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Technical Report

**3rd Generation Partnership Project;
Technical Specification Group Radio Access Networks;
Universal Terrestrial Radio Access (UTRA) and Evolved
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Verification of radiated multi-antenna reception performance of
User Equipment (UE)
(Release 12)**

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Contents

Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

Version x.y.z

where:

x the first digit:

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y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

1 Scope

The present document is the technical report for the work item on MIMO OTA, which was approved at TSG RAN#55 [13]. The scope of the WI is to define a 3GPP methodology or set of comparable methodologies for measuring the radiated performance of multiple antenna reception and MIMO receivers in the UE. The test methodology should be relevant for HSPA and LTE technologies, with particular focus on handheld devices and devices embedded in laptop computers.

RAN WG4 has been working on the study item “Measurement of radiated performance for MIMO and multi-antenna reception for HSPA and LTE terminals" with the objective to define a test methodology for measuring the radiated performance of MIMO and multi-antenna UE reception in UMTS and LTE.

RAN4 has done sufficient work to be confident that the definition of a meaningful test methodology is feasible; however RAN4 does not have sufficient evidence yet to conclude on a single test methodology that would fulfil all requirements for standardisation, and the standardisation of multiple test methodologies may be one eventual outcome, with a view to avoid differences in the decision of what is a “good" or “bad" device from the radiated receiver performance perspective.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] RP-090352: "Proposed new study item: Measurement of radiated performance for MIMO and multi-antenna reception for HSPA and LTE terminals."

[3] TD(09) 766, COST2100 SWG 2.2, Braunschweig, Germany, Pekka Kyösti et. al. "Proposal for standardized test procedure for OTA testing of multi-antenna terminals", Elektrobit.

[4] 3GPP TS 34.114: "User Equipment (UE) / Mobile Station (MS) Over The Air (OTA) antenna performance; Conformance testing".

[5] 3GPP TS 25.214: "Physical layer procedures (FDD)"

[6] TD(09) 742, COST 2100 SWG 2.2, Braunschweig, Germany, February 2009, J. Takada: "Handset MIMO Antenna Testing Using a RF-controlled Spatial Fading Emulator".

[7] 3GPP TS 36.212: "Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding".

[8] 3GPP TS 36.213: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures".

[9] CTIA: "Test Plan for Mobile Station Over the Air Performance - Method of Measurement for Radiated RF Power and Receiver Performance", Revision 3.0, 4/30/2009.

[10] 3GPP TS 36.101: "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception".

[11] 3GPP TR 25.914: "Measurements of radio performances for UMTS terminals in speech mode".

[12] 3GPP TS 36.521-1: "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) conformance specification Radio transmission and reception; Part 1: Conformance testing"

[13] RP-120368: Revised WID on "Verification of radiated multi-antenna reception performance of UEs in LTE/UMTS – performance aspects".

[14] B. Yanakiev, J. O. Nielsen, M. Christensen, G. F. Pedersen: "The AAU 3D antenna pattern format-proposal for IC1004".

[15] 3GPP TR 25.996: "Spatial channel model for Multiple Input Multiple Output (MIMO) simulations".

[16] IEC 61000-4-21: "Electromagnetic compatibility (EMC) – Part 4-21: Testing and measurement techniques – Reverberation chamber test methods", Edition 2.0 2011-01.

[17] IEEE.149-1979.R2008: "IEEE Standard Test Procedures for Antennas," IEEE, October 2003.

[18] B. Yanakiev, J. Nielsen, M. Christensen, G. Pedersen: "Antennas In Real Environments," EuCAP 2011.

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in TR 21.905 [1].

example: text used to clarify abstract rules by applying them literally.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

H	Channel matrix
ϕ	Adjacent probe separation angle
θ	Zenith angle in the spherical co-ordinate system
ϕ	Azimuth angle in the spherical co-ordinate system

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1].

AoA	Angle of Arrival
AoD	Angle of Departure
BS	Base Station
BSE	Base Station Emulator
BTS	Base Transceiver Station
COST	Cooperation of Scientific and Technical
CTIA	Cellular and Telecommunication Industry Association
DL	Downlink
DUT	Device Under Test
FRC	Fixed Reference Measurement Channel
FTP	File Transfer Protocol
HSPA	High Speed Packet Access
HTTP	HyperText Transfer Protocol
LTE	Long Term Evolution
MCS	Modulation and Coding Scheme
MIMO	Multiple Input Multiple Output
OTA	Over-the-Air
SCM	Spatial Channel Model
SCME	Spatial Channel Model Extension
SI	Study Item
SISO	Single Input Single Output
SIR	Signal-to-Interference Ratio
SNR	Signal-to-Noise Ratio
SS	System Simulator
TBS	Transport Block Size
TTI	Transmission Time Interval
UE	User Equipment
UDP	User Datagram Protocol
UL	Uplink
VRC	Variable Reference Measurement Channel

4 Introduction

4.1 Background

The use of MIMO and receiver diversity in the UE is expected to give large gains in downlink throughput performance for HSPA and LTE devices. 3GPP already defined conducted tests for MIMO and multiple antenna receivers (type 1 and type 3 in TS 25.101 for HSPA demodulation), but it is clear that the ability to duplicate these gains in the field is highly dependent on the performance of the receive-antenna system.

At TSG RAN#41, Sep 2008, it was indicated that there is a need for a test methodology to be created with the aim of measuring and verifying the radiated performance of multi-antenna and MIMO receiver in UEs for both HSPA and LTE devices. As an outcome of the discussion, an LS was sent to COST 2100 SWG2.2 and CTIA ERP to ask them for feedback on their plans/ongoing work in this area, and also the timescales for which such work could be completed to define such a methodology, with particular focus on handheld devices and devices embedded in laptop computers.

Since then, feedback from COST 2100 and CTIA has suggested they are happy to work on this topic. However, given that 3GPP is the customer for this work as well as being a potential contributor, it is important to aim for commonly-accepted measurement and test methodology to be used across the industry.

4.2 Work item objective

The high level objective of this work item is to define a test methodology (ies) for verifying the radiated performance of multiple antenna reception in the UE and such methodology shall be able to:

- Verify the radiated “over-the-air" (OTA) performance of multiple antenna reception in the UE.
- Accurately able to reflect MIMO and SIMO performance under realistic MIMO and SIMO channel conditions. Be able to distinguish between UEs of “Good" and “Bad" multi-Rx antenna OTA performance, and offer a good reflection of the likely experience in the field.
- Offer good reliability, repeatability and an acceptable level of measurement uncertainty.

Such test methodology(ies) shall enable performance verification for:

- Handheld devices, devices embedded in laptop computers, and other devices (such as M2M equipment).
- All transmission modes of LTE and HSDPA, including spatial multiplexing (MIMO) and single spatial layer operation. However the transmission modes used in the test shall be defined as part of the work.
    - Initially tests shall use of LTE Transmission Mode 3, Fixed Reference Channel, and forced Rank 2. As the work progresses, other transmission modes of LTE and HSPA shall be introduced.
    - The utilization of Variable Reference Channels and other-cell interference shall also be studied at a later stage.

The following is required for the analysis phase of this work item:

- In order to compare results across the different methods, absolute throughput shall be used as the Figure of Merit.
- In order to analyse and accurately validate a method(s) the following work shall be performed:
    - eNodeB settings shall be agreed.
    - Realistic MIMO conditions and realistic channel models shall be identified to be used as a reference radio environment.
    - The MIMO conditions and channel models shall be validated for the proposed test methods.

- Calibration of the power levels in the methodology shall be performed.
- The absolute throughput measured for each test method shall be compared with the absolute throughput measured in the reference radio environment, in order to identify the capability of each method to provide a measurement result that matches what is observed in realistic environments.
- In order to minimize the variables associated with testing of production UEs with unknown antenna characteristics, utilize reference antennas in combination with a known UE baseband receiver (verified via conducted RF tests with and without channel impairments). This is intended to verify whether the characteristics of the receive antenna design (i.e. correlation, gain imbalance, etc) affecting receiver performance can be accurately distinguished by proposed test methods.

In the event that more than one test methodology is agreed to be standardised, differences between methodologies in the decision of what is a “good" or “bad" device from the radiated receiver performance perspective shall be avoided.

When selecting the method(s) for specification for LTE MIMO, applicability to LTE-SIMO UMTS-SIMO/MIMO shall be described.

During the course of this Work Item, maintain ongoing communication with COST and CTIA MOSG to ensure industry coordination on this topic and to distribute tasks according to expertise or resource availability.

TSG RAN should contact TSG GERAN to get feedback on the applicability of such a test methodology for GERAN.

4.3 High level requirements

The following high level requirements are agreed by RAN4:

1. Measurement of radiated performance for MIMO and multi-antenna reception for HSPA and LTE terminals must be performed over-the-air, i.e. without RF cable connections to the DUT.

   NOTE 1: DUTs to the test house will have accessibility to temporary antenna port for conducted purposes.

   NOTE 2: Temporary antenna port is used to assess to DUT receiver.

   NOTE 3: UE special function to measure antenna pattern is not desirable for MIMO OTA purposes.

2. The MIMO OTA method(s) must be able to differentiate between a good terminal and a bad terminal in terms of MIMO OTA performance.
3. The desired primary Figure of Merit (FOM) is absolute throughput. This will easily allow meaningful comparison of the ability of different methods to evaluate MIMO OTA performance.

5 Performance metrics

<Editor: list down the essential parameters to be measured, metrics of measuring OTA performance>

5.1 Figure of Merits

Absolute throughput performance is used in order to be able to compare the different proposed methodologies in their ability to distinguish good and bad MIMO devices.

The performance metric applies to both HSPA and LTE system.

Other Figure of Merits and their applicability on the assessment of MIMO performance is for further study.

5.1.1 Definition of MIMO throughput

MIMO throughput is defined here as the time-averaged number of correctly received transport blocks in a communication system running an application, where a Transport Block is defined in the reference measurement channel. From OTA perspective, this is also called MIMO OTA throughput.

The MIMO OTA throughput is measured at the top of physical layer of HSPA and LTE system. Therefore, this is also measured at the same point as in the conductive measurement setup: under the use of FRC, the SS transmit fixed-size payload bits to the DUT. The DUT signals back either ACK or NACK to the SS. The SS then records the following:

- Number of ACKs,
- Number of NACKs, and
- Number of DTX TTIs

Hence the MIMO (OTA) throughput can be calculated as

$$MIMO\ (OTA)\ Throughput = \frac{Transmitted\ TBS \times Num\ of\ \ ACKs}{Measurement\ Time}$$

where Transmitted TBS is the Transport Block Size transmitted by the SS, which is fixed for a FRC during the measurement period. MeasurementTime is the total composed of successful TTIs (ACK), unsuccessful TTIs (NACK) and DTX-TTIs.

The time-averaging is to be taken over a time period sufficiently long to average out the variations due to the fading channel. Therefore, this is also called the average MIMO OTA throughput. The throughput should be measured at a time when eventual start-up transients in the system have evanesced.

5.1.2 Definition of SIR

6 Measurement methodologies

6.1 Fixed Reference measurement Channels (FRCs)

<Editor: add texts>

6.2 Void

6.3 Downlink measurement methodologies

The methodologies defined in this subclause are candidate methodologies being studied for the purpose of defining procedures for conformance testing of over the air performance.

6.3.1 Methodologies based on Anechoic RF Chamber

An OTA method based on the use of an Anechoic RF Chamber is described consisting of a number of test antenna probes located in the chamber transmitting signals with temporal and spatial characteristics for testing multiple antenna devices.

This clause describes the methodologies based on Anechoic RF Chamber, where a number of test antennas are located in different positions of the chamber, and the Device Under Test (DUT) is located at center position. The DUT is tested over the air without RF cables.

6.3.1.1 Candidate Solution 1

An Anechoic Chamber technique is defined, consisting of a number of source elements at one end or surrounding the DUT to create a realistic geometric based spatio-temporal radio channel for testing MIMO performance. The latter implementation is illustrated in Figure 6.3.1.1-1.

By utilizing specific geometries of the test probes in the chamber, a range of possible channels are emulated. The exact number and positioning of the source antenna probes will be fixed in a final design; however they may be optimized for the best performance when the OTA channel models are defined. In other words, depending on the types of channel models required and the range of parameters needed for testing, the number of probes may be optimized to produce the best performance with the fewest number of probes. For example, based on the range of channels defined by the SCM, SCME, Winner I & II channel models, the optimized number of probes may vary from 6 to 8 for a given polarization. In general, the most flexible configurations require the higher number of probes.

Azimuth spread is created by energizing sets of probes separated in azimuth with signals that will combine over the air at a specific delay to emulate a path or cluster. Elevation spread may be created by installing probes at different elevations, however doing this tends to constrain their flexibility.

The components of the solution include:

- Anechoic Chamber
- System Simulator (SS)
- N channel RF emulator, with OTA Channel Generation Features
- N antenna elements configured with V, H or co-located V&H or slant X polarizations
- K azimuthally separated antenna positions with predefined angles at radius R
- Channel Model definition for each test case

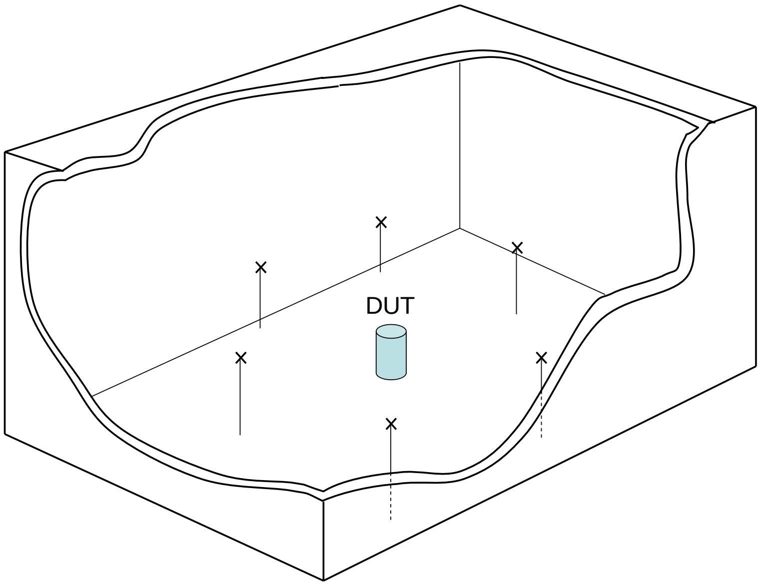


Figure 6.3.1.1-1: N-element Anechoic Chamber approach (Absorbing tiles and cabling not shown)

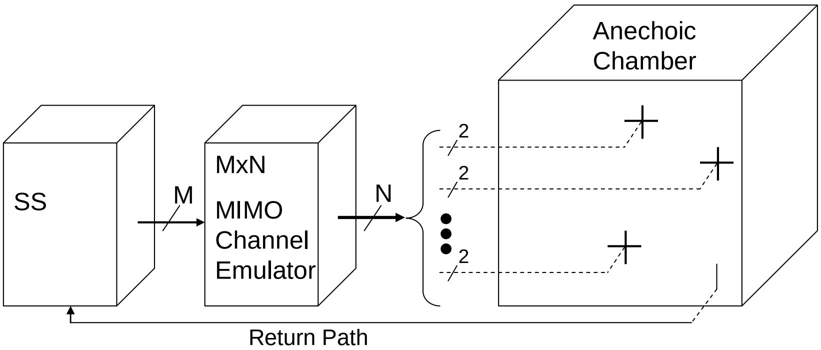


Figure 6.3.1.1-2: OTA system level block diagram

A system level block diagram is shown in Figure 6.3.1.1-2, which includes the SS to generate the M branch MIMO signal, and an RF Channel Emulator with an OTA Channel Generation Feature to properly correlate, fade, scale, delay, and distribute the signal to each test probe in the chamber.

For research purposes, a range of possible channel models and parameterizations are used to specify the most generic and versatile antenna test probe configuration. For performance and conformance testing, the channel model is expected to be limited in scope or simplified, which may allow an optimized design to reduce the number of test probes required. Thus the number of test probes is selected to best meet the requirements of the test so that the most efficient and economical design can be achieved.

6.3.1.1.1 Concept and configuration

6.3.1.1.1.1 Emulating spatial channels

Spatial channel models, including SCM, SCME, Winner I & II, and ITU-A, were developed from measured data, and attempt to preserve the measured behaviour of the channel at the path (cluster) level, including spatial, temporal, polarization, and delay characteristics. Reference [3] described a technique for reproducing the spatial characteristics of a narrow angle spread signal with a reduced number of antenna probes. This technique uses pre-faded signals at each probe wherein the power-adjusted signals from the multiple probes, i.e. typically 2-4 or more, are combined over the air to produce an accurate narrow angle spread representation of the signal for each delay. This technique is able to maintain its close match to an ideal narrow angle spread signal even for severe antenna variations.

The spacing of the antenna probes in the chamber are constrained by the range of angle spreads being emulated, and therefore the channel model is a key determining factor in optimizing an OTA chamber design. For the angle spreads defined by SCM, SCME, Winner I & II, and the ITU-A channel models, the optimum number of probes may vary from 6 to 8 for a given polarization, depending on the device type, and for large devices the number of probes may increase. In general, the most flexible configurations will tend to require the higher number of probes. Once the design of parameters of the system are decided, it is expected that the number of probes will be fixed to a value that works for all channel models and devices being simulated. Figure 6.3.1.1.1.1-1 illustrates some practical antenna probe configurations to support devices such as handsets and laptops. The single cluster approach can be performed using probes distributed over a portion of a circle or in a full ring-like distribution.

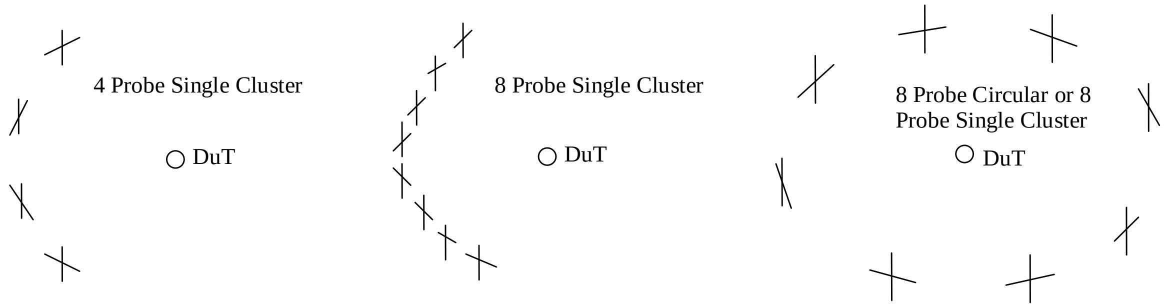


Figure 6.3.1.1.1.1-1: Some practical antenna probe configurations (shown with dual polarization)

The probe separation angle, ϕ used in the Chamber design, shown in Figure 6.3.1.1.1.1-1, will be defined in conjunction with the channel models as described below. In general, the angles will not be exact even integer fractions of pi, to avoid symmetries. i.e. exact symmetry will produce convergence problems due to correlated Doppler, e.g. $\cos(\alpha) = -\cos(\alpha + \pi)$.

6.3.1.1.1.2 Joint selection of a channel model and a chamber design

Since link modelling is usually associated with a single "drop" or single "channel realization" from the channel model, a few specific channel realizations will likely be specified and standardized for evaluation purposes. From a testing standpoint, only a few channel realizations will be measured in an OTA performance/conformance system, and it would be useful to align the channel model clusters with the probe locations in an optimized chamber design. However, there is enough flexibility inherent in these probe configurations to emulate clusters from arbitrary angles if desired.

Specifically, since the chamber layout has probes at specific angles, and since most spatial channel models draw channel AoAs randomly from specified distributions, it is reasonable that specific AoAs are chosen to align with the chamber layout for these few test channels.

For research purposes, a more generic OTA chamber design is possible, but generally at the cost of having the maximum number of probes. Also, there is a trade-off in modelling signals with arbitrary AoA while controlling the signals Angle Spread at the same time. By selecting specific AoAs within a valid channel realization, a more precise AS can be obtained. Thus performance of the OTA design is closely tied to the channel modelling assumptions used, and can be specified more completely when the channel model and it's associated parameters are specified.

6.3.1.1.2 Test conditions

For performance and conformance testing purposes, only a small number of channel realizations is practical due to the nature of the OTA measurements. Based on this, it is reasonable to define a range of conditions for testing that can be represented in 2-3 channel realizations. It is anticipated that these channel realizations would represent a Low, Medium, and High correlation cases, which generally align to the ability of the channel to support MIMO operation.

These channels may also be used to optimize the design and layout of the chamber to reduce the number of probes and achieve the most efficient and cost effective design.

6.3.1.2 Candidate solution 2

The MIMO OTA test setup is composed of a number of OTA chamber antennas, a multidimensional fading emulator, an anechoic chamber, communication tester / BS emulator and a device under test (DUT). The following figure depicts an example of the OTA concept. The purpose of the figure is not to restrict the implementation, but rather to clarify the general idea of the MIMO OTA concept. For simplicity, uplink cabling is not drawn here.

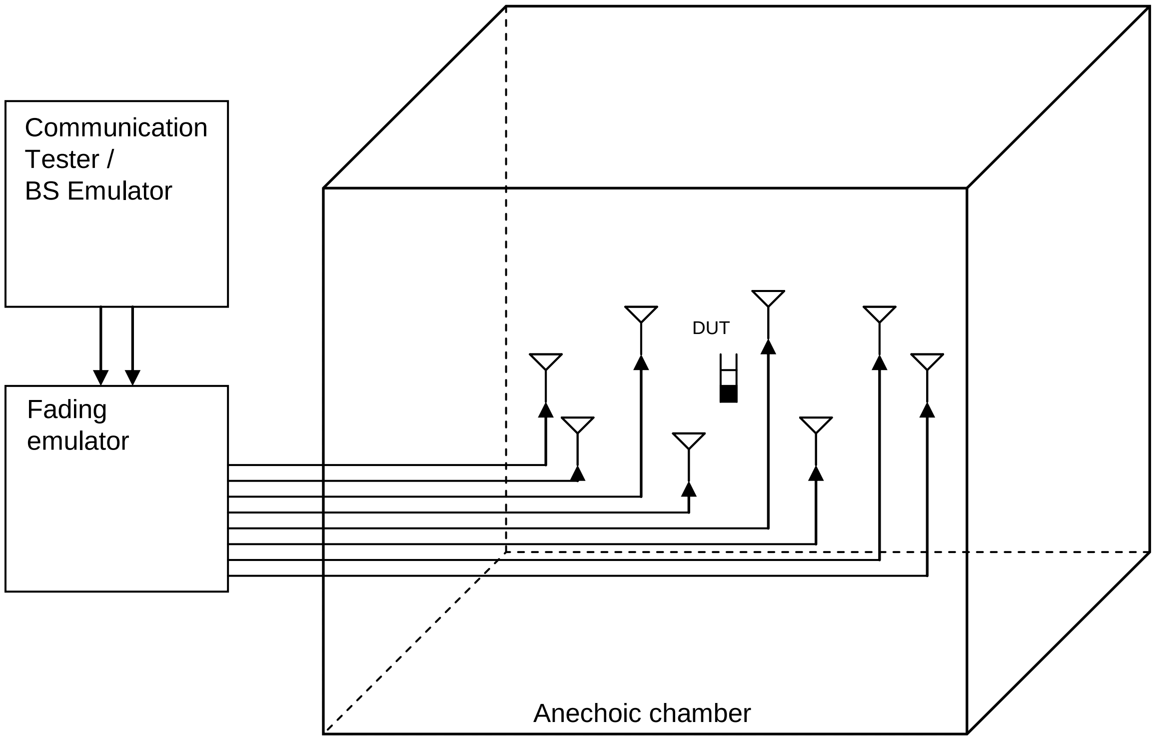


Figure 6.3.1.2-1: Example of MIMO/multi-antenna OTA test setup (Uplink signal path omitted in the figure)

The DUT is located at center of the anechoic chamber. The idea of locating DUT into centre provides a possibility to create a radio channel environment where the signal can arrive from various possible directions simultaneously to the DUT. This is the key aspect of the wideband MIMO radio channel models implemented today.

The proposed test setup is composed of a transmitter, a multidimensional radio channel emulator, an anechoic chamber equipped with OTA antennas and a DUT with multiple antennas. The crucial challenge is to generate realistic angular and polarization behaviour within the anechoic chamber. The family of geometry-based stochastic channel models (GSCM) is well suitable for MIMO OTA testing. The GSCM include 3GPP SCM, SCME, WINNER and IMT-Advanced channel models. This angular and polarization behaviour creates appropriate correlation at the DUT antennas. The correlation is defined implicitly via the per-path angle of arrival and real antennas. Correlation matrix based model is not suitable for this, because it includes the antenna information in the model itself.

Geometry based channel modelling methodology models BS and UE antenna arrays and the propagation between them (including angular power spectra). The parameters that are included are Doppler, Angle of Arrival, Angle of Departure, delay and polarization. The parameters are based mainly on measurements. The measurements define certain statistics and radio channel realizations are then created by these statistical properties.

The geometrical models are divided in to three parts:

1) BS antenna arrangement and the angular power spectrum as well as the AoD from the BS are modelled in the channel emulator.

2) AoA is created by dividing the appropriate clusters based on their original AoA to corresponding OTA antennas. The user terminal is not physically in a motion, thus the fading and Doppler spectrum are built in the channel model.

3) The angular power spectrum at DUT is created by radiating the signal from multiple OTA antennas.

UE (DUT) antenna characteristics are assumed unknown. In other words we do not use this information in the OTA modeling.

6.3.1.2.1 Concept and configuration

The idea of the MIMO OTA modelling is that the geometric channel models are mapped into the fading emulator. The mapping process covers all the required mathematics when converting the traditional geometric channel model to fading emulator tap coefficients as well as the calibration. The modelling process is shown in Figure 6.3.1.2.1-1.

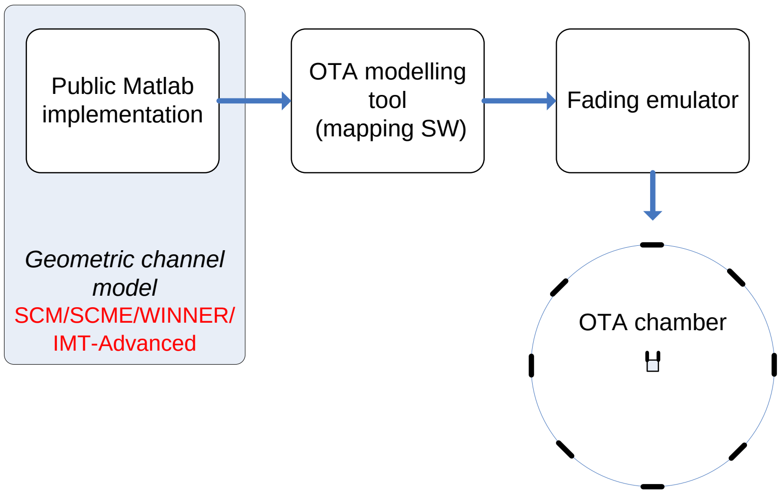


Figure 6.3.1.2.1-1: Modelling process

The setup of OTA chamber antennas with eight antenna elements is depicted in Figure 6.3.1.2.1-2. DUT is at center and the antennas are on a circle around DUT with uniform spacing (e.g. 45° with 8 elements). Let us denote directions of K OTA antennas with θ_k, $k = 1, \ldots, K$, and antenna spacing in the angle domain with $\Delta\theta$. Each antenna is connected to a single fading emulator output port. If single antenna BS is considered the fading emulator configuration is 1x8 SIMO, with two BS antennas 2x8 MIMO etc. If dual polarized OTA antennas are used like in Figure 6.3.1.2.1-3 the fading emulator configuration will be with 1 BS antenna 1x16 SIMO, with two BS antennas 2x16 MIMO etc. In the figure for example antenna A_{1V} denotes the first OTA antenna position and vertically (V) polarized element, A_{8H} denotes the eight OTA antenna position and horizontally (H) polarized element, etc.

