Understanding MIMO OTA Testing: Simple Solution to a Complex Test

Moderated by
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ETS-Lindgren

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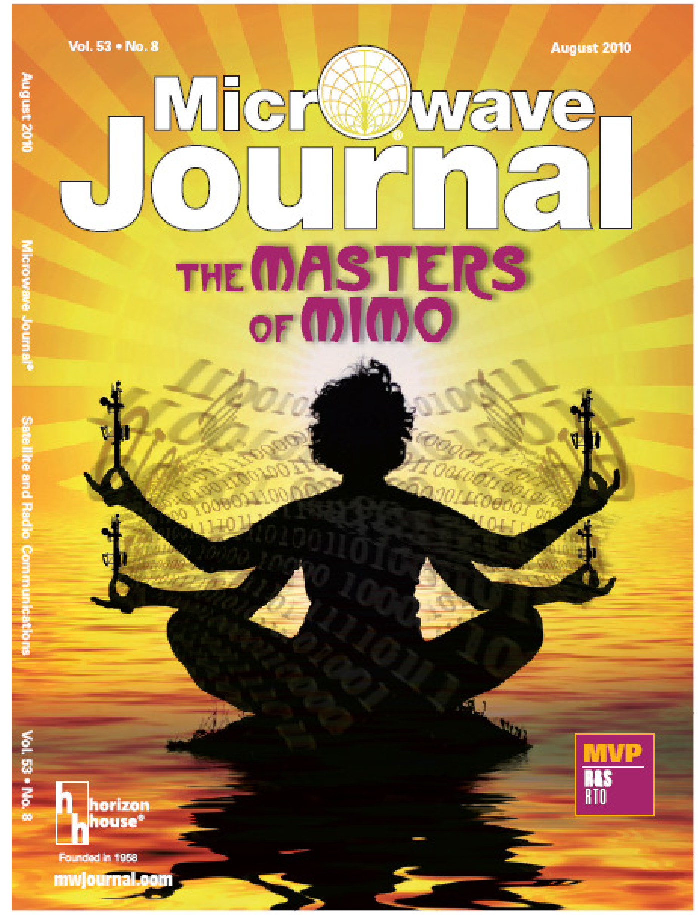
The Growing Importance of the Mobile Phone Antenna

