OTA Testing of IoT Device
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1 Introduction

1.1 Overview

OTA (Over the Air) testing is the key method to evaluate the antenna performance and radiated performance of wireless devices. Poor OTA performance would result in high Block Error Rate (BLER) in communication and potential access failure.

The number of IoT connected devices has experienced exceptional growth in recent years. Some of these IoT devices suffer from very poor radiated antenna performance and cause a bad user experience.

Unlike traditional devices, IoT devices come in various sizes, shapes, materials and work in different environments. This presents lots of challenges for OTA testing of IoT devices. CTIA have set up an IoT working group and have released OTA test methods for LTE-M devices, however the details about working scenarios and benchmarks have not been defined.

Given the fast development of the IoT industry, the importance of OTA measurements and the existing standardization status, the GSMA is developing the specification of OTA Testing of IoT devices, which includes test set-up, test method, test procedures and performance requirements.

To measure the radiation power and receiver performance of IoT devices, this document provides test solutions for measuring the Total Radiation Power (TRP) and Total Radiated Sensitivity (TRS), which can be carried out using two test systems: An Anechoic Chamber (AC) and a Reverberation Chamber (RC).

1.2 Scope

This document defines the OTA Testing of cellular IoT devices, including test set-up, test method, test procedure and performance requirements of Total Radiated Power and Total Radiated Sensitivity for different types of cellular IoT devices.

The cellular IoT devices covered by this document are those using 3GPP communication technology; for example NB-IoT, LTE-M, Cat1/Cat1bis, etc.

1.3 Abbreviations

Term	Description
AC	Anechoic Chamber
BER	Bit Error Rate
BLER	Block Error Rate
DUT	Device Under Test
FS	Free Space
HARQ	Hybrid automatic repeat request
NPDCCH	Narrowband Physical Downlink Shared Channel
PUMAX	The measured configured maximum UE output power
QPSK	Quadrature Phase Shift Keying
RC	Reverberation chamber

Term	Description
RF	Radio Frequency
TRP	Total Radiated Power
TRS	Total Radiated Sensitivity
UE	User Equipment

1.4 References

Ref	Doc Number	Title
[1]	CTIA	Cellular Telecommunications & Internet Association OTA Test Plan
[2]	3GPP	TS 34.114 v12.2.0, TS 37.544 v16.0.0, TS 36.521-1 v16.6.0, TS 36.101 v16.7.0 (or later)
[3]	CTIA	CTIA Test plan for wireless device over the air performance ver 3.8.2 (or later)
[4]	3GPP TS 36.521-1	User Equipment (UE) conformance specification; Radio transmission and reception; Part 1: Conformance Testing V16.1.0 (or later)
[5]	3GPP TS 36.508	Common test environments for User Equipment (UE) conformance testing V16.1.0 (or later)
[6]	CTIA	Test Plan for Wireless Large Form Factor Device Over the Air Performance Version 1.2 (or later)
[7]	RFC 2119	“Key words for use in RFCs to Indicate Requirement Levels”, S. Bradner, March 1997. Available at http://www.ietf.org/rfc/rfc2119.txt
[8]	RFC 8174	Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words

1.5 Conventions

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 (RFC2119) [7] (RFC8174) [8] when, and only when, they appear in all capitals, as shown here.

2 Overview of Access Technology of Cellular IoT

This section compares Cat1/Cat1bis, LTE-M & NB-IoT in terms of various performance requirements against a number of critreia (bandwidth, coverage, bitrate, mobility and voice), as outlined in the following Table.

		NB-IoT	LTE-M		Cat1/Cat1bis
			LTE TDD Cat. M	LTE FDD Cat. M	
Bandwidth		200kHz	1.4MHz	1.4MHz	10MHz/20MHz
Coverage (NOTE 1)		About 164dB	Mode A: about 148 dB Mode B: about 156 dB	Mode A: about 148 dB Mode B: about 156 dB	About 130dB
Bitrate	**Uplink**	R13:62kbit/s(MT) R14:150kbit/s(MT) （NOTE2）	R13:200kbit/s R14:655kbit/s	R13: FD:1Mbit/s HD:375kbit/s R14: FD:2.98Mbit/s HD:1.11Mbit/s	5Mbilt/s
	Downlink	R13:21kbit/s R14:120kbit/s	R13:750kbit/s R14:750kbit/s	R13: FD:800kbit/s HD:300kbit/s R14: FD:1Mbit/s HD:588kbit/s	10Mbit/s
Mobility		Support low speed mobility; Support relocation; Not support handover;	Support high speed mobility; Support relocation; Support handover;	Support high speed mobility; Support relocation; Support handover;	Support high speed mobility; Support relocation; Support handover;
Voice		NOT Support	Support	Support	Support

NOTE 1: Coverage refers to the ideal coverage capacity in the scene without interference. Coverage shrinks when there is significant interference in the system.
NOTE2: For peak bitrate on uplink NB is used for multi-frequency transmission. If single frequency transmission is used, the rate will be reduced.

Table 1: Comparison of NB-IoT, LTE-M and Cat1/Cat1bis

3 Test Set-up

3.1 General

The Device Under Test (DUT) can be evaluated in either an Anechoic Chamber or Reverberation Chamber already specified in both 3GPP and CTIA specifications. Test equipment is described below.

