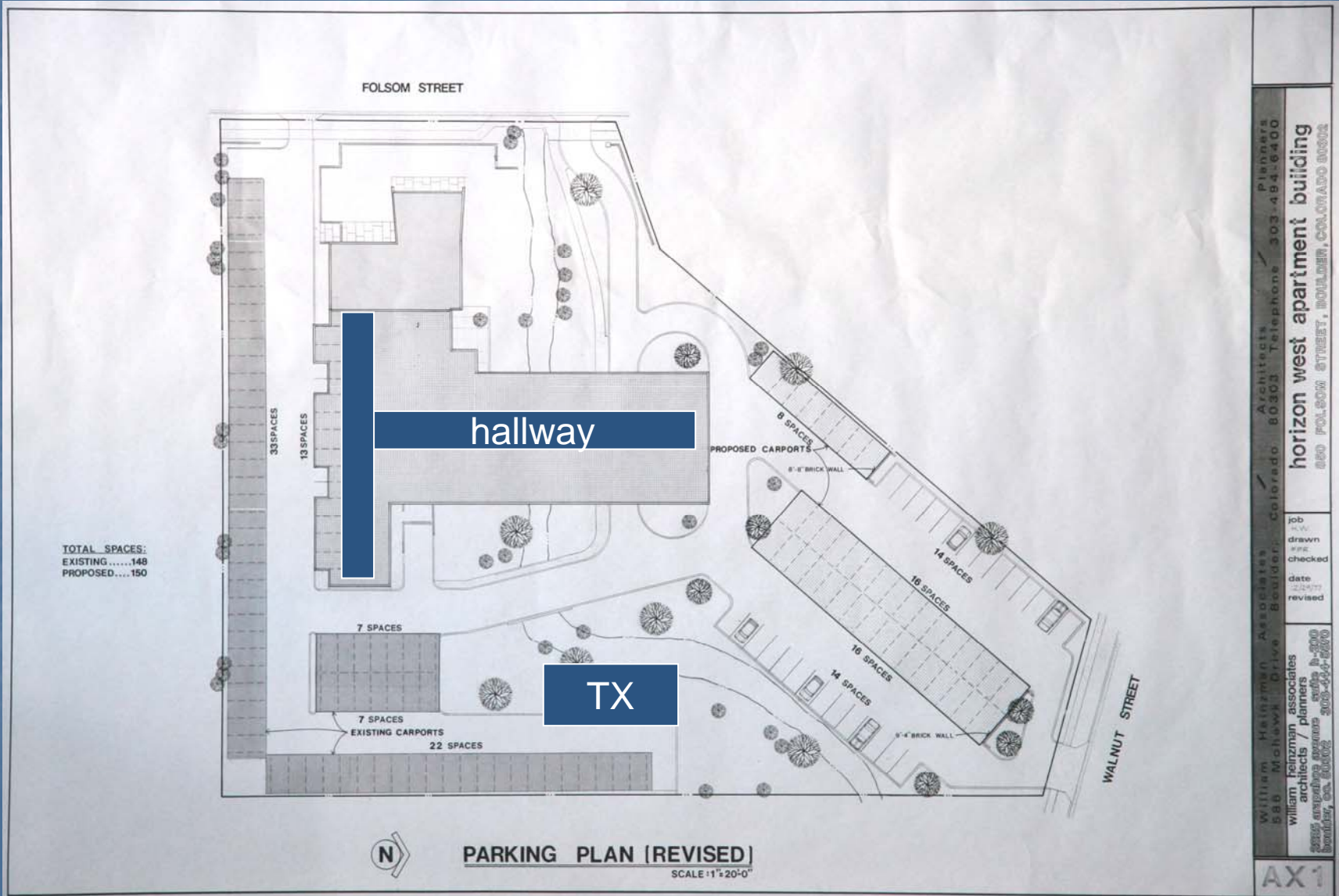
12-story brick and steel apartment building

- apartments on floors 2 and 7
- detailed measurements in hallways on floors 2 and 7

Work in support of COPS/SAFECOM network simulation studies, through NIST OLES FY06



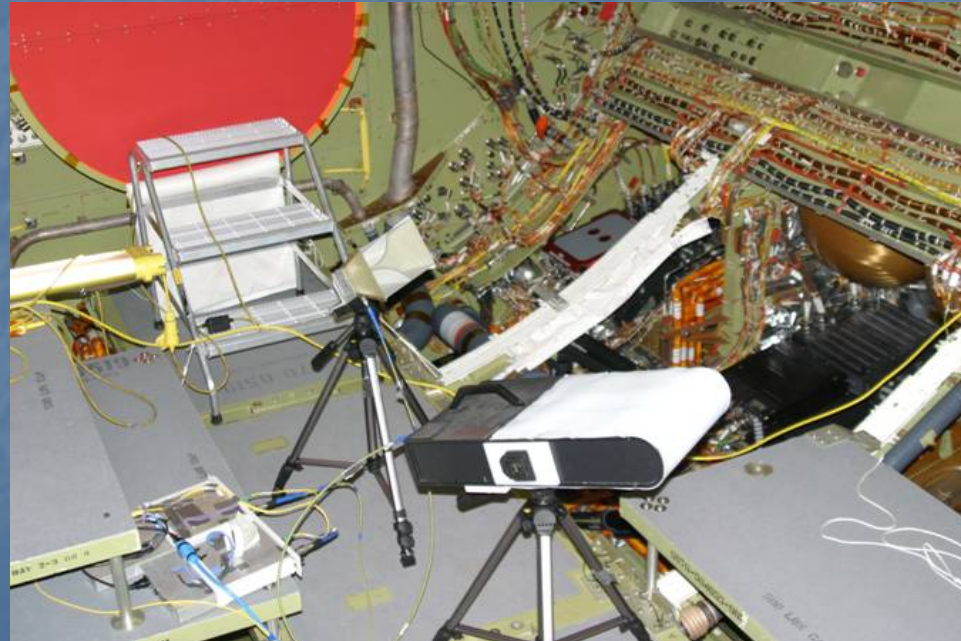
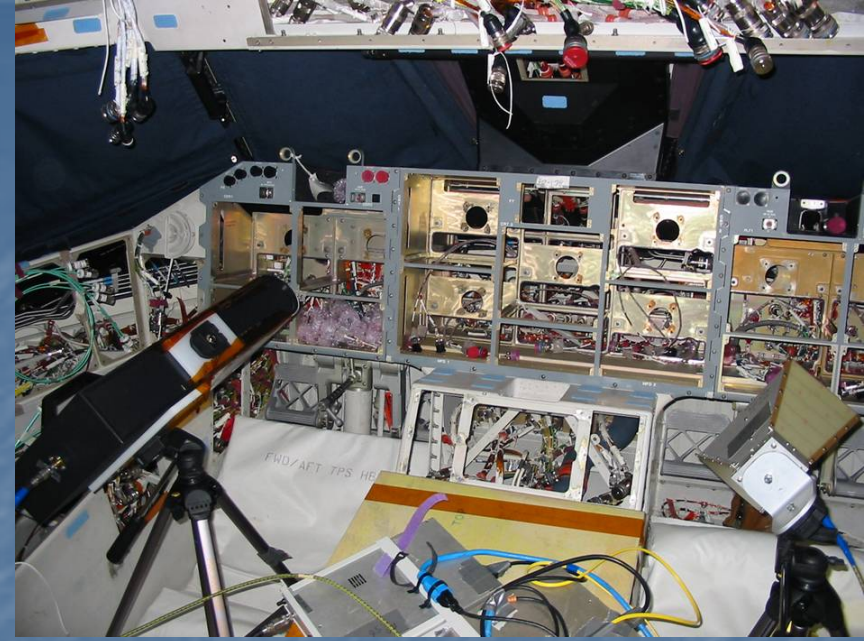
# Horizon West Layout



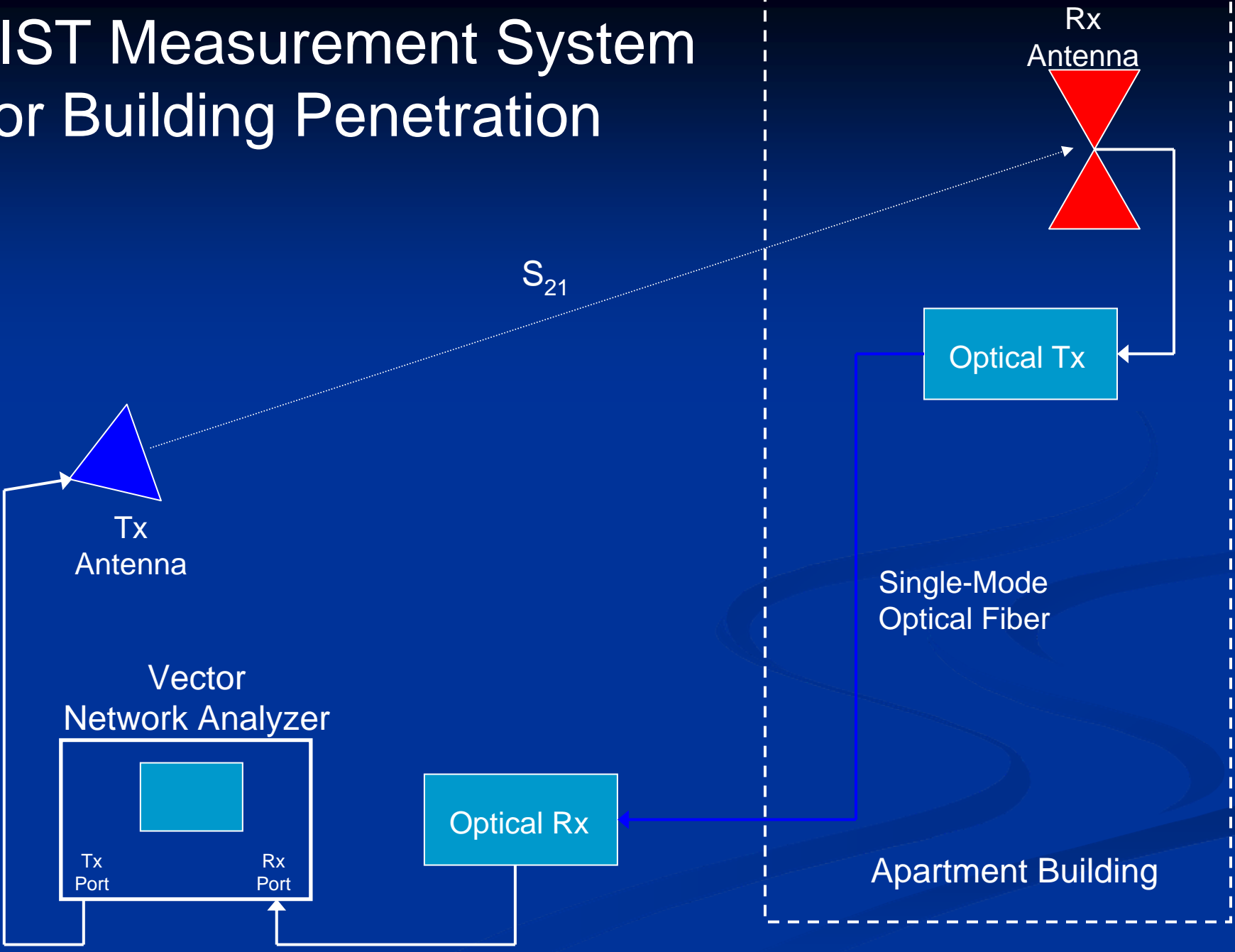
William Heinzman Associates 586 Molokini Drive Boulder, CO 80502	Architects 80303 Telephone 303-494-6400	Planners 303-494-6400
William Heinzman Associates architects / planners 2835 Annapolis Avenue Boulder, CO 80502	horizon west apartment building 150 FOLSOM STREET, BOULDER, COLORADO 80502	
job # 0000	drawn RFE	checked
date 12/2/07	revised	
<b>AX1</b>		

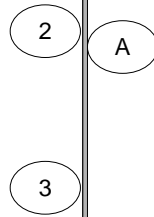
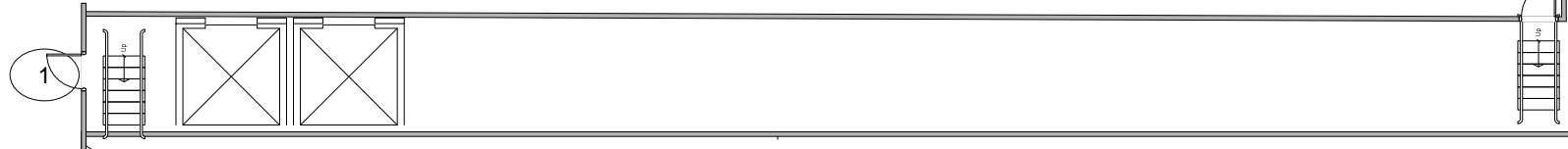
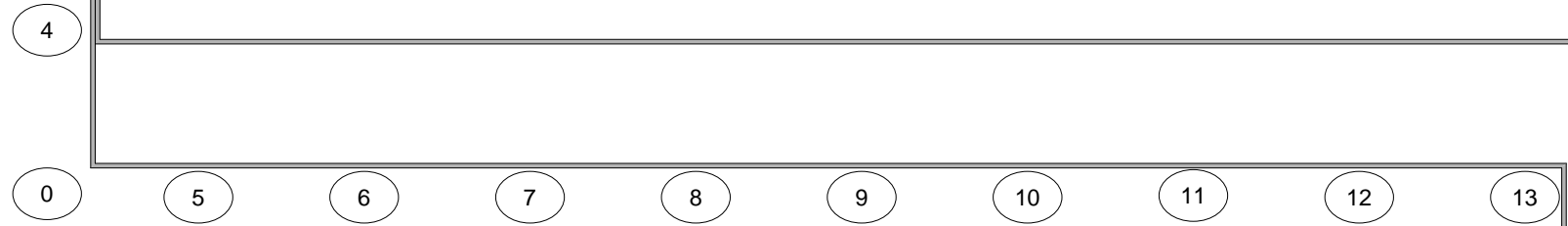
# System Originally used for Airframe Penetration Studies...






