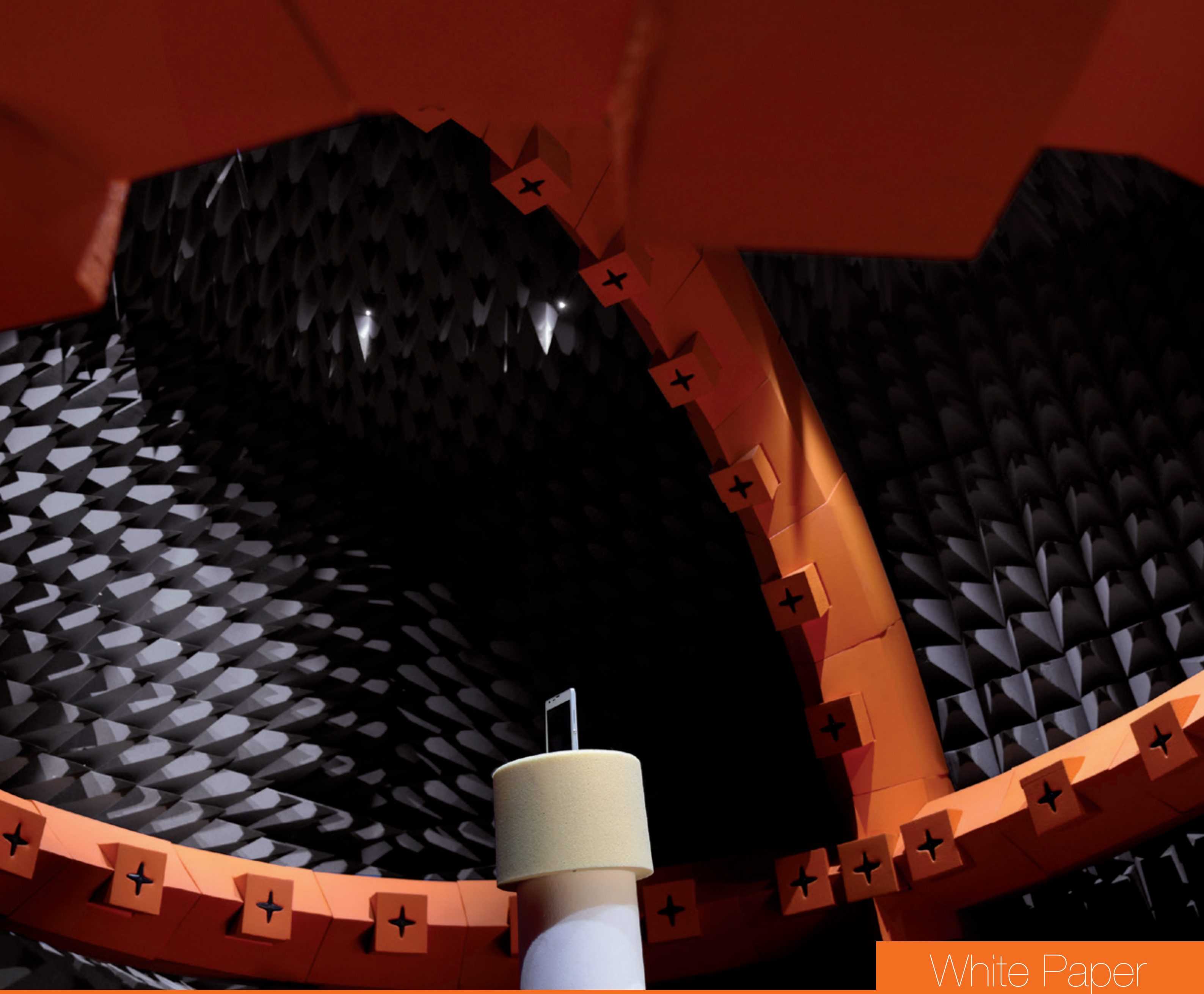


White Paper

Over-The-Air Testing of Receive Diversity and MIMO Capable Terminals

A plan to optimize MIMO antenna systems across a wide range of real-world environments

mvg
Microwave Vision Group

EXECUTIVE SUMMARY

In this paper, you will learn the current testing methodologies under evaluation to ensure consistent MIMO antenna performance. You will also gain firsthand knowledge on how to setup and execute your own MIMO OTA Tests.

TOPICS INCLUDE:

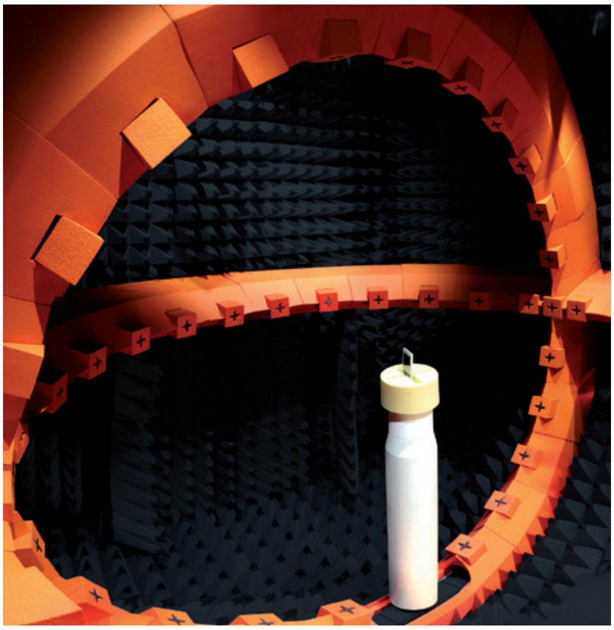
- Why effective MIMO testing is so critical to successful deployment of the latest antenna systems
- The current MIMO test solutions under evaluation
- System set-up and calibration
- Proven data and results from using this approach
- Insights discovered and what it means for the future of MIMO testing

Why Effective MIMO Testing is so Important

MIMO (multiple input multiple output) devices make 4G performance possible through their ability to function in complex RF environments. Multiple antennas increase data throughput and quality of service without increasing transmission power or bandwidth. But these devices need testing systems capable of simulating various RF environments in a repeatable and controlled manner in order to find the right antenna configuration.

