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Intelligent Transport Systems (ITS);
Study on receiver requirements in ETSI EN 302 571

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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1 Scope

1.1 Rationale for the present document

The rationale for the present document is twofold.

Firstly, the initiative to study the possibility to include improved receiving parameters such as selectivity and sensitivity in future releases of ETSI EN 302 571 [i.1] is based on recommendations given in ETSI EG 203 336 [i.5].

Secondly, the Harmonised Standard ETSI EN 302 571 [i.1] was first published when only a single technology was considered for Cooperative ITS communication.. Reformulation of (some of) the requirements defined in ETSI EN 302 571 [i.1] in a technology neutral manner is therefore strongly desirable, to address the various technologies existing today, and also future technologies.

Therefore, a new technical study item was proposed and approved: DTR/ERM-TG37-275, resulting in the present document.

1.2 Need for receiver performance requirements

The intention of article 3.2 of Directive 2014/53/EU [i.7] in relation to a receiver is explained in recitals 10 and 11 of the Directive, which states:

"...in the case of a receiver, it has a level of performance that allows it to operate as intended and protects it against the risk of harmful interference, in particular from shared or adjacent channels, and, in so doing, supports improvements in the efficient use of shared or adjacent channels.

Although receivers do not themselves cause harmful interference, reception capabilities are an increasingly important factor in ensuring the efficient use of radio spectrum by way of an increased resilience of receivers against harmful interference and unwanted signals on the basis of the relevant essential requirements of Union harmonization legislation."

1.3 Scope of the present document

The scope of the present document is to review requirements on the receiver sensitivity, adjacent channel rejection and the alternate adjacent channel rejection (hereafter referred to as "receiver requirements") as defined in ETSI EN 302 571 [i.1] with the aim:

- To analyse those receiver requirement limits and investigate if it is possible to tighten them, taking state-of-the-art technologies into account.
- To assess the feasibility of defining such receiver requirements and associated tests for demonstrating compliance in a technology neutral manner.
- If not feasible, to specify alternative receiver requirements and associated tests for demonstrating compliance.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long-term validity.

The following referenced documents are not necessary for the application of the present document, they assist the user with regard to a particular subject area.

[i.1] ETSI EN 302 571 (V2.1.1): "Intelligent Transport Systems (ITS); Radiocommunications equipment operating in the 5 855 MHz to 5 925 MHz frequency band; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU".

[i.2] ETSI EN 302 663 (V1.3.1): "Intelligent Transport Systems (ITS); ITS-G5 Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band".

[i.3] IEEE 802.11™-2016: "IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks-Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications".

[i.4] ETSI TS 136 101 (V14.21.0): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (3GPP TS 36.101 version 14.21.0 Release 14)".

[i.5] ETSI EG 203 336 (V1.2.1): "Guide for the selection of technical parameters for the production of Harmonised Standards covering article 3.1(b) and article 3.2 of Directive 2014/53/EU".

[i.6] 3GPP TR 36.786 (V14.0.0): "Vehicle-to-Everything (V2X) services based on LTE; User Equipment (UE) radio transmission and reception".

[i.7] Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC, (OJ L153, 22.5.2014, p62).

[i.8] Massachusetts Institute of Technology lecture notes: "Principles of Digital Communication II".

NOTE: Available at https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-451-principles-of-digital-communication-ii-spring-2005/readings-and-lecture-notes/MIT6_451S05_FullLecNotes.pdf.

[i.9] John G. Proakis: "Digital Communications", McGraw-Hill International Edition, 4th Edition, 2001.

[i.10] ETSI TS 138 101-1 (V16.7.0): "5G; NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone (3GPP TS 38.101-1 version 16.7.0 Release 16)".

[i.11] ETSI TS 136 521-1 (V14.6.0): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) conformance specification; Radio transmission and reception; Part 1: Conformance testing (3GPP TS 36.521-1 version 14.6.0 Release 14)".

