Test Plan for Wireless Device Over-the-Air Performance

CTIA 01.21 Test Methodology, SISO, Reverberation Chamber

Version 6.0.1

September 2023

Use Instructions

All testing shall be performed in a CTIA Certification Authorized Test Lab and shall be initiated through one of the following methods:

1. By submitting a PTCRB or IoT Network Certified device certification request at https://certify.ptcrb.com/
2. By submitting an OTA Test Plan use request at https://certify.ctiacertification.org/

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Table of Contents

List of Figures

List of Tables

Section 1 Reverberation Chamber Test Overview

Cellular-enabled machine-to-machine (M2M) and wireless-internet-of-things (W-IoT) devices can take on many shapes and form factors, from health and fitness monitors worn on the wrist to vending machines and car dashboards. The over-the-air (OTA) performance of larger IoT devices, those having a physical dimension greater than 42 cm and smaller W-IoT devices, including tests conducted with phantoms, may be evaluated using reverberation chambers, as described in Section 1.3 of *CTIA 01.01* [1]. The exact placement of the device within the valid test volume of a reverberation chamber is not critical. This can be an advantage in some cases, for example, for large devices that may be heavy or awkward to position precisely or for devices where the exact location of the radiating element is not known. When properly configured, the reverberation chamber provides Total Radiated Power (TRP) and Total Isotropic Sensitivity (TIS) values for SISO wireless devices with uncertainties comparable to anechoic chambers.

The reverberation chamber produces a multipath environment with a decaying time response. In loaded reverberation chambers, instantaneous channels corresponding to individual, stepped, mode-stirring states have a time and spatial dependence (also manifested as a frequency dependence). For most metrics of interest, the ensemble of stepped mode-stirring states is averaged to provide statistically determinable channel characteristics. By carefully loading the chamber, the frequency dependence can be reduced to a level that allows viable wireless communication (e.g. approximating a flat-fading channel) while still maintaining the statistical nature of the measurement result. That is the approach taken in this test plan.

In stepped mode, each measurement is acquired over a static multipath channel that is assumed to be relatively flat in frequency over the coherence bandwidth to be tested. No Doppler component or other time dependent variations are present during each error rate measurement. Note that when the reverberation chamber is continuously stirred, additional time-dependent fading occurs. Consequently, TIS measurements are made using step-wise stirring to eliminate this additional temporal fading during each TIS measurement.

The reverberation chamber configuration(s) necessary to allow accurate SISO testing of large-form-factor IoT devices and small-form-factor IoT devices in free space or with phantoms is thoroughly described in this document. In addition to proper configuration and validation steps, chamber pre-characterization is described. Because the reverberation chamber must typically be loaded with RF absorber for wireless-system tests ([2], [3], [4]) and the RF absorbing properties of the equipment under test may affect the performance of the reverberation chamber ([5], [6]) the chamber's power transfer function characterization steps must be carried out under the loading conditions under which the DUT will be tested. Pre-characterization allows the test lab to measure certain parameters in advance of the actual device test in order to save time during actual DUT performance testing.

The testing requirements fall into three categories:

1. Procedures for configuring and pre-characterizing certain parameters of the test system.
2. Pre-characterizing certain parameters of the test system.
3. Estimating the power transfer function (path loss) of the test system for the DUT test and measuring the performance of the wireless device.

The methodologies required for characterizing the test system are documented in *CTIA 01.73* [7], including chamber configuration for measurement of S parameters (*CTIA 01.73* Section 6.1.1), calculation of chamber coherence bandwidth (*CTIA 01.73* [7] Section 6.1.2), and determination of the reverberation chamber's power transfer function (*CTIA 01.73* [7] Section 6.1.3).

Test procedures for chamber characterization are described *CTIA 01.73* as well, including cable assembly loss measurement (*CTIA 01.73* [7] Section 6.2.1.) Two pre-characterization steps are described for determining parameters that are time-consuming to measure during device test: Chamber pre-characterization of the proximity effect (*CTIA 01.73* [7] Section 6.2.2) and Chamber pre-characterization of uncertainty due to lack of spatial uniformity (*CTIA 01.73* [7] Section 6.2.3).

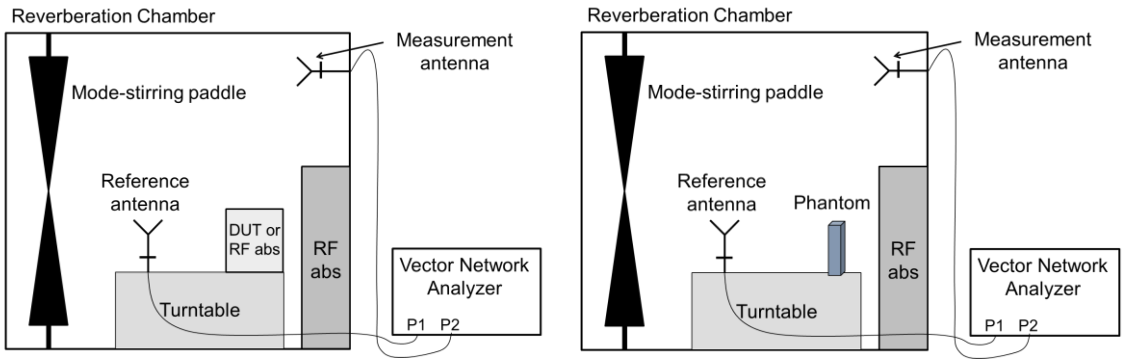
The DUT measurements described in this document include estimating the reference power transfer function and corresponding uncertainty for an DUT measurement (Section 2.1), measurement of total radiated power (Section 2.2), and measurement of total isotropic sensitivity (Section 2.3).

