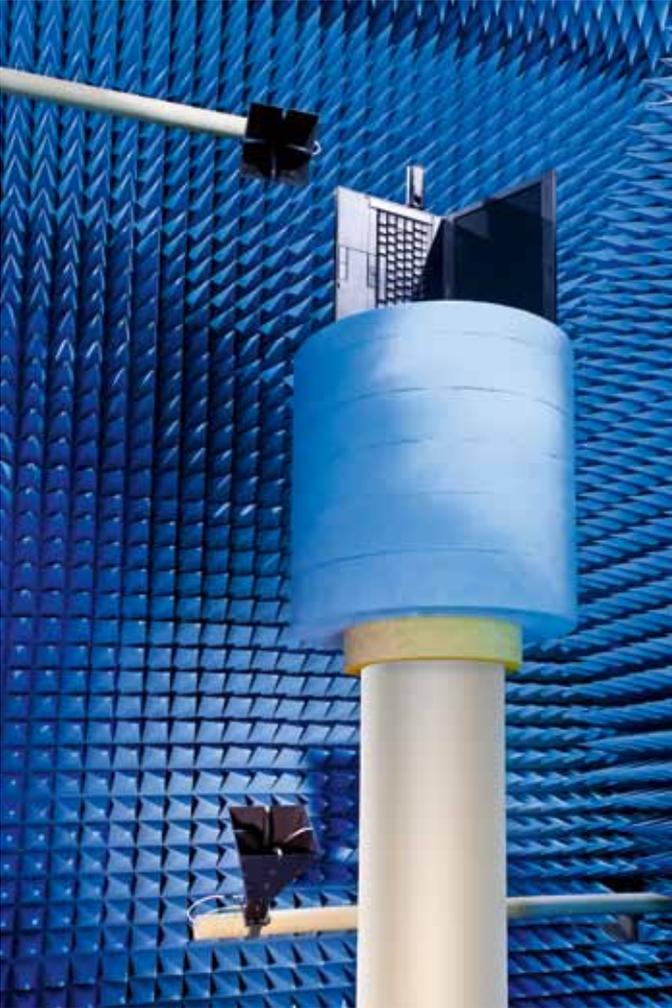


OTA performance measurements of MIMO-enabled devices

Cost-effective solution with 3D evaluation and easy-to-use test setup



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Modern wireless devices provide a carefully engineered target shape radiation pattern and largely uniform antenna sensitivity pattern in all directions.

The Rohde & Schwarz MIMO OTA test method is a cost-effective extension to the established R&S®TS8991 SISO solution. Highly reproducible reliable scalar results with full spherical evaluation are obtained.

Applicable Rohde & Schwarz product:

R&S®TS8991 test system

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MIMO OTA performance testing

Multiple input multiple output (MIMO) techniques have been introduced to improve network performance for data applications in particular. The channel capacity of the allocated frequency spectrum is increased by making use of spatial multiplexing. In the case of 2x2 downlink MIMO, the data throughput can be doubled compared to SISO operation. This results in added device complexity and a more cluttered angular pattern.

Data throughput gains in MIMO mode are verified by manufacturers, test houses and network operators. Measurements in conducted mode (with channel emulation) focus on the RF frontend characteristics in conjunction with the receiver firmware implementation.

Radiated mode measurements help to identify whether the antenna subsystem comprising RF frontend and antennas is responsible for variations in device performance.

To obtain a complete picture of MIMO OTA performance, user equipment (UE) needs to be tested under varying orientations in a 3D environment. The device under test (DUT) is positioned inside the fields of two moving, cross-polarized test antennas, each radiating different signals of a transmit diversity or spatial multiplexed MIMO downlink. Repeating the measurements in several different geometrical constellations and polarizations provides a comprehensive overview of UE antenna characteristics.

Key facts

- Verifies MIMO performance in free space or with a phantom head and/or hand, for maximum reality in test results
- Cost-effective solution with easy-to-use test setup
- Simple upgrade of existing SISO OTA test systems
- Simulates any possible UE antenna orientation
- Statistical metrics indicate the performance of the UE in the network
- No channel emulator required
- High reproducibility between test laboratories
- Clearly structured test plan



Anechoic test chamber for MIMO OTA measurements.

New test methods for MIMO OTA measurements

Currently, OTA performance tests for single input single output (SISO) devices are standardized for 2G and 3G mobile radio and WLAN. These tests provide vital information about the behavior of user devices in a network. The 3D angular patterns of both the output power and the receiver sensitivity are typically measured in an anechoic environment, and used to derive figure of merits (FOM) as specified by CTIA, and similarly by 3GPP:

- Total radiated power (TRP)
- Total isotropic sensitivity (TIS)