[i.12] 3GPP TR 36.785: "Vehicle to Vehicle (V2V) services based on LTE sidelink; User Equipment (UE) radio transmission and reception".

[i.13] ETSI EN 300 328 (V2.2.2): "Wideband transmission systems; Data transmission equipment operating in the 2,4 GHz band; Harmonised Standard for access to radio spectrum".

3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

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

K_B	Boltzmann constant
L_{CRB}	Sidelink allocated RB size
N_{RB}	Number of Resource Blocks
N_C	Number of OFDM data subcarriers
$P_{E\ QAM}$	QAM symbol error probability
P_I	Power of the Interferer
$P_{S\ dBm}$	Receiver sensitivity
R_{MCS}	Nominal data rate depending on MCS

3.3 Abbreviations

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

3GPP	3rd Generation Partnership Project
5G	5th generation of cellular mobile communications
AACR	Alternate Adjacent Channel Rejection
AACS	Alternate Adjacent Channel Selectivity
AC	Access Category
AC_BE	Access Category Best Effort
ACR	Adjacent Channel Rejection
ACS	Adjacent Channel Selectivity
AIFS	Arbitration InterFrame Space
AT	Access Terminal
AWGN	Additive White Gaussian Noise
BLER	BLock Error Rate
BPSK	Binary Phase Shift Keying
BW	Bandwidth
CAM	Cooperative Awareness Message
CR	Coding Rate
CRC	Cyclic Redundance Check
CW	Continuous Wave
DG GROW	Directorate General for Internal Market, Industry, Entrepreneurship and Small and medium-sized enterprises (of the European Commission)
DUT	Device Under Test
GNSS	Global Navigation Satellite System
HARQ	Hybrid Automatic Repeat Request
HD	Half Duplex
IM	Implementation Margin
ITS	Intelligent Transport Systems
ITS-G5	Access layer technology

NOTE: As defined in ETSI EN 302 663 [i.2].

LTE	Long Term Evolution
MAC	Media Access Control
MCS	Modulation and Coding Scheme
MMI	Man Machine Interface
NC	Number of (sub)Carriers

NF	Noise Figure
NR	New Radio
NR-V2X	New Radio Vehicle-to-Everything
OFDM	Orthogonal Frequency Division Multiplexing
PC5	Interface between the ITS stations used for V2X sidelink communication
PE	Probability of Error
PER	Packet Error Rate
PHY	PHYsical layer
PRR	Packet Reception Ratio
PS	Sensitivity Power
PSCCH	Physical Sidelink Control CHannel
PSDU	PLCP Service Data Unit
PSK	Phase Shift Keying
PSSCH	Physical Sidelink Shared CHannel
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QPSK	Quadrate Phase Shift Keying
RB	Resource Block
RMC	Reference Measurement Channel
RS	Reference Symbol
RX	Radio receiver
SA	Spectrum Analyser
SCI	Sidelink Control Information
SCS	SubCarrier Spacing
SER	Symbol Error Rate
SL	SideLink
SNR	Signal to Noise Ratio
S-SSB	Sidelink Synchronization Signal Block
SS	System Simulator
STA	Station
TBS	Transport Block Size
TDD	Time Division Duplex
TH	Temperature High
TL	Temperature Low
TS	Technical Specification
TX	Radio transmitter
UE	(3GPP) User Equipment
UTC	Coordinated Universal Time
VH	Higher extreme Voltage
VL	Lower extreme Voltage
V2V	Vehicle to Vehicle
V2X	Vehicle-to-Everything

4 Study on definitions used in reference documents

4.1 Introduction

This clause intends to clarify definitions of key technical terms used in the present document. Firstly, definitions from several reference documents are recalled. Secondly, proposal definitions for use in the present document are detailed.

4.2 Existing definitions in reference documents

4.2.1 Definitions in ETSI EN 302 571

The following italic text shows the definitions taken from ETSI EN 302 571 [i.1]. These definitions are to be understood with the partitioning of the band into 7 channels of 10 MHz: the frequency offsets mentioned are relative to this organization and are not generically transposable to other channel bandwidths. Also, it should be noted that the ± 50 MHz blocking offset may fall in-band, since the ITS band is 70 MHz wide. Regarding receiver sensitivity, the assumed noise margins may have to be checked if still valid.

