# ETSI TR 102 654 V1.1.1 (2009-01)

*Technical Report*

**Electromagnetic compatibility and Radio spectrum Matters (ERM); Road Transport and Traffic Telematics (RTTT); Co-location and Co-existence Considerations regarding Dedicated Short Range Communication (DSRC) transmission equipment and Intelligent Transport Systems (ITS) operating in the 5 GHz frequency range and other potential sources of interference**

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# Foreword

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

# 1 Scope

European CEN Dedicated Short Range Communication (DSRC) equipment operating in the frequency range from 5 795 MHz to 5 815 MHz can suffer from interference caused by Intelligent Transport System (ITS) transmitters and other users of the same and adjacent frequency bands. The present document provides guidance on how to achieve co-existence between existing DSRC equipment and other users such as ITS equipment.

# 2 References

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## 2.1 Normative references

The following referenced documents are indispensable for the application of the present document. For dated references, only the edition cited applies. For non-specific references, the latest edition of the referenced document (including any amendments) applies.

Not applicable.

## 2.2 Informative references

The following referenced documents are not essential to the use of the present document but they assist the user with regard to a particular subject area**.** For non-specific references, the latest version of the referenced document (including any amendments) applies.

[i.1] CEN EN 12253: "Road transport and traffic telematics - Dedicated short-range communication - Physical layer using microwave at 5,8 GHz".

[i.2] CEPT ECC Report 101: "Compatibility studies in the band 5 855 - 5 925 MHz between Intelligent Transport Systems (ITS) and other systems".

[i.3] ETSI EN 302 571: "Intelligent Transport Systems (ITS); Radiocommunications equipment operating in the 5 855 MHz to 5 925 MHz frequency band; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive".

[i.4] CEPT ECC Report 127: "The impact of receiver parameters on spectrum management".

[i.5] ETSI EN 300 674 (all parts): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Road Transport and Traffic Telematics (RTTT); Dedicated Short Range Communication (DSRC) transmission equipment (500 kbit/s / 250 kbit/s) operating in the 5,8 GHz Industrial, Scientific and Medical (ISM) band".

[i.6] ISO 21218:"Intelligent Transport Systems - Communications access for land mobiles (CALM) - Medium Service Access Points".

# 3 Definitions, symbols and abbreviations

## 3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

**adjacent band:** part of the radio-frequency spectrum that is close to the DSRC spectrum defined by [i.7] and [i.8]

**amplitude envelope:** magnitude of the complex analytic representation of the modulated signal.

NOTE: It describes the amplitude variation of a modulated sinusoidal signal as a function of time.

**boresight:** direction of maximum radiation of a directional antenna

NOTE: If boresight cannot be determined unambiguously, then boresight is declared by the provider.

**broadband interferer:** noise like interfering signal that covers more than one of the DSRC channels in the frequency domain

**carrier frequency:** frequency to which the RSU transmitter is tuned

NOTE: In DSRC, the carrier frequency is in the centre of a channel.

**channel:** continuous part of the radio-frequency spectrum to be used for a specified emission or transmission

NOTE: A radio-frequency channel may be defined by two specified limits, or by its centre frequency and its bandwidth, or any equivalent indication. It is often designated by a sequential number. A radio-frequency channel may be time-shared in order to allow radio communication in both directions by simplex operation. The term "channel" is sometimes used to denote two associated radio-frequency channels, each of which is used for one of two directions of transmission, i.e. in fact a telecommunication circuit.

**communication zone:** spatial region within which the OBU is situated such that its transmissions are received by the RSU with a bit error ratio of less than a specified value

**cross-polar discrimination, ellipticity of polarization:** ratio $P^{rd} / P^{rd}$ of power level $P^{rd}$ of the left hand circular polarized wave to the power level $P_{RHCP}$ of the right hand circular wave when the total power of the transmitted wave is $P^{rd} + P^{rd}$

NOTE: Antennas designed to transmit left hand circular waves may transmit some right hand circular waves in addition.

**cross polarization:** See cross-polar discrimination.

**down link:** signal transmitted from the RSU to the OBU

**equivalent isotropically radiated power:** signal power fed into an ideal loss-less antenna radiating equally well in all directions that generates the same power flux at a reference distance as the one generated by a signal fed into the antenna under consideration in a predefined direction within its far field region

**narrowband interferer:** interfering signal with a bandwidth much smaller than the DSRC sub-channel bandwidth

**OBU sleep mode:** optional mode for battery powered OBUs that allows to save battery power

NOTE 1: In this mode, the OBU can only detect the presence of a DSRC down-link signal which under certain defined conditions, see CEN EN 12253 [i.1], will lead to wake-up, i.e. a transition to the transmit mode.

NOTE 2: An OBU may be either in sleep mode, the stand-by mode, or the transmit mode.

**polarization:** locus of the tip of the electrical field strength vector in a plane perpendicular to the transmission vector

**power envelope:** describes the power variation of a modulated sinusoidal signal as a function of time

**RSU active angle:** defines a cone where it is allowed to transmit maximum EIRP (parameter D4 in EN 12253 [i.1])

NOTE: Ranges from 0° to $\Theta = 70°$ relative to a vector perpendicular to the road surface pointing downwards (parameter D4a in EN 12253 [i.1]) (see figure 1). The RSU provider may declare a smaller value for $\Theta$.

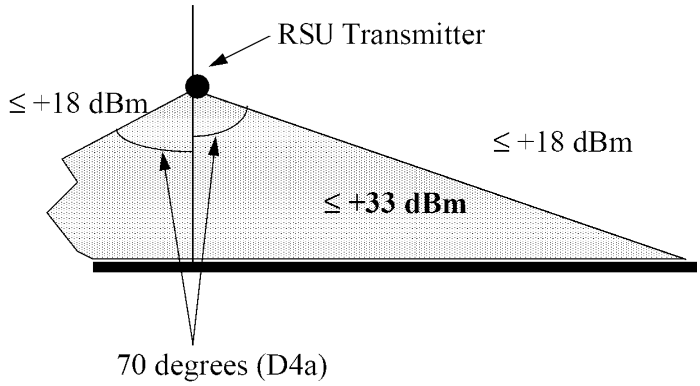


**Figure 1: RSU active angle**

**sub-channel:** part of a channel to be used for a specified purpose

NOTE: For DSRC the purpose can be up link or down link.

**total peak power level:** maximum time domain instantaneous power level defined by the peak voltage $\hat{V}$ at a resistive load $R^{rd}$

$$\hat{P} = \frac{\hat{V}^2}{R_l} \tag{1}$$

NOTE: For a sinusoidal signal, the total peak power level is twice the average power level measured with a power meter. For a modulated signal the peak power level is given by the power envelope maximum.

**up link:** signal transmitted from the OBU to the RSU

## 3.2 Symbols

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

| | |
|---|---|
| $\hat{P}$ | Instantaneous peak power level |
| $\hat{V}$ | Instantaneous peak Voltage |
| $\Theta$ | Angle relative to a vector perpendicular to the road surface |
| $\sigma$ | Standard deviation |
| $a_N$ | Noise amplitude |
| $Att$ | Free space attenuation |
| $BER_i$ | Bit error rate with interference signal |
| $d$ | Distance between phase centres of transmitting and receiving antenna |
| $f$ | Frequency |
| $I3a_{rms}$ | Average interference power limit |
| $N_0$ | Noise power level |
| $p_{AN}$ | Noise amplitude density |
| $P_d$ | Discriminator value |
| $P_{emax}$ | Maximum possible OFDM peak power level |
| $P_{env}$ | Mean envelope power level (average of RF *peak* power levels) |
| $p_{env}(t)$ | Power envelope |

| | |
|---|---|
| $P_{ev}$ | Power envelope value |
| $P_{LHCP}$ | Power level of left hand circular polarized wave |
| $p_{ni}$ | Superposition of noise and interferer amplitude density |
| $P_{OBUsens}$ | OBU sensitivity limit |
| $p_{pe}$ | Probability of power envelope value |
| $P_{RHCP}$ | Power level of right hand circular polarized wave |
| $P_{RMS}$ | Mean RMS power level |
| $R_l$ | Resistive load |

## 3.3 Abbreviations

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

| | |
|---|---|
| 2-PSK | Binary Phase-Shift Keying |
| AM | Amplitude Modulation |
| BER | Bit Error Ratio |
| C/I | Carrier to Interference Ratio |
| CEN | Comité Européen de Normalization |
| DFT | Discrete Fourier Transformation |
| DL | Down Link |
| DSRC | Dedicated Short Range Communication |
| EIRP | Equivalent Isotropically Radiated Power also called e.i.r.p., eirp, E.I.R.P. |
| EN | European Standard |
| ERM | Electromagnetic compatibility and Radio spectrum Matters |
| ETSI | European Telecommunication Standard Institute |
| IPR | Intellectual Property Rights |
| ISM | Industrial, Scientific, Medical |
| ITS | Intelligent Transport System |
| LHCP | Left Hand Circular Polarized |
| LP | Linear Polarized |
| OBU | On Board Unit |
| OFDM | Orthogonal Frequency-Division Multiplexing |
| RF | Radio Frequency |
| RHCP | Right Hand Circular Polarized |
| RMS | Root Mean Square |
| RSU | Road Side Unit |
| RTTT | Road Transport and Traffic Telematics |
| RX | Receiver |
| S/I | Signal to Interference Ratio |
| SNR | Signal to Noise Ratio |
| TR | Technical Report |
| TX | Transmitter |
| UL | Up Link |
| UWB | Ultra WideBand |

EN 12253 [i.1] list of down-link parameter abbreviations:

| | |
|---|---|
| D1 | Carrier frequencies |
| D4 | Maximum EIRP |
| D4a | Angular EIRP mask |
| D5 | Polarization |
| D5a | Cross polarization |
| D8 | DL bit rate |
| D9 | DL bit error ratio |
| U1-0 | Sub-carrier frequency 1,5 MHz |
| U1-1 | Sub-carrier frequency 2 MHz |
| U5 | Polarization |
| U5a | Cross polarization |
| U8 | UL bit rate |

# 4 Summary

## 4.1 Overview

The following elementary interference scenarios to CEN DSRC by other users of the same and adjacent frequency bands have been identified:

a) Interferer located within RSU active angle at UL frequency.

b) Interferer located outside RSU active angle at UL frequency.

c) Interference to OBU receiver.

d) Disturbance of OBU power save mode.