# NIST Measurement System For Building Penetration





\*\*All numbered points are 5m apart

### Measurements on 2<sup>nd</sup> and 7<sup>th</sup> floors + entrance

Tx Antenna 

# Test Set-up: Outside







# NIST/ITS Interagency Cooperation..



Are we truly down in the dumpster?

# Test Set-up: Inside



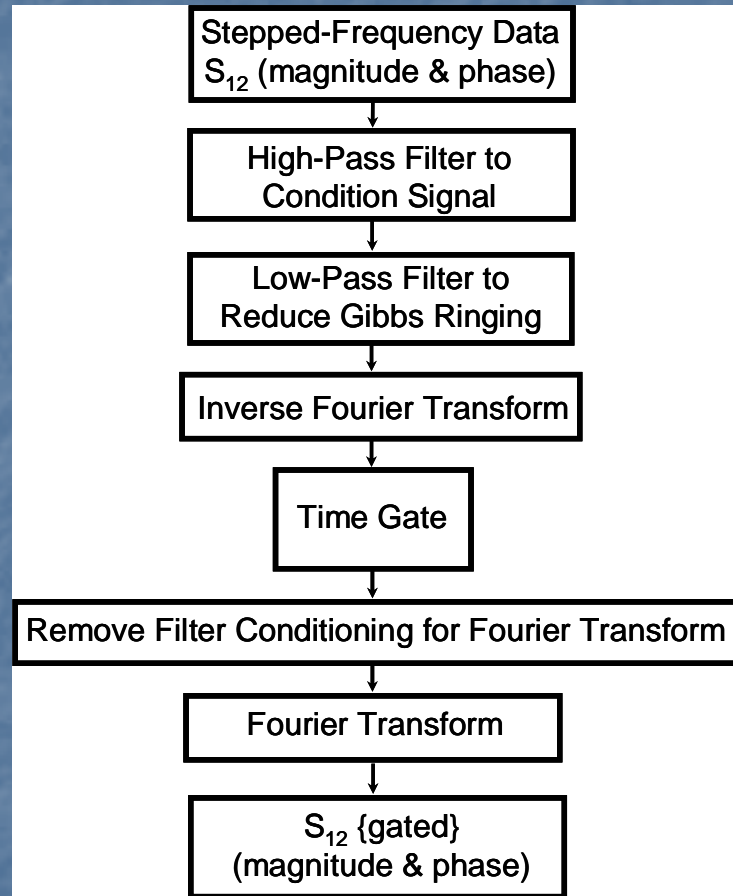
# Low-Freq Discone



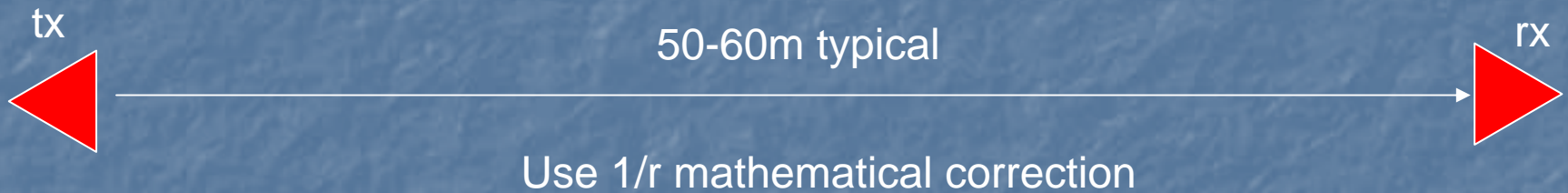
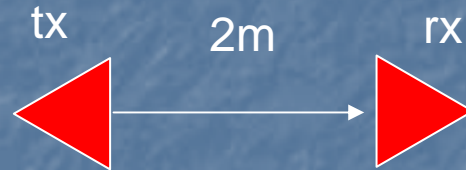
# Signal Processing Sequence

- Acquire magnitude/phase data as a function of stepped frequencies (as many as 48,000 frequencies)
- Two sets of measurements performed:
  - 100 MHz-1.5 GHz—discone antennas
  - 700 MHz-18 GHz—antenna issues above 14 GHz
  - DRH (Tx) & Discone (Rx)
- Filter, transform, gate data
- High resolution time-domain waveforms—can be used to identify direct path & reflected components
- Waveforms can be gated to isolate desired scattering events
- Building penetration can be compared with antenna-to-antenna references (mathematically corrected) to yield excess path loss

# Signal Processing Sequence cont'd...

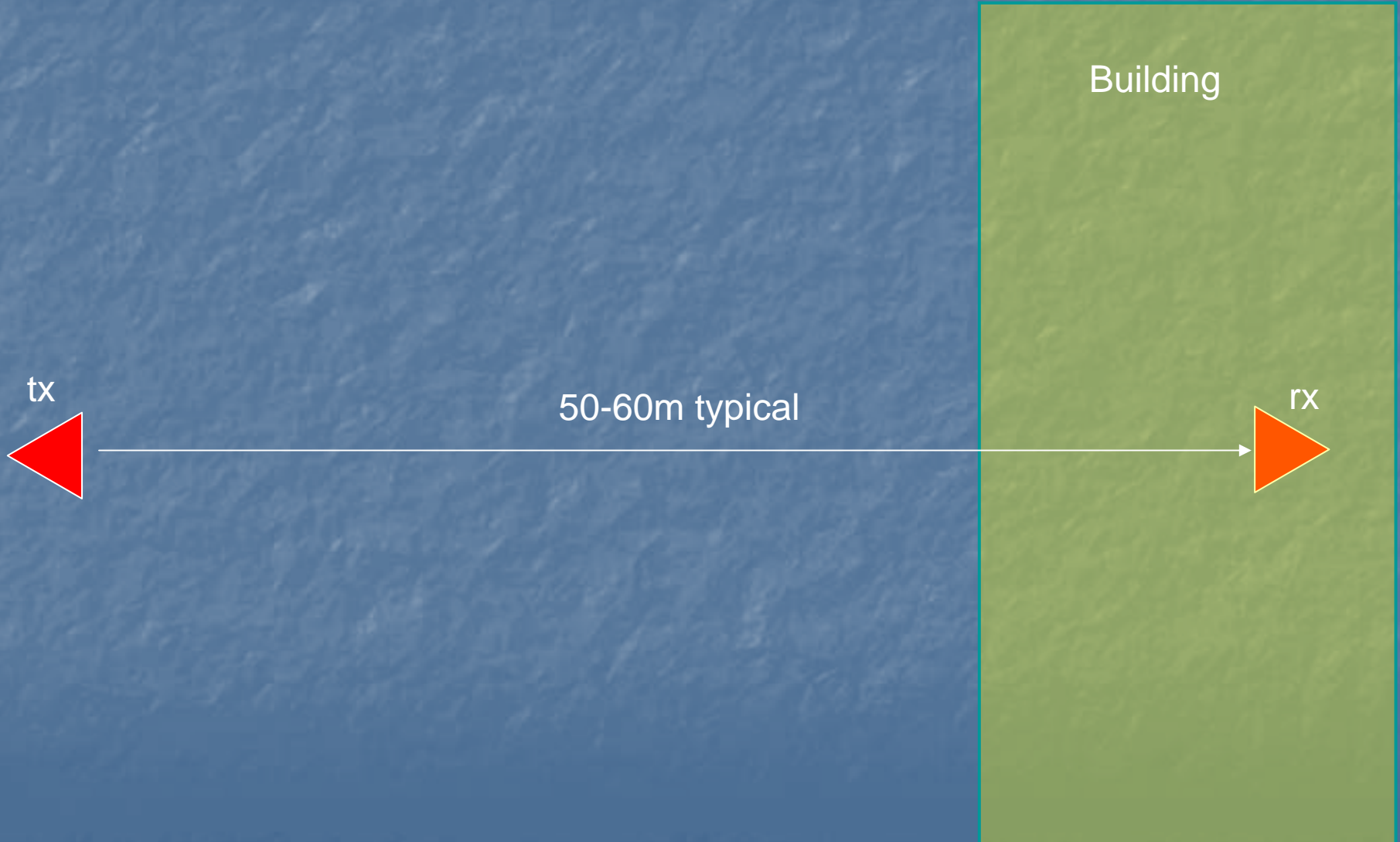


# Building Penetration Metric Step 1— Free-Space (fs) Reference



Correct to estimated antenna separation...

# Building Penetration Metric Step 2— rx Antenna inside the Building





# Compute Building Penetration Step 3 (post processing):

## Building Penetration Metric

$$\text{BP (dB)} = 20 \text{ Log}_{10} \left( \frac{|S21_{\text{gated}}(\text{building})|}{|S21_{\text{gated}}(\text{corrected fs reference})|} \right)$$

We compare transmission into a building with a corrected “free-space” reference...

This metric is the negative of excess path loss...

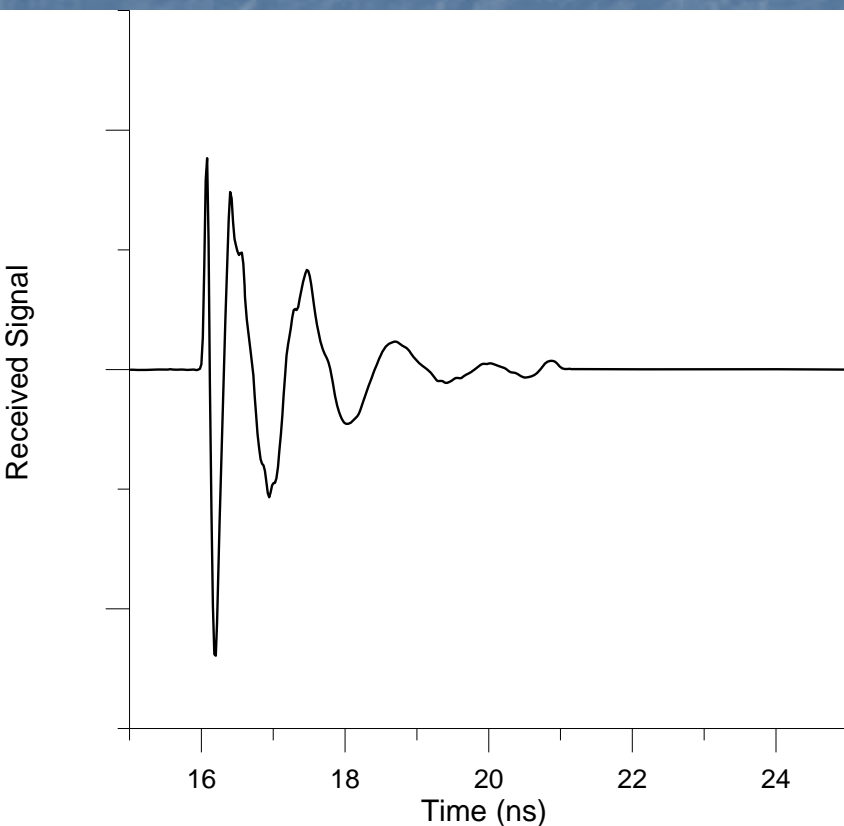
# There are other benefits from this ratio as well...

$S21\_gated(\text{building}) / S21\_gated(\text{corrected fs reference})$

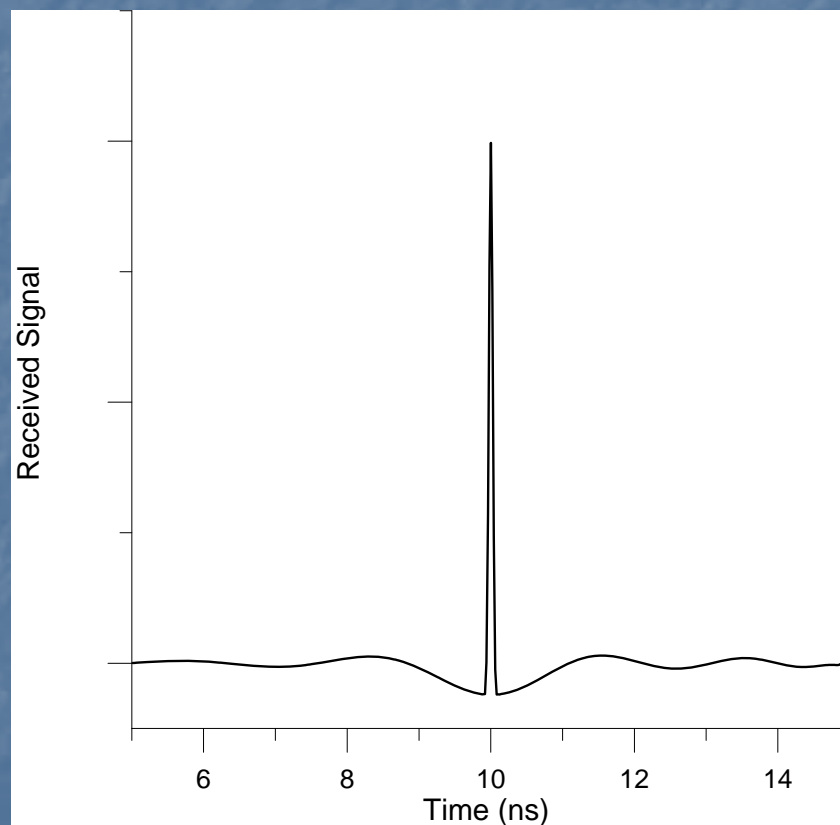
- Antenna effects cancel out in this ratio
- Spectral flattening
- “Sharper” waveform characteristics
- Higher range resolution