*"**Receiver selectivity** is a measure of the receiver's ability to discriminate between wanted signal to which the receiver is tuned to and unwanted signals stemming from other frequency bands. Receiver selectivity herein is comprised of:*

i) adjacent channel rejection;

ii) alternate channel rejection; and

iii) blocking.

The adjacent channel rejection is a measure of the capability of the receiver to operate satisfactorily in the presence of a signal in the adjacent channel, which differs in frequency from the wanted signal by ± 10 MHz.

The alternate channel rejection is a measure of the capability of the receiver to operate satisfactorily in the presence of a signal in the alternate adjacent channel, which differs in frequency from the wanted signal by ± 20 MHz.

***Blocking** is a measure of the capability of the receiver to operate satisfactorily in the presence of a signal in frequency band further away and it shall be tested at ± 50 MHz, ± 100 MHz, and ± 200 MHz. Blocking testing shall be performed at least at 6 different frequency offset positions. The manufacturer of the equipment can add additional frequency offsets positions.*

***Receiver sensitivity** is defined as the minimum receive signal level at the antenna connector required for a given error rate, coding rate and modulation scheme (noise factor of 10 dB and 5 dB implementation margins are assumed). The sensitivity test shall be performed with a single antenna transmitter. The manufacturer of the equipment may use one or several receiver antennas. The sensitivity tests shall be performed without message retransmissions."*

4.2.2 Definitions in ETSI EG 203 336

The following italic text shows the definitions taken from ETSI EG 203 336 [i.5]. These definitions may be more generic, potentially covering for any channel bandwidth. The receiver selectivity definition is maybe less straightforward, pointing to single signal & multiple response rejection selectivity components.

*"**adjacent channels:** channel offset from the wanted channel by the channel spacing*

***alternate channels:** channel(s) offset from the wanted channel by twice the channel spacing*

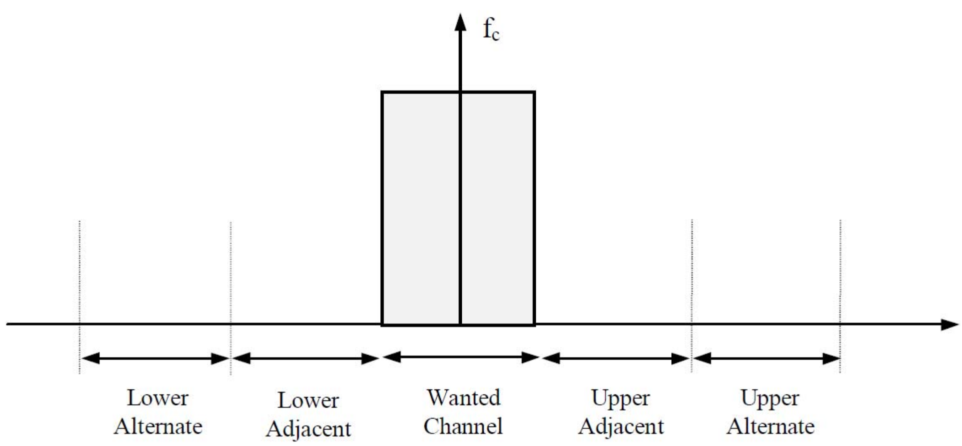

Figure 1: Adjacent and alternate channel definitions (picture from ETSI EG 203 336 [i.5])

Receiver selectivity *is described in Recommendation ITU-R SM.332-4 [19] identifying the capability to receive a wanted signal, without exceeding a given degradation, due to the presence of an unwanted signal which differs in frequency from the wanted signal by a specified amount. Recommendation ITU-R SM.332-4 [19] makes a distinction between single signal selectivity and multiple signal selectivity.*

Single signal selectivity *refers to effects measured within the linear range of the receiver. For the purposes of the present document these are:*

- *attenuation slope; and*
- *spurious response rejection.*

Attenuation slope is a parameter that was mainly applicable to historic systems using analogue modulation; an acceptable alternative in a Harmonised Standard is to specify adjacent signal (or channel) selectivity.

