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Foreword

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1 Scope

The present document establishes the minimum RF characteristics for Ambient IoT device.

2 References

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

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
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[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] Void

[3] 3GPP TS 38.291: "NR; Ambient IoT Physical layer".

[4] ITU-R Recommendation SM.329, "Unwanted emissions in the spurious domain".

[5] 3GPP TS 38.870: “Enhanced Over-the-Air (OTA) test methods for NR FR1 Total Radiated Power (TRP) and Total Radiated Sensitivity (TRS)”.

[6] 3GPP TS 38.391: "NR; Ambient IoT Medium Access Control (MAC) protocol".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in 3GPP TR 21.905 [1].

3.2 Symbols

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

$BW_{Channel}$ *channel bandwidth*
BW_{Config} *Transmission bandwidth*, where $BW_{Config} = N_{RB}$ x SCS x 12
$BW_{GB,low}$ The minimum guard band defined in clause 5.3.1 for lowest assigned component carrier
$BW_{GB,high}$ The minimum guard band defined in clause 5.3.1 for highest assigned component carrier
Δf Separation between the *channel edge* frequency and the nominal -3 dB point of the measuring filter closest to the carrier frequency
ΔF_{Global} Global frequency raster granularity
Δf_{max} f_offset_{max} minus half of the bandwidth of the measuring filter
Δf_{OOB} Δ Frequency of Out Of Band emissionΔF_{Raster} Channel raster granularity
F_C *RF reference frequency* on the channel raster, given in table 5.4.1.2-1

$F_{DL,low}$	The lowest frequency of the downlink *operating band*
$F_{DL,high}$	The highest frequency of the downlink *operating band*
f_offset	Separation between the *channel edge* frequency and the centre of the measuring
f_offset_{max}	The offset to the frequency Δf_{OBUE} outside the downlink *operating band*
F_{OOB}	The boundary between the A-IoT out of band emission and spurious emission domains
F_{REF}	RF reference frequency
$F_{REF-Offs}$	Offset used for calculating F_{REF}
$F_{UL,low}$	The lowest frequency of the uplink *operating band*
$F_{UL,high}$	The highest frequency of the uplink *operating band*
$GB_{Channel}$	Minimum guard band defined in clause 5.3.1
n_{PRB}	Physical resource block number
N_{RB}	*Transmission bandwidth configuration*, expressed in resource blocks
N_{REF}	A-IoT Absolute Radio Frequency Channel Number (AIoT-ARFCN)
$N_{REF-Offs}$	Offset used for calculating N_{REF}
$P_{REFSENS}$	Conducted Reference Sensitivity power level

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in 3GPP TR 21.905 [1].

1SB	Single sideband
2SB	Double sideband
ACLR	Adjacent Channel Leakage Ratio
ACS	Adjacent Channel Selectivity
AWGN	Additive White Gaussian Noise
A-IoT	Ambient IoT
A-IoT RAN	Ambient IoT Radio Access Network
BPSK	Binary phase-shift keying
BS	Base Station
BW	Bandwidth
CFO	Carrier-frequency offset
CP	Cyclic prefix
CW	Carrier-wave
CW2D	Carrier-wave, or carrier-wave node, to device
D2R	Device to reader
ED	Envelope detector
E-UTRA	Evolved UTRA
FAR	False alarm rate
FEC	Forward error-correction code
FR	Frequency Range
FRC	Fixed Reference Channel
IF	Intermediate frequency
IoT	Internet of Things
LPWA	Low-power, wide-area
MCS	Modulation and coding scheme
MDR	Missed detection rate
OOK	On-off keying
PDRCH	Physical device-to-reader channel
PRDCH	Physical reader-to-device channel
R2D	Reader to device
RE	Resource Element
REFSENS	Reference Sensitivity
RF	Radio frequency
RFID	Radio frequency identification
R-TAS	R2D timing acquisition signal
SCS	Sub-Carrier Spacing
SER	Sample error rate
SFO	Sampling-frequency offset

UEM Unwanted Emissions Mask
ZIF Zero IF

4 General

4.1 Relationship between minimum requirements and test requirements

The present document is a Single-RAT specification for NR Ambient IoT device, covering RF characteristics and minimum performance requirements. Conformance to the present specification is demonstrated by fulfilling the test requirements specified in the conformance specification TS 5xx [2].

The Minimum Requirements given in this specification make no allowance for measurement uncertainty. The test specification TS 38.5xx [2] defines test tolerances. These test tolerances are individually calculated for each test. The test tolerances are used to relax the minimum requirements in this specification to create test requirements. For some requirements, including regulatory requirements, the test tolerance is set to zero.

The measurement results returned by the test system are compared - without any modification - against the test requirements as defined in TS 38.5xx [2].

4.2 Applicability of minimum requirements

a) In this specification the Minimum Requirements are specified as general requirements and additional requirements. Where the Requirement is specified as a general requirement, the requirement is mandated to be met in all scenarios

b) For specific scenarios for which an additional requirement is specified, in addition to meeting the general requirement, the Ambient IoT device is mandated to meet the additional requirements.

c) The spurious emissions power requirements are for the long-term average of the power. For the purpose of reducing measurement uncertainty, it is acceptable to average the measured power over a period of time sufficient to reduce the uncertainty due to the statistical nature of the signal

5 Operating bands and channel arrangement

5.1 General

The channel arrangements presented in this clause are based on the operating bands and channel bandwidths defined in the present release of specifications.

NOTE: Other operating bands and channel bandwidths may be considered in future Releases.

5.2 Operating bands

Ambient IoT is designed to operate in the NR operating bands defined in Table 5.2-1.