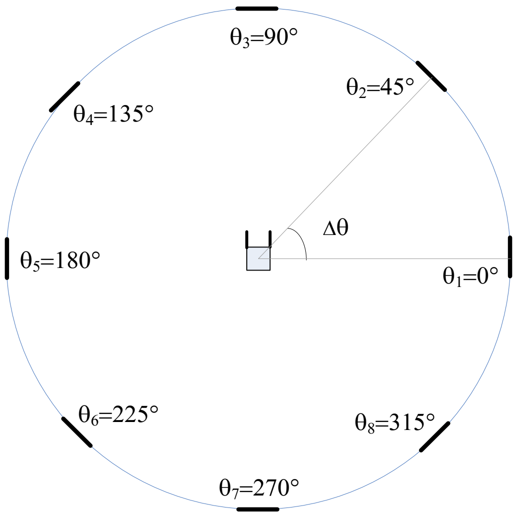


Figure 6.3.1.2.1-2: OTA chamber antenna setup with eight uniformly spaced chamber antennas

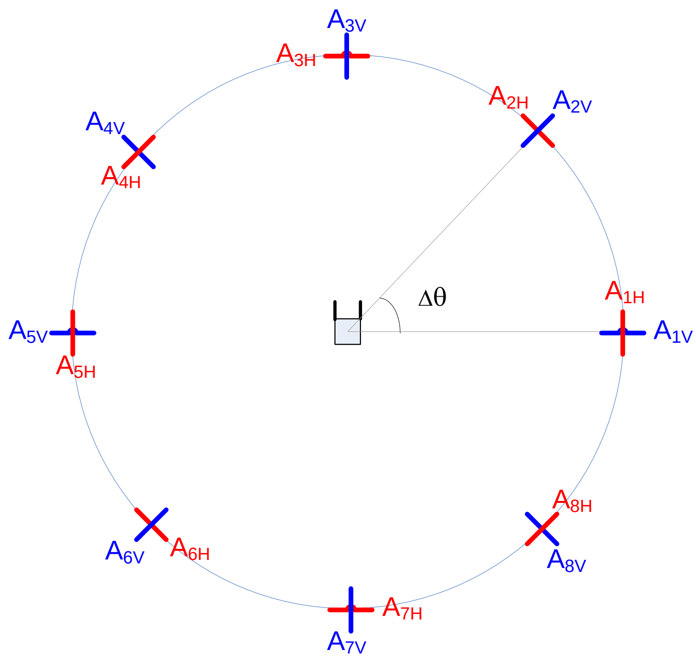


Figure 6.3.1.2.1-3: OTA chamber antenna setup with eight uniformly spaced dual polarized chamber antennas. The V-polarized elements are actually orthogonal to the paper (azimuth plane)

6.3.1.2.1A Scalability of the methodology

The number of antennas is scalable. In theory, there is no upper limit and the lower limit is one. The required number of channels depends on three main aspects: channel model, DUT size, and polarization. The key question is how accurately the channel model is emulated. Based on the quiet zone discussion, it was proposed to use 8 antennas in the case of single polarization and 16 antennas in the case of dual polarization. However, for single cluster case, less antennas may be enough. On the other hand, if elevation is needed, the antenna number will be higher. Additionally, the antenna positions can be adjusted to optimize the accuracy with limited number of antennas.

Other aspect is the channel model. Most of the Geometry-based Stochastic Channel Models (GSCMs) are two-dimensional, i.e. azimuth plane only, but the proposed MIMO OTA concept is not limited into azimuth plane. It can also be extended to elevation plane, when we talk about 3D MIMO OTA. However, the 3D MIMO OTA is rather complex and it does not provide very much additional information about the DUT. Therefore, 3D MIMO OTA can be considered as one future development, but it is not the recommended solution in the beginning of MIMO OTA testing.

Downscaling of the proposed method is more attractive due to the possibility to save the cost of the test system. Full SCME requires at least 8 probe antennas, but single cluster SCME can be implemented with lower number of antennas. The difference between full SCME and Single Cluster model is depicted in Figure 6.3.1.2.1A-1. Basically the only difference is that the mean Angle-of-Arrival (AoA) of each cluster is turned to the same direction. Obviously, one AoA requires lower number of antennas than multiple AoAs especially when angular spread is narrow, e.g., 35 degrees. The number of fading channels is the same as the number of antennas. Therefore, single cluster SCME would require less fading channels as well.

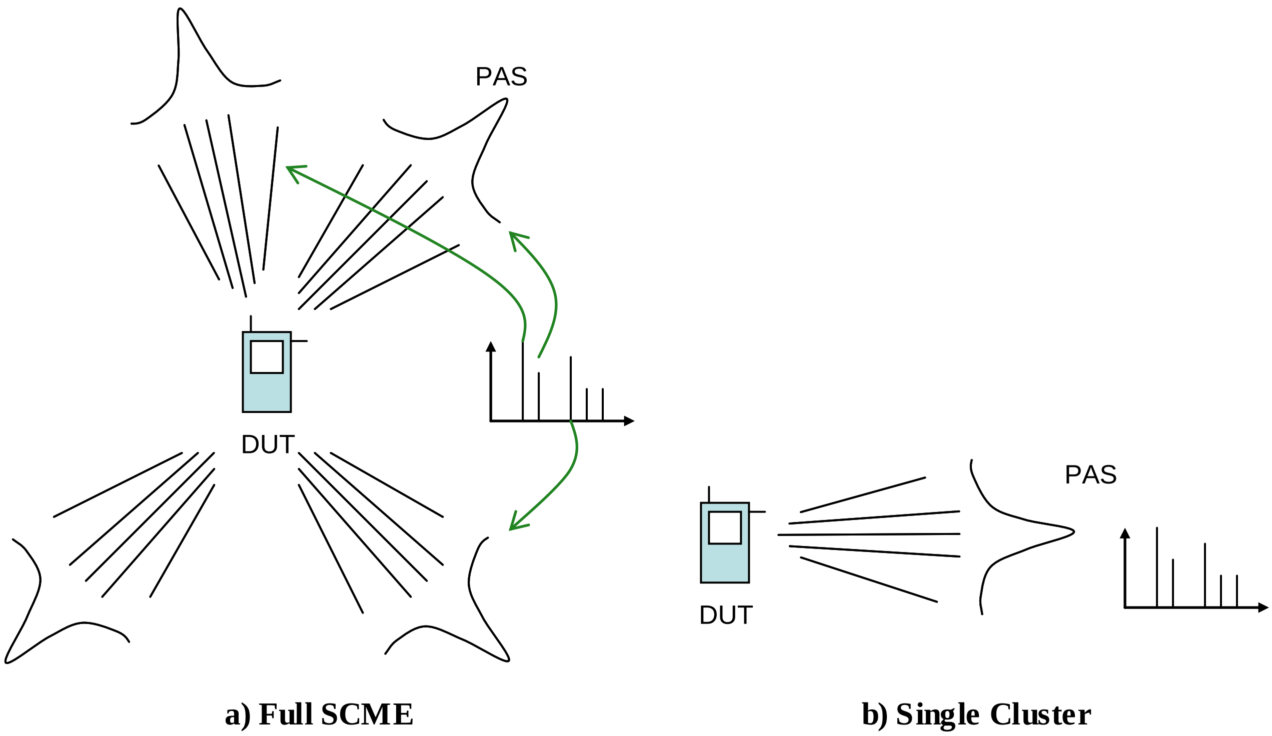


Figure 6.3.1.2.1A-1: Full SCME vs. Single Cluster model

6.3.1.2.2 Test conditions

This candidate solution supports testing of different figure of merits. It is also applicable for any 3GPP Release, and even for other standards. It supports different channel models from SCM to IMT-Advanced. Due to its generality, it does not restrict the test conditions. However, for simplicity, it is good to start from downlink throughput testing.

The downlink throughput testing can be done e.g. in following manner.

BS transmits signal through a radio channel emulator. This signal is routed to several antennas in anechoic chamber. The DUT is placed at center of the chamber and the performance is measured from the DUT.

- OTA antennas are located along a circle around the DUT.
- The circular geometry is needed because we need signal from many directions at the same time (requirement from the channel models)

The test steps can be, e.g., according to [3] or as follows:

1) Calibrate the full system with a test signal.

2) Set the first test case (e.g. channel model) to the fading emulator.

3) Generate test signal by the communication tester / BS emulator.

4) Measure the DUT performance (downlink throughput).

5) If the performance exceeds the specified limit, the DUT passes the test case.

6) If all test cases done, go to step 7. Otherwise, set the next test case (e.g. channel model) to the fading emulator and go back to step 3.

7) If DUT passed all the test cases, the DUT passes the full MIMO OTA test.

8) If DUT failed in at least one test case, the DUT failed the full MIMO OTA test.

6.3.1.3 Candidate solution 3

The principle of two-stage MIMO OTA method is based on the assumption that the far-field antenna radiation pattern will contain all the necessary information for evaluation the antenna's performance like radiation power, efficiency and correlation and that with channel model approaches, the influence of antenna radiation pattern can be correctly incorporated into the channel model. Thus the method will first measure the MIMO antenna patterns and then incorporate the measurement antenna patterns with chosen MIMO OTA channel models for real-time emulation. In order to accurately measure the antenna pattern of the intact device, the chipset needs to support amplitude and relative phase measurements of the antennas. If the EUT has dynamic antenna tuning elements, detailed information on the implementation is required to understand the consequences for the pattern measurement. The BTS and DUT can then be connected to the real-time channel emulator through the standard temporary antenna connectors or by using a calibrated radiated connection to do the test on throughput, etc., to test how the MIMO antennas will influence the performance.

It should be noted that should this methodology be chosen for conformance testing, the method for antenna gain and phase measurement would require to be standardized. The details for proposed antenna gain and phase measurements are FFS. Further details will be provided before the RAN4 evaluation of this methodology can progress.

6.3.1.3.1 Concept and configuration

The assumption of the two-stage MIMO OTA method is that the measured far field antenna pattern of the multiple antennas can fully capture the mutual coupling of the multiple antenna arrays and their influence. Thus to do the two-stage MIMO OTA test, the antenna patterns of the antenna array needs to be measured accurately in the first stage. In order to accurately measure the antenna pattern of the intact device, the chipset needs to support amplitude and relative phase measurements of the antennas.

Stage 1: Test multiple antennas system in a traditional anechoic chamber. The chamber for antenna pattern measurement is set up as described in Annex A.2 in [4], where the DUT is put into a chamber and each antenna element's far zone pattern is measured. Clause B.4.3 gives description on how to measure each antenna element's pattern using non-intrusive method. The influence of human body loss can be measured by attaching the DUT to a SAM head and or hand when doing the antenna pattern measurements. The DUT is placed against a SAM phantom, and the characteristics of the SAM phantom are specified in Annex A.1 of [4]. The chamber is equipped with a positioner, which makes it possible to perform full 3-D far zone pattern measurements for both Tx and Rx radiated performance. The measurement antenna should be able to measure two orthogonal polarizations (typically linear theta (θ) and phi (ϕ) polarizations as shown in Figure 6.3.1.3.1-1).

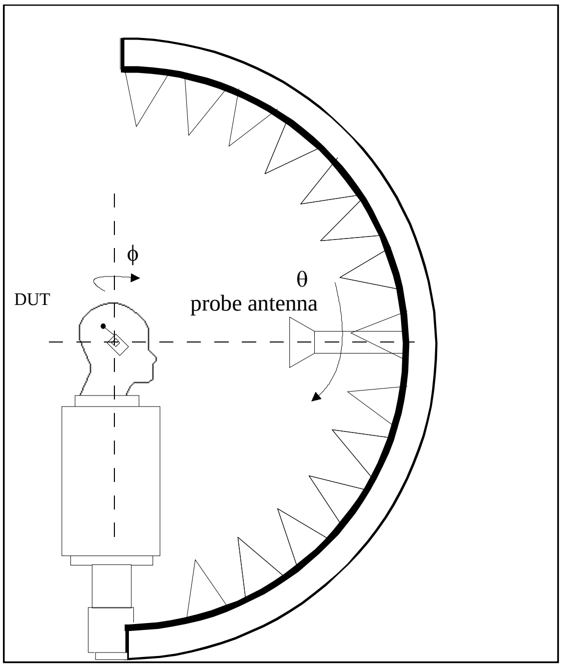


Figure 6.3.1.3.1-1: The coordinate system used in the measurements

Stage 2: Combine the antenna patterns measured in stage 1 into MIMO channel model, emulate the MIMO channel model with the measured antenna patterns incorporated in the commercial channel emulator and perform the OTA test in conducted or calibrated radiated approach.

The MIMO OTA method based on the above mentioned two-stage method is illustrated in Figure 6.3.1.3.1-2. The integrated channel model with both MIMO antenna effect and the multipath channel effect can be emulated with a commercial MIMO channel emulator. The BS emulator is connected to the MIMO channel emulator and then to the MIMO device's temporary antenna ports via approved RF cables. These ports are the standard ones provided for conducted conformance tests. An alternative to using a conducted connection is to use a calibrated radiated connection in an anechoic environment. This technique exploits the Eigen modes of the transmission channel to provide independent radiated connections between the probe antennas and each receiver after the antenna. By controlling the power settings of the channel emulator and also the integrated channel model, the end-to-end throughput with the MIMO antenna radiation influence can be measured using either connection method. The radiated connection method intrinsically includes the effects of EUT self-interference.

There are two different approaches to combine the antenna patterns with MIMO channel model.

a) Apply antenna patterns to Ray-based channel models. Ray-based models are capable to support arbitrary antenna patterns under predefined channel modes in a natural way as described above. If Ray-based model like SCM model is specified to be used for MIMO OTA test, then the channel emulator needs to be able to support SCM channel model emulation and support loading measured antenna patterns.

b) Apply antenna patterns to correlation-based channel models. MIMO channel model. With a correlation matrix calculation method for arbitrary antenna patterns under multipath channel conditions, the correlation matrix and the antenna imbalance can be calculated and then emulated by the channel emulator.

c) This method can be used to measure the following figure of merit:

   1) Throughput

   2) TRP and TRS

   3) CQI, BLER

   4) Antenna efficiency and MEG

   5) Antenna correlation, MIMO channel capacity.

The coupling between the UE antenna and internal spurious emission of the UE might be characterized during the antenna pattern measurement stage inside the chamber by lowering down the signal power and is for further research.

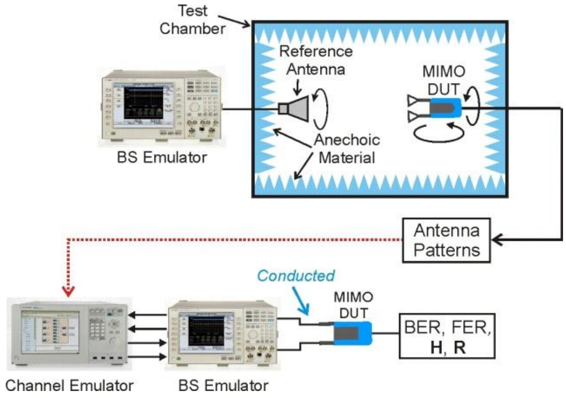


Figure 6.3.1.3.1-2: Proposed two-stage test methodology for MIMO OTA test

The alternative radiated method of connecting to the EUT in the second stage is shown in Figure 6.3.1.3.1-3.

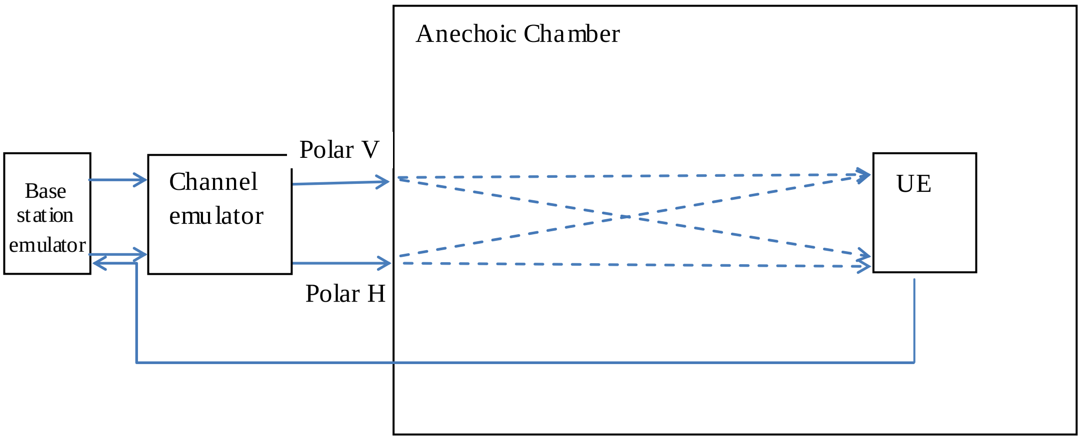


Figure 6.3.1.3.1-3: Alternative radiated connection for two-stage test methodology for MIMO OTA test

Figure 6.3.1.3.1-3 shows the fully radiated two-stage test setup. Two probe antennas with polarization V and H are co-located in the anechoic chamber. The only change from the conducted second stage is to replace the RF cables with the radiated channel inside the chamber. Due to the propagation channel in the chamber, signals transmitted from each probe antenna are received by both UE antennas which is different from the cable conducted case where the signals are isolated. However, by precoding the transmitted signals using spatial multiplexing techniques it is possible by calculating the radiated channel matrix and by applying its inverse to the transmitted signals, to create an identity matrix allowing the transmitted signals to be received independently at each receiver after the antenna thus recreating the cable conducted situation but with radiated self-interference now included.

Assume $x_1$andx_2 are the transmitted signals from the PXT base station emulator, after applying the desired multipath fading channel and convolving with the complex antenna pattern we get:

$f(x_1)$ and $f(x_2)$.

The radiated channel matrix between the probe antennas and the UE antennas is $= \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix}$.

If the channel emulator applies the inverse of the radiated channel matrix $H^{-1} = \begin{pmatrix} \alpha & \beta \\ \gamma & \delta \end{pmatrix}$ to $f(x_1)$ and $f(x_2)$, the signal received at the UE antennas is same as the cable-conducted method as follows:

$$\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} \begin{pmatrix} \alpha & \beta \\ \gamma & \delta \end{pmatrix} \begin{pmatrix} f(x_1) \\ f(x_2) \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} f(x_1) \\ f(x_2) \end{pmatrix} = \begin{pmatrix} f(x_1) \\ f(x_2) \end{pmatrix}$$

6.3.1.3.2 Test conditions

This candidate solution supports testing of different figure of merits. It is also applicable for any 3GPP Release, and even for other standards.

This method can reuse existing SISO OTA anechoic chambers to make the antenna pattern measurements; the channel emulator number is required to match the number of device receiver inputs regardless of the complexity of the chosen channel model, the method is consequently easily scalable to higher order MIMO due to the reduced number of instruments required; the channel models are highly accurate due to being implemented electronically and are also fully flexible and can be altered to suit any desired operating conditions such as indoor-outdoor, high or low Doppler spread, high or low delay spread, beam width, in 2D or full 3D etc.

This method requires the chipset in DUT to support amplitude and relative phase measurements of the antennas, and it cannot directly measure self-desensitization since the antenna pattern measurement does not take account of possible signal leakage from the device transmit antennas into the receive antennas.

The detailed test procedure can be found in Annex B.

6.3.1.4 Candidate solution 4

In this method an assessment of the antenna's performance in MIMO or Diversity operation is performed. Several simplifications are used in order to optimise the testing.

A test of the UE in an anechoic environment with the help of a base station emulator is proposed, with a limited number of faded channels and transmitting antennas, and in a simple geometrical set-up.

The underlying principle is to decompose the task for evaluating MIMO performance. Since in the conformance test many properties of the DUT are already tested in a conducted environment, the OTA test only has to add information not achievable by a cabled set-up.

For that reason it then is sufficient to define some abstract channel environment during the test which does not need to be very close to reality. Abstraction on the environment makes it easier to interpret the obtained results.

The channel information available in the UE can be used to deliver a quick answer to the test system about the current receive quality. Such a measurement is much faster than the evaluation of a throughput figure, but it is nevertheless closely related to it. If necessary, an explicit scaling from one quantity onto the other one can be made.

6.3.1.4.1 Concept and configuration

The test set-up uses an anechoic chamber. In case of an RX diversity measurement the signal from the base station emulator is routed via a two-channel fading to two antennas in the chamber. For an RX MIMO measurement, the two signals from the base station emulator can undergo a 2x2 channel fading simulation before reaching the antennas in the chamber, or can be routed directly to the probe antennas with some chosen polarization.

Figure 6.3.1.4.1-1 is a sketch of the chamber set-up. For obtaining various angles of arrival (AoA) at the EUT, two antennas A1 and A2 can be rotated in a vertical plane and can be put to angles θ1 and θ2. The UE is placed on a turntable rotating around the vertical axis by some angle φ. In addition, the UE may be tilted by some additional rotation around the horizontal axis, not shown in the figure. By this arrangement the two antennas A1 and A2 can send the signals from the base station emulator to any position on the unit sphere around the UE, thus creating arbirtrary AoA.

As an alternative to moving the antennas by mechanically rotating them it is possible to arrange the antennas in a horizontal plane and to move one antenna with respect to the other in order to vary the angle difference between the two. In that case the positioner rotating the UE will be designed in a more complex way.

Typically, the antennas are dual-polarised ones. In the usual configuration each antenna is sending its signal in one polarization only. Tests are made for the various combinations of antenna polarizations in order to generate either co-polarized or cross-polarized signals. As a special case it is also possible to test with one antenna where each polarization is transmitting one MIMO data stream. This will lead to identical AoAs for the two data streams.

If one wants to extend this method to 3D AoA, a third antenna outside the plane can be used.

The figure does not show an additional antenna used for the uplink communication. This antenna may be placed in the vicinity of the UE, for example in the φ positioner. It is common practise to use circularly polarized antennas for this purpose, and to use a limiting amplifier in the path towards the BSE in order to get a good and constant UL level.

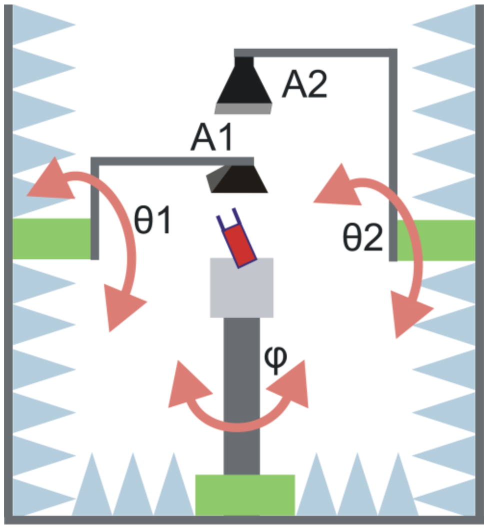


Figure 6.3.1.4.1-1: Two (2) Channel Method, antenna arrangement in anechoic chamber

A test point is described by:

1) Signal from BSE, e.g. frequency, MCS, data rate, MIMO mode, …
2) Fading characteristics (if applicable) and antenna polarisations
3) Antenna positions
4) UE position elevation, azimuth

The detailed settings for the various parameters describing a test point are for further study.

The measurement then uses the quantities CQI, RI and PMI for a quick evaluation of the channel characteristics for each given test point. More precisely, the DL power will be changed until a change in the returned channel information is observed.

In case the required figure of merit is some other quantity such as throughput, some mapping from the channel information onto the figure of merit can be made. This mapping of course depends on the signal settings on the BSE and possibly on other parameters. The mapping can be derived in a series of measurements where changes to the channel parameters lead to different channel information values and to different corresponding values of the figure of merit. It is also possible but more time-consuming to measure the figure of merit for each test point.

The OTA performance can better be described by taking statistical evaluations into account. If, for example, for each test point a relative throughput value is obtained as function of subcarrier power, one can plot the results for different points in a histogram and to obtain some CCDF indicating the conditions for getting at least a given TP value.

6.3.1.5 Candidate solution 5

The RF-controlled spatial fading emulator can directly reproduce a multipath radio propagation environment by radio waves emitted from antenna-probe units arranged around a handset tested. Moreover, the emulator has an advantage of measuring radiation characteristics of a handset antenna for the present OTA testing in 3GPP as well as the multipath testing because of its RF operation [6].

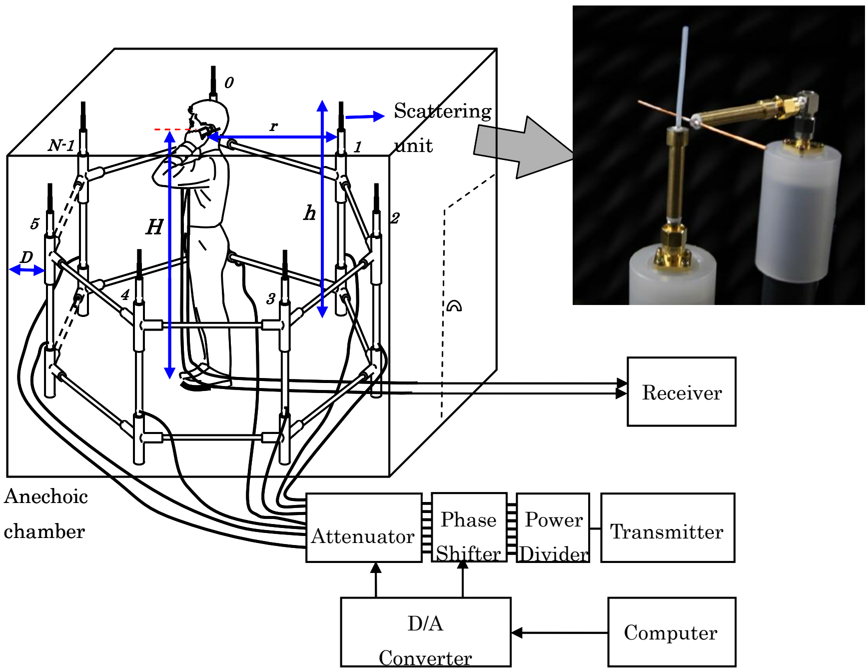
6.3.1.5.1 Concept and configuration

The RF-controlled spatial fading emulator can directly reproduce multipath radio propagation environments both in line-of-sight (LOS) and non line-of-sight (NLOS) situations by radio waves emitted from antenna probes arranged around a DUT. Thus, the emulator can be easily used for measurement of the MIMO characteristics of a HSPA/LTE multiple antenna device in a multipath fading environment.

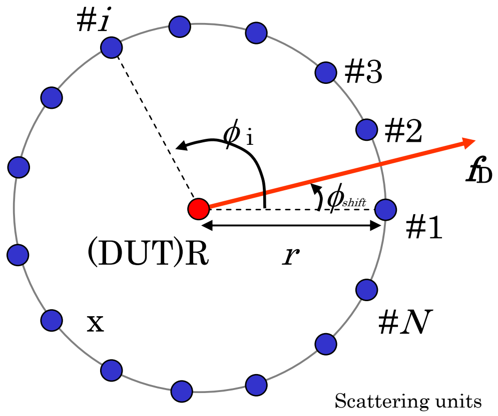
Figure 6.3.1.5.1-1 (a) and (b) show the configuration and arrangement of the antenna probes of the RF spatial fading emulator in an anechoic chamber. In this method, the DUT is designated as any device that possesses multiple antennas, including a HSPA or LTE device.

The height of DUT from the floor of the anechoic chamber is $\boldsymbol{H}$. The DUT can also be placed at a rotatable turn-table in order to set and vary the horizontal angle of the DUT. The DUT is surrounded by $\boldsymbol{N}$ numbers of antenna probes. The distance between DUT and each antenna probe is $\boldsymbol{r}$. The antenna probe consists of two antennas. The one is a half-wavelength dipole set vertically for emitting the vertically-polarized wave and the other is a horizontally-located half-wavelength dipole for the horizontally-polarized wave. This configuration of the antenna-probe unit can represent a cross polarization power ratio, XPR, of incoming wave. The separation between vertical and horizontal antennas is $\boldsymbol{d}$. The height of the antenna probe from the anechoic chamber floor is $\boldsymbol{h}$. The distance between the ring of antenna probes and the walls of anechoic chamber is $\boldsymbol{D}$. (Note if the anechoic chamber is not square, then $\boldsymbol{D_1}$ and $\boldsymbol{D_2}$ are used).