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

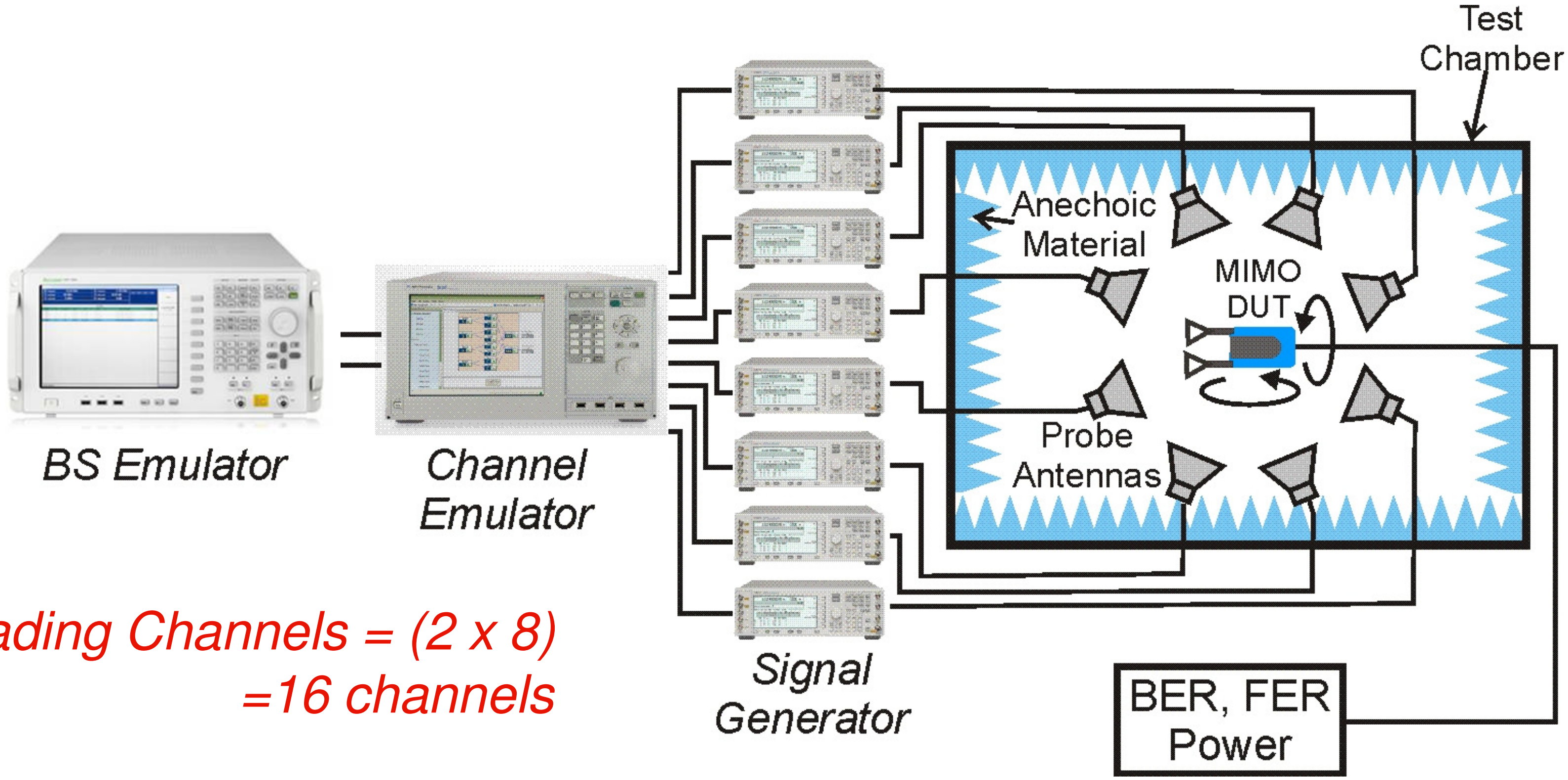
MIMO OTA Test Methodologies

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

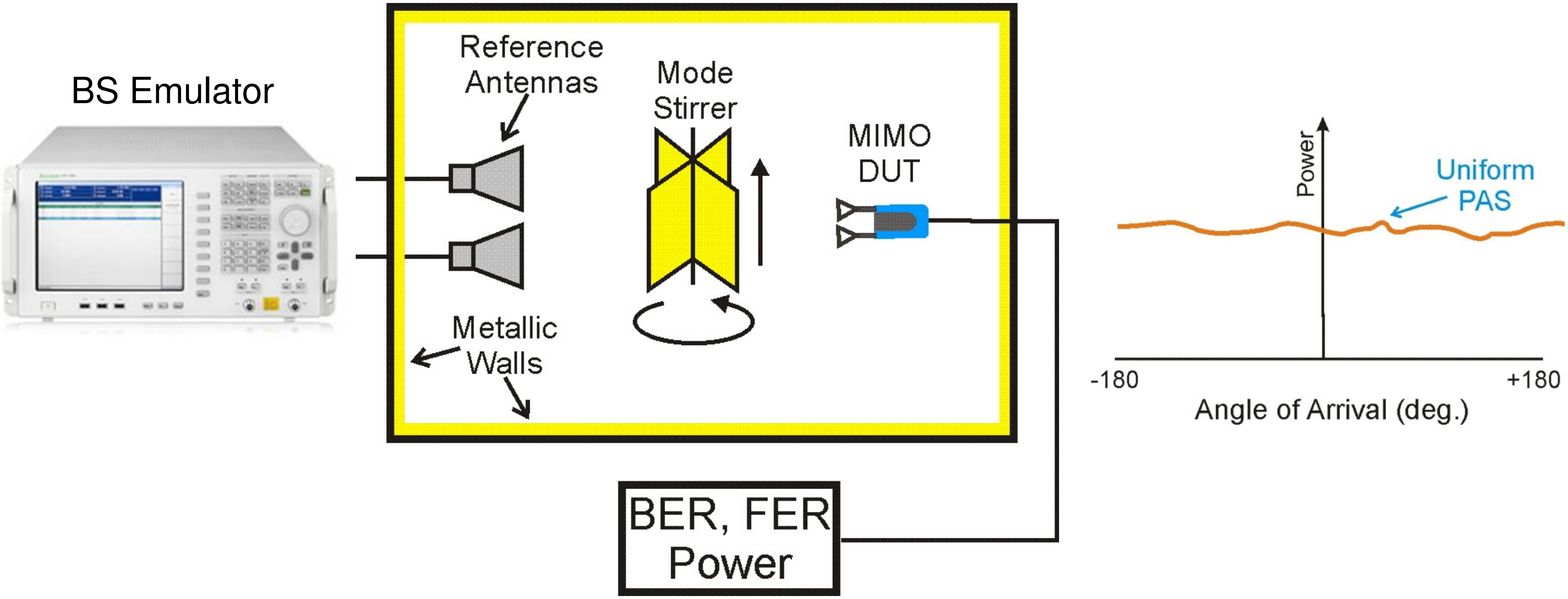
Multi-antenna Anechoic Methods



Fading Channels = (2 x 8)
=16 channels

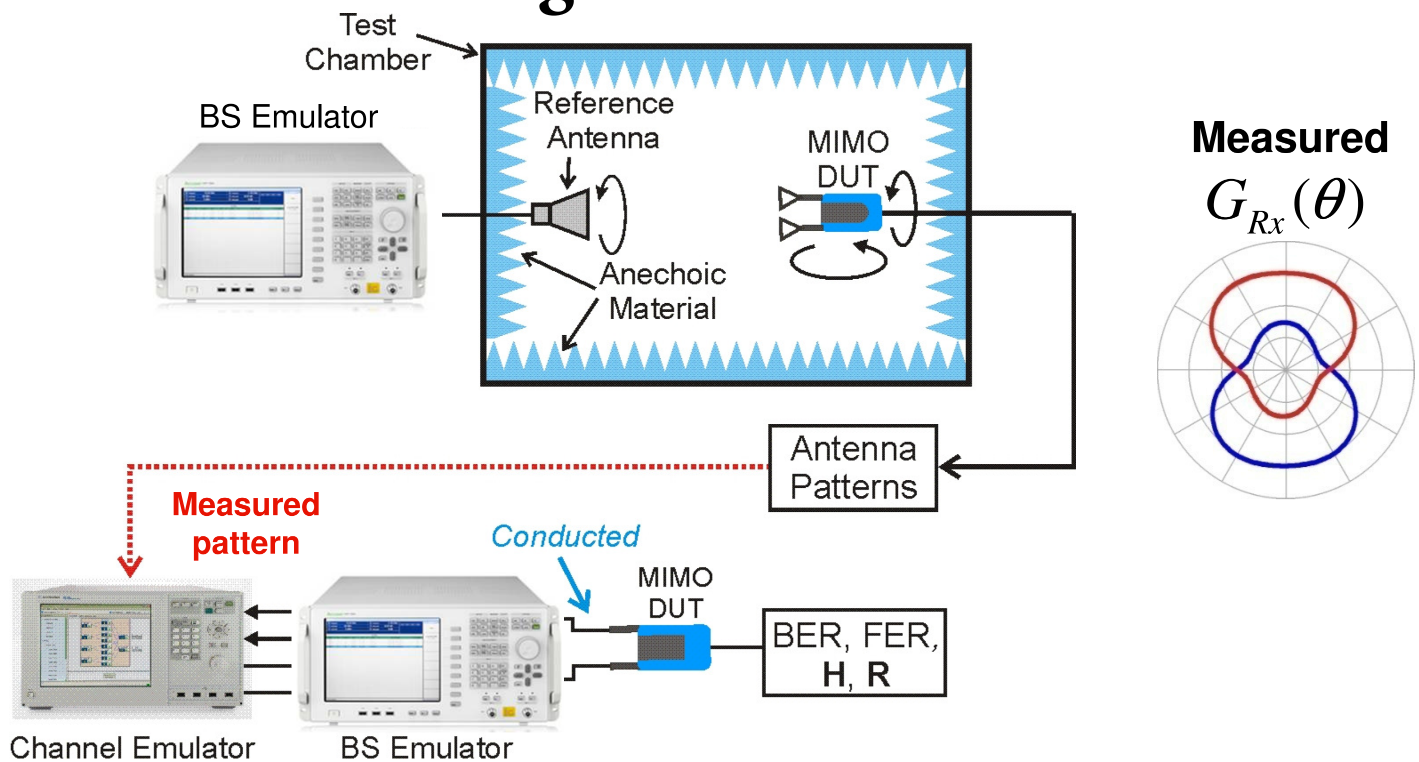
- Conceptually simple
- Requires precise system calibration
- Many probes (16?) in full circle required for arbitrary channel emulation
- Full circle requires large chamber (single cluster is smaller)
- Full 3D channel emulation is a challenge, partial 3D may be possible

Reverberation Chamber Methods



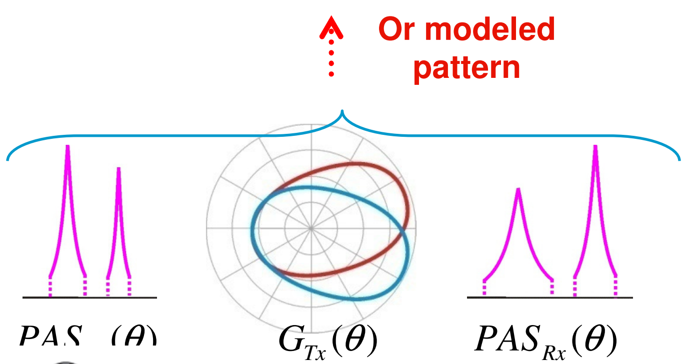
- The basic power delay profile (PDP) is modified using absorbers
- Adding a channel emulator can further modify the PDP
- Chambers can also be cascaded to create directional content
- Cost effective
- Good for assessing self-blocking
- Limited ability to generate standard channel profiles

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 measurement challenges and the Two-stage Methodology

Moray Rumney
24th March 2011

Agenda

1. High level criteria for MIMO OTA
   - Efficacy
   - Test system cost
   - Test coverage
2. What is it we are trying to measure?
3. Factors affecting MIMO OTA performance
4. Antenna pattern and two-stage MIMO OTA methods
5. Summary

1. High level criteria for MIMO OTA Efficacy

A test is only useful if it can discriminate between acceptable and unacceptable performance

This requires two key factors

- The **test conditions** and figure of merit have to be relevant
  - This does not mean an exact match to real life but there needs to be an identified correlation
- The **measurement uncertainty** of the test system has to be significantly less than the difference between acceptable and unacceptable performance
  - Otherwise a bad device may pass (or a good device may fail if the requirements are not relaxed)
  - Or looking at it another way a SISO device might pass the MIMO tests

1. High level criteria for MIMO OTA
Test system cost

Most new tests do not fundamentally change the accepted balance between knowledge gained and test cost

In the early stages of considering different test methods it is the technical aspects that are uppermost and cost is not a primary driver

- An example from 3GPP where cost had an early impact on test scope was in multi-cell radio resource management tests where six-cell scenarios were ruled out even though test coverage was reduced

After technical evaluation the pros and cons of different MIMO OTA methods can be discussed, and cost will be a factor in recommending an industry solution

1. High level criteria for MIMO OTA Test coverage

In addition to the initial cost of a MIMO OTA test system is the operational costs or test time defined by the test coverage

Existing SISO tests already take many days to execute on expensive test systems and MIMO has many more variables

The scope of MIMO testing is driven by:

- The number of frequency bands (4+?)
- The number of radio propagation/Doppler/noise conditions (3+)
- The number of transmission modes (and transitions) (7)
- The use of adaptive modulation and coding (2)
- The number of DUT mechanical modes (2)
- Various head/hand loading conditions (5?)

These factors could multiply to create 1680 scenarios!

2. What is it we are trying to measure? Factors affecting system performance

Supercar Vs. Smartphone

Car performance attributes
1. Transmission
2. Suspension
3. Tyres
4. Road conditions
5. Traffic
6. Fuel economy

Phone performance attributes
1. Baseband
2. Adaptive modulation & coding
3. Antennas
4. Channel conditions
5. Interference
6. Battery life

The importance of defining what to measure
What attributes matter for a teapot?

We could propose to measure:

- Capacity
- Water tightness
- Thickness of wall
- Pouring ability
- Aesthetic appeal
- Cost
- And of course speed of pouring (Teaput!)

Tests could then be defined for all the above

But what if…

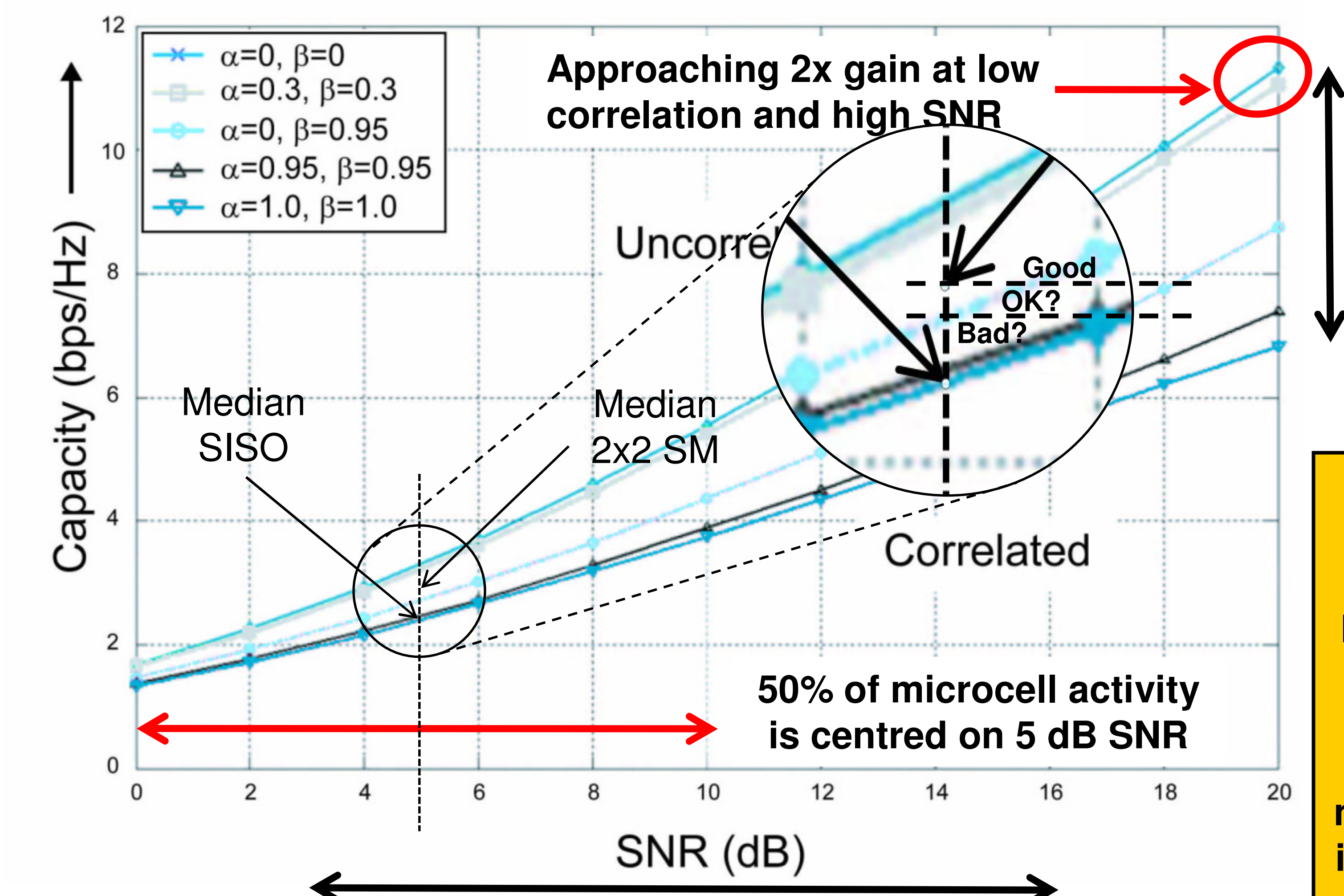
A teapot is presented for test made entirely of chocolate.

