Understanding MIMO OTA Testing: Simple Solution to a Complex Test

Moderated by
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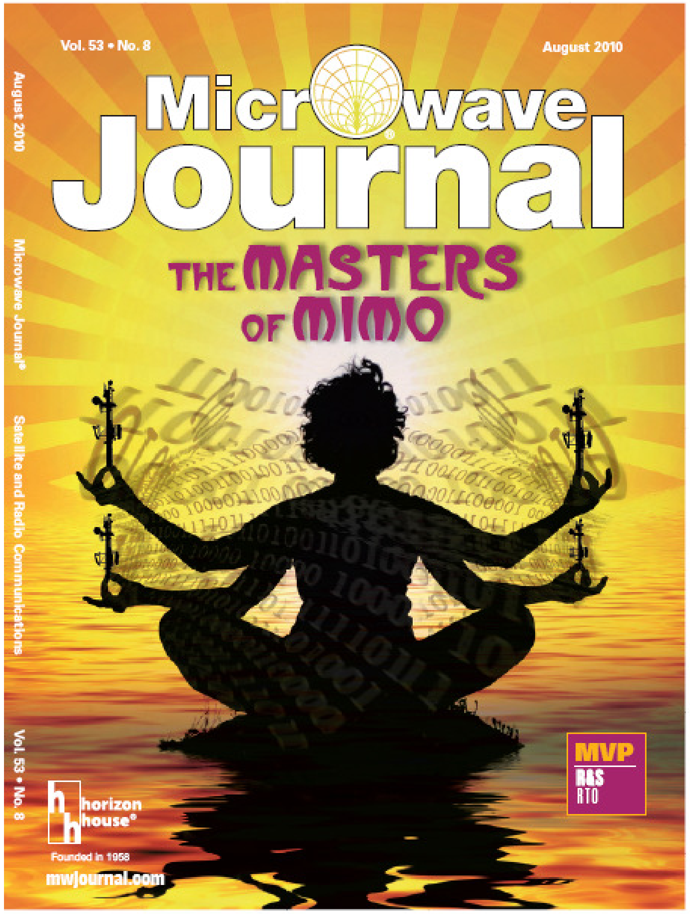
ETS-Lindgren

March 24th, 2011

The Growing Importance of the Mobile Phone Antenna

August 2010 MWJ Cover feature:

- MIMO multiplies the number of required antennas, 2x, 4x...
- Multi-band phones multiply the number of antennas
- Devices sizes are shrinking
- Antenna design is getting very hard!
- And yet there are no MIMO test methods or performance targets



Testing MIMO Performance OTA "Over The Air"

CTIA, COST273 and RAN WG4 developed test methods and performance requirements for SISO

The work on SISO OTA took many years to finalize. The figures of merit are:

TRP - Total Radiated Power
TIS – Total Isotropic Sensitivity (TRS)

CTIA, COST2100 and 3GPP RAN WG4 are now investigating methods for testing the radiated performance of MIMO devices

MIMO performance is much more complicated than SISO!
It is a function of the complex antenna patterns, the propagation channel, baseband algorithms, noise and interference

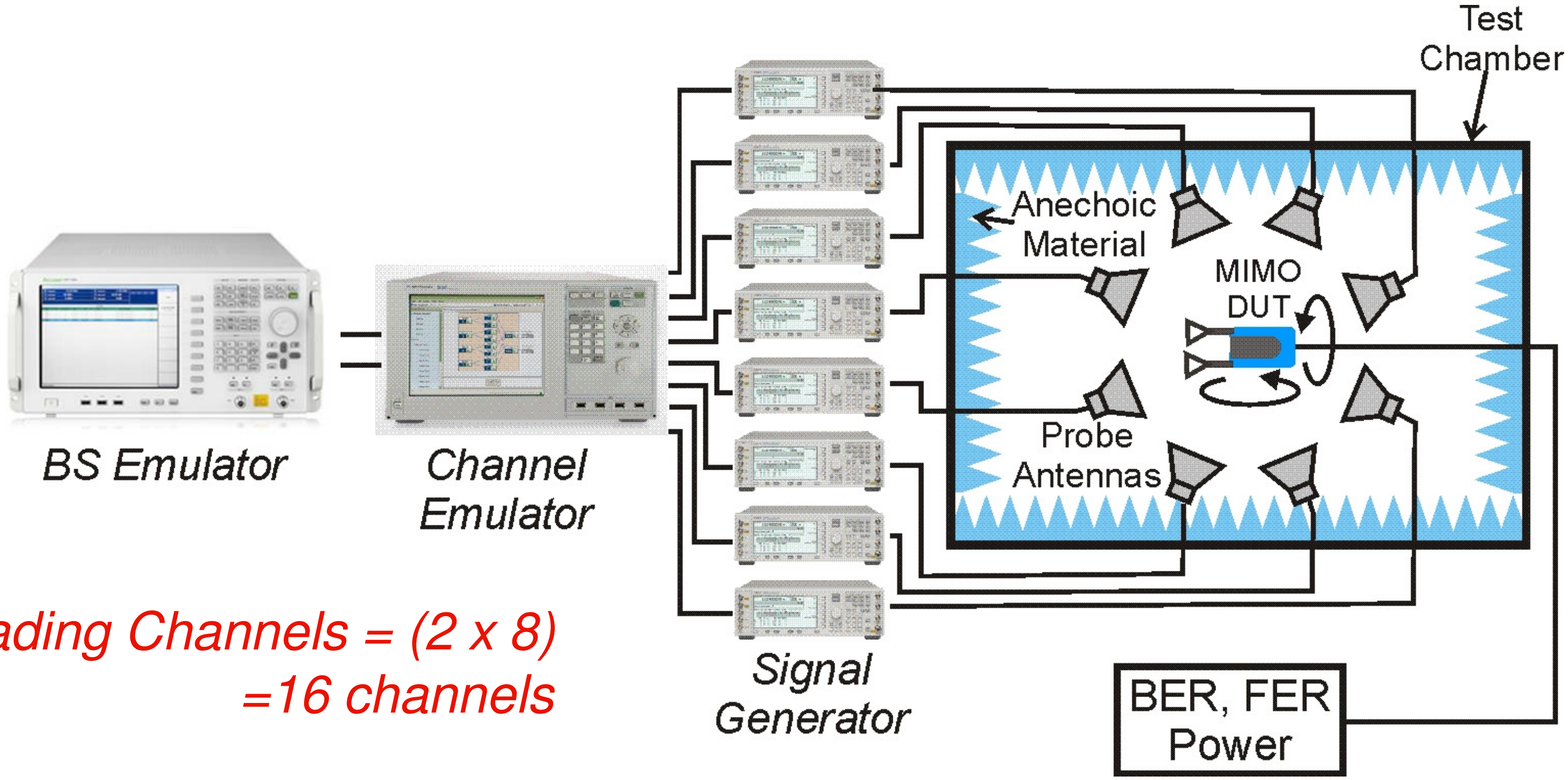
MIMO OTA Test Methodologies

Many test methodologies have been proposed for the study item

They can be grouped into three main methods:

1. Multi-antenna anechoic chamber methods
   - Configurations vary from simple two antenna up to as many as 16 dual polarized antennas
2. Reverberation chamber methods
   - These vary from simple single chamber to more complex multi-chamber with or without the addition of a fading emulator
3. Antenna pattern method and two-stage method
   - Antenna-only methods and the more advanced two-stage method involving throughput measurement

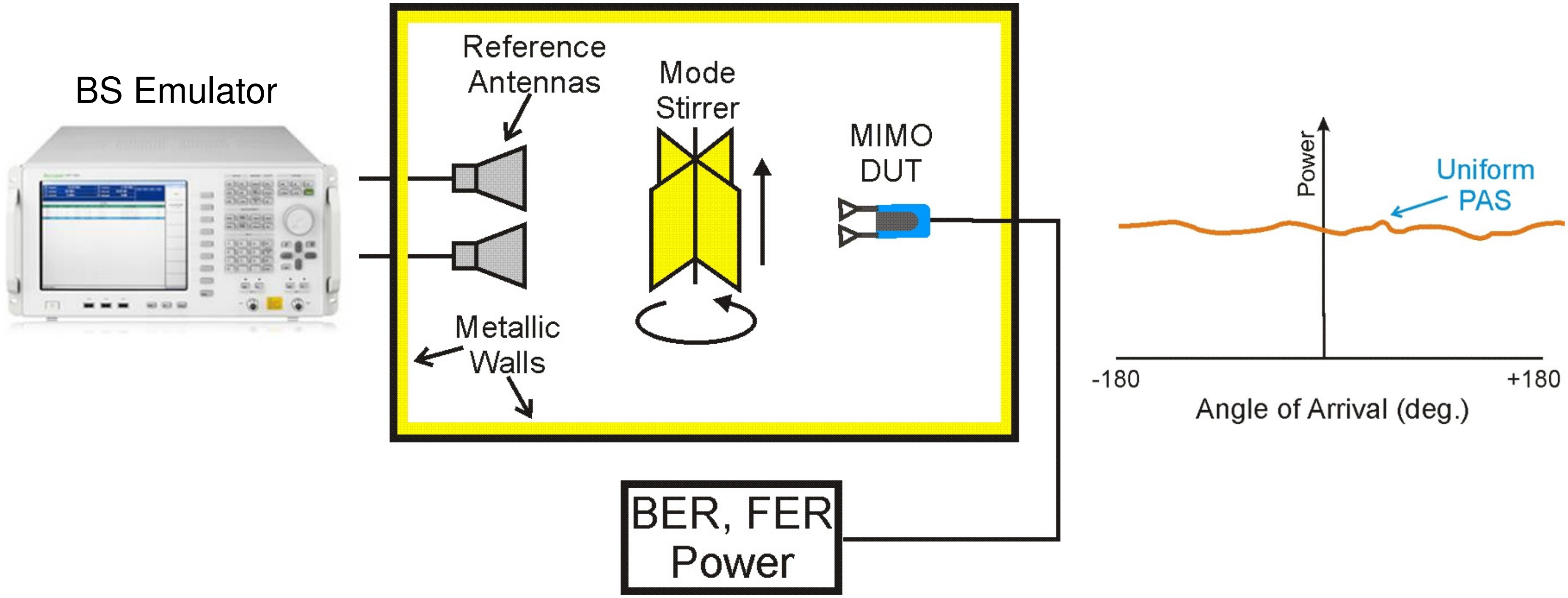
Multi-antenna Anechoic Methods



Fading Channels = (2 x 8)
=16 channels

- Conceptually simple
- Requires precise system calibration
- Many probes (16?) in full circle required for arbitrary channel emulation
- Full circle requires large chamber (single cluster is smaller)
- Full 3D channel emulation is a challenge, partial 3D may be possible