These interference scenarios are elementary. Most practical cases are represented by one or more of those elementary interference scenarios.

While scenarios a) and b) can be handled by means of frequency regulation - e.g. output power or unwanted emission restrictions for interferers, scenarios c) and d) address also the OBU manufacturers to amend their design to reduce the susceptibility to interference presently caused by the enormous receiver bandwidth as compared with the transmitter signal bandwidth. This aspect is also recognized in ECC Report 127 [i.4].

Since in Europe more than 10 million OBUs are in the market at the time of creation of the present document, such improvements for new OBUs will not have an instantaneous effect. However, these necessary improvements will only reduce the impact of the interference but can not avoid it. Strong interferers will need to implement an additional mitigation technique on their own. Furthermore, it is expected that ITS systems will commence to be placed on the market in 3 to 5 years from the time of creation of the present document.

Annex A of the present documents introduces possible solutions to improve coexistence situations.

## 4.2 Interference scenarios

Scenarios a) and b) shown in figure 2 apply to interferers that use the UL frequencies shown in figures 7 and 8.

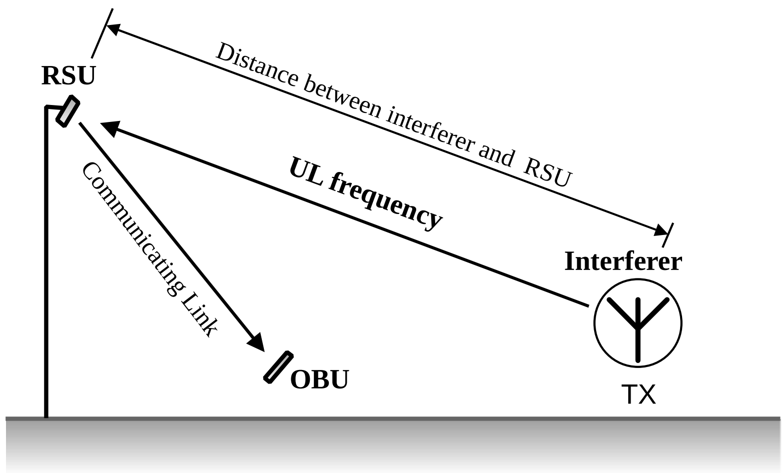


**Figure 2: Schematic of interference scenarios a) and b)**

From the definition of the active angle of a typical RSU mounted at 5,5 meters height above ground follows that:

Scenario a) applies to interferers within a distance of less than 16 m from this RSU. The interference is typically caused by devices mounted in cars driving through the communication zone.

Scenario b) applies to interferers outside the 16 m range. The interference is typically caused by fixed or mobile interferers located outside the communication zone of the RSU.

Figure 3 shows, under these assumptions, the recommended maximum transmit power spectral density for different polarized interference signals.

The result in figure 3 is in line with the result of ECC report 101 [i.2] which specifies unwanted ITS emission levels of less than -55 dBm/MHz below 5 850 MHz and -65 dBm/MHz below 5 815 MHz. The ITS harmonized European standard EN 302 571 [i.3] includes these limits as a technical requirement.

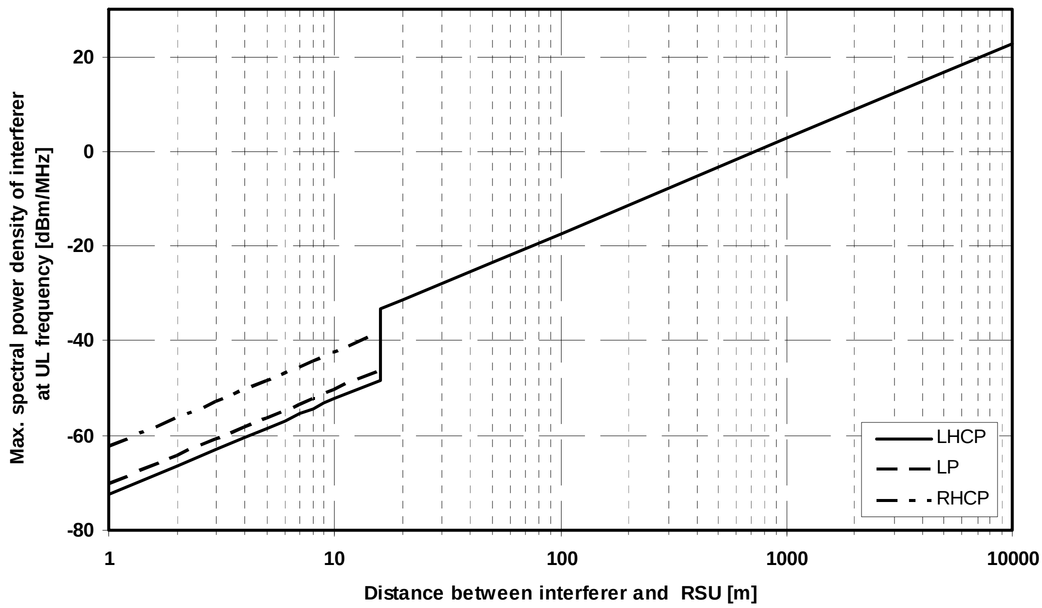


**Figure 3: Recommended maximum power spectral density for interference signals**

Figure 3 summarizes the results derived from using formulae B.1 and parameters I1b, I1c, I1d, and I2b.

Scenario c) as shown in figure 4 describes data reception interference to OBUs located within the communication zone of an RSU. This interference is caused by fixed or mobile interferers located inside or outside the RSU communication zone.

The RF frontend of the OBU is a broadband design to cope with typical tolling scenarios on highways (multilane free flow), where it is essential that all DSRC channels are processed simultaneously. Therefore the significant parameter that defines an interference limit to this design is the total incident RF peak power level at the OBU (within the DSRC and its adjacent bands). Therefore, a relation between distance to the OBU and total interference peak power level can be defined to protect DSRC.

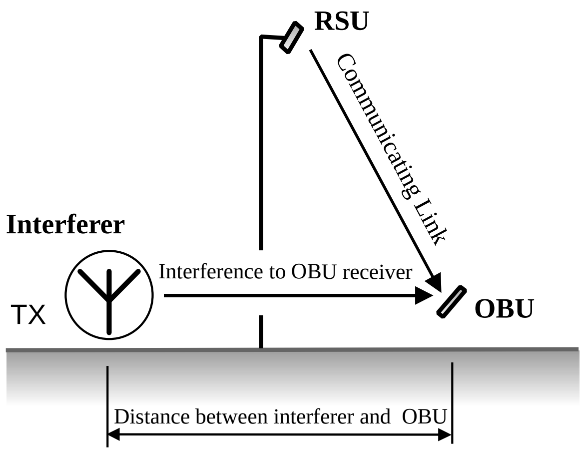


**Figure 4: Schematic of interference scenario c)**

Figure 5 shows the relation between recommended maximum total peak output power level for interferers with different kinds of polarization and the distance to the OBU, under the worst case assumption of free space propagation and 3 dB windscreen attenuation.

Figure 5 summarizes the results derived from using formulae B.1 and parameters I3a, I3b, and I3c.

NOTE: The peak power level of a sinusoidal signal is 3 dB higher than the average power level measured with a power meter or a spectrum analyzer for constant envelope modulations. For non sinusoidal signals, e.g. pulsed signals, the ratio between peak and average power can be much larger than 3 dB.

