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Foreword

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- will** indicates that something is certain or expected to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document
- will not** indicates that something is certain or expected not to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document
- might** indicates a likelihood that something will happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

might not indicates a likelihood that something will not happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

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is (or any other verb in the indicative mood) indicates a statement of fact

is not (or any other negative verb in the indicative mood) indicates a statement of fact

The constructions "is" and "is not" do not indicate requirements.

1 Scope

The present document is a Technical Report for Rel-19 Radio Frequency (RF) requirements for Low-Power Wake-up Signal and Receiver (LP-WUS/WUR). The purpose is to gather the relevant background information and analysis to address RF requirements for LP-WUS/WUR.

This TR contains discussions and agreements for LP-WUS/WUR RF. The actual RF requirements are added to the corresponding technical specifications.

2 References

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- [1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".
- [2] 3GPP TR 38.869: "Study on low-power Wake-up Signal and Receiver for NR".
- [3] 3GPP TS 38.101-1: "NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone".
- [4] 3GPP TS 38.101-2: "NR; User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone".
- [5] 3GPP TS 38.104: "NR; Base Station (BS) radio transmission and reception".

3 Definitions of terms, symbols and abbreviations

3.1 Terms

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

Main radio (MR): the Tx/Rx module operating for NR signals/channels apart from signals/channel related to low-power wake-up.

LP-WUR (LR): The Rx module operating for receiving/processing signals/channel related to low-power wake-up.

LP-WUS power boosting: difference between the average power of LP-WUS REs (which occupy certain REs within a NR transmission bandwidth configuration) and the average power over all REs (from both LP-WUS and the NR carrier containing the LP-WUS REs)

3.2 Symbols

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

<symbol>	<Explanation>
N_{RB}	Transmission bandwidth configuration, expressed in units of resource blocks
$N_{RB,LP-WUS}$	Number of RBs for LP-WUS

3.3 Abbreviations

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

<ABBREVIATION>	<Expansion>
ACS	Adjacent Channel Selectivity
ADC	Analog to Digital Converter
ASCS	Adjacent Subcarrier selectivity
BB	Base Band
BLER	Block Error Rate
BPF	Band Pass Filter
BS	Base Station
CFO	Center frequency offset
FAR	False Alarm Rate
FR1	Frequency range 1
FR2	Frequency range 2
ICS	In-channel Selectivity
IF	Intermediate Frequency
LP-WUS	Low Power-Wake Up Signal
LP-WUR	Low Power-Wake Up Receiver
LP-SS	Low Power- Synchronization Signal
LO	Local Oscillator
LNA	Low Noise Amplifier
LPF	Low Pass Filter
LR	LP-WUR
MDR	Miss Detection Rate
MR	Main Radio
NF	Noise Figure
OOB	Out-of-band
OOK	On-Off keying
OFDM	Orthogonal Frequency Division Multiplexing
RE	Resource Element
REFSENS	Reference Sensitivity
RF	Radio Frequency
SCS	Subcarrier spacing
SINR	Signal to Interference plus Noise Ratio
SNR	Signal to Noise Ratio
UE	User Equipment
Tx	Transmitter

4 Background

The present document is a technical report for Rel-19 Radio Frequency (RF) requirements for Low-Power Wake-up Signal and Receiver (LP-WUS/WUR). It covers RF requirements analysis for both UE and BS side. Some initial analysis of RF aspects for LP-WUS/WUR were captured in TR 38.869 [2].

5 System parameters

5.1 General

The channel arrangements presented in this clause for LP-WUS are based on the operating bands and channel raster defined in sub-clause 5.2 and 5.3 below.

5.2 Operating bands

LP-WUS is designed to operate in the operating bands defined in Table 5.2-1 of TS 38.101-1 [3] and TS 38.101-2 [4], excluding bands n46, n47, n96, n102 and SDL bands.

5.3 Channel raster

The PRB grid between LR and MR is aligned and the LP-WUS RBs can be flexibly allocated within the wider NR carrier. How to make sure the RB alignment between LP-WUS RB and MR RB grid is aligned is UE implementation specific.

6 Simulation assumptions and evaluation

6.1 Performance metric

For RF requirements and conformance testing, the performance metric is 1% MDR. Meanwhile, the FAR assumption for MDR evaluation is $\leq 1\%$.

6.2 Simulation assumption

6.2.1 General

To evaluate the RF performance of LP-WUS/WUR, the link level simulation is performed in this WI. This clause captures the simulation assumption for LP-WUS UE RF and BS RF analysis.

6.2.2 Simulation parameters

For RF performance analysis, the following simulation assumptions are considered.

Table 6.2.2-1 General Link level simulation assumption for FR1 LP-WUR

Attributes	Assumptions
Waveform	OOK-4 waveform
Center frequency	900MHz, 2.6GHz and 3.5GHz
Channel structure	5 bits
RM coding	8/16/32bit for OOK
CRC	NO
Chip rate	M=4
overlaid OFDM sequence	4 candidates overlaid sequences for M=4
WUS duration	OOK: RM coding length*2/M OFDM: $\text{ceil}(5/\log_2(4)/(M/2))$
Coding	1/2 rate Manchester coding
Time error	0/0.9 us
Residual Frequency error	0/10/20 ppm
SCS	30kHz
UE Channel BW	20MHz (51 RB)-case 1 10MHz (24 RB)-case 2 5MHz (11 RB)-case 3
WUS RB	- Fixed 11RB ~ 3.96MHz for 10MHz and 20MHz cases
Position within channel	- For 10/20MHz CBW, Center for ASCS, edge for ACS [assume no ASCS impact] - For 5MHz CBW, fixed center of channel
Guardband of NR channel, both wanted	- For wanted signal: 505kHz for 5MHz, 665kHz for 10MHz, 805kHz for 20MHz - For interference cell2 5MHz: fixed 505kHz

