Understanding MIMO OTA Testing: Simple Solution to a Complex Test

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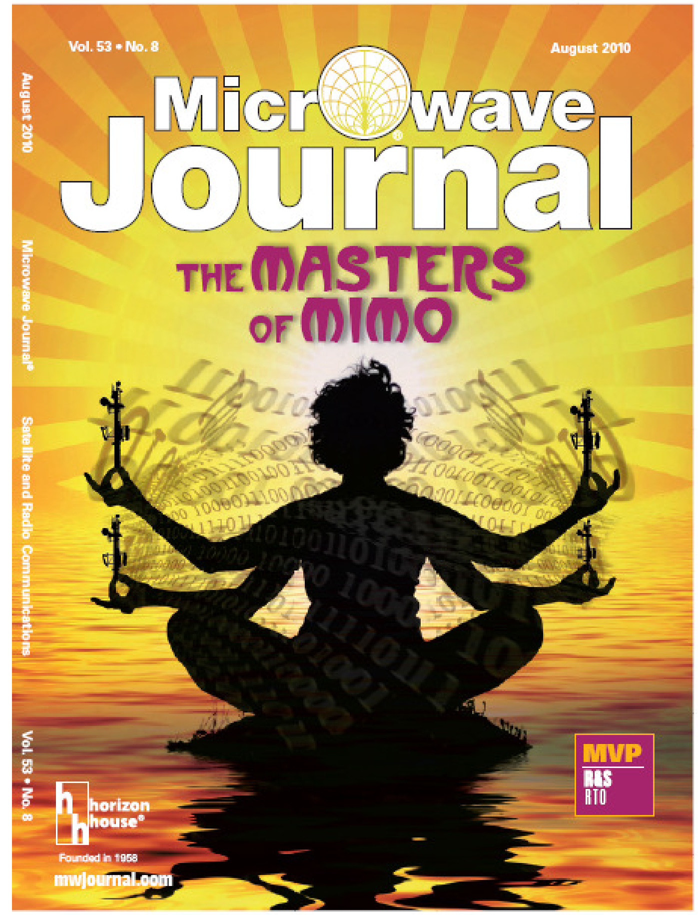
The Growing Importance of the Mobile Phone Antenna

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

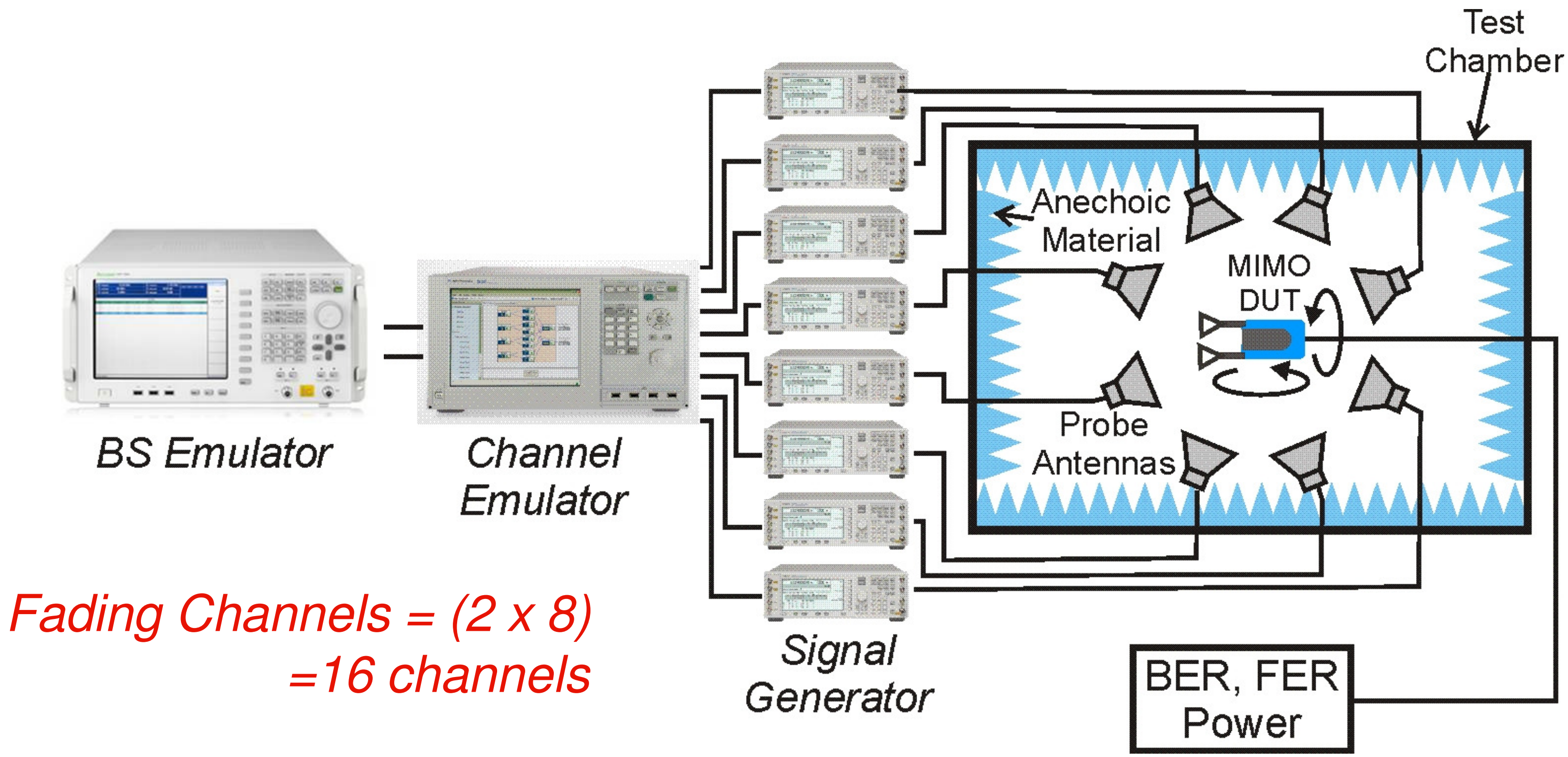
MIMO OTA Test Methodologies

Many test methodologies have been proposed for the study item

They can be grouped into three main methods:

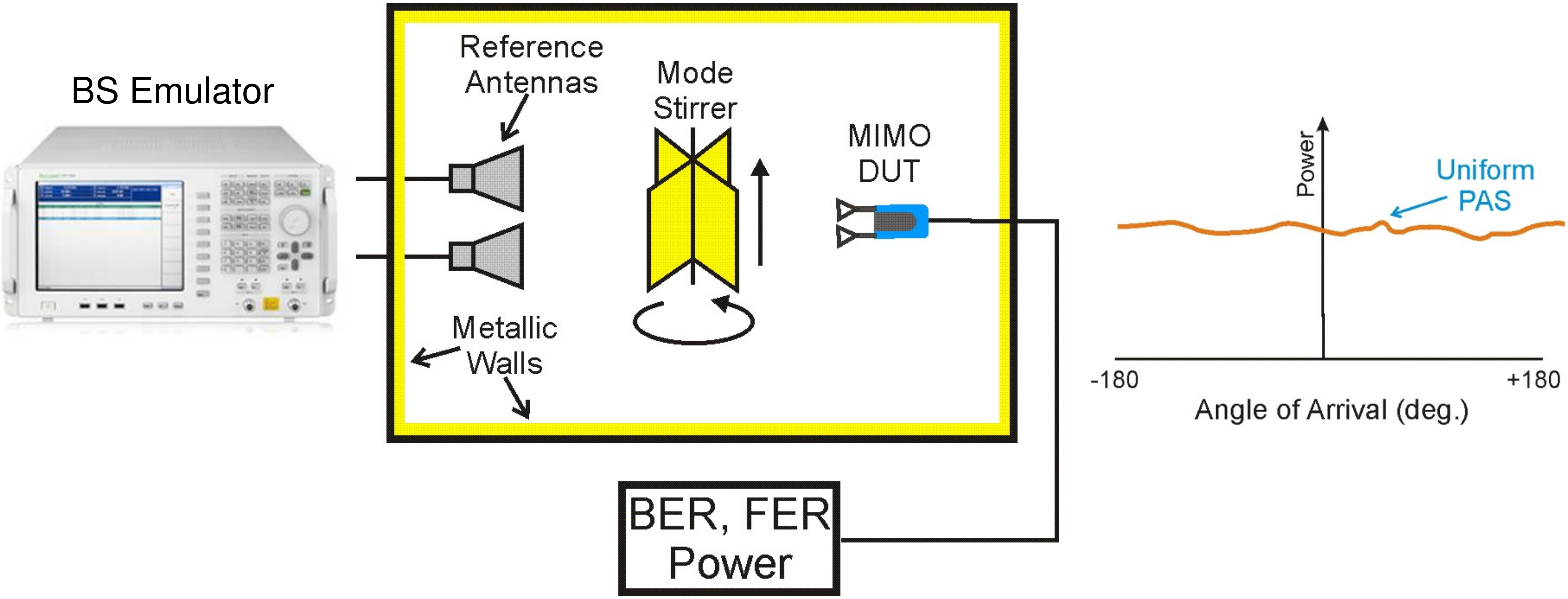
1. Multi-antenna anechoic chamber methods
   - Configurations vary from simple two antenna up to as many as 16 dual polarized antennas
2. Reverberation chamber methods
   - These vary from simple single chamber to more complex multi-chamber with or without the addition of a fading emulator
3. Antenna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

