3GPP TR 38.803 V14.2.0 (2017-09)

Technical Report

3rd Generation Partnership Project;
Technical Specification Group Radio Access Network;
Study on new radio access technology:
Radio Frequency (RF) and co-existence aspects
(Release 14)

Keywords
<New Radio>

3GPP

Postal address

3GPP support office address
650 Route des Lucioles - Sophia Antipolis
Valbonne - FRANCE
Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Internet
http://www.3gpp.org

Contents

Foreword

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

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

Version x.y.z

where:

- x the first digit:
  - 1 presented to TSG for information;
  - 2 presented to TSG for approval;
  - 3 or greater indicates TSG approved document under change control.
- y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.
- z the third digit is incremented when editorial only changes have been incorporated in the document.

Introduction

Work has started in ITU and 3GPP to develop requirements and specifications for new radio (NR) systems, as in the Recommendation ITU-R M.2083 “Framework and overall objectives of the future development of IMT for 2020 and beyond”, as well as 3GPP SA1 study item New Services and Markets Technology Enablers (SMARTER) and SA2 study item Architecture for NR System. 3GPP has to identify and develop the technology components needed for successfully standardizing the NR system timely satisfying both the urgent market needs, and the more long-term requirements set forth by the ITU-R IMT-2020 process. In order to achieve this, evolutions of the radio interface as well as radio network architecture are considered in the study item “New Radio Access Technology” [1].

1 Scope

The present document covers the RF and co-existence aspects of the study item “New Radio Access Technology” [1].

2 References

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

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

[1] 3GPP RP-160671: "New SID Proposal: Study on New Radio Access Technology".

[2] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[3] Recommendation ITU-R SM.328-10, “Spectra and Bandwidth of Emissions”.

[4] Recommendation ITU-R SM.329-12, “Unwanted emissions in the spurious domain”

[5] “International Telecommunications Union Radio Regulations”, Edition 2016, Volume 1 – Articles, ITU.

[6] “Title 47 of the Code of Federal Regulations (CFR)”, Federal Communications Commission.

[7] Recommendation ITU-R SM.1539-1, “Variation of the boundary between the out-of-band and spurious domains required for the application of Recommendations ITU-R SM.1541 and ITU-R SM.329”.

[8] Recommendation ITU-R SM.1540, “Unwanted emissions in the out-of-band domain falling into adjacent allocated bands”.

[9] Recommendation ITU-R SM.1541-6, “Unwanted emissions in the out-of-band domain”.

[10] Recommendation ITU-R M.2012, “Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-Advanced (IMT-Advanced)”.

[11] Recommendation ITU-R M.2070, “Generic unwanted emission characteristics of base stations using the terrestrial radio interfaces of IMT-Advanced”.

[12] Recommendation ITU-R M.2071, “Generic unwanted emission characteristics of mobile stations using the terrestrial radio interfaces of IMT-Advanced”.

[13] Report ITU-R M.2292, “Characteristics of terrestrial IMT-Advanced systems for frequency sharing/interference analyses”.

[14] ECC Recommendation (02)05, “Unwanted Emissions”, October 2002, amended March 2012.

[15] CEPT/ERC/RECOMMENDATION 74-01, “Unwanted Emissions in the Spurious Domain”, Cardiff 2011.

[16] ETSI EN 301 908, “IMT cellular networks; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive;” (22 parts).

[17] FCC Report and Order and Further Notice of Proposed Rulemaking, “Use of Spectrum Bands Above 24 GHz For Mobile Radio Services…”, FCC 16-89, July 14, 2016.

[18] 3GPP TR 25.942, Technical Report,"3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Radio Frequency (RF) system scenarios"

[19] 3GPP TR 36.942, Technical Report, "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) system scenarios"

[20] 3GPP TR 37.900, Technical Report, "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Radio Frequency (RF) requirements for Multicarrier and Multiple Radio Access Technology (Multi-RAT) Base Station (BS)"

[21] TR 37.842, Radio Frequency (RF) requirement background for Active Antenna System (AAS) Base Station (BS)

[22] R4-166432, AAS and NR BS requirements, Huawei

[23] R4-164168, "On PA models", Ericsson

[24] R4-165901, "Further elaboration on PA models for NR", Ericsson.

[25] R4-163314, "Realistic power amplifier model for the New Radio evaluation", Nokia

[26] R4-167263, "PA model using a Memory Polynomial", Intel

[27] ECC PT1 (16)083_A31, Liaison Statement on IMT 2020/ 5G spectrum in Europe

[28] ECC decision (11)06, Harmonised frequency arrangements for mobile/fixed communications networks (MFCN) operating in the bands 3400-3600 MHz and 3600-3800 MHz

[29] "Flex5Gware Project, "Deliverable 2.1: Requirements and concepts for the analogue HW in 5G mobile systems", Dec. 2015.

[30] TR 37.977, Technical Report, "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Universal Terrestrial Radio Access (UTRA) and Evolved Universal Terrestrial Radio Access (E-UTRA); Verification of radiated multi-antenna reception performance of User Equipment (UE)"

[31] RP-170021, "Reply LS to ITU-R WP5D/374 (Attachment 4.13) on Characteristics of terrestrial IMT systems for frequency sharing/interference analysis in the frequency range between 24.25 GHz and 86 GHz" (RAN4).

[32] R4-1610616,"Way forward on IMT parameters WP5D" (Ericsson).

[33] R4-1700287, "Way Forward on BS SEM" (Ericsson, Nokia, Alcatel-Lucent Shanghai Bell).

[34] R4-1700076, "NR unwanted emissions for BS and UE in ITU-R response" (Ericsson).

[36] R4-1700302, "Way forward on ACLR and ACS for WP5D LS" (Huawei,Nokia, Ericsson, Qualcomm).

[36] R4-1700303, "Way Forward on UE ACLR and BS ACS" (Qualcomm Incorporated).

[37] R4-1700288, "Way Forward on BS Spurious Emissions" (Ericsson).

[38] R4-1700279, "Way forward on UE and BS NF for mm-waves" (Ericsson).

[39] R4-1700268, "WF on BS sensitivity and blocking for WP5 response" (Nokia, Alcatel-Lucent Shanghai Bell, Ericsson).

[40] R4-1700276, "WF on UE sensitivity blocking response for the ITU-R LS" (Ericsson).

[41] R4-1700254, "Text improvement of throughput vs SINR mapping" (SAMSUNG Electronics Co., Ltd.).

[42] R4-1609014, "LS on Characteristics of terrestrial IMT systems for frequency sharing / interference analysis in the frequency range between 24.25 GHz and 86 GHz" (ITU-R WP 5D).

[43] 3GPP TR 38.804, Study on New Radio Access Technology; Radio Interface Protocol Aspects

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in 3GPP TR 21.905 [2] 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 [2].

Beam determination: an operation for TRxP(s) or UE to select at least one of its own transmit/receive beam(s).

Beam management: a set of L1/L2 procedures to acquire and maintain a set of TRxP(s) and/or UE beams that can be used for DL and UL transmission/reception, which include at least following aspects: beam determination, beam measurement, beam reporting, beam sweeping.

Beam measurement: an operation for TRxP(s) or UE to measure characteristics of received and/or transmitted beamformed signals.

Beam reporting: an operation for UE to report information of beamformed signal(s) based on beam measurement.

Beam sweeping: an operation of covering a spatial area, with beams transmitted and/or received during a time interval in a predetermined way.

Transmission Reception Point (TRxP): antenna array with one or more antenna elements available to the network located at a specific geographical location for a specific area.

3.2 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [2] 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 [2].

BS	Base Station
CA	Carrier Aggregation
DUT	Device Under Test
gNB	NR Node B
IF	Intermediate Frequency
LNA	Low Noise Amplifier
NR	New RAT
NR-SS	NR Synchronization Signals (composed on NR-PSS and NR-SSS)
NSA	Non-StandAlone (NR)
OTA	Over The Air
PA	Power Amplifier
RAT	Radio Access Technology
Rx	Receiver
TRP	Total Radiated Power
TRxP	Transmission Reception Point
Tx	Transmitter
UE	User Equipment

4 Background

This section describes the objective and the guidelines for studying the RF and co-existence aspects for the New Radio Access Technology.

4.1 Study item objective

The study aims to develop an NR access technology to meet a broad range of use cases including enhanced mobile broadband, massive MTC, critical MTC, and additional requirements defined during the RAN requirements study.

The new RAT will consider frequency ranges up to 100 GHz [TR38.913].

Detailed objectives of the study item are:

(1) Target a single technical framework addressing all usage scenarios, requirements and deployment scenarios defined in TR38.913 including

- o Enhanced mobile broadband
- o Massive machine-type-communications
- o Ultra reliable and low latency communications

(2) The new RAT shall be inherently forward compatible

- o It is assumed that the normative specification would occur in two phases: Phase I (to be completed in June 2018) and Phase II (to be completed in December 2019)
- o Phase I specification of the new RAT must be forward compatible (in terms of efficient co-cell/site/carrier operation) with Phase II specification and beyond, and backward compatibility to LTE is not required
- o Phase II specification of the new RAT builds on the foundation of Phase I specification, and meets all the set requirements for the new RAT.
- o Smooth future evolution beyond Phase II needs to be ensured to support later advanced features and to enable support of service requirements identified later than Phase II specification.

(3) Initial work of the study item should allocate high priority on gaining a common understanding on what is required in terms of radio protocol structure and architecture to fulfil objective 1 and 2, with focus on progressing in the following areas

- o Fundamental physical layer signal structure for new RAT
  - Waveform based on OFDM, with potential support of non-orthogonal waveform and multiple access
    - FFS: other waveforms if they demonstrate justifiable gain
  - Basic frame structure(s)
  - Channel coding scheme(s)
- o Radio interface protocol architecture and procedures
- o Radio Access Network architecture, interface protocols and procedures,

  Study on the above 2 bullets shall at least cover:

  - Study the feasibility of different options of splitting the architecture into a “central unit” and a “distributed unit”, with potential interface in between, including transport, configuration and other required functional interactions between these nodes [RAN2, RAN3];
    - Study the alternative solutions with regard to signaling, orchestration, …, and OAM, where applicable [in co-operation with SA5];
  - Study and outline the RAN-CN interface and functional split [in co-operation with SA2] [RAN2, RAN3];
  - Study and identify the basic structure and operation of realization of RAN Networks functions (NFs). Study to what extent it is feasible to standardize RAN NFs, the interfaces of RAN NFs and their interdependency [RAN3];
  - Study and identify specification impacts of enabling the realization of Network Slicing [in co-operation with SA2] [RAN2, RAN3];

- Study and identify additional architecture requirements e.g. support for QoS concept, SON, support of sidelink for D2D [RAN1, RAN2, RAN3].

o Fundamental RF aspects – especially where they may impact decisions on the above, e.g.,

- Study and identify the aspects related to the testability of RF and performance requirements

(4) Study and identify the technical features necessary to enable the new radio access to meet objective 1 and 2, also including:

o Tight interworking between the new RAT and LTE

o Interworking with non-3GPP systems

o Operation in licensed bands (paired and unpaired), and licensed assisted operations in unlicensed bands

 [Standalone operation in unlicensed bands is FFS]

o Efficient multiplexing of traffic for different services and use cases on the same contiguous block of spectrum

o Stand alone operation in licensed bands

Note 1: The scope of Phase I will be determined when agreeing on Phase I WID(s).

Note 2: Stated KPI values and deployment scenarios to be aligned to scenarios and requirement SI outcome

(5) Provide performance evaluation of the technologies identified for the new RAT and analysis of the expected specification work

(6) Identify relevant RF parameters used to be used for sharing and co-existence studies

(7) Study and identify technical solutions that enable support for wireless relay

4.2 Preconditions

Editor's note: Preconditions common to study item are captured if any

5 Co-existence study

5.1 Co-existence simulation scenario

Table 5.1 summarizes the proposed initial simulation scenarios for above 6GHz. Scenarios whose simulation frequency is 45GHz (i.e. No. 11, 12, 13 and 14) are proposed as optional scenarios.

Table 5.1: Summary of initial simulation scenarios for above 6GHz

No.	Usage scenario	Aggressor	Victim	Direction	Simulation frequency	Deployment Scenario
1	eMBB	NR, 200MHz	NR, 200MHz	DL to DL	30 GHz	Indoor hotspot
2	eMBB	NR, 200MHz	NR, 200MHz	DL to DL	30 GHz	Urban macro
3	eMBB	NR, 200MHz	NR, 200MHz	DL to DL	30 GHz	Dense urban
4	eMBB	NR, 200MHz	NR, 200MHz	UL to UL	30 GHz	Indoor hotspot
5	eMBB	NR, 200MHz	NR, 200MHz	UL to UL	30 GHz	Urban macro
6	eMBB	NR, 200MHz	NR, 200MHz	UL to UL	30 GHz	Dense urban
7	eMBB	NR, 200MHz	NR, 200MHz	DL to DL	70 GHz	Indoor hotspot
8	eMBB	NR, 200MHz	NR, 200MHz	DL to DL	70 GHz	Dense urban
9	eMBB	NR, 200MHz	NR, 200MHz	UL to UL	70 GHz	Indoor hotspot
10	eMBB	NR, 200MHz	NR, 200MHz	UL to UL	70 GHz	Dense urban
11	eMBB	NR, 200MHz	NR, 200MHz	DL to DL	45 GHz	Indoor hotspot
12	eMBB	NR, 200MHz	NR, 200MHz	DL to DL	45 GHz	Dense urban
13	eMBB	NR, 200MHz	NR, 200MHz	UL to UL	45 GHz	Indoor hotspot
14	eMBB	NR, 200MHz	NR, 200MHz	UL to UL	45 GHz	Dense urban

5.2 Co-existence simulation assumption

5.2.1 Network layout model

5.2.1.1 Urban macro

Details on urban macro network layout model are listed in Table 5.2.1.1-1 and 5.2.1.1-2.

Table 5.2.1.1-1: Single operator layout for urban macro

Parameters		Values	Remark
Network layout		hexagonal grid, 19 macro sites, 3 sectors per site with wrap around	
Inter-site distance		200m (baseline) 300m (optional)	
BS antenna height		25 m	
UE location	Outdoor/indoor	Outdoor and indoor	
	Indoor UE ratio	20%	
	Low/high Penetration loss ratio	50% low loss, 50% high loss	
	LOS/NLOS	LOS and NLOS	
	UE antenna height	Same as 3D-UMa in TR 36.873	
UE distribution (horizontal)		Uniform	
Minimum BS - UE distance (2D)		35 m	
Channel model		UMa	
Shadowing correlation		Between cells: 1.0 Between sites: 0.5	

Table 5.2.1.1-2: Multi operators layout for urban macro

Parameters	Values	Remark
Multi operators layout	coordinated operation (0% Grid Shift)	

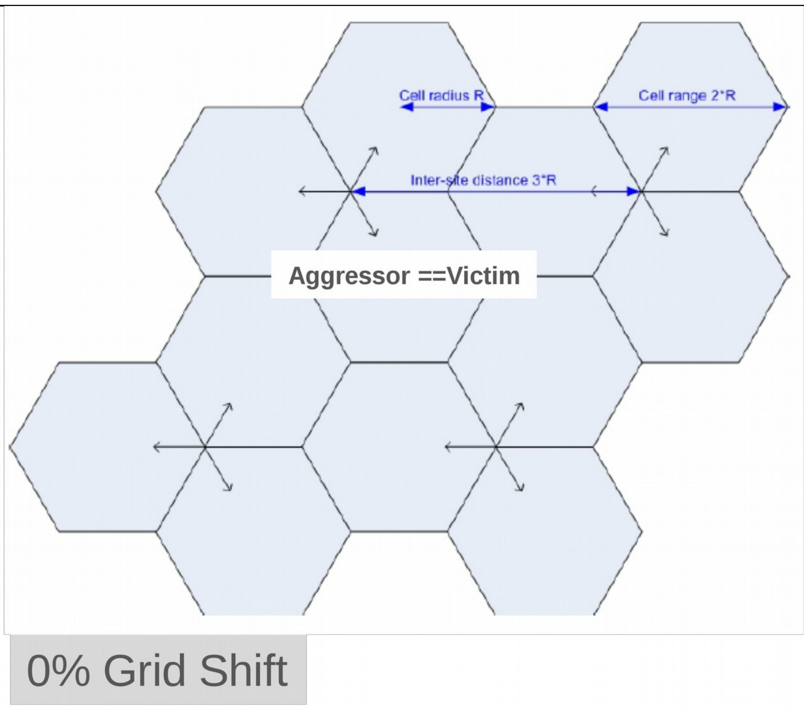
Coordinated Operation: each network with co-location of sites	

Figure 5.2.1.1-1: Coordinated operation

5.2.1.2 Dense urban

Details on dense urban network layout model are listed in Table 5.2.1.2-1 and 5.2.1.2-2.

Table 5.2.1.2-1: Single operator layout for dense urban

Parameters		Values	Remark
Network layout		Fixed cluster circle within a macro cell.	note1
Number of micro BSs per macro cell		3	3 cluster circles are in a macro cell. 1 cluster circle has 1 micro BS.
Radius of UE dropping within a micro cell		< 28.9 m	
BS antenna height		10 m	
UE location	Outdoor/indoor	Outdoor and indoor	
	Indoor UE ratio	80 %	
	50% low loss, 50% high loss	Low/high Penetration loss ratio	
	LOS/NLOS	LOS and NLOS	
	UE antenna height	Same as 3D-UMi in TR 36.873	
UE distribution (horizontal)		Uniform	
Minimum BS - UE distance (2D)		3m	
Channel model		UMi	
Shadowing correlation		Between cite: 0.5	
Note 1: Micro BS is randomly dropped on an edge of the cluster circle. All UEs communicate with micro BS, i.e. macro cell is only used for determining position of micro BS. As a layout of macro cell, hexagonal grid, 19 macro sites, 3 sectors per site model with wrap around with ISD = 200m is assumed.			

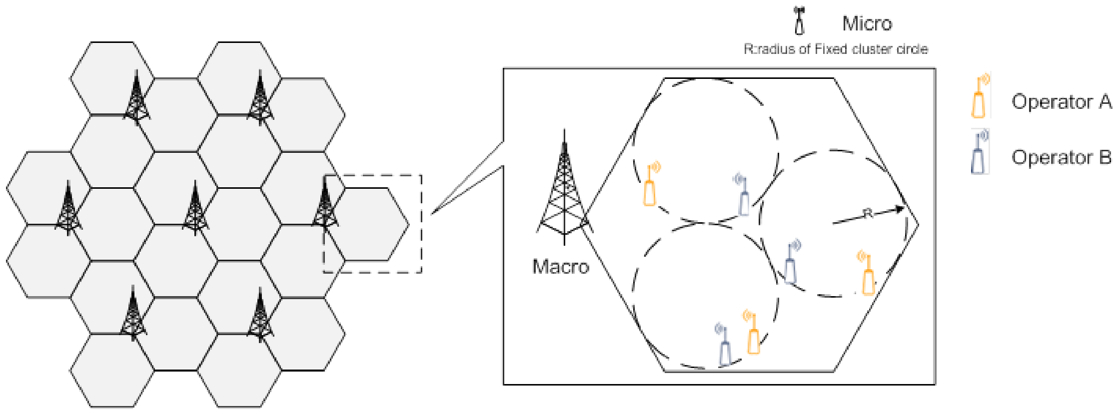


Figure 5.2.1.2-1: Network layout for dense urban

Table 5.2.1.2-2: Multi operators layout for dense urban

Parameters	Values	Remark
Multi operator layout	Cluster circle is coordinated	Note 1
Minimum distance between micro BSs in different operator	10 m	
Note 1: Macro cell is collocated. Micro BS itself is randomly dropped.		

5.2.1.3 Indoor

Details on indoor network layout model are listed in Table 5.2.1.3-1 and 5.2.1.3-2.

Table 5.2.1.3-1: Single operator layout for indoor

Parameters		Values	Remark
Network layout		50m x 120m, 12BSs	
Inter-site distance		20m	
BS antenna height		3 m	ceiling
UE location	Outdoor/indoor	Indoor	
	LOS/NLOS	LOS and NLOS	
	UE antenna height	1 m	
UE distribution (horizontal)		Uniform	
Minimum BS - UE distance (2D)		0 m	
Channel model		Indoor Office	
Shadowing correlation		NA	

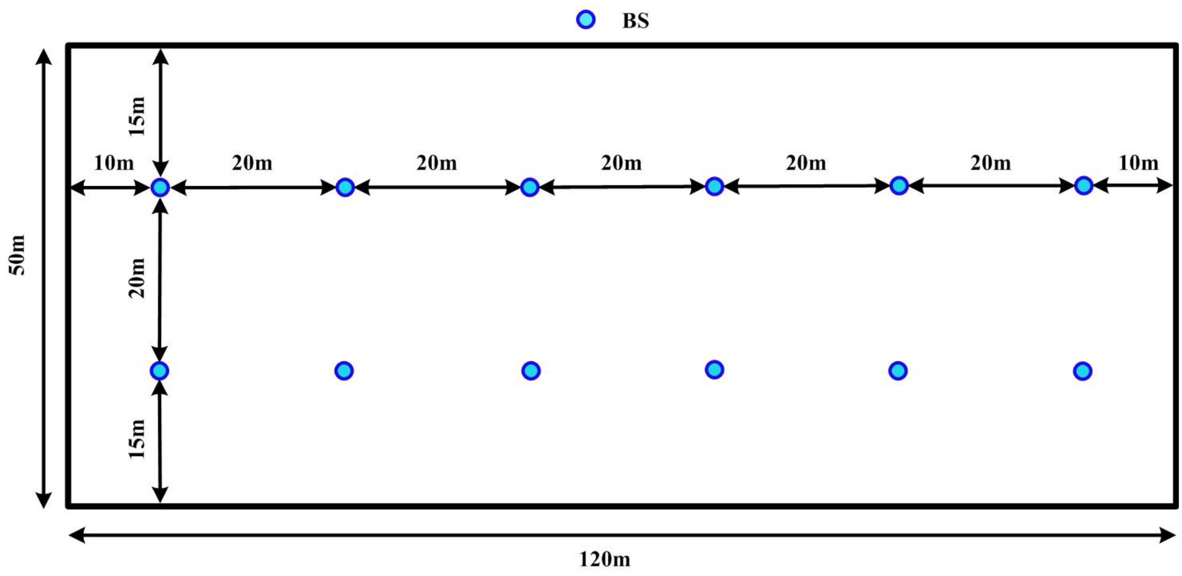


Figure 5.2.1.3-1: Network layout for indoor

Table 5.2.1.3-2: Multi operators layout for indoor

Parameters	Values	Remark
Multi operator layout	Coordinated operation (0% Grid Shift)	

5.2.2 Propagation model

5.2.2.1 Path loss

The Path loss model is summarized in Table 5.2.2.1-1 and the distance definitions are indicated in Figure 5.2.2.1-1. Note that the distribution of the shadow fading is log-normal, and its standard deviation for each scenario is given in Table 5.2.2.1-1.

Table 5.2.2.1-1: Pathloss models

Scenario	Pathloss [dB], f_c is in GHz and d is in meters [(6)]	Shadow fading std [dB]	Applicability range, antenna height default values
UMa LOS	$PL_1 = 32.4 + 20\log10(d_{3D}) + 20\log10(f_c)$ $PL_2 = 32.4 + 40\log10(d_{3D}) + 20\log10(f_c) - 10\log10((d'_{BP})^2 + (h_{BS} - h_{UT})^2)$	σ_{SF}=4.0 σ_{SF}=4.0	10m < d_{2D} < d'_{BP} [1)] d'_{BP} < d_{2D} <5000m 1.5m ≦ h_{UT} ≦ 22.5m h_{BS} = 25 m
UMa NLOS	$PL = \max(PL_{UMa-LOS}, PL_{UMa-NLOS})$ $PL_{UMa-NLOS} = 13.54 + 39.08\log_{10}(d_{3D}) + 20\log_{10}(f_c) - 0.6(h_{UT} - 1.5)$	σ_{SF} =6	10 m < d_{2D} < 5 000 m 1.5 m ≦ h_{UT} ≦ 22.5 m h_{BS} = 25 m Explanations: see note 3
UMi - Street Canyon LOS	$PL = 32.4 + 21\log10(d_{3D}) + 20\log10(f_c)$ $PL = 32.4 + 40\log10(d_{3D}) + 20\log10(f_c) - 9.5\log10((d'_{BP})^2 + (h_{BS} - h_{UT})^2)$	σ_{SF}=4.0 σ_{SF}=4.0	10m < d_{2D} < d'_{BP} [1)] d'_{BP} < d_{2D} <5000m 1.5m ≦ h_{UT} ≦ 22.5m h_{BS} = 10 m
UMi – Street Canyon NLOS	$PL = \max(PL_{UMi-LOS}(d_{3D}), PL_{UMi-NLOS}(d_{3D}))$ $PL_{UMi-NLOS} = 35.3\log_{10}(d_{3D}) + 22.4 + 21.3\log_{10}(f_c) - 0.3(h_{UT} - 1.5)$	σ_{SF}=7.82	10 m < d_{2D} < 5000m 1.5m ≦ h_{UT} ≦ 22.5m h_{BS} = 10 m Explanations: see note 4
InH - Office LOS	$PL = 32.4 + 17.3\log10(d_{3D}) + 20\log10(f_c)$	σ_{SF}=3.0	1<d_{3D}<100m
InH - Office NLOS	$PL = \max(PL_{InH-LOS}, PL_{InH-NLOS})$ $PL_{InH-NLOS} = 38.3\log_{10}(d_{3D}) + 17.30 + 24.9\log_{10}(f_c)$	σ_{SF}=8.03	1<d_{3D}<86m

Note 1: $d'_{BP} = 4\, h'_{BS}\, h'_{UT}\, f_c/c$, where f_c is the centre frequency in Hz, $c = 3.0\times10^8$ m/s is the propagation velocity in free space, and h'_{BS} and h'_{UT} are the effective antenna heights at the BS and the UT, respectively. In UMi scenario the effective antenna heights h'_{BS} and h'_{UT} are computed as follows: $h'_{BS} = h_{BS} – 1.0$ m, $h'_{UT} = h_{UT}–1.0$ m, where h_{BS} and h_{UT} are the actual antenna heights, and the effective environment height is assumed to be equal to 1.0 m. In UMa scenario the effective antenna heights h'_{BS} and h'_{UT} are computed as follows: $h'_{BS} = h_{BS} – h_E$, $h'_{UT} = h_{UT} – h_E$, where h_{BS} and h_{UT} are the actual antenna heights, and the effective environment height h_E is a function of the link between a BS and a UT. In the event that the link is determined to be LOS, h_E=1m with a probability equal to $1/(1+C(d_{2D}, h_{UT}))$ and chosen from a discrete uniform distribution uniform(12,15,…,(h_{UT}-1.5)) otherwise.

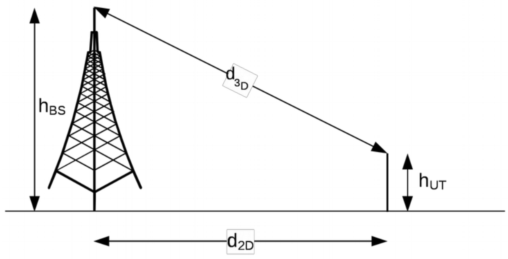
Note 2: The applicable frequency range of the PL formula in this table is $0.8 < f_c < f_H$ GHz, where f_H = 30 GHz for RMa and f_H = 100 GHz for all the other scenarios. It is noted that RMa pathloss model for >7 GHz is validated based on a single measurement campaign conducted at 24 GHz.

Note 3: UMa NLOS pathloss is from TR36.873 with simplified formatand and $PL_{UMa-LOS}$ = Pathloss of UMa LOS outdoor scenario.

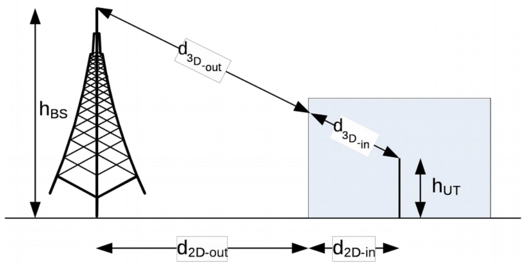
Note 4: $PL_{UMi-LOS}$ = Pathloss of UMi-Street Canyon LOS outdoor scenario.

Note 5: Break point distance $d_{BP} = 2\pi\, h_{BS}\, h_{UT}\, f_c/c$, where f_c is the centre frequency in Hz, $c = 3.0 \times 10^8$ m/s is the propagation velocity in free space, and h_{BS} and h_{UT} are the antenna heights at the BS and the UT, respectively.

Note 6: f_c denotes the center frequency normalized by 1GHz, all distance related values are normalized by 1m, unless it is stated otherwise.



Definition of d_{2D} and d_{3D} for outdoor UEs



Definition of d_{2D-out}, d_{2D-in} and d_{3D-out}, d_{3D-in} for indoor UEs. Note that

$$d_{3D-out}+d_{3D-in}=\sqrt{(d_{2D-out}+d_{2D-in})^2+(h_{BS}-h_{UT})^2}$$

Figure 5.2.2.1-1: Distance definitions

5.2.2.2 LOS probability

The Line-Of-Sight (LOS) probabilities are given in Table 5.2.2.2-1.

Table 5.2.2.2-1: LOS probability

Scenario	LOS probability (distance is in meters)
UMi – Street canyon	Outdoor users: $P_{LOS} = \min(18/d_{2D},1)(1-\exp(-d_{2D}/36))+\exp(-d_{2D}/36)$ Indoor users: Use d_{2D-out} in the formula above instead of d_{2D}
UMa	Outdoor users: $P_{LOS} = \min(18/d_{2D},1)(1-\exp(-d_{2D}/63))+\exp(-d_{2D}/63)(1+C(d_{2D}$ where $C(d_{2D},h_{UT}) = \begin{cases} 0 & ,h_{UT} < 13\text{m} \\ \left(\frac{h_{UT}-13}{10}\right)^{1.5} g(d_{2D}) & ,13\text{m} \le h_{UT} \le 23\text{m} \end{cases}$ and $g(d_{2D}) = \begin{cases} 0 & ,d_{2D} \le 18\text{m} \\ (1.25e-6)(d_{2D})^3 \exp(-d_{2D}/150) & ,18\text{m} < d_{2D} \end{cases}$ Indoor users: Use d_{2D-out} in the formula above instead of d_{2D}
Indoor – Open office	$P_{LOS}^{Open\_office} = \begin{cases} 1, & d_{2D} \le 5 \\ \exp(-(d_{2D}-5)/70.8), & 5 < d_{2D} \le 49 \\ \exp(-(d_{2D}-49)/211.7)\cdot 0.54, & d_{2D} > 49 \end{cases}$
Note:	The LOS probability is derived with assuming antenna heights of 3m for indoor, 10m for UMi, and 25m for UMa

5.2.2.3 O-to-I penetration loss

The Path loss incorporating O-to-I building penetration loss is modelled as in the following:

$\mathrm{PL} = \mathrm{PL}_b + \mathrm{PL}_{tw} + \mathrm{PL}_{in} + N(0, \sigma_P^2)$

where PL_b is the basic outdoor path loss given in Section 5.1.2.2.1. PL_{tw} is the building penetration loss through the external wall, PL_{in} is the inside loss dependent on the depth into the building, and σ_P is the standard deviation for the penetration loss.

PL_{tw} is characterized as:

$$\mathrm{PL}_{tw} = \mathrm{PL}_{npi} - 10\log_{10}\sum_{i=1}^{N}\left(p_i \times 10^{\frac{L_{material\_i}}{-10}}\right)$$

PL_{npi} is an additional loss is added to the external wall loss to account for non-perpendicular incidence;

$L_{material\_i} = a_{material\_i} + b_{material\_i} \cdot f$, is the penetration loss of material i, example values of which can be found in Table 5.2.2.3-1.

p_i is proportion of i-th materials, where $\sum_{i=1}^{N} p_i = 1$; and

N is the number of materials.

Table 5.2.2.3-1: Material penetration losses

Material	Penetration loss [dB]
Standard multi-pane glass	$L_{glass} = 2 + 0.2 \cdot f$
IRR glass	$L_{IRRglass} = 23 + 0.3 \cdot f$
Concrete	$L_{concrete} = 5 + 4 \cdot f$
Wood	$L_{wood} = 4.85 + 0.12 \cdot f$
Note: f is in GHz	

Table 5.2.2.3-2 gives PL_{tw}, PL_{in} and σ_P for two O-to-I penetration loss models. The O-to-I penetration is UT-specifically generated, and is added to the SF realization in the log domain.

Table 5.2.2.3-2 O-to-I penetration loss model

	Path loss through external wall: PL_{tw} [dB]	Indoor loss: PL_{in} [dB]	Standard deviation: σ_P [dB]
Low-loss model	$5 - 10\log_{10}\left(0.3 \cdot 10^{-L_{glass}/10} + 0.7 \cdot 10^{-L_{concrete}/10}\right)$	$0.5d_{2D\text{-}in}$	4.4
High-loss model	$5 - 10\log_{10}\left(0.7 \cdot 10^{-L_{IRRglass}/10} + 0.3 \cdot 10^{-L_{concrete}/10}\right)$	$0.5d_{2D\text{-}in}$	6.5

$d_{2D\text{-}in}$ is minimum of two independently generated uniformly distributed variables between 0 and 25 m for RMa, UMa and UMi-Street Canyon. $d_{2D\text{-}in}$ shall be UT-specifically generated.

Both low-loss and high-loss models are applicable to UMa and UMi-Street Canyon.

Only the low-loss model is applicable to RMa.

The composition of low and high loss is a simulation parameter that should be determined by the user of the channel models, and is dependent on the use of metal-coated glass in buildings and the deployment scenarios. Such use is expected to differ in different markets and regions of the world and also may increase over years to new regulations and energy saving initiatives. Furthermore, the use of such high-loss glass currently appears to be more predominant in commercial buildings than in residential buildings in some regions of the world.

The pathloss incorporating O-to-I car penetration loss is modelled as in the following:

$$PL = PL_b + N(\mu, \sigma_P^2)$$

where PL_b is the basic outdoor path loss given in Section 7.4.1. $\mu = 9$, and $\sigma_P = 5$. Optionally, for metallized car windows, $\mu = 20$ can be used. The O-to-I car penetration loss models are applicable for at least 0.6-60 GHz.

5.2.3 Antenna and beam forming pattern modelling

5.2.3.1 General

A general antenna model is a uniform rectangular panel array, comprising M_gN_g panels, as illustrated in Figure 5.2.3.1-1.

- M_g is number of panels in a column
- N_g is number of panels in a row
- Antenna panels are uniformly spaced in the horizontal direction with a spacing of $d_{g,H}$ and in the vertical direction with a spacing of $d_{g,V}$.
- On each antenna panel, antenna elements are placed in the vertical and horizontal direction, where N is the number of columns, M is the number of antenna elements with the same polarization in each column.
    - Antenna numbering on the panel illustrated in Figure 5.2.3.1-1 assumes observation of the antenna array from the front (with x-axis pointing towards broad-side and increasing y-coordinate for increasing column number).
    - The antenna elements are uniformly spaced in the horizontal direction with a spacing of d_H and in the vertical direction with a spacing of d_V.
    - The antenna panel is either single polarized (P=1) or dual polarized (P=2).

The rectangular panel array antenna can be described by the following tuple (M_g, N_g, M, N, P).

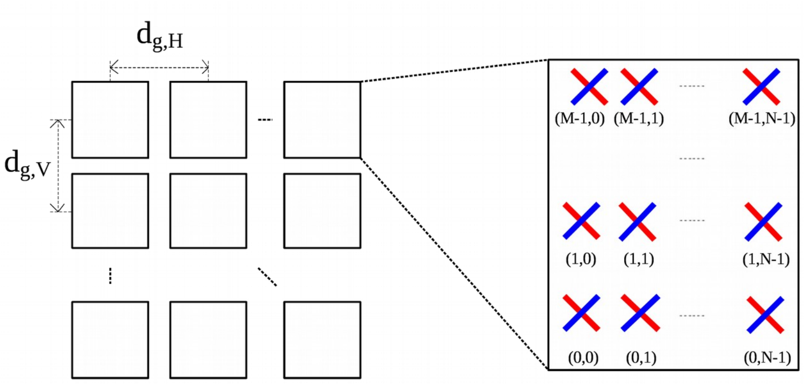


Figure 5.2.3.1-1: General antenna model

For a uniformly distributed array (ULA) antenna, as shown in Figure 5.2.3.1-2, the radiation elements are placed uniformly along the vertical **z**-axis in the Cartesian coordinate system. The **x-y** plane constructs the horizontal plane. A signal acting at the array elements is in the direction of **u**. The elevation angle of the signal direction is denoted as θ (defined between 0° and 180°, 90° represents perpendicular angle to the array antenna aperture) and the azimuth angle is denoted as φ (defined between -180° and 180°).

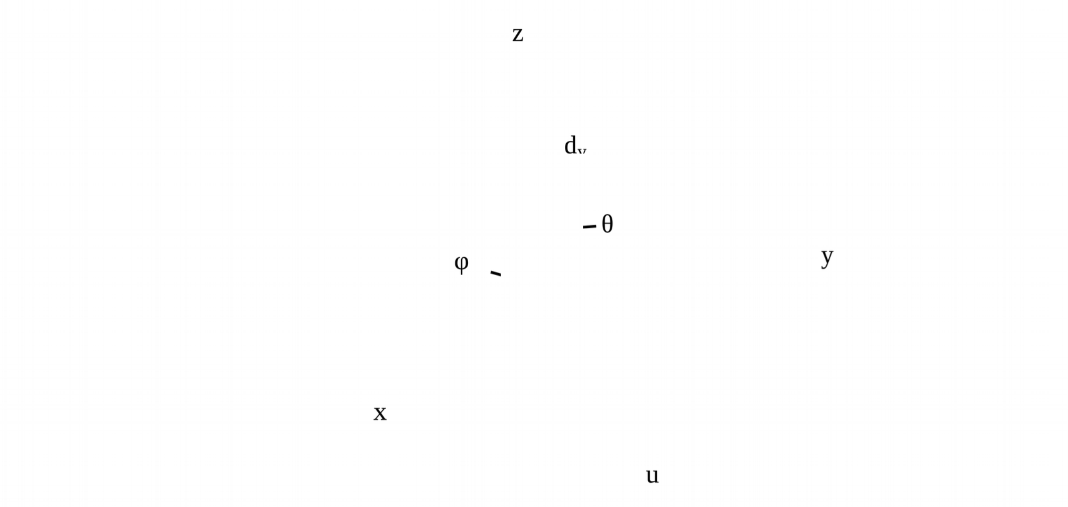


Figure 5.2.3.1-2: Antenna Array Geometry

The linear phase progression based beamforming is assumed, as described in Table 5.2.3.1-1.

Table 5.2.3.1-1: Composite antenna pattern

Parameter	Values
Composite Array radiation pattern in dB $A_A(\theta,\varphi)$	For beam i: $A_{A,Beami}(\theta,\varphi) = A_E(\theta,\varphi) + 10\log_{10}\left[\left\|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V} w_{i,n,m}\cdot v_{n,m}\right\|^2\right]$ the super position vector is given by: $v_{n,m} = \exp\left(i\cdot 2\pi\left((n-1)\cdot\frac{d_V}{\lambda}\cdot\cos(\theta) + (m-1)\cdot\frac{d_H}{\lambda}\cdot\sin(\theta)\cdot\sin(\varphi)\right)\right),$ $n = 1,2,\ldots N_V;\ m = 1,2,\ldots N_H;$ the weighting is given by: $w_{i,n,m} = \frac{1}{\sqrt{N_H N_V}}\exp\left(i\cdot 2\pi\left((n-1)\cdot\frac{d_V}{\lambda}\cdot\sin(\theta_{i,etilt}) - (m-1)\cdot\frac{d_H}{\lambda}\cdot\cos(\theta_{i,etilt})\right)\right)$

In this simulation, there is one beam formed using all the antenna elements. Each beam is directed to one scheduled UE.

Note the above gives the correct antenna array radiation pattern, however the correct gain is only achived if the element pattern $A_A(\theta,\varphi)$ is selected for the exact element spacing. For other element spacings, the element pattern $A_A(\theta,\varphi)$ must be separately calculated such that it is correct for the element spacing ($d_{g,H}$ *and* $d_{g,V}$). If $A_A(\theta,\varphi)$ is not linked to the element spacing then the calculated absolute gain may diverge from the correct value in a manner that varies as the beam is steered.

The correct composite array radiation pattern directivity(D) is given by:

$$D_A(\theta,\varphi) = 10\cdot\log\left(\frac{4\pi\left(\left|A_A(\theta,\varphi)\right|^2\right)}{\int_{-\pi}^{\pi}\int_{0}^{\pi}\left|P(\theta,\varphi)\right|^2\sin(\theta)\,d\theta\,d\varphi}\right),$$

The composite array radiation pattern gain can then be calculated as:

$$G_A(\theta,\varphi) = D_A(\theta,\varphi) - L$$

Where L is the Loss ascotiated with the antenna. This is currently included in the estimate for element gain $A_E(\theta,\varphi)$, and is 1.8dB.

5.2.3.2 BS Antenna modelling

5.2.3.2.1 Urban macro scenario

Table 5.2.3.2.1-1: BS antenna modelling for Urban macro scenario

Parameter	Values
Antenna element vertical radiation pattern (dB)	$A_{E,V}(\theta'') = -\min\left\{12\left(\frac{\theta''-90^\circ}{\theta_{3dB}}\right)^2, SLA_V\right\}, \theta_{3dB}=65^\circ, SLA_V=30\,\mathrm{dB}$
Antenna element horizontal radiation pattern (dB)	$A_{E,H}(\varphi'') = -\min\left\{12\left(\frac{\varphi''}{\varphi_{3dB}}\right)^2, A_m\right\}, \varphi_{3dB}=65^\circ, A_m=30\,\mathrm{dB}$
Combining method for 3D antenna element pattern (dB)	$A''(\theta'',\varphi'') = -\min\left\{-\left[A_{E,V}(\theta'')+A_{E,H}(\varphi'')\right], A_m\right\}$
Maximum directional gain of an antenna element $G_{E,max}$	8 dBi
(M_g, N_g, M, N, P) note	For 30GHz: (1, 1, 8, 16, 2)
(d_v, d_h)	(0.5λ, 0.5λ)
Note: An additional 3dB gain is added to the total beamforming gain to account for the two polarization directions. Boresight direction is horizontal.	

5.2.3.2.2 Dense urban scenario

Table 5.2.3.2.2-1: BS antenna element pattern for Dense urban scenario

Parameter	Values
Antenna element vertical radiation pattern (dB)	$A_{E,V}(\theta'') = -\min\left\{12\left(\frac{\theta''-90^\circ}{\theta_{3dB}}\right)^2, SLA_V\right\}, \theta_{3dB}=65^\circ, SLA_V=30\,\mathrm{dB}$
Antenna element horizontal radiation pattern (dB)	$A_{E,H}(\varphi'') = -\min\left\{12\left(\frac{\varphi''}{\varphi_{3dB}}\right)^2, A_m\right\}, \varphi_{3dB}=65^\circ, A_m=30\,\mathrm{dB}$
Combining method for 3D antenna element pattern (dB)	$A''(\theta'',\varphi'') = -\min\left\{-\left[A_{E,V}(\theta'')+A_{E,H}(\varphi'')\right], A_m\right\}$
Maximum directional gain of an antenna element $G_{E,max}$	8 dBi
(M_g, N_g, M, N, P) note	For 30GHz: (1, 1, 8, 16, 2) For 45GHz and 70GHz: (1, 1, 8, 16, 2)
(d_v, d_h)	(0.5λ, 0.5λ)
Note: An additional 3dB gain is added to the total beamforming gain to account for the two polarization directions. Boresight direction is horizontal.	

5.2.3.2.3 Indoor scenario

Table 5.2.3.2.3-1: BS antenna element pattern for Indoor scenario

Parameter	Values
Antenna element vertical radiation pattern (dB)	$A_{E,V}(\theta'') = -\min\left\{12\left(\frac{\theta'' - 90^\circ}{\theta_{3dB}}\right)^2, SLA_V\right\}, \theta_{3dB} = 90^\circ, SLA_V = 25\text{dB}$
Antenna element horizontal radiation pattern (dB)	$A_{E,H}(\varphi'') = -\min\left\{12\left(\frac{\varphi''}{\varphi_{3dB}}\right)^2, A_m\right\}, \varphi_{3dB} = 90^\circ, A_m = 25\text{dB}$
Combining method for 3D antenna element pattern (dB)	$A''(\theta'', \varphi'') = -\min\left\{-\left[A_{E,V}(\theta'') + A_{E,H}(\varphi'')\right], A_m\right\}$
Maximum directional gain of an antenna element $G_{E,max}$	5 dBi
(M_g, N_g, M, N, P) note	For 30GHz: (1, 1, 4, 8, 2) For 45GHz and 70GHz: (1, 1, 8, 16, 2)
(d_v, d_h)	(0.5λ, 0.5λ)
Note:	An additional 3dB gain is added to the total beamforming gain to account for the two polarization directions. Boresight direction is perpendicular to the ceiling.

5.2.3.3 UE antenna element pattern

Table 5.2.3.3-1: UE antenna element pattern

Parameter	Values
Antenna element vertical radiation pattern (dB)	$A_{E,V}(\theta'') = -\min\left\{12\left(\frac{\theta'' - 90^\circ}{\theta_{3dB}}\right)^2, SLA_V\right\}, \theta_{3dB} = 90^\circ, SLA_V = 25\text{dB}$
Antenna element horizontal radiation pattern (dB)	$A_{E,H}(\varphi'') = -\min\left\{12\left(\frac{\varphi''}{\varphi_{3dB}}\right)^2, A_m\right\}, \varphi_{3dB} = 90^\circ, A_m = 25\text{dB}$
Combining method for 3D antenna element pattern (dB)	$A''(\theta'', \varphi'') = -\min\left\{-\left[A_{E,V}(\theta'') + A_{E,H}(\varphi'')\right], A_m\right\}$
Maximum directional gain of an antenna element $G_{E,max}$	5 dBi
(M_g, N_g, M, N, P)	(1, 1, 2, 2, 2)
(d_v, d_h)	(0.5λ, 0.5λ)
UE orientation	Random orientation in the azimuth domain: uniformly distributed between -90 and 90 degrees* Fixed elevation: 90 degrees
NOTE:	This is done to emulate two panels: the configuration is equivalent to 2 panels with 180 shift in horizontal orientation and UE orientation uniformly distributed in the azimuth domain between -180 and 180 degrees.

5.2.4 Transmission power control model

For downlink scenario, no power control scheme is applied.

For uplink scenario, TPC model specified in Section 9.1 TR 36.942 is applied with following parameters.

- $CL_{x\text{-}ile}$ = 88 + 10*log10(200/X), where X is UL transmission BW (MHz)

- $\gamma = 1$

5.2.5 Received power model

The received power in downlink and uplink scenarios is defined as below:

RX_PWR = TX_PWR – Path loss + G_TX + G_RX

where:

RX_PWR is the received power

TX_PWR is the transmitted power

G_TX is the transmitter antenna gain (directional array gain)

G_RX is the receiver antenna gain (directional array gain).

5.2.6 ACLR and ACS modeling

From the AAS study [21], in which coexistence simulation was conducted to gain understanding of the AAS BS ACLR requirement. It was observed

"The impact of correlation level to the system coexistence is evaluated. Simulation results in Case 1a(AAS to Legacy) and Case 1b(AAS to AAS) show that different correlation levels have little impact on the throughput loss due to the fact that the dominant source of adjacent channel interference is due to UE ACS"

Note the study was done based on two key assumptions, i.e. UE antenna pattern is omni-directional with 0dBi gain and the UE ACS level is 33dB.

With this observation, it was concluded that it is not the spatial direction of ACLR, but the total amount of adjacent channel power radiated that matters in the coexistence performance. Also, it is noted that the current discussion in AAS for ACLR OTA requirement seems to indicate that TRP is the choice due to practical difficulties in implementation and testing [22].

For the UE antenna model, if UE has some kind of beamforming capacity, i.e. the omni-directional antenna model is no longer valid, in general the victim UE will experience less interference. This is because the inference will most likely come from a different direction than the wanted signal thus may experience less beamforming gain.

Therefore, for DL it seems reasonable from the perspective of simulating worst case scenarios that we assume BS ACLR is modeled as flat in space, and the UE ACS can be modeled flat in space.

If this assumption is for DL, then the similar assumption could be made for the UL because:

- UE has a much small number of antennas, thus the effect of directivity should be smaller for ACLR (or the adjacent channel interference). It can also be reasonably assumed that the UE ACLR will play a dominant role than the BS ACS in the adjacent channel interference.
- Again, BS ACS flat in space might mean worse coexistence performance than actual performance because BS has better capability of steering its receive antennas to suppress interference.

It should be noted that flat ACLR assumption implies the spatial pattern of the adjacent channel emissions is exactly the same as the spatial pattern of the wanted signal, such that their ratio is the same. Similarly flat ACS assumption implies that the receiver directivity pattern is the same for both the wanted signal and the adjacent channel signal.

The assumption was made for ITU WP 5D was based on consideration of the likely impact of the assumption on spatial pattern to co-existence performance and not on consideration of whether the spatial pattern of unwanted emissions is really aligned to the wanted signal. This will depend on the correlation between unwanted emissions signals from different transmitters, which has not as yet been investigated.

In terms of flatness in frequency, both ACLR and ACS would be flat based on the analysis above. If a UE occupies a smaller bandwidth than the channel bandwidth for transmission, a two stop ACLR model could be considered in frequency to avoid overly estimating interference, as done in LTE coexistence study [19].

Therefore, it is assumed that both ACLR (or the adjacent channel interference) and ACS are flat in both space and frequency. The ACIR model can be express as

$$ACIR = \frac{1}{\frac{1}{ACLR} + \frac{1}{\mathrm{ACS}}}$$

(assuming ACLR, ACS and ACIR to be linear)

5.2.7 Link level performance for 5G NR coexistence

The throughput of a modem with link adaptation can be approximated by an attenuated and truncated form of the Shannon bound. (The Shannon bound represents the maximum theoretical throughput than can be achieved over an AWGN channel for a given SNIR). The following equations approximate the throughput over a channel with a given SNIR, when using link adaptation:

$$Throughput\ (SNIR), bps/Hz = \begin{cases} 0 & for\ SNIR \\ \propto \cdot S(SNIR) & for\ SNIR_{MIN} \leq SNIR < SNIR_{MAX} \\ \propto \cdot S(SNIR_{MAX}) & for\ SNIR \geq SNIR_{MAX} \end{cases}$$

Where:

S(SNIR) Shannon bound, S(SNIR) $=\log_2(1+SNIR)$ bps/Hz
α Attenuation factor, representing implementation losses
$SNIR_{MIN}$ Minimum SNIR of the code set, dB
$SNIR_{MAX}$ Maximum SNIR of the code set, dB

The parameters α, $SNIR_{MIN}$ and $SNIR_{MAX}$ can be chosen to represent different modem implementations and link conditions. The parameters proposed in table 5.2.7-1 represent a baseline case, which assumes:

- 1:1 antenna configurations
- AWGN channel model
- Link Adaptation (see table 5.2.7-1 for details of the highest and lowest rate codes)
- No HARQ

Table 5.2.7-1: Parameters describing baseline Link Level performance for 5G NR

Parameter	DL	UL	Notes
α, attenuation	0.6	0.4	Represents implementation losses
$SNIR_{MIN}$, dB	-10	-10	Based on QPSK, 1/8 rate (DL) & 1/5 rate (UL)
$SNIR_{MAX}$, dB	30	22	Based on 256QAM 0.93(DL) & 64QAM 0.93 (UL)

Note that the parameters proposed in table 5.2.7-1 are targeted for eMBB coexistence scenario.

5.2.8 Other simulation parameters

Table 5.2.8-1: Other simulation parameters

Parameters	Indoor	Urban macro	Dense urban
Channel bandwidth	200MHz	200MHz	200MHz
Scheduled channel bandwidth per UE (DL)	200MHz	200MHz	200MHz
Scheduled channel bandwidth per UE (UL)	200MHz	200MHz	200MHz
The number of active UE (DL)	Same as the number of BS beam	Same as the number of BS beam	Same as the number of BS beam
The number of active UE (UL)	Same as the number of BS beam	Same as the number of BS beam	Same as the number of BS beam
Traffic model	Full buffer	Full buffer	Full buffer
DL power control	NO	NO	NO
UL power control	YES	YES	YES
BS max TX power in dBm	23dBm	43dBm	33dBm
UE max TX power in dBm	23dBm	23dBm	23dBm
UE min TX power in dBm	-40dBm	-40dBm	-40dBm
BS Noise figure in dB	Note 1	Note 1	Note 1
UE Noise figure in dB	Note 1	Note 1	Note 1
Handover margin	3dB	3dB	3dB
Note 1: For deriving ACIR/ACS values which are included in respond to WP5D, following NF are used in co-existence simulation study for both UE and BS. 30GHz: 9 and 11 dB, 45GHz: 11 and 13 dB, 70GHz: 13 and 15 dB.			

5.2.9 Noise figure

It is assumed that the performance differs less between UE and BS for mm-waves on transceiver level compared to lower frequencies below 6 GHz. The estimated NF for both BS and UE are used as same values for the ITU-R related coexistence simulations.

Two sets of noise figure values have been used for the simulations, as shown below in Table 5.2.9-1.

Table 5.2.9-1: Two sets of noise figure values for coexistence simulations

Frequency	Set 1		Set 2	
	UE	BS	UE	BS
30GHz	9dB	9dB	11dB	11dB
45GHz	11dB	11dB	13dB	13dB
70GHz	13dB	13dB	15dB	15dB

The following noise figure values are finally agreed for reporting to ITU WP5D sharing studies, as shown in Table 5.2.9-2.

Table 5.2.9-2: Noise figure values for ITU WP5D response

Frequency	UE	BS
30GHz	10dB	10dB
45GHz	12dB	12dB
70GHz	14dB	14dB

These NF values in Table 5.2.9-2 shall be used only for WP5D response. Further study on the actual noise figure to be used to define RF requirements for UE and BS shall be performed in the WI phase.

5.3 Co-existence simulation methodology

Adopt following simulation steps.

1. Aggressor and victim network are generated.
   - UEs are distributed randomly across the network.
2. UE associations: UEs are associated to base station based on coupling loss.
   - Associations are made assuming a single element at both UE and BS.
3. Once association is done, round robin scheduling is used. BF weights are adjusted to point to the LOS direction between BS-UE. This is done for both victim and aggressor networks.
4. Throughput is computed in the victim systems without considering ACI as below:
   - $Thput_{\mathrm{NO\ ACI}}[bpshz] = f(SINR_{ICI}) = f\left(\frac{S}{N+I_{ICI}}\right)$, where I_{ICI} is the inter-cell interference.
5. Throughput is computed considering ACI as below:
   - $\mathrm{Thput}_{\mathrm{ACI}}[\mathrm{bpshz}] = \mathrm{f}(\mathrm{SINR}_{\mathrm{ICI+ACI}}) = \mathrm{f}\left(\frac{\mathrm{S}}{\mathrm{N}+\mathrm{I}_{\mathrm{ICI}}+\mathrm{I}_{\mathrm{ACI}}}\right)$, where I_{ACI} is the adjacent channel interference.
6. RF parameters are determined based on the degradation cause by ACI as below:
   - $Loss_{ACI} = 1 - \frac{\mathrm{Thput}_{\mathrm{ACI}}}{\mathrm{Thput}_{\mathrm{SINGLE}}}$.

5.4 Co-existence simulation results

This sub-clause captures the co-existence simulation results in the simulation scenarios listed in Table 5.1.

5.4.1 Scenario 1: 30GHz DL Indoor scenario

Simulation results for the average throughput loss are presented in table 5.4.1-1, table 5.4.1-2 and figure 5.4.1-1. Simulation results for the 5%-tile throughput loss are presented in table 5.4.1-3, table 5.4.1-4 and figure 5.4.1-2.

Table 5.4.1-1: Simulation results for average throughput loss (NF = 9)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	17.80	10.36	5.42	2.53	1.02	0.33	0.10	0.03
Ericsson *	19.59	10.86	5.39	2.32	0.92	0.32	0.11	0.03
NEC	16.99	9.80	5.11	2.28	0.88	0.25	0.08	0.02
China Telecom								
Huawei	17.50	10.17	5.40	2.61	0.98	0.20	0.06	0.02
ZTE	17.66	10.55	5.71	2.76	1.12	0.33	0.08	0.02
Samsung	17.52	10.21	5.39	2.53	1.02	0.33	0.10	0.03
CATT	17.66	10.22	5.26	2.36	0.88	0.28	0.10	0.03
Qualcomm	17.97	10.60	5.68	2.77	1.08	0.24	0.06	0.02
Intel	17.92	10.58	5.37	2.50	1.03	0.32	0.09	0.02
LG	38.05	22.77	11.42	4.42	1.43	0.40	0.12	0.04
* NF = 10 is assumed								

Table 5.4.1-2: Simulation results for average throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	17.79	10.35	5.42	2.53	1.02	0.33	0.10	0.03
Ericsson								
NEC	18.61	10.87	5.65	2.68	1.06	0.28	0.08	0.02
China Telecom								
Huawei	17.50	10.18	5.40	2.61	0.99	0.21	0.06	0.02
ZTE	17.61	10.54	5.72	2.78	1.14	0.36	0.10	0.02
Samsung	17.51	10.21	5.39	2.53	1.02	0.34	0.10	0.03
CATT	17.65	10.22	5.26	2.36	0.88	0.29	0.10	0.03
Qualcomm	17.97	10.60	5.69	2.78	1.09	0.24	0.06	0.02
Intel	17.92	10.32	5.52	2.62	1.05	0.31	0.09	0.03
LG	38.05	22.77	11.42	4.42	1.43	0.40	0.12	0.04

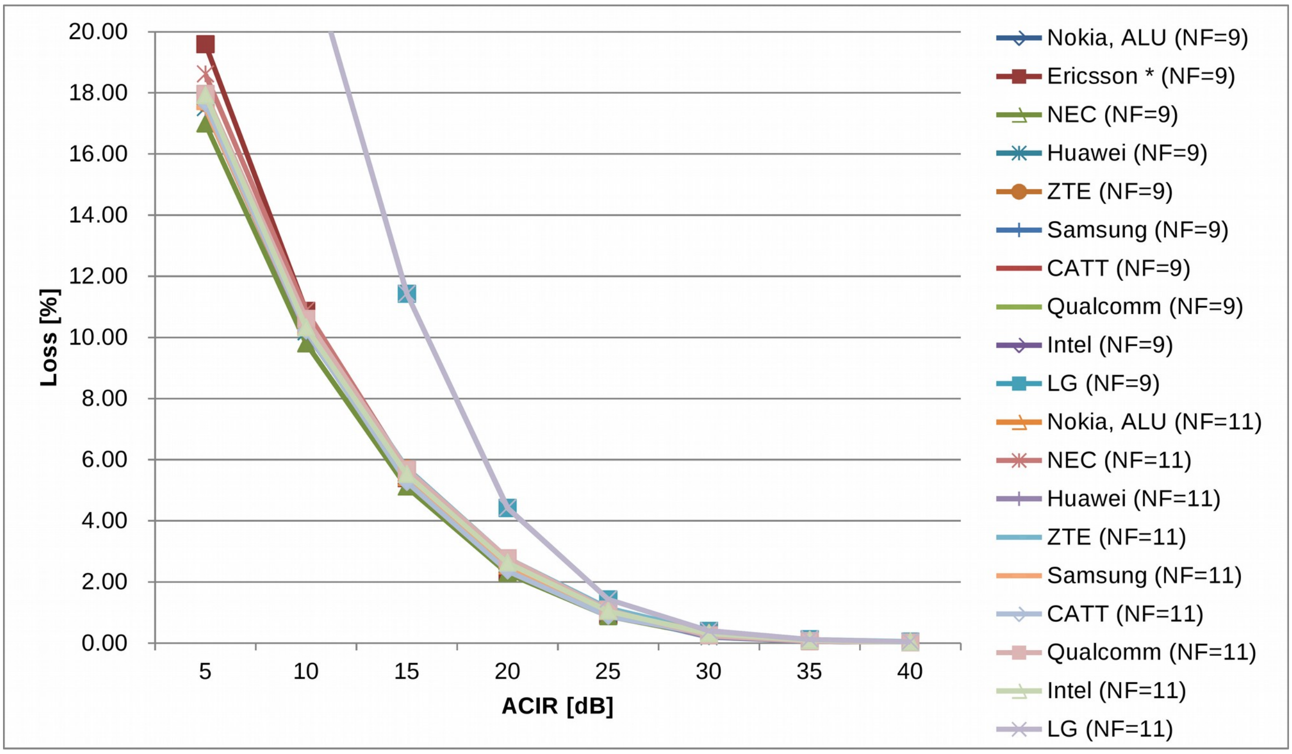


Figure 5.4.1-1: Simulation results for average throughput loss

Table 5.4.1-3: Simulation results for 5%-tile throughput loss (NF = 9)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	36.50	16.07	4.72	0.68	0.31	0.00	0.00	0.00
Ericsson *	24.05	13.21	6.72	3.02	0.94	0.17	0.08	0.02
NEC	28.70	17.03	1.15	0.00	0.00	0.00	0.00	0.00
China Telecom								
Huawei	45.20	19.54	3.28	0.40	0.13	0.01	0.00	0.00
ZTE	37.22	16.07	4.43	0.87	0.25	0.01	0.00	0.00
Samsung	34.46	15.04	4.18	1.02	0.33	0.10	0.03	0.01
CATT	26.67	7.82	3.32	0.34	0.04	0.01	0.00	0.00
Qualcomm	39.53	12.29	1.79	0.39	0.15	0.01	0.00	0.00
Intel	39.38	17.89	5.80	0.66	0.36	0.02	0.00	0.03
LG	42.11	16.92	5.40	1.49	0.48	0.14	0.04	0.01
* NF = 10 is assumed								

Table 5.4.1-4: Simulation results for 5%-tile throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	36.48	16.04	4.71	0.65	0.29	0.00	0.00	0.00
Ericsson								
NEC	33.29	14.56	5.82	2.08	0.83	0.42	0.42	0.00
China Telecom								
Huawei	45.19	19.54	3.29	0.38	0.15	0.03	0.01	0.00
ZTE	36.67	16.38	5.80	1.41	0.03	0.01	0.00	0.00
Samsung	34.46	15.06	4.18	1.07	0.33	0.10	0.03	0.01
CATT	26.66	7.83	3.32	0.34	0.04	0.01	0.00	0.00
Qualcomm	39.53	12.29	1.79	0.39	0.14	0.01	0.00	0.00
Intel	38.65	17.95	3.71	0.99	0.22	0.04	0.03	0.06
LG	42.11	16.92	5.40	1.49	0.48	0.14	0.04	0.01

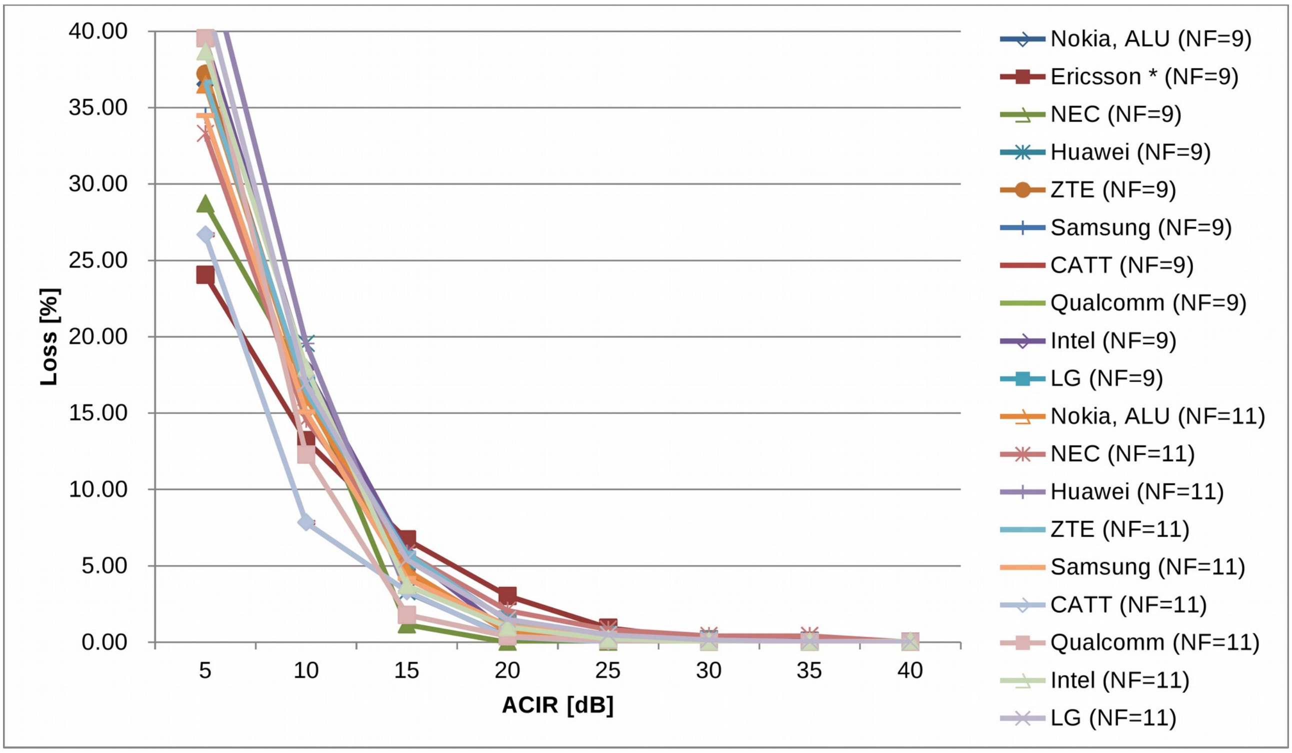


Figure 5.4.1-2: Simulation results for 5%-tile throughput loss

5.4.2 Scenario 2: 30GHz DL urban macro scenario

5.4.2.1 ISD = 200m case

Simulation results for the average throughput loss are presented in table 5.4.2.1-1, table 5.4.2.1-2 and figure 5.4.2.1-1. Simulation results for the 5%-tile throughput loss are presented in table 5.4.2.1-3, table 5.4.2.1-4 and figure 5.4.2.1-2.

Table 5.4.2.1-1: Simulation results for average throughput loss (NF = 9)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	9.84	5.92	3.44	1.89	0.92	0.38	0.16	0.07
Ericsson *	13.13	8.08	4.68	2.49	1.24	0.56	0.24	0.09
NEC	12.35	6.63	3.33	1.53	0.55	0.12	0.03	0.01
China Telecom	13.50	7.92	4.36	2.26	1.08	0.48	0.21	0.08
Huawei	12.01	7.24	4.10	2.17	1.06	0.48	0.21	0.09
ZTE	7.67	4.48	2.53	1.42	0.82	0.50	0.33	0.24
Samsung	7.90	4.17	2.11	0.99	0.33	0.05	0.01	0.00
CATT	13.92	8.60	5.06	2.78	1.39	0.63	0.28	0.10
Qualcomm	11.98	6.46	3.31	1.56	0.56	0.11	0.03	0.01
Intel	7.55	3.52	2.08	1.04	0.47	0.18	0.05	0.02
LG	10.63	3.43	0.00	0.00	0.00	0.00	0.00	0.00
* NF = 10 is assumed								

Table 5.4.2.1-2: Simulation results for average throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	9.81	5.90	3.42	1.88	0.92	0.38	0.16	0.07
Ericsson								
NEC	12.34	6.63	3.34	1.54	0.55	0.12	0.03	0.01
China Telecom	13.43	7.88	4.34	2.25	1.07	0.48	0.20	0.08
Huawei	11.96	7.21	4.08	2.16	1.06	0.48	0.21	0.09
ZTE	7.89	4.63	2.63	1.49	0.87	0.55	0.38	0.28
Samsung	7.88	4.16	2.11	0.99	0.33	0.05	0.01	0.00
CATT	13.88	8.58	5.05	2.78	1.39	0.64	0.28	0.11
Qualcomm	11.96	6.45	3.30	1.56	0.56	0.11	0.03	0.01
Intel	7.15	3.94	1.91	1.20	0.42	0.10	0.05	0.02
LG	11.22	4.18	0.00	0.00	0.00	0.00	0.00	0.00

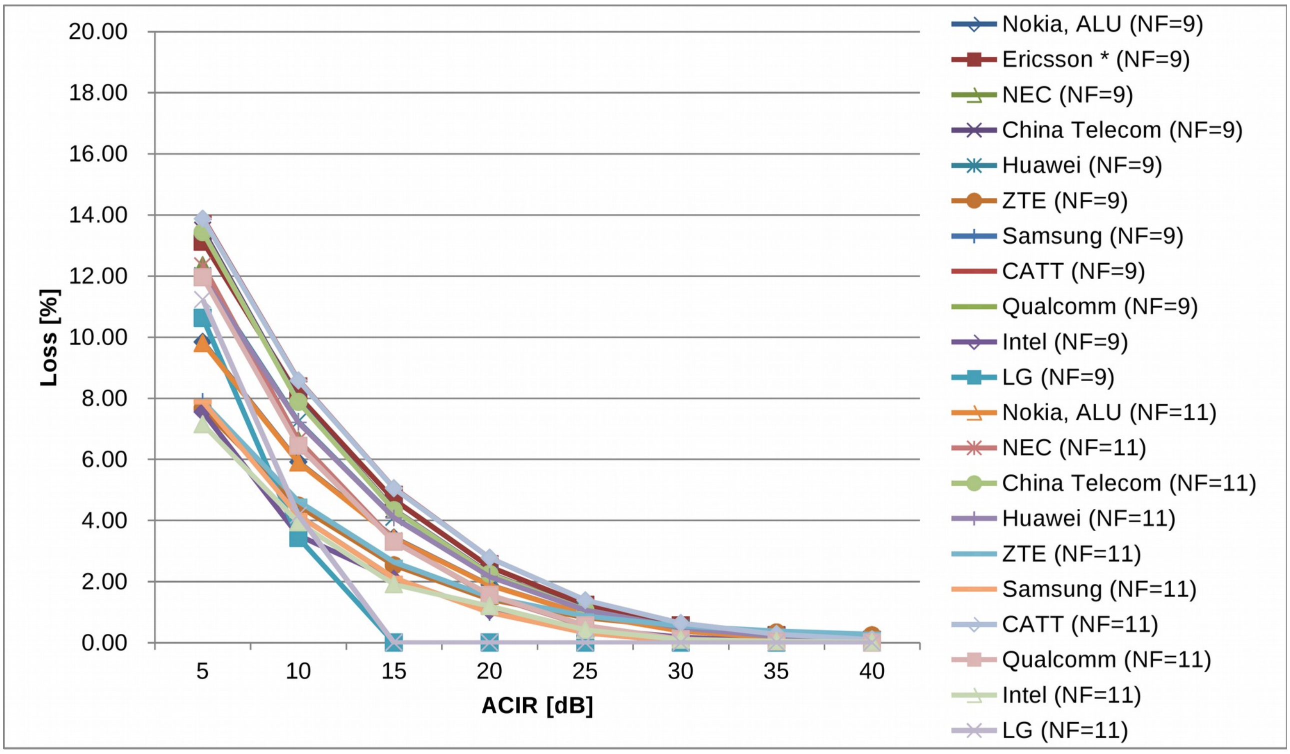


Figure 5.4.2.1-1: Simulation results for average throughput loss

Table 5.4.2.1-3: Simulation results for 5%-tile throughput loss (NF = 9)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	46.27	26.18	13.51	4.83	1.78	0.58	0.00	0.00
Ericsson *	21.90	12.93	6.78	4.38	1.66	0.36	0.20	0.05
NEC	19.32	7.49	2.13	0.35	0.09	0.03	0.01	0.00
China Telecom	43.91	26.01	11.25	5.59	1.90	0.55	0.18	0.00
Huawei	45.39	25.78	14.57	7.41	3.84	1.61	0.16	0.00
ZTE	36.13	22.95	13.57	8.47	4.85	3.43	2.65	2.33
Samsung	33.65	15.30	1.07	0.36	0.12	0.02	0.01	0.00
CATT	40.53	28.12	14.33	5.50	1.15	0.00	0.00	0.00
Qualcomm	34.76	14.04	1.09	0.35	0.08	0.02	0.01	0.00
Intel	25.10	12.13	6.75	0.85	0.00	0.00	0.00	0.00
LG	45.33	27.98	16.26	8.16	3.55	1.31	0.61	0.08
* NF = 10 is assumed								

Table 5.4.2.1-4: Simulation results for 5%-tile throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	43.28	22.16	14.58	4.90	4.59	1.49	0.00	0.00
Ericsson								
NEC	18.12	6.43	1.38	0.25	0.07	0.00	0.00	0.00
China Telecom	42.60	23.64	12.15	5.03	1.97	1.19	0.32	0.00
Huawei	43.17	25.86	13.19	6.25	3.44	1.14	0.28	0.00
ZTE	37.22	22.97	14.49	8.43	6.13	4.17	3.30	2.49
Samsung	31.03	11.68	0.61	0.10	0..02	0.00	0.00	0.00
CATT	44.52	30.76	20.46	7.24	4.33	1.49	0.62	0.04
Qualcomm	33.20	11.20	1.39	0.30	0.04	0.03	0.00	0.00
Intel	27.02	11.79	7.25	3.49	1.00	0.04	0.00	0.00
LG	43.72	26.95	14.81	7.47	3.21	1.11	0.39	0.04

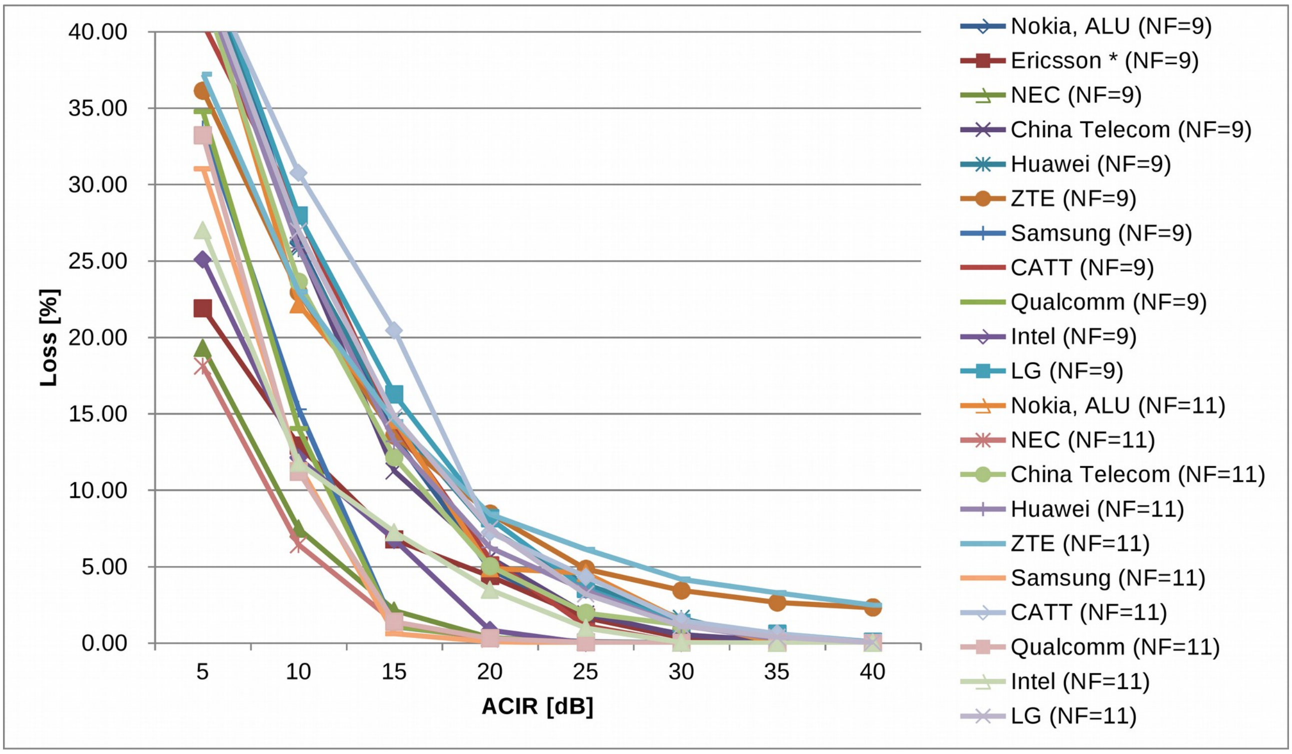


Figure 5.4.2.1-2: Simulation results for 5%-tile throughput loss

5.4.2.2 ISD = 300m case

Simulation results for the average throughput loss are presented in table 5.4.2.2-1, table 5.4.2.2-2 and figure 5.4.2.2-1. Simulation results for the 5%-tile throughput loss are presented in table 5.4.2.2-3, table 5.4.2.2-4 and figure 5.4.2.2-2.