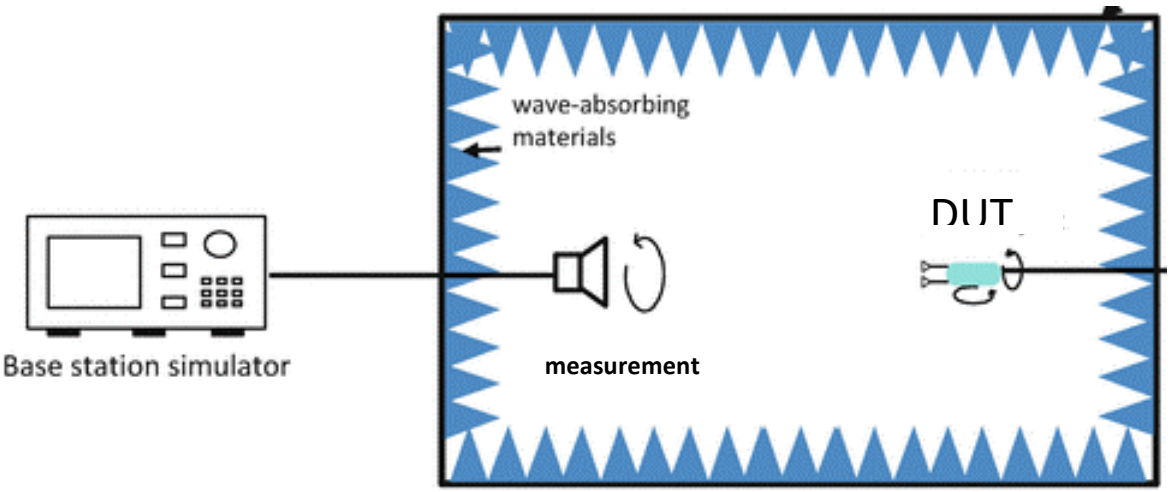

Figure 1: Anechoic chamber

3.1.2 Reverberation Chamber

DUT can be set in a reverberating chamber which allows multipath signal.

Stirrers can be moved continuously or step by step to create a uniform distribution of waves around the DUT.

The number of sample measurements need to be set at least for 200 for TRP (Total Radiated Power) measurement and 300 for TRS (Total Radiated Sensitivity) measurement.

Figure 2: Reverberating chamber

4 Total Radiated Power

4.1 Test Method of Total Radiated Power

The test method defined herein will:

a) clarify general requirements for power measurement;
b) define test methods of TRP in both an anechoic chamber and reverberation chamber.

The radiated Radio Frequency (RF) performance of the DUT is measured by sampling the radiated transmit power of the mobile at various locations surrounding the device. All of the measured power values will be integrated to give a single figure of merit referred to as TRP.

Due to the diversity working scenarios of IoT devices, tests shall be configured according to the DUT's working scenarios, i.e., free space configurations to metering devices, forearm phantom to wrist worn devices.

Coordinating systems and positioning requirements for all configurations are described in Appendix A of CTIA Test plan for wireless device over the air performance [3]. The requirements for the wrist worn devices are also defined in Appendix Q of ref [3].

It is the responsibility of the manufacturer to define which options represent the "baseline" configuration and to provide adequate supporting data that validates assumptions for reduced testing of the remaining options. At a minimum, a complete set of measurements is required for the baseline DUT configuration.

4.1.1 General requirement for Power measurement

The LTE system simulator and the DUT shall be configured as per Section 6.2 of ref [4] 3GPP TS 36.521-1, using the default settings specified in ref [4] 3GPP TS 36.521-1 and [5] 3GPP TS 36.508 as applicable. The power radiated by the DUT shall be measured using a calibrated and accurate RF measuring instrument.

For NB-IoT type devices, since NB-IoT is a separate system different from LTE, a separate parameter set is required in the system configuration, and the test configuration is different.

For LTE-M type devices, the OTA test methodology is fundamentally same as the LTE devices.

In the maximum transmission power test, since the NB-IoT has no closed loop power control and only open loop power control, it is not possible to adjust the DUT to the maximum transmit power through closed loop power control. The DUT can reach the maximum transmit power by setting a higher open-loop target power. At the same time, unless it is demonstrated that there is negligible impact to performance with different options, tests shall be performed on all possible DUT configurations such as battery pack configurations, and different working scenarios. The test can be executed either using and Anechoic Chamber or a Reverberation Chamber

4.1.2 Test method of Total Radiated Power in Anechoic Chamber

CTIA have provided two test methods of scanning the DUT, the "conical" cut method and the "great circle" cut method, which can be found in section 2 of ref [3].

4.1.3 Test method of Total Radiated Power in Reverberation Chamber

CTIA have provided test methods of transmitter performance assessment using the RC, which can be found in the CTIA Test Plan section 2 of ref [6].

4.1.4 Calculation method of Total Radiated Power

The calculation method of TRP for EUT is shown in formulas below, which is described in 3GPP TS 34.114 of ref [2]

$$TRP = \frac{1}{4\pi}\oint\left(EIRP_{\theta}(\Omega; f) + EIRP_{\varphi}(\Omega; f)\right)d\Omega$$ (Formula 4.1.4-1)

Where Ω is the solid angle describing the direction, f is frequency. θ and φ are the orthogonal polarizations. $EIRP_{\theta}$ and $EIRP_{\varphi}$ are the actually transmitted power-levels in corresponding polarizations.

$$TRP \approx \frac{\pi}{2NM}\sum_{n=0}^{N-1}\sum_{m=0}^{M-1}\left[EIRP_{\theta}(\theta_n, \varphi_m; f) + EIRP_{\varphi}(\theta_n, \varphi_m; f)\right]\sin(\theta_n)$$ (Formula 4.1.4-2)

In these formulas N and M are the number of sampling intervals for theta and phi. θ_n and φ_m are the measurement angles.