Reverberation Chamber Methods

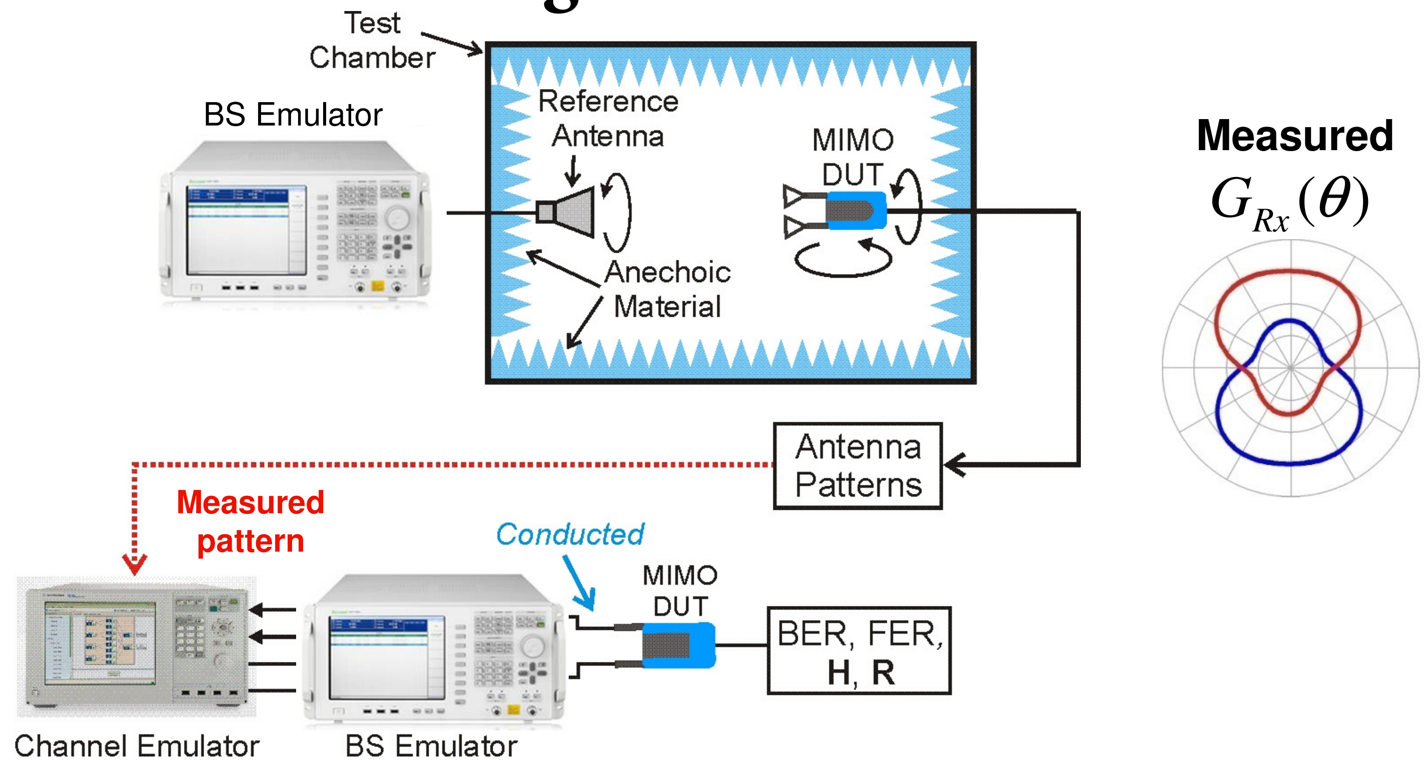


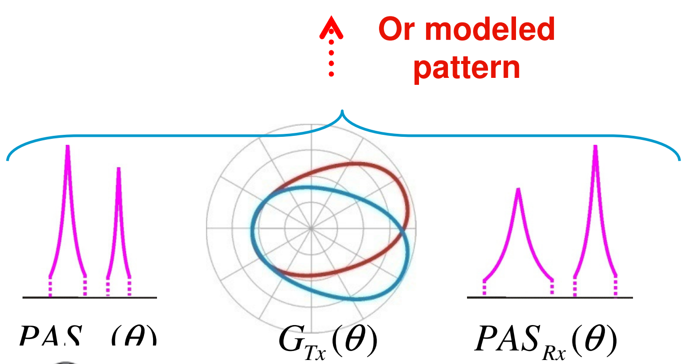
- The basic power delay profile (PDP) is modified using absorbers
- Adding a channel emulator can further modify the PDP
- Chambers can also be cascaded to create directional content
- Cost effective
- Good for assessing self-blocking
- Limited ability to generate standard channel profiles

Antenna Pattern and Two-stage Method

Stage 1
Antenna pattern measurement

Stage 2
Throughput measurement





- Fast and very cost effective
- Uses standard SISO anechoic chamber
- Can models any 2D or 3D channel using correlation or geometry methods
- Does not currently measure self-blocking
- Requires UE test mode for non-intrusive

Today's Program

- **MIMO OTA Antenna Measurements**

  Doug Reed, Solutions Architect, Spirent Communications

- **Radio Channel Aspects**

  Jukka-Pekka Nuutinen, Research Manager, Elektrobit

- **Multi-path Environment Simulator**

  Michael Foegelle, Dir. Of Technology, ETS-Lindgren

- **OTA Test Challenges and the Two-stage Methodology**

  Moray Rumney, Lead Technologist, Agilent

- **30 minute panel discussion with Q&A from live and webcast audience members**

MIMO OTA Antenna Measurements

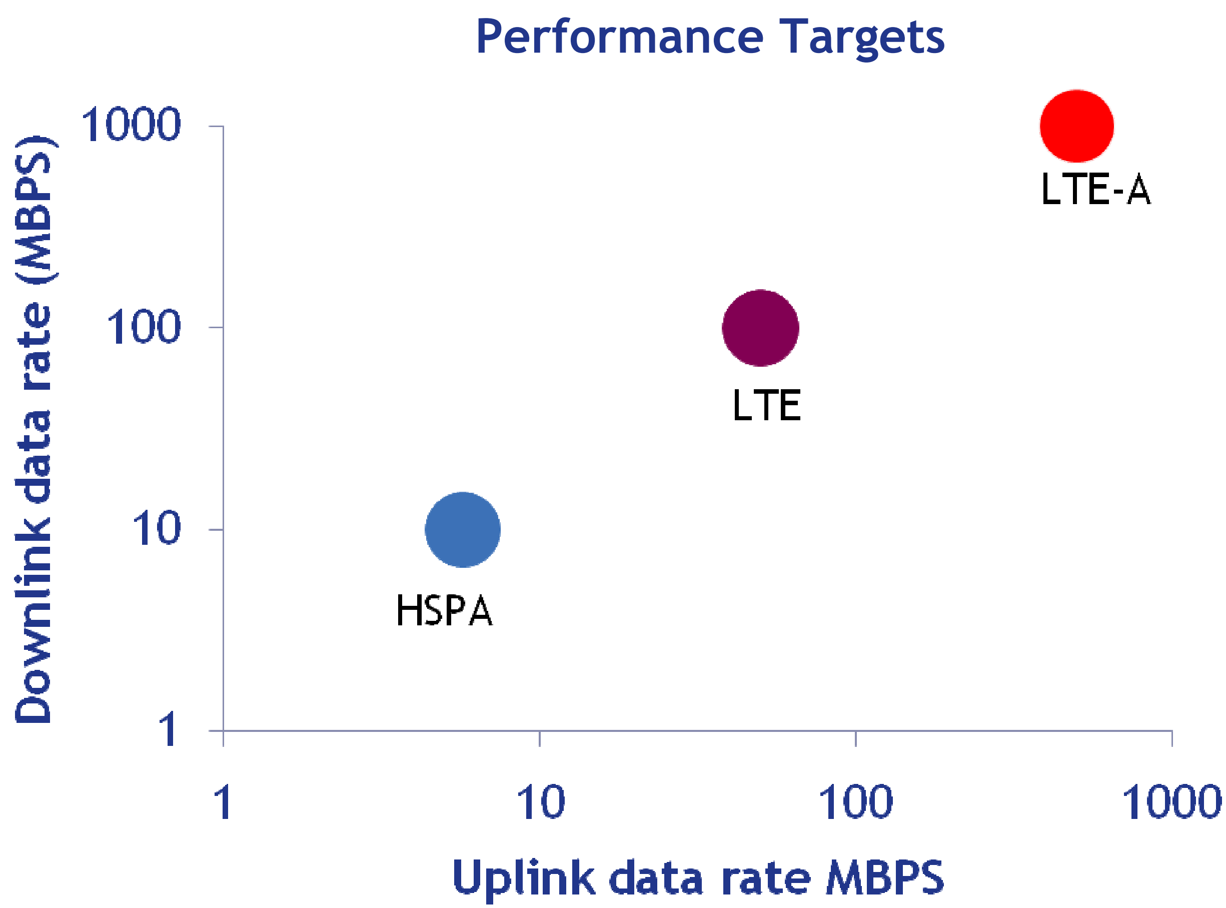
CTIA Panel Session

Doug Reed

March 2011, Orlando

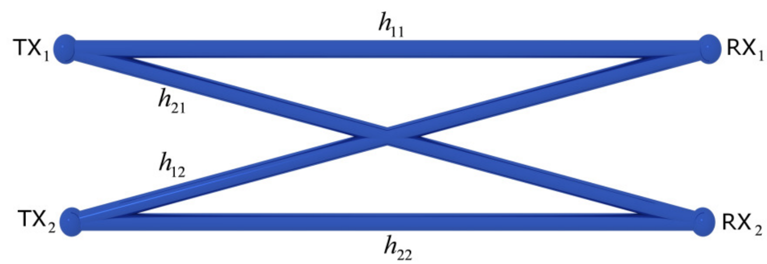
MIMO OTA Testing -- Motivation

- MIMO modes are a key component to achieving higher throughput



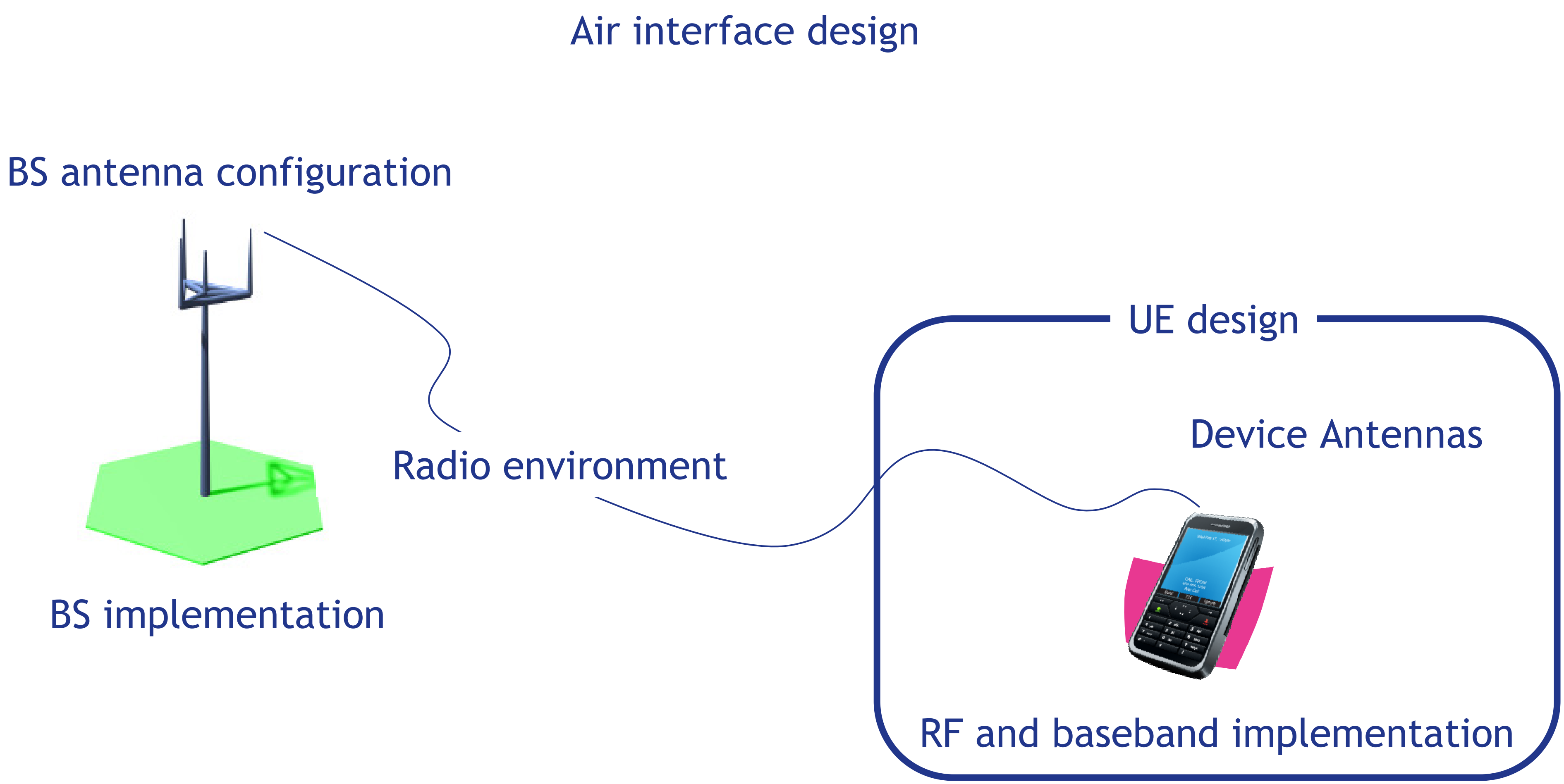
MIMO OTA Testing -- Motivation

- MIMO exploits good channel conditions to increase user throughput
  - MIMO modes are supported when channel feedback indicates positive conditions
  - Channel Quality and Channel Rank Indicators provide feedback
    - Channel Quality indicates adequate SNR
    - Full-rank channels indicate the potential for MIMO gain



$$H = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}$$

What impacts actual MIMO performance?