Multi-antenna Anechoic Methods



- 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

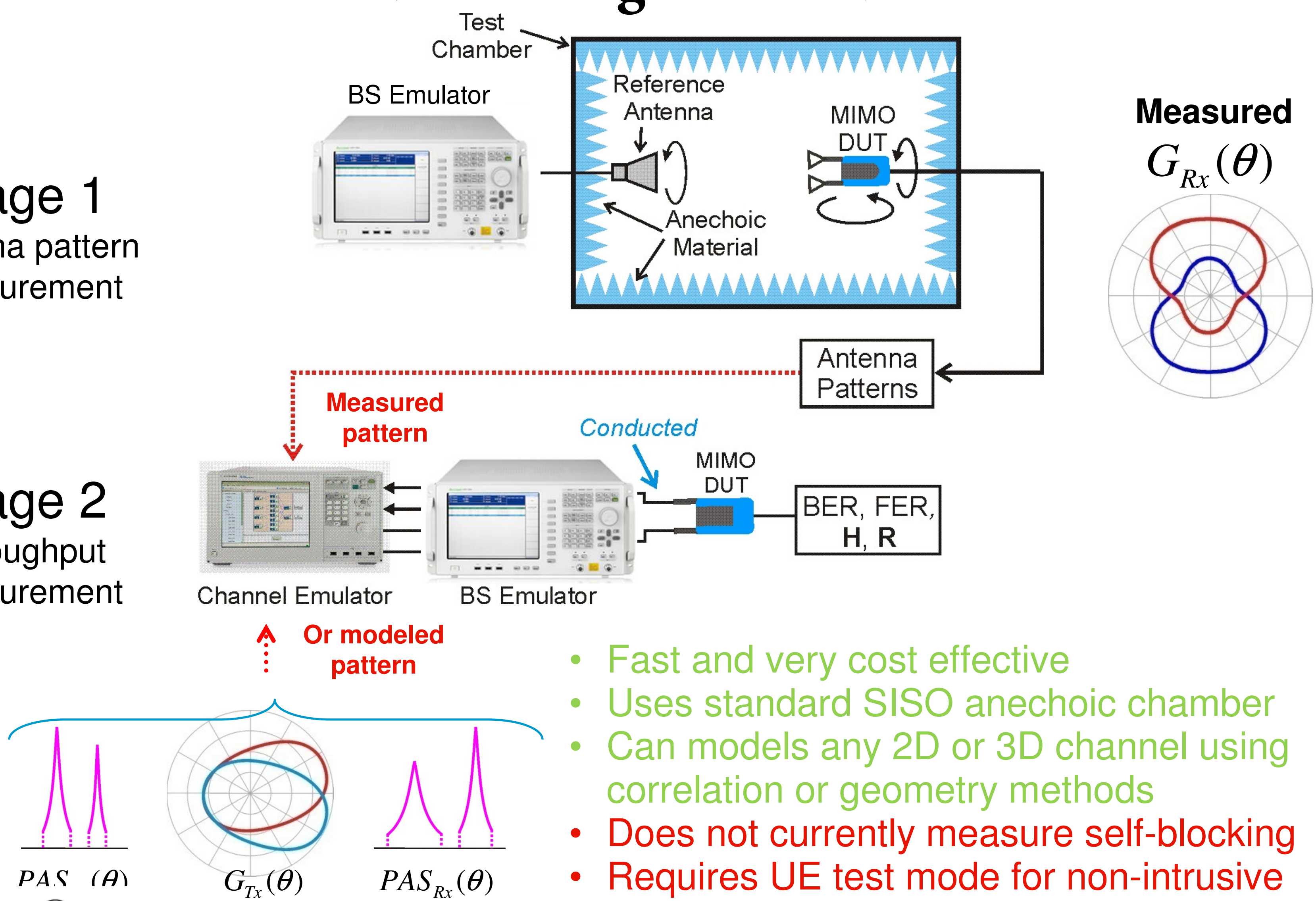


- The basic power delay profile (PDP) is modified using absorbers
- Adding a channel emulator can further modify the PDP
- Chambers can also be cascaded to create directional content
- Cost effective
- Good for assessing self-blocking
- Limited ability to generate standard channel profiles

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: Radio Channel aspects

Jukkka-Pekka Nuutinen

Understanding MIMO OTA Testing: Simple Solution to a Complex Test

Content

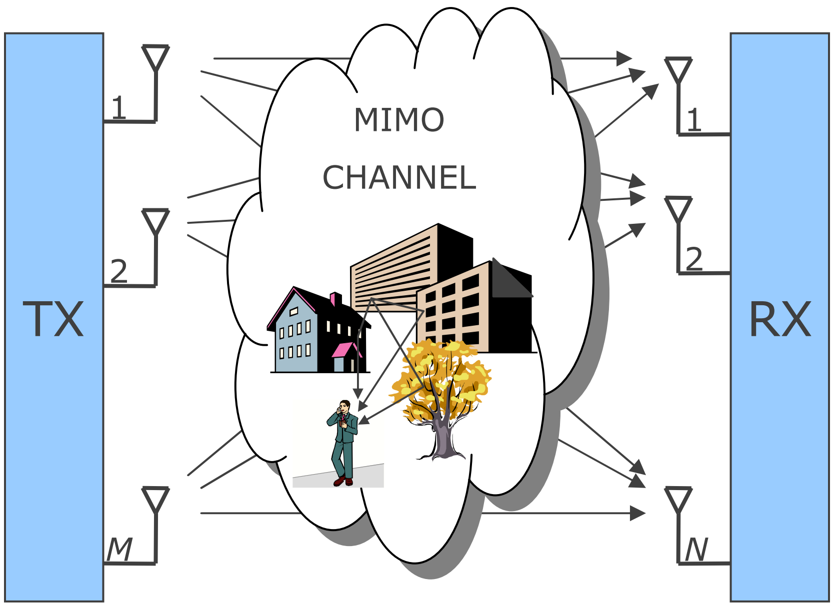
- Introduction
  - What is MIMO?
  - What is OTA testing?
  - What is MIMO OTA? Why is it needed?
- Components of the test set-up
- Channel modelling for MIMO OTA
  - Mapping
  - Pre-faded signals
- Simulation & measurement results
  - Validation, important characteristics
- Summary

Introduction

MIMO: Multi-antenna terminals

- MIMO (Multiple-Input-Multiple-Output) has been a research topic for more than 10 years.
- Now MIMO capable mobile terminals are finally in standardization phase and some commercial devices/networks are already available.

How I'm able to implement several antennas into small device?



MIMO

- MIMO is all about the correlation
  - Correlation is defined by
    - Radio channel (angular spread)
    - Antenna characteristics
  - Good propagation condition for MIMO may be ruined by bad antenna design
  - Good antenna design does not work in environment where correlation is not favourable
  - How to measure both such way that it takes into account both in realistic way
  - MIMO OTA is the answer
  - Design challenge is that we need to put several (2 or more) antennas into small form factor

What is OTA testing?

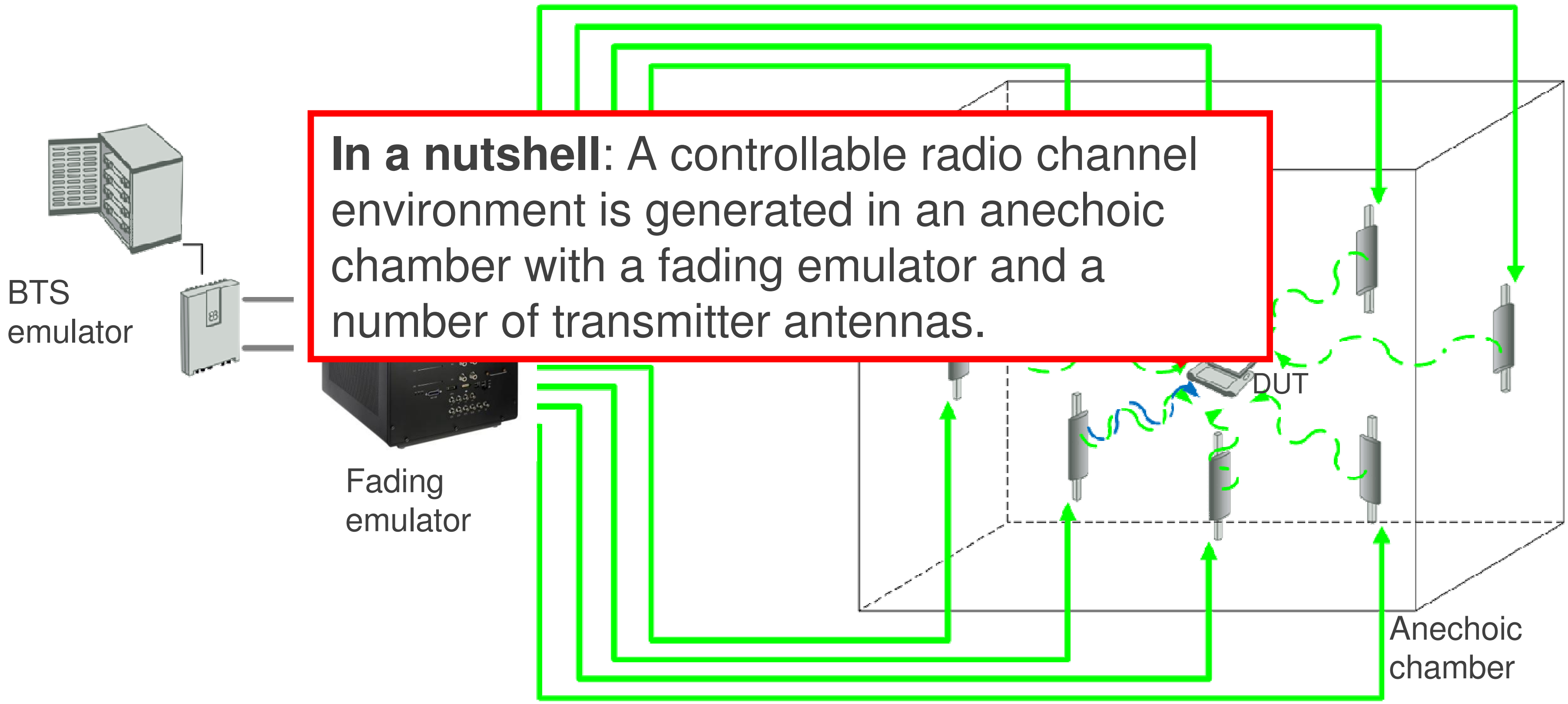
- Radiated testing Over The Air
- OTA is intended for testing of small devices
- Current OTA tests for SISO measure:
  - Total Radiated Power (TRP)
  - Total Isotropic Sensitivity (TIS)
- For SISO it is adequate to measure power based metrics only
- **In MIMO**, we need besides all the SISO measures, the realistic way to measure MIMO performance (throughput), which is defined by **correlation**

What is MIMO OTA?