cell and interfer cell (ACS)	
Guard RB	For ASCS: 0 or 1RB on each side of LP-WUS bandwidth For ACS: 1/2/3/4 RB
Filter	3th/5th Order lowpass Butterworth matching fixed 3.96MHz RF bandwidth for 10MHz/20MHz case - Other order lowpass filter is not precluded The filter bandwidth is adapted with actual WUS RBs, for 5MHz case
ASCS	PDSCH mapped on RBs not used for LP-WUS and Guard RB; EPRE of PDSCH /EPRE of LP-WUS = 0 dB Same PSD with WUS signal
ACS	PDSCH mapped on interference RBs (11RB for 5MHz CBW), one side; EPRE of PDSCH /EPRE of in-band LP-WUS = [20~33] dB NOTE: decide the interference level depending on SNR
Wanted signal level	For ACS, REFSSENS + 14 dB for LP-WUS as baseline, different wanted power level can be also considered
Sampling rate	7.68MHz
ADC bit width	4/8 bits ADC for ASCS/ACS Encourage companies to provide simulation results with both options for comparison
Phase noise	Reciprocal mixing can be optionally considered for ASCS/ACS. Note that actual implementation choice of phase noise is driven by jammer requirement and power consumption target.
Non-linearities	Not modelled
Power boosting	EPRE ratio: 0dB/3dB for OOK-1/OOK-4 NOTE: 3dB is optional for simulation
Channel Model	AWGN
Performance metric	- 1% MDR - false alarm rate 1% as side condition
Note: The detailed Receiver algorithm is UE implementation .	

Table 6.2.2-2 General Link level simulation assumption for FR2 LP-WUR

Attributes	Assumptions		Notes
Case name (waveform)	OOK-1 waveform	OOK-4 waveform	
Center frequency	24300MHz		n258 example band
WUS structure	Total 8/16/32 bits		(placeholder for RAN1 decision)
Chip rate	M=1	M=1/2/4	
Coding	1/2 rate Manchester coding		
Time error	up to UE implementation		Difficult to separate time and frequency errors in realistic receivers
Residual Frequency error	0/10/20 ppm		
SCS	120kHz		
UE Channel BW	200MHz (132 RB)-case 1 100MHz (66 RB)-case 2		
WUS RB	Fixed 11RB		Based on agreement in RAN1#118-Bis
Position within channel	Center for ASCS, edge for ACS [assume no ASCS impact]		
Guardband of NR channel, both wanted cell and interfer cell (ACS)	Refer to 5.3.3 in TS38.101-2		
Guard RB	For ASCS: 0 or 1RB on each side of LP-WUS bandwidth For ACS: 1/2/3/4 RB		
Filter	3th/5th Order lowpass Butterworth		

	Other order lowpass filter is not precluded	
ASCS	PDSCH mapped on RBs not used for LP-WUS and Guard RB; EPRE of PDSCH /EPRE of LP-WUS = 0 dB Same PSD with WUS signal	
ACS	PDSCH mapped on interference RBs (11RB for 5MHz CBW), one side; NOTE: decide the interference level depending on SNR	
Wanted signal level	For ACS, REFSSENS + 14 dB for LP-WUS	
Sampling rate	TBD	
ADC bit width	4/8 bits ADC for ASCS/ACS Encourage companies to provide simulation results with both options for comparison	
Phase noise	FFS	
Non-linearities	Not modelled	
Power boosting	0dB/3dB for OOK-1/OOK-4 NOTE: 3dB is optional for simulation	
Channel Model	Option 1: TDL-C 100 Option 2: AWGN Note: encourage companies to provide simulation results with both options	The procedure for using CDL channel models in demod analysis is not fully established.

6.3 Simulation evaluation results

<Editor’s note: simulation results can be added further, if needed>

6.3.1 General

To evaluate some RF performance, link level simulations are performed to collect analysis input.

6.3.2 SNR simulations

In this sub-clause, SNR simulation results from different companies are collected for analysis of target SNR for LP-WUR.

Table 6.3.2-1 SNR simulation summary for FR1 Envelop-detection LP-WUR (OOK-4 M=4)

Companies Input	SNR	RM coding	Timing error	Note
A	-6 to -2dB	32/16/8	4us	-2.15 dB (8 bit), -4.63 dB (16 bit), -5.94 dB (32 bit)
B	-7 to -3dB		0us	5th order of lowpass Butterworth
C	-7.5 dB to -2.5dB	32/16/8	0us	simulated SNR with 4bit ADC or 8bit ADC is nearly the same
D	-7.1 to -2.5dB	32/16/8		OOK SNR: RM coding, 8bit with -2.5dB, 16bit with -5.3dB, 32bit with -7.1dB.
F	-7.7dB to -3.2dB	32/16/8	0/0.9us	0.9us TE will introduce less than 1dB degradation
G	-9.2 to -5.9dB			8bit with -5.9dB, 16bit with -7.5dB, 32bit with -9.2dB.
H	-8.0 dB	32 bits		under 4us TE has no impact
I	-7.8 to -5.9 dB	32/16/8		Payload: 5 bits with RM, w/o MC

Observations and Summary of SNR simulation outcome for envelop-detection receiver: most companies perform analysis based on RM coding of 8/16/32 bits, and majority views prefer to use 16bit RM coding as RMC and derive target SNR. The final target SNR is agreed as -4.5dB for LP-WUS envelop-detection.