MIMO uses multipath propagation to improve data throughput, therefore a configurable RF environment is needed to reliably test antenna performance. In order to understand the end-to-end reception performance of a MIMO device, Over-the-Air (OTA) testing is needed. This is primarily due to the fact that correlation plays an important role in multiple-antenna systems. The level of correlation cannot be determined based on the antenna characteristics alone without knowing the propagation characteristics.

When testing devices with multiple antennas, it's necessary to include both the antenna and propagation characteristics in the setup, defining the need of a new OTA testing methodology. The SISO OTA measurements setup is no longer suitable for such testing, which relies on measuring the 3D power or received sensitivity pattern measurements with an isotropic weighting, uniform channel model. Therefore, TRP (Total Radiated Power) and TIS (Total Isotropic Sensitivity) are no longer used as a standard figure of merit, since they are not taking into account the propagation model's characteristics. Due to the complexity of multiple antenna setups, a flexible and accurate testing solution becomes a major asset in the antenna design cycle, final product verification—and most importantly—time-to-market for the device.



MIMO Testing Options Defined

Three fundamentally different approaches are currently under evaluation by the wireless industry through 3GPP (3rd Generation Partnership Project), COST2100 (European Cooperation in Science and Technology), and CTIA (International Association for the Wireless Telecommunication Industry)[1]. These include:

- **Anechoic Chamber Based or Spatial Fading Emulator** —(SFE) simulates a complex multi-path environment at the device under test (DUT) location in a repeatable way by using a radio communication tester and a channel emulator connected to a circular array of probes, i.e. Multi-probe technology,within an anechoic chamber.

- **Reverberation Chamber** — utilizes a reverberation chamber either stand alone, or in conjunction with a channel emulator. Reverberation chambers target a statistically uniform power distribution around the DUT, while the antennas and channel emulator can be used to try to generate the desired delay profile. Reverberation chambers suffer from very limited capability to vary the fading environment, and so can only provide very limited evaluation of the terminal.

- **Multi Stage** — consists of measuring the active complex antenna patterns in an isotropic environment by using a traditional anechoic chamber based system with a communication tester for the first stage. The second stage convolves the antenna pattern information with the channel model via either the use of a channel emulator in conducted mode or a theoretical channel capacity calculation where theoretical performance is calculated using the antenna pattern information. Only limited data exists for the multi-stage method at this point, and further investigation is required and ongoing.

The Wireless Industry, through CTIA and 3GPP standardization bodies, has been studying the anechoic-chamber-based OTA technique since 2009. In CTIA, an agreement was reached on a draft MIMO OTA test plan. The goal is the inclusion of this test plan in the CTIA MIMO OTA test plan specification by 2015.

[1] 3GPP TR 37.977 v12.04.0, "Measurement of Radiated Performance for MIMO and Multi-Antenna Reception for HSPA and LTE terminals," (November 2013)