When using

$$TRP \approx \frac{\sum_{n=1}^{N}\left(\frac{P_n}{C_n(1-R_n)}\right)}{\sum_{n=1}^{N}P_{ref,n}}$$

(Formula 4.1.4-3)

Where $P_{ref,n}$ is the reference power transfer function for fixed measurement antenna n, R_n is the reflection coefficient for fixed measurement antenna n and C_n is the path loss in the cables connecting the measurement receiver to fixed measurement antenna n.

P_n is the average power measured by fixed measurement antenna n and can be calculated using the following expression:

$$P_n = \frac{\sum_{m=1}^{M}\left|S_{21,n,m}\right|^2}{M}$$

(Formula 4.1.4-4)

Where $S_{21,n,m}$ is sample number m of the complex transfer function measured with fixed measurement antenna n and M is the total number of samples measured for each fixed measurement antenna.

4.2 Total Radiated Power for NB-IoT UE

Category NB1 and NB2 are designed to operate in the E-UTRA operating bands 1, 2, 3, 4, 5, 8, 11, 12, 13, 14, 17, 18, 19, 20, 21, 25, 26, 28, 31, 41, 66, 70, 71, 72, 73, 74 and 85. Category NB1 and NB2 systems operate in HD-FDD duplex mode or in TDD mode.

4.2.1 Test Procedures

The test procedure is based in principle on CTIA [1] and 3GPP [2] methodologies.

The Total radiated power is measure with the following steps:

- Set the initial conditions as per Table 6.2.2F.4.1-1 test ID3 in sub clause 6.2.2F UE Maximum Output Power for category NB1 and NB2 of 3GPP TS 36.521-1 and they are specified in the table below:

Configuration ID	Downlink Configuration	Uplink Configuration		
1	N/A	Modulation	N_{tones}	Subcarrier spacing
		QPSK	1@0	15kHz

Table 2: UE Maximum Output Power for category NB1 and NB2

- System simulator sends uplink scheduling information for each UL HARQ process via NPDCCH as per 3GPP TS 36.521-1，6.2.2F to make sure UE transmit PUMAX after Initial Conditions setting.
- When using Anechoic chamber Rotate the device in 3D dimensions using 15° step (when using RC, 200 samples need to be measures at least).
- Measure the $EIRP_{\theta}$ and $EIRP_{\varphi}$ with a sample step of 15° in theta (θ) and phi (ϕ) directions.
- Calculate TRP with formula detailed in section 4.1.4-2 when using anechoic chamber and calculate TRP with formula detailed in section 4.1.4-3 when using reverberation chamber.

4.2.2 Performance requirement

The average TRP of Low, Mid and High channels should be higher than the test performance requirements in Table 3, 4, 5. UE category is shown in Annex A.

Category A NB-IoT TRP:

Stationary IoT devices-(Free Space): Devices will not perform handover or extreme cell edge radio conditions for example: smoke detectors, temperature probes, etc.

	Power Class	Band	UE maximum output power (specified in sub clause 6.2.2F of 3GPP TS.36.101)	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRP (dBm)
NB-IoT	**3**	1, 3	23dBm	Less than or equal to 5cm	14
				Greater than 5cm	18
		5, 8, 20	23dBm	Less than or equal to 5cm	12
				Greater than 5cm	18
	5	1, 3	20dBm	Less than or equal to 5cm	11
				Greater than 5cm	15
		5, 8, 20	20dBm	Less than or equal to 5cm	9
				Greater than 5cm	15
NOTE 1: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.					

Table 3 : Average TRP test requirement for NB-IoT UE Category A

Category B NB-IoT TRP:

Mobile IoT devices-(Body Phantoms): The testing condition should be similar to the usage, e.g. with wrist phantom hand or torso etc. However, given that the phantom torso is not yet standardized, the requirements defined will cover wrist phantom hand only.

	Power Class	Band	UE maximum output power (specified in subclause 6.2.2F of 3GPP TS.36.101)	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRP (dBm)
NB-IoT	**3**	1, 3	23dBm	Less than or equal to 5cm	11
				Greater than 5cm	15
		5, 8, 20	23dBm	Less than or equal to 5cm	9
				Greater than 5cm	15
	5	1, 3	20dBm	Less than or equal to 5cm	8
				Greater than 5cm	12
		5, 8, 20	20dBm	Less than or equal to 5cm	6
				Greater than 5cm	12
NOTE 1: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.					

Table 4: Average TRP test requirement for NB-IoT UE Category B

Category C NB-IoT TRP:

Mobile IoT devices-(Free Space): those devices can be in a handover process in the live network or in extreme radio conditions.

	Power Class	Band	UE maximum output power (specified in subclause 6.2.2F of 3GPP TS.36.101)	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRP (dBm)
NB-IoT	3	1, 3	23dBm	Less than or equal to 5cm	14
				Greater than 5cm	18
		5, 8, 20	23dBm	Less than or equal to 5cm	12
				Greater than 5cm	18
	5	1, 3	20dBm	Less than or equal to 5cm	11
				Greater than 5cm	15
		5, 8, 20	20dBm	Less than or equal to 5cm	9
				Greater than 5cm	15
NOTE 1: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.					

Table 5: Average TRP test requirement for NB-IoT UE Category C

4.3 Total Radiated Power for LTE-M UE

UE category M1 (and M2) is designed to operate in the E-UTRA operating bands 1, 2, 3, 4, 5, 7, 8, 11, 12, 13, 14, 18, 19, 20, 21, 25, 26, 27, 28, 31, 66, 71, 72, 73, 74 and 85 in both half duplex FDD mode and full-duplex FDD mode, and in band 39, 40 and 41 in TDD mode.