Table 6.3.2-2 SNR simulation summary for FR1 OFDM-based LP-WUR

Companies Input	SNR	Timing error	Note
A	-4dB		no big difference for the applicable SNR for both OOK based and OFDM based signals
B	-4dB		
C	-5.5dB		
D	-7.4dB		
F	-8.0dB		OFDM-based receiver outperforms OOK-based receiver by 2.5~3dB SNR
G	-13.8 to -9.9dB		
H	-3.5dB		

Observations and Summary of SNR simulation outcome for OFDM-based receiver: There is no repetition for OFDM-based receiver, the simulated SNR from companies is not much far from the simulated performance of LP-WUS envelop-detection. With consideration of other impacted aspects, the final target SNR of OFDM-based receiver is also specified as -4.5dB.

6.3.3 ASCS simulations

In this sub-clause, ASCS simulation results from different companies are collected for analysis of in-band interference performance of LP-WUS. This is for information only, because actual implementation choice of filtering is driven by jammer requirements.

In SI phase, RAN4 reach the following conclusion for ASCS: *Based on the following analysis, RAN4 observed that for 5th order filter, the guard RB number for LP-WUS ASCS is in the range of 0RB ~ 1RBs for 30KHz SCS, or 0RBs ~2RBs for 15KHz SCS. Similar number of guard RBs could be applied also with lower filter orders as performance was observed to remain similar with 3rd order filter.*

In the WI phase, further detailed analysis is performed by companies, these analyses show a similar trend that the ASCS degradation is not that significant (0~1dB), even no guard RB is reserved.

Table 6.3.3-1 ASCS simulation summary for FR1 Envelop-detection and OFDM-based LP-WUR

Companies Input	SNR degradation	Guard RB	Phase noise	Note
A	nonnegligible	1	Considered	
B	negligible	0	N/A	the number of guard RB does not affect the MDR performance significantly
C	Less than 0.2dB	0	Considered	benefit of guard RB in ASCS case is minor
F	negligible	0	Considered	With 1 guard RB, there is minor improvement on the required SNR to achieve 1% BLER compared to 0 guard RB
H	1dB	0	WiFi phase noise	an approximately 1 dB of degradation in sensitivity level at MDR=1% for both AWGN channel and for the TD-L-C300 channel
J	~0.5dB	0	N/A	Maximum of 1 guard RB at each side

6.3.4 ACS simulations

In this sub-clause, ACS simulation results from different companies are collected for analysis of ACS performance of LP-WUR.

Editor: Companies perform analysis of ACS performance of LP-WUR with different approaches, e.g., link-level simulation similar to ASCS analysis (with/without consideration of phase noise), or mathematic analysis with similar equation of MR interferer level and ACS.

7 RF requirements

7.1 UE RF

<Editor's note: Analysis background for UE RF requirements can be added further, if needed.>

7.1.1 General

The minimum requirements will be determined assuming there is only one receiver. A 1% MDR criterion will be used for verification of all core RF requirements. Following LP-WUS parameters will be used

Table 7.1.1-1. Common reference channel parameters

Parameter	Unit	Value
MR Channel bandwidth	MHz	All CBW
LP-WUS bandwidth	RB	11
Subcarrier spacing	kHz	15/30kHz
RM coding	Bits	16
CRC		No CRC
Chip rate		M=4 (4 chips in an OFDM symbol)
Overlaid OFDM sequence		Length 33: generated by 31-length ZC sequence with extension
Number of overlaid OFDM sequence per chip to carry information		4
WUS duration for OOK		8 OFDM symbols
WUS duration for OFDM		2 OFDM symbols
Manchester coding for OOK		1/2
Number of information bits	Bits	5

In the specification, tables will be defined corresponding to 15 kHz and 30 kHz SCS.

7.1.2 Rx SNR evaluations

To derive SNR performance of LP-WUS, it was agreed to select OOK-4 M=4 under AWGN channel model with 1% MDR without repetition as worst case.

7.1.3 Architecture and NF considerations

The basic architecture considered for the LP_WUR is a zero-IF architecture for both envelope and sequence based detectors. This assumption is common for both FR1 and FR2. This is just an assumption made to derive parameters which dictate the requirements. This assumption does not preclude any other RF implementations.

In case of FR1, only single RX is assumed. For FR2 requirement derivation, the baseline assumption is an OFDM based receiver with two receiver chains with mutually orthogonally polarized antennas.

In RAN4, there had been no consensus on what IM includes, and no agreement was achieved on individual values of NF and IM, so a joint number was agreed. There are two sets of NF + IM values agreed, and these will be used for REFSSENS calculations. The values are,

- Set 1: 18 dB,
- Set 2: 13.5 dB.

The above mentioned numbers are for FR1.

7.1.4 REFSENS requirements

It was agreed to derive the REFSENS for LP-WUR in the typical RF manner with AWGN being the channel for which SNR is derived. Thus, the REFSENS for LR is defined as

$$\text{REFSENS}_{\text{LR}} \text{ (dBm)} = -174 + 10\log_{10}(\text{BW}_{\text{LR}}) + (\text{NF}_{\text{LR}} + \text{IM}_{\text{LR}}) + \text{SNR}_{\text{LR}}.$$

Here, BW_{LR} corresponds to the bandwidth of the LP-WUS signal in hertz. RAN1 has decided to have 11 RBs for LP-WUS irrespective of SCS, thus the LP-WUS bandwidth will be 1.98 MHz and 3.96 MHz, for 15 and 30 KHz SCS, respectively. Further, there are two sets of values for $\text{NF}_{\text{LR}} + \text{IM}_{\text{LR}}$, i.e. 18.0dB and 13.5dB for Type 1 and Type 2 LP-WURs, respectively. There is only one Rx antenna port for LP-WUR so there is no diversity gain included in the REFSENS.