Table 5.2-1: Ambient IoT operating bands

NR operating band	Uplink (UL) *operating band* BS receive / UE transmit F_{UL_low} – F_{UL_high} (MHz)	Downlink (DL) *operating band* BS transmit / UE receive F_{DL_low} – F_{DL_high} (MHz)	Duplex Mode
n5	824 – 849	869 – 894	FDD
n8	880 – 915	925 – 960	FDD
n28	703 – 748	758 – 803	FDD

5.3 *Channel bandwidth*

5.3.1 R2D Channel bandwidth

5.3.1.1 General

The *R2D channel bandwidth* supports a single reader RF carrier in R2D link at the reader.

The relationship between the R2D channel bandwidth, the guardband and the *transmission bandwidth* is shown in figure 5.3.1.1-1.

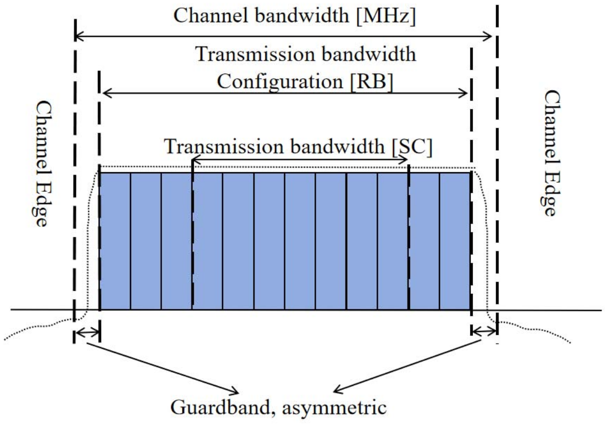


Figure 5.3.1.1-1: Definition of channel bandwidth and *transmission bandwidth configuration* for one reader channel

5.3.1.2 R2D Transmission bandwidth

The *transmission bandwidth* N_{RB} for each *R2D channel bandwidth* and subcarrier spacing is specified in table 5.3.1.2.-1.

Table 5.3.1.2-1: R2D Transmission bandwidth configuration N_{RB} for FR1

SCS (kHz)	200 kHz	400 kHz	600 kHz	800 kHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}
15	1	2	3	4

NOTE: Device Rx requirements are defined based on *transmission bandwidth configuration* specified in table 5.3.1.2-1.

5.3.1.3 Minimum guardband and R2D transmission bandwidth configuration

The minimum guardband for each *R2D channel bandwidth* and SCS is specified in table 5.3.1.3-1.

Table 5.3.1.3-1: Minimum guardband (kHz) (FR1)

R2D CBW	200kHz	400kHz	600kHz	800kHz
Minimum guardband(kHz)	2.5	12.5	22.5	32.5

The number of RBs configured in any *R2D channel bandwidth* shall ensure that the minimum guardband specified in this clause is met.

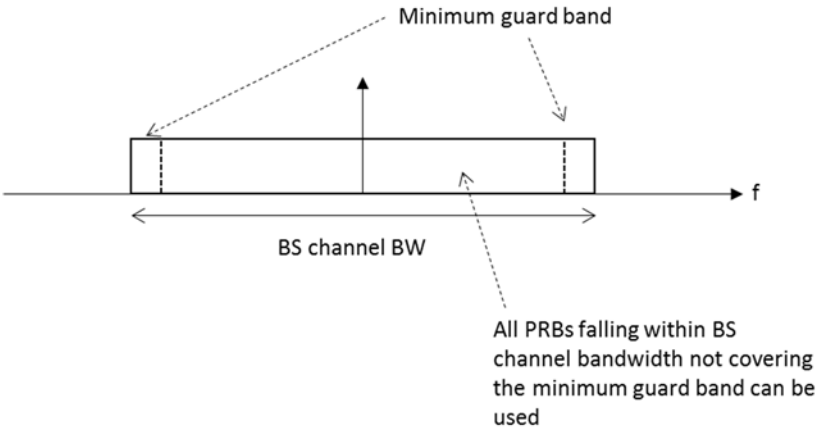


Figure 5.3.1.3-1: reader PRB utilization

5.3.1.4 RB alignment

For each *R2D channel bandwidth, BS transmission bandwidth configuration* must fulfil the minimum guardband requirement specified in clause 5.3.1.3.

5.3.1.5 R2D channel bandwidth per operating band

The requirements in this specification apply to the combination of *R2D channel bandwidths*, SCS and *operating bands* shown in table 5.3.1.5-1 for FR1. The *transmission bandwidth configuration* in table 5.3.1.2-1 shall be supported for each of the *R2D channel bandwidths* within the BS capability. The *R2D channel bandwidths* are specified for the Tx path.

Table 5.3.1.5-1: R2D *channel bandwidths* and SCS per *operating band*

NR Bands	SCS (kHz)	*Reader channel bandwidth* (kHz)			
		200	400	600	800
n5, n8, n28	15	200	400	600	800

5.3.2 D2R Channel bandwidth

5.3.2.1 General

The D2R channel bandwidth supports a single AIoT RF carrier in the D2R link at the device. From a BS perspective, different device channel bandwidths may be supported within the same spectrum for backscattering from devices connected to the BS.

From a device perspective, the device is allocated with its own device channel bandwidth. The device does not need to be aware of the BS channel bandwidth.

5.3.2.2 D2R Transmission bandwidth

The *transmission bandwidth* for each *D2R channel bandwidth* is specified in table 5.3.2.3-1.

5.3.2.3 D2R channel bandwidth per operating band

The requirements specified in table 5.3.2.3-1 for device apply to all the operating bands in Table 5.2-1.

Table 5.3.2.3-1: Device D2R channel bandwidth

Device D2R channel bandwidth (kHz)									
Nominal D2R transmission Bandwidth without SFO (kHz)	Nominal Small frequency shift without SFO (kHz)								
	3.75	7.5	15	30	60	120	240	480	720
15	17	25	42	75	141	273	534	1065	
30		33	50	83	149	281	545	1073	
60			66	99	165	297	561	1089	
120				132	198	330	594	1122	
240					264	396	660	1188	
480						528	792	1320	
960							1056	1584	
2880									3168

Table 5.3.2.3-2: Void

5.4 Channel arrangement

5.4.1 R2D Channel raster

5.4.1.1 AIoT-ARFCN and channel raster

The global frequency raster defines a set of *RF reference frequencies* F_{REF}. The *RF reference frequency* is used in signalling to identify the position of RF channels and other elements. The granularity of the global frequency raster is ΔF_{Global}.

