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TECHNICAL SPECIFICATION

**Transport and Traffic Telematics (TTT);
Dedicated Short Range Communication (DSRC) transmission equipment (500 kbit/s / 250 kbit/s) operating in the 5 795 MHz to 5 815 MHz frequency band; performance tests**

Reference

DTS/ERM-TG37-278

Keywords

DSRC, performance, radio, test

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Foreword

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

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**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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Executive summary

The present document comprises performance test specifications for Transport and Traffic Telematics (TTT) Dedicated Short Range Communication (DSRC) transmission equipment operating in the 5 795 MHz to 5 815 MHz frequency band.

1 Scope

The present document defines the performance test cases for Dedicated Short Range Communication (DSRC) transmission equipment (500 kbit/s / 250 kbit/s) operating in the 5 795 MHz to 5 815 MHz frequency band.

NOTE: Technical requirements for conformance against article 3.2 of the Radio Equipment Directive [i.1] and related test procedures are defined in in ETSI EN 300 674-2-1 [i.2] and ETSI EN 300 674-2-2 [i.3].

2 References

2.1 Normative 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.

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The following referenced documents are necessary for the application of the present document.

[1] EN 12253 (2004): "Road transport and traffic telematics. Dedicated short-range communication. Physical layer using microwave at 5,8 GHz", (produced by CEN).

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.

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

[i.1] 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.

[i.2] ETSI EN 300 674-2-1 (2022): "Transport and Traffic Telematics (TTT); Dedicated Short Range Communication (DSRC) transmission equipment (500 kbit/s / 250 kbit/s) operating in the 5 795 MHz to 5 815 MHz frequency band; Part 2: Harmonised Standard for access to radio spectrum; Sub-part 1: Road Side Units (RSU)".

[i.3] ETSI EN 300 674-2-2 (2019): "Transport and Traffic Telematics (TTT); Dedicated Short Range Communication (DSRC) transmission equipment (500 kbit/s / 250 kbit/s) operating in the 5 795 MHz to 5 815 MHz frequency band; Part 2: Harmonised Standard for access to radio spectrum; Sub-part 2: On-Board Units (OBU)".

[i.4] ISO 14906 (2022): "Electronic fee collection -- Application interface definition for dedicated short-range communication".

[i.5] EN 13372 (2003): "Road transport and traffic telematics (RTTT). Dedicated short-range communication. Profiles for RTTT applications", (produced by CEN).

[i.6] EN 12795 (2003): "Road transport and traffic telematics. Dedicated short range communication (DSRC). DSRC data link layer. Medium access and logical link control", (produced by CEN).

[i.7] EN 12834 (2003): "Road transport and traffic telematics. Dedicated Short Range Communication (DSRC). DSRC application layer", (produced by CEN).

[i.8] IEC 60721-3-4 (2019):"Classification of environmental conditions - Part 3: Classification of groups of environmental parameters and their severities - Section 4: Stationary use at non-weather protected locations".

[i.9] IEC 60721-3-5 (1997): "Classification of environmental conditions - Part 3: Classification of groups of environmental parameters and their severities - Section 5: Ground vehicle installations".

[i.10] ETSI TS 103 052: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Radiated measurement methods and general arrangements for test sites up to 100 GHz".

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

bit: binary digit

NOTE: It can have one out of two possible values, e.g. 0/1 or +1/-1 or low/high.

bit rate: number of bits, in a bit stream, occurring per unit time, usually expressed in bits per second

bore sight: direction of maximum radiation of a directional antenna

NOTE: If bore sight cannot be determined unambiguously, then bore sight may be declared by the provider.

carrier frequency: frequency f_{Tx} to which the RSU transmitter is tuned

NOTE: In DSRC, the carrier frequency is in the centre of a channel, see table 2 of the present document.

carrier signal or carrier: harmonic signal whose nominal single frequency f_{Tx} can vary within a range specified by the carrier frequency tolerance and which is capable of being modulated by a second, symbol-carrying signal

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 radiocommunication 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.

cross-polar discrimination, ellipticity of polarization: antenna designed to transmit left hand circular waves may transmit some right hand circular waves in addition

NOTE: Cross-Polar Discrimination (XPD) is defined as the ratio PLHCP/PRHCP of power PLHCP of the left hand circular polarized wave to the power PRHCP of the right-hand circular wave when the total power of the transmitted wave is PLHCP + PRHCP.

environmental profile: range of environmental conditions under which equipment within the scope of the present document is required to comply with the provisions of the present document

equivalent isotropic radiated power: signal power fed into an ideal loss-less antenna radiating equally 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

integral antenna: antenna, with or without a connector, designed as an indispensable part of the equipment

OBU sleep mode: mode where the OBU can only detect the presence of DSRC down-link signal

NOTE: An OBU may be either in sleep mode, the stand-by mode, or the transmit mode. The sleep mode is an optional mode for battery powered OBUs that allows to save battery power. In this mode, the OBU can only detect the presence of a DSRC down-link signal which under certain defined conditions, see EN 12253 [1], a transition to the stand-by mode is trigger by a wake-up event (detection of a DSRC down-link).

