Test Plan for 2x2 Downlink MIMO and Transmit Diversity Over-the-Air Performance

Version 1.1.1

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Acknowledgements

This test plan was created by the wireless industry with input from the following companies and their representatives:

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Section 1   Introduction

1.1   Purpose

The purpose of this document is to define the CTIA Certification program test methodology for radiated performance measurements of LTE 2x2 downlink MIMO wireless devices. Future revisions of this test plan may also include methodologies for assessing radiated performance during non-MIMO operation using transmit diversity.

1.2   Scope

This test plan defines general requirements for test systems, test conditions, equipment configurations, laboratory techniques, test methodologies, and evaluation criteria that must be met in order to ensure the accurate, repeatable, and uniform testing of wireless devices capable of supporting LTE 2x2 downlink MIMO. Future revisions of this document may include the equipment configurations, test methodologies, and evaluation criteria required to assess the EUT's transmit diversity performance.

This test plan provides high level test procedures and basic test equipment configuration information but does not include detailed test instructions by which to execute certification testing. Such documentation and procedures must be presented by the CTIA Authorized Test Lab (CATL) as part of the CTIA authorization process and subsequently employed and maintained by the CATL to remain authorized to perform Certification testing.

1.3   Applicable Documents

[1] 3GPP TR 37.977: Verification of radiated multi-antenna reception performance of User Equipment (UE)

[2] 3GPP TS 36.213: Physical layer procedures

[3] 3GPP TS 36.508: Common test environments for User Equipment (UE) conformance testing

[4] 3GPP TS 36.521-1: User Equipment (UE) conformance specification; Radio transmission and reception; Part 1: Conformance Testing

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

[6] Baum, D.S.; Hansen, J.; Salo, J., "An interim channel model for beyond-3G systems: extending the 3GPP spatial channel model (SCM)," Vehicular Technology Conference, 2005. VTC 2005-Spring. 2005 IEEE 61st , vol.5, pp.3132-3136

[7] CTIA Test Plan for Wireless Device Over-the-Air Performance; Method of Measurement for Radiated RF Power and Receiver Performance

[8] Guide to the expression of uncertainty in measurement, Genèva, Switzerland, International Organization for Standardization, 1995.

[9] IEEE.149-1979.R2008: "IEEE Standard Test Procedures for Antennas," IEEE, December 2008

[10] TR 102 273: Electromagnetic compatibility and Radio spectrum Matters (ERM); Improvement on Radiated Methods of Measurement (using test site) and evaluation of the corresponding measurement uncertainties; Part 1: Uncertainties in the measurement of mobile radio equipment characteristics; Sub-part 2: Examples and annexes

1.4 Acronyms and Definitions

The following specialized terms and acronyms are used throughout this document.

Acronym/Term	Definition
DML	Data Mode-Landscape
DMP	Data Mode-Portrait
EUT	Equipment Under Test
Measurement Points	The individual data points collected during execution of the requisite test methodology.
MPAC	Multi-Probe Anechoic Chamber utilized for the assessment of MIMO - capable devices.
PDSCH-EPRE	Packet Downlink Shared Channel-Energy Per Resource Element
RS-EPRE	Reference Signal-Energy Per Resource Element
Test Condition	The emulated propagation conditions utilized within the test system. In this version of this test specification, the SCME UMa channel model is the only valid test condition. The test condition is only seen in the validated test volume of the test system.
Test System	The controlled propagation environment used for evaluation of the Equipment Under Test (EUT). In the context of this version of this test specification, the Multi Probe Anechoic Chamber (MPAC) is the only valid test system.
Test Methodology	The process used to execute tests against the EUT using the Test System(s) and Test Condition(s) specified by this document.
Test Volume	The useable volume within the test system in which the EUT can be placed. The test volume is assumed to have a uniform power distribution within the uncertainty specified by the site validation.
Test Zone	The portion of the MPAC test volume in which the test condition criteria are met within the applicable uncertainty limits.

1.5 MIMO OTA Test Overview

Downlink 2x2 MIMO allows LTE wireless devices with MIMO spatial multiplexing receiver implementations to support data rates almost twice as high as the data rates available from a 2x1 MISO downlink. This higher data rate is possible through the use of spatial multiplexing, where the

device's serving network simultaneously transmits two independent, spatially-diverse data streams to the wireless device. In order to realize the full benefit of spatial multiplexing, the wireless device must be able to differentiate between the two downlink data streams. In order to assess radiated downlink 2x2 MIMO performance, the MOSG's test methodology creates a standardized spatial channel within the test zone, with characteristics similar to real-world radio environments. Currently, the test system creates an SCME Urban Macro propagation channel. However, any spatial channel model can be created within the test zone should future industry demands require the use of alternative models.

The test system used to create a spatial radio channel is thoroughly described in this document. In addition to describing the creation of a spatial radio environment, this document also describes a means by which the Signal to Interference Ratio (SIR) can be controlled. The control of SIR is very important, as it allows labs to evaluate the wireless device's spatial multiplexing performance under operating conditions the device will experience in actual networks. SIR control also allows labs to render a performance metric which can be used as a benchmark for each device's spatial multiplexing performance in actual wireless networks.

1.6 MIMO Equipment under Test and Accessories-The Wireless Device

See Section 1.5 of the CTIA OTA test plan [7]. The manufacturer shall not indicate support for any operating band where the MIMO antenna system is not completely contained within the validated spatial correlation sphere as defined in Section 2.3.3. If the UE supports more than 2 antennas, then the UE shall be tested in the antenna configuration used for normal device operation. The UE's antennas shall not be configured or enabled/disabled in a manner that is contrary to the normal operation of the UE.

1.7 Wireless Device Documentation

Wireless devices submitted to a CATL for MIMO performance evaluation shall include information concerning the antenna placement for each band in which MIMO is supported by the EUT. The specific information required is described in Section 2.3.3. In addition, the number of device receive antennas for each band to be tested shall be included in the information submitted to a CATL for MIMO performance evaluation.

1.8 Over-the-Air Test System

The tests described in this document require a test system capable of creating reproducible multi-path over-the-air propagation channels meeting all of the specifications of the required spatial channel models. In this test plan, the test system currently specified is capable of producing the required test conditions for all of the required test cases listed in the following sections, with certain limitations associated with the UE antenna spacing as described in Section 2.3.3. Calibration and validation methodologies are provided as well.

1.8.1 Multi-Probe Anechoic Chamber (MPAC)

The Multi-Probe Anechoic Chamber (MPAC) is based on the anechoic boundary array concept. The anechoic boundary array refers to a mechanism by which any desired near-field RF environment can be created, subject to the limitations imposed by the resolution of the boundary array and the channel emulation applied. By arranging an array of antennas around the Equipment Under Test (EUT), a spatial distribution of angles of arrival may be simulated to expose the EUT to a near field environment that appears to have originated from a complex multipath far field

environment. The anechoic chamber only serves to isolate the test volume from the external laboratory environment and to minimize unwanted internal reflections in the region of the EUT. It is assumed to play no part in the environment generated.

Signals propagate from the base station/communication tester to the EUT through a simulated multipath environment known as a spatial channel model, where appropriate channel impairments such as Doppler and fading are applied to each path prior to injecting all of the directional signals into the chamber simultaneously through the boundary array. The resulting field distribution in the test volume is then integrated by the EUT antenna(s) and processed by the receiver(s) just as it would do so in any non-simulated multipath environment.

The uniformly spaced array resolution required to precisely reproduce any possible environment for a given EUT antenna separation is based on common Nyquist theorem, requiring two samples per wavelength on the circumference of a sphere enclosing antennas. However, the actual resolution required to adequately reproduce a given spatial channel model is dependent on the model itself, since most environments are not spatially uniform. Thus, there are directions where little or no signal is received and therefore it is possible to asymmetrically optimize the antenna distribution to increase the resolution while limiting the number of emulated channels required.

For the purposes of this test plan and the standard multi-cluster spatial channel models used to evaluate the EUT, a boundary array distributed as an azimuthal ring about the EUT is considered sufficient to adequately reproduce the target channel models. The minimum resolution of such an array consists of eight dual-polarized elements spaced every 45° around the EUT in the X-Y plane as defined in Table E.2-1. Arrays with higher resolution (e.g. closer probe spacing), using uniform, or model-specific non-uniform antenna distributions may be used provided the resulting system configuration passes the required channel model and site validation tests, specified in Appendix A.2. Any theoretical references for channel model and site validation for the higher array resolutions or non-uniform antenna distributions will continue to use the existing validation tests in Appendix A.2 and any further extension of the validation tests is out of the scope of this test plan.

Figure 1.8.1-1 illustrates a typical eight element boundary array configuration with 16 channels of spatial channel emulation. Each output channel of the channel emulator typically requires amplification to provide enough signal level to propagate over the air to the EUT. For tests requiring uniform spatial interference, uncorrelated noise is injected uniformly distributed in azimuth around the EUT. While this is typically injected at the output of the channel emulation, independent mechanisms that produce the required uniform interference may be used. For example, systems with non-uniform distributions of the boundary array (distributed to match the cluster(s) of the model being used) may choose to use a uniform array of antennas to inject the interference.

A turntable is normally used to provide azimuthal averaging of the device orientation within the test volume, although rotation of the channel model can also be used to accomplish a similar result, depending on the desired angular resolution. Rotation of the device within the test volume provides for determining a statistical average performance of the device in the specified spatial channel, as opposed to measuring a radiation pattern of the EUT.

FIGURE 1.8.1-1 BLOCK DIAGRAM OF A TYPICAL BOUNDARY ARRAY RF ENVIRONMENT SIMULATION SYSTEM
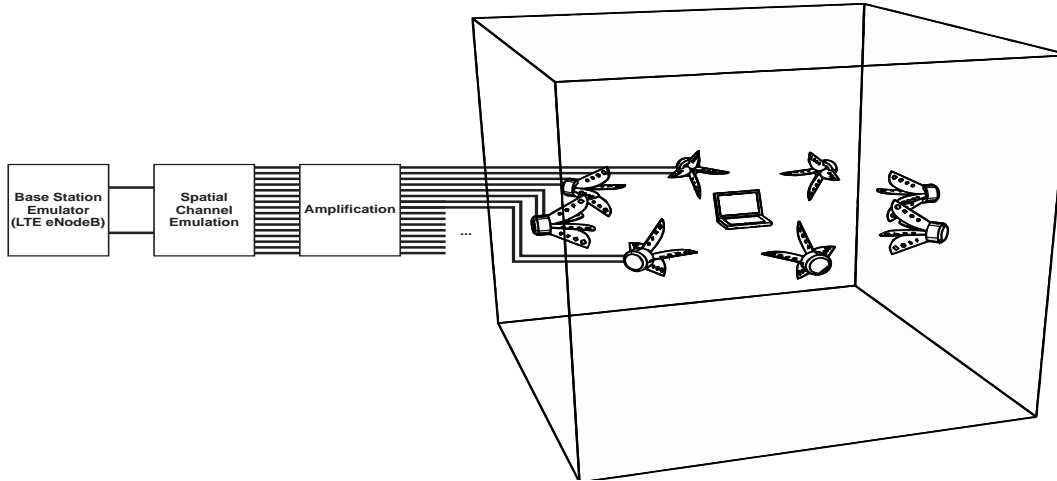
Section 2   MIMO Receiver Performance Assessment (Open-Loop Spatial Multiplexing)

2.1   MPAC General Description

The tests in this section assess the EUT's MIMO OTA throughput performance when the serving eNodeB is utilizing Open-Loop Spatial Multiplexing (OL-SM). During execution of OL-SM tests, the EUT shall be illuminated with an average RS-EPRE that is maintained constant while the on-channel AWGN interferer is varied. All OL-SM tests shall be executed in the MPAC where the spatial and temporal characteristics of the SCME channel may be emulated and controlled.

2.2   MPAC System Setup

This test procedure currently assumes the use of a multi probe anechoic chamber (MPAC) test system for generation of the desired test conditions. In addition to qualifying the implementation of the channel model to be used as specified in Appendix A.2, each system installation shall be calibrated and validated to ensure proper operation.

2.2.1   MPAC Ripple Test

For an azimuthal boundary array, the standard phi-axis ripple test described in Section 3.5.2 of the CTIA OTA Test Plan [7] shall be used. Since the boundary array is arranged in an azimuthal orientation about the device and labs are not expected to have a theta-axis positioner available, the results of a phi-axis ripple test using both a dipole and loop are considered sufficient to evaluate the test volume. As in Section 3.5.2 of the CTIA OTA Test Plan [7], the test covers a cylindrical quiet zone 300 mm in diameter around the phi axis and 300 mm tall. The Notebook PC sized test volume is not required to be measured. The tests shall be performed at the frequencies outlined in Section 3.3 of the CTIA OTA Test Plan [7]

2.2.2   MPAC Calibration

Calibration of the MPAC boundary array system is quite similar to the range reference measurement described in Section 4 of the CTIA OTA Test Plan [7] where each polarized element of the boundary array adds an additional path loss measurement to the two polarizations normally calibrated for a SISO antenna pattern measurement system (see Figure 2.2.2-1). However, unlike traditional TRP/TIS testing where the path loss corrections can all be applied as a post processing step to the measured data, the path loss for each element in the boundary array must be balanced at test time in order to produce the desired field distribution within the test volume. Since all elements are active simultaneously, any relative differences in path loss for different elements would result in an alteration of the angular dependence of the channel model being injected into the chamber.

With the introduction of channel emulation to the system, the path loss from the communication tester to the center of the test volume is split between the cables and components connecting the communication tester output(s) to the channel emulator input(s) and those from the channel emulator outputs to the center of the test volume. This split in the signal path requires a split in the calibration process in order to determine relative offsets in both the input and output components of the system.

For the purposes of calibration of these external components, the channel emulator can be thought of as a variable gain stage (e.g. variable attenuator) with level adjustments at both inputs and outputs as well as an internal loss component associated with the chosen channel model. The

ability to selectively enable specific inputs and outputs allow it to be used as a splitter/switch combination to enable specific signal paths for calibration.

FIGURE 2.2.2-1; TYPICAL DOWNLINK MIMO BOUNDARY ARRAY SYSTEM CONFIGURATION WITH MULTIPLE CHANNEL EMULATORS AND OUTPUT AMPLIFIERS
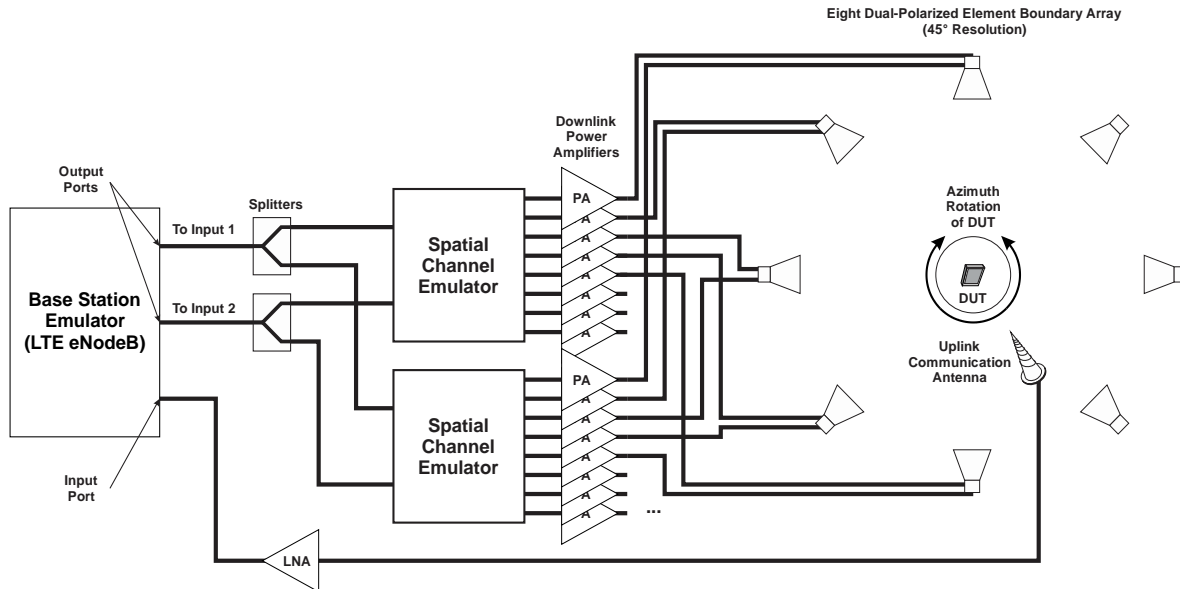
Figure 2.2.2-2 illustrates a single path from the base station emulator/communication tester to the center of the test volume. A typical system implementation will likely have various signal routing options to connect to different communication testers and different antenna configurations, as well as allowing the bypass of various components in the system for calibration or other testing purposes. The various gains and losses of all system components shall be accounted for in the range calibration, along with the associated measurement uncertainties.

FIGURE 2.2.2-2: TYPICAL SINGLE-DOWNLINK PATH FROM THE COMMUNICATIONS TESTER TO THE DUT IN THE CENTER OF THE TEST VOLUME
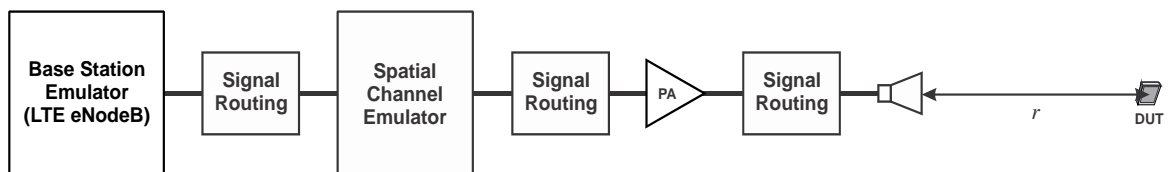
While traditional sensitivity measurements like those used in TIS testing only require one absolute power reference at the communication tester, the addition of signal to interference ratio (SIR) based testing requires a second power reference at the interferer source. A typical approach for introducing interference is to inject the noise at each output of the channel emulator, thus requiring the determination of the difference in path losses between the communication tester output and channel emulator output, in addition to the net path loss from the communication tester to the

center of the test volume. For systems utilizing completely independent noise sources, the path loss from that noise source to the center of the test volume must be determined independently.

The test frequencies to be used when calibrating the MPAC boundary array shall correspond to the frequency of the downlink for mid-range from 3GPP TS 36.508 [3] as required per band for the normative bands defined in Table 2.3.3.2-1 and Table 2.3.3.2-2.

2.2.2.1 Input Calibration

The primary goal of the input calibration is to balance the input levels at the channel emulator such that the outputs of the communication tester arrive at the inputs to the channel emulator with the same magnitude and phase relationship with which they were generated. Depending on the implementation, it may also be necessary to determine the net path loss between the communication tester and channel emulator in order to apply that as a separate correction, usually for SIR based testing.