# Remove Antenna Responses via Deconvolution = better range resolution! exploits system bandwidth

S21\_gated(building)

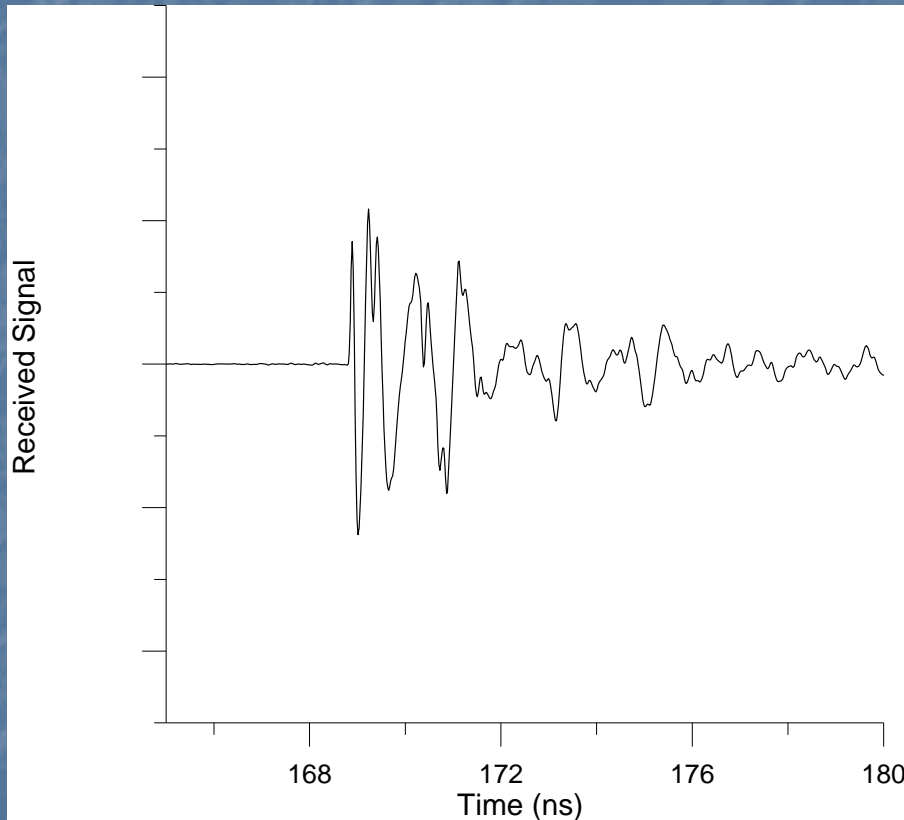


Gated Antenna-to-Antenna  
Approx 5ns duration

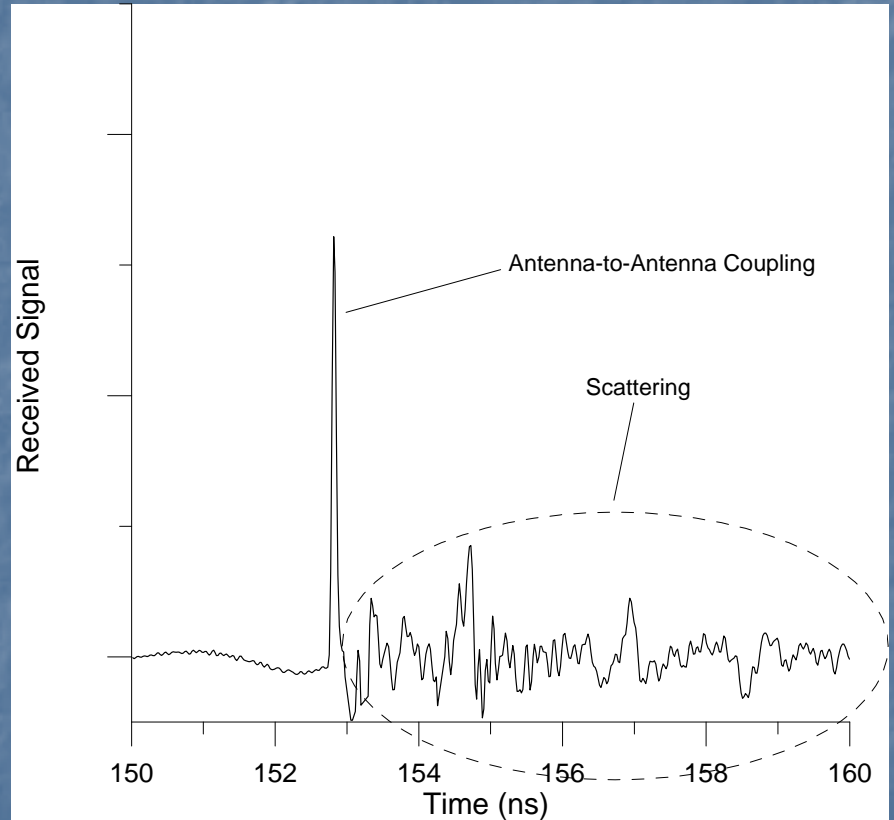


Deconvolved Result  
Approx 0.2ns duration

# Remove Antenna Responses via Deconvolution = better range resolution! Separable direct coupling@ position A

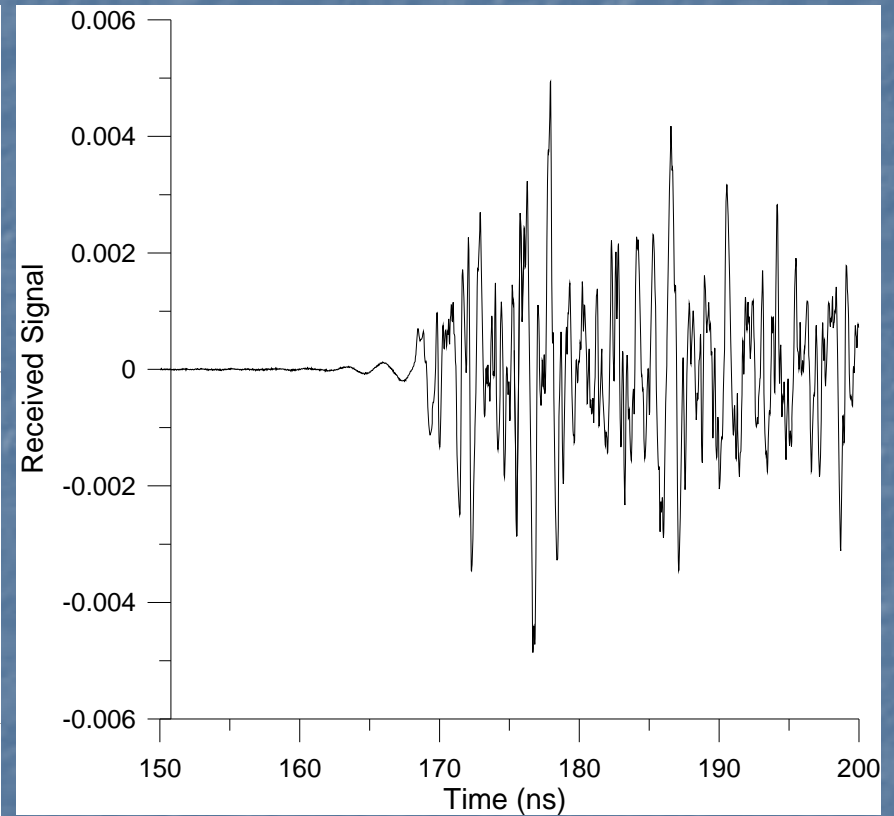
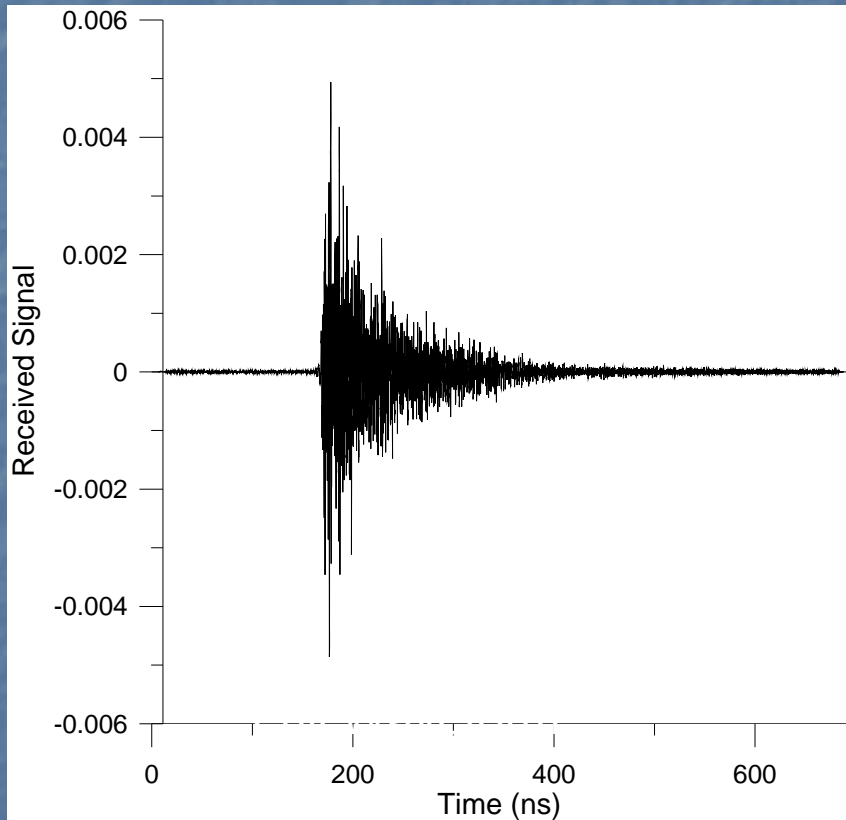


Antenna-to-Antenna--Raw  
143' Separation  
IFT{S21\_gated(building)}



Deconvolved Result

# Typical results...



Floor 7, Station 8 Waveform-After post-processing  
VNA data (deconvolved)