Spurious response rejection includes all possible spurious responses of the receiver but Recommendation ITU-R SM.332-4 [19] specifically identifies image-rejection ratio and intermediate-frequency rejection ratio. Receivers with multiple intermediate-frequencies will have image responses and intermediate-frequency responses for each intermediate-frequency.

Multiple response rejection selectivity *is considered as effective selectivity which includes blocking, adjacent-signal (adjacent-channel), selectivity and radio-frequency intermodulation."*

4.2.3 Definitions in LTE-V2X ETSI TS 136 101

The following italic text shows the definitions used in ETSI TS 136 101 [i.4].

*"**Adjacent Channel Selectivity (ACS)** is a measure of a receiver's ability to receive a E-UTRA signal at its assigned channel frequency in the presence of an adjacent channel signal at a given frequency offset from the centre frequency of the assigned channel. ACS is the ratio of the receive filter attenuation on the assigned channel frequency to the receive filter attenuation on the adjacent channel(s).*

(7.3) The reference sensitivity power level REFSENS *is the minimum mean power applied to each one of the UE antenna ports for all UE categories except category 0, category M1, category M2, and category 1bis, or to the single antenna port for UE category 0, UE category M1, category M2, and UE category 1bis, at which the throughput shall meet or exceed the requirements for the specified reference measurement channel.*

(7.3.1G) Minimum requirements (QPSK) for V2X. When UE is configured for E-UTRA V2X reception non-concurrent with E-UTRA uplink transmissions for E-UTRA V2X operating bands specified in Table 5.5G-1, the throughput shall be ≥ 95% of the maximum throughput of the reference measurement channels.

In-band blocking *is defined for an unwanted interfering signal falling into the UE receive band or into the first 15 MHz below or above the UE receive band at which the relative throughput shall meet or exceed the minimum requirement for the specified measurement channels."*

NOTE: As further elaborated in clause 6.1.3, in-band blocking with 'case1' offsets corresponds to a similar test as the IEEE Alternate Adjacent Channel Rejection described in [i.3].

4.2.4 Relationship between ACS and ACR

It should be noted that the ACR definition used in IEEE 802.11 [i.3] or ETSI EN 302 571 [i.1] differs from the ACS definition from 3GPP. A detailed comparison is provided in clause B.4.

4.2.5 Sensitivity vs required throughput

It is possible to derive an empirical relationship between the receiver sensitivity level and the SNR required for a given throughput based on the noise figure and implementation margin. Corresponding analysis is provided in Annex F.

4.3 Definitions for use in the present document

This clause contains definitions for use in the present document. This clause does not propose any modification of the ITS band channelization. All the definitions from ETSI EN 302 571 [i.1] do apply, except for the terms which are defined in the present clause and which overrule the definitions from ETSI EN 302 571 [i.1]. Modifications are proposed for definitions of adjacent channel rejection and alternate channel rejection in an attempt to make them more generic, as in ETSI EG 203 336 [i.5], in case of change of channel bandwidth in the future. The receiver sensitivity definition is updated to match the outcome of the present study (see details in clause 5.3).

The **adjacent channel rejection** is a measure of the capability of the receiver to operate satisfactorily in the presence of a signal in the lower or upper adjacent channel, which differs in frequency from the wanted signal by ± the channel spacing (e.g. ±10 MHz for 10 MHz channel spacing, ±20 MHz for 20 MHz channel spacing, etc.).

The **alternate channel rejection** is a measure of the capability of the receiver to operate satisfactorily in the presence of a signal in the lower or upper alternate adjacent channel, which differs in frequency from the wanted signal by ± double the channel spacing (e.g. ±20 MHz for 10 MHz channel spacing, ±40 MHz for 20 MHz channel spacing, etc.).