The Goal of OTA Testing for MIMO

- How do we measure MIMO performance?
  - The most practical Figure of Merit is throughput
  - “Good” MIMO handsets will have better throughput for a given channel condition
- How do we tell a good device from a bad device?
- We must measure MIMO throughput performance in realistic conditions with the device antennas included
  - Antenna gain and efficiency
  - Branch imbalance
  - Antenna correlation
  - Effects of hand & head phantoms
  - Realistic channel conditions

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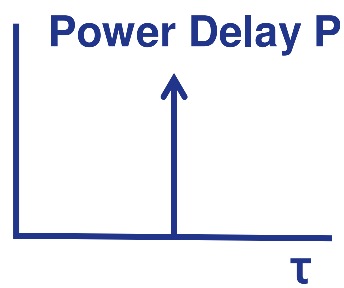
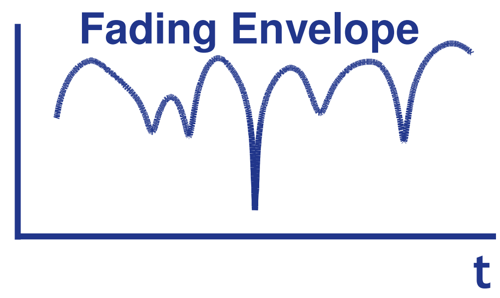
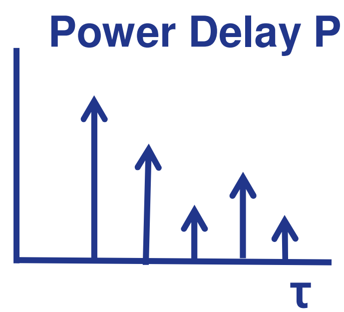
Introduction to Channel Modeling

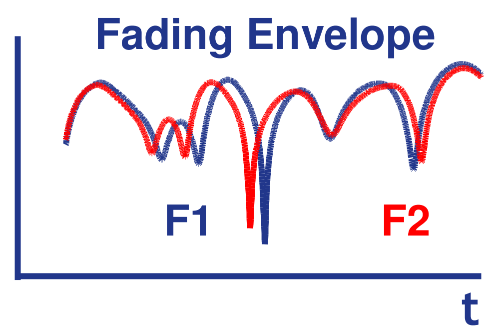
- Narrow-band Model
  - Flat fading



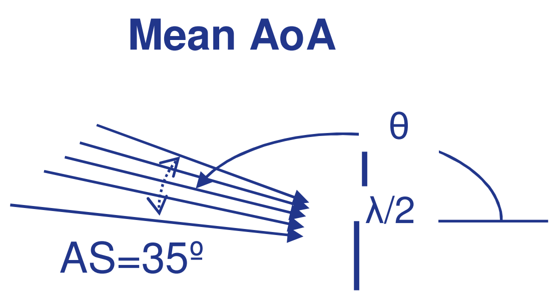


- Wide-band Model
  - Delay Spread
  - Frequency-selective fading





- Multiple antennas
  - Angular discrimination
  - Spatial correlation



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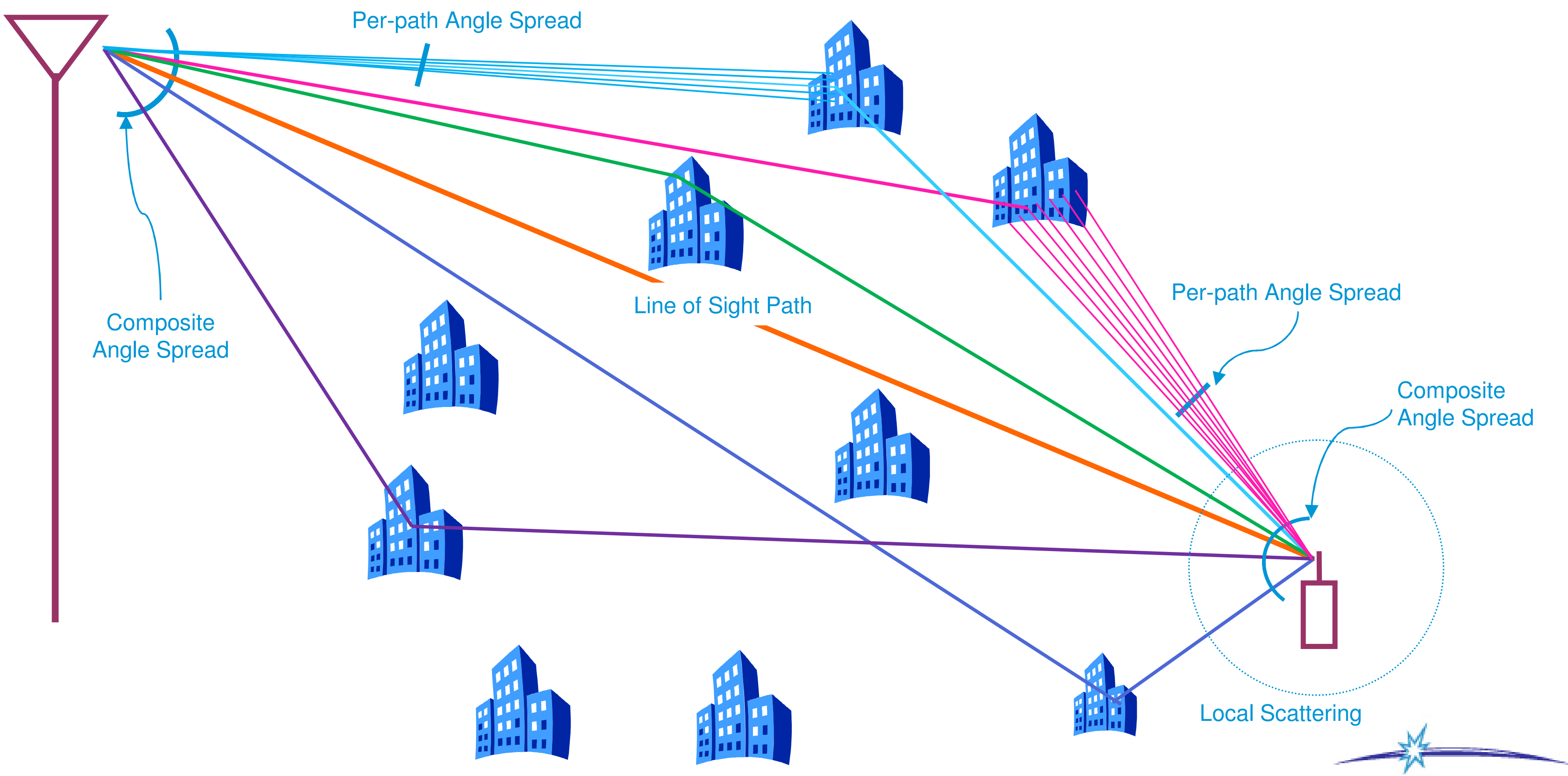
The Wireless Propagation Environment

Wide-Band Cluster Model



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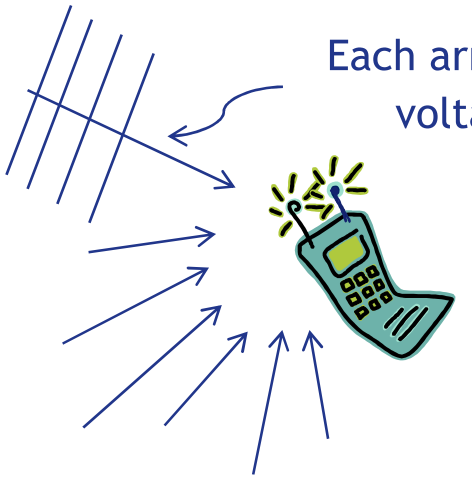
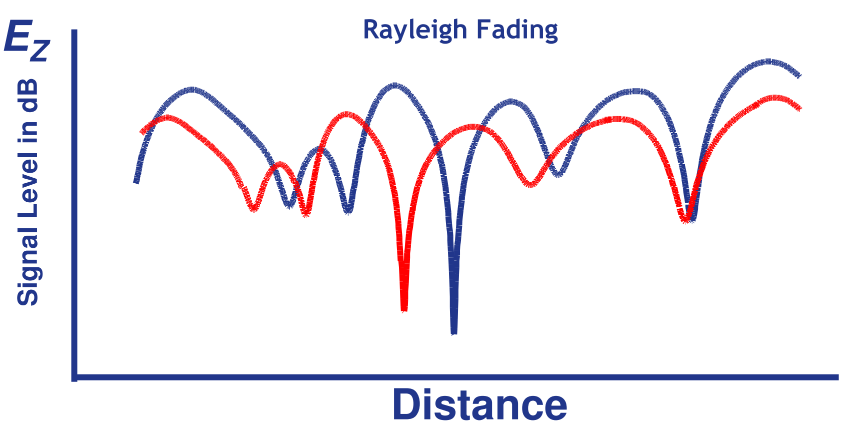
Fading with Multiple Antennas

- Multiple scattered copies of the signal will combine at each antenna

Each arriving plane wave looks like a sinusoidal voltage at a unique frequency ($f_c + f_d$)



Signals combine vector-wise to produce correlated fading



Correlation is a function of:

- **Antenna gain on each antenna**
- **Antenna phase response**

- **Power angle distribution of signal**
  (function of the channel)