A reference antenna probe is designated so that it can be used to determine the direction of motion of DUT. This parameter is designated as ϕ_{shift} . The circular angle between antenna probes from the centre of the ring (i.e. DUT) is ϕ_i with respect to the reference antenna probe.



(a) Experimental Setup



(b) Arrangement of the antenna probes

Figure 6.3.1.5.1-1: Experimental setup of the spatial fading emulator

The key features of this method are that it does not use the sophisticated commercial channel emulator. By using the combination of phase shifters, power dividers and attenuators, operating in the RF band, it has been shown that a realistic fading channel environment can be emulated. To reduce the influence from the measurement equipment, the receiver, phase shifter, power divider, transmitter and computer are set outside of the anechoic chamber. Firstly, we describe channel response between the m^{th} base station, BS, antenna and the n^{th} handset antenna for *M*-by-*N* MIMO radio communication system. The channel response is calculated by following equation:

$$h_{nm} = \sum_{i=1}^{N} E_n(\phi_i)\sqrt{\Omega(\phi_i)}\frac{\lambda}{4\pi \cdot r}\exp[-j\{kr + 2\pi \cdot t \cdot f_D \cos(\phi_0 - \phi_i) + \alpha_{mi}\}] \quad (1)$$

where E_n and f_D are radiation component of the *n*-th handset antenna and the Doppler frequency respectively. ϕ_0 is the direction of motion and ϕ_i is the direction of the *i*-th antenna probe. α_{mi} is initial phase of the signal radiated from the *i*-th antenna probe. The waves radiated from each base station (BS) antenna are uncorrelated each other. For the investigation of MIMO antennas, the waves from different BS antenna are represented by different sets of initial phases, α_{mi}, of the waves. According to the propagation models, such as SCM and SCME, the angular power spectrum Ω of the spatial cluster of incoming waves in the horizontal plane can be modelled by a Laplacian distribution in the following, for instance:

$$\Omega(\phi) = \frac{P}{2\sigma}\exp\left\{-\frac{|\phi - \mu_\phi|}{\sigma}\right\} \quad (2)$$

where P and μ_ϕ are power and average direction of angle of the cluster. σ is a standard deviation of the APS. In this case, the spatial distribution in the vertical plane is modelled by a delta function.

In addition, the strongest point of the spatial fading emulator is to be capable of evaluating radiation characteristics of a handset antenna for the present OTA testing in 3GPP as well as the multipath-fading evaluation since the emulator is operated in a radio frequency (RF) band.

A calibration of the RF-controlled spatial fading emulator is carried out using the following procedure:

1) Firstly a half-wavelength dipole for the receiving antenna is vertically placed at the center of a circle arranging the antenna probes.

2) A radio wave with vertical polarization is radiated only from a vertical dipole of the antenna probe #i (i=1, 2, …, L), and then, the dipole at the center of the emulator can receive the wave. From this, we can obtain amplitude and phase of the RF signal from the transmitter to the receiver via the vertical dipole of the antenna probe #i.

3) The attenuator and phase shifter are adjusted so that the RF signals received by the dipole at the center have the same values in amplitude and phase.

4) Secondly the slotted cylindrical antenna is placed at the center of the antenna probes located on the circle.

5) A radio wave with horizontal polarization is radiated only from a horizontally-located dipole of the antenna probe #i (i=1, 2, …, L). From the received signal from the antenna probe #i, we also obtain amplitude and phase of the RF signal from the transmitter to the receiver via the horizontal dipole of the antenna probe #i.

6) The attenuator and phase shifter are adjusted so that the RF signals received by the slotted cylindrical antenna at the center have the same values in amplitude and phase.

The calibration procedure above mentioned can be performed by using an electrical-controlled RF switch. Thus, the calibration of the emulator can be done automatically using a computer in our system. Once the calibration is finished, we can vary the attenuators in order to produce a special distribution of the incoming wave and to make a cross polarization power ratio (XPR). Moreover, we can set an initial phase to each antenna probe to create a multipath fading channel.

With regard to the signal-to-noise power ratio, SNR, of incoming wave, the signal power can be determined by an average value of faded signal powers received by a half-wavelength dipole antenna for the vertical polarization and a slotted cylindrical antenna for the horizontal polarization. Both antennas have an omni-directional radiation pattern. Thus, SNR can be obtained as the following equation:

$$SNR = \frac{S_V + S_H}{N_0} \tag{3}$$

where S_V and S_H are the average signal powers received by the dipole and slotted cylindrical antennas, respectively. N_0 is the noise power that was calculated as a thermal noise within the frequency bandwidth of the radio communication.

6.3.1.5.2 Test conditions

In this method, all signals are operated and controlled at RF level. A computer (either a laptop or relatively powerful computer) is used to provide the followings:

1) Graphical user interface (GUI) to set the input parameters, determine the measured parameters to be collected, setting of calibration parameters and setting of DUT parameters.

2) Generating control signals to manipulate the phase angle of each Phase Shifter.

3) Collecting measured raw data obtained via the DUT.

4) Post-processing the measured raw data to derive the desired figure of merits (i.e. minimum requirements for DUT).

5) To initiate the BS emulator and start the testing session (by establishing a communication session with DUT)

The RF signals transmitted from the BS emulator's antenna connector are fed to a bank of Power Dividers. Each power divider provides identical RF signal from each of the output ports. The number of Power Dividers required is determined by ***N***.

Each Power Divider output is then fed to a Phase Shifter. The Phase Shifter is used to change the phase of the RF signal according to the parameter setting input to the computer earlier. Note that the control signal from the computer is digital-to-analogue, D/A, converted, before used to control the Phase Shifter. By controlling the phase of each RF signal, a Rayleigh distributed or other relevant multipath distribution can be obtained. The number of Phase Shifters required is determined by ***N***.

The output of the Phase Shifters is connected to the antenna probes. The signal from each Phase Shifter is fed to the vertical and horizontal antennas and radiates toward the DUT. The DUT then measures the signals from each antenna probe and the measurement data is reported back to the computer. The amount of measurement data to be collected can be controlled by the computer by setting the sampling rate, ***R***.

An example below illustrated the principle of creating Rayleigh faded signal by control the phase of each component wave in Figure 6.3.1.5.2-1.

Number of antenna probes N : 15

Direction of motion ϕ_0 : 10 deg.

Doppler frequency f_D : 20 Hz

Sampling frequency f_S : 400 Hz

Radius of circle arranging antenna probes r : 1.0 m

Operating frequency : 2.14 GHz

Receiving antenna (Rx) : half-wavelength Dipole

Radiation pattern of Rx $E_n(\phi)$: omni

APS, $\Omega(\phi)$:Uniform

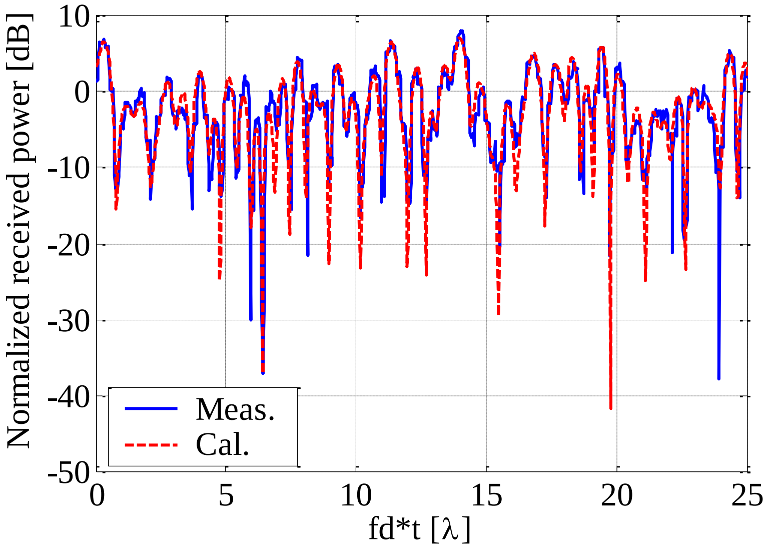


Figure 6.3.1.5.2-1: Rayleigh faded signal by control the phase of each component wave

6.3.1.Y Downlink Transmission Modes

<Editor: add texts>

6.3.2 Methodologies based on Reverberation Chamber

6.3.2.1 Candidate solution 1

The Reverberation Chambers is a metallic cavity or cavities that can emulate an isotropic multi-path environment which represents a reference environment for systems designed to work during fading, similar to how the free space "anechoic" reference environment is used for tests of Line-Of-Sight systems. The Rayleigh environment in a reverberation chamber is well known as a good reference for urban and indoor environments, but does not well represent rural and suburban environments.

For a future Multi-antenna OTA measurement standard it is important to have a fast and repeatable test method to evaluate and compare multi-antenna devices in the environments and under the conditions where most people will use them. The overwhelming majority of calls/data connections with mobile phones are made indoors and in urban areas which can be very well represented by the reverberation chamber. These environments are well characterised by multi-path and 3D distribution of the communication signals and it makes sense to use the reverberation chamber for optimizing/evaluating devices with both single and multiple antenna configurations to be used indoors and in urban areas.

The test setup for testing UE receiver diversity performance is composed of a base station emulator, a reverberation chamber equipped with fixed BS wall-mounted antennas, a switch to direct the base station signal to/from one of the BS wall mounted antennas, mechanical metallic stirrers and a rotating platform to hold the DUT (Figure 6.3.2.1-1). Alternatively, the chamber may contain one or more cavities coupled through waveguides or slotted plates (Figure 7.1-2).

Reverberation chambers have no quiet zone. As long as the DUT is placed at least 0.5 wavelengths from the wall or metallic stirrers the result will be the same within the standard deviation of the chamber.

Mechanical stirrers and switching among different fixed BS wall-mounted antennas (monopoles used for polarization stirring) allow simulating the Rayleigh fading at each antenna of the terminal inside the chamber. Accuracy can even been increased by rotating the platform holding the device.

Each position of the mechanical stirrers for each position of the platform and each fixed BS antenna, represents a point of the Rayleigh distribution in terms of receive power on the device antennas. In that way a Rayleigh fading is artificially created.

In that way, several UE metrics can be measured: throughput with RX-DIV, TRP, TIS (Total isotropic sensitivity), etc.

For each point of the Rayleigh distribution created by the different configurations of the chamber, the metric is noted. This method can be used to measure UE sensitivity and UE radiated power.

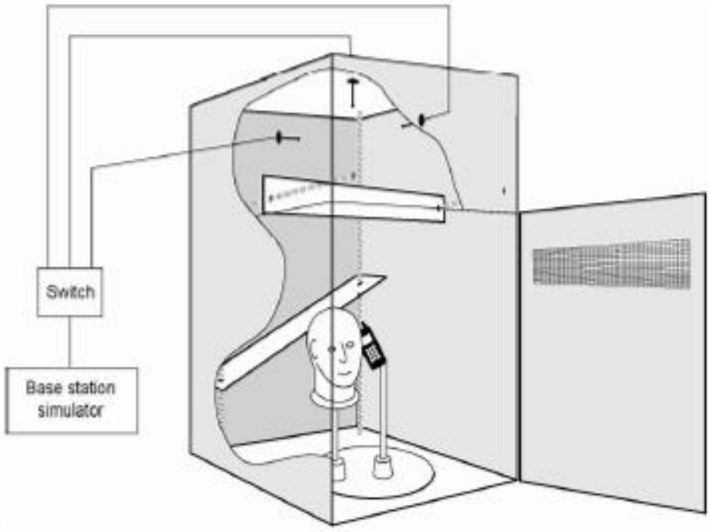


Figure 6.3.2.1-1: Reverberation chamber setup for devices testing with Single Cavity [source: Bluetest AB]

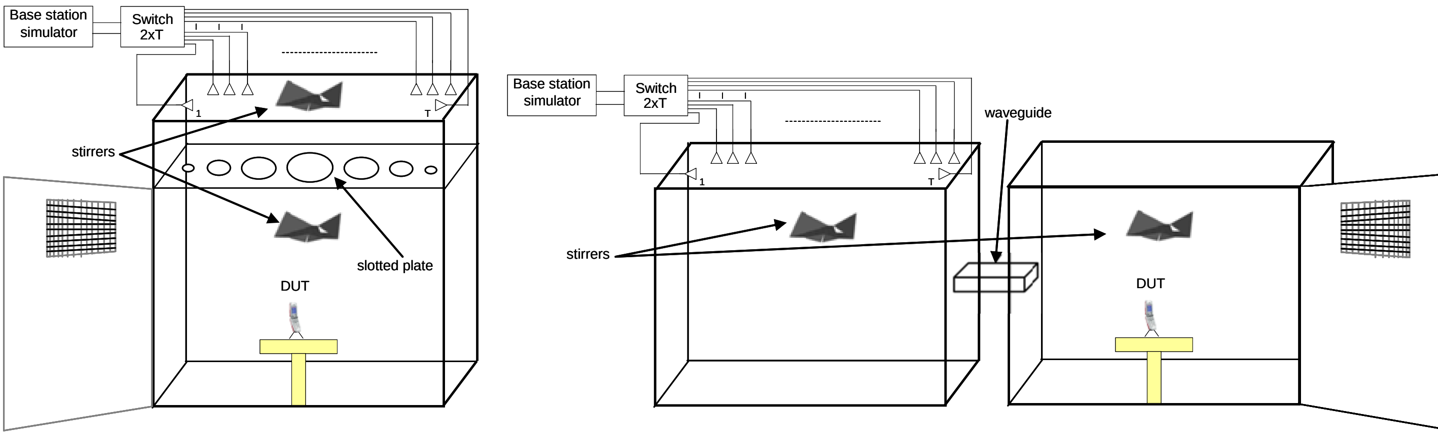


Figure 6.3.2.1-2 Reverberation Chambers with Multiple Cavities [source: EMITE Ing]

6.3.2.1.1 Concept and configuration

In order to calibrate the reverberation chamber a broadband antenna can be used to measure the losses in the chamber with a network analyzer. This takes < 10 minutes. CTIA RCSG is working on a standard methodology for reverberation chamber calibration.

There are no active electronics in the measurement path that needs to be calibrated.

Reflections in turntables, cables, doors, etc, do not degrade accuracy. Reflections increase the richness of the channel in the reverberation chamber.

Existing studies show that low standard deviation (good accuracy) can be achieved by measuring the DUT in sufficient number of different positions and calculate the average of the values. Some analysis (see relevant references in [2]) show a typical standard deviation less than 0.5 dB at about 800 MHz, in a reverberation chamber with a size of 1.2m x1.75m x 1.8m and continuous mode stirring. At higher frequencies or with a chamber of larger dimensions the standard deviation decreases and accuracy increases.

The following figure presents an example for an HSDPA receive diversity test configuration in a reverberation chamber.

For these tests we emulate an HSDPA call with a Node B emulator. The latter is connected to one of the 3 BS wall-mounted antennas through a switch. A fourth antenna allows measuring the DL received signal in the chamber with a spectrum analyzer.

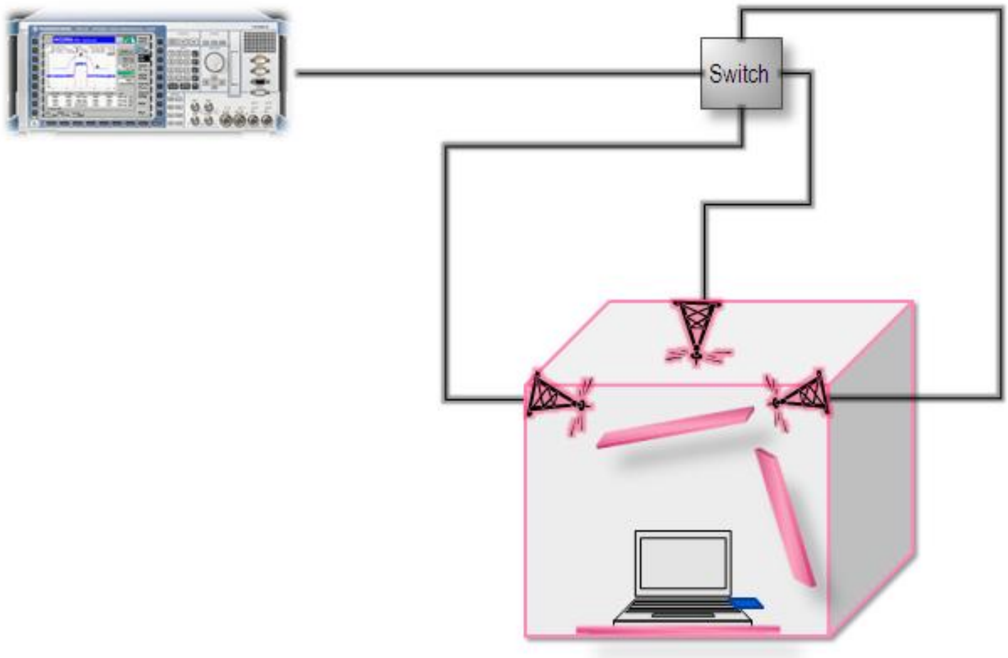


Figure 6.3.2.1.1-1: Test bench configuration for testing in reverberation chamber

In order to create a Rayleigh fading environment, we've got 3 types of parameters that can be set using a tool on a computer plugged to the chamber:

- Antenna among the 3, installed at the top of the cavity with different polarizations, is chosen
- Turning the platform that holds the DUT
- The 2 metallic stirrers near the walls can be moved on their axes

6.3.2.1.2 Test conditions

Once the chamber is calibrated, the downlink throughput testing can be performed as follows to get one throughput averaged measurement:

- The DUT is placed in the chamber at least 0.5 wavelengths from the wall or from the metallic stirrers
- An HSDPA call is emulated using the NodeB emulator with a pre-defined BS TX power.
- To get one measurement sample we set up one of the following possible combinations: position of the rotating platform {0, π/2, π, 3π/2, etc.} + position of the metallic stirrers {0, 25, 50, 75, 100, etc.} + antenna from {1, 2, 3}.
- For each one of these combinations we can record CQI, DL Throughput and DL Power in the chamber. The latter is measured using a fourth antenna and a spectrum analyzer. This constitutes one measurement sample. For each measurement sample, the link adaptation is performed manually or automatically on the NodeB emulator as follows: the HS-DSCH is configured (modulation, transport block size, number of HS-DSCH) depending on the CQI (Channel Quality Indicator) reported by the UE (User Equipment) according to the mapping table in [5].
- Once enough different DL throughput measurement samples (ideally $\geq$ 100), corresponding to different Antenna, rotating platform's position and stirrers' position combinations, are recorded for the same NodeB emulator DL TX power, they can be averaged to have the averaged DL throughput measurement.

The test duration can be significantly reduced if all these steps are automated. With a variable reference channel (VRC) and continuous mode stirring total measurement time of less than 10 minutes could be possible.

6.3.2.2 Candidate solution 2

The reverberation chamber by itself has a limited range of channel modelling capabilities. Specifically,

- The power/delay profile is limited to a single decaying exponential
- The Doppler spectrum and maximum Doppler is limited by the relatively slow motion of the stirrers
- It is difficult to impart a specific, repeatable MIMO fading correlation on the downlink waveform

These limitations can be overcome when a MIMO channel emulator and reverberation chamber are cascaded.

The power/delay profile (PDP) can be enhanced beyond the single decaying exponential by programming the channel emulator with fading taps set at the desired excess delays. The resulting PDP will be the convolution of the taps provided by the channel.

The fading taps provided by the channel emulator allow much higher Doppler spreads than from the reverberation chamber alone. If a classical fading spectrum with a maximum Doppler of 100 Hz is desired, the channel emulator is configured to provide this. The resulting overall Doppler spectrum that results is the convolution of the channel emulator's Doppler spectrum with that of the reverberation chamber.

The fading produced by the cascaded channel emulator and reverberation chamber has a double-Rayleigh amplitude distribution. Because performance simulations generally use Rayleigh fading, simulation results for the double-Rayleigh case are not available.

The benefit is testing with a much higher maximum Doppler, on the order of 100 Hz or higher, than is possible with the reverberation chamber alone. Under these conditions, the reverberation chamber-induced fading will effectively be constant while the channel emulator-induced fading will dominate. Therefore, while a receiver's performance under such circumstances will definitely be different than under normal Rayleigh fading conditions, it should not undermine the receiver's ability to demodulate. Tests have shown that this is indeed the case. However, due to the lack of double-Rayleigh simulation results, measured results should only be compared with other devices using these same test conditions.

The correlation of fading between the downlink MIMO transmission paths can be adjusted using the channel emulator. This is also known as "BS correlation," reflecting the fact that it is controlled on the BS side of the link. The way to set this correlation using the channel emulator is as follows: using the Kronecker model of fading correlation, set the desired correlation of the transmit or BS correlation matrix. The receiver or MS correlation matrix should be set to identity. An example is given for a 2x2 MIMO system:

$$R_{BS} = \begin{bmatrix} 1 & \rho \\ \rho & 1 \end{bmatrix}, \quad R_{MS} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \quad R_{chan} = R_{BS} \otimes R_{MS}$$

The value for ρ is the desired correlation between the two downlink paths. Note that it is not possible to control the phase of the correlation, only the amplitude.

The downlink antennas in the chamber are typically referred to as "wall" antennas. There should be a number of them equal to the number of spatial streams supported by the DUT. The spacing of the wall antennas is not very important. Tests have shown that as the spacing between them is changed over a range between 6 and 80 mm, the measured correlation changes very little, on the order of 5% to 10%.

6.3.2.2.1 Concept and configuration

The general configuration to be used for testing is shown in Figure 6.3.2.2.1-1. The specific example show there is for two BS antennas. If higher order MIMO devices are to be tested, additional antennas are required. The channel emulator is placed between the (e)NodeB emulator and the reverberation chamber. Two calibrations are performed:

1) Calibration of reverberation chamber loading to set the proper chamber impulse response. Most of the time, the chamber will be loaded to produce a specific, desired chamber RMS delay spread. This is achieved using such devices as a phantom head, tank filled with liquid, and RF absorbing foam. For use with the channel emulator, it is

desirable to set the chamber RMS delay spread as low as is allowable (approximately 55 ns)[1], although higher RMS delay spreads are also legitimate, depending on the desired overall PDP.

NOTE 1: If the delay spread is reduced to below this point, the chamber's ability to produce the desired Rayleigh amplitude distribution at the DUT is degraded.

2) Calibration of the losses from (e)NodeB emulator to DUT location. This is already described in the test methodology for the reverberation chamber alone (subclause 6.3.2.1).

The calibrations are performed in this order, using a test antenna as the DUT antenna, and with the DUT in the chamber as it will be during the test. The contents of the chamber should not be disturbed after the calibration is complete. More information about the calibration procedures are found in a later clause.

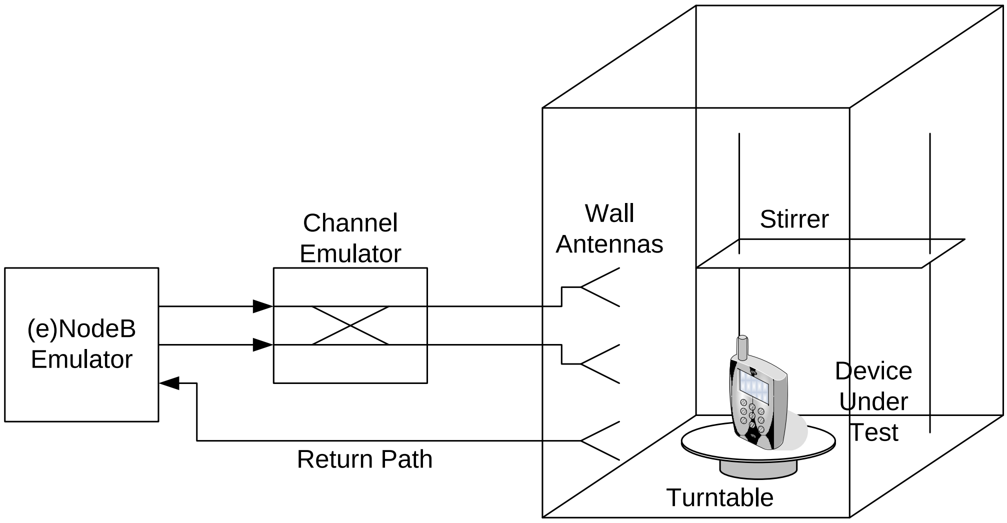


Figure 6.3.2.2.1-1: Test bench configuration for test using channel emulator and reverberation chamber for a 2x2 MIMO configuration

6.3.2.2.2 Test conditions

After the chamber is calibrated, the emulator is configured for the desired channel model, including the end-to-end PDP, the desired fading spectrum and Doppler spread, and the MIMO fading correlation. At this point, the system is ready to test the DUT, and a procedure appropriate to the FOM being measured is carried out.

There are three (3) operating methods, dependent on the motion of the stirrers and the state of the fading in the channel emulator.

In method 1, the stirrers, turntable or source antennas and channel emulator to operate continuously while the specific FOM is measured. A good example of this use would be throughput measurements under the conditions of a high Doppler rate, or, measured while the signal levels are varied over a wide range.

In method 2, the stirrers and turntable or source antennas are positioned in a number of combinations as described in 6.3.2.1.2. The channel emulator is allowed to run for a fixed length of time (usually 1 or 2 seconds is enough) and paused. The FOM is measured while the stirrers and turntable are not in motion, and the channel emulator is paused. In this method, the number of fixed positions and emulator states must be at least enough to guarantee the proper amplitude distribution. Automation of this entire procedure will significantly reduce the test time.

In method 3, the stirrers and turntable and/or source antennas are positioned as in method 2, but for each position, the channel emulator is allowed to run the fading channel model. The FOM is measured with the stirrers and turntable or source antenna stirring fixed and the channel emulator fading. This method is most analogous to the anechoic method which fixes the device rotation and runs the fading channel emulator while the FOM is measured. This method may also facilitate simulation.

6.3.2.Y Downlink transmission modes

<Editor: Text to be added>

7 Base Station (BS) configuration

7.1 eNodeB emulator parameter settings

The eNodeB emulator parameters are set according to Table 7.1-1 for FDD and Table 7.1-2 for TDD.
Testing with 64QAM is considered to be done optionally. The settings for DL stream 1 and stream 2 are the same.

Table 7.1-1: Parameter settings for FDD eNodeB emulator

Parameters (Note 1)	Unit	Value	
		Signal level (Note 2)	
Parameters	**Unit**	**middle**	**high**
Physical channel			
Connection mode of UE		Connection established	
DL MIMO mode		2 x 2 open loop spatial multiplexing	
Duplex mode		FDD	
Operating band (UL channel, DL channel)		[band 7] (21100, 3100) [band 20] (24300, 6300)	
Schedule tyoe		Reference Measurement Channel (RMC)	
Reference Channel		R.11 (Note 3)	R.35 (Note 3)
Bandwidth DL	MHz	10	
Number of RBs DL		50	
Start RB DL		0	
Modulation DL		16QAM	64QAM
Maximum Theoretical Throughput	Mbps	23.328	35.424
TBS Idx DL		13 (RMC defined)	18 (RMC defined, Note 3)
Bandwidth UL	MHz	10	
Number of RBs UL		50	
Start RB UL		0	
Modulation UL		QPSK	16QAM
TBS Idx UL		6 (RMC defined)	19 (RMC defined)
Transmit power control	dBm	-10/10 MHz, open loop (Note 4)	
PDSCH power offset relative to RS EPRE	dB	ρ_A = -3 ρ_B = -3	
Number of HARQ transmissions		1 (no HARQ re-transmissions)	
AWGN		OFF	
DL power level (RS EPRE)	dBm / 15 kHz	Set at eNodeB simulator with correction from calibration	
Number of subframes for FOM measurement		2000 minimum for static channel 20000 minimum for faded channel (Note 5)	

NOTE 1: This set of parameters is aligned with R&S CMW500, Anritsu MTC8820C, AT4 S3110B, and Agilent E6621A (to be confirmed).
NOTE 2: The indications for the signal level to be middle or high are describing the channel conditions under which either a 16QAM or a 64QAM modulation, as selected for the test, usually would be applied.
NOTE 3: This RMC is defined in 3GPP TS 36.521-1, Table A.3.3.2.1-1. R.35 subframes 1-4 and 6-9 utilize DL TBS 18, while R.35 subframe 0 utilizes TBS 17 (See Table A.3.3.2.1-1 Fixed Reference Channel two antenna ports in 3GPP TS 36.521-1, V10.1.0).
NOTE 4: No uplink power control.
NOTE 5: These values might need to be increased for frequency and mobile speed reasons.