- The purpose is to **create a controllable radio channel environment in an anechoic chamber around the device under test that takes into account also the antennas**

Components of the test set-up

MIMO OTA test set-up



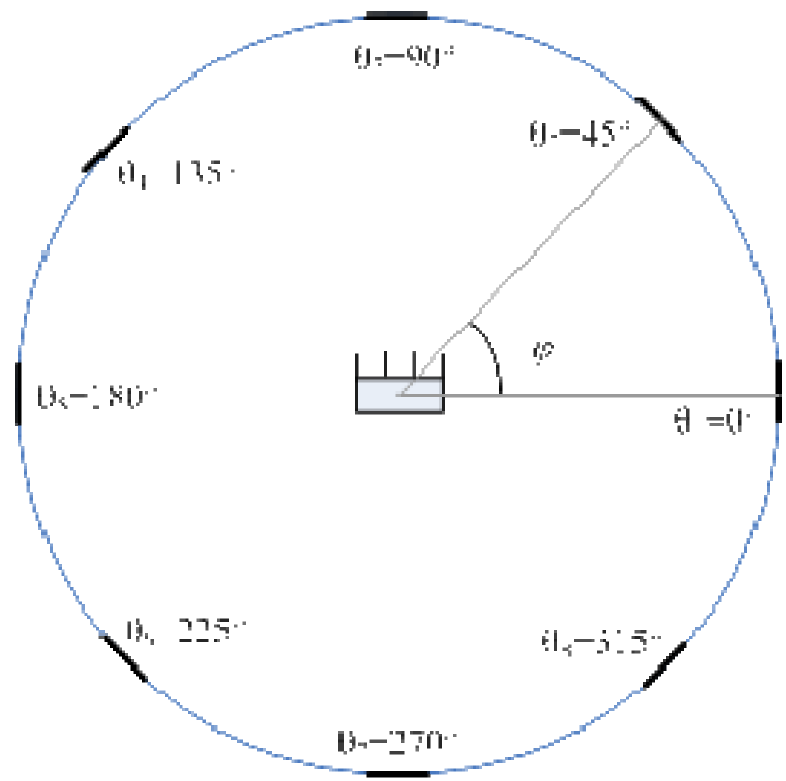
In a nutshell: A controllable radio channel environment is generated in an anechoic chamber with a fading emulator and a number of transmitter antennas.

MIMO OTA set-up

- The system has K OTA antennas in directions θ_k and DUT with an antenna array of M elements.
- The signal received by the mth DUT antenna is

$$y_m(t) = \sum_{k=1}^{K} c_{mk} x_k(t)$$

- where the signal transmitted from the kth OTA antenna is x_k, and c_{mk} is the complex channel gain from OTA antenna k to DUT antenna m.

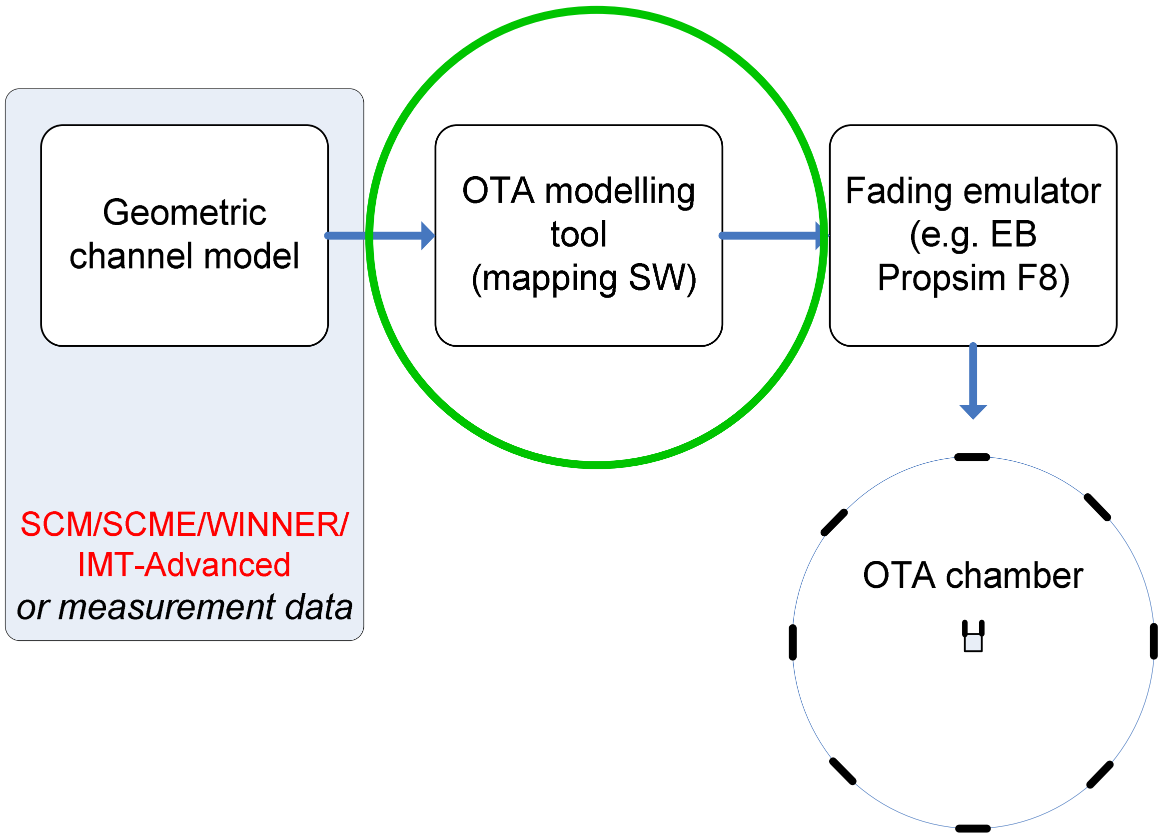


Channel modelling

Channel modelling topics

I. Basics of geometry based channel models
   – Why models have to be geometric based?
II. Transmission of *pre-faded signals*
   – Mapping of channel model to OTA antennas
   – Antenna weighting
III. 3D modelling
IV. Number of OTA antennas wrt channel model & DUT size

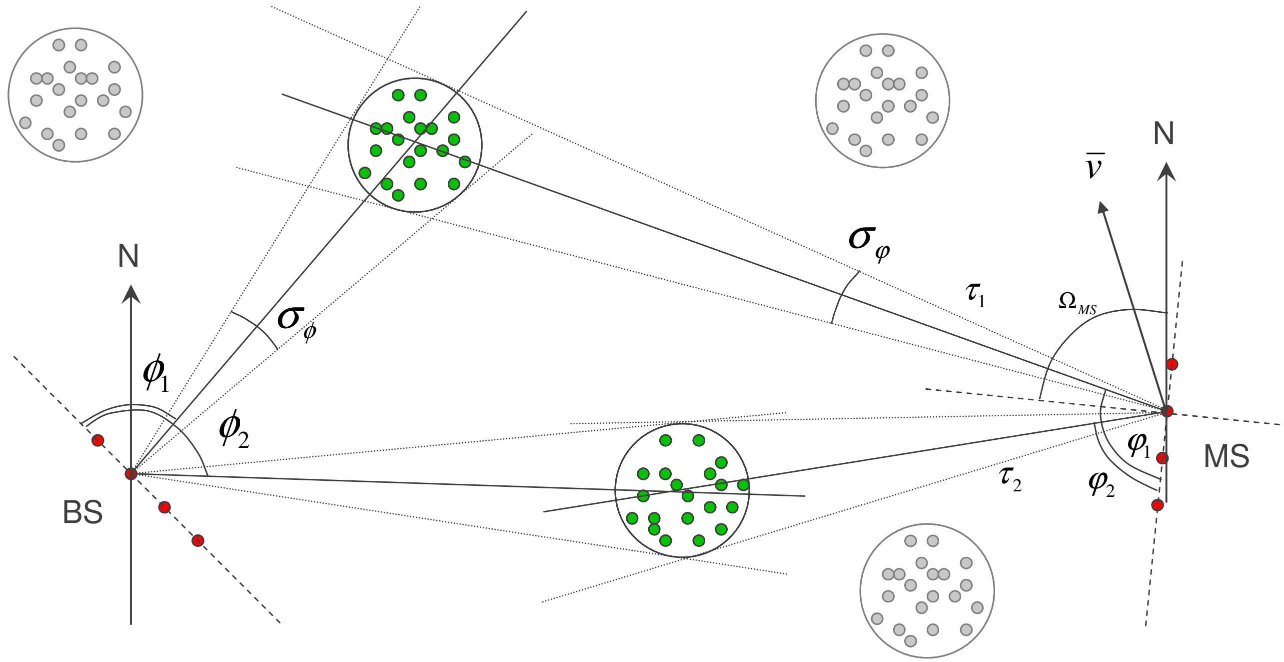
Channel modelling



I. Geometric channel models

Propagation parameters are
- cluster powers
- delays
- nominal arrival and departure angles
- XPRs
- angle spreads of clusters on both arrival and departure ends

$$H_{u,s,n}(t,\tau)=\sqrt{P_n}\sum_{m=1}^{M}\begin{pmatrix} F_{tx,s}(\phi_{n,m})\exp(jd_s k\sin(\phi_{n,m}))\cdot \\ F_{rx,u}(\varphi_{n,m})\exp(jd_u k\sin(\varphi_{n,m}))\cdot \\ \exp(j(\Phi+2\pi\upsilon_{n,m}t))\delta(\tau-\tau_{n,m}) \end{pmatrix}$$