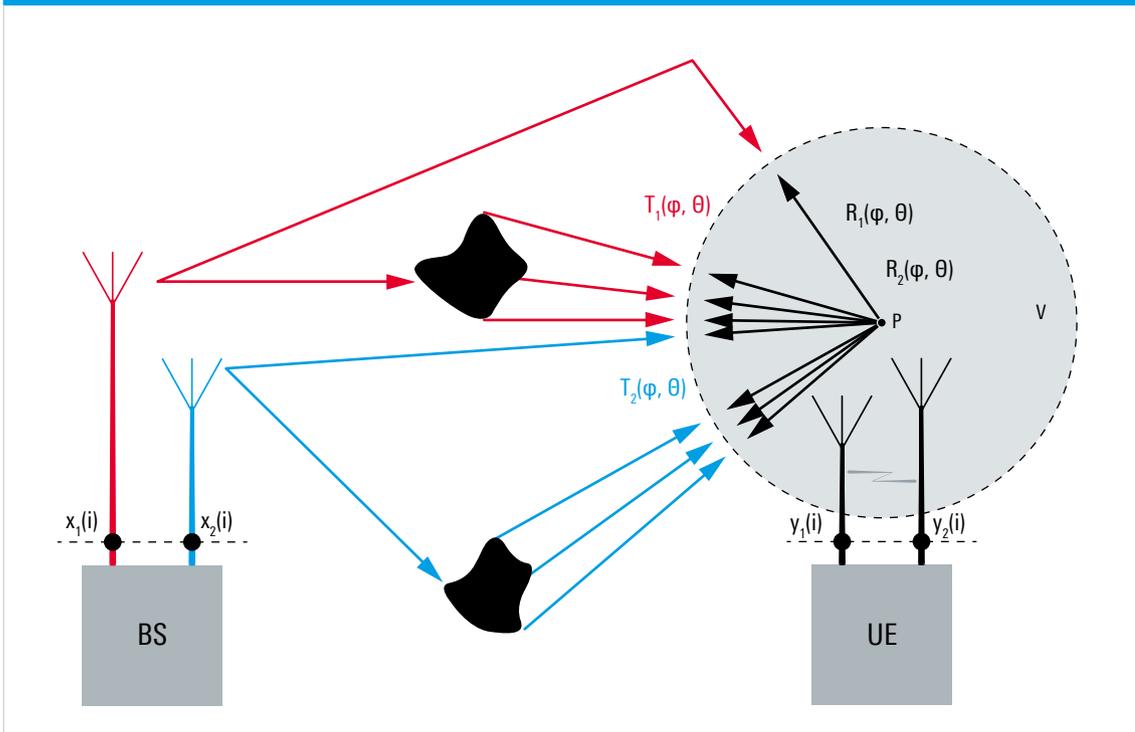
Testing different MIMO operation modes

In MIMO 2x2 mode there are two downlink data streams, and the user equipment has two receiving antennas. The correlation of the UE's RX antennas needs to be as low as possible to achieve a good separation of simultaneously received data streams. To evaluate the performance of the antenna subsystem, it is not sufficient to analyze the pattern of each receiving antenna separately in passive mode only. Using the RF frontend to establish a real-world load for the antennas and contribute noise terms to the input signal streams is the more realistic case.

OTA performance tests can verify the following transmission modes:

- SISO as basic operation mode
- Transmit diversity with redundant data streams for an increased signal range
- Spatial multiplexing with multiple data streams for higher data throughput

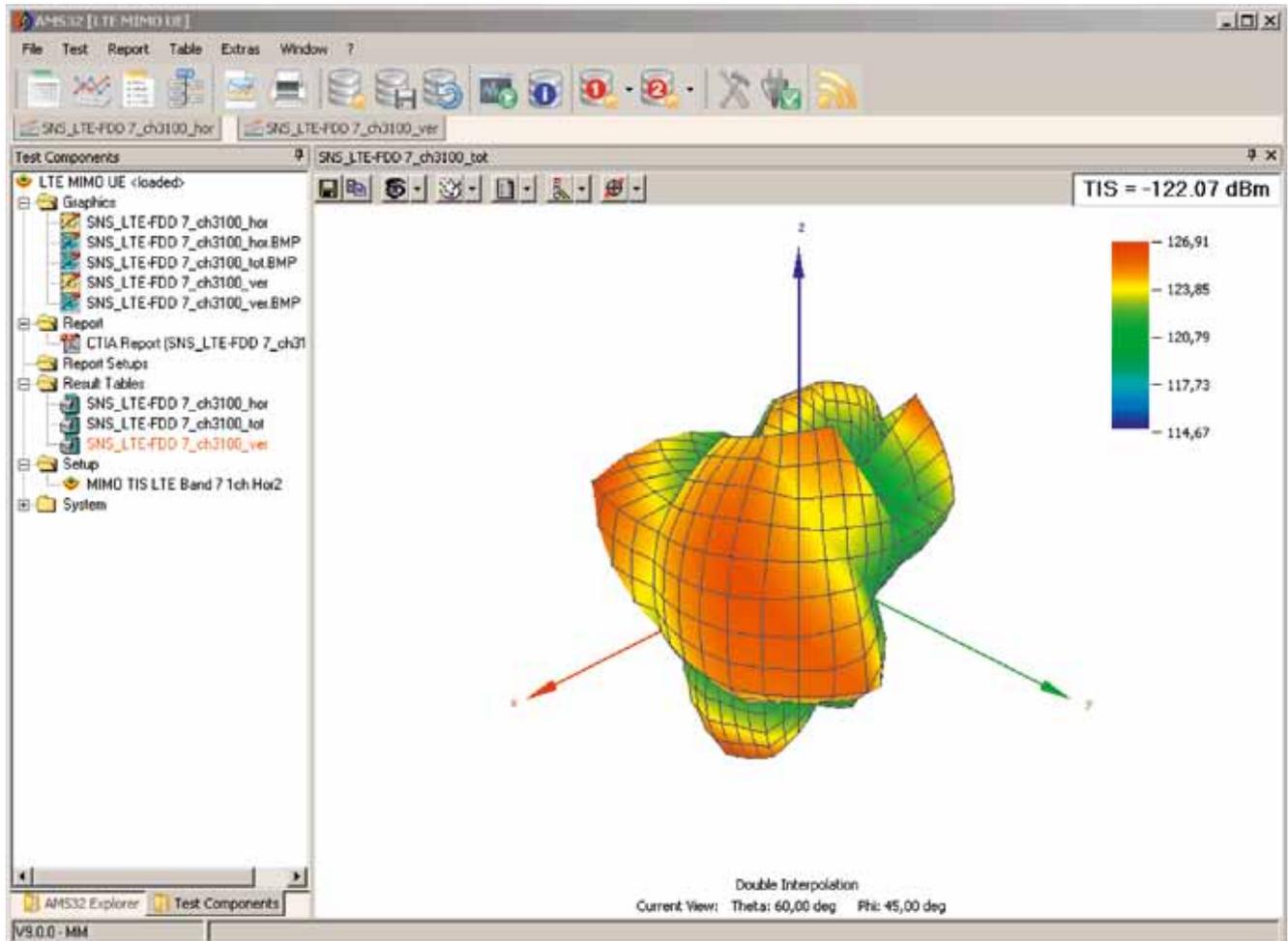
General radio downlink transmission in MIMO 2x2 mode



Full 3D evaluation for realistic test results

Wireless devices are operated in arbitrary positions. Furthermore, signal propagation will create signals arriving from arbitrary directions. As a result, full 3D evaluation is required to assess the impact on antenna performance of multipath reception, from all angles of arrival (AoA). A test approach that makes it possible to locate either of the two transmit test antennas at any point on a sphere centered on the DUT, providing simulated real-world test conditions.