RF reference frequencies are designated by an A-IoT Absolute Radio Frequency Channel Number (AIoT-ARFCN) in the range [0…3279165] on the global frequency raster. The relation between the AIoT-ARFCN and the *RF reference frequency* F_{REF} in MHz is given by the following equation, where $F_{REF-Offs}$ and $N_{Ref-Offs}$ are given in table 5.4.1.1-1 and N_{REF} is the AIoT-ARFCN.

$$F_{REF} = F_{REF-Offs} + \Delta F_{Global} (N_{REF} - N_{REF-Offs})$$

Table 5.4.1.1-1: AIoT-ARFCN parameters for the global frequency raster

Range of frequencies (MHz)	ΔF_{Global} (kHz)	$F_{REF-Offs}$ (MHz)	$N_{REF-Offs}$	Range of N_{REF}
0 – 3000	5	0	0	0 – 599999

The *channel raster* defines a subset of *RF reference frequencies* that can be used to identify the RF channel position in the uplink and downlink. The *RF reference frequency* for an RF channel maps to a resource element on the carrier. For each *operating band*, a subset of frequencies from the global frequency raster are applicable for that band and forms a channel raster with a granularity ΔF_{Raster}, which may be equal to or larger than ΔF_{Global}.

The mapping between the *channel raster* and corresponding resource element is given in clause 5.4.1.2. The applicable entries for each *operating band* are defined in clause 5.4.1.3.

5.4.1.2 Channel raster to resource element mapping

The mapping between the *RF reference frequency* on the channel raster and the corresponding resource element is given in table 5.4.1.2-1 and can be used to identify the RF channel position. The mapping depends on the total number of RBs that are allocated in the channel and applies to both UL and DL. The mapping must apply to at least one numerology supported by the BS.

Table 5.4.1.2-1: Channel Raster to Resource Element Mapping

	$N_{RB}\ mod\ 2 = 0$	$N_{RB}\ mod\ 2 = 1$
Resource element index k	0	6
Physical resource block number n_{PRB}	$n_{PRB} = \left\lfloor \frac{N_{RB}}{2} \right\rfloor$	$n_{PRB} = \left\lfloor \frac{N_{RB}}{2} \right\rfloor$

k, n_{PRB} and N_{RB} are as defined in TS 38.211 [3].

5.4.1.3 Channel raster entries for each *operating band*

The RF channel positions on the channel raster in each NR *operating band* are given through the applicable NR-ARFCN in table 5.4.1.3-1, using the channel raster to resource element mapping in clause 5.4.1.2.

Channel raster is defined with $\Delta F_{Raster} = 2 \times \Delta F_{Global}$. In this case every 2th NR-ARFCN within the operating band are applicable for the channel raster within the operating band and the step size for the channel raster in Table 5.4.1.3-1 is given as <2>.

Table 5.4.1.3-1: Applicable NR-ARFCN per operating band for enhanced channel raster

NR operating band	ΔF_{Raster} (kHz)	Uplink Range of N_{REF} (First – <Step size> – Last)	Downlink Range of N_{REF} (First – <Step size> – Last)
n5	10	164800 – <2> – 169800	173800 – <2> – 178800
n8	10	176000 – <2> – 183000	185000 – <2> – 192000
n28	10	140600 – <2> – 149600	151600 – <2> – 160600
NOTE 1: The channel numbers that designate carrier frequencies so close to the operating band edges that the carrier extends beyond the operating band edge shall not be used. These channel numbers shall also be such that the minimum guard band for each channel bandwidth and SCS specified in Table 5.3.3-1 are met for carriers located at the upper or lower edge of an operating band.			

6 Transmitter characteristics

6.0 General

Unless otherwise stated, the transmitter characteristics are specified over the air (OTA).

6.1 Backscatter power

6.1.1 Device backscatter power

The backscatter power is defined as mean filtered power measured over the duration of the D2R signal, excluding the power at the carrier frequency. The backscatter loss is defined as the difference between the input CW power at the device antenna in dB scale to the backscatter power at the device antenna in dB scale.

The backscatter power is measured with the test metric of EIRP as specified in clause 8.2.1. The minimum requirement on backscatter loss in Table 6.1.1.1-1 shall apply to all device D2R channel bandwidth defined in Table 5.3.2.3-1 and shall be met with the test parameters defined in Annex A, at the peak antenna gain direction declared by the device vendor.

Table 6.1.1.1-1: Maximum allowable backscatter loss

Operating bands	Maximum backscatter loss (dB)		CW power at the device antenna (dBm)
n5, n8, 28	OOK	10	-27
	BPSK	6	
	OOK	15	-10
	BPSK	11	

6.2 Output RF spectrum emissions

6.2.1 Out of band emissions

6.2.1.1 General

The Out of band emissions are unwanted emissions immediately outside the assigned channel bandwidth resulting from the modulation process and non-linearity in the transmitter but excluding spurious emissions.

6.2.1.2 Spectrum emission mask

The spectrum emission mask of the device applies to frequencies (Δf_{OOB}) starting from the centre of the assigned D2R channel bandwidth. For frequencies offset greater than Δf_{OOB} as specified in Table 6.2.1.2-1 the spurious requirements in clause 6.2.2 are applicable.

The emission within Δf_{OOB} of a device shall be lower than the level specified in Table 6.2.1.2-1 compared to the D2R backscatter power under same incident CW power level. The spectrum emission limits in Table 6.2.1.2-1 apply for all D2R channel bandwidths. The requirement is verified with the test metric of EIRP and the incident CW power level at the device set to -5 dBm. The test direction is the same as the backscatter output power as specified in clause 6.1.