# Horizons West Penetration Results Time-Domain Waveforms...



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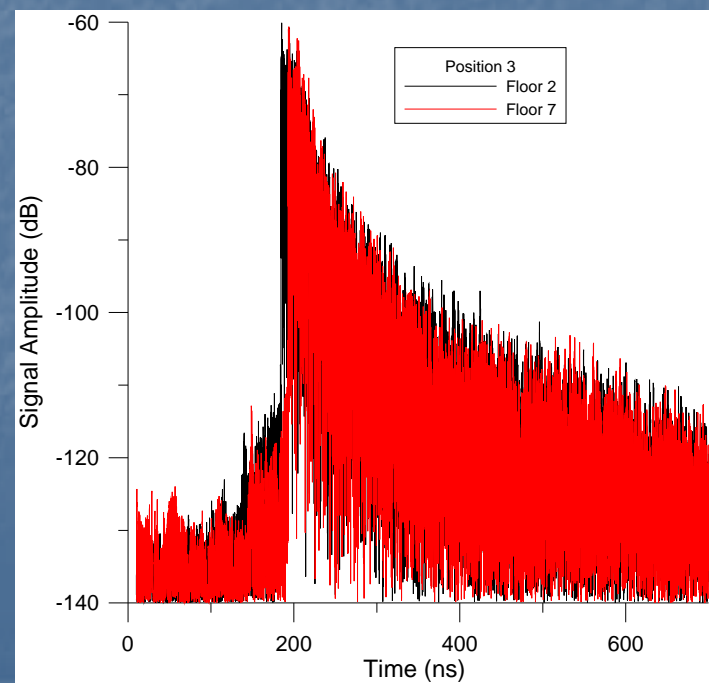
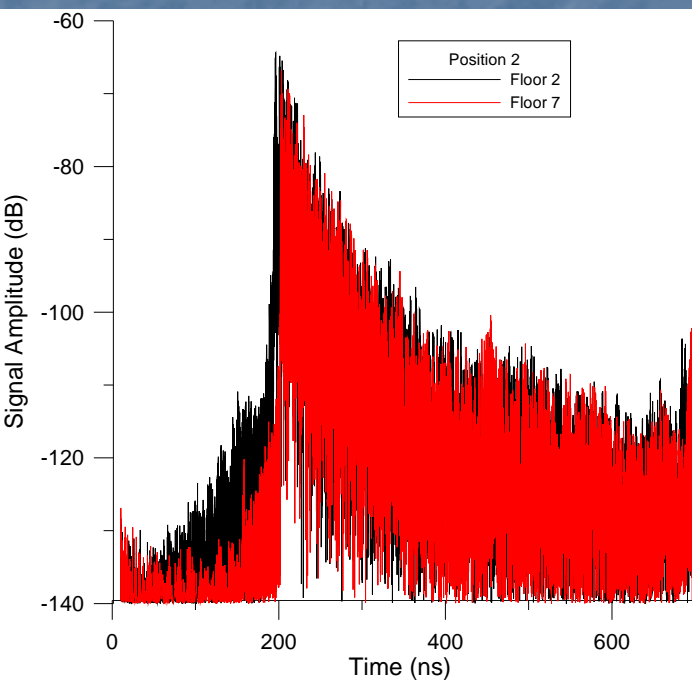
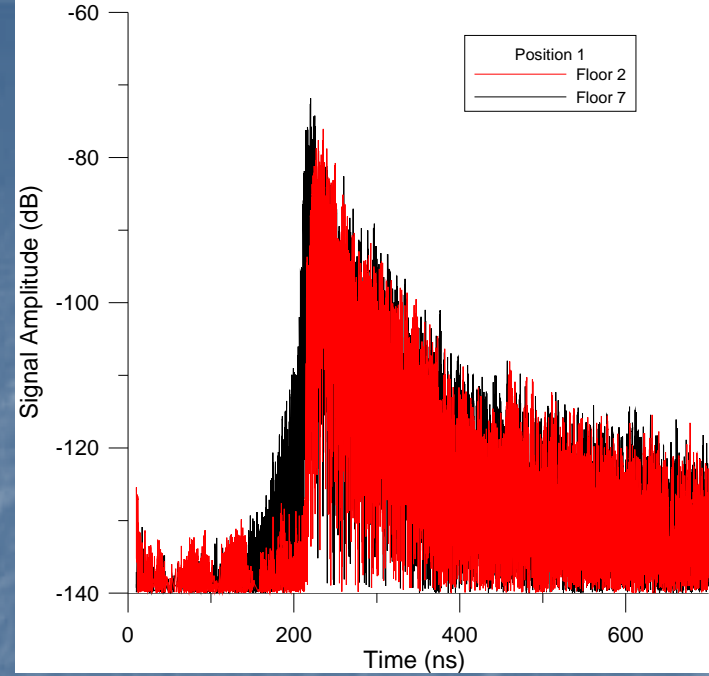
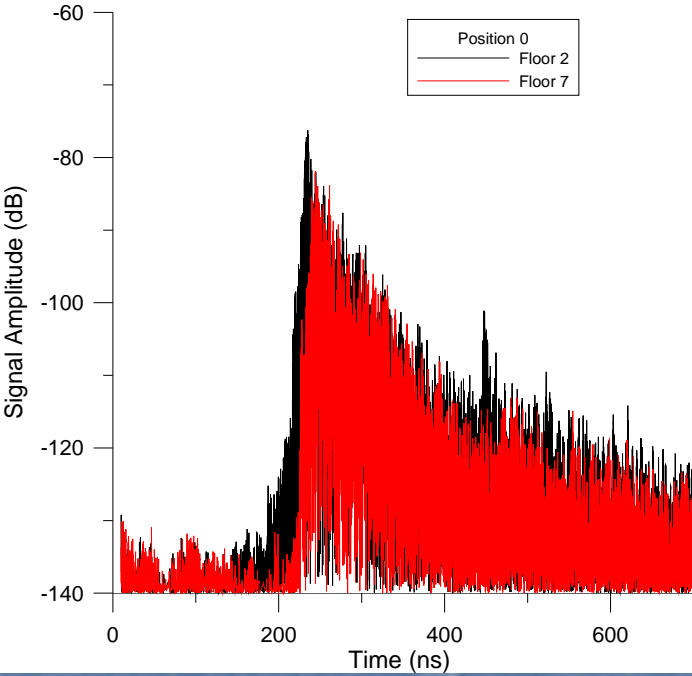
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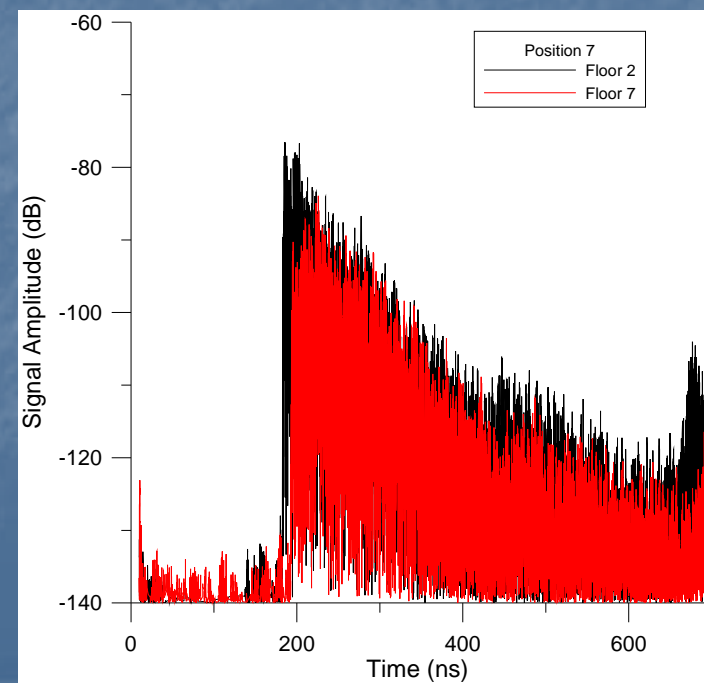
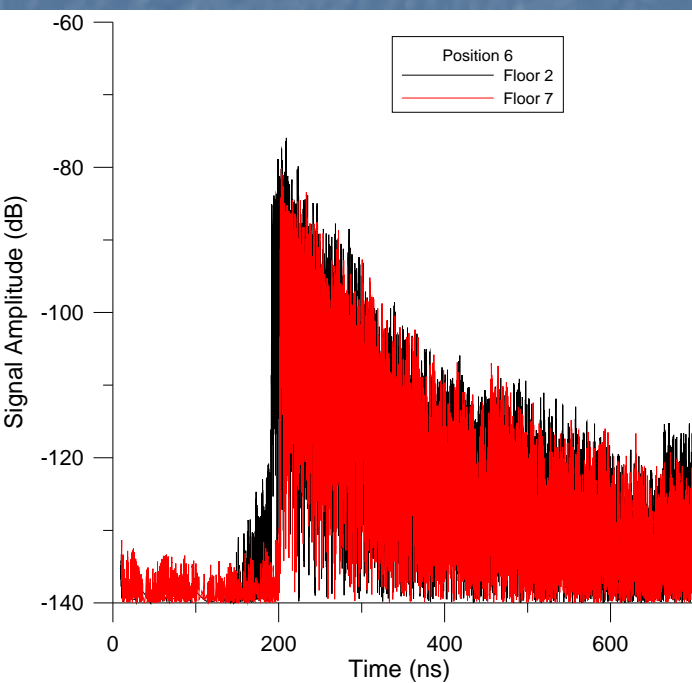
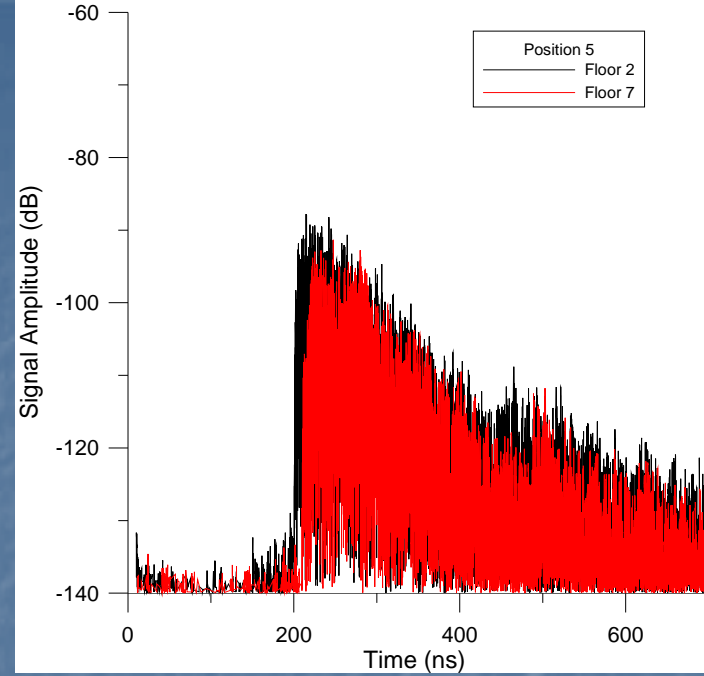
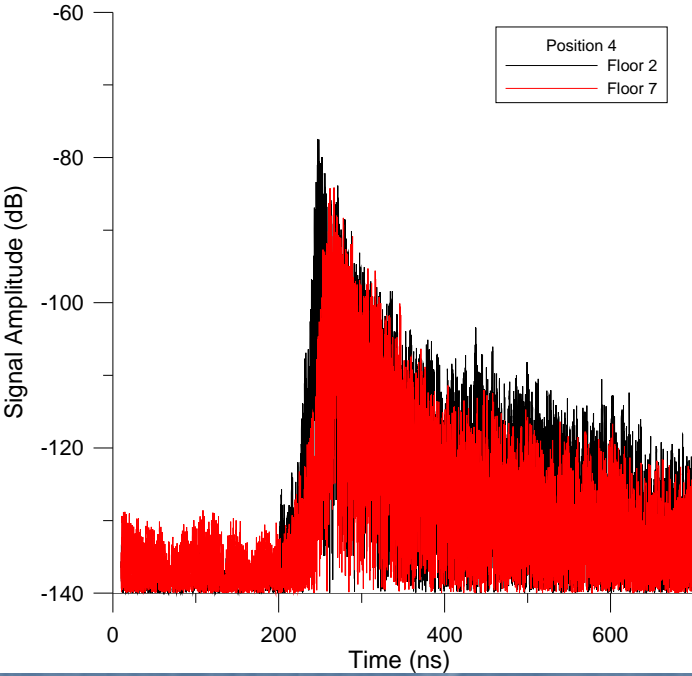
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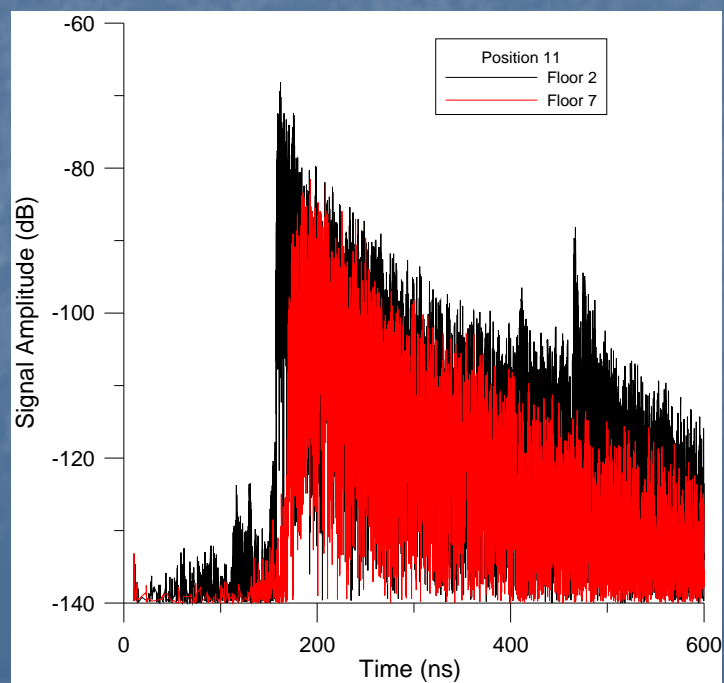
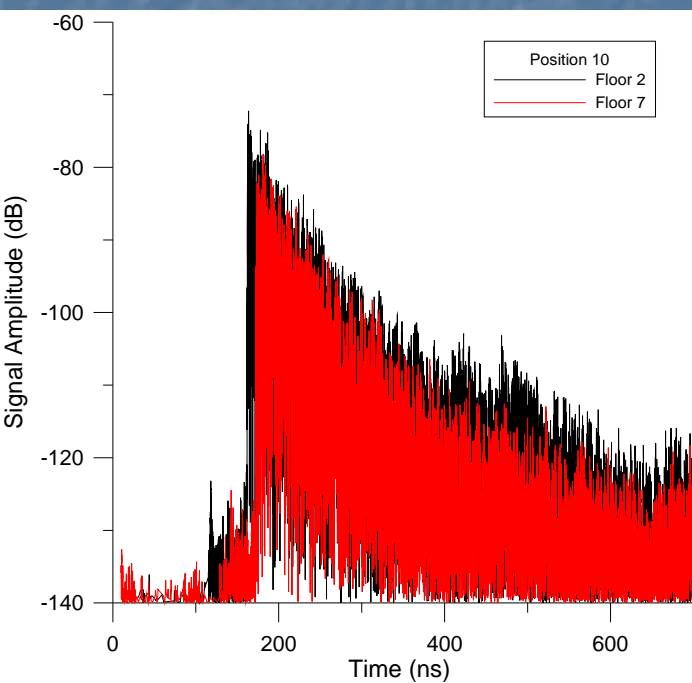
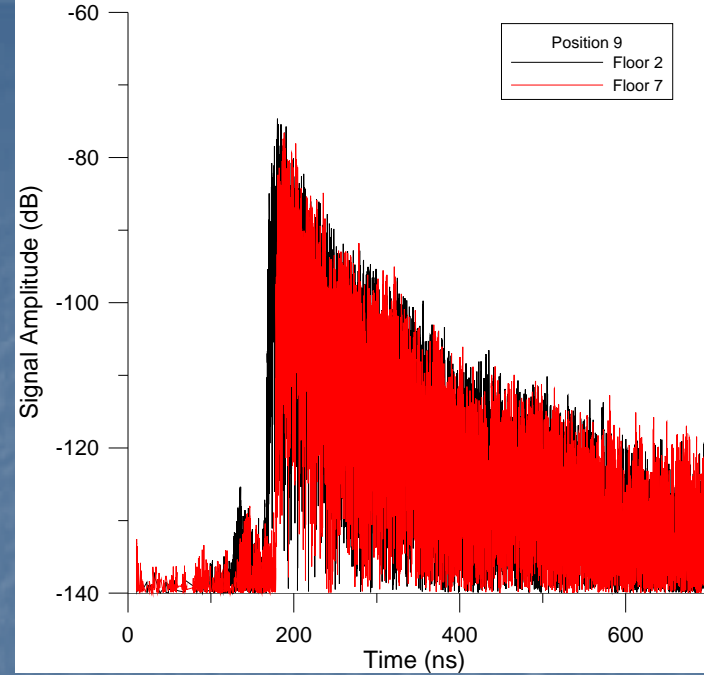
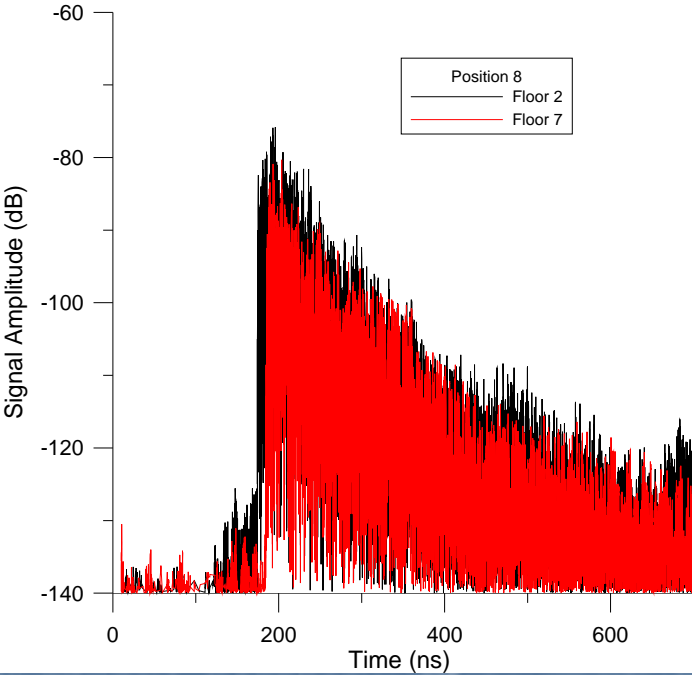
\*\*All numbered points are 5m apart