It would pass all the tests because the critical environment (hot tea) was not explicitly defined!

To date there have been many interesting and unpredictable results from OTA testing of RX diversity. MIMO will be more interesting.

Its what you don't know you don't know that kills you

What should we expect from MIMO in median conditions?



Variation due to fading and statistical interference

Variation due to antenna correlation

(Additional variation in the channel and frequency domain not shown)

In median conditions the capacity gain between SISO & acceptable spatial multiplexing may be only 10% i.e. fractions of a dB SNR

3. Factors affecting MIMO OTA performance

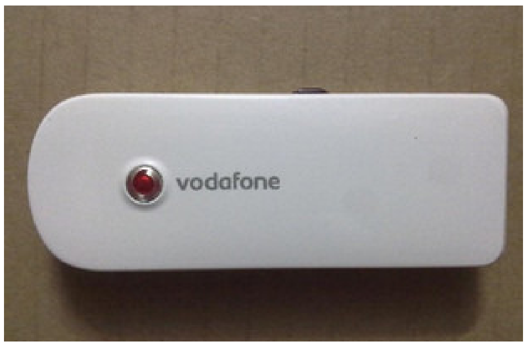
Unlike SISO OTA performance which was entirely a function of the DUT, MIMO OTA performance is intricately linked to the channel and operating conditions

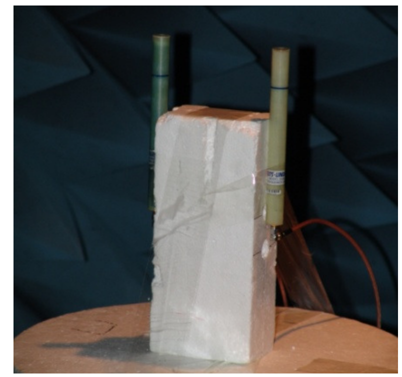
Expected performance is impacted among other things by:

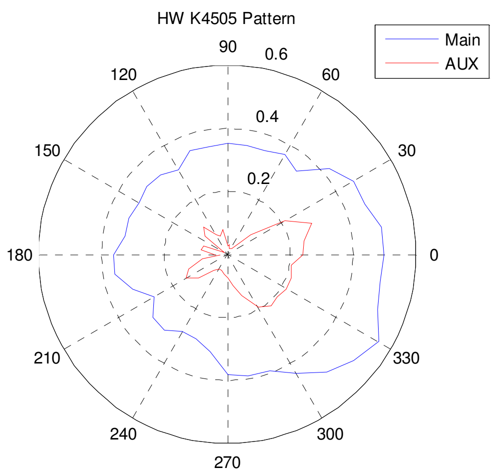
- Choice of channel model
- Doppler speed
- Degree of spatial diversity
- Impact of adaptive modulation and coding
- Noise and interference conditions
- Transmission mode used and transitions between modes

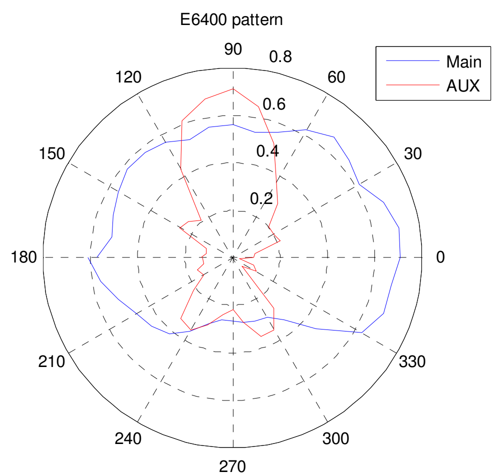
Investigation of impact of channel model on three different antennas for HSDPA RX Diversity

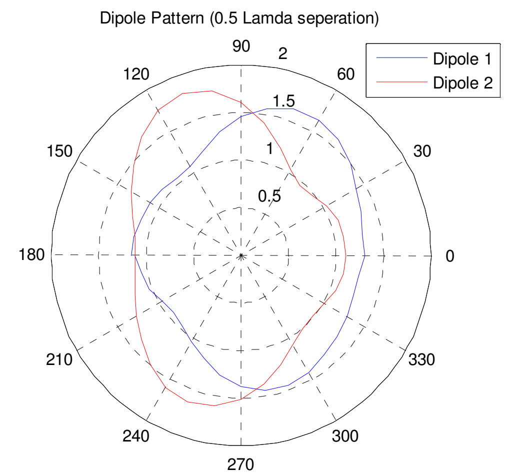
ANT #1	ANT #2	ANT #3 Dipole (0.5 λ interval)