Table 6.2.1.2-1 Spectrum emission mask for device

Δf_{OOB} (MHz)	Spectrum emission limit (dBc)	Measurement bandwidth
± 0.5*D2R CBW - F_{OOB}	10	0.5* Nominal D2R transmission Bandwidth without SFO
NOTE 1: F_{OOB} is the OOB boundary frequency specified in Table 6.2.1.2-1.		

6.2.2 Spurious emissions

Spurious emissions are emissions which are caused by unwanted transmitter effects but exclude out of band emissions unless otherwise stated. The spurious emission limits are specified in terms of general requirements in line with SM.329 [4].

Unless otherwise stated, the spurious emission limits apply for the frequency ranges that are more than F_{OOB} (MHz) in Table 6.2.2.2-1 from the centre of the D2R channel bandwidth. The spurious emission limits in Table 6.2.2.2-2 apply for all D2R channel bandwidths. The requirement is verified with the test metric of EIRP under the incident CW power level at the device is set to -5 dBm. The test direction is the same as the transmitter output power as specified in clause 6.1.

Table 6.2.2.2-1: Boundary between out of band and spurious emission domain for device

D2R Channel bandwidth	OOB boundary F_{OOB} (MHz)
D2R CBW<1.4 MHz	max (500kHz, 10*D2R CBW)
D2R CBW≥1.4 MHz	7.5 MHz

Table 6.2.2.2-2: Requirement for spurious emissions limits

Frequency Range	Maximum Level	Measurement bandwidth	NOTE
30 MHz ≤ f < 1000 MHz	-36 dBm	100 kHz	
1 GHz ≤ f < 5 GHz	-30 dBm	1 MHz	
5 GHz ≤ f < 12.75 GHz	-30 dBm	1 MHz	1
NOTE 1: Applies for Band for which the upper frequency edge of the UL Band is greater than 1 GHz and less than or equal to 2.55 GHz.			

7 Receiver characteristics

7.1 General

Unless otherwise stated, the receiver characteristics are specified over the air (OTA). The power levels for all R2D signals are defined assuming a 0dBi reference antenna located at the center of the quiet zone. The minimum requirements on effective isotropic sensitivity (EIS) apply to two measurements, corresponding to DL signals in orthogonal polarizations.

7.2 Reference sensitivity power level

7.2.1 General

The reference sensitivity power level REFSENS is defined as the EIS level at the centre of the quiet zone in the RX gain peak direction, at which the successful detection rate shall meet or exceed the requirements for the specified reference measurement channel.

7.2.2 Reference sensitivity power level

The successful detection rate shall be ≥ 90% of the reference measurement channels as specified in Annexes B.1, B.2 and B.3 with peak reference sensitivity specified in Table 7.2.2-1. The requirement is applied to all R2D channel bandwidth defined in Table 5.3.1.5-1 and verified with the test metric of EIS at the peak antenna gain direction as specified in clause 8.2.1.

Table 7.2.2-1: Reference sensitivity

Operating band	Sensitivity Level	REFSENS (dBm)
According to subclause 5.2	L1	-34

NOTE: The peak reference sensitivity is measured at the low, middle and high frequency of the supported band(s), and the average value is verified against the requirement.

7.2.3 EIS partial sphere coverage

The reference measurement channels and detection criterion shall be as specified in clause 7.2.2

The maximum EIS measured over the partial sphere around the device is defined as the partial sphere coverage requirement and is found in Table 7.2.3-1 below. The requirement is applied to all R2D channel bandwidth defined in Table 5.3.1.5-1 and verified with the test metric of EIS as specified in clause 8.2.1.

Table 7.2.3-1: EIS partial sphere coverage

Operating band	EIS (dBm)	Angular width
According to subclause 5.2	-28.5	±45 degrees

NOTE: The EIS partial sphere coverage requirement is verified at the middle frequency of the supported band(s).

7.3 Maximum input level

Maximum input level is defined as the maximum mean power received at the device peak antenna gain direction, at which the specified success rate shall meet or exceed the minimum requirements for the specified reference measurement channel. The successful detection rate shall be ≥ 90% of the reference measurement channels as specified in Annex B with parameters specified in Table 7.3.-1.

Table 7.3-1: Maximum input level

R2D Parameter	Units	Channel bandwidth (kHz)
		200,400,600,800
Power in Transmission Bandwidth Configuration	dBm	-4

8 OTA test characteristics

8.1 General

8.1.1 Testing bands

The testing bands are based on operating bands as specified in sub-clause 5.2. The frequency ranges to be tested will be all low, middle and high frequency ranges. The detailed testing parameters as the channel bandwidth, D2R and R2D configuration for each band is defined by RAN5.

8.2 Performance metrics

8.2.1 Performance metric of Tx requirements

Transmitter power measurements shall be performed using the Effective Isotropic Radiated Power (EIRP) as the measurement metric.

The EIRP is combined from θ and ϕ polarizations:

$$EIRP(\theta,\phi) = EIRP_\theta(\theta,\phi)|_{CW_\theta(\theta,\phi)} + EIRP_\phi(\theta,\phi)|_{CW_\theta(\theta,\phi)} + EIRP_\theta(\theta,\phi)|_{CW_\phi(\theta,\phi)} + EIRP_\phi(\theta,\phi)|_{CW_\phi(\theta,\phi)}$$

Where $EIRP_\theta$ and $EIRP_\phi$ are the EIRP in the corresponding θ and ϕ polarizations, CW_θ and CW_ϕ are the incident CW in the corresponding θ and ϕ polarizations,

For backscatter power measurement, the EIRP only contains the power of 1st sidebands within D2R channel bandwidth and excludes power of CW.

8.2.2 Performance metric of Rx requirements

Receiver sensitivity measurements shall be performed using successful detection rate of R2D as the measurement metric. The DUT's receiver sensitivity corresponds to the minimum R2D signal power required to provide a successful detection rate no less than 90% under the fixed reference channel (FRC) specified in Annex B.