Currently available channel emulators have integrated power measurement functions that can be used to evaluate the power level at each input. While this function can typically be used to automatically balance the inputs to the average power measured, this introduces a number of problems if modulated wireless signals are used. The downlink signal generated by an LTE communication tester prior to establishing a connection to the EUT does not generally have the same occupied bandwidth as the downlink signal used for the sensitivity test, so the average power measured will be different. In addition, the average broadband power measured for the specified test signal does not exactly reflect the required RS-EPRE setting due to the unoccupied subframes in the reference measurement channel. For this reason, the preferred approach is to use a CW signal to determine the path loss of each of the paths and use the resulting information to set the reference levels used for output calibrations and device testing. Note, however, that any changes to the input reference level of the channel emulator alter the net path loss of the system, so any function that automatically measures the power and adjusts the reference level must be accounted for in the total path loss corrections.

Figure 2.2.2.1-1 shows a typical setup for calibrating the relative input levels of each channel emulator input from the same CW source. A stable CW source (e.g. signal generator or VNA in zero span mode) is used to inject a constant signal level into each cable that would normally connect to the MIMO channel outputs of the communication tester. A fixed attenuator at the end of the source cable minimizes the measurement uncertainty contribution due to changes in standing wave contributions for the various paths. Alternately, the communication tester may be used as the CW source as shown in Figure 2.2.2.1-2 if it supports that option. Since the same communication tester is used during the calibration and EUT measurement, any standing wave contribution from the cables as well as any internal offsets in the communication tester outputs are included in the relative offsets determined by the input calibration.

By using a direct connection to one of the channel emulator ports, as shown in Figure 2.2.2.1-3, the reference power level at the input to the cables can be determined in order to calculate the path loss of each input path in addition to the relative offsets between them. In this way, the measurement uncertainty for the path loss of the cables is based primarily on the linearity of the channel emulator power meter. For the case of using the communication tester as a dual CW signal source, the net path losses of the cables cannot be directly determined since a second power reference point is not being measured at the other end of the cable. However, with the assumption that turning modulation on or off on the tester does not alter the absolute power level of the signal (or that appropriate compensation is applied) setting the channel emulator input reference level to the measured power level has the effect of correcting for the input cable loss such that any applied signal-to-noise ratio at the channel emulator outputs will have the proper relative noise level. Note, however, that if the automatic measurement function of the channel emulator is used on a CW

signal, the crest factor setting must be adjusted to address the effect of the applied modulation for EUT testing and avoid overdriving the inputs. The effect of this adjustment must also be accounted for in the total path loss correction.

FIGURE 2.2.2.1-1: TYPICAL INPUT CALIBRATION SETUP TO BALANCE INPUT REFERENCE LEVELS USING A SINGLE CW SOURCE

(a)   (b)
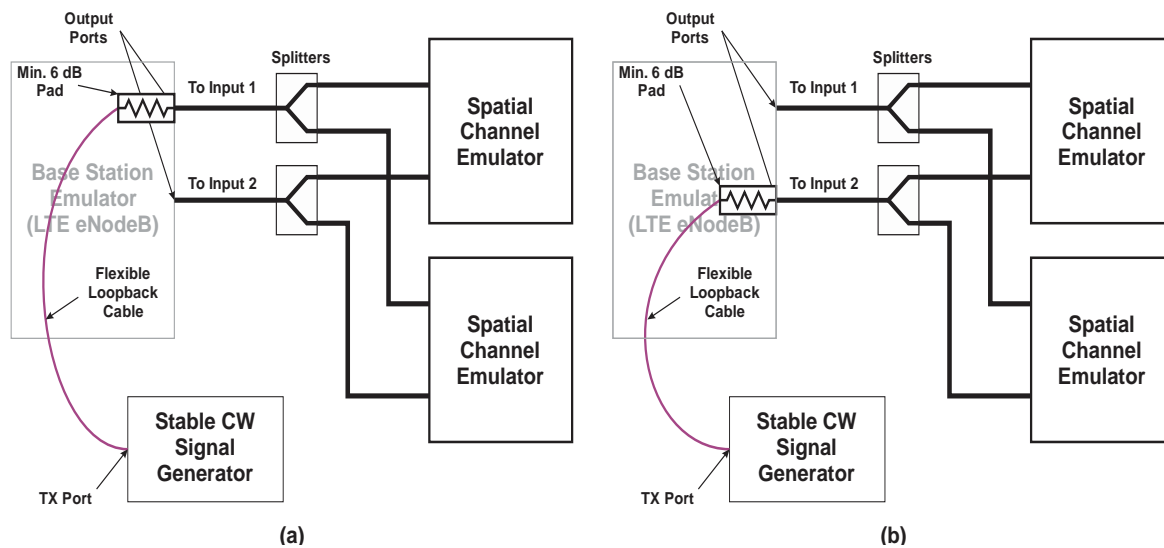
FIGURE 2.2.2.1-2: TYPICAL INPUT CALIBRATION SETUP TO BALANCE INPUT REFERENCE LEVELS USING A DUAL CW SOURCE
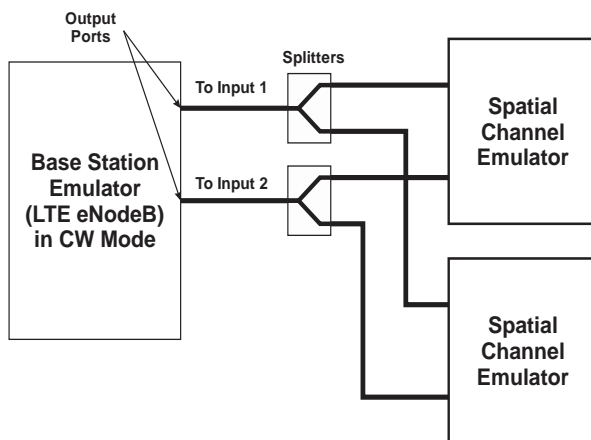
FIGURE 2.2.2.1-3: EXAMPLE OF USING THE CHANNEL EMULATOR POWER METER TO OBTAIN A REFERENCE FOR DETERMINING NET PATH LOSS OF EACH INPUT PATH
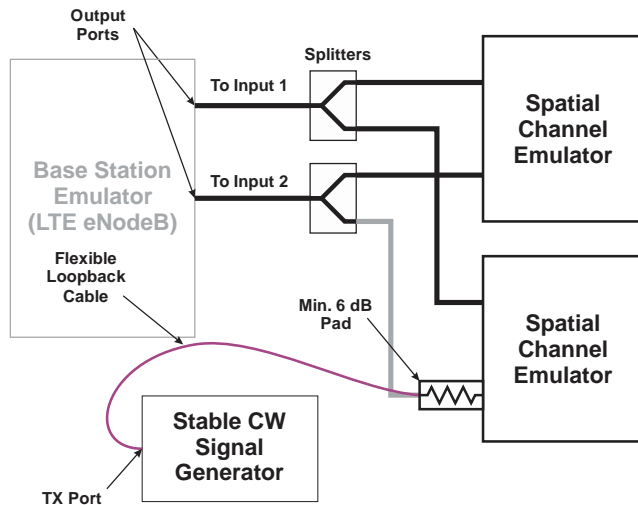
The following list describes a typical process for determining the relative and absolute input path losses using a single CW source.

1. Connect an isolation attenuator (minimum 6 dB recommended) to the end of an RF cable attached to a stable CW signal generator.

2. Attach the attenuated end of the cable to the end of the system cable that normally connects to the first output of the communication tester.

3. Set the signal generator and channel emulators to the frequency to be measured. Alternately, multiple frequencies may be calibrated for a single center frequency setting of the channel emulator (CE), provided the same center frequency setting of the CE is used for subsequent tests of the same frequency range(s).

4. For the corresponding input of each channel emulator, measure the received power, ensuring that the power is at or below the reference level setting of the channel emulator in order to avoid overdriving, but close enough to remain in the linearity region of the input.

5. Repeat steps 3 and 4 for each frequency to be calibrated.

6. For each subsequent input cable (communication tester output connection), move the end of the signal source cable to the corresponding input cable and repeat steps 3 through 5.

7. If it is necessary to determine net path loss of each cable in each frequency band of interest, measure the power at the attenuated end of the signal source cable, ideally using a direct connection to one of the inputs of the channel emulator, applying the same considerations used in steps 3 and 4 above.

8. Compute the relative difference between the highest power measured across all inputs and the rest of the inputs. This offset is then applied to the reference level for each input for all subsequent tests to bring all digitized inputs to the same level.

9   Alternately, determine the average power level of each output of the communication tester and subtract the path loss to each input port to set the corresponding reference level.

10   To obtain the target reference levels using the communication tester in CW mode instead of a single CW source, attach the communication tester as it will be used for device testing and repeat steps 3 to 4 for each input of the channel emulator. The measured levels are then used to set the required reference level for the corresponding communication tester output power settings. In the event that specific implementation details differ from these steps, proper documentation shall be generated describing the method to be employed.

2.2.2.2   Output Calibration

The primary goal of the output calibration is to balance the outputs of the channel emulator to compensate for the differences in path loss to the center of the test volume. Thus, for SIR testing, only the relative path losses between each output, as well as any relative losses between signal source and interference source, are required to sufficiently calibrate the system. The net path loss of the calibrated system is only required for throughput vs. power testing, and is useful for ensuring that the signal is sufficiently above the platform noise to obtain the desired SIR. However, if a suitable calibrated reference antenna is used during the output calibration, then the necessary end-to-end path loss correction can also be extracted from the same set of measured data. Otherwise, once the relative corrections have been applied to the outputs, a separate path loss measurement can be performed on any one of the individual paths to determine the net path loss, since all of the relative errors are compensated separately.

Figure 2.2.2.2-1 illustrates a single path from the communication tester to the center of the test volume. While the channel emulation and other components are part of the signal path, the definition of the total path loss from the communication tester to the center of the test volume remains the same as that for the OTA test plan. Thus, the mechanisms for measuring the end-to-end loss are the same. Since the channel model and other input and output level setting controls of the channel emulator will alter the net path loss, the components can be separated into the internal gain or loss of the channel emulator and the external gain or loss of all of the other system components, as shown in Figure 2.2.2.2-2. By measuring the end-to-end loss and subtracting the internal loss term, the resulting external loss corrections can be combined with any other channel emulator settings to determine the signal levels in the test volume. For isolated signal paths that are not altered between the calibration step and the EUT measurement step (e.g., between the channel emulator and amplifier or amplifier and antenna) any standing wave contributions from these components can be assumed to be corrected by the range calibration. The calibration also embeds any residual offsets from the inputs and outputs of the channel emulator into the net path loss that is measured.

Alternatively, subsets of these paths may be measured independently, and the total path gain/loss of each component combined, minus the loss terms of any additional cables, switches, or other accessories used during the calibration process that are not part of the test signal path.

FIGURE 2.2.2.2-1: ILLUSTRATION OF A SINGLE PATH FROM THE COMMUNICATION TESTER
TO THE CENTER OF THE TEST VOLUME
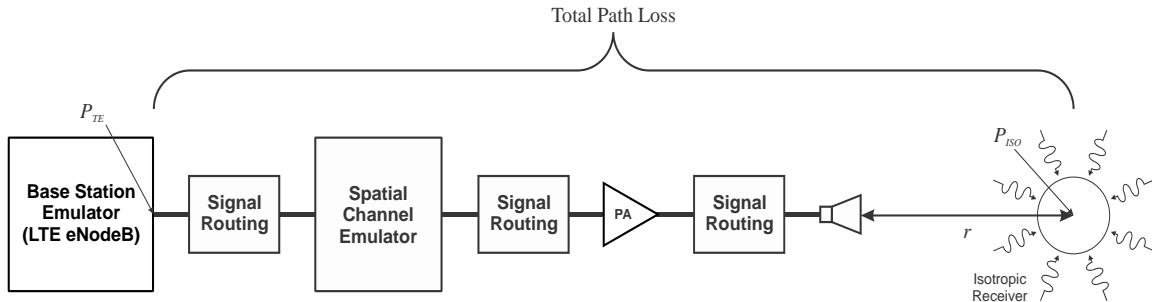
FIGURE 2.2.2.2-2: TYPICAL CONFIGURATION WHERE THE END-TO-END PATH LOSS CAN BE SEPARATED
INTO THE EXTERNAL LOSS (GAIN) COMPONENTS AND THE INTERNAL LOSS (GAIN) COMPONENTS DEFINED
BY THE CHANNEL MODEL AND OTHER CHANNEL EMULATOR SETTINGS
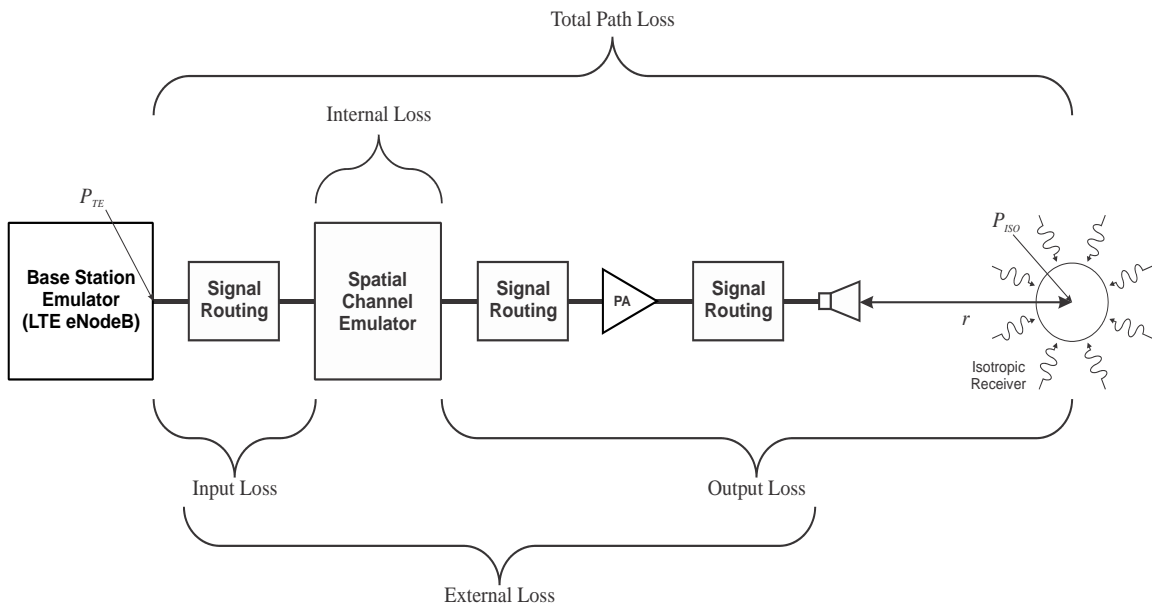
The following list describes a typical process for determining the relative and absolute input path losses from the communication tester to the center of the test volume. The procedure below is based on the range calibration procedure described in Section 4.4.1 of the CTIA OTA Test Plan [7] and can be adapted for multiple step calibrations where different segments of the path loss are measured independently and the individual losses and corresponding uncertainties are combined to obtain the total path loss for each measurement path.

1   Configure and perform a cable calibration of the VNA or signal generator/receiver combination to be used for the range calibration as described in Section 4.4.1 of the CTIA OTA Test Plan [7]. Since this is a downlink direction calibration, the receiver or the receive port will be connected to the reference antenna cable and the loopback cable will attach to

the transmit port (typically this is the same cable and attenuator used for the input calibration step in the previous section).

2   Following the guidance of steps 1 through 4 of Section 4.4.2 of the CTIA OTA Test Plan [7], attach the attenuated end of the transmit cable to the end of the system cable that normally connects to the first output of the communication tester. (Note the choice of input cable is arbitrary so long as only one input is enabled on each channel emulator.)

3   Set the signal generator and channel emulators to the frequency to be measured. Alternately, multiple frequencies may be calibrated for a single center frequency setting of the channel emulator (CE), provided the same center frequency setting of the CE is used for subsequent tests of the same frequency range(s). At each frequency, apply the relative offsets determined from the input calibration to the reference level setting of the channel emulator to correct for any relative input path loss. Ensure that the power into the channel emulator is at or below the reference level setting of the channel emulator in order to avoid overdriving, but close enough to remain in the linearity region of the input.

4   Set the output level of each used port of the channel emulator to the maximum level supported for each frequency to be tested, being sure to remain in the linear region of any external amplification to the test volume.

5   Use a static constant tap (straight through) channel model to produce a direct connection from the input to the output of the channel emulator.

6   Iterate through each output port of the channel emulator, enabling only one path from the input cable to the center of the test volume at a time, and ensuring that the reference antenna is oriented at bore sight to the direction and polarization of the active array element.

7   Measure the total path loss following the guidance of Section 4.4.2 of the CTIA OTA Test Plan [7] for each frequency of interest.

8   Repeat steps 3 through 7 for each frequency and output path to be calibrated. The order of iteration through frequencies and outputs can be interchanged as necessary for speed or ease of operation.

9   Compute the relative difference between the worst path loss and all other paths at each frequency. These offsets are then applied to the output power setting for each corresponding output to create the same net path loss between the channel emulator and the center of the test volume for each output path. Since the signal generators of the CE can never go above maximum output, the outputs of the paths with lower losses must be reduced to correspond to the path with the highest path loss.

10 The loss for the worst-case path, corrected for the channel model and number of active inputs and outputs (the internal gain of the CE) then becomes the reference path loss of the entire system. This loss is used to compute the power in the test volume relative to the output power of the communication tester.

11 After applying the relative offsets to each output, it is recommended to perform a spot check of the residual relative error, determined by repeating the calibration process with offsets applied. This provides a validation of the calibration process and an estimate of the residual error due to the total path loss and non-linearities in the system components. In the event specific implementation details differ from this procedure, proper documentation shall be generated describing the appropriate process.

2.2.2.3 Channel Emulator Input Phase Calibration

The use of highly correlated channel models such as the SCME UMa model introduces a unique set of problems. One is the phase relationship between the LTE streams from the base station. While the average power doesn't vary as a function of the input phase in the test volume of the MPAC, the LTE MIMO receiver is capable of detecting a difference that can result in a shift of the EUT measured performances. The effect is a variation of the throughput up and down when a constant average power is at the EUT. The maximum throughput performances are seen when the base station LTE signals are in-phase or 180 degrees out-of-phase with minimums at ±90 degrees. Thus, it is necessary to ensure that the relative phase between the two communication tester outputs as applied to the digital channel model inputs is zero. However, since the phase relationship of the communication tester signal generators and the channel emulator receivers cannot be guaranteed, it is not possible to simply correct for the phase differences of the input cables. Instead, the system shall be calibrated and corrected for the input phase offsets just prior to the start of the test, since any changes in frequency or other related settings may change the phase relationship of the outputs and inputs. For communication testers that are unable to maintain a constant phase relationship between the outputs when signaling is disabled, care shall be taken to ensure that the communication tester downlink signal remains enabled throughout the entire test.

Several methods have been developed to perform the phase calibration. The simplest involves configuring the communication tester to output the same signal on both outputs. This can be a CW (modulation disabled) provided that the modulation can be re-enabled and the device test performed without changing the phase relationship of the outputs. It can also be accomplished with a modulated signal using an output H-matrix operation or other test feature capable of outputting a single stream on both outputs. The calibration can be performed using external equipment (e.g. a spectrum analyzer) to monitor the output power of the channel emulator in a straight-through (constant tap) scenario while the phase offset of one of the inputs is rotated through 360 degrees. When the result shows a null, the two inputs are 180 degrees out-of-phase at the channel model. Applying the phase offset 180 degrees from the null will result in the inputs to the channel model being in-phase.