Table 5.4.2.2-1: Simulation results for average throughput loss (NF = 9)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	11.57	7.90	4.52	2.61	1.36	0.63	0.29	0.13
Ericsson *								
NEC	12.56	6.75	3.41	1.59	0.59	0.14	0.04	0.01
China Telecom	15.69	9.85	5.81	3.23	1.70	0.85	0.40	0.18
Huawei	13.95	8.93	5.43	3.17	1.75	0.92	0.46	0.21
ZTE								
Samsung	8.50	4.51	2.30	1.10	0.39	0.06	0.02	0.00
CATT								
Qualcomm	12.20	6.58	3.38	1.60	0.58	0.12	0.03	0.01
Intel	8.41	5.35	2.85	1.72	0.59	0.31	0.19	0.05
LG	16.50	9.54	4.49	1.07	0.00	0.00	0.00	0.00
* NF = 10 is assumed								

Table 5.4.2.2-2: Simulation results for average throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	11.49	7.34	4.49	2.59	1.34	0.63	0.29	0.12
Ericsson								
NEC	12.43	6.68	3.38	1.57	0.58	0.14	0.04	0.01
China Telecom	15.60	9.80	5.79	3.21	1.69	0.85	0.40	0.18
Huawei	13.82	8.84	5.37	3.13	1.73	0.91	0.45	0.21
ZTE								
Samsung	8.47	4.50	2.30	1.10	0.39	0.06	0.02	0.01
CATT								
Qualcomm	12.14	6.54	3.37	1.60	0.58	0.12	0.03	0.01
Intel	8.27	4.80	2.58	1.56	0.62	0.28	0.15	0.06
LG	17.33	10.61	5.85	2.63	0.46	0.00	0.00	0.00

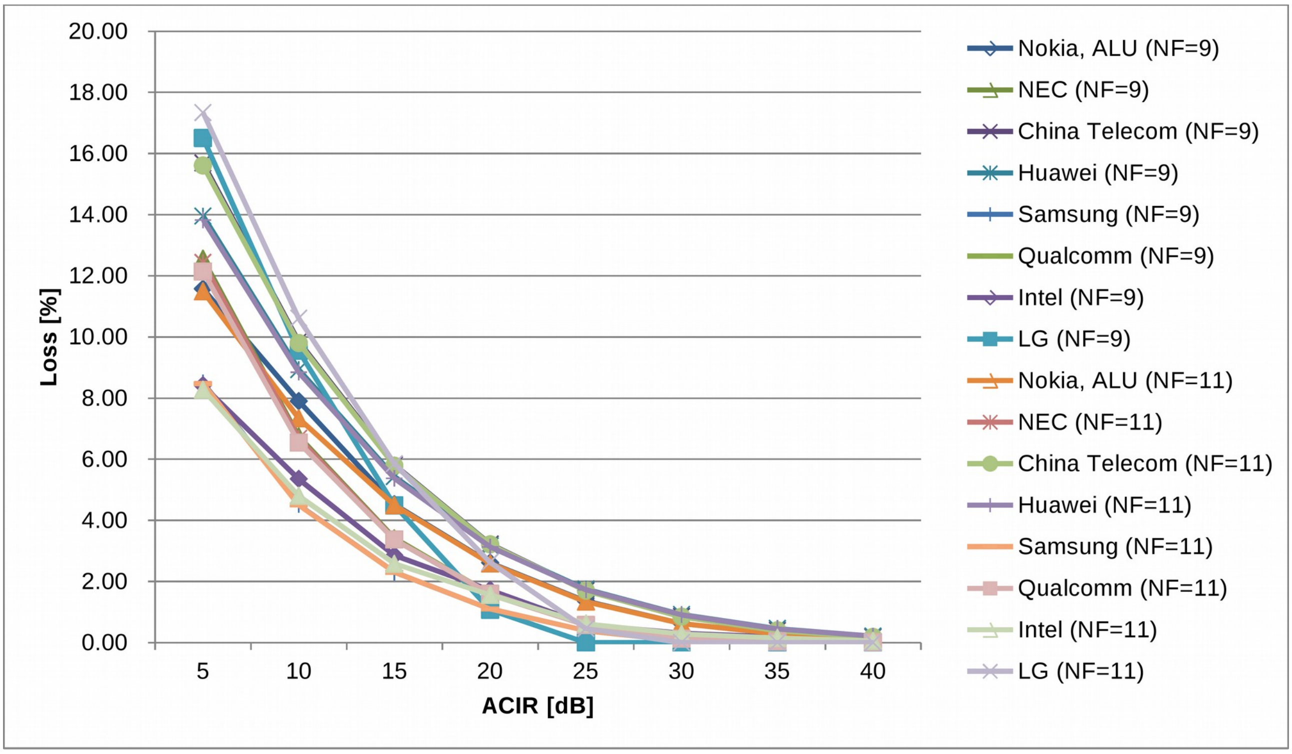


Figure 5.4.2.2-1: Simulation results for average throughput loss

Table 5.4.2.2-3: Simulation results for 5%-tile throughput loss (NF = 9)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	47.92	29.33	14.57	6.19	4.22	0.00	0.00	0.00
Ericsson *								
NEC	13.67	2.37	0.39	0.10	0.06	0.01	0.00	0.00
China Telecom	59.18	40.05	24.76	11.74	6.14	2.26	1.23	0.31
Huawei	55.54	37.54	22.73	14.48	5.32	2.27	1.32	0.44
ZTE								
Samsung	21.72	1.53	0.23	0.11	0.00	0.00	0.00	0.00
CATT								
Qualcomm	26.00	2.90	0.38	0.05	0.00	0.00	0.00	0.00
Intel	32.72	18.80	10.34	3.79	0.76	2.00	0.90	0.00
LG	46.85	29.17	16.25	8.14	3.47	1.26	0.39	0.06
* NF = 10 is assumed								

Table 5.4.2.2-4: Simulation results for 5%-tile throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	45.15	28.26	13.64	4.23	4.12	0.00	0.00	0.00
Ericsson								
NEC	8.98	1.38	0.32	0.11	0.06	0.01	0.00	0.00
China Telecom	58.18	39.98	24.17	13.65	5.99	1.60	0.55	0.00
Huawei	55.70	35.19	22.57	12.36	5.99	2.30	1.10	0.00
ZTE								
Samsung	13.40	0.85	0.29	0.03	0.01	0.00	0.00	0.00
CATT								
Qualcomm	20.61	1.76	0.38	0.05	0.04	0.00	0.00	0.00
Intel	31.48	17.95	9.55	4.10	0.54	0.00	0.22	0.00
LG	45.13	28.32	15.43	7.73	3.26	1.09	0.19	0.02

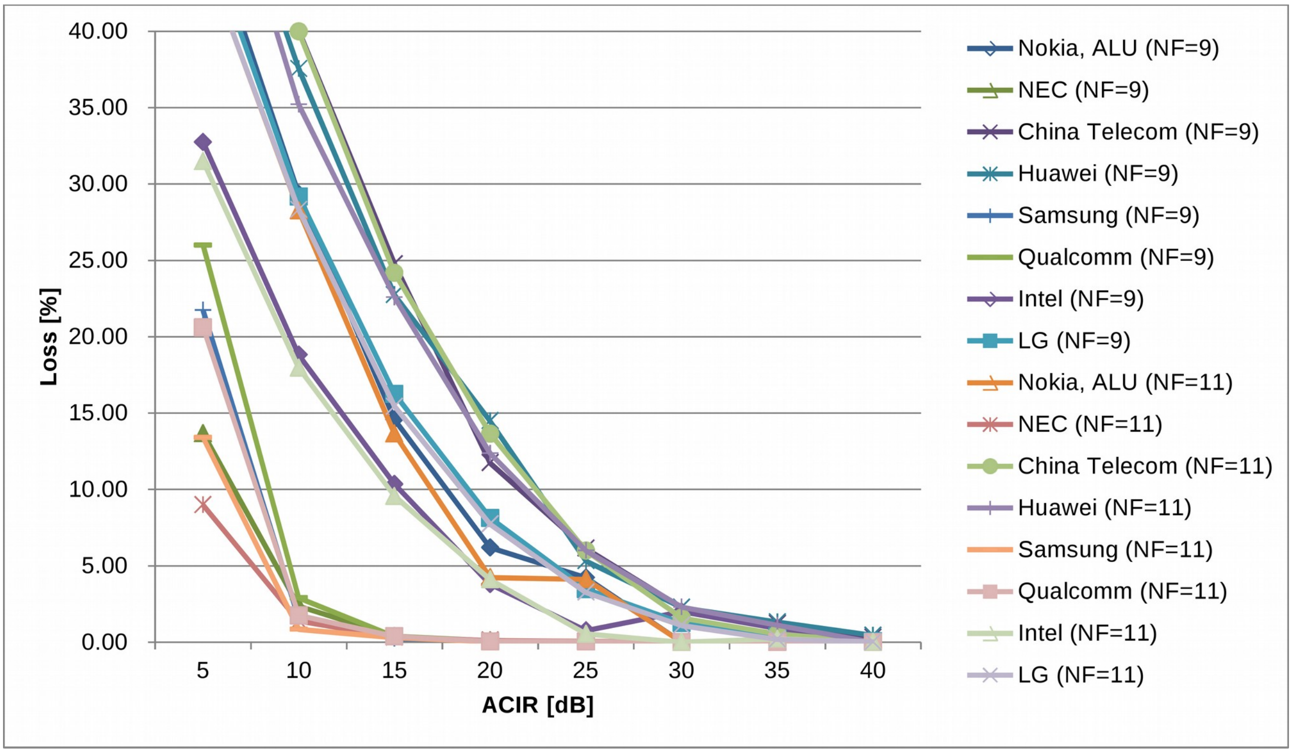


Figure 5.4.2.2-2: Simulation results for 5%-tile throughput loss

5.4.3 Scenario 3: 30GHz DL dense urban scenario

Simulation results for the average throughput loss are presented in table 5.4.3-1, table 5.4.3-2 and figure 5.4.3-1. Simulation results for the 5%-tile throughput loss are presented in table 5.4.3-3, table 5.4.3-4 and figure 5.4.3-2.

Table 5.4.3-1: Simulation results for average throughput loss (NF = 9)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	4.92	2.54	1.20	0.53	0.23	0.09	0.03	0.01
Ericsson *	11.13	6.31	3.36	1.65	0.77	0.33	0.14	0.05
NEC	8.89	4.71	2.31	1.04	0.43	0.15	0.05	0.02
China Telecom								
Huawei	6.17	3.38	1.72	0.82	0.37	0.15	0.06	0.02
ZTE	5.02	2.78	1.46	0.72	0.32	0.12	0.04	0.01
Samsung	4.76	2.60	1.34	0.66	0.30	0.13	0.05	0.02
CATT	8.86	5.05	2.73	1.39	0.66	0.31	0.13	0.05
Qualcomm	5.58	2.99	1.51	0.71	0.31	0.12	0.05	0.02
Intel	3.94	2.20	1.62	0.60	0.22	0.06	0.03	0.01
LG	7.54	3.05	0.00	0.00	0.00	0.00	0.00	0.00
* NF = 10 is assumed								

Table 5.4.3-2: Simulation results for average throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	4.79	2.47	1.17	0.52	0.22	0.03	0.08	0.01
Ericsson								
NEC	8.39	4.40	2.11	0.94	0.40	0.16	0.06	0.02
China Telecom								
Huawei	6.00	3.27	1.64	0.78	0.34	0.14	0.05	0.02
ZTE	5.23	2.87	1.47	0.67	0.27	0.09	0.03	0.01
Samsung	4.62	2.51	1.29	0.63	0.29	0.12	0.05	0.02
CATT	8.68	4.93	2.68	1.36	0.65	0.30	0.13	0.05
Qualcomm	5.40	2.89	1.45	0.68	0.30	0.12	0.05	0.02
Intel	4.66	2.08	1.18	0.34	0.23	0.04	0.01	0.01
LG	9.73	5.27	2.35	0.51	0.00	0.00	0.00	0.00

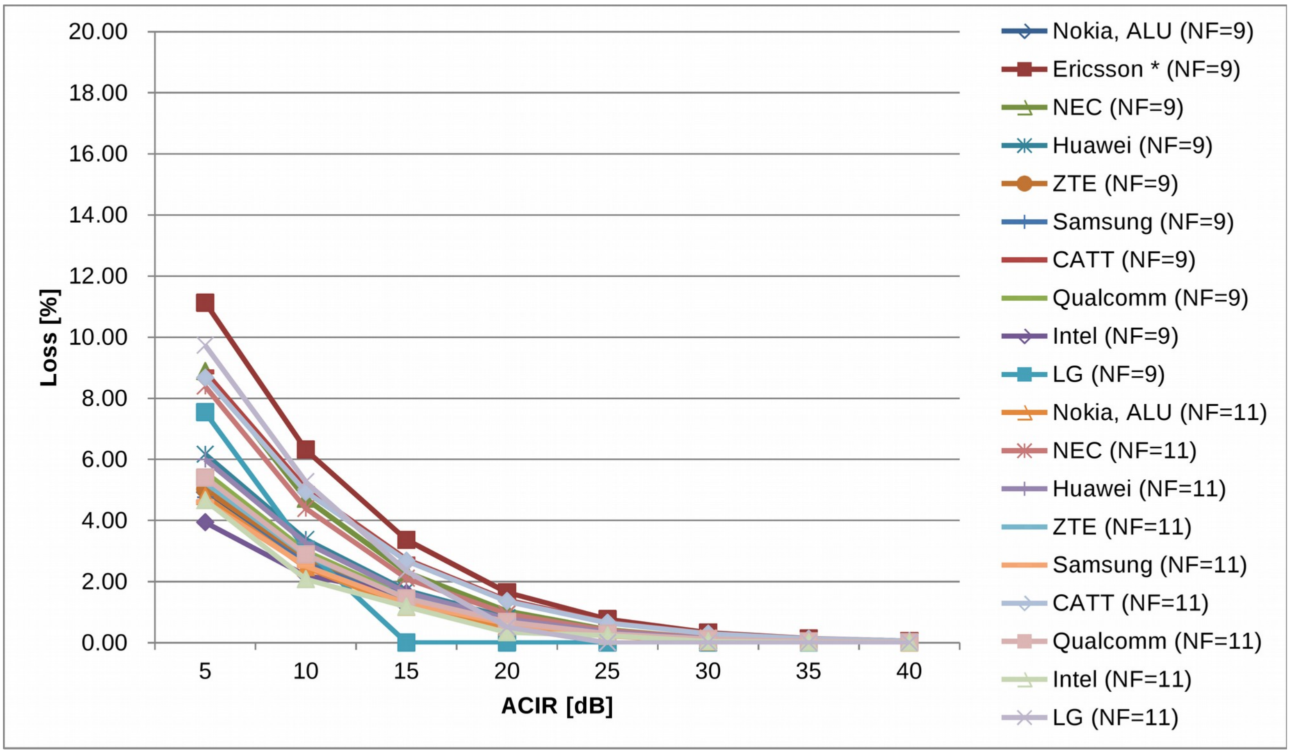


Figure 5.4.3-1: Simulation results for average throughput loss

Table 5.4.3-3: Simulation results for 5%-tile throughput loss (NF = 9)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	6.51	3.32	1.23	0.38	0.03	0.03	0.00	0.00
Ericsson *	18.67	9.29	4.66	1.95	1.01	0.06	0.01	0.06
NEC	11.79	5.50	1.83	0.25	0.04	0.01	0.00	0.00
China Telecom								
Huawei	15.70	6.89	1.97	0.35	0.00	0.00	0.00	0.00
ZTE	30.42	17.84	10.65	3.24	1.63	1.11	0.00	0.00
Samsung	9.33	3.82	1.34	0.60	0.04	0.04	0.00	0.00
CATT	21.60	11.62	3.62	1.90	0.37	0.12	0.04	0.01
Qualcomm	11.37	5.21	1.95	0.75	0.28	0.11	0.05	0.00
Intel	7.05	0.07	0.86	0.00	0.00	0.00	0.00	0.00
LG	21.96	11.54	5.29	2.09	0.90	0.40	0.14	0.05
* NF = 10 is assumed								

Table 5.4.3-4: Simulation results for 5%-tile throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	7.04	4.14	0.79	0.40	0.00	0.00	0.00	0.00
Ericsson								
NEC	7.09	3.01	1.32	0.45	0.09	0.03	0.01	0.00
China Telecom								
Huawei	13.76	7.28	3.10	0.01	0.00	0.00	0.00	0.00
ZTE	24.68	15.54	7.31	1.97	0.31	0.00	0.00	0.00
Samsung	7.19	2.82	1.20	0.46	0.18	0.00	0.00	0.00
CATT	23.09	9.78	2.97	0.40	0.13	0.03	0.00	0.00
Qualcomm	9.54	3.81	1.44	0.40	0.09	0.01	0.01	0.00
Intel	2.75	1.20	0.19	0.00	0.00	0.00	0.00	0.00
LG	20.03	9.88	4.58	2.11	0.79	0.34	0.05	0.02

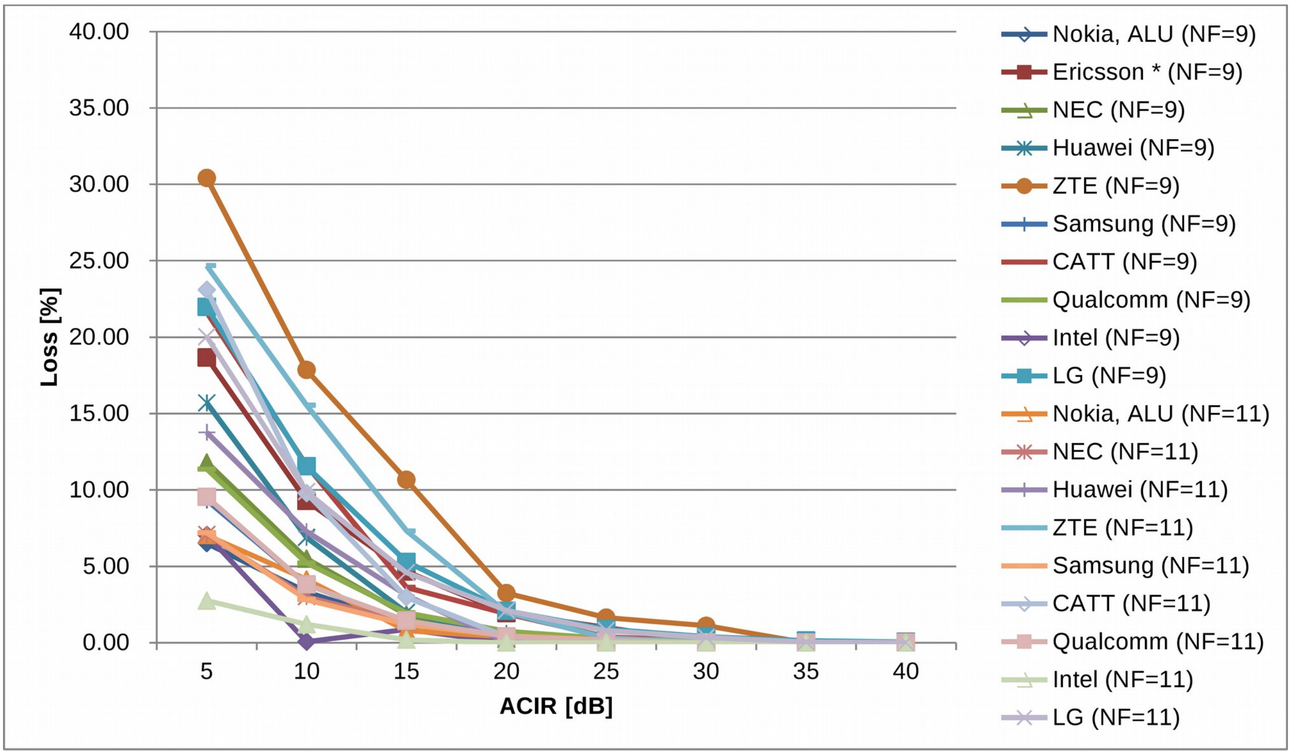


Figure 5.4.3-2: Simulation results for 5%-tile throughput loss

5.4.4 Scenario 4: 30GHz UL indoor scenario

Simulation results for the average throughput loss are presented in table 5.4.4-1, table 5.4.4-2 and figure 5.4.4-1. Simulation results for the 5%-tile throughput loss are presented in table 5.4.4-3, table 5.4.4-4 and figure 5.4.4-2.

Table 5.4.4-1: Simulation results for average throughput loss (NF = 9)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	10.59	5.47	2.51	1.02	0.37	0.13	0.04	0.01
Ericsson *	15.80	8.30	3.91	1.61	0.61	0.21	0.07	0.02
NEC	10.38	5.26	2.30	0.87	0.30	0.10	0.03	0.01
China Telecom								
Huawei	9.52	4.83	2.13	0.81	0.28	0.09	0.03	0.01
ZTE	11.25	5.88	2.67	0.97	0.24	0.05	0.01	0.00
Samsung	8.61	4.20	1.81	0.69	0.24	0.08	0.03	0.01
CATT	7.88	3.75	1.58	0.60	0.22	0.07	0.02	0.01
Qualcomm	7.39	3.41	1.34	0.47	0.15	0.05	0.02	0.00
Intel	9.73	4.95	2.16	0.84	0.30	0.10	0.03	0.01
LG	35.03	20.67	10.20	3.98	1.24	0.39	0.11	0.03
* NF = 10 is assumed								

Table 5.4.4-2: Simulation results for average throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	9.28	4.63	2.04	0.80	0.28	0.09	0.03	0.01
Ericsson								
NEC	8.45	3.99	1.63	0.58	0.19	0.06	0.02	0.01
China Telecom								
Huawei	8.24	4.01	1.68	0.61	0.21	0.07	0.02	0.01
ZTE	11.44	6.01	2.74	1.00	0.27	0.07	0.02	0.00
Samsung	8.61	4.20	1.81	0.69	0.24	0.08	0.03	0.01
CATT	6.76	3.09	1.26	0.47	0.16	0.05	0.02	0.01
Qualcomm	6.25	2.73	1.02	0.35	0.11	0.04	0.01	0.00
Intel	8.55	4.07	1.74	0.66	0.24	0.07	0.02	0.01
LG	32.43	18.56	8.91	3.41	1.05	0.33	0.09	0.03

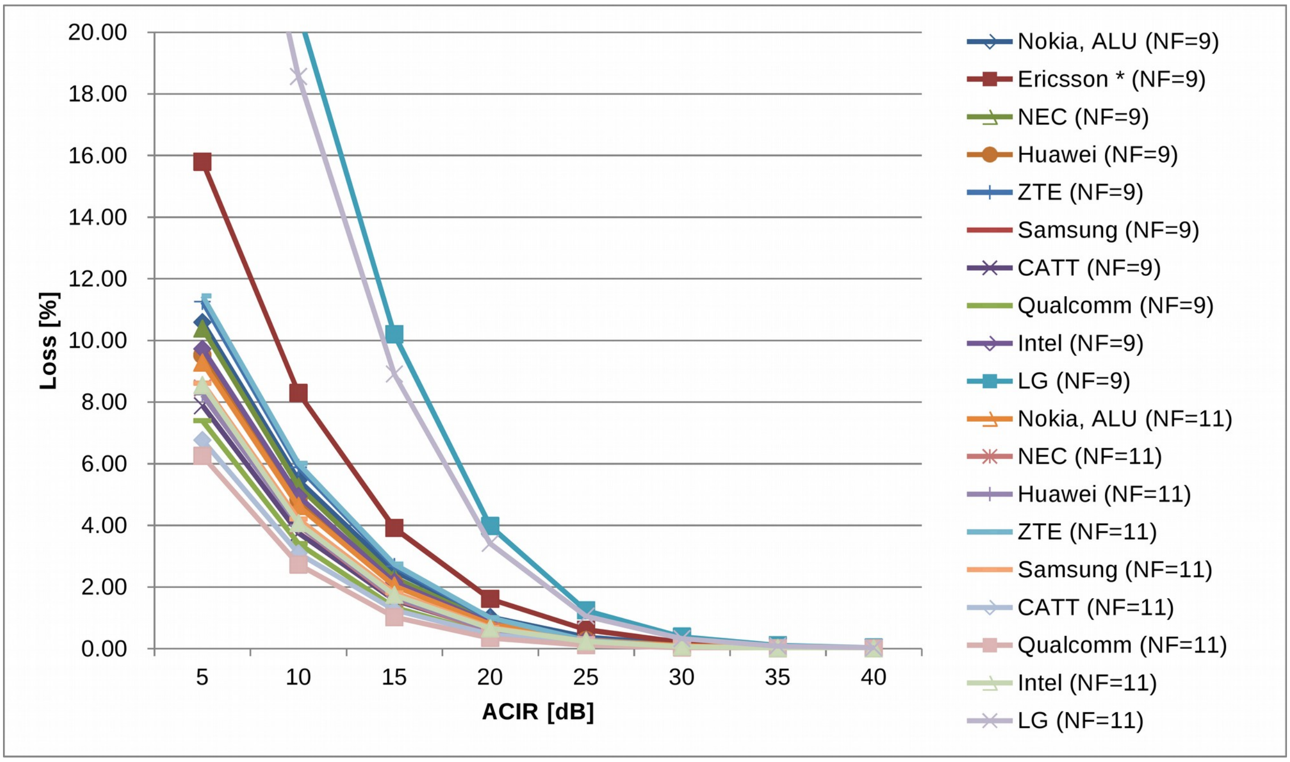


Figure 5.4.4-1: Simulation results for average throughput loss

Table 5.4.4-3: Simulation results for 5%-tile throughput loss (NF = 9)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	36.67	16.69	4.63	0.47	0.04	0.03	0.02	0.02
Ericsson *	25.12	11.69	4.46	1.52	0.30	0.15	0.02	0.00
NEC	25.50	2.25	0.00	0.00	0.00	0.00	0.00	0.00
China Telecom								
Huawei	40.71	15.43	1.55	0.49	0.16	0.00	0.00	0.00
ZTE	38.01	17.20	4.61	0.93	0.07	0.07	0.07	0.05
Samsung	31.18	13.37	3.72	0.52	0.22	0.08	0.05	0.00
CATT	22.11	4.11	1.26	0.25	0.03	0.01	0.00	0.00
Qualcomm	33.57	10.18	0.81	0.18	0.05	0.02	0.00	0.00
Intel	35.09	15.30	4.43	1.09	0.05	0.05	0.00	0.00
LG	33.24	10.24	2.47	0.66	0.17	0.11	0.03	0.01
* NF = 10 is assumed								

Table 5.4.4-4: Simulation results for 5%-tile throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	35.44	15.85	4.35	0.44	0.04	0.03	0.02	0.02
Ericsson								
NEC	24.00	7.89	2.06	1.03	0.11	0.00	0.00	0.00
China Telecom								
Huawei	38.95	14.28	1.40	0.44	0.14	0.00	0.00	0.00
ZTE	36.20	16.35	4.78	1.56	0.35	0.00	0.00	0.00
Samsung	31.18	13.37	3.72	0.52	0.22	0.08	0.05	0.00
CATT	21.26	3.90	1.18	0.24	0.03	0.01	0.00	0.00
Qualcomm	30.70	8.86	0.69	0.15	0.04	0.02	0.00	0.00
Intel	33.09	14.52	2.95	0.68	0.13	0.17	0.00	0.01
LG	32.96	10.12	2.44	0.65	0.17	0.11	0.03	0.01

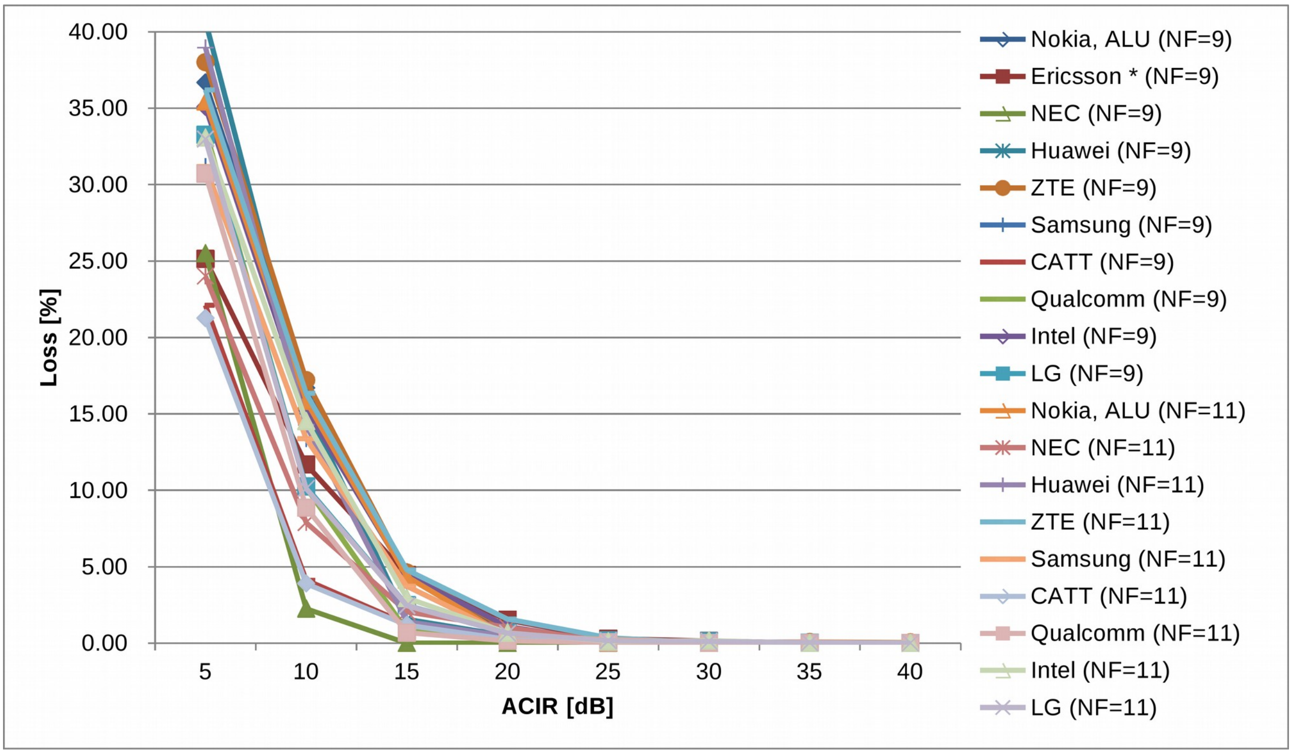


Figure 5.4.4-2: Simulation results for 5%-tile throughput loss

5.4.5 Scenario 5: 30GHz UL urban macro scenario

5.4.5.1 ISD = 200m case

Simulation results for the average throughput loss are presented in table 5.4.5.1-1, table 5.4.5.1-2 and figure 5.4.5.1-1. Simulation results for the 5%-tile throughput loss are presented in table 5.4.5.1-3, table 5.4.5.1-4 and figure 5.4.5.1-2.

Table 5.4.5.1-1: Simulation results for average throughput loss (NF = 9)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	5.34	2.92	1.51	0.74	0.35	0.15	0.06	0.02
Ericsson *	7.16	3.75	1.81	0.78	0.32	0.11	0.04	0.01
NEC	5.38	2.60	1.10	0.41	0.14	0.05	0.01	0.00
China Telecom	7.18	4.05	2.15	1.08	0.51	0.23	0.10	0.04
Huawei	6.38	3.57	1.88	0.93	0.43	0.19	0.07	0.03
ZTE	2.38	1.15	0.52	0.22	0.09	0.03	0.01	0.00
Samsung	2.46	1.16	0.48	0.17	0.06	0.02	0.01	0.00
CATT	8.15	4.67	2.52	1.29	0.62	0.27	0.11	0.04
Qualcomm	5.16	2.51	1.07	0.40	0.14	0.04	0.01	0.00
Intel	3.22	1.58	0.82	0.36	0.11	0.06	0.02	0.01
LG	2.71	1.36	0.71	0.38	0.21	0.11	0.06	0.03
* NF = 10 is assumed								

Table 5.4.5.1-2: Simulation results for average throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	4.62	2.48	1.26	0.61	0.28	0.12	0.05	0.02
Ericsson								
NEC	4.52	2.09	0.84	0.30	0.10	0.03	0.01	0.00
China Telecom	6.34	3.52	1.83	0.89	0.42	0.18	0.07	0.03
Huawei	5.59	3.06	1.56	0.74	0.33	0.13	0.05	0.02
ZTE	1.17	0.58	0.31	0.16	0.09	0.05	0.02	0.01
Samsung	2.42	1.14	0.47	0.17	0.06	0.02	0.01	0.00
CATT	7.23	4.06	2.15	1.08	0.51	0.22	0.08	0.03
Qualcomm	4.35	2.03	0.82	0.29	0.10	0.03	0.01	0.00
Intel	2.69	1.26	0.55	0.28	0.09	0.02	0.01	0.00
LG	1.92	0.95	0.49	0.27	0.14	0.08	0.04	0.02

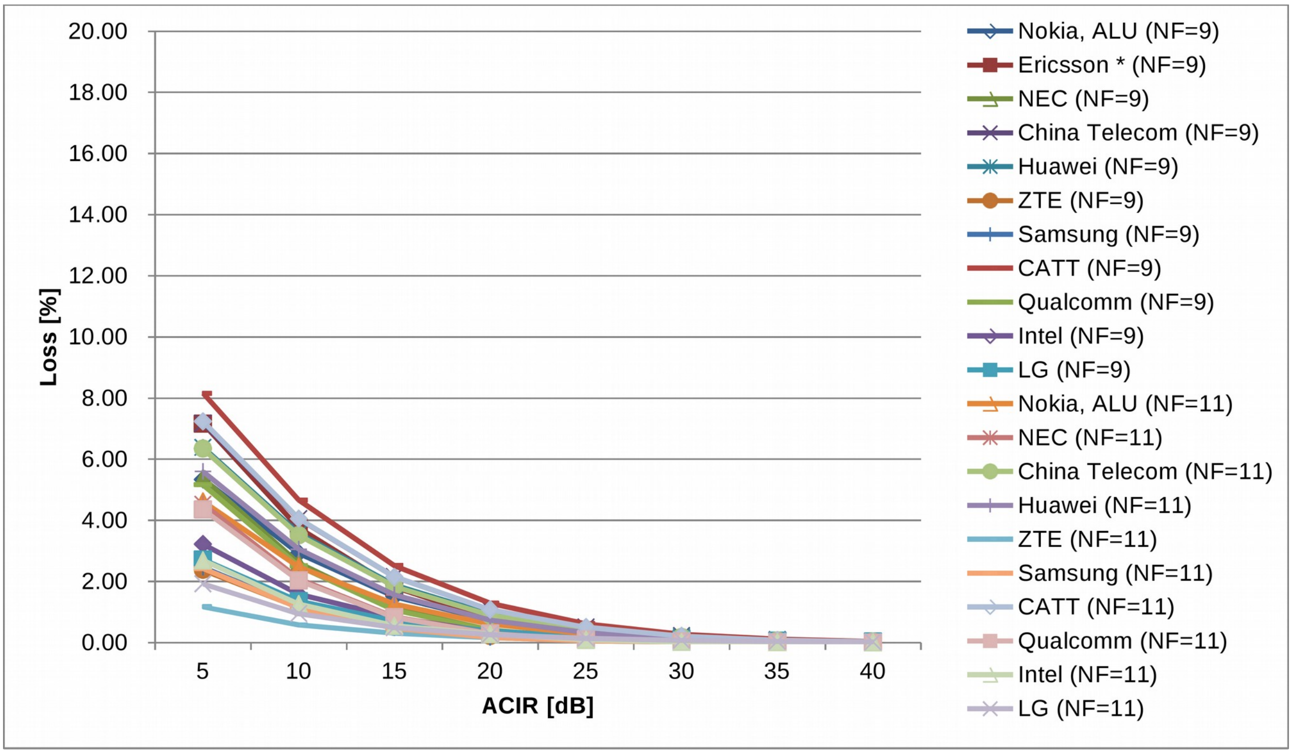


Figure 5.4.5.1-1: Simulation results for average throughput loss

Table 5.4.5.1-3: Simulation results for 5%-tile throughput loss (NF = 9)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	22.35	12.35	4.91	3.41	2.94	1.58	1.03	0.15
Ericsson *	14.48	7.84	3.12	0.45	0.11	0.00	0.00	0.00
NEC	22.13	9.15	3.73	1.10	0.36	0.17	0.08	0.00
China Telecom	37.61	21.97	12.52	5.87	2.23	0.32	0.06	0.06
Huawei	32.53	16.15	6.87	2.09	0.50	0.18	0.00	0.00
ZTE	18.23	7.16	2.38	0.73	0.03	0.03	0.01	0.00
Samsung	8.14	3.50	1.33	0.44	0.10	0.00	0.00	0.00
CATT	55.93	28.89	15.00	3.36	0.05	0.02	0.00	0.00
Qualcomm	13.70	6.53	3.08	1.25	0.29	0.10	0.00	0.00
Intel	22.39	8.50	1.03	0.06	0.02	0.18	0.00	0.00
LG	33.75	19.16	9.04	3.80	1.37	0.52	0.04	0.00
* NF = 10 is assumed								

Table 5.4.5.1-4: Simulation results for 5%-tile throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	20.01	7.47	5.07	0.49	0.05	0.04	0.00	0.00
Ericsson								
NEC	19.53	8.56	3.43	1.35	0.33	0.05	0.05	0.03
China Telecom	32.46	20.67	11.88	3.72	0.82	0.27	0.00	0.00
Huawei	25.84	14.77	6.41	4.72	0.71	0.51	0.01	0.00
ZTE	18.22	10.90	5.55	2.78	1.16	0.37	0.12	0.04
Samsung	8.56	3.57	1.42	0.48	0.04	0.00	0.00	0.00
CATT	47.26	23.90	10.55	8.84	2.01	0.00	0.00	0.00
Qualcomm	10.82	4.74	2.31	0.76	0.52	0.18	0.03	0.00
Intel	16.57	4.50	2.23	0.03	0.00	0.01	0.01	0.00
LG	31.66	17.42	8.77	3.34	0.89	0.22	0.10	0.05

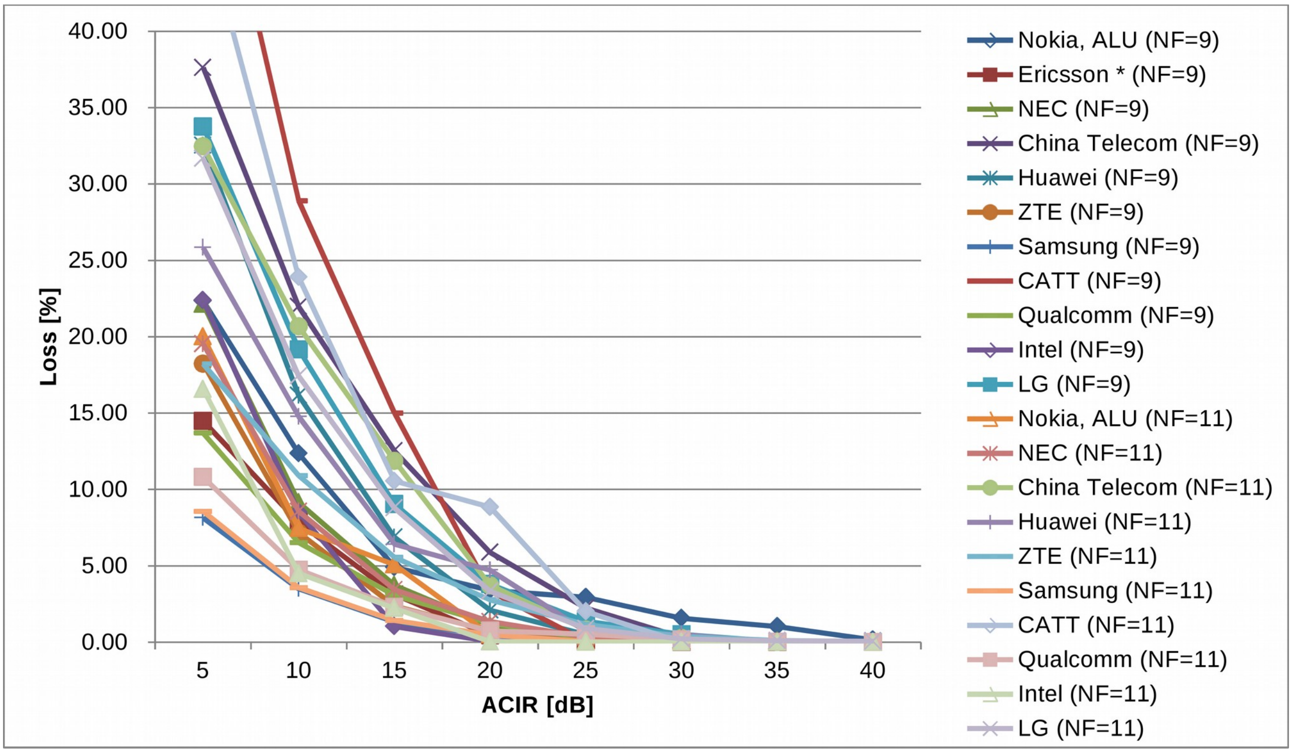


Figure 5.4.5.1-2: Simulation results for 5%-tile throughput loss

5.4.5.2 ISD = 300m case

Simulation results for the average throughput loss are presented in table 5.4.5.2-1, table 5.4.5.2-2 and figure 5.4.5.2-1. Simulation results for the 5%-tile throughput loss are presented in table 5.4.5.2-3, table 5.4.5.2-4 and figure 5.4.5.2-2.

Table 5.4.5.2-1: Simulation results for average throughput loss (NF = 9)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	6.13	3.48	1.88	0.97	0.48	0.22	0.09	0.03
Ericsson *								
NEC	5.01	2.42	1.02	0.38	0.13	0.04	0.01	0.00
China Telecom	9.35	5.39	2.89	1.45	1.29	0.30	0.13	0.05
Huawei	8.70	5.29	3.06	1.68	0.86	0.40	0.17	0.06
ZTE								
Samsung	2.51	1.19	0.49	0.18	0.06	0.02	0.01	0.00
CATT								
Qualcomm	4.89	2.37	1.01	0.37	0.13	0.04	0.01	0.00
Intel	3.74	2.28	1.07	0.52	0.16	0.08	0.04	0.01
LG	4.41	2.22	1.14	0.60	0.31	0.16	0.08	0.04
* NF = 10 is assumed								

Table 5.4.5.2-2: Simulation results for average throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	5.34	2.98	1.58	0.81	0.39	0.17	0.07	0.03
Ericsson								
NEC	4.23	1.96	0.79	0.28	0.09	0.03	0.01	0.00
China Telecom	8.29	4.68	2.46	1.21	0.56	0.24	0.10	0.04
Huawei	7.73	4.64	2.65	1.42	0.71	0.32	0.13	0.05
ZTE								
Samsung	2.44	1.15	0.47	0.17	0.36	0.17	0.07	0.03
CATT								
Qualcomm	4.10	1.91	0.77	0.27	0.09	0.03	0.01	0.00
Intel	3.17	1.62	0.81	0.43	0.14	0.05	0.03	0.01
LG	3.22	1.57	0.79	0.42	0.22	0.11	0.06	0.03

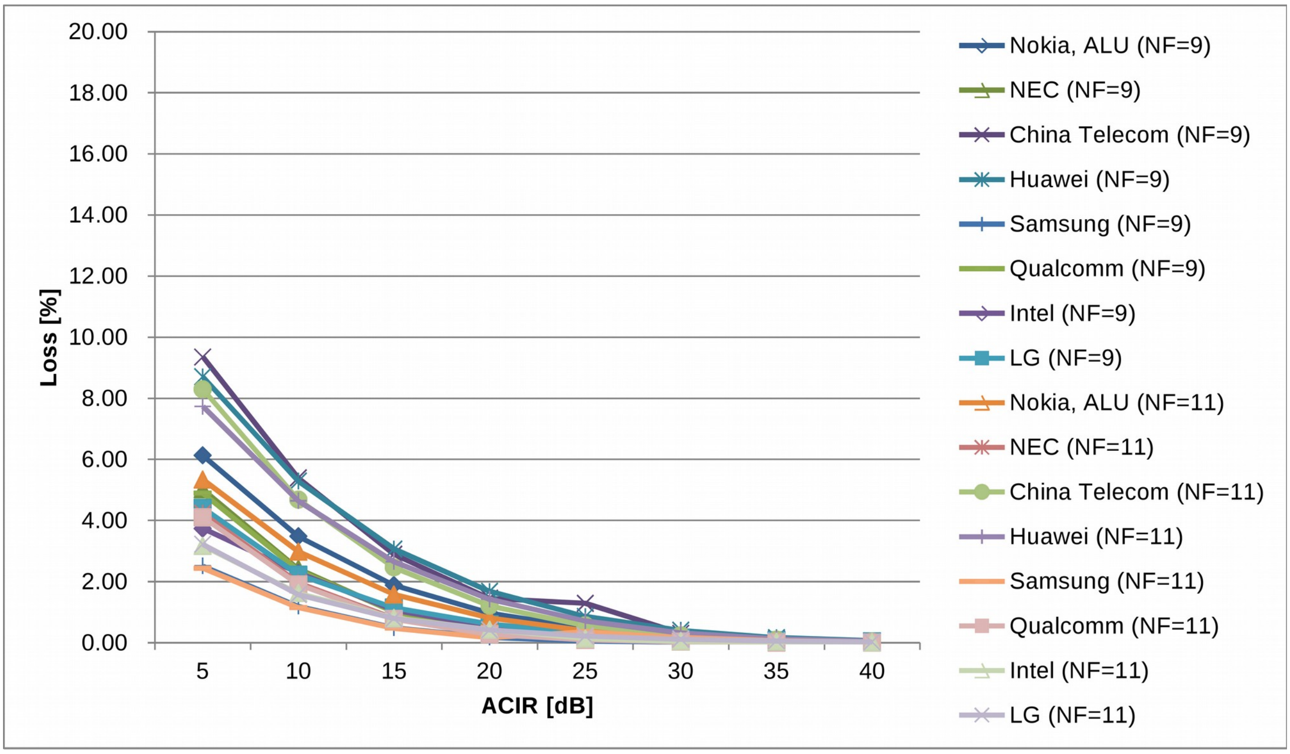


Figure 5.4.5.2-1: Simulation results for average throughput loss

Table 5.4.5.2-3: Simulation results for 5%-tile throughput loss (NF = 9)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	NA	NA	NA	NA	NA	NA	NA	NA
Ericsson *								
NEC	35.93	15.36	5.43	1.30	0.41	0.19	0.00	0.00
China Telecom	NA	NA	NA	NA	NA	NA	NA	NA
Huawei	NA	NA	NA	NA	NA	NA	NA	NA
ZTE								
Samsung	NA	NA	NA	NA	NA	NA	NA	NA
CATT								
Qualcomm	18.35	8.96	3.72	0.88	0.45	0.04	0.01	0.00
Intel	NA	NA	NA	NA	NA	NA	NA	NA
LG	31.21	18.17	8.59	3.84	1.63	0.70	0.29	0.20
* NF = 10 is assumed								

Table 5.4.5.2-4: Simulation results for 5%-tile throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	NA	NA	NA	NA	NA	NA	NA	NA
Ericsson								
NEC	NA	NA	NA	NA	NA	NA	NA	NA
China Telecom	NA	NA	NA	NA	NA	NA	NA	NA
Huawei	NA	NA	NA	NA	NA	NA	NA	NA
ZTE								
Samsung	NA	NA	NA	NA	NA	NA	NA	NA
CATT								
Qualcomm	NA	NA	NA	NA	NA	NA	NA	NA
Intel	NA	NA	NA	NA	NA	NA	NA	NA
LG	28.50	16.64	7.51	3.21	1.41	0.45	0.21	0.17

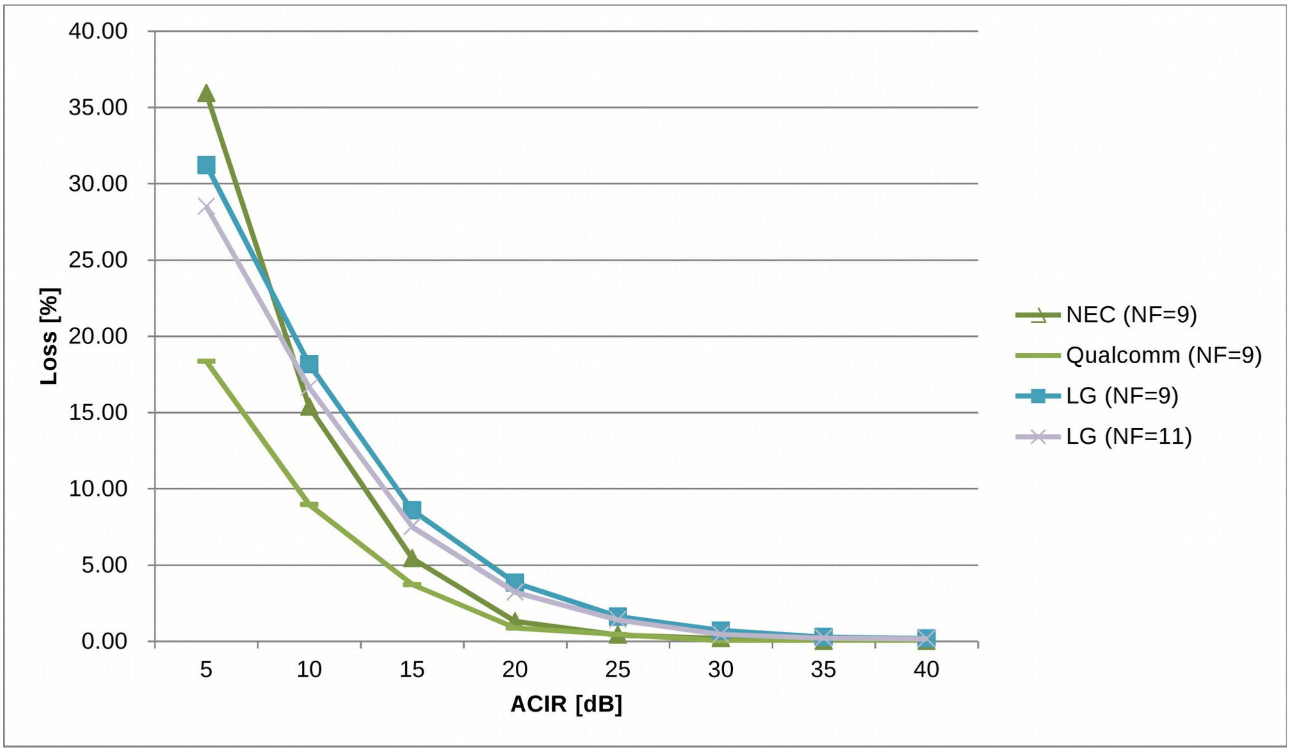


Figure 5.4.5.2-2: Simulation results for 5%-tile throughput loss

5.4.6 Scenario 6: 30GHz UL dense urban scenario

Simulation results for the average throughput loss are presented in table 5.4.6-1, table 5.4.6-2 and figure 5.4.6-1. Simulation results for the 5%-tile throughput loss are presented in table 5.4.6-3, table 5.4.6-4 and figure 5.4.6-2.

Table 5.4.6-1: Simulation results for average throughput loss (NF = 9)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	1.85	0.86	0.37	0.15	0.06	0.02	0.01	0.00
Ericsson *	8.58	4.59	2.25	0.97	0.40	0.14	0.05	0.02
NEC	3.56	1.79	0.85	0.38	0.16	0.06	0.02	0.01
China Telecom								
Huawei	2.52	1.25	0.58	0.26	0.11	0.04	0.02	0.01
ZTE	5.16	2.65	1.31	0.63	0.29	0.13	0.05	0.02
Samsung	1.67	0.84	0.41	0.19	0.08	0.03	0.01	0.00
CATT	4.28	2.25	1.11	0.51	0.22	0.08	0.03	0.01
Qualcomm	2.31	1.12	0.52	0.23	0.09	0.04	0.01	0.00
Intel	1.67	0.64	0.49	0.17	0.06	0.03	0.01	0.00
LG	10.89	6.21	3.43	1.77	0.87	0.40	0.20	0.08
* NF = 10 is assumed								

Table 5.4.6-2: Simulation results for average throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	1.50	0.68	0.29	0.11	0.04	0.01	0.00	0.00
Ericsson								
NEC	2.67	1.25	0.54	0.21	0.08	0.03	0.01	0.00
China Telecom								
Huawei	2.09	1.02	0.46	0.20	0.08	0.03	0.01	0.00
ZTE	5.23	2.87	1.47	0.67	0.27	0.09	0.03	0.01
Samsung	1.57	0.79	0.38	0.18	0.08	0.03	0.01	0.00
CATT	3.65	1.88	0.91	0.41	0.17	0.06	0.02	0.01
Qualcomm	1.90	0.91	0.41	0.18	0.07	0.03	0.01	0.00
Intel	1.36	0.66	0.33	0.09	0.04	0.01	0.00	0.00
LG	8.76	4.83	2.60	1.34	0.65	0.29	0.15	0.06

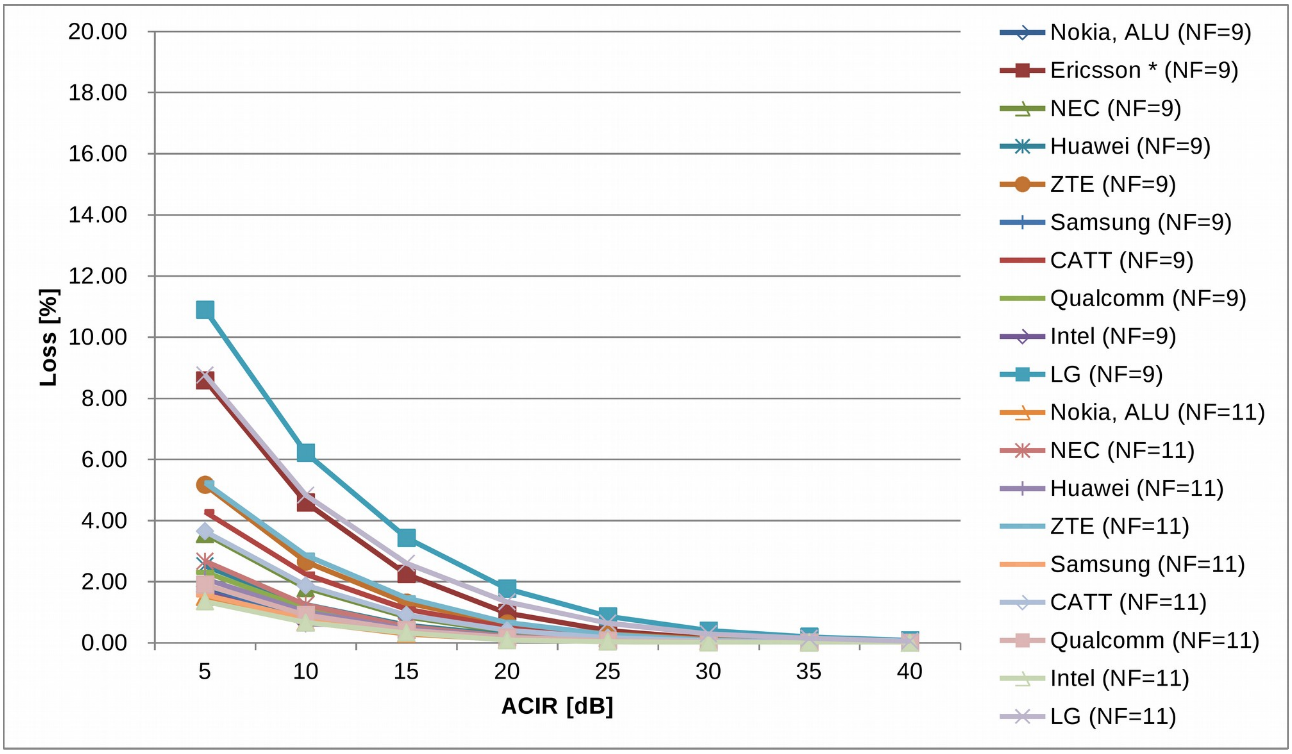


Figure 5.4.6-1: Simulation results for average throughput loss

Table 5.4.6-3: Simulation results for 5%-tile throughput loss (NF = 9)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	8.46	4.03	1.83	0.92	0.68	0.18	0.00	0.00
Ericsson *	21.02	15.55	9.70	2.98	1.74	0.00	0.05	0.07
NEC	20.34	10.45	3.95	0.38	0.05	0.03	0.02	0.02
China Telecom								
Huawei	10.53	4.71	2.47	0.10	0.03	0.01	0.00	0.00
ZTE	25.67	7.81	5.24	4.15	0.71	0.49	0.33	0.10
Samsung	NA	NA	NA	NA	NA	NA	NA	NA
CATT	22.59	14.57	6.24	0.96	0.30	0.09	0.03	0.01
Qualcomm	11.16	4.88	1.88	0.65	0.17	0.10	0.03	0.00
Intel	4.78	3.46	3.70	0.36	0.06	0.00	0.00	0.00
LG	24.37	13.42	7.04	3.06	1.43	0.59	0.18	0.03
* NF = 10 is assumed								

Table 5.4.6-4: Simulation results for 5%-tile throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	NA	NA	NA	NA	NA	NA	NA	NA
Ericsson								
NEC	25.56	10.67	3.84	2.96	1.52	0.98	0.00	0.00
China Telecom								
Huawei	7.55	4.17	0.95	0.05	0.01	0.00	0.00	0.00
ZTE	27.07	11.08	6.58	4.02	1.53	1.53	1.53	0.00
Samsung	NA	NA	NA	NA	NA	NA	NA	NA
CATT	18.52	9.97	4.12	0.23	0.05	0.01	0.00	0.00
Qualcomm	8.84	3.55	1.63	0.73	0.23	0.05	0.02	0.00
Intel	NA	NA	NA	NA	NA	NA	NA	NA
LG	20.53	10.64	5.17	2.34	1.17	0.43	0.20	0.00

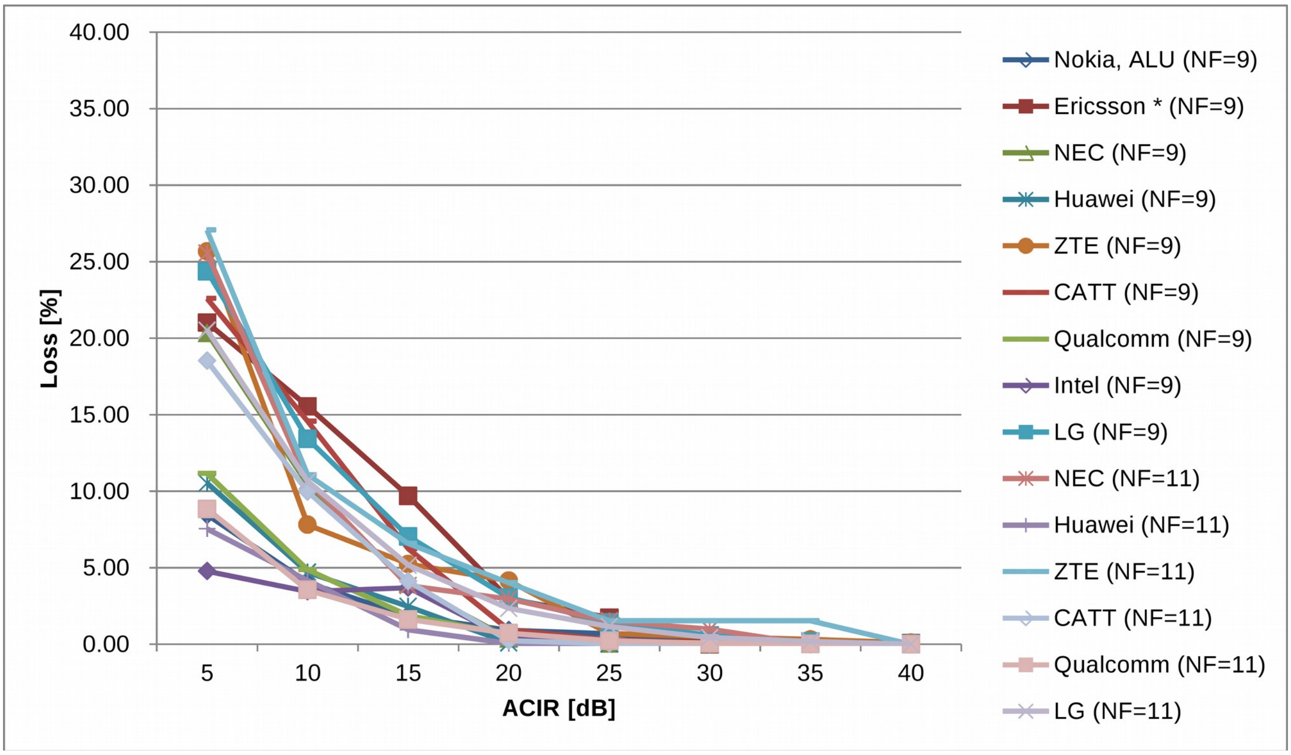


Figure 5.4.6-2: Simulation results for 5%-tile throughput loss

5.4.7 Scenario 7: 70GHz DL indoor scenario

Simulation results for the average throughput loss are presented in table 5.4.7-1, table 5.4.7-2 and figure 5.4.7-1. Simulation results for the 5%-tile throughput loss are presented in table 5.4.7-3, table 5.4.7-4 and figure 5.4.7-2.

Table 5.4.7-1: Simulation results for average throughput loss (NF = 13)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	8.51	4.79	2.49	1.19	0.50	0.17	0.04	0.01
Ericsson *	16.20	8.58	4.09	1.71	0.66	0.23	0.08	0.02
NEC	9.54	5.43	2.88	1.40	0.54	0.12	0.04	0.01
China Telecom								
Huawei	17.45	10.20	5.45	2.67	1.05	0.26	0.07	0.02
ZTE	7.83	4.50	2.39	1.14	0.47	0.15	0.03	0.01
Samsung	8.26	4.57	2.33	1.07	0.41	0.12	0.03	0.01
CATT	8.50	4.70	2.33	1.00	0.36	0.08	0.02	0.01
Qualcomm	18.01	10.72	5.82	2.87	1.15	0.29	0.08	0.02
Intel	8.02	4.59	2.18	1.11	0.40	0.12	0.03	0.01
LG	38.31	22.99	11.38	4.38	1.32	0.39	0.12	0.04
* NF = 14 is assumed								

Table 5.4.7-2: Simulation results for average throughput loss (NF = 15)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	8.52	4.80	2.50	1.20	0.51	0.18	0.05	0.01
Ericsson								
NEC	8.88	5.17	2.72	1.39	0.52	0.11	0.03	0.01
China Telecom								
Huawei	17.50	10.17	5.40	2.61	0.98	0.20	0.06	0.02
ZTE	7.68	4.41	2.36	1.14	0.46	0.14	0.03	0.01
Samsung	8.26	4.58	2.34	1.08	0.42	0.12	0.03	0.01
CATT	8.52	4.73	2.34	1.02	0.37	0.09	0.02	0.01
Qualcomm	17.89	10.65	5.79	2.86	1.16	0.31	0.08	0.02
Intel	8.22	4.58	2.34	1.14	0.39	0.12	0.03	0.01
LG	38.31	22.99	11.38	4.39	1.33	0.39	0.12	0.04

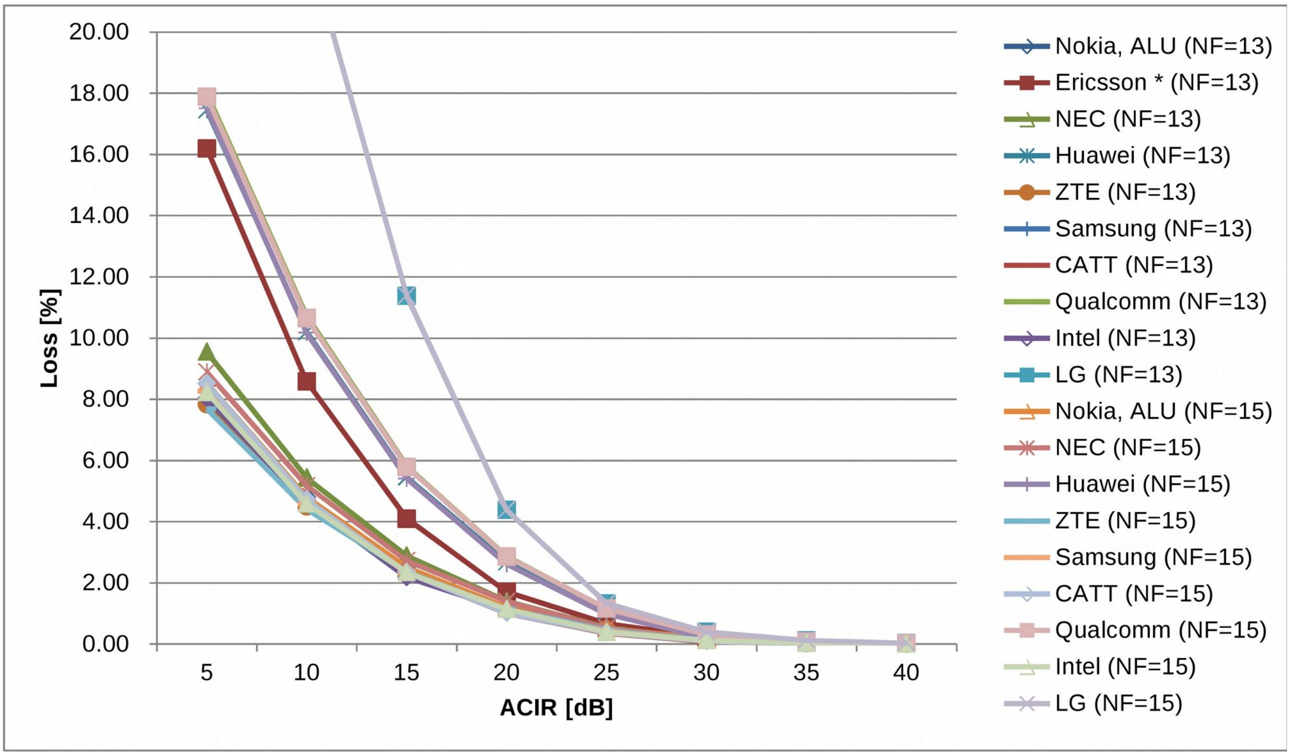


Figure 5.4.7-1: Simulation results for average throughput loss

Table 5.4.7-3: Simulation results for 5%-tile throughput loss (NF = 13)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	32.55	19.30	8.90	2.13	0.81	0.13	0.00	0.00
Ericsson *	22.38	12.18	5.87	2.41	0.82	0.41	0.17	0.09
NEC	31.39	12.82	6.02	0.78	0.00	0.00	0.00	0.00
China Telecom								
Huawei	45.31	19.32	2.87	0.47	0.05	0.02	0.01	0.00
ZTE	35.32	21.84	10.96	3.87	1.16	0.69	0.54	0.27
Samsung	28.55	14.60	4.93	1.55	0.21	0.00	0.00	0.00
CATT	27.26	13.77	3.22	0.14	0.10	0.01	0.00	0.00
Qualcomm	41.08	14.36	2.32	0.54	0.31	0.15	0.04	0.01
Intel	30.19	18.01	7.47	1.47	0.32	0.11	0.03	0.00
LG	42.10	16.53	5.16	1.48	0.48	0.16	0.04	0.01
* NF = 14 is assumed								

Table 5.4.7-4: Simulation results for 5%-tile throughput loss (NF = 15)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	32.47	19.17	8.95	2.32	0.82	0.32	0.21	0.09
Ericsson								
NEC	24.53	14.20	10.07	3.61	0.26	0.00	0.00	0.00
China Telecom								
Huawei	45.20	19.54	3.28	0.40	0.13	0.01	0.00	0.00
ZTE	35.48	21.61	9.45	2.35	0.68	0.34	0.11	0.00
Samsung	28.58	14.59	4.92	1.57	0.21	0.00	0.00	0.00
CATT	27.22	13.77	3.19	0.14	0.08	0.01	0.00	0.00
Qualcomm	41.02	14.33	2.38	0.47	0.24	0.11	0.04	0.00
Intel	32.49	15.96	7.79	2.17	0.08	0.00	0.00	0.00
LG	42.10	16.53	5.16	1.48	0.48	0.16	0.04	0.01

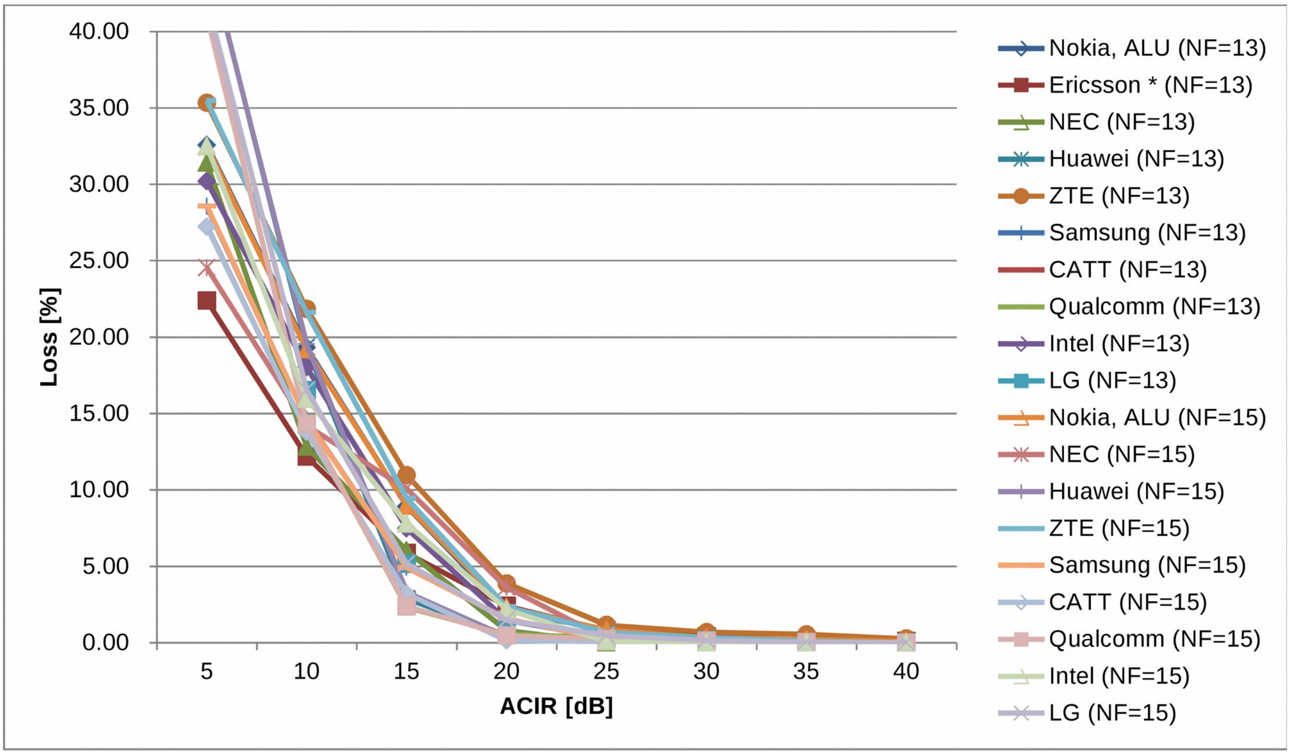


Figure 5.4.7-2: Simulation results for 5%-tile throughput loss

5.4.8 Scenario 8: 70GHz DL urban macro scenario

Simulation results for the average throughput loss are presented in table 5.4.8-1, table 5.4.8-2 and figure 5.4.8-1. Simulation results for the 5%-tile throughput loss are presented in table 5.4.8-3, table 5.4.8-4 and figure 5.4.8-2.