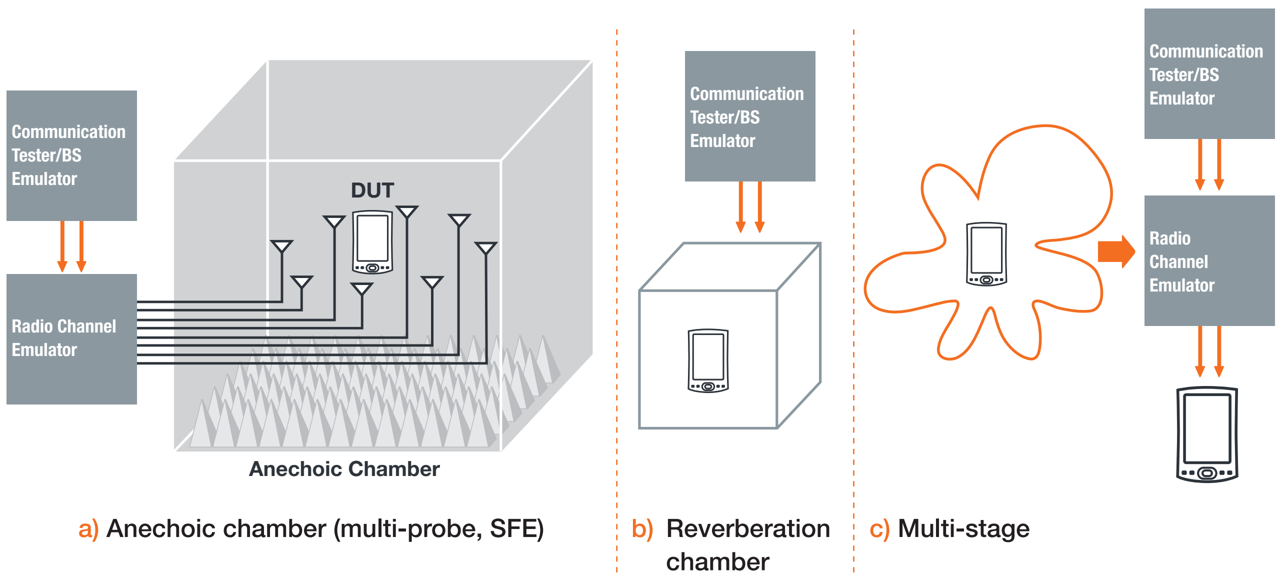


Figure 1 - Three MIMO Testing Options

Anechoic Chamber Based OTA: A Deeper Look

As opposed to a SISO OTA multi-probe test range, where probes are operating sequentially and are in turn singularly selected, in a MIMO OTA setup signals are coming simultaneously from different directions around the device. This characteristic setup, combined with a channel emulator, enables the simulation of complex spatial-temporal propagation environments at the DUT location[2,3].

MIMO OTA testing in an anechoic chamber provides the possibility to measure realistic mobile terminal performances without using artificial cabling in the test setup. MIMO OTA testing can evaluate the end-user experience of the final product, in areas such as data throughput, against realistic radio channel conditions where performance varies greatly according to the environment. All critical parts of the mobile terminal design (antennas, RF front end, baseband processing) are tested at once. This also allows performance comparisons of off-the-shelf mobile terminals.

SCALABLE SYSTEM SET-UP

The Anechoic Chamber method using the StarMIMO system is scalable from a single cluster to a full 3D implementation. The single cluster configuration is an entry-level solution for differentiating between a good terminal and a bad terminal in terms of performance (throughput). With a narrow angular spread, the correlation is high and the DUT rotation will affect the performance result significantly. With a wide angle spread, the correlation is low, and the channel is easier for Spatial Multiplexing (SM). With the full circle system, any 2D channel model (e.g., SCM, SCME, WINNER, IMT-Advanced) can be simulated. The full 3D implementation enables testing the effect of not only azimuth, but also elevation spreads, and the system is upgradeable from single-cluster to full-ring to 3D configurations.

[2] COST 2100 TD(09)780, "Discussion On Some Topical Issues Related To The Spatial Fading Emulation Based OTA Test Method For Multi-Antenna Terminals", Nokia, (February 2009)

[3] EuCap2010, PID1127961 "OTA Throughput Measurements by Using Spatial Fading Emulation Technique", (April 2010)

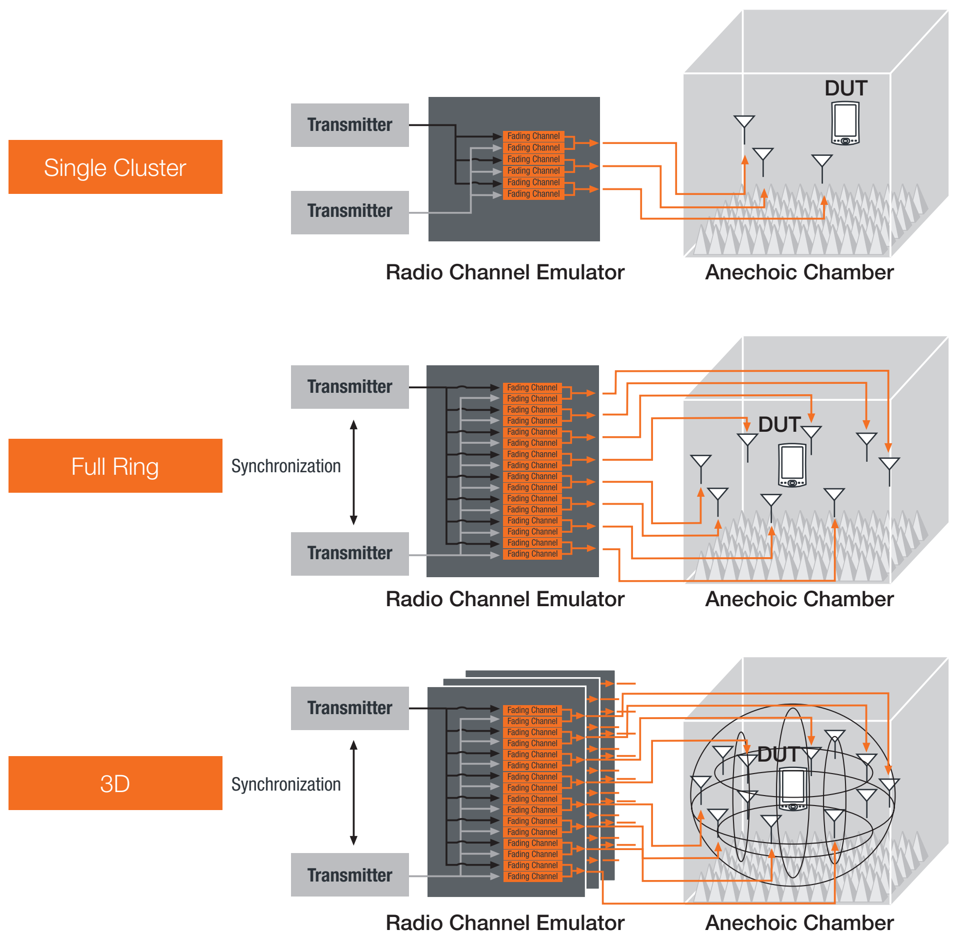


Figure 2 - Scalability of MIMO OTA Test System

RADIO CHANNEL EMULATORS

As the radio channel plays a key role in MIMO performance, the radio channel emulator is a crucial part of the MIMO OTA test system. A test signal from a transmitter or base station emulator goes through the radio channel emulator, which emulates the radio channel according to a pre-defined channel model. The signal is then split inside the emulator and distributed to probes in the chamber. The signal is then radiated independently from various probes according to the channel model selected. The outcome is that the radiated multipath signals are summed in the center of the chamber and the desired radio channel environment is generated around the DUT.