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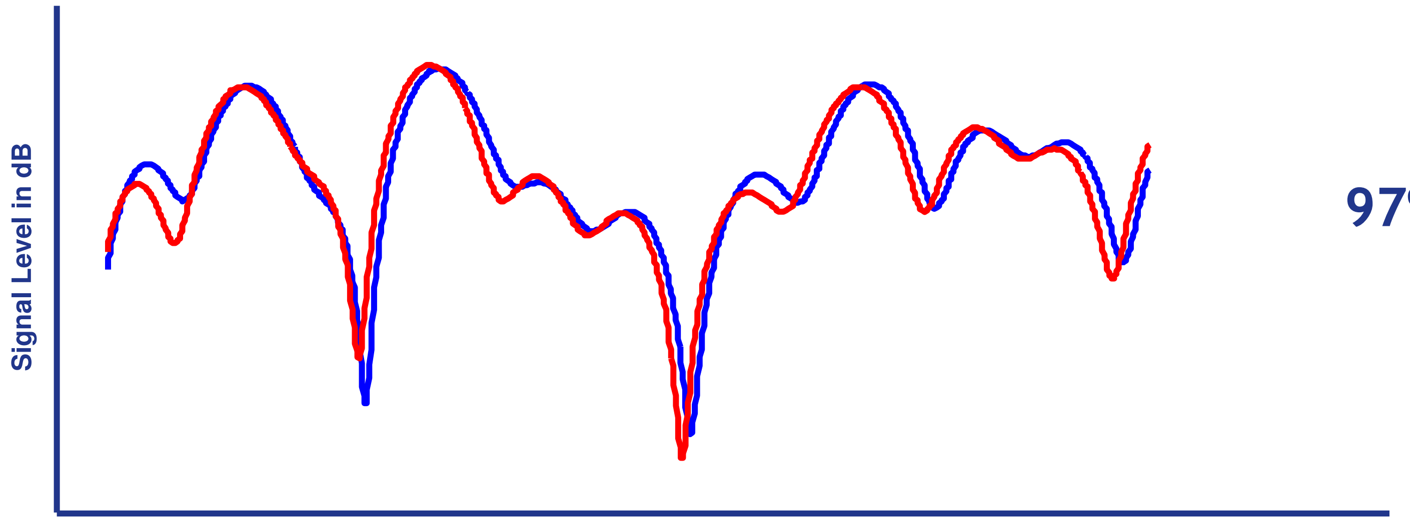
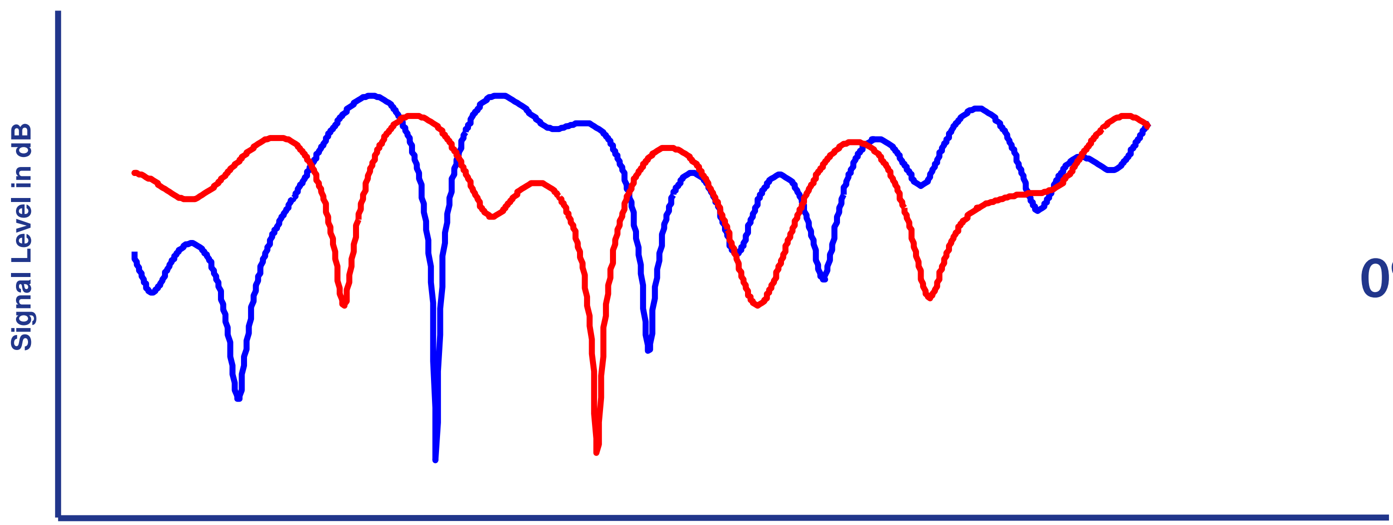
Correlated Fading

What is Correlation?



97% Correlation

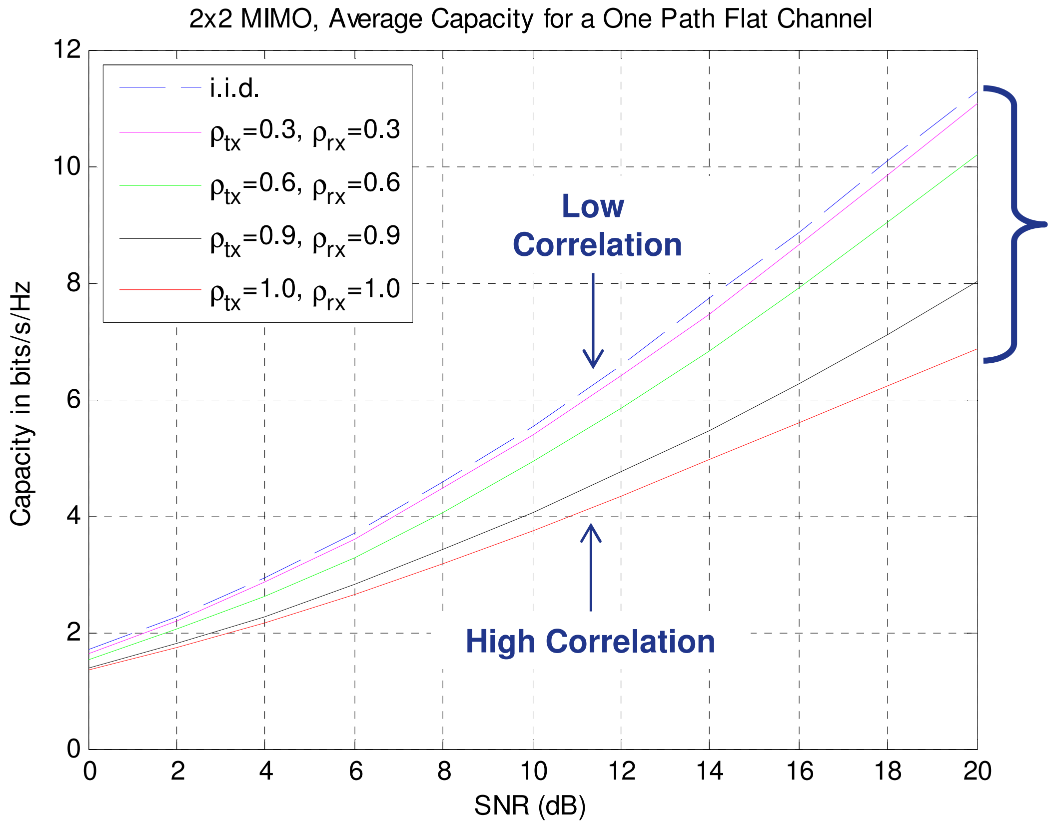


0% Correlation

MIMO Throughput

$$C = \log_2\left[\det\left(\mathbf{I} + \frac{\Phi}{m}\mathbf{H}\mathbf{H}^H\right)\right]$$

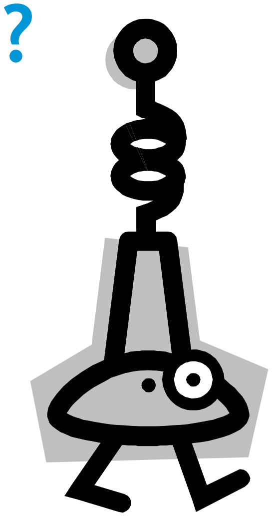
- Consider the log-det formula
- Average capacity is a function of:
  - Number of antennas
  - SNR
  - Correlated channel matrix (channel model + antenna behaviors)



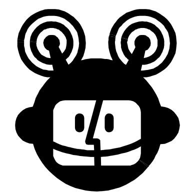
Effect of Correlation on Throughput

(2x2 Example)

What Makes Good Antennas for MIMO?



- A desirable antenna would have:
  - Wide bandwidth
  - Occupy minimal space
  - Very Low Cost
  - High efficiency (not too much Loss)
  - High gain in the direction that we need it
    - This implies an omni-directional pattern for a handset
  - Similar Gain on each Antenna Branch
  - Low correlation between fading signals in realistic channel conditions
    - This implies a non-problematic phase response
  - Adaptive to external conditions (including channel model)



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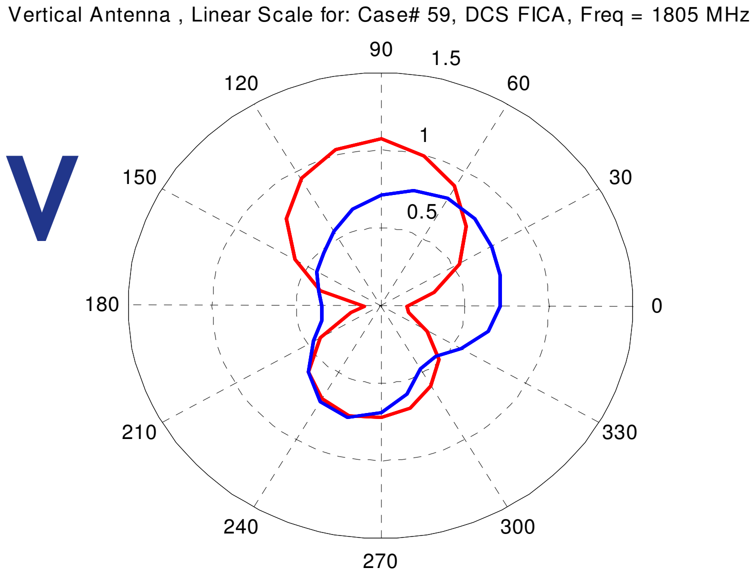
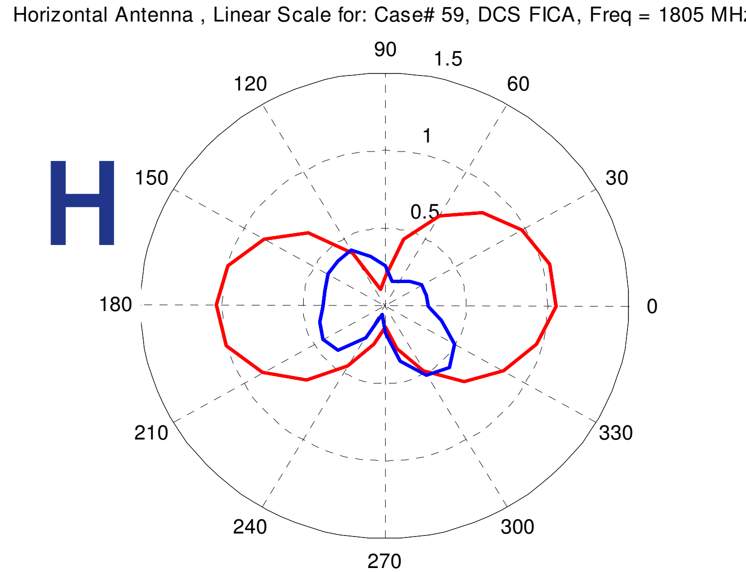
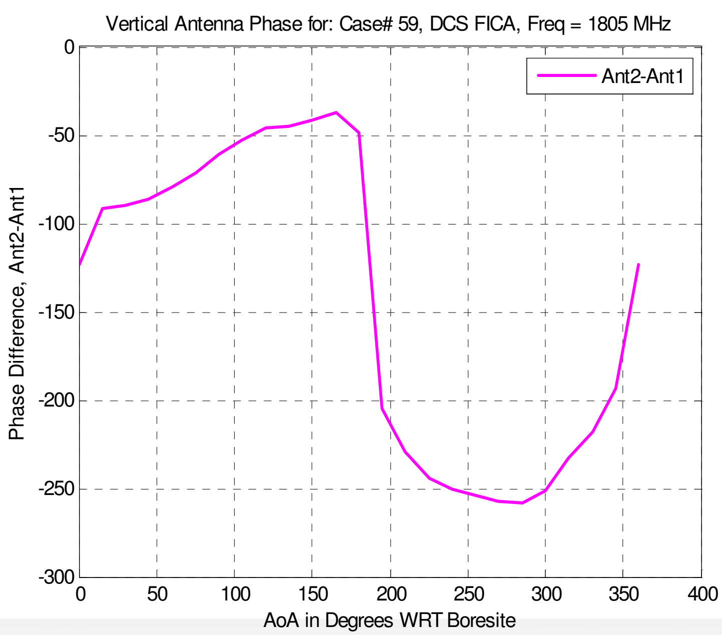
A real antenna… Is it good?