In the REFSENS test, only the RBs allocated for LP-WUS are populated with the LP-WUS and the rest of the RBs for a given channel bandwidth are left empty. This configuration, however, does not correspond to the real-life case where NR signals in other RBs are generally present and thus can create a coverage shortfall. Separately, the ASCS requirement allows a maximum degradation of 0.5 dB and the side conditions incorporate populated adjacent RBs.

Given the small value of the ASCS degradation factor (0.5 dB), it was agreed not to include this factor in the REFSENS.

For FR1, a SNR value of -4.5 dB for both Type 1 and Type 2 LP-WURs was selected by RAN4 to be used for the REFSENS equation.

To keep the specifications simpler and given the frequency and NF assumptions made, it was agreed to keep the REFSENS same for majority of bands, irrespective of the band to band variation. For some specific bands with $F_{\text{DL,low}}$ higher than 2400 MHz and higher noise figure, there can be additional relaxation and that relaxation will be recorded in the specification.

7.1.5 ASCS requirements

Adjacent subcarrier selectivity (ASCS) is a measure of a receiver's ability to receive an LP-WUS signal at its configured channel frequency in the presence of adjacent in-band NR signal(s). The in-band LP-WUS and NR signal should be same PSD and be separated by a given frequency offset (guard RB) between LP-WUS and NR, and the NR signal occupies the remaining RB resources within the maximum transmission bandwidth configuration, excluding the LP-WUS RBs.

7.1.6 ACS requirements

7.1.6.1 Motivation and general comments

The basis of jammer requirements for the LPWUS feature is that the LR and MR cohabit the same UE, and the UE must withstand the same jammers whether it is receiving PDSCH for MR or monitoring the WUS for LR in some power-saving mode.

In LPWUS monitoring mode, the UE can autonomously and transparently flip between using the LR and MR, as part of its RAN1- and RAN2-defined behavior. The overall goal is to preserve reliability of PDCCH/paging while supporting the LPWUS feature, compared to legacy operation without LPWUS. The inherent flexibility designed into the UE for the LPWUS feature means it is not possible to delineate LR behavior from MR behavior.

The analysis in subsequent sections assume that the LR's NF variation across bands tracks that of the MR, This assumption allows band-agnostic analysis.

7.1.6.2 Deriving the requirement from system level considerations, FR1

7.1.6.2.1 General

The challenge for deriving the ACS requirement is translating ‘the UE must withstand the same jammers whether it is receiving PDSCH or monitoring the WUS in some power-saving mode’ into a mathematically relatable principle. Three were considered in the work phase:

1. Extension of legacy ACS side conditions: Same jammer levels as legacy requirement side conditions would apply and wanted signal strength would relate to its REFSSENS in the same way as the legacy case.
2. Real world consideration: The coverage of PDSCH and the coverage of LPWUS both degrade by similar amounts in the presence of an interferer
3. Alternative method to derive requirements from legacy ACS requirements

Despite the same interfering jammer level, it should be noted that different LP-WUR types, namely Type 1 LR and Type 2 LR, exhibit varying ACS handling capabilities, which are reflected in their differing ACS requirements due to inherent implementation differences.

7.1.6.2.2 ACS consideration 1

LPWUS ACS requirements can be derived based on extension of legacy ACS requirement. Specifically, it is assumed that the same jammer levels as legacy requirement side conditions would apply and the LPWUS wanted signal strength would relate to its REFSSENS in the same way as the legacy case (+14 dB).

For the main radio with diversity gain D_G , the absolute interferer level for the legacy interferer at each UE input can be calculated as:

$$Intrfr_{legacy} = -174 + NF_{legacy} - D_G + 10 \log(CBW) + 10 \log\left(10^{\frac{14}{10}} - 1\right) + ACS_{legacy}$$

A similar equation can be written for the absolute level of the interferer for the LPWUS case, assuming the LPWUS (wanted) signal is also 14 dB stronger than the LPWUS REFSSENS, and there is no diversity gain (1Rx case):

$$Intrfr_{LPWUS} = ACS_{LPWUS} + N_{LPWUS} + 10 \log(BW_{LPWUS}) + 10 \log\left(10^{\frac{14}{10}} - 1\right)$$

If the absolute interferer power levels are the same for both cases (legacy and LPWUR), then the legacy interferer per connector and LPWUS interferer are equal, i.e. the right-hand sides of the 2 equations can be directly compared:

$$NF_{LPWUS} + 10 \log(BW_{LPWUS}) + ACS_{LPWUS} = -D_G + NF_{legacy} + 10 \log(CBW) + ACS_{legacy}$$

$$\text{i.e. } ACS_{LPWUS} = NF_{legacy} - NF_{LPWUS} - D_G + 10 \log\left(\frac{CBW}{BW_{LPWUS}}\right) + ACS_{legacy}$$

$$\text{i.e. } ACS_{LPWUS} = ACS_{legacy} + 10 \log\left(\frac{NRB}{RB_{LPWUS}}\right) + (NF_{legacy} - NF_{LPWUS}) - D_G \quad \text{EQ 7.1.6.2.2-1}$$

7.1.6.2.3 ACS consideration 2

A real-world ACS performance expectation is ‘the coverage of PDSCH and the coverage of LPWUS both degrade by similar amounts in the presence of an interferer’. This expectation can be translated to ‘for a given interferer, the desensitization suffered by the UE for LPWUS detection is no greater than the desensitization suffered by the main radio’. This real-world scenario is analyzed below.