CTIA 01.73 [7] Section 3, Tables 3-4 and 3-5 describe the number of test frequencies to be used in the DUT measurements and the number of precharacterization test frequencies to be used, respectively.

Finally, the method for calculation of measurement uncertainty is presented (Section 3). Components specific to reverberation chamber measurements are presented in *CTIA 01.70* [8].

1.1 Equipment Required for Device Testing in Reverberation Chambers

The equipment required to make radiated performance measurements using a reverberation chamber are specified in the paragraphs below. A typical reverberation chamber measurement setup is shown in Figure 1.1-1 (a) for large-form-factor devices and in Figure 1.1-1 (b) for a small-form-factor device with a phantom. A reference antenna, measurement antenna, and RF absorber used to broaden the coherence bandwidth are placed within the chamber. S-parameters are measured by means of the VNA for the chamber power transfer function characterization procedures. The VNA is replaced by a base station emulator for TRP and TIS measurements.



(a) (b)

Figure 1.1-1 Typical Measurement Set-Up for Characterizing the Chamber Power Transfer Function in a Reverberation Chamber. (a) Large-form-factor device. (b) Small-form-factor Device with Phantom

The characterization of the chamber power transfer function (chamber loss/gain) is performed with a vector network analyzer (VNA). In *CTIA 01.73* [7] Section 6.1.1, RF absorber ("RF abs") has been added to broaden the coherence bandwidth (see *CTIA 01.73* [7] Section 6.1.2). The DUT or RF absorber is placed on the DUT fixture. Other set-ups, reference planes, and stirring mechanisms may be used.

1.1.1 The Reverberation Chamber

The reverberation chamber shall be large enough to contain the largest DUT to be tested, when the DUT is physically located within the valid test volume. No DUT and supporting equipment (including RF absorber used to load the chamber, RF absorber used in the proximity effect test, and test fixtures) shall occupy more than 8% of the chamber volume [9]. The valid test volume is the volume for which uncertainties have been established per *CTIA 01.73* [7] Section 6.2.3 that satisfies the Proximity Effect Test (*CTIA 01.73* [7] Section 6.2.2 and [5]), and that in other regards is suitable to hold a device under test. A test volume satisfying the Proximity Effect Test is shown in Figure 1.1.1-1, where Aux1 and Aux2 are defined in *CTIA 01.73* [7] Section 6.2.2. Valid test volume boundaries shall be located at least 0.5 λ at the frequency of operation from the walls, mechanical mode-stirrers (if used), and the antennas [10]. The test volume shall encompass both the reference antenna and the DUT. The separation between the reference antenna and the DUT shall exceed the minimum distance determined by the proximity effect evaluation specified in *CTIA 01.73* [7] Section 6.2.2. The chamber must support a mode-stirring sequence that shall be chosen such that the measurement uncertainty is below the threshold values specified in Section 3.4.

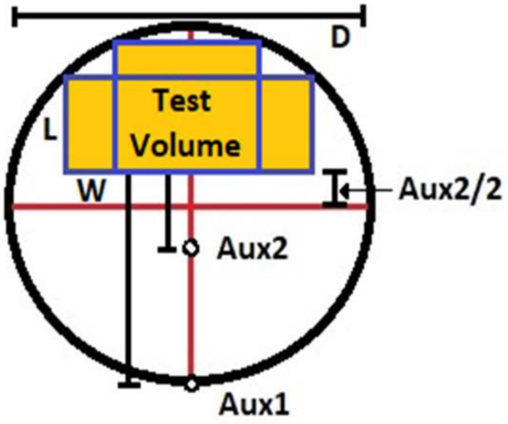


Figure 1.1.1-1 Test Volume For a Reverberation Chamber Using a Turntable, Where Aux1 And Aux2 Are Defined In *CTIA 01.73* [7] Section 6.2.2.

The DUT shall be placed a minimum distance R with respect to the surfaces of the reverberation chamber, where R corresponds to at least 0.5 λ for the frequency band of interest. Floor-standing devices may be placed closer than 0.5 λ to the floor of the reverberation chamber.

1.1.2 Measurement Antenna(s)

The measurement antenna shall be a monopole-like antenna fixed to a chamber wall or a more directive antenna pointing away from the reference antenna and the DUT antenna(s). If a monopole-like antenna is used, the increased uncertainty created by direct coupling of unstirred energy can be reduced by either cross-polarizing it with respect to the reference and DUT antennas or by use of multiple antennas having various polarizations. Directional measurement antennas shall not be pointed toward the reference antenna or DUT, as this will create large coupling of unstirred energy and thereby increase the uncertainty.

1.1.3 Reference Antenna

To adequately estimate uncertainty of the DUT measurement, it is desirable that the reference antenna have characteristics similar to the DUT antenna in terms of directivity. The radiation efficiency and free-space reflection coefficient of this antenna must be known over the required test frequency points. The efficiency may be provided by manufacturer’s specifications or from a direct measurement, such as a three-antenna measurement. In both cases, the uncertainty in the antenna efficiency shall be included in the uncertainty calculation. It is preferred that the reference antenna be mounted on a low-loss dielectric fixture to avoid reflections from the fixture itself.

1.1.4 Vector Network Analyzer

The VNA must cover the frequency bands of interest. In Figure 1.1.1-1, the VNA's calibration reference plane is located where the cables from the VNA connect to the measurement antenna and the reference antenna. Other choices of reference plane may be used with proper de-embedding techniques [11]. The network analyzer is configured to perform a frequency sweep for each mode-stirring sample, and, as such, automated acquisition is highly desirable.