OBU stand-by mode: mode in which the OBU is capable of receiving DSRC down-link signals

NOTE: In stand-by mode the OBU is never transmitting.

operating frequency: nominal frequency at which equipment is operated; also referred to as the operating centre frequency

NOTE: Equipment may be able to operate at more than one operating frequency.

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

EXAMPLE: The polarization can be horizontal or vertical linear polarized, or left or right-hand circular polarized.

provider: manufacturer, supplier, or person responsible for placing the apparatus on the market

radiated measurements: measurements which involve the measurement of a radiated electromagnetic field

3.2 Symbols

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

A_{CW}	Amplitude of CW signal
A_{mod}	Amplitude of modulated signal
ATN_{AT2}	Attenuation of attenuator AT2
ATN_{BLN}	Attenuation of balun BLN
ATN_{CA1}	Attenuation of calibrated coaxial cable 1
BER	Bit Error Ratio
C_{F}	Number of frames transmitted
C_{E}	Number of erroneous frames received
d	Distance between phase centres of transmitting and receiving antenna
d_{displace}	Horizontal displacement of TTA and RTA antenna phase centres
d_{F1}	Distance from transmitting antenna to first Fresnel ellipse
d_{F2}	Distance from first Fresnel ellipse to receiving antenna
D_{fb}	Distance between neighbouring ferrite beads
D_{i}	Directivity relative to an isotropic radiator
$D_{0,\mathrm{TA}}$	Largest linear dimension of test antenna
$D_{0,\mathrm{EUT}}$	Largest linear dimension of EUT antenna
$EIRP_{\mathrm{ObuTx}}$	e.i.r.p. generated by the OBU within a single side band
f	Frequency
FER	Frame error ratio
f_{s}	Nominal OBU sub-carrier frequency
f_{Tx}	Nominal RSU carrier frequency
f_{u}	Nominal centre frequency of unwanted signal
f_{u1}, f_{u2}	Centre frequencies of unwanted signal
G_{c}	Conversion gain
$G_{\mathrm{OBU,Rx}}$	Gain of OBU receiving antenna
$G_{\mathrm{OBU,Tx}}$	Gain of OBU transmitting antenna
G_{RSA}	Gain of receiving substitution antenna

G_{TA}	Gain of test antenna
G_{TSA}	Gain of transmitting substitution antenna
lg(.)	Logarithm to the base ten
m	Modulation index
N	Total number of transmitted bits within a single frame
P_{CW}	Power of CW signal
P_{D11a}	Power limit for communication (upper)
P_{D11b}	Power limit for communication (lower)
P_{inc}	Incident signal power as received by an ideal isotropic receiving antenna
$P_{inc,dBm}$	P_{inc} in dBm
P_{LHCP}	Signal power of left hand circular polarized wave
P_{mod}	Power of modulated signal
P_{MMS2}	Output signal power of MSS2
P_{ObuRx}	Incident signal power to OBU, referred to an ideal isotropic receiving antenna
P_{reTx}	Retransmitted signal power
P_{RSA}	Signal power obtained from receiving substitution antenna
P_{RHCP}	Signal power of right hand circular polarized wave
P_{ssb}	Signal power within single side band
P_{u}	Power of unwanted signal
RBW	Resolution bandwidth
T_{CW}	Duration of CW signal
T_{mod}	Duration of modulated signal
V_{max}, V_{min}	Maximal amplitude of modulated output signal of RSU caused by data bit 1, or 0
α	Tilt angle of test antenna
$\alpha_{displace}$	Displacement angle between TTA and RTA
θ	Angle relative to OBU bore sight indicating worst case direction
λ	Wavelength
ρ_{RSA}	Reflection coefficient at antenna connector of the receiving substitution antenna
ρ_{TSA}	Reflection coefficient at antenna connector of the transmitting substitution antenna

3.3 Abbreviations

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

General abbreviations:

AT1	Attenuator 1
AT2	Attenuator 2
BER	Bit Error Ratio
BLN	Balun
BST	Beacon Service table
CA	Corresponding Antenna
CC	Coaxial Circulator
CEN	Comité Européen de Normalisation
CRC	Cyclic Redundancy Checking
CW	Continuous Wave
DC	Direct Current
DSRC	Dedicated Short Range Communication
e.i.r.p.	Equivalent Isotropic Radiated Power
EFC	Electronic Fee Collection
EU	European Union
EUT	Equipment Under Test
FCCA	Ferrited Coaxial CAble
FCCA1	Ferrited Coaxial CAble 1
FER	Frame Error Ratio
IEC	International Electrotechnical Commission

ISO	International Organization for Standardization
LHCP	Left Hand Circular Polarized
LOS	Line-Of-Sight
LP	Linear Polarized
Mc	Location of the OBU antenna phase centre
M_{centre}	Centre point between phase centres of TTA and RTA
MSS1	Monochromatic Signal Source 1
MSS2	Monochromatic Signal Source 2
n.a.	not applicable
OBU	On Board Unit
PM1	Power Meter 1
RBW	Resolution BandWidth
RD	Receiving Device
RF	Radio Frequency
RRxA	RSU Receiving Antenna
RSA	Receiving Substitution Antenna
RSU	Road Side Unit
RTA	Receiving Test Antenna
RTTT	Road Transport and Traffic Telematics
RTxA	RSU Transmitting Antenna
Rx	Receiver
SMS1	Signal or Message Source 1
SR	Special Report
SSB	Single Side Band
TA	Test Antenna
TM1	Test Message 1
TS1	Test Signal 1
TS2	Test Signal 2
TSA	Transmitting Substitution Antenna
TTA	Transmitting Test Antenna
TTT	Transport and Traffic Telematics
Tx	Transmitter
VBW	Video BandWidth
VST	Vehicle Service table
VSWR	Voltage Standing Wave Ratio
XP	Cross Polarized
XPD	Cross-Polar Discrimination