I. MIMO Impulse response

Tx ant. s, Rx ant. u, cluster n

Antenna field patterns

Gains, XPRs

$$\mathbf{H}_{\mathbf{u,s,n}}(\mathbf{t};\boldsymbol{\tau}) = \sum_{m=1}^{M} \begin{bmatrix} F_{rx,u,V}(\varphi_{n,m}) \\ F_{rx,u,H}(\varphi_{n,m}) \end{bmatrix}^T \begin{bmatrix} \alpha_{n,m,VV} & \alpha_{n,m,VH} \\ \alpha_{n,m,HV} & a_{n,m,HH} \end{bmatrix} \begin{bmatrix} F_{tx,s,V}(\phi_{n,m}) \\ F_{tx,s,H}(\phi_{n,m}) \end{bmatrix}$$
$$\times \exp\left(j2\pi\lambda_0^{-1}(\bar{\varphi}_{n,m} \cdot \bar{r}_{rx,u})\right) \exp\left(j2\pi\lambda_0^{-1}(\bar{\phi}_{n,m} \cdot \bar{r}_{tx,s})\right)$$
$$\times \exp\left(j2\pi \upsilon_{n,m} t\right) \delta(\tau - \tau_{n,m})$$

Phase shifts due to antenna locations

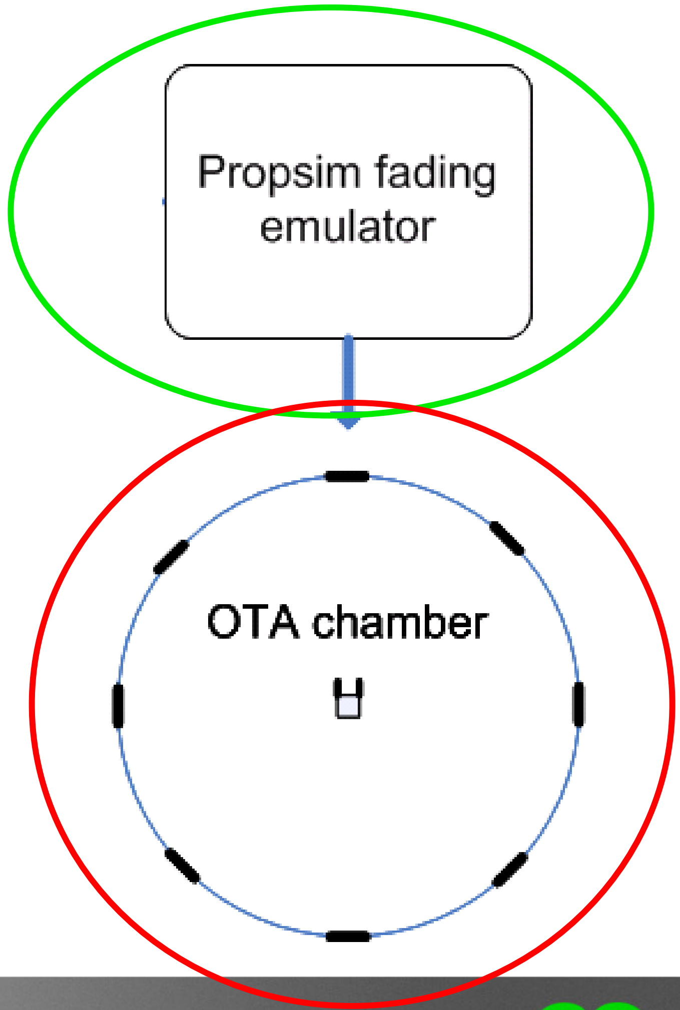
Phase shifts due to movement (Doppler)

Delays

- **Antenna field patterns can be separated from the channel.**
- **Genaralisation to N clusters and all antenna pairs is straightforward.**

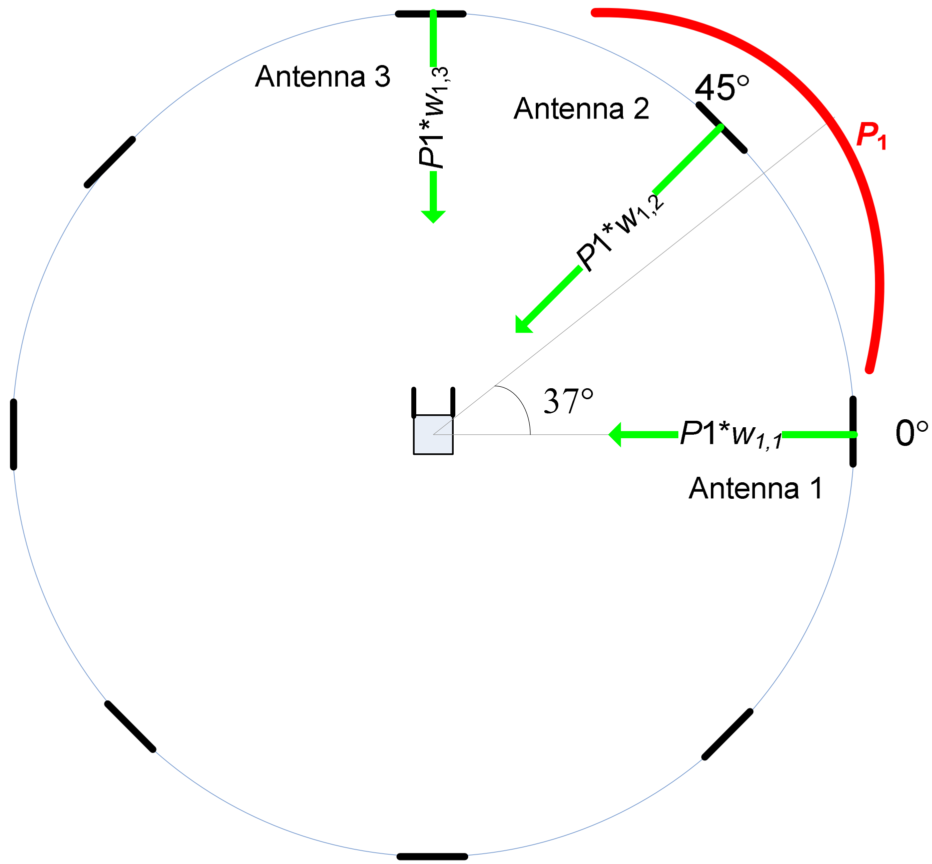
I. Modelling propagation effects in MIMO OTA

- **Small-scale fading**
- **Delay dispersion**
- **Direction dispersion** (at both **Tx** and **Rx** sites)
- **Doppler dispersion**
- **Polarisation** (**Tx** / **Rx**)