The effective isotropic sensitivity (EIS) is defined as the minimum power level at which the successful detection rate no less than 90% under the specified FRC, at each given test point.

The EIS is combined from θ and ϕ polarizations:

$$EIS(\theta,\phi) = \frac{1}{\left(\frac{1}{EIS_\theta(\theta,\phi)} + \frac{1}{EIS_\phi(\theta,\phi)}\right)}$$

Where EIS_θ and EIS_ϕ are the EIS in the corresponding θ and ϕ polarizations.

The EIS partial sphere coverage metric is defined as the maximum R2D EIS radiated in the Theta and Phi range from partial surface within ±45° angular width degrees.

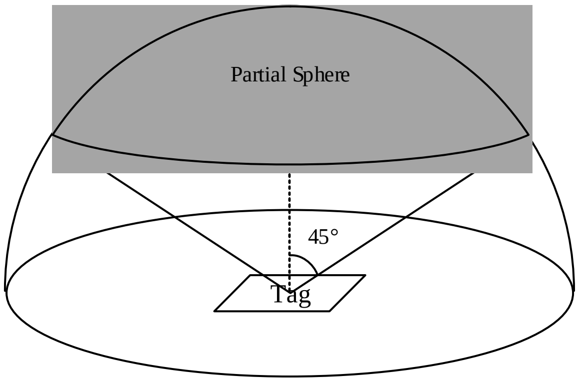


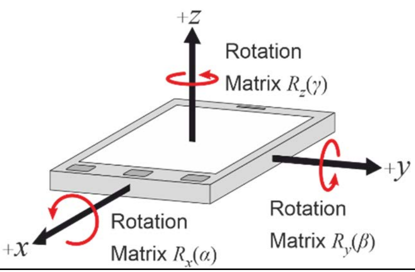
Figure 8.2.2-1: Visualization of Partial sphere within ±45° angular range

8.3 Device positioning guidelines

8.3.1 Free space

For Free space configuration, the centre of the reference coordinate system shall be aligned with the geometric centre of the DUT in order to minimize the offset between antenna arrays integrated at any position of the device and the centre of the quiet zone.

Table 8.3.1-1: Device positioning for Free space

Test condition	DUT orientation	Diagram
Free space DUT	α = 0º; β = -90º; γ = 0º	

For Ambient IoT device, if the device has a rectangular shape, the DUT orientation in Table 8.3.1-1 is applied. The front and back side of device is based on device declaration. Otherwise, the device positioning is based on device declaration.

8.4 Anechoic Chamber method

8.4.1 General

Test frequency band in clause 8.1.1 is used for tests described in this clause. A device shall be positioned according to the positioning guideline in clause 8.3. Device manufacturers shall declare direction of maximum backscattering to enable efficient measurement as this eliminates the need for spherical scan to find the direction of maximum backscattering.

During tests, device is placed on a platform with either combined axis or distributed axis at the origin of a Cartesian coordinate. Test antenna with two linear orthogonal polarizations supports both CW and Reader, namely CW and Reader share the same antenna with CW and Reader using both polarizations.

Declaration of maximum backscattering direction by device manufacturers can only made in 15-degree step size in both θ- and ϕ-direction in the coordinate system with reference to (0º, 0º) shown in Table 8.3.1-1 of clause 8.3.

8.4.2 Backscattering measurement procedure

Backscattered power is only measured at the direction of maximum backscattering declared by device manufacturers with two CW incident power levels.

The measurement procedure includes the following steps:

1) Place the DUT inside the QZ following the UE positioning guidelines defined in clause 8.3.

2) Position the measurement antenna such that the DUT direction of maximum backscattering faces the measurement antenna according to the declaration from device manufacturers.

3) DUT must be fully charged before the measurement according to device declaration on the required energy conditions.

4) Set the signal generator (i.e., R2D signal) and the CW generator to transmit at the target test frequency with θ-polarization. The transmit power of the signal generator shall be set such that the received power at DUT's antenna is larger than minimum reference sensitivity requirement of the DUT. The transmit power of the CW generator shall be such that the CW incident power at the device antenna is -27dBm as given in clause 6.

5) Measure the power received in both θ-polarization and ϕ-polarization, either simultaneously or sequentially, and calculate $EIRP_{DUT}(Pol_{CW} = \theta)$ by adding the composite loss of the entire transmission path, then summing up the power received in θ-polarization and ϕ-polarization.

6) Repeat step 4) and 5) setting the signal generator and the CW generator to transmit in ϕ-polarization and calculate $EIRP_{DUT}(Pol_{CW} = \phi)$ by adding the composite loss of the entire transmission path, then summing up the power received in θ-polarization and ϕ-polarization.

7) Calculate the backscattered power at the direction declared by device manufacturers as:

$$P_{backscatter} = \left(EIRP_{DUT}(Pol_{CW} = \theta)\right) + \left(EIRP_{DUT}(Pol_{CW} = \phi)\right),$$

   where $EIRP_{DUT}(Pol_{CW} = \theta)$ and $EIRP_{DUT}(Pol_{CW} = \phi)$ are measured backscatter power at the device antenna when incident CW power is in θ-polarization and the ϕ-polarization, respectively.

8) Repeat step 4) to 7) with the CW incident power at the device antenna set to -10dBm as given in clause 6.

8.4.3 Sensitivity measurement procedure

Sensitivity is measured at 4 edge points of a partial sphere of 45º degrees in elevation or θ-direction, namely (θ=45º, ϕ=0º), (θ=45º, ϕ=90º), (θ=45º, ϕ=180º), (θ=45º, ϕ=270º).

The measurement procedure includes the following steps:

1) Place DUT inside the QZ following the UE positioning guidelines defined in clause 8.3.

2) DUT must be fully charged before the measurement according to device declaration on the required energy conditions.