4.3.1 Test Procedures

The test procedure is based in principle on CTIA [1] and 3GPP [2] methodologies

The test can be executed using an anechoic chamber or reverberation chamber

The power can be measured using a spectrum analyser, a receiver of test equipment, or power meter.

The total radiated power is measured with the following steps:

- Set the Network simulator as described in the table below.
- Send continuously Up power control commands to the UE.
- When using Anechoic chamber Rotate the device in 3D dimensions using 15° step (when using RC, 200 samples need to be measured at least).
- Measure the $EIRP_{\theta}$ and $EIRP_{\varphi}$ with a sample step of 15° in theta (θ) and phi (ϕ) directions.

- Calculate TRP with formula in section 4.1.4-2 when using anechoic chamber and calculate TRP with formula in section 4.1.4-3 when using a reverberation chamber.

Band	Channel Bandwidth (MHz)	Channel	Power Class 3	Power Class 5	DL RB Allocation
			UL RB allocation	UL RB allocation	
1	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
2	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
3	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
4	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
5	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
7	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
8	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
11	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
12	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
13	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
14	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
17	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
18	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6

Band	Channel Bandwidth (MHz)	Channel	Power Class 3	Power Class 5	DL RB Allocation
			UL RB allocation	UL RB allocation	
19	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
20	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
21	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
25	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
26	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
28	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
31	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
41	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
66	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
70	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
71	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
72	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
73	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
74	10	Low	4	5	6
	10	Mid	4	5	6
	10	High	4	5	6
85	10	Low	4	5	6

Band	Channel Bandwidth (MHz)	Channel	Power Class 3	Power Class 5	DL RB Allocation
			UL RB allocation	UL RB allocation	
	10	Mid	4	5	6
	10	High	4	5	6

Table 6: Network Simulator configuration

4.3.2 Performance requirement

The average TRP of Low, Mid and High channels should be higher than the test performance requirements in Table 7, 8, 9. UE category is shown in Annex A.

Category A LTE-M TRP:

Stationary IoT devices-(Free Space): such device will not perform handover or extreme cell edge radio condition in example: smoke detector, temperature probe, etc.

	Power Class	Band	UE maximum output power (specified in subclause 6.2.2F of 3GPP TS.36.101)	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRP (dBm)
LTE-M	3	1, 3, 7	23dBm	Less than or equal to 5cm	14
				Greater than 5cm	18
		8, 20	23dBm	Less than or equal to 5cm	12
				Greater than 5cm	18
	5	1, 3, 7	20dBm	Less than or equal to 5cm	11
				Greater than 5cm	15
		8, 20	20dBm	Less than or equal to 5cm	9
				Greater than 5cm	15
NOTE 1: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.					

Table 7: Average TRP test requirement for LTE-M UE Category A

Category B LTE-M TRP:

Mobile IoT devices-(Body Phantoms): The testing condition should be similar to the usage, e.g. with a wrist phantom hand or torso, etc. However, given that the phantom torso is not yet standardized, the requirements defined will cover wrist phantom hand only.

	Power Class	Band	UE maximum output power (specified in subclause 6.2.2F of 3GPP TS.36.101)	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRP (dBm)
LTE-M	**3**	1, 3, 7	23dBm	Less than or equal to 5cm	11
				Greater than 5cm	15
		8, 20	23dBm	Less than or equal to 5cm	9
				Greater than 5cm	15
	5	1, 3, 7	20dBm	Less than or equal to 5cm	8
				Greater than 5cm	12
		8, 20	20dBm	Less than or equal to 5cm	6
				Greater than 5cm	12
NOTE 1: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.					

Table 8: Average TRP test requirement for LTE-M UE Category B

Category C LTE-M TRP:

Mobile IoT devices-(Free Space): These devices can be in the handover process in the live network or in extreme radio condition.

	Power Class	Band	UE maximum output power (specified in sub clause 6.2.2F of 3GPP TS.36.101)	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRP (dBm)
LTE-M	**3**	1, 3, 7	23dBm	Less than or equal to 5cm	14
				Greater than 5cm	18
		8, 20	23dBm	Less than or equal to 5cm	12
				Greater than 5cm	18
	5	1, 3, 7	20dBm	Less than or equal to 5cm	11
				Greater than 5cm	15
		8, 20	20dBm	Less than or equal to 5cm	9
				Greater than 5cm	15
NOTE 1: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.					

Table 9: Average TRP test requirement for LTE-M UE Category C

4.4 Total Radiated Power for Cat1/Cat1bis

UE category 1 is designed to operate in all E-UTRA operating bands, including full duplex FDD mode and TDD mode.

UE category 1bis is designed to operate in the E-UTRA operating bands 1, 2, 3, 4, 5, 7, 8, 12, 13, 18, 20, 26, 28, 31, 66 and 72 in full duplex FDD mode and in bands 34, 39, 40 and 41 in TDD mode.

4.4.1 Test Procedures

The test procedure is based in principle on CTIA [1] and 3GPP [2] methodologies

The test can be executed using an anechoic chamber or reverberation chamber

The power can be measured using a spectrum analyser, a receiver of test equipment, or power meter.

The total radiated power is measured with the following steps:

- Set the Network simulator as described in the table below.
- Send continuously Up power control commands to the UE.
- When using Anechoic chamber Rotate the device in 3D dimensions using 15° step (when using RC, 200 samples need to be measured at least).
- Measure the $EIRP_{\theta}$ and $EIRP_{\varphi}$ with a sample step of 15° in theta (θ) and phi (ϕ) directions.
- Calculate TRP with formula in section 4.1.4-2 when using anechoic chamber and calculate TRP with formula in section 4.1.4-3 when using a reverberation chamber.