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

D1	Carrier frequencies
D3	OBU minimum frequency range
D5	Polarization
D5a	Cross polarization
D6	Modulation
D6a	Modulation index
D6b	Eye pattern
D7	Data coding
D8	Bit rate
D8a	Tolerance of bit clock
D9a	BER for communication
D11a	Power limit for communication (upper)
D11b	Power limit for communication (lower)
D12	Cut-off power level of OBU

EN 12253 [1] list of up-link parameter abbreviations:

U1	Sub-carrier frequencies
U1b	Use of side bands
U4a	Maximum single side band e.i.r.p. (bore sight)
U4b	Maximum single side band e.i.r.p. (35°)
U5	Up-link polarization

U5a	Cross polarization
U6	Sub-carrier modulation
U6b	Eye pattern/duty cycle
U6c	Modulation on carrier
U7	Data coding
U8	Bit rate
U8a	Tolerance of symbol clock
U9a	BER for communication
U12	Conversion gain

4 General characteristics for testing

4.1 Units

Units can be either Road Side Units or On Board Units.

Transmitters and receivers may be individual or combination units; some units may be transmitter only, some units may be receiver only and some units may combine transmitter and receiver functionalities.

4.2 Environmental profiles

4.2.1 Environmental profile for testing

The technical requirements of the present document shall apply under the mandatory environmental profile for intended operation of the equipment as specified in clause 4.2.2. The equipment shall always comply with all the technical requirements of the present document when operating within the boundary limits of the mandatory environmental profile.

The provider may additionally select environmental profiles as specified in clause 4.2.3 for testing.

An environmental profile shall include at least the minimum and maximum value of the operational temperature range.

The environmental conditions for tests shall be any convenient selection of environmental parameter values within the selected ranges from clause 4.2.2 and optionally from clause 4.2.3.

4.2.2 Mandatory environmental conditions

The normal temperature and humidity conditions for tests shall be any convenient combination of temperature and relative humidity within the following ranges:

- temperature: +15 ºC to +35 ºC;
- relative humidity: 20 % to 75 %.

4.2.3 Extreme environmental conditions

Extreme environmental conditions are classified in categories according to table 1.

Table 1: Extreme environmental conditions

Temperature category	RSU	OBU
Category I (General):	temperature: -20 °C to +55 °C	temperature: -20 °C to +55 °C
Category ll:	IEC 60721-3-4 [i.8] / 4K2	IEC 60721-3-5 [i.9] / 5K2
Category III	IEC 60721-3-4 [i.8] / 4K3	IEC 60721-3-5 [i.9] / 5K3
Category IV:	IEC 60721-3-4 [i.8] / 4K4	IEC 60721-3-5 [i.9] / 5K4

The extreme environmental conditions for tests shall be any convenient selection of environmental parameter values, except temperature, of a single category. For tests at extreme temperature, measurements shall be made at both, the upper and lower bound of the temperature range of the selected category.

5 General characteristics of Road Side Unit

5.1 Power supply

The power supply shall meet the requirements given in clause A.1.2 for the selected operational conditions of the EUT.

The power can be supplied by a built-in battery, an external battery or a stabilized power supply.

5.2 Carrier frequencies

The present document applies to RSUs operating in some or all of the following channels detailed in table 2.

The centre frequencies f_{Tx} indicated in table 2 are referred to as parameter D1 in EN 12253 [1].

Table 2: Frequency bands and centre frequencies f_{Tx} allocated for DSRC

	Pan European Service Frequencies	National Service Frequencies
Channel 1	5,795 GHz to 5,800 GHz, f_{Tx} = 5,7975 GHz	
Channel 2	5,800 GHz to 5,805 GHz, f_{Tx} = 5,8025 GHz	
Channel 3		5,805 GHz to 5,810 GHz, f_{Tx} = 5,8075 GHz
Channel 4		5,810 GHz to 5,815 GHz, f_{Tx} = 5,8125 GHz

Where equipment can be adjusted to operate at different operating frequencies other than channels 1 and 2, a minimum of two operating frequencies shall be chosen for the tests described in the present document such that the lower and higher limits of the provider's declared operating ranges of the equipment are covered.

5.3 Antenna characteristic

All RSU antennas shall be LHCP in accordance with parameters D5 and D5a in EN 12253 [1].

5.4 Modulation

The carrier of frequency f_{Tx}, see table 2, shall be modulated in accordance with parameters D6, D6a and D6b in EN 12253 [1].