With advanced radio channel emulators it is possible to recreate real life scenarios in the chamber such as:

- Path loss
- Multipath fading
- Delay spread
- Doppler spread
- Polarization
- Spatial parameters such as Angle of Arrival (AoA) and Angular Spreads (AS)

In order to get useful results from MIMO OTA testing, the radio channel emulator must have excellent RF performance. Error Vector Magnitude (EVM) and internal noise level needs to be very low in order to minimize errors impacting the measurement results.

Also, the fading process has to be repeatable in order to have consistent test results across different test rounds. This is very important when benchmarking the performances of different DUTs. The use of an advanced radio channel emulator minimizes these risks as the channel condition repeatability is sustained at 100%.

CHANNEL MODELS

The channel models used for MIMO OTA testing are Geometry-based Stochastic Channel Models (GSCM) in which the radio channels are defined by:

- Transmit antenna location and pattern
- Propagation characteristics (delay, Doppler, AoD, AoA, ASD, ASA, and polarization)
- Mobile velocity and direction of travel
- Receiver antenna location and pattern
- Multiple additional large-scale parameters

These measurement-based channel models include all dimensions of the radio channel (time, frequency, space and polarization). Space and polarization are especially important since they are crucial parameters for the spatial correlation (on which MIMO performance is strongly dependent). This approach accurately and realistically models the environment required for the testing of MIMO devices.

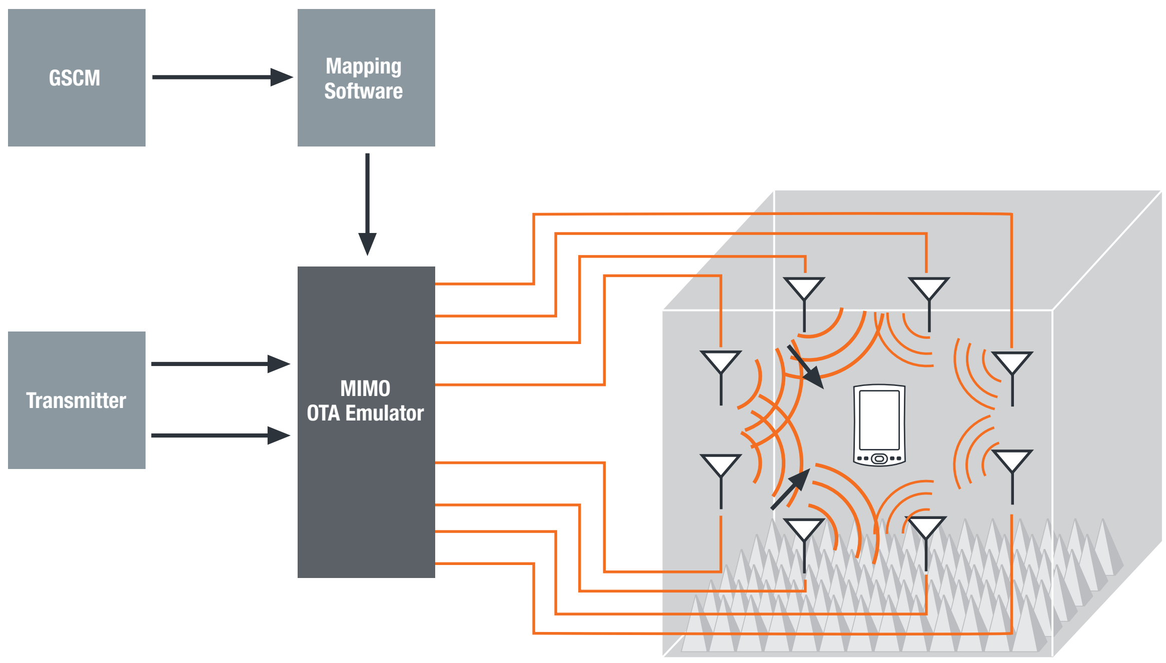


Figure 3 - Anechoic Chamber Method for MIMO OTA Testing

MIMO OTA Channel Model Mapping

In MIMO OTA testing, the receiver antenna is not modeled, but its actual influence on the DUT performance is automatically incorporated as an integral component of the test configuration. The crucial challenge in MIMO OTA testing is to generate realistic propagation characteristics, especially AoA and ASA, within the anechoic chamber. This geometry based information, like in GSCM, creates appropriate correlation at the DUT antennas. Also, information on the transmitter antenna arrays (base station), including both array geometry and antenna field patterns, are required. Finally, either the terminal velocity vector or the Doppler frequency components for each cluster/clusters are needed.

These clusters are then simultaneously mapped to OTA antennas so that the sum of the transmitted signals in the center of the chamber is as defined in the model.

This mapping is done by the spatial radio channel emulator. Each cluster is split between several OTA antennas in order to enable accurate angular spreads. As a result the geometry based environment of the channel model is accurately transferred to the anechoic chamber.