Table 5.4.8-1: Simulation results for average throughput loss (NF = 13)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	3.94	1.97	0.92	0.40	0.17	0.07	0.02	0.01
Ericsson *	9.99	5.46	2.82	1.36	0.63	0.27	0.11	0.04
NEC	6.13	3.05	1.42	0.62	0.24	0.09	0.03	0.01
China Telecom								
Huawei	4.87	2.56	1.24	0.55	0.22	0.08	0.02	0.01
ZTE	3.64	1.82	0.84	0.35	0.10	0.02	0.01	0.00
Samsung	3.83	2.13	1.12	0.56	0.26	0.11	0.04	0.01
CATT	7.29	4.00	2.06	1.02	0.45	0.18	0.06	0.02
Qualcomm	4.02	2.05	0.98	0.43	0.18	0.07	0.02	0.01
Intel	2.92	1.95	0.83	0.50	0.20	0.07	0.01	0.01
LG	8.20	4.25	2.04	0.90	0.33	0.11	0.03	0.01
* NF = 14 is assumed								

Table 5.4.8-2: Simulation results for average throughput loss (NF = 15)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	3.89	1.94	0.92	0.40	0.17	0.07	0.02	0.01
Ericsson								
NEC	6.21	3.18	1.52	0.67	0.27	0.10	0.03	0.01
China Telecom								
Huawei	4.76	2.49	1.20	0.52	0.21	0.07	0.02	0.01
ZTE	4.08	2.36	1.19	0.55	0.23	0.10	0.03	0.01
Samsung	3.74	2.08	1.10	0.55	0.26	0.10	0.03	0.01
CATT	7.13	3.92	2.01	0.99	0.44	0.17	0.06	0.02
Qualcomm	3.97	2.03	0.97	0.43	0.18	0.07	0.02	0.01
Intel	4.09	2.14	0.89	0.36	0.12	0.09	0.01	0.01
LG	7.29	3.91	1.88	0.85	0.36	0.13	0.04	0.00

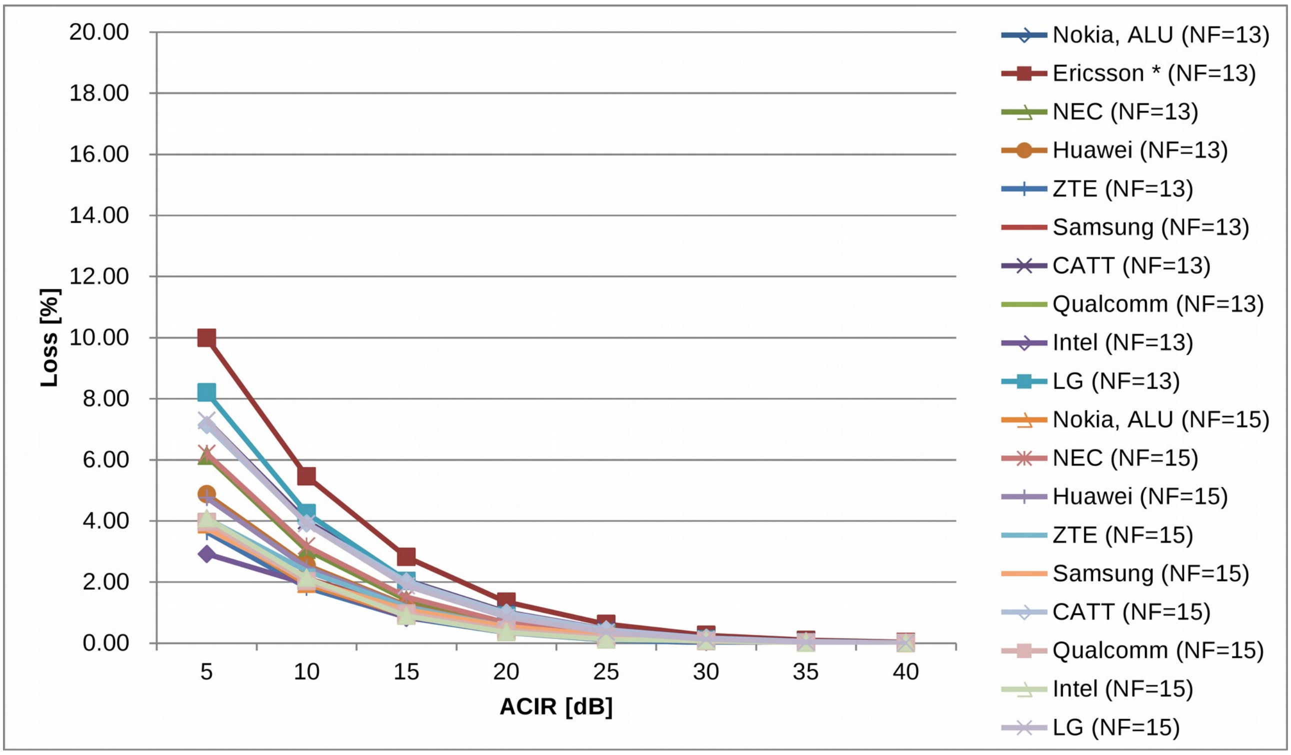


Figure 5.4.8-1: Simulation results for average throughput loss

Table 5.4.8-3: Simulation results for 5%-tile throughput loss (NF = 13)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	NA	NA	NA	NA	NA	NA	NA	NA
Ericsson *	NA	NA	NA	NA	NA	NA	NA	NA
NEC	NA	NA	NA	NA	NA	NA	NA	NA
China Telecom								
Huawei	NA	NA	NA	NA	NA	NA	NA	NA
ZTE	NA	NA	NA	NA	NA	NA	NA	NA
Samsung	NA	NA	NA	NA	NA	NA	NA	NA
CATT	NA	NA	NA	NA	NA	NA	NA	NA
Qualcomm	NA	NA	NA	NA	NA	NA	NA	NA
Intel	NA	NA	NA	NA	NA	NA	NA	NA
LG	2.44	0.84	0.23	0.03	0.01	0.01	0.00	0.00
* NF = 14 is assumed								

Table 5.4.8-4: Simulation results for 5%-tile throughput loss (NF = 15)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	NA	NA	NA	NA	NA	NA	NA	NA
Ericsson								
NEC	NA	NA	NA	NA	NA	NA	NA	NA
China Telecom								
Huawei	NA	NA	NA	NA	NA	NA	NA	NA
ZTE	NA	NA	NA	NA	NA	NA	NA	NA
Samsung	NA	NA	NA	NA	NA	NA	NA	NA
CATT	NA	NA	NA	NA	NA	NA	NA	NA
Qualcomm	NA	NA	NA	NA	NA	NA	NA	NA
Intel	NA	NA	NA	NA	NA	NA	NA	NA
LG	1.62	0.63	0.25	0.07	0.03	0.02	0.00	0.00

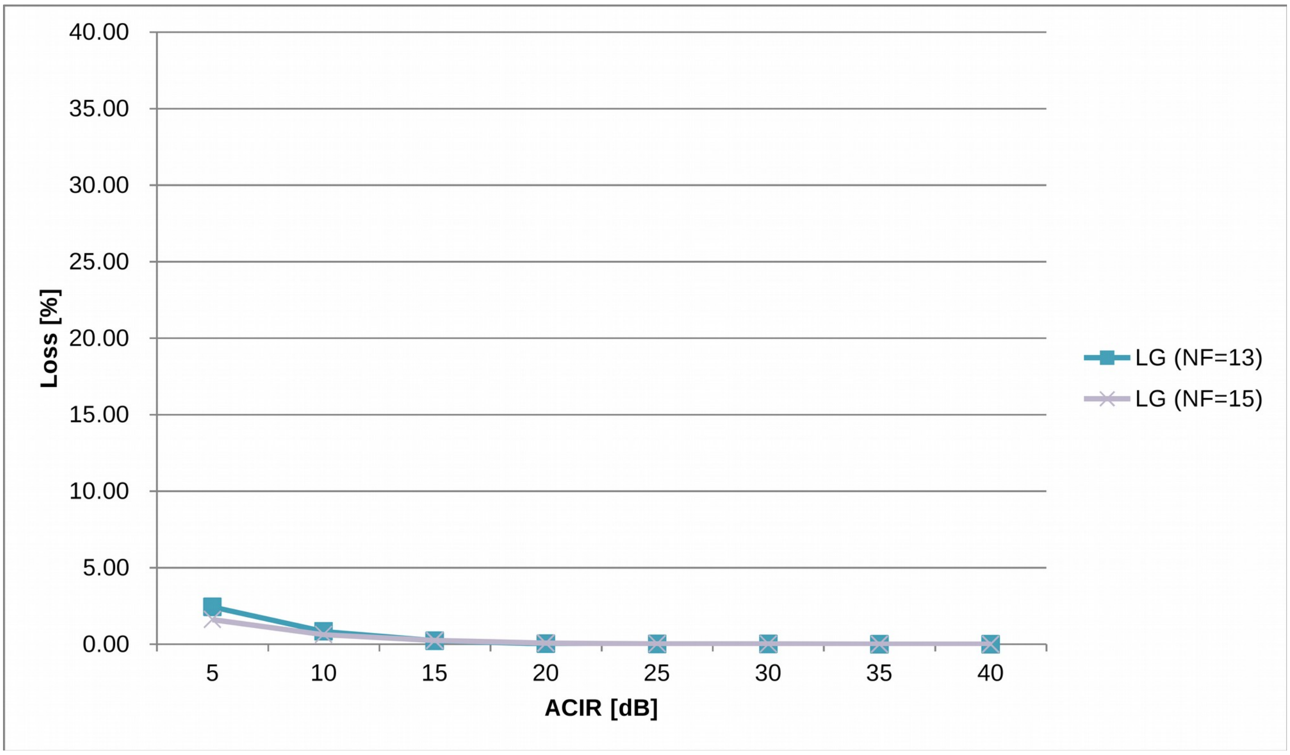


Figure 5.4.8-2: Simulation results for 5%-tile throughput loss

5.4.9 Scenario 9: 70GHz UL indoor scenario

Simulation results for the average throughput loss are presented in table 5.4.9-1, table 5.4.9-2 and figure 5.4.9-1. Simulation results for the 5%-tile throughput loss are presented in table 5.4.9-3, table 5.4.9-4 and figure 5.4.9-2.

Table 5.4.9-1: Simulation results for average throughput loss (NF = 13)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	3.14	1.48	0.62	0.23	0.08	0.03	0.01	0.00
Ericsson *	11.14	5.37	2.35	0.93	0.37	0.13	0.05	0.01
NEC	3.71	1.68	0.65	0.22	0.07	0.02	0.01	0.00
China Telecom								
Huawei	7.12	3.31	1.32	0.46	0.15	0.05	0.02	0.00
ZTE	5.14	2.71	1.27	0.50	0.15	0.03	0.01	0.00
Samsung	3.52	1.69	0.72	0.28	0.10	0.03	0.01	0.00
CATT	2.32	1.01	0.40	0.15	0.05	0.02	0.01	0.00
Qualcomm	9.78	4.63	1.85	0.65	0.21	0.07	0.02	0.01
Intel	2.82	1.36	0.52	0.22	0.06	0.02	0.01	0.00
LG	29.43	16.31	7.68	2.96	0.89	0.27	0.09	0.03
* NF = 14 is assumed								

Table 5.4.9-2: Simulation results for average throughput loss (NF = 15)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	2.64	1.20	0.48	0.17	0.06	0.02	0.01	0.00
Ericsson								
NEC	3.08	1.33	0.49	0.17	0.05	0.02	0.01	0.00
China Telecom								
Huawei	6.02	2.66	1.00	0.34	0.11	0.04	0.01	0.00
ZTE	5.25	2.85	1.41	0.63	0.26	0.09	0.03	0.01
Samsung	3.52	1.69	0.72	0.28	0.10	0.03	0.01	0.00
CATT	1.91	0.80	0.31	0.11	0.04	0.01	0.00	0.00
Qualcomm	8.35	3.74	1.41	0.48	0.16	0.05	0.02	0.01
Intel	2.40	1.00	0.43	0.17	0.05	0.02	0.01	0.00
LG	25.74	13.70	6.26	2.37	0.70	0.21	0.07	0.02

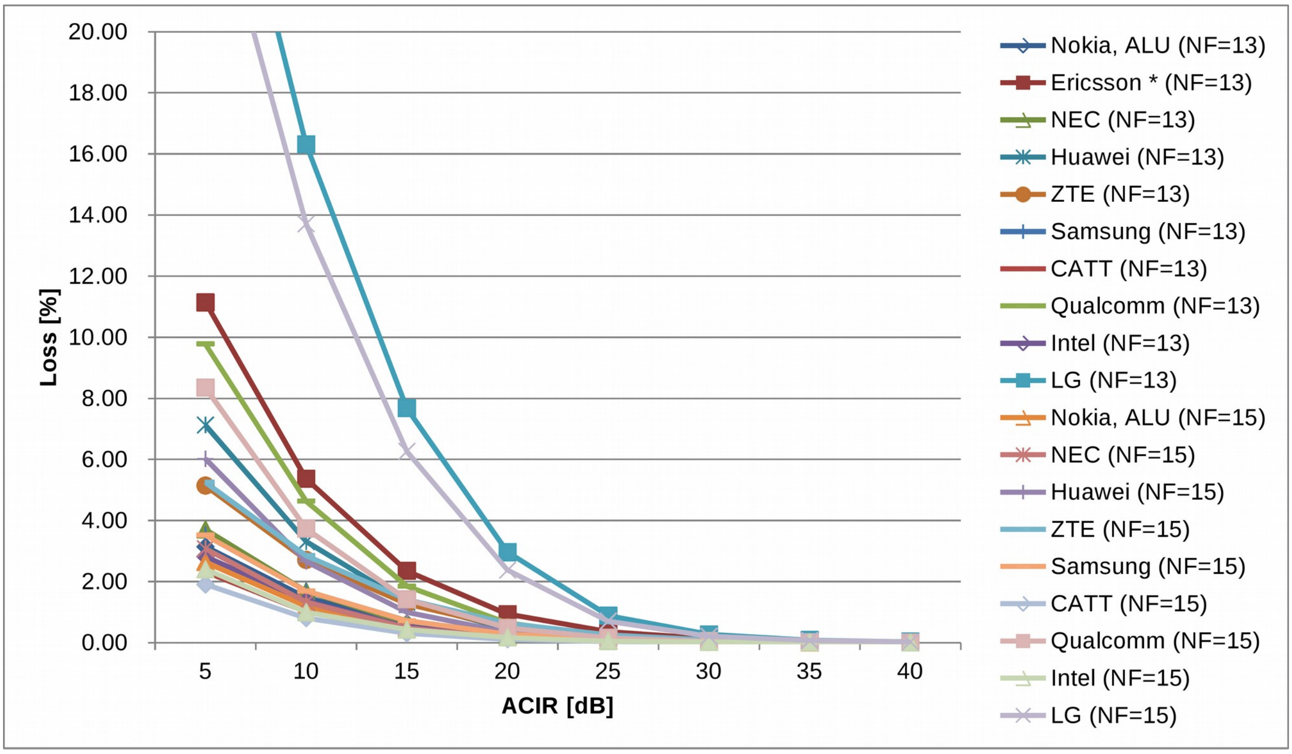


Figure 5.4.9-1: Simulation results for average throughput loss

Table 5.4.9-3: Simulation results for 5%-tile throughput loss (NF = 13)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	19.70	11.28	5.06	0.90	0.01	0.00	0.00	0.00
Ericsson *	17.90	9.04	3.88	1.24	0.35	0.07	0.02	0.00
NEC	12.58	1.60	0.23	0.11	0.04	0.00	0.00	0.00
China Telecom								
Huawei	36.96	13.27	1.25	0.34	0.07	0.01	0.00	0.00
ZTE	34.13	19.04	8.97	2.67	0.46	0.00	0.00	0.00
Samsung	21.39	10.31	3.58	0.76	0.06	0.00	0.00	0.00
CATT	13.31	4.93	0.55	0.46	0.14	0.00	0.00	0.00
Qualcomm	39.14	12.17	2.26	0.54	0.22	0.11	0.04	0.02
Intel	18.43	8.88	3.80	0.73	0.15	0.00	0.00	0.00
LG	32.51	10.00	2.38	0.66	0.24	0.06	0.01	0.01
* NF = 14 is assumed								

Table 5.4.9-4: Simulation results for 5%-tile throughput loss (NF = 15)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	16.78	9.34	4.10	0.72	0.01	0.00	0.00	0.00
Ericsson								
NEC	5.67	0.48	0.25	0.18	0.09	0.00	0.00	0.00
China Telecom								
Huawei	33.88	11.53	1.05	0.29	0.06	0.01	0.00	0.00
ZTE	30.47	17.11	8.16	2.45	0.74	0.07	0.00	0.00
Samsung	21.39	10.31	3.58	0.76	0.06	0.00	0.00	0.00
CATT	11.35	4.07	0.44	0.36	0.11	0.00	0.00	0.00
Qualcomm	36.10	10.62	1.92	0.46	0.19	0.09	0.03	0.02
Intel	17.23	6.97	3.40	0.86	0.10	0.01	0.00	0.00
LG	31.85	9.73	2.31	0.64	0.23	0.05	0.01	0.01

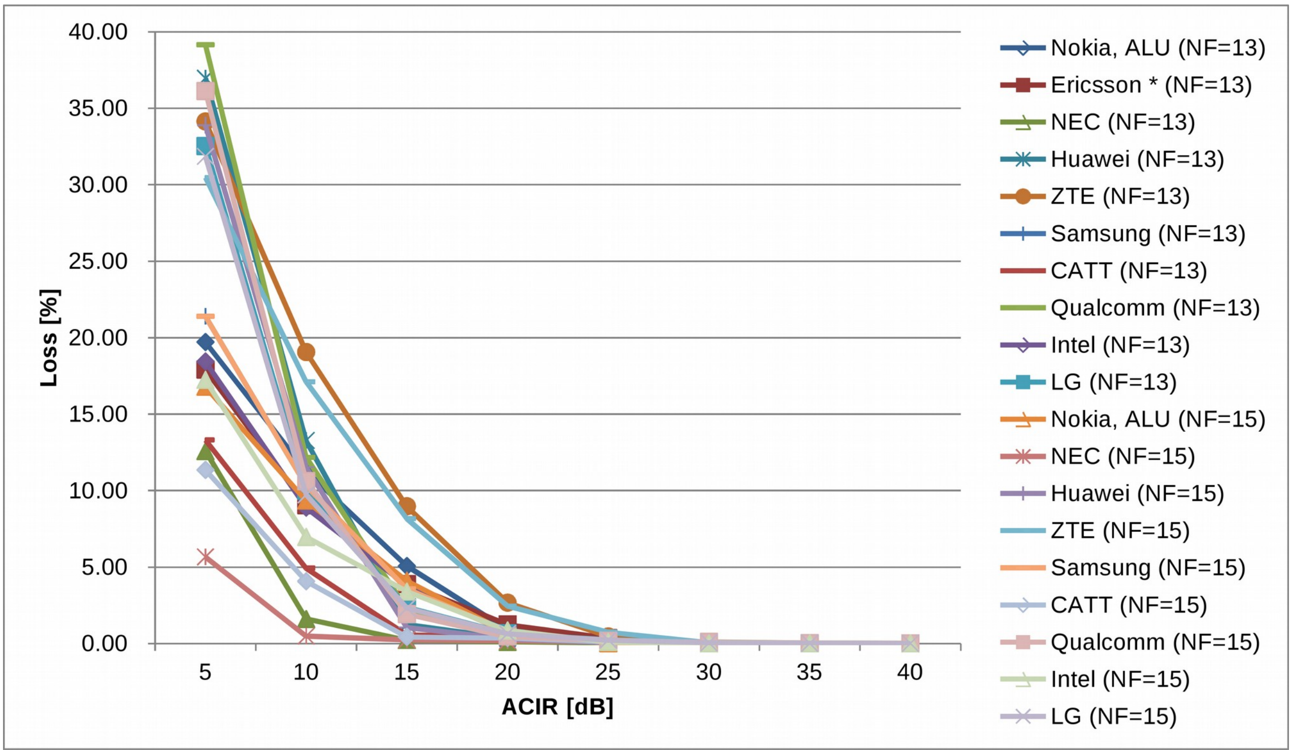


Figure 5.4.9-2: Simulation results for 5%-tile throughput loss

5.4.10 Scenario 10: 70GHz UL urban macro scenario

Simulation results for the average throughput loss are presented in table 5.4.10-1, table 5.4.10-2 and figure 5.4.10-1. Simulation results for the 5%-tile throughput loss are presented in table 5.4.10-3, table 5.4.10-4 and figure 5.4.10-2.

Table 5.4.10-1: Simulation results for average throughput loss (NF = 13)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	5.26	2.80	0.12	0.05	0.02	0.01	0.00	0.00
Ericsson *	5.32	2.65	1.25	0.55	0.23	0.09	0.03	0.01
NEC	1.61	0.76	0.33	0.13	0.05	0.02	0.00	0.00
China Telecom								
Huawei	1.06	0.51	0.22	0.09	0.03	0.01	0.00	0.00
ZTE	1.41	0.63	0.25	0.09	0.03	0.01	0.00	0.00
Samsung	0.90	0.47	0.24	0.11	0.05	0.02	0.01	0.00
CATT	2.60	1.46	0.75	0.34	0.13	0.05	0.02	0.00
Qualcomm	0.80	0.37	0.16	0.07	0.03	0.01	0.00	0.00
Intel	0.58	0.24	0.16	0.07	0.01	0.02	0.00	0.00
LG	6.07	3.20	1.65	0.80	0.34	0.10	0.05	0.01
* NF = 14 is assumed								

Table 5.4.10-2: Simulation results for average throughput loss (NF = 15)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	4.42	2.30	0.09	0.03	0.01	0.00	0.00	0.00
Ericsson								
NEC	1.19	0.54	0.23	0.09	0.03	0.01	0.00	0.00
China Telecom								
Huawei	0.88	0.41	0.18	0.07	0.02	0.01	0.00	0.00
ZTE	2.10	1.16	0.59	0.30	0.14	0.06	0.02	0.01
Samsung	0.86	0.45	0.23	0.11	0.04	0.02	0.01	0.00
CATT	2.27	1.26	0.63	0.27	0.10	0.03	0.01	0.00
Qualcomm	0.65	0.30	0.13	0.05	0.02	0.01	0.00	0.00
Intel	0.61	0.38	0.10	0.05	0.01	0.00	0.00	0.00
LG	6.26	3.34	1.76	0.79	0.24	0.10	0.03	0.01

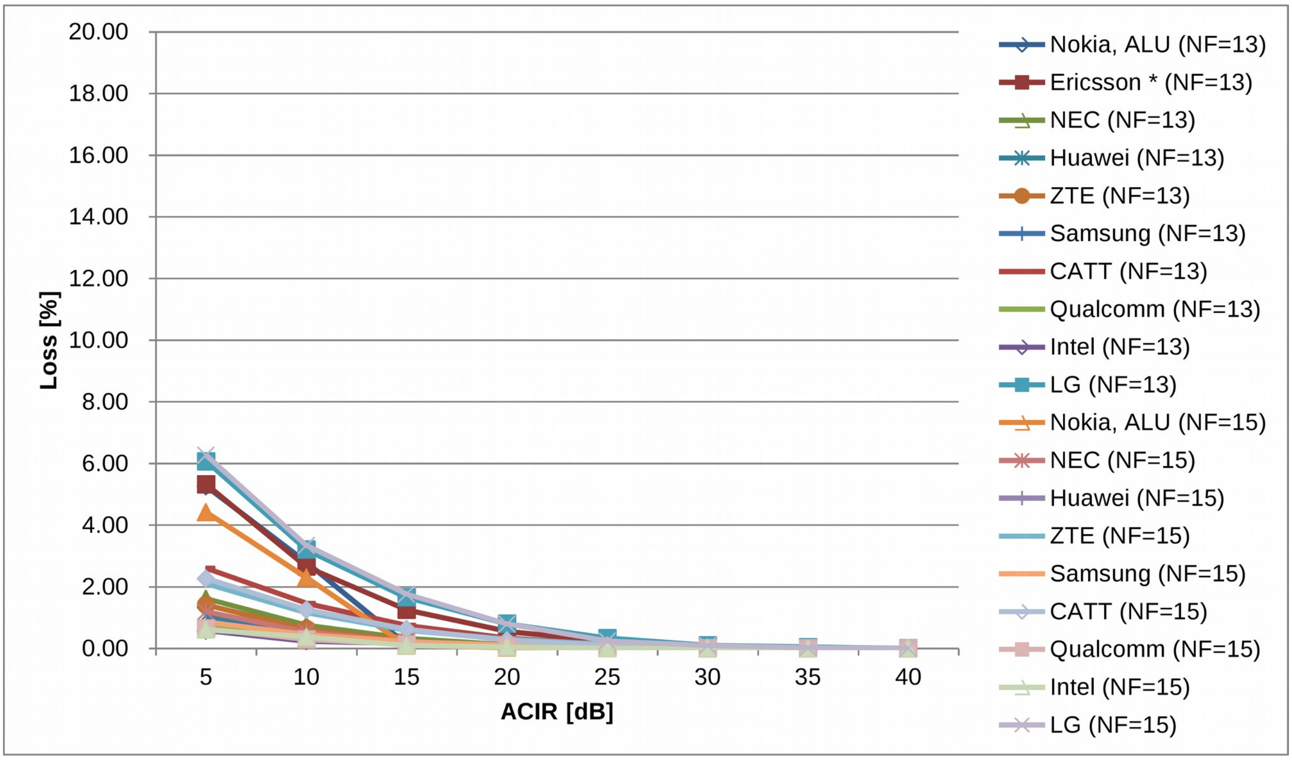


Figure 5.4.10-1: Simulation results for average throughput loss

Table 5.4.10-3: Simulation results for 5%-tile throughput loss (NF = 13)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	NA	NA	NA	NA	NA	NA	NA	NA
Ericsson *	NA	NA	NA	NA	NA	NA	NA	NA
NEC	NA	NA	NA	NA	NA	NA	NA	NA
China Telecom								
Huawei	NA	NA	NA	NA	NA	NA	NA	NA
ZTE	NA	NA	NA	NA	NA	NA	NA	NA
Samsung	NA	NA	NA	NA	NA	NA	NA	NA
CATT	NA	NA	NA	NA	NA	NA	NA	NA
Qualcomm	NA	NA	NA	NA	NA	NA	NA	NA
Intel	NA	NA	NA	NA	NA	NA	NA	NA
LG	9.48	5.03	2.28	0.81	0.28	0.13	0.03	0.01
* NF = 14 is assumed								

Table 5.4.10-4: Simulation results for 5%-tile throughput loss (NF = 15)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU	NA	NA	NA	NA	NA	NA	NA	NA
Ericsson								
NEC	NA	NA	NA	NA	NA	NA	NA	NA
China Telecom								
Huawei	NA	NA	NA	NA	NA	NA	NA	NA
ZTE	NA	NA	NA	NA	NA	NA	NA	NA
Samsung	NA	NA	NA	NA	NA	NA	NA	NA
CATT	NA	NA	NA	NA	NA	NA	NA	NA
Qualcomm	NA	NA	NA	NA	NA	NA	NA	NA
Intel	NA	NA	NA	NA	NA	NA	NA	NA
LG	7.31	3.73	1.72	0.91	0.27	0.07	0.01	0.01

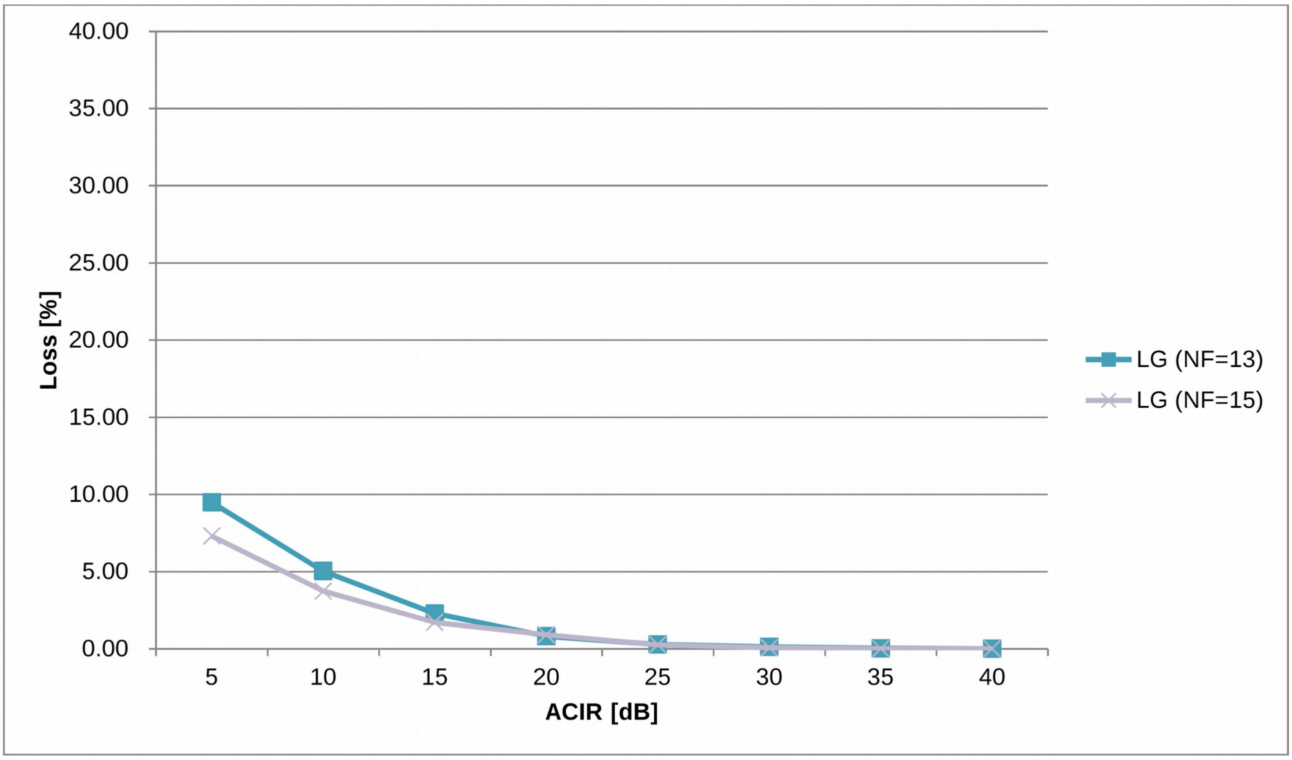


Figure 5.4.10-2: Simulation results for 5%-tile throughput loss

5.4.11 Scenario 11: 45GHz DL indoor scenario

Simulation results for the average throughput loss are presented in table 5.4.11-1, table 5.4.11-2 and figure 5.4.11-1. Simulation results for the 5%-tile throughput loss are presented in table 5.4.11-3, table 5.4.11-4 and figure 5.4.11-2.

Table 5.4.11-1: Simulation results for average throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU								
Ericsson *	18.18	10.01	4.94	2.12	0.84	0.29	0.10	0.03
NEC								
China Telecom								
Huawei								
ZTE								
Samsung								
CATT								
Qualcomm	18.33	10.91	5.90	2.88	1.12	0.26	0.07	0.02
Intel	8.36	3.11	2.27	1.16	0.43	0.13	0.02	0.01
LG	38.38	23.07	11.50	4.49	1.42	0.43	0.14	0.05
* NF = 12 is assumed								

Table 5.4.11-2: Simulation results for average throughput loss (NF = 13)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU								
Ericsson								
NEC								
China Telecom								
Huawei								
ZTE								
Samsung								
CATT								
Qualcomm	18.32	10.91	5.90	2.89	1.14	0.27	0.07	0.02
Intel	7.86	4.52	2.22	1.08	0.42	0.13	0.03	0.01
LG	38.38	23.07	11.50	4.49	1.42	0.43	0.14	0.05

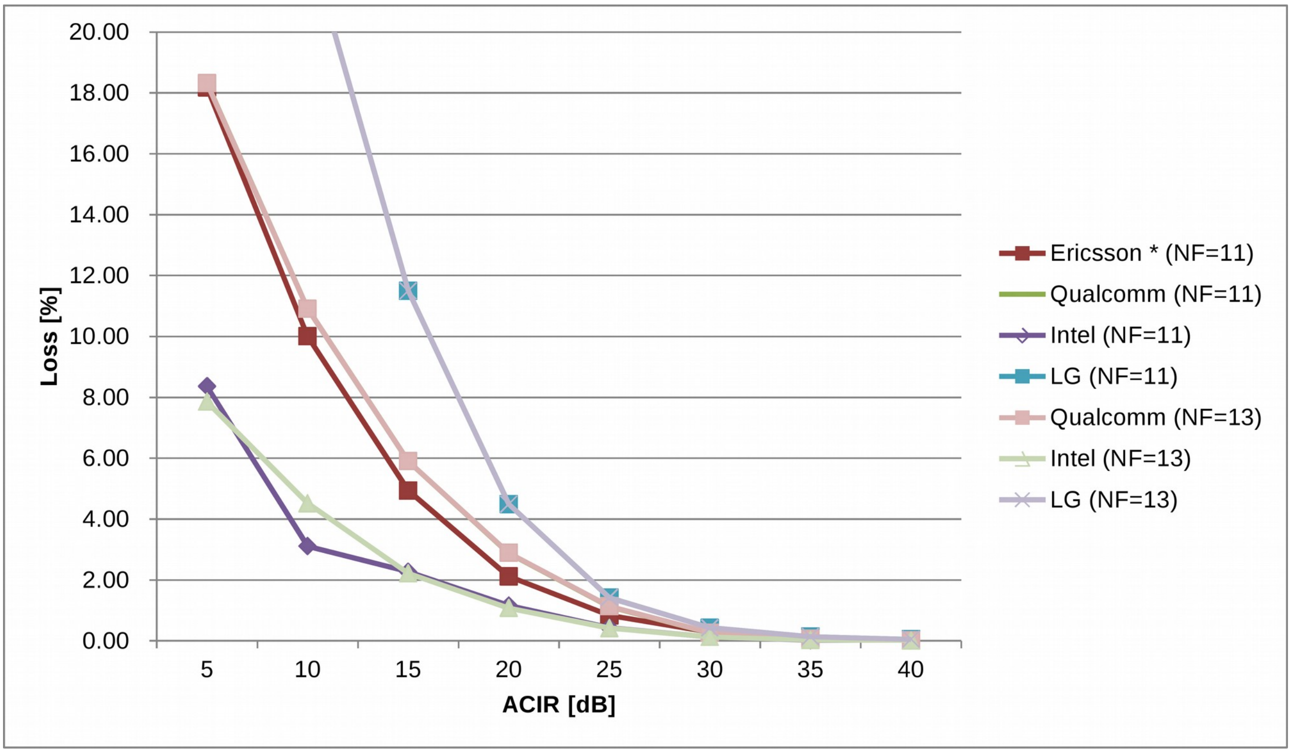


Figure 5.4.11-1: Simulation results for average throughput loss

Table 5.4.11-3: Simulation results for 5%-tile throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU								
Ericsson *	23.94	13.68	6.99	2.89	1.13	0.46	0.16	0.06
NEC								
China Telecom								
Huawei								
ZTE								
Samsung								
CATT								
Qualcomm	40.58	13.79	2.53	0.57	0.18	0.01	0.00	0.00
Intel	31.98	15.06	7.30	1.95	0.62	0.00	0.07	0.05
LG	42.49	17.03	5.20	1.40	0.40	0.12	0.05	0.02
* NF = 12 is assumed								

Table 5.4.11-4: Simulation results for 5%-tile throughput loss (NF = 13)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU								
Ericsson								
NEC								
China Telecom								
Huawei								
ZTE								
Samsung								
CATT								
Qualcomm	40.56	13.77	2.54	0.66	0.22	0.05	0.00	0.00
Intel	31.08	19.72	9.04	2.13	0.29	0.02	0.00	0.00
LG	42.49	17.03	5.20	1.40	0.40	0.12	0.05	0.02

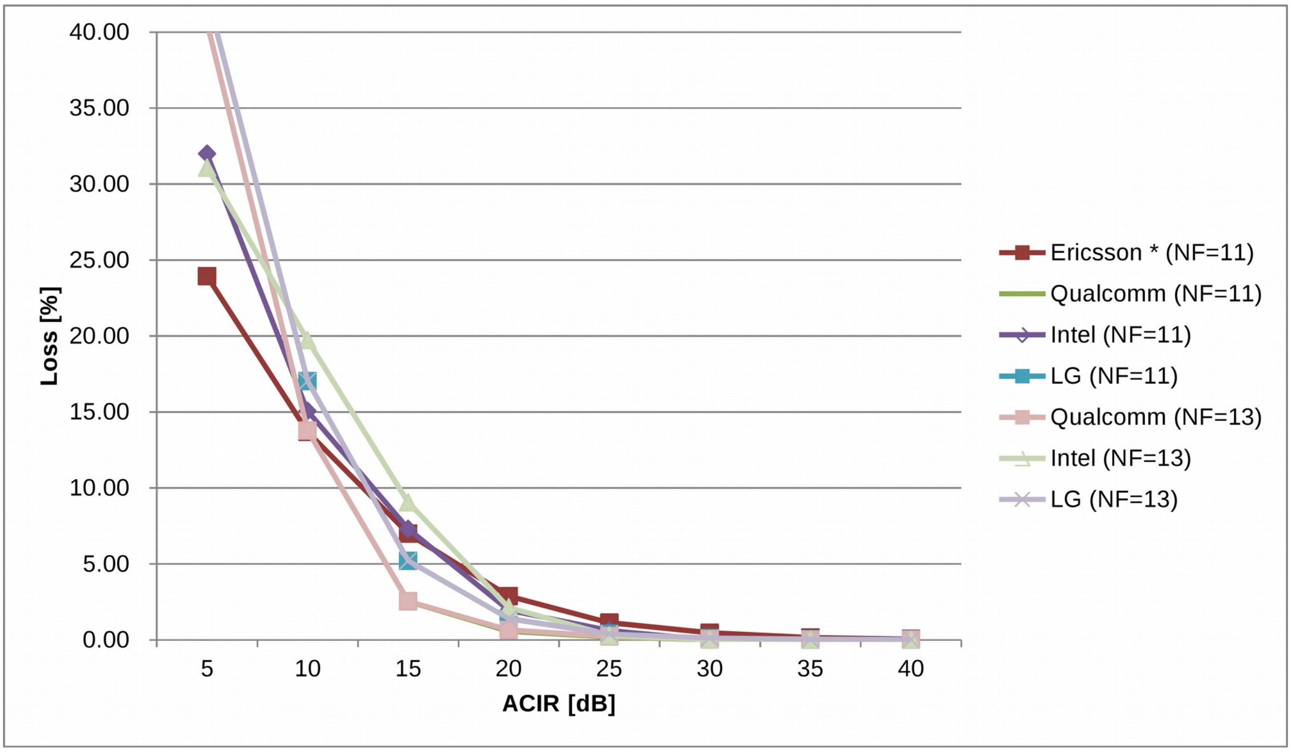


Figure 5.4.11-2: Simulation results for 5%-tile throughput loss

5.4.12 Scenario 12: 45GHz DL urban macro scenario

Simulation results for the average throughput loss are presented in table 5.4.12-1, table 5.4.12-2 and figure 5.4.12-1. Simulation results for the 5%-tile throughput loss are presented in table 5.4.12-3, table 5.4.12-4 and figure 5.4.12-2.

Table 5.4.12-1: Simulation results for average throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU								
Ericsson *	10.32	5.81	3.10	1.52	0.71	0.30	0.12	0.04
NEC								
China Telecom								
Huawei								
ZTE								
Samsung								
CATT	8.16	4.57	2.41	1.17	0.52	0.21	0.08	0.03
Qualcomm	4.75	2.48	1.22	0.56	0.24	0.09	0.04	0.01
Intel	3.79	2.37	1.02	0.46	0.22	0.08	0.02	0.00
LG	10.88	6.53	3.52	1.71	0.79	0.34	0.12	0.06
* NF = 12 is assumed								

Table 5.4.12-2: Simulation results for average throughput loss (NF = 13)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU								
Ericsson								
NEC								
China Telecom								
Huawei								
ZTE								
Samsung								
CATT	7.98	4.45	2.34	1.14	0.49	0.20	0.07	0.03
Qualcomm	4.54	2.36	1.15	0.53	0.22	0.09	0.03	0.01
Intel	3.33	2.21	0.09	0.36	0.13	0.09	0.01	0.01
LG	10.54	6.13	3.30	1.65	0.71	0.29	0.11	0.05

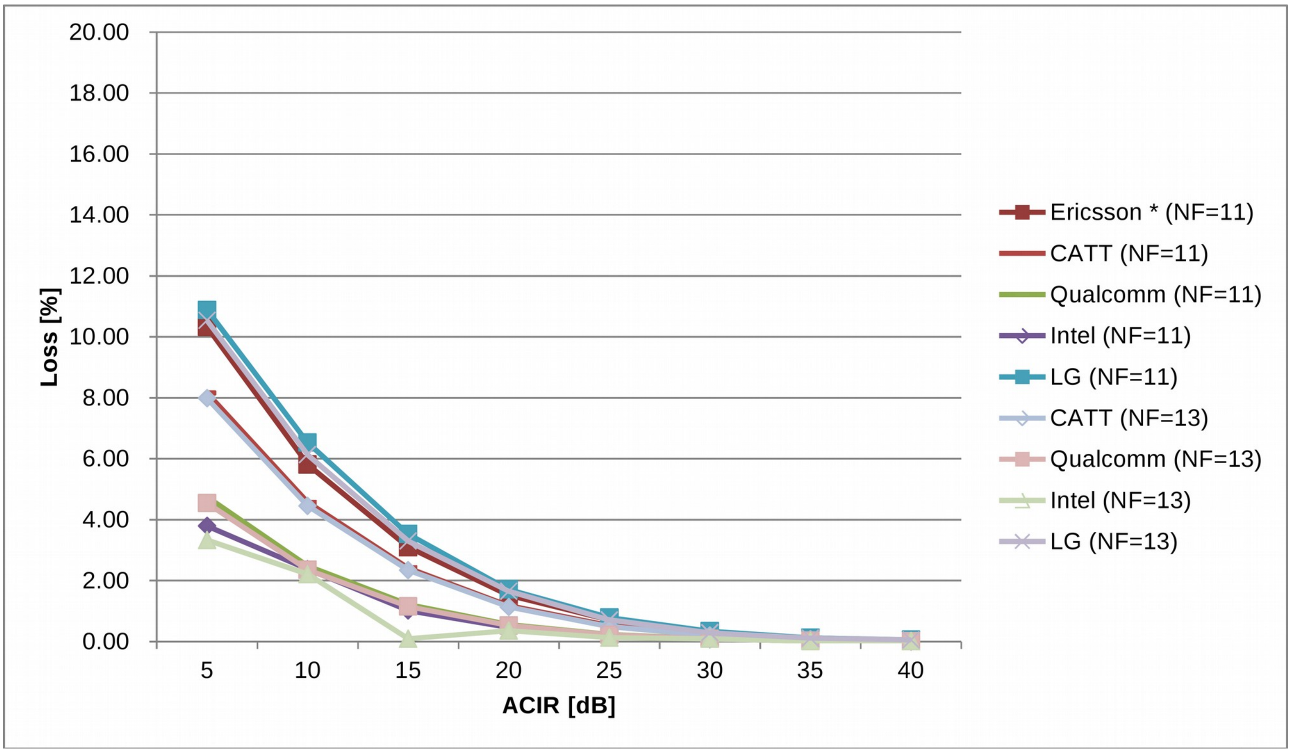


Figure 5.4.12-1: Simulation results for average throughput loss

Table 5.4.12-3: Simulation results for 5%-tile throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU								
Ericsson *	7.80	2.93	1.00	0.57	0.28	0.18	0.18	0.00
NEC								
China Telecom								
Huawei								
ZTE								
Samsung								
CATT	15.55	2.82	0.01	0.00	0.00	0.00	0.00	0.00
Qualcomm	3.35	1.17	0.33	0.06	0.02	0.00	0.00	0.00
Intel	0.02	0.04	0.02	0.00	0.00	0.00	0.00	0.00
LG	12.13	5.87	2.25	0.84	0.32	0.12	0.09	0.01
* NF = 12 is assumed								

Table 5.4.12-4: Simulation results for 5%-tile throughput loss (NF = 13)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU								
Ericsson								
NEC								
China Telecom								
Huawei								
ZTE								
Samsung								
CATT	7.46	0.02	0.01	0.00	0.00	0.00	0.00	0.00
Qualcomm	2.25	0.63	0.17	0.01	0.00	0.00	0.00	0.00
Intel	NA	NA	NA	NA	NA	NA	NA	NA
LG	10.17	4.01	1.43	0.47	0.11	0.06	0.04	0.03

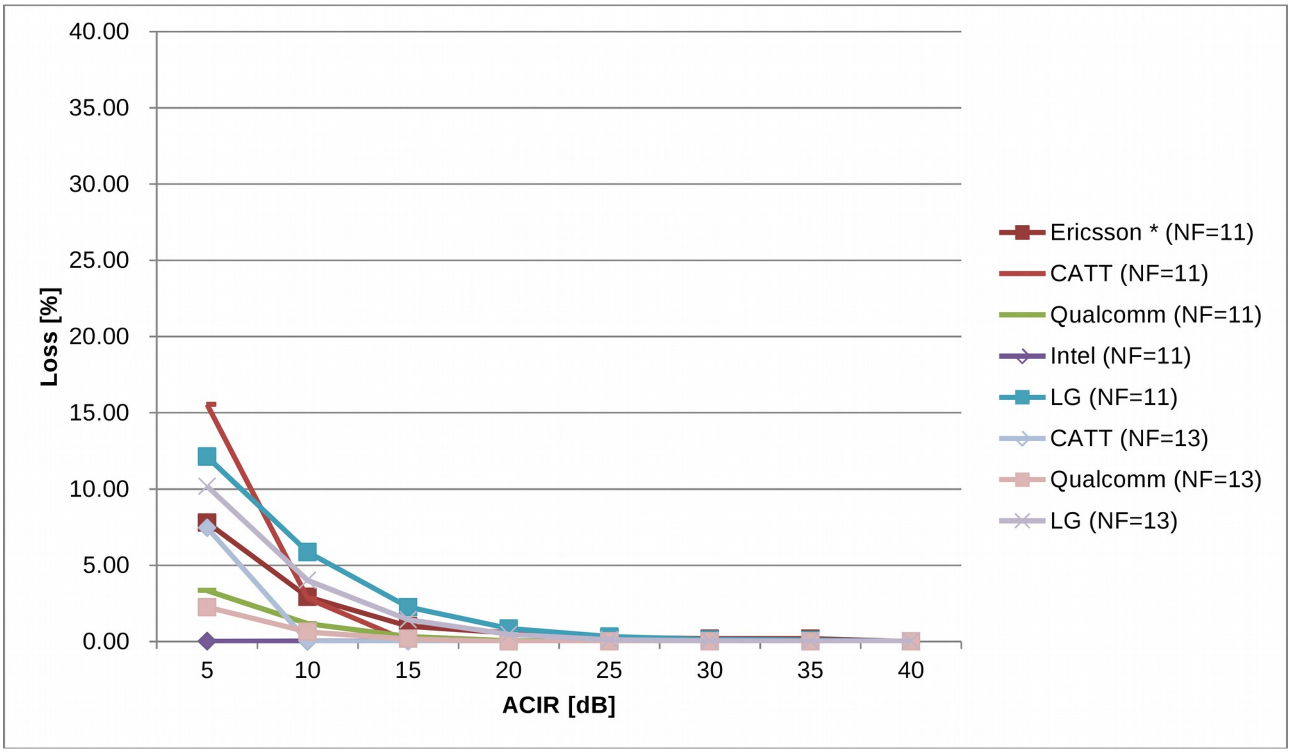


Figure 5.4.12-2: Simulation results for 5%-tile throughput loss

5.4.13 Scenario 13: 45GHz UL indoor scenario

Simulation results for the average throughput loss are presented in table 5.4.13-1, table 5.4.13-2 and figure 5.4.13-1. Simulation results for the 5%-tile throughput loss are presented in table 5.4.13-3, table 5.4.13-4 and figure 5.4.13-2.

Table 5.4.13-1: Simulation results for average throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU								
Ericsson *	12.20	6.28	2.96	1.25	0.50	0.19	0.07	0.02
NEC								
China Telecom								
Huawei								
ZTE								
Samsung								
CATT	3.00	1.38	0.57	0.21	0.07	0.02	0.01	0.00
Qualcomm	8.64	4.18	1.74	0.63	0.21	0.07	0.02	0.01
Intel	3.49	3.10	0.68	0.31	0.10	0.03	0.01	0.00
LG	29.26	16.22	7.63	2.89	0.95	0.28	0.09	0.02
* NF = 12 is assumed								

Table 5.4.13-2: Simulation results for average throughput loss (NF = 13)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU								
Ericsson								
NEC								
China Telecom								
Huawei								
ZTE								
Samsung								
CATT	2.51	1.11	0.44	0.16	0.05	0.02	0.01	0.00
Qualcomm	7.40	3.41	1.34	0.47	0.15	0.05	0.02	0.00
Intel	2.83	1.37	0.52	0.20	0.07	0.02	0.01	0.00
LG	29.26	16.22	7.63	2.89	0.95	0.28	0.09	0.02

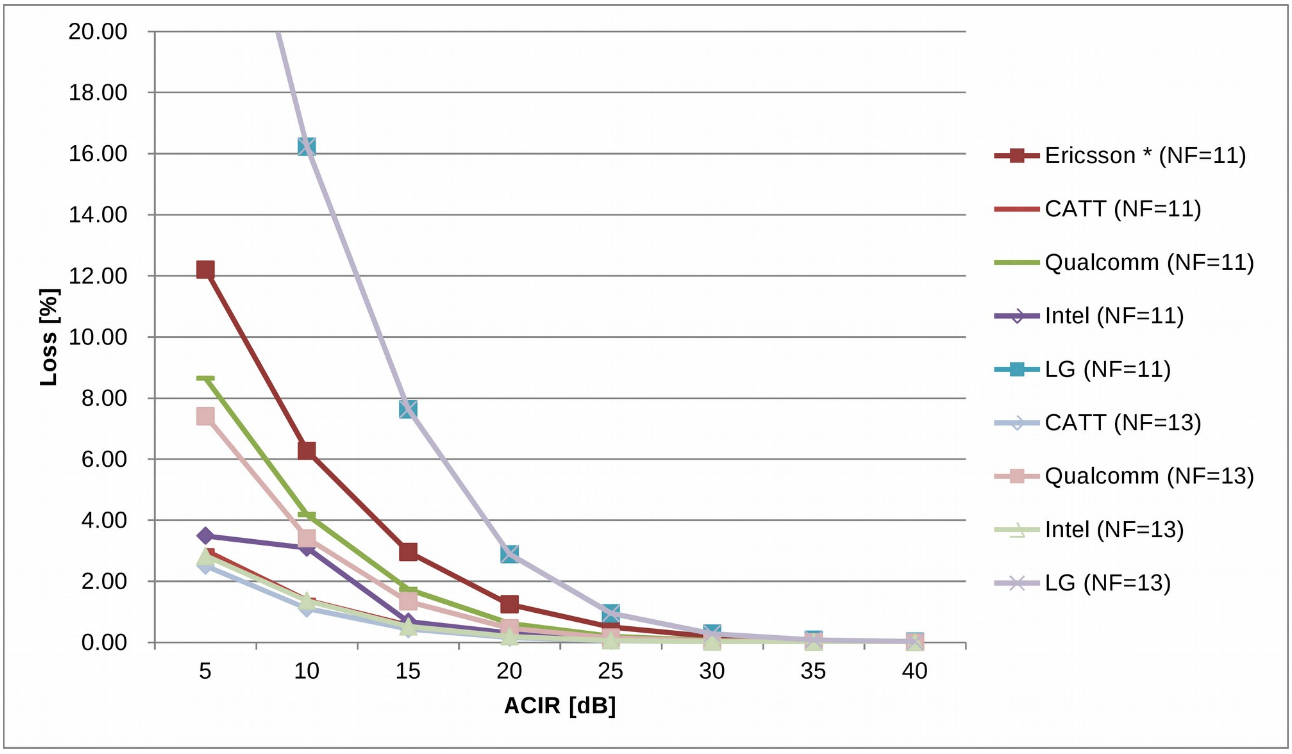


Figure 5.4.13-1: Simulation results for average throughput loss

Table 5.4.13-3: Simulation results for 5%-tile throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU								
Ericsson *	21.56	10.04	4.54	2.04	0.41	0.06	0.08	0.00
NEC								
China Telecom								
Huawei								
ZTE								
Samsung								
CATT	20.48	8.12	1.70	0.80	0.03	0.00	0.00	0.00
Qualcomm	35.65	10.95	1.24	0.44	0.10	0.00	0.00	0.00
Intel	22.95	14.99	3.98	1.38	0.05	0.00	0.00	0.00
LG	32.70	10.22	2.67	0.69	0.17	0.05	0.01	0.00
* NF = 12 is assumed								

Table 5.4.13-4: Simulation results for 5%-tile throughput loss (NF = 13)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU								
Ericsson								
NEC								
China Telecom								
Huawei								
ZTE								
Samsung								
CATT	18.29	6.99	1.44	0.67	0.03	0.00	0.00	0.00
Qualcomm	33.45	9.87	1.09	0.39	0.09	0.00	0.00	0.00
Intel	19.39	10.60	3.69	0.82	0.16	0.03	0.00	0.00
LG	32.70	10.22	2.67	0.69	0.17	0.05	0.01	0.00

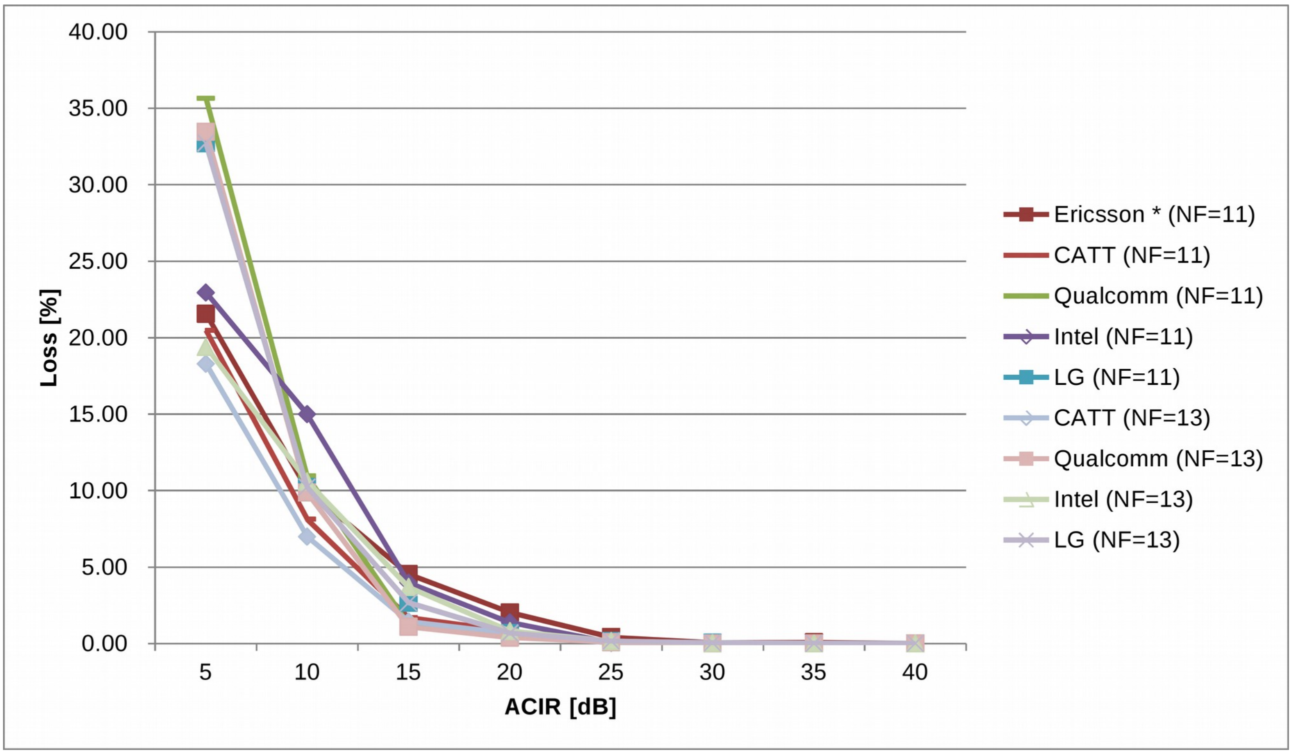


Figure 5.4.13-2: Simulation results for 5%-tile throughput loss

5.4.14 Scenario 14: 45GHz UL urban macro scenario

Simulation results for the average throughput loss are presented in table 5.4.14-1, table 5.4.14-2 and figure 5.4.14-1. Simulation results for the 5%-tile throughput loss are presented in table 5.4.14-3, table 5.4.14-4 and figure 5.4.14-2.

Table 5.4.14-1: Simulation results for average throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU								
Ericsson *	8.74	4.76	2.43	1.12	0.49	0.19	0.07	0.02
NEC								
China Telecom								
Huawei								
ZTE								
Samsung								
CATT	3.67	2.03	1.05	0.50	0.21	0.08	0.03	0.01
Qualcomm	1.48	0.70	0.32	0.13	0.05	0.02	0.01	0.00
Intel	1.02	0.79	0.28	0.14	0.02	0.01	0.00	0.00
LG	9.86	5.73	3.22	1.66	0.79	0.34	0.15	0.06
* NF = 12 is assumed								

Table 5.4.14-2: Simulation results for average throughput loss (NF = 13)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU								
Ericsson								
NEC								
China Telecom								
Huawei								
ZTE								
Samsung								
CATT	3.17	1.73	0.88	0.41	0.16	0.06	0.02	0.01
Qualcomm	1.21	0.56	0.25	0.10	0.04	0.01	0.00	0.00
Intel	0.75	0.40	0.18	0.08	0.02	0.01	0.00	0.00
LG	8.52	4.91	2.69	1.39	0.69	0.30	0.13	0.05

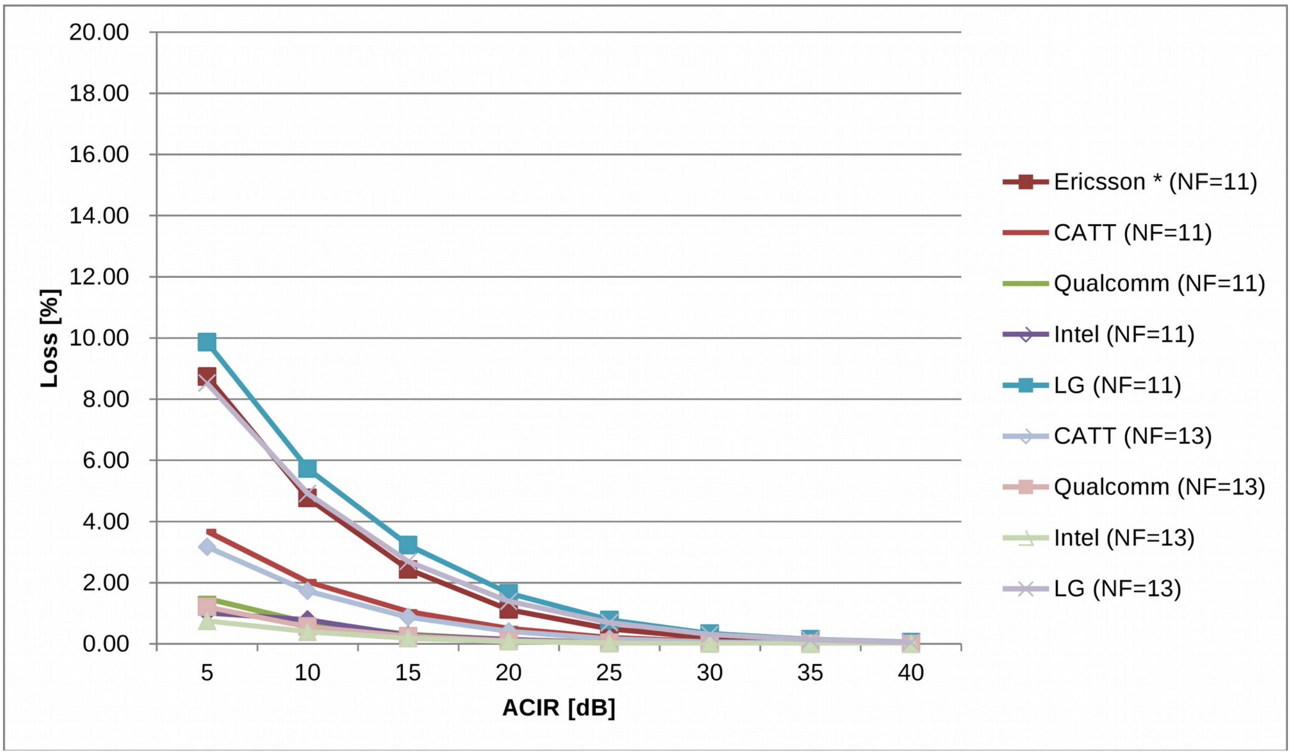


Figure 5.4.14-1: Simulation results for average throughput loss

Table 5.4.14-3: Simulation results for 5%-tile throughput loss (NF = 11)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU								
Ericsson *	NA	NA	NA	NA	NA	NA	NA	NA
NEC								
China Telecom								
Huawei								
ZTE								
Samsung								
CATT	NA	NA	NA	NA	NA	NA	NA	NA
Qualcomm	NA	NA	NA	NA	NA	NA	NA	NA
Intel	NA	NA	NA	NA	NA	NA	NA	NA
LG	15.13	7.80	3.98	1.95	0.83	0.44	0.13	0.06
* NF = 12 is assumed								

Table 5.4.14-4: Simulation results for 5%-tile throughput loss (NF = 13)

ACLR [dB]	5	10	15	20	25	30	35	40
Nokia, ALU								
Ericsson								
NEC								
China Telecom								
Huawei								
ZTE								
Samsung								
CATT	NA	NA	NA	NA	NA	NA	NA	NA
Qualcomm	NA	NA	NA	NA	NA	NA	NA	NA
Intel	NA	NA	NA	NA	NA	NA	NA	NA
LG	12.07	6.10	2.82	1.44	0.65	0.24	0.11	0.10

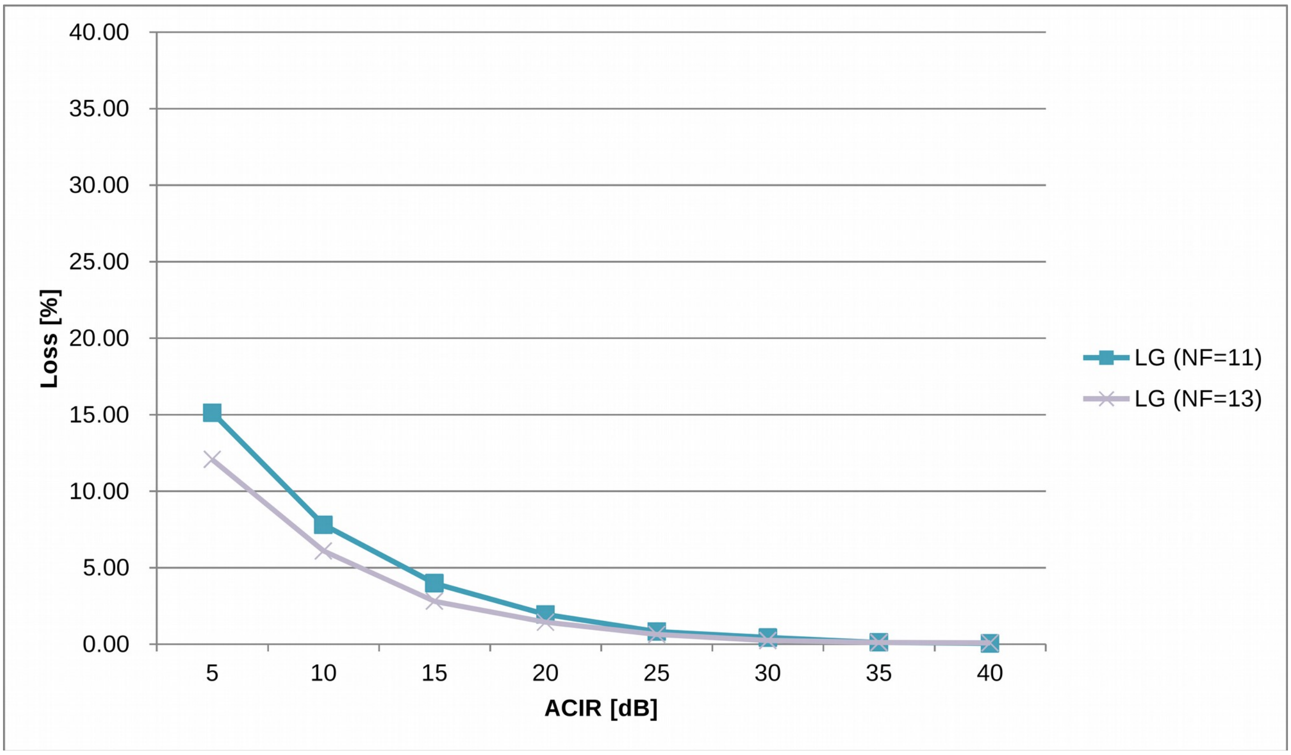


Figure 5.4.14-2: Simulation results for 5%-tile throughput loss

5.5 Summary of co-existence study

This sub-clause captures the summary of the co-existence studies. Based on the simulation results captured in sub-clause 5.4, several observations are made as below. It should be noted that most of the co-existence studies in the SI phase are conducted for the ITU-R WP5D response and the ACLR/ACS parameters captured in this sub-clause are developed for the purpose of sharing and compatibility studies with other systems in ITU-R WP5D. These parameters are aimed at describing the expected behaviour we see of NR with present knowledge and should not be seen as an agreement of what the final NR parameters and characteristics will be.

For the mmWave frequency range, ACLR/ACS values are determined taking into account both ACIR values to meet the 5% throughput loss criteria and feasibility analyses of ACLR/ACS in the mmWave frequency range.

For uplink, the interpolated ACIR values to meet the 5% throughput loss criteria derived by using linear interpolation are summarized in Table 5.5-1, Table 5.5-2, and Table 5.5-3 at 30GHz, 45GHz, and 70GHz, respectively. In order to determine ACLR/ACS values, average ACIR values in the worst case across all the scenarios for each frequency range are considered, which are summarized in Table 5.5-4. Based on the ACIR values in Table 5.5-4 and considering the feasibility analyses of UE ACLR, UE ACLR values are determined as captured in Table 5.5-5. Given the ACIR values in Table 5.5-4 and the UE ACLR values in Table 5.5-5, BS ACS values need to satisfy ≥ 19.9dB at 30GHz, ≥ 20.6dB at 45GHz, ≥ 20.0dB at 70GHz. With this condition, considering the feasibility analyses, the BS ACS values are determined for WP5D as captured in Table 5.5-6.

For downlink, the interpolated ACIR values to meet the 5% throughput loss criteria derived by using linear interpolation are summarized in Table 5.5-7, Table 5.5-8, and Table 5.5-9 at 30GHz, 45GHz, and 70GHz, respectively. To determine the ACIR values from companies' results, two options were discussed.

1) Average the ACIR values across all the companies for each scenario and frequency, and then consider the maximum ACIR value across all scenarios for each frequency range.

2) Consider the maximum ACIR value from each company across all scenarios for each frequency range, andthen average the ACIR values across all the companies for each frequency range,

UE ACS values and BS ACLR values are determined in the similar way as it is done for UL. Table 5.5-10 and Table 5.5-11 capture the the UE ACS values and BS ACLR values determined for WP5D, respectively.

It should be noted that the model of the antenna composite radiation pattern described in sub-clause 5.2.3.1 if used without correct normalisation for antenna gain may diverge somewhat from the physically correct value. It has been shown that this divergence would anyhow not significantly affect the results in sub-clause 5.4 and has or on the conclusions for ACIR captured in this section, however care should be taken to use the normalization if the model document in this TR is applied for any other array types in the future.

Table 5.5-1: Interpolated ACIR values for UL to meet the 5% throughput loss criteria at 30GHz

Scenario		Indoor		Urban macro, ISD=200m		Urban macro, ISD=300m		Dense urban	
NF [dB]		9	11	9	11	9	11	9	11
Nokia, ALU	Average	10.79	9.60	5.70	5.00	7.13	5.72	5.00	5.00
	5%-tile	14.85	14.72	14.94	15.08	NA	NA	8.91	NA
Ericsson *	Average	13.76		8.17				9.48	
	5%-tile	14.63		13.01				18.50	
NEC	Average	10.44	8.87	5.69	5.00	5.03	5.00	5.00	5.00
	5%-tile	9.41	12.48	13.82	13.47	15.52	NA	14.19	14.15
China Telecom	Average			8.48	7.37	10.78	9.56		
	5%-tile			21.20	19.21	NA	NA		
Huawei	Average	9.82	8.83	7.46	6.17	10.65	9.42	5.00	5.00
	5%-tile	13.76	13.60	16.96	19.18	NA	NA	9.75	8.77
ZTE	Average	11.38	11.54	5.00	5.00			5.33	5.49
	5%-tile	14.84	14.91	12.26	15.99			16.11	18.09
Samsung	Average	9.09	9.09	5.00	5.00	5.00	5.00	5.00	5.00
	5%-tile	14.34	14.34	8.38	8.57	NA	NA	NA	NA
CATT	Average	8.49	7.40	9.52	8.52			5.00	5.00
	5%-tile	9.75	9.68	19.29	22.81			16.17	14.25
Qualcomm	Average	8.00	6.78	5.31	5.00	5.00	5.00	5.00	5.00
	5%-tile	12.76	12.36	12.21	9.79	13.78	NA	9.90	8.63
Intel	Average	9.95	8.96	5.00	5.00	5.00	5.00	5.00	5.00
	5%-tile	14.74	14.11	12.34	9.79	NA	NA	5.00	NA
LG	Average	19.18	18.56	5.00	5.00	5.00	5.00	12.18	9.79
	5%-tile	13.37	13.33	18.86	18.47	NA	NA	17.57	15.30
* NF=10 is assumed									

Table 5.5-2: Interpolated ACIR values for UL to meet the 5% throughput loss criteria at 45GHz

Scenario		Indoor		Dense urban	
NF [dB]		11	13	11	13
Nokia, ALU	Average				
	5%-tile				
Ericsson *	Average	11.92		9.70	
	5%-tile	14.58		NA	
NEC	Average				
	5%-tile				
China Telecom	Average				
	5%-tile				
Huawei	Average				
	5%-tile				
ZTE	Average				
	5%-tile				
Samsung	Average				
	5%-tile				
CATT	Average	5.00	5.00	5.00	5.00

	5%-tile	12.43	11.79	NA	NA
Qualcomm	Average	9.09	8.01	5.00	5.00
	5%-tile	13.06	12.77	NA	NA
Intel	Average	5.00	5.00	5.00	5.00
	5%-tile	14.54	14.05	NA	NA
LG	Average	18.64	17.77	11.45	9.88
	5%-tile	13.52	13.46	13.67	11.67
*NF = 12 is assumed.					