For the main radio with diversity gain D_G , assume an interferer that causes ‘x’ dB desensitization of PDSCH. The absolute interferer level (dBm) at each UE input can be calculated as:

$$Intrfr_{legacy} = -174 + NF_{legacy} - D_G + 10 \log(CBW) + 10 \log\left(10^{\frac{x}{10}} - 1\right) + ACS_{legacy}$$

In the real world, LPWUS is likely to have adjacent non LPWUS RBs. Desensitization due to these adjacent non-LPWUS RBs is assumed to be ‘d’ (dB). The ‘real-world principle’ to apply here is that that the adjacent channel

interferer that causes ‘x’ dB desens in the MR causes no more than a further ‘x’ dB desensitization at the UE for LPWUS detection. i.e the net desens for LPWUS reception would be ‘d+x’. The required ACS that should apply to the UE for LPWUS reception can then be calculated as:

$$ACS_{LPWUS} = Intrafr_{legacy} + 174 - NF_{LPWUS} - 10 \log(BW_{LPWUS}) - 10 \log\left(10^{\frac{x}{10}} - 1\right) - d$$

Combining the two equations above by eliminating $Intrafr_{legacy}$:

$$ACS_{LPWUS} = -NF_{LPWUS} - 10 \log(BW_{LPWUS}) + NF_{legacy} - D_G + 10 \log(CBW) + ACS_{legacy}$$

i.e. $ACS_{LPWUS} = NF_{legacy} - NF_{LPWUS} - D_G + 10 \log\left(\frac{CBW}{BW_{LPWUS}}\right) + ACS_{legacy}$

i.e. $ACS_{LPWUS} = ACS_{legacy} + 10 \log\left(\frac{NRB}{RB_{LPWUS}}\right) + (NF_{legacy} - NF_{LPWUS}) - D_G \dots \dots \dots$ EQ 7.1.6.2.3-1

7.1.6.2.4 ACS consideration 3

It is agreed that the LR and MR has the same jammer level for ACS test case. The ACS of LR is derived using the below formular.

As an example, the conversion formula between the ACS and the interference signal levels can be written as

$$a N = N + I/ACS$$

$$ACS = I / \{(a-1)N\}$$

Where a is the margin of wanted signal level above reference sensitivity in linear unit; N is the noise floor in linear unit; I is the adjacent channel interference signal level expressed in linear unit, ACS is the adjacent Channel Selectivity expressed in linear unit.

Assuming the relaxing factor for MR is 11 dB, the MR interfeer level can be expressed with the formular below:

$$Intrafr_{MR} = ACS + N + A1 = ACS_{MR} + Thermal_{noise} + N_{MR} + 10 \log(N_{RB}) + 10 \log\left(10^{\frac{11}{10}} - 1\right)_{MR}$$

The relaxing factor for LR can be 14 dB, the LR interfeer level can be expressed with the formular below:

$$\begin{aligned} Intrafr_{LR} &= ACS + N + A1 \\ &= ACS_{LR} + IM_{ACS} + Thermal_{noise} + N_{LR} + 10 \log(N_{RB,LPWUS}) + 10 \log\left(10^{\frac{14}{10}} - 1\right)_{LR} \end{aligned}$$

With the equal jammer level of LR and MR, the ACS of LR is derived below

$$\begin{aligned} ACS_{LR} &= NF_{MR} - NF_{LR} + 10 \log\left(\frac{N_{RB}}{N_{RB,LPWUS}}\right) + ACS_{MR} + 10 \log\left(\frac{10^{\frac{11}{10}} - 1}{10^{\frac{14}{10}} - 1}\right) \\ &= NF_{MR} - NF_{LR} + 10 \log\left(\frac{N_{RB}}{N_{RB,LPWUS}}\right) + ACS_{MR} - 3 \end{aligned}$$

7.1.6.2.5 LPWUS ACS requirement summary

The table below summarizes the implied ACS requirements for the considerations or motivating principles identified above (assuming for simplicity that LR NF tracks MR NF across bands):

Motivating principle	Implied LPWUS ACS Requirement	ACS Requirement for type 1 LR	ACS Requirement for type 2 LR
1. RAN4 agreements on LPWUS	$ACS_{LPWUS} = Z + (NF_{legacy} - NF_{LPWUS})$	$ACS_{LPWUS} = Z - 9.5$	$ACS_{LPWUS} = Z - 5.0$

	EQ. 7.1.6.2.2-1		
2. The coverage of PDSCH and the coverage of LPWUS both degrade by similar amounts in the presence of an interferer	$ACS_{LPWUS} = Z + (NF_{legacy} - NF_{LPWUS})$ EQ. 7.1.6.2.3-1	$ACS_{LPWUS} = Z - 10.0$	$ACS_{LPWUS} = Z - 5.0$
3. Alternative derivation method	$ACS_{LPWUS} = Z + (NF_{legacy} - NF_{LPWUS})$ EQ. 7.1.6.2.4-1	$ACS_{LPWUS} = Z - 9.5$	$ACS_{LPWUS} = Z - 5.0$
NOTE: $Z = ACS_{legacy} + 10 \log \left(\frac{NRB}{RB_{LPWUS}} \right) - D_G$			

All approaches yield the same expression, which is therefore considered the baseline requirement for FR1.

$$\text{i.e. } ACS_{LPWUS} = ACS_{legacy} + 10 \log \left(\frac{NRB}{RB_{LPWUS}} \right) + (NF_{legacy} - NF_{LPWUS}) - D_G - d$$

7.1.6.3 FR2-specific considerations

In general, agreements made for FR1 can be carried over to FR2. One legacy FR2 requirement assumptions that is useful to co-opt is that the jammer is ‘polarization matched to the wanted signal’. For simplicity this assumption can be carried over. For legacy operation with the main radio, the following expression relates the max. strength of the interferer to the ACS requirement and the side condition of providing the wanted signal 14 dB higher than REFSENS, where $G_{ant} = 10 \log(N_{elem}) + G_{elem}$ is the array gain in each pol. of the module

$$Intrfr_{legacy} = ACS_{legacy} + N_{legacy} + 10 \log(CBW) + 10 \log \left(10^{\frac{14}{10}} - 1 \right) - G_{ant}$$

Similarly, for LPWUS reception with a single element and pol. selection diversity (EQ. 5.2-1)

$$Intrfr_{LPWUS} = ACS_{LPWUS} + N_{LPWUS} + 10 \log(BW_{LPWUS}) + 10 \log \left(10^{\frac{14}{10}} - 1 \right) - C_G - G_{elem}$$

Note here that $C_G = -3$ for LPWUS (for pol. selection diversity) Setting both interferers to the same value,

$$ACS_{LPWUS} = NF_{legacy} - NF_{LPWUS} + C_G - 10 \log(N_{elem}) + 10 \log \left(\frac{CBW}{BW_{LPWUS}} \right) + ACS_{legacy}$$

i.e. the FR2 LPWUS ACS requirement also takes on a form similar to that of FR1.