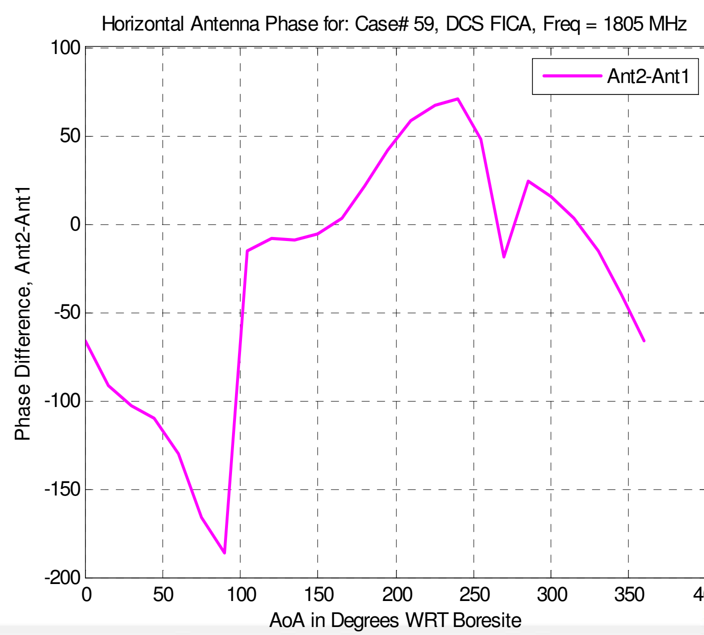
V



H







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Consider These MIMO OTA Measurement Methods

- Reverb Chamber Method
  - Already used for SISO testing
  - Being considered for 1st tier MIMO OTA measurement
  - Produces a basic fading channel
  - Produces a simplified "go/no-go" result, won't tell you *why*
- Anechoic Chamber Method
  - Already used for SISO testing
  - Can support advanced techniques, e.g. adaptive device antennas
  - Can emulate generic channels, including standards-based channel models
  - Produces detailed results to examine why a device is good or bad
- Virtual OTA or Multi-Step Approach (covered by other presenter)
  - Can Emulate Standards Based channel models

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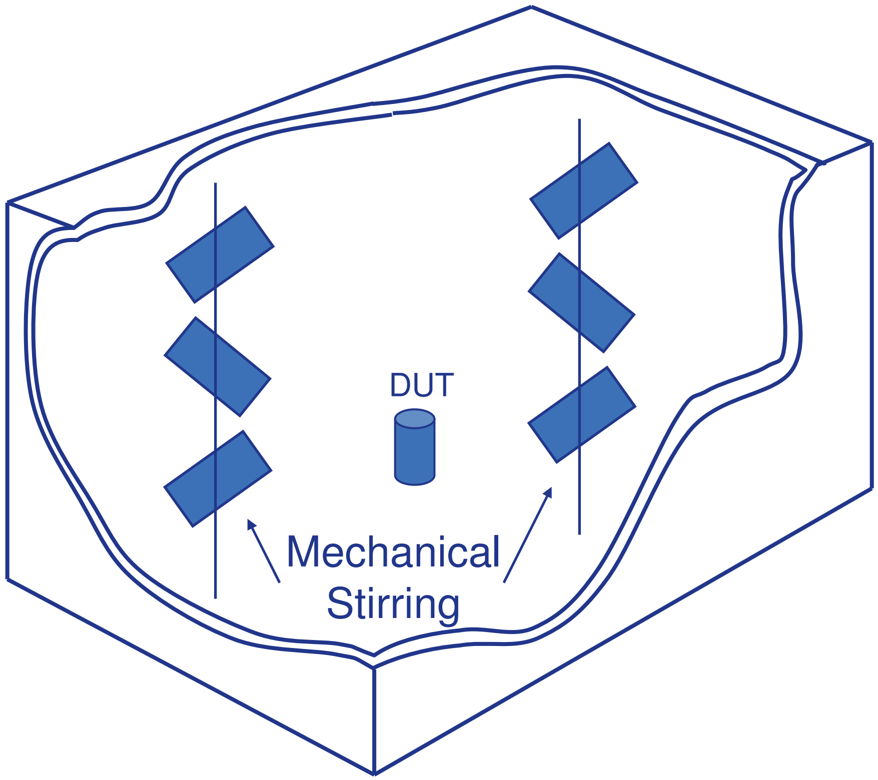
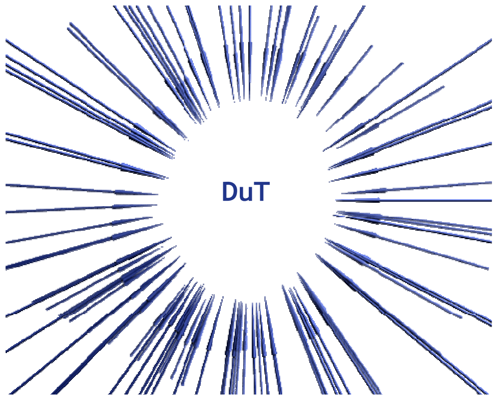
Reverb Chambers

- Metal chamber
- Injected signal creates static field
- Fading based on mechanical stirring



- Characteristics
  - Averaging built into channel model:
    - Uniform Power Angle Spectrum
    - Doppler, limited by stirring method
    - Linear Power Delay Profile
  - Spatial effects are function of instantaneous fades



  - Antenna patterns are “averaged out”
  - Measurement loses all directional properties
  - Fading signal correlation → 0

- Results in a single measure of the device

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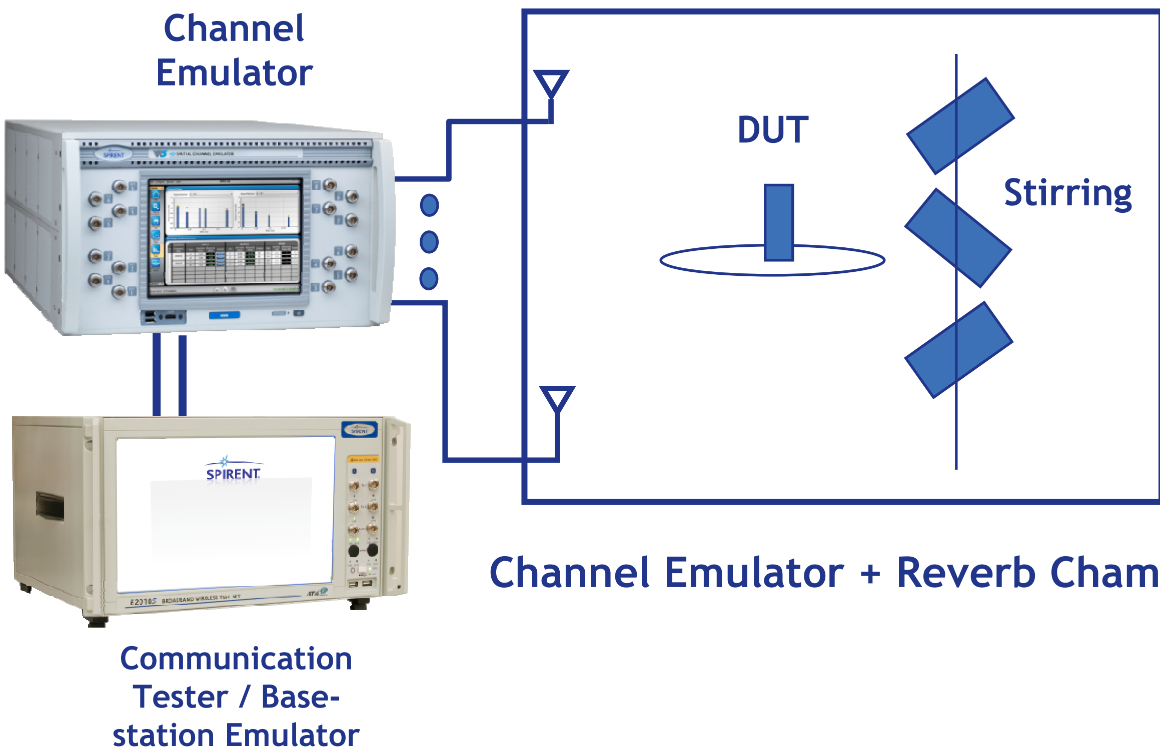
Reverb Chambers

- Combine a Channel Emulator and a Reverb Chamber



Channel Emulator + Reverb Chamber

Channel emulator provides:

- More realistic Doppler
- More precise channel impulse response
- Base station effects
  - Antenna correlation

- The CE + RC combination is being used in 3GPP MIMO OTA trials
  - The technical issues on their interaction is a topic for further research

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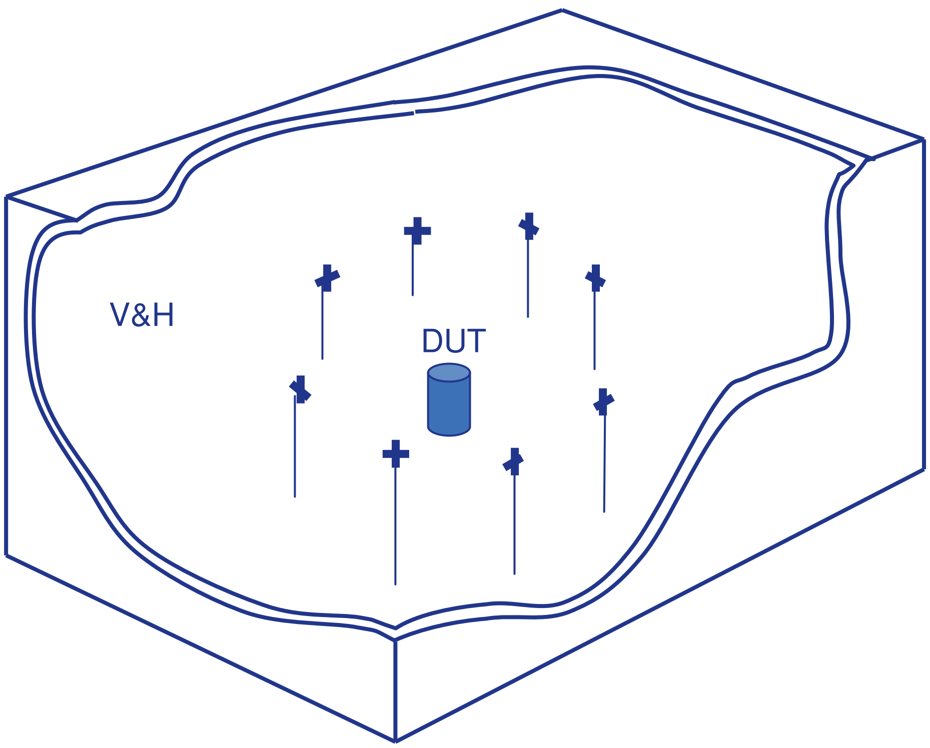
Anechoic Chamber-Based OTA

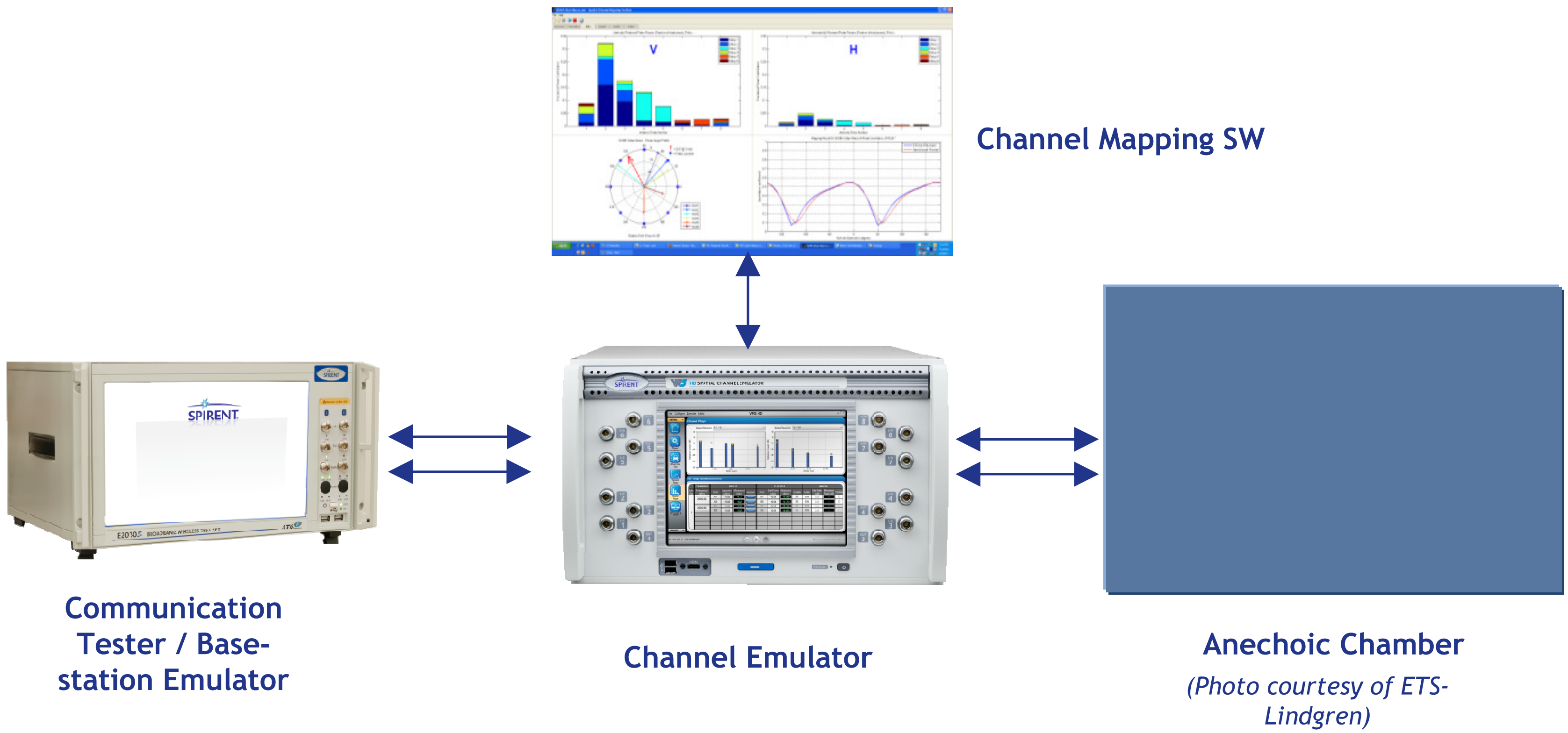
N transmit probes to produce a spatial channel for MIMO testing