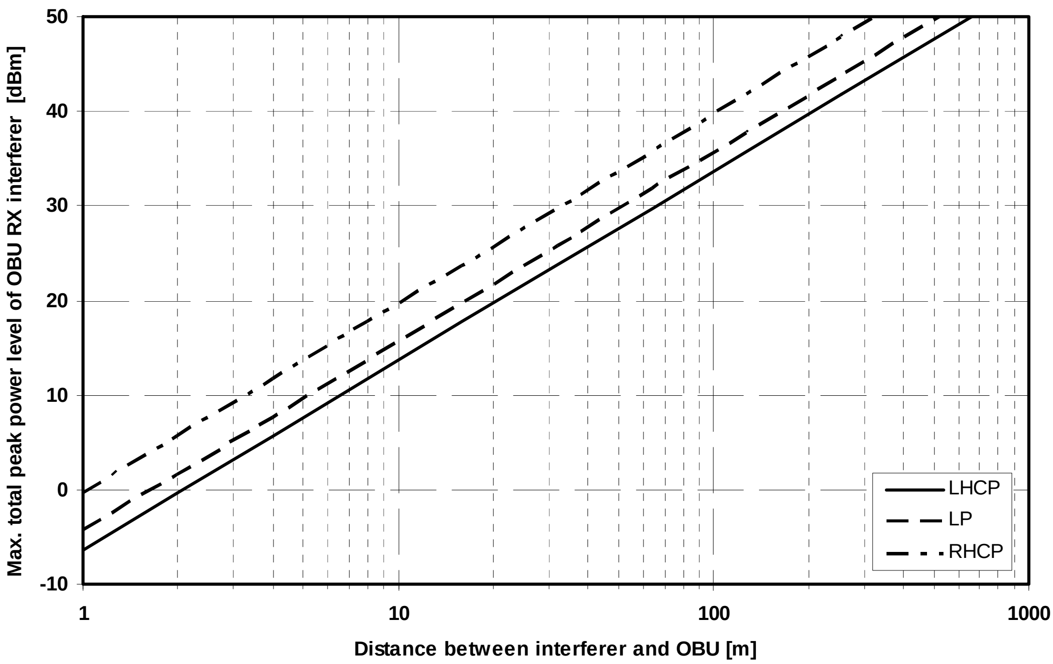


**Figure 5: Recommended maximum total peak power level to avoid interference to an OBU mounted behind a windscreen**

Scenario d) as shown in figure 6, applies to a battery powered OBU with power save mode. This interference occurs outside the communication zone of an RSU and is caused by a fixed or mobile interferer.

An interference signal can trigger the OBU to switch from power save mode to operational mode. This causes a reduction of battery lifetime. The relation between the recommended maximum total peak power level and interferer distance is similar to scenario c).

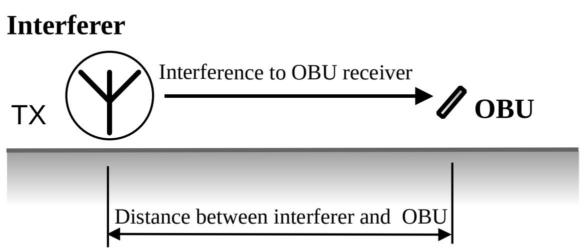


**Figure 6: Schematic of interference scenario d)**

# 5 Interference Limits

## 5.1 DSRC frequency table

Table 1 summarizes the carrier frequencies and channels specified for DSRC byEN 12253 [i.1] and EN 300 674 [i.5] (parameter D1).

Figure 7 shows which UL and DL sub-channels are utilized when a 1,5 MHz UL sub-carrier is used (parameter U1-0 in EN 12253 [i.1] and EN 300 674 [i.5]).

Figure 8 shows which UL and DL sub-channels are utilized when a 2 MHz UL sub-carrier is used (parameter U1-1 in EN 12253 [i.1] and EN 300 674 [i.5]).

The nominal bandwidth of the UL sub-channel is 250 kHz for each side band. The nominal bandwidth of the DL sub-channel is 500 kHz for each side band.

NOTE: The bandwidth values result from the bit rates defined in EN 12253 [i.1] and EN 300 674 [i.5] (parameter U8, D8).

**Table 1: DSRC channels defined by EN 12253 [i.1] and EN 300 674 [i.5]**

| **Pan European Service Frequencies** | **Channel Start** | **Channel End** | **Carrier (D1)** |
|---|---|---|---|
| Channel 1 | 5 795 MHz | 5 800 MHz | 5 797,5 MHz |
| Channel 2 | 5 800 MHz | 5 805 MHz | 5 802,5 MHz |
| **National Service Frequencies** | **Channel Start** | **Channel End** | **Carrier** |
| Channel 3 | 5 805 MHz | 5 810 MHz | 5 807,5 MHz |
| Channel 4 | 5 810 MHz | 5 815 MHz | 5 812,5 MHz |

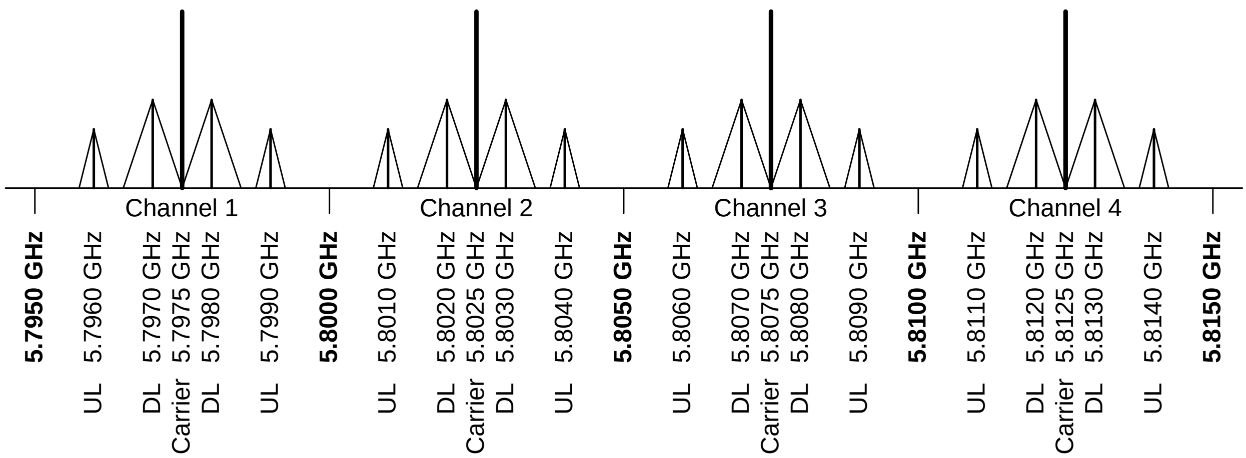


**Figure 7: DSRC frequency utilization for 1,5 MHz sub-carrier frequency (U1-0)**

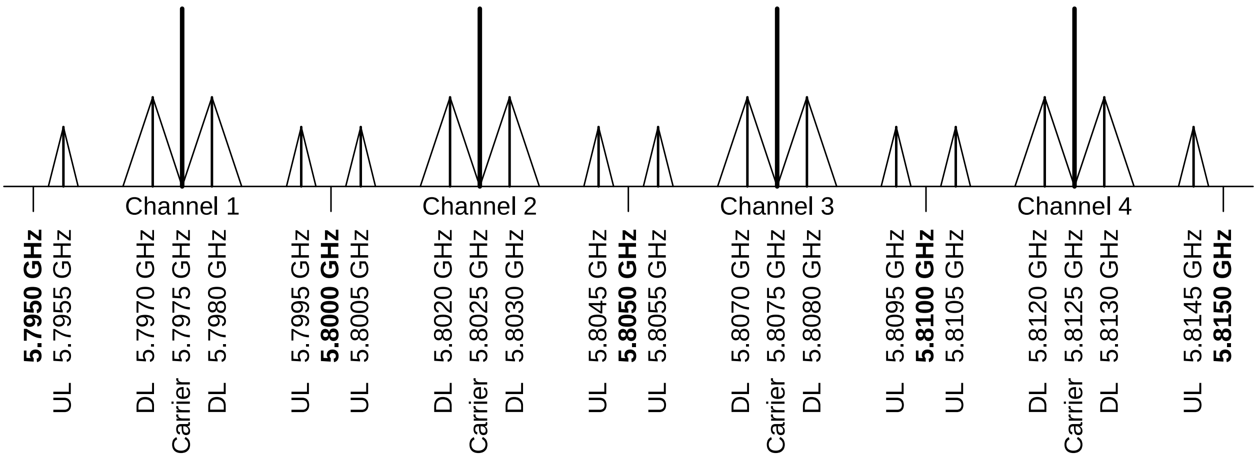


**Figure 8: DSRC frequency utilization for 2 MHz sub-carrier frequency (U1-1)**

## 5.2 Typical RF parameters of DSRC equipment

The RF parameters of a typical RSU are provided in table 2 and are also indicated in ECC Report 101 [i.2].

**Table 2: Parameters of a typical RSU**

| DSRC Road Side Unit (RSU) | Value | Units |
|---|---|---|
| Receiver bandwidth | 500 | kHz |
| Receiver sensitivity | -104 | dBm |
| Antenna gain bore sight | 13 | dBi |
| Antenna gain outside RSU active angle (worst case as in [i.1]) | -2 | dBi |
| Antenna polarization | LHCP | |
| cross-polar discrimination, ellipticity of polarization | 10 | dB |
| TX output power level, EIRP | 33 | dBm |
| RSU mounting height above ground | 2,5 to 7 | m |
| Protection criterion (S/I) | 6 | dB |
| TX Frequency / Bandwidth | see clause 5.1 | |

The RF parameters of a typical OBU are provided in table 3 and are also indicated in ECC Report 101 [i.2].

**Table 3: Parameters of a typical OBU**

| DSRC On Board Unit (OBU) | Value | Units |
|---|---|---|
| OBU sensitivity (typical) | -60 to -50 | dBm |
| Wakeup sensitivity | -60 to -43 | dBm |
| Antenna polarization | LHCP | |
| cross-polar discrimination, ellipticity of polarization | 6 | dB |
| Car windscreen loss | 3 | dB |
| OBU mounting height above ground | 1 to 2,2 | m |
| Protection criterion (S/I) | 10 | dB |
| TX Frequency / Bandwidth | see clause 5.1 | |

NOTE: The OBU maximum usable sensitivity value of -60 dBm is defined as cut-off power level in [i.1]. However, considering measurement uncertainty in testing, the value of -60 dBm is unlikely to be implemented. The lowest reasonable value does exceed the value of -60 dBm by the measurement uncertainty.