7.1.6.4 UE Implementation considerations for ACS

The previous sections have evaluated UE ACS requirements demanded by the system, i.e. a ‘top-down’ approach. These requirements do not conflict with the ‘low power’ goal of this feature because of the flexibility of the UE to use the LR or MR,

A UE’s implementation choice of the LR and the handover logic between the LR or legacy operation with the MR are two sides of the same coin. For example, a UE design with an ultra-low consumption LR is more likely to fall back to legacy operation with the MR due to interferers, while another UE with sufficient filtering and LO quality will not need to fall back to MR operation as often. The handover logic is unique to each UE implementation and is integral to the support of this feature.

To encourage implementation in UE despite the complications of executing the LR to MR switch, the requirements for one of the FR1 variants have been relaxed from the baselines derived in previous sections. For FR2, the specified requirement was tightened relative to the analytically derived value because the requirements were deemed ‘too relaxed’ to the casual observer.

7.1.7 In-Band Blocking

The blocking characteristic is a measure of the receiver's ability to receive a wanted signal at its assigned channel frequency in the presence of an unwanted interferer on frequencies other than those of the spurious response or the adjacent channels.

In the specification, the absolute interferer levels are adopted for both in-band blocking (IBB) and out-of-band blocking (OBB) for MR. IBB refers to interference that occurs within the second adjacent and next adjacent channels, while OBB occurs outside a frequency range 15 MHz below or above the UE receive band.

The main challenges for receiver design in presence of strong interferer are the Rx chain dynamic range as well as the filter suppression capability, which could be the channel filters to alleviate interfering by ACS or IBB, or could be the band filter/duplexer to suppress OBB.

Regarding the dynamic range, the main determining components are ADC and AGC. The more ADC bits, the larger dynamic range for the receiver. However, the ADC bits cannot be increased without limitation. The relationship between ADC bit depth and power consumption is typically inversely proportional. Higher bit-depth ADCs generally offer greater precision and resolution but tend to consume more power due to the increased complexity of circuitry required for finer quantization and digitalization. Conversely, lower bit-depth ADCs consume less power but sacrifice resolution and dynamic range.

In the context of 5G smartphones, ADCs with 12 bits or higher are commonly employed. These higher precision ADCs are favoured to accommodate the demanding requirements of 5G communication, such as higher data rates and broader spectrum ranges. While some 5G smartphones may opt for even higher bit-depth ADCs like 14 or 16 bits for enhanced performance, the general trend revolves around 12 bits.

However, there's a trade-off to consider. LP-WUR which aims to minimize power consumption in smartphones, often utilize lower bit-depth ADCs to reduce power consumption. While this approach yields power-saving benefits, it may compromise the dynamic range and overall performance of the ADC. During the SI evaluation, 4 bits, 6 bits and 8 bits are considered for LLS simulation. Apparently, if low power consumption is the main target for LP-WUR design, it may not be possible that a LP-WUR could adopt the same ADC as MR, which means the dynamic range for LP-WUR could be sacrificed to some extent.

Apart from ADC, the dynamic range of AGC is another main factor which could have impact on the possibly large interferer handled by LP-WUR. On the other hand, due to the limited suppression capability of the LP-WUR filters, it may not guarantee the same level of resistance against IBB and OBB interference as the main receiver (MR). Or if the same interference levels are kept as MR, the wanted signal for blocking requirements should be relaxed more instead.

7.1.8 Out-of-Band Blocking

For out-of-band blocking (OBB), with suppression of the out-of-band interferer by band filter and the analog filter before ADC, the blocking could be suppressed to relatively low level even with less dynamic range of LR, unless band filter is not considered for better coverage with less insertion loss for LP-WUR design.

7.1.9 Narrow Band Blocking

Narrow Band Blocking (NBB), it was initially considered to address coexistence scenarios with GSM at a 200 kHz frequency offset, inherited from LTE for NR. Given the close offset to the desired signal, NBB can significantly degrade REFSENS, particularly if the phase noise of the interferer is poor.

7.1.10 Max Input Level

It is agreed that a single maximum input power level is specified for all channel bandwidths. It is also agreed to introduce two test cases. One test case without the NR signal and the other one NR signal with the same PSD. This is to make sure the LR operate in the presence of the NR signal near the cell centre.

7.1.11 Other Rx requirements

For other Rx requirements for LP-WUR, only spurious emissions is defined for LP-WUR because this is a regularity requirement.

The spurious emissions power is the power of emissions generated or amplified in a receiver that appear at the UE antenna connector. For receiver, the emissions at the antenna connector usually come from the reverse LO leakage. As illustrated in Figure 7.1.11-1 marked with the green line, the LO leakage ends at the antenna or antenna connector. The main LO frequency will dominate in-band spurious emissions, and the harmonic will dominate out-of-band spurious emissions. In a design with potential low isolation from LO to RF input, an LNA is required to attenuate the in-band spurious, and a band pass filter is required to ensure that out-of-band spurious is suppressed. Since the emissions could be considered as kind of regulatory requirements, the same levels for MR should also be defined for LR. Namely, the spurious emissions as specified in clause 7.9 in TS38.101-1 still applies.