1.1.5 RF Absorber

RF absorbing material may be required to broaden the coherence bandwidth of the chamber, as described in *CTIA 01.73* [7] Section 6.1.2. Standard, commercially-available RF absorber covering the appropriate frequency range shall be used. Special "low-loss" formulations shall not be used.

1.1.6 Cables and Adapters

Cables and adapters are utilized as needed, to implement the measurement scenario illustrated in Figure 1.1.1-1.

1.2 Acronyms and Definitions

The following specialized terms and acronyms are used throughout this document. Where possible, terms are defined from *IEEE Std 100* [12].

Note: Only terms unique to the reverberation chamber should be included in this glossary.

Table 1.2-1 Glossary

Acronym/Term	Definition
Coherence Bandwidth	The average bandwidth over which the correlation between frequency components exceeds a specified threshold. For the purposes of this test plan, correlation is defined by use of TBD.
Isotropy	A hypothetical, convenient reference reverberation chamber channel characteristic in which radiation intensity is received equally from all directions.
Mode-Stirring Method	A technique that allows a user to obtain samples of the quantity of interest (field strength, power, etc.) either by randomizing the modal structure in the reverberation chamber (e.g., mechanical paddle stirring) or by selecting samples from a given modal structure from different physical locations (e.g., antenna stirring, position stirring) or polarizations (polarization stirring). For the purposes of this test plan, frequency averaging (sometimes called frequency stirring) is used across the channel bandwidth.
Mode-Stirring Sample	A single measurement sample from within a mode-stirring sequence. For the purposes of this test plan, samples typically correspond to a single acquisition of data from either a vector network analyzer or base-station emulator.
Mode-Stirring Sequence	A collection of mode-stirring samples that form a single, averaged measurement from which a quantity of interested is estimated.
Power Transfer Function	The loss in the reverberation-chamber for a given set-up. Typically measured with a VNA through reference and measurement antennas having known efficiencies. The efficiencies of the antennas are corrected for in post processing. The Power Transfer Function is corrected for in post processing to derive power-based metrics such as TRP and TIS.
Reverberation Chamber	An enclosure especially designed to have a long reverberation time and to produce a field (e.g., sound or electric field) as diffuse as possible.
RF Absorber	A material designed to absorb electromagnetic energy. The material may have a flat face or may be formed into pyramids, wedges, or cones.

1.3 Document References

The following documents are referenced in this test plan:

Document Number, *Document Name*
[1] CTIA 01.01, *Test Scope, Requirements, and Applicability*
[2] Chen, X., Kildal, P.-S., Orlenius, C., Carlsson, J., *Channel Sounding of Loaded Reverberation Chamber for Over-the-Air testing of Wireless Devices: Coherence Bandwidth Versus Average Mode Bandwidth and Delay Spread*, IEEE Antennas and Wireless Propagation Letters, vol. 8, pp. 678-681, June 2009.
[3] Chen, X., Kildal, P.-S., Orlenius, C., Carlsson, J., *Corrections to Channel Sounding of Loaded Reverberation Chamber for Over-the-Air Testing of Wireless Devices: Coherence Bandwidth Versus Average Mode Bandwidth and Delay Spread*, IEEE Antennas and Wireless Propagation Letters, vol. 12, pp. 1728,, Dec. 2013.
[4] K. A. Remley et al., *Configuring and Verifying Reverberation Chambers for Testing Cellular Wireless Devices*, IEEE Trans. Electromagn. Compat., vol. 58, no. 3, pp. 661–672, Jun. 2016.

Document Number, *Document Name*
[5] Aan Den Toorn, J., Remley, K. A., Holloway, C. L., Ladbury, J. M., and Wang, C.-M, *Proximity-Effect Test for Lossy Wireless-Device Measurements in Reverberation Chambers, IET Science, Measurement and Technology*, vol. 9, no. 5, 2015, pp. 540-546, August 2015.
[6] Carlberg, U., Kildal, P-S., Wolfgang, A., Sotoudeh, O., Orlenius, C., *Calculated and Measured Absorption Cross Sections of Lossy Objects in Reverberation Chamber*, IEEE Transactions on Electromagnetic Compatibility, vol. 46, no. 2, pp. 146-154, May 2004.
[7] CTIA 01.73, *Supporting Procedures*
[8] CTIA 01.70, *Measurement Uncertainty*
[9] ISO.61000-4-21:2011, Electromagnetic Compatibility (EMC) - Part 4.21: *Testing and Measurement Techniques - Reverberation Chamber Test Methods*, 2011.
[10] Hill, D.A., *Boundary Fields in Reverberation Chambers*, IEEE Transactions on Electromagnetic Compatibility, May 2005.
[11] Remley, K.A., Wang, C.-M., Pirkl, R. J., Kirk, A. T., Aan Den Toorn, J., Williams, D. F., Holloway, C. L., Jargon, J. A., and Hale, P. D., *A Significance Test for Reverberation-Chamber Measurement Uncertainty in Total Radiated Power of Wireless Devices*, IEEE Transactions on Electromagnetic Compatibility, vol. 58, no. 1, pp. 207-219, February 2016.
[12] IEEE Std 100, *The Authoritative Dictionary of IEEE Standards Terms*.
[13] Kildal, P.-S, Chen, X., Orlenius, C., Franzen, M. and Patané, C. Lötbäck,, *Characterization of Reverberation Chambers for OTA Measurements of Wireless Devices: Physical Formulations of Channel Matrix and New Uncertainty Formula*, IEEE Transactions On Antennas and Propagation, August 2012.
[14] CTIA 01.50, *Wireless Technology, 3GPP Radio Access Technologies*
[15] CTIA 01.03*, Reporting Tables*
[16] CTIA 01.20, *Test Methodology, SISO, Anechoic Chamber*

Section 2 Transmitter and Receiver Performance Assessment of IoT Devices

The tests in Section 2.1 are performed once for each DUT configuration (i.e., mechanical mode, usage mode, etc.). The tests in Sections 2.2 and 2.3 are performed for each configuration, operating band, cellular radio mode, applicable procedures and settings as given in *CTIA 01.01* [1].