## 5.3 Interference to DSRC

### 5.3.1 Categorization of interference types

Depending on location and frequency, different types of interferers can be categorized:

- Interferer located within RSU active angle at UL frequency.
- Interferer located outside RSU active angle at UL frequency.
- Interference to OBU receiver.
- Disturbance of OBU power save mode.

The RF parameter limits **I1a** to **I4a** necessary to allow coexistence under these conditions are listed in table 4 in clause 5.4.

### 5.3.2 Interferer at UL frequency located in RSU active angle

The power level of a narrowband LHCP interference signal in one of the UL sub-channels, radiated in direction of the RSU receiver antenna, from an interferer which is located within the RSU active angle, should not exceed a value of **I1a** at the RSU referred to a loss-less isotropic LHCP antenna.

NOTE: It is assumed that RSU receiver and RSU transmitter antennas are similar. Hence, the maximum RSU receiver sensitivity is expected to be within the RSU active angle.

For a broadband interferer (e.g. wideband noise-like or carrierless UWB unwanted emissions) covering the whole DSRC channel, a receiver bandwidth of 500 kHz should be considered (250 kHz upper and lower side band). Hence, the broadband LHCP interferer power spectral density at the RSU referred to a loss-less isotropic LHCP antenna should be less than **I1b**.

For linear polarized interferers, an additional attenuation of **I1c** should be considered.

Respectively for RHCP interferers, an additional attenuation of **I1d** should be considered (parameter D5a in EN 12253 [i.1]).

NOTE: Examples can be found in clause B.1.

### 5.3.3 Interferer at UL frequency located outside RSU active angle

If an interferer is located outside the RSU active angle, 15 dB less receiver antenna gain should be considered.

NOTE 1: It is assumed that RSU receiver and RSU transmitter antennas are similar. The angular dependence of the receiver antenna gain follows from the definition of parameter D4a in EN 12253 [i.1].

Under this condition, the power level of a narrowband interference signal in one of the UL sub-channels shown in figures 7 and 8 should not exceed a value of **I2a** at the RSU referred to a loss-less isotropic antenna.

For a broadband interferer (e.g. wideband noise-like or carrierless UWB unwanted emissions) covering the whole DSRC channel, a receiver bandwidth of 500 kHz should be considered (250 kHz upper and lower side band). Hence, the power spectral density of a broadband interferer outside the communication zone of the RSU should be less than **I2b** at the RSU referred to a loss-less isotropic antenna.

These limits apply to all kinds of polarization, since outside the communication zone the antenna polarization is not specified.

NOTE 2: Examples can be found in clause B.2.

### 5.3.4 Interference to OBU receiver

The total peak power level of an LHCP interference signal, radiated in direction of the OBU receiver antenna, should not exceed a value of **I3a** at the OBU, referred to a loss-less isotropic LHCP antenna (see note 1).

This parameter applies to both, narrowband and broadband interferers, since only the total peak power level is relevant.

For linear polarized interferers, an additional attenuation of **I3b** should be considered.

Respectively for RHCP interferers, an additional attenuation of **I3c** should be considered (parameter U5a in EN 12253 [i.1]).

NOTE 1: In typical multilane free flow tolling scenarios on highways it is essential that OBUs process all DSRC channels simultaneously. Therefore the RF frontend is a broadband design with poor blocking of adjacent channels. The only significant parameter that defines an interference limit to this design is the total incident RF peak power level at the OBU.

NOTE 2: Examples can be found in clause B.3.

### 5.3.5 Disturbance of OBU power save mode

This clause applies to OBUs with power save mode (see note 1).

The total peak power level of an interference signal, radiated in direction of the OBU receiver antenna, should not exceed a value of **I4a** referred to a loss-less isotropic antenna, at the battery powered OBU.

For linear polarized interferers, an additional attenuation of **I3b** should be considered.

Respectively for RHCP interferers, an additional attenuation of **I3c** should be considered (parameter U5a in EN 12253 [i.1]).

NOTE 1: This interference causes a transition from OBU sleep mode to stand-by mode, resulting in an increase of power consumption by some orders of magnitude. Hence, in this case a built in OBU battery will be discharged within short time. Because of the broadband design of the OBU (see note 1 in clause 5.3.4) the total incident peak power level at the OBU applies as limiting interference parameter.

NOTE 2: Examples can be found in clause B.4.

## 5.4 Interference limit parameters

Table 4 defines all relevant interference parameters.

**Table 4: Interference parameters**

| Item No. | Parameter | Value | Remark |
|---|---|---|---|
| I1a | Power level limit for narrowband LHCP interferers at UL frequency within RSU active angle | -123 dBm | Incident power level at RSU antenna |
| I1b | Power spectral density limit for broadband LHCP interferers at UL frequency within RSU active angle | -120 dBm/MHz | |
| I1c | Additional attenuation for LP interferers within RSU active angle at UL frequency | 2 dB | Circular to linear polarization ratio |
| I1d | Additional attenuation for RHCP interferers within RSU active angle at UL frequency | 10 dB | Cross polarization ratio |
| I2a | Power level limit for narrowband interferers at UL frequency outside RSU active angle | -108 dBm | Incident power level at RSU antenna |
| I2b | Power spectral density limit for broadband interferers at UL frequency outside RSU active angle | -105 dBm/MHz | |
| I3a | Total instantaneous peak power level limit for LHCP interference signals to the OBU receiver | -57 dBm | Incident peak power level at OBU antenna |
| | Power spectral density limit for broadband interference to the OBU receiver | I3a should not be exceeded, i.e. power level I3a is the relevant parameter. | |
| I3b | Additional attenuation for LP interferers at OBU | 2 dB | Circular to linear polarization ratio |
| I3c | Additional attenuation for RHCP interferers at OBU | 6 dB | Cross polarization ratio |
| I4a | Total incident instantaneous peak power level limit for OBU wake-up | -57 dBm | Only applicable to OBUs with power save mode |

NOTE: Parameter **I1a** and **I1b** result from the RSU receiver sensitivity level of -104 dBm, an antenna gain of 13 dBi in bore sight, the receiver bandwidth of 500 kHz, and an S/I of 6 dB typical for BPSK modulation. These parameters are the same as used in ECC Report 101 [i.2] covering RTTT DSRC and as in table 2.

Parameter **I2a** and **I2b** result from **I1a** and **I1b** by adding 15 dB to take the smaller antenna gain outside the RSU active angle into account, as listed in table 2.

Parameter **I3a** results from a typical OBU receiver sensitivity level of -50 dBm and a necessary S/I of 10 dB for a sinusoidal interference signal with 3 dB peak to average power ratio. These parameters are the same as used in ECC Report 101 [i.2] covering RTTT DSRC and as in table 3.

Parameter **I4a** is given by the OBU wake up circuitry.

Specific Implementations of RTTT DSRC can have different receiver and wake-up sensitivity levels and different S/I values (see also tables 2 and 3).

# Annex A: Solutions to improve co-existence

## A.1 Interference mitigation techniques applicable to interfering transmitters

Depending on the interference scenario, different mitigation techniques are applicable to interfering transmitters. Table A.1 summarises the applicability of the most common mitigation techniques to scenarios defined by the type categorization of Clause 5.3.1 and the mobility of the interferer.

**Table A.1: Mitigation techniques and their applicability**

| Mitigation technique | Applicability |
|---|---|
| Total avoidance | Fixed interferers inside the RSU active angle |
| Recommended minimum distance | Fixed interferers (outside the RSU active angle) with known output power level and antenna pattern |
| Recommended maximum fixed output power level | Mobile low power interferers without dynamic transmit power control |
| Distance dependent maximum recommended dynamic output power level | Mobile interferers |

### A.1.1 Recommended minimum distance

This mitigation technique foresees that a minimum distance between interferer and RSU is always observed.

Usually this mitigation technique will apply to fixed installed interferers outside the RSU active angle.

If the interferer frequency covers one of the UL sub-channels shown in figure 7 or 8, interference as described in clause 5.3.3 occurs and the interference limits **I2a** and **I2b** apply. Clause B.2 shows how to calculate the recommended minimum distance between interferer and RSU in order to provide coexistence.

In practice, for all interferers at UL frequency with an output power level higher than **I1a** or **I1b**, a minimum distance between RSU and interferer should be assured.

In case of interference to the OBU receiver as described in clauses 5.3.4 and 5.3.5, the maximum total peak power limits **I3a** and **I4a** apply. Clauses B.3 and B.4 show how to calculate the recommended minimum distances between interferer and OBU in order to provide coexistence.

In practice, for all interferers with a total instantaneous peak power level higher than **I3a** or **I4a,** a minimum distance between OBU and interferer should be assured.

### A.1.2 Recommended maximum output power level

This mitigation technique foresees that a recommended maximum output power level is always applied by the interferer, both to avoid interference to the RSU and to potential OBUs within the RSU's communication zone.

Usually this mitigation technique applies to low power devices mounted within cars and it is useful to combine a recommended fixed output power level with a recommended minimum distance between the interferer and the DSRC OBU.