6 General characteristics of On Board Unit

6.1 OBU sets

There exist two sets of OBUs called Set A and Set B which differ by the following parameters listed in table 3 either in terms of value or applicability, and which are defined in EN 13372 [i.5].

Table 3: Differences in OBU Sets

EN 12253 [1] parameter abbreviation	Set A	Set B
D11a	Power limit for communication (upper)	
D12	n.a.	Cut off power level of OBU
U4a	Maximum SSB e.i.r.p. (bore sight)	
U4b	n.a.	Maximum SSB e.i.r.p. (35°)
U12b	n.a.	Conversion gain (upper limit)

The provider shall declare which Set the unit complies with.

6.2 OBU assemblies

The OBU as identically supplied for testing and usage by the end-user is a physical assembly which is located and operated in or on the vehicle to transmit and receive DSRC signals. The OBU may be assembled such that it is:

- mountable in or on any part of the vehicle structure by the end-user according to guidelines in the user-manual, and optionally removable after proper installation; or
- bonded to a part of the vehicle by a service station being authorized by the provider; or
- an integral part of a vehicle component, such as a windscreen, bumper, or licence plate.

In case the OBU is removable from its mounting device by the end-user, tests shall be performed with the OBU properly attached to its mounting device.

The provider shall declare the physical assembly of the OBU.

6.3 Power supply

The power supply shall meet the requirements given in clause A.1.2 for the selected operational conditions of the EUT.

The power supply may be a built-in battery, an external battery, or a stabilized power supply, etc.

6.4 Up-link sub-carrier frequencies

The sub-carrier signal or also called sub-carrier is a signal whose nominal single frequency f_s can vary within a range specified by the sub-carrier frequency tolerance. It shall be capable of being modulated by a second, symbol-carrying signal, see clause 6.7.

The up-link sub-carrier frequency is referred to as parameter U1 of EN 12253 [1].

Every DSRC OBU shall support the two sub-carrier frequencies f_s of 1,5 MHz and 2,0 MHz.

6.5 Antenna characteristic

All equipment antennas shall be LHCP according to parameters U5 and U5a in EN 12253 [1].

An OBU may provide either none, one, or two antenna connectors.

In case an OBU does not provide an antenna connector, then either one antenna for receiving and transmitting, or one antenna for receiving and one antenna for transmitting are implemented. For a single antenna solution the phase centre of the OBU antenna is entitled Mc, see figure 1. For separated receive and transmit antennas it is assumed that they are close to each other and point approximately to the same direction. The centre between these two antennas then is entitled Mc. For easy reading of the present document Mc is referred to as "phase centre of the OBU antenna".

The minimum operational direction of the OBU receive and transmit antenna is characterized by a cone with opening angle θ around bore sight as depicted in figure 1. The OBU shall provide specific properties inside the cone. The border of the cone itself is referred to as worst case direction. The direction M0 and the phase centre Mc of the OBU antenna are related to measurements described in the present document.

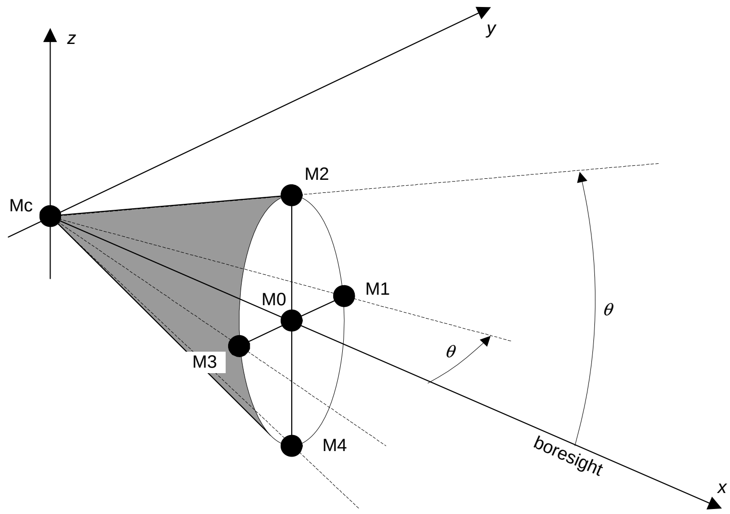

Figure 1: OBU antenna characteristic

The angle θ is used in different tests of the present document.

A value of $\theta = 35°$ is required for OBU minimum conversion gain and for OBU maximum single side band e.i.r.p. according to EN 12253 [1].

For other properties of the OBU, like sensitivity, the provider may declare an opening angle θ other than 35°.

6.6 Carrier frequencies

According to parameter D3 in EN 12253 [1] every OBU shall be able to operate in all DSRC channels as indicated in table 2.

For tests of OBU parameters described in the present document, only the carrier frequencies f_{Tx} defined for channel 1 and channel 4 in table 2 shall be considered.

6.7 Modulation

The up-link sub-carrier, see clause 6.4, shall be modulated according to parameters U1b, U6, U6b and U6c in EN 12253 [1]. The modulated up-link sub-carrier then shall be used to modulate the carrier at frequency f_{Tx} received from an RSU, i.e.: the modulated up-link sub-carrier shall be multiplied with the received carrier.