3GPP and CTIA have agreed on the channel models used in the evaluation of MIMO OTA performances. The models consist of Clustered Delay Line (CDL) models and some simplified single cluster models, as can be seen from Table 1.

The emulated base station antennas are:

- Vertically-polarized elements
  - with a fixed 4 λ separation, specified at the center frequency, or
  - uncorrelated to allow the UE to be measured independently from BS effects.
- Dual-polarized-equal-power elements that are uncorrelated with a fixed 10 λ separation, 45 degree slanted.

An example of the channel models is shown in Table 2. The cluster number here refers to different delay clusters, each having different AoD and AoA characteristics.
In each cluster, there are three taps with slightly different delays to ensure good frequency correlation and wide bandwidth.

The Single Cluster model is based on the SCME Urban Micro-cell model with all AoAs assumed to be zero degrees, meaning that the model has only one cluster in the spatial domain. The delay positions are the same as in the original multi-cluster model. XPR values, Direction of Travel, and Mobile Velocity are similar for both single cluster and multi-cluster models. An option in the single cluster model allows a cluster angle spread to be specified with AS AoA = 35°, or with AS AoA = 25°, to enable a range of spatial correlations for different types of devices.

MIMO OTA Channel Models

	#	Model is based on	Number of spatial clusters	Number of temporal clusters
Generic Models	1	SCME Urban micro-cell	6	6
	2	Modified SCME Urban micro-cell	6	6
	3	SCME Urban macro-cell	6	6
	4	WINNER II Outdoor-to-indoor	12	12
Single Cluster Models	5	SCME Urban micro-cell	1	6
	6	Extended Pedestrian A (EPA)	1	6
Uniform Models	7	Extended Pedestrian A (EPA)	1	6
	8	Exponential decay	1	1

SCME Urban Micro-Cell

Cluster #	Delay [ns]			Power [dB]			AoD [°]	AoA [°]
1	0	5	10	-3.0	-5.2	-7.0	6.6	0.7
2	285	290	295	-4.3	-6.5	-8.3	14.1	-13.2
3	205	210	215	-5.7	-7.9	-9.7	50.8	146.1
4	660	665	670	-7.3	-9.5	-11.3	38.4	-30.5
5	805	810	815	-9.0	-11.2	-13.0	6.7	-11.4
6	925	930	935	-11.4	-13.6	-15.4	40.3	-1.1

Delay spread [ns]		294
Cluster AS AoD / AS AoA [°]		5 / 35
Cluster PAS shape		Laplacian
Total AS AoD / AS AoA [°]		18.2 / 67.8
Mobile speed [km/h] / Direction of travel [°]		3, 30 / 120
XPR	Note: V & H components based on assumed BS antennas	9 dB
Mid-paths Share Cluster parameter values for:		AoD, AoA, AS, XPR

System Calibration

The goal of the calibration process is to ensure equal responses from each probe, in both amplitude and phase, by compensating for errors caused by the setup. Errors can include probe misplacements and cable differences in gain and phase.

The calibration process consists of measuring the total path loss for each channel from the input of the channel emulator to the device location by using a static channel model (single tap). Compensation for the path loss differences is accomplished by adjusting the amplitude and phase weighting for each path by utilizing the channel emulator general user interface (GUI). The calibration process is complete when the amplitude and phase adjustments are stored on the channel emulator for each channel. Usually, reference antennas with known gain characteristics are used for the calibration. This process is done for both polarizations of the probes (Vertical, Horizontal). SATIMO electric and magnetic dipoles can be used for accomplishing the calibration of the V and H components of the transmitted signal, respectively.

Calibration time is a key element of an OTA test range. Antenna designer and testing engineers need a tool that is easy to use and quick to set up for testing. The following are the drawbacks of the depicted calibration procedure:

- Dipoles are narrow band.
- Dipoles are singly polarized, so that for each frequency to be calibrated, electric and magnetic dipoles must be used.
- Each path contains active elements such as mixers and amplifiers. They are time and temperature dependent, so that calibration must be performed up to several times per week.
- The probe array itself is not calibrated. The radioelectric axis of each probe should still be calibrated for high-quality testing.

MVG (SATIMO)'s expertise in multi-probe systems has made it possible to perform an automated, fast, and simple MIMO OTA Test system calibration with MV-Cal™. The calibration setup is shown in Figure 4.