Table 7.1-2: Parameter settings for TDD eNodeB emulator

Parameters	Unit	Value	
		Signal level (Note 1)	
Parameters	Unit	middle	high
Physical channel			
Connection mode of UE		Connection established	
DL MIMO mode		2 x 2 open loop spatial multiplexing	
Duplex mode		TDD	
Operating band (UL / DL channel)		[band 38] (38000) [band 39] (38450) [band 40] (39150) [band 41] (40620)	
Schedule tyoe		Reference Measurement Channel (RMC)	
Reference Channel		R.30 TDD (Note 2)	R.31-4 TDD (Note 2)
Up/Downlink Frame Configuration		1	
Special Frame configuration		7	
Bandwidth DL	MHz	20	
Number of RBs DL		100	
Start RB DL		0	
Modulation DL		16QAM	64QAM
TBS Idx DL		13 (RMC defined)	26 (RMC defined)
Bandwidth UL	MHz	20	
Number of RBs UL		100	
Start RB UL		0	
Modulation UL		QPSK	16QAM
TBS Idx UL		6 (RMC defined)	19 (RMC defined)
Transmit power control	dBm	-10/20 MHz, open loop (Note 3)	
PDSCH power offset relative to RS EPRE	dB	ρ_A = -3 ρ_B = -3	
Number of HARQ transmissions		1 (no HARQ re-transmissions)	
AWGN		OFF	
DL power level (RS EPRE)	dBm / 15 kHz	Set at eNodeB simulator with correction from calibration	
Number of subframes for FOM measurement		2000 minimum for static channel 20000 minimum for faded channel (Note 4)	
NOTE 1: The indications for the signal level to be middle or high are describing the channel conditions under which either a 16QAM or a 64QAM modulation, as selected for the test, usually would be applied. NOTE 2: This RMC is defined in 3GPP TS 36.521-1, Table A.3.4.2.1-1 and Table A.3.9.2-1. NOTE 3: No uplink power control. NOTE 4: These values might need to be increased for frequency and mobile speed reasons.			

8 Channel Models

8.1 Introduction

In order to understand how different methodologies are able to similarly distinguish good and bad MIMO devices, it is important to ensure that the radio propagation conditions that are implying to a particular DUT are the same or similar to a certain extent.

The different channel models are used as a simple way to create complex multipath radio propagation conditions and RAN4 has agreed to compare the realization of those channel models across the different methods.

8.2 Channel Model(s) to be validated

<Editor: Initially a small set of representative channel models shall be agreed and use to validate channel model realization. Other channel models could be used at a later stage. This clause shall also contain the identification of the main properties that characterize a given channel model as well as the expected results when realizing a channel model regardless of the methodology. >

The following channel models are to be used in evaluation of MIMO OTA methodologies.

The generic models are

- SCME Urban micro-cell, and
- SCME Urban macro-cell.

In the following we define the cross polarization power ratio a propagation channel as $XPR = XPR_V = XPR_H$, where

$$XPR_V = \frac{S_{VV}}{S_{HV}} \quad \text{and} \quad XPR_H = \frac{S_{HH}}{S_{VH}}$$

and

- S_{VV} is the coefficient for scattered/reflected power on V-polarization and incident power on V-polarization
- S_{VH} is the coefficient for scattered/reflected power on V-polarization and incident power on H-polarization
- S_{HV} is the coefficient for scattered/reflected power on H-polarization and incident power on V-polarization
- S_{HH} is the coefficient for scattered/reflected power on H-polarization and incident power on H-polarization

Note: for Vertical only measurements, the powers per delay are used without regard to the specified XPR values.

The following SCME Urban Micro-cell is unchanged from the original SCME paper, with added XPR values, Direction of Travel, and Velocity.

Table 8.2-1: SCME urban micro-cell channel model

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

The following SCME Urban Macro-cell is unchanged from the original SCME paper, with added XPR values, Direction of Travel, and Velocity.

Table 8.2-2: SCME urban macro-cell channel model

SCME Urban macro-cell								
Cluster #	**Delay [ns]**			**Power [dB]**			**AoD [°]**	**AoA [°]**
1	0	5	10	-3	-5.2	-7	82	66
2	360	365	370	-5.2	-7.4	-9.2	81	46
3	255	260	265	-4.7	-6.9	-8.7	80	143
4	1040	1045	1050	-8.2	-10.4	-12.2	99	33
5	2730	2735	2740	-12.1	-14.3	-16.1	102	-91
6	4600	4605	4610	-15.5	-17.7	-19.5	107	-19
Delay spread [ns]								839.5
Cluster AS AoD / AS AoA [°]								2 / 35
Cluster PAS shape								Laplacian
Total AS AoD / AS AoA [°]								7.8 / 62.6
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

The parameters of the channel models are the expected parameters for the MIMO OTA channel models. However, the final channel model achieved for different methods could be a combined effect of the chamber and the channel emulator.

The Rayleigh fading may be implementation specific. However, the fading can be considered to be appropriate as long as the statistics of the generated Rayleigh fading are within standard requirement on Rayleigh fading statistics.

<Editor: NIST channel model is not ruled out, but before it can be used, more information on the AoA values would need to be provided. >

8.2.1 Channel Model spatial and temporal characteristics and expected realization regardless the methodology

<Editor: Text to be added. Description of the set-up, calibration and validation process for this method, as well as how the main properties will be measured in order to enable comparison with expected results.>

8.3 Verification of Channel Model implementations

<Editor: Text to be added. Description of the process of validation of a channel model and commonalities between methods in the validation process.>

Channel Models have been specified in clause 8.2. This clause describes the MIMO OTA validation measurements, in order to ensure that the channel models are correctly implemented and hence capable of generating the propagation environment, as described by the model, within a test area, Measurements are done mainly with a vector network analyser (VNA) and a spectrum analyzer.

8.3.1 Measurement instruments and setup

The measurement setup includes the following equipment:

Table 8.3.1-1: Measurement equipment list for the verification procedure

Item	Quantity	Item
1	1	Channel Emulator
2	1	Signal Generator
3	1	Spectrum Analyzer
4	1	VNA
5	1	Magnetic Dipole
6	1	Sleeve Dipole

8.3.1.1 Network Analyzer (VNA) setup

Most of the measurements are performed with a VNA. An example set of equipment required for this set-up is shown in Figure 8.3.1.1-1. VNA transmits frequency sweep signals thorough the MIMO OTA test system. A test antenna, within the test area, receives the signal and VNA analyzes the frequency response of the system. A number of traces (frequency responses) are measured and recorded by VNA and analyzed by a post processing SW, e.g., Matlab. Special care has to be taken into account to keep the fading conditions unchanged, i.e. frozen, during the short period of time of a single trace measurement. The fading may proceed only in between traces. This setup can be used to measure PDP, Spatial Correlation and Polarization of the Channel models defined in Clause 8.2.

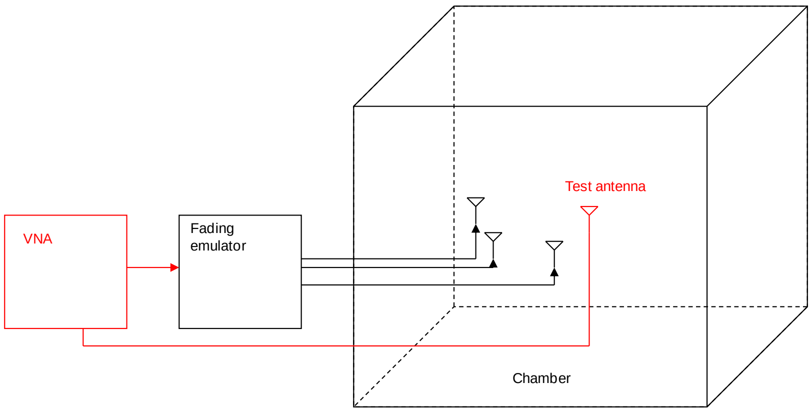


Figure 8.3.1.1-1: Setup for VNA measurements

8.3.1.2 Spectrum Analyzer (SA) setup

The Doppler spectrum is measured with a Spectrum analyzer as shown in Figure 8.3.1.2-1. In this case a Signal generator transmits CW signal through the MIMO OTA test system. The signal is received by a test antenna within the test area. Finally the signal is analyzed by a Spectrum analyzer and the measured spectrum is compared to the target spectrum. This setup can be used to measure Doppler Spectrum of the Channel models defined in clause 8.2.

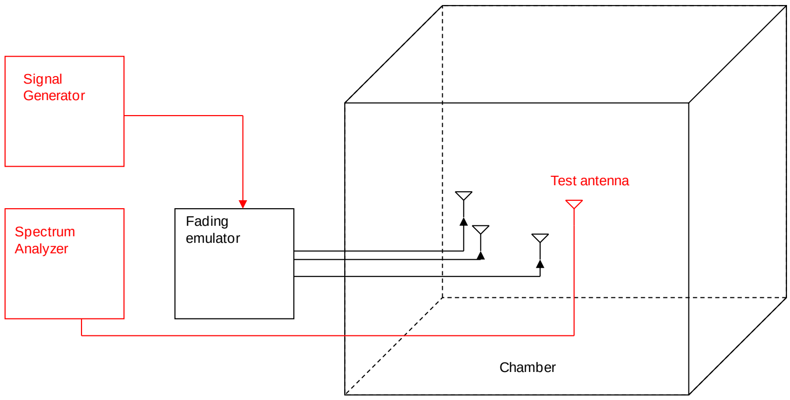


Figure 8.3.1.2-1: Setup for VNA measurements

8.3.2 Validation measurements

8.3.2.1 PDP

This measurement checks that the resulting power delay profile (PDP) is like defined in the channel model.

Method of measurement:

Step the emulation and store traces from VNA. I.e. run the emulation to CIR number 1, pause, measure VNA trace, run the emulation to CIR number 10, pause, measure VNA trace. Continue until 1000 VNA traces are measured.

VNA settings:

Table 8.3.2.1-1: VNA settings for PDP

Item	Unit	Value
Center frequency	MHz	Downlink center frequency in 3GPP TS 36.508 [xy} as required per band
Span	MHz	200 [TDB]
RF output level	dBm	-15
Number of traces		1000
Distance between traces in channel model	wavelength (Note)	> 2
Number of points		1101
Averaging		1
NOTE: Time [s] = distance [λ] / MS speed [λ/s] MS speed [λ/s] = MS speed [m/s] / Speed of light [m/s] * Center frequency [Hz]		

Channel model specification:

Table 8.3.2.1-2: Channel model specification for PDP

Item	Unit	Value
Center frequency	MHz	Downlink center frequency in 3GPP TS 36.508 [xy] as required per band
Channel model samples	wavelength	> 2000
Channel model		As specified in clause 8.2

Method of measurement result analysis:

Measured VNA traces (frequency responses H(t,f)) are saved into a hard drive. The data is read into, e.g., Matlab. The analysis is performed by taking the Fourier transform of each FR. The resulting impulse responses h(t,tau) are averaged in power over time:

$$P(\tau) = \frac{1}{T}\sum_{t=1}^{T}\left|h(t,\tau)\right|^2$$

Finally the resulting PDP is shifted in delay, such that the first tap is on delay zero. The reference PDP plots from Table 8.2-1 and Table 8.2-2 are shown in Figure 8.3.2.1-1.

OTA antenna configuration:

For e.g. 1 full ring (or single cluster configuration) of V polarized elements.

Measurement antenna:

For e.g. Vertically oriented sleeve dipole.

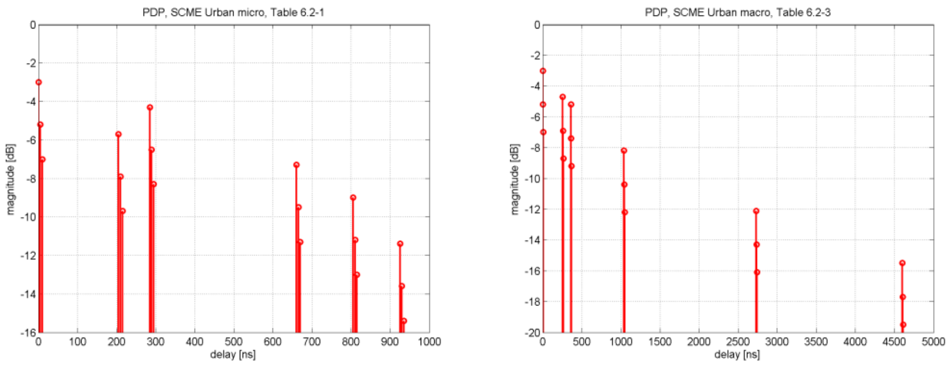


Figure 8.3.2.1-1: Reference PDP values for SCME Urban Macro / SCME Urban Micro plotted from Table 8.2-1 and Table 8.2-2

8.3.2.2 Doppler/Temporal correlation

This measurement checks the Doppler/temporal correlation.

Method of measurement:

Sine wave (CW, carrier wave) signal is transmitted from the signal generator. The signal is connected from the signal generator to fading emulator via cables. The fading emulator output signals are connected to power amplifier boxes via cables. The amplified signals are then transferred via cables to the probe antennas. The probe antennas radiate the signals over the air to the test antenna The Doppler spectrum is measured by the spectrum analyzer and the trace is saved.

Signal generator settings:

Table 8.3.2.2-1: Signal generator settings for Doppler/Temporal correlation

Item	Unit	Value
Center frequency	MHz	Downlink center frequency in 3GPP TS 36.508 [xy] as required per band
Output level	dBm	-15
Modulation		OFF

Spectrum analyzer settings:

Table 8.3.2.2-2: Spectrum analyzer settings for Doppler/Temporal correlation

Item	Unit	Value
Center frequency	MHz	Downlink center frequency in 3GPP TS 36.508 [xy] as required per band
Span	Hz	4000
RBW	Hz	1
VBW	Hz	1 or use FFT
Number of points		8001
Averaging		100

Channel model specification:

Table 8.3.2.2-3: Channel model specification for Doppler/Temporal correlation

Item	Unit	Value
Center frequency	MHz	Downlink center frequency in 3GPP TS 36.508 [xy] as required per band
Channel model		As specified in Clause 8.2
Mobile speed	km/h	100

Method of measurement result analysis: Measurement data file (Doppler power spectrum) is saved into hard drive. The data is read into, e.g., Matlab. The analysis is performed by taking the Fourier transformation of the Doppler spectrum. The resulting temporal correlation function $R_t(\Delta t)$ is normalized such that $\max(\mathrm{Re}(R_t(\Delta t)))=1$. Then the function values left from the maximum is cut out. Further on the function values after, e.g., seven periods is cut out. The reference temporal correlation plots from Table 8.2-1 and 8.2-2 are shown in Figure 8.3.2.2-1.

OTA antenna configuration:

For e.g. 1 full ring (or single cluster configuration) of V polarized elements.

Measurement antenna:

For e.g. vertically oriented dipole.

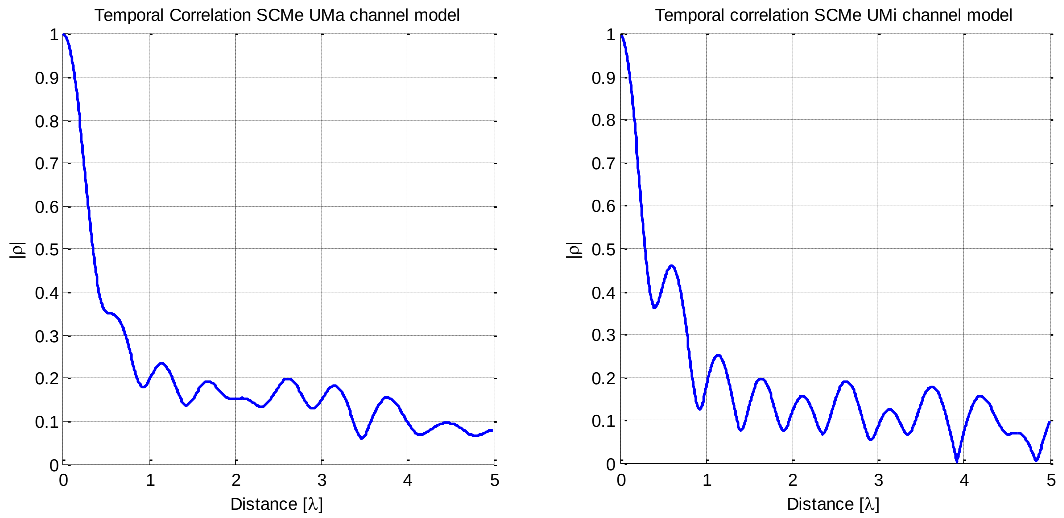


Figure 8.3.2.2-1: Reference Temporal Correlation Functions for SCME Urban Macro (left) and SCME Urban Micro (right) plotted from Table 8.2-1 and Table 8.2-2

8.3.2.3 Spatial correlation

This measurement checks whether the measured correlation curve follows the theoretical curve.

Method of measurement:

Step the emulation and store traces from VNA. I.e. run the emulation to CIR number 1, pause, measure VNA traces in 11 different DUT positions, run the emulation to CIR number 10, pause, measure VNA traces in 11 different DUT positions, … etc. Continue until frequency response of 1000 CIRs in 11 positions (=1000* 11 VNA traces) are measured.

11 test antenna positions sample a segment of line of length 1 wavelength with sampling interval of 0.1 wavelengths. Antenna spacing (wave lengths): -0.5 to +0.5 step of 0.1.

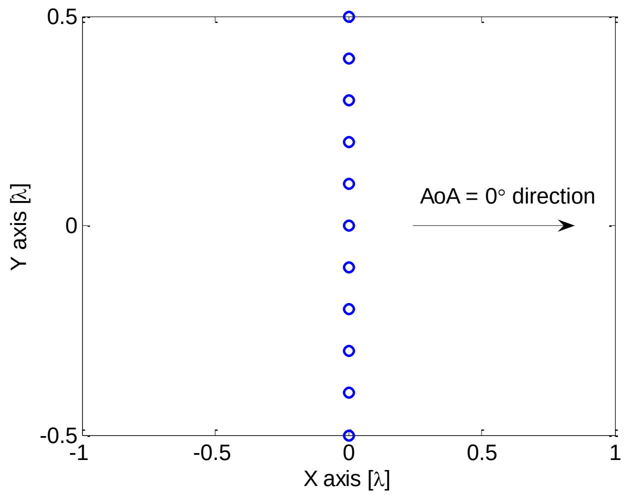


Figure 8.3.2.3-1: Test antenna positions

VNA settings:

Table 8.3.2.3-1: VNA settings for spatial correlation

Item	Unit	Value
Center frequency	MHz	Downlink center frequency in 3GPP TS 36.508 [xy] as required per band
Span	MHz	10
RF output level	dBm	-15
Number of traces		1000
Distance between traces in channel model	Wavelength (Note)	> 2
Number of points		1 (or the smallest possible)
Averaging		1
NOTE: Time in seconds = distance [λ] / MS speed [λ/s] MS speed [λ/s] = MS speed [m /s] / Speed of light [m/s] * Center frequency [Hz]		

Channel model specification:

Table 8.3.2.3-2: Channel model specification for spatial correlation

Item	Unit	Value
Center frequency	MHz	Downlink center frequency in 3GPP TS 36.508 [xy] as required per band
Channel model samples	Wavelength	> 2000
Channel model		As specified in Clause 8.2
Mobile speed	km/h	30

Measurement Procedure

CALIBRATE

OPEN corrVNATrace trace file

FOR EACH gridPoint **IN** [test zone grid set]

MOVE measurement antenna to gridPoint

FOR EACH chanIRNumber **IN** [0:SD:1000*SD]

MEASURE Freq Resp with VNA

SAVE freq resp trace to trace file

END

END

CLOSE corrVNATrace_<calibMethod>_<polarization> trace file

Method of Measurement Results Analysis

Calculate correlation of 1000 x 11 matrix **H**(*f*) of frequency response samples. The procedure is to correlate sixth column (the trace measured at the centre of chamber) with the 10 other columns as follows (Matlab example)

```
for ind = 1:11;
   Corr(: , : , ind) = abs(corrcoef(H(: , 1),H(: , ind)));
end
Correlation = squeeze(Corr(1, 2, :));
```

The reference spatial correlation plots from Table 8.2-1 and 8.2-2 are shown in Figure 8.3.2.3-2.

OTA antenna configuration:

For e.g. 1 full ring (or a single cluster configuration) of V polarized elements.

Measurement antenna:

For e.g. Sleeve dipole.

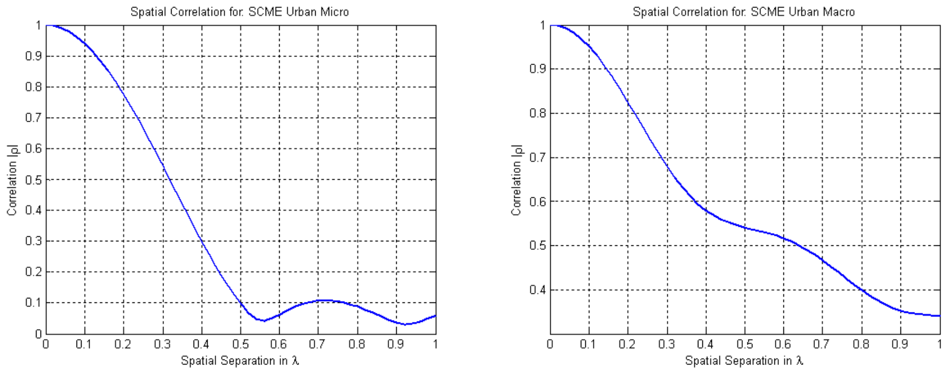


Figure 8.3.2.3-2: Reference Spatial Correlation Functions for SCME Urban Macro / SCME Urban Micro plotted from Table 8.2-1 and Table 8.2-2

8.3.2.4 Cross-polarization

This measurement checks how well the measured vertically or horizontally polarized power levels follow expected values.

Method of measurement:

Step the emulation and store traces from VNA.

VNA settings:

Table 8.3.2.4-1: VNA settings for cross-polarization

Item	Unit	Value
Center frequency	MHz	Downlink Center Frequency in 3GPP TS 36.508 [xy] as required per band
Span	MHz	10
RF output level	dBm	-15
Number of traces		1000
Distance between traces in channel model	Wavelength (Note)	> 2
Number of points		201
Averaging		1
NOTE: Time [s] = distance [λ] / MS speed [λ/s] MS speed [λ/s] = MS speed [m /s] / Speed of light [m/s] * Center frequency [Hz]		

Channel model specification:

Table 8.3.2.4-2: Channel model specification for cross-polarization.

Item	Unit	Value
Center frequency	MHz	Downlink center frequency in 3GPP TS 36.508 [xy] as required per band
Channel model samples	wavelength	> 2000
Channel model		As specified in Clause 8.2
Mobile speed	km/h	30

Measurement Procedure

1. Play or step through the channel model -> SCME UMi, or UMa X Corr.
2. Measure the absolute power received at the center of the array, averaged over a statistically significant number of fades.
    a. Use a vertically polarized sleeve dipole to measure the V component.
    b. Use a horizontally polarized (vertically oriented) magnetic loop dipole, or a horizontally polarized sleeve dipole measured in two orthogonal horizontal positions and summed to measure the H component.
3. Calculate the V/H ratio.
4. Compare it with the theory -> 0.83dB for UMi, and 8.13dB for UMa.

Expected measurement results

V/H ratio (composite, i.e., all 6 paths combined) of the 3GPP SCME Umicro model is 0.83 dB and for Umacro 8.13 dB. The BS antennas are isotropic dipoles with +/- 45 degrees slant and subject to a foreshortening of the slanted radiating element. See channel model details specified in Clause 8.2.

8.3.3 Reporting

Additionally, the results should be summarized in the following table:

Table 8.3.3-1: Table template for reporting validation results

Item	Parameter	Result	Tolerances (Note)	Comments
1	Power delay profile			
2	Doppler / Temporal Correlation			
3	Spatial Correlation			
4	Cross Polarization			
NOTE: The exact tolerances are FFS.				

8.4 Channel Model validation results

8.4.1 Scope

Clauses 8.4.2-6 contain the validation results of channel models defined in Clause 8.2 for companies using methods as described in Clauses 6.3.1.1 and 6.3.1.2. These results are based on two different types of channel emulators and setup vendors, and both sets of results are included here for comparison.

8.4.2. Power Delay Profile

The power delay profiles of the channel models specified in Clause 8.2 have been measured according to the procedures in 8.3.2.1. Figure 8.4.1-1 below illustrates the measured results for Band 13 for both channel emulators.

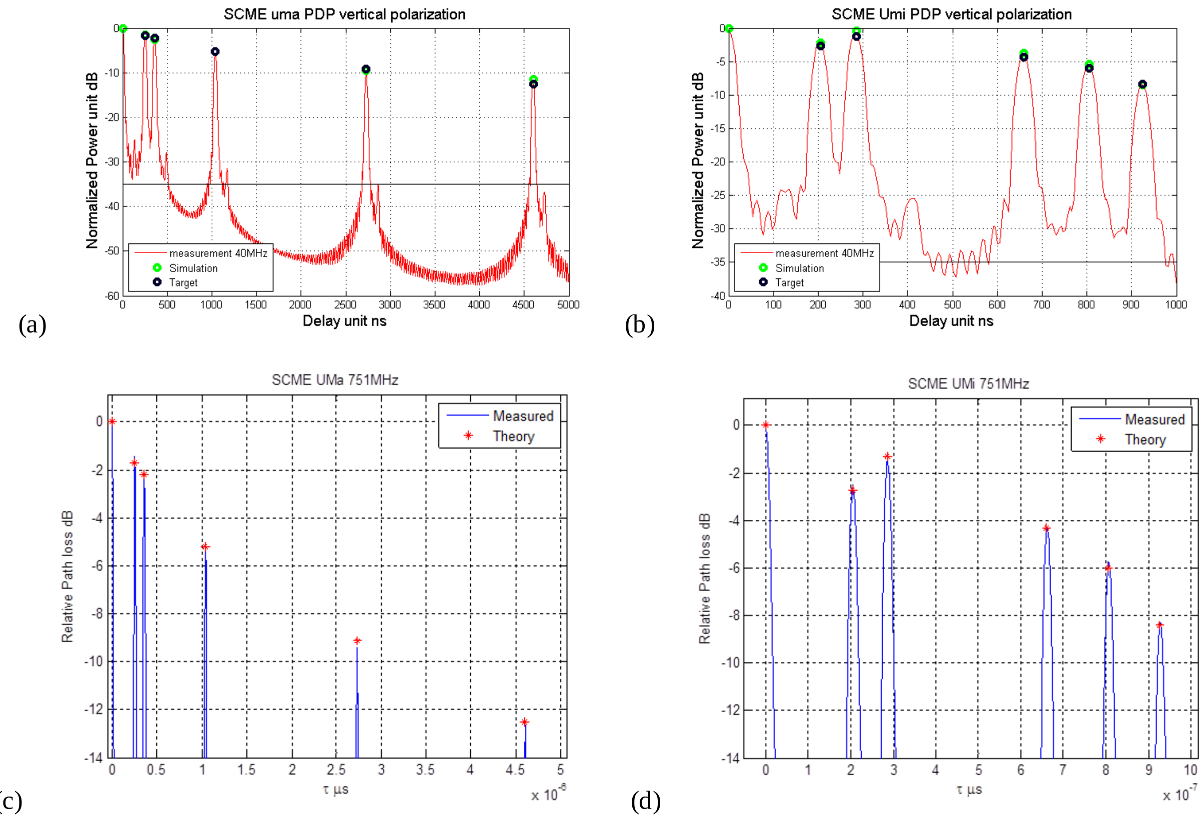


Figure 8.4.2-1: For Band 13, SCMe UMa (a) and SCMe UMi (b) PDP verification measurement for channel emulator A; SCMe UMa (c) and SCMe UMi (d) PDP verification measurement for channel emulator B

Table 8.4.2-1 below summarizes the PDP verification results.