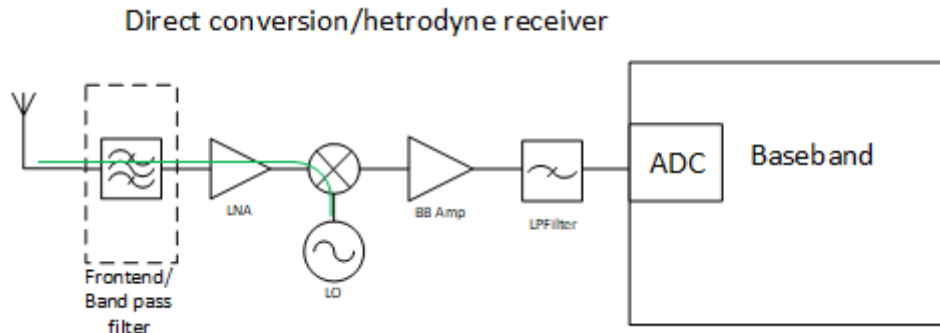


Figure 7.1.11-1 Illustration of a DC receiver

7.2 BS RF

7.2.1 General

LP-WUS is transmitted within the NR channel bandwidth and occupies 11 consecutive RBs irrespective of channel bandwidth and SCS. The discussions for the BS RF requirements by introduction of LP-WUS are included in the following sub-clauses.

7.2.2 LP-WUS power boosting

Two approaches to define the LP-WUS power boosting are discussed, e.g., legacy dynamic range similar to NB-IoT power boosting and EPRE ratio. The definitions for these two approaches are:

For legacy dynamic range similar to NB-IoT power boosting, the LP-WUS power boosting is defined as the difference between the average power of LP-WUS REs (which occupy certain REs within a NR transmission bandwidth configuration) and the average power over all REs (from both LP-WUS and the NR carrier containing the LP-WUS REs).

For EPRE ratio, the LP-WUS power boosting is defined as the difference between the average power of LP-WUS REs (which occupy certain REs within a NR transmission bandwidth configuration) and the average power over NR REs (the NR carrier excluding the LP-WUS REs).

The above two approaches are mathematically related, and the specific analysis can be found in R4-2407547 and R4-2419482.

RAN4 decides to adopt legacy dynamic range similar to NB-IoT power boosting. The declaration on the support of LP-WUS and support of LP-WUS power boosting should be separate. The minimum power boosting level should be included in the BS manufacturer declaration table, but not defined as a minimum requirement.

Moreover, RAN4 agrees that transmission power is shared between NR OFDM signal and NR LP-WUS for the same carrier, so the rated carrier output power and rated total output power are not changed with LP-WUS power boosting.

7.2.3 Regulation relevant spectrum requirements

For transmitted signal with LP-WUS and NR in the same carrier, existing NR regulation relevant spectrum requirements, e.g. spectrum emission mask, spurious emission, are applied.

7.2.4 Transmitted signal quality

It is agreed that overlaid OFDM sequence is designed for LP-WUS and the sequence is ZC sequence. This applies in the time domain before the DFT transform for both OOK-1 and OOK-4. RAN1 also agrees on the processing for the OOK signal, and this is illustrated in Figure 7.2.4-1. After the DFT transform, the OOK-4 frequency domain pattern is illustrated in Figure 7.2.4-2.

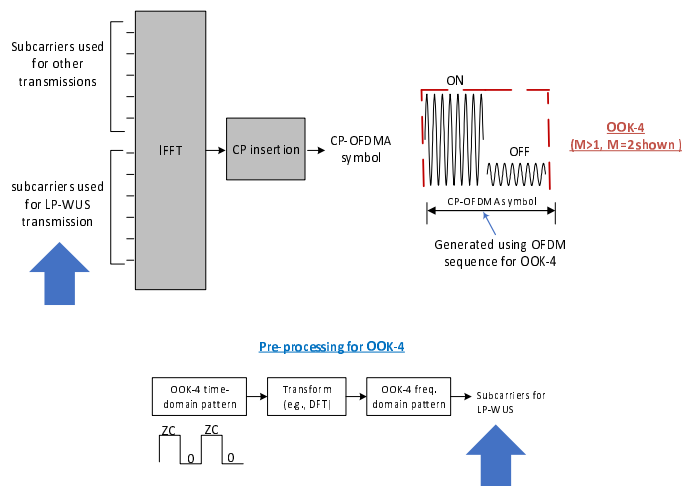


Figure 7.2.4-1: OOK-4 signal processing and subcarrier mapping before IFFT

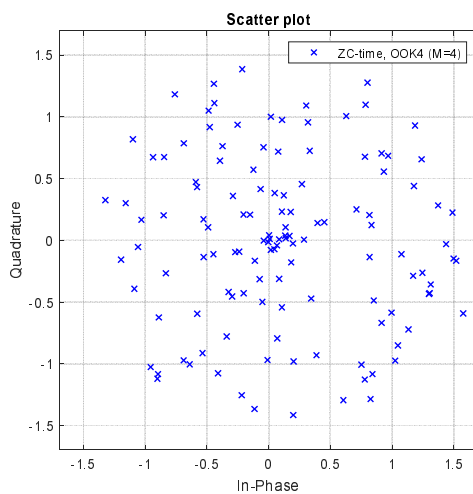


Figure 7.2.4-2: ZC sequence in frequency domain after DFT processing before IFFT

The simulation results on the WUR performance degradation due to the EVM impairment from different companies are listed in Table 7.2.4-1.