3D distribution of effective isotropic sensitivity (MIMO 2x2).



Cost-effective MIMO OTA measurements

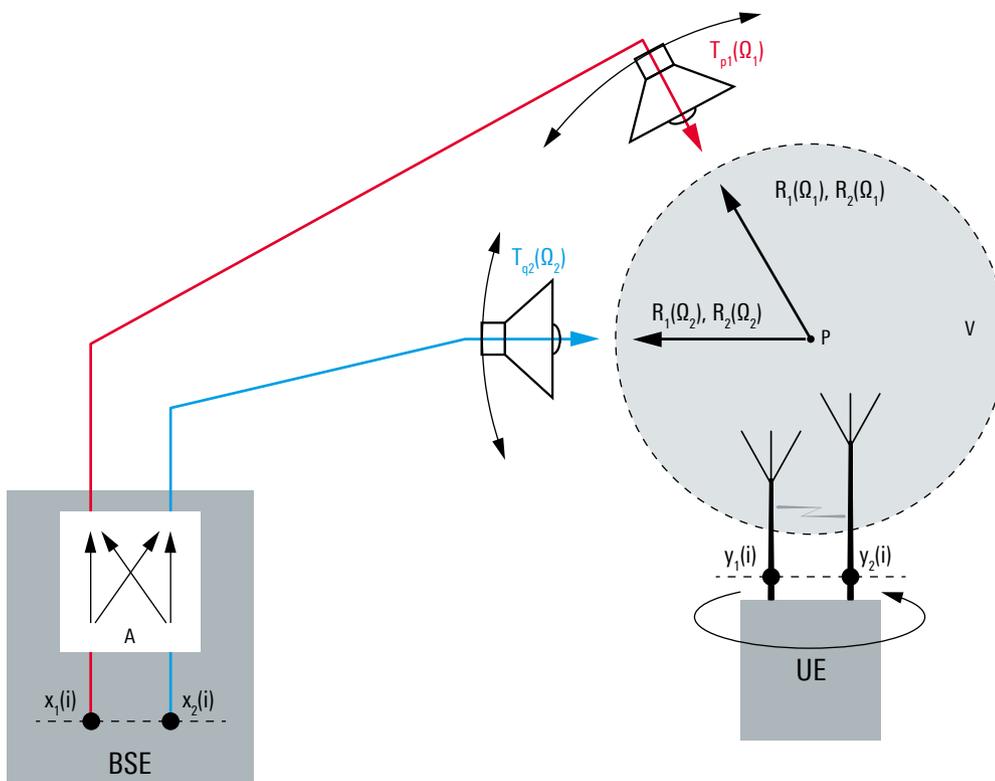
R&S®TS8991 MIMO OTA performance test system

The R&S®TS8991 OTA performance test system also supports MIMO OTA measurements¹⁾. The concept is based on a conventional SISO OTA test chamber and contains two conical cut positioners. Both carry dual-polarized test antennas, TA1 and TA2, that provide the DL signal. TA1 and TA2 may be moved independently of each other, allowing a wide angle of arrival spread for the signals to be generated. The UE is placed on an azimuth positioner containing a communications antenna (COMM ANT) for the uplink path. The 3D evaluation uses test antennas that move independently over the surface of a sphere in space centered on the DUT.

Test instruments include the R&S®CMW500 wideband radio communication tester as base station emulator (BSE) and the R&S®OSP130 open switch and control platform as switch matrix.

¹⁾ More details available in Rohde&Schwarz white paper 1SP12 "Two-Channel Method for OTA Performance Measurements of MIMO-Enabled Devices".

Principle of Rohde&Schwarz two-channel method for MIMO 2x2 mode



Cross-polarized test antennas provide four polarization combinations.

Includes SISO measurements without changes to test setup

SISO OTA measurements for 2G and 3G legacy technologies are a mandatory part of device characterization. Thanks to the unique two-channel method devised by Rohde&Schwarz, the anechoic chamber can be used for both SISO and MIMO tests without hardware modification; one of the cross-polarized test antennas is simply driven into a non-interfering parking position.

Measurements in free space as well as with phantom head and/or hand are possible in SISO and MIMO mode.