Table 8.4.2-1: Summary of PDP verification results at Band 13 for both channel emulator vendors

SCMe UMa	**Channel Emulator A**			**Channel Emulator B**		
Cluster	**Simulated Power (dB)**	**Measured Power (dB)**	**Delta**	**Simulated Power (dB)**	**Measured Power (dB)**	**Delta**
1	0	0	0	0	0	0
2	-1.6	-2.2	-0.6	-1.7	-1.6	+0.1
3	-2.5	-2.7	-0.2	-2.2	-2.25	-0.05
4	-5.2	-5.9	-0.7	-5.2	-5.35	-0.15
5	-9.5	-10.1	-0.6	-9.1	-9.25	-0.15
6	-11.5	-11.6	-0.1	-12.5	-12.6	-0.1
SCMe UMi	Channel Emulator A			Channel Emulator B		
Cluster	Simulated Power (dB)	Measured Power (dB)	Delta	Simulated Power (dB)	Measured Power (dB)	Delta
1	0	0	0	0	0	0
2	-2.2	-2.2	0	-2.7	-2.75	-0.05
3	-0.4	-0.7	-0.3	-1.3	-1.35	-0.05
4	-3.7	-3.8	-0.1	-4.3	-4.35	-0.05
5	-5.4	-5.5	0.1	-6.0	-5.95	+0.05
6	-8.4	-8.4	0	-8.4	-8.45	-0.05

8.4.3. Doppler / Temporal Correlation

The Doppler spread and temporal correlation of the channel models defined in Clause 8.2 have been characterized according to Clause 8.3.2.2. Figure 8.4.3-1 below illustrates the measured results for Band 13.

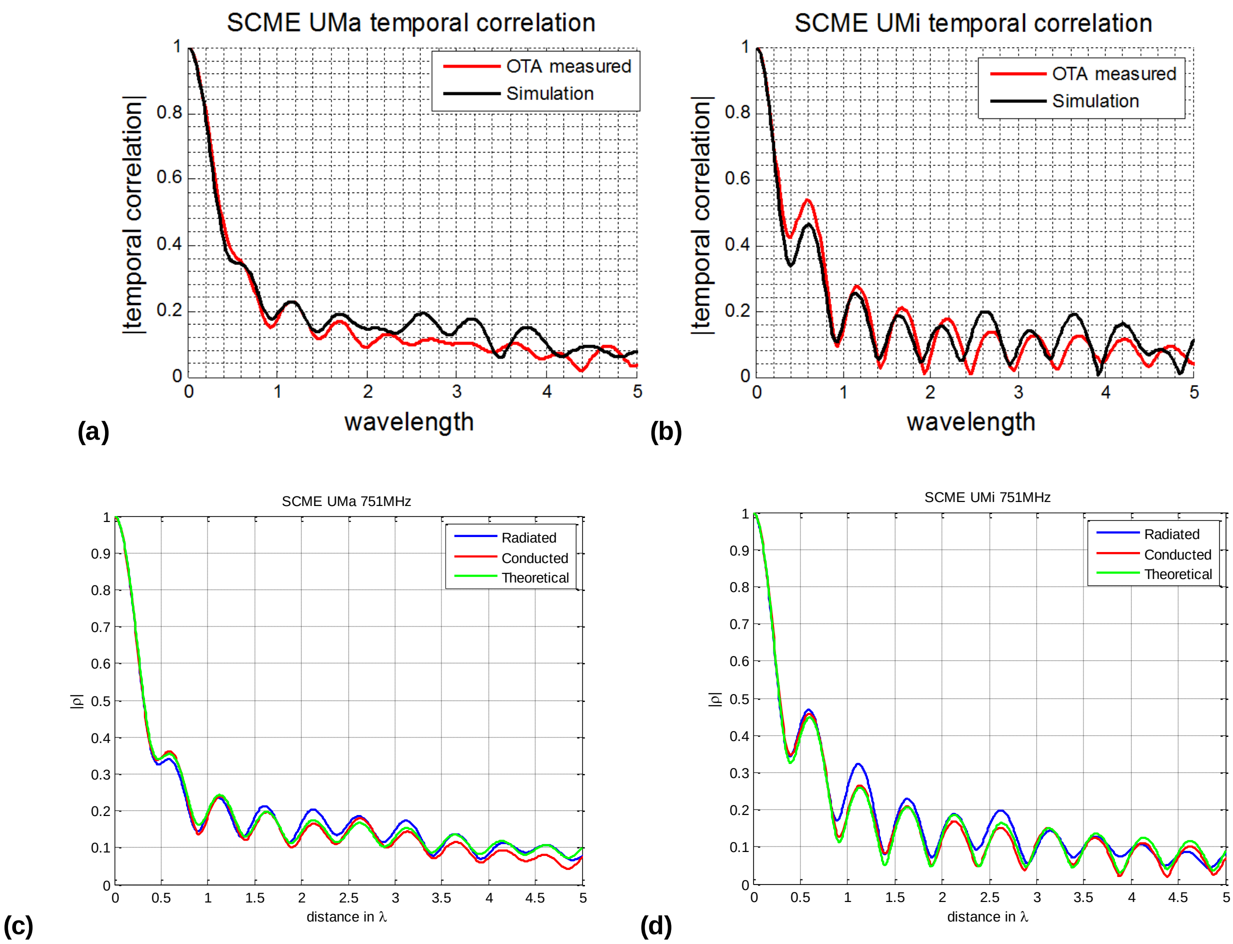


Figure 8.4.3-1: Temporal correlation measurements of SCMe UMa (a) and SCMe UMi (b) emulated by channel emulator A; SCMe UMa (c) and SCMe UMi (d) with channel emulator B, both for Band 13

8.4.4. Spatial correlation

The spatial correlation properties of the channel models defined in Clause 8.2 have been characterized according to Clause 8.3.2.3. Figure 8.4.4-1 below illustrates the measured results for Band 13.

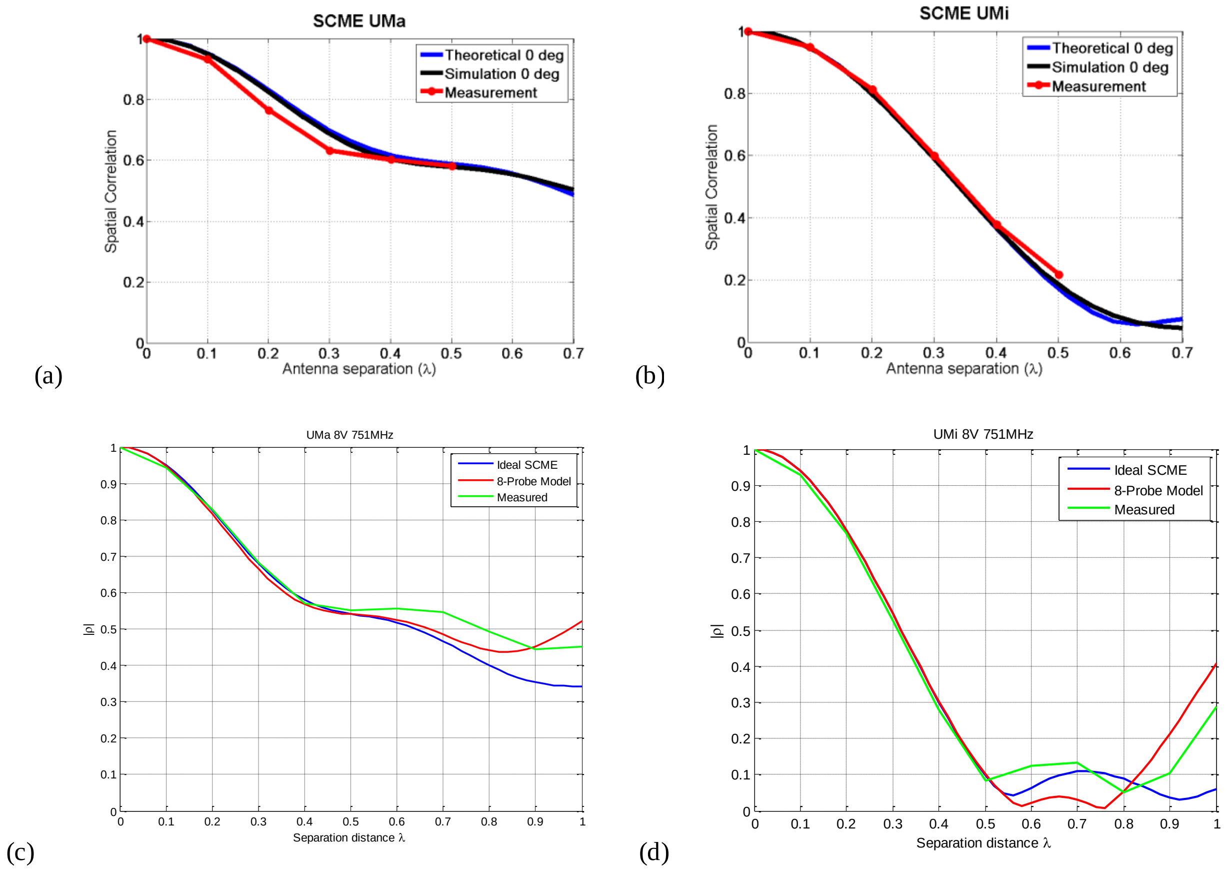


Figure 8.4.4-1: Spatial correlation measurements of SCMe UMa (a) and SCMe UMi (b) emulated by channel emulator A; SCMe UMa (c) and SCMe UMi (d) with channel emulator B, both for Band 13

8.4.5. Cross polarization

The cross polarization properties of the channel models defined in Clause 8.2 have been characterized according to Clause 8.3.2.3. The measured results shown in Table 8.4.5-1 below are reported considering the antenna gain difference of the reference antennas.

Table 8.4.5-1: Summary of cross polarization verification results for Band 13

	Channel emulator A		**Channel emulator B**	
	SCMe UMi	**SCMe UMa**	**SCMe UMi**	**SCMe UMa**
Target	0.83 dB	8.13 dB	To be added[1]	To be added[1]
Measurement considering antenna gain difference	2.0 dB	9.0 dB	To be added[1]	To be added[1]
Deviation	1.2dB	0.9dB	To be added[1]	To be added[1]
NOTE 1: XPR values for channel emulator B will be added at a later stage.				

8.4.6. Summary

The summary of the channel model validation activity is provided in Table 8.4.6-1 below.

Table 8.4.6-1: Summary of channel model validation results

Item	Parameter	Result	Tolerances	Comments
1	Power delay profile	See 8.4.2	FFS[1]	
2	Doppler / Temporal Correlation	See 8.4.3	FFS[1]	
3	Spatial Correlation	See 8.4.4	FFS[1]	
4	Cross Polarization	See 8.4.5	FFS[1]	
NOTE 1: Further investigation of channel model validation metrics and their corresponding tolerances is on-going within the framework of measurement uncertainty budget development				

8.5 Channel Model emulation of the Base Station antenna pattern configuration

<Editor: To include the agreed X-polarized method. Any additional approach would need to be clearly specified.>

The emulated base station antennas shall be assumed to be dual polarized equal power elements with a fixed 0λ separation, 45 degrees slanted.

The slant 45 degree antenna is an “X" configuration and is modelled as an ideal dipole with isotropic gain and subject to a foreshortening of the slanted radiating element, which is observed to vary as a function of the path angle of departure. This foreshortening with AoD is a typical slanted dipole behaviour and is a source of power variation in the channel model. The effective antenna pattern for this antenna is illustrated in Figure 8.5-1.

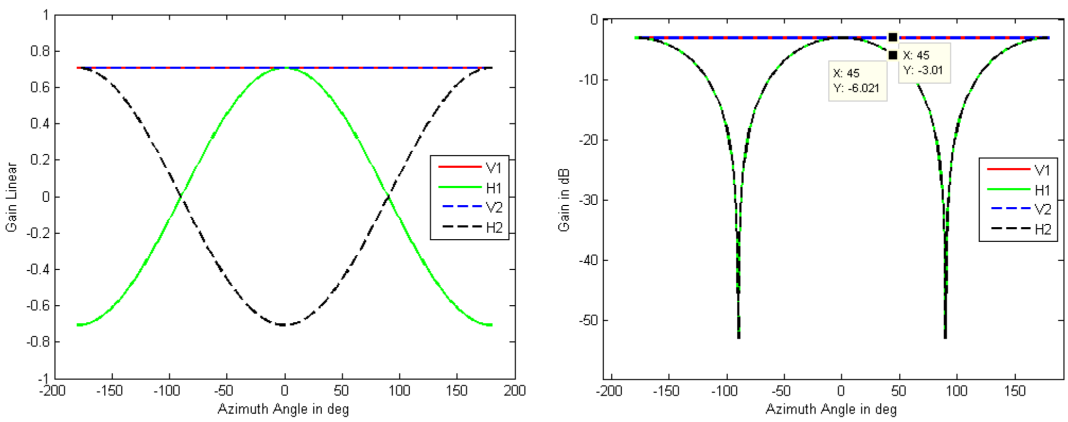


Figure 8.5-1, X antenna gain assumption (a) Linear gain (b) dB gain

9 Reference antennas and devices testing

9.1 Reference antennas design

<Editor: Text to be added>

9.2 Reference devices

9.3 Description of tests with reference antennas and devices

9.3.1 The Absolute Data Throughput Comparison Framework

9.3.1.1 Introduction

In an effort to compare different MIMO OTA methodologies' results to conducted results under the implementations of channel models defined in Clause 8.2, the absolute data throughput comparison framework has been defined. By utilizing the reference antennas (Clause 9.1) and reference devices (Clause 9.2), this framework shall be used to compare each MIMO OTA testing method's ability to emulate the specified network and channel propagation characteristics based on an absolute data throughput metric.

The framework consists of a set of conducted (Figure 9.3.1.1-1) and radiated (Figure 9.3.1.1-2) measurements of MIMO throughput (Clause 5.1.1). The details for the application of this framework are described in Clause 9.3.1.6.

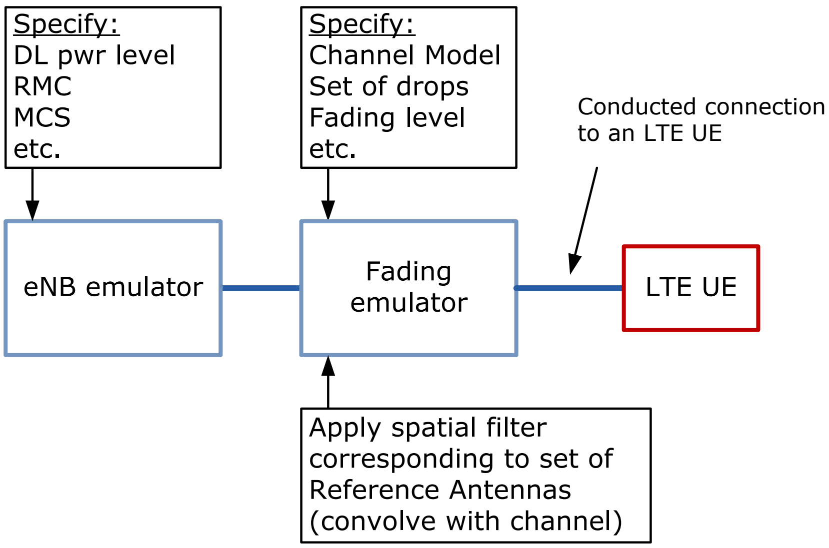


Figure 9.3.1.1-1: Method of measuring the conducted absolute throughput reference performance

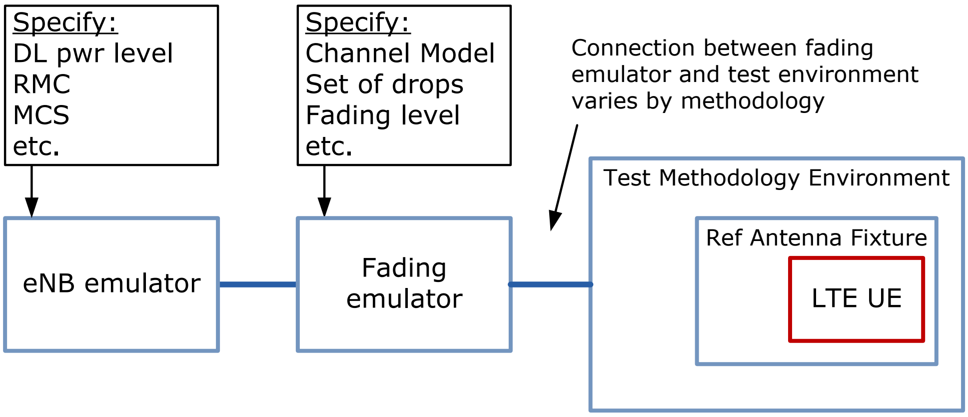


Figure 9.3.1.1-2: Method of measuring the absolute radiated data throughput metric with the reference antennas

The following sub-clauses define the antenna pattern data format, emulation of antenna pattern rotation, absolute data throughput measurement enabler, and the output data format.

9.3.1.2 Antenna pattern data format

The antenna pattern data format—used in the conducted portion of the measurements—shall be in the 3D AAU format as defined by COST IC1004 [14]. Table 9.3.1.2-1 and 9.3.1.2-2 below illustrates the header structure with a sample data set respectively.

Table 9.3.1.2-1: Auxiliary informational header

Line(s)	Pos.	Description	Values - *examples* or **defaults**
1	1	Pattern frequency	free (*750*)
	2	Frequency units	{Hz,KHz,**MHz**,GHz}
	3	Port index (to resolve antennas automatically)	free (*1*)
	4	Pattern type (Directivity, Gain, Realized Gain, E-field)	{D,G,**Gr**,E} - possible more
	5	Units format (as in touchstone plus the E-field format)	{DB,MA,**RI**,V/m}
2	NOTE: There is no freedom in the column arrangement but the labels can vary. Done for ease of use.		
	1	θ scan stepping - must be constant	Theta [deg]
	2	ϕ scan stepping - must be constant	Phi [deg]
	3	Absolute of the field X(1-4) in [units(1-5)]	Abs X [units]
	4	θ polarized field X(1-4) in [units(1-5)]	XTh [units]
	5	phase of the θ polarized field - always in degrees	phase Th [deg]
	6	ϕ polarized field X(1-4) in [units(1-5)]	XPh [units]
	7	phase of the ϕ polarized field - always in degrees	phase Ph [deg]
3,4 ...	NOTE: Any number additional lines can be added, always beginning with Matlab comment sign %		
	N/A	Some custom comment, ID etc.	`% File version 1.0`

Note: A semicolon should be used as a delimiter in the header.

Table 9.3.1.2-2: 3D AAU file format example

%	750; MHz; 1; G; DB						
%	Theta [deg];	Phi [deg];	Abs G [dB];	GTh [dB];	phase Th [deg];	GPh [dB];	phase Ph [deg]
%	File version 1.0						
	0.0000000e+00	0.0000000e+00	-7.1488243e+00	-8.8275753e+00	2.9473810e+02	-1.2089176e+01	2.9741836e+02
	5.0000000e+00	0.0000000e+00	-5.9290614e+00	-6.9276561e+00	2.8631853e+02	-1.2802746e+01	2.9300649e+02
	1.0000000e+01	0.0000000e+00	-4.6884986e+00	-5.2974347e+00	2.8098081e+02	-1.3521536e+01	2.8790096e+02
	1.5000000e+01	0.0000000e+00	-3.5323323e+00	-3.9212541e+00	2.7745182e+02	-1.4204563e+01	2.8204220e+02
	2.0000000e+01	0.0000000e+00	-2.4979324e+00	-2.7615381e+00	2.7503474e+02	-1.4797363e+01	2.7547303e+02
	2.5000000e+01	0.0000000e+00	-1.5926370e+00	-1.7843443e+00	2.7333007e+02	-1.5239593e+01	2.6841058e+02
	...	...	...	...	...	...	...

In this table we further define the following parameters:

- Position 1 on Line 1 shall indicate the measurement frequency.
- Position 2 on Line 1 shall indicate the frequency units to be MHz.

- Position 3 on Line 1 shall indicate the antenna index 1 or 2.
- Antenna index is defined as: antenna index 1 defined as left antenna (portrait front view, from RF enclosure side), antenna index 2 defined as right antenna (portrait front view, from RF enclosure side)
- Position 4 on Line 1 shall be G.
- Position 5 on Line 1 shall be dBi
- Positions 3, 4, and 6 on Line 2 shall describe the measured gain in dBi.

The file name format shall be defined as "(lab acronym)_(antenna serial number)_CTIA_MIMO 2x2_Band(B7, B13..Bxx)_(Good, Nominal, or Bad)_Ant(1 or 2).3daau".

Based on experiments taken with low (<1GHz) and high (>1.8GHz) frequency band antennas, the magnitude of the complex correlation coefficient generated from measured data remains unchanged from higher resolution antenna pattern measurements up to 15 degrees resolution in theta and phi orientations. To align with current COST IC1004 TWGO MIMO OTA topic group proposed resolution for 3D MIMO OTA complex radiation pattern measurements, the antenna pattern measurement step size in theta and phi shall be no more than 5 degrees. In the specific case of 2D measurements theta is fixed at 90 degrees.

9.3.1.3 Emulation of antenna pattern rotation

For the conducted portion of the absolute data throughput framework, it is necessary to generate the spatially filtered channel impulse response per polarization and then combine to generate the emulated channel impulse response coefficients. The measured antenna pattern shall be interpolated to match the spatial resolution of the angles of arrival of the SCME channel emulator (this value is typically 1 degrees). Figure 9.3.1.3-1 below illustrates an example of this procedure using a simplified antenna pattern and channel PAS.

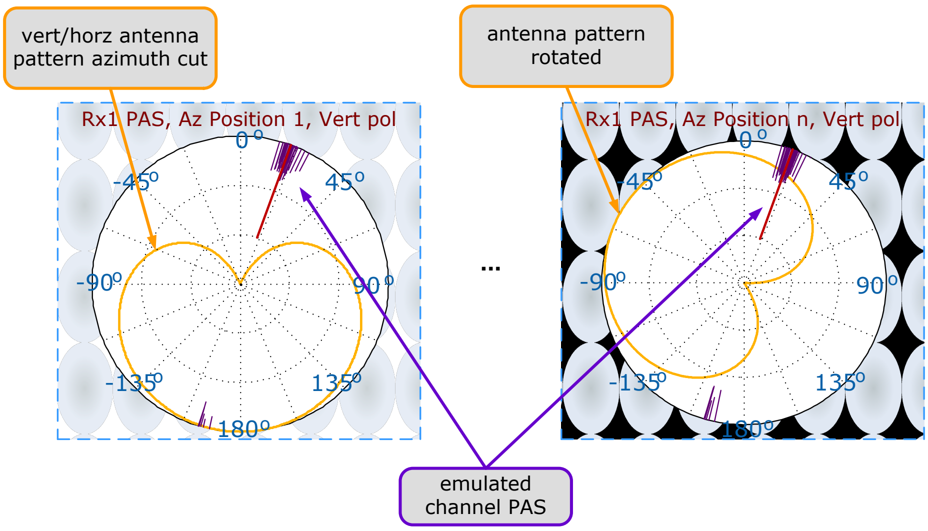


Figure 9.3.1.3-1: Rotation of antenna pattern over azimuth positions

In general, the emulation of antenna pattern rotation is specific to the channel model. For 2D channel models antenna pattern rotation shall be performed over 360 degrees in 30 degree steps (12 total positions). For other channel models this process is FFS.

A spatial filtering operation alone does not capture the behaviour of the 2D channel model as a function of DUT rotation. Figure 9.3.1.3-2 below illustrates the geometric parameters of the 2D channel model [15] for two DUT rotations.

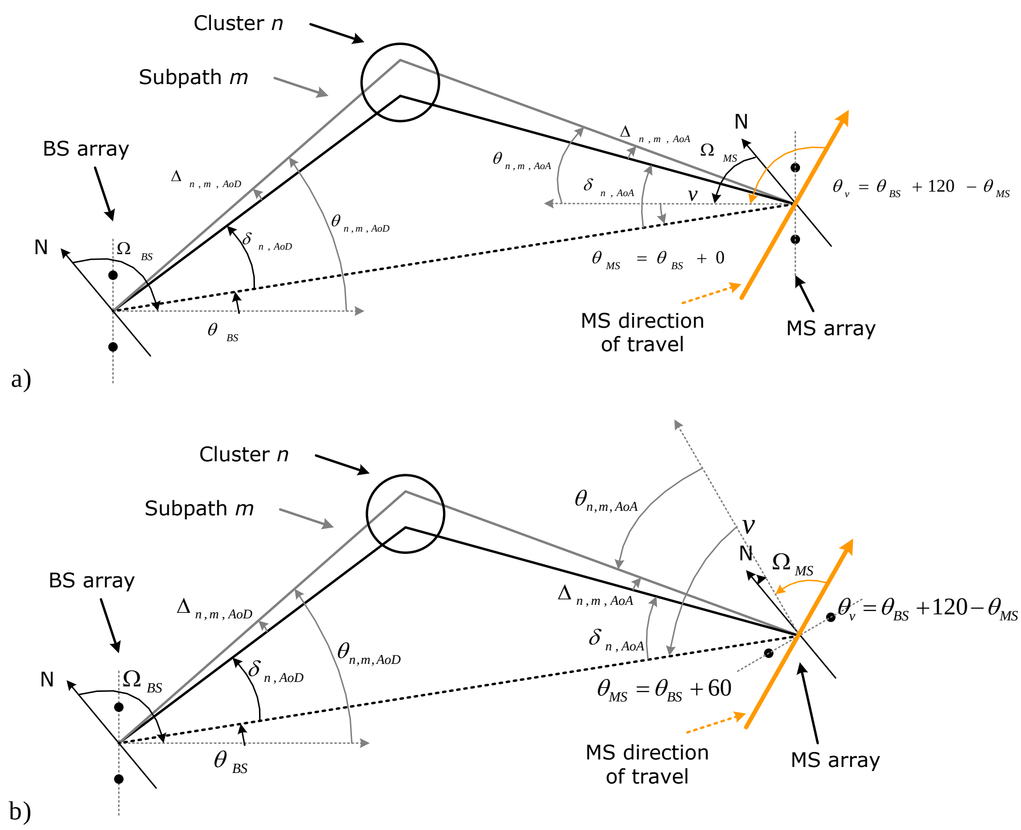


Figure 9.3.1.3-2: (a) 2D channel model geometric parameters for MS array direction = 0 degrees; (b) MS array direction = 60 degrees

For a given rotation of the DUT, the angle of the MS array relative to the cluster angles of arrival changes. Thus, MS array rotation together with the spatial filtering operations described above is necessary to emulate the conducted portion of the framework properly. Doppler spread, which is a function of the MS direction of travel relative to the channel model clusters' angles of arrival, shall remain the same for all rotations of the DUT.

This process may be automated with channel emulator control software or performed manually. The output data format is described in Clause 9.3.1.5.

9.3.1.4 Absolute Data Throughput measurement enabler

The fundamental enabler for the adoption of the Absolute Data Throughput metric is the ability to apply the complex radiation pattern to the channel for the conducted portion of the test. Such conducted measurements can be performed manually; however, without an application (SW) to rotate the loaded antenna complex radiation pattern, the measurement may become very time consuming and prone to human errors. Automation of this process is highly recommended.

9.3.1.5 Output data format

A unified data format for recording the conducted and radiated test results by each lab is defined in Tables 9.3.1.5-1 and 9.3.1.5-2 below.