FIGURE 2.2.2.3-1: SAMPLE INPUT PHASE CALIBRATION USING A SPECTRUM ANALYZER TO MONITOR THE OUTPUT AS A PHASE OFFSET IS APPLIED TO ONE INPUT OF THE CHANNEL EMULATOR
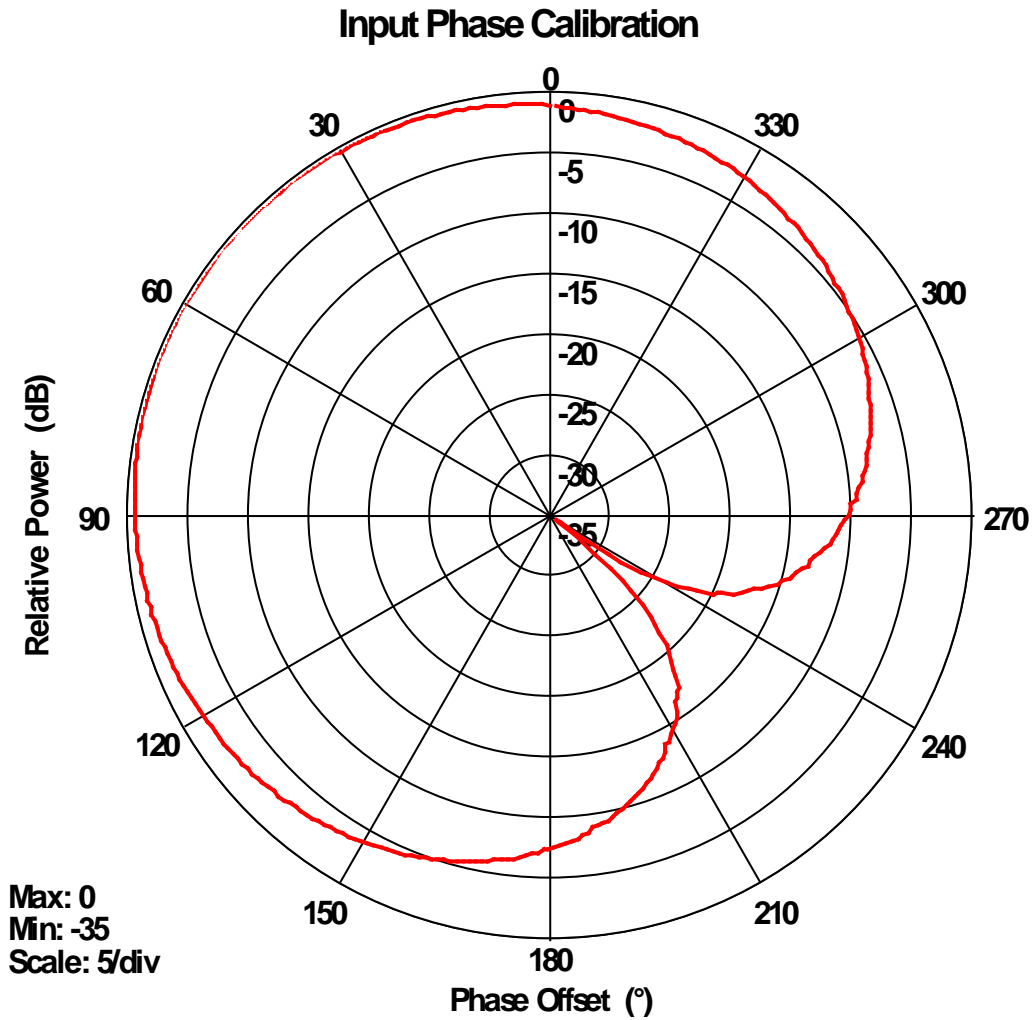
FIGURE 2.2.2.3-2: RESULT OF APPLYING A FIXED -52° OFFSET CORRECTION TO THE CHANNEL EMULATOR INPUT DUE TO THE NULL FOUND AT 232°.
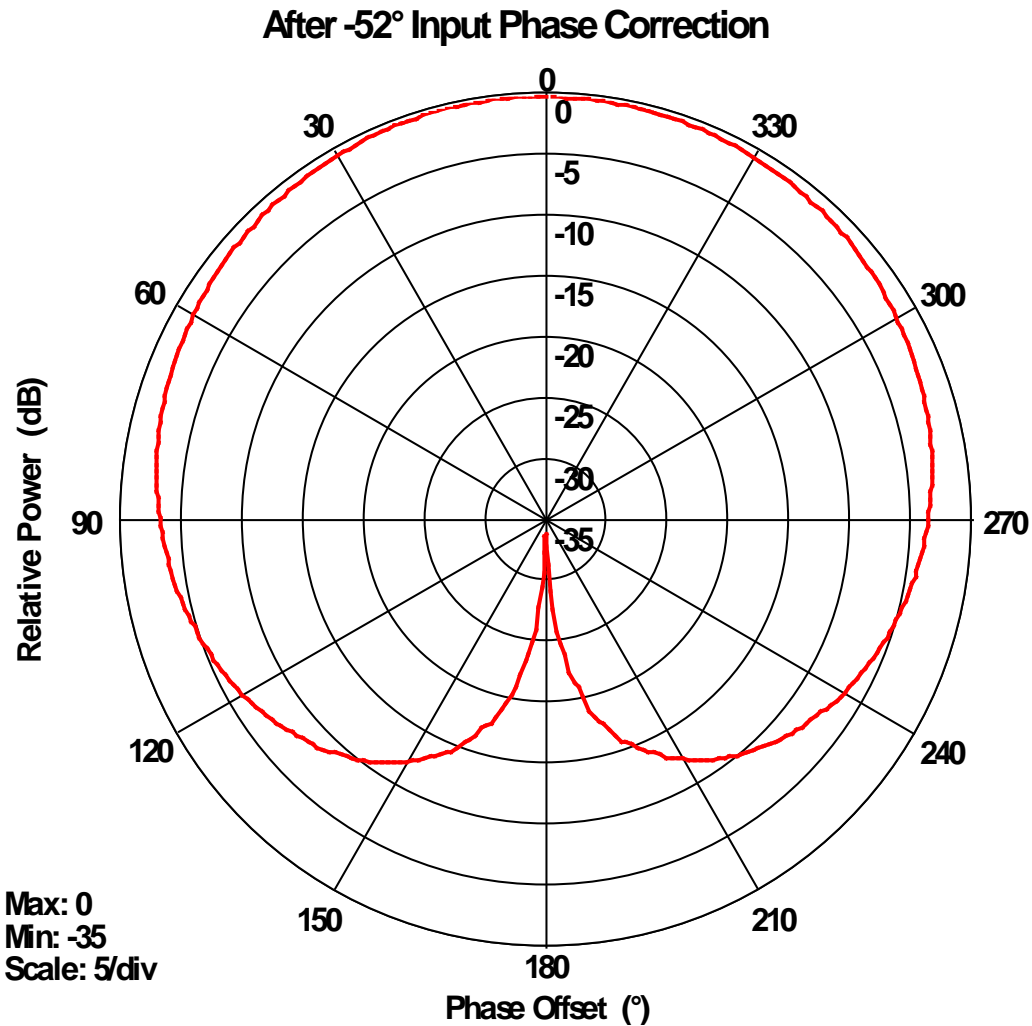
A more advanced approach suitable only for LTE requires demodulation of the LTE signal to detect the phases of the pilot channels and adjust the input phase reference appropriately. Test platform systems approved for CTIA testing must implement a variant of one of these approaches to provide quick input phase calibration and correction prior to the start of a device test.

2.3 EUT Positioning within the MPAC Test Volume

2.3.1 EUT Free-Space Orientation within the MPAC Test Zone

In order to minimize measurement uncertainty, it's important that CATLs ensure the EUT is oriented within the chamber's test zone in a standardized manner. Appendix D provides a preliminary set of normative EUT orientation conditions and the informational EUT orientation conditions are found in Appendix E. MIMO OTA performance testing of handsets and tablets in free-space shall use the normative device orientations shown in Table D.2-1. The MIMO OTA performance assessment of notebooks is not currently normative, and this device type is included in Appendix E.

Labs shall confirm the direction of rotation and rotate the EUT about its Z axis in 30-degree phi angle increments, beginning with the EUT's +X Axis oriented at phi =0 degrees. The EUT shall be situated in DMP FS and DML FS testing conditions, as shown in Table D.2-1 such that its Z axis is perpendicular to the turntable with the +Z axis facing away from the turntable. Device positioning requirements are specified in Section 2.3.3.

2.3.2 MPAC EUT Orientation within the Test Zone using Phantoms

The use of phantoms during the execution of MIMO OTA tests using the MPAC approach is FFS.

2.3.3 Maximum EUT Antenna Spacing and Placement of EUT within the Test Zone

In order for the MPAC system to emulate the intended propagation statistics within the region of space incident on the EUT antennas, two aspects determine the associated antenna spacing and positioning guidelines. The maximum antenna spacing in the EUT shall be within the limit determined by the MPAC system's ability to emulate the spatial correlation function and the power stability of the field incident on the EUT antennas as previously verified as part of the system validation utilizing the channel model validation procedures in Appendix A.2. The EUT shall wholly reside within the 300mm ripple zone as defined in Section 2.2.1 under all EUT positioning conditions.

FIGURE 2.3.3-1: ILLUSTRATION OF EUT ANTENNA SPACING AND POSITIONING GUIDELINES

(a)

(b)
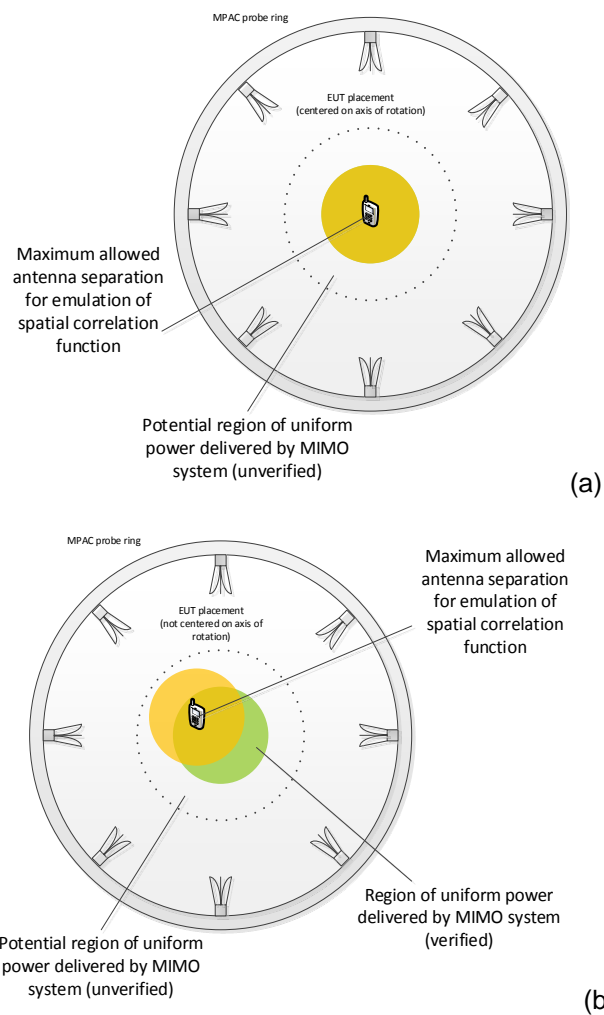
(a) Guideline in this Test Plan

(b) Example with EUT Meeting the Maximum Allowed Antenna Separation but not Within the Verified Power Stability Region

The maximum antenna spacing in the EUT shall be defined as 1 wavelength at the center frequency of the middle channel of the downlink for the band under test (refer to Table 2.3.3.2-1 and Table 2.3.3.2-2). Testing is not required in any band where the maximum antenna spacing is greater than 1 wavelength. A verification of power stability can be derived from the spatial correlation verification results in Appendix A.2.3. Given that this verification spans a region with a diameter of 1 wavelength centered on the axis of rotation in the chamber, the region where EUT antennas shall be placed (the MIMO OTA test zone) shall be defined in the same way (see Figure 2.3.3-1a). Figure 2.3.3-1b provides an example of an EUT meeting the maximum allowed antenna separation but not within the verified power stability region; this placement of an EUT shall not be used. The optimization of the maximum allowed antenna spacing of the EUT as well as the verification of the test zone is expected as part of future work.

The EUT maximum antenna spacing and placement within the test zone shall be defined by the following two-tier methodology:

2.3.3.1   EUT Placement, Frequency of Operation < 1GHz

When operating in frequency bands lower than 1GHz, the physical center of the EUT shall be placed in the chamber center, the EUT shall be completely contained within the volume defined by the respective operating band equivalent to a sphere with a radius equal to $\lambda/2$ as defined in Table 2.3.3.2-1 and Table 2.3.3.2-2 for normative bands as described in the CTIA OTA Test Plan [7]. Dimensional information for other bands that may be considered by other certification bodies can be found in Table F.1-1 and Table F.1-2.

2.3.3.2   EUT Placement, Frequency of Operation > 1GHz

When operating in frequency bands higher than 1 GHz the equidistant physical point between the EUT MIMO antenna system shall be placed in the chamber center following guidance defined in Figure 2.3.3.2-1 and the EUT MIMO antenna system (further physical dimension or both antennas maximum E-field regions) shall be completely contained within the volume defined by the respective operating band equivalent to a sphere with a radius equal to $\lambda/2$ defined in Table 2.3.3.2-1 and Table 2.3.3.2-2 for normative bands as described in the CTIA OTA Test Plan [7]. Dimensional information for other bands that may be considered by other certification bodies can be found in Table F.1-1 and Table F.1-2. The definition of the equidistant point between the EUT MIMO antennas shall be provided through manufacturer declaration. The manufacturer shall mark the equidistant point on the DUT for each operating band greater than 1 GHz such that the test laboratory has a clear indication for EUT positioning purposes.

FIGURE 2.3.3.2-1: DEFINITION OF DISTANCE BETWEEN MIMO ANTENNAS AND EUT CENTER, MAXIMUM

PHYSICAL SEPARATION, OR E-FIELD MAXIMUM SEPARATION DEFINED BY MANUFACTURER
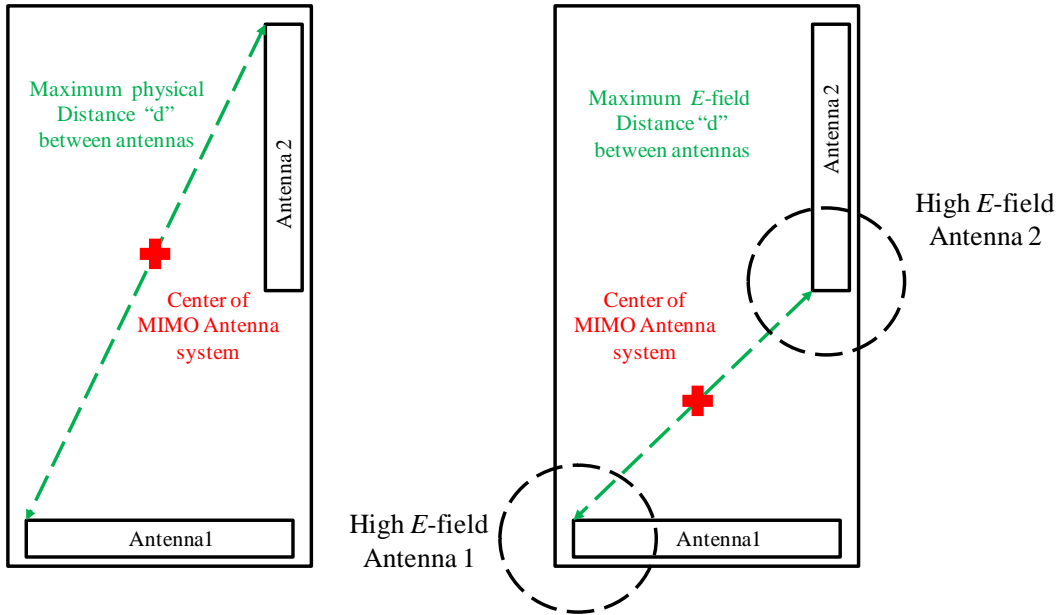
TABLE 2.3.3.2-1: TEST ZONE DIMENSION DEFINITION FOR NORMATIVE FDD BANDS OF OPERATION

Operating Band	DL Channel Bandwidth (MHz)	DLChannel Number	DL Center Channel Frequency (MHz)	λ (m) at Center DL Channel	Test Volume Sphere Radius (m)
2	10	900	1960	0.153	0.076
4	10	2175	2132.5	0.141	0.070
5	10	2525	881.5	0.340	0.170
7	10	3100	2655	0.113	0.056
12	10	5095	737.5	0.406	0.203
13	10	5230	751	0.399	0.200
14	10	5330	763	0.393	0.196
17	10	5790	740	0.404	0.203
25	10	8365	1962.5	0.153	0.076
26	10	8865	876.5	0.342	0.171
30	10	9820	2355	0.127	0.064

TABLE 2.3.3.2-2: TEST ZONE DIMENSION DEFINITION FOR NORMATIVE TDD BANDS OF OPERATION

Operating Band	DL Channel Bandwidth (MHz)	DLChannel Number	DL Center Channel Frequency (MHz)	λ (m) at Center DL Channel	Test Volume Sphere Radius (m)
41	20	40620	2593	0.116	0.058

2.4 MIMO Average Radiated SIR Sensitivity (MARSS)

2.4.1 Introduction

This test is intended to determine the average MIMO receiver performance of an EUT for a given usage case and RF environmental condition. The test evaluates the EUT in a range of typical orientations for a given usage case and then determines a single figure of merit for that model and usage case combination. The MARSS orientation dependent performance should not be thought of as a radiation pattern, since at each orientation of the EUT, signals from multiple directions are received simultaneously and combined by the antennas and radio receivers in whatever manner the EUT supports. There is no single direction around the EUT for which a given measurement defines the receiver performance in that direction. Instead, the MARSS orientation dependent information simply reflects the receiver performance for a given EUT orientation relative to the origin coordinates of the simulated RF environment in which it's being tested. The selection of orientations to be tested are intended to reflect a uniform distribution of the most common range of orientations such that no additional weighting is required to determine average performance.

2.4.2 eNodeB Emulator Configuration

The eNodeB emulator used to execute the Open-Loop Spatial Multiplexing (OL-SM) tests described in this document shall be configured according to Table 2.4.2-1 for FDD EUTs) or Table 2.4.2-2 (for TDD EUTs) below.