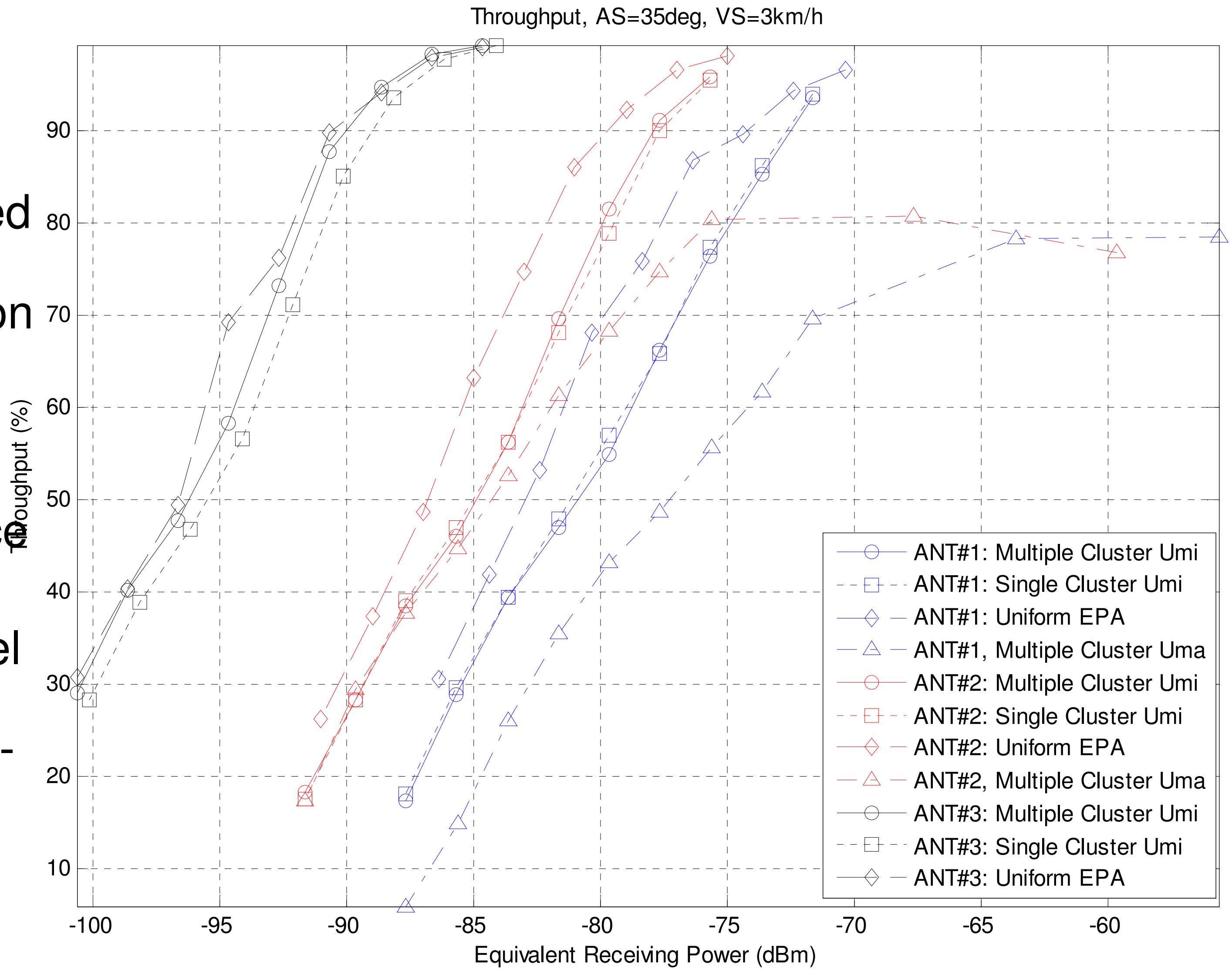






Two-stage results for HSDPA RX diversity

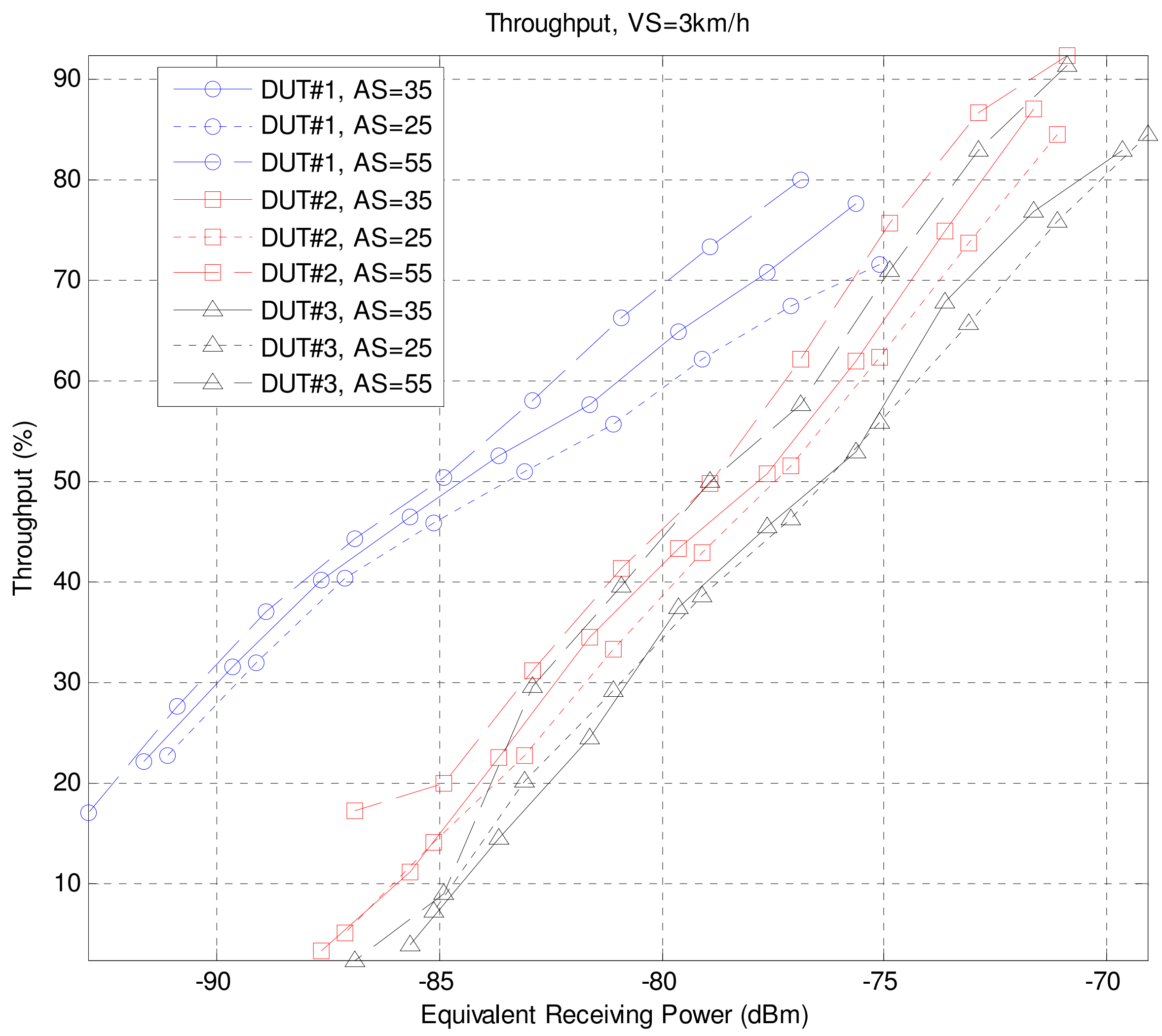
- RX diversity performance is largely determined by antenna gain and not correlation or power imbalance
- Uma channel limits performance to 80%
- Choice of channel model is more important for non-ideal antennas (ANT #1, 2)



Multiple Probe Antenna Based Method: HSDPA RX diversity Results (1)

HSDPA Throughput under scenarios VS=3km/h using single cluster multiple probe antenna method

DUT #1 Laptop
DUT #2 Dongle 1
DUT #3 Dongle 2

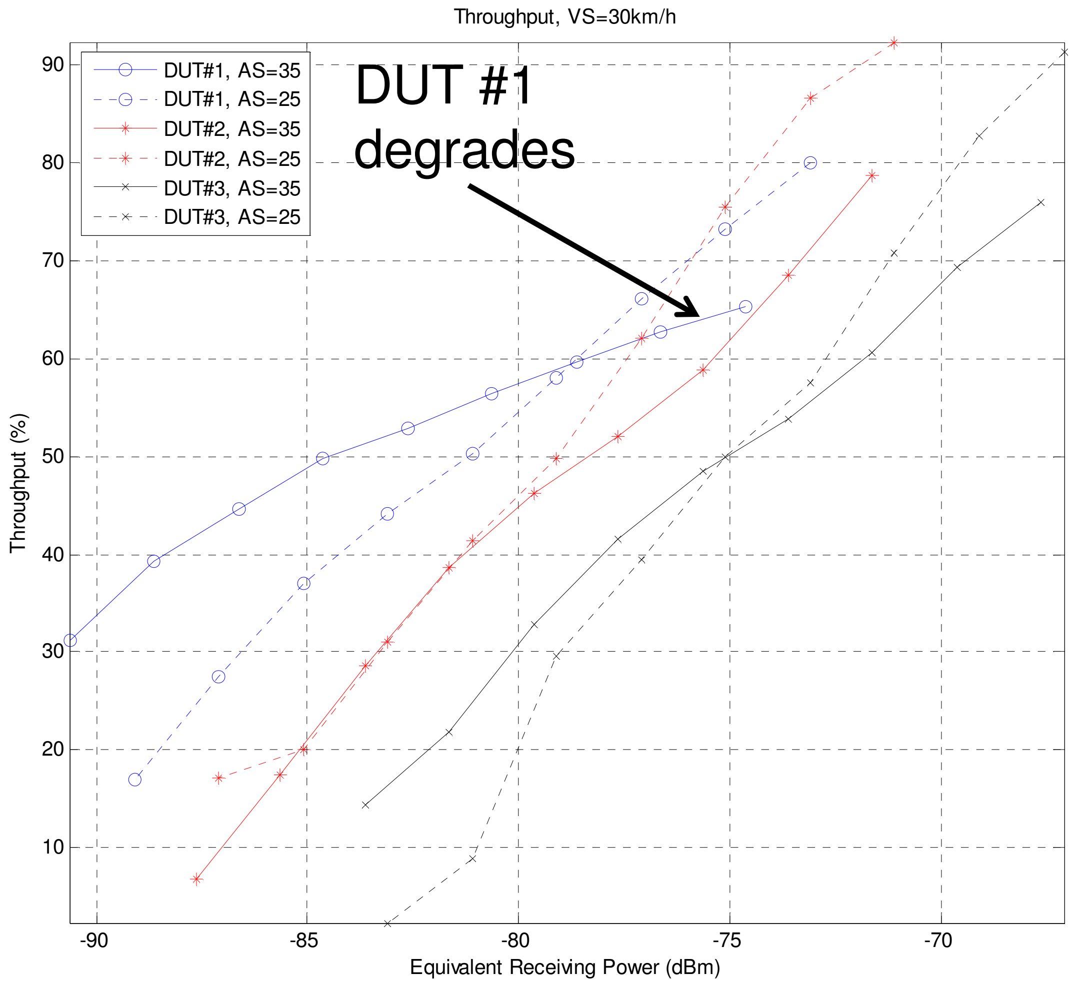


Multiple Probe Antenna Based Method: HSDPA RX diversity Results (2)