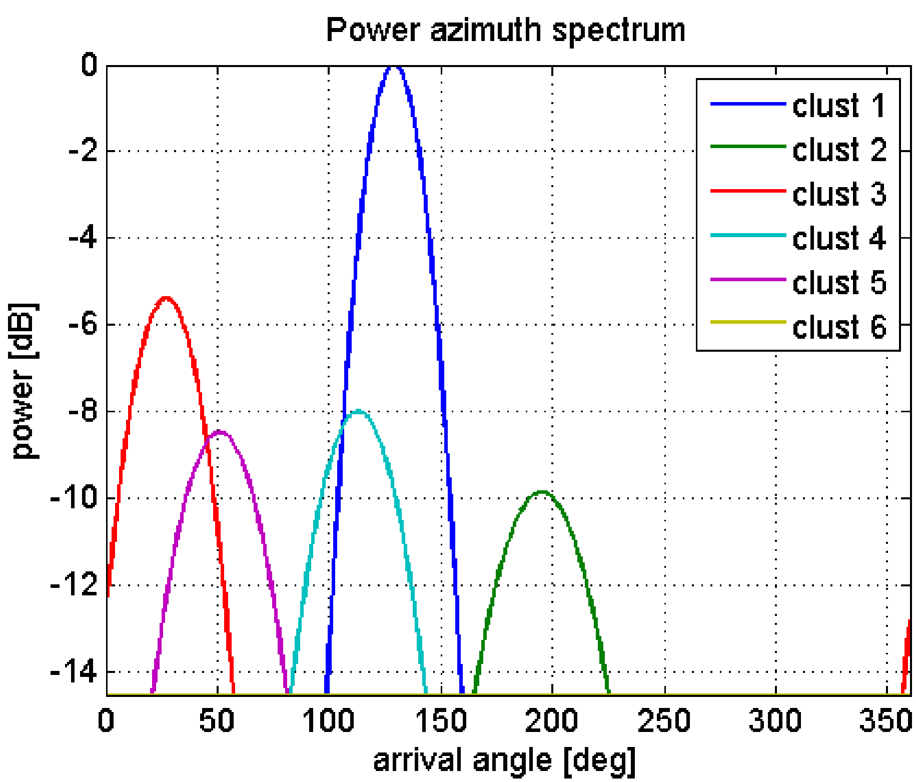


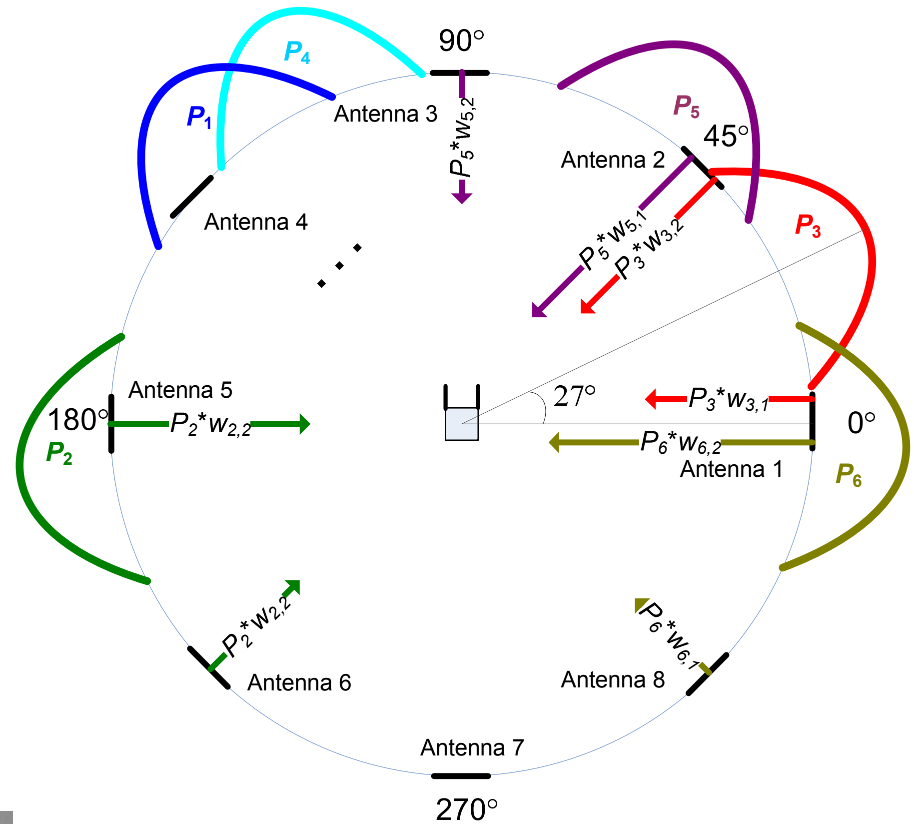
II. Angular mapping

- Example of the cluster mapping on OTA chamber with eight antennas.
- Red curve is the spatial cluster to be modelled.
- Green arrows denote the radiated power.
- If only a single antenna represented single cluster the DUT antenna correlation will not be correct



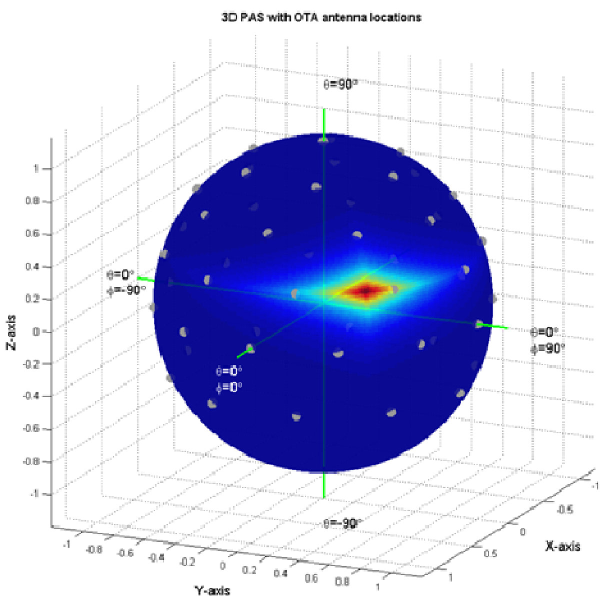
II. Mapping of spatial clusters

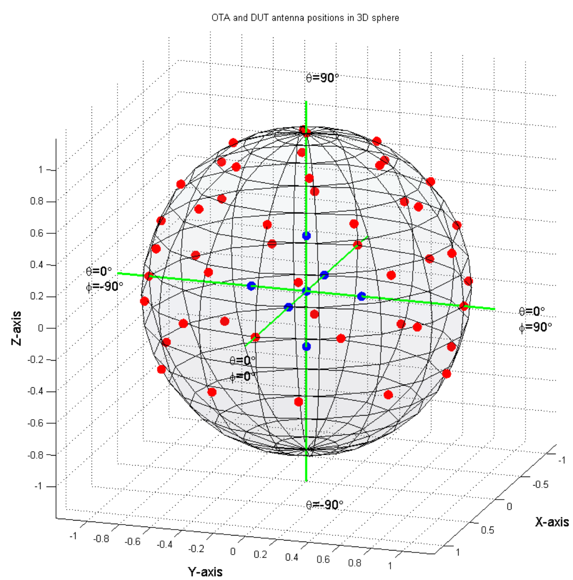


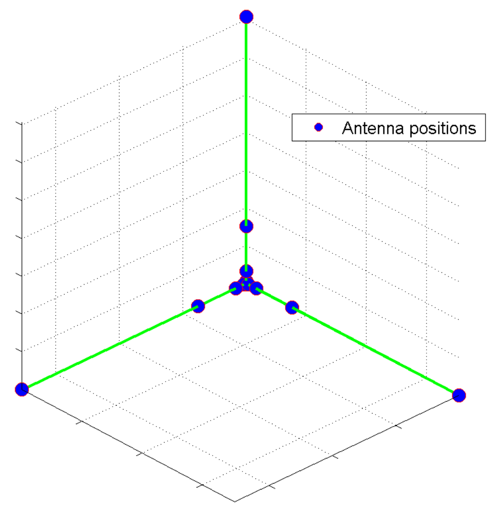


III. 3-dimensional modelling

- 3D channel models can be created with MIMO OTA
- Requires: channel models with elevation parameters, 3D OTA antenna configurations and mapping algorithm



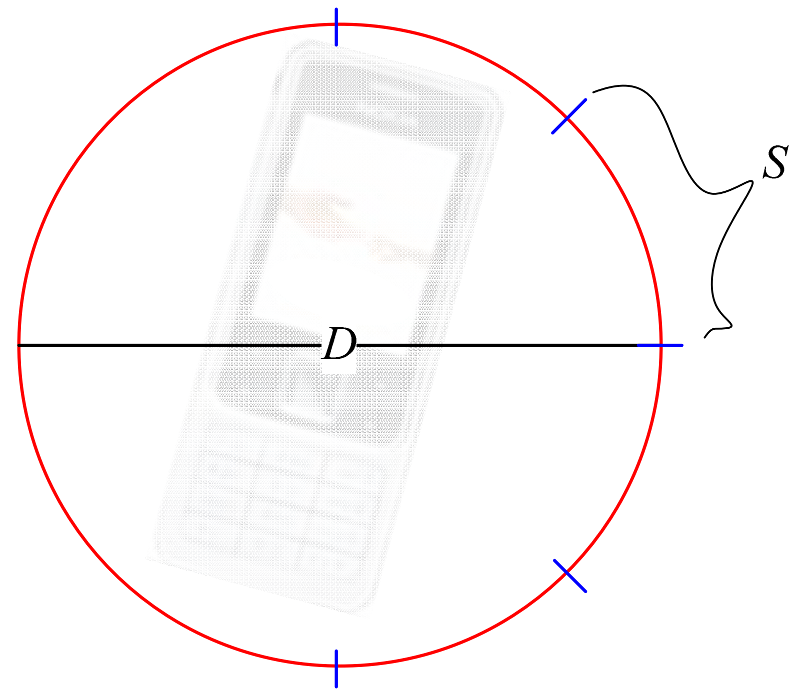




IV. Number of OTA antennas

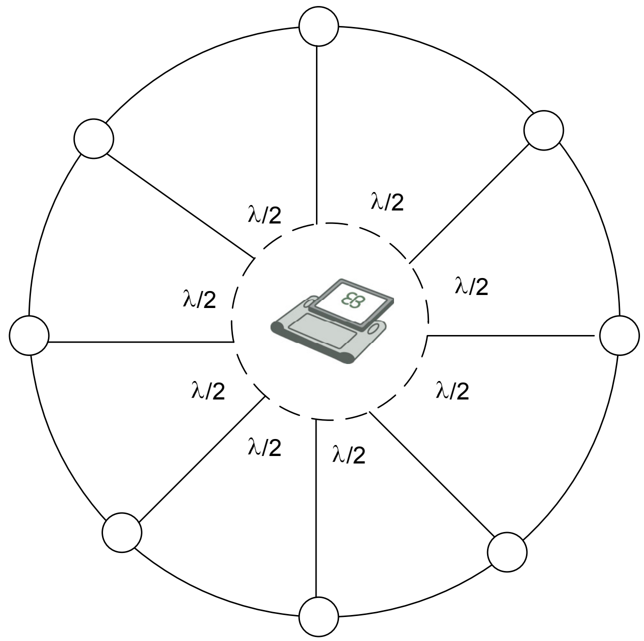
- Minimum sphere (cylinder in 2-dim) around DUT with diameter *D*
- Spatial sampling to segment lengths *S*
- With Nyquist sampling $S = \lambda/2$
- With uniform antenna spacing the number of OTA antennas is approximated by

$$\#\mathrm{OTA} > \frac{2\pi D}{\lambda}$$



IV. Size of the DUT is limited

- Sampling of the test volume boundary has to fulfil the Nyqvist criterion in space