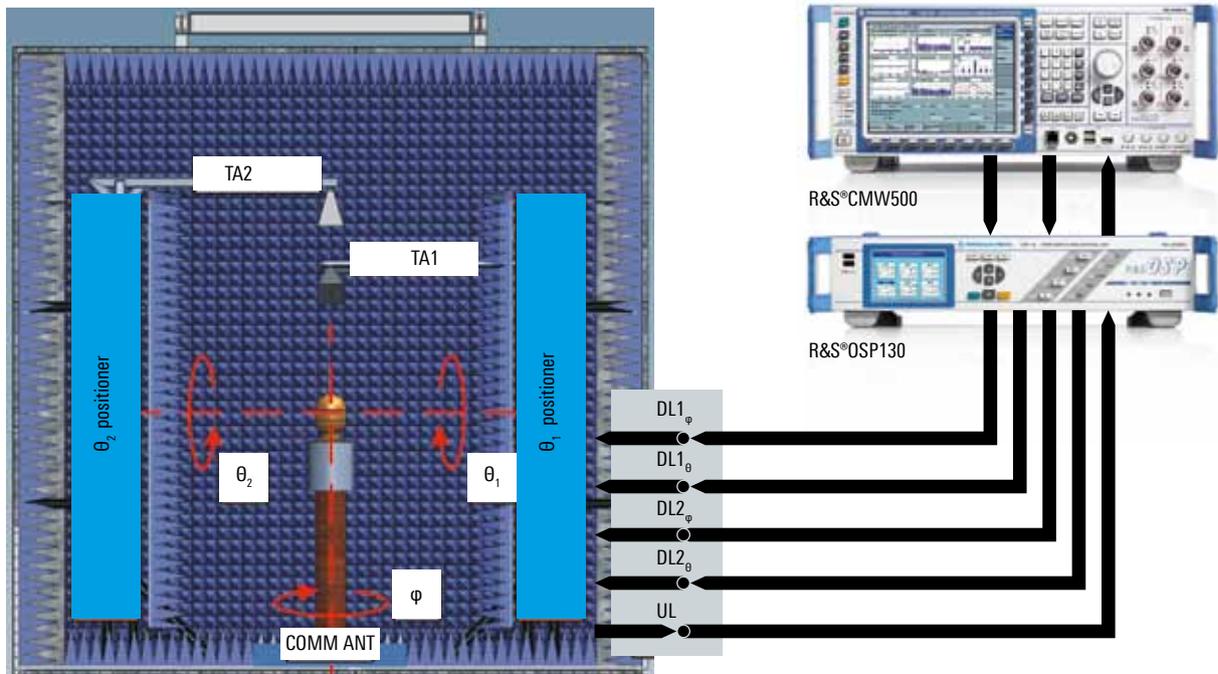
Verification of smart UE receive antennas

The two-channel method can also verify the performance of smart UE antennas with adaptive receiving characteristics. This is assured since the two-channel method does not require any auxiliary RF cabling connected to the antenna ports of the UE during the test. Therefore the interface between antenna and RF frontend is untouched – the actual UE antennas are connected to their real-world load impedance during the test.

Extension of SISO chamber for MIMO testing

Most existing manufacturer's SISO setups can be upgraded to cover MIMO testing. Chambers used for today's SISO OTA work are typically large enough to accommodate the R&S®AMS32 MIMO-OTA upgrade. A second dual-polarized test antenna with dedicated elevation positioner is added.

Main components of the R&S®TS8991 OTA performance test system for MIMO



Clearly structured MIMO OTA test plan

Two basic test cases are usually sufficient to characterize true MIMO OTA performance. Each test case covers a practical extreme condition under aspects of real-world use of the UE implementation. Both test cases are directly related to the spatial properties of the UE antenna system. These two test cases are referred to in the following two sections as:

- Noise limited performance in transmit diversity mode, NLTD
- Peak performance in spatial multiplexing mode, PPSM

Noise-limited OTA performance in transmit diversity mode (NLTD)

Downlink transmit diversity (TD) is the most likely transmission mode for LTE user equipment operated close to the cell edge. It ensures good link reliability and throughput. In this scenario, the downlink signal approaches the level of noise generated by the UE itself. The test case amounts to characterization of UE sensitivity in a noise-limited scenario using robust low-order (i.e. QPSK) modulation. It is similar to traditional total isotropic sensitivity (TIS) measurements for SISO devices.

Investigating UE sensitivity in a noise-limited scenario amounts to baseline performance characterization which covers the following physical implementation aspects:

- Antenna efficiency
- Receiver noise figure
- Self-interference

Test setup

The anechoic chamber is compatible with SISO OTA tests, including a dual-polarized test antenna. Two output ports from the R&S®CMW500 MIMO base station emulator are connected directly to the ports of the test antenna for the two polarizations. In the TD scheme, two orthogonal signals are simultaneously routed to the two polarizations of the test antenna. The test antenna is moved across the surface of a sphere in space in a defined grid in order to access all relevant angles of arrival.

Test procedure

The sensitivity threshold search usually decreases DL power while measuring the block error rate (BLER).

The effective isotropic sensitivity value (EIS) is reported for each test position for a BLER of e.g. 10%.

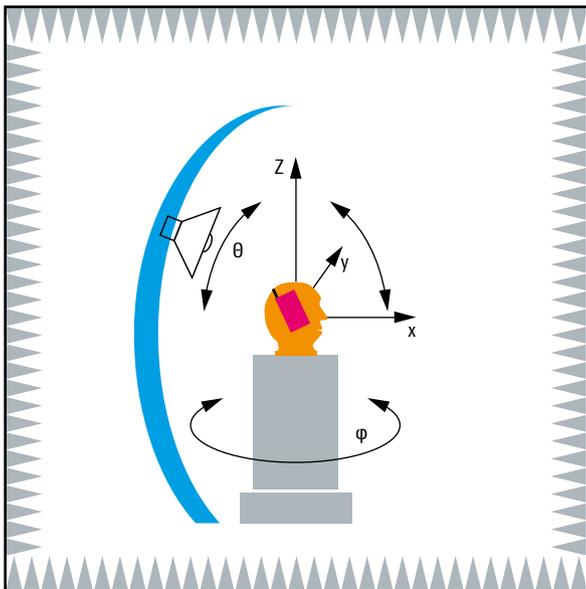
The measurement is repeated by repositioning the test antenna and rotating the UE until the sphere is completely sampled, using a predefined step size (e.g. 30°). This results in 60 throughput measurements based on 60 constellations and one polarization case.

Set of geometrical constellations for NLTD test

Parameter	Value	Description
ϕ	0°, 30°, ... , 330°	Azimuth position (total of 12)
θ	30°, 60°, ... , 150°	Elevation position of test antenna (total of 5)

The step size may be changed and measurements can be limited to dedicated pattern areas in order to decrease the test time.