Test shall be carried out for different frequency pairs (FDD) or frequencies (TDD) and RB allocations across the bands supported by the UE, as defined in the table below.

Band	Channel Bandwidth (MHz)	Channel	Power Class	UL RB allocation	DL RB Allocation
1,2,3,4,7,66	10	Low	3	12	50
	10	Mid	3	12	50
	10	High	3	12	50
5,8,12,13,18, 20,26,28,31, 72	10	Low	3	12	50
	10	Mid	3	12	50
	10	High	3	12	50
34,39,40,41	10	Low	3	12	50
	10	Mid	3	12	50
	10	High	3	12	50

Table 10: Network Simulator configuration for category 1/1bis

4.4.2 Performance requirement

The average TRP of Low, Mid and High channels should be higher than the test performance requirements in Table 11, 12, 13 . UE category is shown in Annex A.

Category A Cat1/1bis TRP:

Stationary IoT devices-(Free Space): such device will not perform handover or extreme cell edge radio condition.

	Power Class	Band	UE maximum output power (specified in subclause 6.2.2 of 3GPP TS.36.101)	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRP (dBm)
Cat1/1bis	**3**	1, 3, 7	23dBm	Less than or equal to 5cm	14
				Greater than 5cm	18
		8, 20	23dBm	Less than or equal to 5cm	12
				Greater than 5cm	18
		34,39,40,41	23dBm	Less than or equal to 5cm	14
				Greater than 5cm	18
NOTE 1: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.					

Table 11: Average TRP test requirement for Cat1/1bis UE Category A

Category B Cat1/1bis TRP:

Mobile IoT devices-(Body Phantoms): The testing condition should be similar to the usage, e.g. with a wrist phantom hand or torso, etc. However, given that the phantom torso is not yet standardized, the requirements defined will cover wrist phantom hand only.

	Power Class	Band	UE maximum output power (specified in subclause 6.2.2 of 3GPP TS.36.101)	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRP (dBm)
Cat1/1bis	**3**	1, 3, 7	23dBm	Less than or equal to 5cm	11
				Greater than 5cm	15
		8, 20	23dBm	Less than or equal to 5cm	9
				Greater than 5cm	15
		34,39,40,41	23dBm	Less than or equal to 5cm	11
				Greater than 5cm	15
NOTE 1: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.					

Table 12: Average TRP test requirement for Cat1/1bis UE Category B

Category C Cat1/1bis TRP:

Mobile IoT devices-(Free Space): These devices can be in the handover process in the live network or in extreme radio condition.

	Power Class	Band	UE maximum output power (specified in subclause 6.2.2 of 3GPP TS.36.101)	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRP (dBm)
Cat1/1bis	**3**	1, 3, 7	23dBm	Less than or equal to 5cm	14
				Greater than 5cm	18
		8, 20	23dBm	Less than or equal to 5cm	12
				Greater than 5cm	18
		34,39,40,41	23dBm	Less than or equal to 5cm	14
				Greater than 5cm	18
NOTE 1: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.					

Table 13: Average TRP test requirement for Cat1/1bis UE Category C

5 Total Radiated Sensitivity

5.1 Test Method of Total Radiated Sensitivity

The test method defined herein will:

a) define general requirement for receiver performance measurement;
b) define test method of TRS in both AC and RC.

Receiver sensitivity measurements shall be performed using data throughput as the measurement metric. The DUT's receiver sensitivity corresponds to the minimum downlink signal power required to provide a data throughput rate greater than or equal to 95% of the maximum throughput of the reference measurement channel.

The receiver performance of the DUT is measured utilizing BLER, or other error criteria. A three-dimensional characterization of the receiver performance of the DUT is pieced together by analyzing the data from the spatially distributed measurements. All of the measured sensitivity values for each DUT test condition will be integrated to give a single figure of merit referred to as Total Radiated Sensitivity.

For the TRS test, tests shall be configured according to DUT’s working scenarios, i.e., free space configurations to metering devices, forearm phantom to wrist worn devices.

Coordinate systems and positioning requirements for all configurations are described in Appendix A of ref [3]. The requirements for the wrist worn devices are defined in Appendix Q of ref [3].

5.1.1 General requirement for receiver performance measurement

The LTE system simulator and DUT shall be configured per 3GPP TS 36.521-1Section 7.3 of ref [4], using the default settings specified in 3GPP TS 36.521-1 ref [4] and 3GPP TS 36.508 [5] as applicable. The power radiated by the DUT shall be measured using a calibrated and accurate RF measuring instrument. If the DUT has multiple receivers, the receiver sensitivity measurements should be performed independently, and all receivers in the DUT other than the receiver under test should be disabled.

For NB-IoT type devices, since NB-IoT is a separate system different from LTE, a separate parameter set is required in the system configuration, and all frequencies and resource block (RB) allocations should be tested.

For LTE-M type devices, the OTA test methodology is the same as LTE devices.

Total Radiated Sensitivity shall be fully measured and calculated pursuant to ref [3] [6] for the channel(s) specified in Section 4.2 and 4.3 for all frequency bands supported by the DUT.

Since the process of measuring effective radiated receiver sensitivity is typically less accurate than measuring transmitter radiated power, this test specification allows for a relaxation in the spatial separation to 30 degrees in the theta (ɵ) and in the phi (ϕ) axis for TRS. The test can be executed either using AC or RC.

5.1.2 Test method of Total Radiated Sensitivity in Anechoic Chamber

Receiver Sensitivity procedures will utilize the same spherical measurement procedure as specified for the Transmitter power measurements in this document Section 4.1.2 with the exception of angular step size. Receiver Performance measurements may be made simultaneously with tests performed in this document Section 4.1.2.