2.1 Test Procedure - Estimating the Reference Power Transfer Function and Corresponding Uncertainty for a DUT Measurement

During the pre-characterization step of *CTIA 01.73* [7] Section 6.2.3, the chamber's power transfer function is estimated from VNA measurements made over multiple sets of a proposed mode-stirring sequence. These multiple sets are made at spatially uncorrelated locations within the chamber. At each stirring state in the sequence a sweep of S-parameters over frequency is collected and stored. From the collected S parameter data the power transfer function is computed per *CTIA 01.73* [7] Section 6.1.3.

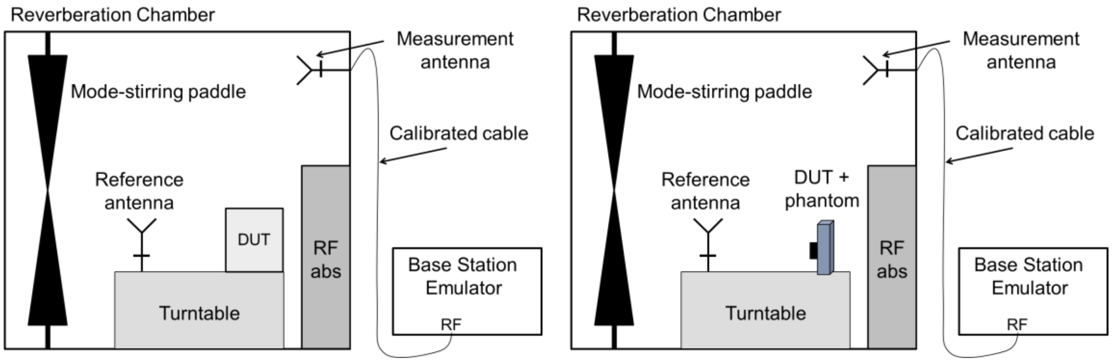
For the DUT measurement, the user performs a minimum of $T_{cal} = 1$ calibration measurements (over a mode-stirring sequence) to estimate the reference power transfer function for each chamber set-up. As defined here, the "set-up" includes the same antennas as were used in the pre-characterization step, the DUT, the phantom, if used, and the number and location of RF absorbers that will be used during testing of the DUT. The reference power transfer function is estimated from the T_{cal} samples and the user estimates the uncertainty due to lack of spatial uniformity from the pre-characterization data derived in *CTIA 01.73* [7] Section 6.2.3. Note that the use of $T_{cal} > 1$ calibration measurements typically results in lower uncertainties.

1. Configure the chamber to measure S parameters and calibrate the VNA as described in *CTIA 01.73* [7] Section 6.1.1. Place into the reverberation chamber the DUT, the phantom, if used, additional loading, reference antenna, and measurement antenna(s) that will be used during the reference, TRP and TIS measurements.
2. Place the reference antenna at a location within the test volume of the chamber representative of where an DUT or DUT mounted to a phantom may be placed, as shown in Figure 1.1.1-1. If multiple reference measurements are made for the DUT measurement, antennas shall be placed at uncorrelated positions (correlation less than 0.3) within the test volume, where correlation between positions is determined by use of *CTIA 01.73* [7] Equation 6.2-2. These positions may correspond to those used in pre-characterization *CTIA 01.73* [7] Section 6.2.3, or they may be other uncorrelated positions. The reference antenna shall be placed in the test volume of the chamber in such a way that it undergoes the same stirring sequence as the DUT antenna during the TRP or TIS measurements and is a minimum of 0.5 λ from any walls, mode-stirrers, or other metallic objects. Directional reference antennas shall be pointed away from both the DUT and the measurement antennas.
3. Determine the loading needed for a given coherence bandwidth, using the pre-characterization table described in *CTIA 01.73* [7] Section 6.2.3.
4. Perform S-parameter measurements over a complete stirring sequence over a frequency band that includes each channel in each band to be tested.
5. Calculate the reference power transfer function, $G_{ref\ DUT.lin}$, with a minimum of $T_{cal} = 1$ from *CTIA 01.73* [7] Section 6.1.3 over the bandwidth for each radio technology and band being tested.
6. Perform S-parameter measurements over a complete stirring sequence over a 100 MHz bandwidth centered at the center frequency for each band to be tested.
7. Calculate the coherence bandwidth over a 100 MHz bandwidth centered at the center frequency for each band to be tested using the method of *CTIA 01.73* [7] Section 6.1.2.

8. Utilize the value of σ^{i}_{Gref} [dB] from the precharacterization table calculated in *CTIA 01.73* [7] Section 6.2.3 that corresponds to the coherence bandwidth calculated in Step 7 for the radio technology and band being tested.
9. Use $G_{ref\ DUT,lin}$ as G_{ref} in Equation 2.2-1 (TRP) or Equation 2.3-1 (TIS). Use σ^{i}_{Gref} [dB] in *CTIA 01.70* [8] to find the value of uncertainty due to lack of spatial uniformity in the uncertainty budget for the TRP or TIS measurement for each channel in each band being tested, as described in Section 3.