TABLE 2.4.2-2 ENODEB CONFIGURATION PARAMETERS FOR FDD OPEN-LOOP SPATIAL MULTIPLEXING (TM3, RANK 2) TESTS EMPLOYING SIR CONTROL

Parameter	Value
Downlink Bandwidth	10 MHz
Duplex Mode	FDD
Downlink Reference Channel	R.35 FDD as defined in 3GPP TS 36.521-1 Table A.3.3.2.1-1 [1]
Downlink Modulation	64QAM
Maximum Theoretical Throughput	35.424 Mbps
Minimum Number of Subframes per Stream	20000 (Note 1)
Downlink RS-EPRE	(Note 2)
Downlink TBS Index Subframe 0: Subframes 1-4, 6-9: Subframe 5:	17 18 Unused (0 RBs) (Note 3)
Downlink Transmission Mode	TM3
Number of MIMO eNodeB Transmit Antennas	2
Uplink TBS Index	6
Number of Uplink RBs	50
Uplink RB$_{Start}$	0

Transmit Power Control
        p-Max:
        TX power control:
	(Note 4)
	Max Power/All +1 dB

Downlink Power Level Offsets	PSS = SSS = 0 dB PBCH = PCFICH = PHICH = PDCCH = -3 dB

Parameter	Value
PDSCH Power Offset Relative to RS-EPRE	ρ_A= -3 dB ρ_B= -3 dB
HARQ Transmissions	1 (No HARQ)
OCNG Pattern	None
AWGN Power Level	None

Note 1: Throughput measurements performed at or adjacent to the target SIR sensitivity level shall be measured for the specified minimum number of subframes. Since the throughput and corresponding SIR sensitivity is a function of the variability caused by the fading of the channel model, a minimum test time is required to properly determine the fading throughput, and therefore statistical early exit techniques are not allowed when determining the final figure of merit. Labs are free to use any mechanism they wish to narrow the search to the approximate location of the SIR sensitivity point so long as the measurement(s) used to determine the SIR sensitivity target throughput meet or exceed the specified minimum number of subframes.

Note 2: The RS-EPRE level generated in the test volume should be set near the maximum linear output level of the test system, while still providing enough headroom for linear amplification of both signal and interference for SIR testing. The signal must be far enough above the platform noise of the DUT to have a negligible impact on the resulting SINR but shall be no less than REFSENS as defined in Table 7.3.5-1 of 3GPP TS 36.521-1 [4] plus 40 dB. When determining the minimum RS-EPRE level generated in the test volume, the REFSENS value shall be converted to an equivalent RS-EPRE value based on the channel BW.

Note 3: R.35 subframes 1-4 and 6-9 utilize DL TBS 18, while R.35 sub-frame 0 utilizes TBS 17. R.35 subframe 5 has zero resource blocks allocated. (See Table A.3.3.2.1-1 Fixed Reference Channel two antenna ports in 3GPP TS 36.521-1 [4] and 3GPP TS 36.213 [2] for additional information).

Note 4: p-Max shall be set to a fixed value that is equivalent to 10 dB below the nominal maximum output power defined by the DUT power class (e.g. p-Max would be set to +13 dBm for a DUT with UE Power Class 3 as defined in clause 6.2.2.3 of 3GPP TS 36.521-1 [4]).

TABLE 2.4.2-2 ENODEB CONFIGURATION PARAMETERS FOR TDD OPEN-LOOP SPATIAL MULTIPLEXING

(TM3, RANK 2) TESTS EMPLOYING SIR CONTROL

Parameter	Value
Downlink Bandwidth	20 MHz
Duplex Mode	TDD
Downlink Reference Channel	3GPP TR 37.977 Table 7.1-3 [1]
Uplink/Downlink Frame Configuration	1
Special Subframe Configuration	7
Number of Downlink RBs	100
Downlink RBStart	0
Downlink Modulation	64QAM
Maximum Theoretical Throughput	29.512 Mbps
Minimum Number of Subframes per Stream	20000 (Note 1)
Downlink RS-EPRE	(Note 2)
Downlink TBS Index	16 , RMC Defined (Note 3)
Downlink Transmission Mode	TM3
Number of MIMO eNodeB Transmit Antennas	2
Rank Indicator	2 (forced)
Uplink Bandwidth	20 MHz
Uplink Modulation	QPSK
Uplink TBS Index	6
Number of Uplink RBs	100
Uplink RB$_{Start}$	0
Transmit Power Control p-Max: TX power control:	(Note 4) Max Power/All +1 dB
Downlink Power Level Offsets	PSS = SSS = 0 dB PBCH = PCFICH = PHICH = PDCCH = -3 dB
PDSCH Power Offset Relative to RS-EPRE	ρ_A= -3 dB ρ_B= -3 dB
HARQ Transmissions	1 (No HARQ)

Parameter	Value
OCNG Pattern	None
AWGN Power Level	None

Note 1: Throughput measurements performed at or adjacent to the target SIR sensitivity level shall be measured for the specified minimum number of subframes. Since the throughput and corresponding SIR sensitivity is a function of the variability caused by the fading of the channel model, a minimum test time is required to properly determine the fading throughput, and therefore statistical early exit techniques are not allowed when determining the final figure of merit. Labs are free to use any mechanism they wish to narrow the search to the approximate location of the SIR sensitivity point so long as the measurement(s) used to determine the SIR sensitivity target throughput meet or exceed the specified minimum number of subframes.

Note 2: The RS-EPRE level generated in the test volume should be set near the maximum linear output level of the test system, while still providing enough headroom for linear amplification of both signal and interference for SIR testing. The signal must be far enough above the platform noise of the DUT to have a negligible impact on the resulting SINR but shall be no less than REFSENS as defined in Table 7.3.5-1 of 3GPP TS 36.521-1 [4] plus 40 dB. When determining the minimum RS-EPRE level generated in the test volume, the REFSENS value shall be converted to an equivalent RS-EPRE value based on the channel BW.

Note 3: This RMC is defined in 3GPP TS 37.977 Table 7.1-3 [1], Subframes 0, 1, 4, 6 and 9 utilize DL TBS 16, subframe 5 is unused for DL data transmission, and other subframes are for UL.

Note 4: p-Max shall be set to a fixed value that is equivalent to 10 dB below the nominal maximum output power defined by the DUT power class (e.g. p-Max would be set to +13 dBm for a DUT with UE Power Class 3 as defined in clause 6.2.2.3 of 3GPP TS 36.521-1 [4]).

2.4.3 Channel Model Definition

The SCME Urban macro-cell (SCME UMa) channel model shall be used for the evaluation of MARSS performance. The cross polarization power ratio in an SCME propagation channel is defined 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

In Table 2.4.3-1, the following SCME Urban Macro-cell is unchanged from the original SCME paper [6], with added XPR values, Direction of Travel, and Velocity.

TABLE 2.4.3-1 SCME URBAN MACRO-CELL CHANNEL MODEL (UMA)

SCME Urban macro-cell							
Cluster #	Delay [ns]			Power [dB]			AoD [°]	AoA [°]
1	0	5	10	-3	-5.2	-7	82.0	65.7
2	360	365	370	-5.2	-7.4	-9.2	80.5	45.6
3	255	260	265	-4.7	-6.9	-8.7	79.6	143.2
4	1040	1045	1050	-8.2	-10.4	-12.2	98.6	32.5
5	2730	2735	2740	-12.1	-14.3	-16.1	102.1	-91.1
6	4600	4605	4610	-15.5	-17.7	-19.5	107.1	-19.2
Delay spread [ns]								839.5

SCME Urban macro-cell				
Cluster #	**Delay [ns]**	**Power [dB]**	**AoD [°]**	**AoA [°]**
Cluster AS AoD / AS AoA [°]				2/35
Cluster PAS shape				Laplacian
Total AS AoD / AS AoA [°]				7.9/62.4
Mobile speed [km/h] / Direction of travel [°]				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

2.4.4 Channel Model Emulation of the Base Station Antenna Pattern

The emulated base station antennas shall be assumed to be dual polarized equal power elements with a fixed 0λ separation, 45 degrees slanted [1].

The slant 45 degree antenna is an "X" configuration and is modeled 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 represents typical slanted dipole behavior and is a source of power variation in the channel model. The effective antenna pattern for this antenna is illustrated in the figure below.

FIGURE 2.4.4-1: "X" ANTENNA GAIN ASSUMPTION (A) LINEAR GAIN (B) DB
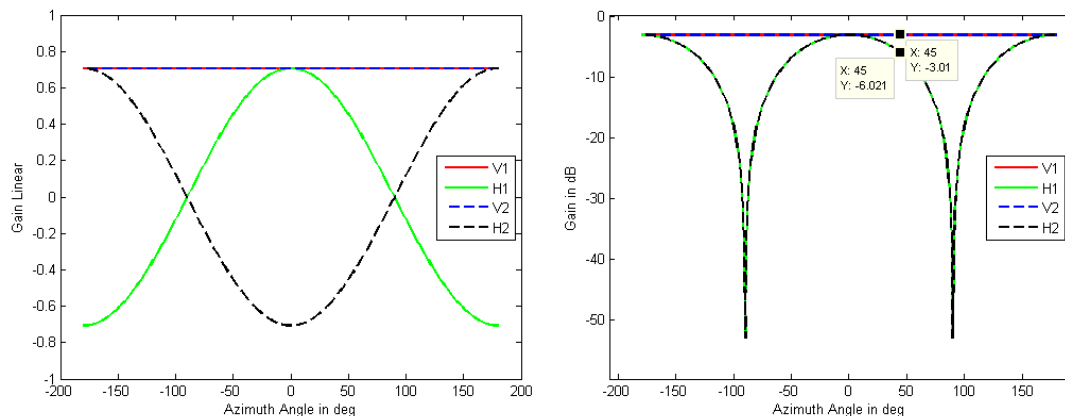
2.4.5 Signal to Interference Ratio (SIR) Control for MARSS Measurement

2.4.5.1 SIR Control for the MPAC Test Environment

The MIMO OTA portion of this test plan utilizes a test equipment configuration based on control of the downlink signal to interference ratio (SIR) seen by the EUT. This test environment differs from that normally employed to assess receiver performance.

Receiver sensitivity is typically assessed in terms of the minimum downlink power which will provide a defined level of performance at the output of the receiver. For example, a test system used to measure reference sensitivity of an LTE EUT will establish the minimum downlink power required to obtain a specified data throughput. In this test configuration, the EUT's low-signal performance is typically limited by its internal noise floor. While such a measurement is useful for the assessment of receiver sensitivity, it is not useful for MIMO performance assessment. Only in cases where a MIMO-capable EUT experiences no co-channel interference will its spatial-multiplexing performance be limited by its internal noise. Areas in which no co-channel interference exists are rare in actual networks.

In a typical network, co-channel interference (and therefore the SIR) will determine when spatial multiplexing can be supported. Therefore it's appropriate to assess the EUT's spatial multiplexing performance in terms of the lowest SIR value at which a pre-defined data throughput can be obtained.

In the MIMO portion of this test plan, the MIMO-capable EUT will be exposed to a relatively high downlink signal power (PDSCH-EPRE) from the emulated serving cell while the level of an AWGN power source (which is used to emulate co-channel interference in an actual network) is varied. The AWGN noise power used to create the desired SIR within the test zone shall be represented by an unfaded, omnidirectional signal. Details of this AWGN injection approach are described in Section 2.4.5.2 of this document.

2.4.5.2 SIR Validation within the MPAC Test Zone

The interference level necessary to achieve a given SIR inside the test zone shall be generated as an independent process at each antenna probe with equal power, regardless of the signal power transmitted through that probe. The SIR is defined at resource element level as per 3GPP TS 36.521-1 clause 8.1.1 [4]. The figure below illustrates a typical configuration for measuring the power levels within the test volume. This may be used to determine the net power produced after balancing the output paths and in validating the SIR generated by the system.

FIGURE 2.4.5.2-1: TYPICAL SETUP FOR VERIFYING SIR LEVEL IN THE ANECHOIC CHAMBER MULTI-PROBE MIMO OTA TEST SYSTEM
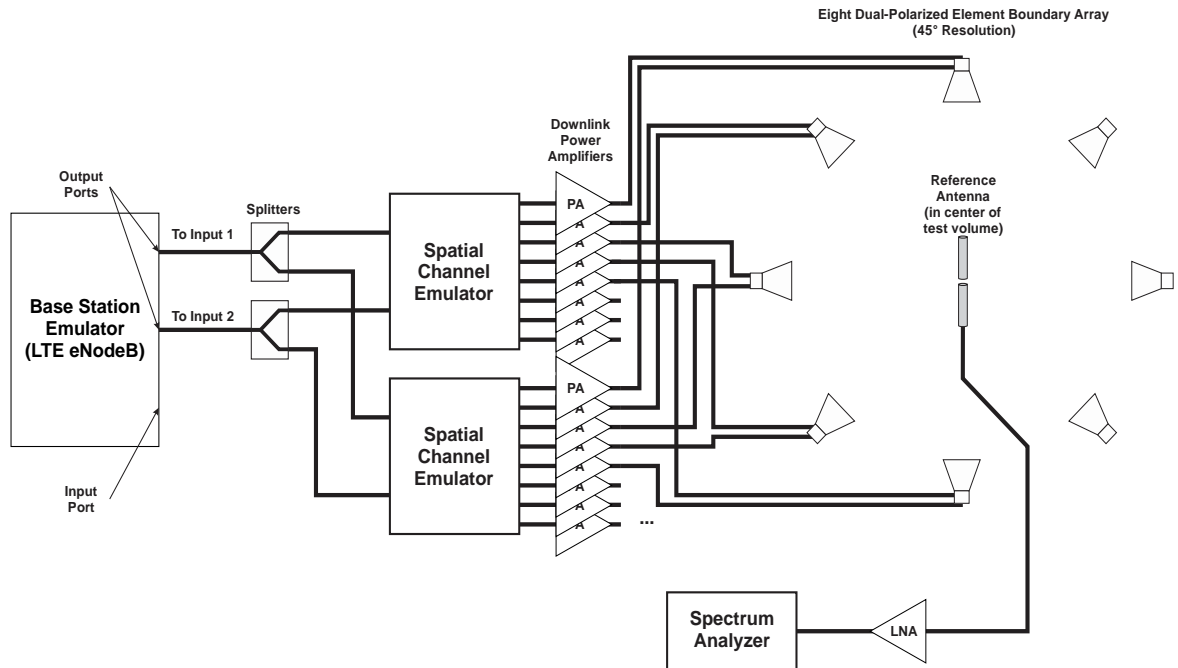
The power and SIR validation shall be performed to ensure that all of the system corrections have been applied properly. Since the test essentially measures the residual error term in the system, and any measured error should be corrected for, the validation process may also be used as a final path loss correction. While the power validation process has a measurement uncertainty of its own, defined primarily by the reference antenna gain uncertainty, the cable loss correction uncertainty, and the receiver uncertainty, this may be smaller than the net uncertainty of the signal source components and path loss corrections applied. The results of the power and SIR validation may be used to correct for system-level offset(s) to further reduce measurement uncertainty if the validation uncertainty is less than the path loss measurement uncertainty. Note however that especially when determining the SIR, the interference level can easily be biased by the noise floor of the instrumentation. Care should be taken not to introduce invalid offsets due to noise in the validation test.

1   Configure the spectrum analyzer with the settings given in Table 2.4.6.2-1 below. Use the integrated channel power method described in Appendix D of the CTIA OTA Test Plan [7] with appropriate bandwidth filter corrections to determine the total power in the channel bandwidth for each measurement.

2   Load the target channel model into the channel emulator.

3   Configure the system gains for the LTE signal and injected interfering signal paths such that the signal is at the level to be used during EUT testing, and the interfering signal is set to achieve a target SIR of 0 dB.

4   Disable interfering signal injection (depending on the system configuration this may be configured within the channel emulator itself or in an external signal generator)

5 Connect a reference dipole to the spectrum analyzer via a cable and place the dipole vertically polarized in the center of the test volume. A low noise amplifier may be needed to properly measure the downlink and interference signals. Ensure that any amplifier is not overdriven.

6 With the channel emulator outputs disabled, measure the received power with the spectrum analyzer until the average power converges to within 0.1 dB to establish a noise floor of the instrumentation and record the value as P_{NRX}.

7 Enable the channel emulator outputs, start the emulation and measure the received signal power with the spectrum analyzer until the average power converges to within 0.1 dB and record the value as P_{VSRX}.

8 Compare the ratio of signal power to measurement noise (P_{VSRX} - P_{NRX}) to ensure that the downlink signal is at least 20 dB above the noise at the receiver.

9 Compensate for the loss of the cable and any amplifier between the reference antenna and the spectrum analyzer (α_{Cable}), the gain of the dipole reference antenna (G_{RA}) and the unoccupied bandwidth and time slots of the LTE signal (C_{LTE}) such that:

$$P_{VS} = P_{VSRX} - \alpha_{Cable} - G_{RA} - C_{LTE}$$

10 Without moving the antenna in the test volume, disable the LTE signal source and enable interference injection (depending on the system configuration this may be configured within the channel emulator itself or in an external signal generator).

11 Measure the received power with the spectrum analyzer until the average power converges to within 0.1 dB and record the value as P_{VIRX}.

12 Compare the ratio of interference power to measurement noise (P_{VIRX} - P_{NRX}) to ensure that the signal is at least 20 dB above the noise at the receiver.

13 Compensate for the loss of the cable and any amplifier between the reference antenna and the spectrum analyzer (α_{Cable}) and the gain of the dipole reference antenna (G_{RA}) such that:

$$P_{VI} = P_{VIRX} - \alpha_{Cable} - G_{RA}$$

14 Repeat steps 2 to 13 using either a horizontally-polarized magnetic loop meeting the CTIA symmetry requirements and having a valid reference gain, or a horizontally polarized sleeve dipole instead of the vertically polarized reference dipole. For the loop, it is a good idea to perform a gain reference transfer between the loop and reference dipole to minimize error in the XPR validation. For the dipole, it is necessary to average multiple phi orientations of the dipole within the test volume and use the average of the theta gain pattern cut as the gain correction. This can be done by averaging across multiple steps, or slowly rotating the turntable continuously while the average power data is collected. A similar approach may also serve to address asymmetries in the loop pattern. Determine the resulting:

$$P_{HS} = P_{HSRX} - \alpha_{Cable} - G_{HRA} - C_{LTE}$$

and

$$P_{HI} = P_{HIRX} - \alpha_{Cable} - G_{HRA}.$$

15 Calculate the total signal power received as

$$P_{Signal} = 10 \cdot \log_{10}(10^{P_{VS}/10} + 10^{P_{HS}/10}).$$

16 Calculate the total interfering signal power received as

$$P_{Interference} = 10 \cdot \log_{10}(10^{P_{VI}/10} + 10^{P_{HI}/10}).$$

17 Calculate the achieved signal to interference ratio as

$$SIR_{Achieved} = P_{Signal} - P_{Interference}.$$

and validate that it matches the target SIR within the expected measurement uncertainty.

18 Calculate the achieved V/H ratio for the signal (P_{VS} - P_{HS}) and report the results.

19 Calculate the V/H ratio for the interference (P_{VI} - P_{HI}) and report the results.

TABLE 2.4.5-1 SPECTRUM ANALYZER SETTINGS FOR SIR CONTROL VERIFICATION USING INTEGRATED CHANNEL POWER

Parameter	Value
Center frequency	Channel frequency of band under test
Integrated Channel Span	9 MHz (Note 1)
Resolution BW	30 kHz
Video BW	≥10 MHz (Maximum supported)
Number of Points	≥400
Detector	RMS
Number of traces averaged	≥100 or until result converges to better than 0.1 dB uncertainty
Note 1: This value is based on a 10 MHz channel bandwidth. The integrated channel span shall be scaled as necessary if a bandwidth other than 10 MHz is employed.	