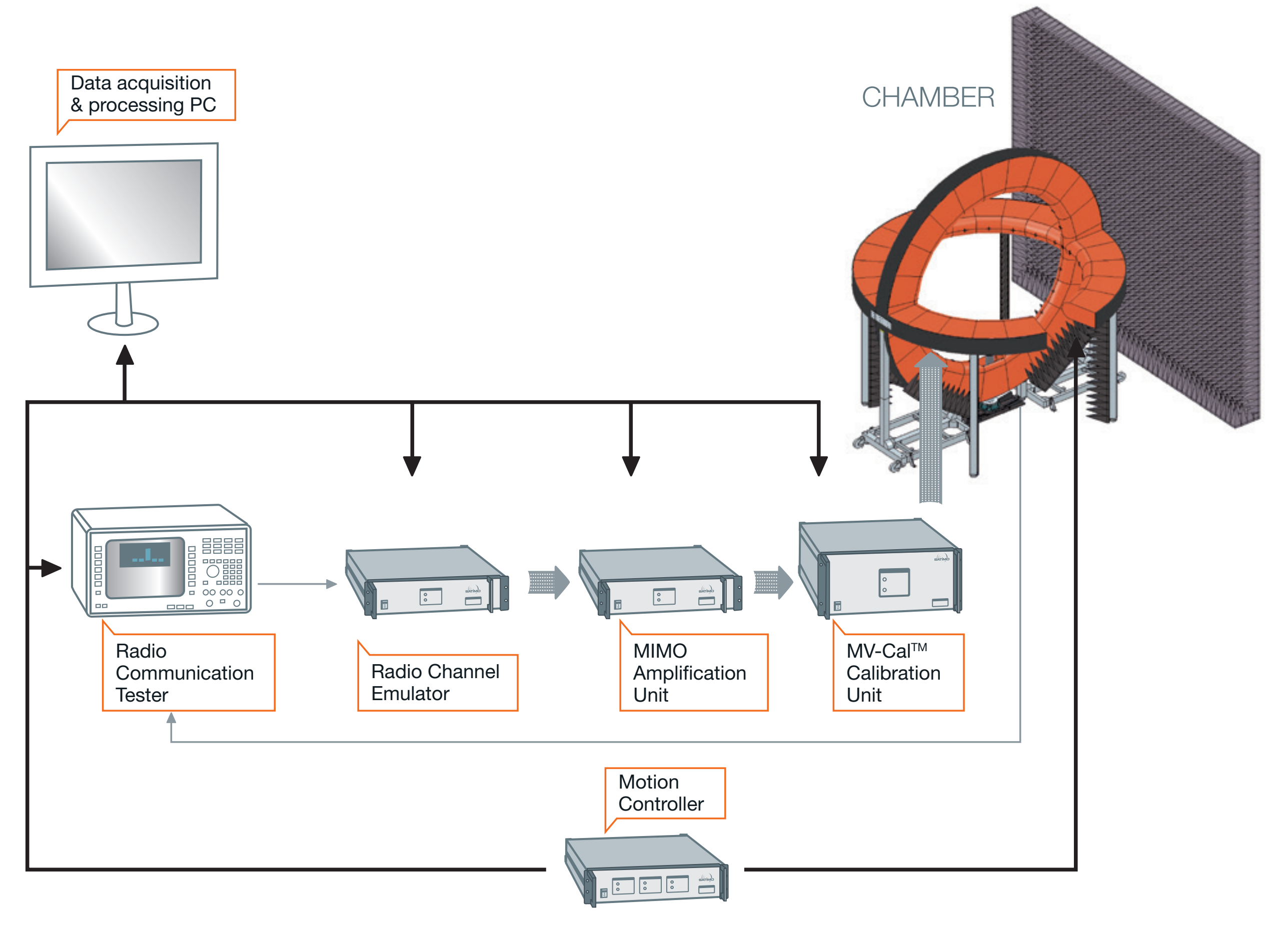


Figure 4 - MIMO OTA set-up with MV-Cal™

Two sets of coefficients are processed and stored:

- The first set calibrates the equipment (RF and BB) outside the anechoic chamber. It is done quasi-instantaneously at any time by using the MV-Cal™ box.
- The second set calibrates the probe array itself. The probe array calibration procedure is the same for SISO or MIMO measurements. MVG (SATIMO)'s well-validated calibration process ensures that each probe has the same amplitude, phase, and polarization response.

As the probe and cable characteristics do not vary over short time periods, the second step of the calibration process is generally done annually for high accuracy results.
Both sets of coefficients are then applied during the measurements. Calibration time is greatly reduced due to the fact that there is no need to recalibrate the system by using a set of dipoles, which normally takes significant time if more than one frequency range is calibrated.

Results

The following are test results performed using the described setup of the MVG (SATIMO) StarMIMO system, plus the Anite Propsim® F8 MIMO OTA channel emulator. Some of the results are shown here, and are part of the ongoing CTIA Round Robin testing[4] effort.

Tests were performed using the multiple cluster (8 dual-polarized probes) approach in which 8 dual polarized probes are placed in a full array ring evenly spaced at 45deg. SCME UMi, and UMa channel models were also used for the testing effort. The wireless industry, through 3GPP and CTIA, has agreed on having at this stage Throughput vs Channel Power as a FoM for testing the system performances, antennas, and chipsets of multiple-antenna terminals. Some results are presented here for two LTE MIMO capable tested devices: SAMSUNG S4 (Smartphone), and LG LS740. Those devices support LTE FDD BAND 25, LTE FDD BAND 26, and LTE FDD BAND 2. Due to the fact that this is a 2D throughput measurement, the placement of the DUT in the test setup plays an important role here. The DUTs have been tested when using two mechanical modes, portrait 45deg and landscape 45deg.