In case of interference to the RSU receiver, as described in clause 5.3.2, the interference limits **I1a** and **I1b** apply. Clause B.1 shows how to calculate the recommended maximum output power level for UL sub-channel interference.

In case of interference to the OBU receiver as described in clauses 5.3.4 and 5.3.5, the maximum total peak power limits **I3a** and **I4a** apply. Clauses B.3 and B.4 show how to calculate the recommended maximum output power level to avoid OBU receiver interference.

### A.1.3 Distance dependent dynamic output power level

This mitigation technique foresees that the interferer adjusts the transmit power level in accordance with the distance to the RSU communications zone.

It applies to more complex interference scenarios, where a high power transmitter is vehicle-mounted and the vehicle being close to an OBU located inside the RSU communication zone.

NOTE 1: This solution assumes that the interferer can either detect the RSU or has knowledge of the RSU site.

In case of the interferer frequency covers one of the UL sub-channels, interference as described in clause 5.3.2 can occur and the interference limits **I1a** and **I1b** apply. Clause B.1 shows how to calculate the recommended maximum output power level in relation to the distance between interferer and RSU.

For OBU receiver interference as described in clause 5.3.4 , the maximum total peak power limits **I3a** and **I4a** apply. Clauses B.3 and B.4 show how to calculate the recommended worst case output power levels as function of distance between interferer and OBU in order to provide coexistence. In addition, in clause B.3, a more realistic example of an ITS 5,9 GHz communication link is explained.

NOTE 2: Detection of the OBU is not technically feasible, i.e. unwanted triggering of the OBU wake-up cannot be avoided (see clause 5.3.5).

## A.2 Recommended improvements to DSRC devices

It is recommended that the OBU wakeup mechanism is designed in a way to detect the RSU signal more selectively, to avoid unnecessary wakeup events due to RF interference.

In addition, narrowing the OBU receiver exclusion band and/or amending the receiver selectivity capabilities will improve coexistence.

The design should be amended without reducing the capability of an OBU to handle all DSRC channels simultaneously in a multi-lane environment.

NOTE: This may impose changes to the base standards [i.1] and [i.5].

## A.3 System level measures to provide coexistence

The following system level measures can provide coexistence:

- Network topology planning of co-located ITS/DSRC fixed stations.
- DSRC site registration, e.g. used as an overlay for a digital map.
- Notification of DSRC activity to ITS station management (ISO 21218 [i.6]).
- Definition of best practise scenarios.

# Annex B: Examples of coexistence scenario calculations

## B.1 Example for interferers at UL frequency located within RSU active angle

The RSU is usually mounted at a height of 5,5 m to 6,5 m above ground with its RX bore sight pointing downwards. While a DSRC transaction is performed, an interfering device mounted on the rooftop of a truck, can be expected to be at least 2 m in bore sight away from the RSU. The free space attenuation *Att* /dB is calculated by:

$$Att/dB = 32{,}4 + 20 \cdot \lg(f/MHz) + 20 \cdot \lg\left(\frac{d/m}{1000}\right) \tag{B.1}$$

This results in an attenuation value of 53,7 dB for a distance *d* of 2 m and a frequency *f* of 5,8 GHz. From the requirements in clause 5.3.2, the transmission power limit of an LHCP interferer results to -69,3 dBm EIRP. Hence, a linear polarized interferer has to meet only a limit of -67,3 dBm EIRP, since an additional attenuation value of 2 dB has to be considered.

The maximum transmitted power levels of the interfering signal, depending on free space distance *d* from interferer to RSU and polarization, are summarized in tables B.1 and B.2. Interferers at a distance of more than 16 m from the RSU are usually not within the RSU active angle and therefore omitted in tables B.1 and B.2.

**Table B.1: UL frequency coexistence limits for narrowband interferers located within RSU active angle**

| Min. distance *d*/m to RSU | LHCP interferer max. transmit power level in dBm EIRP | LP interferer max. transmit power level in dBm EIRP |
|---|---|---|
| 1 | -75,3 | -73,3 |
| 2 | -69,3 | -67,3 |
| 3 | -65,8 | -63,8 |
| 4 | -63,3 | -61,3 |
| 5 | -61,4 | -59,4 |
| 6 | -59,8 | -57,8 |
| 7 | -58,4 | -56,4 |
| 8 | -57,3 | -55,3 |
| 9 | -56,2 | -54,2 |
| 10 | -55,3 | -53,3 |
| 15 | -51,8 | -49,8 |

**Table B.2: UL frequency coexistence limits for broadband interferers located within RSU active angle**

| Min. distance *d*/m to RSU | LHCP interferer max. transmit power spectral density level in dBm/MHz EIRP | LP interferer max. transmit power spectral density level in dBm/MHz EIRP |
|---|---|---|
| 1 | -72,3 | -70,3 |
| 2 | -66,3 | -64,3 |
| 3 | -62,8 | -60,8 |
| 4 | -60,3 | -58,3 |
| 5 | -58,4 | -56,4 |
| 6 | -56,8 | -54,8 |
| 7 | -55,4 | -53,4 |
| 8 | -54,3 | -52,3 |
| 9 | -53,2 | -51,2 |
| 10 | -52,3 | -50,3 |
| 15 | -48,8 | -46,8 |

# B.2 Example for interferers at UL frequency located outside RSU active angle

Table B.3 shows, as an example, maximum transmitted interferer power levels as function of distance *d* to the RSU to meet the requirements from clause 5.3.3. This is calculated under the worst-case assumption of free space propagation by use of equation B.1.

**Table B.3: Coexistence limits for interferers at UL frequency located outside RSU active angle**

| Min. distance *d*/m to RSU | Narrowband Interferer max. transmit power level in dBm EIRP | Broadband interferer max. transmit power spectral density level in dBm/MHz EIRP |
|---|---|---|
| 5 | -46,4 | -43,4 |
| 10 | -40,3 | -37,3 |
| 20 | -34,3 | -31,3 |
| 50 | -26,4 | -23,4 |
| 100 | -20,3 | -17,3 |
| 1 000 | -0,3 | 2,7 |

In flat areas, the maximum possible line of sight distance is the radio horizon distance $d_{rh}$ that can be calculated by:

$$d_{rh} = 4{,}12 \cdot \left(\sqrt{h_1 / m} + \sqrt{h_2 / m}\right)\mathrm{km} \tag{B.2}$$

Where $d_{rh}$ is measured in km and $h_1$ and $h_2$ are the antenna heights measured in meters. This is also understood as the so-called "radar horizon" and is relevant in cases of interfering systems such as high-powered radionavigation (maritime or military).

EXAMPLE: For an interferer 2 m above ground and a typical RSU in 6,5 m height no interference can be assumed if the interferer is more than $d_{rh}$ = 16 km away from the RSU.

# B.3 Example of interference to OBU receivers

Table B.4 shows, as an example, maximum transmitted instantaneous interference peak power levels as function of distance *d* to the OBU to meet the requirements from clause 5.3.4. This is calculated under the worst-case assumption of free space propagation without windscreen attenuation by use of equation B.1.

**Table B.4: Coexistence limits for LHCP interferers to OBU receivers**

| Min. distance *d*/m to OBU | Total max. instantaneous peak power level in dBm EIRP |
|---|---|
| 1 | -9,3 |
| 2 | -3,3 |
| 4 | 2,7 |
| 8 | 8,7 |
| 16 | 14,8 |
| 32 | 20,8 |
| 64 | 26,8 |
| 128 | 32,8 |
| 256 | 38,8 |

As practical example, it is assumed that an ITS transmitter transmits a linear polarized signal with a total maximum mean power level of 33 dBm into the adjacent frequency band *f* from 5 855 MHz to 5 925 MHz. An ITS modulation scheme employs OFDM with 52 subcarriers. The modulation schemes 2-PSK, 4-PSK and 16-QAM are considered. Furthermore, subcarrier spacing of 156,25 kHz and a 4 µs symbol length is assumed.

To understand how this signal affects the OBU receiver circuitry, some knowledge about the signal shape and the OBU receiver is necessary.

Figure B.1 shows for this kind of signal the amplitude envelope of a typical symbol.

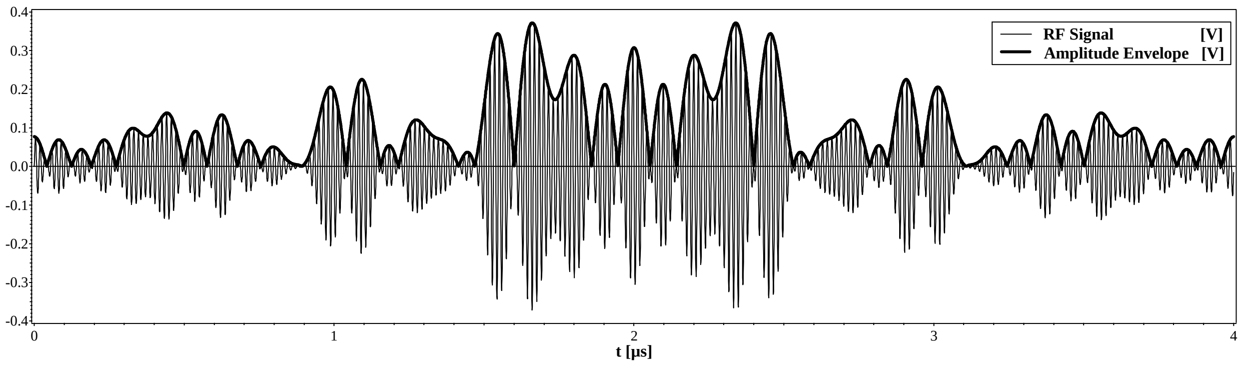


**Figure B.1: Illustration of a typical OFDM amplitude envelope**

The DSRC OBU uses a diode to detect the power envelope of the RSU AM signal. The power envelope is proportional to the squared amplitude envelope. Figure B.2 shows the power envelope of the RF signal from figure B.1. The mean envelope power level in this typical example is 7,2 times or 8,6 dB smaller than the maximum instantaneous total peak power level.