Table 5.5-3: Interpolated ACIR values for UL to meet the 5% throughput loss criteria at 70GHz

Scenario		Indoor		Dense urban	
NF [dB]		13	15	13	15
Nokia, ALU	Average	5.00	5.00	5.53	5.00
	5%-tile	15.07	14.14	NA	NA
Ericsson *	Average	10.61		5.61	
	5%-tile	13.92		NA	
NEC	Average	5.00	5.00	5.00	5.00
	5%-tile	8.45	5.64	NA	NA
China Telecom	Average				
	5%-tile				
Huawei	Average	7.78	6.52	5.00	5.00
	5%-tile	13.44	13.12	NA	NA
ZTE	Average	5.28	5.52	5.00	5.00
	5%-tile	18.15	17.77	NA	NA
Samsung	Average	5.00	5.00	5.00	5.00
	5%-tile	13.95	13.95	NA	NA
CATT	Average	5.00	5.00	5.00	5.00
	5%-tile	9.96	9.36	NA	NA
Qualcomm	Average	9.64	8.63	5.00	5.00
	5%-tile	13.62	13.23	NA	NA
Intel	Average	5.00	5.00	5.00	5.00
	5%-tile	13.82	12.76	NA	NA
LG	Average	17.84	16.62	6.87	7.16
	5%-tile	13.28	13.19	10.06	8.23
*NF = 14 is assumed.					

Table 5.5-4: Average ACIR values for UL in the worst case across all scenarios

	30GHz	45GHz	70GHz
ACIR value [dB]	15.2	14.7	13.8

Table 5.5-5: UE ACLR

	30GHz	45GHz	70GHz
UE ACLR value [dB]	17	16	15

Table 5.5-6: BS ACS

	30GHz	45GHz	70GHz

BS ACS value [dB]	23.5	22.5	21.5

Table 5.5-7: Interpolated ACIR values for DL to meet the 5% throughput loss criteria at 30GHz

Scenario		Indoor		Urban macro, ISD=200m		Urban macro, ISD=300m		Dense urban	
NF [dB]		9	11	9	11	9	11	9	11
Nokia, ALU	Average	15.73	15.73	11.85	11.81	14.29	14.11	5.00	5.00
	5%-tile	14.88	14.87	19.90	19.95	23.02	19.59	7.37	8.52
Ericsson *	Average	15.63		14.53				12.23	
	5%-tile	17.32		18.72				14.63	
NEC	Average	15.19	16.10	12.47	12.47	12.62	12.55	9.66	9.24
	5%-tile	13.79	16.10	12.32	11.41	8.83	7.62	10.68	7.56
China Telecom	Average			14.11	14.06	16.57	16.53		
	5%-tile			20.80	20.04	26.47	26.13		
Huawei	Average	15.72	15.72	13.57	13.53	15.95	15.83	7.10	6.83
	5%-tile	14.47	14.47	23.38	22.22	25.52	26.34	11.92	12.73
ZTE	Average	16.21	16.23	9.19	9.43			5.05	5.49
	5%-tile	14.75	15.92	24.79	27.89			18.81	17.17
Samsung	Average	15.68	15.68	8.89	8.87	9.39	9.37	5.00	5.00
	5%-tile	14.62	14.62	13.62	13.02	9.14	8.35	8.93	7.51
CATT	Average	15.45	15.45	15.13	15.12			10.10	9.91
	5%-tile	13.14	13.14	20.58	23.85			14.14	13.51
Qualcomm	Average	16.17	16.18	12.32	12.30	12.47	12.43	6.12	5.80
	5%-tile	13.47	13.47	13.49	13.16	9.55	9.14	10.33	8.96
Intel	Average	15.64	15.90	8.16	8.35	10.70	9.71	5.00	5.00
	5%-tile	15.78	14.55	16.48	17.99	19.08	19.17	6.47	5.00
LG	Average	19.59	19.59	8.91	9.42	14.49	16.32	7.83	10.46
	5%-tile	15.51	15.51	23.43	22.90	23.36	23.05	15.46	14.60
* NF=10 is assumed									

Table 5.5-8: Interpolated ACIR values for DL to meet the 5% throughput loss criteria at 45GHz

Scenario		Indoor		Dense urban	
NF [dB]		11	13	11	13
Nokia, ALU	Average				
	5%-tile				
Ericsson *	Average	14.94		11.49	
	5%-tile	17.42		7.87	
NEC	Average				
	5%-tile				
China Telecom	Average				
	5%-tile				
Huawei	Average				
	5%-tile				
ZTE	Average				
	5%-tile				
Samsung	Average				
	5%-tile				
CATT	Average			9.40	9.23
	5%-tile			9.14	6.65

Qualcomm	Average	16.49	16.50	5.00	5.00
	5%-tile	13.90	13.90	5.00	5.00
Intel	Average	8.20	9.28	5.00	5.00
	5%-tile	17.15	17.92	5.00	NA
LG	Average	19.64	19.64	12.54	11.99
	5%-tile	15.27	15.27	11.20	9.20
*NF = 12 is assumed.					

Table 5.5-9: Interpolated ACIR values for DL to meet the 5% throughput loss criteria at 70GHz

Scenario		Indoor		Dense urban	
NF [dB]		13	15	13	15
Nokia, ALU	Average	9.72	9.73	5.00	5.00
	5%-tile	17.88	17.98	NA	NA
Ericsson *	Average	13.99		10.88	
	5%-tile	16.25		NA	
NEC	Average	10.84	10.36	6.84	6.99
	5%-tile	15.97	18.93	NA	NA
China Telecom	Average				
	5%-tile				
Huawei	Average	15.81	15.72	5.00	5.00
	5%-tile	14.35	14.47	NA	NA
ZTE	Average	9.25	9.10	5.00	5.00
	5%-tile	19.21	18.13	NA	NA
Samsung	Average	9.42	9.43	5.00	5.00
	5%-tile	14.96	14.96	NA	NA
CATT	Average	9.61	9.64	8.48	8.32
	5%-tile	14.16	14.14	NA	NA
Qualcomm	Average	16.39	16.34	5.00	5.00
	5%-tile	13.89	13.90	NA	NA
Intel	Average	9.40	9.42	5.00	5.00
	5%-tile	17.06	17.48	NA	NA
LG	Average	19.56	19.56	9.05	8.38
	5%-tile	15.21	15.21	5.00	5.00
*NF = 14 is assumed.					

Table 5.5-10: UE ACS

	30GHz	45GHz	70GHz
UE ACS value [dB]	22.5	21.5	20.5

Table 5.5-11: BS ACLR

	30GHz	45GHz	70GHz
BS ACLR value [dB]	27.5	25.5	23.5

6 RF feasibility

6.1 Common issues for UE and BS

6.1.1 General

Agreement in SI and issue should be addressed in WI are summarized in Table 6.1.1-1 for Common RF aspects.

Table 6.1.1-1: Summary on Outcome in SI and topic to be addressed in WI

Requirement	Outcome in SI	Topic to be addressed in WI
Operation bands	- Frequency ranges for NR requested by operators [R4-1702444]	- Operation bands for NR - Operation bands combinations for DC (LTE+NR) - Operation bands for CA (intra NR). Note that the necessity in Rel-15 will depend on maximum channel bandwidth.

Channel bandwidth/Transmission bandwidth configuration	- Subcarrier spacing
	  - 15kHz, 30kHz, 60kHz are feasible for sub 6GHz
	  - 160kHz, 120kHz, 240kHz are potential candidates. 480kHz is FFS.
	- Maximum CBW
	  - Range for further study is 100MHz ~ 200MHz for sub 6GHz
	  - Range for further study is 100MHz ~ 1GHz for above 6GHz
	- FFT size
	  - 4096 FFT size is feasible as the maximum FFT size. 8192 is FFS.
	- Transmission bandwidth configuration adaptation
	  - Initial analysis on transition time (RF aspects) [R4-1702029]
	- Spectrum Utilization
	  - Above 90% is feasible
		- Subcarrier spacing to be supported for NR bands
		- Maximum CBW and subsets of CBW to be supported for NR bands
		- How to specify transmission bandwidth configuration adaptation
		- Whether RF requirements are scalable or not
		- How to handle wider channel

Channel spacing	- FFS	- Channel spacing for NR
Channel raster	- FFS	- Channel raster for NR, - possibility of sparse synchronization channel raster
Frequency channel number	- FFS	- Frequency channel number for NR
TX-RX frequency separation	- FFS	- TX-RX frequency separation for NR

6.1.2 NR spectrum utilization

In RAN4 NR spectrum utilization study, it was agreed that [R4-168814]

- Carrier spectrum utilization, denoted by Y, is assumed to be higher than 90% in RAN4 future study and RAN4 requirements should be defined based on this assumption.
    - Y may depend on specific numerology and carrier bandwidth.
    - Y may depend on the BS/UE implementation complexity and declared capability. It is possible to define different value of Y for different BS/UE capabilities with compliance of related RF requirements, e.g. EVM, ACLR, SEM, etc.

In [R4-1610922], it was further agreed that,

- For some combinations of bandwidth and subcarrier spacing e.g. 10MHz@120kHz and 5MHz@60kHz, the theoretic maximum spectrum utilization Y will be below 90% when integer number of PRBs are used for the transmission bandwidth configuration as in LTE.
  - How to improve Y over 90% is FFS.
- The maximum spectrum utilization based on RAN4 requirements may vary with numerology, carrier bandwidth and different BS/UE capabilities, considering the capabilities of spectrum confinement techniques including both filtering and windowing , e.g., indicated as a range [YL, YH] for each group of (BW subset @ SCS subset) .
  - How to group (BW subset @ SCS subset) is FFS.
  - YL and YH are with compliance of related RF requirements, e.g. EVM, ACLR, SEM, selectivity, demodulation etc.
    - EVM evaluation should include high order modulations up to 256QAM.
  - FFS for UE capability needed or not
- The guard band for a carrier in case of mixed numerology may be asymmetric and defined with the assumption that single numerology is applied, and the assumed numerology refers to the numerology applied at band edge.
- The need and size of GB between two numerologies is FFS. The granularity of GB, i.e. 1 PRB or fractional PRB, will be further evaluated
- Compare filtering and windowing,
  - To decide the guard band at the edge of the channel the analysis should focus on the following aspects:
    - Emission levels complying with SEM while achieving highest spectrum utilization
    - EVM analysis over the entire channel bandwidth (preferably per RB)
    - Impact of uneven EVM
    - Impact of spectrum confinement techniques to ISI (i.e. BLER performance in fading channel)
    - Complexity of spectrum confinement technique used (complexity of the filter used)
    - Impact of PA over emission levels and EVM (Start with the PA models and operating points used in RAN1 evaluation. PA models with memory effects are not ruled out)
    - Impact to ICI is FFS
    - Impact to other timing critical procedures
    - Coexistence to LTE in applicable bands
- Compare filtering and windowing,
  - To decide the guard band between different numerologies within the same channel the analysis should focus on the following aspects:
    - Required in-band emissions levels (emissions from one numerology into the other)
    - EVM in the subband assigned to each numerology
    - Impact of uneven EVM
    - Impact of spectrum confinement techniques to ISI (i.e. BLER performance in fading channel)
    - Assumptions on the filter used for the EVM measurement (complexity of the filter)
    - Impact of PA over emission levels and EVM (Start with the PA models and operating points used in RAN1 evaluation. PA models with memory effects are not ruled out)
- Impacts to other timing critical procedures

- Companies should provide the details of the simulation configuration and the parameters of any spectrum confinement techniques applied.
- For some combinations of bandwidth and subcarrier spacing e.g. 10MHz@120kHz and 5MHz@60kHz, the theoretic maximum spectrum utilization Y will be below 90% when integer number of PRBs are used for the transmission bandwidth configuration as in LTE.
  - How to improve Y over 90% is FFS.
- For spectrum utilization in cases where utilization is <90% with integer number of PRBs
  - Actual use cases for these combinations of CHBW and SCS
  - Number of bits that can be transmitted in 1 TTI with integer and fractional number of PRBs

Further in RAN4 NR spectrum utilization study, it was agreed in [R4-168776] that

- RAN 4 should define the Tx unit emission requirements and Rx unit selectivity requirements in the presence of predefined interfering signals.
- RAN 4 should define signal quality performance targets for Tx and Rx unit testing in predefined channels, while noting the possible balancing of EVM between Tx and Rx units.
- Independent Tx and Rx unit requirements and corresponding test setups will be defined in RAN4

Further in RAN4 NR spectrum utilization study, the following should be considered,

- Some analysis of spectral efficiency was made; more analysis is needed
- The BS narrowband blocking requirement should be considered when considering the uplink spectral utilization
- Any implications to coexistence or signaling complexity should be considered further
- Implications of needing to switch position or length of filtering need further examination

6.1.3 Channel bandwidth/Transmission bandwidth configuration

6.1.3.1 Subcarrier spacing

Editor's note: This section will capture backgrounds and discussions on how outcome of SI related to SCS were derived.

Feasible subcarrier spacing for NR would depend on frequency range. Based on the initial study, for below 6 GHz, the feasible sub-carrier spacings were identified, while above 6 GHz, the study was able to go no further than identifying potential candidates:

- For below 6GHz: 15kHz, 30 kHz and 60kHz are feasible
- For above 6GHz: 60kHz, 120kHz and 240kHz are potential candidates of feasible subcarrier spacing.

It should be noted which of the above mentioned subcarrier spacings are supported depends on NR bands where UE and gNB operate.

6.1.3.2 Channel bandwidth

6.1.3.2.1 Maximum Channel bandwidth

Editor's note: This section will capture backgrounds and discussions on how outcome of SI related to Maximum Channel Bandwidth were derived.

Maximum channel bandwidth was studied based on at least possible sub-carrier spacings in a certain frequency range considering aspects such as phase noise impact, FFT size etc. As the result, it was concluded that from physical layer specification perspective the maximum supportable channel bandwidth at this stage is 400MHz while from RF feasibility perspective the ranges of the maximum channel bandwidth are as follows:

- For below 6GHz: Maximum CBW will be further studied in range of 100MHz ~ 200MH.
- For above 6GHz: Maximum CBW will be further studied in range of 100MHz ~ 1GHz

In addition, the necessity of the investigation of possibility to support the above maximum channel bandwidth with carrier aggregation was identified.. It should be noted that the maximum channel bandwidth mentioned above may be not applicable to all bands.

6.1.3.2.2 Flexible channel bandwidth

Editor's note: This section will capture backgrounds and discussions on how outcome of SI related to Flexible channel bandwidth were derived.

It is clarified that the flexible channel bandwidth can potentially be specified if it is established that RF requirements can be linearly scalable with channel bandwidth or if RF requirements for a finite set of channel bandwidth can ensure UE/gNB performance.

6.1.3.3 UE transmission bandwidth configuration adaptation

Editor's note: This section will capture backgrounds and discussions on how outcome of SI related to UE transmission bandwidth configuration adaptation (i.e. UE RF bandwidth adaptation) were derived.

In this concept, transmission bandwidth configuration within a channel bandwidth is not always the maximum unlike LTE. The maximum transmission bandwidth as well as its position can be adjusted to suitable one. To study this feature, at least transmission time in both RF and baseband side and power saving aspects were considered. As an initial analysis, the following observations were obtained for transition time specifically in terms of RF aspects:

- For intra-band operation, at least for below 6GHz, the transition time can be up to 20µs if the centre frequency is the same before and after the transmission bandwidth configuration adaptation.
- For intra-band operation, at least for below 6GHz, the transition time is 50~200µs if the centre frequency is different before and after the transmission bandwidth configuration adaptation.
- For inter-band operation, at least for below 6GHz, the transition time can be up to 900µs.

6.1.4 Channel spacing

Editor's note: This section will capture backgrounds and discussions on how outcome of SI related to Channel spacing were derived.

6.1.5 Channel raster

Editor's note: This section will capture backgrounds and discussions on how outcome of SI related to Channel raster were derived.

6.1.6 Frequency channel number

Editor's note: This section will capture backgrounds and discussions on how outcome of SI related to Frequency channel number were derived.

6.1.7 TDD timing budget

Editor's note: This section will capture backgrounds and discussions on how outcome of SI related toTDD timing budget were derived.

6.1.8 NR in-band requirements

Based on the discussions and agreed WFs [R4-1610921, R4-1702093], it can be concluded that for NR in-band requirements,

- NR will develop DL and UL in-band emission, and in-band selectivity requirements with different numerologies on the same NR carrier
  - In the first phase, two different numerologies within one carrier are assumed to define in-band requirements
    - Sub-block 1 with 15kHz subcarrier spacing
    - Sub-block 2 with 60kHz subcarrier spacing
  - Start evaluations of in-band performance and needed requirements for mixed numerology case by evaluating 20 MHz NR carrier with roughly two 10 MHz sub-blocks with different numerologies (15 kHz and 60 kHz SCS) for <6 GHz frequencies at the first phase
  - When RAN4 defines 5G NR requirements, RAN4 should ensure sufficiently good spectral efficiency in both single and mixed numerology cases
  - Flexibility in approach to allocating non used PRBs (guard) and filtering/windowing in order to maximize spectral efficiency for each specific link situation and different reference measurement channels e.g. with different MCSs should be enabled
  - For NR mixed numerology case RAN4 should specify new type of minimum requirements to define. These might include some of the following
    - how close to each other in frequency BS Tx can transmit two sub-blocks with different numerologies while still meeting the other relevant requirements like the EVM
      - The possibility of several requirements with different sub-block spacing, different reference measurement channels (e.g. different MCS) and EVM may need to be considered
      - Requirements should consider both the interference arising from the other numerology and impact to EVM due to filtering of a numerology
    - how close to each other in frequency two sub-blocks with different numerologies could be while BS Rx and UE Rx still need to meet the relevant receiver requirements like the selectivity
      - The possibility of several requirements with different sub-block spacing and selectivity may need to be considered
  - It is FFS how many requirements are needed for ensuring flexibility to optimize for different link situations and whether all requirements should be mandatory
    - Companies should express analysis & views on which requirements are needed and whether they should be mandatory
- NR UL in-band emission and EVM requirements at UE Tx
  - Develop UE Tx in-band emission and EVM requirements for the baseline CP-OFDM baseline waveform

    assuming suitable spectral confinement methods
  - Perform link simulations with two numerologies next to each other in frequency domain to study how stringent UL in-band emission requirements would benefit frequency domain multiplexing of different numerologies within the same spectrum block
  - If the current LTE based UE Tx in-band emission requirement definition is reused in NR, update the UE Tx in-band emission requirement definition so that both the same and different numerologies are verified as victim and aggressor UEs by checking all the numerologies in the test equipment receiver
    - Before agreeing the exact definition of NR UE Tx in-band emission requirement, study if it is feasible to define NR UE Tx in-band emission requirements in a new numerology independent way
  - Define both average UE Tx EVM requirements measured over all the allocated PRBs and a few edge PRBs
    - Study further to decide if 1 PRB EVM measurement could be assumed as narrow bandwidth UE Tx EVM measurement

    - TRX impairments like Image and carrier leakages and PA ACLR impact must be carefully budgeted when interference between different numerologies are studied
        - TRX impairments are to be considered at any UL power levels where ACLR is only to be considered for the upper part of the UE power levels
        - Need for Improved TRX impairments compared to LTE and achievable sub6GHz and mmW UE image and carrier leakage values should be further studied
- NR DL selectivity requirements at UE Rx
    - Define DL in-band selectivity requirements at UE Rx with different numerologies in adjacent wanted and interfering sub-blocks
    - Definition in mixed numerology case should follow the same format as uplink,
    - Investigate the necessity of guard band for the targeted modulation
    - Receiver complexity should be considered when defining the requirements
- NR DL EVM and in-band emission requirements at BS Tx
    - EVM is required regardless on single or mixed numerology
        - Define two numerology EVM requirements with two sub-blocks with different numerologies
        - Further study on the issue that EVMs are unevenly distributed among the allocated resource blocks
        - High order modulation up to 256QAM can be studied in the evaluation
    - In the two numerology case, EVM will be measured for both of the sub-blocks using the numerology used in a given sub-block edge PRBs
        - EVM performance of the edge subcarrier shall be covered
    - Investigate the necessity of guard band for the two numerology EVM requirements
        - Evaluate also the feasibility of zero guard band case
        - BS scheduler may decide the used guard band
        - FFS if granularity is based on PRB or SCS
    - For single numerology case define both average BS Tx EVM requirements over all the PRBs and over 1 PRB for the edge PRBs
    - For mixed numerology case define both average BS Tx EVM requirements over all the PRBs of a given numerology and over 1 PRB for the edge PRBs
    - Consider reducing the number of test cases and testing in first phase NR specification development by defining only EVM based requirements for BS Tx in-band requirements with the mixed numerology case
    - Define the receiver assumptions for validating the requirements as Tx EVM measurement depends on the implementation of the receiver used for the measurement
    - Tx and Rx complexity should be taken into account
- NR UL selectivity requirements at BS RX
    - The uplink in-band selectivity requirement definition in single and mixed numerology case should target for sub-block edge PRB(s)
        - Verify the overall performance in addition
    - Spatial aspects to be considered
    - RAN4 will use the following assumptions and priorities for developing UL in-band selectivity requirements at BS Rx:

- First requirements using the baseline CP-OFDM signal both for wanted and inferring signals
- Requirements both with the same and different numerologies for wanted and interfering signals
- First requirements using time-aligned wanted and interfering signals. Later requirements for asynchronous cases with non-time-aligned signals
- Investigate suitable guard band between the wanted and interfering signals in case of mixed numerologies and/or non-time aligned signals

- Define the minimum requirement for NR BS in-channel selectivity requirements with mixed numerologies as follows:

  For NR, the throughput shall be ≥ TBD % of the maximum throughput of the reference measurement channel as specified in Annex TBD with parameters specified in Table TBD for NR TBD type BS.

NR channel bandwidth (MHz)	Reference measurement channel	Wanted signal mean power [dBm]	Interfering signal mean power [dBm]	Type of wanted signal	Type of interfering signal
[10]	TBD	TBD	TBD	[10 MHz] NR CP-OFDMA signal, TBD RBs*	[10 MHz] NR CP-OFDMA signal, TBD RBs*
Note*: Wanted and interfering signal are placed around F_c with TBD RBs between the signals					

Note: One NR channel bandwidth is listed in the table as an example to illustrate the meaning of different columns

Additionally in [R4-1700053] for NR UL in-band emissions and EVM requirements at UE TX, it was agreed that in order to enable better UL coverage for CP-OFDM waveform RAN4 should study a possibility to define two sets of in-band emissions and EVM requirements for NR UE Tx; more and less stringent requirements.

With the above agreed methodology and assumptions, the detailed requirements for both DL and UL can be further investigated.

It was agreed in [R4-168776] that

- RAN 4 should define the Tx unit emission requirements and Rx unit selectivity requirements in the presence of predefined interfering signals.
- RAN 4 should define signal quality performance targets for Tx and Rx unit testing in predefined channels, while noting the possible balancing of EVM between Tx and Rx units.
- Independent Tx and Rx unit requirements and corresponding test setups will be defined in RAN4

6.1.9 Common issues for mmWave

6.1.9.1 PA efficiency in relation to unwanted emission for mm-wave technologies

Radio Frequency (RF) building block performance generally degrades with increasing frequency. The power capability of power amplifiers for a given integrated circuit technology roughly degrades by 20 dB per decade, as shown in Figure 6.1.9.1-1. There is a fundamental cause for this degradation; increased power capability and increased frequency capability are conflicting requirements as observed from the so-called Johnson limit. In short, higher operational frequencies require smaller geometries, which subsequently result in lower operational power in order to prevent dielectric breakdown from the increased field strengths. Moore’s Law does not favor power capability performance.

A remedy is however found in the choice of integrated circuit material. Mm-wave integrated circuits have traditionally been manufactured using so called III-V materials, i.e. a combination of elements from groups III and V of the periodic table, such as Gallium Arsenide (GaAs) and more recently Gallium Nitride (GaN). Integrated circuit technologies based on III-V materials are substantially more expensive than conventional silicon-based technologies and they cannot handle the integration complexity of e.g. digital circuits or radio modems for cellular handsets. Nevertheless, GaN-based technologies are now maturing rapidly and deliver power levels an order of magnitude higher compared to conventional technologies.

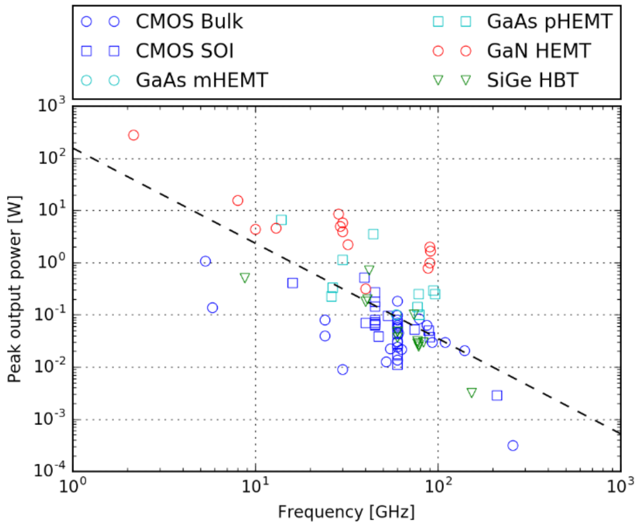


Figure 6.1.9.1-1: Power amplifier output power versus frequency for various semiconductor technologies. The dashed line illustrates the observed reduction in power capability versus frequency (-20 dB per decade).

There are mainly three semiconductor material parameters that affect the efficiency of an amplifier: the maximum operating voltage, maximum operating current density and knee-voltage. Due to the knee-voltage, the maximum attainable efficiency is reduced by a factor proportional to:

$$\frac{1-k}{1+k}$$

Where k is the knee-voltage to the maximum operating voltage ratio. For most transistor technologies the ratio k is in the range of 0.05 to 0.01, resulting in an efficiency degradation of 10% to 20%.

Figure 6.1.9.1-2 shows the saturated power added efficiency (PAE) as function of frequency. The maximum reported PAE is about 40% and 25% at 30 GHz and 77 GHz, respectively.

PAE is expressed as PAE = $100*\{[P_{OUT}]_{RF} – [P_{IN}]_{RF}\} / [P_{DC}]_{TOTAL}$.

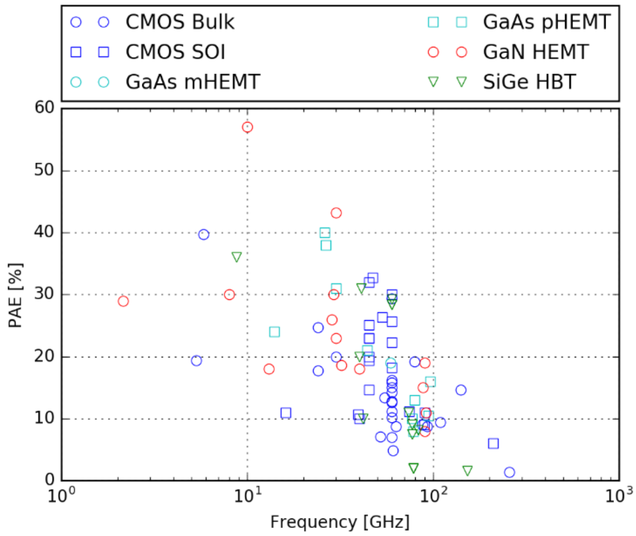


Figure 6.1.9.1-2: Saturated power added efficiency versus frequency for various semiconductor technologies. The data points are taken from published microwave and mm-wave power amplifier circuits.

At mm-wave frequencies the available output power is fundamentally limited by semiconductor technologies. Furthermore, the efficiency is also degraded with frequency.

Considering the PAE characteristics in Figure 6.1.9.1-2, and the non-linear behavior of the AM-AM/AM-PM characteristics of the power amplifier, significant power back-off would be necessary to reach certain linearity requirement such as ACLR. Considering the heat dissipation aspects and significantly reduced area/volume for mm-wave products, the complex interrelation between linearity, PAE and output power in the light of heat dissipation should be considered.

6.1.9.2 Noise figure, dynamic range and bandwidth dependencies for mm-wave technologies

The dynamic range (DR) of a cellular receiver will in general be limited by the front-end insertion loss (IL), the receiver (RX) LNA and the ADC noise and linearity properties.

Typically $DR_{LNA} \gg DR_{ADC}$ so the RX use AGC and selectivity (distributed) in-between the LNA and the ADC to optimize the mapping of the wanted signal and the interference to the DR_{ADC}. For simplicity only a fixed gain setting is considered here. This example in Figure 6.1.9.2-1 shows a TDD implementation

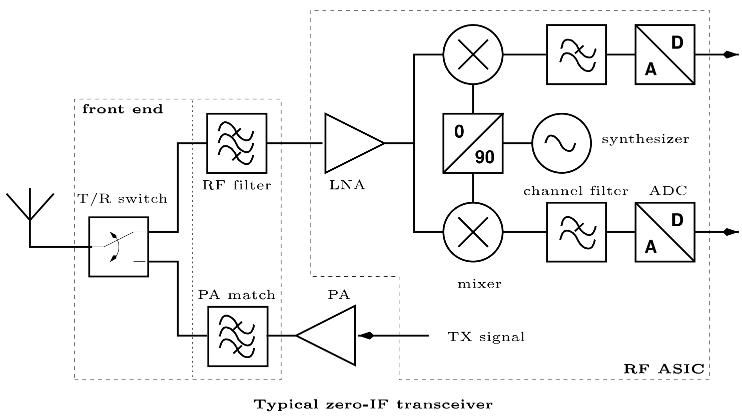


Figure 6.1.9.2-1: Typical zero-IF transceiver schematic

6.1.9.2.1 Noise figure model

A simplified receiver model can be derived by lumping the FE, RX and ADC into three cascaded blocks. This model cannot replace a rigorous analysis but will show the main parameter inter dependencies.

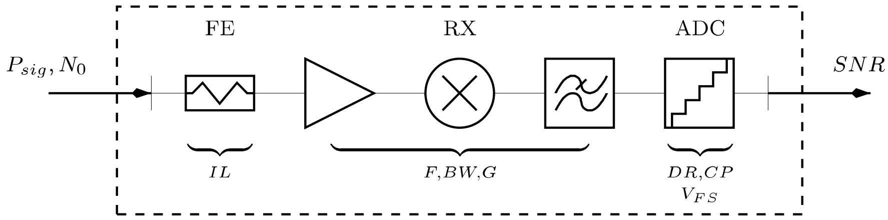


Figure 6.1.9.2.1-1: A simplified receiver model

Focusing on the small signal co-channel noise floor, the impact of various signal and linearity impairments can be studied to arrive at simple noise factor, or noise figure, expression.

6.1.9.2.2 Noise factor and noise floor

Assuming matched conditions Friis' formula can be used to find the noise factor at the receiver input as (linear units unless noted), $F_{RX} = 1+(F_{LNA} -1)+(F_{ADC} -1)/G$.

The RX input referred small-signal co-channel noise floor will then be equal to

$N_{RX} = F_{LNA} \cdot N_0 + N_{ADC}/G$,

where $N_0 = k \cdot T \cdot BW$ and N_{ADC} are the available noise power and the ADC effective noise floor in the channel bandwidth, respectively (k and T being Boltzmann's constant and absolute temperature, respectively). The ADC noise floor is typically set by a combination of quantization, thermal and intermodulation noise, but here we just assume a flat noise floor as defined by the ADC effective number of bits ($SINAD = 3/2 \cdot 2^{2 \cdot ENOB}$).

The effective gain from LNA input to ADC input, (G) depends on small-signal gain, AGC setting, selectivity and desensitization (saturation), but here it is assumed that the gain is set such that the antenna referred input compression point (CP_i) corresponds to the ADC clipping level, i.e. the ADC full scale input voltage (V_{FS}).

For weak nonlinearities, there is a direct mathematical relation between CP (1dB compression point) and the third-order intercept point (IP_3) such that $IP_3 \approx CP + 10$ dB. For higher-order nonlinearities, the difference can be larger than 10 dB, but then CP is still a good estimate of the maximum signal level while inter-modulation for lower signal levels may be overestimated.

6.1.9.2.3 1dB Compression point and gain

Between the antenna and the RX we have the FE with its associated insertion loss (IL>1), e.g. due to a T/R switch, a possible RF filter, and PCB/substrate losses. These losses have to be accounted for in the gain and noise expressions. Knowing IL, the CP_i can be found that corresponds to the ADC clipping as

$CP_i = IL \cdot N_{ADC} \cdot DR_{ADC}/G$.

The antenna referred noise factor and noise figure will then become

$F_i = IL \cdot F_{RX} = IL \cdot F_{LNA} + CP_i/(N_0 \cdot DR_{ADC})$, and, $NF_i = 10 \cdot \log_{10}(F_i)$, respectively.

When comparing two designs, e.g. at 2 and ~30 GHz, respectively, the ~30 GHz IL will be significantly higher than that of the 2GHz. From the F_i expression it can be seen that to maintain the same noise figure (NF_i) for the two carrier frequencies, we need to compensate the higher FE loss at ~30 GHz by improving the RX noise factor. This can be accomplished (i) by using a better LNA (ii) by relaxing the input compression point, i.e. increasing G, or (iii) by increasing the DR_{ADC}. Usually a good LNA is already used at 2GHz to achieve a low NF_i so this option is rarely possible. Relaxing CP_i is an option but this will reduce IP_3 and linearity performance will degrade. Finally, increasing DR_{ADC} comes at a power consumption penalty (4× per extra bit). Especially wideband ADCs may have a high power consumption, i.e. when BW is below some 100 MHz the $N_0 \cdot DR_{ADC}$ product (i.e. $BW \cdot DR_{ADC}$) is proportional to the ADC power consumption, but for higher bandwidths the ADC power consumption is proportional to $BW^2 \cdot DR_{ADC}$, penalizing higher BW, see the ADC section. Increasing DR_{ADC} is typically not an attractive option and it is inevitable that the ~30 GHz receiver will have a significantly higher NF_i than that of the 2GHz receiver.

6.1.9.3 Filtering aspect for mm-wave technologies

Various types of filters have been deployed in 3GPP based BS and UE implementations below 6 GHz. The filters mitigated the unwanted emissions arising from e.g. non-linearity in the transmitters generated due to intermodulation, harmonics generation etc. In the receiver chain filters where deployed to handle either own transmitter in paired bands or suppress the interferer at adjacent or other frequencies.

The requirements have also been differentiated in terms of levels e.g. for spurious emission, general, co-existence in the same geographical areas and co-location has been specified while the requirement levels for in-band to out-of-band has also been considered by exclusion zones defining e.g. the in-band and spurious emission domain respectively.

For mm-wave frequencies depending on the waveform design and OFDM numerology, different modulation spectrums affecting the filtering and size of the exclusion zones should be considered.

Considering the limited size (area/volume) and level of integrations needed for mm-wave frequencies, the filtering can be challenging where discrete mm-wave filters are far too bulky to be fitted in limited size as well as the challenge it poses to embed such filter into highly integrated structures for mm-wave products.

It is worth mentioning here that, the above mentioned issues can become challenging (or even prohibitive) especially for UE implementation for operation in mmwave spectrum.

6.1.9.3.1 Possibilities of filtering in the analogue front-end

Different implementations provide different possibilities for filtering. The implementations can be roughly distinguished between two main cases:

- Low-cost, monolithic integration with one or a few multi-chain CMOS/BiCMOS core-chip with built-in power amplifiers and built in down-converters. This case will give limited possibilities to include high performance filters along the RF-chains since the Q-values in on chip filter resonators will be poor (5-20).

- High performance, heterogeneous integration with several CMOS/BiCMOS core chips, combined with external amplifiers and external mixers. This implementation allows the inclusion of external filters along the RF-chains (at a higher complexity, size, and power consumption).

There are at least three places where it makes sense to put filters, depending on implementation:

- Behind or inside the antenna element (F1 or F0), where loss, size, cost and wide-band suppression is important.

- Behind the first amplifiers (looking from the antenna side), where low loss is less critical (F2).

- On the high frequency side of mixers (F3), where signals have been combined (in the case of analogue and hybrid beam forming).

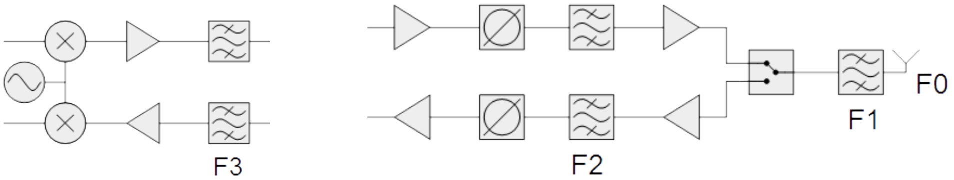


Figure 6.1.9.3.1-1: Possible filter placements

The main purpose of F1/F0 is to suppress interference and emissions far from the desired channel across a wide frequency range (e.g. DC-60 GHz). There should not be any un-intentional resonances or passbands in this wide frequency range. This filter will help relax the design challenge (bandwidth to consider in optimizations, and linearity requirements) of all following blocks. Insertion loss must be very low, and there is a strict size and cost requirements since there possibly will be one filter at each sub-array.

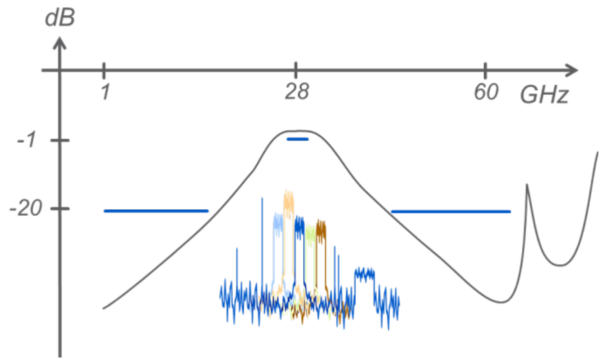


Figure 6.1.9.3.1-2: Filter example

The main purpose of F2 would be to suppress LO leakage and unwanted mixing products, and it will also add image rejection and rejection of general interference a few channels away from the carrier. There are still strict size requirements, but more loss can be accepted (behind the amplifiers) and also un-intentional passbands (since F1/F0 will handle that). This enables better frequency precision (half-wave resonators) and better discrimination (more poles).

The main purpose of F3 would be to suppress LO leakage and unwanted mixing products, but there is also a possibility to obtain suppression in neighbouring channels, to protect mixer and ADC. For analogue (or hybrid) beam-forming it is enough to have just one (or a few) such filter(s). This relaxes requirements on size and cost, which opens the possibility to achieve high Q and high precision.

The deeper in the RF-chain the filtering is placed (starting from the antenna element) the better protected the circuits will get.

For the monolithic integration case it is difficult to implement filters F2 and F3. One can expect performance penalties for this case. In addition, output power is typically lower.

In addition, the shielding to achieve isolation over high frequency range can be challenging, as microwaves have a tendency to bypass filters by propagating in ground structures around them.

6.1.9.3.2 Insertion loss (IL) and bandwidth

Sharp filtering on each branch (at positions F1/F0) with narrow bandwidth leads to excessive loss at microwave and mm-wave frequencies. To get the insertion loss down to a reasonable level one the passband can be made significantly larger than the signal bandwidth. A drawback of such an approach is that several unwanted neighbouring wideband channels will pass the filter. In choosing the best loss-bandwidth trade-off there are some basic dependencies to be aware of:

IL increases with increasing fc (for fixed BW).
IL decreases with increasing Q.
IL increases with increasing N.

To exemplify the trade-off we study a 3-pole LC-filter with Q=20, 100, 500 and 5000, for 100 and 800 MHz 3dB-bandwidth, tuned to 15 dB equal ripple (with Q=5000) is examined in Figure 6.1.9.3.2-1.

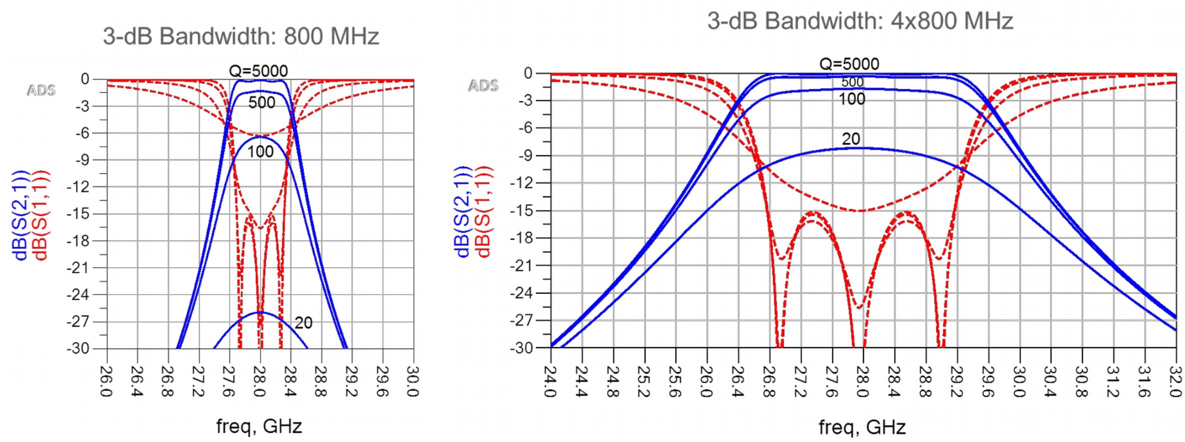


Figure 6.1.9.3.2-1: Example 3-pole LC filter with 800 and 4x800 MHz bandwidth, for different Q value

From this study it is observed that:

- 800 MHz bandwidth or smaller, requires exotic filter technologies, with a Q-value around 500 or better to get an IL below 1.5 dB. Such Q-values are very challenging to achieve considering constraints on size and cost.
- By relaxing the requirement on selectivity to 4x800 MHz, it is sufficient to have a Q-value around 100 to get 2 dB IL. This should be within reach with a low-loss, PCB. The margin in terms of bandwidth will help to accommodate typical production tolerances of the PCB.

6.1.9.4 Carrier frequency and mm-wave technology aspects

Designing a receiver at, e.g., ~30 GHz with a 1 GHz signal bandwidth leaves much less design margin than what would be the case for a 2 GHz carrier with e.g. 50 MHz signal bandwidth as the IC technology speed is similar in both cases but the design margin and performance depends on the technology being much faster than the required signal processing.

The free space wavelength at ~30 GHz is only 1 cm which is one tenth of what we are used to from existing 3GPP bands below 6 GHz. Antenna size and path loss are related to wavelength and carrier frequency, and to compensate the small physical size of a single antenna element we will have to use multiple antennas, e.g. array antennas. Then, when beam forming is used the spacing between antenna elements will still be related to the wavelength constraining the size of the FE and RX. Some of the implications of these frequency and size constraints are:

- The ratios $f_t/f_{carrier}$ and $f_{max}/f_{carrier}$, where f_t is the transistor transit frequency (i.e. when the RF device´s current gain is 0 dB), and where f_{max} is the maximum frequency of oscillation (i.e. when the extrapolated power gain is 0 dB), will be much lower at millimeter wave frequencies than for below 6 GHz applications. As receiver gain drops with operating frequency when this ratio is less than some $10-100\times$, the available gain at millimeter waves will be lower and consequently the device noise factor F_i higher (similar as if Friis' formula was applied to a transistor's internal noise sources).
- The breakdown voltage of active devices is inversely proportional to the maximum speed of the device due to the Johnson limit. I.e. $v_{sat} \cdot E_{br}$ = const. or $f_{max} \cdot V_{dd}$ = const. As a consequence the supply voltage will be lower for millimeter-wave devices compared to low GHz ones. This will limit the CP_i and the maximum available dynamic range.
- Higher level of transceiver integration is required to save space, either as System-On-Chip or System-In-Package. This will limit the number of technologies suitable for the RF transceiver and limit F_{RX} .
- RF filters will have to be placed close to the antenna elements and fit into the array antenna. Consequently they have to be small, resulting in higher physical tolerance requirements, possibly at the cost of insertion loss and stop-band attenuation. That is, IL and selectivity gets worse.

Increasing the carrier frequency, $f_{carrier}$ from, say 2 GHz to ~30 GHz (i.e. >10×) has a significant impact on the circuit design and its RF performance. For example, modern high-speed CMOS devices are velocity saturated and their maximum operating frequency is inversely proportional to the minimum channel length, or feature size. This dimension halves roughly every four years, as per Moore's law (stating that complexity, i.e. transistor density, doubles every other year). With smaller feature sizes internal voltages must also be lowered to limit electrical fields to safe levels. Thus, designing a 30 GHz RF receiver corresponds to designing a 2 GHz receiver using about 15 years old low-voltage technology (i.e. today's breakdown voltage but 15 years old f_t, see figure based on ITRS device targets). With such a mismatch in device performance and design margin it is not to be expected to maintain 2GHz performance and power consumption at 30 GHz.

The signal bandwidth at mm-wave frequencies will also be significantly higher than at, say, 2GHz. For an active device, or circuit, the signal swing is limited by the supply voltage at one end and by thermal noise at the other. The available thermal noise power of a device is proportional to BW/g_m, where g_m is the intrinsic device gain (trans-conductance). As g_m is proportional to bias current we can see that the dynamic range then becomes the ratio

$DR \propto V_{dd}^2 \cdot I_{bias}/BW = V_{dd} \cdot P/BW$, or

$P \propto BW \cdot DR/ V_{dd}$

Where P is the power dissipation.

Receivers for mm-wave frequencies will have increased power consumption due to higher BW, aggravated by the low-voltage technology needed for speed, compared to typical 2GHz receivers.

Thus, considering the thermal challenges given the significantly reduced area/volume for mm-wave products, the complex interrelation between linearity, NF, bandwidth and dynamic range in the light of power dissipation should be considered.

6.1.9.5 Phase noise for mm-wave frequencies

Phase noise is quite an important parameter in relation to mm-wave technologies considering the choice of sub-carrier spacing and achievable signal quality. As the sub-carrier spacing for mm-wave frequencies is not settled, it is important to consider achievable values for the mm-wave frequency ranges due to phase noise frequency dependencies.

Considering the VCO and PLL (to suppress the phase noise) performance and limitations for mm-wave frequencies for different technologies, some general limitations are given below:

1. PN could increase by 6 dB every time when f_0 doubles (assuming FoM and other things do not change)
2. PN is inversely proportional to the square of the loaded quality factor of the resonator, Q
3. 1/f noise up-conversion gives rise to close-to-carrier PN increase (small offset)

6.1.9.6 LO generation and distribution

Array antenna transceivers may be based on different strategies in implementation of local oscillator (LO) signal generation and distribution. Put simply, there are two options:

1. Centralized LO generation with a single PLL for all transceivers
2. Distributed LO generation with one PLL per transceiver.

These are two extreme cases and one could of course envision a combination of the two such that the transceivers are grouped together and where the transceivers within each group shares a common LO generation, i.e. semi-distributed LO generation.

This aspect has not been very much addressed before, rather a single centralized LO generation has been assumed and this leads to low phase noise performance in turn increasing EVM and pushing required sub-carrier spacing upwards. The LO generation strategy thus needs more attentation.

The phase noise performance might affect the receiver requirement in a different manner compared to the transmitter which also needs to be considered.

6.1.9.6.1 Centralized LO generation

With a centralized PLL the phase noise as seen by respective transceiver will be essentially the same, i.e. fully correlated. The primary downside of this solution is that the performance requirements on the PLL will be high and that the distribution of the LO signal over the array of transceivers will be very power consuming as the LO signal integrity must be maintained over long distances of distribution on chip. The latter aspect may partly be alleviated somewhat by distributing a sub-harmonic (1/N) of the target LO frequency and use transceiver-localized frequency multipliers (xN) to generate the target LO frequency. This solution is however suffers from sub-harmonic responses as the frequency multiplier output will not only output the desired frequency but will also contain some residuals of its input and harmonics thereof. This in turn will impact spurious emission and spurious response behavior.

6.1.9.6.2 Distributed LO generation

With distributed LO generation the phase noise as seen by respective transceiver will be partially uncorrelated. This is beneficial from an EVM perspective as the phase noise induced EVM is improved by 10log(M) where M is the number of transceivers (and associated PLLs). This may be used to lower the phase noise requirements on the PLLs. Instead of distributing the LO signal only the low-frequency reference to respective PLL needs to be distributed. The downside is primarily increased circuit complexity while the power consumption can be kept low by low phase noise requirements and no need for high frequency LO distribution.

6.1.9.6.3 Semi-distributed LO generation

With a semi-distributed LO generation the phase noise as seen by respective transceiver will be partially uncorrelated between groups of transceivers and fully correlated within the group. Thus, there is still a benefit from an EVM perspective but the phase noise induced EVM is now only improved by 10log(P) where P is the number of transceiver groups. Within each group the LO signal still needs to be distributed to respective transceiver but the distances and associated power become significantly smaller compared to the centralized LO generation while the phase noise requirements on the PLLs will be moderate.

6.1.10 Example 1: 30 GHz SSB phase noise model

In sub-clause 6.1.10 and 6.1.11 two example phase noise models are presented. The first example (in this subclause) is based upon measurements made on a prototype CMOS device, with a larger PLL bandwidth. The second example (in subclause 6.1.11) is based on recent research on technology capabilities, considers CMOS for the UE but GaAs for the BS and assumes a lower PLL bandwidth than the first example.

The phase noise model presented in this sub-clause is based on measurements of a research prototype receiver designed in a 28nm FD-SOI CMOS process. The PLL within this receiver has been designed for distributed LO generation [2] and since the number of PLLs will be large (~number of sub-arrays) power consumption is of utmost importance. In fact, the power consumption of this PLL is around 20mW (the XO with buffers adds another 2.5mW) therefore making it suitable also for UE performance considerations. A high frequency XO is used to reduce the impact from the $20log(f_0/f_{xo})$ phase noise upconversion but also allows a larger PLL bandwidth, which in turn reduce the VCO phase noise contribution. The PLL operates at a frequency of 2/3 the carrier frequency (29.55 GHz for this particular measurement) as it is used in a sliding IF receiver architecture (two-step down-conversion) as outlined in Figure 6.1.10-1. The sliding IF technique is a well-known receiver architecture. However, the models presented here are by no means to be viewed as limited by this receiver architecture.

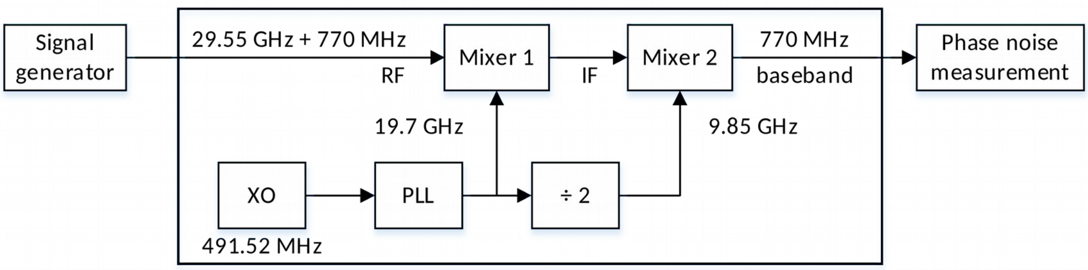


Figure 6.1.10-1: Simplified receiver architecture view and phase noise measurement setup

The phase noise measurements have been performed through the receiver by applying a receiver input CW at 770MHz offset from the carrier frequency of 29.55 GHz and measuring the phase noise of the CW at the baseband output of the receiver. Thus, the phase noise measured will not be that of the PLL output itself but the effective phase noise in downconverting from 29.55 GHz to baseband.

The phase noise model used here is a generalization of the multi-pole/zero model extended to fractional orders and is given by:

$$S(f_o) = PSD0 \frac{\prod_{n=1}^{N} 1 + (\frac{f_o}{f_{z,n}})^{\alpha_{z,n}}}{\prod_{m=1}^{M} 1 + (\frac{f_o}{f_{p,m}})^{\alpha_{p,m}}}$$

The measured phase noise and corresponding fractional order model is shown in Figure 6.1.10-2 with the associated model parameters as listed in Table 6.1.10-1. The offset range of the measurement is 100 Hz to 400MHz. At 400 MHz the phase noise floor has not yet been reached. Therefore the model parameters have been set conservatively such that the noise floor levels out at approximately -140dBc/Hz.

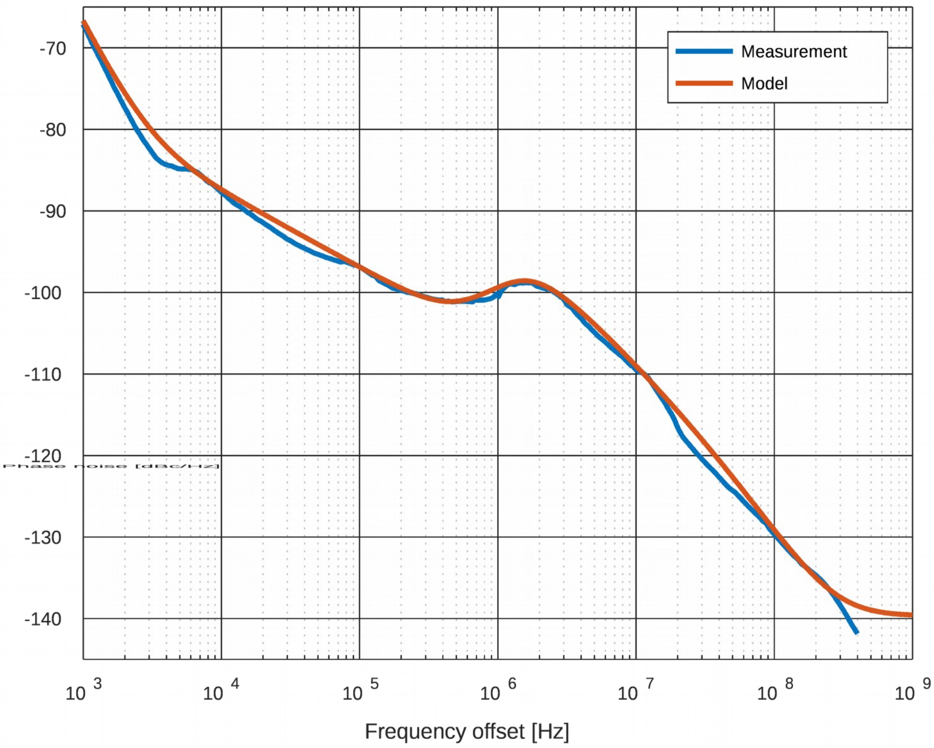


Figure 6.1.10-2: Measured phase noise and corresponding model for 29.55 GHz

Table 6.1.10-1: Parameters for PLL phase noise model operating at 29.55 GHz valid from 100 Hz and upwards

PSD0	**1585 (32 dB)**			
n,m	***$f_{z,n}$***	***$\alpha_{z,n}$***	***fp,m***	***$\alpha_{p,m}$***
1	3e3	2.37	1	3.3
2	550e3	2.7	1.6e6	3.3
3	280e6	2.53	30e6	1

6.1.10.1 Example 1: 45 GHz and 70 GHz SSB phase noise models

The 29.55 GHz model described above is used to derive models for 45 GHz and 70 GHz based on scaling with respect to frequency as discussed below. We may assume that the reference frequency will not increase and thus the PLL loop bandwidth will not change either. Therefore the reference and PLL phase noise contributions to a first order approximation will scale as 20log(f_c/f_{xo}). Similarily, the VCO phase noise scales as 20log(f_c) but only if we assume that the attainable VCO Figure-of-Merit (FoM) is frequency agnostic. The FoM does however degrade somewhat for increasing frequencies as shown in Figure 6.1.10.1-1, which shows FoM v.s oscillation frequency f_0 for a number of published VCOs. The FoM envelope indicated by the dashed line (showing the trend of the best VCOs) has a 9dB per decade slope and will be used below to derive parameters for phase noise models at 45 GHz and 70GHz.

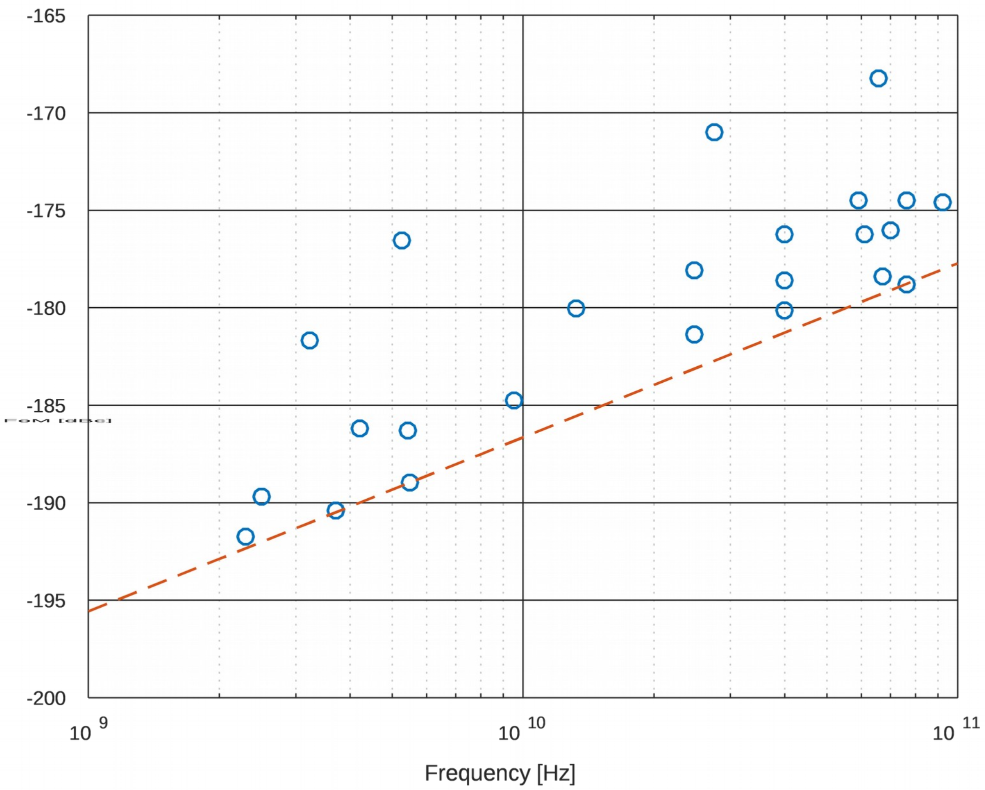


Figure 6.1.10.1-1: FoM for various published VCOs vs. frequency implemented in CMOS and SiGe technologies

The step from 29.55 GHz to {45,70} GHz corresponds to {0.18,0.38} decades and the corresponding phase noise degradations are listed in Table 6.1.10.1-1. The 20log( ) degradation is an overall degradation for the phase noise characteristics except for the high frequency noise floor region that is assumed to be constant. The FoM degradation, however, only affects the VCO contribution (the -20dB/decade slope starting at an offset of a few MHz).

Table 6.1.10.1-1: Phase noise degradation vs. frequency

f_c	20log( ) degradation	FoM degradation
29.55 GHz	0 dB	0 dB
45 GHz	3.7 dB	1.7 dB
70 GHz	7.5 dB	3.4 dB

In the following the degradations listed in Table 6.1.10.1-1 have been applied to the original 29.55 GHz model in Figure 6.1.10-2. An accurate application of the FoM degradation would require the VCO phase noise contribution to be separated from other contributions followed by a redesign of the PLL characteristics. Here, a pragmatic approach is used where the parameters have been altered as follows First, *PSD0* is increased by the 20log( ) degradation according to Table 6.1.10.1-1. Secondly, parameters $f_{z,n}$ $\alpha_{z,n}$ $f_{p,m}$ $\alpha_{p,m}$ are altered to obtain specified VCO FoM degradation at 30MHz offset while maintaining a constant phase noise of -140dBc/Hz at large offset and at the hump around 1.55MHz offset. The resulting models are shown in Figure 6.1.10.1-2. with parameters listed in Table 6.1.10.1-2 and 6.1.10.1-3 for 45 GHz and 70 GHz, respectively.

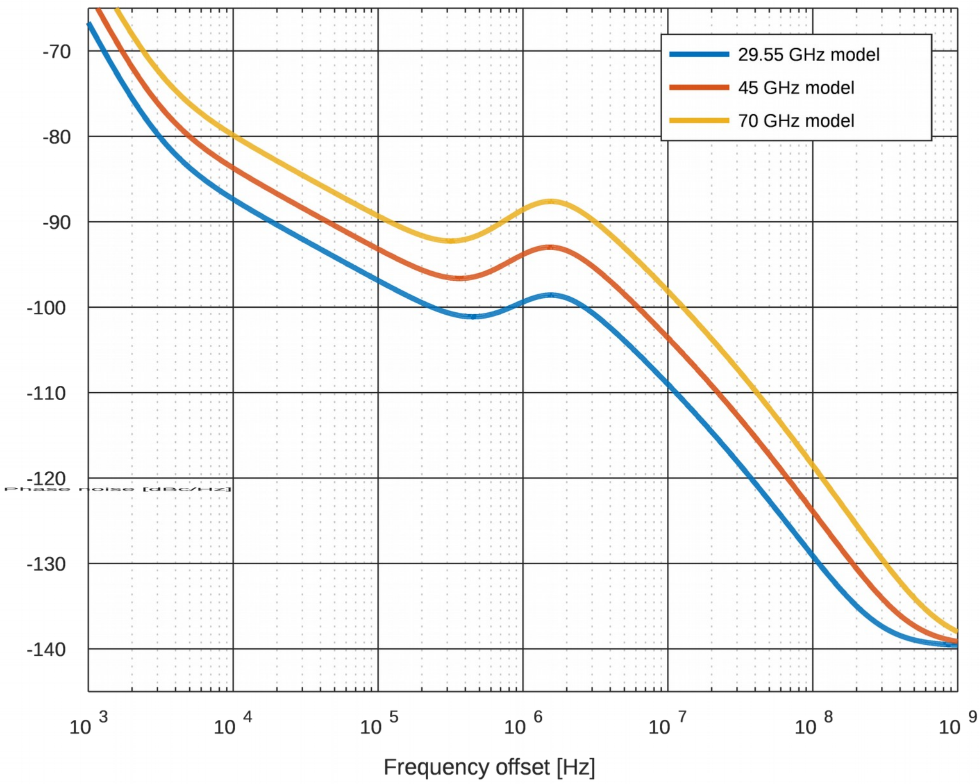


Figure 6.1.10.1-2: Phase noise models

Parameters for 45 GHz and 70 GHz PLL phase noise model are presented in Table 6.1.10.1-2 and Table 6.1.10.1-3 respectively.

Table 6.1.10.1-2: Parameters for 45 GHz PLL phase noise model valid from 100 Hz and upwards

PSD0	**3675 (35.65dB)**			
n,m	$f_{z,n}$	$\alpha_{z,n}$	***fp,m***	$\alpha_{p,m}$
1	3e3	2.37	1	3.3
2	451e3	2.7	1.54e6	3.3
3	458e6	2.53	30e6	1

Table 6.1.10.1-3: Parameters for 70 GHz PLL phase noise model valid from 100 Hz and upwards

PSD0	**8894 (39.49dB)**			
n,m	$f_{z,n}$	$\alpha_{z,n}$	***fp,m***	$\alpha_{p,m}$
1	3e3	2.37	1	3.3
2	396e3	2.7	1.55e6	3.3
3	754e6	2.53	30e6	1

6.1.11 Example 2: mmWave SSB phase noise model

6.1.11.1 Fabrication Methods and Materials

While there are many different fabrication methods, the most common fabrication materials are CMOS, GaAs, SiGe and GaN. With a review of the state of the art, a summary on the phase noise level achieved by different fabrication methods and materials is given in 6.11-1. From this it can be seen that:

Observation: For 30GHz band, the typical phase noise level measured at 1 MHz offset is from -114 to -93 dBc/Hz, while that for 70 GHz band is from -108 to -81 dBc/Hz.

While GaAs-based devices can provide a lower phase noise level, it is still expensive and power-consuming. The CMOS-based devices are available at lower cost and have less power consumption. Taking the cost and power constraint at the UE side into consideration, it appears reasonable to assume CMOS-based design for the UE side. For the BS, depending on the BS class, architecture etc. GaAs may be considered as the performance gains may outweight the power consumption/cost.

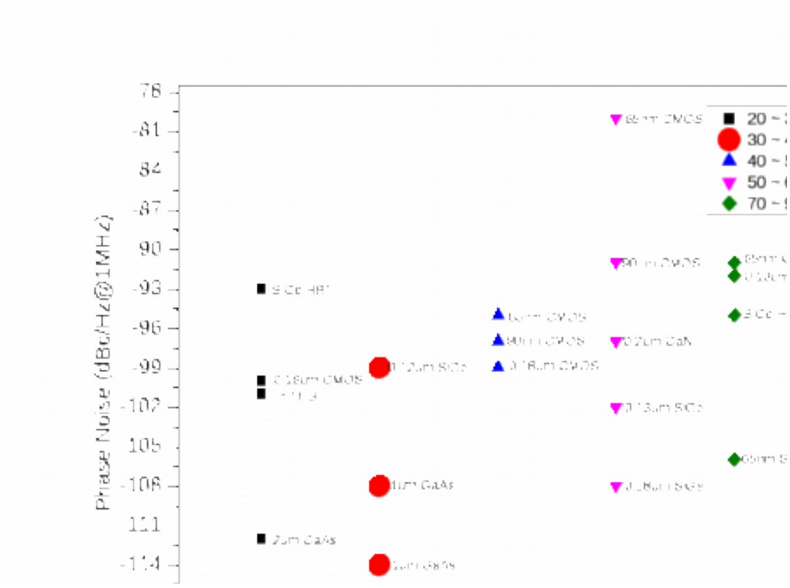


Figure 6.1.11.1-1: A brief summary of the phase noise level achieved by different fabrication methods and materials

6.1.11.2 Proposed Model and Parameters

In this subclause, we utilize the PLL-based phase noise model to express the phase noise. To be specific, the PSD of the phase noise is characterized by:

$$S_{Total}(f) = \begin{cases} S_{Ref}(f) + S_{PLL}(f), & \text{when } f \le loop\ BW \\ S_{VCO\_v2}(f) + S_{VCO\_v3}(f), & \text{when } f > loop\ BW \end{cases} \quad (6.1.11.2\text{-}1)$$

where

$$S_{Ref/PLL/VCO\_v2/VCO\_v3} = PSD0 \cdot \left[\frac{1+(f/f_z)^k}{1+f^k}\right] \text{(dB)} \quad (6.1.11.2\text{-}2)$$

$$PSD0 = FOM + 20\log f_c - 10\log\left(\frac{P}{1\,mW}\right) \text{(dB)} \quad (6.1.11.2\text{-}3)$$

FOM is the figure of merit, f_c is the carrier frequency and P is the consumed power. Considering the expectation for the phase noise level achievable with reasonable cost and power consumption as presented above, in this example the following parameters are suggested for the phase noise model at the UE (CMOS-based) and BS (GaAs-based) side, respectively (see 6.1.11-1). The PSD of the proposed phase noise models at both UE and BS side for 30 GHz are depicted in Figure 6.1.11.2-1.

Table 6.1.11.2-1: Parameters for proposed phase noise models

	Model 1, UE, Loop BW = 187kHz				Model 2, BS, Loop BW = 112kHz			
	REF clk	**PLL**	**VCO V2**	**VCO V3**	**REF clk**	**PLL**	**VCO V2**	**VCO V3**
FOM	-215	-240	-175	-130	-240	-245	-187	-130
f_z	Inf	1.00E+04	50.30E+06	Inf	Inf	1.00E+04	8.00E+06	Inf
P (mW)	10	20	20		10	20	50	
k	2	1	2	3	2	1	2	3

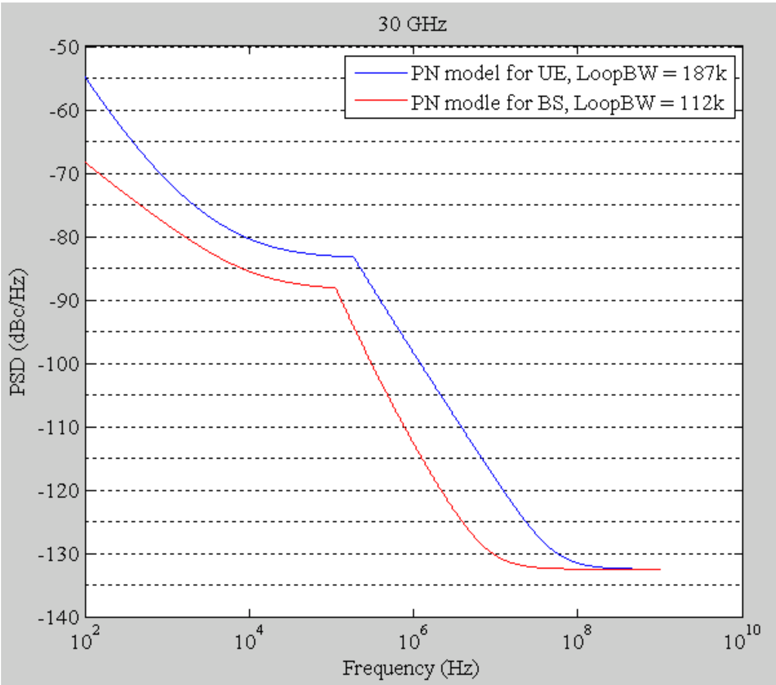


Figure 6.1.11.2-1: PSD of proposed phase noise model at both UE and BS side

6.2 UE requirements

6.2.1 General

Agreement in SI and issue should be addressed in WI are summarized in Table 6.2.1 -1 for UE RF aspects.

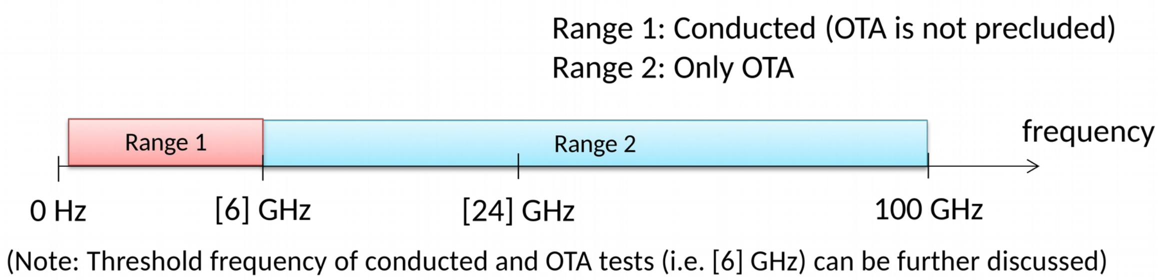


Figure 6.2.1-1: Frequency range 1/2 and the threshold.