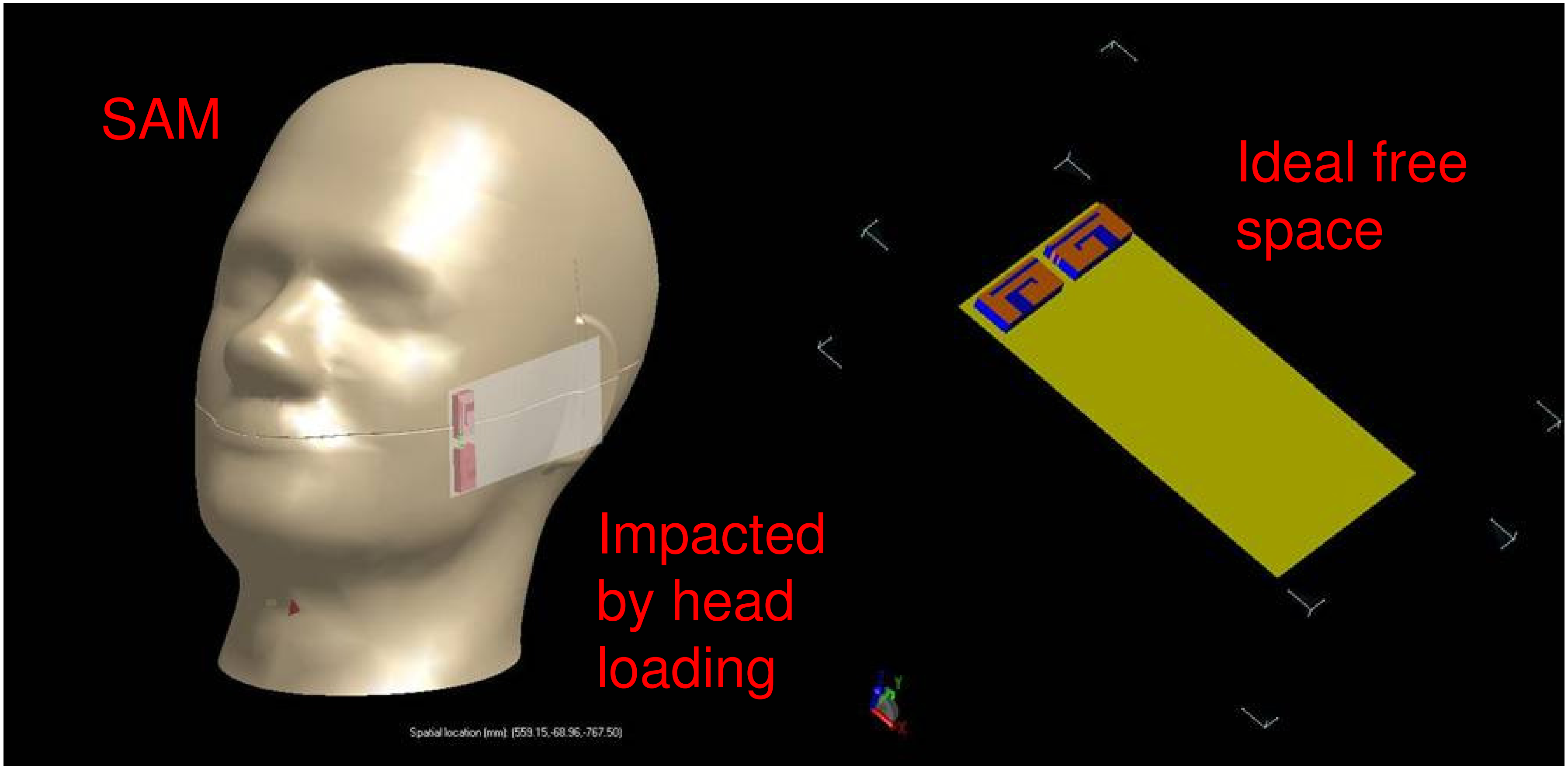
HSDPA Throughput under scenarios VS=30km/h using single cluster multiple probe antenna method

DUT #1 Laptop
DUT #2 Dongle 1
DUT #3 Dongle 2

Significant impact from higher speed for DUT #1 only



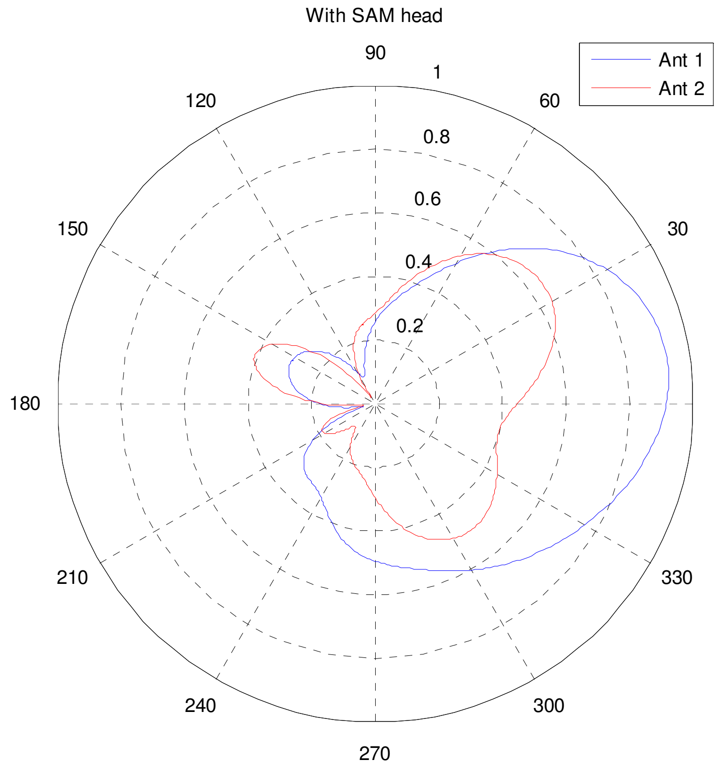
Analysis of impact of spatial channel model on known good and bad patch antenna patterns



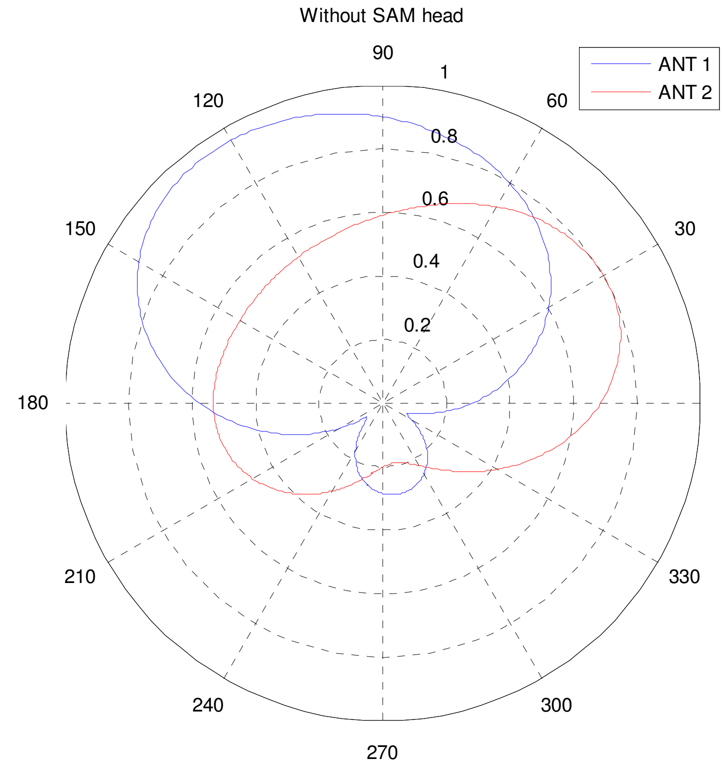
Antenna pattern #1 with SAM head influence