CTIA have provided two test methods of scanning the DUT are proposed, the “conical” cut method and the “great circle” cut method, which can be found in sections 2 of ref [3].

5.1.3 Test method of Total Radiated Sensitivity in Reverberation Chamber

CTIA have provided test methods of receiver performance assessment using the RC, which can be found in sections 2 of ref [6].

5.1.4 Calculation method of Total Radiated Sensitivity

The calculation method of TRS for EUT is shown in formulas below, which is described in 3GPP TS 34.114 of ref [2]:

The TRS is a measure of the minimum power required to achieve a specified Block error rate (BLER). The TRS is defined as:

$$TRS = \frac{4\pi}{\oint\left[\frac{1}{EIS_{\theta}(\Omega; f)} + \frac{1}{EIS_{\varphi}(\Omega; f)}\right]d\Omega}$$

(Formula 5.1.4-1)

Where the effective isotropic sensitivity (*EIS*) is defined as the power available at the antenna output such as the sensitivity threshold is achieved for each polarization. Ω is the

solid angle describing the direction, f is frequency. θ and φ are the orthogonal polarizations.

$$TRS \approx \frac{2NM}{\pi \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} \left[\frac{1}{EIS_{\theta}(\theta_n, \varphi_m; f)} + \frac{1}{EIS_{\varphi}(\theta_n, \varphi_m; f)} \right] \sin(\theta_n)}$$

(Formula 5.1.4-2)

In these formulas N and M are the number of sampling intervals for theta and phi. θ_n and φ_m are the measurement angles.

The TRS can also be calculated from measurements in a Rayleigh fading 3 dimensional isotropic environment with in average uniform elevation and azimuth distribution. The calculation of the TRS is in this case based on searching for the lowest power received by the UE/MS for a discrete number of field combinations in the chamber that gives a BLER that is better than 5% (BLER <5%). By calibrating the average power transfer function, an absolute value of the TRS can be obtained. The following expression can be used to find the TRS.

$$TRS \approx 2N \frac{\left(\sum_{n=1}^{N} \left(C_n (1 - R_n) P_{thres,n} \right) \right)^{-1}}{\sum_{n=1}^{N} P_{ref,n}}$$

(Formula 5.1.4-3)

where $P_{ref,n}$ is the reference power transfer function for fixed measurement antenna n, R_n is the reflection coefficient for fixed measurement antenna n and C_n is the path loss in the cables connecting the measurement receiver to fixed measurement antenna n. These parameters are calculated from the calibration measurement. $P_{thres,n}$ is calculated by using the following equation:

$$P_{thres,n} = \frac{\sum_{m=1}^{M} \frac{1}{\left| S_{21,n,m}^{thres} \right|^2}}{M}$$

(Formula 5.1.4-4)

where $S_{21,n,m}^{thres}$ is the m:th value of the transfer function for fixed measurement antenna n, which gives 5% BLER threshold. M is the total number of values of the BLER threshold power measured for each fixed measurement antenna.

5.2 Total Radiated Sensitivity for NB-IoT UE

5.2.1 Test Procedures

The test procedure is based in principle on CTIA [1] and 3GPP [2] methodologies.

The power can be measure using, receiver of test equipment.

The Total Isotropic is measure with the following steps:

- Set the initial conditions as per Table 7.3F.1.4.1-1 in sub-clause 7.3F.1 of 3GPP TS 36.521-1 and they are specified in the table below:

Configuration ID	Downlink Configuration		Uplink Configuration		
1	Modulation	Subcarriers	Modulation	N_{tones}	Subcarrier spacing
	QPSK	12	BPSK	1@0	15kHz

Table 14: Initial Conditions

- Measure the receiver sensitivity by adjusting the downlink signal level to 95 % throughput of the maximum throughput of the reference channel (maximum throughput is per Annex A of 3GPP TS 36.521-1).
- When using Anechoic chamber repeat Step 1) with 3-D sampling grid specified in Sub clause 4.4 of 3GPP TS 37.544. The minimum RF power level resulting in a data throughput greater than or equal to 95 % throughput of the maximum throughput for each test shall be recorded for integration pursuant to Sub clause 7.1.10.1 of 3GPP TS 37.544 to calculate TRS.
- When using Reverberation chamber Repeat Step 1) for a long enough time to get the statistic result. The minimum RF power level resulting in a data throughput greater than or equal to 95 % throughput of the maximum throughput.
- Repeat the measurement of the DUT on low, mid and high channels.
- Calculate the linear average and minimum TRS.

5.2.2 Performance requirement

The average TRS of Low, Mid and High channels should be lower than the test performance requirements in Table 15, 16, 17. UE category is shown in Annex A.

Category A NB-IoT TRS:

Stationary IoT devices-(Free Space): Devices will not perform handover or extreme cell edge radio conditions for example: smoke detectors, temperature probes, etc.

	Power Class	Band	Reference sensitivity (specified in subclause 7.3.1F.1 of 3GPP TS.36.101)	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRS (dBm)
NB-IoT	3	1, 3	-108.2dBm	Less than or equal to 5cm	-99
				Greater than 5cm	-103
		5, 8, 20	-108.2dBm	Less than or equal to 5cm	-97
				Greater than 5cm	-103
	5	1, 3	-108.2dBm	Less than or equal to 5cm	-99
				Greater than 5cm	-103
		5, 8, 20	-108.2dBm	Less than or equal to 5cm	-97
				Greater than 5cm	-103
NOTE 1: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.					