UE coordinate system for NLTD test case with one test antenna



Peak performance measurements in spatial multiplexing mode (PPSM)

Another aspect of MIMO performance is the ability of a device to benefit from multipath propagation to achieve peak data rate. Peak performance measurements in spatial multiplexing mode simulate scenarios in which high throughput is demanded. MIMO peak performance results when an optimal channel exists in spatial multiplexing mode with transmission using high order modulation (i.e. 64QAM in case of LTE).

PPSM aims to evaluate whether the antenna system can meet the UE's designed performance target, including the following physical properties:

- Complex pattern correlation
- Gain imbalance
- Polarization and spatial diversity
- Spherical sensitivity pattern
- MIMO detector performance

Test setup

A second dual-polarized test antenna has to be added, Both antennas can be positioned independently. Two output ports from the R&S®CMW500 MIMO base station emulator are routed to the dual-polarized test antennas and connected to a polarization plane on each antenna. Open-loop spatial multiplexing (OLSM) is selected as the transmission mode.

Test procedure

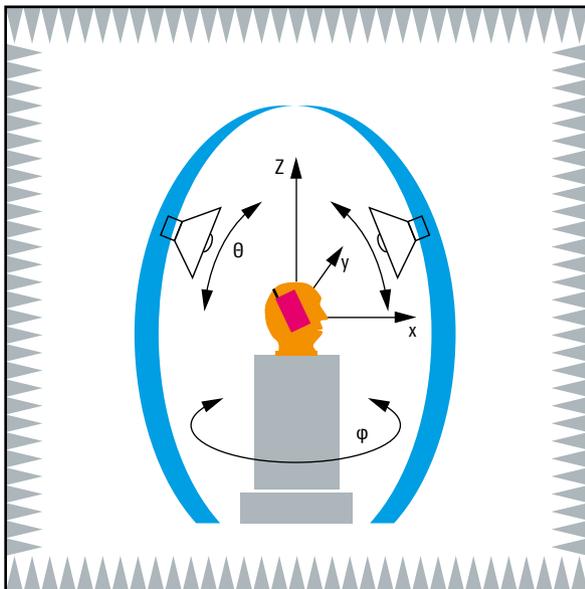
The downlink throughput to the UE is recorded for a fixed downlink power level at predefined spherical constellations of the two test antennas. For each constellation, all four possible polarization combinations of the two dual-polarized test antennas are applied ($\varphi - \vartheta$, $\vartheta - \vartheta$, $\varphi - \vartheta$, $\vartheta - \varphi$). The set of applied constellations assures an appropriate representation of angles of arrival (AoA). Constellations with low probability for real-world scenarios can be omitted to reduce test time.

Both test antennas are moved in even steps, each placed in its own hemisphere. Finally the UE is rotated about its vertical axis using a predefined step size. All areas of the sphere are sampled with a uniform step size (e.g. 30°). This results in 144 throughput measurements based on 36 constellations and four polarization cases.

Set of geometrical constellations for PPSM test

Parameter	Value	Description
φ	0°, 30°, ... , 150°	Azimuth position (total of 6) of test antennas
$\Theta_1 = \Theta_2$	15°, 45°, ... , 165°	Elevation position (total of 6) of test antennas

UE coordinate system for PPSM test case with two test antennas in vertical plane



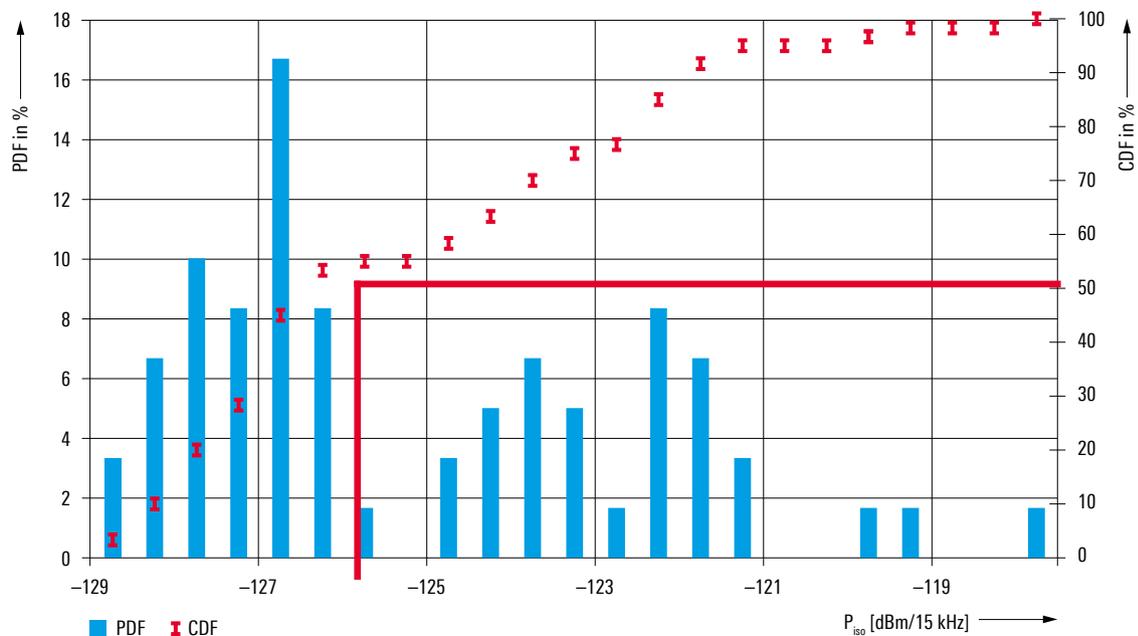
Statistical evaluation of OTA measurements indicates network performance

The definition of the metrics must provide a criterion for performance in a real network. The UE should perform well in all propagation scenarios. This can only be described statistically; average quantities are not suitable for characterizing the OTA performance of a UE. A UE model A, which achieves approximately 50% throughput with small deviation over all applied test constellations, cannot be rated as equivalent in performance to model B, which shows nearly 100% for half of the test constellations and almost zero for the other half.