Antenna pattern #2 without SAM head influence

Simulated antenna patterns with and without SAM influence



Antenna pattern #1 impacted by head loading



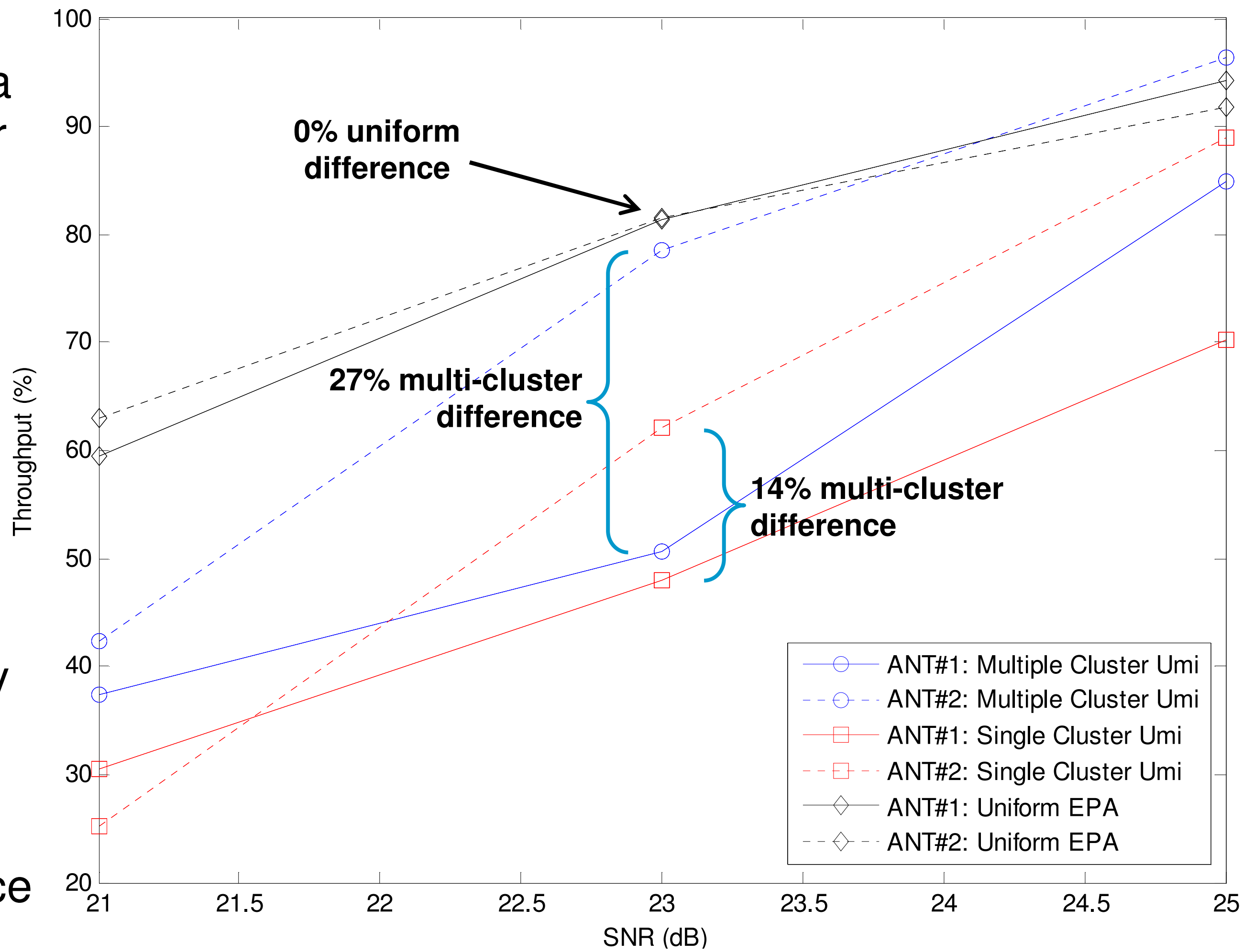
Antenna pattern #2 ideal free space

Simulation: Complex spatial channels better differentiate antenna performance (LTE 2x2 MIMO)

Results are normalized to remove impact of antenna gain. Both multiple cluster and single cluster can differentiate ANT #1 and ANT #2.

Uniform model does not differentiate
ANT #1 and ANT #2

However, the latest analysis of reverb chambers is that the instantaneous field is very non-uniform (hence the need for mode stirrers) which is why reverb can detect pattern performance differences



The importance of AMC - Adaptive Modulation and Coding

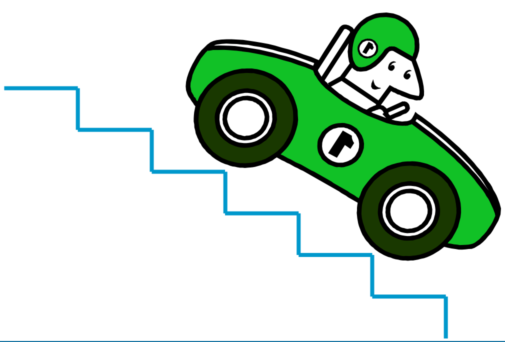
HSDPA and LTE UE receivers are designed to take advantage of AMC – UE feedback is used to ensure a constant signal to noise ratio to achieve a constant BLER target e.g. 10%

But conducted conformance tests switch off AMC

This means the SNR at the receiver can vary by 30 – 40 dB

Conformance tests turn receivers into fading discriminators

- The signal is either way too good or way too bad so subtle differences between receivers is lost and the result is dominated by the chosen fading
- Like trying to discriminate between Hi-Fi products in a noisy environment



- Or like driving down steps in a car with the suspension locked
- You can simulate a requirement, you can measure the performance but what do you learn?

Some noise about interference

HSDPA performance is measured against a constant power omni-directional broadband Gaussian noise source

In SISO CDMA systems this is a reasonable approximation since all transmissions are spread across the full channel

- Interference cancellation receivers can further discriminate based on scrambling codes

Simulations of OFDM capacity outperform CDMA primarily due to the increased gains available from narrowband scheduling

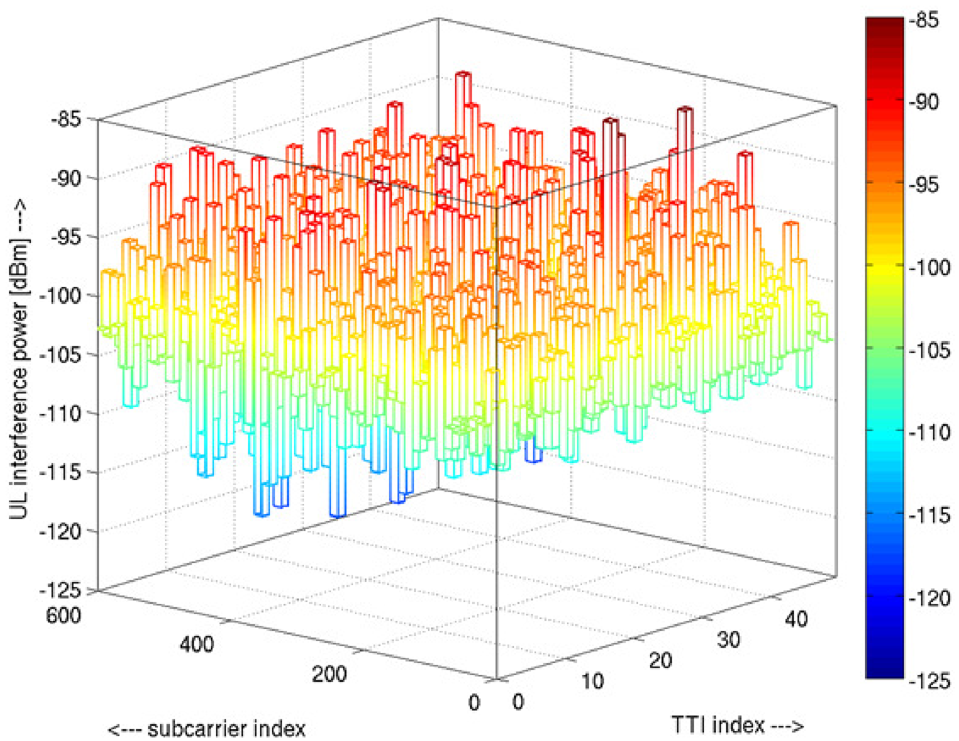
But narrowband schedulers create narrowband interference which is **statistical and directional**

- CQI/PMI reports may be accurate but could be out of date 1ms later

Current LTE conformance tests still use flat Gaussian noise which does not represent realistic conditions

Realistic OFDM interference

Agilent has been working with Nomor Research GmbH to emulate OFDM interference from 3GPP system simulations



Uplink inter-cell interference snapshot for VoIP scenario

This concept has been proposed to 3GPP RAN WG4 as a basis for developing closed loop UE performance tests to more realistically model real life conditions (R4-103235)

The uplink example shown here has been used in LTE field trials to emulate UEs

LTE (Release 8) has seven downlink transmission modes

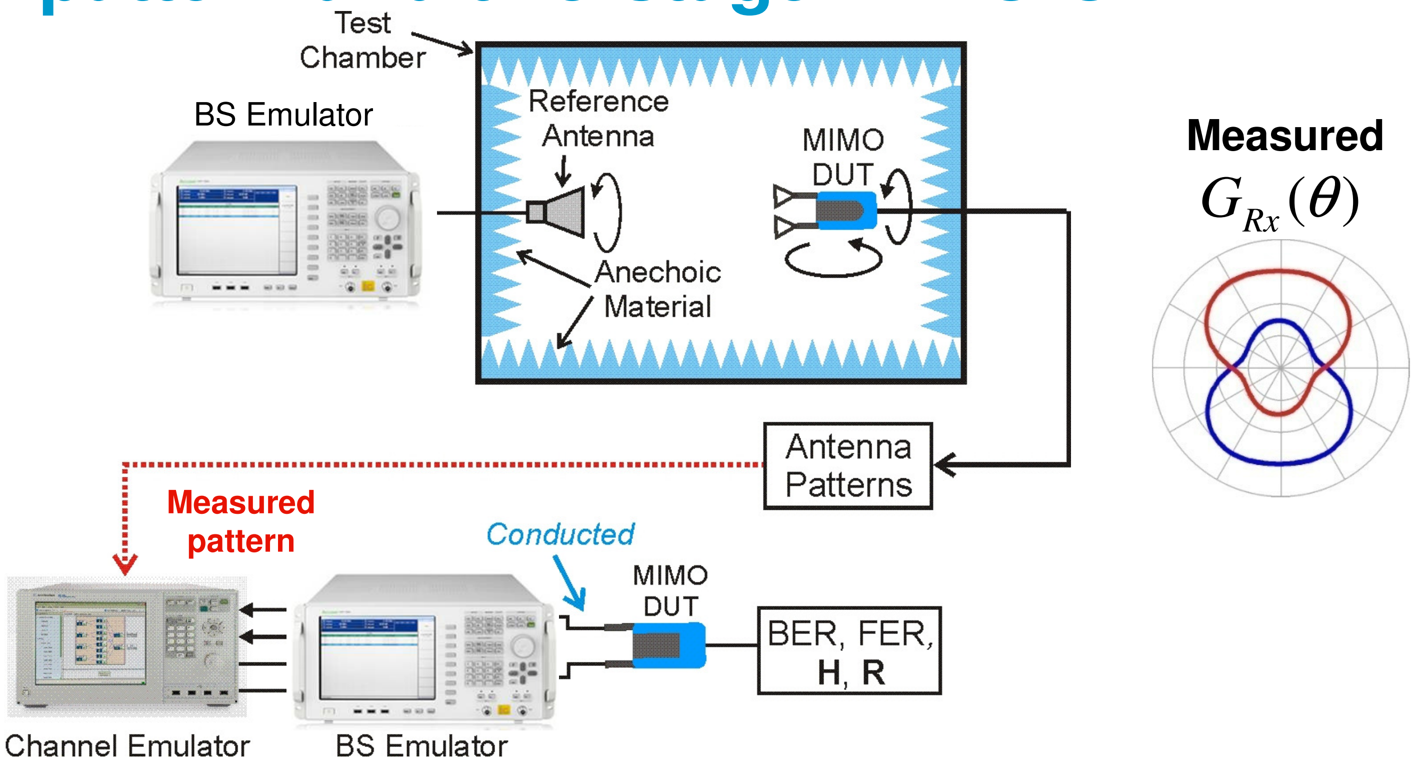
1. Single-antenna port; port 0	SISO (Rx diversity)
2. Transmit diversity	MISO
3. Open-loop spatial multiplexing	MIMO
4. Closed-loop spatial multiplexing	MIMO
5. Multi-user MIMO	MIMO (separate UE)
6. Closed-loop Rank=1 precoding	MISO (beamsteering)
7. Single-antenna port; port 5	MISO (beamsteering)