Table 15: Average TRS test requirement for NB-IoT UE Category A

Category B NB-IoT TRS:

Mobile IoT devices-(Body Phantoms): The testing condition should be similar to the usage, e.g. with wrist phantom hand or torso, etc. However, given that the phantom torso is not yet standardized, the requirements defined will cover wrist phantom hand only.

	Power Class	Band	Reference sensitivity (specified in subclause 7.3.1F.1 of 3GPP TS.36.101)	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRS (dBm)
NB-IoT	3	1, 3	-108.2dBm	Less than or equal to 5cm	-96
				Greater than 5cm	-100
		5, 8, 20	-108.2dBm	Less than or equal to 5cm	-94
				Greater than 5cm	-100
	5	1, 3	-108.2dBm	Less than or equal to 5cm	-96
				Greater than 5cm	-100
		5, 8, 20	-108.2dBm	Less than or equal to 5cm	-94
				Greater than 5cm	-100
NOTE 1: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.					

Table 16 : Average TRS test requirement for NB-IoT UE Category B

Category C NB-IoT TRS:

Mobile IoT devices-(Free Space): those devices can be in handover process in the live network or in extreme radio condition.

	Power Class	Band	Reference sensitivity (specified in subclause 7.3.1F.1 of 3GPP TS.36.101)	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRS (dBm)
NB-IoT	**3**	1, 3	-108.2dBm	Less than or equal to 5cm	-99
				Greater than 5cm	-103
		5, 8, 20	-108.2dBm	Less than or equal to 5cm	-97
				Greater than 5cm	-103
	5	1, 3	-108.2dBm	Less than or equal to 5cm	-99
				Greater than 5cm	-103
		5, 8, 20	-108.2dBm	Less than or equal to 5cm	-97
				Greater than 5cm	-103
NOTE 1: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.					

Table 17: Average TRS test requirement for NB-IoT UE Category C

5.3 Total Radiated Sensitivity for LTE-M UE

5.3.1 Test Procedures

The test procedure is based in principle on CTIA [1] and 3GPP [2] methodologies with specific configuration which will be indicated in this document whenever needed.

Band	Channel Bandwidth (MHz)	Channel	Power Class 3	Power Class 5	UL RB Allocation
			DL RB allocation	DL RB allocation	
1	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
2	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
3	10	Low	4	4	6

Band	Channel Bandwidth (MHz)	Channel	Power Class 3	Power Class 5	UL RB Allocation
			DL RB allocation	DL RB allocation	
	10	Mid	4	4	6
	10	High	4	4	6
4	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
5	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
7	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
8	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
11	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
12	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
13	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
14	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
17	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
18	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
19	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6

Band	Channel Bandwidth (MHz)	Channel	Power Class 3	Power Class 5	UL RB Allocation
			DL RB allocation	DL RB allocation	
20	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
21	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
25	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
26	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
28	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
31	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
41	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
66	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
70	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
71	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
72	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
73	10	Low	4	4	6
	10	Mid	4	4	6

Band	Channel Bandwidth (MHz)	Channel	Power Class 3	Power Class 5	UL RB Allocation
			DL RB allocation	DL RB allocation	
	10	High	4	4	6
74	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6
85	10	Low	4	4	6
	10	Mid	4	4	6
	10	High	4	4	6

Table 18: Table 5.3.1-1: Network Simulator configuration

5.3.2 Performance requirement

The average TRS of Low, Mid and High channels should be lower than the test performance requirements in Table 19, 20, 21. UE category is shown in Annex A.

Category A LTE-M TRS:

Stationary IoT devices-(Free Space): such device will not perform handover or extreme cell edge radio condition in example: smoke detector, temperature probe, etc.

	Power Class	Band	Reference sensitivity (NOTE 1)	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRS (dBm)
LTE-M	**3**	1, 3, 7	-101dBm	Less than or equal to 5cm	-92
				Greater than 5cm	-96
		8, 20	-101dBm	Less than or equal to 5cm	-90
				Greater than 5cm	-96
	5	1, 3, 7	-101dBm	Less than or equal to 5cm	-92
				Greater than 5cm	-96
		8, 20	-101dBm	Less than or equal to 5cm	-90
				Greater than 5cm	-96
NOTE 1: Reference sensitivity for the test bands are set to -101dBm in GSMA referring to sub clause 7.3.1E of 3GPP TS.36.101. NOTE 2: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.					

Table 19: Average TRS test requirement for LTE-M UE Category A

Category B LTE-M TRS:

Mobile IoT devices-(Body Phantoms): the testing condition should be similar to the usage, e.g. with wrist phantom hand or torso, etc. However, given that the phantom torso is not yet standardized, the requirements defined will cover wrist phantom hand only.

	Power Class	Band	Reference sensitivity	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRS (dBm)
LTE-M	3	1, 3, 7	-101dBm	Less than or equal to 5cm	-89
				Greater than 5cm	-93
		8, 20	-101dBm	Less than or equal to 5cm	-87
				Greater than 5cm	-93
	5	1, 3, 7	-101dBm	Less than or equal to 5cm	-89
				Greater than 5cm	-93
		8, 20	-101dBm	Less than or equal to 5cm	-87
				Greater than 5cm	-93
NOTE 1: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.					

Table 20 : Table 5.3.2-2: Average TRS test requirement for LTE-M UE Category B

Category C LTE-M TRS:

Mobile IoT devices-(Free Space): those devices can be in handover process in the live network or in extreme radio condition.