2.2 Test Procedure – Total Radiated Power

The TRP measurement configuration is similar to that of the reference power transfer function characterization measurements described above, with the network analyzer replaced by a base station emulator and power meter or spectrum analyzer. The base station emulator is used to establish and maintain an airlink connection to the device under test and control its traffic channel and output power. The power meter or spectrum analyzer is used to sample the transmitted power. A base station emulator with an integrated power meter may also be used. Figure 2.2-1 (a) and (b) show the configuration for TRP measurements with a base station emulator used for the power sampling for LFF devices and SFF devices with phantoms, respectively.



(a) (b)

Figure 2.2-1 Example Setup for Total Radiated Power and Total Isotropic Sensitivity Measurements in a Reverberation Chamber. RF Absorber ("RF abs") Has Been Included to Broaden the Coherence Bandwidth. (a) Setup for a Large-Form-Factor Device Test. (b) Setup for a Small-Form-Factor IoT Device Test with a Phantom.

The TRP measurement is performed as follows:

1. Conduct the reference power transfer function characterization procedure described in the previous sections, including the determination of the antenna mismatch, reference power transfer function, and cable-assembly loss measurement, if applicable. The antenna used during the reference power transfer function characterization step shall be terminated in a $50\ \Omega$ load and remain located within the chamber. The DUT or DUT mounted on a phantom shall be positioned within the test volume of the chamber so that the chamber loading is the same for the reference power transfer function characterization and DUT measurement steps and so that it undergoes the same stirring sequence as the reference antenna during the calibration and characterization tests.
2. With the base station emulator, establish an airlink connection to the DUT and control it to radiate at its maximum output power on the traffic channel to be measured.

3. With the power meter, spectrum analyzer, or base station emulator, measure the power in each mode-stirring sample using the same mode-stirring sequence determined in the reference power transfer function characterization step.
4. Calculate the TRP value by taking an average of all power samples and applying the reference power transfer function as (see [11], [13]).

Equation 2.2-1

$$P_{\mathrm{TRP,lin}} = \frac{1}{N}\frac{\sum_{n=1}^{N} P_n}{G_{ref,lin}\ e_{mismatch,meas}\ \ \eta_{meas}\ \ G_{cable}}$$

where P_n is measured for mode-stirring sample *n*, *N* is the total number of mode-stirring samples, G_{cable} is the loss in the cable assembly (which may include a cable and power splitter, as discussed above), $G_{ref,lin} = G_{ref\ DUT,lin}$ (Section 2.1 and $e_{mismatch,meas}$ is the measurement antenna mismatch factor as found from the reference power transfer function measurements. The uncertainty in P_{TRP} must not exceed the uncertainty specified in Section 3.4. Note that the summation is performed using linear power values, even though the result P_{TRP} is reported in dBm.

2.3 Test Procedure – Receiver Performance

This section describes how to perform measurements of (TIS) in a reverberation chamber (see [4]) for IoT devices. The chamber reference power transfer function characterization procedure for these measurements is the same as for the (TRP) measurements, and is found in Section 2.2 above.

The TIS procedure is based on searching for the lowest base station emulator output power in each mode-stirring sample that gives a performance metric (e.g., BER, BLER, throughput) that is lower than the specified target error rate, or above the target throughput, as given in *CTIA 01.50* [14]. The TIS procedure is executed with the following steps:

1. Perform the reference power transfer function characterization procedure described in Section 2.1 including the calculations of mismatch and chamber reference power transfer function, and measurement of transmission loss of the cable connecting the base station emulator to the measurement antenna. The DUT or DUT mounted on a phantom and reference antenna shall remain located within the chamber. The DUT shall be positioned so that the chamber loading is the same for the characterization and measurement steps and so that it undergoes the same stirring sequence as the reference antenna during the characterization tests and is a minimum of 0.5 λ from any walls, mode-stirrers, or other object. The reference antenna shall be terminated in a $50\ \Omega$ load.
2. Page the DUT, direct it to the traffic channel of interest and place it in loopback mode to enable a digital error rate or throughput measurement, as applicable to the airlink technology under test.
3. Set the base station emulator to a specific output power and perform a digital error rate or throughput measurement.
4. Increase or decrease the base station output power as needed, and repeat step 3 until the lowest output power (power step size shall be no more than 0.5 dB when the RF power level is near the final declared sensitivity level) is found that gives a digital error rate lower than the specified target BER or a throughput above the target, as applicable.
5. Repeat steps 2.3.2 through 2.3.4 for each of the mode-stirring samples in the measurement sequence.
6. Calculate the TIS value from the following equation:

Equation 2.3-1

$$P_{TIS,lin} = G_{ref,lin} e_{mismatch,meas} \eta_{meas} G_{cable} \left(\frac{1}{N} \sum_{n-1}^{N} \frac{1}{P_{BSS\ (n)}} \right)^{-1}$$

where $P_{BSS\ (n)}$is the output power from the base station emulator when it is adjusted to give the specified digital error rate or throughput from the DUT for mode-stirring sample *n*, *N* is the total number of mode-stirring positions, G_{cable} is the loss in the cable assembly connecting the base station emulator to the measurement antenna, and G_{ref}= $G_{ref\ DUT}$, and $e_{mismatch,meas}$ are the reference power transfer function and measurement antenna mismatch factor as found in the characterization steps. The uncertainty in P_{TIS} must not exceed the uncertainty specified in Section 3.4. Note that the summation is performed using linear power values, even though the result P_{TIS} is reported in dBm.