7 Parameter description and required limits

7.1 RSU

7.1.1 Modulation index

Figure 2 illustrates a two level amplitude modulated RSU carrier signal as required by parameter D6, D6a, and D6b in EN 12253 [1].

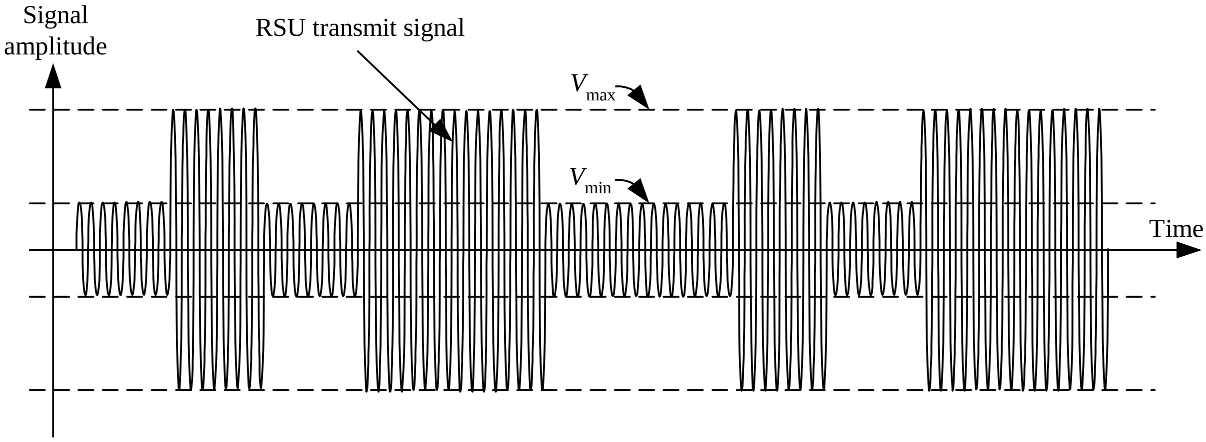

Figure 2: Modulated RSU transmit signal

The modulation index *m* is defined in equation (1) as:

$$m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}} \qquad (1)$$

where V_{max}, and V_{min} are, respectively, maximum amplitudes of the modulated output signal of the RSU caused by bits 1 and 0.

The modulation index is referred to as parameter D6a in EN 12253 [1].

The modulation index *m* shall be in the range $0,5 \leq m \leq 0,9$.

7.1.2 Intermodulation immunity

The intermodulation immunity is a measure of the capability of the receiver to receive a wanted modulated signal without exceeding a given degradation due to the presence of two or more unwanted signals with specific and different frequency relationships to the wanted signal frequency. This measure is given in terms of signal power P_u of the unwanted signals at the receiver antenna.

For the purpose of the present document exactly two unwanted monochromatic signals shall be considered.

The frequencies f_{u1} and f_{u2} of the two unwanted monochromatic signals shall be either at f_{u1} = 5 MHz and f_{u2} = 10 MHz displaced from the centre frequency of the wanted signal, or f_{u1} = -5 MHz and f_{u2} = -10 MHz displaced from the centre frequency of the wanted signal.

The power levels P_u of the two unwanted monochromatic signals shall be equal.

The power level of the wanted signal shall be 6 dB above the declared sensitivity level of the RSU receiver.

The degradation limit is defined by the maximum allowed BER of $2,0 \times 10^{-2}$.

If not declared otherwise by the provider, then the intermodulation immunity shall be $P_u \geq -25$ dBm.

7.2 OBU

7.2.1 Upper power limit for communication

Table 4: OBU upper power limit for communication for Sets A and B

Upper power limit for communication P_{D11a} according to parameter D11a of EN 12253 [1]	
Set A	**Set B**
–17 dBm	–24 dBm

The OBU shall provide a BER of less than or equal to 10^{-6} at the upper power limit for communication P_{D11a}.

7.2.2 Cut-off power level

This parameter applies only to Set B OBUs.

The cut-off power level is the incident power level as received by a loss-less isotropic antenna below which an OBU shall not respond to a properly coded and modulated DSRC down-link signal.

NOTE: There are protocol related requirements that request an OBU not to respond. These requirements are outside the scope of the present document.

The cut-off power level is -60 dBm.

7.2.3 Conversion gain

The conversion gain G_c is defined by $G_c = EIRP_{ObuTx} / P_{ObuRx}$, where P_{ObuRx} is the incident received carrier power level as referred to an isotropic loss-less antenna, and $EIRP_{ObuTx}$ is the re-transmitted e.i.r.p. of the OBU in a single side-band.

The OBU conversion gain is referred to as parameter U12 in EN 12253 [1].

NOTE: The OBU conversion gain includes receive antenna gain, transmit antenna gain and OBU losses.

The OBU conversion gain G_c shall be at least 1 dB within a cone of $\theta = 35°$ relative to bore sight as depicted in figure 1.

For Set B OBUs the OBU conversion gain G_c shall not exceed 10 dB.

8 Testing of Road Side Unit

8.1 Modulation index

8.1.1 General

This test shall be performed either with radiated or conducted measurements.

Basic requirements and guidelines for measurements are provided in Annex A.

Parameter descriptions and limits are provided in clause 7.1.1.