2.5 MPAC MIMO OTA Test Requirements

2.5.1 Introduction

The MARSS performance tests described in this section utilize throughput as the quality metric. In addition, the tests described in this document require the execution of multiple test runs to obtain throughput under varying signal to interference ratios and/or EUT orientations. Consequently, in many cases it is necessary to average the results in order to provide a single figure of merit for the EUT. However, the results can be averaged using data taken from one of two possible axes, and it's important that CATLs follow proper procedures when determining the final averaged results in order for results between labs to be comparable. For MIMO OTA tests utilizing the MPAC, only the MARSS figure of merit as defined in Section 2.6.3 shall be used.

2.5.2 Throughput Calculation

All tests described in this document call for the lab to calculate throughput. The definition of throughput described in 3GPP TR 37.977, Clause 5.1.1 [1] shall be used.

2.5.3 MIMO OTA Test Frequencies

Unless otherwise noted, all tests described in this document shall be executed at the test frequencies for each operating band supported by the EUT as defined in Table 2.3.3.2-1 and Table 2.3.3.2-2.

2.6 MPAC MIMO OTA Test Methodology

2.6.1 Introduction

For each MIMO EUT, a set of measurement points shall be obtained which describe the EUT's MIMO receiver performance as a function of azimuthal positions within the simulated environment. For each azimuthal position, the average signal to interference ratio (SIR) level that would result in 95%, 90% and 70% of the maximum throughput shall be determined. Regardless of the method used to determine each throughput point, there shall be no more than 0.5 dB of separation between two complete throughput measurements. An average performance metric is then determined from the individual SIR levels determined at each orientation.

2.6.2 SIR-Controlled Test Procedure Using the MPAC

To perform an OL-SM SIR-controlled test using the MPAC, position the EUT within the test zone according to Section 2.3.1 with the azimuth positioner at zero degrees. Establish a connection to the EUT with the specified SCME UMa channel model and an SIR setting of 30 dB.

> *Note:* In this test plan, SIR refers to the SIR illuminating the EUT in the test volume, as opposed to the SIR seen by the EUT's receiver.)

Beginning with the initial orientation of the EUT at 0 degrees azimuth within the test volume, determine the SIR values associated with the 95%, 90%, and 70% outage levels based on the theoretical throughput rate using the specified minimum number of subframes and the maximum theoretical throughput called for in Table 2.4.2-1 (for FDD devices) or Table 2.4.2-2 (for TDD devices).

> *Note:* Ensure that the transmitted power available from the EUT is sufficient to support error-free operation on the uplink.

When performing this measurement, the desired SIR result may be determined by interpolating to an SIR level between two throughput points measured within 0.5 dB of each other, or by reporting the last passing (higher) measured throughput point within 0.5 dB of the target. Algorithms that use fewer subframes and/or larger step sizes are acceptable provided the final reported data for each level is based on the result of two throughput measurements within 0.5 dB of each other and with the specified number of subframes. Due to the nature of the faded signal, early exit statistical measurement techniques are not allowed. Repeat the SIR sensitivity measurement described above every 30 degrees in azimuth, rotating the EUT clockwise, for a total of twelve positions. The SIR associated with each throughput outage point and azimuthal orientation shall be documented in Table C.1-1.

If the EUT is unable to reach the throughput point(s) defined in Section 2.6.3 at an SIR of 30 dB, the lab shall document one of the following in Table C.1-1 for each azimuthal orientation where the EUT failed to meet the target throughput:

a)   An SIR value of 30 dB, or

b)   The linear average of the remaining SIR values where the DUT was able to reach the throughput point(s), plus 10 dB

The SIR substitution value employed for failing azimuthal orientations shall be the maximum SIR obtained from the two options above.

2.6.3 MARSS Figure of Merit

Let the MIMO average radiated SIR sensitivity (MARSS) be the figure of merit for the TM3 tests with SIR control. The sensitivity point is defined as the SIR value (in dB) required to reach the 70%, 90%, and 95% of the theoretical maximum throughput of the test case. Using these outage points for each throughput curve associated with each EUT rotation, let the SIR value (in dB) associated with each outage point at the mth EUT rotation be the effective throughput SIR sensitivity ($P_{ETSS,70,m}$, $P_{ETSS,90,m}$, and $P_{ETSS,95,m}$). The MARSS is computed as a linear average from effective radiated sensitivity measurements across EUT rotations and is given by Equation 2.6.3-1 through Equation 2.6.3-3.

EQUATION 2.6.3-1

$$P_{MARSS,70} = 10 \log_{10}\left[\frac{1}{M}\sum_{m=1}^{M}10^{\frac{P_{ETSS,70,m}}{10}}\right]$$

EQUATION 2.6.3-2

$$P_{MARSS,90} = 10 \log_{10}\left[\frac{1}{M}\sum_{m=1}^{M}10^{\frac{P_{ETSS,90,m}}{10}}\right]$$

EQUATION 2.6.3-3

$$P_{MARSS,95} = 10 \log_{10}\left[\frac{1}{M}\sum_{m=1}^{M}10^{\frac{P_{ETSS,95,m}}{10}}\right]$$

where M is the total number of EUT orientations.

Once SIR values associated with the 95%, 90% and 70% outage points have been obtained for all 12 azimuthal orientations of the EUT, enter the measured SIR values (to at least 0.5 dB resolution) in Table C.1-1. The EUT's pass/fail performance shall be assessed based on the following rules:

a)   The EUT must meet 70% throughput in all 12 azimuthal orientations. If the EUT fails to meet this criterion, the EUT shall fail the MIMO OTA test.

b)   The EUT must meet 95% throughput in at least 10 of the 12 azimuthal orientations. If the EUT fails to meet this criterion, the EUT shall fail the MIMO OTA test.

If both criteria above are met, the SIR values for the 70%, 90% and 95% outage levels shall be linearly averaged using Equation 2.6.2-1, Equation 2.6.2-2 and Equation 2.6.2-3 respectively, after applying the substitution value (s), if applicable, for azimuthal orientations where the throughput outage point was not obtained.

Section 3   Transmit Diversity Receiver Performance Evaluation

This section to be added in a future revision of this document

Section 4   Implementation Conformance Statements Applicable to MIMO and Transmit Diversity OTA Performance Measurement

Implementation Conformance Statement (ICS) information pertinent to MIMO OTA testing will be added to a future revision of this document.

Section 5   Measurement Uncertainty

5.1   Introduction

For the 2x2 Downlink MIMO and Transmit Diversity receiver performance described in this Test Plan, the chosen method for calculation of the measurement uncertainty is based on the "Guide to the Expression of Uncertainty in Measurement" [8].

The ISO guide gives a general approach to calculating measurement uncertainty that is applicable to all types of measurements; the process involving the combination of the standard deviations (known as standard uncertainties) of the individual contributors by the root-sum squares method. This method assumes that all systematic errors have been identified and corrected for, and that any remaining errors in individual uncertainty components are random in nature such that they can be combined as normal distributions. Note that this may not be the case when combining multiple identical measurements in series. Likewise, multiple parallel measurements (e.g., the different paths in the test system) do not reduce the systematic error contribution through averaging.

Using the above approach to determine the method for uncertainty analysis, the following illustrates the practical steps involved:

1   Compile a complete list of the individual measurement uncertainties that contribute to a measurement;

2   Determine the maximum value of each uncertainty;

3   Determine the distribution of each uncertainty (rectangular, U-shaped, etc.);

4   Calculate (if necessary) the standard uncertainty (i.e., standard deviation) of each uncertainty;

5   Convert the units (if necessary) of each uncertainty into the chosen unit i.e. dB;

6   Combine ALL the standard uncertainties by the root-sum-squares method to derive the 'combined standard uncertainty';

7   Under the assumption that the probability distribution of the combined standard uncertainty is Gaussian/Normal, multiply the resulting combined standard uncertainty by an expansion factor 'k' (taken from Student's T-distribution, W.S. Gosset 1908) to derive the 'expanded uncertainty' for a given confidence level. All expanded uncertainties are quoted to 95% confidence level, so k is taken as 2 (theoretically k should be 1.96, but for convenience, the value 2 had been agreed). Expressed a different way, this gives 95% confidence that the true value is within 2 times the combined standard uncertainty of the measured value.

The following subsections of Section 5 lists all contributions that are identified to have relevance for the measurement uncertainty budget in MIMO receiver performance and associated uncertainty analysis using Multi Probe Anechoic Chamber test environment. Sections 5.2 through 5.8 describe various uncertainty contributions in measurement of MIMO receiver OTA performance using MPAC Section 5.9 covers uncertainty contributions for reference measurement. Section 5.10 provides the list of path loss measurement uncertainty components. Section 5.11 provides the summary of common uncertainty contributions for MIMO Receiver performance. Section 5.12 covers combined and expanded uncertainties and compliance criteria for the MIMO Receiver performance.

5.2   Common Uncertainty Contributions due to Mismatch

For automated test systems, there will be impedance mismatch between the various RF cables and components used within the system. Reflections occur when a signal reaches a discontinuity in impedance. Standing waves are created by the reflections between any two discontinuities in the system. These standing waves create uncertainty in the signal level and this uncertainty is normally referred to as mismatch uncertainty.

Since the range calibration corrects for the total path loss, any standing wave contributions that remain the same between the range calibration and the EUT measurement (e.g., from reflections between two fixed components within the system) will be embedded in the range calibration and applied as part of the path loss correction. Only standing wave contributions that change between the calibration and measurement steps (i.e., due to the calibration process itself) need to be accounted for by a measurement uncertainty contribution.

If only the magnitude of the mismatch at a given connection were to change and the cable length between the two mismatches remains the same, then the measurement uncertainty for that change could be estimated using the difference in VSWR magnitudes before and after the change. A change in cable length results in a change in the frequency dependence of the mismatch therefore this method does not apply in this case. Thus, when path lengths are changed through the addition or removal of cables between the calibration and measurement steps, the full mismatch uncertainty applies to each junction point at each step of the process (calibration and device test).

Adding an attenuator at the connection port reduces the uncertainty due to mismatch by increasing the loss of the reflected path by twice that of the direct path. The overall standing wave contribution in the system (including frequency-dependent ripple) may be reduced by leaving an attenuator on a piece of equipment with a poor impedance match. The loss of the embedded attenuator would be measured as part of the overall path loss. When used at the ends of any extra cables used during the range reference calibration, the attenuators serve to isolate the electrical length of the system cabling from the additional cable lengths added, thereby minimizing the change in frequency dependence of the internal standing wave contribution in the system. The losses of the attenuators and external cables are determined and corrected for as a separate step of the calibration process.

The mismatch uncertainty can be evaluated at the individual component level, with each of the terms evaluated and root-sum squared to generate a single term. Another method is to treat the entire system as a single component on which the mismatch uncertainty is evaluated. In order for this method to be valid the system which is being treated as a single component must remain the same for both the OTA measurement and the range reference measurement.

The maximum error due to VSWR between two ports is given in general form by Equation 5.2-1 below:

<div align="center">

EQUATION 5.2-1

</div>

$$\varepsilon_{VSWR} = 20\log\left(1 + |\Gamma_1| \times |\Gamma_2| \times |S_{21}| \times |S_{12}|\right)$$

where Γ_1 and Γ_2 are the complex reflection coefficients of the two ports in question and S_{21} and S_{12} are the forward and reverse transmission coefficients between the two ports. From this it is evident that reducing the reflection coefficients (by reducing mismatches) or reducing the transmission coefficients (by adding attenuation) will reduce the resulting error contribution. The reflection coefficient can be expressed in terms of the VSWR at a given connector by Equation 5.2-2 below:

EQUATION 5.2-2

$$|\Gamma| = \frac{VSWR-1}{VSWR+1}$$

From Equation 5.2-2, a simpler two-port formulation can be derived to represent the VSWR error contribution due to the reflectivity of each side of a cable connection point. This allows estimating the required uncertainty contribution by simply measuring the reflection coefficients of each side of a cable connection that is changed between the calibration and measurement steps as shown in Equation 5.2-3 below:

EQUATION 5.2-3

$$\varepsilon_{VSWR} = 20\log(1+|\Gamma_1| \times (|\Gamma_2| \times |S_{21}| \times |S_{12}|))$$

$$= 20\text{LOG}(1+|\Gamma_{SOURCE}| \times (|\Gamma_{LOAD}|)$$

where Γ_{source} and Γ_{load} are the complex reflection coefficients of the cable/connector ends looking towards the source or load respectively.

The cable junctions associated with the calibration routine and the actual measurement shall be included in the evaluation of the mismatch uncertainty.

Since the error due to VSWR has a sinusoidal nature, it causes a deviation that clusters equally above and below the initial transmitted signal. This U-shaped distribution shall be converted to an equivalent normal distribution probability by using Equation 5.2-4 to determine the standard uncertainty.

EQUATION 5.2-4

$$u_i = \frac{a_i}{\sqrt{2}} = \frac{\varepsilon_{VSWR}}{\sqrt{2}}$$

5.3 Common Uncertainty Contributions for a Receiving Device

The receiving device is used during the calibration and validation processes. The uncertainty components related to the receiver are non-linearity and absolute level accuracy. The components which impact the uncertainty of the measurement depend on the measurement procedure.

For individual absolute power measurements such as the power validation test, if the manufacturer's datasheet provides the absolute level uncertainty specification that encompasses all contributions, this specification is usually all that is needed In some cases, manufacturer's data sheets may not provide a single absolute uncertainty specification and may require combining multiple specifications to obtain the correct value u.

For relative measurements such as range calibration and single-point offset measurements where the same receiver is used for both test configurations, usually only the non-linearity needs to be considered. If two different instruments are used then the absolute uncertainties of both devices will contribute.

These uncertainty contributions shall be taken from the manufacturer's data sheet and converted to dB if necessary. The worst case data sheet values shall be used.

Note that the measurement uncertainty specification of the instrument may vary as a function of the chosen bandwidth setting or other parameters. The lab shall ensure that appropriate manufacturer's uncertainty contributions are specified for the settings used.

5.4   Common Uncertainty Contributions for a Signal Source

The signal source can contribute to the measurement uncertainty in two ways: absolute level and stability. The uncertainty terms that need to be considered depend on the measurement process. The uncertainties related to both the SIR measurement and the range reference calibration must be considered.

For individual absolute power measurements such as the receiver sensitivity test, if the manufacturer's datasheet provides the absolute level uncertainty specification that encompasses all contributions, this specification is usually all that is needed. In some cases, manufacturer's data sheets may not provide a single absolute uncertainty specification and may require combining multiple specifications to obtain the correct value.

For relative measurements such as the range calibration, if the same source is used to measure both test configurations, usually only the stability contributes to the uncertainty. If two different instruments are used between steps, then the absolute uncertainties for both devices will contribute.

In the case of a Network Analyzer the signal generator is combined with the receiver in one unit that measures the relative difference between the output signal and received signal. Thus, the uncertainty contribution of the signal generator is included in one overall uncertainty contribution of the instrument and does not need to be entered separately.

These uncertainty contributions shall be taken from the manufacturer's data sheet and converted to dB if necessary.

- If using the manufacturer's data sheet, the worst case values shall be used.

- An allowed alternative is to use an alternate measurement device to normalize the signal generator RF output level.

- An allowed alternative is to use the calibration report plus the MU and aging terms from the calibration lab.

5.5   Common Uncertainty Contributions for Measurement/Probe Antennas

5.5.1   Substitution Components

Where any cable or other system component is used in only one part of a test (e.g. as part of an external cable loop for the range calibration) and its insertion loss is used in the calculations, then either the overall combined standard uncertainty of an independent insertion loss measurement (per Section 5.10) shall be used in the relevant table, or the manufacturer's data sheet shall be consulted where applicable. In the latter case, this uncertainty will usually be quoted as ±x dB. Unless something specific is stated about the distribution of this uncertainty, it shall be assumed to be rectangularly distributed, in which case the standard uncertainty shall be calculated as shown in Equation 5.5.1-1 below:

EQUATION 5.5.1-1

$$\frac{\text{maximum value}}{\sqrt{3}}$$

5.6 Common Uncertainty Contributions for Measurement Setup

5.6.1 Offset of the Phase Center of the Calibrated Reference Antenna from Axis(es) of Rotation

For the Range Reference Measurement (i.e., where the Calibrated Reference Antenna is involved), any uncertainty in the accuracy of positioning its phase center on the axis(es) of rotation will directly generate an uncertainty in this part of the measurement. For sleeve dipoles and loops, provided that care is taken in their positioning the uncertainty should be 0.00 dB since their phase centers are easily identifiable. However, for ridged horn antennas and LPDAs (for both of which the position of the phase center varies with frequency), the phase center could be at any point within the tapered sections, giving:

- For a ridged horn: A maximum positional uncertainty, $\pm d$, where d equals 0.5 times the length of taper

- For an LPDA: A maximum positional uncertainty, $\pm d$, where d equals 0.5 times the length of the boom

The level uncertainty resulting from these positional uncertainties shall be calculated as described in Equation 5.6.1-1 below:

EQUATION 5.6.1-1

$$\pm 20\log_{10}\left(\frac{measurement\ distance - d}{measurement\ distance}\right)$$

Since this level uncertainty is assumed to be rectangularly distributed, the standard uncertainty shall be derived by dividing by $\sqrt{3}$.

5.6.2 Influence of the Ambient Temperature on the Test Equipment

Temperature is the only influence quantity in the tests covered by this test plan. This measurement uncertainty must be included when the test equipment is used outside of the certified temperature range. The methods for evaluating the uncertainty are outlined in Appendix G.9 of the CTIA OTA Test Plan [7].

5.6.3 Miscellaneous Uncertainty

If a lab is aware of uncertainty terms not included in this specification, they should be included in the lab's documentation and must be reported.

5.6.4 Minimum Downlink/Interference Power Step Size:

The step size in the power level used in the throughput versus power measurement has to be included as uncertainty contribution. Depending on the solution provider implementation, either the

system simulator or the channel emulator is used for adjusting downlink power. The uncertainty term has to be considered only for one of the two possibilities.

There are two possible approaches for the downlink power uncertainty term. The most simple is related to a fixed step size in the leveling process. Excluding other uncertainty contributions, the actual throughput threshold level ranges from the reported level to one step below the reported level. This can be represented as an asymmetric uncertainty contribution of +0/-step size, with a rectangular distribution. However, on average, the actual threshold, and thus the resulting throughput threshold level, will be one-half step below the reported value. For the purposes of this test plan, this uncertainty contribution is assumed to be symmetrical with a fixed uncertainty contribution of ± one-half of the step size.

For a 0.5 dB step size, a fixed uncertainty contribution of ±0.25 dB with a rectangular distribution (standard uncertainty contribution of 0.144 dB) should be reported for the step size uncertainty.