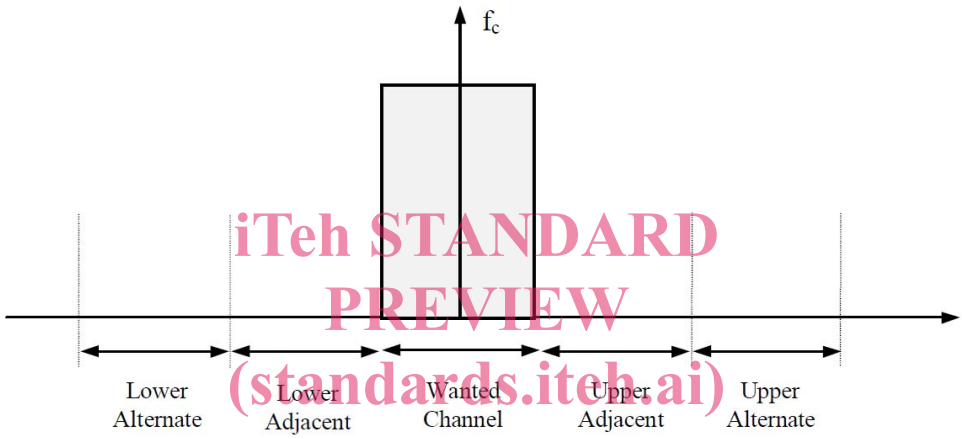

Figure 2: Adjacent and alternate channel definitions

Receiver sensitivity is defined as the minimum receive signal level at the antenna connector required for a given packet error rate and effective data-rate. The sensitivity test should be performed with a single antenna transmitter. The manufacturer of the equipment may use one or several receiver antennas. The sensitivity test should be performed without message retransmissions.

5 Study on receiver sensitivity requirements

5.1 Requirements as published in reference documents

5.1.1 Requirements in IEEE 802.11

IEEE Std 802.11-2016 [i.3] clause 17.3.10.2 defines sensitivity requirements based on 10 % PER and packets of 1 000 bytes. The minimum sensitivity levels are defined for each modulation and coding scheme, for 5, 10 and 20 MHz channel bandwidth (for example -82 dBm for QPSK ½ for 10 MHz channel) as per [i.3] Table 17-18, assuming 10 dB noise factor and 5 dB implementation margin, as shown in Table 1.

Table 1: Limits for receiver sensitivity as specified by IEEE 802.11-2016 [i.3] for 10 MHz channel

Modulation	Coding rate	Minimum sensitivity (dBm)
BPSK	1/2	-85
BPSK	3/4	-84
QPSK	1/2	-82
QPSK	3/4	-80
16-QAM	1/2	-77
16-QAM	3/4	-73
64-QAM	2/3	-69
64-QAM	3/4	-68

NOTE: It should be noted that the IEEE 802.11-2016 [i.3] access layer is often referred to as IEEE 802.11p, which is its older name, and the letter 'p' refers to an amendment in earlier versions of the IEEE 802.11 standard.

5.1.2 Requirements in ETSI EN 302 571

The minimum sensitivity requirements defined in the published ETSI EN 302 571 [i.1] are instructed in clause 4.2.8.2, as shown in the below italic text:

"The receiver sensitivity shall be less or equal to the values given in Table 9 for a packet error rate (PER) of 10-1 for 1 000 octet frames assuming stationary, non-fading channel conditions.

Table 9: Receiver sensitivity

Modulation	*Coding rate*	*Minimum sensitivity for 10 MHz channel spacing (dBm)*
BPSK	*1/2*	*-85*
BPSK	*3/4*	*-84*
QPSK	*1/2*	*-82*
QPSK	*3/4*	*-80*
16-QAM	*1/2*	*-77*
16-QAM	*3/4*	*-73*
64-QAM	*2/3*	*-69*
64-QAM	*3/4*	*-68*

NOTE: Limits apply only to the applicable modulations to the DUT."