Table 9.3.1.5-1: Conducted measurement data table format

Absolute data throughput: conducted measurement data				
ID	<measurement ID>			
Lab info	<lab name, location, chamber ID>			
Date	<YYYY-MM-DD>			
eNodeB emulator	<manufacturer name, model number, serial number>			
eNodeB emulator version	<hardware and firmware version numbers>			
eNodeB test application name and version	<test application name and version>			
eNodeB ant config	Sec 8.5 in 37.977			
eNodeB PHY config	Sec 7.1 in 37.977			
Band	<band num>			
DL channel	<channel num			
UL channel	<channel num			
RMC	<R.11 or R.35>			
Transmission Mode	<TM2 or TM3>			
Num subframes per SIR pt				
Channel emulator	<manufacturer name, model number, serial number>			
Channel emulator version	<hardware and firmware version numbers>			
Channel model config	Sec 8.2 in 37.977			
Channel model	<UMi, UMa, etc>			
Emulated vehicular speed	<speed in km/h>			
Reference antenna classification	<good, nominal, or bad>			
Ant1 pattern	<filename of reference antenna data as described in Sec 9.3.1.2>			
Ant2 pattern	<filename of reference antenna data as described in Sec 9.3.1.2>			
UE manufacturer	<manufacturer name>			
UE model	<model name>			
UE ID	<IMEI and possible additional unique ID number>			
Max theoretical throughput	<kbps>			
Num theta positions	Sec 9.3.1.3 in 37.977			
Theta positions	Sec 9.3.1.3 in 37.977			
Num phi positions	Sec 9.3.1.3 in 37.977			
Phi positions	Sec 9.3.1.3 in 37.977			
Test plan name and version				
Comments				
Test points per single position below	Skip if not applicable			
Theta (deg)	Phi (deg)	RS EPRE (dBm/15 kHz)	DL SIR (dB)	DL TPT (kbps)
90	0	r_max	s_max	TPT_max

...	...	…	...	...
90	0	r_1	s_1	TPT_1
90	0	r_2	s_2	TPT_2
...	...	…	...	...
90	0	r_min	s_min	TPT_min
90	30	r_max	s_max	TPT_max
...	...	…	...	...
90	30	r_1	s_1	TPT_1
90	30	r_2	s_2	TPT_2
...	...	…	...	...
90	30	r_min	s_min	TPT_min
Spatial average results below				
RS EPRE (dBm/15 kHz)	DL SIR (dB)	AVG DL TPT (kbps)	Comments	
r_max	s_max	TPT_max		
…	...	...		
r_1	s_1	TPT_1		
r_2	s_2	TPT_2		
…	...	...		
r_min	s_min	TPT_min		

Table 9.3.1.5-2: Radiated measurement data table format

Absolute data throughput: radiated measurement data				
ID	<measurement ID>			
Lab info	<lab name, location, chamber ID>			
Date	<YYYY-MM-DD>			
Test methodology				
eNodeB emulator	<manufacturer name, model number, serial number>			
eNodeB emulator version	<hardware and firmware version numbers>			
eNodeB test application name and version	<test application name and version>			
eNodeB ant config	Sec 8.5 in 37.977			
eNodeB PHY config	Sec 7.1 in 37.977			
Band	<band num>			
DL channel	<channel num			
UL channel	<channel num			
RMC	<R.11 or R.35>			
Transmission Mode	<TM2 or TM3>			
Num subframes per SIR pt				
Channel emulator	<manufacturer name, model number, serial number>			
Channel emulator version	<hardware and firmware version numbers>			
Channel model config	Sec 8.2 in 37.977			
Channel model	<UMi, UMa, etc>			
Emulated vehicular speed	<speed in km/h>			
Reference antenna classification and serial number	<(good, nominal, or bad)_SN>			
Ant 1	<Tx/Rx port of the UE>			
Ant 2	<Rx port of the UE>			
UE manufacturer	<manufacturer name>			
UE model	<model name>			
UE ID	<IMEI and possible additional unique ID number>			
Max theoretical throughput	<kbps>			
Num theta positions	<if applicable>			
Theta positions	<if applicable>			
Num phi positions	<if applicable>			
Phi positions	<if applicable>			
Configuration of testing antennas in chamber	<detailed description>			
Test plan name and version				
Comments				
Test points per single position below	Skip if not applicable			
Theta (deg)	Phi (deg)	RS EPRE (dBm/15 kHz)	DL SIR (dB)	DL TPT (kbps)
90	0	r_max	s_max	TPT_max
...	...	…	...	...
90	0	r_1	s_1	TPT_1
90	0	r_2	s_2	TPT_2
...	...	…	...	...

90	0	r_min	s_min	TPT_min
90	30	r_max	s_max	TPT_max
...	...	…	...	...
90	30	r_1	s_1	TPT_1
90	30	r_2	s_2	TPT_2
...	...	…	...	...
90	30	r_min	s_min	TPT_min
Spatial average results below				
RS EPRE (dBm/15 kHz)	DL SIR (dB)	AVG DL TPT (kbps)	Comments	
r_max	s_max	TPT_max		
…	...	...		
r_1	s_1	TPT_1		
r_2	s_2	TPT_2		
…	...	...		
r_min	s_min	TPT_min		

9.3.1.6 Application of the framework and scenarios for comparison

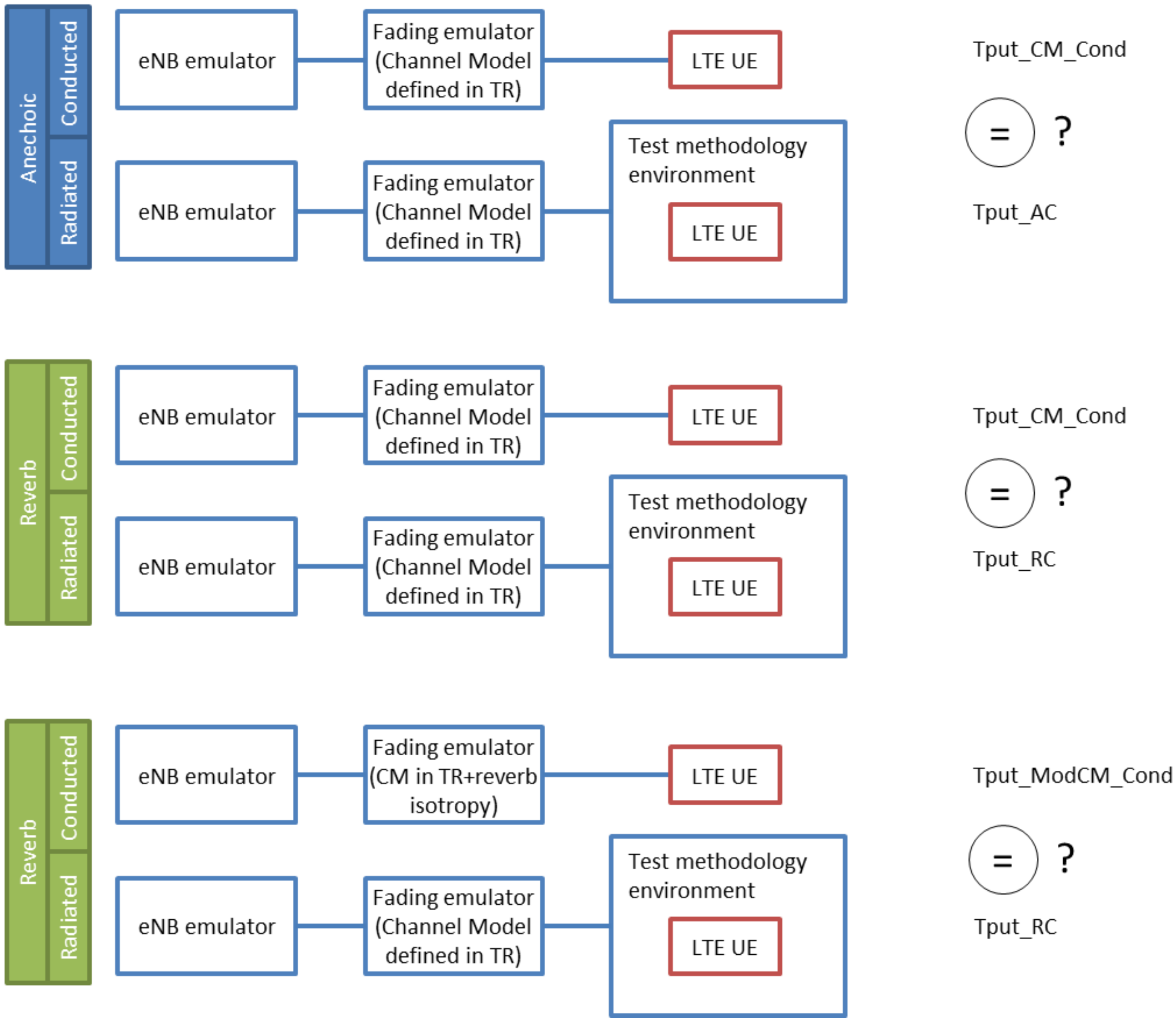
This framework is methodology agnostic, and shall be used to compare each MIMO OTA testing method's ability to emulate the specified network and channel propagation characteristics based on an absolute data throughput metric (Clause 5.1.1).

The purposes of this framework are:

- For the agreed Channel Models, currently SCME Umi and Uma, to understand and quantify what are the deviations (if any) introduced by the chamber used in radiated mode compared to the conducted mode (when reference antennas are embedded). This shall be applied inter labs for the same method and inter methods.
- For methods that are able to reproduce channel models that are not agreed in the TR, it can be used to define the channel model details that need to be injected in the conducted test to obtain same results in the radiated part. And therefore it is easier to reproduce those conditions across methods.

The above use cases for the framework are required to be conducted for inter methodology comparison. Other applications for the framework are optional and not excluded.

And more concretely, the following scenarios for comparison are defined:



These scenarios are intended to address the following aspects:

1. **The first scenario**, anechoic based: intended to compare the conducted portion of the test (with embedded radiation pattern antennas) with the same results of the radiated test. Throughputs are compared to understand any artifacts introduced by the setup.
2. **The second scenario**, reverberation based: intended to compare the conducted portion of the test (with embedded radiation pattern antennas) with the same results of the radiated test. Throughputs are compared to understand any artifacts introduced by the setup.
3. **The third scenario**, reverberation based: intended to compare the conducted portion of the test (with embedded radiation pattern antennas) and with 3D isotropic channel model with the same results of the radiated test. Throughputs are compared to understand any artifacts introduced by the setup. Additionally this scenario will help to define the 3D isotropic properties of the channel model as perceived by the UE in the reverb chamber, and compare its realization in the conducted portion.

Note: if scenario 2 holds true, it would mean that for the agreed setup anechoic method and reverberation method provides comparable results for the agreed channel models in TR, currently 2D SCME.

9.3.1.7 Proof of concept

9.3.1.7.1 The first scenario, anechoic based

The implementation of the Absolute Data Throughput Framework based in the first scenario; i.e. anechoic chamber; is defined on 9.3.1.6 and table 9.3.1.7.1-1. The figure 9.3.1.7.1-2 indicates variation equal or less than 0.5dB when comparing OTA measurements with correspondent conducted measurements, therefore validating the framework concept.

Table 9.3.1.7.1-1 Absolute Data Throughput proof of concept measurement setup

Anechoic based measurement setup	Conducted	Radiated
Lab	Conducted lab "A"	Radiated "B"
Methodology	Conducted	Radiated
eNodeB emul.	model "A"	model "A"
eNodeB ant config	Sec 7.2 in 37.977	Sec 7.2 in 37.977
eNodeB PHY config	Sec 7.1 in 37.977	Sec 7.1 in 37.977
Band	13	13
DL channel	5230	5230
UL channel	23230	23230
RMC	R11	R11
Num subframes per SNR pt	20000	20000
Channel emul.	model "B1"	model "B2"
Channel model config	Sec 8.2 in 37.977	Sec 8.2 in 37.977
Channel model	SCME Umi, SCME Uma	SCME Umi, SCME Uma
Emul. veh. speed	30 km/h	30 km/h
UE mfg	Commercially available	Commercially available
Transmission Mode	TM3	TM3

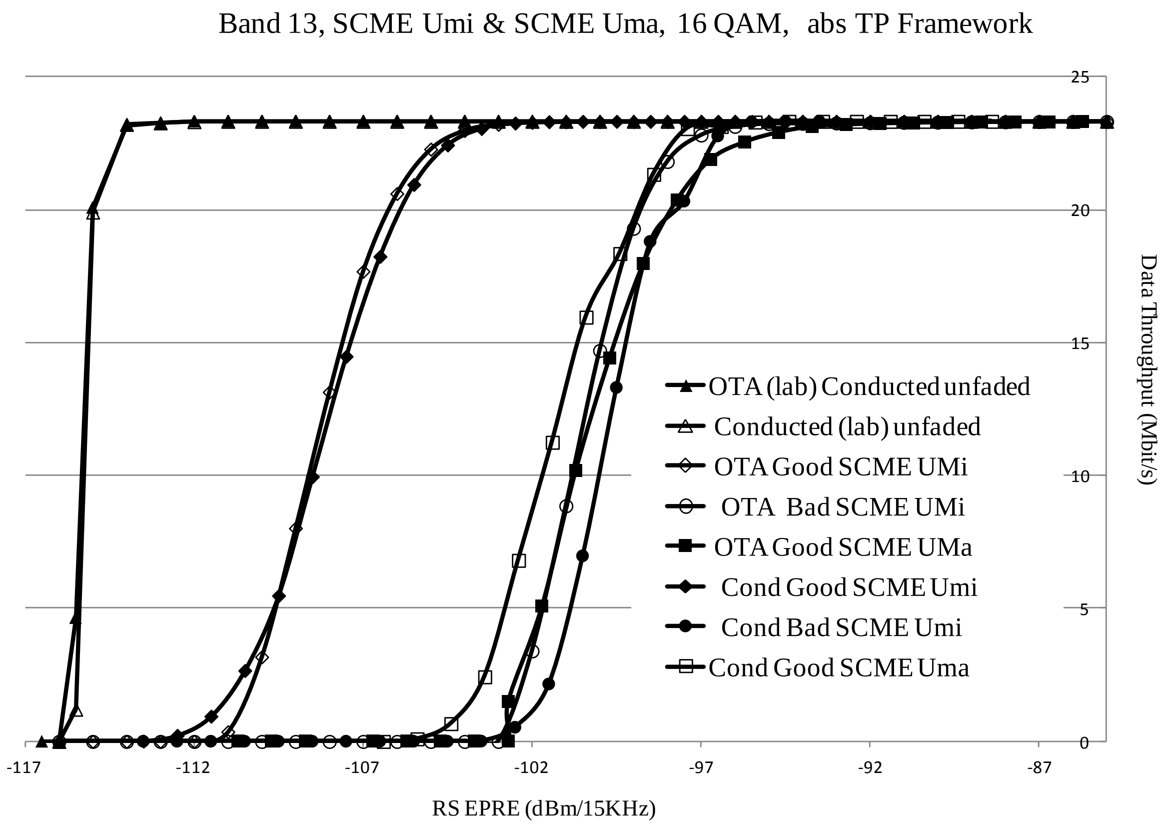


Figure 9.3.1.7.1-2 First Scenario (anechoic based) proof of concept, measurement results

9.4 Device positioning

9.4.1 Handheld UE

Handheld UE is a device which is primarily used in a handgrip like normal mobile/smart phones.

Browsing mode testing method is used for MIMO OTA performance measurements in case of handheld types of UE form factors as defined in TR 25.914 subclause 5.1.7.

9.4.2 Laptop mounted equipment (LME)

Laptop mounted equipment (LME) type UE is a plug-in device that hosts on the laptop (like USB dongles).

A laptop ground plane phantom is used for radiated MIMO OTA performance measurements in case of LME plug-in DUT as defined in TR 25.914 subclauses 5.1.3 and 5.1.4.

9.4.3 Laptop embedded equipment (LEE)

Laptop embedded equipment are notebook PC's or tablets.

A notebook PC is a portable personal computer combining the computer, keyboard and display in one form factor. Typically the keyboard is built into the base and the display is hinged along the back edge of the base. The largest single dimension for a notebook is limited to 0.42 m.

As notebooks are not body worn equipment nor recommended for use placed directly on the lap, the notebook shall be tested in a free space configuration without head and hand phantoms.

LEE Notebook PC's shall be tested in free space configuration as defined in TR 25.914 subclause 5.3.1.

Tablet positioning is FFS.

10 Measurement results from outside of 3GPP

10.1 CTIA

<Editor: Text to be added>

11 Conclusions

12 Final agreed test methodology

Annex A: eNodeB Emulator Downlink power verification

A.1 Introduction

The measurements described in this clause serve three primary purposes:

1) Confirm that the PDSCH total power is balanced between the MIMO transmit ports of an eNodeB emulator

2) Confirm that the PDCCH-EPRE vs. PDSCH-EPRE is balanced per eNodeB emulator antenna port within a given RB

3) Confirm that the RS-EPRE vs. PDSCH-EPRE ratio is correct per eNodeB emulator antenna port within a given RB

A.2 Test prerequisites

The parameters specified in Table A.1-1 and Table A.1-2 below are based on the eNodeB emulator settings described in Table 7.1-1 and Table A.1-2.

Table A.1-1: FDD eNodeB Emulator Configuration for Downlink Power Verification

Parameter	Value	
Operating Band/Channel (Note 1)	Band 7 (3100 DL/21100 UL) Band 13 (5230 DL/23230 UL) Band 20 (6300 DL/24300 UL)	
Downlink Bandwidth	10 MHz	
Duplex Mode	FDD	
Schedule Type	Reference Measurement Channel (RMC)	
Downlink Reference Channel	R.11 FDD	R.35 FDD
Downlink Modulation	16QAM	64QAM
Downlink TBS Index	13 (RMC Defined)	24 (RMC Defined)
Downlink MIMO Mode	2x2 Open Loop Spatial Multiplexing	
Number of Downlink RBs	50	
Downlink RB_{Start}	0	
Downlink Power Level, eNodeB emulator	-50 dBm/15 kHz (RS-EPRE at each eNodeB emulator port)	
Uplink Bandwidth	10 MHz	
Uplink Modulation	QPSK	16QAM
Uplink TBS Index	6 (RMC Defined)	19(RMC Defined)
Number of Uplink RBs	50	
Uplink RB_{Start}	0	

Transmit Power Control	-10 dBm/10 MHz (open loop)
PDSCH Power Offset Relative to RS EPRE	ρ_A= -3 dB ρ_B= -3 dB
HARQ Transmissions	1 (No HARQ)
AWGN	Off
OCNG	Off
NOTE 1: Labs executing this test may use any one of the three bands listed in Table A.1-1 according to test UE availability and band support in the eNodeB emulator.	

Table A.1-2: TDD eNode B Emulator Configuration for Downlink Power Verification

Parameter	Value	
Operating Band / Channel (Note 1)	Band 38 (38000) Band 39 (38450) Band 40 (39150) Band 41 (40620)	
Downlink Bandwidth	20 MHz	
Duplex Mode	TDD	
Schedule Type	Reference Measurement Channel (RMC)	
Downlink Reference Channel	R.30 TDD	R.31-4 TDD
Downlink Modulation	16QAM	64QAM
Downlink TBS Index	13 (RMC defined)	26 (RMC defined)
Up/Downlink Frame Configuration	1	
Special Frame configuration	7	
Downlink MIMO Mode	2x2 Open Loop Spatial Multiplexing	
Number of Downlink RBs	100	
Downlink RB_{Start}	0	
Downlink Power Level, eNodeB emulator	-50 dBm/15 kHz (RS-EPRE at each eNodeB emulator port)	
Uplink Bandwidth	20 MHz	
Uplink Modulation	QPSK	16QAM
Uplink TBS Index	6 (RMC Defined)	19(RMC Defined)
Number of Uplink RBs	100	
Uplink RB_{Start}	0	
Transmit Power Control	-10 dBm/20 MHz (open loop)	
PDSCH Power Offset	ρ_A= -3 dB	

Relative to RS EPRE	ρ_B= -3 dB
HARQ Transmissions	1 (No HARQ)
AWGN	Off
OCNG	Off
NOTE 1: Labs executing this test may use any one of the four bands listed in Table A.1-2 according to test UE availability and band support in the eNodeB emulator.	

A.3 Test Methodology

For the purpose of verifying channel power levels called for in this document, the eNodeB emulator shall be connected to a test UE (DUT) according to the configuration shown in Figure A.3-1 below:

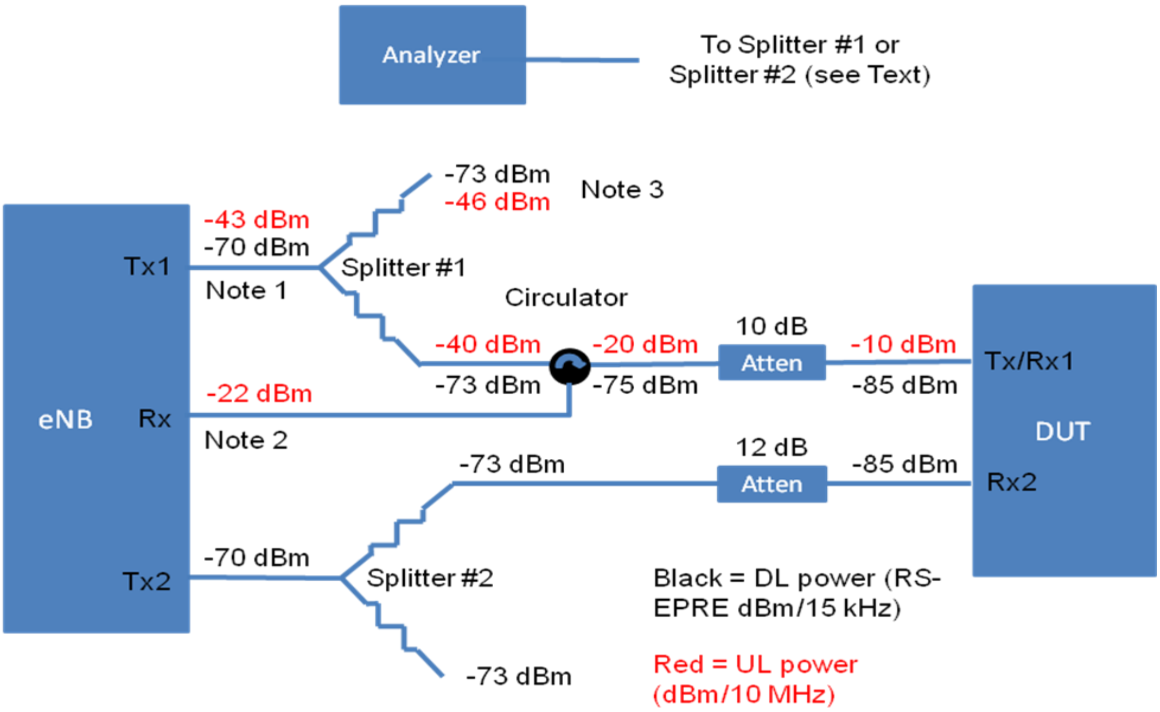


Figure A.3-1: eNodeB Connections for Downlink Power Verification

Note 1: TX Port #1 is used as transmit-only on eNodeB emulators with a separate uplink RX port.

Note 2: If the eNodeB emulator supports full duplex operation on TX port #1, the circulator's RX port shall be terminated in a 50-ohm load.

Note 3: These splitter ports will be used to provide a downlink RF sample to the analyzer and shall be terminated in a 50-ohm load when not in use.

The analyzer shown in Figure A.3-1 above must be capable of measuring the eNodeB emulator's average PDCCH power independent of the eNodeB emulator's average PDSCH power, expressed as a PSD in dBm/15 kHz. The analyzer must also be capable of measuring RS EPRE and PDSCH EPRE in dBm/15 kHz. Any instrument capable of making these measurements is acceptable.