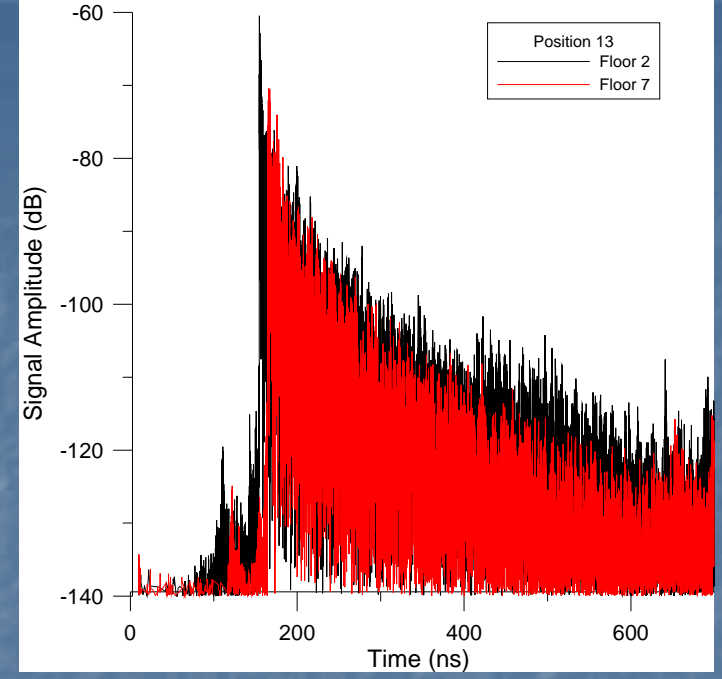
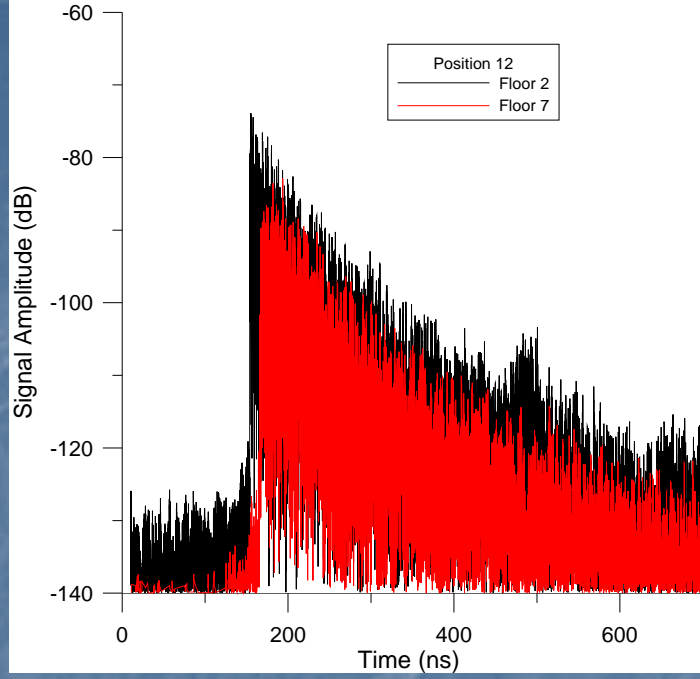


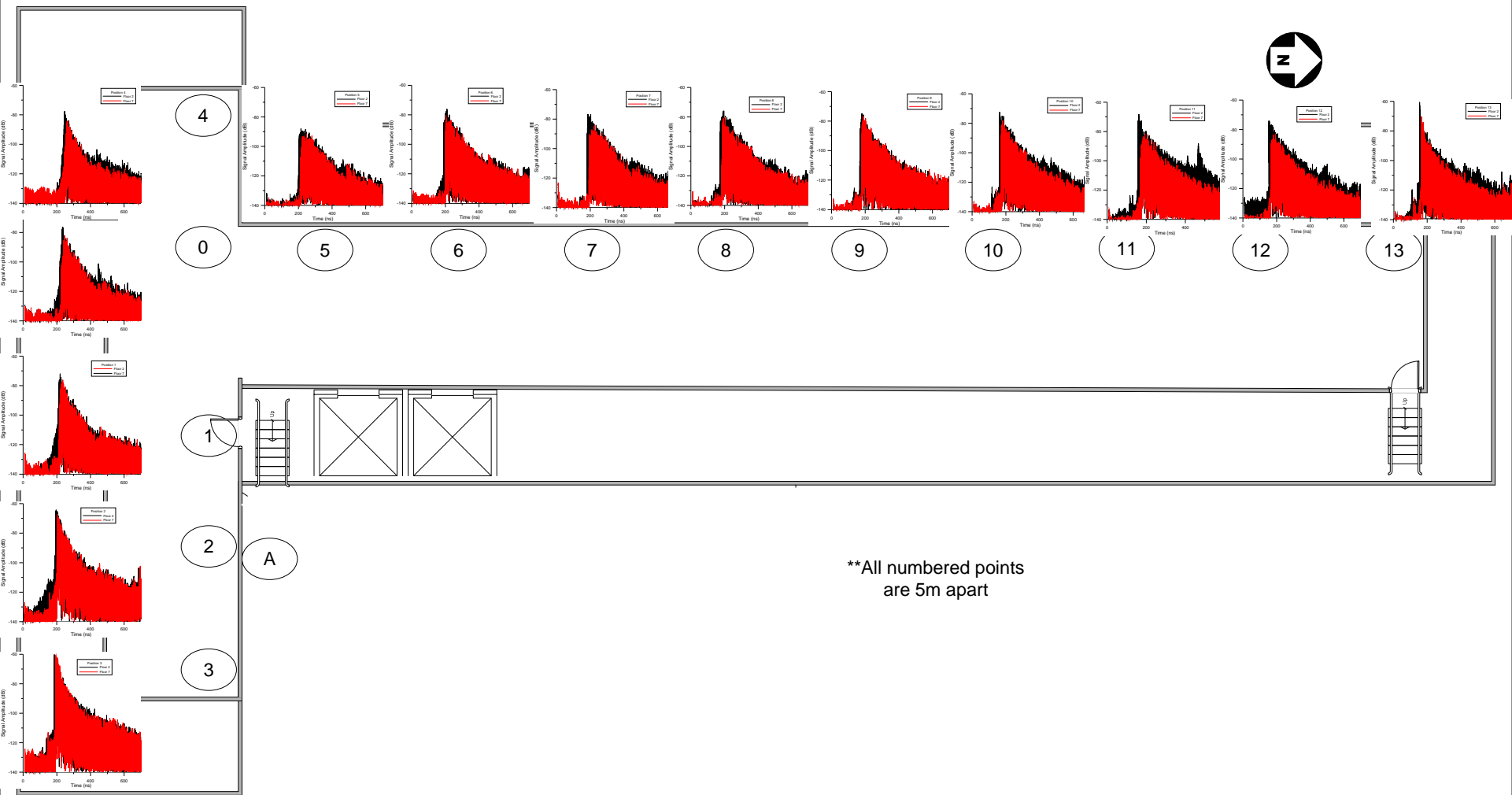










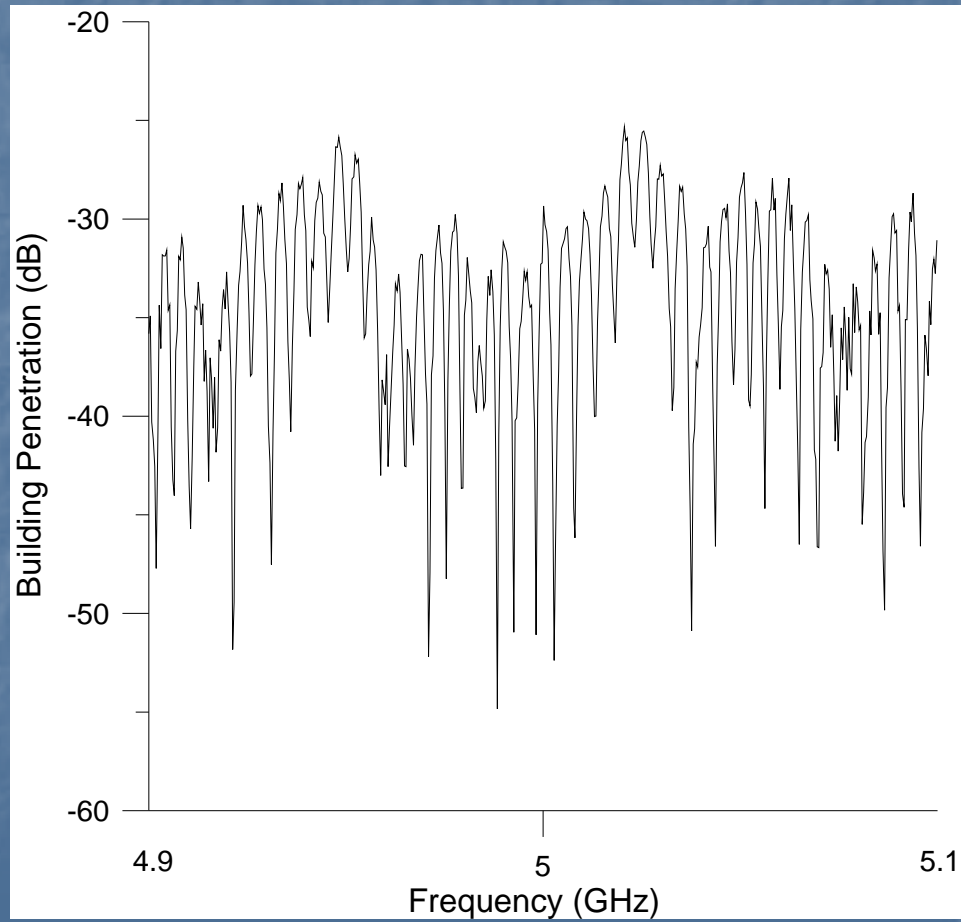
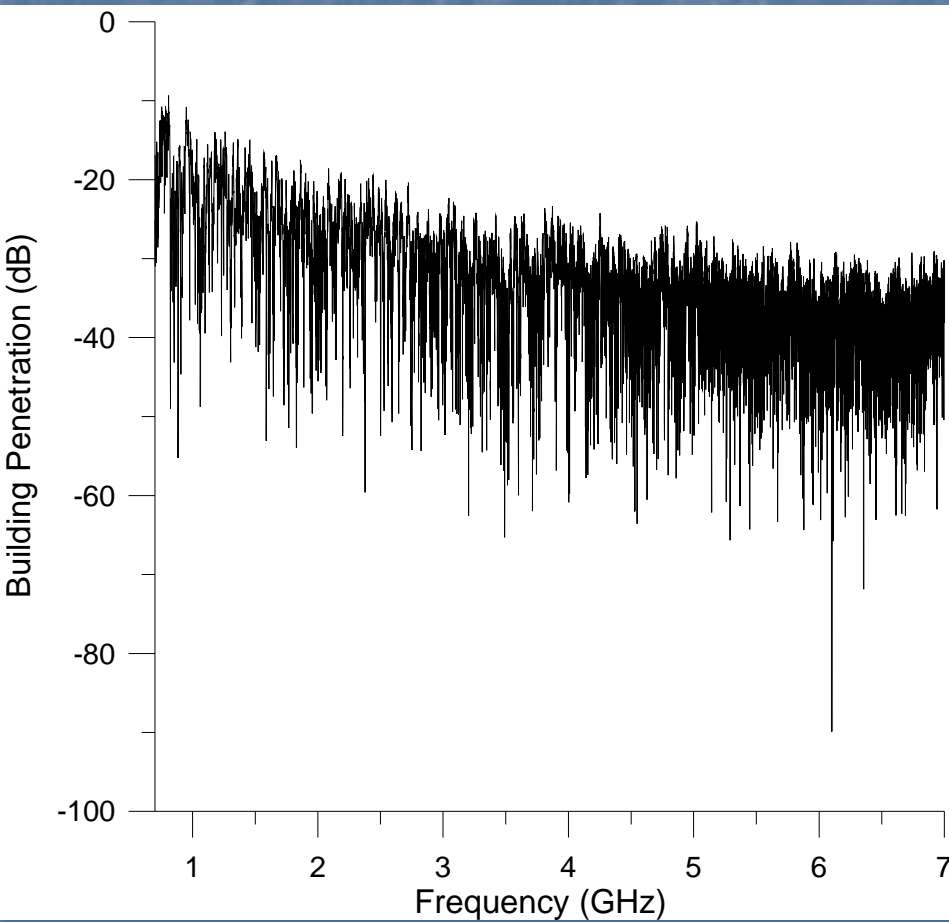