The second approach performs the leveling with power steps but calculates the power level required for obtaining a nominal throughput threshold by interpolating on a curve of measurement points. This approach is preferred since it reduces the uncertainty even further.

The resulting uncertainty term has to be evaluated from the typical smoothness of the curve and the spacing of its points. Guidance for a quantitative estimate of the uncertainty comes from the solution providers. The lab shall indicate on which grounds the uncertainty term was evaluated.

5.7   Typical Uncertainty Contributions for External Amplifier

The uncertainty associated with the external amplifier is contingent on the system setup and calibration method.

5.7.1   Gain

If the external amplifier has been characterized individually then the measurement uncertainty associated with the gain measurement should be included in the overall uncertainty. If the external amplifier has been characterized as part of the system then there is no additional uncertainty over that of the associated system path loss measurement.

For more information on the gain uncertainty see Section 5.10.

5.7.2   Mismatch

If the external amplifier has been characterized individually then the mismatch uncertainty at both the input and output should be included in the overall uncertainty. If the external amplifier has been characterized as part of the system then the mismatch uncertainty in this case is 0 (zero). For this to stand true the range reference calibration must be performed with the external amplifier connected to the rest of the components in the exact configuration as the SIR is performed.

For more information on the mismatch uncertainty see Section 5.2.

5.7.3   Stability

This term quantifies the stability of the output signal over time. This term needs to be considered for all systems in which an external amplifier is present. Stability cannot be accounted for in the range reference calibration of any method. The stability shall be evaluated for the range of laboratory conditions seen during normal operation, including any variation in initial conditions and laboratory

temperature. The variation may be measured directly over a minimum of 24 hours of normal operating conditions (e.g., three non-contiguous eight hour-sessions) or determined from manufacturer's specifications if the stability as a function of laboratory conditions are clearly indicated.

5.7.4 Linearity

The linearity of the amplifier comes into play when the system or amplifier calibration is performed at a different input/output level than will be used during the EUT test. For SIR testing it is likely that the calibration and EUT test can be per-formed at similar levels and thus the linearity error between the two will be small. However, given that the total output will change by a few dB as the SIR is changed and that there will be many dB of modulation variation, linearity cannot be completely ignored. For a sensitivity search where the power level is reduced significantly from the level used during calibration, any non-linearities in the amplifier are likely to be evident.

5.7.5 Amplifier Noise Figure/Noise Floor

All amplifiers add noise to the signal that they amplify, reducing the SNR at the output compared to that at the input. As the signal level input to the amplifier is lowered, the resulting signal + noise may be measurably higher than the signal alone. More importantly for a receiver sensitivity test, the noise of the amplifier plus the amplified noise of the signal source could become significant relative to the platform noise. Thus the noise floor of the amplifier defines an absolute minimum of the linear dynamic range of the system. The error introduced in the desired signal affects the EVM of the signal and correspondingly the chances of the receiver to decode the signal. This can be treated as a voltage error due to the noise power:

EQUATION 5.7.5-1

$$\varepsilon_{EVM} = 20 \cdot \log\left(1 + 10^{\frac{-SNR}{20}}\right)$$

where SNR is the signal to noise ratio in dB at the signal level used for the SIR test.

The noise power can be assumed to be Gaussian and thus simply summed with the interference power. The error in the interference power due to the noise is thus:

EQUATION 5.7.5-2

$$\varepsilon_{INR} = 10 \cdot \log\left(1 + 10^{\frac{-INR}{10}}\right)$$

where INR is the interference to noise ratio in dB.

5.8 Common Uncertainty Contributions for EUT

5.8.1 Measurement Setup Repeatability

Select a representative device and repeat the corresponding measurement 10 times. Calculate the standard deviation of the metric obtained and use that as the measurement uncertainty. For tests that require multiple setups (i.e. Portrait and Landscape), the worst-case standard deviation shall be used.

5.8.2   Effect of Ripple on EUT Measurement

The uncertainty contribution related to ripple shall be determined using the ripple test described in Section 2.2.1. The overall multipath nature of the environment simulation implies that only the average power contribution of the chamber ripple has any direct impact on the measured quantity, so the surface standard deviation measurement uncertainty would apply similar to that for the integrated quantities of TRP and TIS. See Appendix G.8.1.1 of the CTIA OTA Test Plan [7].

5.9   Typical Uncertainty Contributions for Reference Measurement

5.9.1   Effect of Ripple on Range Reference Measurements

The Range Reference Measurement can potentially suffer the effects of the signal ripple. Since the range reference measurement may be performed with various support structure components removed, the impact on the measurement uncertainty is based only on the ripple of components in the test volume during the calibration process. The value of the uncertainty component arising from ripple depends on the directivity of the reference antenna, with higher gain antennas typically seeing lower chamber induced ripple, but more uncertainty related to the phase center position of the reference antenna.

- Where the Calibrated Reference Antenna is a sleeve dipole or magnetic loop placed in the center of the test volume, the standard uncertainty shall be calculated by dividing the maximum ripple, as measured in a volume greater than half a wavelength in diameter, by $\sqrt{3}$ since the uncertainty is considered to be rectangularly distributed.

- Where the Calibrated Reference Antenna is a ridged horn, the positional uncertainty (assuming the phase center is unknown) shall be considered equal to 0.5 times the length of the flared section. The resulting signal level ripple shall be taken as described by Equation 5.9.1-1 below:

<div align="center">

EQUATION 5.9.1-1

$$\sin\left(\left(\frac{0.5 \text{x } length\ of\ flared\ section\ in\ mm}{150}\right)\text{x}0.90\right)\text{x } max\ ripple$$

</div>

and the standard uncertainty calculated by dividing by since the uncertainty is considered to be rectangularly distributed.

- Where the Calibrated Reference Antenna is a LPDA, the positional uncertainty (assuming the phase center is unknown) shall be considered equal to ±0.5 times the length. The resulting signal level ripple shall be taken as described in Equation 5.9.1-2 below:

<div align="center">

EQUATION 5.9.1-2

$$\left(\left(\frac{0.5 \text{x } length\ in\ mm}{150}\right)\text{x}0.90\right)\text{x } max\ ripple$$

</div>

and the standard uncertainty calculated by dividing by since the uncertainty is considered to be rectangularly distributed.

5.10 Path Loss Measurement Uncertainty

Table 5.9.1-1 lists the common uncertainty contributions for common path loss measurements used within this test plan. Depending on the range calibration approach used, the system may have one or more path loss measurement contributions to the measurement uncertainty.

TABLE 5.10-1 COMMON UNCERTAINTY CONTRIBUTIONS FOR RANGE PATH LOSS MEASUREMENTS

No	Uncertainty Contribution	Reference	Comment
1	Mismatch: Loopback Cable	Section 5.2	Mismatch contribution when obtaining reference level
2	Mismatch: Source Cable	Section 5.2	Mismatch contribution at system input
3	Mismatch: Receive Cable	Section 5.2	Mismatch contribution at system output
4	Signal Source Stability	Section 5.4	
5	Receiving Device Linearity	Section 5.3	
6	Reference Antenna: Gain/Efficiency of the calibrated reference antenna	G.6 [7]	For OTA range loss measurements only.
7	Reference Antenna: Range loss ripple contribution	Section 5.9.1	For OTA range loss measurements only.
8	Reference Antenna: Offset of phase center of calibrated reference antenna from the axis(es) of rotation	G.7.2 [7]	For OTA range loss measurements only.
9	Additional Insertion Loss(es) or Gains:	Section 5.10.1	Any additional components (cables, switches, attenuators) not measured directly as part of the two-step path loss process will have their own path loss measurement uncertainty associated with the corrections applied.
10	Additional Mismatch Terms:	Section 5.2	Any additional junction points (e.g. switches, cables, etc.) changed between calibration and device test steps will introduce additional mismatch uncertainty.

5.10.1 Substitution Components:

Where any cable or other system component is used in only one part of a test (e.g. as part of an external cable loop for the range calibration) and its insertion loss is used in the calculations, then either the overall combined standard uncertainty of an independent insertion loss measurement (per this section) shall be used in the relevant table, or the manufacturer's data sheet shall be consulted where applicable. In the latter case, this uncertainty will usually be quoted as ±x dB. Unless something specific is stated about the distribution of this uncertainty, it shall be assumed to be rectangularly distributed, in which case the standard uncertainty shall be calculated as shown in Equation 5.10.1-1 below:

EQUATION 5.10.1-1

$$\frac{\text{maximum value}}{\sqrt{3}}$$

5.11 Summary of Common Uncertainty Contributions for MIMO Receiver Performance

Table 5.11.1-1 lists common uncertainty contributions for the MIMO EUT receiver performance measurement defined in this test plan.

TABLE 5.11.1-1: COMMON UNCERTAINTY CONTRIBUTIONS FOR MIMO EUT RECEIVER PERFORMANCE

MEASUREMENT

No	Uncertainty Contribution	Reference	Comment
1.	Range Loss Measurement(s)	Section 5.10	Net path loss measurement MU from signal reference to EUT.
2.	Mismatch: Communication Tester	Section 5.2	Final system side mismatch between instrumentation and system.
3.	Signal Source Absolute Power Reference or Stability: Communication Tester	Section 5.4	Depends on SIR Implementation
4.	Receiver Stability: Channel Emulator	Section 5.3	
5.	Signal Source Linearity: Channel Emulator	Section 5.4	Applies for variable power control.
6.	Signal Source Stability: Channel Emulator	Section 5.4	Applies for variable interference control.
7.	Signal Source Absolute Power Reference or Linearity and Relative Error: AWGN Source	Section 5.4	Contribution type depends on whether AWGN source is a separate generator or part of existing test equipment.

No	Uncertainty Contribution	Reference	Comment
8.	Range Loss Measurement(s): AWGN Source	Section 5.10	Applies to the associated portion of the path if a separate AWGN source with all or partially separate path to test volume is used.
9.	Mismatch: AWGN Generator(s)	Section 5.2	Final system side mismatch between instrumentation and system. Applies if separate AWGN generator is used, requiring a separate calibration path.
10.	Measurement Antenna Cable Factor	G.2 [7]	
11	Blocking Effect of the EUT on the Measurement Antenna (if too close)	G.7.3 [7]	
12	Influence of the ambient temperature on the test equipment	G.9 [7]	
13	Miscellaneous uncertainty	Section 5.6.3	
14	Minimum downlink/interference power step size uncertainty	Section 5.6.4	
15.	Stability	Section 5.6	
16.	Linearity	Section 5.6	
17.	Amplifier Noise	Section 5.6	
18.	EUT Positioning Uncertainty Relative to Phantoms and Fixtures	G.21 [7]	
19.	Measurement Setup Repeatability	Section 5.8.1	
20.	Effect of Ripple on EUT Measurements	Section 5.8.2	
21.	Test System Frequency Flatness Uncertainty	G.22 [7]	

5.12 Combined and Expanded Uncertainties for Overall MIMO Receiver Performance

After calculation the combined standard uncertainties for EUT Measurement Sections of 5.2 through 5.8 and Reference Measurement of Section 5.11, they should be combined as follows to derive the overall combined standard uncertainty:

EQUATION 5.12-1

$$u_c = \sqrt{u_{c\ contribution\ from\ the\ EUT\ measurement}^2 + u_{c\ contribution\ from\ the\ reference\ measurement}^2}$$

Next, the expanded uncertainty, U, is calculated as $U = 2 \cdot u_c$ for a 95 % confidence level. The resulting value for expanded uncertainty for MIMO receiver performance should be stated in the results sheet.

5.12.1 Compliance Criteria for the Overall MIMO Receiver Performance Uncertainty

TABLE 5.12.1-1: EXPANDED UNCERTAINTY MAXIMUM LIMIT FOR MIMO RECEIVER PERFORMANCE

Test Configuration	Expanded Uncertainty Max Limit (dB)
Free Space	2.75

5.13   Combined and Expanded Uncertainties and Compliance Criteria for the Transmit Diversity Receiver Performance

[This section to be added in a future revision of this document.]

Appendix A—Validation and Verification of Test Environments and Test Conditions (Normative)

This Appendix describes the MIMO OTA validation measurements required to ensure that the test conditions are correctly implemented and hence capable of generating the propagation environment, as described by the model, within the designated test zone, Measurements are performed mainly with a vector network analyzer (VNA) and a spectrum analyzer. The system provider shall perform the validation tests at the frequency of the downlink for mid-range from 3GPP TS 36.508 [3] as required per band for the normative bands defined in Table 2.3.3.2-1 and Table 2.3.3.2-2.

The specific settings of the VNA may be adjusted if other settings lead to better results.

A.1 Measurement Instrument Overview

A.1.1 Measurement instruments and Setup

The measurement setup includes the following equipment:

TABLE A.1.1-1: REQUIRED MEASUREMENT EQUIPMENT

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

A.1.2 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 A.1.2-1. The VNA transmits frequency sweep signals thorough the MIMO OTA test system and a test antenna, within the test area, receives the signal and the VNA analyzes the frequency response of the system. A number of traces (frequency responses) are measured and recorded by the 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 SCME UMa channel model defined in Section 2.4.3.

FIGURE A.1.2-1: SETUP FOR ANECHOIC CHAMBER VNA MEASUREMENTS
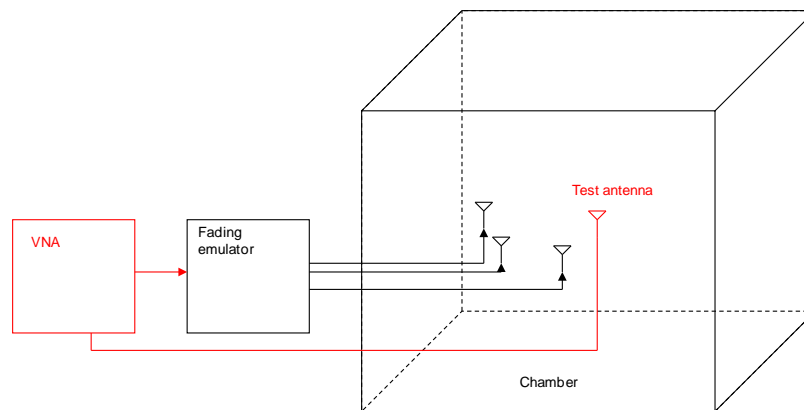
A.1.3 Spectrum Analyzer (SA) Setup

The Doppler spectrum is measured with a Spectrum analyzer as shown in Figure A.1.3-2. In this case a Signal generator transmits a CW signal through the MIMO/Transmit Diversity 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 SCME UMa channel model defined in Section 2.4.3.

FIGURE A.1.3-2: SETUP FOR SPECTRUM ANALYZER MEASUREMENTS
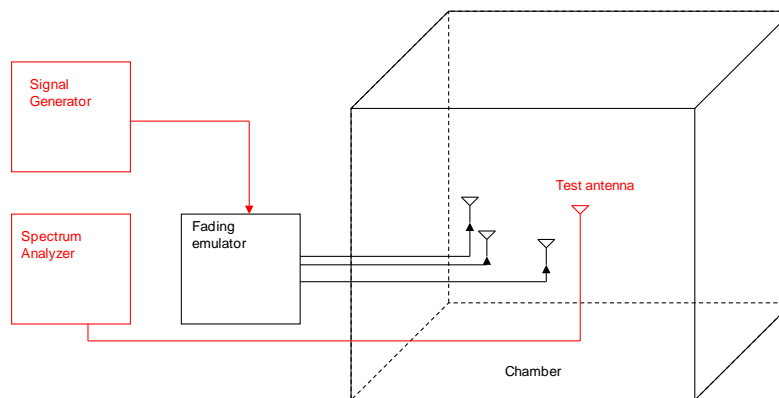
A.2 Validation of the MPAC MIMO OTA Test Environment and Test Conditions

A.2.1 Validation of SIR-Controlled MPAC Test Environment

A.2.1.1 Validation of MPAC Power Delay Profile (PDP)

This measurement checks that the resulting power delay profile (PDP) is in-line with the PDP defined for the channel model.

Method of measurement: Step the emulation and store traces from the VNA. I.e. run the emulation to Channel Impulse Response (CIR) number 1, pause, measure the VNA trace, run the emulation to advance the time such that the distance between traces specified in Table A.2.1.1-1 is met, pause, measure the VNA trace. Continue until 1000 VNA traces are measured.

TABLE A.2.1.1-1: MPAC PDP VNA SETTINGS

Item	Unit	Value
Center frequency	MHz	Downlink Center Frequency in 36.508 [3] as required per band
Span	MHz	200
Number of traces		1000
Number of points		1101
Averaging		1

TABLE A.2.1.1-2: MPAC PDP CHANNEL MODEL SPECIFICATION

Item	Unit	Value
Center frequency	MHz	Downlink Center Frequency in 3GPP TS 36.508 [3] as required per band
Distance between traces in channel model	wavelength (Note 1)	> 2
Channel model		As specified in Section 2.4.3
Note 1: Time [s] = distance [λ] / MS speed [λ/s] MS speed [λ/s] = MS speed [λ/s] / Speed of light [m/s] * Center frequency [Hz]		

A.2.1.2 Power Delay Profile Result Analysis

The measured VNA traces are recorded as linear relative voltage frequency responses $H(t, f)$, for each CIR time step t (i.e. run the emulation to advance the time such that the distance between

traces specified in Table A.2.1.1-1 is met) The analysis is performed by taking the Fourier transform of each frequency response to generate impulse responses $h(t, \tau)$. The resulting impulse responses are averaged in power over the total number of CIR steps, T, as shown in Equation A.2.1.2-1 below:

EQUATION A.2.1.2-1

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

The resultant time domain data does not have enough resolution to resolve individual taps. In order to obtain an adequate representation of the relative power in each cluster, a running average is performed on each point of the resulting time domain power trace as shown in Equation A.2.1.2-2 . Note that for indices greater than the total number of points, N, the indexed power value wraps around to zero as indicated by the modulus operator, %,

EQUATION A.2.1.2-2

$$PDP_i = \sum_{j=i}^{i+8} P_{j\%N}$$

Finally the resulting PDP is shifted in delay, such that the first tap is on delay zero and normalized so that the peak value is one (zero dB). Finally, convert the PDP relative power trace to dB.

A.2.1.3   Measurement Antenna

The measurement antenna shall be a vertically-oriented sleeve dipole.

A.2.1.4   Pass/Fail Criteria

The following table indicates the expected target values for each cluster of the vertically polarized PDP after smoothing and normalization. The peak of each pulse for clusters 2-6 of the measured PDP shall meet these values to within ±0.85 dB and ±11 ns.

TABLE A.2.1.4-1: SCME URBAN MACRO TARGET VALUES

Cluster #	Time (ns)	Relative Power (dB)
1	0	0
2	360	-2.2
3	255	-1.7
4	1040	-5.2
5	2730	-9.2
6	4600	-12.7

A.2.2 Validation of Doppler/Temporal Correlation for MPAC

This measurement checks the Doppler/temporal correlation.

A.2.2.1 MPAC Doppler/Temporal Correlation Method of Measurement

A signal generator is used to inject a CW signal as specified in Table A.2.2.1-1 into one input of the channel emulator with the other input disabled. The channel emulator is configured as specified in Table A.2.2.1-3 and configured for free-run playback of the channel model. A vertically polarized sleeve dipole is used to probe the generated field structure in the center of the test volume and feed that signal to a spectrum analyzer. The Doppler power spectrum is measured by the spectrum analyzer using the settings provided in Table A.2.2.1-2 and the result is recorded.