Table 6.2.1-1: Summary on Outcome in SI and topic to be addressed in WI

Requirement		Range	Outcome in SI	Topic to be addressed in WI
Tx	Tx maximum output power	1	- At least conductive test is needed.	- Conducted value - Conducted tolerance - Power sharing mechanism with LTE in NSA if specified

		2	- At least EIRP is used as a metric
			- Develop requirements for one power class as priority
			- After requirements are understood for one PC, then, other PCs will be added.
			- Develop different spatial coverage requirement. Smartphone (i.e. Full sphere) is the baseline of UE types in Rel-15
			- For CDF method, RAN4 method for describing spherical coverage of RF parameters is CDF where each point represents equal surface area in sphere surrounding the UE.
			  - To study the advantage of this CDF method.
			  - The other method(s) are not precluded.
				- EIRP value
				- EIRP tolerance
				- How to categorise the UE type with different spatial coverage
				- Necessity of TRP considering regulation and/or 3GPP point of view
				- How to specify different power classes depending on "TRP or EIRP" and band dependency
				- Necessity of power sharing mechanism with LTE in NSA

	MPR	1	- At least conductive test is needed.	- MPR values for both contiguous and non-contiguous resource allocation (MOP and emission requirements need to be defined first) - Granularity of MPR spec table
		2	- At least EIRP is used as a metric	- Same as range 1 - Necessity of TRP
	A-MPR	1	- At least conductive test is needed.	- Whether the same values as LTE are reused or not (MPR requirement is needed first)
		2	- At least EIRP is used as a metric	- Same as range 1 - Necessity of TRP
	P_{CMAX}	1	- At least conductive test is needed.	- Calculation mechanism (e.g. reference SF) - PCMAX tolerance
		2	- At least EIRP is used as a metric	- Same as range 1 - Necessity of TRP
	Minimum output power	1	- At least conductive test is needed. - To specify -40dBm in sub-6GHz	- No open issue
		2	- At least EIRP is used as a metric	- Whether the same limit (-40 dBm) can be reused in mmWave considering NF, MCL and degradation level of noise floor and system perspective. - Necessity of TRP - How to categorise the UE type with different spatial coverage
	Tx OFF power	1	- At least conductive test is needed. - To specify -50dBm/MHz in sub-6GHz	- No open issue

		2	- TRP is used as a metric	- Whether -50dBm should be used in mmWave considering; - NF of NR UE - MCL between the aggressive and victim UE - Degradation level of noise floor due to interference from aggressive NR UE transmit OFF power
	ON/OFF mask	1	- At least conductive test is needed.	- ON/OFF mask value - Whether shorter transient period (20 us) can be reused in sub-6GHz according to possible sub-carrier spacing
		2	- At least Beam peak is used as a metric	- Same as range 1 - Necessity of TRP - Achievable transient period in mmWave (e.g., 28 GHz) devices assuming dynamic range of 63dB which is starting point
	Power control	1	- At least conductive test is needed.	- Power control requirements based on RAN1 agreement
		2	- At least Beam peak is used as a metric	- Same as range 1 - Necessity of TRP
	Frequency error	1	- At least conductive test is needed. - To specify 0.1ppm in sub-6GHz	- No open issue
		2	- Beam peak is used as a metric	- Frequency error value - Whether the same frequency error (0.1 ppm) can be reused in mmWave considering settling time, etc.
	EVM	1	- At least conductive test is needed. - Develop first requirements for the baseline CP-OFDM assuming suitable spectral confinement methods - Similar Transmitter impairments to LTE will be used as baseline for sub-6 and mmWave studies (IQ Image, Carrier leakage, CIM3, Phasenoise)	- EVM value for both average EVM measured over all the allocated PRBs and a few edge PRBs - How to limit sub-carrier spacing for the Rel-15 WID - EVM equalizer spectrum flatness value
		2	- Beam peak is used as a metric - Same as range 1	- Same as range 1
	Carrier leakage	1	- At least conductive test is needed. - Develop first requirements for the baseline CP-OFDM assuming suitable spectral confinement methods - Similar Transmitter impairments to LTE will be used as baseline for sub-6 and mmWave studies (IQ Image, Carrier leakage, CIM3, Phasenoise)	- Carrier leakage value - TRx impairment impact to multiple numerology case - How to limit sub-carrier spacing for the Rel-15 WID
		2	- Beam peak is used as a metric - Same as range 1	- Same as range 1
	In-band emissions	1	- At least conductive test is needed. - Develop first requirements for the baseline CP-OFDM assuming suitable spectral confinement methods - Similar Transmitter impairments to LTE will be used as baseline for sub-6 and mmWave studies (IQ Image, Carrier leakage, CIM3, Phasenoise)	- In-band emission values - TRx impairment impact to multiple numerology case - How to limit sub-carrier spacing for the Rel-15 WID

		2	- Beam peak is used as a metric - Same as range 1	- Same as range 1
	Occupied BW	1	- At least conductive test is needed.	- Occupied BW value
		2	- TRP is used as a metric	- Same as range 1 - Necessity of EIRP
	SEM	1	- At least conductive test is needed. - Assume different numerologies and RB allocations - NR UE shall meet the same SEM limit as that of LTE up to 20 MHz CBW. How to treat larger bandwidth than 20 MHz of NR is FFS.	- SEM value
		2	- TRP is used as a metric - Same as range 1	- Same as range 1 - Whether there is any justification not to follow the ITU response
	ACLR	1	- At least conductive test is needed. - NR ACLR requirements for UTRA and E-UTRA are to be specified	- ACLR value for UTRA, E-UTRA and NR
		2	- TRP is used as a metric - NR ACLR requirements for UTRA and E-UTRA are not to be specified	- Same as range 1
	General spurious	1	- At least conductive test is needed. - NR UE shall meet the same spurious limit as that of LTE. How to treat FOOB of larger bandwidth than 20 MHz of NR is FFS.	- General spurious value - Actual required level in mmWave should also be investigated from system point of view (sub-6GHz -> mmWave)
		2	- TRP is used as a metric - For above 13 GHz transmission, upper frequency limits should be specified as 2nd harmonics of the upper edge of the UL operating band including the full harmonic spectrum.	- Same as range 1 - Whether there is any justification not to follow the ITU response - Feasibility of post PA filtering taking harmonics and other spurious levels into account - Actual required level in mmWave should also be investigated from system point of view (mmWave -> mmWave) - OOB boundary
	Additional spurious	1	- At least conductive test is needed. - The same limits are reused in legacy victim bands in sub-6GHz	- How to treat NS applicable bands
		2	- TRP is used as a metric	- Same as range 1 - Additional limit on top of the ITU response
	UE-to-UE coexistence	1	- At least conductive test is needed. - The same limits are reused in legacy victim bands in sub-6GHz	- Actual required level in mmWave should also be investigated from system point of view (sub-6GHz -> mmWave)
		2	- TRP is used as a metric - -50dBm/MHz (mmWave -> sub-6GHz)	- Actual required level in mmWave should also be investigated from system point of view. (mmWave -> mmWave)
	Tx intermodulation	1	- At least conductive test is needed.	- Tx intermodulation value
		2	- TRP is used as a metric with the blocker from the same direction of transmitted signal.	- Same as range 1 considering probability of being same direction when deciding blocker level
	[New] Beam correspondence	1		
		2	- UE capability is introduced (RAN1 agreement)	- How to define Beam correspondence requirement

Rx	REFSENS	1	- At least conductive test is needed.	- REFSENS value - MSD impact in NSA of sub-6GHz and mmWave for both 1UL and 2UL.

		2	- At least EIS is used as a metric
			- Develop different spatial coverage requirement. Smartphone (i.e. Full sphere) is the baseline of UE types in Rel-15.
			- For CDF method, RAN4 method for describing spherical coverage of RF parameters is CDF where each point represents equal surface area in sphere surrounding the UE.
			  - To study the advantage of this CDF method.
			  - The other method(s) are not precluded.
				- Same as range 1
				- How to categorise the UE type with different spatial coverage
				- Necessity of TRS

	Maximum input level	1	- At least conductive test is needed.	- Maximum input level value and the test modulation order
		2	- At least beam peak is used as a metric	- Same as range 1
	ACS	1	- At least conductive test is needed.	- ACS value
		2	- Beam peak is used as a metric (to be further investigated) i.e. the blocker from the same direction of wanted signal.	- Same as range 1 considering probability of being same direction when deciding blocker level - Necessity of TRS
	In-band blocking	1	- At least conductive test is needed.	In-band blocking value
		2	- Beam peak is used as a metric (to be further investigated) i.e. the blocker from the same direction of wanted signal.	- Same as range 1 considering probability of being same direction when deciding blocker level - Necessity of TRS
	Out-of-band blocking	1	- At least conductive test is needed.	- Out-of-band blocking value
		2	- Beam peak is used as a metric (to be further investigated) where OOB blocker is <±FFS% away from the center frequency of the wanted signal	- Blocker frequency offset value - Same as range 1 considering receiver tolerance and possibility of blocker in mmWave. - Necessity of TRS
	Narrow-band blocking	1	- At least conductive test is needed.	- Narrow-band blocking value considering applicable bands
		2		- Necessity of this requirement - Same as range 1
	Spurious response	1	- At least conductive test is needed.	
		2	- See Out-of-band blocking	- See Out-of-band blocking
	Rx intermodulation	1	- At least conductive test is needed.	- Rx intermodulation value
		2	- Beam peak is used as a metric i.e. the both blockers from the same direction of wanted signal.	- Same as range 1 considering probability of being same direction when deciding blocker level
	Rx spurious emission	1	- At least conductive test is needed.	- Rx spurious emission value
		2	- TRP is used as a metric - For above 13 GHz transmission, upper frequency limits should be specified as 2nd harmonics of the upper edge of the DL operating band including the full harmonic spectrum.	- Same as range 1
	Receiver image	1	- At least conductive test is needed.	- Receiver image value
		2		- Receiver image metric Same as range 1

	[New] In-channel selectivity	1	- At least conductive test is needed. - Definition in mixed numerology case should follow the same format as uplink, taking the possible power imbalance level between numerologies into consideration	- In-channel selectivity value for different numerologies (15 and 60 kHz SCS)
		2	- Same as range 1 - Beam peak is used as a metric i.e. the blocker from the same direction of wanted signal.	- Same as range 1

6.2.1.1 UE antenna arrangement and feasibility of UE beamforming

In this sub-section we consider the number of TX antennas and the PA architecture that should be assumed for setting relevant UE transmitter requirements. Multiple UE transmitter antennas make possible UL beamforming and we consider its potential performance for devising a suitable antenna arrangement for UE reference architecture(s) to be used for setting UE transmitter requirements.

6.2.1.1.1 Multiple antennas at mmW frequencies

UE implementation of multiple antennas is feasible if the device is large compared to the wavelength. Already today 4RX antenna ports are specified for LTE and are considered feasible for high bands in typical UE form factors (e.g. above 1.7 GHz), although some form factors could support more than two ports also at lower frequencies.

Devices are large in terms of wavelengths if used in potential NR bands above 24 GHz:

- Due to design constraints antenna elements get more directive compared to around 2 GHz;
- a single element will not offer sufficient omnidirectional coverage;
- the use of multiple elements with beam patterns pointing in different directions and with different polarizations will improve link budget and offer omnidirectional coverage.

Moreover, distributed PAs are likely to be used since the losses by the feeder networks will be reduced, and integration of radio and antennas is likely so UL/DL coherency within the RFIC can probably be achieved with sufficient accuracy (CSI acquisition relies on coherency).

6.2.1.1.2 Number of UE antennas

While the coexistence studies consider an UE antenna arrangement of 32 patches, a more realistic number of antenna elements for implementation is 8 or up to 16, at least around 30 GHz. This is also considering that the UE must also accommodate antennas for LTE.

One example of a possible arrangement is shown in Figure 6.2.1.1.2-1 with the mmW antennas arranged in groups, the LTE antennas and NR antennas for below 6 GHz operation are arranged at the bottom of the device. Other arrangements are also possible. 8 or possibly 16 mmW elments is more realistic than 32 elements at 30 GHz considering typical UE form factors.

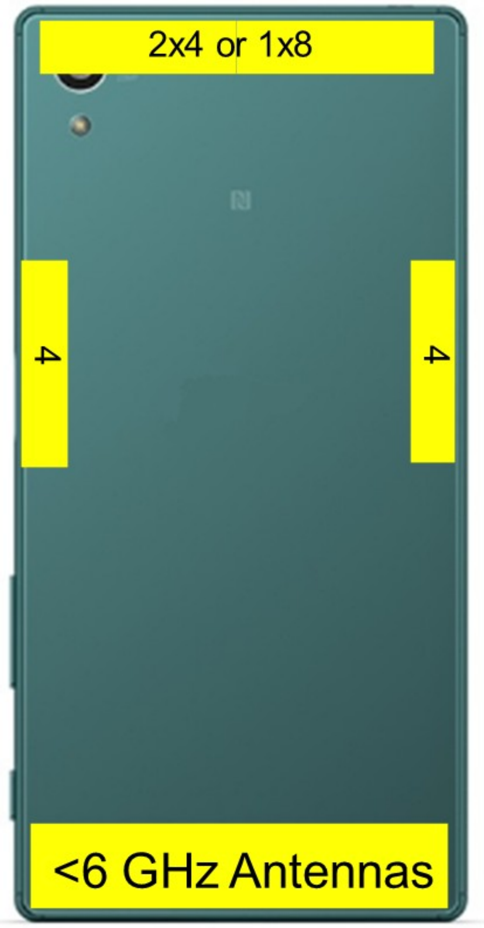


Figure 6.2.1.1.2-1: antenna arrangement on the UE with groups of mmWave antennas.

For the assessment of the performance of UE beamforming below we consider 4 or 8 antennas in an array arrangement as shown in Figure 6.2.1.1.2-2

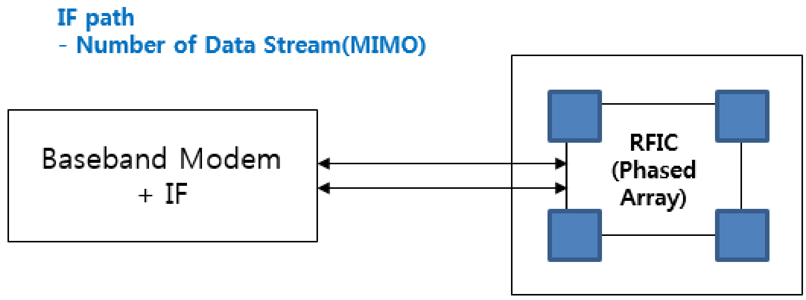
Figure 6.2.1.1.2-2: antenna arrangement on the UE used for the evaluation of beamforming gain.

In rel-15 NR SI phase, 3GPP RAN consider both standalone 5G UE type and LTE + mmWave (NSA) 5G UE type. Basically, shared antenna RF architectures are considered LTE + sub-6GHz 5R UE RF architecture.

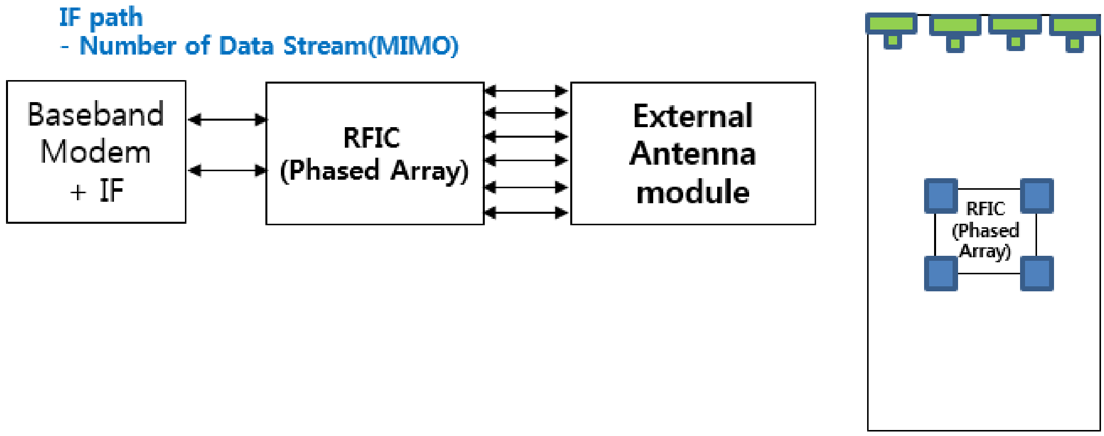
However, 5G NR non-stand-alone (NSA) UE to support both LTE service and mmWave NR service is quite different RF architecture compare to legacy LTE-A UE. Currently, 5G NSA UE architecture considered that have two different baseband modem chips, one is for LTE or 5G sub-6GHz NR system and the other is for 5G mmWave NR system. So these two modems have connected different RFICs in a typical UE form factors.

Figure 6.2.1.1.2-3 shows the 5G NR stand-alone UE RF architecture according to the antenna type.

One candidate RF architecture is antenna packaged within RFIC and the other candidate RF architecture is separated RFIC and external antenna type as shown in Figure 6.2.1.1.2-3.



(a) Packaged antenna RF architecture



(b) External antenna RF architecture

Figure 6.2.1.1.2-3: Candidate Stand-alone 5G mmWave RF architectures

Based on the UE design flexibility and optimal antenna performance aspect, RAN4 should consider two candidate RF architectures for 5G mmWave NR UE.

6.2.1.1.3 PA architecture

The distributed resource is more likely at mm-wave frequencies with the PA closer to the antenna to reduce feeder losses rather than a common PA shown in Figure 6.2.1.1.3-1. Antenna precoders with constant modulus are designed with the architecture in mind.

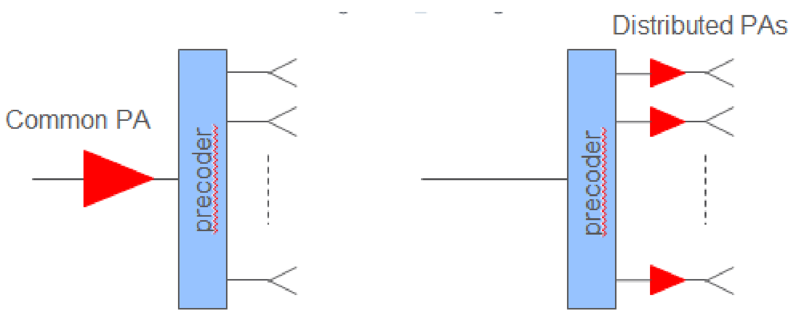


Figure 6.2.1.1.3-1: PA arrangement with the more likely distributed architecture on the right-hand side.

Hybrid archirectures with the ”precoder” replaced by an analogue beamforming network is also feasible around 30 GHz, e.g. 4 x 2 antenna elements or 2 x 4 antenna elements.

6.2.1.1.4 UE beamforming performance

In this sub section estimated UE beamforming performance with 4 or 8 antennas arranged in an array as shown in Figure 6.2.1.1.2-1 is discussed. The prerequisites of the study are described in detail in Annex D. The results are obtained at 15 GHz but it can be expected that similar performance gains can be observed above 24 GHz.

Various scenarios with different number of rays (directions) per channel realization, number of blocks (fading) in frequency and antenna precoding are considered. For the latter a channel information degeneration in terms of a rotational and a phase error is also introduced. The former is a UE rotation with regard to the optimal precoder configured by the channel estimation, and modeled as normally distributed with zero mean and standard deviation per angle of 0, 1, or 10 degrees (the UE is rotated before the optimal precoder is used for UL transmission). The phase error is assumed to be normal distributed with zero mean with a standard deviation of 0 (no error) or 30 degrees in the results shown below, and is independent between all radio branches and channel realizations.

Besides the wanted signal to the connected BS the signal received by interfered BS is also evaluated. The precoder for the desired signal is selected based on channel knowledge between the serving (connected) BS and the UE, while the UL received power per antenna at the interfered BS is estimated by a making a random channel realization (including direction of rays) towards the interfered BS given the selected precoder for the desired signal. The average channel gain is the same for all channel realizations allowing relative comparison between signals received. No interference suppression/rejection assumed at the interfered BS.

In all scenarios considered we assume two BS “beams”, i.e. two orthogonal polarizations each with a set of DL RS (two ports), while the number of UE antennas are either 4 or 8. MRC combining is used in the BS receiver. Only single-layer UL transmission is considered (one stream), and the codebook size is always 32. Recall that the AOA (=AOD) of the rays at the UE is uniform $[-180^{\circ} 180^{\circ}]$ in azimuth and uniform $[60^{\circ}\ 90^{\circ}]$ in elevation as described in Annex D. The scenarios considered are summarized in Table 6.2.1.1.4-1.

Table 6.2.1.1.4-1: scenarios

Scenario	Number of pairs of rays (N_{ray})	Number of fading blocks in frequency	Phase error (Degrees)	Rotational error (Degrees)
1	1	1	0 or 30	0
2	1	1		1
3	1	1		10
4	10	1		0
5	50	1		0
6	50	25		0
7	10	1		1
8	10	1		10
9	1	25		10
10	1	25		0
11	10	25		0

The simulation results for the scenarios in Table 6.2.1.1.4-1 are shown in Figure 6.2.1.1.4-1 for all scenarios with 8 UE antennas and a zero-degree phase error (but with a rotational error for each scenario as shown in the table). The graphs show the received power level at the 50% level normalized to the total output power of the UE (with the average channel gain of unity). Single PMI and Multiple PMI refer to feedback-based precoding; the precoding granularity is the same as that for the fading blocks (see Section 2 for an explanation of the notions of reciprocity based precoding).

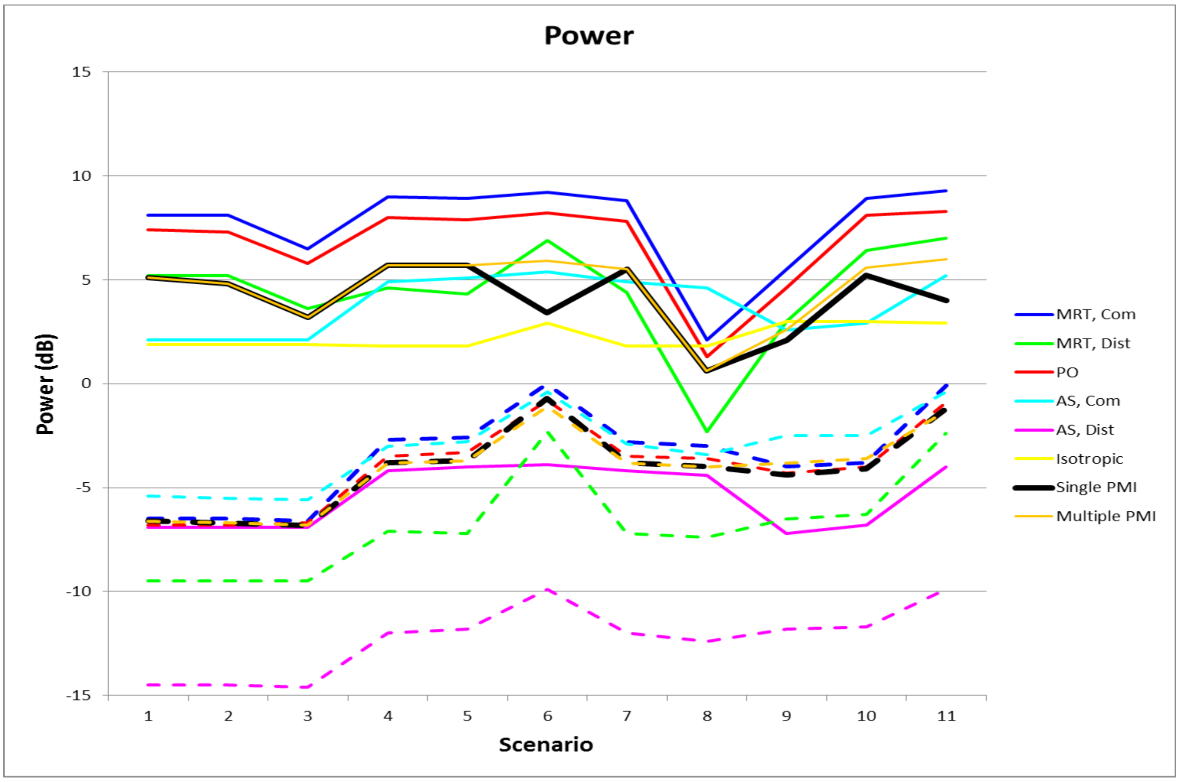


Figure 6.2.1.1.4-1: results for the scenarios with an assumed phase error of 0 degrees.

First we note that the gain of the wanted signal is almost 2 dB for the isotropic antenna for all scenarios, this is close to the theoretical result for MRC combining of two independent exponentially distributed outcomes (one per polarization) with a mean of unity.

In general we observe that

- the UL beamforming results in significant gain for the serving BS and reduced interference at other BS compared to the isotropic antenna. The interference increases when the channel gets richer (e.g. scenario 6)

- the wanted signal is very sensitive to large (10 degree) rotations.

Moreover, the reciprocity-based schemes outperform the feedback based. Multiple PMI gives improved performance than Single PMI in scenarios for which the number of fading blocks is 25. Note that the codebooks are designed for, and with an assumed, distributed PA architecture so it is relevant to compare the feedback-based schemes with PO.

The corresponding results for a 30 degree phase error are shown in Figure 6.2.1.1.4-2. Then we observe some reduction in the wanted signal, whereas the interference is unaffected as expected.

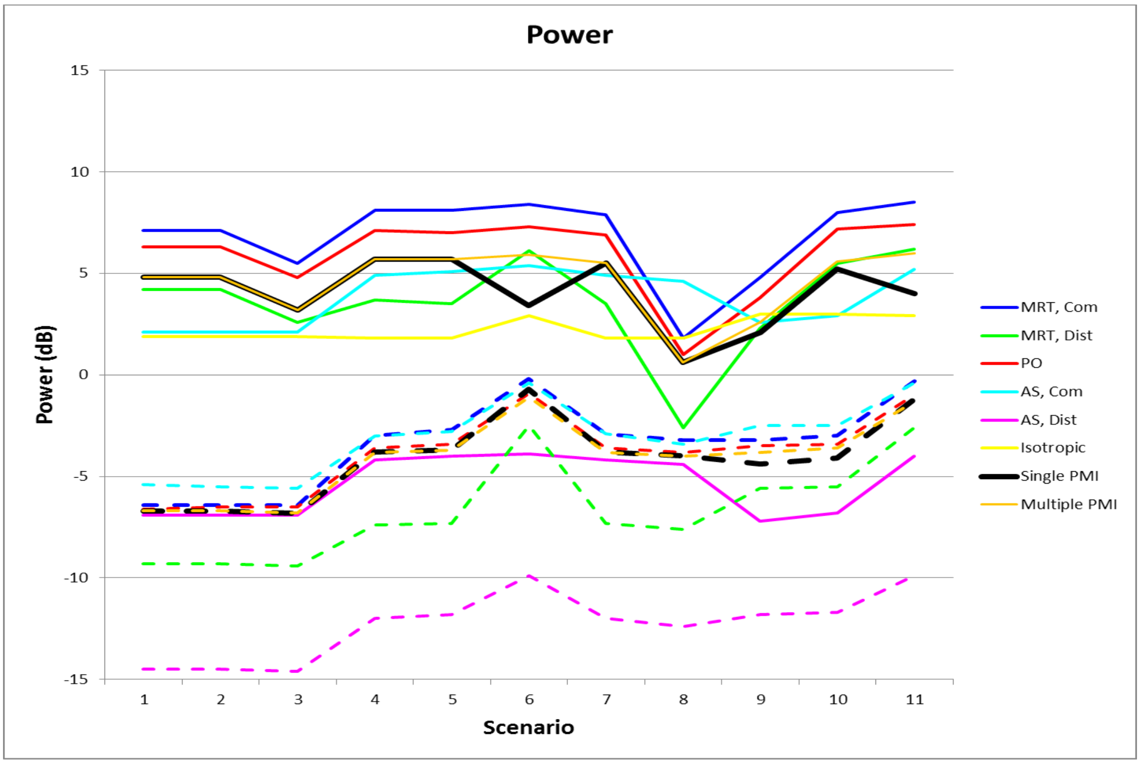


Figure 6.2.1.1.4-2: results for the scenarios with an assumed phase error of 30 degrees.

Next we look at the performance with 4 UE antennas for the cases in Table 6.2.1.1.4-1 assuming the same UE output t spower. Figure 6.2.1.1.4-3 shows the results with a zero phase error. Comparing with the results displayed in Figure 6.2.1.1.4-1 for 8 antennas we note an expected decrease in the wanted signal level but the interference is almost the same.

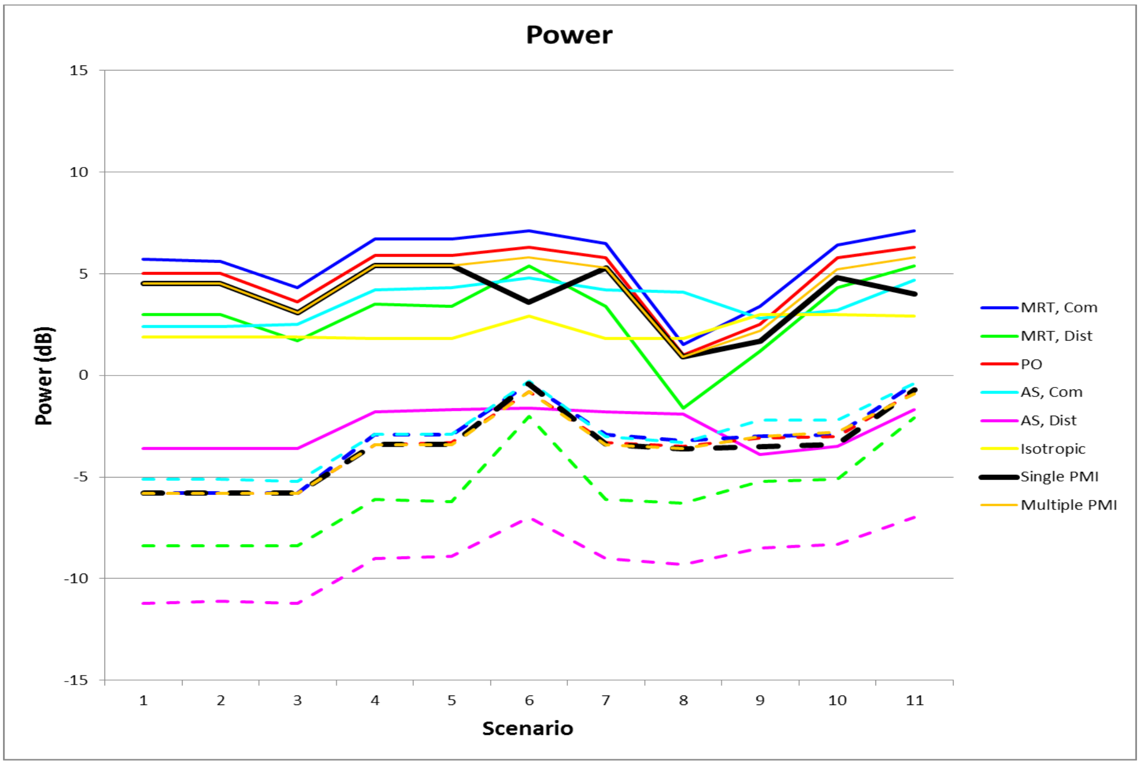


Figure 6.2.1.1.4-3: results for the scenarios with an assumed phase error of 0 degrees (4 UE antennas).

It is recalled that these results are obtained at 15 GHz but it can be expected that similar performance gains can also be seen at lower frequencies if physical dimensions are scaled with the wavelength. Hence UL beamforming can give performance gains below 6 GHz using four UE antennas, which is already specified for the RX for bands around 2 GHz.

6.2.1.1.5 UE antenna arrangement for a UE architecture

In the above beamforming gains in terms of an increased wanted signal power at the BS and reduced interference to other BS are demonstrated for 4 or 8 UE antennas in an array; the evaluations show

- a significant potential for an increased wanted signal power at the serving BS;
- that the interference reduction is significant at other BS for both reciprocity and feedback-based precoding schemes.

The gains obtained for 8 UE antennas are relevant for the arrangement Figure 6.2.1.1.2-1, while the gains obtained for 4 RX could be relevant for the arrangement with sub-arrays in Figure 6.2.1.1.2-2 (the results for 4 RX are obtained with the antennas located at the bottom of the phone).

6.2.1.2 Transceiver architecture at mmWave

For high frequency broadband systems - especially at mmWave range-, the nonlinearity of analogue components used in RF front ends gives increased challenges in the implementation. The principal impairments at RF front end of the transceiver architecture and the key requirements need to be analysed for achieving high performance, which will be outlined in this subsection.

6.2.1.2.1 Transceiver architectures

Wireless communication requires several stages of signal processing in digital and analogue domain. Once the signal is converted from digital to analogue, it is exposed to several analogue impairment sources. Therefore, transceiver architectures selection can influence differently to the performance of the system. The transceiver architecture can be either direct (Homodyne) conversion, as shown in Figure 6.2.1.2.1.1-1 or IF (Heterodyne) conversion, as shown in 6.2.1.2.1.2-1. [29]

6.2.1.2.1.1 Homodyne transceiver architecture

In a direct conversion architecture, the I and Q modulation is carried out in the analogue domain, having as a drawback the deficiency of the modulator; as for example the IQ-imbalance, DC offset and degradation of transmitted signal resulting in degradation of EVM. However, the major advantage of direct conversion architecture is that the image problem is avoided because the IF is zero, and therefore the requirement of a single LO realization is fulfilled. Another disadvantage of this architecture is that there are no other filters than RF-band selection filter, which means that the creation of a DC signal can contribute directly as interference in the band of interest.

6.2.1.2.1.2 Heterodyne transceiver architecture

In the heterodyne architecture, the IF-sampling architecture has the modulation in the digital domain, thus becomes immune to the problems related to the I and Q modulator. Nevertheless, it requires a wide bandwidth DAC, which is more sensible to errors and require more stages of LOs and filters to eliminate the IF spectral images. The heterodyne architecture has an advantage in the phase noise requirements compared to homodyne architecture, since the phase noise is logarithmically proportional to the LO frequency having two sources of LO reduce the phase noise of the system.

The UE reference architecture in Figure 6.2.1.2.1.2-1 with IF conversion is proposed in mmWave, this does not preclude from using direct conversion at a more advance stage in NR.

6.2.1.2.2 UE Reference architecture

The RF Frontend consists of all components between the antenna and the digital baseband system of a transceiver, which is divided mainly in mixers, RF Phase shifter and power amplifier. The demand of high data rate increases the research on conflicting requirements. Furthermore, high bandwidth requires operation in high frequency RF band and this creates big challenges to achieve high efficiency and good performance. The balance that must be found in size, capacity and cost should be taken into account in NR.

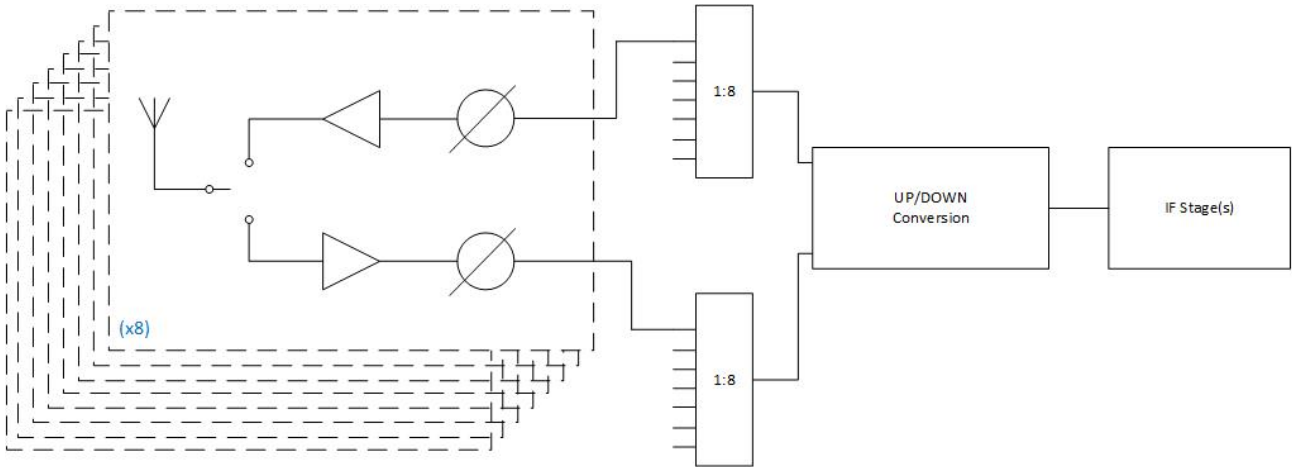


Figure 6.2.1.2.2-1: UE reference architecture

Besides the RF front end, it must be considered that mixers, oscillators, quadrature modulators are also sources of impairments, due to low port isolation, generating imperfections in the output signal.

Mixing the RF signal with the LO realizes frequency conversion within the RF transceivers. The phase of the LO can be non-stationary as a free running oscillator or time varying modelled as a stationary process of a PLL synthesizer. Ideally, the outcome of an LO is a single tone in the frequency domain. However, in reality, the outcome is a modulated tone with a phase shift. Phase noise – which increases with LO frequency - causes significant degradation in the performance and reduces the effective SNR at the receiver, limiting the BER and data rate. The phase noise gives several constraints on the design of oscillators. These are further constraints besides the limitations at the RF frond end – explained in the next subsections - that make the choice of a UE transceiver architecture important.

6.2.1.2.2.1 TX Chain

This subsection discusses the most relevant components in the RF front of end in the transmitter chain, which should be considered as key building blocks for further study in NR. The transmitter is less complex than the receiver, thus a less variety of implementations can be studied.

Power Amplifier

For transmitting large amount of data modulated in complex waveforms, a high linear amplification stage is required to minimize distortion. The drawback of high linear PA is the lack of efficiency. At higher frequency the efficiency and output power decreases. This means that for transmitting a certain amount of signal power, more power is required by the PA compared to the systems operating at carrier frequency under 6 GHz. The major imperfection of the PA is its nonlinear response and memory effects. The nonlinearity problem of the PA becomes evident as requirement of larger bandwidth and higher order modulation schemes are needed to achieve high data rate.

Phase Shifter

Phase shifters are source of imbalance and they can be implemented by power divisor and all – pass filters producing 90 degree phase shift. The accuracy depends on the components so that the 90 degree phase shift is not really exact. There are different phased-array architectures (i.e., RF phase shifters, LO phase shifters) which differ in functionality of phase shifting and signal combining and have as critical factors power consumption, losses and bandwidth. Possible examples of phase shifters (i.e., RF and LO phase shifters) can be seen in Figure 6.2.1.2.2.1-1.

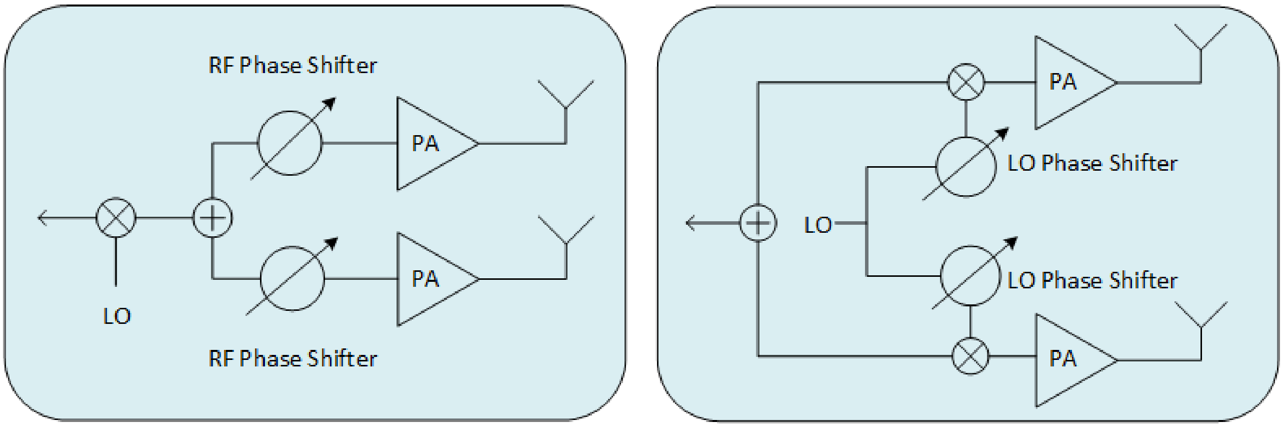


Figure 6.2.1.2.2.1-1: RF and LO Phase Shifters

LO phase shifters - compared to RF phase shifter - has a LO path, which is less sensitive to bandwidth because single tone LO is usually delivered. Bandwidth only translates to conversion gain difference in the mixer while using different LO frequencies and can be compensated pushing up the gain in the LO driver. The penalty for this is the higher power consumption, LO phase shifter has as drawback the high number of mixers. Every element needs a mixer to down convert before phase shifting.

In the case of the RF phase shifter, it needs an RF gain stage prior signal combining for noise reasons due to signal insertion loss. Additionally, it should meet tougher linearity specifications, which increases the losses of RF phase shifter. A way to cancel out the losses is to use an amplifier stage. The bandwidth of RF phase shifter is also challenging and demand more power consumption. The advantage is that requires one single mixer.

6.2.1.2.2.2 RX Chain

The Rx chain is composed by switch, LNA and phase shifter. This subsection includes the most relevant components in the receiver chain, which should be considered as key building blocks for further study in NR.

Low Noise Amplifier

One of the most important blocks in the receiver is the LNA. It is needed at the input of the receiver to amplify the received signal and suppress the noise contribution of the downconverter. The first stage is the RF block, which begins with the antenna, followed by the switch, the LNA and ends with the phase shifter as explained in the NF will be mainly determined by the LNA. Therefore, the design for the LNA should be optimize for high gain and low NF.

Phase Shifter

In receiver element the phase shifted signal are combined before arriving at the downconverter. The RF phase shifter kind can phase out the interference and then relax power consumption on the blocks down the chain. The advantage of RF phase shifter over the LO phase shifting is that the output signal after RF combiner has a high pattern directivity and can reject an interference before receiving units, maximizing the value of the phased array as a spatial filter. Another advantage is the elimination of LO distribution network resulting in a simple system architecture.

Filter

With the increasing complexity of the transceiver at mmWave, the filter has to satisfy more constraints at the same time, which puts a number of requirements on the filter such as resonance frequency, coupling factor, quality factor, temperature sensitivity, etc. Besides the technical limitation of filter at high frequencies, filters at the RF front end have the disadvantage of including a considerable insertion loss to both the TX and RX paths of the transceiver. At mm-wave frequencies, it is much more difficult than at frequencies below 6 GHz to get a high output power and adding a filter will implies extra loss, which is not easy to compensate. In particular, if the filter is not impedance matched to the PA, the mismatch will cause power losses. Moreover, difference in loading of the PA's across different branches of an array will cause mismatches in gain and phase of the PA. Another issue is the increased die size or PCB area of the transceiver. For these reasons FDD will probably remain a main duplex method for lower frequencies and TDD for mmWave range.

6.2.1.2.2.3 Beamforming

Due to high path loss encounter at mmWave, beamforming (BF) assumes an important role to stablish and maintain a robust communication link. There are several discussions about digital and analogue BF implementation. Digital beamforming provides a high flexibility in shaping beams at cost of increasing complexity. The high cost, power consumption and complexity of mmWave mixed signal components constrains the use of fully-digital BF architectures at the UE unlike simpler, lower antenna count more conventionally used in sub-6 GHz systems. On the other hand, analogue BF has fewer RF chain than antenna elements, which is more cost effective with lower power consumption and therefore, more suitable for the UE at mmWave. The disadvantage of this approach is having less flexibility compared to digital BF, since it can only handle one beam at a time.

The hybrid BF architecture is another approach that consists of reducing the hardware complexity with limited number of RF chains but using digital precoding in order to have similar performance to the digital BF, which enables multi-stream communication and maximizes the sum rate with minimum interference.

6.2.1.3 Spherical coverage requirement for mmWave UE

For mmWave NR UEs, RF requirements are specified as OTA requirements, using the applicable metrics. When defining these requirements, it is important to align the spatial coverage of the requirement with the UE's working condition acceptable in expected directions.

It is identified, however, NR is expected to be used in more than one type of UEs and different spatial coverage requirements may apply to different UE types. Identified UE types include (others not precluded):

- Smart phone
- Laptop mounted equipment (such as plug-in devices like USB dongles)
- Laptop embedded equipment
- Tablet
- Wearable devices
- Vehicular mounted device
- Fixed Wireless Access (FWA) terminal
- Fixed mounted devices (e.g. sensors, automation etc.)

For some UE types, a specific portion of its radiation sphere may be blocked and the spatial requirement on the blocked directions should be excluded. Two typical scenarios are the wearable devices, such as virtual reality glasses, and the vehicular mounted device. In case of virtual reality glasses, a portion of the radiation sphere is blocked by the human head, and in case of vehicular mounted device, a portion of the radiation sphere is blocked by the car body.

6.2.2 UE Transmitter characteristic

6.2.2.1 Tx maximum output power

- For Range 1
  - The UE testing methodology (i.e., conducted test) from LTE (TS 36.101) can be reused even in case of non-standalone (NSA) with control channel communicated via a high frequency band (f > [6] GHz). If necessity of OTA test such as beamforming aspects is identified, then requirements associated with array gain (e.g. EIRP) need to be specified accordingly.
- For Range 2
  - Beamforming feature is expected to compensate the higher pass-loss. Since it is necessary to specify transmission power including antenna array gain from system performance point of view, it should be specified in EIRP. Spatial coverage requirement assuming full sphere with one power class will be specified as a baseline in Rel-15. After that, different UE types (e.g. laptop, vehicle) and other power classes will also be introduced to accommodate each use case.

  - How to guarantee spatial coverage had been intensively discussed in SI phase. One of possible approaches is to use CDF to describe spherical coverage. On the other hand, there was also a concern that it couldn't guarantee uniform surface density i.e. spatial bias. Although it was agreed for CDF method that each point represents equal surface area in sphere surrounding the UE, the advantage of this method and other possible approaches need further study.

  - How to specify different power classes had also been discussed for two approaches. One is to define power class based on EIRP considering link budget perspective. The other is to specify it by TRP considering potential power of the UE regardless of antenna configuration and/or operating mode. On top of them, TRP may need to be specified from regulatory point of view and to mitigate interference in co-channel. In light of this, necessity of TRP needs to be discussed in the WI phase.

- For NSA operation

  - For NSA in bands below [6] GHz and above [24] GHz, power sharing mechanism between LTE and NR was discussed in the SI phase. It was observed that in some regions there are the radiation exposure/absorption rules of SAR [W/Kg] for below 6 GHz and MPE [mW/cm2] for above 6 GHz. However, necessity of the power sharing required further discussions from system and/or regulatory point of view for the WI phase.

  - For NSA in both bands below [6] GHz, it was identified that power sharing mechanism between LTE and NR should be specified to meet SAR requirement in a same principle as UL CA/DC, however RAN4 was not sure whether power sharing between different RATs is feasible from RAN1/2 and implementation point of view and couldn't exclude other methods at that time. One possible way is to simply define independent maximum power for LTE and NR and compliance with the SAR is left to implementation. However, this could require SAR back-off which cannot be controlled by the NW. Therefore, RAN4 sent an LS to ask RAN1 and RAN2 to study the feasibility of the power sharing mechanism in RAN4#82. How to treat this aspect will be discussed in the WI phase.

6.2.2.2 MPR and A-MPR

- For Range 1

  - Since MPR values for both contiguous and non-contiguous resource allocation will be specified in the WI phase, it was observed that granularity of MPR table need to be determined considering spec complexity perspective.

- For Range 2

  - Since this requirement is related to maximum output power, at least EIRP is used as a metric. Necessity of TRP was also proposed to align with metric of emission requirements. However it is still unclear if the power reduction of TRP is beneficial from link budget point of view, thus the necessity is FFS.

6.2.2.3 Configured transmitted power

- For Range 1

  - Since this specification requires power calculation mechanism based on RAN1 decision which had not been identified at the time, there was little discussion on this topic.

- For Range 2

  - Since this requirement is related to maximum output power, at least EIRP is used as a metric. Necessity of TRP is FFS.

6.2.2.4 Minimum output power

- For Range 1

  - Since it was identified that the same requirement as LTE (i.e., -40 dBm/MHz) can be reused, there is no open issue for the WI phase.

- For Range 2

    - Since this requirement verifies own transmission power near the BS maintaining necessary signal quality such as EVM, at least EIRP is used as a metric. Necessity of TRP is FFS. It is also FFS whether the same limit as Range 1 (i.e. -40 dBm) can be reused considering NF, MCL and degradation level of noise floor and system perspective.

6.2.2.5 Tx OFF power

- For Range 1
    - Since it was identified that the same requirement as LTE (i.e., -50 dBm/MHz) can be reused, there is no open issue for the WI phase.
- For Range 2
    - TRP is used as a metric to be equivalent with existing (conductive) emission requirement. It is FFS whether -50 dBm should be used in this range considering following aspects.
        - NF of NR UE
        - MCL between the aggressive and victim UE
        - Degradation level of noise floor due to interference from aggressive NR UE transmit OFF power

6.2.2.6 ON/OFF time mask

- For Range 1
    - For NR, it is expected to apply shortened TTI compared to legacy LTE. Based on this, it was agreed to study whether shorter transient period (20 us) can be reused in sub-6GHz according to possible sub-carrier spacing. The exact value will be specified in the WI phase.
- For Range 2
    - It was agreed that at least beam peak is used as a metric. On the other hand, necessity of TRP has been proposed since this requirement is not to directly measure the transient period itself but ON/OFF power before/after the mask. However there was no consensus on the necessity. And also, based on the same reason of Range 1, it was agreed to study achievable transient period in mmWave (e.g., 28 GHz) devices assuming dynamic range of 63dB which was used in the coexistence study for WP5D as a starting point.

6.2.2.7 Power control

- For Range 1
    - Since this specification requires power calculation mechanism based on RAN1 decision which had not been identified at the time, there was little discussion on this topic.
- For Range 2
    - Since this requirement is related to own transmission signal, at least beam peak is used as a metric. Necessity of TRP is FFS.

6.2.2.8 Frequency error

- For Range 1
    - Since it was identified that the same requirement as LTE (i.e. 0.1 ppm) can be reused, there is no open issue for the WI phase.
- For Range 2
    - Since this spec verifies own signal quality, beam peak is used as a metric. It is FFS whether the same frequency error (0.1 ppm) can be reused in this range considering settling time, etc.

6.2.2.9 EVM

- For Range 1
  - The detail can be found in clause 6.4.1 in this TR.
- For Range 2
  - The metric is beam peak and the detail can be found in clause 6.4.1 in this TR

6.2.2.10 Carrier leakage

- For Range 1
  - The detail can be found in clause 6.4.1 in this TR.
  - TRx impairments impact to multiple numerologies case should be investigated.
- For Range 2
  - The metric is beam peak and the detail can be found in clause 6.4.1 in this TR
  - TRx impairments impact to multiple numerologies case should be investigated.

6.2.2.11 In-band emissions

- For Range 1
  - The detail can be found in clause 6.1.8 in this TR.
  - TRx impairments impact to multiple numerologies case should be investigated.
- For Range 2
  - The metric is beam peak and the detail can be found in clause 6.1.8 in this TR
  - TRx impairments impact to multiple numerologies case should be investigated.

6.2.2.12 Occupied bandwidth

- For Range 1
  - The value is directly related to the channel BW which will be determined in the WI phase.
- For Range 2
  - TRP is used as a metric to be equivalent with existing (conductive) emission requirement. On the other hand, necessity of EIRP was also proposed based on that the signal in the band would be coherent. The need will also be discussed in the WI phase.

6.2.2.13 SEM

- For Range 1
  - It was agreed that NR UE shall meet the same SEM limit as that of LTE up to 20 MHz CBW since it should not be changed regardless of the interferer from victim system's point of view. How to treat larger bandwidth than 20 MHz of NR is FFS.
- For Range 2
  - TRP is used as a metric to be equivalent with existing (conductive) emission requirement. Whether there is any justification not to follow the ITU response is FFS.

6.2.2.14 ACLR

- For Range 1
  - It was agreed that NR ACLR requirements for UTRA, E-UTRA and NR need to be specified in the WI phase.
- For Range 2
  - TRP is used as a metric to be equivalent with existing (conductive) emission requirement. It was agreed that NR ACLR requirements for UTRA and E-UTRA are not to be specified. The values themselves will be determined in the WI phase.

6.2.2.15 Spurious emissions

6.2.2.15.1 General spurious

- For Range 1
  - It was agreed that NR UE shall meet the same spurious limit as that of LTE since it should not be changed regardless of the interferer from victim system’s point of view. How to treat F_{OOB} of larger bandwidth than 20 MHz of NR is FFS. Actual required level in mmWave should also be investigated from system point of view (sub-6GHz -> mmWave).
- For Range 2
  - TRP is used as a metric to be equivalent with existing (conductive) emission requirement. For above 13 GHz transmission, upper measurement frequency limit should be specified as 2nd harmonics of the upper edge of the UL operating band including the full harmonic spectrum based on the ITU recommendation. Whether there is any justification not to follow the ITU response and actual required level in mmWave should also be investigated from system point of view (mmWave -> mmWave).

6.2.2.15.2 Additional spurious

- For Range 1
  - The same limits are reused in legacy victim bands in Range 1 since it should not be changed regardless of the interferer from victim system’s point of view. How to treat NS applicable bands will be decided in the WI phase.
- For Range 2
  - TRP is used as a metric to be equivalent with existing (conductive) emission requirement and the same limits are reused in legacy victim bands in Range 1 since it should not be changed regardless of the interferer from victim system’s point of view. Necessity of additional/regional limit on top of the ITU response is FFS.

6.2.2.15.3 UE-to-UE co-existence

- For Range 1
  - The same limits (i.e., default is -50 dBm/MHz) are reused in legacy victim bands in Range 1 since it should not be changed regardless of the interferer from victim system’s point of view. To avoid unnecessarily tight requirements, actual required level in mmWave should also be investigated from system point of view (sub-6GHz -> mmWave).
- For Range 2
  - TRP is used as a metric to be equivalent with existing (conductive) emission requirement. The same limits (i.e., default is -50 dBm/MHz) are reused in legacy victim bands in Range 1 since it should not be changed regardless of the interferer from victim system’s point of view. To avoid unnecessarily tight requirements, actual required level in mmWave should also be investigated from system point of view. (mmWave -> mmWave).

6.2.2.16 Tx intermodulation

- For Range 1
  - Since necessity of this requirement was identified, the conductive values will be determined in the WI phase.
- For Range 2
  - TRP is used as a metric with the blocker from the same direction of transmitted signal. The level will be determined considering probability of being same direction when deciding blocker level.

6.2.2.17 Beam correspondence

- For Range 1
  - There was no discussion in the SI.
- For Range 2
  - The necessity was proposed and the UE capability was introduced in other working group(s). How to define the requirement will be discussed in the WI phase.

6.2.3 UE Receiver characteristic

6.2.3.1 REFSENS

- For Range 1
  - The UE testing methodology (i.e., conducted test) from LTE (TS 36.101) can be reused even in case of non-standalone (NSA) with control channel communicated via a high frequency band (f > [6] GHz). If necessity of OTA test such as beamforming aspects is identified, then requirements associated with array gain (e.g. EIRP) need to be specified accordingly.
- For Range 2
  - Beamforming feature is expected to compensate the higher pass-loss. Since it is necessary to specify transmission power including antenna array gain from system performance point of view, it should be specified in EIS. Necessity of TRS is FFS. Spatial coverage requirement assuming full sphere as a baseline in Rel-15.
  - How to guarantee spatial coverage is had been intensively discussed in SI phase. One of possible approaches is to use CDF to describe spherical coverage. On the other hand, there was also a concern that it couldn't guarantee uniform surface density i.e. spatial bias. Although it was agreed for CDF method that each point represents equal surface area in sphere surrounding the UE, the advantage of this method and other possible approaches need further study.
- For NSA operation
  - For 1UL cases, MSD impact was investigated in the SI. While some companies showed no interference is expected between sub-6GHz and mmWave, other companies raised design difficulties. For 2UL cases, there was no discussion on IMD level generated by transmissions in sub-6GHz and mmWave. Those impacts will be investigated in the WI phase.

6.2.3.2 Maximum input level

- For Range 1
  - Since the maximum modulation of NR UE had not been determined at the time, the conductive value and the test modulation order is FFS.
- For Range 2

    - Considering the worst case of saturation of the receiver, beam peak is used as a metric considering probability of being same direction when deciding blocker level. Necessity of TRS is FFS. With the same reason as Range 1, the test modulation order is FFS.

6.2.3.3 ACS

- For Range 1
    - The conductive values will be determined in the WI phase.
- For Range 2
    - Considering the worst case of saturation of the receiver, beam peak is used as a metric. The values will be determined considering probability of being same direction when deciding blocker level in the WI phase. Necessity of TRS is FFS to avoid unnecessarily tight requirement.

6.2.3.4 In-band blocking

- For Range 1
    - The conductive values will be determined in the WI phase.
- For Range 2
    - Considering the worst case of saturation of the receiver, beam peak is used as a metric. The values will be determined considering probability of being same direction when deciding blocker level in the WI phase. Necessity of TRS is FFS to avoid unnecessarily tight requirement.

6.2.3.5 Out-of-band blocking

- For Range 1
    - The conductive values will be determined in the WI phase.
- For Range 2
    - Considering the worst case of saturation of the receiver, beam peak is used as a metric where OOB blocker is < ± FFS% away from the center frequency of the wanted signal since the beam peak will change according to the blocker offset. The values will be determined considering probability of being same direction when deciding blocker level in the WI phase. Necessity of TRS is FFS to avoid unnecessarily tight requirement.

6.2.3.6 Narrow-band blocking

- For Range 1
    - The conductive values will be determined considering applicable bands in the WI phase.
- For Range 2
    - Necessity of this requirement was discussed since there may not be such narrow band systems in mmWave. However there was no consensus. If specified, considering the worst case of saturation of the receiver, beam peak is used as a metric where OOB blocker is < ± FFS% away from the center frequency of the wanted signal since the beam peak will change according to the blocker offset. The values will be determined considering probability of being same direction when deciding blocker level in the WI phase. Necessity of TRS is FFS to avoid unnecessarily tight requirement.

6.2.3.7 Spurious response

- See Out-of-band blocking.

6.2.3.8 Rx intermodulation

- For Range 1
  - The conductive values will be determined in the WI phase.
- For Range 2
  - Considering the worst case of saturation of the receiver, beam peak is used as a metric i.e. the both blockers from the same direction of wanted signal. The values will be determined in the WI phase considering probability of being same direction when deciding blocker level.

6.2.3.9 Rx spurious emission

- For Range 1
  - It was agreed that NR UE shall meet the same spurious limit as that of LTE since it should not be changed regardless of the interferer from victim system's point of view.
- For Range 2
  - TRP is used as a metric to be equivalent with existing (conductive) emission requirement. For above 13 GHz transmission, upper measurement frequency limit should be specified as 2nd harmonics of the upper edge of the DL operating band including the full harmonic spectrum.

6.2.3.10 Receiver image

- For Range 1
  - The conductive values will be determined in the WI phase
- For Range 2
  - The metric and values will be determined in the WI phase.

6.2.3.11 In-channel selectivity

- For Range 1
  - The detail can be found in clause 6.1.8 in this TR.
- For Range 2
  - Considering the worst case of saturation of the receiver, beam peak is used as a metric i.e. the blocker from the same direction of wanted signal. The detail can be found in clause 6.1.8 in this TR.

6.3 BS requirements

6.3.1 General

Agreements in SI and issues should be addressed in WI are summarized in Table 6.3.1-1 for BS RF aspects. These are summarized based on the following Ranges (two frequency ranges, conducted or OTA, and Non-AAS type or AAS type BS).

- Range 1: at least below 6 GHz. In here, both conducted and OTA requirements will be required. (Note: The applicability may depend on the requirements.)
  - Range 1-C: Conducted requirement for Range 1.
    - Range 1-C-N: Conducted requirement for Range 1 Non-AAS type BS (which doesn't have antenna functionality).

  - Range 1-C-A: Conducted requirement for Range 1 AAS type BS (which has antenna functionality).

    Note: For some requirements Range 1-C-N and Range 1-C-A will have different “outcome” and “topic should be addressed in WI”, for others they are the same.

  - Range 1-O: OTA requirement for Range 1.

- Range 2: at least above 24 GHz. In here, only OTA requirements will be required.

Table 6.3.1-1: Summary on Outcome in SI and topic to be addressed in WI

	Requirement	Range- (Conducted or OTA, non-AAS or AAS type)	Outcome in SI	Topic should be addressed in WI
General	BS class	1-C-N/1-C-A	For BS with antenna connectors - a BS to UE minimum coupling loss is used as a description - 70 dB for Wide area BS - 53 dB for Medium Range BS - 45 dB for Local area BS For BS without antenna connectors - a BS to UE minimum distance along the ground is used as a description - 35 m for Wide area BS - 5 m for Medium Range BS - 2 m for Local area BS Note: The deployment scenarios associated with and definitions of BS classes are exactly the same for BS both with and without connectors. An MCL of 70dB corresponds to a minimum distance of around 35m, 53dB to around 5m and 45dB to around 2m respectively for BS with connectors.	- If NR Home BS class is introduced or not.
		1-O	- Same as Range 1-C-N/1-C-A	- Same as Range 1-C-N/1-C-A
		2	- Intention of BS classification is captured in R4-1700277 - BS class unit is per BS equipment - a BS to UE minimum distance along the ground is used as a description - 35 m for Wide area BS - 5 m for Medium Range BS - 2 m for Local area BS Note: The deployment scenarios associated with and definitions of BS classes are exactly the same for BS both with and without connectors. An MCL of 70dB corresponds to a minimum distance of around 35m, 53dB to around 5m and 45dB to around 2m respectively for BS with connectors.	- Same as Range 1-C-N/1-C-A
TX	BS output power	1-C-N	- For below 6GHz, output power accuracy value should be +/-2dB.	- Output power limit. (it will be different between 1-C-N and 1-C-A)
		1-C-A	- Same as Range 1-C-N	- Output power limit. (it will be different between 1-C-N and 1-C-A)
		1-O	- EIRP is used as a metric for output power accuracy requirement - Declaration of the range of direction to meet EIRP accuracy will follow eAAS WF [R4-1610800] - For MR and LA BS, TRP is used for the power limit. - For below 6GHz, output power accuracy value should be +/-2.2dB.	- (Accuracy value above 6GHz.) [Note 1] - (EIRP accuracy modelling for above 6GHz (whether can reuse AAS EIRP accuracy modelling or not).)[Note 1]

		2	- EIRP is used as a metric for output power accuracy requirement - Declaration of the range of direction to meet EIRP accuracy will follow eAAS WF [R4-1610800]	- If the power limit is needed or not for some BS class if BS class is introduced. - If the power limit is needed, if the metric should be EIRP or TRP. - Whether the same EIRP accuracy equation with AAS can be reused or not. If not, accuracy modeling method would be studied.
	Output power dynamics	1-C-N	FFS	- If the same dynamic range can be reused for below 6GHz.
		1-C-A	FFS	- Same as Range 1-C-N
		1-O	FFS	- (Dynamic range value for above 6GHz if needed) [Note 1] - If the same dynamic range can be reused for below 6GHz. - (Whether this requirement is needed or can be excluded for above 6GHz.) [Note 1]
		2	FFS	- Dynamic range value if needed - Whether this requirement is needed or can be excluded. - Study what are needed parameters to decide required dynamic range.
	Transmit ON/OFF power	1-C-N/1-C-A	FFS	- Transient period length value. - For TDD, required and achievable transient period length.
		1-O	FFS	- TX OFF power level TRP or EIRP and means of measuring it OTA - For TDD, required and achievable transient period length.
		2	FFS	- Same as Range 1-O.
	Transmitted signal quality			
	Frequency error	1-C-N/1-C-A	FFS	- Frequency error accuracy value. - If it is possible to reuse the same frequency error (±0.05, 0.1, 0.25ppm) accuracy for below 6GHz. - (Study of the needed parameters to decide frequency error accuracy for above 6GHz) [Note 1]
		1-O	FFS	- Frequency error accuracy value. - If it is possible to reuse the same frequency error (±0.05, 0.1, 0.25ppm) accuracy for below 6GHz. - (Study of the needed parameters to decide frequency error accuracy for above 6GHz) [Note 1] - Direction of measurement.
		2	FFS	- Study of the needed parameters to decide frequency error accuracy. - Frequency error accuracy value. - Direction of measurement.

	EVM	1-C-N/1-C-A	- Needed regardless on single or mixed numerology. **<u>For both single and mixed numerology case</u>** - define both average BS Tx EVM requirements over all the PRBs and over 1 PRB for the edge PRBs **<u>For mixed numerology case</u>** - define both average BS Tx EVM requirements over all the PRBs of a given numerology and over 1 PRB for the edge PRBs - in first phase NR specification development by defining only EVM based requirements for BS Tx in-band requirements	- EVM value for below 6GHz(and above 6GHz respectively [Note 1]). **<u>For both single and mixed numerology case</u>** - If the same EVM value can be reused for below 6GHz (and above 6GHz respectively [Note 1]). - Study of the needed parameters to decide EVM value. **<u>For mixed numerology case</u>** - Necessity of guard band for the numerologies. - How to achieve a requirement that is implementation agnostic
		1-O	- Define at the centre of the main beam for UE specific beam. - Needed regardless on single or mixed numerology. **<u>For both single and mixed numerology case</u>** - Same as Range 1-C-N/1-C-A. **<u>For mixed numerology case</u>** - Same as Range 1-C-N/1-C-A.	- Same as Range 1-C.
		2	- Same as Range 1-O.	- EVM value. **<u>For both single and mixed numerology case</u>** - If the same EVM value can be reused. - Study of the needed parameters to decide EVM value. **<u>For mixed numerology case</u>** Same as Range 1-C.
	TAE	1-C-N/1-C-A	FFS	- TAE value. - If the same TAE value can be reused.
		1-O	FFS	- TAE value if needed - Quantitative evaluation is needed to confirm whether TAE is needed or not. - If TAE is needed, the same TAE can be reused for below 6GHz.
		2	FFS	- TAE value if needed - Quantitative evaluation is needed to confirm whether TAE is needed or not. - If TAE is needed, the same TAE can be reused.
	DL RS power	1-C-N	FFS	- Accuracy value if requirement needed - Whether this requirement is really needed or can be excluded - If the same RS power accuracy can be reused for below 6GHz if requirement needed. - Study of the needed parameters to decide required accuracy.
		1-C-A	FFS	- Same as Range 1-C-N
		1-O	FFS	- Same as Range 1-C.

		2	FFS	- Whether this requirement is really needed or can be excluded. - Accuracy value if requirement needed - Whether this requirement is really needed or can be excluded - If the same RS power accuracy can be reused for below 6GHz if requirement needed. - Study of the needed parameters to decide required accuracy.
	Unwanted emissions			
	Occupied bandwidth	1-C-N/1-C-A	FFS	- The same principle with existing (99% power should be within CBW) can be reused or not for below 6GHz(and above 6GHz respectively [Note 1]).
		1-O	FFS	- TRP or directional requirement. - The same principle with existing (99% power should be within CBW) can be reused or not for below 6GHz(and above 6GHz respectively [Note 1]).
		2	FFS	- TRP or directional requirement. - The same principle with existing (99% power should be within CBW) can be reused or not.
	ACLR	1-C-N	FFS	- If it is possible to reuse the same ACLR value (45dBc) for below 6GHz. - (ACLR value from co-existence studies for above 6GHz.) [Note 1]
		1-C-A	FFS	- Same as Range 1-C-N
		1-O	- TRP is used as a metric.	- (ACLR value from co-existence studies for above 6GHz.) [Note 1] - If it is possible to reuse the same ACLR value (45dBc) for below 6GHz. - Output power and beam steering conditions for requirement. [Followings will be discussed in eAAS session] - Measurement sampling grids. - How to reduce the number of measurement points.
		2	- Same as Range 1-O.	- ACLR value from co-existence studies. - Output power and beam steering conditions for requirement. - ACLR value from co-existence and feasibility studies. [Followings will be discussed in eAAS session] - Same as Range 1-O.
	Mask	1-C-N	- Adopt 100kHz or 1MHz resolution bandwidth depending on the offset.	- SEM or UEM principle. - Boundary between OOB and spurious domain.
		1-C-A	- Same as Range 1-C-N	- Same as Range 1-C-N

		1-O	- TRP is used as a metric. - Adopt 100kHz or 1MHz resolution bandwidth depending on the offset. - (Do not used AAS emission scaling methodology for above 6GHz. [Note 1])	- Same as Range 1-C. [Following will be discussed in eAAS session] - Emission scaling for <6GHz.
		2	- TRP is used as a metric. - Adopt 1MHz resolution bandwidth. - Do not used AAS emission scaling methodology. - FCC limit for mmWave and ACLR from co-existence studies can be considered as starting point.	- SEM or UEM principle. - Boundary between OOB and spurious domain.

	TX spurious emissions	1-C-N	- Category A and Category B emission limits should be defined.
			- Adapt following resolution bandwidth;
			  - 10kHz for below 30MHz range.
			  - 100kHz for 30MHz to 1GHz range.
			  - 1MHz for above 1GHz range
			- Lower frequency limit;
			  - 9kHz for between 300 MHz to 6GHz.
			  - (30MHz for above 6GHz.) [Note 1]
			- Upper frequency limit;
			  - 5th harmonic for between 300 MHz to 6GHz.
			  - (26GHz for between 6GHz and 13GHz.) [Note 1]
			  - (2nd harmonic for above 13GHz.) [Note 1]
				- (Whether co-location related spurious emissions requirement is needed or can be excluded for above 6GHz.)[Note 1]

		1-C-A	- Same as Range 1-C-N	- Same as Range 1-C-N

		1-O	- Category A and Category B emission limits should be defined.
			- TRP is used as a metric.
			- Adapt the same resolution bandwidth with Range 1-C.
			- Lower frequency limit;
			  - 30MHz for above 300 MHz to 6GHz.
			- Upper frequency limit;
			  - Same as Range 1-C.
				- (Whether co-location related spurious emissions requirement is needed or can be excluded for above 6GHz.)[Note 1]

		2	- Basis is category A limits. More stringent limits to be studied further.
			- TRP is used as a metric.
			- Adapt following resolution bandwidth;
			  - 100kHz for 30MHz to 1GHz range.
			  - 1MHz for above 1GHz range
			- Lower frequency limit;
			  - 30MHz for above 6GHz.
			- Upper frequency limit;
			  - (26GHz for between 6GHz and 13GHz.)[Note 2]
			  - 2nd harmonic for above 13GHz.
				- Whether co-location related spurious emissions requirement is needed or can be excluded.

	TX IM	1-C-N	FFS	- (Whether this requirement is needed or can be excluded for above 6GHz.) [Note 1] - (Interference signal modelling (frequency offset, signal level, signal bandwidth) for above 6GHz) [Note 1]
		1-C-A	FFS	- Same as Range 1-C-N
		1-O	FFS	- Same as Range 1-C.