[4] CTIA Draft CTIA MIMO OTA Test Plan v0.3, (October 2014)

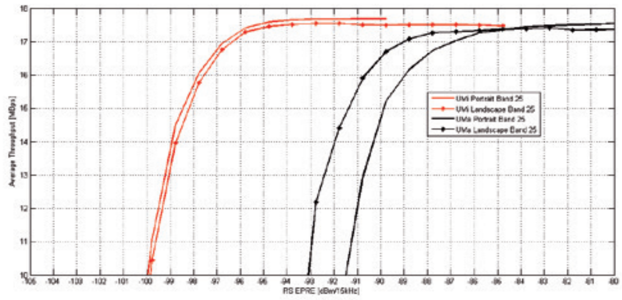


Figure 5 - Throughput Vs Power SCMEUrban Micro-cell versus Urban Macro-cell for Portrait and Landscape mode–LGLS740 LTE Band 25

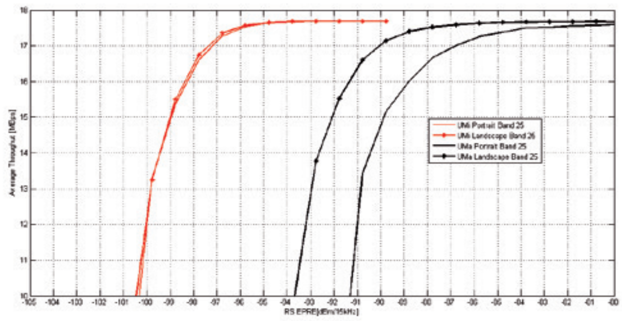


Figure 6 - Throughput Vs Power SCME Urban Micro-cell versus Urban Macro-cell for Portrait and Landscape modes–SAMSUNG S4 LTE Band 25

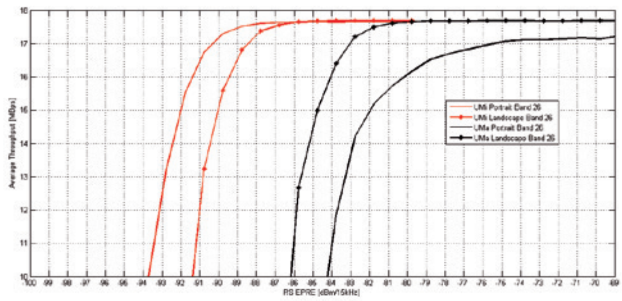


Figure 7 - Throughput Vs Power SCMEUrban Micro-cell versus Urban Macro-cell for Portrait and Landscape mode–LGLS740 LTE Band 26

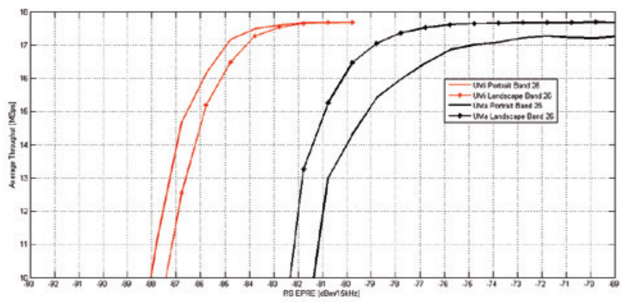


Figure 8 - Throughput Vs Power SCME Urban Micro-cell versus Urban Macro-cell for Portrait and Landscape modes–SAMSUNG S4 LTE Band 26

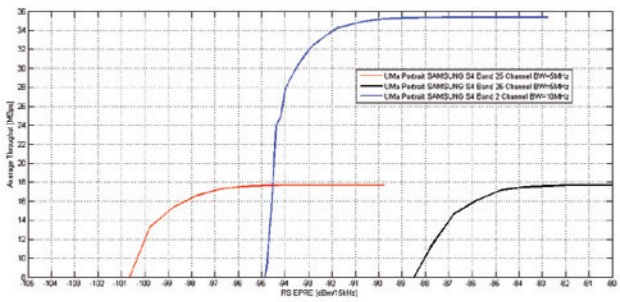


Figure 9 - Throughput Vs Power - SCME Urban-macro cell for Portrait mode – Comparison between Channel BW – SAMSUNG S4

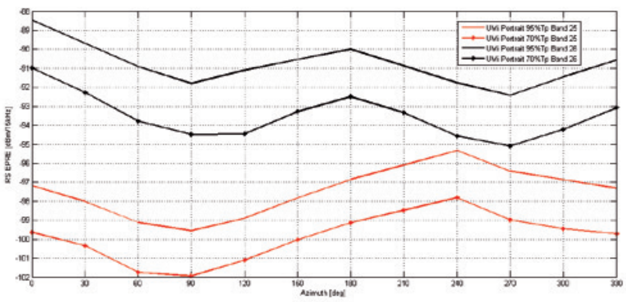


Figure 10 - SCME Urban micro-cell – LG LS740 uniformity vs azimuth rotation for LTE Band 25 and 26 when in portrait mode

Figures 6 through 8 show the comparison between SCME Urban micro and Urban macro cell in terms of throughput performances for two LTE MIMO capable devices when using the multiple cluster approach. Figure 9 shows the throughput performances variation based on the LTE channel BW for the same device when using the SCME Urban Macro model.

Note the following observations:

- Methodology can discriminate between device performances.
- Throughput is decreasing with the Channel Power.
- Urban Macro-cell channel model looks more challenging than Urban Micro-cell.
- The channel model has a great impact on device performance. This can be observed by looking at the Throughput vs Channel Power curves of Urban Microcell vs. Macrocell channel models. The MIMO OTA test system is able to accurately emulate different propagation scenarios, which makes it possible to investigate the impact of different parameters on the system performance.
- As expected, the OTA Throughput vs power performances change when changing the BW of the channel being used.

DUT UNIFORMITY VS AZIMUTH ROTATION

The Throughput performance of the DUT can also be understood by looking at the device uniformity vs the azimuth rotation. This is possible on the StarMIMO setup, since the device is rotated in azimuth and then the throughput vs power is measured at each location. This can be seen as an advantage of the anechoic chamber based OTA testing over other testing methodologies in which only the averaged performance can be measured.