Statistical metrics make comparison of UEs easy, in terms of the probability that a prescribed minimum performance will be achieved. The probabilities are directly related to user experience and network efficiency.

The MIMO OTA test plan defines statistical metrics in terms of the cumulative distribution function (CDF) for the NLTD performance test. The CDF function refers to the probability to meet a specified receiver sensitivity threshold. A rather steep CDF curve indicates an antenna performance that does not vary much at different angles of arrival (AoA). A flat curve indicates that the UE's antenna characteristics change significantly at different AoAs.

CDF result of noise-limited performance test in transmit diversity mode (NLTD) with histogram of 60 AoA constellations

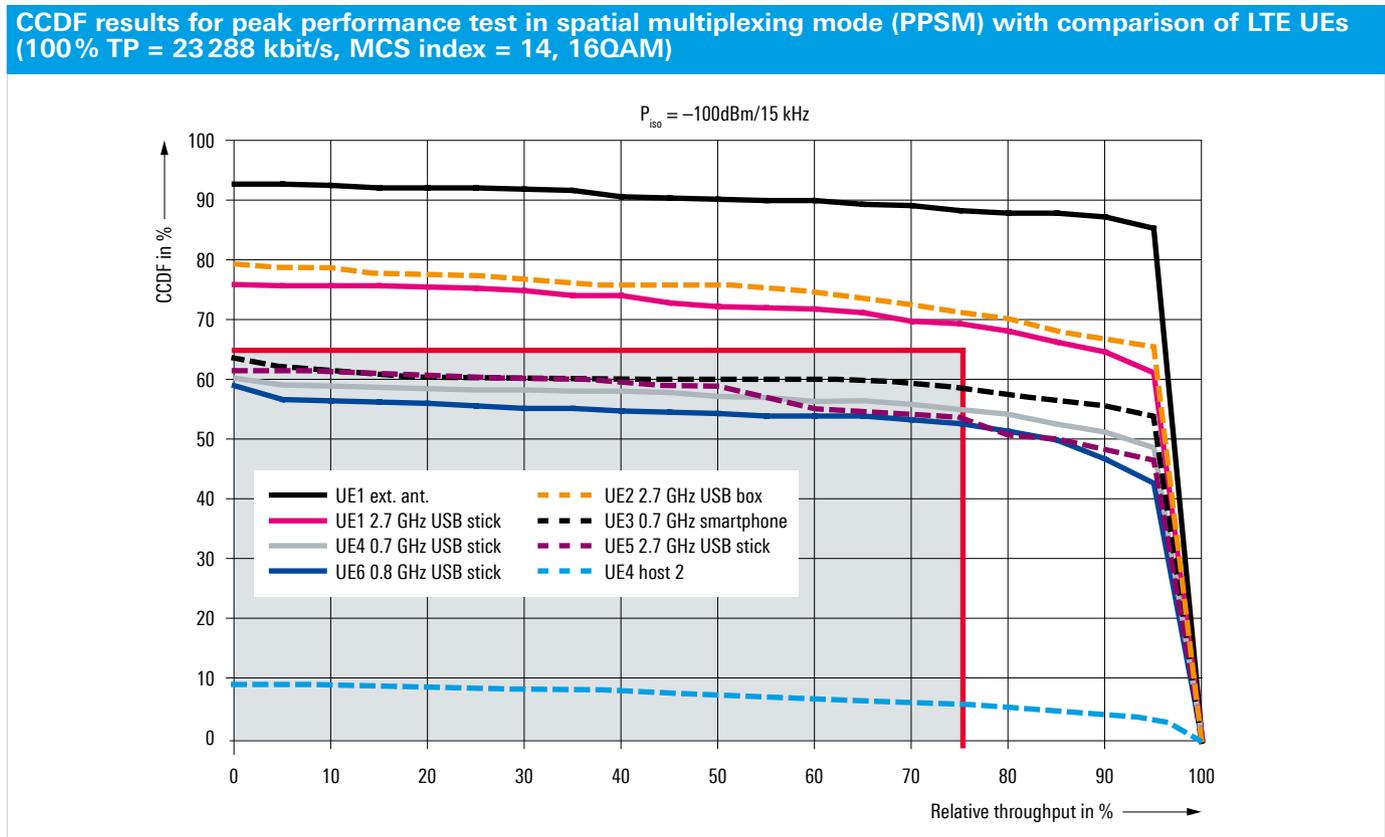


For the PPSM performance test, the complementary cumulative distribution function (CCDF) ($CCDF = 1 - CDF$) is used. It defines the probability of exceeding a specified throughput level for the applied test constellations.

Both statistical metrics allow easy definition of limits and comparison of different devices.

In the example for the NLTD performance test, the device has a sensitivity threshold better than $-126 \text{ dBm}/15 \text{ kHz}$ with a 50% probability related to the measured AoA constellations. The BLER threshold was set to 10%.

In the CCDF diagram for PPSM performance, the user can define a criterion to exceed a relative throughput for a minimum probability. In the example below, only two devices have at least 65% probability of exceeding a relative throughput of 75%.