		2	FFS	- Whether this requirement is needed or can be excluded. - Interference signal modelling (frequency offset, signal level, signal bandwidth)
	In-band emission	1-C-N	- in first phase NR specification development by defining only EVM based requirements for BS Tx in-band requirements (Do not introduce in-band emission requirement in first phase spec)	- If UL based in-band emission can be reused for BS. - How to devise a requirement that is implementation agnostic
		1-C-A	- Same as Range 1-C-A.	- Same as Range 1-C-N
		1-O	FFS	- If UL based in-band emission can be reused for BS. - How to devise a requirement that is implementation agnostic - Directions of wanted signal and unwanted signal.
		2	FFS	- Same as Range 1-O.
RX	REFSENS	1-C-N/1-C-A	FFS	- Sensitivity for below 6GHz.
		1-O	FFS	- Used metric (EIS or TRS) - How to decide EIS or TRS value - If same concept with AAS (vender declares the direction range to meet the requirement) can be reused or different concept
		2	FFS	- Same as Range 1-O.
	Dynamic range	1-C-N/1-C-A	FFS	- If it is possible to reuse the same dynamic range for below 6GHz. - (Study what are needed parameters to decide required dynamic range for above 6GHz.) [Note 1]
		1-O	FFS	- If it is possible to reuse the same dynamic range for below 6GHz. - (Study what are needed parameters to decide required dynamic range for above 6GHz.) [Note 1] - Directions of wanted signal and unwanted signal.
		2	- For simulation to Investigate the noise floor rise, reuse the existing simulation assumptions of WP5D coexistence study captured in the TR 38.803 for preliminary study (other options are not precluded in the future).	- Study what are needed parameters to decide required dynamic range. - Directions of wanted signal and unwanted signal.
	In-channel selectivity	1-C-N/1-C-A	**For mixed numerology case** - define with two different numerology CP-OFDM signals within a carrier	- signal modelling (frequency offset, signal level, signal bandwidth)
		1-O	**For mixed numerology case** - define with two different numerology CP-OFDM signals within a carrier	- Directions of wanted signal and unwanted signal. - Spatial considerations - signal modelling (frequency offset, signal level, signal bandwidth) - Spatial averaging etc.
		2	FFS	- Same as Range 1-O.
	ACS and narrow-band blocking	1-C-N/1-C-A	FFS	- How to decide interference signal modelling - Interference signal modelling (frequency offset, signal level, signal bandwidth)

		1-O	FFS	- How to decide interference signal modelling - Directions of wanted signal and unwanted signal. - Spatial considerations Interference signal modelling (frequency offset, signal level, signal bandwidth) - Spatial averaging etc.
		2	- Narrrowband blocking in the in-band frequency range will be not specified if there is no narrowband system (e.g. GSM) operation in the frequency range.	- Same as Range 1-O.
	Blocking	1-C-N/1-C-A	FFS	- For below 6GHz (and above 6GHz respectively [Note 1]): - How to decide blocking signal modelling - (Whether out of band RX blocking can be excluded for above 6GHz (with some exceptions)) [Note 1] - Blocking signal modelling (frequency offset, signal level, signal bandwidth). - (Blocking interference level reference point for above 6GHz) [Note 1]
		1-O	FFS	- For below 6GHz (and above 6GHz respectively [Note 1]): - How to decide blocking signal modelling - Directions of wanted signal and unwanted signal. - How to set OTA test - (Whether out of band RX blocking can be excluded for above 6GHz (with some exceptions)) [Note 1] - Blocking signal modelling (frequency offset, signal level, signal bandwidth). - (Blocking interference level reference point for above 6GHz) [Note 1]
		2	FFS	- How to decide blocking signal modelling - Directions of wanted signal and unwanted signal. - How to set OTA test. - Whether out of band RX blocking can be excluded (with some exceptions). - Blocking signal modelling (frequency offset, signal level, signal bandwidth). - Blocking interference level reference point.
	RX spurious emissions	1-C-N	FFS	- If it is possible to reuse the same spurious limits for below 6GHz. - (How to decide spurious limit levels for above 6GHz.) [Note 1] - (How to decide lower and upper frequency limits for above 6GHz) [Note 1]
		1-C-A	FFS	- Same as Range 1-C-N

		1-O	FFS	- If it is possible to reuse the same spurious limits for below 6GHz. - (How to decide spurious limit levels for above 6GHz.) [Note 1] - (How to decide lower and upper frequency limits for above 6GHz) [Note 1] - Used metric (TRP or not).
		2	FFS	- How to decide spurious limit levels. - How to decide lower and upper frequency limits. - Used metric (TRP or not)
	RX IM	1-C-N/1-C-A	FFS	- (How to decide interference signal modelling for above 6GHz) [Note 1] - Interference signal modelling (frequency offset, signal level, signal bandwidth)
		1-O	FFS	- (How to decide interference signal modelling for above 6GHz) [Note 1] - Directions of wanted signal and unwanted signal. - Spatial considerations - Interference signal modelling (frequency offset, signal level, signal bandwidth)
		2	- Narrowband intermodulation in the in-band frequency range will be not specified if there is no narrowband system (e.g. GSM) operation in that frequency range.	- How to decide interference signal modelling - Directions of wanted signal and unwanted signal. - Spatial considerations - Spatial considerations Interference signal modelling (frequency offset, signal level, signal bandwidth)
Other	[New] Beam related NR specific	1-C-N/ 1-C-A	- No need.	
		1-O	- Beam characteristics are included in the RAN4 scope.	- Necessity of the beam related new requirements. - If needed, how to specify.
		2	- Same as Range 1-O.	- Same as Range 1-O.

6.3.1.1 Coordinate system

OTA requirements are stated in terms of electromagnetic and spatial parameters. The electromagnetic parameters are specified either in terms of power (dBm) or field strength (dBμV/m). The spatial parameters are specified in a Cartesian coordinate system (*x, y, z*) using spherical coordinates (r, Θ, Φ). The orientation of these coordinates is depicted in the following figures. Φ is the angle in the x/y plane and it is between the x-axis and the projection of the vector onto the x/y plane and is defined between -180° and +180°, inclusive. Θ is the angle between the projection of the vector in the x/y plane and the vector and is defined between -90° and +90°, inclusive.

A point in the Cartesian coordinate system (*x,y,z*) can be transformed to spherical coordinates (r, Θ, Φ) using the following relationships:

$$x = r\cos\Theta\cos\Phi$$

$$y = r\cos\Theta\sin\Phi$$

$$z = -r\sin\Theta$$

The inverse transformation is given by:

$$r = \sqrt{x^2 + y^2 + z^2}$$

$$\Theta = -\arcsin \frac{z}{\sqrt{x^2 + y^2 + z^2}}$$

$$\Phi = \arctan \frac{y}{x}$$

The representation and definitions of angles are described in figure 6.3.1.1-1, figure 6.3.1.1-2 and figure 6.3.1.1-3.

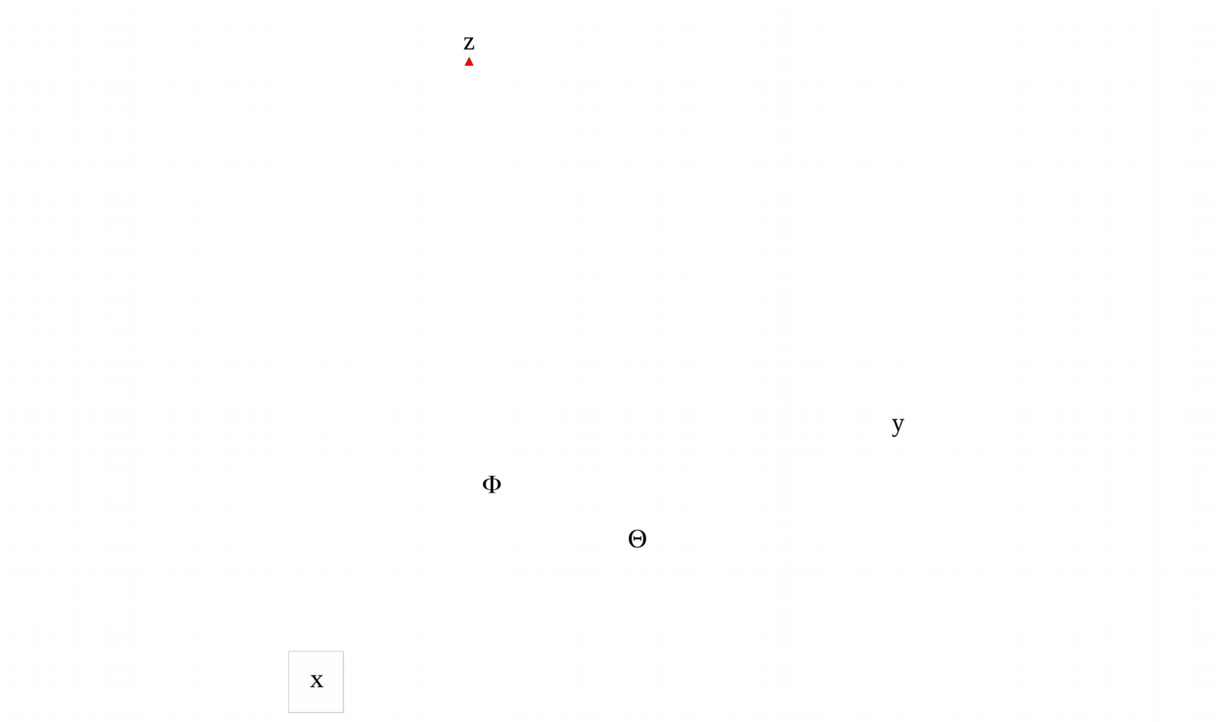


Figure 6.3.1.1-1: Orthogonal representation of coordinate system

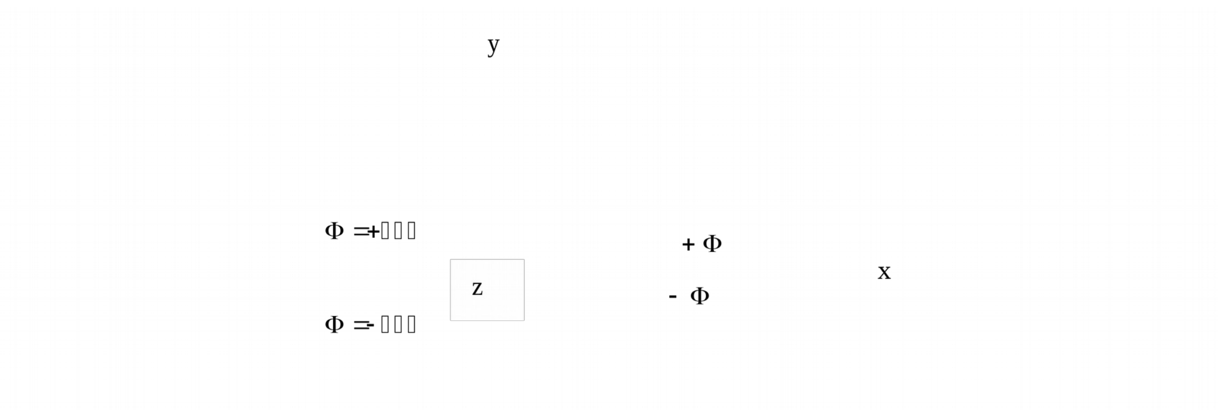


Figure 6.3.1.1-2: Definition of the Φ angle

Figure 6.3.1.1-3: Definition of Θ angle

A different coordinate system can be used in the technical report to carry out simulations, conformance testing, or present results as long as it is clearly indicated that it is different.

The vendor declares the location of this coordinate system origin in reference to an identifiable physical feature of the BS enclosure. The vendor also declares the orientation of this coordinate system in reference to an identifiable physical feature of the BS enclosure.

6.3.1.2 BS class

Definitions of NR BS classes were agreed [R4-1702357].

NR BS classes for BS without antenna connectors are defined as indicated below:

- Wide Area Base Stations are characterised by requirements derived from Macro Cell scenarios with a BS to UE minimum distance along the ground equal to 35 m.
- Medium Range Base Stations are characterised by requirements derived from Micro Cell scenarios with a BS to UE minimum distance along the ground equal to 5 m.
- Local Area Base Stations are characterised by requirements derived from Pico Cell scenarios with a BS to UE minimum distance along the ground equal to 2 m.

NR BS classes for BS with antenna connectors are defined as indicated below:

- Wide Area Base Stations are characterised by requirements derived from Macro Cell scenarios with a BS to UE minimum coupling loss equal to 70 dB.
- Medium Range Base Stations are characterised by requirements derived from Micro Cell scenarios with a BS to UE minimum coupling loss equals to 53 dB.
- Local Area Base Stations are characterised by requirements derived from Pico Cell scenarios with a BS to minimum coupling loss equal to 45 dB.

The following text is added together with any definition of BS classes:

- The deployment scenarios associated with and definitions of BS classes are exactly the same for BS both with and without connectors. An MCL of 70dB corresponds to a minimum distance of around 35m, 53dB to around 5m and 45dB to around 2m respectively for BS with connectors.

NR Home BS class is FFS.

For some BS class, a limit on the maximum output power is applied. For the NR specifications, it was agreed that the output power limit will be based on TRP. [R4-1610923]

6.3.2 BS Transmitter characteristic

6.3.2.1 General

PA models are quite essential investigating the transmitter characteristics. A general overview of a few PA models as well as fully parameterized General Memory Polynomial models which capture the memory effects is described in detail in Annex A. The annex captures some models provided as a starting point for the Study Item; the use of different models during the SI or WI is not precluded. It is noted that the PA model should be applied in conjunction with appropriate RF requirements. CFR and DPD algorithms should also be considered when use the PA model for BS transmitter.

6.3.2.2 BS output power

For Range 1,

- For OTA output power accuracy requirement,
    - It was agreed to use EIRP as an accuracy requirement by following AAS agreement.
    - Declaration of the range of direction to meet EIRP accuracy will follow AAS/eAAS.
    - TRP needs to be declared for BS class related power limit, maximum power condition etc.
- It was confirmed that the same output power accuracy values (+/- 2.0dB and +/- 2.2 dB for conducted and OTA respectively) in existing specifications (TS 36.104 and TS 37.105) can be used in NR as well.

For Range 2

- It was agreed to use EIRP as an accuracy requirement.
- Declaration of the range of direction to meet EIRP accuracy will follow AAS/eAAS.
- It is FFS whether the same EIRP accuracy equation with AAS can be reused or not.
- TRP needs to be declared for BS class related power limit, maximum power condition etc.

6.3.2.3 Output power dynamic range

<*to be added later*>

6.3.2.4 Transmit ON/OFF power

<*to be added later*>

6.3.2.5 Transmitted signal quality

6.3.2.5.1 Frequency error

<*to be added later*>

6.3.2.5.2 EVM

Refer Section 6.1.8.

6.3.2.5.3 TAE

<*to be added later*>

6.3.2.5.4 DL RS power

<*to be added later*>

6.3.2.6 Unwanted emission

6.3.2.6.1 Occupied bandwidth

For Range 1,

- It was agreed that the same principle with existing (99% power should be within CBW) can be reused, i.e. the occupied bandwidth is a measure of the bandwidth containing 99% of the total integrated mean power of the transmitted spectrum on the assigned channel.
- For conduct requirement
  - The minimum requirement for conduct occupied bandwidth shall be less than the channel bandwidth supported by NR.
    - The channel bandwidths supported by NR are FFS
- For OTA requirement,
  - For OTA occupied bandwidth, the beam characteristics are not important. The requirement should however cover the fact that all transmitters are active and the system is operating at the maximum declared rated total radiated power.
  - The minimum requirement for OTA occupied bandwidth shall be less than the channel bandwidth supported by NR.
    - The channel bandwidths supported by NR are FFS

Note: The occupied bandwidth requirement may be a regulatory requirement in some regions. There may also be regional requirements to declare the occupied bandwidth according to the definition.

For Range 2,

- For OTA occupied bandwidth, the beam characteristics are not important. The requirement should however cover the fact that all transmitters are active and the system is operating at the maximum declared rated total radiated power.
- The minimum requirement for OTA occupied bandwidth shall be less than the channel bandwidth supported by NR.
  - The channel bandwidths supported by NR are FFS

Note: The occupied bandwidth requirement may be a regulatory requirement in some regions. There may also be regional requirements to declare the occupied bandwidth according to the definition.

6.3.2.6.2 ACLR

For Range 1,

- For OTA requirement,
  - It was agreed that the ACLR shall be based on TRP of the signal in the wanted channel and TRP of the signal in the adjacent channel.
  - For conformance testing, TRP will be measured on a finite grid that may be optimised to provide the needed accuracy in estimating TRP whilst not causing undue measurement time.

For Range 2

- It was agreed that the ACLR shall be based on TRP of the signal in the wanted channel and TRP of the signal in the adjacent channel.
- For conformance testing, TRP will be measured on a finite grid that may be optimised to provide the needed accuracy in estimating TRP whilst not causing undue measurement time.

Note: BS ACLR was analysed in the context of the response to ITU-R on parameters for the 24-86GHz range. Details of the ITU-R analysis and ACLR values are provided in chapter 11. An ACLR requirement for the 3GPP specification should be decided in the WI.

6.3.2.6.3 Mask

For Range 1,

- The operating band unwanted emissions are a set of absolute power levels which emissions from the BS must not exceed. They are defined by a frequency offset, measurement bandwidths and an absolute power level.
- The absolute power level may be a fixed value in dBm or may be calculated based on the power of the wanted signal and the frequency offset.
- For OTA requirement,
  - the requirement is derived using a similar method but rather than the sum of the conducted power it is based on TRP.

For Range 2

- TRP will be used for a metric for the absolute limits.
- The FCC limit for mm wave and ACLR for the co-existence studies [17] is to be considered the starting point.
- A 1MHz measurement bandwidth will be applied to all frequency offsets.

Note: BS SEM for range 2 was analysed in the context of the response to ITU-R on parameters for the 24-86GHz range. Details of the ITU-R analysis and SEM values are provided in chapter 11. An SEM requirement for the 3GPP specification should be decided in the WI.

6.3.2.6.4 TX spurious emissions

For Range 1,

- Both Category A and Category B emission limits should be defined to align with regional requirements.
- For Conducted,
  - Resolution bandwidth, lower frequency limit and upper frequency limit were agreed to be aligned with non-AAS specifications (TS 36.104, TS 37.104) and ITU-R recommendation SM.329.
- For OTA,
  - Resolution bandwidth, lower frequency limit and upper frequency limit were agreed to be aligned with AAS specification (TS 37.105) and ITU-R recommendation SM.329.
  - TRP is used as a metric to be equivalent with existing conducted requirement.

Note: The boundary between spurious and operating band unwanted emissions may need further study for wide bands and bandwidths.

For Range 2

- Spurious emission limits will be aligned with ITU-R SM.329 [4]. Category A limit is aligned with the U.S. regulation in the telecommunications area set by FCC Title 47 [11]. Category A limits are globally applicable, while the lower Category B limits are used in Europe (ITU region 1) and some additional countries. Category A limits are applied in a substantial part of the world (ITU Regions 2 and 3).
- TRP is used as a metric to be equivalent with existing conducted requirement and to be aligned with FCC regulation.
- Resolution bandwidth, lower frequency limit and upper frequency limit were agreed to be aligned with ITU-R recommendation SM.329.
  - The upper carrier frequency with which the 2^{nd} harmonic can be measured is FFS.

Note: The boundary between spurious and operating band unwanted emissions will need further study and agreement during the WI.

6.3.2.7 TX IM

<*to be added later*>

6.3.2.8 In-band emission

Refer Section 6.1.8.

6.3.3 BS Receiver characteristic

6.3.3.1 Reference sensitivity

<*to be added later*>

6.3.3.2 Dynamic range

The dynamic range is specified as a measure of the capability of the receiver to receive a wanted signal in the presence of an interfering signal inside the received channel bandwidth. The receiver shall fulfill the specified throughput loss requirement for one specific measurement channel of wanted signal in the presence of an AWGN interfering signal in the same reception frequency channel. Therefore for NR BS, the dynamic range requirement should be further investigated considering the channel bandwidth, noise figure, noise floor rise, physical layer design.

For the simulation evaluation of the noise floor rise for dynamic range requirement;

For Range 2

Reuse the existing simulation assumptions of WP5D coexistence study captured in the TR 38.803 for preliminary study. Other options are not precluded in the future.

6.3.3.3 In-channel selectivity

Refer Section 6.1.4.

6.3.3.4 ACS and narrow-band blocking

For Range 2

Narrowband blocking in the in-band frequency range will be not specified if there is no narrowband system (e.g. GSM) operation in that frequency range.

6.3.3.5 Blocking

The blocking performance requirement is specified as a measure of the receiver capability to receive a wanted signal at its assigned channel frequency in the presence of an unwanted interferer. The wanted signal should be depend on this physical layer design and corresponding performance degradation, therefore it could be investigated once physical layer design is finalized.

For the simulation evaluation of the power level interfering signal of in-band blocking;

For Range 2

- Derive a methodology for deriving a OTA interferer and wanted signal level rather than a conducted interferer level

- If possible reuse the existing simulation assumptions of WP5D coexistence study captured in the TR 38.803 with slight modification for preliminary study

- Other options are not precluded in the future.

Statistical method:

  - Discuss and agree on what blocker and wanted signal probabilities to use in the simulations

To further check the interfering signal power level and frequency range of out of band blocking instead of reusing directly as E-UTRA BS for both above 24GHz and below 6GHz. In the absence of guidance on frequency range for out of band blocking requirements for NR, to further check if the proposal to adopt the range from 30 MHz to 26GHz for frequency bands above 6 GHz up to 13GHz and 30MHz to 2nd harmonic for above 13 GHz bands is acceptable or to consider alternative proposal.

6.3.3.6 Receiver spurious emissions

<*to be added later*>

6.3.3.7 Receiver intermodulation

The intermodulation requirement should be investigated considering the joint probability of interfering signals. The wanted signal should be depend on this physical layer design and corresponding performance degradation, therefore it could be investigated once physical layer design is finalized. And power level of interfering signals could potentially be derived according to the system level simulation.

For Range 2

Narrowband intermodulation in the in-band frequency range will be not specified if there is no narrowband system (e.g. GSM) operation in that frequency range.

6.3.4 Other

6.3.4.1 Beam related NR specific requirement

For Range 2

- For OTA requirement,
  - It was proposed the necessity beam related NR specific requirement. Following six potential candidate requirements are proposed in the SI phase.
    - "Guarantee of several fluctuation(Beam stability)" by R4-1700173
    - "EIRP envelope curve" by R4-1700173
    - "Beam steering speed" by R4-1700173
    - "SLSR(Side lobe suppression ratio) by R4-1610576
    - "FBR(Front-back-ratio)" by R4-1700161
    - "multi-beam signal quality and spatial selectivity for spatial requirements" by R4-1700221
  - In order to decide if any new requirement is required,
    - it will be needed to solve and/or mitigate Cons of potential candidate requirement in early WI phase.
      - Any solutions to overcome Cons whose possibility is not clear.
      - Any solutions to minimize Cons which have negative impact on testability such as the number of test.
      - Any advantages, motivation and demand for the introduction of the requirements even with the Cons.

- it will be required to clarify some aspects (e.g., Target frequency, concern to be solved by the requirement, necessary to be specify in 3GPP standard, testability, BS type to which requirement is applied, or requirement type (RF, RRM, demod or new one)).

7 Relation with the existing specifications

The scope of the existing MSR BS, AAS BS and UE specifications in RAN4 was identified to be as follows:

- MSR BS specification
  - MSR specification in TS 37.104 [x] captures BS RF requirements for Rx and Tx for GSM, UTRA and E-UTRA.
  - MSR BS specification captures BS RF conducted requirements.
  - BS demodulation requirements for MSR BS are captured by referring to single RAT UTRA TDD, single RAT UTRA FDD, and single RAT E-UTRA BS demodulation requirements in TS 25.105, TS 25.104 and TS 36.104, respectively.
  - MSR BS specification is consider as non-AAS BS specification (same as single RAT UTRA BS and single RAT E-UTRA BS specifications).
- AAS BS specification
  - AAS BS specification in TS 37.105 captures single RAT UTRA, single RAT E-UTRA and MSR operation.
  - AAS BS specification captures BS RF requirements for Hybrid AAS BS and for OTA AAS BS.
  - AAS BS specification covers single RAT UTRA, single RAT E-UTRA and MSR operation.
  - The Rel-13/14 version of the AAS BS specification comprises a single set of Hybrid requirements, composed of conducted requirements as well as OTA requirements on EIRP and EIS.
  - Rel-15 version of the AAS BS specification will be extended with at least the full set of OTA requirements and possibly a further set of hybrid requirements.
  - BS demodulation requirements for AAS BS are captured by referring to single RAT UTRA TDD, single RAT UTRA FDD, and single RAT E-UTRA BS demodulation requirements in TS 25.105, TS 25.104 and TS 36.104, respectively.
- EMC requirements
  - Conducted EMC requirements for the MSR BS in TS 37.113 cover emissions and immunity requirements.
  - Conducted EMC requirements for the AAS BS in TS 37.114 are captured by referring to the EMC specifications for single RAT UTRA, single RAT E-UTRA and MSR BS in TS 25.113, 36.113 and 37.113, respectively.
- UE specifications are capturing the following:
  - RF and demodulation requirements, single RAT UTRA and E-UTRA
  - RRM requirements, UTRA and E-UTRA

The following is identified as needed to be captured in the specification structure around NR:

- NSA and SA NR, Range 1
  - Conducted and OTA requirements to be defined
  - Single RAT NR BS requirements may be needed; the need for these is FFS
  - MSR NR BS requirements will be needed, aligned to the existing MSR requirements
  - Hybrid and OTA NR BS requirements will be needed, aligned to the existing AAS requirements

  - It is FFS which (if any) BS requirements need to differ between SA and NSA
  - UE conducted RF, RRM and demodulation requirements
- NSA and SA NR, Range 2
  - OTA requirements to be defined
  - Single RAT BS RF requirements, OTA
  - UE RF requirements, OTA
  - BS and UE demodulation requirements, scope FFS
  - RRM requirements, OTA

8 Regulatory aspect

8.1 Overview of international and regional regulation

8.1.1 ITU-R

The Radio Regulations [5] is an international binding treaty for how RF spectrum is used. It is updated and agreed at the World Radiocommunication Conference (WRC) that is held every 3 to 4 years. One RF parameter related to unwanted emissions is defined directly in the radio regulation:

- ITU Radio Regulations No. S1.153 [5] provides a definition of *Occupied bandwidth*.

ITU-R Study Group 1 is responsible for Spectrum management principles and techniques and develops international recommendations for unwanted emissions.

The following ITU-R recommendations provide generic limits and some guidelines for how to specify unwanted emissions:

- ITU-R SM.329-12 [4] provides terminology and definitions in the area of spurious emissions. It also gives recommendations of how limits are applied and recommended limit values and reference bandwidths. Limits are given in different “Categories”, where Category A limits are generally applicable while other Categories have regional application for certain services. Some limits are further described in Annexes to the recommendation, where in particular Annex 7 gives reference bandwidths for Category B limits in the land mobile service.
- ITU-R SM.328-11 [3] provides terminology and definitions in the area of spectra and bandwidth of emissions. It is intended to provide guidance in deriving limits for out-of-band emissions and gives examples of how emitted spectra can be classified and what parameters can be used to specify it. Most of the text concerns analogue and narrowband modulation.
- ITU-R SM.1539-1 [7] specifically deals with the boundary between the out-of-band and spurious domains. It proposes variations to the default “250% rule” for wideband emissions for different frequency ranges, where the highest interval is above 26 GHz.
- ITU-R SM.1540 [8] gives recommendations for emissions falling into an adjacent band allocation.
- ITU-R SM.1541-6 [9] gives recommendations for emission in the out-of-band domain. Annex 11 covers land mobile services, but there is only discussion of narrowband systems (up to 30 kHz).

NOTE: The term *Out-of-band (OOB) emissions* can cause some confusion and is for this reason mostly avoided in 3GPP BS specifications. Regulation defines OOB emissions as "*Emission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emissions*". OOB emissions are thereby the emissions closest to the transmitted carrier(s) and the term "Out-of-band" does not refer to emission being outside the operating band or an operator's assigned band. Note that spurious emissions and OOB emissions are mutually exclusive through the definition, making the boundary between them very important. OOB emissions are for WCDMA and LTE BS defined through ACLR, spectrum mask (for WCMDA) and operating band unwanted emissions (for LTE).

8.1.2 European regulation

The European regulations include unwanted emission levels. As basis, the limits included in ITU-R documents. Limits applicable in Europe are in ITU-R SM.329-12 [4] identified as *Category B* requirements are used. In addition, the following European recommendations are developed and maintained by CEPT/ECC regarding unwanted emissions as follows:

- ECC Rec (02)05 [14] is an "umbrella" recommendation on unwanted emissions, giving general guidelines on out-of-band and spurious emissions, the boundary between out-of-band and spurious domains, with reference to ITU-R recommendations and the ERC Rec. 74-01 on spurious emissions [15]

- ERC Rec. 74-01 [15] provides terminology and definitions in the area of spurious emissions, with recommended limit values and reference bandwidths for the spurious domain. It corresponds to the Category B limits in ITU-R Rec. SM 329-12 [7], but has in addition provisions for mobile services covering multi-carrier and multi-RAT base stations.

CEPT/ECC publishes decisions, recommendations and reports related to spectrum usage. These may include emission limits. In many cases, the spectrum decision s are also confirmed in a spectrum decision by the European Union (EU). Here it should be noted that the EU has 28 member states while CEPT has 48 national administrations as members. The spectrum decisions made by the EU is the basis for national licensing conditions in countries across Europe. In addition, ECC decision and/or recommendations are used.

Information related to the use of spectrum in CEPT member states and used in Annex B are maintained in the ERC Report 25 version that is approved as of June 2016 [2].

Annex B provides information on the services and applications allocated in Europe in the bands of interest for NR [2].

The radio equipment requirements for products in Europe is set by *Harmonized Standards*. The harmonized standard for IMT equipment is EN 301 908 [16], divided into individual parts for each type of equipment. The parts for UMTS and LTE equipment are based on extracts from the 3GPP RAN4 and RAN5 test specifications.

8.1.3 U.S. regulation (FCC)

The U.S. regulation in the telecommunications area is set by FCC Title 47 [11]. The different parts of Title 47 cover licensing requirements and procedures, as well as operational and technical requirements and other provisions. Example of parts covering 3GPP bands are Part 22 (Public mobile services), Part 25 (Personal communication services) and Part 27 (Miscellaneous wireless communications services). The technical requirements include power limits, emission limits, measurement principles and statements on interference protection and other technical provisions.

For bands above 24 GHz, the FCC has recently published a Report and Order and Further Notice of Proposed Rulemaking [17].

These new rules open up nearly 11 GHz of high-frequency spectrum for flexible, mobile and fixed use wireless broadband – 3.85 GHz of licensed spectrum and 7 GHz of unlicensed spectrum. The new rules create a new Upper Microwave Flexible Use service in the 28 GHz (27.5-28.35 GHz), 37 GHz (37-38.6 GHz), and 39 GHz (38.6-40 GHz) bands, and a new unlicensed band at 64-71 GHz.

- Licensed use in the 28 GHz, 37 GHz and 39 GHz bands: Makes available 3.85 GHz of licensed, flexible use spectrum, which is more than four times the amount of flexible use spectrum the FCC has licensed to date.

  - Provides consistent block sizes (200 MHz), license areas (Partial Economic Areas), technical rules, and operability across the exclusively licensed portion of the 37 GHz band and the 39 GHz band to make 2.4 GHz of spectrum available.

  - Provides two 425 MHz blocks for the 28 GHz band on a county basis and operability across the band.

- Unlicensed use in the 64-71 GHz band: Makes available 7 GHz of unlicensed spectrum which, when combined with the existing high-band unlicensed spectrum (57-64 GHz), doubles the amount of high-band unlicensed spectrum to 14 GHz of contiguous unlicensed spectrum (57-71 GHz). These 14 GHz will be 15 times as much as all unlicensed Wi-Fi spectrum in lower bands.

- Shared access in the 37-37.6 GHz band: Makes available 600 MHz of spectrum for dynamic shared access between different commercial users, and commercial and federal users.

A new Part 30 (Upper Microwave Flexible Use Service) is added and licenses issued in the 27.5-28.35 GHz band and licenses in the 38.6-40 GHz band are reassigned to the new service. The following subparts relate directly to RF aspects:

- § 30.202 Power limits: Max EIRP limits

- § 30.203 Emission limits: OOBE and spurious emissions limits (conducted or total radiated power)

The new Part 30 power limits from [17] are shown in Table 8.1.3-1 and the Emission limits in Table 8.1.3-2.

Table 8.1.3-1: Part 30.202 Power limits (from [17])

Stations	Maximum allowable EIRP
Fixed/Base stations	75 dBm/100 MHz[1]
Mobile stations	43 dBm
Transportable stations	55 dBm
NOTE 1: For channel bandwidths less than 100 MHz the EIRP must be reduced proportionally and linearly based on the bandwidth relative to 100 MHz.	

Table 8.1.3-2: Part 30.203 Emission limits (from [17])

Outband frequency range	Conductive power /Total radiated power
Channel assignment[1] edge ~ 10% of the Authorized Bandwidth[2]	-5 dBm
Beyond 10% of Authorized Bandwidth	-13 dBm
Note 1: Channel assignment is the channel that is determined by standards (defining center frequency), the FCC usually defines this as the bandwidth at which 99% of the emission power is contained. Note 2: Authorized bandwidth is the maximum width of the band of frequencies permitted to be used by a station. This is normally considered to be the necessary or occupied bandwidth, whichever is greater. Note 3: Measurement Requirements: 1) Measurement is based on the use of measurement instrumentation employing a resolution bandwidth of 1 megahertz or greater. 2) When measuring the emission limits, the nominal carrier frequency shall be adjusted as close to the licensee's frequency block edges as the design permits. 3) The measurements of emission power can be expressed in peak or average values.	

8.2 Boundary between spurious and OOB domain

One of the fundamental RF parameters to define for NR is the unwanted emissions. In regulation, unwanted emissions are divided into *Spurious emissions* and *Out-of-band emissions* and the boundary between those two domains has a profound impact on the emission limits that can be defined for a radio access technology such as NR. This subclause describes the details of the boundary between the spurious and OOB domain, how it was handled in specifications for WCDMA and LTE and impact for NR.

8.2.1 Application of boundary for UMTS and LTE BS below 6 GHz

When UMTS (UTRA) was first specified by 3GPP as an IMT-2000 technology in 1998-2000, spurious emission limits and the boundary between spurious and out-of-band (OOB) domain were fundamentally based on the international recommendation ITU-R SM.329 [4]. For requirements applicable in Europe, Category B limits were used, which are also covered in ERC Recommendation 74-01 [14]. Those limits are applicable also in many other countries that use European harmonised standards for product certification.

Later in 2005-2006, when new frequency bands were added to WCDMA and LTE (E-UTRA) was included as a new wideband radio access, there was a need to update the way the limits were applied for base stations in particular. This was all done in close co-operation between 3GPP, ETSI and ECC. How the limits are applied is documented in TR 25.942 [18], subclause 14.2.3.

The boundary between the out-of-band and spurious domain is based on the "250% rule" in ITU-R SM.329 [4]. The rule states that "*the spurious domain generally consists of frequencies separated from the centre frequency of the emission by 250% or more of the necessary bandwidth of the emission.*" The application for WCDMA and LTE is as follows:

- The boundary between the out-of-band and spurious domain is for base stations fundamentally based on a 5 MHz channel bandwidth, placing it at 12.5 MHz from the carrier centre (10 MHz from the channel edge). This 10 MHz assumption originates from the UMTS 5 MHz carrier and is in 3GPP also applied for LTE BS transmissions, applying as a stricter requirement also to 10, 15 or 20 MHz RF bandwidth. Note that this is not the case for LTE UEs (terminals), where the 250% rule is applied also for larger carrier bandwidths.

- The limits inside the operating band for a UMTS or LTE BS are based on a reduced measurement bandwidth close to the carrier, as outlined in the recommendations (see Annex 2 of [15]). This reduction is in the 3GPP specifications interpreted as a relaxed limit of -15 dBm/MHz. While the recommendations allow for this reduction in a frequency range up to 10 times the necessary bandwidth, it was agreed that the relaxed limit could be applied in the complete transmitter operating band, plus in 10 MHz on each side of the operating band.

- The agreement above between 3GPP, ETSI and the ECC on the spurious emission limits is based on the following:

  - The limits are in line with the limits used in ERC and ECC compatibility studies.

  - There is no impact on in-band sharing between different IMT technologies.

  - The limits are fair between operators and give mutual advantages, regardless of the technology deployed, the carrier bandwidth, the number of carriers or the position of the operator's license block.

The agreed limits were implemented for both UMTS and LTE at that time. For LTE, the limits are interpreted as Operating band unwanted emission limits, which is a unified definition of all unwanted emission within the operating band, plus in 10 MHz on each side, as shown in Figure 8.2.1-1. Outside of that range, spurious emissions are defined, as shown in Figure 8.2.1-2.

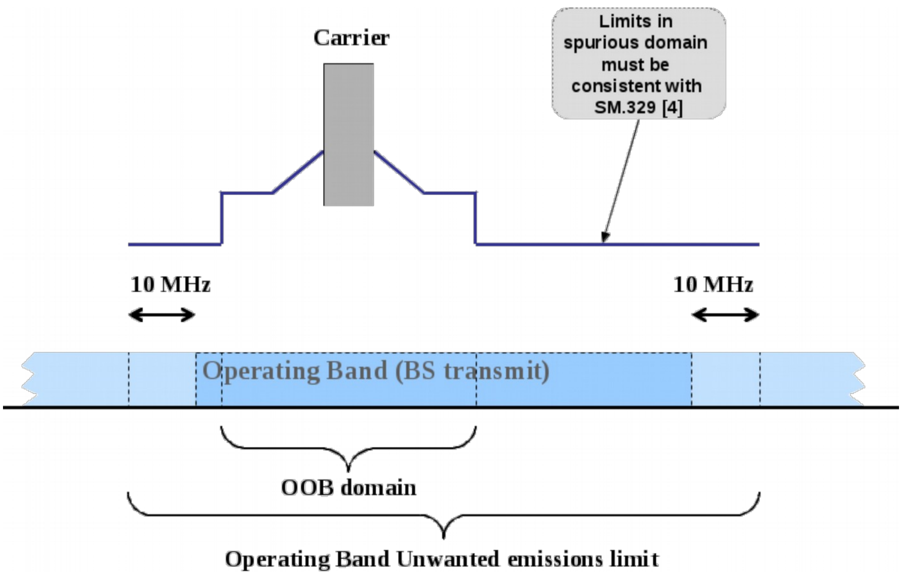


Figure 8.2.1-1: Defined frequency range for LTE Operating band unwanted emissions with an example RF carrier and related mask shape (from TR 36.942).

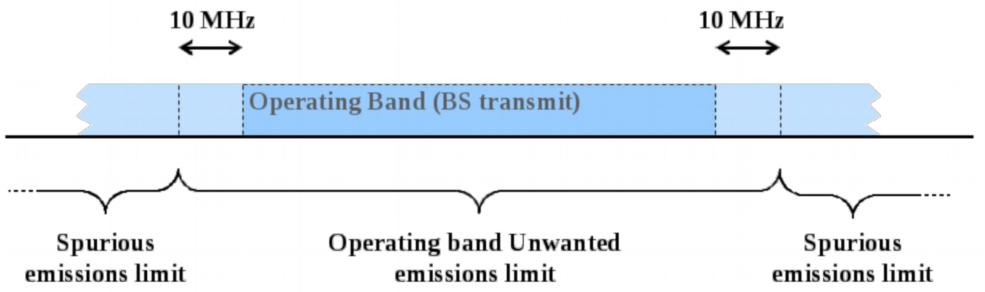


Figure 8.2.1-2: Defined frequency ranges for LTE spurious emissions and operating band unwanted emissions (from TR 36.942).

8.2.2 Application of boundary for UMTS and LTE UE below 6 GHz

<To be added>

8.2.3 Wideband, multicarrier and Multi-RAT transmissions

When LTE (E-UTRA) was developed, the focus was first on single-carrier transmission with flexible channel bandwidth (1.4 to 20 MHz). It was however quite early made clear that BS transmitters with multiple carriers would be deployed, in particular when the MSR standard was developed and later on when intra-band Carrier Aggregation was defined. It was then noted that the existing recommendations for spurious emissions did not give a proper guidance for such multicarrier transmissions and that for the text provided, mobile services were excluded. This is of particular concern for Category B spurious emission limits, since they are stricter.

This resulted in an update of ERC Rec 74-01 [15]. The update was mainly concerned with how the necessary bandwidth is calculated for such a multicarrier/multi-RAT transmitter and how the boundary between out-of-band and spurious domain is determined, with the following elements:

- The *transmitter bandwidth* is used as the necessary bandwidth for determining the limit between the out-of-band and spurious domain, and it is defined as the width of the frequency band covering the envelope of the transmitted carriers.

- Particular guidance is given in for *wideband transmitters*, with reference to ITU-R Rec SM.1539-1 [7].

- Rules are made applicable for both *contiguous and non-contiguous transmissions* within a frequency block.

Present UMTS, LTE and MSR specifications for base stations (and UEs) are fully in line with the updated version of ERC Rec 74-01. A more detailed description of the background and development of the spurious emission limits for multicarrier and multi-RAT transmissions can be found in TR 37.900 [20], subclause 6.6.1.2.

8.2.4 Regulation above 6 GHz and for large carrier bandwidths

With the work on a New Radio access (NR) targeting IMT-2020 as defined by ITU-R, there are a number of regulatory aspects to take into account. For the unwanted emission limits and the boundary between OOB and spurious domain, the following properties of NR must be considered:

- Large BS RF bandwidths covering the full band, which is the norm already today.

- Larger carrier bandwidths with numerology that may give higher out-of-band emission levels. This has a direct impact on the assumed boundary to the spurious domain defined for a transmitted carrier, which is relevant for the Operating band unwanted emission mask (UEM) levels inside the band, assuming that these can be defined in a way similar to what was done for LTE. Such a mask cannot anymore use a 5 MHz carrier as a baseline for setting the limits, due to the wider carriers and the new numerologies.

- For a carrier placed at the edge of a band, the unwanted emission levels outside the band will depend on the carrier bandwidth and numerology, but also on any passband filtering applied for the band. Such a filter will most likely still be employed at lower bands, but is more challenging for higher bands for AAS-type systems, in terms of achieving high attenuation close to the band. This has to do both with the width of the band and the high absolute frequency, as well as the RF properties of mm-wave technologies.

The present WCDMA and LTE unwanted emission limits are defined with a spurious emission level starting 10 MHz outside the operating band. The large carrier bandwidths and new numerologies will make such an assumption challenging already for lower bands and a higher number should be considered. The even larger carrier bandwidths and reduced possibilities for band filtering in higher bands (mm-wave) will in combination with new numerologies imply that the OOB domain will have to stretch further than 10 MHz from the band edge.

It should be noted that the regulation does not in any way stipulate a "10 MHz rule", this is a voluntary constraint put by 3GPP on the emission limits for LTE and WCDMA. In particular for the new bands, we have to go back to what the regulation recommends, which is the "250% rule" as defined above. The rule for wider carriers and higher bands is defined in ITU-R Recommendation SM.1539-1 [7], as shown in Table 8.2.3-1. The recommendation defines a threshold value B_U for the necessary bandwidth B_N of the transmission. When the bandwidth of the transmission is higher than the threshold B_U, the 250% rule (2.5 B_N) is replaced by the rule listed in the "Separation" column, resulting in a separation somewhere between 150% and 250% of the necessary bandwidth.

Table 8.2.4-1: Guideline values for the boundary of the spurious domain (Extracted from ITU-R SM.1539 [6])

Frequency range	Normal separation	Wideband case ($B_N > B_U$)	
		B_U	Separation
30 MHz < f_c < 1 GHz	2.5 B_N	10 MHz	1.5 B_N + 10 MHz
1 GHz < f_c < 3 GHz	2.5 B_N	50 MHz	1.5 B_N + 50 MHz
3 GHz < f_c < 10 GHz	2.5 B_N	100 MHz	1.5 B_N + 100 MHz
10 GHz < f_c < 15 GHz	2.5 B_N	250 MHz	1.5 B_N + 250 MHz
15 GHz < f_c < 26 GHz	2.5 B_N	500 MHz	1.5 B_N + 500 MHz
f_c > 26 GHz	2.5 B_N	500 MHz	1.5 B_N + 500 MHz

Note that the recommended separation to the boundary of the spurious domain stipulated by the rule in [7] gives a considerably larger offset from the carrier edge or band edge than the 10 MHz used today for LTE and WCDMA. Two examples:

- A 100 MHz carrier at any frequency >3 GHz would give a recommended 200 MHz offset from the edge to the start of the spurious domain.

- A 1 GHz carrier at any frequency >15 GHz would give a recommended 1.5 GHz offset from the edge to the start of the spurious domain.

While such large offsets to the boundary between the OOB and spurious domain may not be necessary for an NR specification, it is quite clear that the present way of specifying unwanted emissions cannot remain intact.

8.3 Suitability of technical conditions of ECC DEC (11) 06 for 5G

ECC PT1 sent an LS to 3GPP in April to inform the progress of regulatory work for IMT 2020/ 5G spectrum in Europe [27]. Later in June, ECC Plenary (June 2016) tasked ECC PT1 to assess the suitability of technical conditions of ECC Decision (11)06 to 5G. And in September, ECC PT1 sent an LS to 3GPP to seek feedback on the technical parameters foreseen for introducing 5G technologies in the 3400-3800 MHz band. Corresponding study of suitability of technical conditions of ECC DEC (11) 06 for 5G is carried out in 3GPP RAN4.

8.3.1 Technical conditions in frequency bands 3400-3600MHz and 3600-3800MHz

It is noted that the requirements specified in ECC DEC (11) 06 are mainly for the BS side. For UE side, ECC decision provides a recommended upper limit of 25 dBm for the in-block power of the UEs.And the power limit is specified as e.i.r.p. for UEs designed to be fixed or installed and as TRxP for Ues designed to be mobile or nomadic.

To better understand the requirements specified in [3], the terms used in ECC decision are listed below in Tabel 8.3.1-1 and Table 8.3.1-2:

Table 8.3.1-1 BEM elements

BEM elements	
In-block	Block for which the BEM is derived.
Baseline	Spectrum used for TDD and FDD UL and DL, except from the operator block in question and corresponding transitional regions.
Transitional region	For FDD DL blocks, the transitional region applies 0 to 10 MHz below and above the block assigned to the operator. For TDD blocks, transitional regions apply for unwanted emissions into adjacent blocks allocated to other operators if networks are synchronised. They also apply in-between adjacent TDD blocks with a frequency separation of 5 or 10 MHz. For immediately adjacent unsynchronised TDD networks, there is no transitional region and the baseline levels apply outside the allocated block. The transitional regions do not apply below 3400 MHz or above 3800 MHz.
Guard bands	The following guard bands apply in case of an FDD allocation: 3400-3410, 3490-3510 (duplex gap) and 3590-3600 MHz In case of overlap between transitional regions and guard bands, transitional power limits are used.
Additional baseline	Additional baseline limits apply below 3400 MHz

Table 8.3.1-2 In-block power limit

BEM element	Frequency range	Power limit
In-block	Block assigned to the operator	Not obligatory. In case an upper bound is desired by an administration, a value which does not exceed 68 dBm/5 MHz per antenna may be applied. For femto base stations, the use of power control is mandatory in order to minimize interference to adjacent channels.

The emission requirements for BS defined in ECC DEC (11)06 are copied as below for reference.

Table 8.3.1-3 Baseline power limits

BEM element	Frequency range	Power limit
Baseline	FDD DL (3510-3590 MHz). Synchronized TDD blocks (3400-3800 or 3600-3800 MHz depending on the chosen frequency arrangement, TDD only or FDD and TDD).	Min(P_{Max} – 43, 13) dBm/5 MHz e.i.r.p. per antenna
Baseline	FDD UL (3410-3490 MHz). Unsynchronised TDD blocks (3400-3800 or 3600-3800 MHz depending on the chosen frequency arrangement, TDD only or FDD and TDD).	-34 dBm/5 MHz e.i.r.p. per cell

Table 8.3.1-4 Transitional region power limits

BEM element	Frequency range	Power limit
Transitional region	-5 to 0 MHz offset from lower block edge 0 to 5 MHz offset from upper block edge	Min(P_{Max} – 40, 21) dBm/5 MHz e.i.r.p. per antenna
Transitional region	-10 to -5 MHz offset from lower block edge 5 to 10 MHz offset from upper block edge	Min(P_{Max} – 43, 15) dBm/5 MHz e.i.r.p. per antenna

Note: For TDD blocks the transitional region applies either in the case of synchronized adjacent blocks, or in-between unsynchronised adjacent TDD blocks that are separated by at least 5 MHz. The transition region does not extend below 3400 MHz or above 3800 MHz.

Table 8.3.1-5 Guard band power limits for the FDD frequency arrangement

BEM element	Frequency range	Power limit
Guard band	3400-3410 MHz	-34 dBm/5 MHz e.i.r.p. per cell
Guard band	3490-3500 MHz	-23 dBm/5 MHz per antenna port
Guard band	3500-3510 MHz	Min(P_{Max} – 43, 13) dBm/5 MHz e.i.r.p. per antenna

BEM element	Frequency range	Power limit
Guard band	3590-3600 MHz	Min(P_{Max} – 43, 13) dBm/5 MHz e.i.r.p. per antenna

Note: The power limit for the frequency range 3490-3500 MHz is based on the spurious emission requirement of -30 dBm/MHz at the antenna port, converted to 5 MHz bandwidth.

Table 8.3.1-6 Additional base station baseline power limits below 3400 MHz for country specific cases

Case		BEM element	Frequency range	Power limit
A	CEPT countries with radiolocation systems below 3400 MHz	Additional Baseline	Below 3400 MHz for both TDD and FDD allocation(1)	-59 dBm/MHz e.i.r.p.(2)
B	CEPT countries with radiolocation systems below 3400 MHz	Additional Baseline	Below 3400 MHz for both TDD and FDD allocation(1)	-50 dBm/MHz e.i.r.p.(2)
C	CEPT countries without adjacent band usage or with usage that does not need extra protection	Additional Baseline	Below 3400 MHz for both TDD and FDD allocation	Not applicable

(1) Administrations may choose to have a guard band below 3400 MHz. In that case the power limit may apply below the guard band only.
(2) Administrations may select the limit from case A or B depending on the level of protection required for the radar in the region in question.

The requirements above consider both TDD and FDD frequency arrangement. The limits for synchronised and un-synchronised TDD are illustrated in Figure 8.3.1-1 and Figure 8.3.1-2.

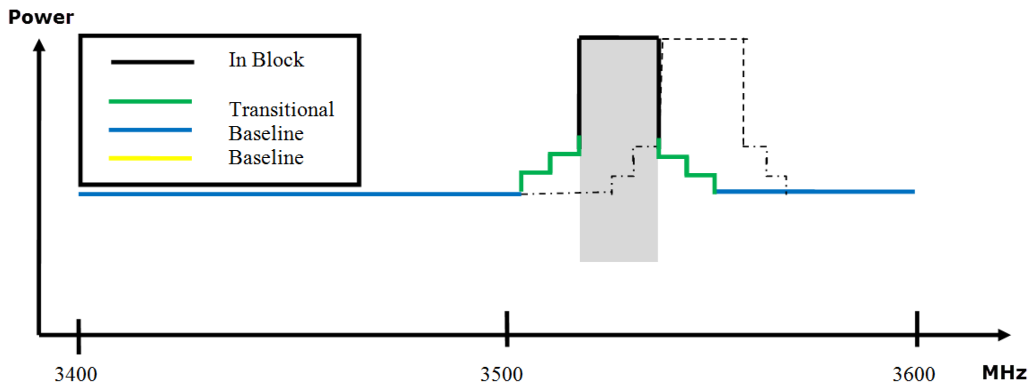


Figure 8.3.1-1 Combined BEM elements for adjacent blocks with synchronised TDD networks

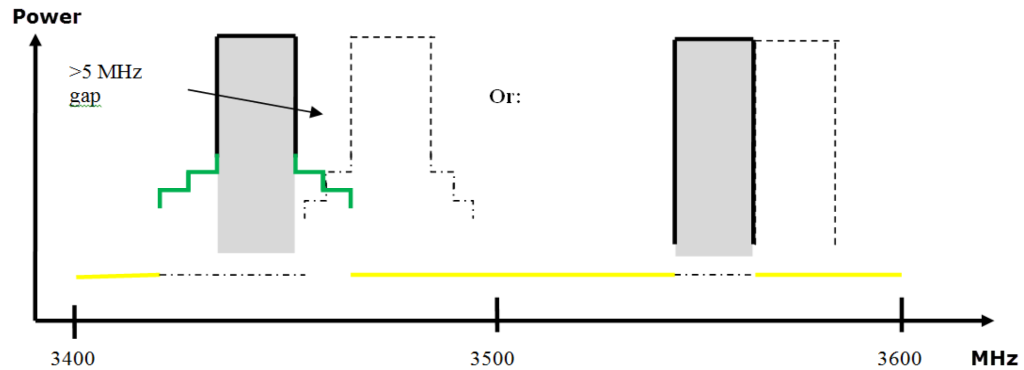


Figure 8.3.1-2 Combined BEM elements for adjacent blocks with non-synchronized TDD networks

Figure 8.3.1-3 provides an example of such a combination of BEM elements for a FDD block in the lower part of the FDD DL spectrum.

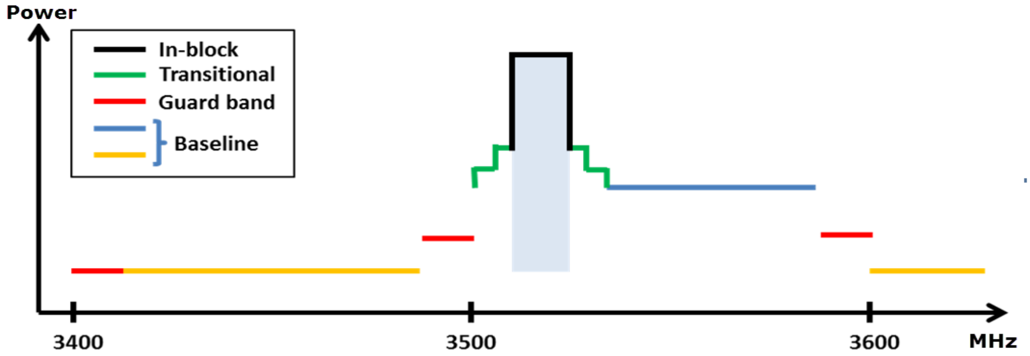


Figure 8.3.1-3 Combined BEM elements for an FDD block starting at 3510 MHz

8.3.2 Suitability study of technical conditions of ECC DEC (11) 06

9 Radio resource management

9.1 Mobility aspects

At least two UE states will be specified in NR: RRC_CONNECTED and RRC_IDLE. A new state, RRC_INACTIVE, also is expected to be introduced for NR UE as outlined in TR 38.804 [43], for which the UE and at least one gNB should keep the AS context information. RAN4 RRM requirements have to ensure NR UE performance while in any of the NR RRC states, as well as smooth transition between the RRC states.

NR cell corresponds to one or multiple TRxPs, which may be co-located or non-collocated. A cell is associated with a cell ID. Detecting a cell by a UE means detecting also at least its cell ID. The cell ID is the same ID as that carried by NR-SS.

In the RRC_IDLE state, the UE camps on a best cell and cell-level mobility is supported based on DL cell-level measurements.

The RRC_IDLE state (in at least standalone) NR involves at least the following UE procedures:

- Cell selection (including cell evaluation)
  - Cell selection refers to initial detection of an NR cell during cell selection procedure (i.e., the NR UE is not yet camped on a cell), e.g. at power ON, resulting in UE camping on the selected cell. To select a cell, the UE has to perform measurements and evaluate whether the cell is suitable for being selected.
- Cell reselection (including at least cell evaluation)
  - NR UE which has been camping on a cell may reselect to another cell.
- Cell identification (including at least cell detection)
  - NR UE camping on a cell can perform cell identification.

For mobility, cell reselection and cell identification RRM requirements will be specified.

In the RRC_CONNECTED state, UE mobility is supported based on DL cell-level and/or beam-level measurements. In multi-beam operation, beam-level measurements can be used to derive cell-level quality of the cell associated with the beams. In the RRC_CONNECTED state, the NR UE can perform:

- Cell identification, including at least cell detection,
- Beam identification, performed in an identified cell and included at least beam detection.

Depending e.g. on RAN1 design and RAN2 signaling, the identification time periods (e.g., for cell or beam identification) may also involve performing and reporting a measurement or receiving a part of the system information.

The mobility procedures in the RRC_INACTIVE state may be different from those in the RRC_IDLE and RRC_CONNECTED states and may also depend on how the RRC state transition is performed.

In addition to intra-RAT mobility, inter-RAT mobility at least between standalone NR and LTE will also be supported.

For the relevant RRC states, RAN4 will specify RRM requirements to ensure UE performance in relation to intra-RAT, including intra-frequency and inter-frequency, as well as inter-RAT mobility to support the agreed NR-based network architectures. If beam-level mobility is supported, RAN4 would need to develop the corresponding mobility requirements too. The mobility requirements need to cover, e.g., RRC connection, random access, handover, cell reselection, cell identification, beam identification, etc. The mobility procedures may need to be performed with and without neighbour list provided by the network.

UL-based mobility for NR has also been discussed in RAN2. If UL-based is supported in NR, RAN4 needs to discuss the necessary requirements during the NR WI.

9.2 Beam management

The following RRM procedures related to beam management can be further studied:

- Beam determination: RAN4 needs to study requirements for this procedure related to select at least one of its own transmit/receive beam(s).
- Beam measurement: RAN4 needs to study requirements for beam measurement. The detailed requirements need further study since the physical layer design has not been finalized. The potential requirement may include beam measurement period, beam measurement accuracy, etc.
- Beam reporting: RAN4 needs to study the potential requirement for beam reporting. The requirement may include at least reporting delay.
- Beam sweeping: Whether RRM requirements for beam sweeping at both NR UE and TRxP sides are needed needs further study in WI phase.

9.3 Timing aspects

Timing aspects of NR RRM shall be investigated in the NR work item phase.

9.4 Power consumption related aspects

9.4.1 Power consumption model for RRM

Power consumption models may be useful for investigating the power consumption impact of different RRM requirements. Models are needed for both gNB and UE. The power consumption models are simplified models and are not intended to capture details or in any way limit gNB or UE implementation. Different models are defined for the UE and the gNB.

9.4.1.1 UE power consumption model

Four different power consumption conditions are defined as shown in figure 9.4.1.1-1:

- Deep sleep: The UE is operating in its lowest power consumption mode, with baseband circuits maintaining timing to the lowest level of accuracy and minimal other baseband activity. RF circuits are not active.

- Light sleep: The UE in this state have maintained timing using a clock and activity level which allows reception to be started with a reasonably small delay. This state represents the UE being ready to start to receive with minimal delay.

- Active RX only: The UE is actively receiving, or attempting to receive a signal. This state is characterised by the RF receiver circuit being active.

- Active TX only: The UE is actively transmitting a signal.

Active TX + RX: The UE is actively receiving and transmitting (RX and TX are active). The power consumption in this state is assumed to be the sum of the active RX only power consumption + active TX only power consumption.

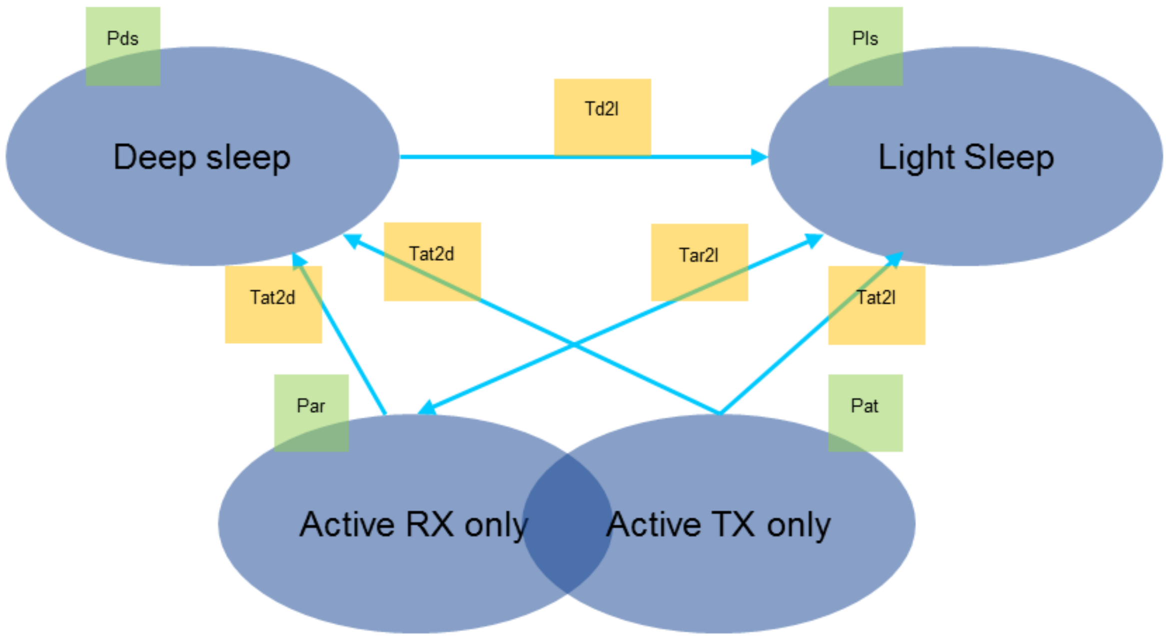


Figure 9.4.1.1-1: Power consumption states for the UE model

The UE or gNB power consumption state can change dynamically based on NR UE requirements for reception and transmission. For example, if DRX is active in a UE it can be expected to spend as much of the DRX off duration as possible in deep sleep. Prior to an RX on period, it may move to light sleep state before it enters active RX and TX depending on requirements for reception and transmission. UE will remain in active state as required according to monitoring and scheduling requirements. When UE is no longer required to receive or transmit, it may move back to light or deep sleep again. Power consumption may be estimated by considering the proportion of time that the UE spends in each state.

RRM activities may extend the duration that the UE needs to remain in either the active RX state or the active TX state.

The parameters used for the NR model are shown in table 9.4.1.1-1.

Table 9.4.1.1-1: Predicted power consumption in different states for the UE model

Parameter	Label/value	Default value
Absolute power consumption in “Active with data TX” state. Relative upper limit set to get some absolute numbers on the graphs	$P_{at, CA-N}$ Note 1	TBD mW
Relative power consumption in “Active data/no data RX” state	$P_{ar, CA-M}$ Note 2	TBD*P_{at}
Relative power consumption in “Deep sleep” state	P_{ds}	TBD*P_{at}
Relative power consumption in “Light sleep” state	P_{ls}	TBD*P_{at}
Duration of transition from “Deep sleep” to “Light sleep” state	T_{d2l}	TBD ms
Relative power consumption while changing from “Deep sleep” to “Light sleep” state	P_{d2l}	TBD * T_{d2l}
Duration of transition from “Light sleep” to “Active with (no) data RX” state	T_{ar2l}	TBD ms
Duration of transition from any active state to any sleep state	T_{at2d} or T_{at2l} or T_{ar2d} or T_{ar2l}	TBD ms
Note 1: This parameter is determined for each possible UL CA configuration. Note 2: This parameter is determined for each possible DL CA configuration.		

9.4.1.2 gNB power consumption model

The gNB power consumption model is characterized by 4 states as illustrated in figure 9.4.1.2-1.

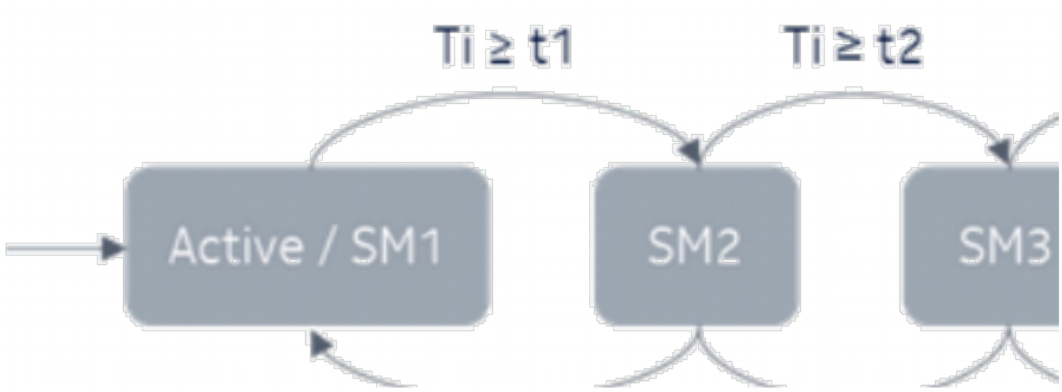


Figure 9.4.1.2-1: Power consumption states for the gNB model

The power consumption assumption and the RRC state transition assumptions are listed in table 9.4.1.2-1.

Table 9.4.1.2-1: Predicted gNB Power consumption under different conditions

TABLE V

BASE STATION POWER CONSUMPTION IN 2020 TEC
MODES 1 TO 4 CORRESPOND TO OFDM SYMBOL, SU
FRAME AND STANDBY, RESPECTIVEI

BS power consumption [W]	Load		Sleep mode (partia	
	Full	None	1	2
			71.4 μs	1 ms
2x2 macro	702.6	114.5	76.5	8.6
4x4 macro	742.2	138.9	86.3	12.4
pico	6.9	2.3	1.5	0.4

The principles of the gNB power consumption model are the same as for the NR UE model. gNB can be in different power saving states each of which depends on the activity (transmission and/or reception) of the gNB. A gNB power consumption depends on the configuration and load. If the gNB is 2x2 macro with full load or no load the power consumption is listed in the Load column in Table 9.4.1.2-1. If the gNB does not need to be active in next symbol it may enter sleep mode 1 (SM1). If gNB does not need to be active for 1ms it can then enter sleep mode 2 (SM2), etc. The gNB wake up procedure goes back to full activity in a step wise manner.

9.4.2 Principles for reducing power consumption

At least the following list of possible techniques for power saving can be studies for NR RRM:

1. Power saving opportunities for transmission of reference signals

- Follow lean carrier principles
  - Transmission of NR-SS synchronization signal as infrequently as possible.
  - Transmission of reference signals as infrequently as possible.
  - Transmission of measurement reference signals necessary to perform time and frequency synchronisation, allow identifying a beam and perform beam measurements.
  - Minimise time duration of individual transmissions e.g. using wideband signals in frequency domain.
  - Provide assistance information on reference signal timing in neighbour nodes to reduce NR UE measurement time (e.g. similar to DMTC window in LTE).
- RAN4 should study the effect of the above principles on the NR RRM requirements.

2. Power saving opportunities for receiving and measuring reference signals

- RAN4 should explore measurements activity in order to enable NR UE power savings.
  - RAN4 should study wideband measurements versus longer measurement time to reach a given level of accuracy.
- RAN4 should take into account the UE power saving opportunities when developing measurements requirements in order to enable UE power savings, e.g. align performance requirements with DRX.
- RAN4 should enable that available assistance information is used to minimize search and measurement time.

9.4.3 Configurability of requirements

Power consumption in RRM requirements is an engineering trade-off. Performance of measurements needs to be good enough to meet the needs of the system but it would be wasteful to have minimum requirements which exceed the needs of the system.

In determining the RRM requirements for NR the goal should be to ensure that power consumption and measurement delay is configurable over a suitable range.

9.5 Measurements and measurement related requirements

9.5.1 Measurement procedures

NR UE can perform measurements at least in the RRC_IDLE state (when it is camped on a cell) and RRC_CONNECTED state. The UE will perform measurements according to the corresponding requirements.

The UE will perform measurements at least for the following purposes:

- Mobility
- Beam management

9.5.2 Measurement reporting

The NR UE will report measurement results at least in RRC_CONNECTED state.

9.5.3 Measurements by carrier frequency relation

9.5.3.1 Intra-frequency measurements

In NR, the UE will support intra-frequency measurements at least for intra-frequency mobility, RRM (e.g., beam management), and RLM. RAN4 needs to study whether UE needs measurements gaps for intra-frequency measurements.

9.5.3.2 Inter-frequency measurements

In NR, UE will support inter-frequency measurements at least for inter-frequency mobility.

The inter-frequency measurements on different frequencies may be for different numerologies, which may further impact the inter-frequency measurement gap configurations.

UE may need measurement gaps to perform inter-frequency measurements.

9.5.3.3 Inter-RAT measurements

In NR, UE will support inter-RAT measurements for inter-RAT mobility at least between NR and LTE. The measurements will be performed according to the corresponding RAN4 requirements.

9.5.3.4 CA measurements

In NR, the UE will support CA measurements at least for serving cells change and RRM (e.g., beam management). RAN4 needs to study whether UE needs measurements gaps for CA measurements.

9.5.4 Measurements in relation to beams

The impact of the beamforming on measurements performed by the NR UE is to be further based on at least following aspects:

A UE may perform measurement with at least one of: DL transmit beam, DL receive beam, UL receive beam, and UL transmit beam.

RAN4 should further discuss whether there is a difference between measurements with and without beamforming and if so, what is the exact difference.

9.5.5 Measurement bandwidth aspects

Requirements for measurements shall be developed for NR UEs supporting different bandwidths. The requirements may include specification of a minimum measurement bandwidth which is the minimum bandwidth upon which the accuracy requirements are based assuming UE is using minimum measurement bandwidth. The possibility to configure wideband measurements (e.g. the measurement bandwidth size and allocation), for example with RRC signalling, is not precluded.

RAN4 should investigate how the minimum measurement bandwidth may scale according to subcarrier spacing. In addition, RAN4 needs to look at whether different NR use cases (such as mobile broadband, machine type communication and/or URLLC) could lead to different minimum measurement BWs.

RAN4 needs to study whether to define minimum measurement bandwidth during the NR work item for different use cases and subcarrier spacings.

9.5.5.1 Measurements for UEs with different supported BW and numerology

In NR, a UE may support a bandwidth which is less than the NR system bandwidth. In addition, for more capable devices which support at least the NR system bandwidth, bandwidth adaptation is being considered, whereby UEs may change operating bandwidth for balancing between power saving and scheduling purposes on a semi-static or dynamic basis.

In either case, the UE requirements should be developed assuming that UE performing RRM measurements over a bandwidth which is not more than the currently configured UE downlink operating bandwidth, i.e. the UEs current operating radio link.

RAN4 should investigate measurement gaps and if they are provided to allow bandwidth reconfiguration of the receiver.

In NR, a cell may operate with multiple OFDM numerologies simultaneously using either FDM or TDM techniques. NR UEs may support a subset of the numerologies which NR cells are currently operating with. In these cases, measurements may be performed only on resource elements which correspond to numerologies supported by the UE.

9.6 Measurement capacity

The impact of the beamforming on the amount of parallel measurements supported by the NR UE should be further studied.

10 Testability

10.1 RRM requirements testability

10.1.1 General

Testability aspects of both gNB and UE have been considered. Unless otherwise indicated below, device under test (DUT) could refer to either gNB or UE nodes. The exact list of RRM tests for UE and gNB can only be determined once the core requirements are settled.

10.1.2 Testability of NR RRM requirements on frequency bands below 6GHz

For low frequency bands below 6GHz, the conducted testing is considered as the baseline approach for NR RRM testability.

If BS RRM requirements and test scenarios are developed, the re-use of the AAS BS measurement setup can be investigated.

NR RRM testing can generally be performed using the antenna connectors and following similar approaches as are applicable for E-UTRA UE or eNB below 6 GHz. The exact details of the tests shall be determined when the tests are implemented.

It is possible that for some specific features of NR such as beamforming, over the air tests developed for frequency bands above 6GHz (as in section 10.1.3) could be reused on frequency bands below 6GHz in order to avoid the need to develop both OTA and conducted tests for beam based measurements.

10.1.3 Testability of NR RRM requirements on frequency bands above 6GHz

For frequency bands above 6GHz (e.g. mm-wave), conducted antenna connectors are assumed not to be available at DUT and the OTA testing is considered as the baseline approach for NR RRM testability.

The possibility of performing conducted tests using an intermediate frequency (IF) were evaluated. It was decided that this approach would be challenging to standardise for various reasons since IF is an internal interface in the DUT and using a standardised IF (signal level, number of IF ports, IF frequency, etc.) would preclude many different DUT implementations including direct conversion receivers. In addition, IF testing excludes all components which operate at the radio frequency such as RF filters, duplexers, transmit receive switch, low noise amplifier (LNA), power amplifier

(PA), analogue beamforming phase shifting elements etc., and the algorithms which control such components from the test.

10.1.3.1 Over the air testing

Further details of a suitable OTA test environment are to be discussed in the work item, and may have impact to the core requirements which are defined. For example, side conditions for the applicability of core requirements should be defined in a way in which they can be ensured in an OTA environment.

The baseline measurement setup of NR RRM characteristics for f > 6 GHz is capable of establishing an OTA link between the DUT and a number of emulated gNB sources and is shown in Figure 10.1.3.1-1 below.

Diagram TBD

Figure 10.1.3.1-1: Baseline measurement setup of RRM characteristics

The RRM baseline measurement setup shares all aspects in common with the UE RF setup defined in 10.2.2.1 and includes the following aspects in addition:

- A positioning system such that the angle between the N antennas (N ≥ 2) transmitting the emulated gNB sources and the DUT has at least two axes of freedom
  - Where N corresponds to the maximum number of emulated gNB sources defined in the RRM test scenarios
  - It is desirable that at least 1 antenna provides for an angular relationship with the DUT that is independently controllable (or the setup should provide equivalent functionality)
  - It is FFS whether all N antennas need to provide independently controllable angular relationships
  - Requirements on the polarization properties and control of each antenna are FFS
- It is likely that the measurement uncertainty budget for the RRM setup may contain additional measurement uncertainty elements relative to the setup defined in 10.2.2.1
- It is FFS how to model propagation conditions between the DUT and the emulated gNB sources

If BS RRM requirements and test scenarios are developed, the re-use of the AAS BS measurement setup can be investigated.

10.2 UE RF requirements testability

10.2.1 General

It is reasonable to expect a high level of integration of high-frequency NR devices (e.g., devices operating above 6 GHz). Such highly integrated architectures may feature innovative front-end solutions, multi-element antenna arrays, passive and active feeding networks, etc. that may not be able to physically expose a front-end cable connector to the test equipment.

For UE RF test methodology at low frequency (f ≤ 6 GHz), the UE testing methodology (i.e., conducted test) from LTE (TS 36.101) can be reused even in case of non-standalone (NSA) with control channel communicated via a high frequency band (f > 6 GHz).

For UE RF test methodology at high frequency (f > 6 GHz), the following general aspects apply:

- OTA measurement is the baseline testing methodology for UE RF at high frequency (f > 6 GHz)
- Possible optimizations, such as near-field approximation or others, are not precluded; such optimizations shall demonstrate methodology equivalence to the baseline

10.2.2 Testability of UE RF TX and RX characteristics – without test interface control of beam direction

10.2.2.1 Baseline measurement setup: centre and off centre of beam measurement setup

The baseline measurement setup of UE RF characteristics for f > 6 GHz is capable of centre and off centre of beam measurements and is shown in Figure 10.2.2.1-1 below.