TABLE A.2.2.1-1: MPAC DOPPLER/TEMPORAL CORRELATION SIGNAL GENERATOR SETTINGS

Item	Unit	Value
Center frequency	MHz	Downlink Center Frequency in 3GPP TS 36.508 [3]as required per band
Modulation		OFF

TABLE A.2.2.1-2: MPAC DOPPLER/TEMPORAL CORRELATION SPECTRUM ANALYZER SETTINGS

Item	Unit	Value
Center frequency	MHz	Downlink Center Frequency in 3GPP TS 36.508 [3] as required per band
Span	Hz	2000
RBW	Hz	1
VBW	Hz	1
Number of points		8001
Averaging		100

TABLE A.2.2.1-3: DOPPLER CHANNEL MODEL SPECIFICATION

Item	Unit	Value
Center frequency	MHz	Downlink Center Frequency in 3GPP TS 36.508 [3] as required per band
Channel model		As specified in Section 2.4.3
Mobile speed	km/h	100 (Note 1)
Note 1: Or the maximum achievable value.		

The measurement result analysis is performed by taking the Fourier transformation of the Doppler power spectrum measured with the spectrum analyzer. The resulting temporal correlation function $R_t(\Delta t)$ is normalized such that $\max(\mathrm{Re}(R_t(\Delta t))) = 1$ and the x-axis is scaled by the mobile speed divided by the wavelength at the center frequency in order to convert the axis from time to wavelengths. The results from the normalized peak of the curve to five wavelengths after that point are then recorded for comparison to the reference curves. The measured results shall fall within the upper and lower limits for the temporal correlation shown in Table A.2.2.1-4 and plotted in Figure A.2.2.1-1.

TABLE A.2.2.1-4: MPAC REFERENCE TEMPORAL CORRELATION LIMITS FOR SCME URBAN MACRO

Separation Distance (Wavelengths)	Lower Correlation Limit	Upper Correlation Limit
0.00	0.980	1.000
0.05	0.940	1.000
0.10	0.880	0.980
0.15	0.790	0.920
0.20	0.690	0.830
0.25	0.580	0.730
0.30	0.470	0.630
0.35	0.385	0.545
0.40	0.320	0.475
0.45	0.301	0.430
0.50	0.290	0.410
0.55	0.282	0.405
0.60	0.276	0.404
0.65	0.261	0.393
0.70	0.238	0.370
0.75	0.193	0.335
0.80	0.153	0.300
0.85	0.118	0.262
0.90	0.110	0.240
0.95	0.108	0.240
1.00	0.123	0.255
1.05	0.143	0.275
1.10	0.156	0.288

Separation Distance (Wavelengths)	Lower Correlation Limit	Upper Correlation Limit
1.15	0.161	0.292
1.20	0.153	0.285
1.25	0.133	0.270
1.30	0.110	0.242
1.35	0.085	0.219
1.40	0.068	0.210
1.45	0.065	0.207
1.50	0.073	0.217
1.55	0.072	0.235
1.60	0.071	0.244
1.65	0.070	0.249
1.70	0.068	0.250
1.75	0.067	0.243
4.50	0.000	0.170
5.00	0.000	0.156

FIGURE A.2.2.1-1: REFERENCE TEMPORAL CORRELATION LIMITS FOR SCME URBAN MACRO PLOTTED FROM TABLE A.2.2.1-4
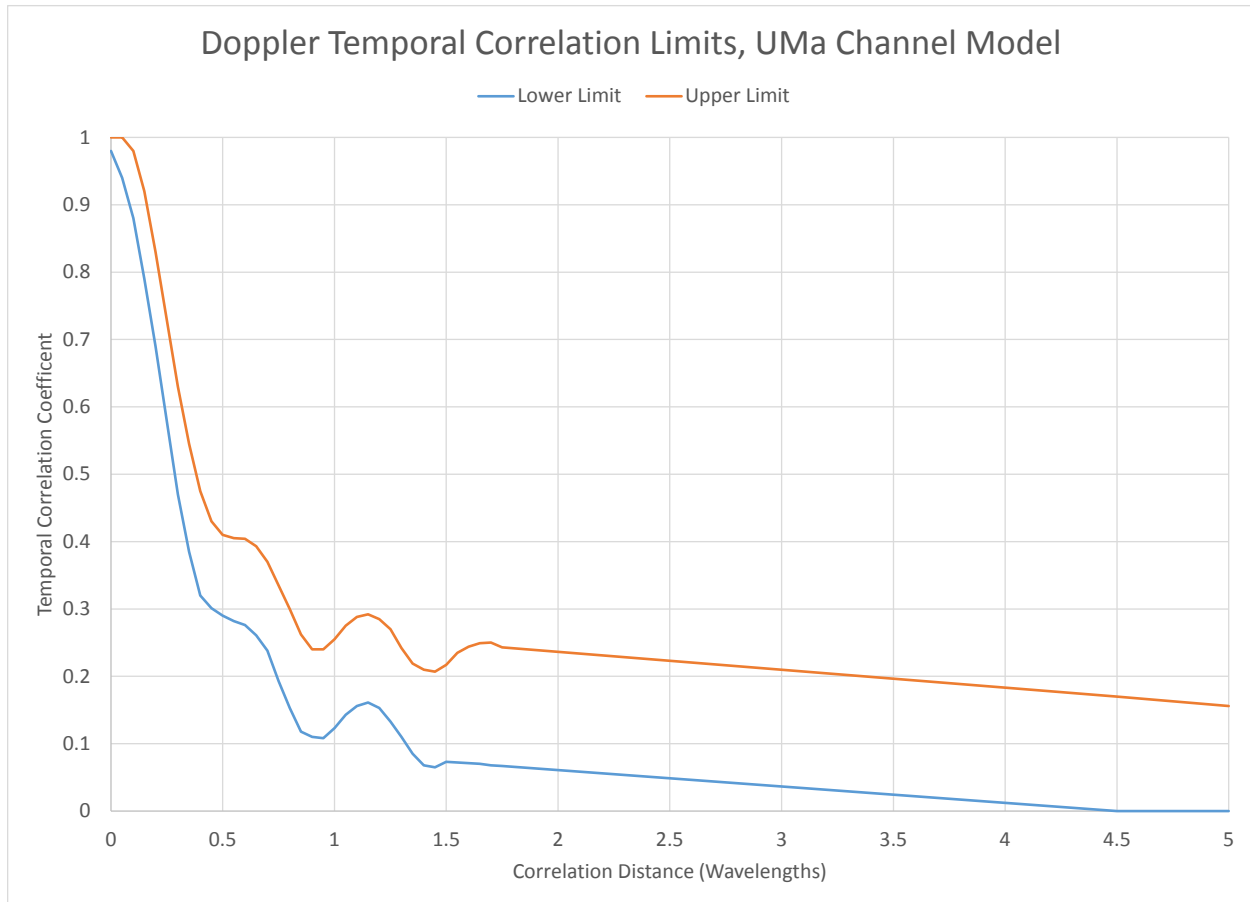
A.2.2.2   MPAC Doppler/Temporal Correlation Measurement Antenna

The measurement antenna shall be a vertically-oriented sleeve dipole.

A.2.3   Validation of MPAC Spatial Correlation

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

A.2.3.1   MPAC Spatial Correlation Method of Measurement

For each of the eleven specified positions and 1000 required CIR steps, step the emulation (i.e. run the emulation to advance the time such that the distance between traces specified in Table A.2.3.1-1 is met) and store traces from VNA. Continue until the center frequency response of 1000 CIRs in 11 positions (=1000*11 VNA traces) are measured. Assuming the channel emulation can be replayed exactly at each step, it's preferable to capture all CIR steps at each position prior to moving the antenna in order to minimize positioning uncertainty. In the event that the channel emulation cannot be replayed and stopped at exactly the same CIR step, each position may be measured at each CIR step while the emulation is paused, provided care is taken to reposition the

antenna to within better than 0.005 wavelengths (±5% positioning error) of the target position for each measurement. In either case, the paused channel emulator shall output the current state of the faded channel model continuously rather that reverting to an idle state.

Eleven test antenna positions shall be used to sample a segment of line of one wavelength in length with a sampling interval of 0.1 wavelengths. The antenna spacing shall be from -0.5 to +0.5 wavelengths from the center of the test volume, with a step size of 0.1 wavelength.

FIGURE A.2.3.1-1. TEST ANTENNA POSITIONS
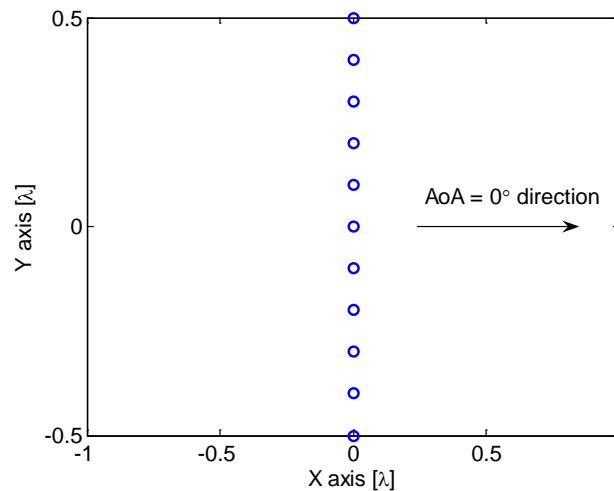
TABLE A.2.3.1-1: MPAC SPATIAL CORRELATION VNA SETTINGS

Item	Unit	Value
Center frequency	MHz	Downlink Center Frequency in 3GPP TS 36.508 [3] as required per band
Span	MHz	0 (Note 1)
Number of traces		1000
Number of points		1
Averaging		1
Note 1: An alternative approach using a non-zero span is acceptable as long as only the center point is used.		

TABLE A.2.3.1-2: MPAC SPATIAL CORRELATION CHANNEL MODEL SPECIFICATION

Item	Unit	Value
Center frequency	MHz	Downlink Center Frequency in 3GPP TS 36.508 [3] as required per band
Distance between traces in channel model	Wavelength (Note 1)	> 2
Channel model		As specified in Section 2.4.3
Mobile speed	km/h	As needed to meet distance between traces requirement in Table A.2.3.1-1.
Note 1: Time [s] = distance [λ] / MS speed [λ/s] MS speed [λ/s] = MS speed [λ/s] / Speed of light [m/s] * Center frequency [Hz]		

A.2.3.2 MPAC Spatial Correlation Measurement Results Analysis

Calculate correlation of 1000 x 11 matrix *H(f)* of frequency response samples. The procedure is to correlate the first column (the first dataset measured at half a wavelength from the center 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 data for the channel model and BS antenna assumptions defined in Sections 2.4.3 and 2.4.4 as shown in Table A.2.3.1-3 and plotted in Figure A.2.3.3-1. The measured spatial correlation data shall fall within the upper and lower limits specified.

TABLE A.2.3.1-3: MPAC REFERENCE SPATIAL CORRELATION FUNCTION FOR SCME URBAN MACRO

Separation Distance (Wavelengths)	Ideal Free Space Correlation	Expected 8 Probe Correlation	Lower Limit	Upper Limit
0.0	1.000	1.000	0.990	1.000
0.1	0.952	0.951	0.925	0.975
0.2	0.828	0.826	0.770	0.870
0.3	0.683	0.680	0.615	0.735
0.4	0.583	0.580	0.530	0.640
0.5	0.543	0.541	0.493	0.595
0.6	0.517	0.518	0.465	0.575
0.7	0.467	0.480	0.410	0.540
0.8	0.401	0.448	0.350	0.510
0.9	0.355	0.466	0.300	0.530
1.0	0.342	0.528	0.290	0.600

FIGURE A.2.3.3-1: MPAC REFERENCE SPATIAL CORRELATION FUNCTION FOR SCME URBAN MACRO PLOTTED FROM TABLE A.2.3.1-3
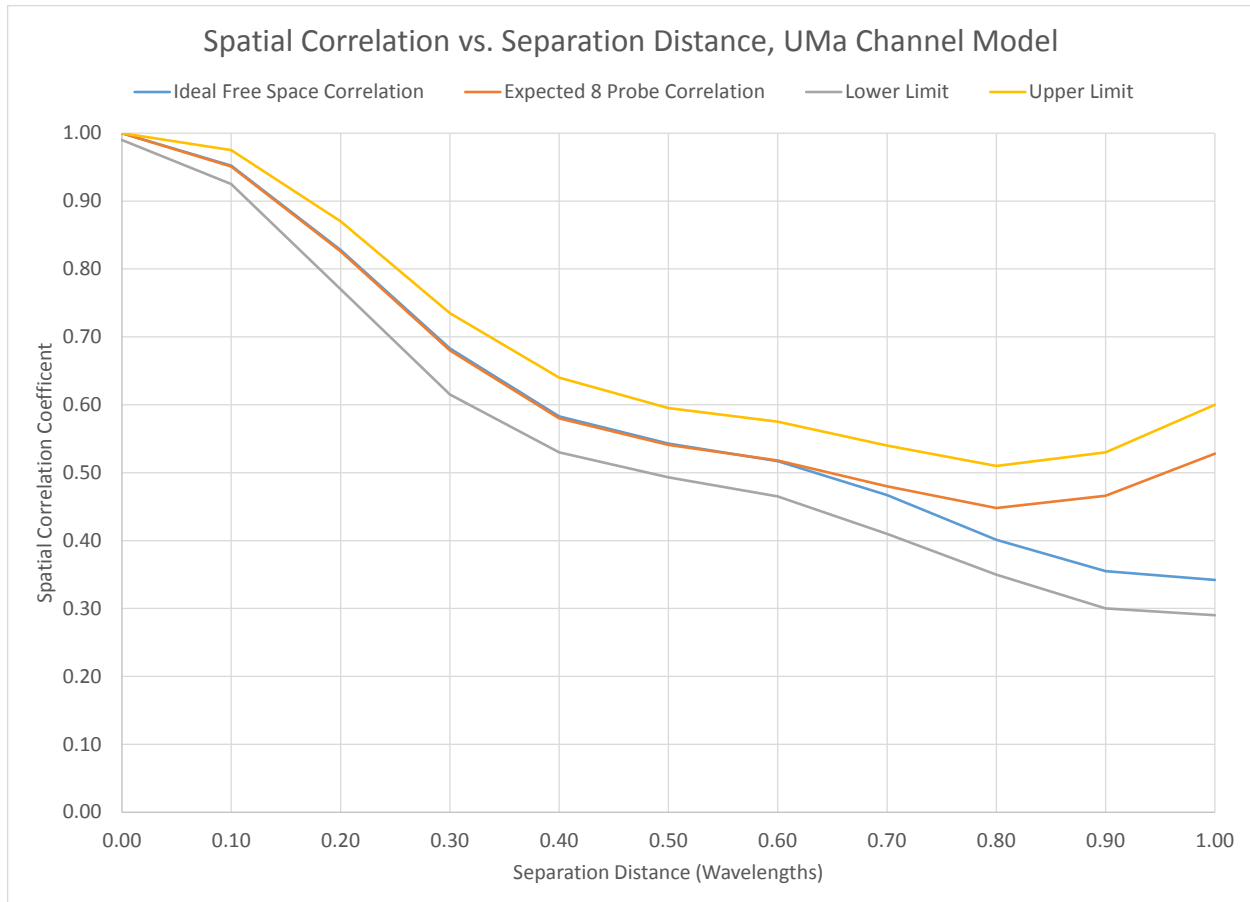
A.2.3.3   MPAC Spatial Correlation Measurement Antenna

The measurement antenna shall be a vertically-oriented sleeve dipole.

A.2.4   Validation of Cross-Polarization for MPAC

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

A.2.4.1 MPAC Cross Polarization Method of Measurement

Step the emulation and store traces from the VNA.

TABLE A.2.4.1-1: MPAC CROSS-POLARIZATION VNA SETTINGS

Item	Unit	Value
Center frequency	MHz	Downlink Center Frequency in 3GPP TS 36.508 [3] as required per band
Span	MHz	10
Number of traces		1000
Number of points		201
Averaging		1

TABLE A.2.4.1-2: MPAC CROSS-POLARIZATION CHANNEL MODEL SPECIFICATION

Item	Unit	Value
Center frequency	MHz	Downlink Center Frequency in 3GPP TS 36.508 [3] as required per band
Distance between traces in channel model	Wavelength (Note 1)	> 2
Channel model		As specified in Section 2.4.3
Mobile speed	km/h	30
Note 1: Time [s] = distance [λ] / MS speed [λ/s] MS speed [λ/s] = MS speed [λ/s] / Speed of light [m/s] * Center frequency [Hz]		

A.2.4.2 MPAC Cross Polarization Measurement Procedure

1   Play or step through the channel model -> UMa X Corr

2   Measure the absolute power received at the center of the array, averaged over a statistically significant number of fades.

3   Use a vertically polarized sleeve dipole to measure the V component.Use a horizontally polarized (vertically oriented) magnetic loop dipole, or a horizontally polarized sleeve dipole to measure the H component. For the horizontally polarized sleeve dipole, it is necessary to average multiple phi orientations of the dipole within the test volume and use the average of the theta gain pattern cut as the gain correction. This can be done by averaging across multiple steps, or slowly rotating the turntable continuously while the average power data is collected.

4   Calculate the V/H ratio.

5   Compare it with the theoretical value of 8.13 dB for UMa.

A.2.4.3 MPAC Cross Polarization Expected Measurement Results

V/H ratio (composite, i.e., all 6 paths combined) of the 3GPP SCME UMa model is 8.13 dB. The Base Station (BS) antennas are isotropic dipoles with ±45 degrees slant and subject to a foreshortening of the slanted radiating element. See channel model details and BS antenna assumptions specified in Sections 2.4.3 and 2.4.4, respectively. The measured validation result shall be within ±0.9 dB of the theoretical target value.

A.2.5 Input Phase Calibration Validation (Normative)

In order to validate the phase calibration algorithms used during a typical test, the manual phase calibration procedure specified in Section 2.2.2.3 shall be performed to measure the result of a typical automated phase calibration. Care shall be taken to ensure that the communication tester is switched to an output mode suitable for such a test (i.e. turning off modulation or switching to a transmission matrix that generates the same signal on both output ports) without disabling the downlink signal and losing the phase reference between the two channels. The resulting null of the combined measurement shall be at 180°±5°.

Appendix B — Validation of Transmit Diversity Receiver Performance Test Environments and Test Conditions

Text may be added to a future revision of this document.

Appendix C — Reporting Test Results (Normative)

C.1 MARSS Radiated Measurement Data Format

The test report shall include the EUT Information Tables specified in Section B.1 of [7]. Data collected during execution of the MIMO OTA tests described in Section 2 shall be documented for each orientation of the EUT as shown in Table C.1-1. The reporting format below is provided as an example.