Table 7.2.4-1: The WUR performance degradation with different EVM of LP-WUS

Companies	LP-WUS EVM	OOK WUR degradation (dB)	OFDM WUR degradation (dB)
Ericsson	12,5% (16QAM)	0.6	0.6

	8% (64QAM)	Minor (< 0.2)	Minor (< 0.2)
Nokia	30%	Minor (< 0.2)	Minor (< 0.2)
ZTE	20%	Minor (< 0.2)	Minor (< 0.2)
CATT	28.5%	1% CDF loss at required SNR	1% CDF loss at required SNR

It can be seen in Table 7.2.4-1 that the degradation the degradation is not significant even with a large EVM up to 30%. Moreover, current NR EVM definition assumes per-subcarrier amplitude/phase and common phase error (CPE) correction using channel estimations based on the reference signals, and reference signals are not directly transmitted in LP-WUS, so a new EVM definition for LP-WUS will need to be agreed without the use of the reference signals if EVM requirement would be specified for LP-WUS. In view of the above, the NR RF requirements for LP-WUS operation in the present release are specified assuming that LP-WUS signal transmitting signal quality is assured in NR BS with NR signal transmission.

7.2.5 Other RF requirements

It has been agreed that the BS unwanted emission, and receiver requirements if applicable, in the current release of the specifications should also be applied for LP-WUS.

8 Testability

8.1 Testability for UE Performance verification

8.1.1 General Framework

It has been agreed that same LP-WUS RF requirements will apply to all RRC states, but only one RRC state needs to be tested. It is agreed to verify LP-WUR based on 1% MDR of LP-WUS which can be tested based on UE's response to the NW/TE upon successfully detecting the LP-WUS (e.g. ACK/NACK in CONNECTED state or MSG1/3 in IDLE state or other methods). The ultimate test method including the potential test mode will be decided by RAN5 based on RAN4 input.

For demodulation requirements FAR will also be used.

8.1.2 Other

The RAN4 UE RF requirements for LP-WUS detection requires long test time due to the usage of MDR performance metric. Therefore, it is necessary to consider test time reduction aspects in testability.

- The LR requirements are applicable for various MR configurations. To verify LR performance, it is not necessary to test all the combinations between LR and MR. RAN4 recommends that LR can be tested with limited set of MR parameters.
- For the case when LR supporting both OOK and OFDM waveforms, test case reduction can be considered.
- For FR2, the LR and MR are assumed to share the same Rx chain so the peak direction for LR is agreed to be the same as legacy Rx beam peak direction for MR.

Annex A (informative): Change history

Change history							
Date	Meeting	TDoc	CR	Rev	Cat	Subject/Comment	New version
2024-10	RAN4#112 bis	R4-2415778				draft TR skeleton	0.0.0
2024-11	RAN4#113	R4-2418215				TR skeleton Updated structure	0.0.1
2024-11	RAN4#113	R4-2418234				R4-2420392 TP to TR 38.774 on Clause 5 (System parameters) R4-2420393 TP to TR 38.774 on LP-WUS	0.1.0
2025-02	RAN4#114	R4-2500753				R4-2501381 TP for TR 38.774 on LP-WUS R4-2503027 TP to TR 38.774 on LP-WUS R4-2500556 TP to TR 38.774 on regulation relevant spectrum requirements (Clause 7.2.3)	0.2.0
2025-04	RAN4#114 bis	R4-2503830				R4-2505236 TP for TR 38.774 on LP-WUS R4-2505148 TP to TR 38.774 on Clause 5 (System parameters) R4-2505149 TP to TR 38.774 on LP-WUS R4-2504743 TP to TR 38.774 on LP-WUS power boosting (Clause 7.2.2)	0.3.0
2025-05	RAN4#115	R4-2506881				R4-2508089 TP for TR 38.774 on LP-WUS R4-2508090 TP to TR 38.774 on testability of LP-WUR R4-2508117 TP to TR 38.774 on LP-WUS UE RF Simulations R4-2508739 TP to TR 38.774 on LP-WUS BS RF general part (Clause 7.2.1) R4-2508769 TP to TR 38.774: Other BS RF requirements for Low-Power Wake-up Signal and Receiver R4-2508770 TP to TR38.774: BS RF requirement overview for LP-WUS	0.4.0
2025-08	RAN4#116	R4-2510292				R4-2511876 TP for TR 38.774 on LP-WUS R4-2511881 TP to TR 38.774 on other Rx requirements (Clause 7.1.9) R4-2511872 TP to TR 38.774 on LP-WUS UE RF General part R4-2511873 TP to TR 38.774 on FR2 UE RF of LP-WUR R4-2511429 TP for TR 38.774 WUR RF requirement of ACS R4-2511879 TP for 38.774: Blocking characteristics for LP-WUR R4-2511431 TP for TR 38.774 WUR RF requirement of Maximum input level R4-2511882 TP to TR 38.774 on testability for LP-WUR	0.5.0
2025-09	RAN#109	RP-252465				For one-step approval in RAN plenary	1.0.0

Change history							
Date	Meeting	TDoc	CR	Rev	Cat	Subject/Comment	New version
2025-09	RAN#109					Approved by plenary – Rel-19 spec under change control	19.0.0
2025-12	RAN#110	RP-253651	0001		F	CR to TR 38.774 on BS rated carrier output power and rated total output power	19.1.0
2025-12	RAN#110	RP-253651	0002		F	CR to TR 38.774 on BS transmitted signal quality	19.1.0
2026-03	RAN#111	RP-260445	0003	1	F	CR to TR38.774 on ACS	19.2.0

History

Version	Date	Status
V19.0.0	October 2025	Publication
V19.1.0	February 2026	Publication
V19.2.0	April 2026	Publication