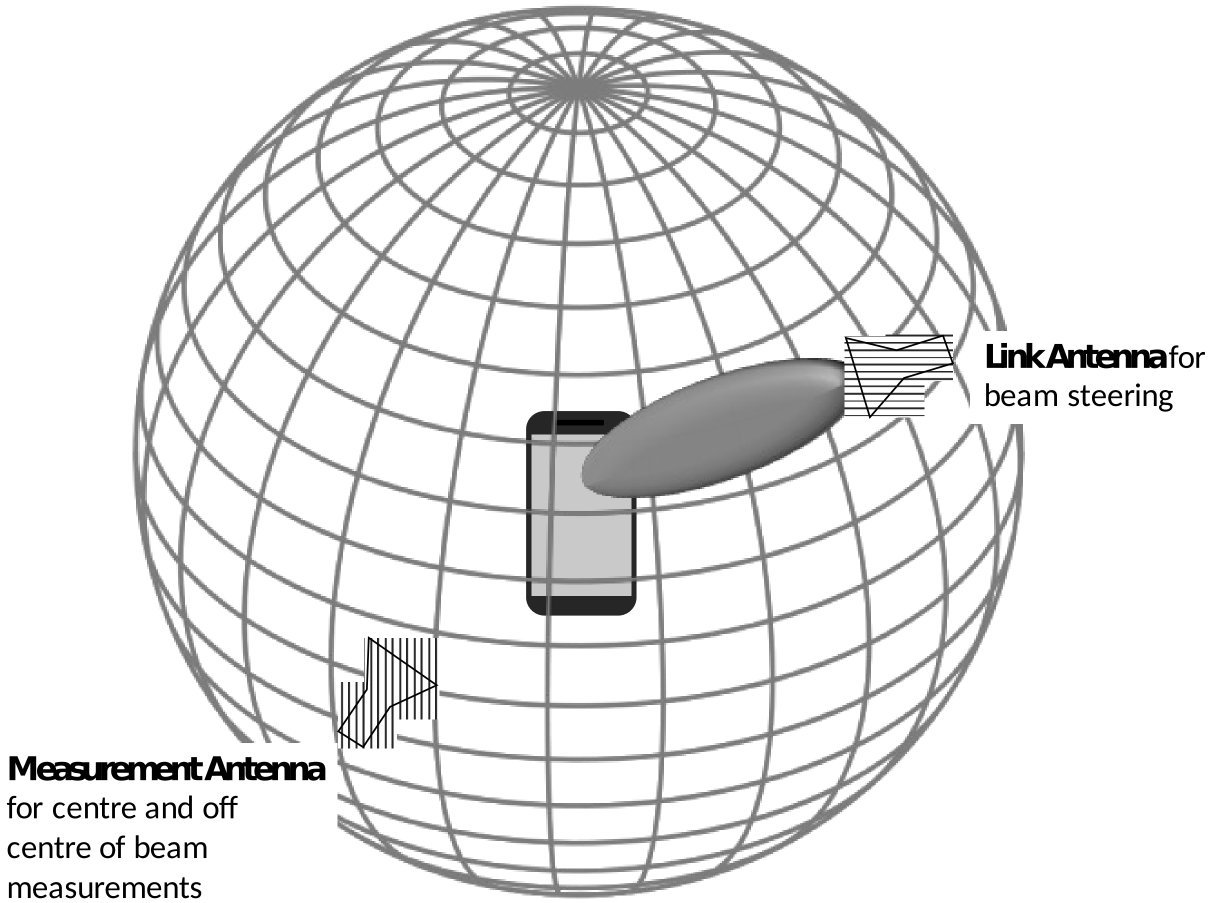


Figure 10.2.2.1-1: Baseline measurement setup of UE RF characteristics

The key aspects of the baseline setup are:

- Far-field measurement system in an anechoic chamber
    - The criterion for determining the far-field distance is TBD
- A positioning system such that the angle between the dual-polarized measurement antenna and the DUT has at least two axes of freedom and maintains a polarization reference
- A positioning system such that the angle between the link antenna and the DUT has at least two axes of freedom and maintains a polarization reference; this positioning system for the link antenna is in addition to the positioning system for the measurement antenna and provides for an angular relationship independently controllable from the measurement antenna

Alternate test methodologies are not precluded and may exist for each requirement. They shall demonstrate equivalence according to the criteria outlined in 10.2.2.3.

10.2.2.2 Centre of beam measurement setup

The baseline setup in 10.2.2.1 can be simplified in the following way to perform centre of the beam measurements:

- The measurement and the link antenna can be combined so that the single antenna is used to steer the beam and to perform UE RF measurements.

The measurement setup of UE RF characteristics for f > 6 GHz capable of centre of beam measurements and is shown in Figure 10.2.2.2-1 below

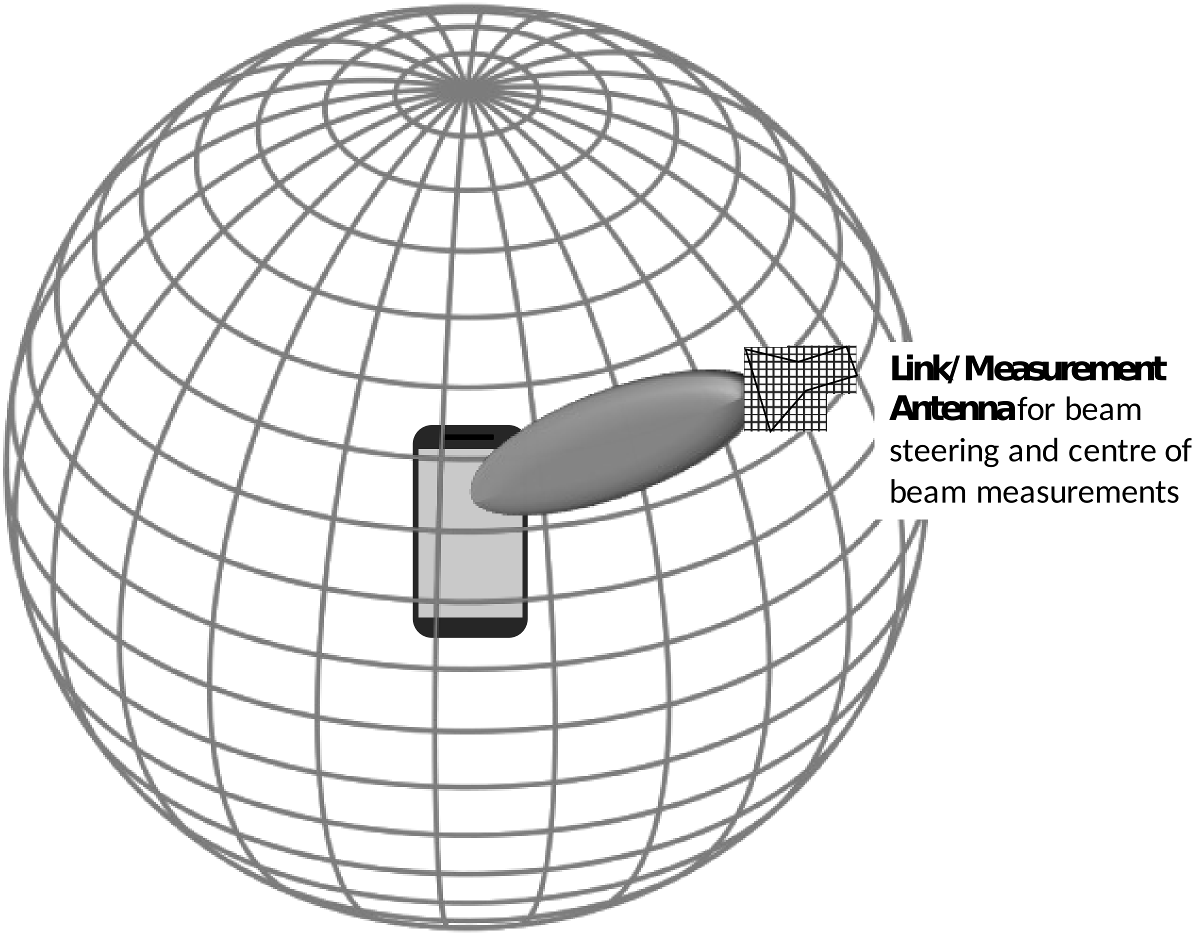


Figure 10.2.2.2-1: Centre of beam measurement setup of UE RF characteristics

Alternate test methodologies are not precluded and may exist for each requirement. They shall demonstrate equivalence according to the criteria outlined in 10.2.2.3.

10.2.2.3 Equivalence Criteria

The following 11 points have been agreed as a framework for developing OTA test to prove equivalence.

1) Multiple test methods may exist for each requirement

2) Each test method will require its own test procedure.

3) A single conformance requirement applies for each core requirement, regardless of test procedure.

4) Common maximum accepted test system uncertainty applies for all test methods addressing the same test requirement. Test methods producing significantly worse uncertainty than others at comparable cost should not impact the common maximum accepted test system uncertainty assessment.

5) Common test tolerances apply for all test methods addressing the same test requirement.

6) A common way of establishing the uncertainty result from all test methods' individual budgets is established.

7) A common method of making an uncertainty budget (not a common uncertainty budget) is established.

8) Establish budget format examples for each addressed test method in the form of lists of uncertainty contributions. Contributions that may be negligible with some DUT and substantial with others should be in this list. For each combination of measurement method and test parameter (EIRP or EIS) develop a list with measurement uncertainties.

9) Describe potential OTA test methods relevant for testing radiated transmit power and OTA sensitivity. The description requires information about the test range architecture and test procedure. Addressing each item in each uncertainty budget with respect to the expected distribution of the errors, the mechanism creating the error and how it interacts with properties of the DUT.

10) Providing example uncertainty budgets in the TS will be useful in order to demonstrate the way a budget should be defined and how calculating its resulting measurement uncertainty is done, but the figures used in the examples will clearly be only examples and not applicable in general.

11) Each test instance may require an individual uncertainty budget applicable for the combination of the test facility, the DUT and the test procedure and property tested. Here, the tester demonstrates that the uncertainty requirement is fulfilled during the conformance testing.

10.2.2.4 Far Field Criteria for the baseline measurement setup

The minimum far-field distance R for a traditional far field anechoic chamber can be calculated based on the following equation: $R > \frac{2D^2}{\lambda}$ where D is the diameter of the smallest sphere that encloses the radiating parts of the DUT. The near/far field boundary for different antenna sizes and frequencies is shown in Table 10.2.2.4-1.

Table 10.2.2.4-1: Near field/far field boundary for different frequencies and antenna sizes for a traditional far field anechoic chamber

D(cm)	Frequency (GHz)	Near/far boundary (cm)	Path Loss(dB)	Frequency (GHz)	Near/far boundary (cm)	Path Loss(dB)
5	28	48	55	100	168	76.9
10	28	188	66.9	100	668	88.9
15	28	420	73.8	100	1500	96
20	28	748	78.9	100	2668	101
25	28	1168	82.7	100	4168	104.8
30	28	1680	85.9	100	6000	108

As can be seen in the table, the distance can be very large for larger antenna sizes and higher frequencies. This could lead to very large chambers that would be prohibitively expensive.

Generally, the exact antenna size of the DUT is unknown since the device will be in its own casing during the test and this also depends on other factors such as ground coupling effects that depend on the design. The largest device size (e.g. diagonal) could be used; however, this would lead to very large chambers even for relatively small devices. A practical way to determine the far field distance is needed.

In [R4-168320], [R4-1700955], it was proposed to determine the testing distance based on a manufacturer declaration. One of the risks of this approach is that a distance shorter than the actual far field is chose. It should be further studied whether this could lead to underperforming devices passing the tests due to measurement inaccuracies (e.g. whether a shorter distance will lead to better measurement results than the actual far field distance).

In [R4-1700531] an experimental method was proposed to determine the far field distance based on path loss measurements. This method is based on the fact that the path loss exponent is different in the near field and the far field. By measuring the path loss gradient over a certain distance, the near/far field boundary could be found. The results of an experiment conducted on a Band 3 LTE device are shown in Figure 10.2.2.4-1. The minimum far field distance can be found at the regression intercept point.

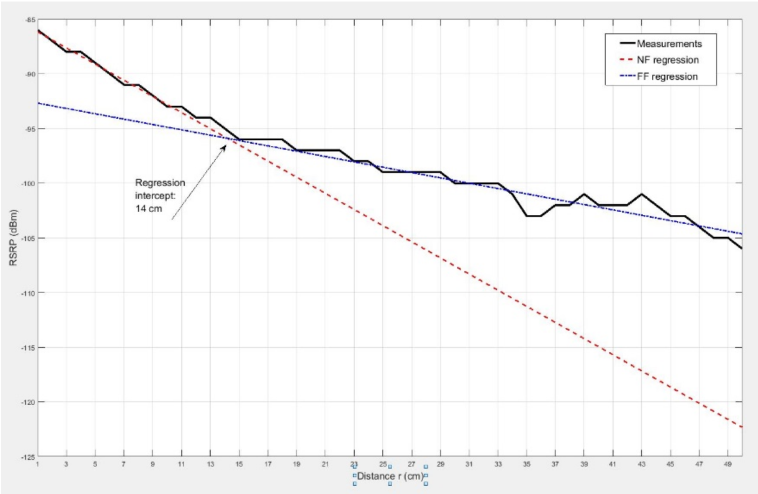


Figure 10.2.2.4-1: LTE UE FDD band 3 measurements to determine the minimum far-field distance.

The figure shows an example result for the case where the frequency is 1.85 GHz. The approximate device dimensions were 13 x 8 cm. Under these conditions, the canonical minimum far-field distance would be 28.7 cm. According to this method, the minimum measurement distance would be 13.8 cm. Further work is required to determine whether this technique provides valid results for much higher frequencies and general device types.

Methods to reduce measurement distance for AAS are Compact Antenna Test Range, One Dimensional Compact Range, and Near Field Test Range which are all listed in [21]. These may be used for NR provided they meet the equivalence criteria relative to the baseline measurement setup. Other methods are not precluded.

10.2.2.5 OTA measurements in the radiative near field

In this sub-clause we discuss measurements of TRP in the radiative near field for both the wanted channel and unwanted emissions.

TRP is a measure of how much power is radiated by radiating device. TRP is a parameter associated to an active measurement, meaning that TRP is associated to a system consisting of antenna and transmitter. The total power is calculated as the power sum over all possible angles (θ, φ). To describe the spatial angles a Cartesian coordinate system according to Figure 10.2.2.5-1 is introduced. The θ angle is defined within the interval $0 \leq \theta \leq \pi$ and φ angle is defined within the interval $0 \leq \varphi \leq 2\pi$. The direction $(\theta, \varphi)=(\pi/2, 0)$ is the direction along the x-axis.

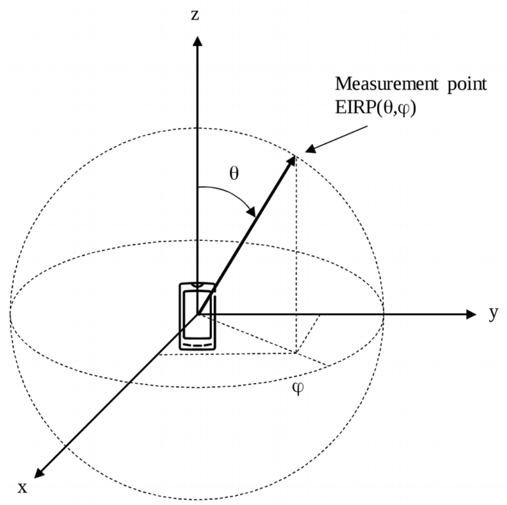


Figure 10.2.2.5-1: Test object located in spherical coordinate system

The origin is supposed to be located in the geometrical centre of the base station, since the phase centre related to radiated unwanted emission is unknown. The exact location of the origin in not important as long as the power going through the sphere is measured.

If the radiation intensity is a continuous function of spatial angles, then the TRP of a given radiating system is defined as:

$$TRP = \oint U(\theta,\varphi) d\Omega ,$$

where U(θ, φ) is the radiation intensity at each angle in Watts/steradian. TRP is defined the sum of all power radiated by a system, regardless of direction or polarization. If the radiating system were enclosed in a perfectly absorbing sphere, the TRP would be the power that would be absorbed by that sphere.

The total radiated power as function of frequency can be expressed as a double integral over θ, φ angles and U substituted too total EIRP as:

$$TRP(f) = \frac{1}{4\pi} \int_{\theta=0}^{\pi} \int_{\varphi=0}^{2\pi} EIRP(\theta,\varphi,f) \sin(\theta) d\theta d\varphi ,$$

$$EIRP(\theta,\varphi,f) = EIRP_{p1}(\theta,\varphi,f) + EIRP_{p2}(\theta,\varphi,f) ,$$

where $EIRP_{p1}$ and $EIRP_{p2}$ is associated to two orthogonal polarizations of the radiated emission. This expression assumes knowledge about the continuous EIRP distribution for two orthogonal polarizations over the whole sphere and as function of frequency.

Currently for GSM, UTRA and E-UTRA the radiated power of the wanted signal is specified and tested using TRP as figure of merit. The RF core requirements for UE OTA characteristics can be found in TS 37.144. The requirement does not say anything about who the requirement is tested. The description of how TRP is measured is captured in 34.114. Traditionally, two main candidates for testing TRP on UEs exists; Anechoic chamber (AC) and Reverberation chamber (RC).

For UEs it is reasonable to believe that the spurious domain reaches up to 140 GHz (maybe even higher), which means that aspects related to transmission losses in the chamber must be studied carefully.

From a straight definition point of view is EIRP a parameter defined in the far-field region, which will set some requirement on the distance where EIRP is measured with known uncertainty. However, there are means to measure TRP based on EIRP samples in the near-field region (outside the reactive near-field region) by using the concept of probe compensation. The probe compensation takes care of the measurement antenna impact with respect to the fact that the wave is not plane. Observe that for TRP, total radiated power through the whole sphere area does not depend on the distance between the test object and the measurement antenna. This means that for TRP, the distance between the test object and measurement antenna can be considerably less than the far-field criteria for a specific frequency and test object size states.

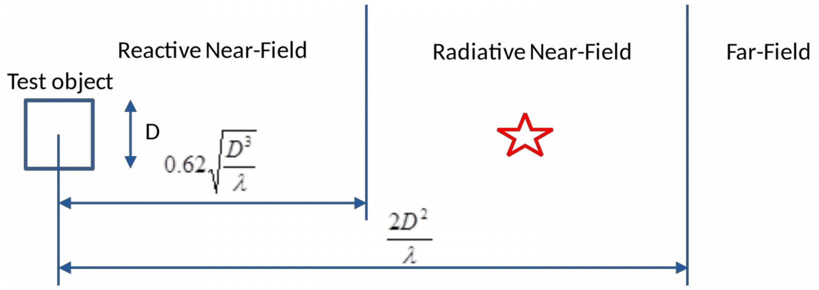


Figure 10.2.2.5-2: Distance to test object

Using the concept of probe compensation TRP can be measured closer to the test object in the region:

$$0.62\sqrt{\frac{D^3}{\lambda}} < R < \frac{2D^2}{\lambda} ,$$

where λ is the wave length in meters and D is the maximum linear dimension of the antenna aperture in meters.

In Figure 10.2.2.5-3, the limit between reactive near-field and radiative near-field is plotted in red and the limit between radiative near-field and far-field is plotted in blue for 28 GHz.

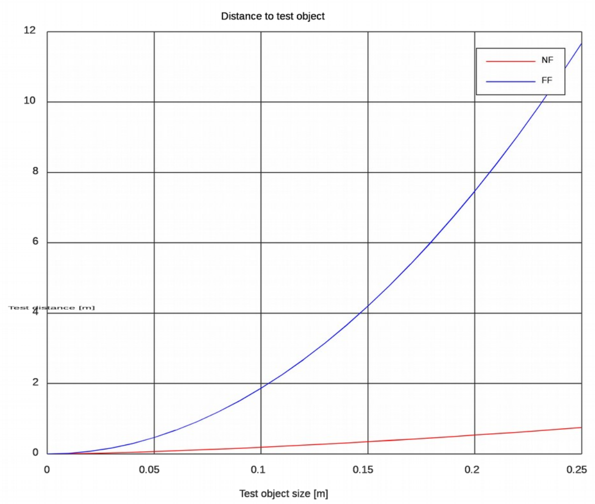


Figure 10.2.2.5-3: Distance to test object

10.2.2.6 Sampling grids for TRP measurements

10.2.2.6.1 Full-sphere uniform sampling grid

TRP can be approximated from a limited number of sampled total EIRP values around the sphere. Assume that EIRP values are available at uniform angular intervals in along θ angle and φ angle. There are N intervals in θ from 0 to π radians, and M intervals in j from 0 to 2π radians. Let n be the index variable used to denote the θ measurement points and m be the index variable used to denote the φ measurement points. A given angle (aka. sample point) is then specified as (θ_n, φ_m), with $(\theta_0, \varphi_0)=(0, 0)$ and $(\theta_N, \varphi_M)=(\pi, 2\pi)$. N and M are chosen, depending on the type of test, to yield the correct angular intervals corresponding to an acceptable measurement uncertainty for each specific emission requirement.

An approximatively numerical expression for calculating TRP from spatial point grid is given below.

$$TRP(f) \approx \frac{\pi}{2NM}\sum_{n=1}^{N-1}\sum_{m=0}^{M-1}\left(EIRP_{p1}(\theta_n,\varphi_m,f)+EIRP_{p2}(\theta_n,\varphi_m,f)\right)\sin(\theta_n)$$

It is important to note that the sample points (θ_n, φ_m) only need to be measured for n=1 through N-1, and for m=0 through M-1. Thus, no data need to be recorded at positions corresponding to θ=0 and π radians, nor at positions corresponding to φ=2π radians (φ=0 measurement data are recorded), because those points are not used.

Decreasing of sampling density to finite amount of samples affects the measurement uncertainty by two different errors. The first factor is due to inadequate number of samples. If the radiated emission tends to have a directive radiation pattern the sampling grid have to be fine to capture the radiated power accurately, or if the emission can be assumed to have an isotropic pattern the grid can be coarse. The second is a systematic discrimination approximation error due to numerical quantization used to derive the expression above.

Based on above mentioned numerically expression, total EIRPs is measured for θ_n and φ_m on the surface of the unit sphere at angular intervals of Δθ and Δφ. This sampling method or equi-angle method is a conventional method for the TRP estimation. However, for NR TRP test, if the same qui-angle method will be used for the directional signal should be discussed further.

Assume an angular resolution of at least 15 degrees, for example, then the division numbers are selected as N=12 and M=24 for Δθ=Δφ=15 degrees, it is required that total EIRP to be measured at 264 sampling points on the surface of the unit sphere.

To overcome the challenges with many sampling points over the whole sphere, TRP can be approximated by measuring and numerically integrating total EIRP along a few cuts, typically one of θ and φ is fixed and the other is changed in the pattern cuts so that the number of sampling points can be reduced.

10.2.2.6.2 Orthogonal axis sampling grid

Total EIRP is sampled along all three orthogonal axes. This approach is based on the fact that TRP is assumed to correspond to the average of $EIRP_{xy}$, $EIRP_{xz}$ and $EIRP_{yz}$, which means the average of EIRP in the xy, xz and yz-plane, respectively. Thus, TRP can be estimated as:

$$TRP(f) \approx \frac{1}{3}\left(EIRP_{xy}(f) + EIRP_{xz}(f) + EIRP_{yz}(f)\right),$$

where

$$EIRP_{xy}(f) = \frac{1}{N_\varphi}\sum_{k=1}^{N_\varphi} EIRP\left(\frac{\pi}{2}, \varphi_k, f\right),$$

$$EIRP_{xz}(f) = \frac{1}{2N_\theta}\sum_{l=1}^{N_\theta+1}\left(EIRP(\theta_l, 0, f) + EIRP(\theta_{N_\theta-l+2}, \pi, f)\right),$$

$$EIRP_{yz}(f) = \frac{1}{2N_\theta}\sum_{l=1}^{N_\theta+1}\left(EIRP\left(\theta_l, \frac{\pi}{2}, f\right) + EIRP\left(\theta_{N_\theta-l+2}, \frac{3\pi}{2}, f\right)\right),$$

where θ_l and φ_k are selected as θ_l=(l-1)Δθ=(l-1)(π/N_θ) and φ_k=(k-1)Δφ=(k-1)(2π/N_φ). In practice, total EIRPs are measured in only three planes so that the number of sampling points, N=4N_θ+N_φ-6, could be considerably small in comparison with the full-sphere uniform sampling grid.

10.2.2.6.3 Constant area sampling grid

To estimate the surface integral, the surface of the unit sphere can be portioned into equal-area regions. If (θ_k, φ_k) represents a point in the k-th region, TRP can be approximated as:

$$TRP(f) \approx \frac{1}{N}\sum_{k=1}^{N} EIRP(\theta_k, \varphi_k, f),$$

where N is the number of the equal-area regions. The challenge with this approach is to find θ and φ angles corresponding to equal-area regions.

UV projection can be a candidate of equal erea test point placement. UV projection is a mapping technique used to project a 2D image to a 3DL model's surface. The mapping can be explained using the following equation.

$$u = \sin\frac{\theta}{2}\cos\varphi \ ; v = \sin\frac{\theta}{2}\sin\varphi \ ;$$

or

$$\varphi = atan\left(\frac{v}{u}\right);\ \theta = 2\,\mathrm{asin}\frac{u}{\cos\varphi}.$$

Table 10.2.2.6.3-1 shows some typical mapping from $\theta\varphi$ projection to UV projection.

Table 10.2.2.6.3-1: Exemplary definitions of the scan ranges as a coverage percentage of the solid angles

Coverage of the solid angles	Spherical coordinates	UV coordinates
100 % (Full sphere)	$\theta = -180$ deg ... 180deg; $\varphi = -90$ deg ... 90deg	u = -1 to +1; v = -1 to +1
90 %	$\theta = -143$ deg ... 143 deg; $\varphi = -90$ deg ... 90deg	u = -0.95 to +0. 95; v = -0.95 to +0.95
75 %	$\theta = -120$ deg ... 120deg; $\varphi = -90$ deg ... 90deg	u = -0.865 to +0.865; v = -0.865 to +0.865
50 % (Half sphere)	$\theta = -90$ deg ... 90deg; $\varphi = -90$ deg ... 90deg	u = -0.707 to +0.707; v = -0.707 to +0.707
25 % (quarter sphere)	$\theta = -60$ deg ... 60deg; $\varphi = -90$ deg ... 90deg	u = -0.5 to +0.5; v = -0.5 to +0.5

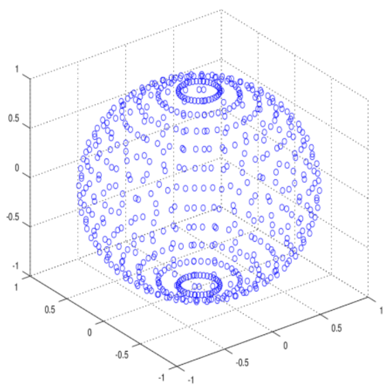
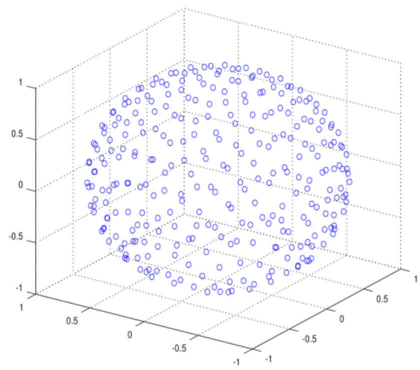
In order to prove that the area of coverage is preserved for UV projection and distorted at $\theta\varphi$ projection, consider a basic example of a single antenna element (single patch antenna). The following step is used for the analysis.

$\theta\varphi$ projection: fixed step dTheta = dPhi = 2 deg.

UV projection:fixed step dU = dV = 0.1.

The 3D view is shown in Table 10.2.2.6.3-2 for the UV projection and $\theta\varphi$ projection.

Table 10.2.2.6.3-2: Example to justify UV projection

 **Non-uniform density of monitoring points, fixed step dTheta = dPhi = 10 deg.**	 **Uniform density of monitoring points, fixed step dU = dV = 0.1.**

According to these results, UV projection monitoring points provides the uniform density test points on the sphere surface.

10.2.3 Test Interface

A Test Interface (TI) is needed for certain control and measurement functions. Detailed functions and implementation of the TI are TBD

10.3 BS RF requirements testability

10.3.1 General

Since NR base stations will operate within a very large frequency range, may be capable of beamforming, a number of new RF core requirements and corresponding conformance test requirements may be required. NR base station testing will consist of both conducted testing at transceiver level (antenna connector or TAB connector) and OTA testing at base station level.

It is envisaged that for non AAS type NR base stations operating at frequencies below 6 GHz, the current BS conformance test specification [TS 36.141, TS 37.141] can be used as guidance deriving the corresponding test specification for NR.

However, for AAS type NR base stations operating below 6 GHz, the Rel-13 AAS specification (TS 37.145) could be used as baseline. In this specification new requirements for radiated transmit power and OTA sensitivity have been added in the OTA domain, keeping all conducted requirements still applicable with some adaptations. The AAS BS specification is currently being extended to include an all OTA specification. AAS BS covers existing UTRA and E-UTRA bands, extending the frequency range support from the upper limit currently in E-UTRA requirements to 6 GHz for NR, may require some further extensions to the AAS BS specification.

For base stations operation above 24 GHz, a specification where all requirements are defined as OTA requirements is required.

10.3.2 Testability of BS RF TX and RX characteristics

10.3.2.1 Over the air testing

It is clear at this point that OTA requirement will play an important role of the systemization of NR base stations. Fundamentally, base station OTA testing can be divided into two main categories; Down-link testing and Up-link testing.

In the Release 13 AAS BS specification [TS 37.145] two radiated requirements were introduced, one for Down-link and one for Up-link:

I. Radiated transmit power, based on EIRP as figure of merit

II. OTA sensitivity, based on EIS as figure of merit

For in-band requirements, EIRP and EIS are key parameters to capture radiated power levels and received sensitivity power levels in dBm in the OTA domain.

For out-of-band requirements, such as unwanted emission, TRP is a relevant parameter.

In RAN4 AAS/eAAS/NR WI extensive studies shows that moving the requirement to the radiated domain requires careful consideration on how the spatial aspects is captured when it comes to test requirement development.

Table 10.3.2.1-1 shows some examples of figure of merits relevant for OTA conformance test requirements, they are not intended to imply agreements for core requirements.

Table 10.3.2.1-1: An example of figure of merits relevant for OTA requirements

Requirement	Figure of merit	Test points	Note
Radiated transmit power	$EIRP_d$	EIRP is measured at few steering directions	
OTA sensitivity	EIS_d	EIS is measured at few points within the declared RoAoA.	
OTA EVM	$EVM=100 \cdot sqrt(EIRP_e/EIRP_d)$	EVM is directly related to the signal-to-noise ratio which is tested for a few steering directions.	EVM is based on the ratio between $EIRP_e$ is the power of the in-carrier emissions and $EIRP_d$ is the power of the desired signal after channel equalization in the measurement receiver.
OTA ACLR	$ACLR=TRP_d/TRP_{em}$	To measure TRP_d and TRP_{em} spatial EIRP samples are required over the whole sphere.	ACLR is a ratio between the total radiated power of the desired signal and the total radiated power of the adjacent channel emission
OTA OBUE	TRPem	To measure TRP_{em} spatial EIRP samples are required over the whole sphere.	
OTA spurious emission	TRPem	To measure TRP_{em} spatial EIRP samples are required over the whole sphere.	Since that the SEM region is outside intended operation the grid could potentially be reduced to 2 axes.
OTA frequency error	$EIRP_d$	Measured in one direction. The test equipment extracts the frequency error from the modulated signal.	The direction doesn't matter. All transmitters enabled.
OTA occupied bandwidth	$EIRP_d$	Measured in one direction. The test equipment extracts the occupied bandwidth from the modulated signal.	The direction doesn't matter. All transmitters enabled.

In Table 10.3.2.1-1, the parameters are defined as:

$EIRP_d$ is the EIRP for the desired transmitted signal.

EIS_d is the EIS for the desired received signal.

$EIRP_e$ is the in-carrier error signal.

TRP_d is the TRP for the desired transmitted signal.

TRP_{em} is the TRP unwanted emission.

The figure of merit for missing requirements in the table above is FFS.

From the table it is clear that some requirements are based on absolute values in terms of EIRP or EIS, while others are defined as a ratio between EIRP's or TRP's. Also there are requirements, such as frequency error, where the signal is measured as EIRP, but the desired figure of merit is extracted by dedicated test equipment.

From a testing perspective it is important to capture EIRP, EIS and TRP, which are the foundation for all OTA requirements. In sub-clause 10.3.2.1.1, sub-clause 10.3.2.1.2 and 10.3.2.1.3 a general overview on how those key parameters can be measured is described.

10.3.2.1.1 EIRP test setup

In Figure 10.3.2.1.1-1, a general test setup for measuring EIRP is showed.

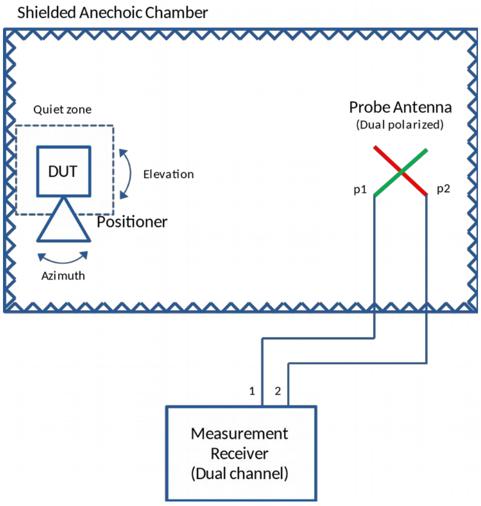


Figure 10.3.2.1.1-1: General test setup for EIRP

The test object is placed at positioner that can rotate the test object allowing different steering angles to be tested. The transmission loss between the test object and the measurement antenna in the chamber is determined by a test range calibration using a reference antenna. More details on test methods and calibration procedures can be found in TR 37.842, clause 10.

The distance between the test object and the measurement antenna is determined by the far-field distance and acceptable measurement uncertainty. For large antenna apertures the chamber size can be minimized using a compact antenna test rage.

From a testing perspective it is always beneficial to measure two orthogonal polarizations at the same time for each spatial sample. By doing this, polarization matching involving physical alignment of the test object with respect to the measurement antenna is avoided.

Also, from the requirement definition point of view, total EIRP is often of interest, where total power refers to the sum over two orthogonal polarizations.

10.3.2.1.2 EIS test setup

In Figure 10.3.2.1.2-1, a general test setup for measuring EIS is showed.

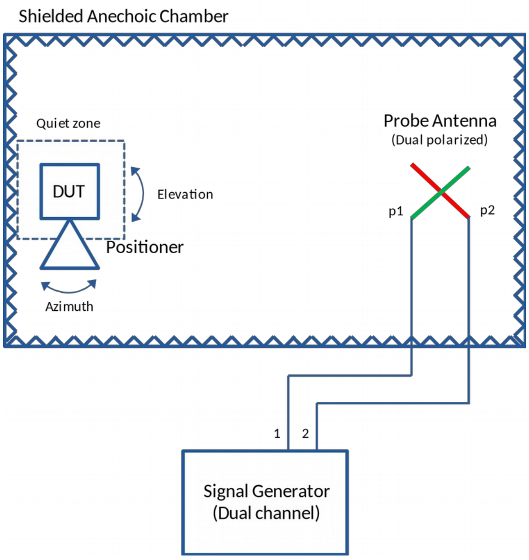


Figure 10.3.2.1.2-1: General test setup for EIS

The test object is placed at positioner that can rotate the test object allowing different impinging signal angle of arrivals to be tested. The transmission loss between the test object and the measurement antenna in the chamber is determined by a test range calibration using a reference antenna. More details on test methods and calibration procedures be found in TR 37.842, clause 10.

The distance between the test object and the measurement antenna is determined by the far-field distance and acceptable measurement uncertainty. For large antenna apertures the chamber size can be minimized using a compact antenna test rage.

For EIS, and efficient test approach is to illuminate the test object two times with orthogonal polarizations. The EIS level should be met at both cases. This approach eliminates the polarizations matching stage.

10.3.2.1.3 TRP test setup

Measuring TRP in a shielded anechoic chamber required EIRP samples from all direction around the test object. However, for base stations where often the power is directed within a certain sector, it is reasonable to measure EIRP samples within the spatial angles where the intended radiation is supposed to be (e.g. the radiation behind traditional 3-sector base station aperture is very low, both for the desired signal and the emission). A concept to measure EIRP samples within the intended region of radiation is required to minimize the test effort needed for TRP.

$$TRP \approx \frac{\pi}{2NM}\sum_{n=0}^{N-1}\sum_{m=0}^{M-1}\left(EIRP_{p1}(\theta_n,\varphi_m)+EIRP_{p2}(\theta_n,\varphi_m)\right)\sin(\theta_n)$$

, where $EIRP_{p1}$ and $EIRP_{p2}$ is associated to two orthogonal polarizations, N is the number of samples along the θ axis and M is the number of samples along the φ axis in a uniform sampling grid.

To conserve test time, it is suggested to only measure samples in directions in which the radiated power from the base station is significant. The sampling resolution and total number of samples Total number of samples that need to be measured will most certainly be different depending of requirement to be tested.

Another aspect of measuring TRP is that total power is defined as the power going through a spherical surface, which means that having sufficient distance to the test object to fulfil the far field criterion is not critical allowing for testing closer than the far-field distance.

11 WP 5D for WRC-19 agenda item 1.13

11.1 Requests by WP 5D for WRC-19 agenda item 1.13

The ITU World Radiocommunication Conference 2015 (WRC-15), which met in November 2015, agreed on agenda item 1.13 regarding additional allocations to the mobile services and identification of additional frequency bands for IMT for consideration at WRC-19.

Working Party 5D (WP 5D) as the lead group for IMT in ITU-R has been requested to provide parameters for use in sharing studies for this new agenda item. WP 5D will need to complete its work on the parameters at its Feb 2017 meeting.

ITU-R WP 5D has previously developed sharing parameters for IMT-2000 and IMT-Advanced technologies, which are contained in ITU-R Reports M.2039-2 and M.2292 respectively. These documents do not contain information for the frequency ranges relevant for AI 1.13. In its meeting (Feb 2016), WP 5D thus started the task of determining such parameters for IMT-2020 systems in the frequency range between 24.25 GHz and 86 GHz and wish to engage support of External Organisations (EO) in this work. During its 24th meeting (June 2016), WP 5D reviewed the list of technology-related parameters further.

WP 5D is seeking the technical support and information relevant to the frequency range (24.25-86 GHz) being considered under AI 1.13:

i) Utilizing the Table 11.1-1, please provide WP 5D with information on IMT-2020 technology-related parameters between 24.25 GHz and 86 GHz to be used in sharing and compatibility studies.

ii) WP 5D kindly asks for information as follows in order to meet the ITU-R WP 5D deadline:

- Initial system characteristics and any views on the items included in Table 11.1-1 by the October 2016 meeting of WP 5D

- Final system characteristics and final values to be included in the attached Table 11.1-1 by the February 2017 meeting of WP 5D

Table 11.1-1: IMT-2020 technology-related parameters in the frequency range 24.25-86 GHz

		IMT-2020	
No.	**Parameter**	**Base station**	**Mobile station**
1	**Duplex Method** (Note 1)		
2	**Channel bandwidth (MHz)**		
3	**Signal bandwidth (MHz)**		
4	**Transmitter characteristics**		
4.1	Power dynamic range (dB)		
4.2	Spectral mask		
4.3	ACLR		
4.4	Spurious emissions		
5	**Receiver characteristics**		
5.1	Noise figure		
5.2	Sensitivity		
5.3	Blocking response		
5.4	ACS		
5.5	SINR operating range		

The planned dates of the relevant WP 5D meetings to finalize the work on sharing parameters are shown in table 11.1-2:

Table 11.1-2: The planned dates of the relevant WP 5D meetings

ITU-R Group	Meeting No.	Start (planned)	Stop (planned)		Deadline for Inputs	Requested from External Organizations
WP 5D	25	5 Oct. 16	13 Oct. 16		28 Sep 2016	**Initial deliverable**
WP 5D	26	14 Feb 17	22 Feb 17		7 Feb 2017	**Final deliverable**

11.2 Response to WP 5D for WRC-19 agenda item 1.13

While the purpose of the response to ITU-R WP5D is to facilitate sharing and compatibility studies, the parameters are developed as an intermediate step of the ongoing work to develop NR. In order not to give the impression that the parameters given are a premature conclusion on RF requirements, the following way forward was agreed for the continued RAN4 work [32]:

- The IMT parameters reported to ITU-R WP5D are developed by RAN4 for the purpose of sharing and compatibility studies with other systems. They are aimed at describing the expected behaviour we see of NR with present knowledge and should not be seen as an agreement of what the final NR parameters and characteristics will be. The parameters for WP5D do also not cover all options and parameter ranges, and further variations will be introduced later in the NR work for the final specifications.

The statement above applies to all IMT parameters listed in subclause 11.2.

It was agreed in [32] that the WP5D response will contain up to three column entries for each IMT parameter, corresponding to the frequency ranges 24.24 – 33.4 GHz, 37 – 52.6 GHz and 66 – 86 GHz and represented in co-existence studies by the proxy frequencies 30 GHz, 45 GHz and 70 GHz respectively.

The full LS response is in Annex F.

11.2.1 Duplex Method

It was agreed in [32] that for the WP5D response, the duplex method will be "TDD". FDD and SDL can be further studied in RAN4.

11.2.2 Channel bandwidth

It was agreed in [32] that for the WP5D response, the Channel bandwidth will be 200 MHz. The scalability of bandwidth and consequently the minimum and maximum channel bandwidth will be further studied in RAN4.

11.2.3 Signal bandwidth

It was proposed in [32] and finally agreed in [31] that for the WP5D response, the signal bandwidth will be ">90% of channel bandwidth".

11.2.4 Transmitter characteristics

11.2.4.1 Power dynamic range

It was agreed in [32] that for the WP5D response, the BS Power dynamic range will be "0 dB for conducted BS output power".

It was proposed in [32] that for the WP5D response, the UE Power dynamic range will be based on assumed minimum and maximum conducted output power of a UE. This was in the LS response [31] further clarified to be 63 dB, based on -40 dBm minimum and 23 dBm maximum conducted output power of a UE.

11.2.4.2 Spectral mask

For the BS unwanted emissions, the following baseline for a spectrum mask was used [34]:

- For the ITU-R response "transmission centric" Spectrum Emissions Mask (SEM) will be used
- The SEM is applicable for a 200 MHz channel bandwidth
- The SEM extends out to 500 MHz from the center of transmission
- A measurement bandwidth of 1 MHz is used
- The emissions limits should have the new limits in FCC Title 47, §30.203 as a baseline [17].

The following was further agreed for the BS spectrum mask in [33]:

- Two masks are defined for BS SEM, based on scenario:
- Indoor
- Outdoor (Urban hotspot, Suburban hotspot)
  - Outdoor mask levels (at 30 GHz, based on ACLR = 27.5 dB)
- For for PTx ≥ 34.5 dBm
  - FCC limits
- For PTx < 34.5 dBm

- Fixed limit of -5 dBm (=FCC limit) for 0-20 MHz offset
- Relative limits based on ACLR-3 dB for 20-400 MHz offset
- Minimum level of the mask at -20 dBm

- Indoor mask levels:
  - FCC limits minus 7 dB

For the UE unwanted emissions, limits in FCC Title 47, §30.203 [17] are used directly for the spectrum mask.

11.2.4.3 ACLR

It was agreed in [35] that for the WP5D response, the BS ACLR will be as shown in Table 11.2.4.3-1:

Table 11.2.4.3-1: BS ACLR values for the WP5D response.

Frequency range	30 GHz (24.24 – 33.4 GHz)	45GHz (37 – 52.6 GHz)	70 GHz (66 – 86 GHz)
ACLR	27.5 dB	25.5 dB	23.5 dB

It was agreed in [35] and [36] that for the WP5D response, the UE ACLR will be as shown in Table 11.2.4.3-2:

Table 11.2.4.3-2: UE ACLR values for the WP5D response.

Frequency range	30 GHz (24.24 – 33.4 GHz)	45GHz (37 – 52.6 GHz)	70 GHz (66 – 86 GHz)
ACLR	17 dB	16 dB	15 dB

These ACLR values shall be used only for WP5D response. Further study on the actual ACLR/ACS to be used to define RF requirements shall be performed in the WI phase.

11.2.4.4 Spurious emissions

It was agreed in [37] that for the WP5D response, the BS spurious response limit will be -13 dBm/MHz (TRP). The text for response to WP5D will be "-13 dBm/MHz Total Radiated Power (Note X). The feasibility of more stringent spurious domain emission limits is under investigation by 3GPP."

For the WP5D response, the UE spurious response limit will be -13 dBm/MHz (TRP).

11.2.5 Receiver characteristics

11.2.5.1 Noise figure

It was agreed in [38] that for the WP5D response, the BS and UE Noise Figure will be as shown in Table 11.2.5.1-1:

Table 11.2.5.1-1: Noise Figure values for the WP5D response.

Frequency range	30 GHz (24.24 – 33.4 GHz)	45GHz (37 – 52.6 GHz)	70 GHz (66 – 86 GHz)
BS	10 dB	12 dB	14 dB
UE	10 dB	12 dB	14 dB

These NF values shall be used only for WP5D response. Further study on the actual noise figure to be used to define RF requirements for UE and BS shall be performed in the WI phase.

11.2.5.2 Sensitivity

It was agreed in [39] and [40] that for the WP5D response, not to report BS or UE sensitivity as it is not crucial for compatibility studies with other systems.

11.2.5.3 Blocking response

It was agreed in [39] that for the WP5D response on BS blocking to introduce a note that the blocking interfering signal level will be at least equal to the ACS interfering level described by the following formula:

BS ACS interfering signal level [dBm] = BS noise floor + NF + ACS + 4.7dB

Assumed interfering signal bandwidth is the same as the wanted signal channel BW (200MHz), assumed interfering signal centre frequency offset to the wanted signal edge is at least 300MHz.

It was agreed in [40] that for the WP5D response on UE blocking to add the following note to the reply LS to ITU to capture the blocking response: “Note 3: Blocking response can be derived from the ACS and NF as being:

UE ACS interfering signal level [dBm] = UE noise floor + NF + ACS + 4.7dB

Assumed interfering signal bandwidth is the same as the wanted signal channel BW (200MHz), assumed interfering signal centre frequency offset to the wanted signal edge is at least 300MHz)”

The actual ACS and blocking requirement will be studied further and decided in the WI phase.

Actual 3GPP NR requirements above 6GHz are OTA system requirements which will give at least as good blocking and ACS protection as envisaged in the response to ITU-R.

11.2.5.4 ACS

It was agreed in [35] and [36] that for the WP5D response, the BS ACS will be as shown in Table 11.2.5.4-1:

Table 11.2.5.4-1: BS ACS values for the WP5D response.

Frequency range	30 GHz (24.24 – 33.4 GHz)	45GHz (37 – 52.6 GHz)	70 GHz (66 – 86 GHz)
ACS	23.5 dB	22.5 dB	21.5 dB

It was agreed in [33] that for the WP5D response, the UE ACS will be as shown in Table 11.2.5.4-2:

Table 11.2.5.4-2: UE ACS values for the WP5D response.

Frequency range	30 GHz (24.24 – 33.4 GHz)	45GHz (37 – 52.6 GHz)	70 GHz (66 – 86 GHz)
ACS	22.5 dB	21.5 dB	20.5 dB

These ACS values shall be used only for WP5D response. Further study on the actual ACLR/ACS to be used to define RF requirements shall be performed in the WI phase.

11.2.5.5 SINR operating range

In the original LS request from ITU-R WP5D, the parameter “SINR Operating Range” was requested. It was further clarified by ITU-R WP5D in an updated LS from ITU-R WP5D [42] that the meaning of SINR range is in fact a mapping table between throughput and SINR for IMT-2020 in order to simulate IMT-2020 throughput loss due to external interference, in a form similar to Tables A.6 and A.7 found in TR 36.942.

Since such an SINR vs. throughout mappings available for the co-existence studies in RAN4, it was agreed to use the text in [41] for the WP5D response.

12 Conclusions

Editor's note: intended to capture conclusions and recommendations from the RF and co-existence aspects of the New Radio Access Technology study item.

Annex A: PA models

There are a few simple models for basic amplifier non-linear behaviour. A more rigorous model would include the Volterra series expansion which can model complex non-linearities such as memory effects. Among the more simple models one can count the Rapp model, Saleh model and the Ghorbani model. Combinations of pure polynomial models and filter models are also often referred to as fairly simple models, of which the Hammerstein model could be mentioned.

The advantage of the simpler models is usually in connection to for a need of very few parameters to model the non-linear behaviour. The drawback is that such a model only can be used in conjunction with simple architecture amplifiers such as the basic Class A, AB and C amplifiers. Amplifiers such as the high efficiency Doherty amplifier can in general not be modelled by one of these simple models.

In addition, to properly capture the PA behaviour for the envisaged large NR bandwidths, it is essential to use PA models capturing the memory effects. Such models would require an extensive set of empirical measurements for proper parameterization.

Rapp Model

The Rapp model has basically 2 parameters by which the general envelop distortion may be described. It mimics the general saturation behaviour of an amplifier and lets the designer set a smoothness of the transition by a P-factor. By extending this also to model phase distortion, one has in total 6 parameters available. The basic simple model may be found as:

$$V_{out} = \frac{V_{in}}{\left(1 + \left(\frac{|V_{in}|}{V_{sat}}\right)^{2P}\right)^{\frac{1}{2P}}}$$

This model produces a smooth transition for the envelope characteristic as the input amplitude approaches saturation. In the more general model, both AM-AM and AM-PM distortion can be modelled. In general terms, the model describes the saturation behaviour of a radio amplifier in a good way.

$$F_{AM-AM} = \frac{Gx}{\left(1 + \left|\frac{Gx}{V_{sat}}\right|^{2P}\right)^{\frac{1}{2P}}}$$

$$F_{AM-PM} = \frac{Ax^{q}}{1 + \left(\frac{x}{B}\right)^{q}}$$

“x” is the envelop of the complex input signal. If signal measurements are at hand of the input/output relationship, the parameters of the model may be readily found for a particular amplifier by for example regression techniques.

The strength of the Rapp model is lies in its simple and compact formulation, and that it gives an estimation of the saturation characteristics of an amplifier. The drawback of this simple model is of course that it cannot model higher order classes of amplifiers such as the Doherty amplifier. It also lacks the ability to model memory effects of an amplifier.

In conclusion, RAPP model similar to other memory less models would capture some aspects in relation to waveform design but could not serve as a complete and comprehensive PA model covering all the effect possibly affecting the waveform design.

Saleh Model

The Saleh model [25] is a similar model to the Rapp model. It also gives an approximation to the AM-AM and AM-PM characteristics of an amplifier. It offers slightly less number of parameters (4) that one can use to mimic the input/output relationship of the amplifier.

The AM-AM distortion relation and AM-PM distortion relation are found to be as:

$$g(r)_{AM-AM} = \frac{\alpha_a r}{1 + \beta_a r^2}$$

$$f(r)_{AM-PM} = \frac{\alpha_\varphi r^2}{1 + \beta_\varphi r^2}$$

“r” is the envelop of the complex signal fed into the amplifier, and α/β are real-valued parameters that can be used to tune the model to fit a particular amplifier.

Ghorbani Model

The Ghorbani model [26] also gives expressions similar to the Saleh model, where AM-AM and AM-PM distortion is modeled. Following Gharbani, the xepressions are symmetrically presented as rephrased below.

$$g(r) = \frac{x_1 r^{x_2}}{1 + x_3 r^{x_2}} + x_4 r$$

$$f(r) = \frac{y_1 r^{y_2}}{1 + y_3 r^{y_2}} + y_4 r$$

In the expressions above, g(r) corresponds to AM-AM distortion, while f(r) corresponds to AM-PM distortion. The actual scalars $x_{1\text{-}4}$ and $y_{1\text{-}4}$ have to be extracted from measurements by curve fitting or some sort of regression analysis.

Taylor (Polynomial) series

The next step in the more complex description of the non-linear behaviour of an amplifier is to view the characterization as being subject to a simple polynomial expansion [5]. This model has the advantage that it is mathematically pleasing in that it for each coefficient reflects higher order of inter-modulations. Not only can it model third order intermodulation, but also fifth/seventh/ninth etc. Mathematically it can also model the even order intermodulation products as well, it merely is a matter of discussion whether these actually occur in a real RF application or not.

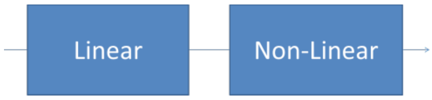
$$y(t) = a_0 + a_1 x(t) + a_2 x(t)^2 + a_3 x(t)^3 + a_4 x(t)^4 \ldots\ldots$$

$$A_{IP3} = \sqrt{{}^{4a_1}/_{3\,|a_3|}}$$

Coefficients may be readily be expressed in terms of Third Order Intercept point IP3 and gain, as described above. This feature makes this model specially suitable in low level signal simulations, since it relates to quantities that usually are readily available and easily understood amongst RF engineers.

Hammerstein model

The Hammerstein model [6] consists of a combination of a Linear + Non-Linear block that is capable of mimicking a limited set of a Volterra Series. As the general Volterra series models a nested series of memory and polynomial representations, the Hammerstein model separates these two defining blocks that can in theory be separately be identified with limited effort.



The linear part is often modelled as a linear filter in the form of a FIR-filter. The non-linear part is then on the other hand simply modelled as polynomial in the envelop domain.

Non-linear

$$y(t) = a_0 + a_1 x(t) + a_2 x(t)^2 + a_3 x(t)^3 + a_4 x(t)^4 \dots\dots$$

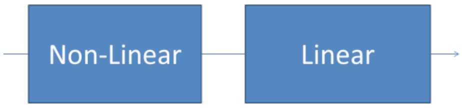
Linear

$$s(n) = \sum_{k=0}^{K-1} h(k)\, x(n-k)$$

The advantage of using a Hammerstein model in favour of the simpler models like Rapp/Saleh or Ghorbani is that it can in a fairly simple way also model memory effects to a certain degree. Although, the model does not benefit from a clear relationship to for example IIP3/Gain but one has to employ some sort of regression technique to derive polynomial coefficients and FIR filter tap coefficients.

Wiener model

The Wiener model describes like the Hammerstein model a combination of Non-linear + Linear parts that are cascaded after each other. The difference to the Hammerstein model lies in the reverse order of non-linear to linear blocks.



In the first block in the figure above, the non-linear block is preferably modelled as a polynomial in the envelope of the complex input signal. This block is the last one in the Hammerstein model as described above. The polynomial coefficients may themselves be complex, depending on what fits measured data best. See expressions for non-linear and linear parts under the Hammerstein section.

The second block which is linear may be modelled as an FIR filter with a number of taps that describes the memory depth of the amplifier.

Volterra series expansion model

The state-of-the-art approaches lean on a fundament of the so called Volterra series, [7]. The Volterra series is in common words described as a kind of “Taylor series with memory” and is able to model all weak non-linearity with fading memory. Common models like for example the memory polynomial can also be seen as a subset of the full Volterra series and can be very flexible in designing the model by simply adding or subtracting kernels from the full series.

The discrete-time Volterra series, limited to causal systems with symmetrical kernels (which is most commonly used for power amplifier modelling) is written as

$$y[n] = \beta_0 + \sum_{p=1}^{P} \sum_{\tau_1=0}^{\mathcal{M}} \sum_{\tau_2=\tau_1}^{\mathcal{M}} \cdots \sum_{\tau_p=\tau_{p-1}}^{\mathcal{M}} \beta_{p,\tau_1,\tau_2,\dots,\tau_p} \prod_{j_1=1}^{p} x[n-\tau_{j1}] \prod_{j_2=p+1}^{2p-1} \bar{x}[n-\tau_{j2}]$$

in which P is the non-linear order and M is the memory-depth.

Further on, there are benefits which the Volterra series hold over other modelling approaches. These are as follows.

- It is linear in parameters, meaning that the optimal parameters may be found through simple linear regression analysis from measured data. It further captures frequency dependencies through the inclusion of memory effects which is a necessity for wideband communication.

- The set of kernels, or basis functions, best suited for modelling a particular power amplifier may be selected using methods which rely on physical insight, [8]. This makes the model scalable for any device technology and amplifier operation class.

- It can be extended into a multivariate series expansion in order to include the effects of mutual coupling through antenna arrays, [9]. This enables the studies on more advanced algorithms for distortion mitigation and pre-coding.

It may be observed that other models such as static polynomials, memory polynomials and combinations of the Wiener and Hammerstein models are all subsets of the full Volterra description.

As previously stated, empirical measurements are needed to parameterized PA model based on Volterra series expansion.

Memory Polynomials

A subset of the Volterra Series is the memory polynomial [8, 9] with polynomial representations in several delay levels. This is a simpler form of the general Volterra series. The advantage of this amplifier model is its simple form still taking account of memory effects. The disadvantage is that the parameters have to be empirically solved for the specific amplifier in use.

$$
\begin{aligned}
PA_{memory} = {} & x(t)\cdot\left[a_0 + a_1\cdot|x(t)| + a_2\cdot|x(t)|^2 + \cdots\right] + \\
& + x(t-t_0)\cdot\left[b_0 + b_1\cdot|x(t-t_0)| + b_2\cdot|x(t-t_0)|^2 + \cdots\right] + \\
& + x(t-t_1)\cdot\left[c_0 + c_1\cdot|x(t-t_1)| + c_2\cdot|x(t-t_1)|^2 + \cdots\right] + \cdots
\end{aligned}
$$

The equation above shows an expression for a memory polynomial representation of an amplifier involving two memory depth layers. Each delayed version of the signal is associated with its own polynomial expressing the non-linear behaviour.

A.1 Detailed Generalized Memory Polynomial (GMP) models

The purpose of a PA behavioural model is to describe the input-to-output relationship as accurately as possible. State-of-the-art approaches lean on a fundament of the so called Volterra series consisting of a sum of multidimensional convolutions. Volterra series are able to model all weak nonlinearities with fading memory and thus are feasible to model conventional PAs aimed for linear modulation schemes.

The GMP model used here is a slightly modified version of equation 24 in [23] and is given by

$$
\begin{aligned}
y_{GMP}(n) = {} & \sum_{k\in K_a}\sum_{l\in L_a} a_{kl}\,x(n-l)\,|x(n-l)|^{2k} \\
& + \sum_{k\in K_b}\sum_{l\in L_b}\sum_{m\in M} b_{klm}\,x(n-l)\,|x(n-m)|^{2k}
\end{aligned}
$$

where $y_{GMP}(n)$ and $x(n)$ represent the complex baseband equivalent output and input, respectively, of the model. The first term represents the double sum of so called diagonal terms where the input signal at time shift l, $x(n-l)$; $l \in L_a$, is multiplied by different orders of the time aligned input signal envelope $|x(n-l)|^{2k}$; $k \in K_a$. The triple sum represents cross terms, i.e. the input signal at each time shifts is multiplied by different orders of the input signal envelope at different time shifts.

The GMP is linear in the coefficients, a_{kl} and b_{klm}, which caters for robust estimation based on input and output signal waveforms of the PAs to be characterized.

As a complement to the above, also memoryless polynomial models have been derived based on:

$$y_P(n) = \sum_{k \in K_p} a_k x(n)|x(n)|^{2k}$$

In this paper, proposals for realistic parameterized PA models based on GMP are given where the parameterization is based on empirical measurements or advanced circuit simulations of designed PAs. The pre-conditions for the presented parameterization are as following:

The PA models aim to fulfil RAN4 requirements on unwanted emission (spectrum emission masks and ACLR) as well as signal quality. Although the models have been derived for a particular operating point, the same parameterized models apply at operating points of the PA as long as the expected performance criterion stated above is fulfilled. Thus the model can be used for waveform evaluations when considering both BS side and UE side ACLR requirements. (Of course, it is the UE PA behaviour that is likely to have the largest impact on waveform selection).

Note that it is a reasonable assumption that for PA models below 6 GHz, the requirements in current specifications (in particular the MSR specification) should apply. For mm-wave frequencies, as there is no 3GPP specification today, the requirements might differ compared to below 6 GHz. However an ACLR in the range of 35 dB seems to be sufficient for the mm-wave frequencies. If needed, the operating point can be adapted to achieve the desired ACLR

None of the models capture the impacts of DPD; this would need to be modelled separately.

Examples Memory polynomial PA model

A) Generalized Memory Polynomial

Due to possible difference in requirement levels for frequency bands below 6 GHz compared to mm-wave frequencies and availability of different PA technologies, the following GMP models are captured as examples for the SI (further models may be developed if/when needed):

1. 2.1 GHz PA model with and without memory (based on measurements of commercially available GaAs PA).
2. 2GHz PA model with and without memory (based on measurement of GaN PA).
3. 28GHz CMOS PA model with and without memory (based on circuit simulations of designed PA).
4. 28GHz GaN PA model with and without memory (based on circuit simulations).

The 2 GHz PA models as well as 28 GHz PA models discussed in this paper are representative for frequency bands below 6 GHz and mm-wave frequencies respectively.

The memoryless polynomial models are defined by coefficients a_k and will be presented in MATLAB notation as column vector $[a_0; a_1; \dots; a_k]$.

The GMP models are defined by the set of coefficients a_{kl} and b_{klm} and will be represented as follows:

a_{kl} is specified as one column vector for each value of l: $[a_{0l}; a_{1l}; \dots; a_{kl}]$

b_{klm} is specified as one column vector for each value of l and m: $[b_{0lm}; b_{1lm}; \dots; b_{klm}]$

All models have been normalized with respect to input such that the valid input range is given by $0 \leq |x| \leq 1$ while the small signal gain is unity (0dB). The accuracy of each model is specified as Normalised Mean Square Error (NMSE) between the modelled PA output and the measured/simulated PA output. The presented NMSE indicate very good agreement between the models and measurements.

PA model for ~2 GHz commercially available GaAs with 40MHz signal bandwidth

The first model is based on a commercially available GaAs PA designed for operation at 2.1GHz (band 1). The model has been derived from measurements with input and output data at a sample rate of 307.2 MHz and an input signal bandwidth of 40 MHz.

The memoryless model has -31.5dB NMSE and is defined by:

$a_k;\ k \in [0,1,\dots,7]$:

[-0.618347-0.785905i; 2.0831-1.69506i; -14.7229+16.8335i; 61.6423-76.9171i;
-145.139+184.765i; 190.61-239.371i; -130.184+158.957i; 36.0047-42.5192i]

The corresponding GMP model has -38.1dB NMSE and is defined by:

$a_{kl};\ k \in [0,1,\dots,7]$:

$l = 2$:

[0.0145707+0.00223568i; 0.0166021+0.0884597i; -0.170987-0.889998i; 0.398012+4.25717i;
-0.922915-11.5296i; 1.51648+16.8822i; -1.31708-12.4992i; 0.443603+3.66282i]

$l = 1$:

[-0.0730384-0.0608598i; 0.316437-0.130488i; -2.64289+1.95766i; 13.9617-8.92706i;
-35.9884+25.271i; 49.5323-38.9777i; -34.8388+30.1032i; 9.83576-9.12289i]

$l = 0$:

[-0.369392-0.616894i; 0.582141-1.54129i; -4.2332+13.9746i; 15.4346-56.4738i;
-34.026+106.817i; 42.3779-83.2642i; -26.6004+5.86237i; 6.4982+15.2082i]

$l = -1$:

[-0.109009-0.0382752i; 1.34619-0.303139i; -7.57533+2.07457i; 30.8214-7.83883i;
-71.9119+13.7515i; 94.7172-10.8742i; -65.1891+3.05573i; 18.1882+0.14561i]

$l = -2$:

[0.0913878+0.029207i; -0.205695-0.0047561i; 0.436792+0.098933i; -0.0447736+0.802472i;
-1.91069-3.64271i; 3.53201+6.10853i; -2.64467-4.81807i; 0.741402+1.46945i]

$b_{klm};\ k \in [0,1,\dots,7]$:

$l = 1, m = 0$:

[-0.0732748-0.0617029i; 1.04861+0.216692i; -7.53774-2.85579i; 29.348+11.8762i;
-68.0727-19.8783i; 92.0079+4.93057i; -66.4247+17.5978i; 19.6384-12.2782i]

$l = -1, m = 0$:

[-0.108885-0.0392921i; -0.65351-0.122316i; 2.7747+3.26333i; -6.41902-23.391i;
9.68476+79.745i; -10.5191-141.613i; 6.89414+125.231i; -1.92908-43.441i]

Figure A.1-1 and Figure A.1-2 show the gain and phase characteristics of the GMP and static model using the same OFDM signal that was used for model estimation.

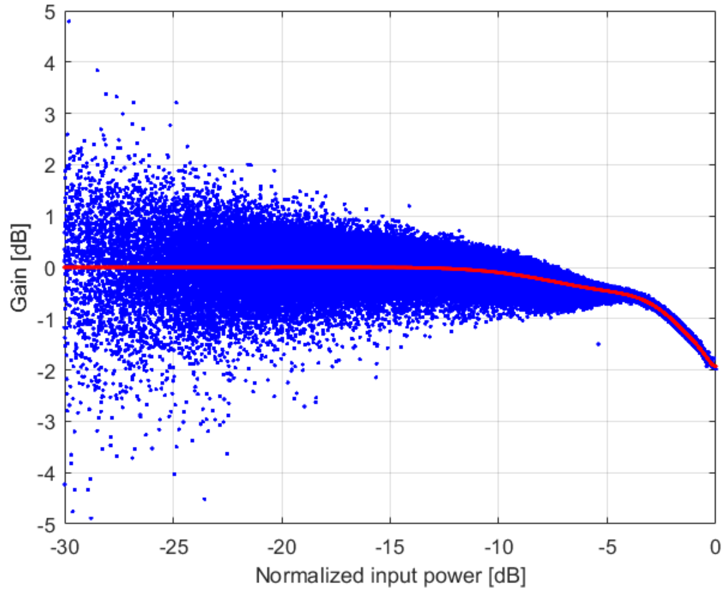


Figure A.1-1 Gain characteristics of 2.1GHz GaAs PA, (blue) GMP model (red) static model.

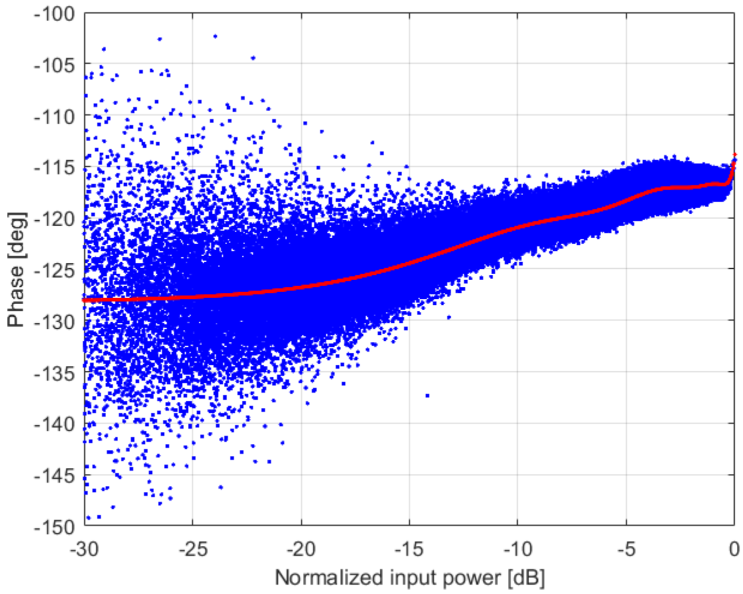


Figure A.1-2Phase characteristics of 2.1GHz GaAs PA, (blue) model (red) static model.

PA model for ~2 GHz, GaN

The second model is based on a GaN PA designed for operation at 2.1GHz (band 1). The model has been derived from measurements with input and output data at a sample rate of 200 MHz and a signal bandwidth of 40 MHz.

The memoryless model has -34.5dB NMSE and is defined by:

$a_k; k \in [0,1,\ldots,4]$:

[0.999952-0.00981788i; -0.0618171+0.118845i; -1.69917-0.464933i; 3.27962+0.829737i; -1.80821-0.454331i]

The corresponding GMP model has -40.6dB NMSE and is defined by:

$a_{kl}; k \in [0,1,\dots,4]$:

$l = 2$:

[-0.0625941-0.0142818i; 0.0956533+0.00900184i; -0.197256-0.0252242i; 0.235044+0.0097242i; -0.101881+0.00776414i]

$l = 1$:

[0.176832+0.0265921i; -0.411554-0.0417628i; 0.795672+0.146965i; -0.904609-0.134671i; 0.364885+0.0256412i]

$l = 0$:

[0.930707-0.0506493i; -0.134627+0.195504i; -1.4589-0.410569i; 2.97014+0.552334i; -1.66244-0.229841i]

$l = -1$:

[-0.000408452+0.0188736i; 0.573671-0.0891485i; -1.43878-0.0446107i; 1.88831+0.11494i; -0.898231-0.0576903i]

$l = -2$:

[-0.114268+0.0207177i; -0.163861-0.0420654i; 0.454916+0.223106i; -0.606208-0.294749i; 0.279233+0.126344i]

$b_{klm}; k \in [0,1,\dots,4]$:

$l = -3, m = 0$:

[0.0946171-0.0134503i; -0.22721+0.102407i; 0.825701-0.485074i; -1.35047+0.945727i; 0.754396-0.612916i]

$l = 3, m = 0$:

[-0.0238986+0.00753547i; 0.224223-0.0511775i; -0.811315+0.176395i; 1.31147-0.269401i; -0.699496+0.152096i]

Figure A.1-3and Figure A.1.4 show the gain and phase characteristics of the GMP and static model using the same OFDM signal that was used for model estimation.

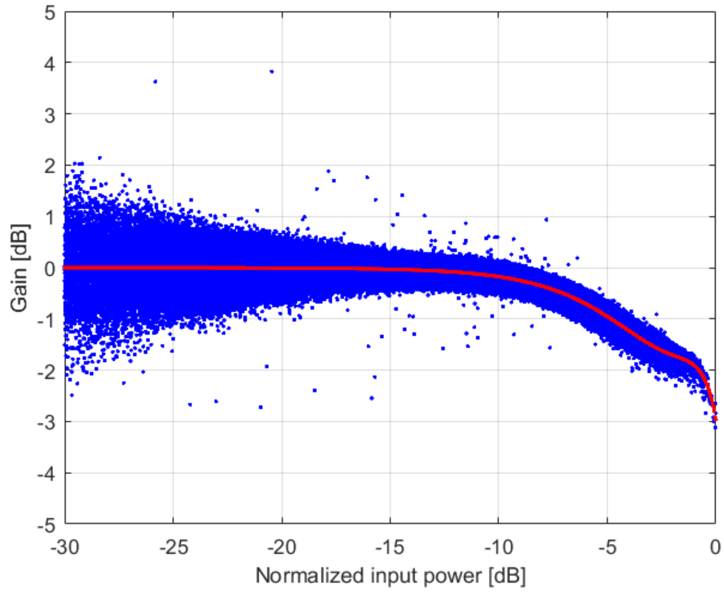


Figure A.1-3 Gain characteristics of 2.1GHz GaN PA, (blue) GMP model (red) static model.

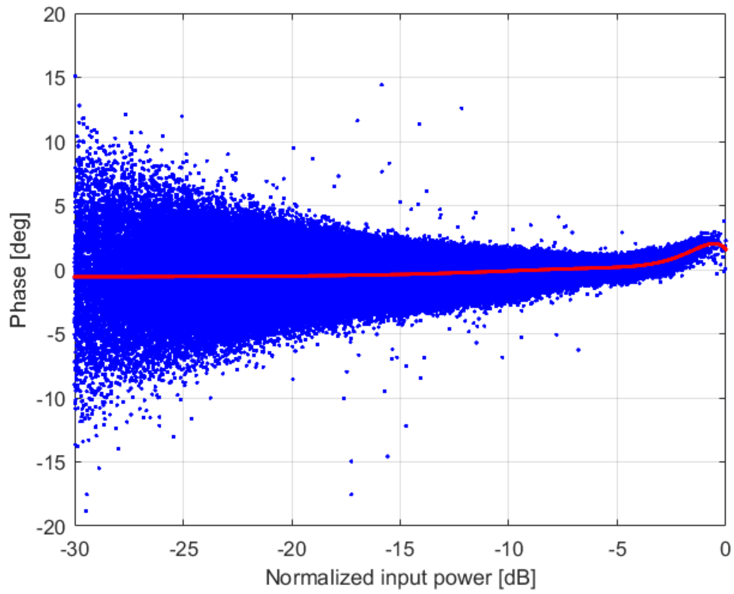


Figure A.1-4 Phase characteristics of 2.1GHz GaN PA, (blue) GMP model (red) static model.