(Absorbers & cabling not shown)

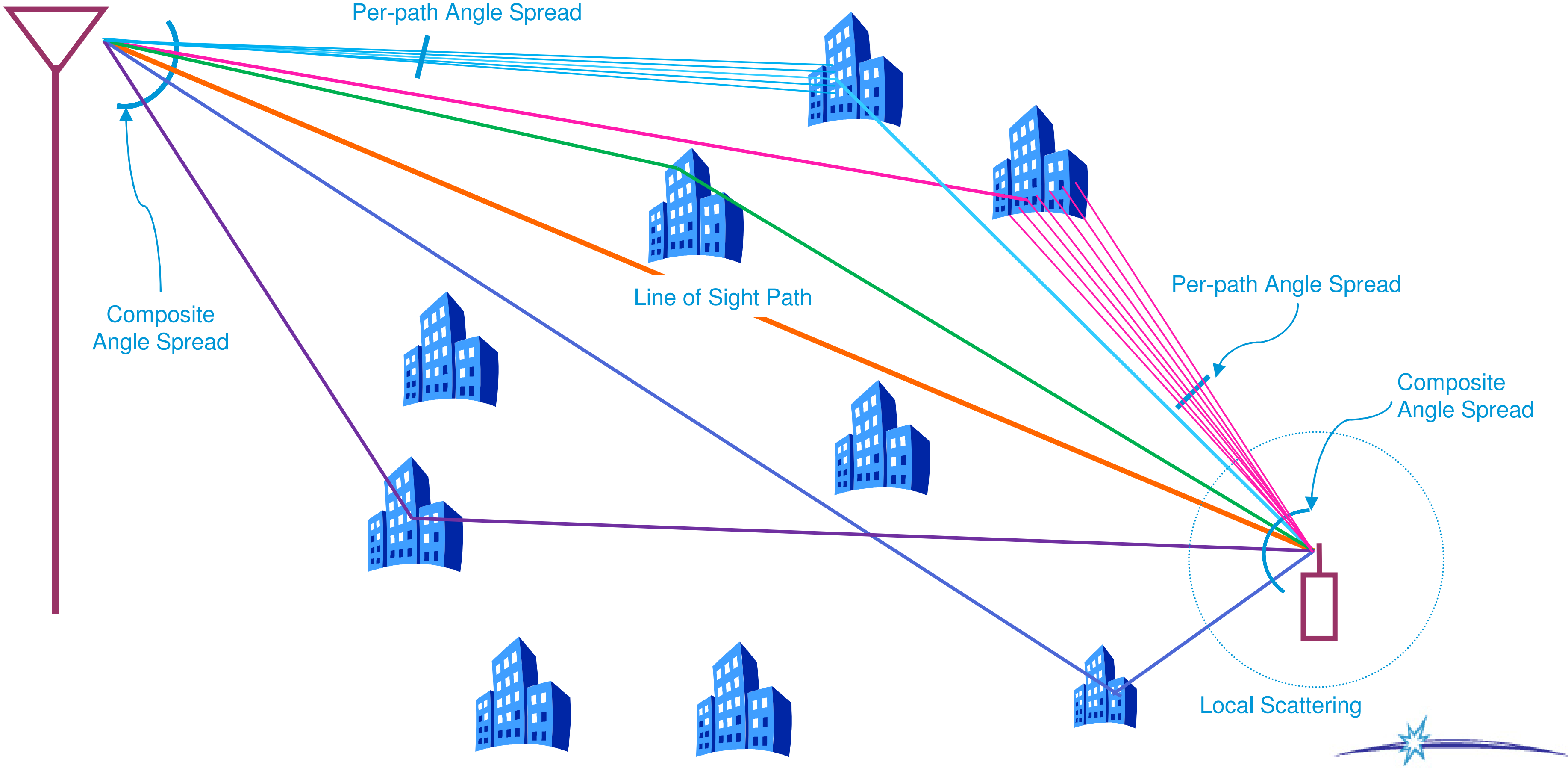
- Characteristics
  - Supports standards-based spatial channels
  - Ability to create an arbitrary channel model
    - Dual polarization, i.e. X, \ /, +, | |, etc.
    - Channel XPR, (e.g. V→H, H→V)
    - N multi-path components
    - Cluster AoD, AoA, Angle Spread
    - Base antenna separation
    - Doppler
  - Measure complex scenarios
    - Spatial interference
    - Adaptive DuT antennas

Anechoic Chamber Based OTA

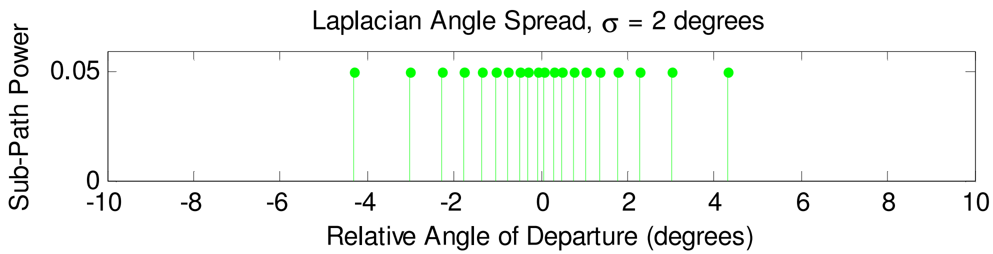


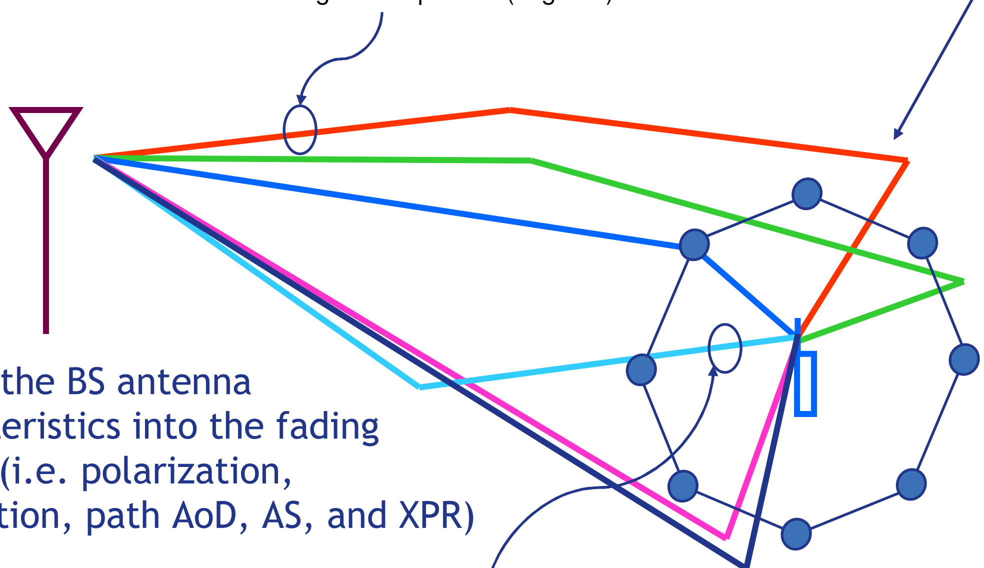
What we are reproducing in the Chamber…

Wide-Band Cluster Model

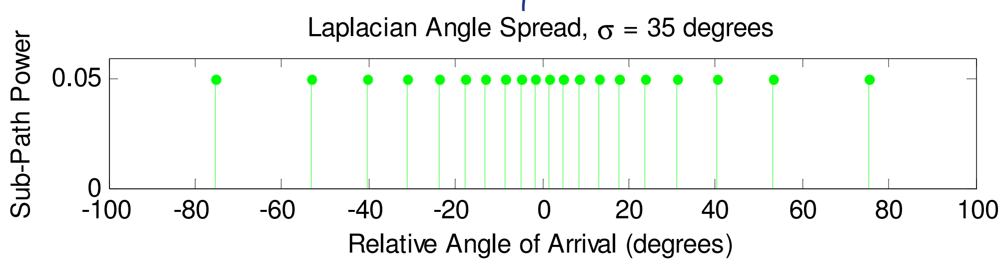


OTA Channel Model Emulation



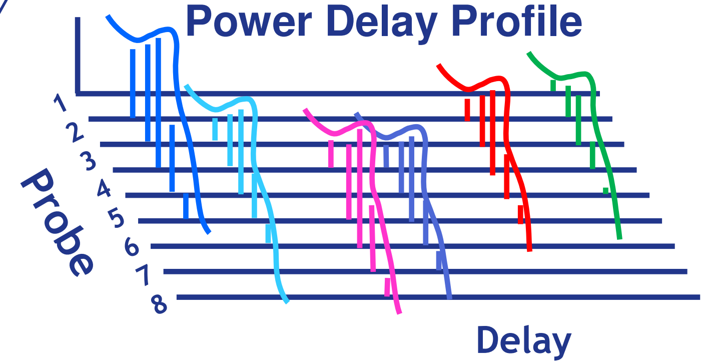


Embed the BS antenna characteristics into the fading signals (i.e. polarization, correlation, path AoD, AS, and XPR)



OTA Concept

Emulate the area near the mobile inside the chamber



Form the full Spatial Channel mapping, (includes: AoA, AS, path delays, Doppler, polarization + BS characteristics)