The following eight measurements shall be made while the UE is in an active data session and sending continuous uplink data to the eNodeB emulator using the settings described in Table A.1-1 and Table A.1-2:

1) Average power at TX Port 1 (through Splitter 1) of all PDCCH RBs expressed as a PSD in dBm/15 kHz

2) Average power at TX Port 1 (through Splitter 1) of all PDSCH RBs expressed as a PSD in dBm/15 kHz

3) PDSCH-EPRE at TX Port 1 (through Splitter 1) in dBm/15 kHz

4) RS-EPRE at TX Port 1 (through Splitter 1) in dBm/15 kHz for the Reference Signals in DL

5) Average power at TX Port 2 (through Splitter 2) of all PDCCH RBs expressed as a PSD in dBm/15 kHz

6) Average power at TX Port 2 (through Splitter 2) of all PDSCH RBs expressed as a PSD in dBm/15 kHz

7) PDSCH-EPRE at TX Port 2 (through Splitter 2) in dBm/15 kHz

8) RS-EPRE at TX Port 2 (through Splitter 2) in dBm/15 kHz

From the eight measurements described above, calculate the following:

- eNodeB TX Port 1/TX Port 2 PDCCH average power balance (in dB) across all DL RBs
- eNodeB TX Port 1/TX Port 2 PDSCH average power balance (in dB) across all DL RBs
- eNodeB RS-EPRE to PDSCH-EPRE power ratio (in dB), TX Port 1
- eNodeB RS-EPRE to PDSCH-EPRE power ratio (in dB), TX Port 2

To be considered compliant with 3GPP TS 36.521-1, the following criteria must be met:

a. eNodeB PDCCH-EPRE TX Port1/TX Port 2 power balance must be 0 dB, +/- 0.7 dB

b. eNodeB PDSCH-EPRE TX Port 1/TX Port 2 power balance must be 0 dB, +/- 0.7 dB

c. eNodeB PDCCH-EPRE to PDSCH-EPRE TX Port 1 power ratio must be 0 dB, +/- 0.7 dB

d. eNodeB PDCCH-EPRE to PDSCH-EPRE TX Port 2 power ratio must be 0 dB, +/- 0.7 dB

In addition, the following criteria must be met per antenna based on the PDSCH EPRE power offset relative to RS EPRE called for in Table A.1-1 and Table A.1-2:

e. eNodeB RS-EPRE to PDSCH-EPRE ratio must be +3 dB, +/- 0.7 dB for TX Port 1

f. eNodeB RS-EPRE to PDSCH-EPRE ratio must be +3 dB, +/- 0.7 dB for TX Port 2

Annex B: Measurement Uncertainty budget

B.1 Measurement uncertainty budged for multiprobe method

Table B.1-1 Measurement uncertainty budged for multiprobe method

Description of uncertainty contribution	Details in
Stage 1, DUT measurement	
1) Mismatch of transmitter chain (i.e. between probe antenna and base station simulator)	TS 34.114 E.1-E.2
2) Insertion loss of transmitter chain	TS 34.114 E.3-E.5
3) Influence of the probe antenna cable	TS 34.114 E.6
4) Uncertainty of the absolute antenna gain of the probe antenna	TS 34.114 E.7
5) Base station simulator: uncertainty of the absolute output level	TS 34.114 E.17, [TS 36.521-1 F.1.3]
6) Throughput measurement: output level step resolution	TS 34.114 E.18
7) Statistical uncertainty of Throughput measurement	TBD
8) Channel flatness within LTE band	TBD
9) Fading channel emulator output uncertainty	TBD
10) Channel model implementation	TBD
11) Measurement distance:	TBD
12) Quality of quiet zone	TS 34.114 E.10
13) DUT sensitivity drift	TS 34.114 E.21
14) Uncertainty related to the use of the phantoms: a) Uncertainty of dielectric properties and shape of the hand phantom. b) Uncertainty related to the use of laptop ground plane phantom:	TR 25.914 [3] A.12.3 A.12.4
15) sampling grid	TBD
16) Random uncertainty (repeatability)	TS 34.114 E.14
Stage 2, Calibration measurement, network analyzer method, TR 25.914 figure 7.5	
17) Uncertainty of network analyzer	TS 34.114 E.15
18) Mismatch in the connection of transmitter chain (i.e. between probe antenna and NA)	TS 34.114 E.1-E.2
19) Insertion loss of transmitter chain	TS 34.114 E.3-E.5
20) Mismatch in the connection of calibration antenna	TS 34.114 E.1
21) Influence of the calibration antenna feed cable	TS 34.114 E.6
22) Influence of the probe antenna cable	TS 34.114 E.6
23) Uncertainty of the absolute gain of the probe antenna	TS 34.114 E.7

24) Uncertainty of the absolute gain/radiation efficiency of the calibration antenna	TS 34.114 E.16
25) Measurement distance:	TBD
26) Quality of quiet zone	TS 34.114 E.10

B.2 Measurement uncertainty budget contributors for 2-stage method

Table B.2-1 Measurement uncertainty budget contributors for 2-stage method

Description of uncertainty contribution	**Details in paragraph**
Stage 1, DUT complex antenna pattern measurement (1st stage of 2-stage method)	
1) Mismatch of transmitter chain (i.e. between probe antenna and base station simulator)	TS34.114 E.1-E.2
2) Insertion loss of transmitter chain	TS34.114 E.3-E.5
3) Influence of the probe antenna cable	TS34.114 E.6
4) Uncertainty of the absolute antenna gain of the probe antenna	TS34.113 E.7
5) Base station simulator: uncertainty of the absolute output level	TS34.114 E.17, TS36.521-1 F.1.3 [3]
6) LTE band channel flatness	TBD
7) DUT receiver amplitude measurement uncertainty	TBD
8) DUT relative phase difference between receiver antennas measurement uncertainty	TBD
9) DUT receiver amplitude linearity	TBD
10) Measurement distance: a) offset of DUT phase centre from axis(es) of rotation b) mutual coupling between the DUT and the probe antenna c) phase curvature across the DUT	TS34.114 E.9
11) Quality of quiet zone	TS34.114 E.10
12 Uncertainty related to the use of phantoms: (applicable when a phantom is used): a) Uncertainty of dielectric properties and shape of the hand phantom b) Uncertainty related to the use of the Laptop Ground Plane phantom	TR 25.914 [4] A.12.3 A.12.4
13) sampling grid	TS34.114 E.13
14) Random uncertainty (repeatability) - positioning uncertainty of the DUT against the SAM or DUT plugged into the Laptop Ground Plane phantom	TS34.114 E.14
Stage 2, Calibration measurement, network analyzer method, figure 7.5	
15) Uncertainty of network analyzer	TS34.114 E.15
16) Mismatch in the connection of transmitter chain (i.e. between probe antenna and NA)	TS34.114 E.1-E.2
17) Insertion loss of transmitter chain	TS34.114 E.3-E.5
18) Mismatch in the connection of calibration antenna	TS34.114 E.1
19) Influence of the calibration antenna feed cable	TS34.114 E.6
20) Influence of the probe antenna cable	TS34.114 E.6
21) Uncertainty of the absolute gain of the probe antenna	TS34.114 E.7

22) Uncertainty of the absolute gain/radiation efficiency of the calibration antenna	TS34.114 E.16
23) Measurement distance: a) Offset of calibration antenna's phase centre from axis(es) of rotation b) Mutual coupling between the calibration antenna and the probe antenna c) Phase curvature across the calibration antenna	TS34.114 E.9
24) Quality of quiet zone	TS34.114 E.10
Stage 3, DUT throughput measurement (2nd stage of 2-stage method)	
25) Mismatch uncertainty between DUT antenna system radiated connectivity and DUT conducted mode test connectivity	TBD
26) Insertion loss of transmitter chain	TS34.114 E.3-E.5
27) Base station simulator: uncertainty of the absolute output level	TS34.114 E.17, TS36.521-1 F.1.3 [3]
28) LTE band channel flatness	TBD
29) Application of antenna patterns into MIMO channel	TBD
30) Channel emulator output uncertainty	TBD
31) Channel model implementation	TBD
32) Throughput measurement: output level step resolution	TS34.114 E.18
33) Statistical uncertainty of throughput measurement	TS34.114 E.19
34) Throughput data rate normalization	TS34.114 E.20

B.3 Measurement uncertainty budget for reverberation chamber method

Table B.3-1 Measurement uncertainty budged for reverberation chamber method

Description of uncertainty contribution	Details in
Stage 1, DUT measurement	
1) Mismatch of transmitter chain (i.e. between fixed measurement antenna and base station simulator)	TS 34.114 E.1-E.2
2) Insertion loss of transmitter chain	TS 34.114 E.3-E.5
3) Influence of the fixed measurement antenna cable	TS 34.114 E.6
4) Uncertainty of the absolute antenna gain of the fixed measurement antenna	TS 34.114 E.7
5) Base station simulator: uncertainty of the absolute output level	TS 34.114 E.17 [TS 36.521-1 F.1.3]
6) Throughput measurement: output level step resolution	TS 34.114 E.18
7) Statistical uncertainty of throughput measurement	TBD
8) Fading channel emulator output uncertainty (if used)	TBD
9) Channel model implementation	TBD
10) Chamber statistical ripple and repeatability	TS 34.114 E.26.A
11) Additional power loss in EUT chassis	TS 34.114 E.26.B
12) DUT sensitivity drift	TS 34.114 E.21
13) Uncertainty related to the use of the phantoms: a) Uncertainty of dielectric properties and shape of the hand phantom b) Uncertainty related to the use of laptop ground plane phantom	TR 25.914 A.12.3 A.12.4
14) Random uncertainty (repeatability)	TS 34.114 E.14
Stage 2 , Calibration measurement	
15) Uncertainty of network analyzer	TS 34.114 E.15
16) Mismatch of receiver chain	TS 34.114 E.1-E.2
17) Insertion loss of receiver chain	TS 34.114 E.3-E.5
18) Mismatch in the connection of calibration antenna	TS 34.114 E.1
19) Influence of the calibration antenna feed cable	TS 34.114 E.6
20) Influence of the fixed measurement antenna cable	TS 34.114 E.6
21) Uncertainty of the absolute gain of the fixed measurement antenna	TS 34.114 E.7
22) Uncertainty of the absolute gain/ radiation efficiency of the calibration antenna	TS 34.114 E.16
23) Chamber statistical ripple and repeatability	TS 34.114 E.26.A

Annex C: Other Environmental Test Conditions for Consideration

C.1 Scope

This annex contains non standard channel models which are described for evaluation purposes. Approved channel models are described in Clause 4.2.

C.2 3D Isotropic Channel Models

This clause proposes three 3D isotropic channel models. One of the models is based on the NIST channel model and two of the models are based on the temporal aspects and base station correlation properties of the SCME UMi and SCME UMa channel models.

The proposed 3D isotropic channel models are not directly based on real life operating conditions, rather, are an attempt to model the properties of the reverberation chamber which has been shown to represent a statistically isotropic environment provided sufficient averaging is performed using mode stirring. The instantaneous conditions within the reverberation chamber are not isotropic.

The following 3D isotropic model is based on the PDP and base station correlation of the SCME Urban Micro-cell model with isotropic AoAs and modified XPR values and Velocity.

Table C.2-1: Short delay spread low correlation channel model

Cluster #	Delay [ns]			Power [dB]			AoD [°]	AoA[1]
1	0	5	10	-3.0	-5.2	-7.0	6.6	Average isotropic[1]
2	285	290	295	-4.3	-6.5	-8.3	14.1	Average isotropic[1]
3	205	210	215	-5.7	-7.9	-9.7	50.8	Average isotropic[1]
4	660	665	670	-7.3	-9.5	-11.3	38.4	Average isotropic[1]
5	805	810	815	-9.0	-11.2	-13.0	6.7	Average isotropic[1]
6	925	930	935	-11.4	-13.6	-15.4	40.3	Average isotropic[1]
Delay spread [ns]								294
Cluster AS AoD / AS AoA [°]								5 / Average isotropic[1]
Cluster PAS shape								3D uniform
Total AS AoD / AS AoA [°]								18.2 / Average isotropic[1]
Mobile speed [km/h]								3, 30
XPR[2]								0 dB
NOTE 1: The angles of arrival are said to be Average Isotropic when the incoming field satisfies the Isotropy requirements established in [16]. NOTE 2: V & H components based on assumed BS antenna array configurations in Clause 7.2.								

The following 3D isotropic model is based on the PDP and base station correlation of the SCME Urban Macro-cell model with isotropic AoAs and modified XPR values and velocity.

Table C.2-2: Long delay spread high correlation channel model

Cluster #	Delay [ns]			Power [dB]			AoD [°]	AoA [°]
1	0	5	10	-3	-5.2	-7	82	Average isotropic[1]
2	360	365	370	-5.2	-7.4	-9.2	81	Average isotropic[1]
3	255	260	265	-4.7	-6.9	-8.7	80	Average isotropic[1]
4	1040	1045	1050	-8.2	-10.4	-12.2	99	Average isotropic[1]
5	2730	2735	2740	-12.1	-14.3	-16.1	102	Average isotropic[1]
6	4600	4605	4610	-15.5	-17.7	-19.5	107	Average isotropic[1]
Delay spread [ns]								839.5
Cluster AS AoD / AS AoA [°]								2 / Average isotropic[1]
Cluster PAS shape								3D uniform
Total AS AoD / AS AoA [°]								7.8 / Average isotropic[1]
Mobile speed [km/h]								3, 30
XPR[2]								0 dB
NOTE 1: The angles of arrival are said to be average isotropic when the incoming field satisfies the isotropy requirements established in [16]. NOTE 2: V & H components based on assumed BS antenna array configurations in Clause 7.2.								

The following 3D isotropic model is based on the NIST model with isotropic AoAs and added XPR values and Velocity. The cluster model described below is a simplification of the full model, where a continuous exponential decaying power transfer function with an RMS delay spread of 80 ns is obtained.

Table C.2-3: Isotropic model based on the NIST channel model

Cluster #	Delay [ns]	Power [dB]	AoD [°]	AoA [°]
1	0	0.0	N/A	Average isotropic[1]
2	40	-1.7	N/A	Average isotropic[1]
3	120	-5.2	N/A	Average isotropic[1]
4	180	-7.8	N/A	Average isotropic[1]
5	210	-9.1	N/A	Average isotropic[1]
6	260	-11.3	N/A	Average isotropic[1]
7	350	-15.2	N/A	Average isotropic[1]
Delay spread [ns]				80
Cluster AS AoD / AS AoA [°]				N/A / Average isotropic[1]
Cluster PAS shape				3D uniform
Total AS AoD / AS AoA [°]				N/A / Average isotropic[1]
Mobile speed [km/h]				1
XPR[2]				0 dB
NOTE 1: The angles of arrival are said to be average isotropic when the incoming field satisfies the isotropy requirements established in [16]. NOTE 2: V & H components based on assumed BS antenna array configurations in Clause 7.2.				

The parameters of the channel models are the expected parameters for the MIMO OTA channel models. However, the final channel model achieved for different methods could be a combined effect of the chamber and the channel emulator.

The Rayleigh fading may be implementation specific. However, the fading can be considered to be appropriate as long as the statistics of the generated Rayleigh fading are within standard requirement on Rayleigh fading statistics.

C.3 Verification of Channel Model Implementations

Channel Models have been specified in clause C.2. This clause describes the MIMO OTA validation measurements, in order to ensure that the channel models are correctly implemented and hence capable of generating the propagation environment, as described by the model, within a test area, Measurements are done mainly with a vector network analyser (VNA) and a spectrum analyzer.

C.3.1 Measurement instruments and setup

The measurement setup includes the following equipment:

Table C.3.1-1: Measurement equipment list for the verification procedure

Item	Quantity	Item
1	1	Channel Emulator
2	1	Signal Generator
3	1	Spectrum Analyzer
4	1	VNA
5	1	Magnetic Dipole
6	1	Sleeve Dipole

C.3.1.1 Network Analyzer (VNA) setup

Most of the measurements are performed with a VNA. An example set of equipment required for this set-up is shown in Figure C.3.1.1-1. VNA transmits frequency sweep signals thorough the MIMO OTA test system. A test antenna, within the test area, receives the signal and VNA analyzes the frequency response of the system. A number of traces (frequency responses) are measured and recorded by VNA and analyzed by a post processing SW, e.g., Matlab. Special care has to be taken into account to keep the fading conditions unchanged, i.e. frozen, during the short period of time of a single trace measurement. The fading may proceed only in between traces. This setup can be used to measure PDP, Spatial Correlation and Polarization of the Channel models defined in Clause C.2.

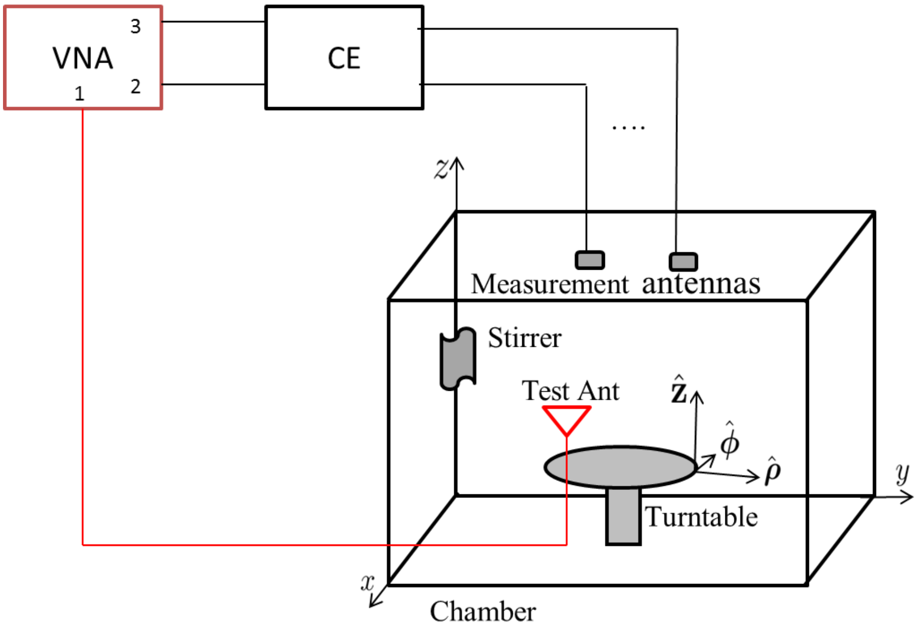


Figure C.3.1.1-1: Setup for VNA measurements for reverberation chamber and channel emulator methods.

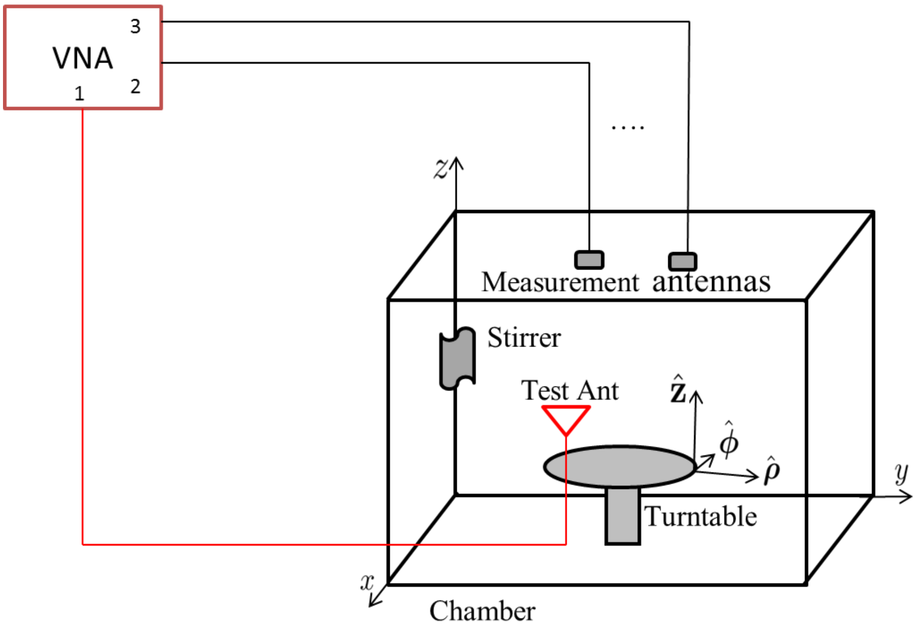


Figure C.3.1.1-2: Setup for VNA measurements for reverberation chamber-only methods

C.3.1.2 Spectrum Analyzer (SA) setup

The Doppler spectrum is measured with a Spectrum analyzer as shown in Figure C.3.1.2-1. In this case a Signal generator transmits CW signal through the MIMO OTA test system. The signal is received by a test antenna within the test area. Finally the signal is analyzed by a Spectrum analyzer and the measured spectrum is compared to the target spectrum. This setup can be used to measure Doppler Spectrum of the Channel models defined in Clause C.2.

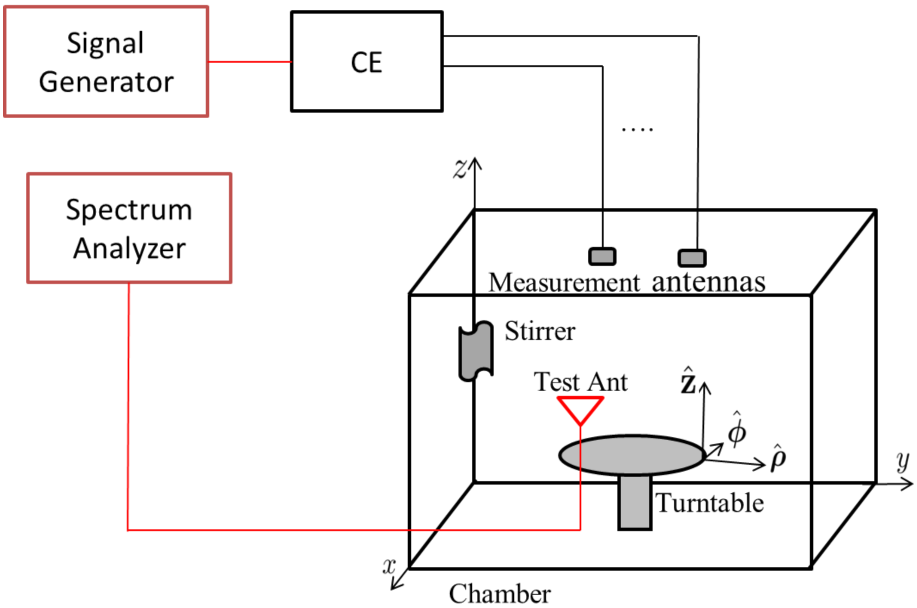


Figure C.3.1.2-1: Setup for SA measurements for reverberation chamber and channel emulator methods

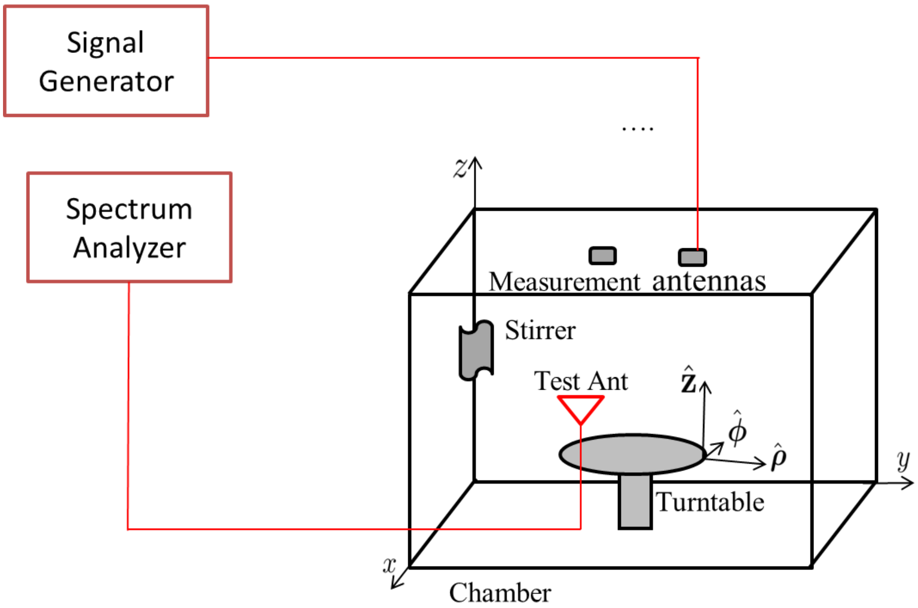


Figure C.3.1.2-3: Setup for SA measurements for reverberation chamber-only methods

C.3.2 Validation measurements

C.3.2.1 PDP

This measurement checks that the resulting power delay profile (PDP) is like defined in the channel model.

Method of measurement:

Step the emulation and store traces from VNA. I.e. run the emulation to CIR number 1, pause, measure VNA trace, run the emulation to CIR number 10, pause, measure VNA trace. Continue until 1000 VNA traces are measured.

VNA settings:

Table C.3.2.1-1: VNA settings for PDP

Item	Unit	Value
Center frequency	MHz	Downlink Center Frequency in 36.508 as required per band
Span	MHz	200 [TBD]
RF output level	dBm	-15
Number of traces		1296 [TBD]
Distance between traces in channel model	wavelength (Note)	> 2
Number of points		1101
Averaging		1
NOTE: Time [s] = distance [λ] / MS speed [λ/s] MS speed [λ/s] = MS speed [m /s] / Speed of light [m/s] * Center frequency [Hz]		

Channel model specification:

Table C.3.2.1-2: Channel model specification for PDP

Item	Unit	Value
Center frequency	MHz	Downlink Center Frequency in 36.508 as required per band
Channel model samples	wavelength	> 2592
Channel model		As specified in Clause C.2

Method of measurement result analysis:

Measured VNA traces (frequency responses H(t,f)) are saved into a hard drive. The data is read into, e.g., Matlab. The analysis is performed by taking the Fourier transform of each FR. The resulting impulse responses h(t, τ) are averaged in power over time:

$$P(\tau) = \frac{1}{T}\sum_{t=1}^{T}\left|h(t,\tau)\right|^2$$

Finally the resulting PDP is shifted in delay, such that the first tap is on delay zero. The reference PDP plots from Table C.2-1, Table C.2-2 and Table C.2-3 are shown in Figure C.3.2.1-1.

In a reverberation chamber, when a channel emulator is not used and the PDP is therefore an exponential decay, such as the NIST channel model, only the inherent RMS Delay Spread of the reverberation chamber needs to be calculated. The selection of the T $h_i(t,\tau)$ measurements has to be performed when the absorber loading technique is used to tune the RMS DS in an RC. Alternatively, the sample selection technique allows for selecting a subset of M $h_i(t,\tau)$ measurements which provide the desired RMS DS, and in this case the averaging has to be performed only over the selected subset of M channel impulse responses.

The calculation of RMS delay spread is performed on the time domain data as the square root of the second central moment of the PDP, that is,

$$\sigma_\tau = \sqrt{\sum^{\tau}\tau^2\frac{PDP(\tau)}{\sum^{\tau}PDP(\tau)} - \left(\sum^{\tau}\tau\frac{PDP(\tau)}{\sum^{\tau}PDP(\tau)}\right)^2}$$

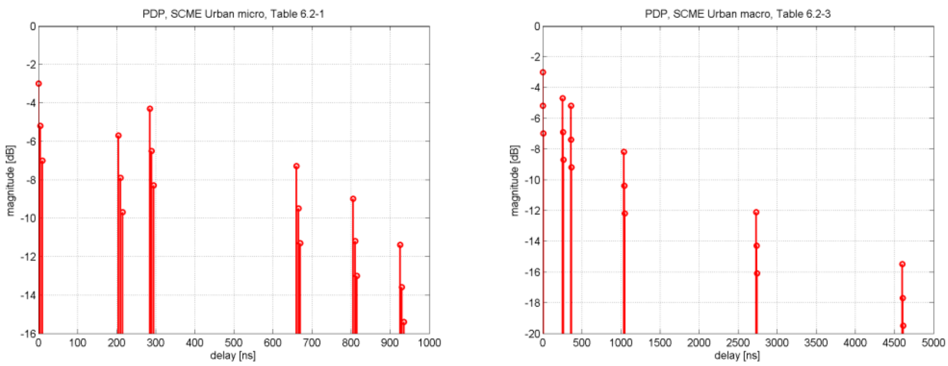
The expected RMS delay spread for the NIST channel model is 80 ns.

OTA antenna configuration:

For e.g. 1 full ring (or single cluster configuration) of V polarized elements **or fixed measurement source antenna**.

Measurement antenna:

For e.g. Vertically oriented sleeve dipole **or wideband test antenna**.



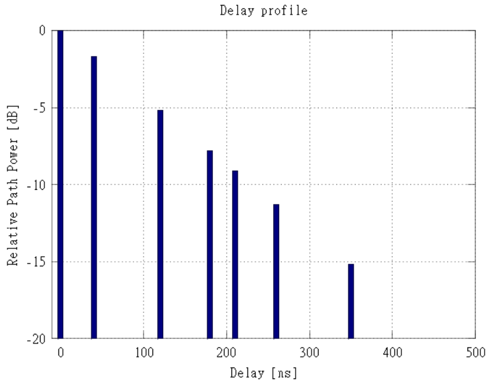


Figure C.3.2.1-1: Reference PDP values for the short delay spread low correlation and long delay spread high correlation and NIST channel models plotted from Table C.2-1, Table C.2-2 and Table C.2-3

C.3.2.2 Doppler for 3D isotropic models

This measurement checks the Doppler.

Method of measurement:

For Doppler validation, two methods could be used to measure the Doppler spectrum. The first uses a CW tone from the Signal Generator fed directly, or via the channel emulator if used, to the fixed measurement antennas and is recorded by the spectrum analyzer. For the second method, the input signal from the VNA is fed directly, or via the channel emulator if used, to the fixed measurement antennas of the chamber.

For the first method, a sine wave (CW, carrier wave) signal is transmitted from the signal generator. The signal is connected from the signal generator to the channel emulator via cables. The channel emulator output signals are connected to power amplifier boxes via cables. The amplified signals are then transferred via cables to the fixed measurement antennas. The fixed measurement antennas radiate the signals over the air to the test antenna. The Doppler spectrum is measured by the spectrum analyzer and the trace is saved.

Alternatively, the Doppler spectrum can be measured with a VNA. Frequency sweeps are measured with the VNA for a complete stirring sequence, thus collecting samples of the chamber transfer function $H(f, s_n)$ for each fixed stirrer position s_n. To get a correct estimate of the Doppler power spectrum, the spatial distance between the stirrer positions should be small enough to satisfy Nyquist theorem. $H(f, s_n)$ is Fourier transformed according to

$$H(f,\rho) = FFT(H(f, s_n))$$

The Doppler spectrum $D(f,\rho)$ can then be calculated using

$$D(f,\rho) = |H(f,\rho)|^2$$

The discrete Doppler power spectrum will now have a frequency axis ranging from 0 to N-1, where N is the number of stirrer positions used. To convert this into a Doppler frequency domain, the sampling theorem gives a frequency axis in the interval [$-\rho_{\max}$, $\rho_{\max}$], where

$$\rho_{\max} = \frac{1}{2\Delta t}$$

and the frequency step between each Doppler frequency sample is given by

$$\Delta\rho = \frac{\rho_{\max}}{N} = \frac{1}{2N\Delta t}$$

Δt is the time step between the measured samples.

Signal generator settings:

Table C.3.2.2-1: Signal generator settings for Doppler

Item	Unit	Value
Center frequency	MHz	Downlink center frequency in 36.508 as required per band
Output level	dBm	-15
Modulation		OFF

Spectrum analyzer settings:

Table C.3.2.2-2: Spectrum analyzer settings for Doppler

Item	Unit	Value
Center frequency	MHz	Downlink center frequency in 36.508 as required per band
Span	Hz	2000
RBW	Hz	1
VBW	Hz	1
Number of points		401
Averaging		100

VNA settings

Table C.3.2.2-3: VNA settings for Doppler

Item	Unit	Value
Center frequency	MHz	Downlink center frequency in 36.508 as required per band
Span	MHz	50 [TBD]
RF output level	dBm	-15
Number of traces		1296 [TBD]
Number of points		501 [TBD]
Averaging		1 [TBD]

Channel model specification:

Table C.3.2.2-4: Channel model specification for Doppler

Item	Unit	Value
Center frequency	MHz	Downlink center frequency in 36.508 as required per band
Channel model		As specified in Clause C.2
Mobile speed	km/h	100 (Note)
NOTE: Or the maximum achievable value		

Method of Measurement Result Analysis:

View the Doppler power spectrum. The reference classical Doppler spectrum is shown in figure C.3.2.2-1. B_d is the maximum Doppler shift expected for the mobile speed used for the measurements.