8.1.2 Radiated measurements

The test procedure shall be as follows:

1) Set up the measurement arrangement as detailed in clause A.6.6.1.
2) Set the transmit power level of the RSU to its maximum possible operational value.
3) Set the modulation index of the RSU to its minimum adjustable value within the allowed range.
4) Set the RSU to the mode, where it transmits continuously test signal TS1 as specified in table 5 in clause A.2.
5) Set the RSU transmit carrier frequency f_{Tx} to the initial value supported by this RSU in accordance with table 2 in clause 5.2.
6) Set the RD into the CW mode, also called zero span mode of operation, where the instrument is not sweeping across a frequency band.
7) Set the RBW to 2 MHz.
8) Measure V_{max} and V_{min} from envelope of RF signal, see figure 2.
9) Calculate the modulation index *m* according to equation 1 in clause 7.1.1.
10) Repeat steps 8 and 9 for the remaining value of the carrier frequency f_{Tx} in accordance with table 2 in clause 5.2.
11) Set the modulation index of the RSU to its maximum adjustable value within the allowed range and repeat steps 8 through 10.
12) For all measurements, the modulation index *m* shall be within the limits as specified in clause 7.1.1.

8.1.3 Conducted measurements

The test procedure shall be as follows:

1) The output of the RSU transmitter shall be connected to the RD.
2) Set the transmit power of the RSU to its maximum possible operational value.
3) Set the modulation index of the RSU to its minimum adjustable value within the allowed range.
4) Set the RSU to the mode, where it transmits continuously test signal TS1 as specified in table 5 in clause A.2.
5) Set the RSU transmit carrier frequency f_{Tx} to the initial value supported by this RSU in accordance with table 2 in clause 5.2.
6) Set the RD into the CW mode, also called zero span mode of operation, where the instrument is not sweeping across a frequency band.
7) Set the RBW to 2 MHz.
8) Measure V_{max} and V_{min} from envelope of RF signal, see figure 2.
9) Calculate modulation index *m* according to equation 1 in clause 7.1.1.
10) Repeat steps 8 and 9 for the remaining value of the carrier frequency f_{Tx} in accordance with table 2 in clause 5.2.
11) Set the modulation index of the RSU to its maximum adjustable value within the allowed range and repeat steps 8 through 10.
12) For all measurements the modulation index *m* shall be within the limits as specified in clause 7.1.1.

8.2 Intermodulation immunity

8.2.1 General

Independent of the environmental profile declared by the provider, this test shall be performed only under normal test conditions defined in clause 4.2.2.

This test shall be performed with radiated measurements.

Basic requirements and guidelines for measurements are provided in Annex A.

Parameter descriptions and limits are provided in clause 7.1.2.

NOTE: The provider may extend the test in order to determine the actual value of the intermodulation immunity.

8.2.2 Radiated measurements

The test procedure shall be as follows:

1) Set up the measurement arrangement as detailed in clause A.6.6.2.
2) Set the RSU to the mode that it transmits an unmodulated carrier.
3) Set the RSU output power to its maximum allowed value.
4) Set the modulation index to any convenient value if it is adjustable.
5) Set the RSU carrier frequency f_{Tx} to the initial value supported by this RSU in accordance with table 2 in clause 5.2.
6) Set the RSU to a mode such that the OBU shall use the lower sub-carrier frequency f_s.
7) Set the frequency of the MSS1 to $f_{Tx} + f_s + 5$ MHz and the frequency of the MSS2 to $f_{Tx} + f_s + 10$ MHz.
8) Ensure that MSS1, MSS2 and the RSU are switched off.
9) Replace the RSU receiver by a power meter PM1.
10) Switch on MSS1 and adjust the power of its output signal such that PM1 measures a value of -25 dBm.
11) Switch off MSS1.
12) Switch on MSS2 and adjust the power of its output signal such that PM1 measures a value of -25 dBm.
13) Switch off MSS2.
14) Switch on the RSU transmitter and adjust AT1 such, that the incident signal power received by a loss-less isotropic antenna at the location of the OBU antenna equals -25 dBm to ensure reliable reception of messages by the OBU.
15) Set the OBU into a test mode that it transmits test signal TS2 as specified in table A.1 in clause A.2.
16) Adjust AT2 such, that the power measured by PM1 equals the sum of the sensitivity of the RSU declared by the provider plus 6 dB.
17) Replace the PM1 by the RSU receiver.
18) Set RSU and OBU to a mode so that they are able to process test messages TM1 as specified in table 5 in clause A.2.
19) Switch on MSS1 and MSS2.
20) Measure the BER of the RSU receiver according to clause A.9. If the BER is larger than $2{,}0 \times 10^{-2}$ the test failed.

21) Set the RSU to a mode such that the OBU shall use the upper sub-carrier frequency f_s.

22) Repeat step 20.

23) Set the RSU to a mode such that the OBU shall use the lower sub-carrier frequency f_s.

24) Set the frequency of the MSS1 to $f_{Tx} + f_s$ - 5 MHz and the frequency of the MSS2 to $f_{Tx} + f_s$ - 10 MHz.

25) Repeat steps 8 through 22.