PA model for ~28 GHz, CMOS

The third model is based on advanced circuit simulation of a CMOS PA research prototype. The model has been derived with input and output data at a sample rate of 2.281 GHz and a signal bandwidth of 400 MHz.

The memoryless model has -32.1 dB NMSE and is defined by:

$a_k; k \in [0,1,\ldots,7]$:

[0.491576+0.870835i; -1.26213+0.242689i; 7.11693+5.14105i; -30.7048-53.4924i; 73.8814+169.146i; -96.7955-253.635i; 65.0665+185.434i; -17.5838-53.1786i]

The corresponding GMP model has -41.7dB NMSE and is defined by:

$a_{kl}; k \in [0,1,\ldots,7]$:

$l = 1$:

[-0.0109821+0.00313982i; -0.00397658-0.0427409i; -0.171194+0.151692i; 0.879844-0.0235651i; -1.97684-0.862044i; 2.32524+1.99694i; -1.34472-1.77602i; 0.289959+0.559338i]

$l = 0$:

[0.473465+0.860276i; -0.953417+0.640666i; 1.9899-2.3847i; 7.5417+6.38381i; -64.8415-60.8762i; 159.01+189.579i; -167.466-225.579i; 65.4247+92.5967i]

$l = -1$:

[0.0164844+0.00671299i; -0.0198519+0.177212i; 0.669594-0.543745i; -2.98038-0.279477i; 6.6717+4.50511i; -8.26935-9.04627i; 5.42365+7.52782i; -1.47259-2.32623i]

$b_{klm}; k \in [0,1,\ldots,7]$:

$l = 1, m = 0$:

[-0.000292543-0.0150556i; -0.122202-0.283752i; 2.56792+4.68957i; -18.4244-34.2816i; 66.3648+126.766i; -124.066-239.871i; 115.273+220.218i; -42.1527-77.6225i]

$l = -1, m = 0$:

[0.0163452+0.00969618i; -0.281971-0.188069i; 3.35025+3.60649i; -24.5434-31.1539i; 87.5451+124.093i; -157.821-243.086i; 139.85+227.416i; -48.6255-81.0794i]

Figure A.1-5 and Figure A.1-6 show the gain and phase characteristics of the GMP and static model using the same OFDM signal that was used for model estimation.

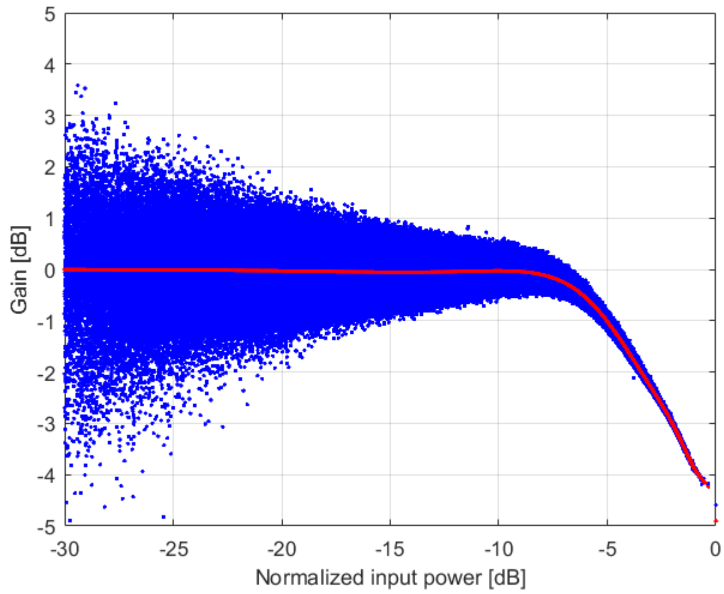


Figure A.1-5 Gain characteristics of 28GHz CMOS PA, (blue) GMP model (red) static model.

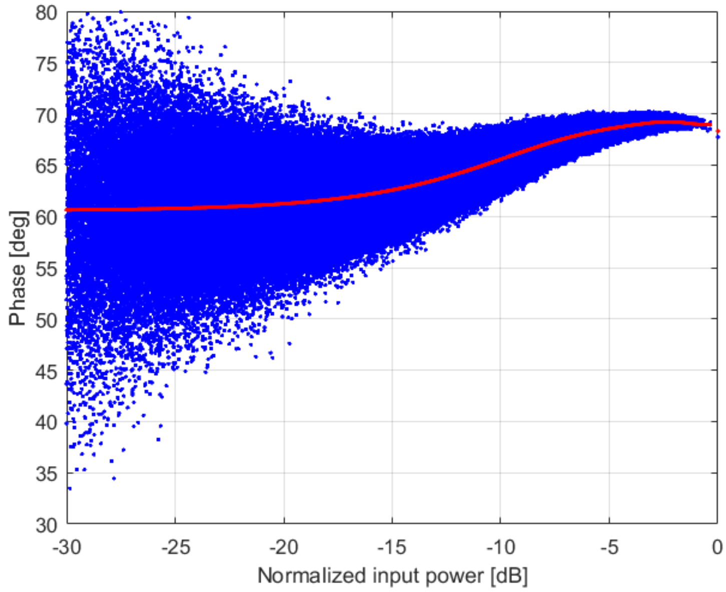


Figure A.1-6 Phase characteristics of 28GHz CMOS PA, (blue) GMP model (red) static model.

PA model for ~28GHz, GaN

The fourth model is based on advanced circuit simulation of a GaN PA research prototype. The model has been derived with input and output data at a sample rate of 2.281 GHz and a signal bandwidth of 400 MHz.

The memoryless model has -33.4dB NMSE and is defined by:

a_k; $k \in [0,1,\ldots,5]$:

[-0.334697-0.942326i; 0.89015-0.72633i; -2.58056+4.81215i;
4.81548-9.54837i; -4.41452+8.63164i; 1.54271-2.94034i]

The corresponding GMP model has -41.1dB NMSE and is defined by:

a_{kl}; $k \in [0,1,\ldots,5]$:

$l = 2$:

[0.023307+0.0467845i; -0.0257521+0.0511316i; 0.083841-0.334476i;
-0.168793+0.770187i; 0.161316-0.770897i; -0.0568524+0.279384i]

$l = 1$:

[-0.045146-0.16848i; 0.131447-0.1201i; -0.320679+0.930956i;
0.604716-2.09601i; -0.594149+2.05955i; 0.22185-0.744002i]

$l = 0$:

[-0.268916-0.707247i; 0.722109-0.647857i; -2.04126+3.97994i;
3.57012-7.51441i; -3.00197+6.42268i; 0.936088-2.05401i]

$l = -1$:

[-0.0539225-0.119444i; 0.081078-0.0363615i; -0.297265+0.246711i;
0.591961-0.510012i; -0.542816+0.502644i; 0.186803-0.187022i]

$l = -2$:

[0.022577+0.04227i; 0.0085171-0.00686566i; -0.0110846+0.0177386i; 0.0157497-0.00255606i; -0.0231175-0.0213148i; 0.012631+0.0109949i]

$b_{klm}; k \in [0,1,\ldots,5]$:

$l = 3, m = 0$:

[-0.00997684-0.0214876i; 0.04625-0.0124587i; -0.315178+0.16066i; 0.841832-0.395568i; -1.02048+0.442096i; 0.463711-0.197228i]

$l = -3, m = 0$:

[-0.0138413-0.0283711i; 0.0103081-0.0570896i; -0.0723643+0.440087i; 0.399287-1.24045i; -0.712003+1.50792i; 0.402778-0.661505i]

Figure A.1-7 and Figure A.1-8 show the gain and phase characteristics of the GMP and static model using the same OFDM signal that was used for model estimation.

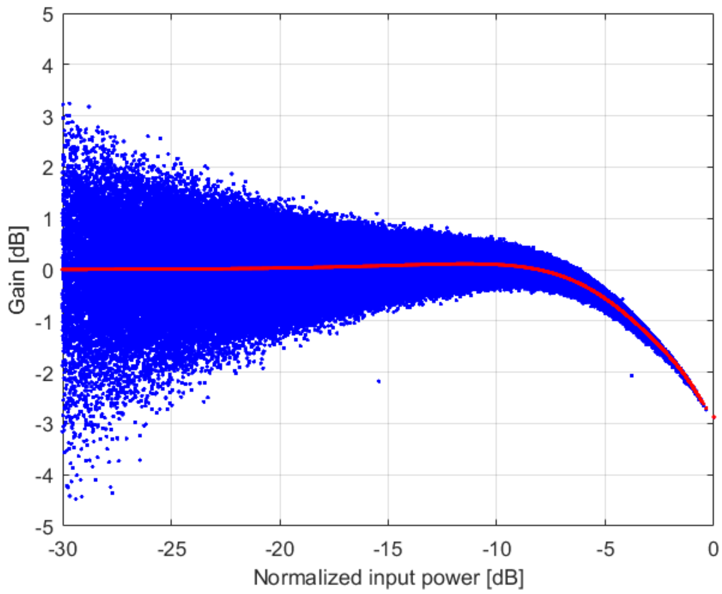


Figure A.1-7 Gain characteristics of 28GHz GaN PA, (blue) GMP model (red) static model.

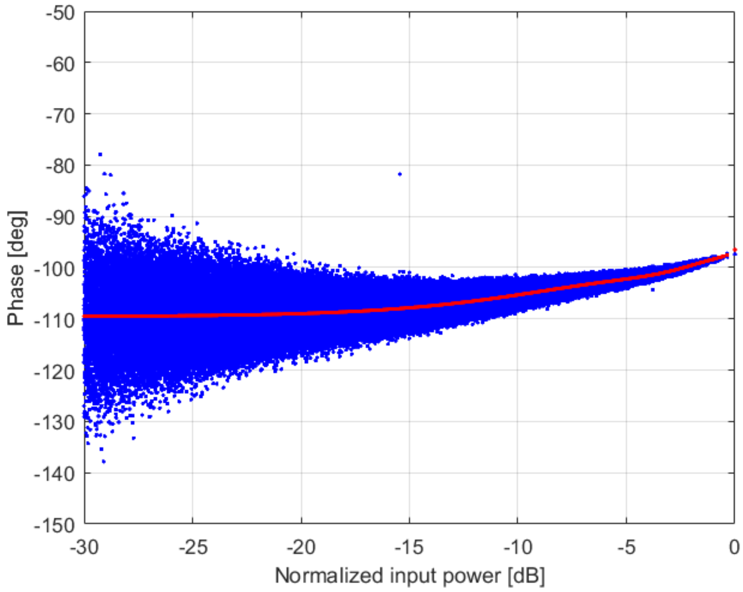


Figure A.1-8 Phase characteristics of 28GHz GaN PA, (blue) GMP model (red) static model.

B) Memory Polynomial

Volterra series version that reduces the number of parameters to be determined. MP decreases the overall system complexity while still maintaining the accuracy of the memory effects description. Before modelling, input and output samples must be aligned. Signal correlation is the most common method to synchronize time series. After alignment and normalization, a part of the samples is used to calculate the coefficients of matrix A in equation below

$$Y = X * A$$

The coefficients can be extracted using the LMS algorithm, which is explained in further detail in [26]. Memory effects and nonlinear distortion can significantly reduce the output signal quality and therefore, degrade the overall system performance. Depending on the frequency range of the signal transmission, the inclusion of memory effects can be crucial for developing a useable and realistic model. Therefore, the models of a PA operating below 6 GHz and another PA operating above 6 GHz will be shown.

PA model below 6 GHz

The PA model was simulated in Matlab using the measurement results from an Intel PA. An OFDM signal with a carrier frequency of 2.44 GHz was fed to the amplifier. Both the I(t) and Q(t) from the input and output signals PA were used to develop a model based on a memory polynomial implementation. The terms used for the evaluation of this model were polynomial degree K with a value of 5 and the polynomial memory depth M with a value of 5. The low value of both terms enabled a fast computational time and ensured good adaptive performance of the algorithm, which resulted in a very near approximation of the modelled output signal to the original output signal.

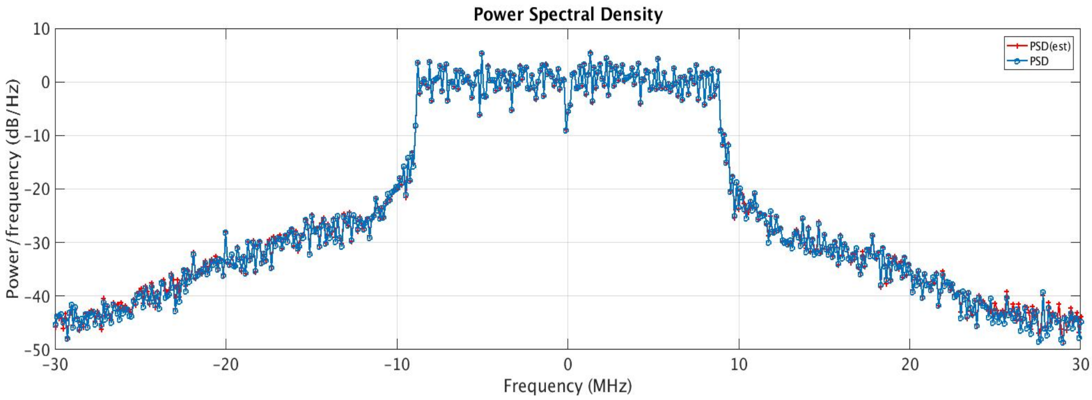


Figure A.1-9 Power Spectral Density at 2.44 GHz

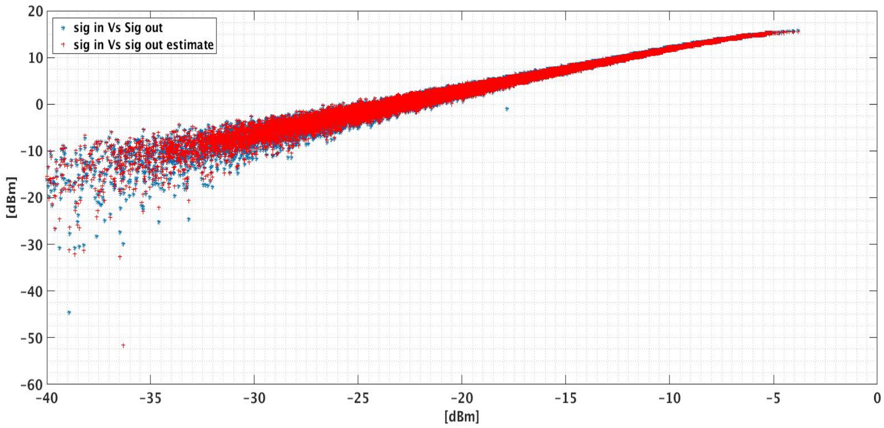


Figure A.1-10 Input Signal VS Output Signal at 2.44 GHz

This can be perceived in Figure A.1-9 and Figure A.1-10 where the Power Spectral Density (PSD) and the input versus the output signal have been plotted based on the number of samples of the measured PA fitted to the simulation model. In both figures the red curves represent the model estimated data and the blue curve the original measurement data. We can find the two traces of PSD fit very well in pass band and adjacent channel. The average error in dB between value of PSD of measured data and that of model output is less than 0.3 dB.

To evaluate the performance of the MP model, the average normalized mean square error (NMSE) has been calculated, which is the most common metric to evaluate models performance. The NMSE is calculated with following equation, where y represents the measured data and y_{est} represents the model data.

$$NMSE = 10 * log \frac{\sum |y - y_{est}|^2}{\sum |y|^2}$$

The calculated value for the NMSE is -67 dB which is much better than the traditional NMSE values of around -38 dB. In Figure A.1-10 it can be seen that the memory effects generate diffusion region and based on these results we propose the use of a memory polynomial model to implement the PA model below 6 GHz considering the memory effects.

The memory parameter calculated with the model are the following:

M = 5, K = 5,
a_{km} = [20.0875 + 0.4240i, -6.3792 - 0.5507i, 0.5809 + 0.0644i, 1.6619 + 0.1040i, -0.3561 - 0.1033i, -59.8327 -34.7815i, -2.4805 + 0.9344i, 4.2741 + 0.7696i, -2.0014 - 2.3785i, -1.2566 + 1.0495i, 3.2738e+02 + 8.4121e+02i, 4.4019e+02 - 3.0714e+01i, -3.5935e+02 - 9.9152e+00i, 1.6961e+02 + 7.3829e+01i, -4.1661 -21.1090i, -1.6352e+03 - 5.5757e+03i, -2.5782e+03 + 3.3332e+02i, 1.9915e+03 - 1.4479e+02i, -9.0167e+02 - 5.4617e+02i, -93.1907 +14.2774i, 2.3022e+03 + 1.2348e+04i, 4.6476e+03 - 1.4477e+03i, -2.9998e+03 + 1.6071e+03i, 9.1856e+02 + 9.8066e+02i, 8.2544e+02 + 6.1424e+02i]

PA model for above 6 GHz

The memory polynomial has been utilized as well for above 6 GHz. The PA model for above 6 GHz was implemented by using the 28nm CMOS PA at 31 GHz designed by the Katholieke Universiteit Leuven (KUL) [2]. A 16-QAM Single Carrier signal was fed to the amplifier. Since we consider that a PA operated in mmWave bands shall support a wider bandwidth compared to a PA below 6 GHz, the memory effects are expected to be more crucial. By this, we see an increase of the complexity to model the nonlinearities. In other words, the calculation effort will be more costly than in the case of the PA below 6 GHz, where the memory effects are not so dominant.

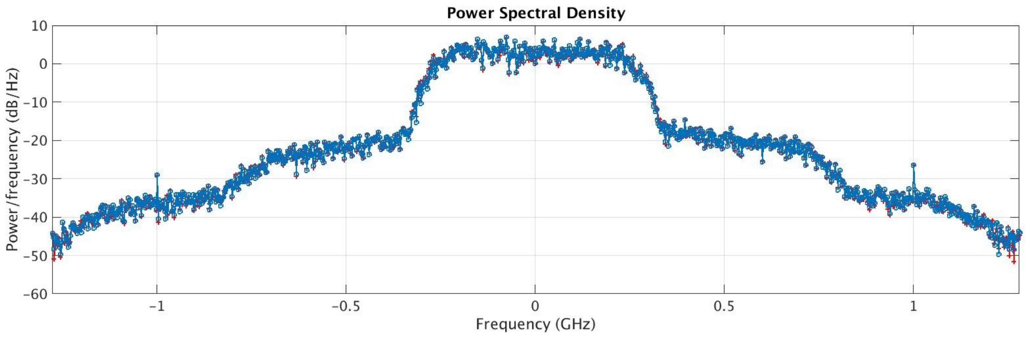


Figure A.1-11 Power Spectral Density at 31 GHz.

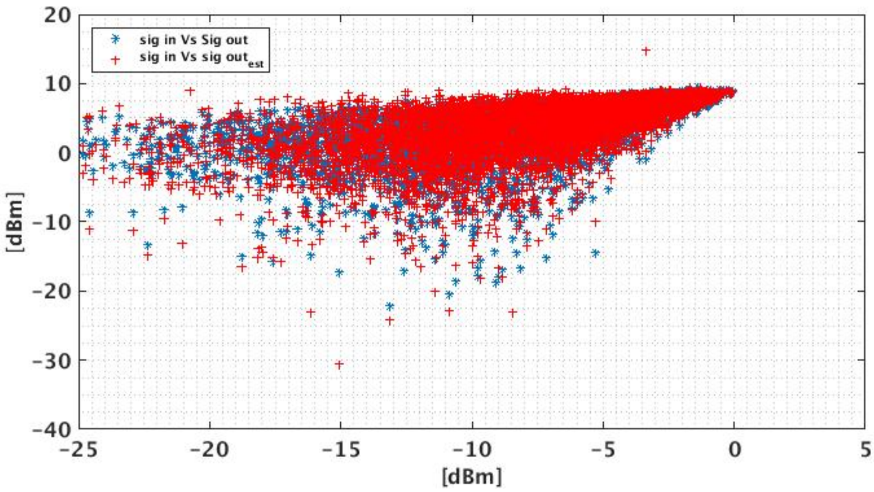


Figure A.1-12 Input Signal VS Output Signal at 31 GHz.

The polynomial degree K used for this PA was 8 and polynomial memory depth M value was 5. The memory polynomial allows the use of high K and M terms for calculating the matrix coefficients but with a less computer complexity compared to Volterra series.

In A.1-11 and A.1-12 the Power Spectral Density (PSD) and the input versus the output signal have been plotted for the 31 GHz PA. The PSD shows more spectral regrowth compared to the PA below 6 GHz. In both figures the red curves represent the model estimated data and the blue curve the original measurement data. We can find the two traces of PSD fit also very well in pass band and adjacent channel. The average error in dB between value of PSD of measured data and that of model output is less than 1 dB. The calculated value of NMSE for this PA model is – 39 dB.

In Figure A.1.-12 it can be seen when including the memory effects that the characteristic of the PA behave no longer as a curve but rather as a diffusion region. These memory effects increase the calculation time to estimate the matrix coefficients of the memory polynomial and accurately model the PA.

The memory parameter calculated with the model are the following:

M = 5, K = 8,
a_{km} = [-10.0624 +14.6485i, 24.6983 -25.5192i, -28.6702 +24.4684i, 18.9709 -12.0500i, -5.3080 + 2.4235i, -63.1123 +

9.4912i, -18.2854 - 9.0971i, -33.6220 - 0.1089i, 28.2194 -25.5253i, -16.7754 +26.7834i, 1.2797e+03 -1.9632e+02i, 5.6546e+02 +1.4583e+02i, 6.7368e+02 -6.4518e+01i, -1.0422e+03 +7.0243e+02i, 5.1510e+02 -6.8161e+02i, -1.1576e+04 +9.9815e+02i, -8.6173e+03 -6.5709e+02i, -5.8579e+03 +1.7786e+02i, 1.4834e+04 -8.9848e+03i, -7.2260e+03 +8.4931e+03i, 5.7725e+04 -1.6098e+03i, 6.1271e+04 +2.1093e+03i, 3.0381e+04 +1.1418e+03i, -1.1167e+05 +6.4821e+04i, 5.6209e+04 -5.9278e+04i, -1.5194e+05 -5.1975e+03i, -2.3711e+05 -1.8474e+03i, -8.7976e+04 -1.4443e+04i, 4.5408e+05 -2.5881e+05i, -2.4165e+05 +2.3195e+05i, 1.8482e+05 +2.2474e+04i, 4.7763e+05 -9.1215e+03i, 1.3200e+05 +5.0018e+04i, -9.4830e+05 +5.3597e+05i, 5.3878e+05 -4.7644e+05i, -6.4854e+04 -2.2706e+04i, -3.9248e+05 +1.9477e+04i, -7.9196e+04 -5.8301e+04i, 7.9804e+05 -4.4917e+05i, -4.8561e+05 +4.0015e+05i]

Annex B: Usage of bands of interest for NR in Europe

The information in this annex are based on ERC Report 25 version that is approved as of June 2016.

Band (GHz)	ECA	Band Usage/Applications
24.25- 27.5 GHz		
Adjacent band: 24.05 – 24.25	RADIOLOCATION Amateur Earth Exploration-Satellite (active) Fixed Mobile 5.150 EU2	Active sensors (satellite) - Rain radars from satellites Amateur - Within the band 24-24.25 GHz Defence systems ISM - Within the band 24-24.25 GHz Non-specific SRDs - Within the band 24-24.25 GHz PMSE - SAP/SAB Radiodetermination applications - Within the band 24.05-27.00 GHz for TLPR application. Includes narrow band SRR. Within the band 24.05-26.50 GHz for LPR applications SRR - New SRR systems shall not be introduced in CEPT countries in the frequency bands 21.65-26.65 GHz as of 1 July 2013 TTT - Automotive radars
24.25- 24.5	FIXED MOBILE EU17A	Fixed - Unidirectional fixed links PMSE - SAP/SAB Radiodetermination applications. Within the band 24.05-27.00 GHz for TLPR application. Within the band 24.05-26.50 GHz for LPR applications SRR - New SRR systems shall not be introduced in CEPT countries in the frequency bands 21.65-26.65 GHz as of 1 July 2013. New SRR systems may only be introduced in CEPT countries in the frequency bands 24.25-26.65 GHz until 1 January 2018; this date is extended by 4 years for SRR equipment mounted on motor vehicles for which a type-approval application has been submitted and has been granted before 1 January 2018 TTT - Automotive radars
24.5 – 24.65	FIXED	BFWA - CRS paired with 25.5-26.5 GHz for FDD systems Fixed Radiodetermination applications - Within the band 24.05-27.00 GHz for TLPR application. Within the band 24.05-26.50 GHz for LPR applications SRR - New SRR systems shall not be introduced in CEPT countries in the frequency bands 21.65-26.65 GHz as of 1 July 2013. New SRR systems may only be introduced in CEPT countries in the frequency bands 21.65-26.65 GHz until 1 January 2018; this date is extended by 4 years for SRR equipment mounted on motor vehicles for which a type-approval application has been submitted and has been granted before 1 January 2018
24.65 – 25.25	FIXED FIXED-SATELLITE (EARTH-TO SPACE) 5.532B	BFWA - CRS paired with 25.5-26.5 GHz for FDD systems Fixed

		Radiodetermination applications - Within the band 24.05-27.00 GHz for TLPR application. Within the band 24.05-26.50 GHz for LPR applications SRR - New SRR systems shall not be introduced in CEPT countries in the frequency bands 21.65-26.65 GHz as of 1 July 2013. New SRR systems may only be introduced in CEPT countries in the frequency bands 21.65-26.65 GHz until 1 January 2018; this date is extended by 4 years for SRR equipment mounted on motor vehicles for which a type-approval application has been submitted and has been granted before 1 January 2018
25.25 – 25.5	FIXED INTER-SATELLITE 5.536 MOBILE	BFWA - CRS paired with 25.5-26.5 GHz for FDD systems Fixed Radiodetermination applications - Within the band 24.05-27.00 GHz for TLPR application. Within the band 24.05-26.50 GHz for LPR applications SRR - New SRR systems shall not be introduced in CEPT countries in the frequency bands 21.65-26.65 GHz as of 1 July 2013. New SRR systems may only be introduced in CEPT countries in the frequency bands 21.65-26.65 GHz until 1 January 2018; this date is extended by 4 years for SRR equipment mounted on motor vehicles for which a type-approval application has been submitted and has been granted before 1 January 2018
25.5 – 26.5	FIXED INTER-SATELLITE 5.536 MOBILE SPACE RESEARCH (SPACE-TOEARTH) 5.536C Earth Exploration-Satellite (space-to-Earth) 5.536B 5.536A	BFWA - TS should be paired with 24.5-25.5 GHz for FDD systems Fixed Radiodetermination applications - Within the band 24.05-27.00 GHz for TLPR application. Within the band 24.05-26.50 GHz for LPR applications SRR - New SRR systems shall not be introduced in CEPT countries in the frequency bands 21.65-26.65 GHz as of 1 July 2013. New SRR systems may only be introduced in CEPT countries in the frequency bands 21.65-26.65 GHz until 1 January 2018; this date is extended by 4 years for SRR equipment mounted on motor vehicles for which a type-approval application has been submitted and has been granted before 1 January 2018 Space research - Satellite payload telemetry
26.5 - 27	INTER-SATELLITE 5.536 MOBILE SPACE RESEARCH (SPACE-TO EARTH) 5.536C Earth Exploration-Satellite (space-to-Earth) 5.536B 5.536A EU27	Land military systems - Harmonised military band for fixed and mobile Systems Radiodetermination applications - Within the band 24.05-27.00 GHz for TLPR application. Within the band 24.05-26.50 GHz for LPR applications SRR - New SRR systems shall not be introduced in CEPT countries in the frequency bands 21.65-26.65 GHz as of 1 July 2013. New SRR systems may only be introduced in CEPT countries in the frequency bands 21.65-26.65 GHz until 1 January 2018; this date is extended by 4 years for SRR equipment mounted on motor vehicles for which a type-approval application has been submitted and has been granted before 1 January 2018 Space research - Satellite payload telemetry
27 – 27.5	FIXED INTER-SATELLITE 5.536 MOBILE Earth Exploration-Satellite	Land military systems - Harmonised military band for fixed and mobile systems

	(space-to-Earth) EU27	
Adjacent band: 27.5 GHz – 28.5 GHz	FIXED FIXED-SATELLITE (EARTH-TO SPACE) 5.484A 5.516B 5.539 5.538 5.540	BFWA - CRS paired with 28.5-29.5 GHz for FDD systems. The Earth-to-Space direction for uncoordinated Earth stations within the band 27.5-27.8285 GHz. The Space-to-Earth direction is limited to beacons for uplink power control 27.5-27.501 GHz FSS Earth stations - The Earth-to-Space direction for uncoordinated Earth stations within the band 27.5-27.8285 GHz..The Space-to-Earth direction is limited to beacons for uplink power control 27.5-27.501 GHz Feeder links Feeder links to be used for Broadcasting satellites (HDTV) 27.5-29.5 GHz Fixed - For frequency arrangement between FS and FSS see ECC/DEC/(05)01 GSO ESOMPs NGSO ESOMPs
31.8-33.4 GHz		
Adjacent band: 31.5 – 31.8 GHz	EARTH EXPLORATION-SATELLITE (PASSIVE) RADIO ASTRONOMY SPACE RESEARCH (PASSIVE) Fixed Mobile except aeronautical mobile 5.149 5.546	Fixed Passive sensors (satellite) Measurement of sea ice, water vapour, oil spills, liquid water, clouds, surface temperature. Emissivity and atmospheric attenuation. Reference window for the 50-60 GHz range Radio astronomy - Continuum observations
31.8 – 32.3	FIXED 5.547A RADIONAVIGATION SPACE RESEARCH (DEEP SPACE) (SPACE-TO-EARTH) 5.547 5.548	Fixed - Point-to-Point and Point-to-Multipoint. High Density FS
32.3 – 33.4	FIXED 5.547A INTER-SATELLITE RADIONAVIGATION 5.547 5.548	Fixed - Point-to-Point and Point-to-Multipoint. High Density FS
Adjacent band above 33.4 GHz	RADIOLOCATION EU2 EU27	Radiodetermination applications - Surveying and measurement Radiolocation (military) - Harmonised military band for radiolocation systems
37-40.5 GHz		
Adjacent band: 36 - 37	EARTH EXPLORATION-SATELLITE (PASSIVE) FIXED MOBILE SPACE RESEARCH (PASSIVE) Radio Astronomy 5.149 5.550A EU27	Land military systems - Harmonised military band for radiolocation systems Passive sensors (satellite) - EESS surface emmissivity, snow, sea ice and Precipitation Radio astronomy - Spectral line observations (Hydrogen cyanide and Hydroxil lines) 36.43-36.50 GHz
37 – 37.5	FIXED SPACE RESEARCH (SPACE-TO EARTH) 5.547 EU2	Fixed - Major use by civil Fixed Service systems. High Density fixed links Land military systems - Low and medium capacity fixed links
37.5 - 38	FIXED-SATELLITE (SPACE-TO EARTH) SPACE RESEARCH (SPACE-TO EARTH) Earth Exploration-Satellite	FSS Earth stations - Uncoordinated Earth stations shall not claim protection from the Fixed Service Fixed - Major use by civil Fixed Service systems. High Density fixed links

	(space-to- Earth) 5.547 EU2	Land military systems - Low and medium capacity fixed links
38 – 39.5	FIXED FIXED-SATELLITE (SPACE-TO EARTH) Earth Exploration-Satellite (space-to- Earth) 5.547 EU2	FSS Earth stations - Uncoordinated Earth stations shall not claim protection from the Fixed Service Fixed - Major use by civil Fixed Service systems. High Density fixed links Land military systems - Low and medium capacity fixed links
39.5 – 40	FIXED FIXED-SATELLITE (SPACE-TO EARTH) 5.516B MOBILE MOBILE-SATELLITE (SPACE-TOEARTH) Earth Exploration-Satellite (space-to- Earth) 5.547 EU2	FSS Earth stations
40 – 40.5	FIXED FIXED-SATELLITE (SPACE-TO EARTH) 5.516B MOBILE MOBILE-SATELLITE (SPACE-TO EARTH) SPACE RESEARCH (EARTH-TO SPACE) Earth Exploration-Satellite (space-to- Earth) EU2	FSS Earth stations
Adjacent band: 40.5 – 41 GHz	BROADCASTING BROADCASTING-SATELLITE FIXED 5.547	FSS Earth stations Fixed - Point-to-point and terrestrial multipoint systems MWS - Point-to-point and terrestrial multipoint systems
40.5-42.5 GHz		
Adjacent band: 40 – 40 - 40.5 GHz	FIXED FIXED-SATELLITE (SPACE-TO EARTH) 5.516B MOBILE MOBILE-SATELLITE (SPACE-TO EARTH) SPACE RESEARCH (EARTH-TO SPACE) Earth Exploration-Satellite (space-to- Earth) EU2	FSS Earth stations
40.5 – 42.5	BROADCASTING BROADCASTING-SATELLITE FIXED 5.547 5.551H 5.551I	FSS Earth stations Fixed - Point-to-point and terrestrial multipoint systems MWS - Point-to-point and terrestrial multipoint systems
Adjacent band : 42.5 – 43.5	FIXED FIXED-SATELLITE (EARTH-TO SPACE) 5.552 MOBILE EXCEPT AERONAUTICAL MOBILE RADIO ASTRONOMY 5.149 5.547	FSS Earth stations - Priority for civil networks Fixed - Point-to-point and terrestrial multipoint systems MWS - Point-to-point and terrestrial multipoint systems Radio astronomy - Continuum and spectral line observations (e.g. silicon monoxide line), VLBI
42.5 – 43.5 GHz		
Adjacent band :	BROADCASTING	FSS Earth stations

40.5 – 42.5	BROADCASTING-SATELLITE FIXED 5.547 5.551H 5.551I	Fixed - Point-to-point and terrestrial multipoint systems MWS - Point-to-point and terrestrial multipoint systems
42.5 – 43.5	FIXED FIXED-SATELLITE (EARTH-TOSPACE) 5.552 MOBILE EXCEPT AERONAUTICAL MOBILE RADIO ASTRONOMY 5.149 5.547	FSS Earth stations - Priority for civil networks Fixed - Point-to-point and terrestrial multipoint systems MWS - Point-to-point and terrestrial multipoint systems Radio astronomy - Continuum and spectral line observations (e.g. silicon monoxide line), VLBI
Adjacent band: 43.5 - 45.5 GHz	MOBILE 5.553 MOBILE-SATELLITE Fixed-Satellite 5.554 EU27	Defence systems - Harmonised military band for satellite uplinks and mobile systems
45.5-47 GHz		
Adjacent band: 43.5 - 45.5 GHz	MOBILE 5.553 MOBILE-SATELLITE Fixed-Satellite 5.554 EU27	Defence systems - Harmonised military band for satellite uplinks and mobile systems
45.5 - 47	MOBILE 5.553 MOBILE-SATELLITE RADIONAVIGATION RADIONAVIGATION-SATELLITE 5.554	Not allocated
Adjacent band: 47 – 47.2	AMATEUR AMATEUR-SATELLITE	Amateur Amateur-satellite
47 – 47.2		
Adjacent band: 45.5 - 47	MOBILE 5.553 MOBILE-SATELLITE RADIONAVIGATION RADIONAVIGATION-SATELLITE 5.554	Not allocated
47 – 47.2	AMATEUR AMATEUR-SATELLITE	Amateur Amateur-satellite
Adjacent band: 47.2 GHz - 47.5	FIXED FIXED-SATELLITE (EARTH-TOSPACE) 5.552 MOBILE 5.552A	FSS Earth stations. For fixed applications. Priority for civil networks Feeder links. For 40 GHz Broadcasting satellites HAPS PMSE SAP/SAB
47.2 – 50.2		
Adjacent band: 47 – 47.2	AMATEUR AMATEUR-SATELLITE	Amateur Amateur-satellite
47.2 GHz - 47.5 GHz	FIXED FIXED-SATELLITE (EARTH-TO SPACE) 5.552 MOBILE 5.552A	FSS Earth stations. For fixed applications. Priority for civil networks Feeder links. For 40 GHz Broadcasting satellites HAPS PMSE SAP/SAB
47.5 – 47.9 GHz	FIXED FIXED-SATELLITE (EARTH-TO SPACE) 5.552 FIXED-SATELLITE (SPACE-TOEARTH) 5.516B 5.554AMOBILE	FSS Earth stations High Density FSS Feeder links For 40 GHz Broadcasting satellites PMSE SAP/SAB

47.9 GHz - 48.2 GHz	FIXED FIXED-SATELLITE (EARTH-TO SPACE) 5.552 MOBILE 5.552A	FSS Earth stations For fixed applications. Priority for civil networks Feeder links For 40 GHz Broadcasting satellites HAPS PMSE SAP/SAB
48.2 GHz - 48.54 GHz	FIXED FIXED-SATELLITE (EARTH-TO SPACE) 5.552 FIXED-SATELLITE (SPACE-TO EARTH) 5.516B 5.554A 5.555B MOBILE	FSS Earth stations High Density FSS Feeder links For 40 GHz Broadcasting satellites Fixed Within the band 48.5-50.2 GHz and 50.9-52.6 GHz PMSE SAP/SAB
48.54 GHz - 49.44 GHz	FIXED FIXED-SATELLITE (EARTH-TO SPACE) 5.552 MOBILE RADIO ASTRONOMY 5.149 EU17A 5.340 5.555	FSS Earth stations For fixed applications. Priority for civil networks Feeder links 48.5-49.2 GHz for 40 GHz Broadcasting satellites Fixed - Within the band 48.5-50.2 GHz and 50.9-52.6 GHz PMSE SAP/SAB Radio astronomy - Spectral line observations (e.g. carbon monosulphide line)
49.44 GHz - 50.2 GHz	FIXED FIXED-SATELLITE (EARTH-TO SPACE) 5.338A 5.552 FIXED-SATELLITE (SPACE-TOEARTH) 5.516B 5.554A 5.555B MOBILE EU17A	FSS Earth stations - High Density FSS Fixed - Within the band 48.5-50.2 GHz and 50.9-52.6 GHz PMSE - SAP/SAB
Adjacent band: 50.2 – 50.4	EARTH EXPLORATION-SATELLITE (PASSIVE) SPACE RESEARCH (PASSIVE) 5.340	Passive sensors (satellite) - Atmospheric temperature sounding. Terrestrial passive radiometers. Reference window for the 52.6-59.3 GHz band Radio astronomy - Continuum and spectral line observations
50.4-52.6 GHz		
Adjacent band: 50.2 – 50.4	EARTH EXPLORATION-SATELLITE (PASSIVE) SPACE RESEARCH (PASSIVE) 5.340	Passive sensors (satellite) - Atmospheric temperature sounding. Terrestrial passive radiometers. Reference window for the 52.6-59.3 GHz band Radio astronomy - Continuum and spectral line observations
50.4 – 51.4	FIXED-SATELLITE (EARTH-TO SPACE) 5.338A Mobile-Satellite (Earth-to-space) EU2	Future satellite and terrestrial applications. Shared civil and non civil allocation Fixed within the band 48.5-50.2 GHz and 50.9-52.6 GHz
51.4 GHz - 52.6 GHz	FIXED 5.338A MOBILE RADIO ASTRONOMY 5.547 5.556	Fixed within the band 48.5-50.2 GHz and 50.9-52.6 GHz Radio astronomy - Continuum and spectral line observations
Adjacent band: 52.6 -54.25	EARTH EXPLORATION-SATELLITE (PASSIVE) SPACE RESEARCH (PASSIVE) 5.340 5.556	Passive sensors (satellite) - Atmospheric temperature sounding. Terrestrial passive radiometers Radio astronomy - Continuum and spectral line observations
66-76 GHz		
Adjacent band: 65 - 66	EARTH EXPLORATION-SATELLITE FIXED INTER-SATELLITE MOBILE EXCEPT AERONAUTICAL MOBILE SPACE RESEARCH	Fixed - High density fixed links Land mobile - Broadband mobile systems for connection to IBCN paired with 62-63 GHz Wideband data transmission systems

	5.547	
66-71	INTER-SATELLITE MOBILE 5.553 5.558 MOBILE-SATELLITE RADIONAVIGATION RADIONAVIGATION-SATELLITE 5.554	ERC Report 25 shows no applications in Europe
71-74	FIXED FIXED-SATELLITE (SPACE-TO EARTH) MOBILE MOBILE-SATELLITE (SPACE-TOEARTH) EU27	Defence systems. Harmonised military band. Pairing with 81-84 GHz is envisaged Fixed
74 – 75.5	BROADCASTING BROADCASTING-SATELLITE FIXED FIXED-SATELLITE (SPACE-TOEARTH) MOBILE Space Research (space-to-Earth) 5.561	Fixed Radiodetermination applications. Within the band 75-85 GHz for TLPR and LPR applications Space research. VLBI measurements within the band 74-84 GHz
75.5 - 76	BROADCASTING BROADCASTING-SATELLITE FIXED FIXED-SATELLITE (SPACE-TOEARTH) Amateur Amateur-Satellite 5.561 EU2, EU35	Amateur Amateur-satellite Radiodetermination applications. Within the band 75-85 GHz for TLPR and LPR applications Space research. VLBI
Adjacent band: 76 – 77.5	BROADCASTING BROADCASTING-SATELLITE FIXED FIXED-SATELLITE (SPACE-TO EARTH) Amateur Amateur-Satellite 5.561 EU2 EU35	Amateur - Within the band 75.5-81.5 MHz Amateur-satellite - Within the band 75.5-81.5 MHz Fixed Radiodetermination applications - Within the band 75-85 GHz for TLPR and LPR applications Space research - VLBI
81-86		
Adjacent band: 79 - 81	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-Satellite 5.149 EU2	Amateur - Within the band 75.5-81.5 GHz Amateur-satellite - Within the band 75.5-81.5 GHz Radio astronomy - Continuum and spectral line observations Radiodetermination applications - Within the band 75-85 GHz for TLPR and LPR applications Radiolocation (civil) Radiolocation (military) SRR
81 - 84	FIXED 5.338A FIXED-SATELLITE (EARTH-TO SPACE) MOBILE MOBILE-SATELLITE (EARTH-TO SPACE) RADIO ASTRONOMY Space Research (space-to-Earth) 5.149 EU27 5.561A	Amateur within the band 75.5-81.5 GHz Amateur-satellite within the band 75.5-81.5 GHz Defence systems. Harmonised military band. Paring with 71-74 GHz is envisaged Radio astronomy Radiodetermination applications. Within the band 75-85 GHz for TLPR and LPR applications
84 - 86	FIXED 5.338A FIXED-SATELLITE (EARTH-TO SPACE) MOBILE	Fixed Radio astronomy

	RADIO ASTRONOMY 5.149	Radiodetermination applications. Within the band 75-85 GHz for TLPR and LPR applications
Adjacent band: 86 - 92	EARTH EXPLORATION-SATELLITE (PASSIVE) RADIO ASTRONOMY SPACE RESEARCH (PASSIVE) 5.340	Passive sensors (satellite) - Measurement of clouds, oil spills, ice, snow, rain, reference window for the temperature sounding near 118 GHz Radio astronomy - Continuum and spectral line observations. VLBI

Annex C: Array antenna theory

In general, an array antenna design consists of several parts; radiating elements, a finite ground plane and mechanical structure components. The elements are typically placed in a lattice on the ground plane. The individual location of each element together with the radiation characteristics of each element determines the composite array antenna characteristics.

The element characteristics in terms of radiation properties (aka. element factor) depends on the area for which the array antenna is intended to provide coverage within.

In general, for a single polarized element, the individual embedded element pattern for an array antenna with N elements is described as:

$R_n(\theta,\varphi,f)$, where n=1..N.

An array antenna consists of many radiating elements located close to each other under a weather proof encapsulation. The locations of the n-th element in an antenna array can be described by; $\mathbf{r}_n = (x_n, y_n, z_n)$.

For the transceiver direction, each element in the array antenna is feed with a signal s(t) from a transmitter. The array antenna beam is determined by the weighting factor $w_n(t)$.

For a single polarized array antenna, the transmitted signal is created from super positioning in the far-field region. The composite field strength can be expressed as:

$$E(\theta,\varphi,f,t) = \sum_{n=1}^{N} R_n(\theta,\varphi,f)s(t)w_n(t)e^{-j\mathbf{k}(\theta,\varphi,f)\mathbf{r}_n}$$

, where $\mathbf{k}$ is the wave vector defined as:

$$\mathbf{k}(\theta,\varphi,f) = (k_x,k_y,k_z) = \frac{2\pi f}{c}(\sin(\theta)\cos(\varphi),\sin(\theta)\sin(\varphi),\cos(\theta))$$

The wave vector refers to a vector that describes the phase variation of a plane wave, in 3 orthogonal directions.

Since elements are located close to each other the radiation characteristics for individual elements will not be the same in the whole array. This phenomenon is referred to as mutual coupling. That means that the element factor R, cannot be seen independent of the element separation. The element separation also relates to radiation characteristics by means of spatial sampling resolution. Typically, for an array implementation where the element separation is larger than 0.5λ, gating lobe performance will be affected.

Generally, the maximum steering without grating lobes can be expressed as:

$$\frac{d}{\lambda} < \frac{1}{1+\sin(\varphi_{\max})}$$

, where d is the element separation and φ_{max} is the maximal steering angle (along one dimension).

If the spatial sampling criterion is not fulfilled folding effect will occur creating a grating lobe response. Therefore, the element separation often is set close to 0.5λ for system using large steering angles. However, when the elements are close the interaction between them is more severe, which results in ripple in radiation pattern per element level. Therefore, the element beam-width will be different. The element directivity is dependent on the element aperture which is of course effected by the element spacing, i.e. a 0.7λ element cannot be spaced at 0.5λ. Hence the interaction between element separation and element radiation characteristics is a delicate challenge to resolve. Typical element separation is in the range of 0.5λ to 0.7λ. The consequence of grating lobes is that energy will be spread in unintended direction, this may or may not be harmful for the system from an interference perspective. Nevertheless, the power in the intended direction drops because of large grating lobes. From a system design perspective, grating lobes, and the fact that the effective antenna area is reduced due to projection will reduce the directivity. This phenomenon is referred to as scan-loss. The scan-loss will impact EIRP in the intended direction. This effect needs considerations from a system perspective.

This means that the radiated power is a complex function of deployment parameters such as steering angle and design parameters such as antenna mutual coupling. A common phenomenon is referred to as scan-blindness, where EIRP drops unexpectedly due to interactions between coupling characteristics and excitation of the array. Note that EIRP can be affected by both scan-loss and scan-blindness at large steering angles, which means that the radiated power will drop considerably.

Another aspect is that radiation the individual radiation patterns or embedded radiation pattern will suffer from mutual coupling. The embedded pattern is distorted with a ripple, where characteristics such as beam pointing direction and beam-width may be impacted.

A simple and ideal, but still quite realistic, model for the element pattern should satisfy the earlier explained relation:

$$E(\theta,\varphi,f,t) = EF \cdot AF$$

Written as power, or gain, patterns, the array antenna gain can be expressed as:

$$G(\theta,\varphi,f,t) = |E(\theta,\varphi,f,t)|^2 = |EF(\theta,\varphi,f)|^2 \cdot |AF(\theta,\varphi,f,t)|^2$$

If the element distances in the array are small enough to not produce any grating lobes, and the array is a planar array, the maximum array gain for any scan angle should equate the gain of a planar aperture, i.e.

$G = \frac{4\pi A}{\lambda^2}\cos(\phi)$, where A is the total area of the antenna array and ϕ is the angle off the normal direction.

Here we also neglect all losses related to reflections and mutual coupling. The factor $\cos(\phi)$ comes from the projection of the array area as seen in the direction of observation. Maximum array gain is achieved when all elements have the same amplitude, and are co-phased in the scan direction, i.e. the array factor.

$$|AF|^2 = \left(\sum_{n=1}^{N} \frac{1}{\sqrt{N}} \right)^2 = N$$

This implies that the element factor should be:

$|EF(\phi)|^2 = \frac{4\pi A}{N\lambda^2}\cos(\phi) = \frac{4\pi d_x d_y}{\lambda^2}\cos(\phi)$, where d_x and d_y are the element distances in x and y direction. The 3 dB beamwidth thus becomes $HPBW = 2a\cos(0.5) = 120$ degrees and the maximum element gain for an array with 0.5λ element spacing is π, or ~5 dBi.

In practice, however, the 3 dB beam width is lower than 120°, typically around 90° to 100°. This discrepancy to the theoretical 120° 3 dB beam width derived above is partly due to power loss from mutual coupling effects, which typically gets higher for larger scan angles. The element pattern beam width should also be related to the element gain, since element gain is only a measure on how focused the energy is in the far-field. An approximate formula for planar arrays [x], relating the gain and beam widths is

$G = \frac{32400}{HPBW_1 \cdot HPBW_2}$, where $HPBW_1$ and $HPBW_1$ are the 3dB beam widths in two orthogonal planes. Combining this way of calculating the maximum gain with the above expression relating the maximum element gain with the antenna area yields

$HPBW_1 \approx \frac{51}{\frac{d_x}{\lambda}}$ [degrees] and $HPBW_2 \approx \frac{51}{\frac{d_y}{\lambda}}$ [degrees]

A practical element pattern model could be a Gaussian pattern with peak gain equal to $G_{0,element} = \frac{4\pi d_x d_y}{\lambda^2}$

and beam widths related to the element distance as described above. This model would thus to some degree account for reflection and mutual coupling losses for large scan angles and losses due to grating lobes. It also scales the antenna element patterns gain and beam widths with the element spacing of the array in such a way that the superposition of all the elements in the array gives a total antenna gain equal to the array area.

Annex D: prerequisites for assessment UE beamforming performance

In this annex we list the prerequisites for the assessment of beamforming performance with 4 and 8 antennas at 15 GHz. The purpose is to indicate the ballpark gains of UL beamforming and how these gains change under different channel conditions, precoding and CSI feedback. The metrics for evaluation are the increase of the wanted UL signal power at the connected BS and any interference reduction seen at the other BS. The *channel model* is as follows: each realization of the channel is a superposition of

- Nray pairs of rays
  - a pair of rays is a model of a path between the BS equipped with two orthogonally polarized antennas (or rather beams) and the UE
  - each ray is dual polarized with the two polarizations subject to independent Rayleigh fading
  - the angle-of-arrival AOA (= AOD) is randomly selected per pair; the azimuth distribution is uniform $[-180^{\circ} 180^{\circ}]$ and the elevation angle is uniform $[60^{\circ}\ 90^{\circ}]$ (see description of the UE antenna patterns below)
  - all antennas on the UE see the same type of channel but channel responses differ due to different locations, orientations and polarizations for the UE antennas, which means that different UE antennas see different sub-channels.

Elevation angles in the range $[60^{\circ}\ 90^{\circ}]$ has been assumed and evaluated for this study; this does not imply any restriction on the UE antenna patterns in general.

Furthermore, a channel realization consists of a set of 1, 10 or 50 pairs of rays. Each pair has the same direction (assuming dual polarized BS antenna) but the polarizations are subject to independent fading modeled as a complex Gaussian. The directions for the pairs of rays are independent from each other. The received signal per UE antenna is the coherent sum of the antenna responses for all rays, see Figure D-1.

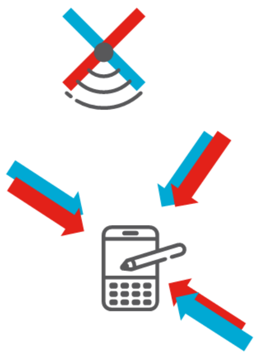


Figure D-1: received DL signal as a coherent sum of dual-polarized rays.

In the frequency domain a block fading channel has been assumed with either 1 block (narrowband) or 25 blocks, where the fading is independent between the blocks. The total power over all the block(s) is observed at the BS.

The *precoding* for UL transmissions is based on either reciprocity or feedback. We assume that the hardware is reciprocal w r t UL and DL.

For reciprocity the following precoders are evaluated for transmission based on reciprocity:

1. Maximum ratio transmission (MRT) for which the precoder w_{MRT} is the eigenvector corresponding to the largest eigenvalue of the channel correlation matrix

2. Phase-only (PO) precoding with $w_{PO,k} = w_{MRT,k} \cdot \frac{1}{|w_{MRT,k}|} \frac{1}{\sqrt{n_{UE}}}$ where n_{UE} is the number of UE antennas, i.e. the phase-only precoder is constant modulus where the phase component is given by w_{MRT}

3. Antenna selection (AS): select the strongest antenna per block

For reference, the performance for a single isotropic antenna is evaluated.

The precoder codebooks for closed-loop beamforming have been defined for rank = 1 only, where the constellation is based on QPSK, i.e. four different phases and equal amplitude. Two types of precoders have been devised:

1. Codebook type 1 for no correlation between antennas (channels), antennas

2. Codebook type 2 for a combination of full correlation and no correlation between antennas (channels), the codebook sizes 16, 32 and 64 evaluated for 4 and 8

Two types of *power distribution (PA configuration)* have been evaluated:

1. Common resource (Com), the total output power is limited

2. Distributed resource (Dist), the total output power is equally shared between antennas; the available, but not necessarily used, output power per antenna in this case is $Ptot/n_{UE}$

The precoders are normalized such that the magnitude is unity for common PA, whereas the maximum magnitude per PA is 1/sqrt(n_{UE}) for distributed PAs. The total output power is the same no matter the number of antennas; the radiated power depends on the precoder configured and the PA configuration. The distributed resource is more likely at mm-wave frequencies with the PA closer to the antenna to reduce feeder losses, see Figure 6.2.1.1.3-1. The PO precoder is designed with this architecture in mind.

The *UE prototype* is of a smartphone form factor as shown in Figure D-2 with the antennas indicated by the blue circles along the y-axis.

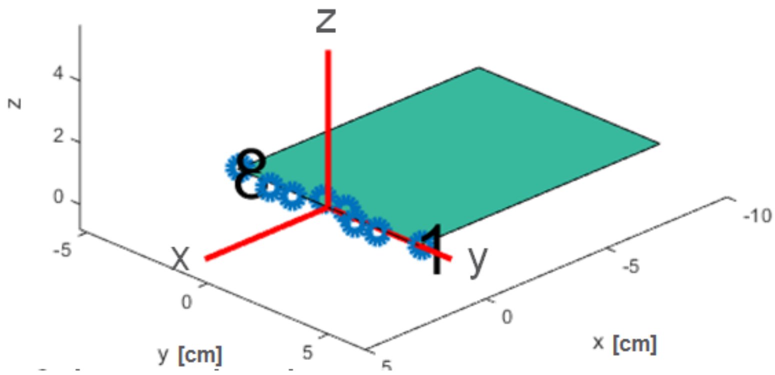


Figure D-2: antenna arrangement on the UE.

A sample pattern of one of the eight antenna elements is shown in Figure D-3 for the two polarization planes. The black rectangle indicates the evaluation area considered in this study: the pairs of rays in the channel model are launched such that the AOA in the DL (AOD in UL) is uniform $[-180^{\circ} 180^{\circ}]$ in azimuth and uniform in $[60^{\circ}\ 90^{\circ}]$ in elevation.

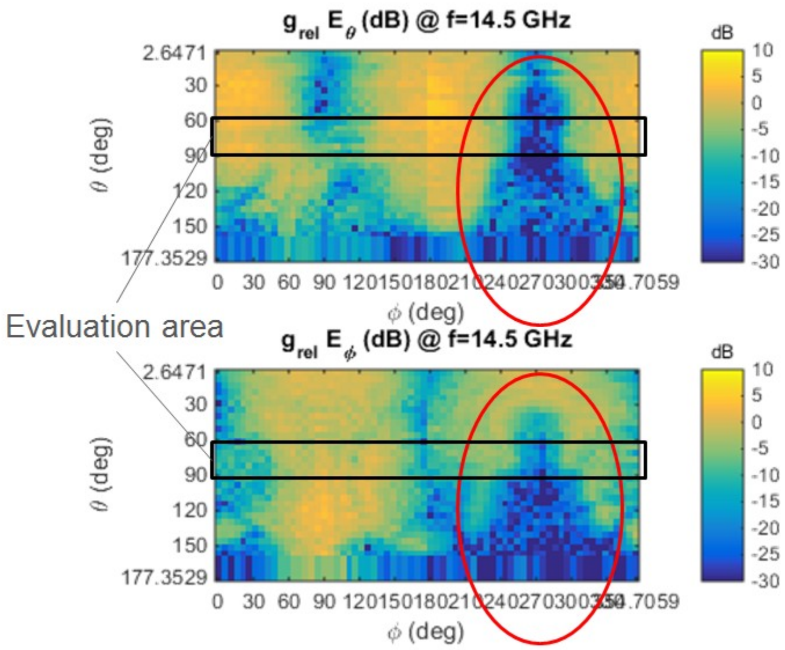


Figure D-3: sample pattern of one of the UE antenna elements.

Shadowing by a user (taking the measurement) is also noticeable: encircled in red is the area where the user is shadowing, which leads to a lower gain measured roughly between 240 and 300 degrees in azimuth.

The *metric for evaluation* is the total power in the UE at the 50% level. Figure D-4 shows the results at line-of-sight (LOS) for which the direction for one pair of rays (the direct path) uniformly distributed in the evaluation area indicated in Figure D-3. The precoding is based on reciprocity. The median gain relative to the "maximum element gain" is 7.5 dB and we observe a 0.8 dB difference between MRT and PO precoding.

The dotted curves indicate the performance in the shadowed region between 240 and 300 degrees azimuth, the gain is then lower than that achieved by a theoretical isotropic antenna (only a single antenna at the UE).

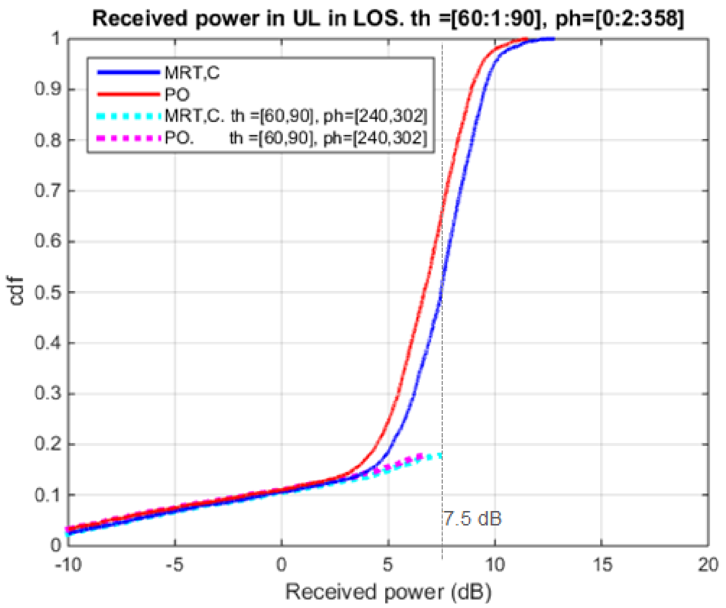


Figure D-4: performance at LOS.

Annex E: UE coordinate system

E.1 Reference coordinate system

This annex defines the measurement coordinate system for the NR UE. The reference coordinate system, reused from the LTE MIMO OTA definition in [30], is provided in Figure E.1-1 below

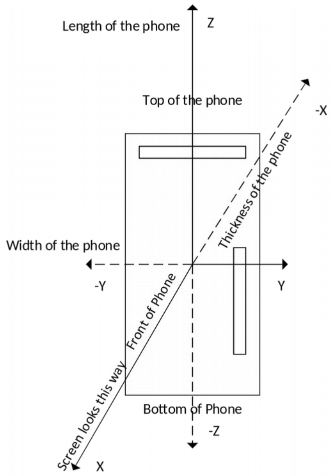


Figure E.1-1: Reference coordinate system

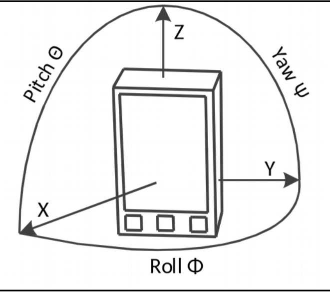
The following aspects are necessary:

- A basic understanding of the top and bottom of the device is needed in order to define unambiguous DUT positioning requirements for the test
- An understanding of the origin of the test system (i.e. the direction in which the x-axis points inside the test chamber) is needed in order to define unambiguous DUT orientation, DUT beam, signal, interference, and measurement angles

E.2 Test conditions and angle definitions

Table E.2-1 below provides the test conditions and angle definitions.

Table E.2-1: Test conditions and angle definitions

Test condition	DUT orientation	Link angle	Measurement angle	Diagram
Free space	Ψ=0; Θ=0; Φ=0	$\theta_{Link;}$ φ_{Link} with polarization reference $Pol_{Link} = \theta$ or ; φ	$\Theta_{Meas;}$ φ_{Meas} with polarization reference $Pol_{Meas} = \theta$ or ; φ	
NOTE 1: A polarization reference, as defined in relation to the reference coordinate system in E.1, is maintained for each signal angle, link or interferer angle, and measurement angle				

For each UE requirement and test case, each of the parameters in Table E.2-1 are defined as single values or ranges of values, such that DUT positioning, DUT beam direction, and angles of the signal, link/interferer, and measurement are specified.

Annex F: LS response on IMT parameters to ITU-R WP5D

This Annex details the Annex attached to the LS response to ITU-R WP5D on “Characteristics of terrestrial IMT systems for frequency sharing/interference analysis in the frequency range between 24.25 GHz and 86 GHz” [31].

IMT-2020 technology-related parameters in the frequency range 24.25-86 GHz

		IMT-2020	
No.	**Parameter**	**Base station**	**Mobile station**
1	**Duplex Method**	TDD	TDD
2	**Channel bandwidth (MHz)**	200 MHz	200 MHz
3	**Signal bandwidth (MHz)**	>90% of channel bandwidth	>90% of channel bandwidth

No.	**Parameter**	**IMT-2020 (Base station)**		
	Band of operation	**24.24 – 33.4 GHz**	**37 – 52.6 GHz**	**66 – 86 GHz**
4	**Transmitter characteristics**			
4.1	Power dynamic range (dB)	0 dB conducted BS output power		
4.2	Spectrum mask (Note 1)	For Indoor scenarios, see Table 1. For Outdoor scenarios and $P_{Tx} \geq 34.5$ dBm, see Table 2. For Outdoor scenarios and $P_{Tx} < 34.5$ dBm, see Table 3.	For Indoor scenarios, see Table 1. For Outdoor scenarios and $P_{Tx} \geq 32.5$ dBm, see Table 4. For Outdoor scenarios and $P_{Tx} < 32.5$ dBm, see Table 5.	For Indoor scenarios, see Table 1. For Outdoor scenarios and $P_{Tx} \geq 30.5$ dBm, see Table 6. For Outdoor scenarios and $P_{Tx} < 30.5$ dBm, see Table 7.
4.3	ACLR (Note 1)	27.5 dB	25.5 dB	23.5 dB
4.4	Spurious emissions	-13 dBm/MHz Total Radiated Power (Note 1). The feasibility of more stringent spurious domain emission limits is under investigation by 3GPP		
5	**Receiver characteristics**			
5.1	Noise figure	10 dB	12 dB	14 dB
5.2	Sensitivity	-	-	-
5.3	Blocking response	(Note 2)	(Note 2)	(Note 2)
5.4	ACS	23.5 dB	22.5 dB	21.5 dB
5.5	SINR operating range	The SINR mapping function is given below.		
Note 1: Unwanted emissions requirements are defined as Total Radiated Power (TRP). Note 2: ACS interfering signal level [dBm] = BS noise floor + NF + ACS + 4.7dB. Assumed interfering signal bandwidth is the same as the wanted signal channel BW (200MHz), assumed interfering				

No.	Parameter	IMT-2020 (Base station)
signal centre frequency offset to the wanted signal edge is at least 300MHz.		

No.	Parameter	IMT-2020 (Mobile station)		
	Band of operation	**24.24 – 33.4 GHz**	**37 – 52.6 GHz**	**66 – 86 GHz**
4	**Transmitter characteristics**			
4.1	Power dynamic range (dB)	63 dB		
4.2	Spectrum mask (Note 1)	See Table 8.		
4.3	ACLR (Note 1)	17 dB	16 dB	15 dB
4.4	Spurious emissions (Note 1)	-13 dBm/MHz		
5	**Receiver characteristics**			
5.1	Noise figure	10 dB	12 dB	14 dB
5.2	Sensitivity	-	-	-
5.3	Blocking response	(Note 2)	(Note 2)	(Note 2)
5.4	ACS	22.5 dB	21.5 dB	20.5 dB
5.5	SINR operating range	The SINR mapping function is given below.		
Note 1: Unwanted emissions requirements are defined as Total Radiated Power (TRP). Note 2: Blocking response can be derived from the ACS and NF as being: UE noise floor + NF + ACS + 4.7dB. Assumed interfering signal bandwidth is the same as the wanted signal channel BW (200MHz), assumed interfering signal centre frequency offset to the wanted signal edge is at least 300MHz.				

Spectrum emission mask tables

Table F-1: BS spectrum mask for Indoor scenarios in the frequency ranges 24.24 – 33.4 GHz, 37 – 52.6 GHz and 66 – 86 GHz

Frequency offset from "edge of transmission" Δf	Emission limit	Measurement bandwidth
0 ≤ Δf < 20 MHz	-12 dBm	1 MHz
20 MHz ≤ Δf < 400 MHz	-20 dBm	1 MHz
Δf > 400 MHz	Spurious domain limits	1 MHz

Table F-2: BS spectrum mask for Outdoor scenarios and P_{Tx} ≥ 34.5 dBm in the frequency range 24.24 – 33.4 GHz

Frequency offset from "edge of transmission" Δf	Emission limit	Measurement bandwidth
0 ≤ Δf < 20 MHz	-5 dBm	1 MHz
20 MHz ≤ Δf < 400 MHz	-13 dBm	1 MHz
Δf > 400 MHz	Spurious domain limits	1 MHz

Table F-3: BS spectrum mask for Outdoor scenarios and P_{Tx} < 34.5 dBm in the frequency range 24.24 – 33.4 GHz

Frequency offset from "edge of transmission" Δf	Emission limit	Measurement bandwidth
0 ≤ Δf < 20 MHz	-5 dBm	1 MHz
20 Mhz ≤ Δf < 400 MHz	Max(P_{Tx} – 47.5 dB, -20 dBm)	1 MHz
Δf > 400 MHz	Spurious domain limits	1 MHz

Table F-4: BS spectrum mask for Outdoor scenarios and P_{Tx} ≥ 32.5 dBm in the frequency range 37 – 52.6 GHz

Frequency offset from "edge of transmission" Δf	Emission limit	Measurement bandwidth
0 ≤ Δf < 20 MHz	-5 dBm	1 MHz
20 MHz ≤ Δf < 400 MHz	-13 dBm	1 MHz
Δf > 400 MHz	Spurious domain limits	1 MHz

Table F-5: BS spectrum mask for Outdoor scenarios and P_{Tx} < 32.5 dBm in the frequency range 37 – 52.6 GHz

Frequency offset from "edge of transmission" Δf	Emission limit	Measurement bandwidth
0 ≤ Δf < 20 MHz	-5 dBm	1 MHz
20 Mhz ≤ Δf < 400 MHz	Max(P_{Tx} – 45.5 dB, -20 dBm)	1 MHz
Δf > 400 MHz	Spurious domain limits	1 MHz

Table F-6: BS spectrum mask for Outdoor scenarios and P_{Tx} ≥ 30.5 dBm in the frequency range 66 – 86 GHz

Frequency offset from "edge of transmission" Δf	Emission limit	Measurement bandwidth
0 ≤ Δf < 20 MHz	-5 dBm	1 MHz
20 MHz ≤ Δf < 400 MHz	-13 dBm	1 MHz
Δf > 400 MHz	Spurious domain limits	1 MHz

Table F-7: BS spectrum mask for Outdoor scenarios and P_{Tx} < 30.5 dBm in the frequency range 66 – 86 GHz

Frequency offset from "edge of transmission" Δf	Emission limit	Measurement bandwidth
0 ≤ Δf < 20 MHz	-5 dBm	1 MHz

20 Mhz ≤ Δf < 400 MHz	Max(P_{Tx} – 43.5 dB, -20 dBm)	1 MHz
Δf > 400 MHz	Spurious domain limits	1 MHz

Table F-8: UE spectrum mask

Frequency offset from “edge of transmission” Δf	Emission limit	Measurement bandwidth
0 ≤ Δf < 20 MHz	-5 dBm	1 MHz
20 MHz ≤ Δf < 400 MHz	-13 dBm	1 MHz
Δf > 400 MHz	Spurious domain limits	1 MHz

SINR operating range and mapping function

The following equations approximate the throughput over a channel with a given SNIR, when using link adaptation:

$$Throughput\ (SNIR), bps/Hz = \begin{cases} 0 & for\ SNIR \\ \propto \cdot S(SNIR) & for\ SNIR_{MIN} \leq SNIR < SNIR_{MAX} \\ \propto \cdot S(SNIR_{MAX}) & for\ SNIR \geq SNIR_{MAX} \end{cases}$$

Where:

S(SNIR) Shannon bound, S(SNIR) $=\log_2(1+SNIR)$ [bps/Hz]
α Attenuation factor, representing implementation losses
$SNIR_{MIN}$ Minimum SNIR of the code set, dB
$SNIR_{MAX}$ Maximum SNIR of the code set, dB

The parameters α, $SNIR_{MIN}$ and $SNIR_{MAX}$ can be chosen to represent different modem implementations and link conditions. The parameters proposed in table 9 represent a baseline case, which assumes:

- 1:1 antenna configurations
- AWGN channel model
- Link Adaptation (see table 9 for details of the highest and lowest rate codes)
- No HARQ

Table F-9: Parameters describing baseline Link Level performance for 5G NR

Parameter	DL	UL	Notes
α	0.6	0.4	Represents implementation losses
$SNIR_{MIN}$, dB	-10	-10	Based on QPSK, 1/8 rate (DL) & 1/5 rate (UL)
$SNIR_{MAX}$, dB	30	22	Based on 256QAM 0.93(DL) & 64QAM 0.93 (UL)

Annex G: Change history

Change history							
Date	**Meeting**	**TDoc**	**CR**	**Rev**	**Cat**	**Subject/Comment**	**New version**
2016-05	R4#79	R4-164535				TR created	0.0.1
2016-08	R4#80	R4-166630				Approved Documents are included: R4-165262, R4-166631, R4-166712, and R4-167080.	0.1.0
2016-10	R4#80bis	R4-168456				Approved Documents are included: R4-168483, R4-167720, R4-168510, R4-168952, R4-168940, and R4-168793	0.2.0
2016-12	RP#74	RP-162256				Documents approved in RAN4#81 are included: R4-1610570, R4-1610573, R4-1610604, and R4-1610625.	1.0.0
2017-02	R4#82	R4-1701469				Approved Documents are included: R4-1609562, R4-1700069, R4-1700122, R4-1700205, R4-1700222, R4-1700254, R4-1700262. Note that R4-1609562 was approved in RAN4#81 but was not captured in version 1.0.0.	1.1.0
2017-03	RP#75	RP-170439				Documents approved in RAN4#82 are included: R4-1702085, R4-1702086, R4-1701564, R4-1702363, R4-1702358, R4-1702373, R4-1702036, R4-1702375, R4-1702372, R4-1702044, R4-1702045, R4-1702095, R4-1702047, R4-1702048, R4-1702377, R4-1702038, R4-1702097, R4-1702018, R4-1702367, R4-1702376, R4-1702059, R4-1702366, R4-1702368, R4-1702065, R4-1702061, R4-1702089, R4-1702053, R4-1702083, R4-1702370, R4-1702362, R4-1702001, R4-1702087, R4-1702088, R4-1702082	2.0.0
2017-03	RP#75	RP-170439				TR Approved	14.0.0
2017-06	RP#76	RP-171452	0002	1	B	Addition of background information on phase noise modelling	14.1.0
2017-06	RP#76	RP-171254	0003	1	F	CR for TR 38.803: Removing an error of conductive test of beam correspondence	14.1.0
2017-06	RP#76	RP-171452	0004	2	F	CR on Channel bandwidth/Transmission bandwidth configuration	14.1.0
2017-06	RP#76	RP-171452	0005	2	B	CR to TR 38.803: Relation with the existing specifications (section 7)	14.1.0
2017-06	RP#76	RP-171452	0006	1	F	CR to TR 38.803: RRM requirements cleanup	14.1.0
2017-06	RP#76	RP-171254	0009		F	OTA measurements in the radiative near field	14.1.0
2017-06	RP#76	RP-171254	0010		F	Sampling grids for UE TRP measurements	14.1.0
2017-06	RP#76	RP-171452	0011	1	B	CR to TR38.803: Occupied bandwidth	14.1.0
2017-09	RP#77	RP-171944	0014	2	F	Clarification on phase noise model	14.2.0
2017-09	RP#77	RP-171944	0015	1	F	CR to TS 38.803: Correction of antenna model gain	14.2.0