Observations:

- Requirements are expressed in form PER $\leq$ 10 %.
- Requirements are expressed per ITS-G5 transmit rate (e.g. modulation coding scheme).
- Requirements are thus not expressed in a technology generic way, being only applicable to IEEE 802.11-2016 [i.3].
- The values specified for sensitivity requirements are identical as the ones indicated in table 17-18 of IEEE 802.11-2016 [i.3], for 10 MHz channel.
- Test procedure is identical to the one taught by IEEE 802.11-2016 [i.3] in clauses 17.3.10.2 (1 000 octets frame, etc.).
- The test assumes only cabled environment (non-fading) conditions (sometimes referred to as "clean channel").

5.1.3 Requirements in 3GPP LTE Release-14

ETSI TS 136 101 [i.4] defines LTE Release14 User Equipment (UE) radio transmission and reception minimum performance requirements:

- Clause 14 "Performance requirement (V2X Sidelink Communication)" addresses Sidelink V2X direct communication (mode 4) demodulation performance requirements. But these are not directly applicable to the context of an EN (for example PSSCH and PSCCH are tested separately, etc.).

- Clause 7.3.1 "Reference sensitivity power level" addresses Sidelink V2X direct communication (mode 4) sensitivity requirements, in subclause 7.3.1G "Minimum requirements (QPSK) for V2X", as shown with the below italic text:

"When UE is configured for E-UTRA V2X reception non-concurrent with E-UTRA uplink transmissions for E-UTRA V2X operating bands specified in Table 5.5G-1, the throughput shall be ≥ 95% of the maximum throughput of the reference measurement channels as specified in Annexes A.8.2 with parameters specified in Table 7.3.1G-1.

Table 7.3.1G-1: Reference sensitivity of E-UTRA V2X Bands (PC5)

Channel bandwidth							
E-UTRA V2X Band	***1.4 MHz (dBm)***	***3 MHz (dBm)***	***5 MHz (dBm)***	***10 MHz (dBm)***	***15 MHz (dBm)***	***20 MHz (dBm)***	***Duplex Mode***
47				*-90.4*		*-87.5*	*HD*
NOTE 1: Reference measurement channel is defined in A.8.2. *NOTE 2: The signal power is specified per port.*							

"

ETSI TS 136 521-1 [i.11], clause 7.3G "Reference sensitivity level for V2X Communication" contains additional information:

- Clause 7.3G.0 "Minimum conformance requirements" provides identical description with identical parameterization. The difference between ETSI TS 136 101 [i.4] and ETSI TS 136 521-1 [i.11] is that the former defines the requirements as "minimum performance requirement" while the latter defines the requirements as "minimum conformance requirement".

- Clause 7.3G.1 "Reference sensitivity level for V2X Communication/Non-concurrent with E-UTRA uplink transmissions" provides test procedure details.

An extract of ETSI TS 136 521-1 [i.11] clause 7.3G "Reference sensitivity level for V2X Communication" is provided in Annex D.

Observations:

- Requirements are expressed in form of throughput to be ≥ 95 % of the maximum throughput of the reference measurement channel A.8.2 (corresponds to PER ≤ 5 %).

- There is only one requirement per channel bandwidth, for a configuration (A.8.2) that is QPSK with coding rate of approximately 1/3.

5.1.4 Requirements in IEEE 802.11bd

The sensitivity requirements defined in IEEE 802.11bd (still under development) will most likely be identical to the ones from IEEE 802.11-2016 [i.3] for the Modulation and Coding Scheme (MCS) that overlap between IEEE 802.11p and IEEE 802.11bd.

5.1.5 Requirements in 3GPP 5G NR V2X

ETSI TS 138 101-1 [i.10] defines NR V2X User Equipment (UE) radio transmission and reception minimum performance requirements. Clause 7.3E Reference defines sensitivity for V2X, as shown with the below italic table. Band n47 indicates the 5,9 GHz ITS band.