Conclusive test results through conducted and radiated measurements

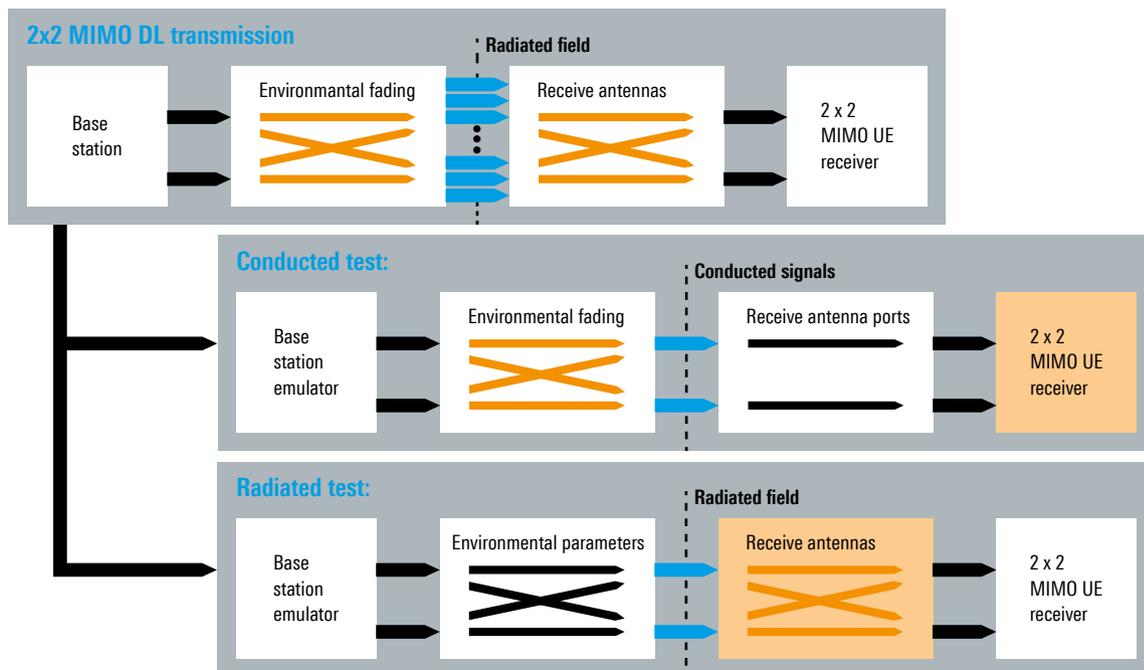
OTA tests characterize MIMO performance of the complete UE under simulated real-world conditions. Splitting the measurements into conducted and radiated makes it easier to locate weak design points.

Conducted measurements determine the performance of the receiver hardware and MIMO detection. They are a mandatory part of the device certification and different fading profiles may be applied.

When tests are performed in conducted and radiated mode with the same BSE signaling settings, the results can easily be correlated.

The MIMO OTA test method can also be extended to verify the effects of multipath propagation (fading). Static channel models are generated by the R&S®CMW500 MIMO base station emulator. Dynamic fading is accomplished by adding the R&S®AMU200A baseband signal generator and fading simulator to the R&S®TS8991 MIMO OTA test system. Fading tests are time-consuming and mainly used in R&D labs.

MIMO testing split into conducted and OTA (radiated) measurements



Automated measurements with ready-to-use test templates

OTA measurements – SISO and MIMO

The comprehensive R&S®AMS32 system software is based on the same software platform as the market-leading R&S®EMC32 solution.

R&S®AMS32 offers:

- Passive antenna measurements
- SISO OTA testing
- MIMO OTA measurements
- Calibration and analysis tools

It also supports assisted GPS testing with the popular and highly cost-effective R&S®AMS32-K28 A-GPS solution.

Test procedure flexibility

With the R&S®AMS32-K31 MIMO OTA option, users can customize the parameters of the test procedure, such as an arbitrary set of geometrical constellations and polarization cases or the base station emulator's transmission modes.

Standard-specific templates included

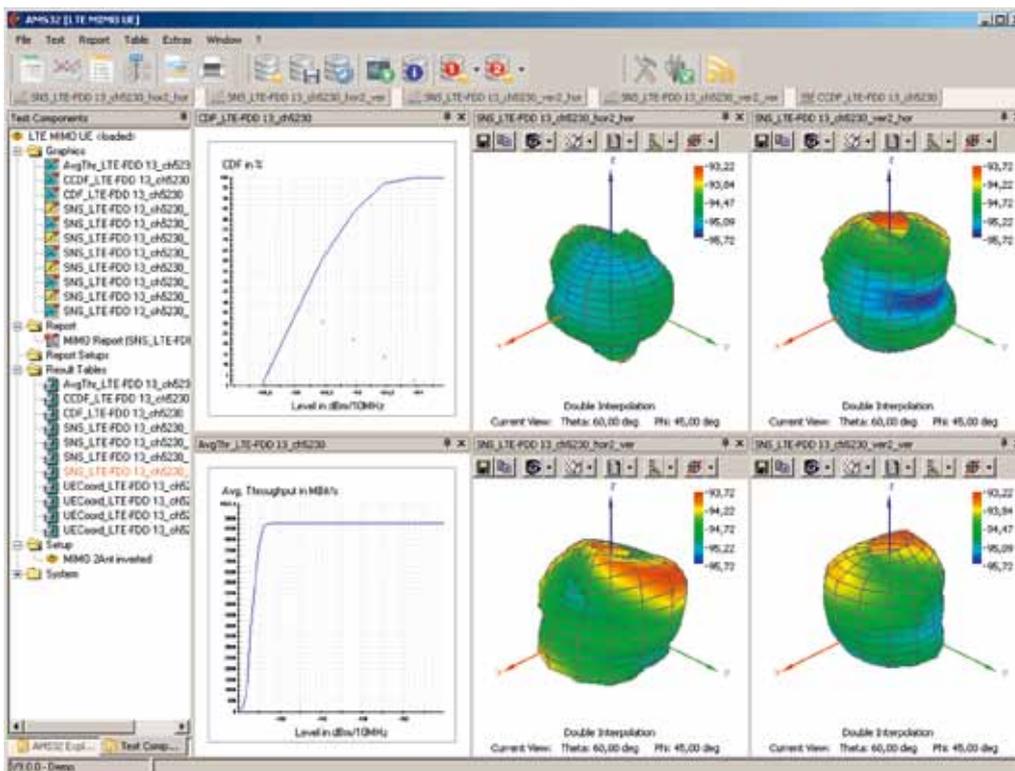
A wide variety of test templates for all common wireless standards are available for the R&S®AMS32 option. The templates are ready to use without any programming. The individual test plan for a test run is easily configured using a menu-driven parametric setup (such as cellular band, channel list, power level).