Section 3 Measurement Uncertainty

This section treats the calculation of measurement uncertainty for the tests described in this test plan. The uncertainty in a reverberation-chamber measurement will depend on chamber size, frequency of operation, type of stirring in the sequence, stirrer types and shapes, polarization stirring (if any), frequency averaging bandwidth, and the degree of loading of the chamber. All of these factors must remain the same for the reference power transfer function characterization and DUT measurement procedures. If the total expanded uncertainty exceeds the required level of uncertainty, the stirring sequence may be altered, typically by adding additional mode-stirring samples. For measurement of large-form-factor devices, these additional positions often utilize antenna-location stirring.

For the reverberation-chamber measurement setups described in this section, many, but not all, of the error contributions are identical to those described for the anechoic-chamber setup. These components and those specific reverberation-chamber measurements of large-form factor or small-form-factor IoT devices in free space or small-form-factor IoT devices tested with phantoms are described in *CTIA 01.70* [8].

3.1 General Considerations

CTIA 01.70 [8] gives general guidelines for how the measurement uncertainty contributions shall be calculated for TRP and TIS tests, respectively, and also the practical steps involved in the determination and compilation of a complete uncertainty budget. The same general guidelines shall be applied to tests performed in reverberation-chamber measurement setups where applicable, as described below.

In Sections 3.2 and 3.3, this calculation process is fully described for the TRP and TIS tests of this test procedure, respectively.

3.2 TRP Tests

The TRP test method determines the unknown performance of the DUT by correcting the absolute power measurements at the input port of the test instrumentation using a relative correction value determined using the Reference Measurement described *CTIA 01.73* [7] Section 6.1.3 (Methodology – Calculation of the reference power transfer function). The test procedure for TRP is described in Section 2.2. To reduce the overall measurement uncertainty, the same cable configuration and equipment used during the reference measurement should be used during the DUT measurement. In this way, a number of the individual uncertainty contributions will cancel. Examples include the uncertainty in the insertion loss of the cable(s) between the Measurement Antenna and the spectrum analyzer/measurement receiver, the uncertainty in the efficiency of the Measurement Antenna, etc.

3.2.1 DUT Measurement

The DUT or the DUT mounted on a phantom and other RF-absorbing material including RF absorbers that load the chamber to increase the coherence bandwidth (*CTIA 01.73* [7] Section 6.1.2) and support structures, if any, shall be placed within the chamber during the chamber characterization, reference, and DUT measurements, as described in *CTIA 01.73* [7] Section 6.1.1 (Reverberation Chamber Configuration to and Measurement of S-Parameters). At the receiving end, the spectrum analyzer, measurement receiver or base station emulator shall be connected via a cable and/or attenuator to the measurement antenna through a chamber bulkhead adapter.

The identified uncertainties in this part are listed in Table 3.2.1-1. Where 0.00 dB values are entered in Table 3.2.1-1, this means that the uncertainty contribution appears in the reference measurement also and therefore cancels. The uncertainty contributions that can be assumed to cancel are those contributions associated with system components that are the same as those utilized in the reference measurement. If the configuration changes between the DUT measurement and the reference measurement, an estimation of the uncertainty contributions shall be made to replace the 0.00 dB values. Since components such as the measurement antenna and associated cables are measured in the reference measurement, there is one lump uncertainty associated with that measurement, rather than the individual uncertainties of each component.

Table 3.2.1-1 TRP Standard Uncertainties for the Contributions in the DUT Measurement Part

Description of Uncertainty Contributions	Standard Uncertainty, dB
Mismatch: receiving part (i.e. between receiving device & Measurement Antenna)	See Section 2.1 in *CTIA 01.70* [8]
Cable factor: Measurement Antenna	See Section 2.2 in *CTIA 01.70* [8]
Insertion loss: Measurement Antenna cable	0.00
Insertion loss: Measurement Antenna attenuator (if present)	0.00
Receiving device: absolute level	See Section 2.4 in *CTIA 01.70* [8]
DUT: influence of the ambient temperature on the ERP of the carrier	See Section 2.12 in *CTIA 01.70* [8]
Miscellaneous uncertainty (measurement system repeatability)	See Section 2.22 in *CTIA 01.70* [8]
Frequency resolution for TRP measurement	0.00 See Section 2.29 in *CTIA 01.70* [8] and Table 3-5 in *CTIA 01.73* [7] regarding frequency stirring, which accounts for frequency flatness of the test set-up for TRP measurements.
Chamber lack of spatial uniformity (based on standard deviation of multiple pre-characterized reference measurements and single user DUT measurement)	See Section 2.30 in *CTIA 01.70* [8]
Unknown K factor	For future study for large-form-factor device measurements; See Section 2.8.3 in *CTIA 01.70* [8] for small-form-factor device measurements.

Once all the relevant standard uncertainty values in Table 3.2.1-1 have been calculated, they shall be combined (by RSS) to give the combined standard uncertainty $U_{c\ contribution\ from\ the\ DUT\ measurement}$ for this part of the test.

3.2.2 Reference Measurement

This is the reference power transfer function of the chamber G_{ref} in terms of power loss, as given in *CTIA 01.73* [7] Section 6.1.3 (Methodology – Calculation of the reference power transfer function). The uncertainty of the reference measurement is a significant factor in the accuracy of the measured TRP value. Any error in the determination of G_{ref} (e.g., error in the determination of the efficiency of the Reference Antenna) will result in an error in the TRP value.