26) Repeat steps 6 through 25 for the remaining value of the carrier frequency f_{Tx} in accordance with table 2 in clause 5.2.

9 Testing of On Board Unit

9.1 Upper power limit for communication

9.1.1 General

This test shall be performed either with radiated or conducted measurements.

Basic requirements and guidelines for measurements are provided in Annex A.

Parameter descriptions and limits are provided in clause 7.2.1.

The description below assumes that a RSU is used to transmit down-link signals and to receive up-link signals, both of type TM1 as specified in table A.1 in clause A.2.

NOTE: The provider may extend the test to determine the actual value of the upper power limit for communication.

9.1.2 Radiated measurements

The test procedure shall be as follows:

1) Prepare the test site according to clause A.6.5.2.

2) Set the SMS1 such that it continuously transmits test signal TS1 as specified in table A.1 in clause A.2.

3) Set the carrier frequency f_{Tx} of SMS1 defined for channel 1 according to table 2 and clause 6.6.

4) Set the modulation index of the signal transmitted by the SMS1 to 0,9 or to the greatest possible value within the allowed range of 0,5 to 0,9 supported by the SMS1.

5) Replace the OBU receiver by an RSA such that their phase centres and bore sights coincide. Connect the RSA to the power meter PM1.

6) Adjust the output signal power level of the SMS1 such that the signal power level P_{RSA} measured by the power meter PM1 amounts to:

$$P_{RSA} = P_{inc} \times G_{RSA} \times (1 - |\rho_{RSA}|^2) \quad (2)$$

where P_{inc}, and ρ_{RSA} denote, respectively, the maximum allowed value according to table 4 converted to Watt, and the reflection coefficient at the connector of the RSA.

7) Replace RSA by the OBU receiver.

8) Measure the BER of the OBU receiver according to clause A.9. If the BER is larger than 10^{-6} the test failed.

9) Repeat steps 5 through 8 for the carrier frequency f_{Tx} defined for channel 4 according to table 2 and clause 6.6.

9.1.3 Conducted measurements

The test procedure shall be as follows:

1) Prepare the test site according to clause A.5.4.2.
2) Set the SMS1 such that it continuously transmits test signal TS1 as specified in table A.1 in clause A.2.
3) Set the carrier frequency f_{Tx} of SMS1 defined for channel 1 according to table 2 and clause 6.6.
4) Set the modulation index *m* of the signal transmitted by the SMS1 to 0,9 or to the greatest possible value within the allowed range of 0,5 to 0,9 supported by the SMS1.
5) Replace the OBU receiver by a power meter PM1.
6) Adjust the output signal power of the SMS1 such that the signal power indicated by the power meter PM1 equals the sum of the maximum allowed value according to table 4 in dBm and the gain in dB of the OBU receive antenna as declared by the provider.
7) Replace PM1 by the OBU receiver.
8) Measure the BER of the OBU receiver according to clause A.9. If the BER is larger than 10^{-6} the test failed.
9) Repeat steps 5 through 8 for the carrier frequency f_{Tx} defined for channel 4 according to table 2 and clause 6.6.

9.2 Cut-off power level

9.2.1 General

This test shall be performed either with radiated or conducted measurements.

Basic requirements and guidelines for measurements are provided in Annex A.

Parameter descriptions and limits are provided in clause 7.2.2.

The description below assumes that an RSU is used to receive up-link signals and to generate down-link signals, both of type TM1 as specified in table A.1 in clause A.2. The test can be performed accordingly based on laboratory instruments, i.e. an RSU simulator, to generate down-link messages of type TM1 and to receive and evaluate up-link signals of type TM1.

9.2.2 Radiated measurements

The test procedure shall be as follows:

1) Prepare the test site according to clause A.6.5.2.
2) Set the SMS1 such that it continuously transmits test message TM1 as specified in table A.1 in clause A.2, i.e. it invites the OBU for initialization by sending BSTs.
3) Set the carrier frequency f_{Tx} of SMS1 defined for channel 1 according to table 2 and clause 6.6.
4) Set the modulation index *m* of the signal transmitted by the SMS1 to 0,9.
5) Replace the OBU receiver by an RSA of gain G_{RSA} such that their phase centres and bore sights coincide. Connect the RSA to the power meter PM1.

6) Adjust the output signal power of the SMS1 such that the signal power indicated by the power meter PM1 amounts to:

$$P_{\mathrm{RSA}} = P_{\mathrm{inc}} \times G_{\mathrm{RSA}} \times (\ 1 - |\rho_{\mathrm{RSA}}|^2) \quad (3)$$

where P_{inc} equals -61 dBm converted to Watt, and ρ_{RSA} denotes the reflection coefficient at the connector of the RSA.

7) Switch off the SMS1.

8) Replace the RSA by the OBU receiver and wait until the OBU is in sleep mode.

9) Switch on the SMS1.

10) Observe for the time needed for transmitting 100 subsequent BST messages whether the OBU responds with a VST. If a VST is received, then the test failed.

11) Repeat steps 5 through 10 for the carrier frequency f_{Tx} defined for channel 4 according to table 2 and clause 6.6.

9.2.3 Conducted measurements

The test procedure shall be as follows:

1) Prepare the test site according to clause A.5.4.2.