3) Set the CW generator to transmit at the target test frequency with θ-polarization. The transmit power of the CW generator shall be set such that the CW incident power at the device antenna is 10dB higher than the receiver sensitivity requirement.

4) Set the signal generator (i.e., R2D signal) to transmit at the target test frequency with θ-polarization. The transmit power of the signal generator shall be set such that the received power at DUT's antenna is at least 10dB above minimum reference sensitivity requirement of the DUT.

5) Confirm that the DUT can send correct response in D2R channel within correct timing relationship and the test equipment is able to decode the responses by measuring the power received in both θ-polarization and ϕ-polarization either simultaneously or sequentially.

6) Determine $EIS_{DUT}(Pol_{Meas} = \theta; Pol_{CW} = \theta)$, i.e., by sweeping the transmit power level for the signal generator (i.e., R2D signal), until 90% response decode success rate is achieved, determined by whether DUT can send correct response in D2R channel within correct timing relationship and the test equipment is able to decode 90% of the responses.

7) Repeat step 5) for all grid points and record $EIS_{DUT}(Pol_{Meas} = \theta; Pol_{CW} = \theta)$.

8) Switch the signal generator (i.e., R2D signal) to transmit at the target test frequency with ϕ-polarization.

9) Calculate the EIS at every grid point using linear values:

$$EIS_{total}(Pol_{CW} = \theta) = \left[\frac{1}{EIS_{DUT}(Pol_{Meas}=\theta;Pol_{CW}=\theta)} + \frac{1}{EIS_{DUT}(Pol_{Meas}=\phi;Pol_{CW}=\theta)}\right]^{-1}$$

10) Switch the CW generator to transmit at the target test frequency with ϕ-polarization and repeat step 4) to 8), and calculate the EIS under CW with ϕ-polarization

$$EIS_{total}(Pol_{CW} = \phi) = \left[\frac{1}{EIS_{DUT}(Pol_{Meas}=\theta;Pol_{CW}=\phi)} + \frac{1}{EIS_{DUT}(Pol_{Meas}=\phi;Pol_{CW}=\phi)}\right]^{-1}$$

11) For each grid point, select the minimum EIS_{total}:

$$EIS_{total}(\theta, \phi) = \min\{EIS_{total}(\theta, \phi, Pol_{CW} = \theta), EIS_{total}(\theta, \phi, Pol_{CW} = \phi)\}$$

12) Select the worst result from all grid points and compare with the core requirement in clause 7.2.

The sensitivity at peak direction is measured at the first position of the measurement antenna in the maximum performance direction declared by device manufacturers, then use the above test procedure without step 7).

8.4.4 Unwanted emission measurement procedure

Unwanted emission power is only measured at the direction of maximum backscattering declared by device manufacturers.

The measurement procedure includes the following steps:

1) Place the DUT inside the QZ following the UE positioning guidelines defined in clause 8.3.

2) Position the measurement antenna such that the DUT direction of maximum backscattering faces the measurement antenna according to the declaration from device manufacturers.

3) DUT must be fully charged before the measurement according to device declaration on the required energy conditions.

4) Set the CW generator to transmit at the target test frequency with θ-polarization.

5) Use a spectrum analyser to measure unwanted power.

6) Repeat step 4) and 5) setting the CW generator to transmit in ϕ-polarization

7) Calculate the backscattered emission power at the direction declared by device manufacturers:

$$P_{emission} = \left(EIRP_{DUT}(Pol_{CW} = \theta)\right) + \left(EIRP_{DUT}(Pol_{CW} = \phi)\right)$$

8) Compare measurement results with core requirements in clause 6.2

9 RRM

9.1 Random access

9.1.1 Introduction of random access

This clause contains requirements for A-IoT device(s) random access procedure. The random access procedure is specified in clause 5.3 of TS 38.391 [6] , and the D2R physical layer transmission is specified in clause 6.1 of TS 38.291 [3]. The requirements for the CBRA type procedure are described in clause 9.1.2, whereas the requirements for the CFA type procedure are described in clause 9.1.3 of this specification.

9.1.2 Requirements for contention based random access

9.1.2.1 Correct behaviour when transmitting A-IoT Msg1

When an A-IoT device is indicated to perform CBRA by the *A-IoT Paging* message according to the procedure described in clause 5.2 in TS 38.391 [6], the A-IoT device shall have the capability to randomly select an access occasion among access occasions configured in the *A-IoT paging* message according to the procedure described in clause 5.3.1.1 and shall have the capability to transmit the A-IoT Msg1 (i.e., *random ID* message) on this selected access occasion according to the procedure described in clause 5.3.1.2 in TS 38.391[6].

9.1.2.2 CBRA: Correct behaviour when receiving A-IoT MSG2

The UE shall initiate the D2R message transmission as defined clause 5.3.1 in TS 38.391 [6].

9.1.2.3 CBRA: Correct behaviour when not receiving A-IoT MSG2

The UE shall not initiate any D2R transmission.

9.1.3 Requirements for contention free access

9.1.3.1 CFA: Correct behaviour when transmitting First D2R message

Upon *reception of A-IoT Paging message*, if the RA type is indicated as CFA in paging message, UE shall initiate contention-free access, and initiate D2R message transmission, as defined in TS 38.391 [6] clause 5.2 and 5.3.2.

9.2 D2R timing

9.2.1 D2R transmit timing

For D2R transmission, the reference point for the device transmission timing is $T_{\mathrm{R}\rightarrow\mathrm{D}}$ after the end of the corresponding R2D transmission for the device as define in TS 38.291. The device transmission timing error shall be less than or equal to Te. The value of Te is equal to 10%*T_{SFO}, where T_{SFO} is the length in microseconds from the last transition edge of PRDCH intended for the device in the corresponding R2D transmission to the starting time of the D2R transmission.