All need some level of test. Currently only TM1 and shortly TM4 will be getting attention

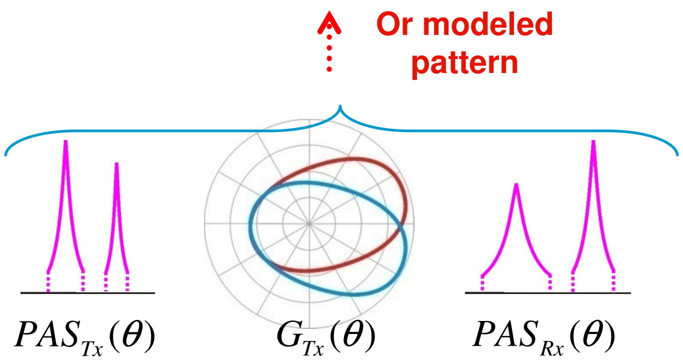
The transition between modes is also critical

4. Antenna pattern and two-stage MIMO OTA methods

Stage 1
Antenna pattern measurement



Stage 2
Throughput measurement

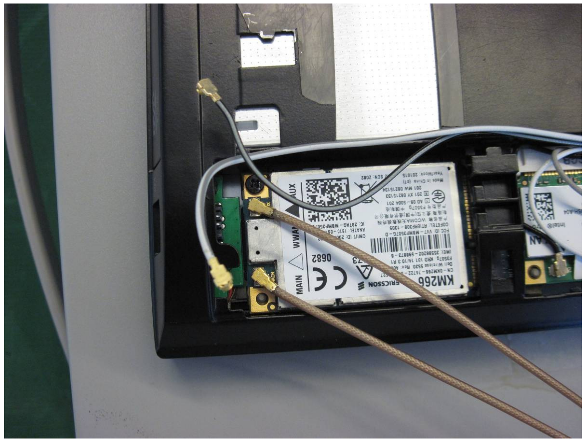


- Fast and very cost effective
- Uses standard SISO anechoic chamber
- Can models any 2D or 3D channel using correlation or geometry methods
- Does not currently measure self-blocking
- Requires UE test mode for non-intrusive antenna pattern measurement

Early results for two-stage method using intrusive antenna pattern measurement

The initial measurements for the two-stage methodology involved "intrusive" antenna pattern measurement using cable connections

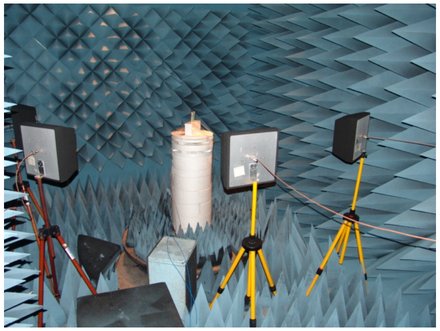
- For the laptop device with cabled antenna ports the mismatch was measured and removed
- The dongle had to be physically modified to gain access to the antenna so mismatch could not be removed



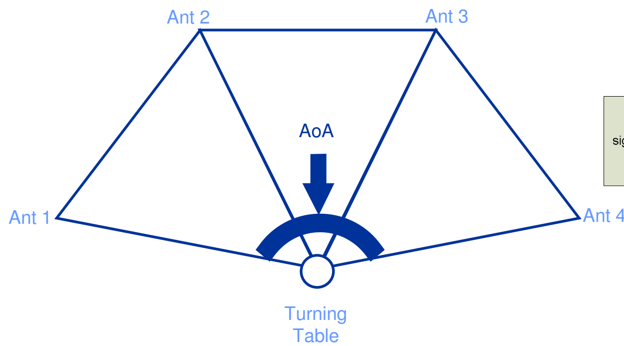
Laptop with antenna access via cables

Modified dongle with balun on cables

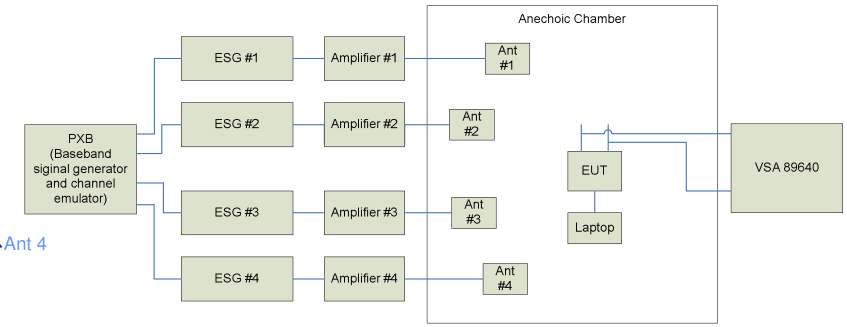
Comparison of OTA Test Methods: Channel Power Correlation Coefficient and Capacity



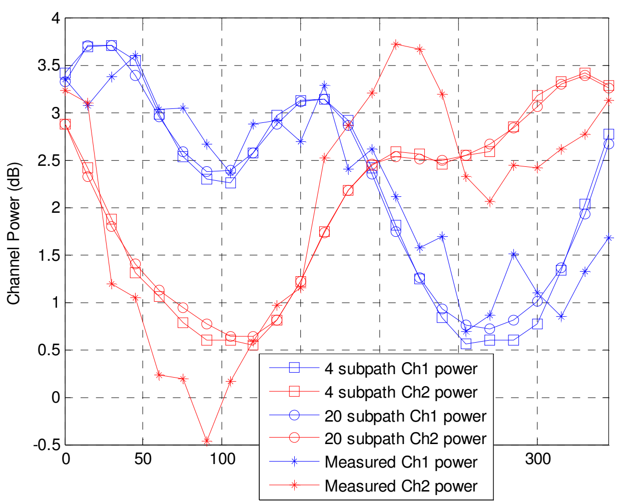
Setup inside chamber



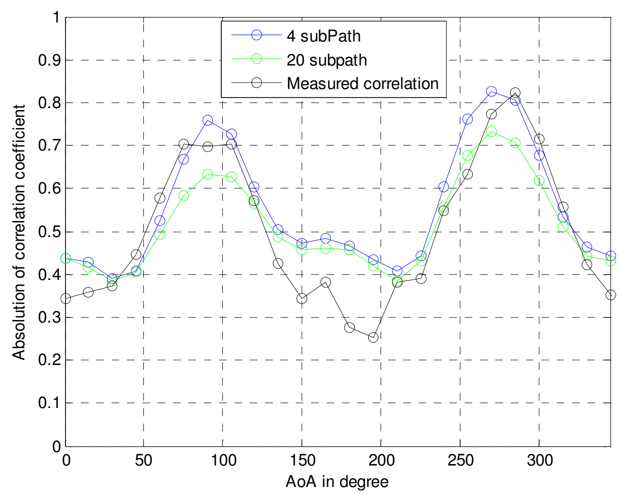
Single path over four probes



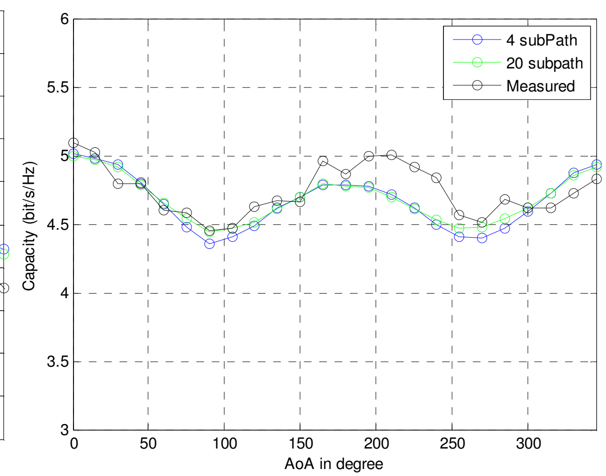
Channel measurement with multiple probe setup