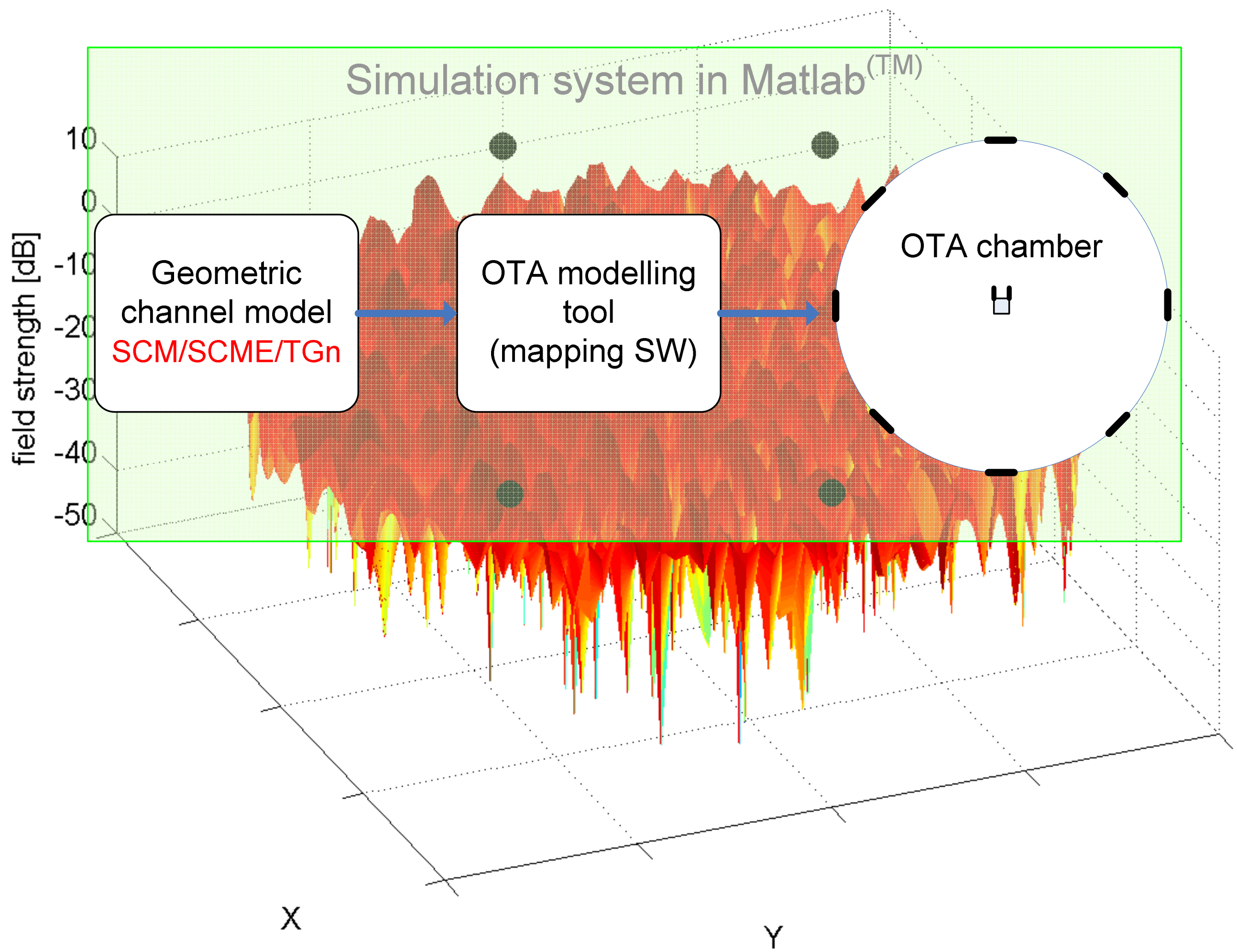
- Increasing the number of OTA antennas increases also size of the test volume!

Validation: Simulation & measurement results

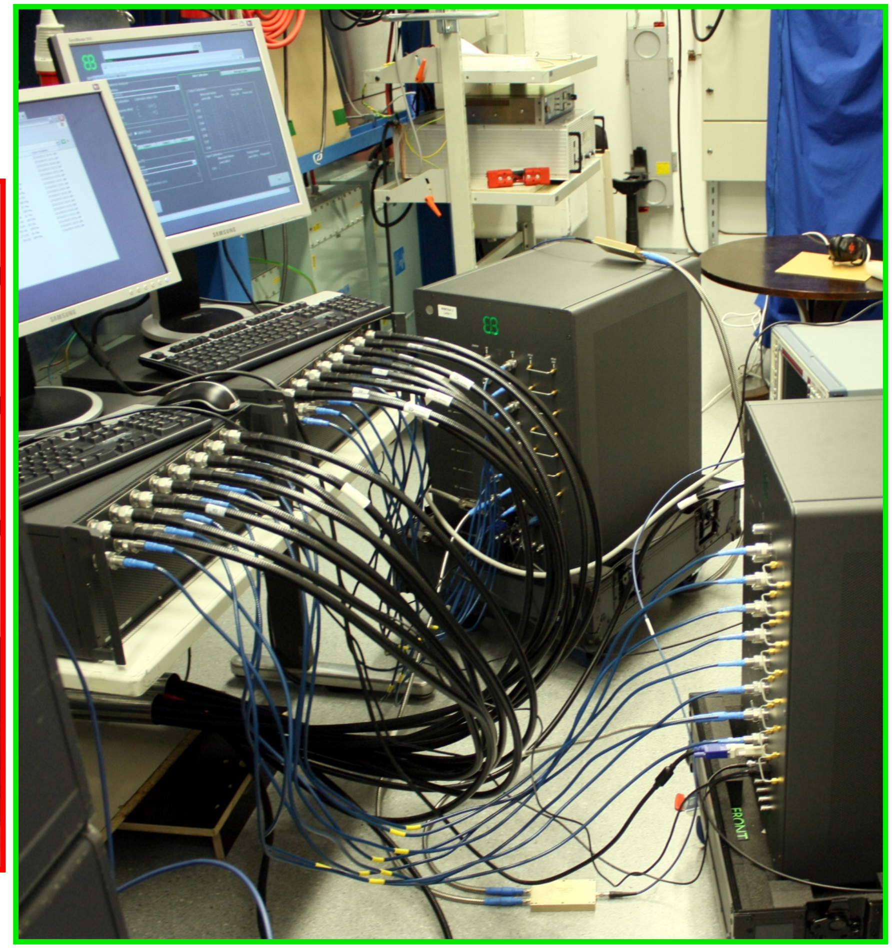
Important parameters

- Target is to verify the capability to create required characteristics of radio channel models inside a chamber
- Evaluated propagation characteristics are
  - *amplitude distribution of the fading coefficient*
  - *power delay profile*
  - *Doppler power spectrum*
  - *spatial correlation function*
  - *cross polarization power ratio*
- The reference radio channel models are
  - SCME (3GPP + WINNER)
  - TGn (IEEE 802.11n)