9.3 T_{D2R_min}

A device is not required to monitor a corresponding R2D transmission earlier than T_{D2R_min} after the end of a D2R transmission from the device. The value of T_{D2R_min} is max {3* $T_{\mathrm{chip}}^{\mathrm{D2R}}$, 10 us}, where $T_{\mathrm{chip}}^{\mathrm{D2R}}$ is the duration of a D2R chip as specified in TS38.291 [3].

Annex A (normative): The test configuration for backscattering loss

The test configuration in Table A.1-1 is defined to be used for testing the backscattering loss requirement defined in section 6.1.1

Annex B (normative): Measurement channels

B.1 General

Unless stated otherwise, the transmitter and receiver performances are measured through the contention-free access (CFA) procedure, consisting of one R2D message and one D2R message.

B.2 R2D reference measurement channels

B.2.1 Fixed Reference Channels for reference sensitivity level (OOK)

Table B.2.1-1: Fixed Reference Channels for reference sensitivity level (OOK)

Component	Parameter	Unit	Value
General	PRB	RBs	1
	SCS	kHz	15
SIP	Bit length	Bits	8
	Mapping to OFDM	Chips/Symbol	4
CAP	Bit length	Bits	4
	M	Chips/Symbol	6
PRDCH	TBS	Bits	Depending on the size of the MAC PDU of A-IoT CFA paging message
	CRC	Bits	16
	M	Chips/Symbol	6
Postamble	Bit length	Bits	4
	M	Chips/Symbol	6
Padding	Padding for last OFDM symbol	Chips	Depending on the TBS

B.2.2 Fixed Reference Channels for maximum input level

Table B.2.2-1: Fixed Reference Channels for maximum input level

Component	Parameter	Unit	Value
General	PRB	RBs	3
	SCS	kHz	15
SIP	Bit length	Bits	8
	Mapping to OFDM	Chips/Symbol	4
CAP	Bit length	Bits	4
	M	Chips/Symbol	24
PRDCH	TBS	Bits	Depending on the size of the MAC PDU of A-IoT CFA paging message
	CRC	Bits	16
	M	Chips/Symbol	24
Postamble	Bit length	Bits	4
	M	Chips/Symbol	24
Padding	Padding per OFDM symbol excluding SIP and Postamble	Chips	2
Padding	Padding for last OFDM symbol	Chips	Depending on the TBS

B.3 D2R reference measurement channels

B.3.1 Fixed Reference Channels for transmitter characteristics

Table B.3.1-1: Fixed Reference Channels for backscatter power, SEM and spurious emissions

Parameter	Unit	Value
Transmission BW	kHz	15
TBS	Bits	Depending on the length of AIoT device ID
CRC	Bits	16
FEC code rate		1/3
Block repetition number		1
Preamble length	Bits	31
Midamble length	Bits	31
Interval for midamble insertion	Bits	48
Additional midamble insertion		No
Small frequency shift	kHz	480
Modulation		BPSK/OOK (NOTE1)
NOTE 1: The modulation scheme used is up to device implementation.		

Annex C (normative): Device coordinate system

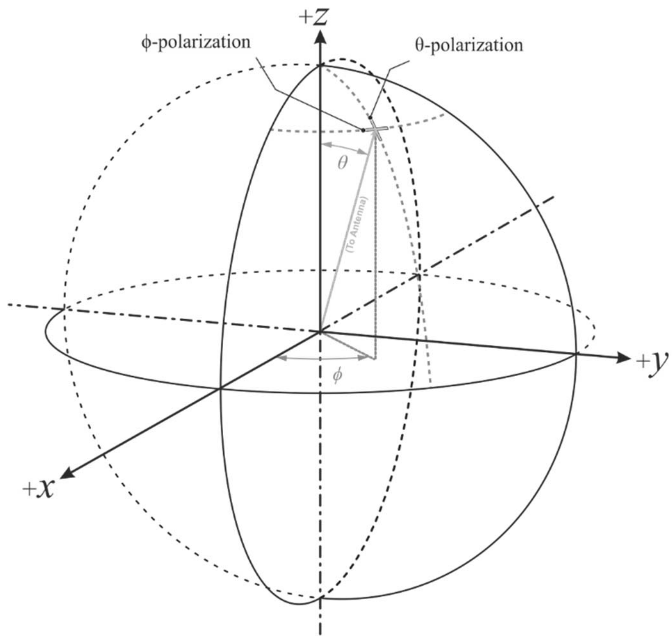


Figure C-1: Reference coordinate system

The reference coordinate system is shown in Figure C-1. If device has a rectangular shape, its orientation in the coordinate system is shown in Figure C-2 with front and back side declared by device manufacturers. Otherwise, device positioning is based on device declaration.

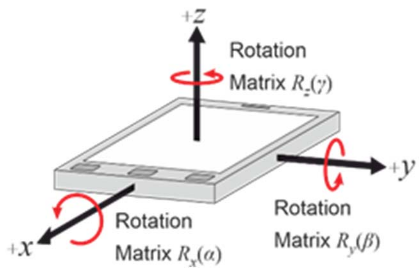


Figure C-2: Reference coordinate system

Annex D (normative): Estimation of Measurement uncertainty

Based on Measurement Uncertainty (MU) values in TS 38.870[5], the MU values of ambient IoT measurements for backscatter power and sensitivity are given below.