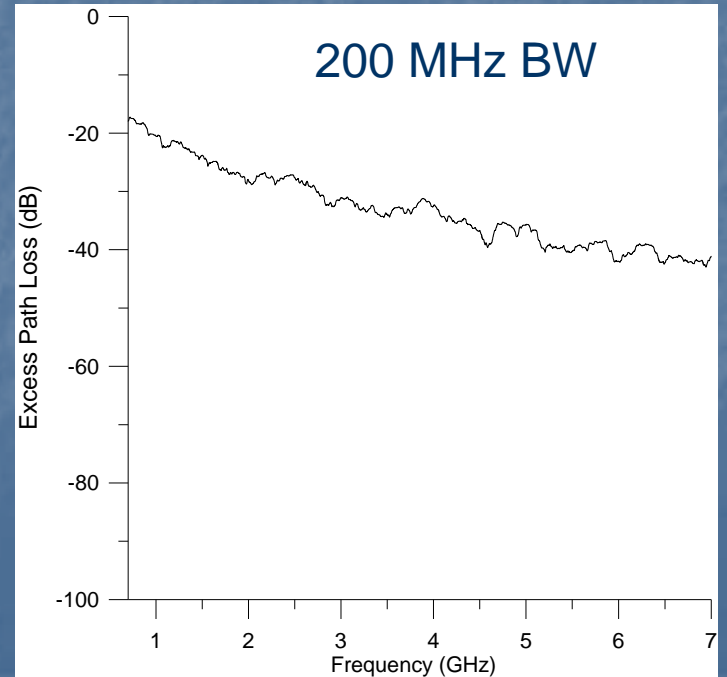
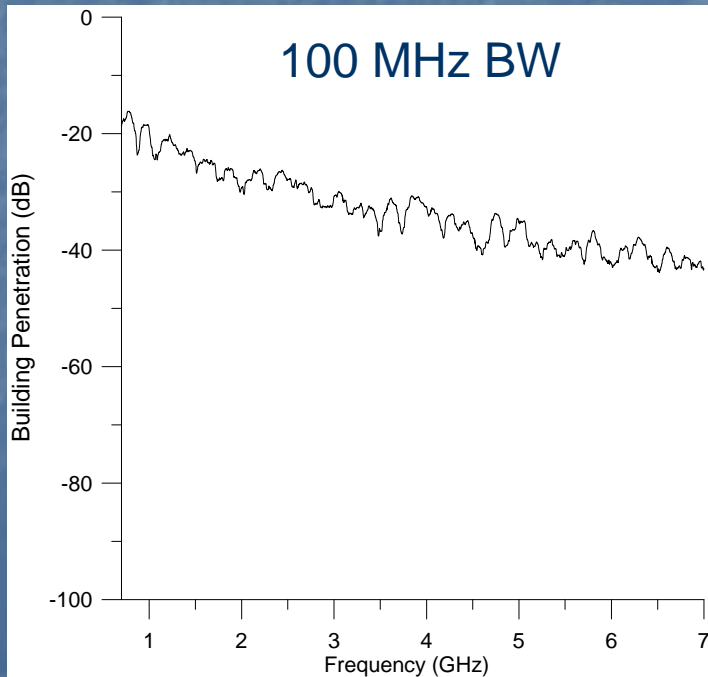
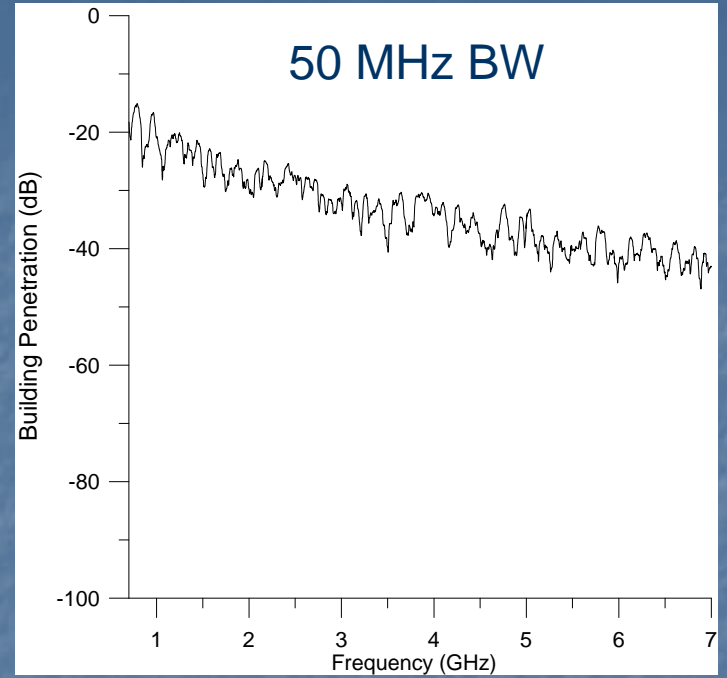
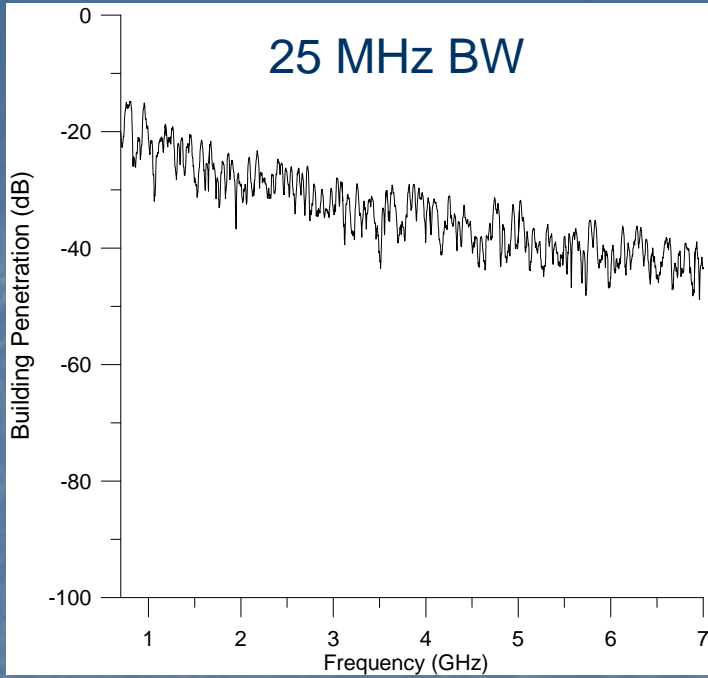
Tx  
Antenna 

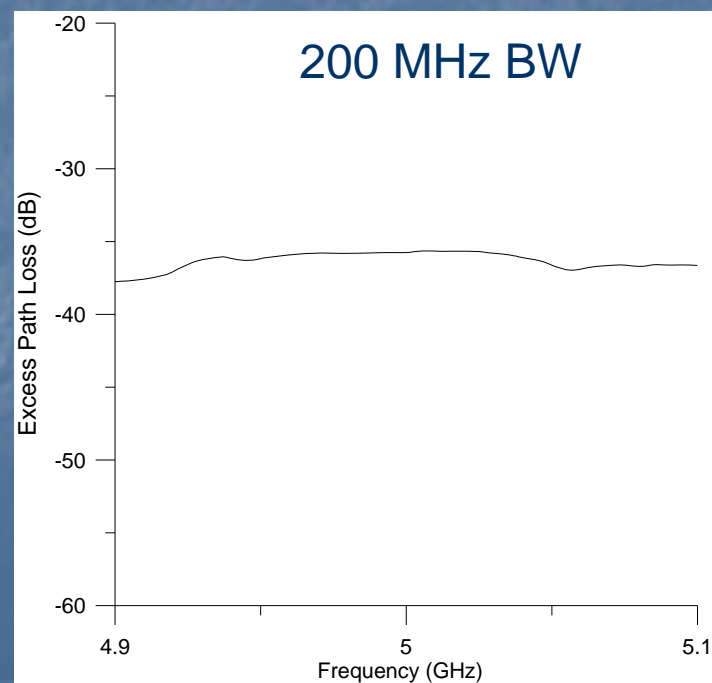
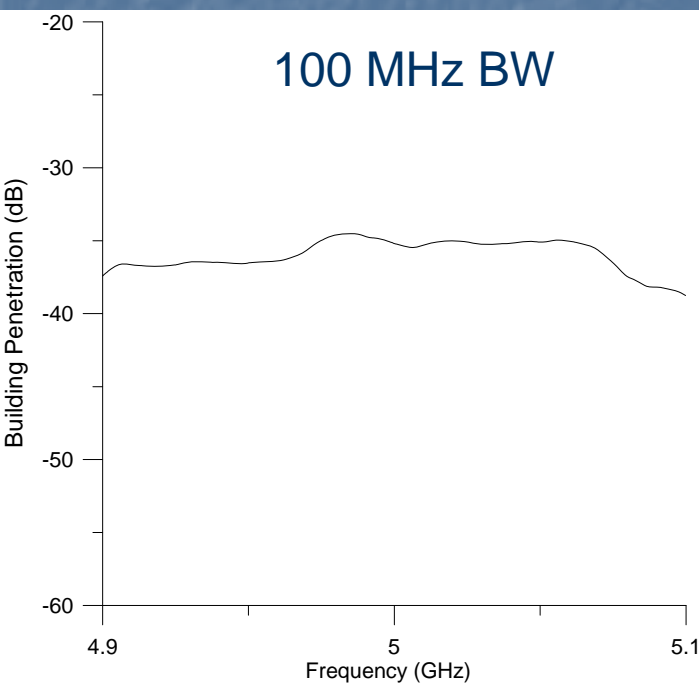
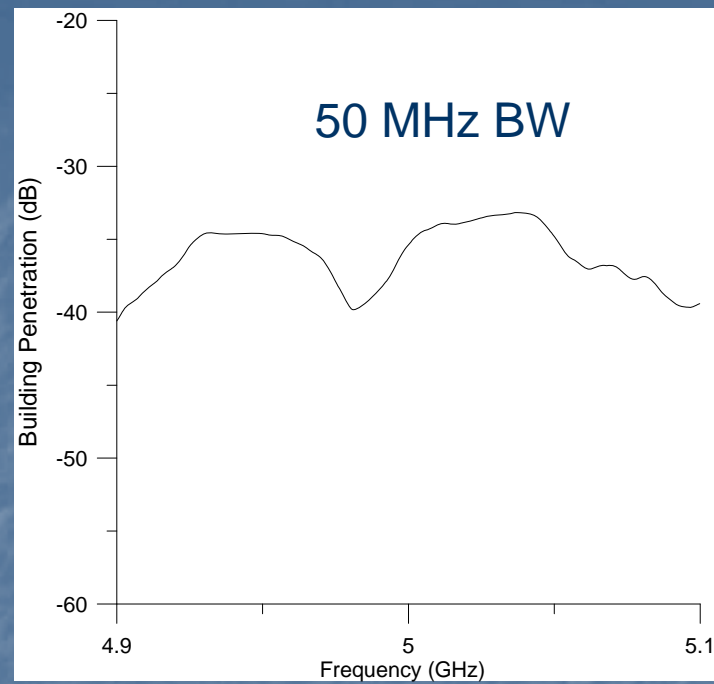
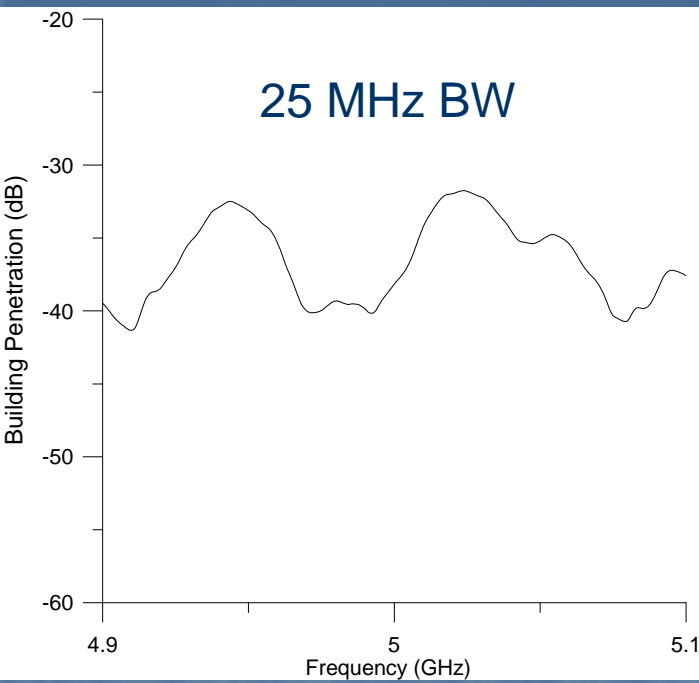
# Horizons West Penetration Results Frequency-Domain Results...