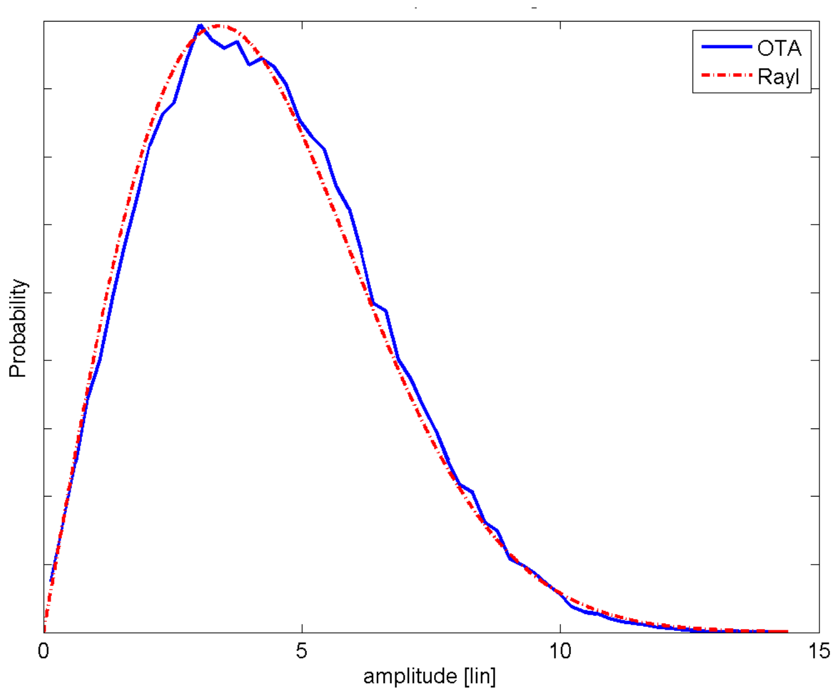
Simulation system



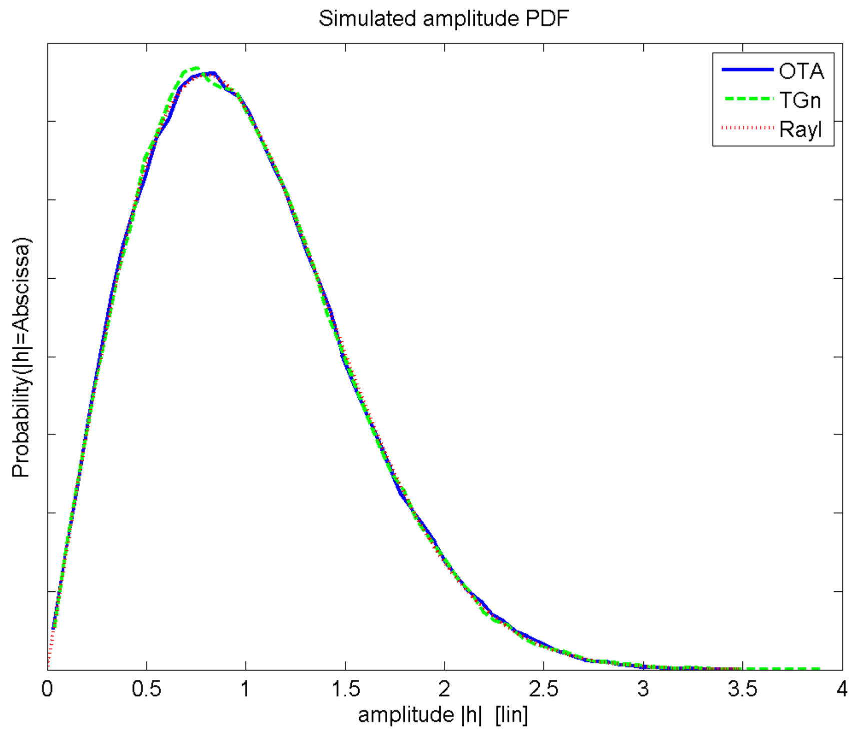
Measurement system



Amplitude distribution

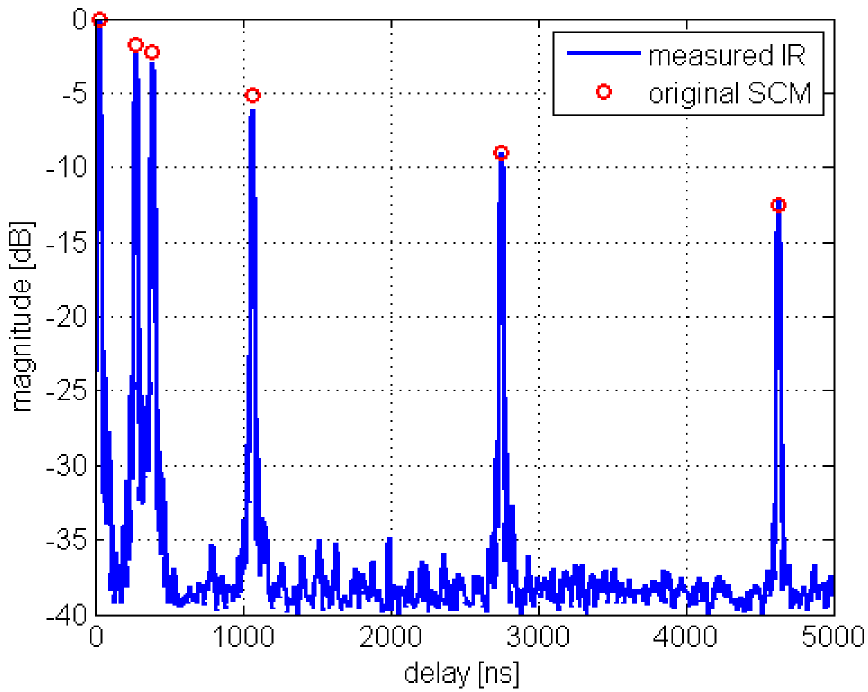


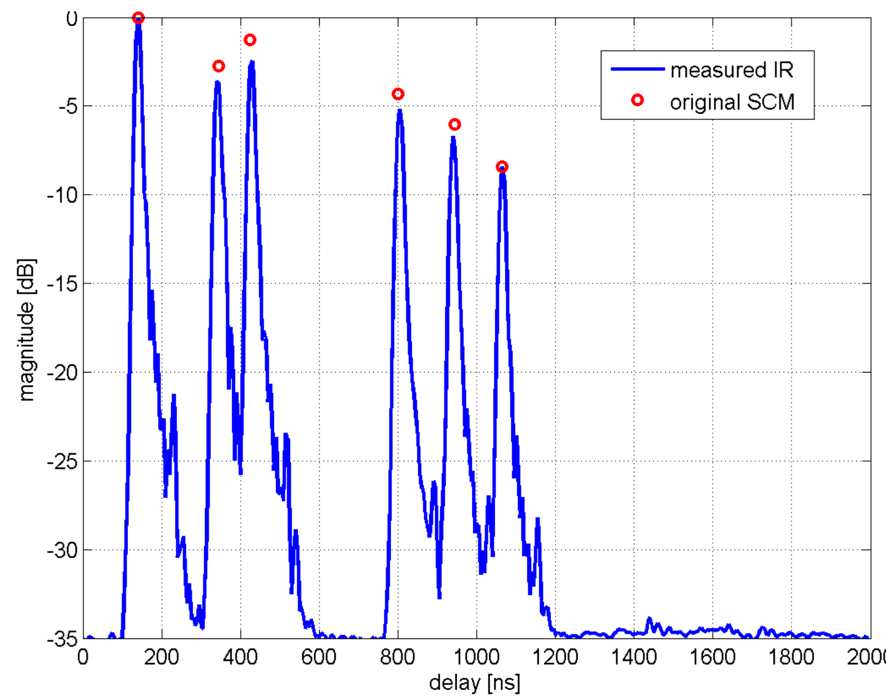
Measured SCME



Simulated TGn

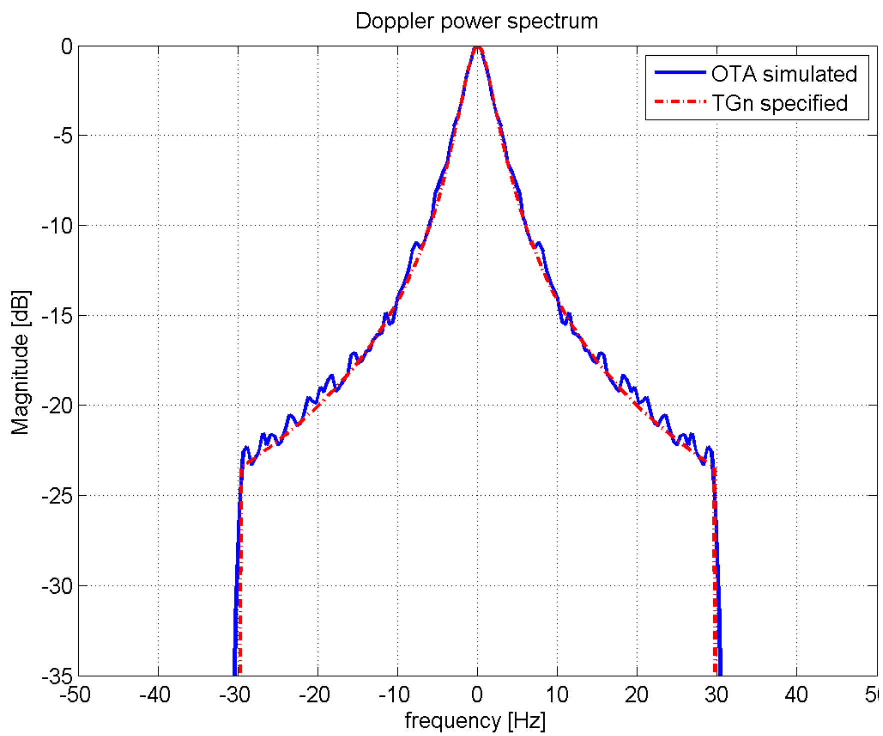
Power delay profile

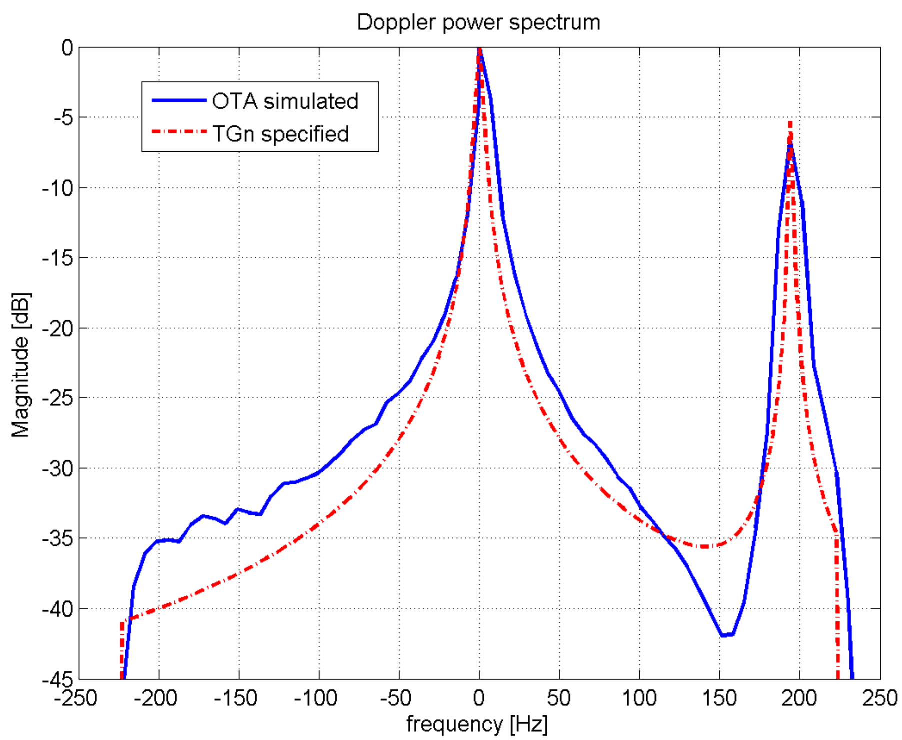




Measured SCM

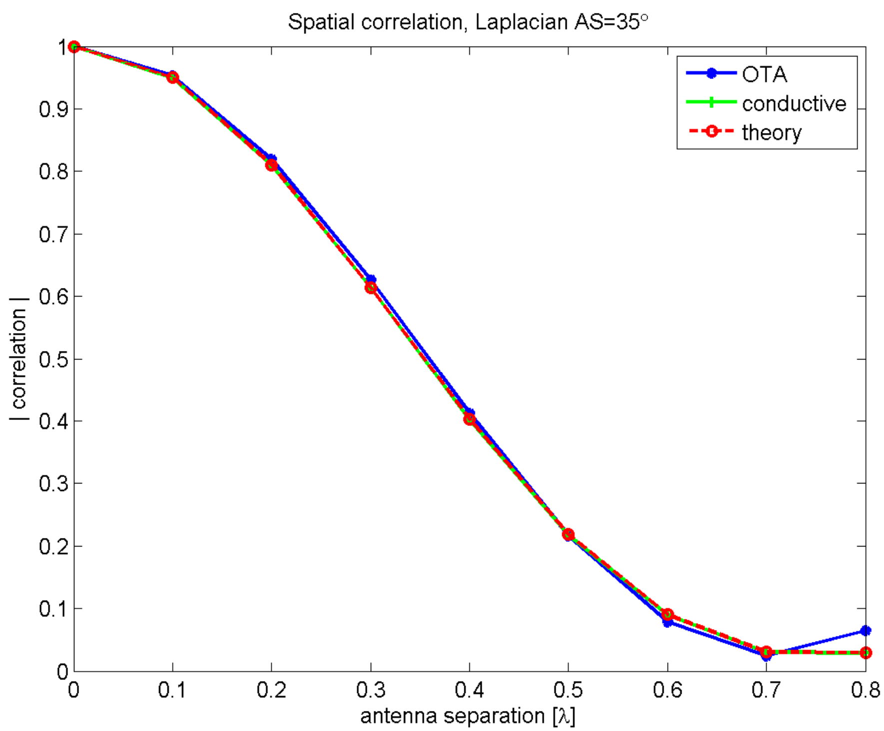
Doppler spectrum



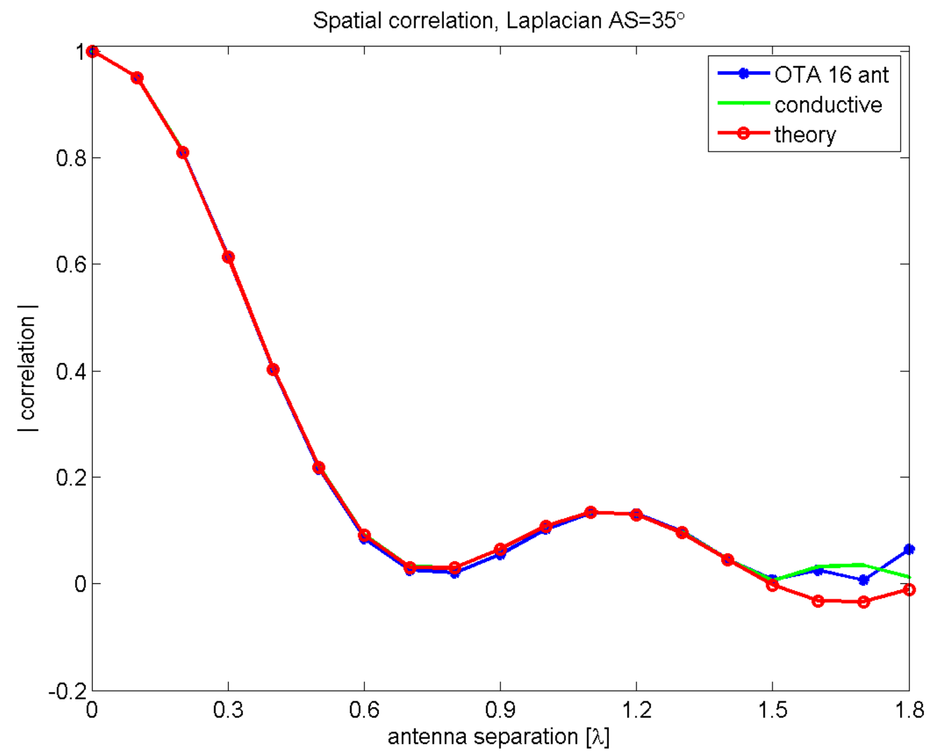


Simulated TGn

Spatial correlation

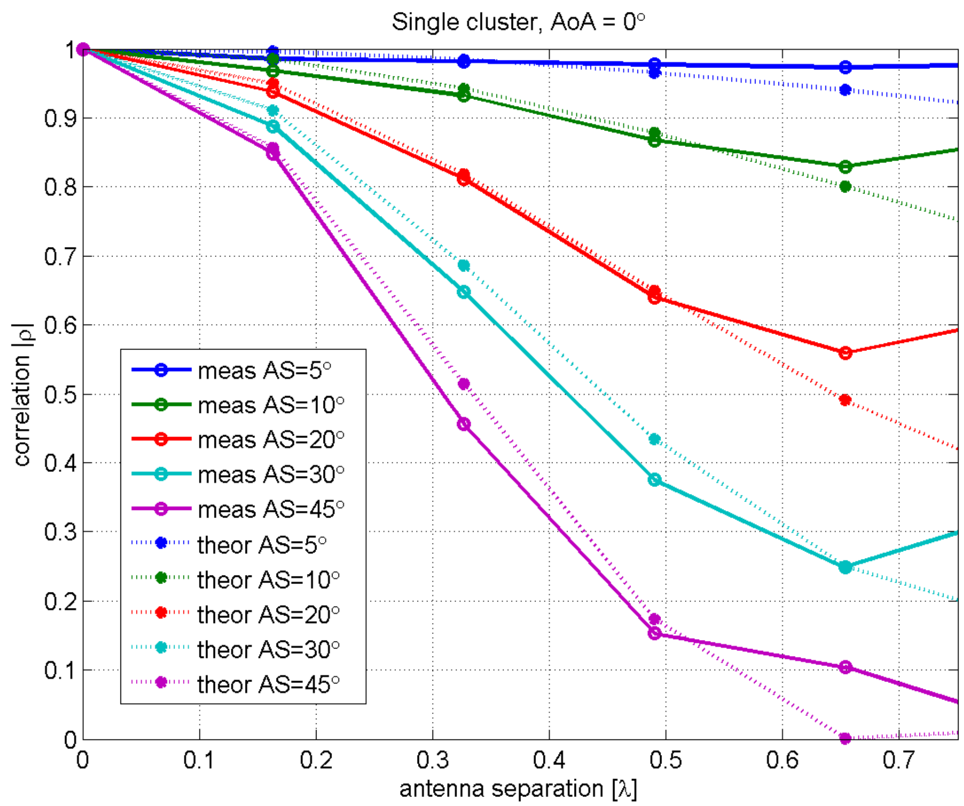


Simulated SCME, 8 antennas



Simulated SCME, 16 antennas

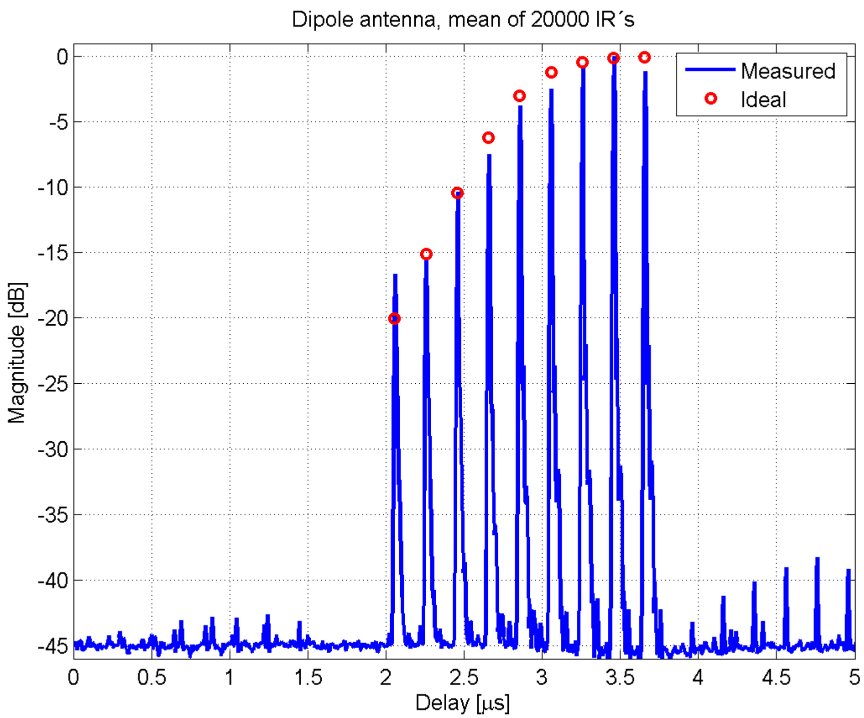
Spatial correlation



Measured: Laplacian PAS, AS=35°, 8 antennas

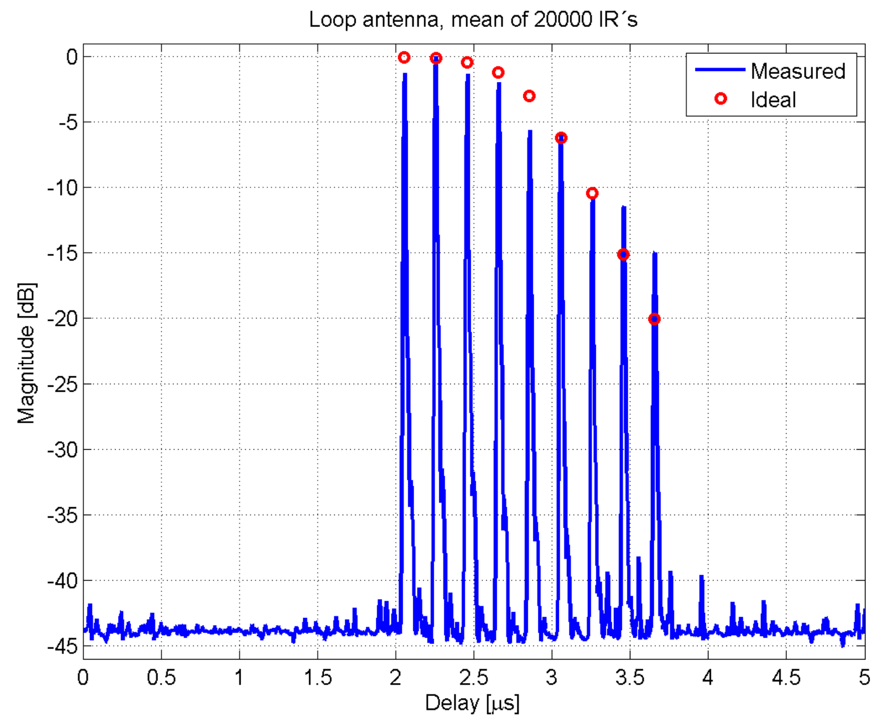
XPR

Dipole Rx antenna



Measured $RX_V = \frac{XPR_V}{1 + XPR_V}$

Magnetic loop (SATIMO) Rx antenna



Measured $RX_H = \frac{1}{1 + XPR_V}$

Summary

Summary

- **Realistic and controllable MIMO test** environment for multi-antenna terminals can be composed with:
  - BTS emulator, anechoic chamber, a number of OTA antennas, fading emulator and spatial channel models
- **Widely approved MIMO channel models or measurement data** may be used
  - With measurement data the propagation parameters must be extracted first
- **The goal is to emulate different propagation environments without moving the OTA antennas**
- System is flexible and expandable

Summary

- MIMO OTA is the only known test methodology to measure simultaneously antennas and propagation
  - MIMO is all about the correlation!
  - Correlation is defined by
    - Antennas
    - Propagation environment
- To generate appropriate environment, we need radio channel emulator which is
  - Multichannel
  - Capable to emulate geometry based stochastic models

Thank you