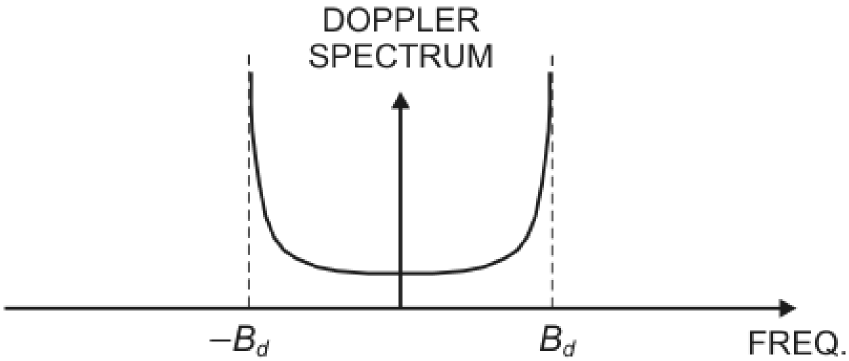


Figure C.3.2.2-1: Reference Doppler Spectrum for Jakes fading models

OTA antenna configuration:

Fixed measurement source antennas.

Measurement antenna:

A suitably wideband test antenna.

C.3.2.3 Base Station Antenna Correlation for 3D Isotropic Models

This measurement checks that the resulting base station antenna correlation follows the computed values from the channel parameters given in tables C.2-1, C.2-2 and C.2-3.

Method of measurement:

For correlation validation, the input signal from the VNA is fed directly (for table C.2.-3), or via the channel emulator (for tables C.2-1 and C.2-2), to the fixed measurement antennas of the reverberation chamber.

Step the emulation and stirrer sequence and store traces from the VNA. i.e. run the emulation channel impulse response (CIR) number 1with the reverberation chamber's stirrer sequence fixed at a point, pause, measure VNA trace, run the emulation to the next CIR and move the reverberation chamber's stirrer sequence to the next point, pause, measure VNA trace. Continue until all VNA traces are measured.

VNA settings:

Table C.3.2.3-1: VNA settings for base station antenna correlation

Item	Unit	Value
Center frequency	MHz	Downlink center frequency in 36.508 as required per band
Span	MHz	50 [TBD]
RF output level	dBm	-15
Number of traces		1296 [TBD]
Distance between traces in channel model	wavelength (Note)	> 2
Number of points		501 [TBD]
Averaging		1 [TBD]
NOTE: Time [s] = distance [λ] / MS speed [λ/s] MS speed [λ/s] = MS speed [m /s] / Speed of light [m/s] * Center frequency [Hz]		

Channel model specification:

Table C.3.2.3-2: Channel model specification for base station antenna correlation

Item	Unit	Value
Center frequency	MHz	Downlink center frequency in 36.508 as required per band
Channel model samples	wavelength	> 2592 [TBD]
Channel model		As specified in Clause C.2

Method of Measurement Results Analysis

Compute the correlation between two traces (S21 and S31 in Figure C.3.1.1-1 and Figure C.3.1.1-2) which represents the correlation between two transmit streams. This correlation should match that of the channel model used.

OTA antenna configuration:

Fixed measurement antennas.

Measurement antenna:

A suitably wideband test antenna.

C.3.2.4 Rayleigh Fading

This measurement checks that the resulting fading of the MIMO OTA system is Rayleigh as per the channel model.

Method of measurement:

For Rayleigh Fading validation, the input signal from the VNA is fed directly, or via the channel emulator, to the fixed measurement transmit antennas of the reverberation chamber.

Step the emulation and stirrer sequence and store traces from VNA. i.e. run the emulation to CIR number 1 with the reverberation chamber's stirrer sequence fixed at a point, pause, measure VNA trace, run the emulation to next CIR and move the reverberation chamber's stirrer sequence to the next point, pause, measure VNA trace. Continue until all VNA traces are measured.

VNA settings:

Table C.3.2.4-1: VNA settings for Rayleigh fading

Item	Unit	Value
Center frequency	MHz	Downlink center frequency in 36.508 as required per band
Span	MHz	50 [TBD]
RF output level	dBm	-15
Number of traces		1296 [TBD]
Distance between traces in channel model	wavelength (Note)	> 2
Number of points		501 [TBD]
Averaging		1 [TBD]
NOTE: Time [s] = distance [λ] / MS speed [λ/s] MS speed [λ/s] = MS speed [m /s] / Speed of light [m/s] * Center frequency [Hz]		

Channel model specification:

Table C.3.2.4-2: Channel model specification for Rayleigh fading

Item	Unit	Value
Center frequency	MHz	Downlink Center Frequency in 36.508 as required per band
Channel model samples	wavelength	> 2592
Channel model		As specified in clause [TBD]

Method of Measurement Results Analysis

The primary performance criteria to evaluate Rayleigh fading is the Cumulative Probability Density Function (CPDF) of the received signal amplitude (x) at the DUT. CPDF describes the probability of a signal level being less than the mean level. The CPDF of x in a set of measured samples (or a selected subset) in a mode-stirred reverberation chamber [FC(x)] is defined as,

$$F_C(x) = \text{Prob}(x \le \overline{x}) = \int_0^{2^x - 1} p_\gamma(\gamma)\, d\gamma$$

The evaluation of the measured CPDF has to provide:

1) The difference (dB) to theoretical Rayleigh-fading values for power levels ranging from 10dB above to 20 dB below the mean power level.

2) The differences (dB) to theoretical Rayleigh-fading values for power levels ranging from 20 dB below to 30 dB below the mean power level.

The requirement for CPDF is:

1) The tolerance shall be within [TBD] dB of theoretical Rayleigh-fading, for power levels from 10dB above to 20 dB below the mean power level.

2) The tolerance shall be within [TBD] dB of theoretical Rayleigh-fading, for power levels from 20 dB below to 30 dB below the mean power level.

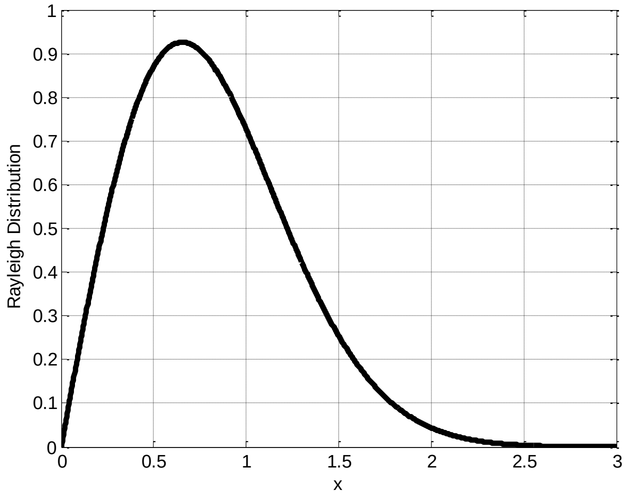


Figure C.3.2.4-1: Reference Rayleigh distribution

OTA antenna configuration:

Fixed measurement antennas.

Measurement antenna:

A suitably wideband test antenna.

C.3.2.5 Isotropy for 3D isotropic models

This measurement checks that MIMO OTA system provides an isotropic environment over time.

Method of measurement:

For isotropic validation, the input signal from the VNA is fed directly, or via the channel emulator, to the fixed measurement antennas of the reverberation chamber. If a channel emulator is used, it has to be placed in Bypass mode where no fading is used. Instead of the test antenna, an electric dipole is placed on the turn table. Three orthogonal components of the electric field are recorded with the dipole in three different orientations (see Figure C.3.1.1-2 and Figure C.3.1.1-3).

Step the stirrer sequence and store traces from VNA. i.e. with the reverberation chamber's stirrer sequence fixed at a point, pause, measure a VNA trace for each wall antenna, move the reverberation chamber's stirrer sequence to the next fixed point, pause, measure VNA trace for each wall antenna. Continue until all VNA traces are measured. Follow this procedure with the dipole in all three positions.

VNA settings:

Table C.3.2.5-1: VNA settings for isotropy

Item	Unit	Value
Center frequency	MHz	Downlink center frequency in 36.508 as required per band
Span	MHz	NA
RF output level	dBm	-15
Number of traces per wall antenna		1296 [TBD]
Distance between traces in channel model	wavelength (Note)	NA
Number of points		NA
Averaging		NA
NOTE: Time [s] = distance [λ] / MS speed [λ/s] MS speed [λ/s] = MS speed [m /s] / Speed of light [m/s] * Center frequency [Hz]		

Channel model specification:

Table C.3.2.5-2: Channel model specification for isotropy

Item	Unit	Value
Center frequency	MHz	Downlink center frequency in 36.508 as required per band
Channel model samples	wavelength	NA
Channel model		As specified in Clause C.2

Method of Measurement Results Analysis

Compute and evaluate the anisotropy coefficients as described in [16]. The reference anisotropy coefficients are shown in Figure C.3.2.5-1 where one type is from processing two orientations, 3 total plots, and the other is for all orientations.

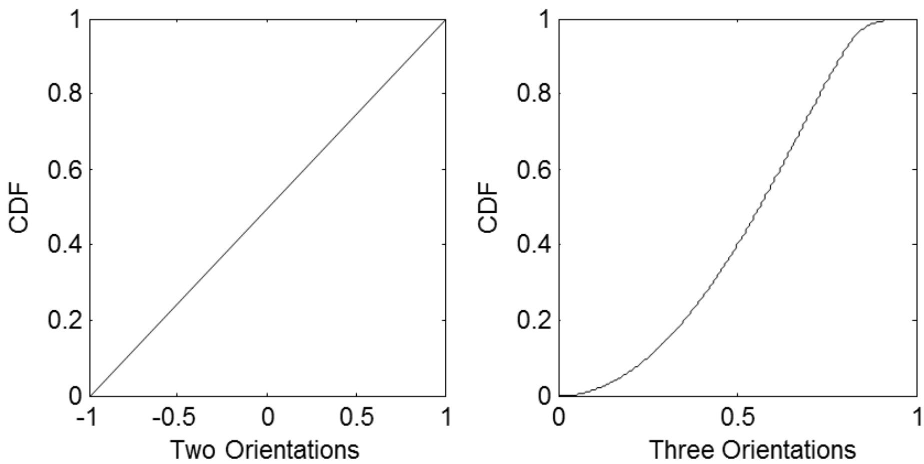


Figure C.3.2.5-1: Reference anisotropy coefficients

OTA antenna configuration:

Fixed measurement antennas.

Measurement antenna:

The electric dipole.

C.3.3 Reporting

Additionally, the results should be summarized in the following table (some entries like isotropy apply only to certain methods):

Table C.3.3-1: Template for reporting validation results

Item	Parameter	Result	Tolerances (Note 1)	Comments
1	Power delay profile			
2	Doppler			
3	BS antenna correlation			
4	Rayleigh fading			
5	Isotropy			
NOTE 1: The exact tolerances are for further study. NOTE 2: In addition to the validation of channel model parameters stated here, in order to properly identify test tolerances it is important to verify test repeatability. Though not required for channel model verification, individual labs are encouraged to run test repeatability experiments, such as the one described in Annex G.A.2 in [4]. For future uncertainty analyses, test repeatability of all methodologies has to be reported.				

Annex D: Environmental requirements

The requirements in this clause apply to all types of UE(s) and MS(s).

D.1 Ambient temperature

All the MIMO OTA requirements are applicable in room temperature e.g. 25°C.

D.2 Operating voltage

The device under test shall be equipped with a real battery that is fully charged (in the beginning of the Test).

Annex E:
DUT Orientation Conditions

E.1 Scope

This annex lists the testing environment conditions for all DUT types relevant to MIMO OTA testing. The positioning discussed here may be applicable for some methodologies only, and not for some other methodologies.

E.2 Testing Environment Conditions

Table E.2-1 below lists the testing environment conditions along with a diagram and applicable references.

The reference coordinate system and orientation of devices in that coordinate system is shown in Figure E.2-1 below, which includes the mechanical alignment of a phone. For tablets the home button, charging connector and similar components can be used to define top and bottom. For laptops the definitions specified in [11] (and repeated here in Table E.2-1) are used.

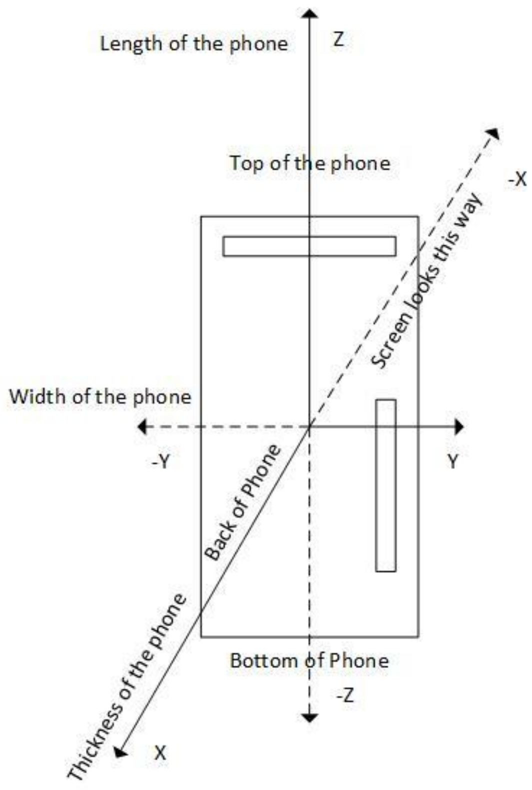
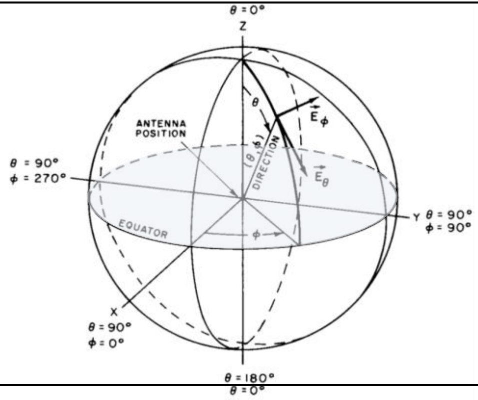
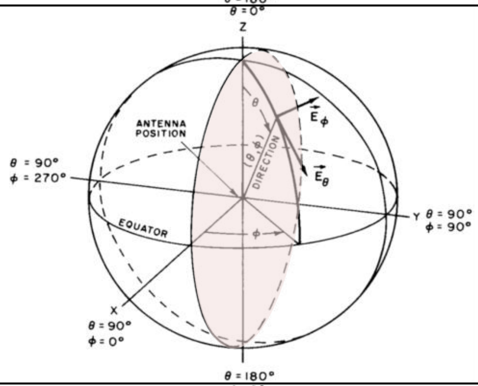
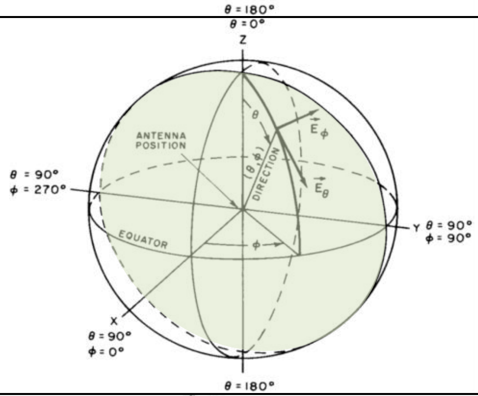
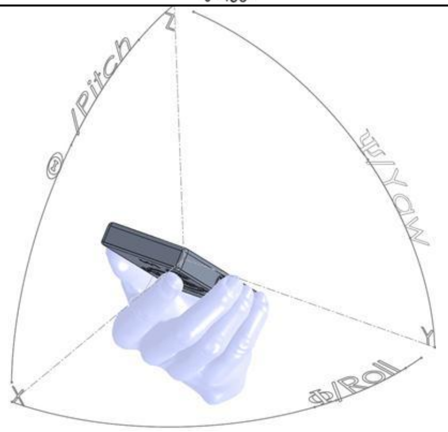
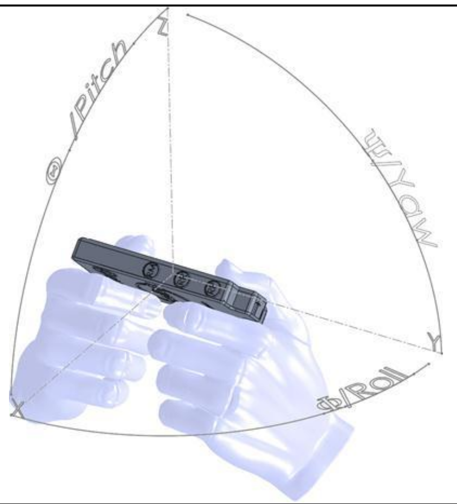
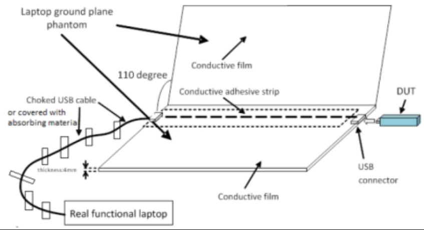
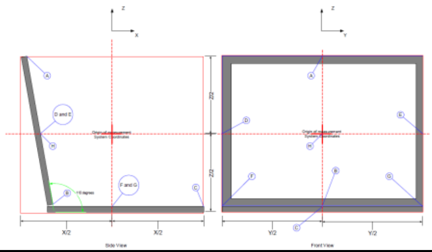


Figure E.2-1: Reference device orientation

The principal antenna pattern cuts (XY plane, XZ plane, and YZ plane) are defined in the IEEE.149-1979.R2008 [17]. The XY plane cut corresponds to the absolute throughput testing condition applied to the CTIA reference antennas for the IL/IT activity. They XZ plane and YZ plane cuts are shown for completeness and are not required for the absolute data throughput framework. The YZ plane cut corresponds to a device positioned with its screen up in a USB/WLAN tethering scenario and may be a useful testing point for handset devices expected to achieve performance metrics under such usage conditions.

Table E.2-1: Summary of possible testing environment conditions for devices supporting DL MIMO data reception

DUT type and dimensions	Usage mode	Testing condition	DUT orientation angles[1]	Diagram	Reference
CTIA reference antennas[2]	Absolute throughput in free space, XY plane[3]	XY plane	Ψ=0; Θ=0; Φ=0		[17]
CTIA reference antennas[2]	Absolute throughput in free space, XZ plane[4]	XZ plane	Ψ=90; Θ=0; Φ=0		[17]
CTIA reference antennas[2]	Absolute throughput in free space, YZ plane[4]	YZ plane	Ψ=0; Θ=90; Φ=0		[17]
Handset, any size	Data mode screen up flat[5]				
Handset, width < 56mm	Data mode portrait (DMP)	Left and Right hand narrow DUT phantom	Ψ=0; Θ=453; Φ=0		[11],[18], CTIA Test Plan for Wireless Device OTA Performance, V3.2
Handset, 56 mm < width < 72 mm		Left and Right hand PDA phantom			
Handset, width > 72mm		Free space DMP			

Handset, dimensions FFS	Data mode landscape (DML)[6]	Free space DML	Ψ=90; Θ=45; Φ=0 – left tilt[7] Ψ=-90; Θ=45; Φ=0 – right tilt[7]		[18]
LME	Free space with ground plane phantom	XY plane	Ψ=0; Θ=0; Φ=0		[11]
LEE	Free space	XY plane8	Ψ=0; Θ=0; Φ=0		[11], CTIA Test Plan for Wireless Device OTA Performance , V3.2

NOTE 1: Rotation is defined in Euler rotation angles, where Ψ denotes rotation around the X axis (yaw), Θ denotes rotation around the Y axis (pitch), and Φ denotes rotation around the Z axis (roll) [18]

NOTE 2: The CTIA reference antennas have been defined for inter-lab inter-technique testing for the purposes of comparing MIMO OTA methodologies.

NOTE 3: For DMP, other pitch positions can be considered FFS.

NOTE 4: The absolute throughput usage mode is defined only within the framework of the CTIA reference antennas and is used for comparison of results within/across MIMO OTA methodologies.

NOTE 5: Screen up flat positioning reference corresponds to a possible USB/WLAN tethering case, details of implementing this DUT orientation condition such as additional cabling, etc., are FFS.

NOTE 6: Left/right/both hand phantoms for the DML usage scenario are not currently defined in 3GPP; until these phantom designs become available, is possible to only define a DML usage scenario in free space.

NOTE 7: For a symmetric 2D coverage of testing points in azimuth, DML left and right tilts are expected to produce identical results in free space. Once phantom designs become available, we expect the interaction of the phantom with the antennas to be dependent on the tilt.

NOTE 8: The 110 degree angle of the notebook screen opening is a standard reference for all measurements of antennas embedded in notebooks; as a result, the LEE measurement in free space is the principal XY plane cut with respect to this reference.

NOTE 9: Talk mode conditions to facilitate VoLTE testing may be added to this table following further study.

The data mode portrait (DMP) conditions are defined in TR 25.914 [11], and are included in this table for completeness. The data mode landscape (DML) testing conditions are not currently defined in any standard testing methodology but benefit from a thorough treatment in academic literature [18]. This testing condition considers free space for all handset sizes until a DML phantom design becomes available, at which time the testing condition will be revisited.

The Laptop Mounted Equipment (LME) and Laptop Embedded Equipment (LEE) testing conditions are well defined in TR 25.914 [11] and constitute an XY plane cut measurement, given the proper orientation of the lid of the laptop ground plane phantom (in the case of LME) or of the laptop itself (in the case of LEE).

Given a 2D ring of symmetrically distributed probes:

- The XZ plane is similar to the DML mode except for the additional 45 degrees pitch in the DML case

- For the phantom case the tilt of the DML case is very relevant since the interaction of the phantoms with the antennas will depend on it – see Figure E.2-2

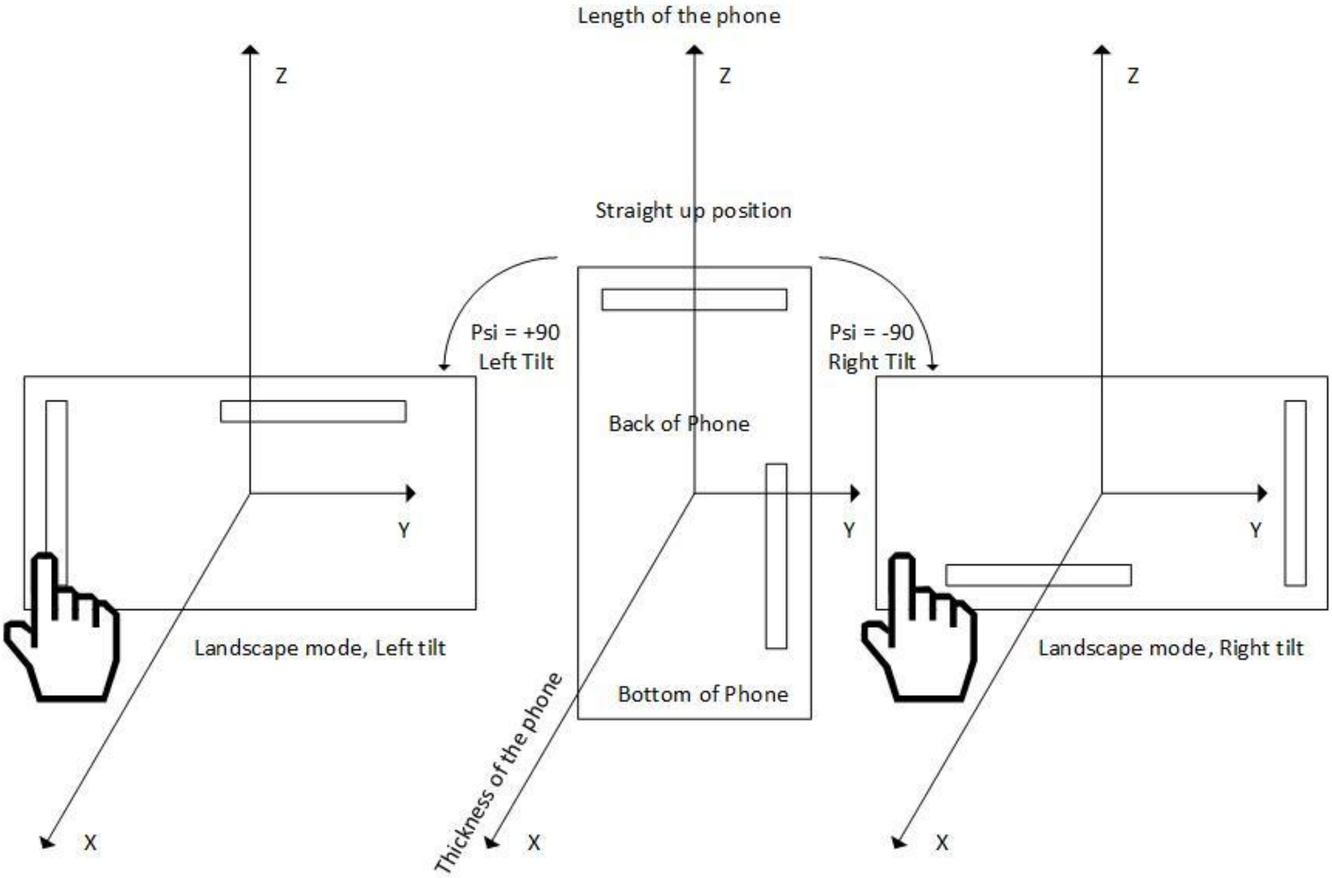


Figure E.2-2: Left and Right tilts for landscape mode with left hand phantom shown to interact differently with the antennas depending on the tilt

Annex F:
Change history

Change history							
Date	**TSG #**	**TSG Doc.**	**CR**	**Rev**	**Subject/Comment**	**Old**	**New**
2012-03	R4#62bis	R4-121734			Blank report: initial content to be incorporated from TR 37.976 v1.8.0		0.0.1
2012-03	R4#62bis	R4-122118			Updated TR incorporating agreed text proposals R4-122096, R4-122097, and R4-122099.	0.01	0.1.0
2012-05	R4#64	R4-124568			Updated TR incorporating agreed text proposals: R4-123526 (proposed change to 6.4 is applied to clause 8.3) R4-123271.	0.1.0	0.2.0
2012-11	R4#65	R4-126204			Updated TR incorporating agreed text proposals: R4-125975 R4-125939	0.2.0	0.3.0
2013-01	R4#66	R4-130645			Updated TR incorporating agreed text proposals: R4-126911 R4-126926	0.3.0	0.4.0
2013-02	RAN #59	RP-130342			Presentation of TR 37.977 v0.4.0: Verification of radiated multi-antenna reception performance of User Equipment (UE) Moved to Release 12	0.4.0	0.4.0
2013-04	R4 #66bis	R4-131665			Updated TR incorporating agreed text proposals: R4-131672 R4-131673 R4-131674	0.4.0	0.5.0
2013-05	R4 #67	R4-132685			Updated TR incorporating agreed text proposals: R4-131993 R4-131211 Agreed text proposals from R4#66 R4-130881 R4-130710 R4-130742 R4-130751	0.5.0	0.6.0
2013-08	R4 #68	R4-133205			Updated TR incorporating agreed text proposals: R4-133086 R4-133000 R4-133088 R4-133133 R4-132843 R4-132161 R4-132887	0.6.0	0.7.0
2013-09	-	-			MCCclean-up	0.7.0	0.7.1
2013-09	RP#61	RP-131221			Presented to RP#61 for information	0.7.1	1.0.0