# Floor 7, Station 8 Building Penetration

After post-processing VNA data (reference & Penetration)









# Horizons West Penetration Results

## Frequency Averaged Results

- Examine systematic shifts in penetration
- Frequency dependence
- Location dependence
- Larger bandwidth used to examine global effects & trends



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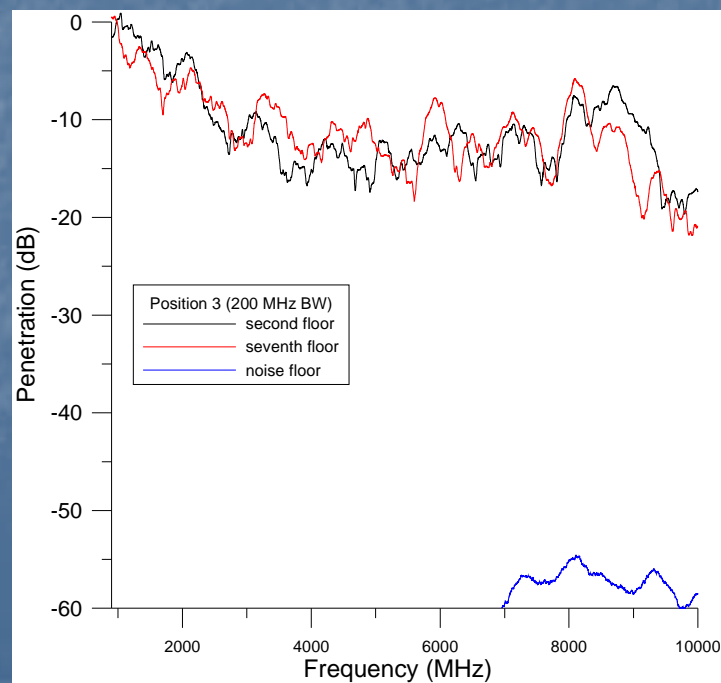
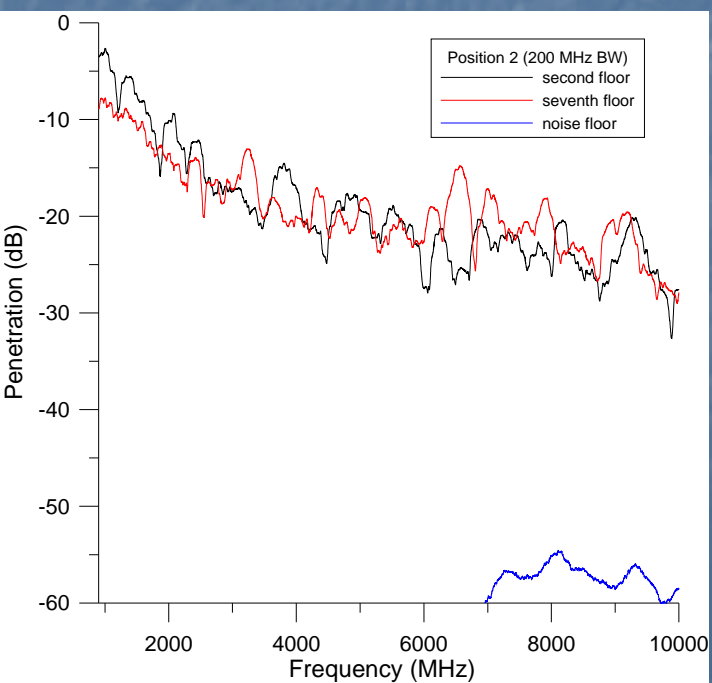
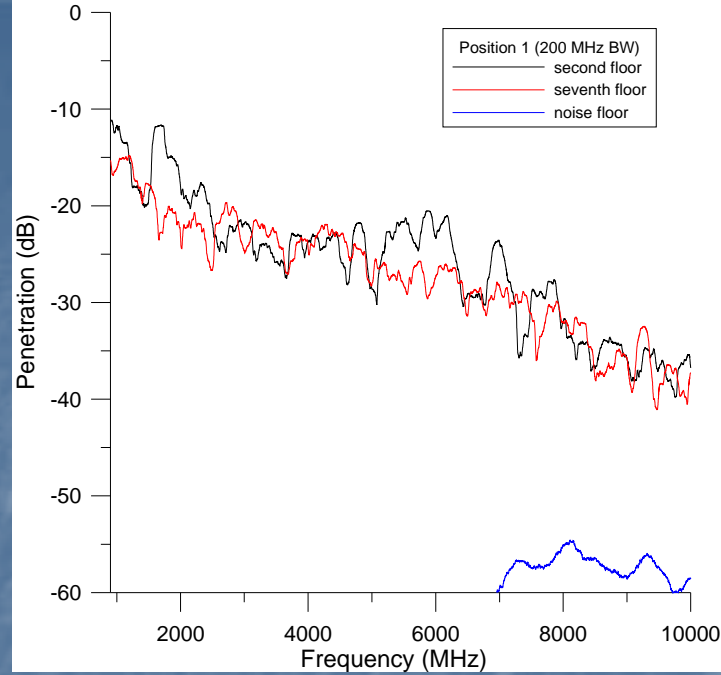
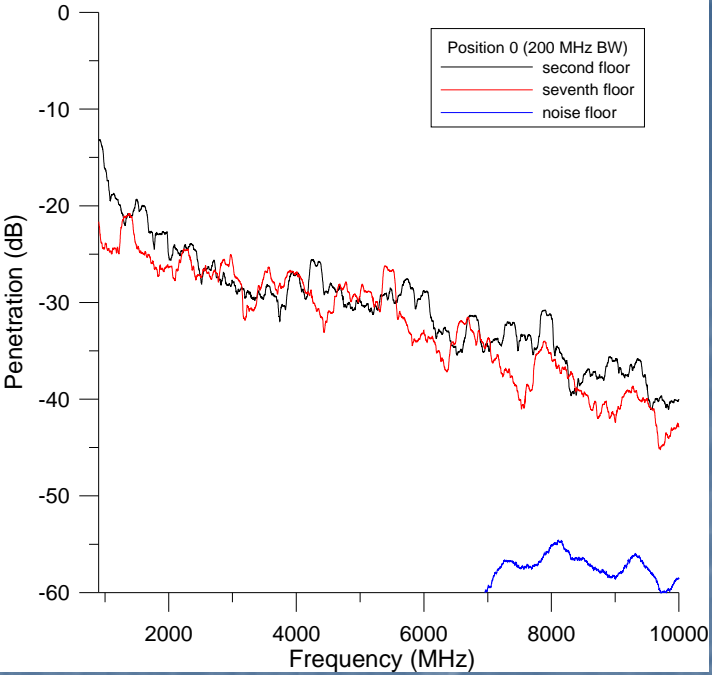
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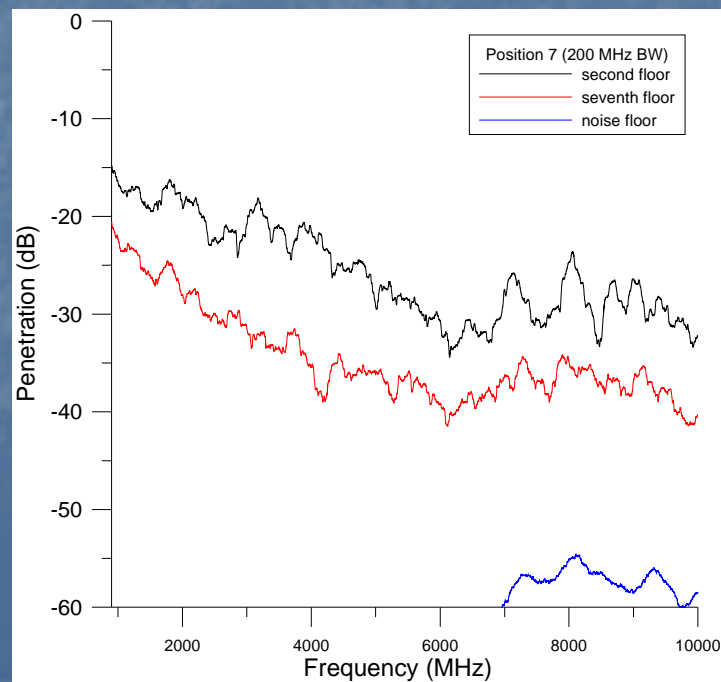
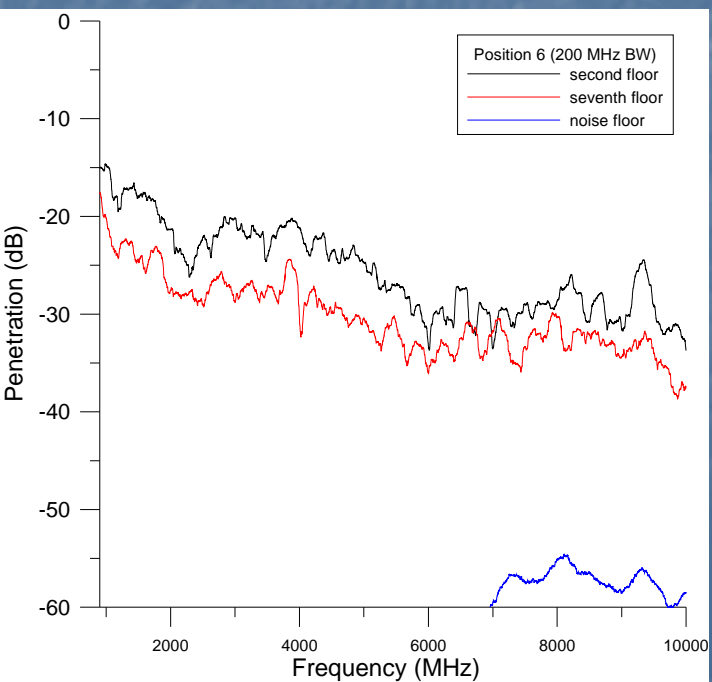
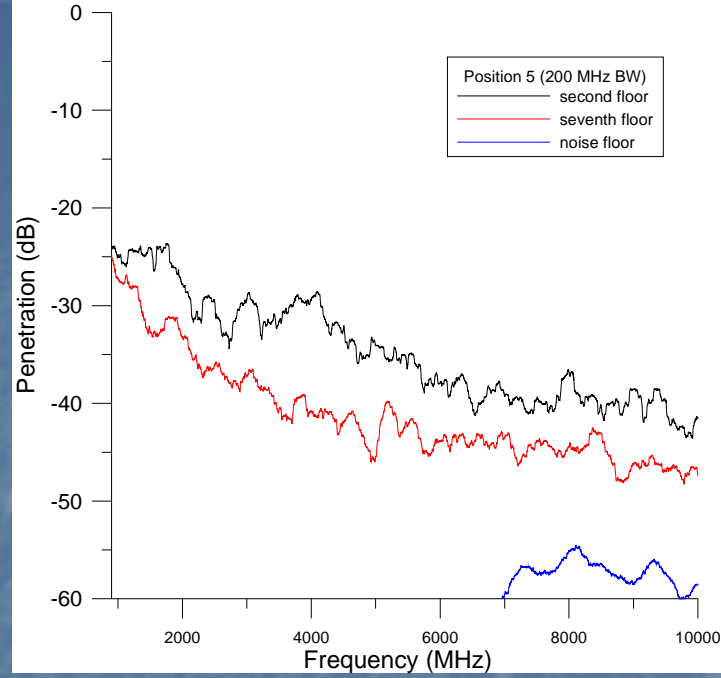
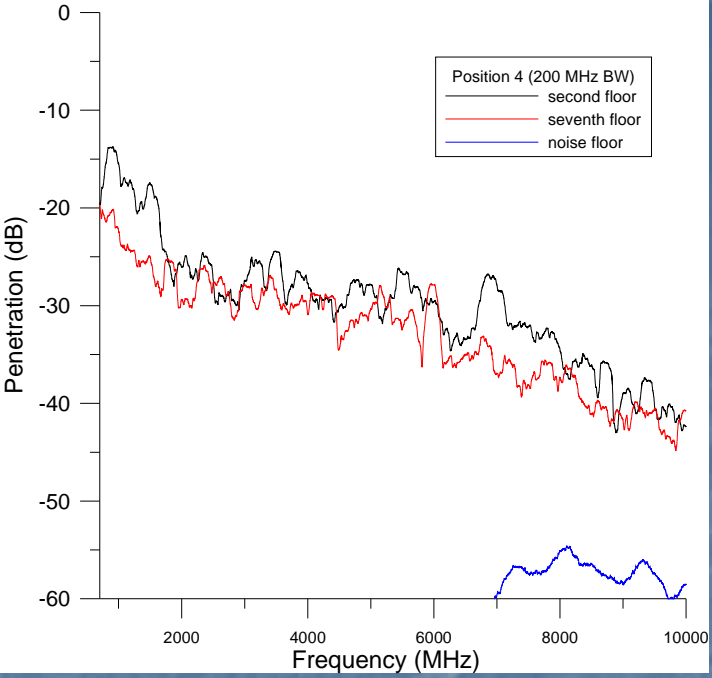
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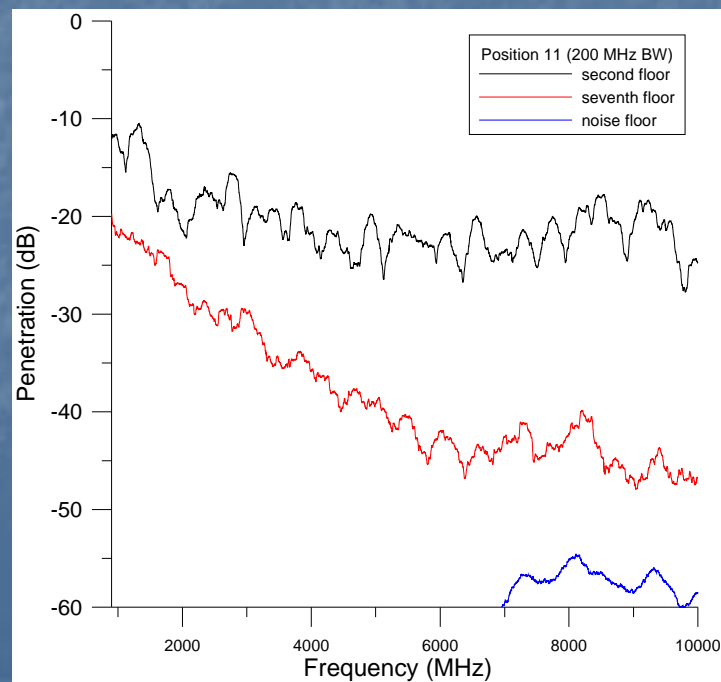
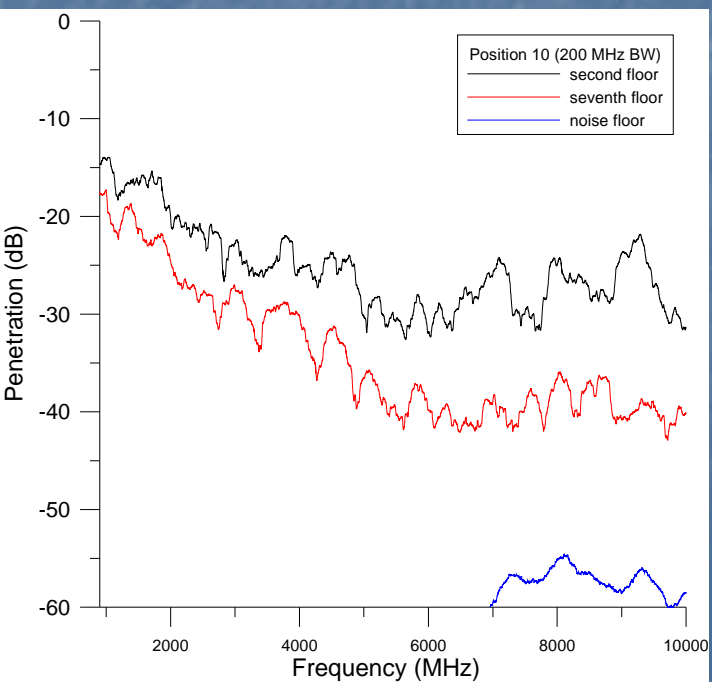
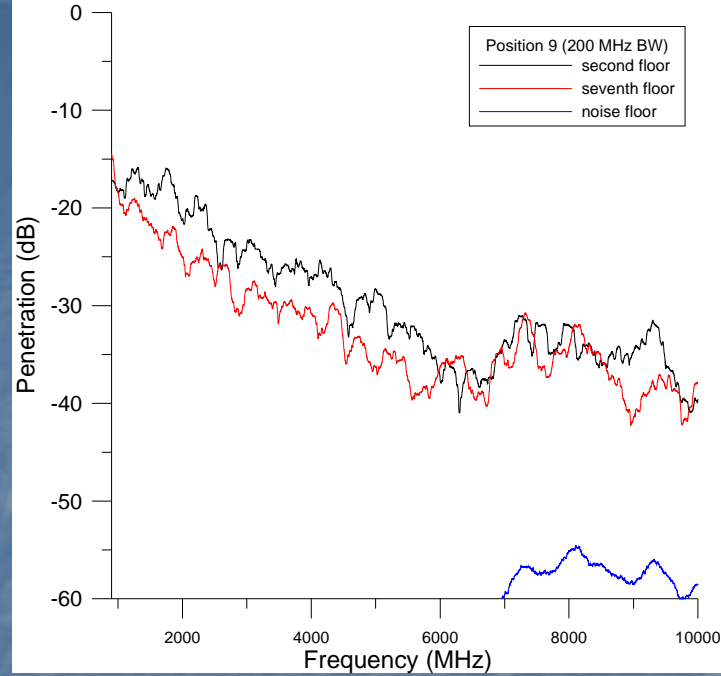
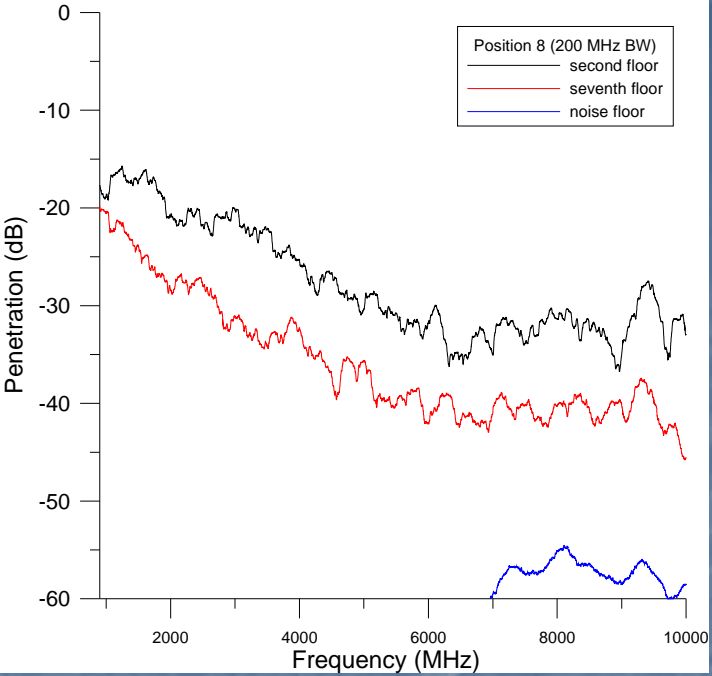
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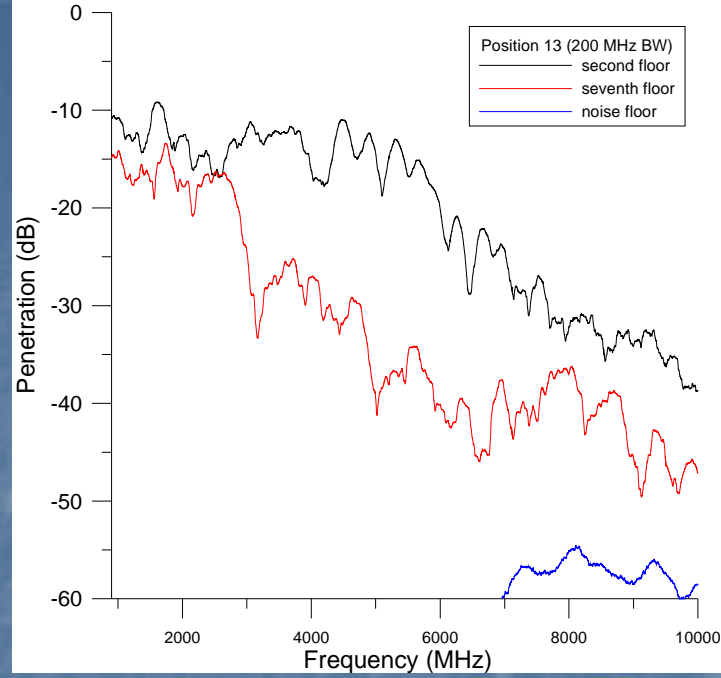
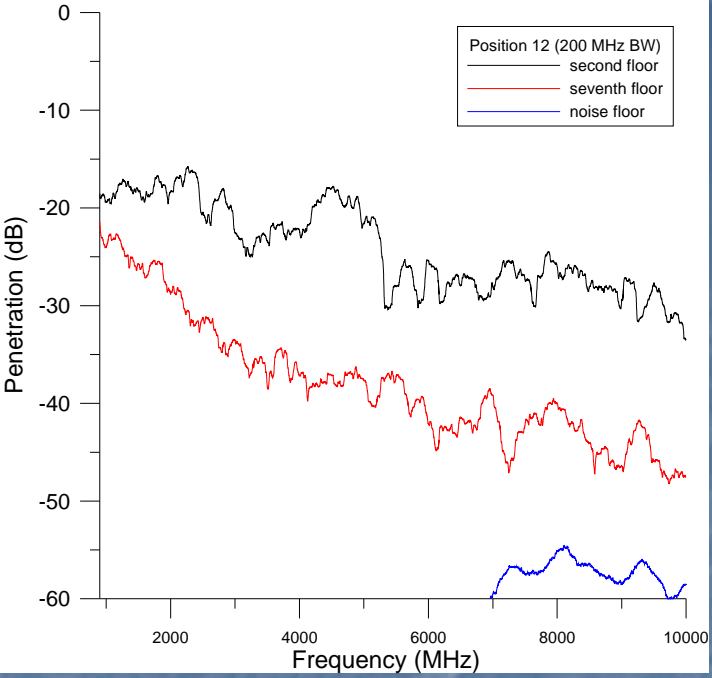
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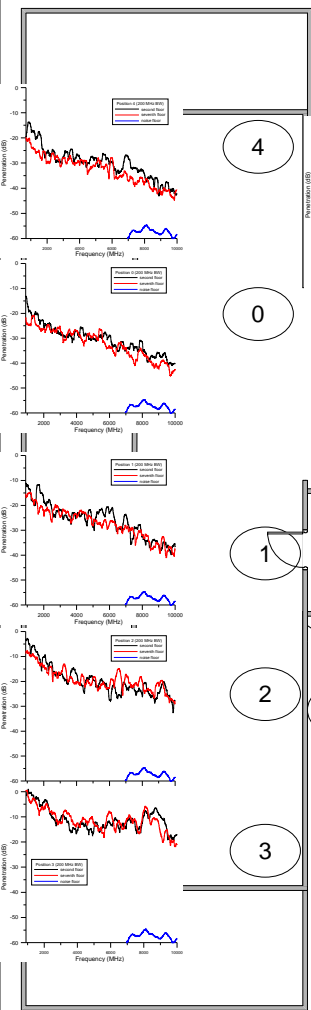