The DUT or the DUT mounted on a phantom and other RF-absorbing material including RF absorbers that load the chamber to increase the coherence bandwidth (*CTIA 01.73* [7] Section 6.1.2) and support structures, if any, shall be placed within the chamber during both the Reference measurement, as described in *CTIA 01.73* [7] Section 6.1.2 (Reverberation Chamber Configuration and Measurement of S-Parameters). At the receiving end, the vector network analyzer shall be connected via a cable and/or attenuator to the Measurement Antenna through a chamber bulkhead adapter.

The contributors to the overall uncertainty of this part of the measurement are given in Table 3.2.2-1. Again, the contributors that appear in both parts of the measurement are set equal to 0.00 dB because they have the same effect in both parts, provided the relevant components of the test set-up have not been changed. If the configuration changes during the individual reference measurement steps, an estimation of the uncertainty contributions shall be made to replace the 0.00 dB values.

Table 3.2.2-1 TRP Standard Uncertainties for the Contributions in the Reference Measurement Part

Description of Uncertainty Contributions	Standard Uncertainty, dB
Mismatch: transmitting part (between vector network analyzer excitation port and Reference Antenna)	See Section 2.1 in *CTIA 01.70* [8]
Mismatch: receiving part (between vector network analyzer receiving port and Measurement Antenna)	See Section 2.1 in *CTIA 01.70* [8]
Vector network analyzer: absolute level	See Section 2.5 in *CTIA 01.70* [8]
Vector network analyzer: level stability	See Section 2.5 in *CTIA 01.70* [8]
Insertion loss: calibrated Reference Antenna cable	See Section 2.3 in *CTIA 01.70* [8]
Insertion loss: Measurement Antenna cable	0.00
Insertion loss: Calibrated Reference Antenna attenuator (if present)	See Section 2.3 in *CTIA 01.70* [8]
Insertion loss: Measurement Antenna attenuator (if present)	0.00
Chamber lack of spatial uniformity (based on standard deviation of multiple pre-characterized reference measurements and single user reference measurement)	See Section 2.30 in *CTIA 01.70* [8]
Antenna: radiation efficiency of the calibrated Reference antenna	See Section 2.8.2 in *CTIA 01.70* [8]

Once all the standard uncertainty values have been derived, they shall be combined (by RSS) to give the following combined standard uncertainty $u_{c\ contribution\ from\ the\ reference\ measurement}$ for this part of the test.

3.2.3 Calculation of the Combined and Expanded Uncertainties for the Overall TRP Measurement

Having calculated the combined standard uncertainties from the two parts of the measurement, they shall be combined as follows to derive the overall combined standard uncertainty:

$$u_c = \sqrt{u^2_{c\ contribution\ from\ the\ DUT\ measurement} + u^2_{c\ contribution\ from\ the\ reference\ measurement}}$$

From this, the expanded uncertainty, *U*, is calculated with a coverage factor of 2. This is the resulting value of the TRP expanded uncertainty and shall be stated in the test report, See *CTIA 01.03* [15].

3.3 TIS Tests

The TIS test method is similar to the TRP method above, in that the Reference measurement is used to correct the unknown performance of the DUT back to values relative to that of a theoretical isotropic receiver. The test procedure for TIS is described in Section 2.3 (Receiver Performance). DUT measurements are corrected for the chamber reference by use of techniques described in *CTIA 01.73* [7] Section 6.1.3 (Methodology – Calculation of the reference power transfer function). To reduce the overall measurement uncertainty, the same cable configuration and equipment used during the reference measurement should also be used during the DUT measurement, rather than measuring individual components and applying the corrections separately. In this way, a number of the individual uncertainty contributions will cancel because they contribute the same uncertainty to both the reference measurement and the DUT measurement. Examples include the uncertainty in the insertion loss of the cable(s) between the measurement antenna and the base station emulator, the uncertainty in the gain of the measurement antenna, etc.

3.3.1 DUT Measurement

The DUT or the DUT mounted on a phantom and other RF-absorbing material including RF absorbers that load the chamber to increase the coherence bandwidth (*CTIA 01.73* [7] Section 6.1.2) and support structures, if any, shall be placed within the chamber during the chamber characterization and DUT measurements, as described in *CTIA 01.73* [7] Section 6.1.1 (Reverberation Chamber Configuration and Measurement of S-Parameters). At the receiving end, the base station emulator shall be connected via a cable and/or attenuator to the Measurement Antenna through a chamber bulkhead adapter. If the configuration changes between the DUT measurement and the reference measurement, an estimation of the uncertainty contributions shall be made to replace the 0.00 dB values.

The identified uncertainties in this part are listed in Table 3.3.1-1.

Table 3.3.1-1 TIS Standard Uncertainties for the Contributions in the DUT Measurement Part

Description of Uncertainty Contributions	Standard Uncertainty, dB
Mismatch: transmitting part (i.e. between Base Station Simulator and Measurement Antenna)	See Section 2.1 in *CTIA 01.70* [8]
Base station simulator: absolute output level	See Section 2.5 in *CTIA 01.70* [8]
Base station simulator: output level stability	See Section 2.5 in *CTIA 01.70* [8]
Cable factor: Measurement Antenna	0.00
Insertion loss: Measurement Antenna cable	0.00
Insertion loss: Measurement Antenna attenuator (if present)	0.00
Sensitivity search step size	See Section 2.20 in *CTIA 01.70* [8]
DUT influence of ambient temperature on the EIS	See Section 2.12 in *CTIA 01.70* [8]
Miscellaneous uncertainty (measurement system repeatability)	See Section 2.22 in *CTIA 01.70* [8]
Chamber lack of spatial uniformity (based on standard deviation of multiple pre-characterized reference measurements and single user DUT measurement)	See Section 2.30 in *CTIA 01.70* [8]
Unknown K factor	For future study for large-form-factor device measurements; See Section 2.8.3 in *CTIA 01.70* [8]for small-form-factor device measurements.
Frequency flatness for TIS measurement	See Section 2.29 in *CTIA 01.70* [8]

The standard uncertainties from Table 3.3.1-1 should be combined by RSS to give the combined standard uncertainty $u_{c\ \text{contribution from the DUT measurement}}$ for this part of the test.