NOTE: The mean envelope power level is an average of the RF total peak power levels, and therefore twice the power level that can be measured with a power meter.

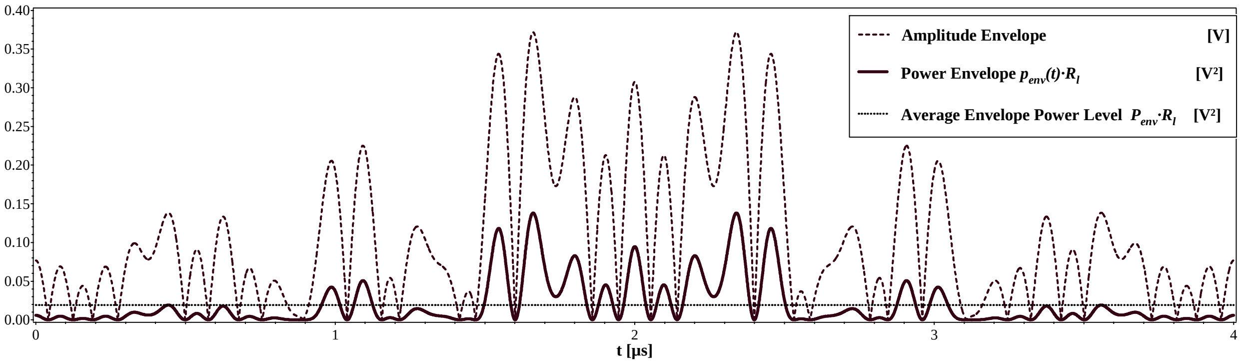


**Figure B.2: Power envelope and mean power of a typical OFDM signal**

The theoretical worst case interference occurs when all OFDM subcarriers are in phase. The resulting symbol has a high power peak. The peak power level of this signal is given by the sum of all subcarrier amplitudes. Figure B.3 shows this case for 52 OFDM subcarriers with the same subcarrier amplitude as used in the example in figure B.2. The maximum instantaneous total peak power level is 52 times higher than the average envelope power level.

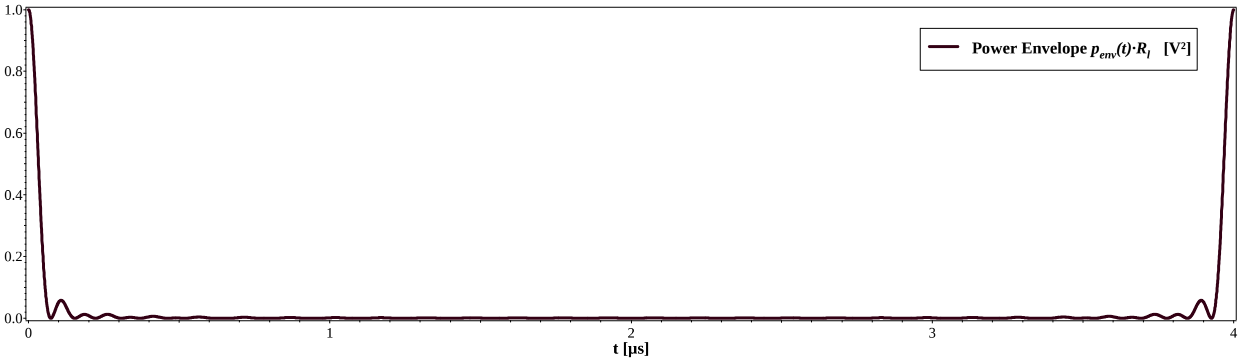


**Figure B.3: Worst case power envelope**

Assuming a uniform distribution of all possible symbols over time, the probability of this maximum possible envelop power value is $1/2^{52} = 2{,}2 \times 10^{-16}$. This is much less than the specified bit error ratio for DSRC (parameter D9 in EN 12253 [i.1]). The pulse would also be too short to be recognized by the OBU receiver.

For these and some more ITS implementation reasons this worst case scenario is an irrelevant interference criterion, since the signal statistic is ignored. A more practical criterion is that a small amount of power peaks are allowed to be higher than the peak power criterion **I3a** in table 4. This number of high amplitude peaks related to the number of DSRC symbols over the same period can be determined from the tolerable bit error ratio degradation at the OBU sensitivity limit. **I3a** defines indirectly this tolerable bit error ratio as shown in the following calculation.

Since any interference signal raises the signal to noise ratio SNR in the OBU receiver circuitry, the total instantaneous total peak power level limit for LHCP interference signals to the OBU receiver **I3a** has to be understood as the power level, at which the thermal noise plus the interference signal leads to a tolerable DSRC bit error ratio $BER_i$ higher than $10^{-6}$ (D9) specified at the OBU sensitivity limit $P_{OBUsens}$ of -50 dBm.

Assuming a Gaussian noise signal with a standard deviation $\sigma$ in the OBU detector circuitry, the amplitude density $p_{AN}$ for a given amplitude $a_N$ of this signal can be described by:

$$p_{AN} = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{a_N{}^2}{2\sigma^2}} \qquad \text{(B.3)}$$

If this noise signal exceeds the discriminator limit, low data amplitudes will be interpreted as high values. With the same probability, high data amplitudes can erroneously be interpreted as low values.

The bit error ratio BER is the probability that the noise amplitude is higher than the discriminator limit. Since the diode detector output is proportional to the data signal's envelope power value, this discriminator value, even though it is a voltage as $a_N$ represents a certain peak power value $P_d$.

Integrating the amplitude density $p_{AN}$ starting from the discriminator value $P_d$ to infinity will directly yield the BER:

$$BER = \frac{1}{\sigma\sqrt{2\pi}} \int_{P_d}^{\infty} e^{-\frac{a^2}{2\sigma^2}} da \qquad \text{(B.4)}$$

Substituting $\frac{a}{\sigma\sqrt{2}} = t$ leads to:

$$BER = \frac{\sigma\sqrt{2}}{\sigma\sqrt{2\pi}} \int_{\frac{P_d}{\sigma\sqrt{2}}}^{\infty} e^{-t^2} dt = \frac{1}{\sqrt{\pi}} \int_{\frac{P_d}{\sigma\sqrt{2}}}^{\infty} e^{-t^2} dt$$

Since

$$\int_0^{\infty} p_{AN} = \frac{1}{2} \qquad \text{(B.5)}$$

the BER can be rewritten to:

$$BER = \frac{1}{2} - \frac{1}{\sqrt{\pi}} \int_0^{\frac{P_d}{\sigma\sqrt{2}}} e^{-t^2} dt \qquad \text{(B.6)}$$

This integral multiplied by 2 is known as complementary error function *erfc*(*x*):

$$erfc(x) = 1 - \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt \qquad \text{(B.7)}$$

From this the bit error ratio BER without interferer results to:

$$BER = 0{,}5 \cdot erfc(\frac{P_d}{\sigma\sqrt{2}}) \qquad \text{(B.8)}$$

At the OBU sensitivity limit the discriminator value $P_d$ is equal to the average power envelope value of the modulated DL signal after the diode detector. The average power level at the OBU sensitivity limit before the diode detector is given by $P_{OBUsens}$. Since this is a mean value, the average power envelope value is 3 dB higher:

$$P_d = P_{OBUsens} + 3\,dB = -47{,}0\,dBm \hat{=} 20\,nW \qquad \text{(B.9)}$$

For a BER of $10^{-6}$ at the OBU sensitivity limit, the expression $\frac{P_d}{\sigma\sqrt{2}}$ results to the value 3,361. From this, the standard deviation of the envelope power noise $\sigma$ can be calculated to:

$$\sigma = 4{,}21 nW \qquad \text{(B.10)}$$

A sinusoidal interference signal with a fixed peak power level as defined by **I3a** virtually reduces the discriminator value to:

$$P_i = P_d - \mathrm{I3a} = 20nW - 2nW = 18\,nW \qquad \text{(B.11)}$$

since it can be treated as offset to the noise signal.

The increased bit error ratio $BER_i$ caused by an additional sinusoidal interference signal with a peak power level as defined by **I3a** evaluates to:

$$BER_i = 0{,}5 \cdot erfc(\frac{P_i}{\sigma\sqrt{2}}) = 0{,}5 \cdot erfc(\frac{18}{4{,}21 \cdot \sqrt{2}}) = 9{,}5 \cdot 10^{-6} \qquad \text{(B.12)}$$

An OFDM signal has no constant power envelope like a sinusoidal signal. To compute a reasonable interference limit for such a signal, the probability $p_{pe}(P_{ev})$ of a certain power envelope value $P_{ev}$ within one data symbol has to be known. This probability depends on the number of OFDM subcarriers and the type of subcarrier modulation. If the power envelope histogram $p_{pe}(P_{ev})$ is known, the resulting bit error ratio as a function of the mean RMS power level and the receiver noise level can be calculated.