IMPACT OF NUMBER OF BLOCKS ON MEASUREMENT TIME

Measurement time is a key parameter in OTA testing. Antenna designers and test houses need to perform measurements with high accuracy in relatively short amounts of time. Test time is also important in that typically the performance is evaluated under several different propagation conditions. Considering throughput as the FoM of MIMO OTA testing, measurement time can be decreased by calculating the throughput using a smaller number of blocks. Based on the statistical nature of the channel models, a trade-off between the number of blocks and channel model statistics must be found.

Figure 11 shows Throughput vs Channel Power comparison curves using 20000 and 10000 as the number of blocks. It can be seen that the decrease in number of blocks, from 20000 to 10000, doesn't have a significant impact in the Throughput vs Channel Power curves, although it does significantly reduce the measurement time. Decreasing the blocks from 20000 to 10000 cuts the measurement time from 1 hour and 10 minutes to nearly 40 minutes.

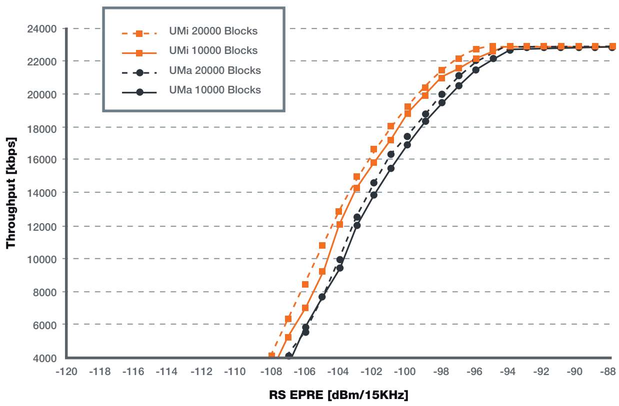


Figure 11 - Throughput versus number of blocks

WHAT WE LEARNED

MIMO OTA measurement technology enables both pass/fail type testing as well as real-world performance evaluation by providing the answer to the simple, but critical question: "How good is my terminal?"

That's a question that should not be taken lightly. The 4G market is saturated and highly-competitive, and the development of each new MIMO system brings significant risk to the enterprise willing to invest so much effort and expense in R&D, production, system compliance and marketing.

Correlation is the key component of success with MIMO testing. It has a major impact on the throughput of the wireless link. Since correlation is purely a function of the antenna characteristics and the propagation channel, MIMO OTA measurements enable direct measurement of true terminal performances.

The design of a good antenna is a highly complex task, especially considering the form factor requirements imposed on the terminal. Through this paper we present the MVG (SATIMO) StarMIMO system, specially designed for measuring the end-to-end performance of multi-antenna MIMO terminals. A system set-up such as this facilitates the characterization of the complete terminal performance, including baseband, RF front-end, and antennas emulating RF environments with particular spatial and temporal characteristics at the DUT location.

The CTIA standardization body is planning to release a CTIA MIMO OTA test plan in the first half of 2015. The anechoic chamber-based OTA solution stands out as the testing methodology selected to ensure consistent MIMO OTA testing results. StarMIMO meets the challenges of these multi-antenna device testing needs as it performs full spacial fading emulation as an anechoic chamber-based OTA solution.

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ABBREVIATIONS

- 3GPP → 3rd Generation Partnership Project
- AoA → Angle of Arrival
- AoD → Angle of Delay
- AS → Angular Spread
- ASA → Angle spread at receiver
- ASD → Angle spread at transmitter
- BB → Based Band
- BF → Beam Forming
- BS → Base Station
- CDL → Clustered Delay Line
- COST2100 → European Cooperation in Science and Technology
- CTIA → International Association for the Wireless Telecommunication Industry
- DUT → Device Under Test
- EB → Elektrobit
- EPA → Extended Pedestrian A
- EVM → Error Vector Magnitude
- FoM → Figure of Merit
- GSCM → Geometry-based Stochastic Channel Models
- GUI → General User Interface
- HSDPA → High Speed Downlink Packet Access
- IMT → International Mobile Telecommunications Advanced
- ITU → Union Internationale des Télécommunications
- LTE → Long Term Evolution
- MIMO → Multiple-Input and Multiple-Output
- OTA → Over-the-Air
- PAS → Power Angular Spectrum
- QoS → Quality of Service
- RF → Radio Frequency
- RX → Downlink
- SCM → Spatial Channel Model
- SCME → SCM Extended
- SFE → Spatial Fading Emulator
- SISO → Single-Input Single-Output
- SM → Spatial Multiplexing
- TIS → Total Isotropic Sensitivity
- TRP → Total Radiated Power
- UE → User Equipment
- USB → Universal Serial Bus
- WiMAX → Worldwide Interoperability for Microwave Access
- WINNER → Wireless World INitiative NEw Radio
- XPR → Cross Power Ratio

MVG - Meeting the Testing Challenges of a Fully Connected World

The Microwave Vision Group (MVG) has developed unique expertise in the visualization of electromagnetic waves. These waves are at the heart of our daily lives: smartphones, computers, tablets, cars, trains, planes - these devices and vehicles would not work without them. MVG expertise brings measurement solutions to R&D teams for the characterization of antennas and their performance within these devices, and chamber solutions for EMC testing. MVG innovation remains focused on supplying the world with the most advanced EMF measurement technology to date.

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To discover more about how to develop a successful, efficient and accurate approach to MIMO testing, visit:
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