	Power Class	Band	Reference sensitivity	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRS (dBm)
LTE-M	3	1, 3, 7	-101dBm	Less than or equal to 5cm	-92
				Greater than 5cm	-96
		8, 20	-101dBm	Less than or equal to 5cm	-90
				Greater than 5cm	-96
	5	1, 3, 7	-101dBm	Less than or equal to 5cm	-92
				Greater than 5cm	-96
		8, 20	-101dBm	Less than or equal to 5cm	-90
				Greater than 5cm	-96
NOTE 1: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.					

Table 21: Average TRS test requirement for LTE-M UE Category C

5.4 Total Radiated Sensitivity for Cat1/Cat1bis

5.4.1 Test Procedures

The test procedure is based in principle on CTIA [1] and 3GPP [2] methodologies with specific configuration which will be indicated in this document whenever needed.

Band	Channel Bandwidth (MHz)	Channel	Power Class	UL RB allocation	DL RB Allocation
1,2,3,4,7,66	10	Low	3	12	50
	10	Mid	3	12	50
	10	High	3	12	50
5,8,12,13,18, 20,26,28,31, 72	10	Low	3	12	50
	10	Mid	3	12	50
	10	High	3	12	50
34,39,40,41	10	Low	3	12	50
	10	Mid	3	12	50
	10	High	3	12	50

Table 22: Network Simulator configuration

5.4.2 Performance requirement

The average TRS of Low, Mid and High channels should be lower than the test performance requirements in Table 23, 24, 25. UE category is shown in Annex A.

Category A Cat1/1bis TRS:

Stationary IoT devices-(Free Space): such device will not perform handover or extreme cell edge radio condition.

	Power Class	Band	Reference sensitivity (NOTE 1)	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRS for Cat1bis (dBm)	Reference Average TRS for Cat1 (dBm) (NOTE 2)
Cat1/1 bis	**3**	1, 3, 7	-94dBm	Less than or equal to 5cm	-85	-88
				Greater than 5cm	-89	-92
		8, 20	-94dBm	Less than or equal to 5cm	-83	-86
				Greater than 5cm	-89	-92
		34,39,40,41	-94dBm	Less than or equal to 5cm	-85	-88
				Greater than 5cm	-89	-92
NOTE 1: Reference sensitivity for the test bands are set to -94dBm in GSMA referring to sub clause 7.3.1E of 3GPP TS.36.101. NOTE 2: Cat1 assumes 2 antennas. If only 1 antenna is used, the TRS value cannot be be more than 3dB worse. NOTE 3: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.						

Table 23: Average TRS test requirement for Cat1/1bis UE Category A

Category B Cat1/1bis TRS:

Mobile IoT devices-(Body Phantoms): the testing condition should be similar to the usage, e.g. with wrist phantom hand or torso, etc. However, given that the phantom torso is not yet standardized, the requirements defined will cover wrist phantom hand only.

	Power Class	Band	Reference sensitivity	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRS for Cat1bis (dBm)	Reference Average TRS for Cat1 (dBm) (NOTE 1)
Cat1/1 bis	**3**	1, 3, 7	-94dBm	Less than or equal to 5cm	-82	-85
				Greater than 5cm	-86	-89
		8, 20	-94dBm	Less than or equal to 5cm	-80	-83
				Greater than 5cm	-86	-89
		34,39,40,41	-94dBm	Less than or equal to 5cm	-82	-85
				Greater than 5cm	-86	-89
NOTE 1: Cat1 assumes 2 antennas. If only 1 antenna is used, the TRS value cannot be more than 3dB worse NOTE 2: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.						

Table 24: Average TRS test requirement for Cat1/1bis UE Category B

Category C Cat1/1bis TRS:

Mobile IoT devices-(Free Space): those devices can be in handover process in the live network or in extreme radio condition.

	Power Class	Band	Reference sensitivity	Final DUT Size (The largest dimension in any direction should be within these limits)	Reference Average TRS for Cat1bis (dBm)	Reference Average TRS for Cat1 (dBm) (NOTE 1)
Cat1/1 bis	**3**	1, 3, 7	-94dBm	Less than or equal to 5cm	-85	-88
				Greater than 5cm	-89	-92
		8, 20	-94dBm	Less than or equal to 5cm	-83	-86
				Greater than 5cm	-89	-92
		34,39,40,41	-94dBm	Less than or equal to 5cm	-85	-88
				Greater than 5cm	-89	-92
NOTE 1: Cat1 assumes 2 antennas. If only 1 antenna is used, the TRS value cannot be more than 3dB worse NOTE 2: No measured channel shall be more than 2dB worse than the performance limits defined for that frequency band.						

Table 25: Average TRS test requirement for Cat1/1bis UE Category C

Annex A Classification of DUT Catagory

This specification requires the classification of the DUT in accordance with the table below. New categories could be added to this table in future versions.

UE Catagory	Description
UE Catagory A	Stationary IoT devices-(Free Space)
UE Catagory B	Mobile IoT devices-(Body Phantoms)
UE Catagory C	Mobile IoT devices-(Free Space)

Table 26: Classification of DUT

Annex B Document Management

B.1 Document History

Version	Date	Brief Description of Change	Approval Authority	Editor / Company
1.0	March 2020	New PRD TS.51	TSG#38 TG#20	Anni Wei / China Mobile
2.0	Feb 2021	Implementing changes in TS.51 CR1002	TSG#42 ISAG#6	Ya Liu / China Mobile Lei Wang / China Telecom Momar Goumballe / Orange Abbas Alpaslan / Vodafone

B.2 Other Information

Type	Description
Document Owner	Terminal Steering Group
Editor / Company	Ya Liu / China Mobile

It is our intention to provide a quality product for your use. If you find any errors or omissions, please contact us with your comments. You may notify us at prd@gsma.com

Your comments or suggestions & questions are always welcome.