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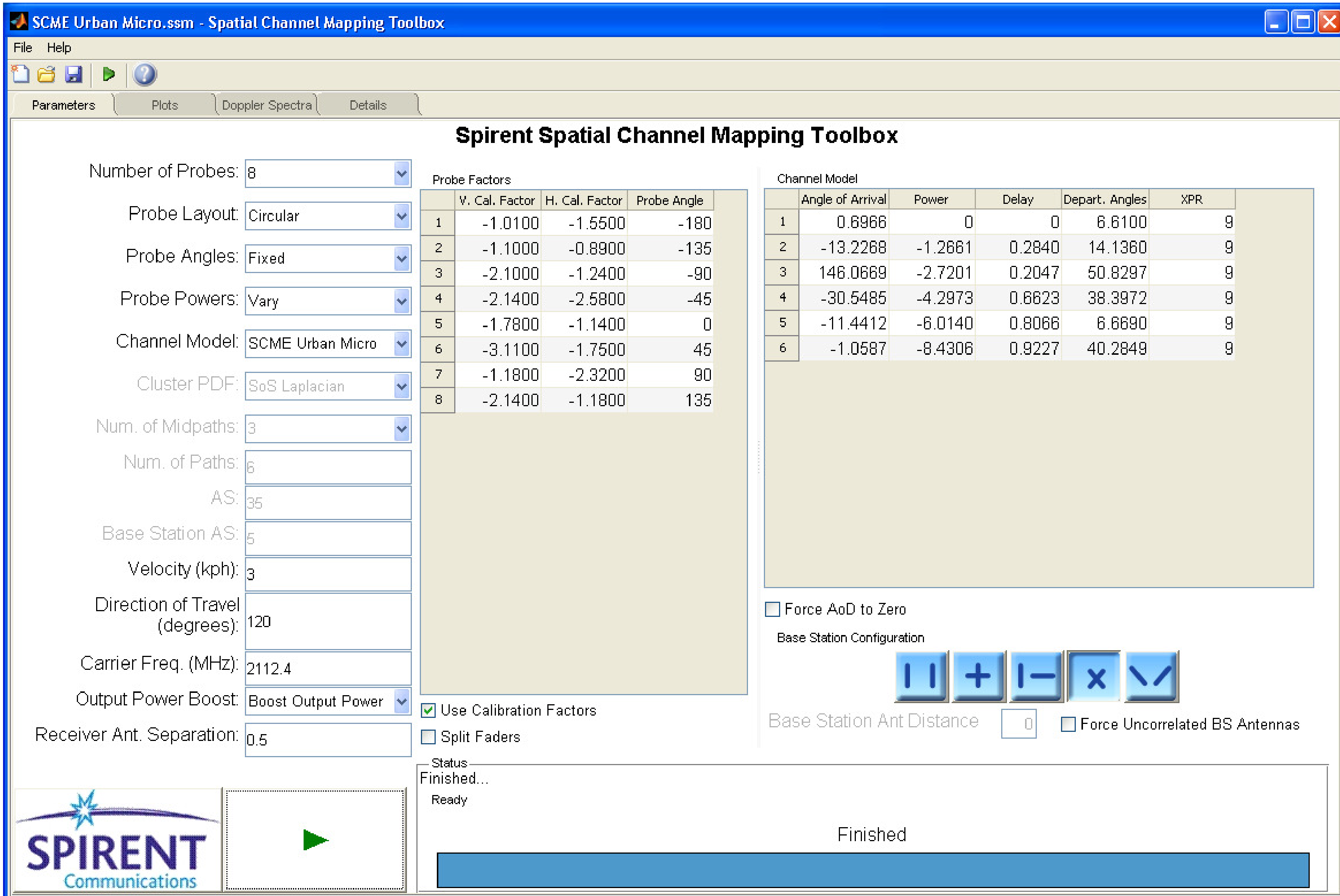
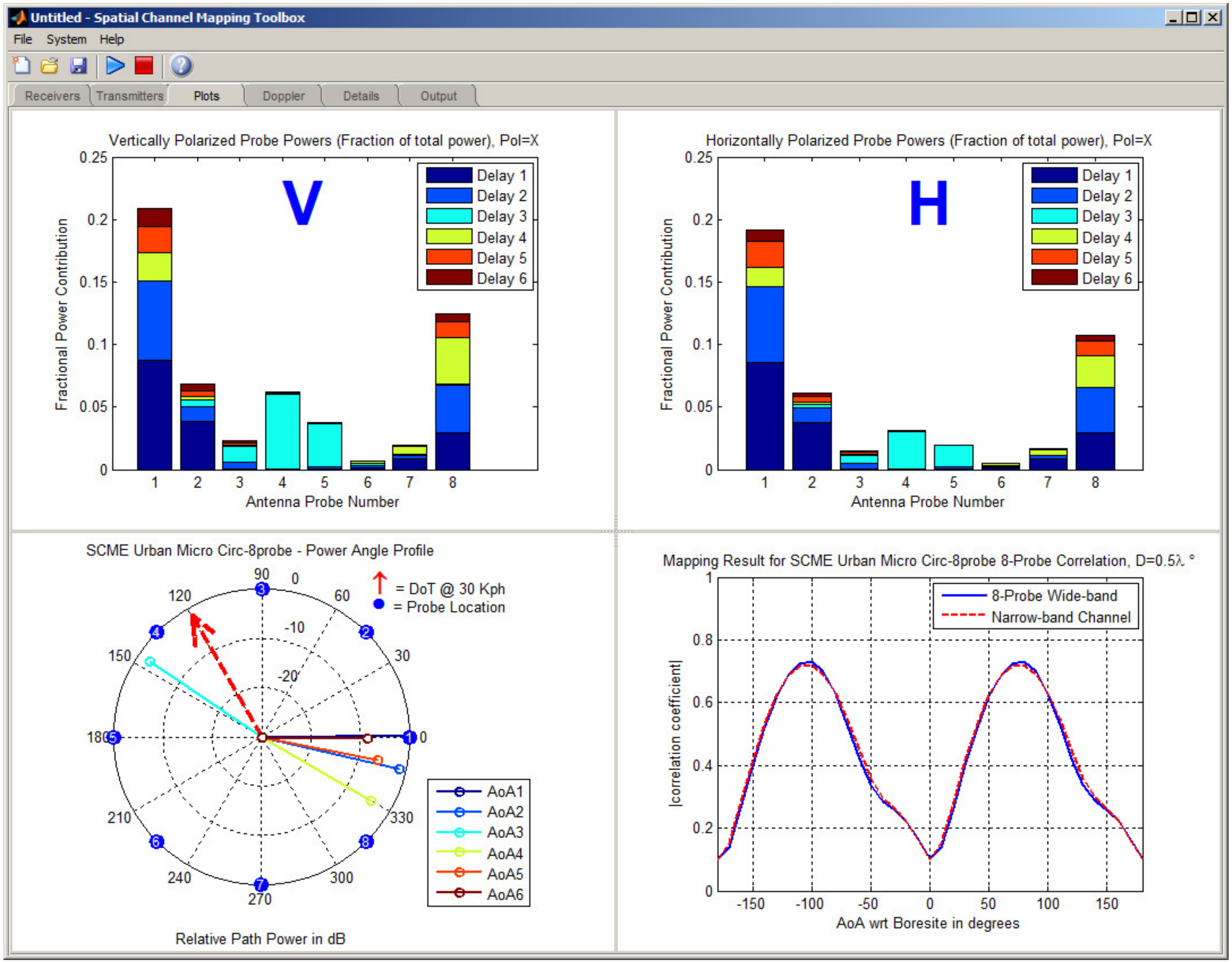
Mapping Spatial Channel Environment to Probes



Mapping Spatial Channel Environment to Probes



- Example of:
- X-Pol
- SCME Urban Micro Channel Model

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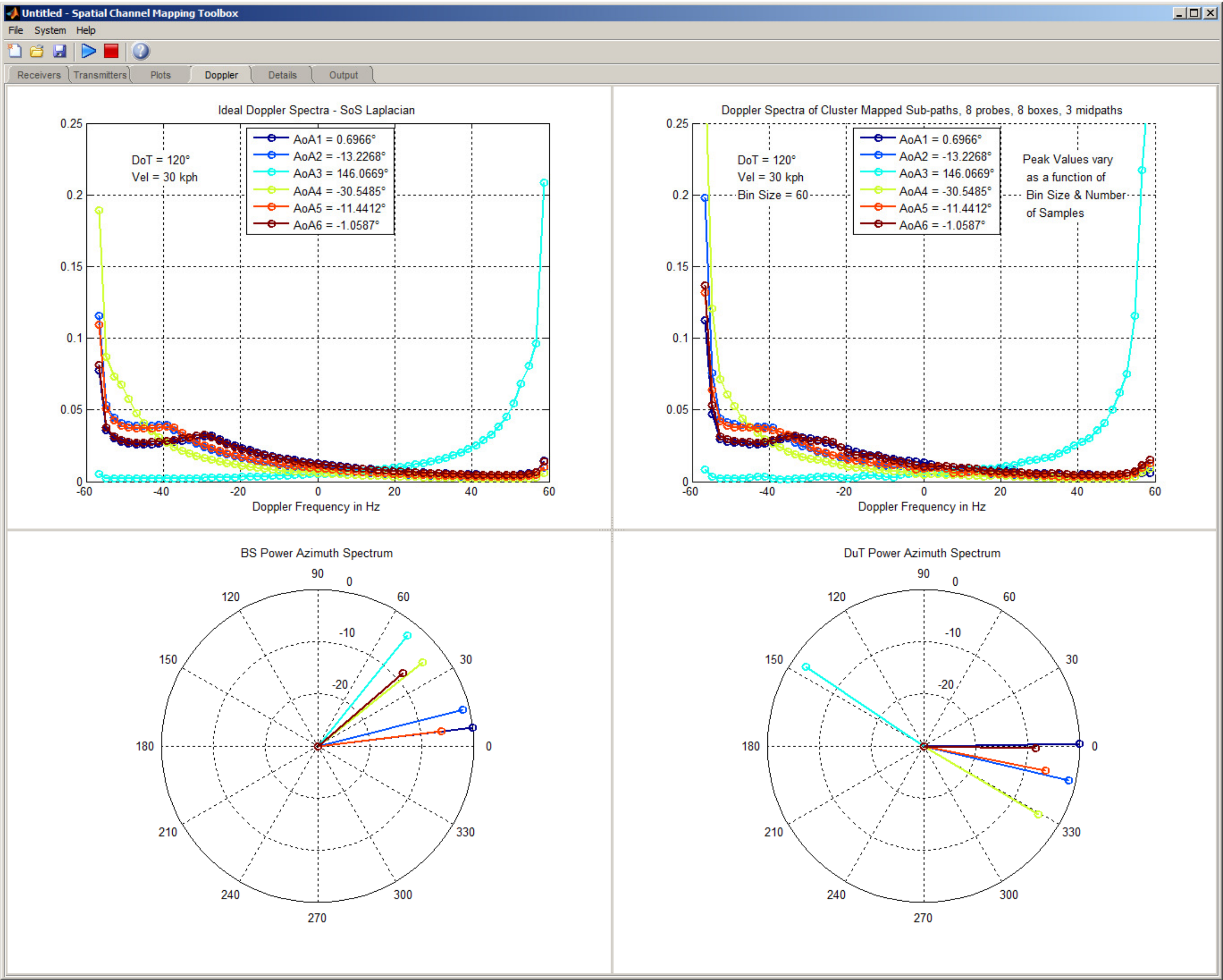
Mapping Spatial Channel Environment to Probes

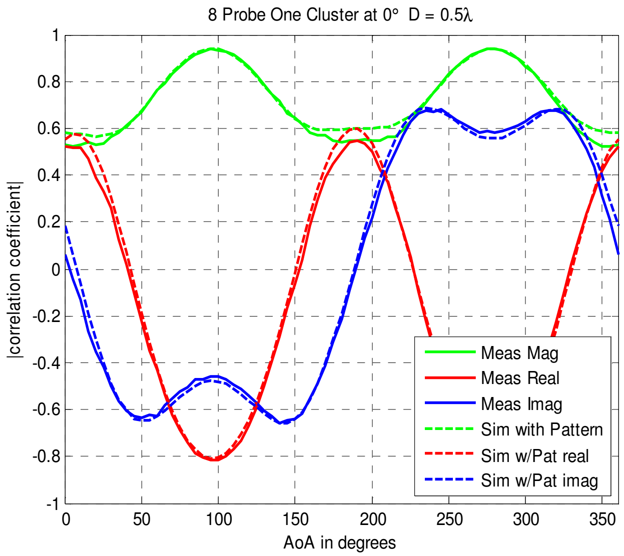


- Ideal Doppler vs
- Achieved Doppler

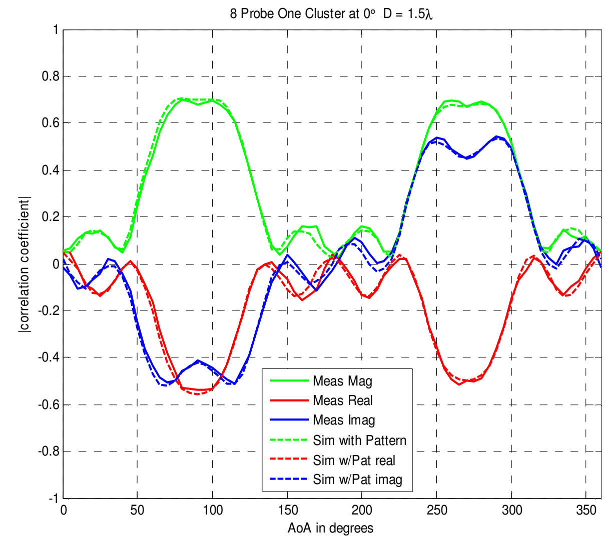
- BS Angle Spectrum
- MS Angle Spectrum

Did we achieve the desired channel model?