TABLE C.1-1: MARSS MEASUREMENT DATA TABLE FORMAT

Device Orientation, Operating Band, Number of Device Receive Antennas (for Operating Band Under Test)	<Portrait/Landscape>, <Operating Band>, <Number of Device Receive Antennas for Operating Band Under Test>		
Azimuth Position (degrees)	**Downlink SIR @ 95% Throughput (dB)**	**Downlink SIR @ 90% Throughput (dB)**	**Downlink SIR @ 70% Throughput (dB)**
0			
30			
60			
90			
120			
150			
180			
210			
240			
270			
300			
330			
MARSS (P MARSS)			

C.2 Transmit Diversity Radiated Measurement Data Format

Text may be added to a future revision of this document.

**Appendix D— EUT Orientation Conditions (Normative)**

D.1   Scope

This Appendix lists the normative EUT orientation conditions for all EUT types relevant to MIMO and transmit diversity OTA testing. Additional orientation conditions will be added to this Appendix as they become normative.

D.2   Testing Environment Conditions

Table D.2-1 below lists the testing environment conditions along with a diagram and applicable references. Appendix E.2 defines the Euler rotation angles in three-dimensional space. The reference coordinate system and orientation of devices in that coordinate system is shown in Figure D.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. In the case of methodologies utilizing a spatial channel model in Figure D.2-1, the X axis points towards the channel model reference 0 degree location. For tablets or other EUTs with no clear features that can help to distinguish top and bottom, a manufacturer declaration shall be used to define the top and bottom of the device.

FIGURE D.2-1: REFERENCE DEVICE ORIENTATION
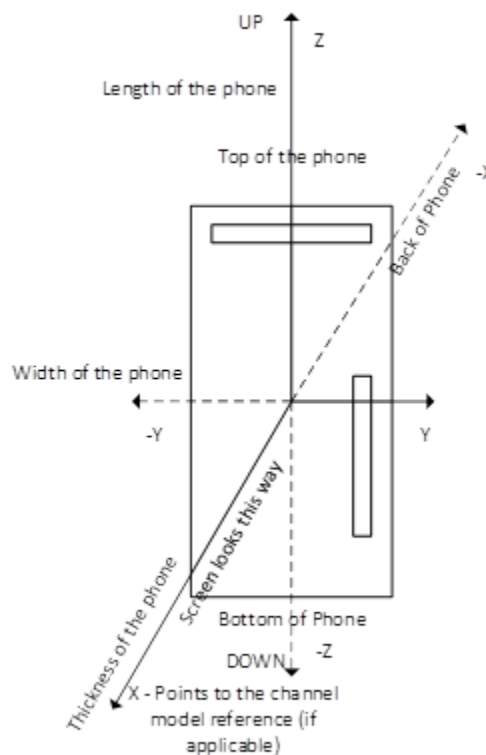
For the landscape case, the antenna positions relative to the channel will be different and the interaction of any future-defined phantoms with the antennas will depend on its orientation as shown in Figure D.2-2.

FIGURE D.2-2: LEFT AND RIGHT TILTS FOR LANDSCAPE MODE RELATIVE TO PORTRAIT MODE SHOWN TO INTERACT DIFFERENTLY WITH THE ANTENNAS DEPENDING ON THE TILT
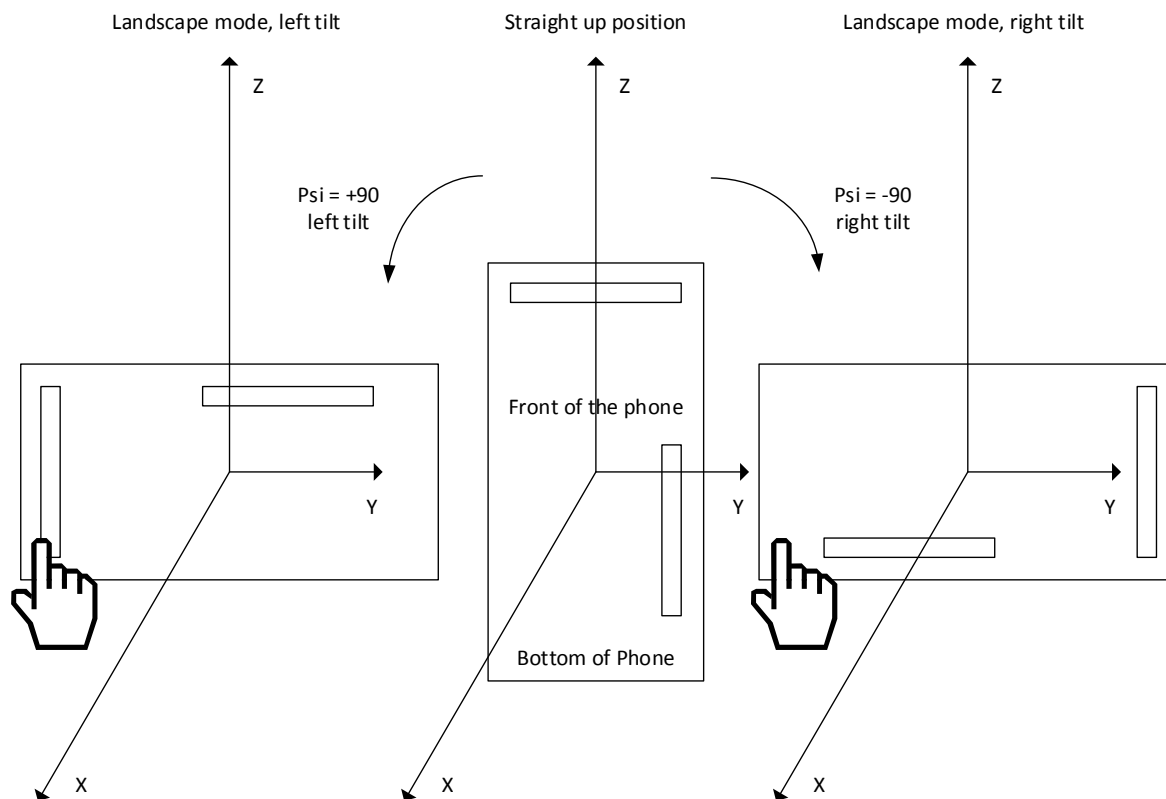
The usage mode of an EUT indicates how it relates to its environment. This includes the following example use cases: free space, beside head, beside head and hand, hand only etc. Since to date only isotropic metrics have been used (TRP/TRS) the definition of positioning the device for a certain use case has been equivalent to orienting it relative to the environment. With the introduction of spatial channel models, the positioning for a specific use case has to be separated from the actual orientation relative to the spatial incoming signals.

The EUT orientation angle in three-dimensional space is defined using the three Euler angles – Ψ-yaw; Θ-pitch; Φ-roll as defined in: "Antennas In Real Environments" [5] and linked to the reference coordinate systems and reference orientation from Figure D.2-1 and Figure D.2-2 above.

After positioning the EUT in its initial position for a specific testing condition (note that EUT positioning guidelines inside the MIMO OTA test zone described in 2.3.3 shall be followed), labs implement the rotation of the EUT defining a vector of Euler angles as shown in Table D.2-1 below:

TABLE D.2-1: NORMATIVE TESTING ENVIRONMENT CONDITIONS FOR DEVICES SUPPORTING DL MIMO

DATA RECEPTION

EUT Type and Dimension	Usage Mode	Testing Condition	EUT Orientation Angles	Diagram	Notes
Handset and Tablet, any size	Data mode portrait (DMP)	Free space DMP	Ψ=0; Θ=-45; Φ=0	Figure D.2-1 plus adjusting for EUT Orientation Angles	1
Handset and Tablet, any size	Data mode landscape (DML)	Free space DML	Ψ=-90; Θ=-45; Φ=0 – right tilt	Figure D.2-1 plus adjusting for EUT Orientation Angles	1, 2, 3

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) from "Antennas in Real Environments" [5]

Note 2: Left/right/both hand phantoms for the DML usage scenario are not currently defined in 3GPP or CTIA; until these phantom designs become available, it is possible to only define a DML usage scenario in free space.

Note 3: 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.

The data mode portrait (DMP) conditions are defined in the CTIA OTA Test Plan [7]. 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, for example, "Antennas in Real Environments" [5]. Currently, CTIA utilizes free space as the normative test condition for all handset and tablet sizes until a DMP and a DML phantom design becomes available, at which time the normative testing conditions described in this Appendix will be updated.

Appendix E — EUT Orientation Conditions (Informative)

E.1   Scope

This Appendix lists the informative EUT orientation conditions for all EUT types relevant to MIMO and transmit diversity OTA testing. The diagrams included in Table E.2-1 and Table E.2-2 of this Appendix may also be useful for gaining further familiarity with the spatial coordinate system utilized in Appendix D of this specification.

E.2   Testing Environment Conditions

The reference coordinate system and orientation of devices in the coordinate system is described in Appendix D of this document and in Table E.2-1 through Table E.2-3 below. For laptops, the definitions specified in the CTIA OTA Test Plan [7] (and repeated here in Table E.2-3) are used. In the case of methodologies utilizing a spatial channel model, the X axis points towards the channel model reference 0 degree location. For other EUT device types with no clear features that can help to distinguish top and bottom, a manufacturer declaration may be used to define the top and bottom of the device.

The principal antenna pattern cuts called for in this Appendix (XY plane, XZ plane, and YZ plane) are defined in IEEE.149-1979.R2008 [9]. The XY plane cut corresponds to the absolute throughput testing condition applied to the CTIA reference antennas for test plan development as part of the IL/IT Phase 2 test effort. 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.

The EUT orientation angle in three dimensional space is defined using the three Euler angles – Ψ-yaw; Θ-pitch; Φ-roll as defined in: "Antennas In Real Environments" [5] and linked to the reference normative coordinate systems and reference orientations from Appendix D, Figure D.2-1 and Figure D.2-2 and Appendix E, Table E.2-1 through Table E.2-3.

After positioning the EUT in its initial position for a specific testing condition (note that EUT positioning guidelines inside the MIMO OTA test zone described in 2.3.3 shall be followed), labs implement the rotation of the EUT defining a vector of Euler angles as shown in the example below:

EXAMPLE: Consider a DUT measured in an anechoic chamber as described in Section 2.

To measure the free space use case in the YZ plane (see Table E.2-1, for example, at every 30 degrees, the rotation vectors would be as follows:

  Ψ = [0 0 0 0 0 0 0 0 0 0 0 0] - a vector of 12 zeros indicating no rotation from the reference position for any phi value below

  Θ = [-90 -90 -90 -90 -90 -90 -90 -90 -90 -90 -90 -90] – a vector of 12 values equal to -90 indicating a constant tilt of 90 degrees for all phi values below

  Φ = [0 30 60 90 120 150 180 210 240 270 300 330] – a vector of 12 distinct rotations from the reference position representing a rotation along the azimuth plane with a step of 30 degrees.

These vectors unambiguously define that the DUT is to be oriented with the screen up and rotated in azimuth every 30 degrees.

TABLE E.2-1: INFORMATIVE TESTING ENVIRONMENT CONDITIONS FOR MIMO OTA TESTING USING PRINCIPAL ANTENNA PATTERN CUTS

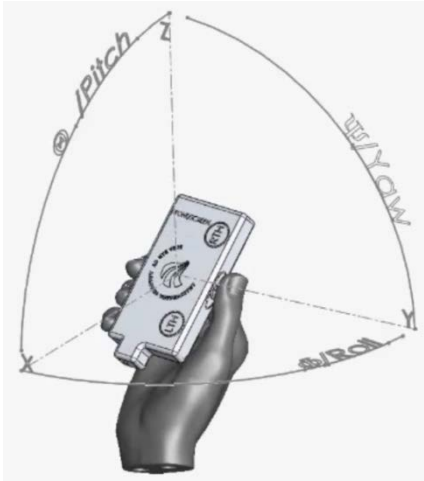| EUT Type and Dimension	Usage Mode	Testing Condition	EUT Orientation Angles	Diagram	Reference/ Notes
CTIA reference antennas	Absolute throughput in free space, XY plane	XY plane	Ψ=0; Θ=0; Φ=0		[9] Note 1, 2, 3
CTIA reference antennas	Absolute throughput in free space, XZ plane	XZ plane	Ψ=90; Θ=0; Φ=0		[9] Note 1,2,3
CTIA reference antennas	Absolute through-put in free space, YZ plane	YZ plane	Ψ=0; Θ=-90; Φ=0		[9] Note 1,2,3,4
Handset and Tablet, any size	Data mode screen up flat				

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) from "Antennas in Real Environments" [5]

Note 2: The CTIA reference antennas have been defined for the purposes of comparing MIMO OTA methodologies.

Note 3: 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 4: Screen-up flat positioning reference corresponds to a possible USB/WLAN tethering case, details of implementing this EUT orientation condition such as additional cabling, etc., are FFS.

TABLE E.2-2: INFORMATIVE TESTING ENVIRONMENT CONDITIONS FOR DEVICES SUPPORTING DL MIMO

DATA RECEPTION WHILE USING HAND PHANTOMS

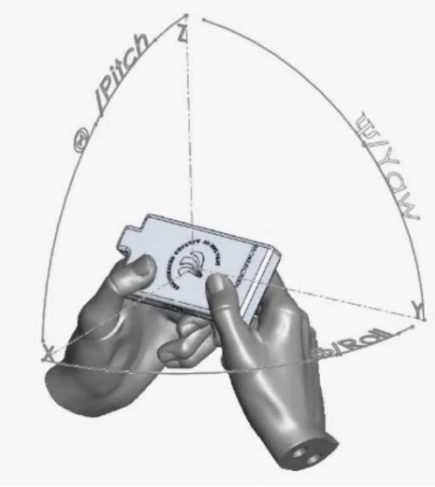| EUT Type and Dimension	Usage Mode	Testing Condition	EUT Orientation Angles	Diagram	Reference/ Notes
Handset, width < 56mm	Data mode portrait (DMP)	Left and Right Narrow Data Grip Hand Phantom	Ψ=0; Θ=-45; Φ=0		[5] Note 1
Handset, 56 mm ≤ width ≤ 72 mm		Left and Right PDA Hand Phantom			
Handset, 72 mm < width ≤ 92 mm		Left and Right Wide Grip Hand Phantom			

EUT Type and Dimension	Usage Mode	Testing Condition	EUT Orientation Angles	Diagram	Reference/ Notes
Handset, any size	Data mode landscape (DML)	Hand Phantom DML (FFS)	Ψ=90; Θ=-45; Φ=0 – left tilt Ψ=-90; Θ=-45; Φ=0 – right tilt		[5] Notes 1, 2, 3

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) from "Antennas in Real Environments" [5]

Note 2: Left/right/both hand phantoms for the DML usage scenario are not currently defined in 3GPP or CTIA; until these phantom designs become available, it is possible to only define a DML usage scenario in free space.

Note 3: 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 4: Talk mode conditions to facilitate VoLTE testing may be added to this table following further study.

Note 5: Where applicable, device positioning in hand phantoms shall follow the existing guidelines given in Appendix A.1.5 of the CTIA OTA Test Plan [7]

TABLE E.2-3: INFORMATIVE TESTING ENVIRONMENT CONDITIONS FOR NOTEBOOK DEVICES SUPPORTING

DL MIMO DATA RECEPTION

EUT Type and Dimension	Usage Mode	Testing Condition	EUT Orientation Angles	Diagram	Reference/ Notes
Notebook	Free space	XY plane	Ψ=0; Θ=0; Φ=0		[7] Notes 1, 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) from "Antennas in Real Environments". [5]

Note 2: 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 notebook measurement in free space is the principal XY plane cut with respect to this reference.

Appendix F — Test Zone Dimension Definitions for Optional Bands

Certification bodies may utilize the test zone size dimensions described in the tables below.

TABLE F.1-1: TEST ZONE DIMENSION DEFINITION FOR OPTIONAL FDD BANDS OF OPERATION

Operating Band	DL Channel Bandwidth (MHz)	DLChannel Number	DL Center Channel Frequency (MHz)	λ (m) at Center DL Channel	Test Volume Sphere Radius (m)
1	10	300	2140	0.140	0.070
3	10	1575	1842.5	0.163	0.081
6	10	2700	880	0.341	0.170
8	10	3625	942.5	0.318	0.159
9	10	3975	1862.4	0.161	0.080
10	10	4450	2140	0.140	0.070
11	10	4850	1485.9	0.202	0.101
18	10	5925	867.5	0.346	0.173
19	10	6075	882.5	0.340	0.170
20	10	6300	806	0.372	0.186
21	10	6525	1503.4	0.199	0.100
22	10	7000	3550	0.084	0.042
23	10	7600	2190	0.137	0.068
24	10	7870	1542	0.194	0.097
27	10	9125	860.5	0.348	0.174
28	10	9410	778	0.385	0.192
31	5	9895	465	0.645	0.322

TABLE F.1-2: TEST ZONE DIMENSION DEFINITION FOR OPTIONAL TDD BANDS OF OPERATION

Operating Band	DL Channel Bandwidth (MHz)	DLChannel Number	DL Center Channel Frequency (MHz)	λ (m) at Center DL Channel	Test Volume Sphere Radius (m)
34	15	36275	2017.5	0.149	0.074
35	20	36650	1880	0.159	0.080
36	20	37250	1960	0.153	0.076
37	20	37650	1920	0.156	0.078
38	20	38000	2595	0.116	0.058
39	20	38450	1900	0.158	0.079
40	20	39150	2350	0.128	0.064
42	20	42590	3500	0.086	0.043
43	20	44590	3700	0.081	0.041
44	20	46090	753	0.398	0.199

Appendix G—Change History

Date	Version	Description
August 2015	1.0	• Initial release of document
August 2016	1.1	• Added reference [6] in section 1.3. • Updated Band 17 entry in Table 2.3.3.2-1. • Updated Band 41 downlink channel number entry in Table 2.3.3.2-2. • Updated Note 2 and added Note 4 in Table 2.4.2-1 and Table 2.4.2-2. • Updated section 2.6.2 "SIR-Controlled Test Procedure Using the MPAC". • Updated section 2.6.3 "MARSS Figure of Merit". • Updates to address validation of the MPAC MIMO test environment: power delay profile validation (section A.2.1), Doppler/temporal correlation validation (section A.2.2), spatial correlation validation (section A.2.3), cross polarization validation (section A.2.4), and input phase calibration validation (section A.2.5). • Updates to test results reporting in section C.1. • Updates to Table E.1-1 and Table E.1-2 for optional bands.
September 2017	1.1.1	• Updated section 1.6 to clarify the antenna configuration used for DUT testing. • Updated section 1.7 to clarify the DUT information required to be provided to the test laboratory. • Updated section 2.3.3 to clarify the ripple zone requirements based on DUT positioning conditions and that no testing is required in any operating band where the maximum antenna separation is greater than 1 wavelength. • Added clarification to section 2.4.5.2 concerning the SIR definition. • Updated the test report template in Appendix C.1. • Changed Appendix D to "Normative" by removing all test conditions considered to be informative, clarified that tablets shall be tested in the same free-space test positions as handsets, and modified DML test position to use right tilt. • Created a new Appendix E which describes the informative test positions relevant to MIMO OTA performance testing. • Moved former Appendix E (Test Zone Dimensions for Optional Bands) to Appendix F.