Channel Power

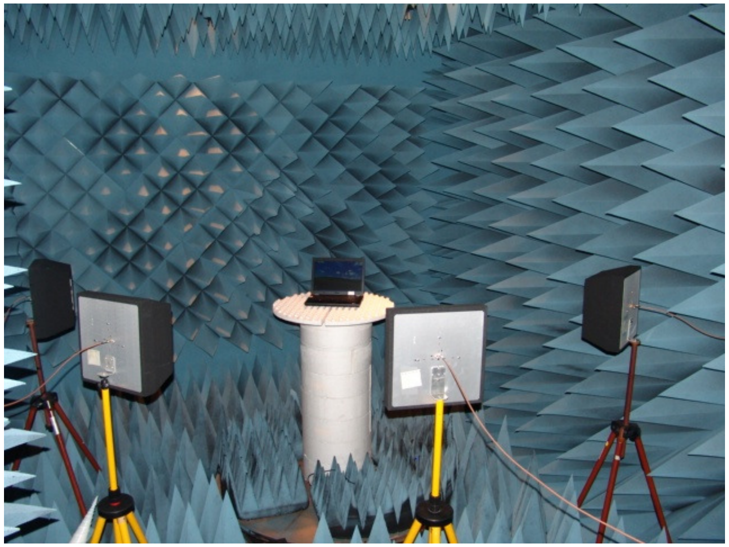


correlation

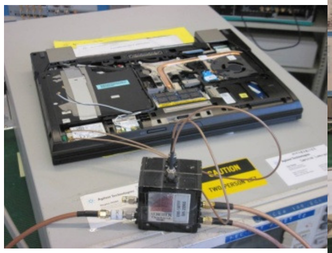


Channel capacity

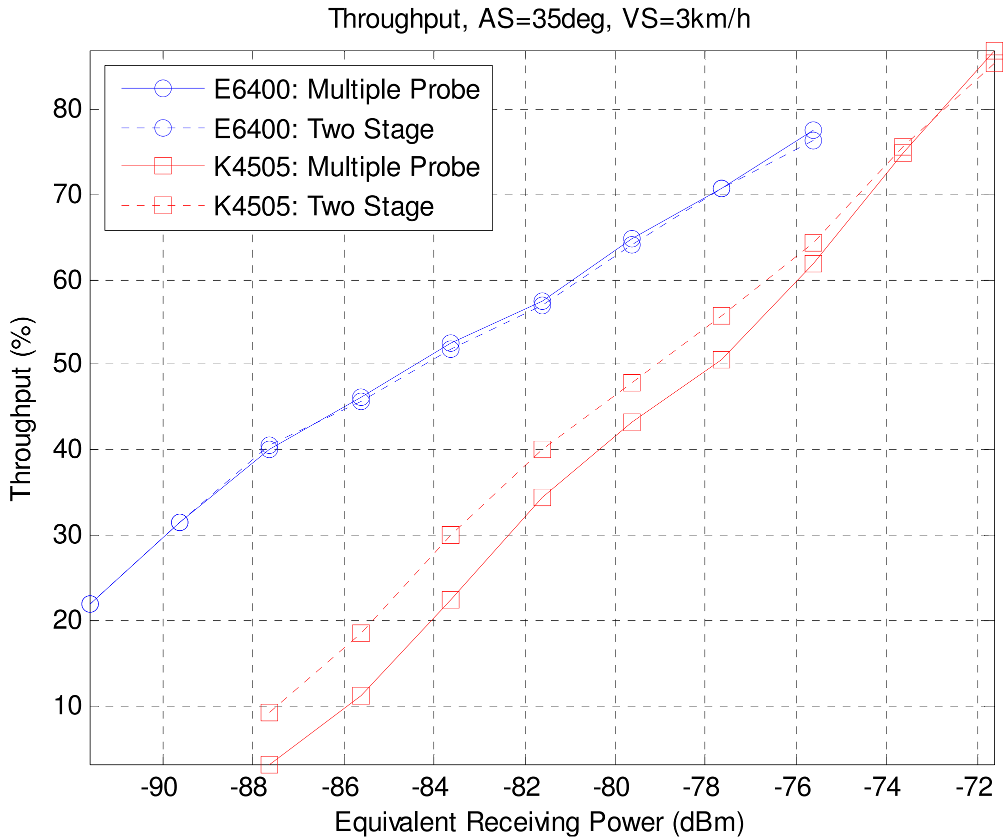
Comparison of OTA Test Methods: Throughput



Laptop with multiple probe antenna setup



Laptop with two-stage method setup



Excellent correlation for laptop which had antenna ports, less good for modified dongle

Agilent Technologies

Moving towards non-intrusive antenna pattern measurement

Work is well underway to implement antenna pattern measurement using the receiver of the UE

Given a uni-directional signal the UE can measure:

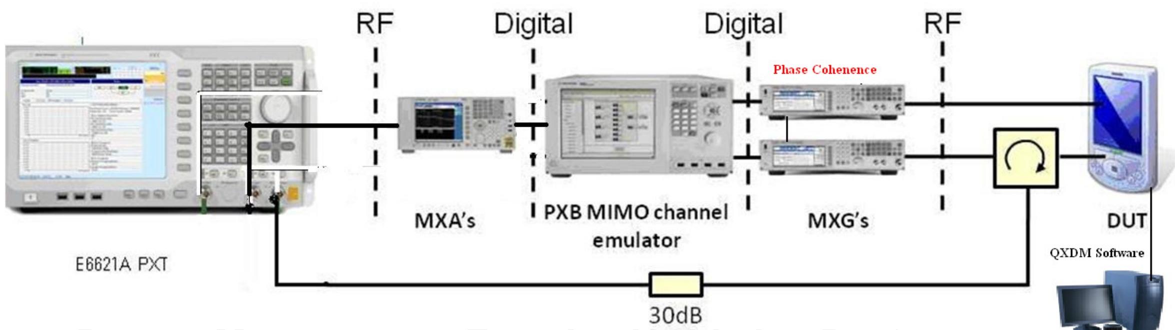
- Absolute amplitude for each antenna
- Relative phase between the antennas

The absolute accuracy of the amplitude measurement is not important since it is calibrated against the known signal in the chamber.

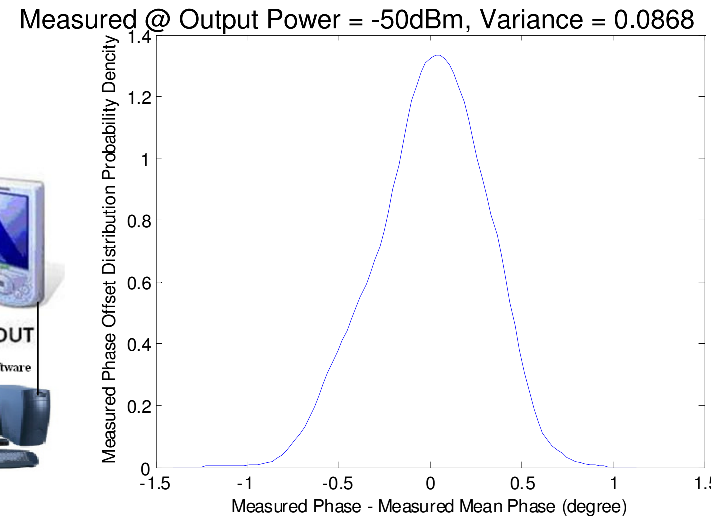
Amplitude linearity is important as is relative phase accuracy.

From this data it is possible to construct the complex antenna pattern as seen by the receiver

Pattern Measurement Accuracy Validation (±0.1 dB linearity, ± 1 degree)



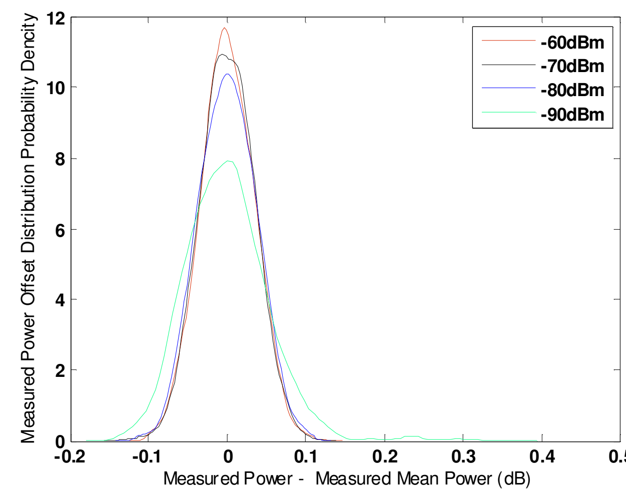
Pattern Measurement Function Validation Platform



Pattern Phase Measurement Validation Results

Table 1 Pattern Power Measurement Validation Results

MXG #0 Output Power (dBm)	MXG #1 Output Power (dBm)	Measured RSSI_RX0 (dBm)	Measured RSSI_RX1 (dBm)	RSSI_RX0 Power Step Error (dB)	RSSI_RX1 Power Step Error (dB)
-30	-30	-31.433	-30.1804	0	0
-40	-40	-41.2886	-40.0433	0.1444	0.137
-50	-50	-51.6027	-50.5056	-0.1698	-0.3252
-60	-60	-61.5879	-60.2891	-0.155	-0.1087
-70	-70	-71.6828	-71.5867	-0.2498	-1.4064
-80	-80	-81.6261	-81.6424	-0.1931	-1.4621
-90	-90	-90.5122	-90.973	0.9207	-0.7927



Measured Power Distribution at Different Levels

5. Summary

Evaluating MIMO OTA performance is complex and is influenced by many factors

- Antenna gain
- Antenna power imbalance
- Antenna pattern / correlation
- Antenna loading effects (SAM head/hand)
- Channel model & channel speed
- Downlink transmission mode
- Adaptive modulation and coding
- Interference statistics, level and direction

There is still a lot of work left to do before choosing a viable test method and determining UE performance requirements!

Thank you for listening!