Simulated vs Measured



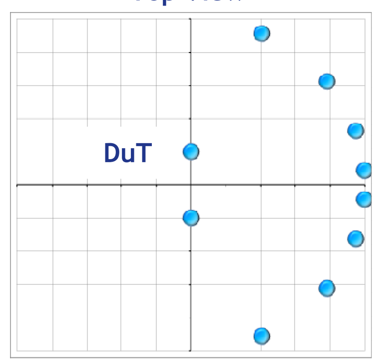
Simulated vs Measured



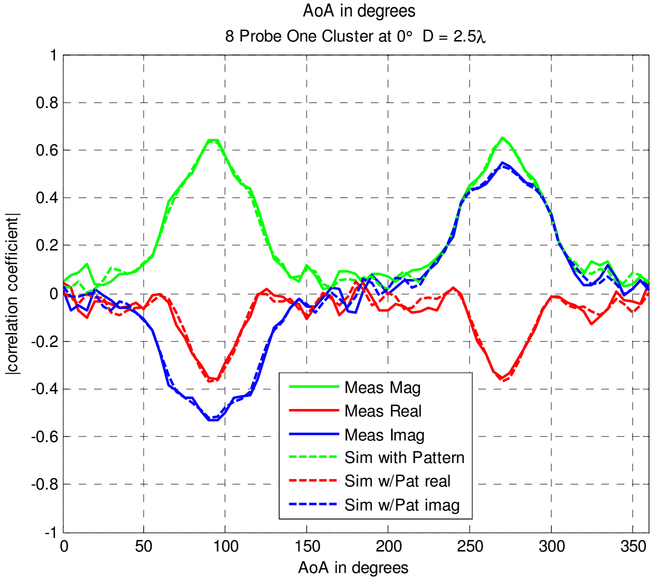
DuT Antenna Separation:

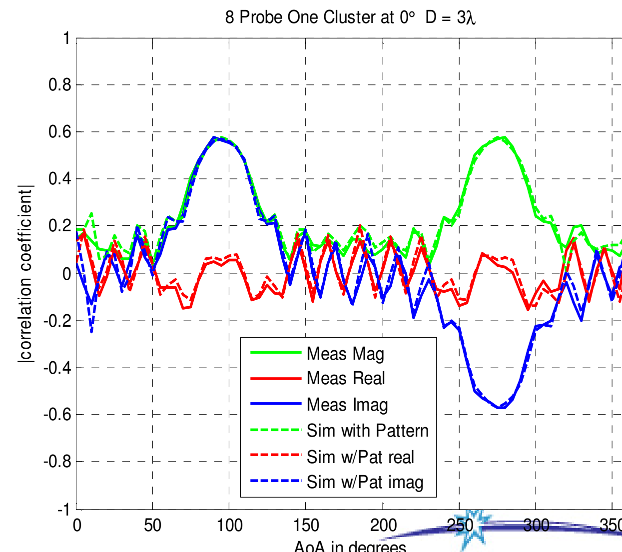
0.5λ **1.5λ**

Top View



2.5λ **3λ**





Measured Spatial Correlation Matches Simulated using Actual Probe Patterns

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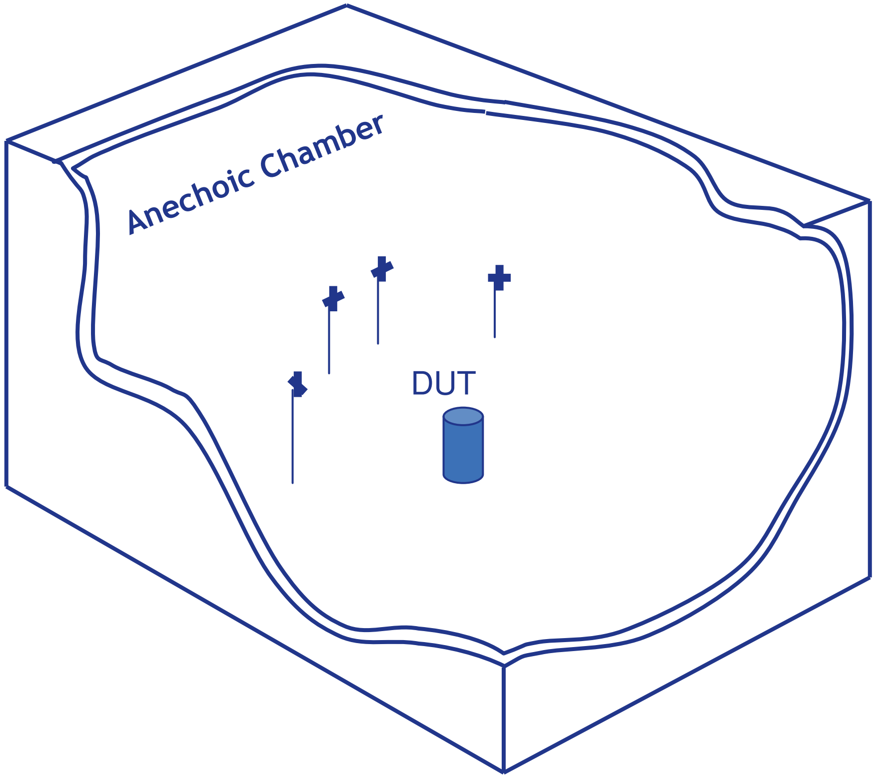
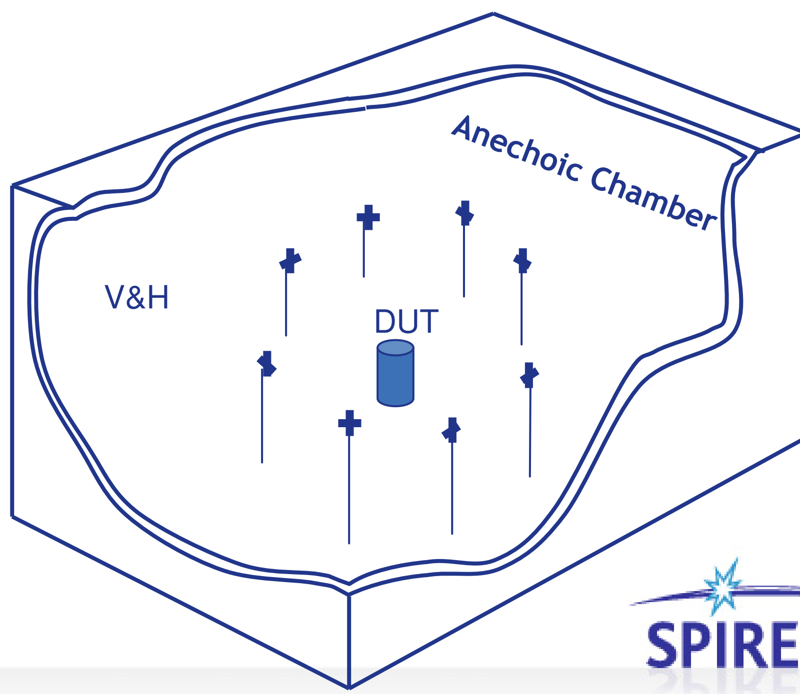
Anechoic Chamber Techniques



Single Cluster Modeling

Generic Channel Modeling



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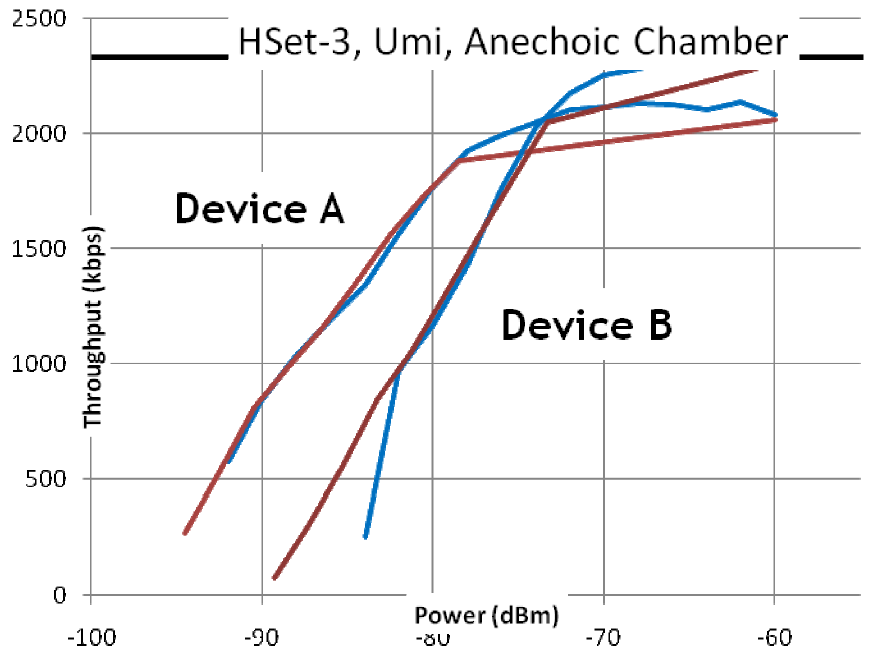
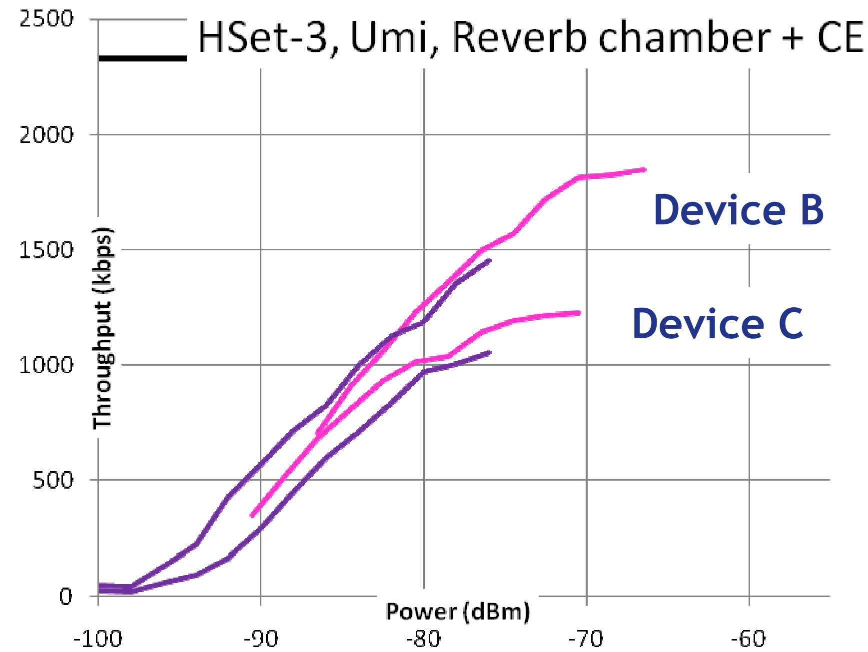
Early Comparisons using HSPA "Diversity"

- Full data available in 3GPP*
- These plots are simplified to show 2 RC and 2 AC results





- MIMO results are expected to be more sensitive to the Channel

UMi = SCME Urban Micro Channel
Hset-3 = HSPA Fixed Reference Channel, QPSK

*R4-104768 Round-Robin Measurement Campaign: Summary of Results Part 1, Vodafone, Nov 2010

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MIMO OTA

- Summary
  - Over-the-Air testing for MIMO devices is here!
  - This testing could take the form of:
    - Anechoic Chamber method
      - More advanced, offers more control of the spatial field
      - More Information about the Device Performance
    - Reverb Chamber
      - Simplest measure of “composite” antenna behaviors
    - Reverb Chamber + Channel Emulator
      - Some parameters can be matched to standard values
    - Each method has merit in determining a good from a bad device
  - Spirent is supporting multiple OTA measurement methods
    - These techniques are in-use by industry leaders and ready for evaluation now
    - Standards will take more time to converge on specifics

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Thank You!