3.3.2 Reference Measurement

The same analysis as described in *CTIA 01.73* Section 3.2.2 (Reference Measurement in the TRP case) applies here. If the configuration changes during the individual reference measurement steps, an estimation of the uncertainty contributions shall be made to replace the 0.00 dB values. The same contributions as stated in Table 3.3.2-1 shall be used to calculate the combined standard uncertainty $u_{c\ contribution\ from\ the\ reference\ measurement}$ for the reference part of the measurement.

Table 3.3.2-1 TIS Standard Uncertainties for the Contributions in the Reference Measurement Part

Description of Uncertainty Contributions	Standard Uncertainty, dB
Mismatch: transmitting part (between vector network analyzer excitation port and Reference Antenna)	See Section 2.1 in *CTIA 01.70* [8]
Mismatch: receiving part (between vector network analyzer receiving port and Measurement Antenna)	See Section 2.1 in *CTIA 01.70* [8]
Vector network analyzer: absolute level	See Section 2.5 in *CTIA 01.70* [8]
Vector network analyzer: level stability	See Section 2.5 in *CTIA 01.70* [8]
Insertion loss: calibrated Reference Antenna cable (if used)	See Section 2.3 in *CTIA 01.70* [8]
Insertion loss: Measurement Antenna cable	0.00
Insertion loss: Calibrated Reference Antenna attenuator (if present)	See Section 2.3 in *CTIA 01.70* [8]
Insertion loss: Measurement Antenna attenuator (if present)	0.00
Chamber lack of spatial uniformity (based on standard deviation of multiple pre-characterized reference measurements and single user reference measurement)	See Section 2.30 in *CTIA 01.70* [8]
Antenna: radiation efficiency of the calibrated Reference antenna	See Section 2.8.2 in *CTIA 01.70* [8]

The standard uncertainties from Table 3.3.2-1 should be combined by RSS to give the combined standard uncertainty $u_{c\ \ contribution\ from\ the\ reference\ measurement\ for\ this\ part\ of\ the\ test}$.

3.3.3 Calculation of the Combined and Expanded Uncertainties for the Overall TIS Measurement

Having calculated the combined standard uncertainties from the two parts of the measurement, they shall be combined as follows to derive the overall combined standard uncertainty:

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

From this, the expanded uncertainty, *U*, is calculated with a coverage factor of 2. This is the resulting value of the TIS expanded uncertainty and shall be stated in the test report.

3.4 Criteria—Measurement Uncertainty

The results of the calculations for expanded uncertainty for both TRP and TIS measurements shall be reported, along with full documentation to support the resulting values. The test performance requirements shall not be adjusted by the measurement uncertainty when determining compliance of the DUTs.

The expanded TRP and TIS uncertainties must not exceed the values in Table 3.3.2-1 at a 95% confidence level. These values shall be the same as those provided in Table 5.6-1 “Expanded Uncertainty Maximum Limits for Different Configurations for TRP and TIS” of CTIA 01.20 [16].

Note that an Additional Allowance of 0.3 dB corresponds to approximately 1 dB of additional uncertainty due to the Fast TIS method.

Table 3.4-1 Expanded Uncertainty Maximum Limits for Different Configurations for TRP and TIS

Expanded Uncertainty (dB)		
Test Configuration	**TRP**	**TIS**
Free Space	2	2.3
Wrist-Worn Left and Wrist-Worn Right	2.2	2.4
Additional MU allowance for Fast TIS	0	0.3

Appendix A Revision History

Date	Version	Description
February 2022	4.0.0	Updates to v.1.2 of Test Plan for Wireless Large-Form-Factor Device Over-the-Air Performance: • Section 1 Overview: Include mention of smaller W-IoT devices, including tests conducted with forearm phantoms. • Section 1.1: Include new Figure 1.1-1(b) and related text to illustrate forearm phantom for small-form-factor device testing. • Section 2.1: Extend discussion and steps to include smaller IoT devices and phantoms. • Section 2.2: Procedure extended to include smaller IoT devices and phantoms. New Figure 2.2-1(b) illustrates forearm phantom for small-form-factor device testing. • Section 2.3: Procedure extended to include smaller IoT devices and phantoms. • Table 3.2.1-1 TRP Standard Uncertainties for the Contributions in the DUT Measurement Part updated to include Unknown K Factor for small-form-factor IoT device testing. • Table 3.3.1-1 TIS Standard Uncertainties for the Contributions in the DUT Measurement Part updated to include Unknown K Factor for small-form-factor IoT device testing. • New Table 3.4-1 with Expanded Uncertainty Maximum Limits for Different Configurations for TRP and TIS.
December 2022	5.0.0	No changes in this release.
March 2023	6.0.0	• Section 3.4: Added a note to include additional uncertainty for the Fast TIS method. • Table 3.4-1: Additional MU allowance for Fast TIS method.
September 2023	6.0.1	• Fixed reference [9]