There is no analytic way to calculate the power envelope histogram. Figure B.4 shows as a result of a Monte Carlo simulation the relative probability of one power envelope value compared to another. The x-axis is normalized to the maximum possible peak power level $P_{emax}$. The y-axis represents only a relative scale between two points. It is not normalized in this diagram. The three modulation types 2-PSK, 4-PSK, and 16-QAM exhibit significantly different power envelope histograms.

The mean envelope power level $P_{env}$ of a long symbol sequence, is determined by averaging the power envelope histogram values $p_{pe}(P_{ev})$ weighted with their corresponding amplitude value $P_{ev}$.

$$P_{env} = \frac{1}{P_{e\max}} \int_0^{P_{e\max}} P_{ev} \cdot p_{pe}(P_{ev})\, dP_{ev} \qquad \text{(B.13)}$$

This mean envelope power level is 3 dB higher than the mean power level $P_{RMS}$ one measures with a broadband power meter. For ITS systems, it is standardized to not exceed 33 dBm. Table B.5 shows the relation between the mean envelop power level, the mean power level and the maximum possible total peak power level for different modulation schemes.

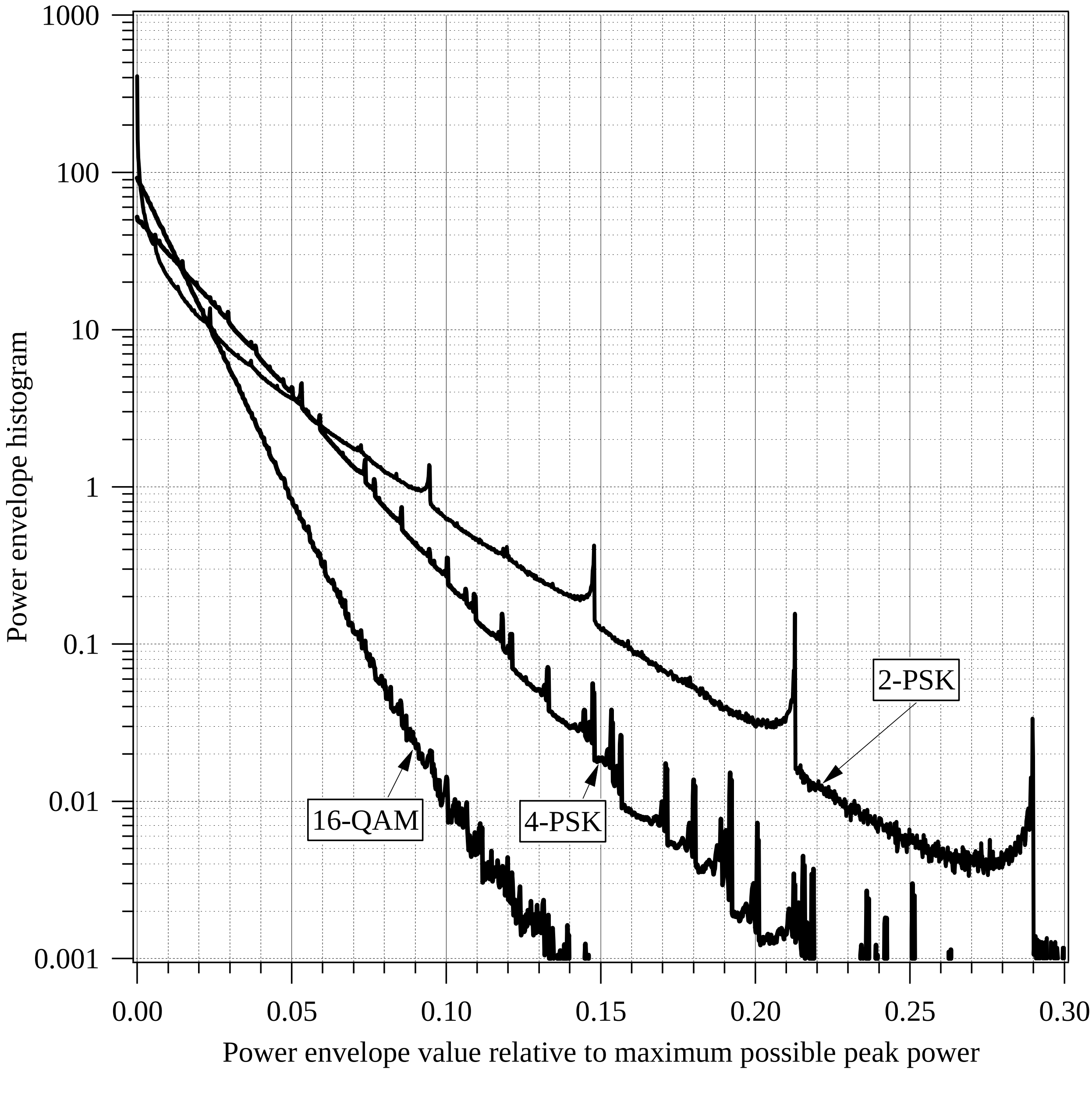


**Figure B.4: Relative probabilities of different interferer power envelope values $p_{pe}(P_{ev})$ for 52 subcarrier OFDM signals with 2-PSK, 4-PSK, and 16-QAM modulation schemes**

**Table B.5: Mean power level in relation to the maximum possible peak power level**

| | $P_{env}$ / $P_{emax}$ | $P_{RMS}$ / $P_{emax}$ |
|---|---|---|
| **Unmodulated** | 1,00000 | 0,500 |
| **2-PSK** | 0,01913 | $9{,}565 \times 10^{-3}$ |
| **4-PSK** | 0,01913 | $9{,}565 \times 10^{-3}$ |
| **16-QAM** | 0,01059 | $5{,}295 \times 10^{-3}$ |

The cumulated power envelope histogram $p_{ce}(P_{ev})$ in figure B.5 shows how likely a power envelope value above a certain limit will occur over time. It is calculated by integrating the probability $p_{pe}$ of all power envelope values.

$$p_{ce}(P_{ev}) \; = \int_{P_{e\max}}^{P_{ev}} p_{pe}(t)\, dt \quad . \tag{B.14}$$

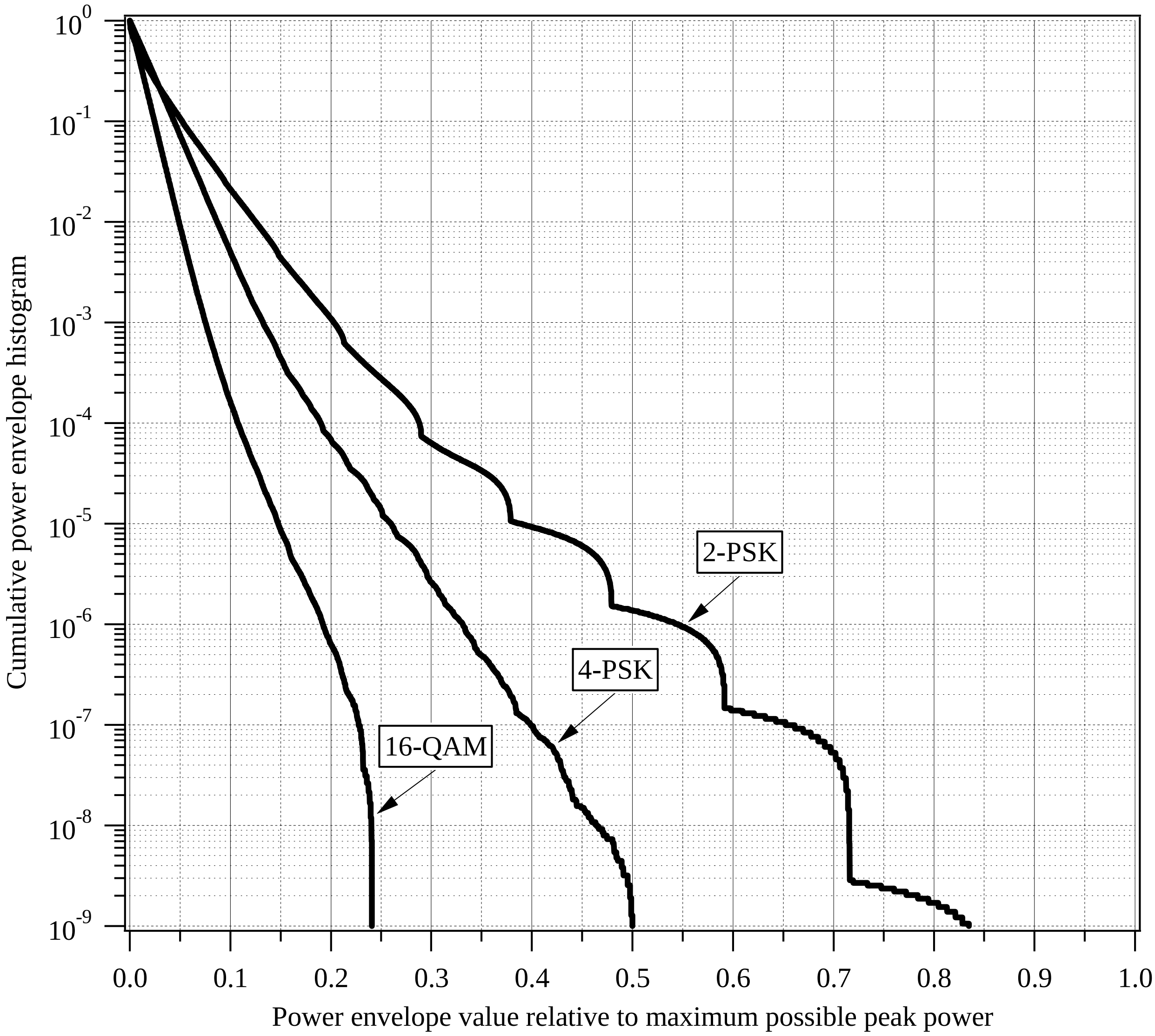


**Figure B.5: Cumulative power envelope histogram $p_{ce}(P_{ev})$ for 52 subcarrier OFDM signals with 2-PSK, 4-PSK, and 16-QAM modulation schemes**