Table D-1: MU for backscatter power

UID	Description of uncertainty contribution for backscatter power	Uncertainty value
Stage 2: DUT measurement		
1	Mismatch of receiver chain	0.22
2	Insertion loss of receiver chain	0
3	Influence of the measurement antenna cable	0
4	CW for backscatter measurement uncertainty of the absolute output level	-0.65
5	Sensitivity measurement: output level step resolution	0
6	Measurement distance	0
7	Quality of quiet zone	0.5
8	Coarse sampling grid	0.1
9	Random uncertainty	0.4
10	Frequency Response	0
Stage 1: Calibration measurement, network analyzer method		
11	Uncertainty of network analyzer	0.2
12	Mismatch of receiver chain	0
13	Insertion loss of receiver chain	0
14	Mismatch in the connection of calibration antenna	0
15	Influence of the calibration antenna feed cable	0.3
16	Influence of the measurement antenna cable	0
17	Uncertainty of the absolute gain/radiation efficiency of the calibration antenna	0.58
18	Measurement distance	0
19	Quality of quiet zone	0.5
Systematic Errors		
20	Systematic Error related to grids	0

Table D-2: MU for sensitivity

UID	Description of uncertainty contribution for sensitivity	Uncertainty value
Stage 2: DUT measurement		
1	Mismatch of receiver chain	0.22
2	Insertion loss of receiver chain	0
3	Influence of the measurement antenna cable	0
4	R2D for sensitivity measurement: uncertainty of the absolute output level	0.27
5	Sensitivity measurement: output level step resolution	0
6	Measurement distance	0
7	Quality of quiet zone	0.5
8	DUT sensitivity drift	0.12
9	Coarse sampling grid	0.1
10	Random uncertainty	0.4
11	Frequency Response	0
Stage 1: Calibration measurement, network analyzer method (Figure 7.3-1)		
12	Uncertainty of network analyzer	0.2
13	Mismatch of receiver chain	0
14	Insertion loss of receiver chain	0
15	Mismatch in the connection of calibration antenna	0
16	Influence of the calibration antenna feed cable	0.3
17	Influence of the measurement antenna cable	0
18	Uncertainty of the absolute gain/radiation efficiency of the calibration antenna	0.58
19	Measurement distance	0
20	Quality of quiet zone	0.5
Systematic Errors		
21	Systematic Error related to grids	0

Annex E (informative): D2R channel bandwidth

The following describes the equation to derive device D2R channel bandwidth.

D2R CBW for device (kHz)

= ceiling (2SB Transmission BW without SFO× (1/2) +2× Small frequency shift without SFO)

$= \text{ceiling}\left((2+2R)/T_b \times (1+|SFO|)\right)$

$= \text{ceiling}\left((1+R)/(T_c \times R) \times (1+|SFO|)\right)$

Annex F (informative): Change history

Change history							
Date	**Meeting**	**TDoc**	**CR**	**Rev**	**Cat**	**Subject/Comment**	**New version**
2025-04	RAN4#114-bis	R4-2505227				Initial Skeleton	0.0.1
2025-09	RAN4#116	R4-2511749				Agreed TP in RAN4#116: R4-2511723 TP for TR 38.191 section 3 Definitions, symbols and abbreviations CMCC R4-2511733 TP for TS 38.191 Clause 4 on General CATT R4-2509809 TP for TS 38.191: General and Operating bands R4-2511734 TP for TR 38.191 section 5.3 Channel bandwidth and 5.4 Channel Arrangement Xiaomi R4-2511737 TP for TS 38.191 Clause 7.3 Maximum input level Spreadtrum,UNISOC R4-2511738 TP to TS 38.191 on device unwanted emssion vivo R4-2511739 TP to TS38.191 FRC for device 1 REFSENS ZTE Corporation, Sanechips R4-2511740 TP to TS38.191 Introduction of receiver sensitivity requirements for Ambient IoT devices Huawei, HiSilicon R4-2511741 TP for 38.191 backscatter power loss Ericsson, Sony R4-2511744 Text Proposal for 38.191 clause 8.4 Huawei, HiSilicon R4-2511745 Text Proposal for 38.191 Annex A and Annex B Huawei, HiSilicon R4-2511746 TP for TR 38.191 section 8.3 device positioning guidelines CMCC R4-2511747 TP to TS 38.191 on OTA performance metric vivo R4-2511748 TP on OTA test aspect OPPO	0.0.1
2025-09	RAN4#116	R4-2512353				Agreed TP in RAN4#116: R4-2512235 TP for TS 38.191 to introduce CBRA correct behaviour when transmitting A-IoT MSG1 CATT R4-2512236 draftCR on Rel19 AIoT (9.1.2.3 CBRA: Correct behaviour when not receiving A-IoT MSG2) Xiaomi R4-2512237 DraftCR on D2R Timing requirements CMCC R4-2510606 Draft CR on CFA RRM requirements for A-IoT Huawei, HiSilicon R4-2512238 CBRA: Correct behaviour when receiving A-IoT MSG2 ZTECorporation,Sanechips R4-2512239 Draft CR on A-IoT random access Ericsson	0.0.1
2025-09	RAN#109	RP-252339				v1.0.0 submitted for plenary approval. Merge Contents from R4-2511749 and R4-2512353	1.0.0
2025-09	RAN#109	RP-252811				Delete clause 6.1 and 10 since there is no content on top of v1.0.0	1.1.0

Change history							
Date	**Meeting**	**TDoc**	**CR**	**Rev**	**Cat**	**Subject/Comment**	**New version**
2025-09	RAN#109					Approved by plenary – Rel-19 spec under change control	19.0.0
2025-12	RAN#110	RP-253654	0005		F	CR on RRM core requirements for A-IoT	19.1.0
2025-12	RAN#110	RP-253654	0001	1	F	CR for TS 38.191, Correction on A-IoT Device Symbol	19.1.0
2025-12	RAN#110	RP-253654	0002	1	F	CR for TS 38.191, Correction on A-IoT Device Output RF spectrum emissions	19.1.0
2025-12	RAN#110	RP-253654	0006	1	F	Corrections for device RF requirements	19.1.0
2025-12	RAN#110	RP-253654	0003	1	F	CR on 38.191 for A-IoT device testing	19.1.0
2025-12	RAN#110	RP-253843	0004	4	B	CR for TS 38.191 on including n5 and n28 for A-IoT [Ambient_IoT_n5_n28]	19.1.0

History

Version	Date	Status
V19.0.0	October 2025	Publication
V19.1.0	February 2026	Publication