Network operator test solution

The R&S®TS8991 test system and R&S®AMS32 test software with the R&S®AMS32-K30 LTE OTA option for Verizon Wireless is the first available network-operator-specific test solution. It characterizes LTE MIMO devices in accordance with the over-the-air performance test plan published as part of the Verizon Wireless Open Development Initiative.

Result documentation made easy

The integrated report function of the R&S®AMS32 software collects all measured test data such as graphics and numerical results, test environments, EUT information and hardware setup in a single document. The report layout can be customized and the summary report file is stored in standard formats, e.g. XML or PDF.



MIMO measurement mode of R&S®AMS32 system software.

Glossary

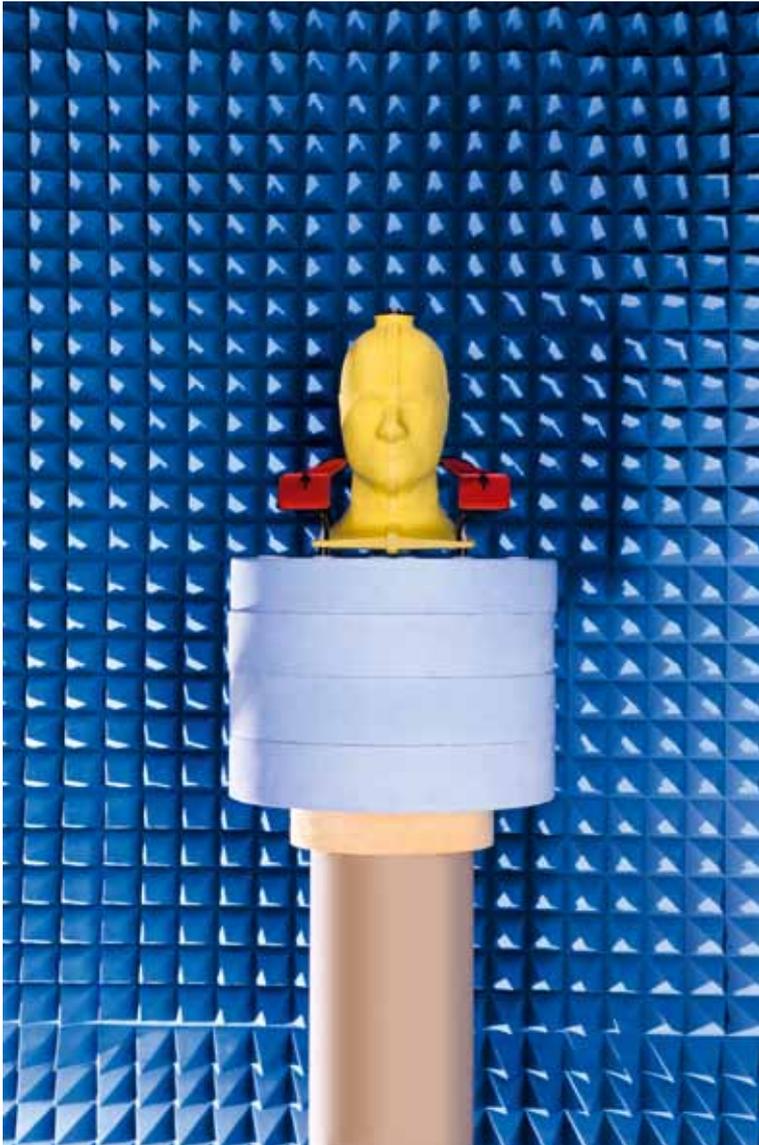
Term	Explanation
3GPP	3rd Generation Partnership Project
AoA	Angle of arrival
BLER	Block error rate
BSE	Base station emulator
CDF	Cumulative distribution function
CCDF	Complementary cumulative distribution function
CTIA	Cellular Telecommunications Industry Association
DL	Downlink
EIS	Effective isotropic sensitivity (single geometric point)
EUT	Equipment under test
FOM	Figure of merit
LTE	Long term evolution
MCS	Modulation and coding scheme
MIMO	Multiple input multiple output
OLSM	Open-loop spatial multiplexing
OTA	Over the air
PDF	Probability distribution function
SISO	Single input single output
TD	Transmit diversity
TIS	Total isotropic sensitivity
TP	Throughput
TRP	Total radiated power
UE	User equipment

Ordering information

Designation	Type	Order No.
OTA Performance Test System	R&S®TS8991	1119.4309.02
Over-The-Air (OTA) Performance Measurement Software ¹⁾	R&S®AMS32	1508.6650.02
Option for R&S®AMS32 OTA Software: LTE ECC	R&S®AMS32-K30	1508.6680.30
Option for R&S®AMS32 OTA Software: MIMO	R&S®AMS32-K31	1508.6680.31

¹⁾ Project specific configuration required.

Your local Rohde&Schwarz expert will help you determine the optimum solution for your requirements. To find your nearest Rohde&Schwarz representative, visit www.sales.rohde-schwarz.com



Phantom head on azimuth positioner simulates real operation of user equipment (UE).

Service you can rely on

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- | Local and personalized
- | Customized and flexible
- | Uncompromising quality
- | Long-term dependability

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Rohde & Schwarz is an independent group of companies specializing in electronics. It is a leading supplier of solutions in the fields of test and measurement, broadcasting, radiomonitoring and radiolocation, as well as secure communications. Established more than 75 years ago, Rohde & Schwarz has a global presence and a dedicated service network in over 70 countries. Company headquarters are in Munich, Germany.

Environmental commitment

- | Energy-efficient products
- | Continuous improvement in environmental sustainability
- | ISO 14001-certified environmental management system

Certified Quality System
ISO 9001

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PD 5214.6545.92 | Version 01.00 | November 2011 | R&S®TS8991
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