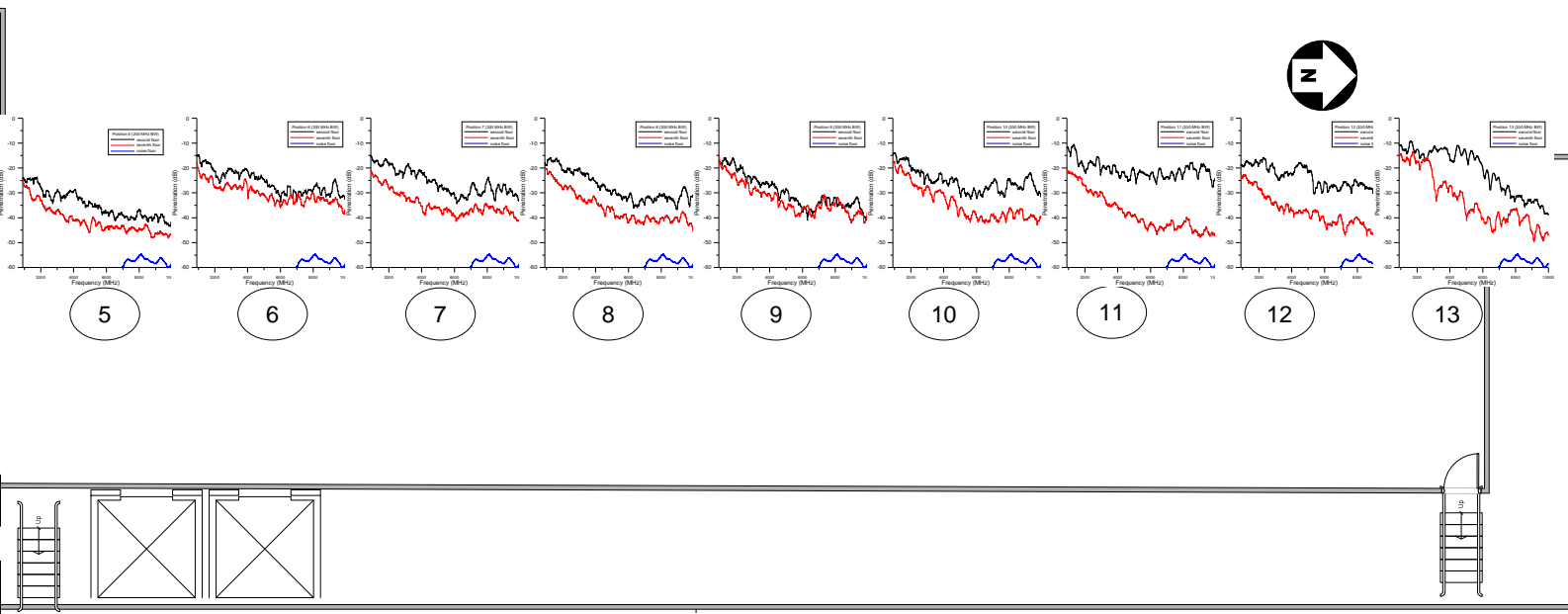
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\*\*All numbered points are 5m apart

Tx  
Antenna 

# Conclusions

- NIST VNA based system looks promising for short range UWB propagation measurements
- High resolution td waveforms useful for channel modeling
- Useful freq domain parameters...excess path loss, effects of shadowing, multipath, etc.
- Geeky fun!



# Next Steps

- Low-frequency data processing...need antenna cal...waiting for good wx
- System Improvements & Optimization
- Oil Refinery Measurements
- Tunnel Measurements
- More tests at NIST...
- Clearly a lot more “geeky” fun!

# Thanks to...

- NIST team
- ITS folks
- The good-natured folks at the Horizons West Apartments