Since the histogram of the normalized interferer power envelope $p_{pe}$ and the probability of each receiver noise value $p_{AN}$ are known, the histogram of the superposition of both signals $p_{ni}$ can be calculated as follows:

$$p_{ni}(P_x, P_{e\max}) = \int_{-\infty}^{P_x} p_{pe}\left(\frac{t}{P_{e\max}}\right) \cdot p_{AN}(P_x - t)\, dt \tag{B.15}$$

This is a convolution integral that can be computed numerically very efficient by use of a DFT algorithm.

The BER is the probability that the power envelope is higher than the discriminator value $P_d$ and can be calculated from

$$BER(P_d, P_{e\max}) = \int_{P_d}^{\infty} p_{ni}(t, P_{e\max})\, dt \tag{B.16}$$

Figure B.6 shows the result of this calculation, where the x-axis was rescaled to mean power levels by use of the relations given in table B.5. The interference mean power limits for different modulation schemes are summarized in table B.6.

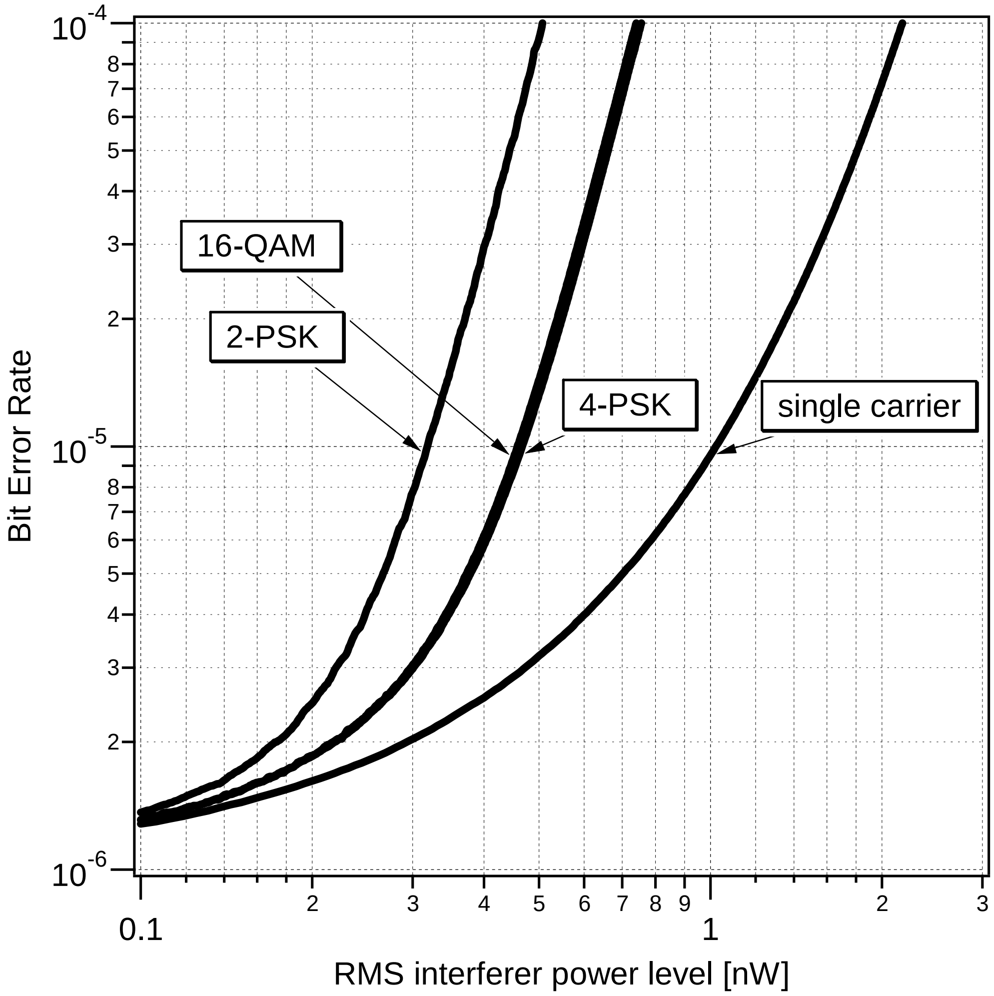


**Figure B.6: Bit error ratio at an OBU receiver with Gaussian noise at its sensitivity limit for 52 subcarrier OFDM interference signals with 2-PSK, 4-PSK, 16-QAM modulation schemes and for an unmodulated single carrier interference signal**

**Table B.6: Mean power limits for 52 subcarrier OFDM interference signals with 2-PSK, 4-PSK, 16-QAM modulation schemes and for an unmodulated single carrier interference signal**

| Type of interference signal | maximum mean power level in nW | maximum mean power level in dBm |
|---|---|---|
| **Unmodulated single carrier** | 1,000 | -60,0 |
| **2-PSK 52 OFDM subcarriers** | 0,315 | -65,0 |
| **4-PSK 52 OFDM subcarriers** | 0,461 | -63,4 |
| **16-QAM 52 OFDM subcarriers** | 0,452 | -63,4 |

The maximum mean power levels from table B.6 are marked in figure B.6 with arrows.

As expected, 4-PSK and 16-QAM show the same behaviour. The 2-PSK signal is the most threatening interference signal. At the OBU antenna, less than -65 dBm mean power level from the interferer should be present to provide for coexistence. In practice the OBU is mounted behind a windscreen with a loss of 3 dB according to table 3. An ITS transmitter uses a linear polarized antenna, which introduces additional 2dB attenuation at the circular polarized OBU antenna.

Table B.7 shows all relevant parameters to calculate the necessary attenuation *Att* to avoid interference. The free space propagation distance *d* can be calculated from this attenuation *Att* and the frequency *f* by:

$$d = 10^{\left[\frac{Att/dB - 32{,}4}{20} - \lg\left(f/MHz\right) + 3\right]} \text{ m} = 184{,}7\text{m} \qquad \text{(B.17)}$$

**Table B.7: Coexistence calculation of an ITS signal**

| Parameter | Value |
|---|---|
| OBU interference limit for a 2-PSK ITS signal | -65,0 dBm |
| Linear polarized | -2,0 dB |
| Windscreen | -3,0 dB |
| Total transmitted average power level of ITS system | 33,0 dBm |
| Resulting attenuation Att to ensure coexistence | 93,0 dB |
| Free space propagation distance d to ensure coexistence | 184,7 m |

Table B.8 shows the relation between average power level of a 2-PSK ITS signal and the necessary distance between ITS transmitter and OBU to provide coexistence.

**Table B.8: Coexistence calculation of an ITS signal**

| Average power level of 2-PSK ITS signal in dBm | Distance d to ensure coexistence in m |
|---|---|
| 0 | 4,1 |
| 3 | 5,8 |
| 6 | 8,3 |
| 9 | 11,7 |
| 13 | 18,5 |
| 23 | 58,4 |
| 28 | 103,9 |
| 33 | 184,7 |

The above considerations depict the theoretical worst case of a 33 dBm ITS transmission into the OBU (main beam to main beam) under free space propagation condition and using a constant power envelope.

Baseband filtering at the OBU reduces the interference distance as well as the intermittent ITS transmitter activity characteristics, antenna misalignment, reduced ITS channel load, and different propagation conditions.

Practical measurements with commercial equipment demonstrated also significant less interference potential.

# B.4 Example of disturbance of OBU power save mode

Table B.9 shows as an example the minimum free space distances *d* between the interferer and the OBU calculated by using equation B.17 in order to meet the requirements from clause 5.3.5.

This result shows the worst case situation, in case of no windscreen attenuation, a LHCP interference signal, and maximum specified wakeup sensitivity of -57 dBm instantaneous total peak power level. Therefore, this result will not apply to all OBUs on the market.

**Table B.9: Interference limits to ensure no disturbance of OBU power save mode**

| Total instantaneous peak power level of interferer in dBm EIRP | Minimum distance *d*/m to OBU |
|---|---|
| 3 | 4,1 |
| 6 | 5,8 |
| 9 | 8,3 |
| 13 | 13,1 |
| 18 | 23,3 |
| 23 | 41,4 |
| 28 | 73,5 |
| 33 | 130,8 |
| 36 | 184,7 |
| 43 | 413,6 |

For the same rationale as stated in clause B.3, the assumed interference potential will be different from the theoretical worst case consideration in the present clause.

# History

| Document history | | |
|---|---|---|
| V1.1.1 | January 2009 | Publication |
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