2) Set the SMS1 such that it continuously transmits test message TM1 as specified in table A.1 in clause A.2, i.e. invites the OBU for initialization by sending BSTs.

3) Set the carrier frequency f_{Tx} of SMS1 defined for channel 1 according to table 2 and clause 6.6.

4) Set the modulation index *m* of the signal transmitted by the SMS1 to 0,9.

5) Replace the OBU receiver by the power meter PM1.

6) Adjust the output power level of the SMS1 such that the signal power level indicated by the power meter PM1 equals the sum of -61 dBm plus the maximum gain in dB of the OBU receive antenna as declared by the provider.

7) Switch off the SMS1.

8) Replace PM1 by the OBU receiver and wait until the OBU is in sleep mode.

9) Switch on the SMS1.

10) Observe for the time needed for transmitting 100 subsequent BST messages whether the OBU responds with a VST. If a VST is received, the test failed.

11) Repeat steps 5 through 10 for the carrier frequency f_{Tx} defined for channel 4 according to table 2 and clause 6.6.

9.3 Conversion gain

9.3.1 General

This test shall be performed either with radiated or conducted measurements.

Basic requirements and guidelines for measurements are provided in Annex A.

Parameter descriptions and limits are provided in clause 7.2.3.

9.3.2 Radiated measurement

The test procedure shall be as follows:

1) Prepare the test site according to clause A.6.5.1. The initial alignment of the OBU as needed in step 4 shall be according to M0 in figure 1, i.e.: the bore sight of the OBU antenna shall point towards the phase centre of the TA.

2) Switch on the MSS1, tune its frequency to the carrier frequencies f_{Tx} defined for channel 1 according to table 2 and clause 6.6.

3) Adjust the output power of the MSS1 such that the power P_{RSA} measured by the power meter PM1 amounts to:

$$P_{\mathrm{RSA}} = P_{\mathrm{inc}} \times G_{\mathrm{RSA}} \times (\ 1 - |\rho_{\mathrm{RSA}}|^2) \qquad (4)$$

where P_{inc}, and ρ_{RSA} denote, respectively, the minimum allowed incident signal power level P_{D11b} = -43 dBm (given by the OBU sensitivity limit), and the reflection coefficient at the connector of the RSA.

4) Replace the RSA by the OBU such that its phase centre Mc is as coincident with the axis of rotation of the turntable as possible. If the phase centre Mc of the OBU is unknown and no antenna is visible, the volume centre of the OBU shall be used instead. Align the OBU's bore sight as required.

5) Set the OBU to a test mode such that it re-transmits test signal TS2 as specified in table 5 in clause A.2 with sub-carrier frequency f_{s}.

6) Measure the smaller of the power levels P_{ssb} within the two side bands by the RD with a RBW of 100 kHz and report this value together with the value of f_{s} and f_{Tx} and the orientation Mi, i = 0…4, see figure 1.

7) Repeat step 6 for the other value of the sub-carrier frequency f_{s}.

8) Repeat steps 3 through 7 for the carrier frequency f_{Tx} defined for channel 4 according to table 2 and clause 6.6.

9) Repeat steps 2 through 8 for all remaining OBU orientations Mi as indicated in figure 1.

10) Replace the OBU by a LHCP calibrated TSA of gain G_{TSA} and reflection coefficient ρ_{TSA} at its connector suited for the range of carrier frequencies f_{Tx} listed in table 2 in such a way that its phase centre coincides with the one of the OBU transmitting antenna. If the measurement arrangement with one test antenna is used, then the bore sight of the TSA shall point towards the phase centre of the TTA. If the measurement arrangement with two test antennas is used, then the bore sight of the TSA shall point towards position $\mathrm{M}_{\mathrm{centre}}$.

11) Connect the output of the TSA via the optional balun BLN, if required, of feed through attenuation ATN_{BLN}, and the calibrated FCCA1 of feed through attenuation ATN_{CA1} to the calibrated MSS2 that shall be tuned to the frequency which is the sum of the carrier frequency f_{Tx} as set in step 2 and the sub-carrier frequency $\pm f_{\mathrm{s}}$ as set in step 5. The sign of the sub-carrier frequency is defined by the side band, which provided the smaller of the two power levels P_{ssb} in step 6.

12) Adjust the output signal level P_{MSS2} of the MSS2 until the level, measured on the RD, becomes identical to the corresponding value of P_{ssb} recorded in step 6. Calculate the retransmitted power:

$$P_{\mathrm{reTx}} = \frac{P_{\mathrm{MSS2}} \times G_{\mathrm{TSA}} \times (\ 1 - |\rho_{\mathrm{TSA}}|^2)}{ATN_{\mathrm{CA1}} \times ATN_{\mathrm{BLN}}} \qquad (5)$$

where all the parameters in equation (5) are related to the corresponding measurement frequencies, and report it together with the value of f_{s} and f_{Tx}.

13) Repeat step 12 for all remaining combinations of f_{s} and f_{Tx} for which a result is available from step 6.

14) The conversion gain G_{c} of the OBU shall be calculated by:

$$G_c = \frac{P_{\mathrm{reTx}}}{P_{\mathrm{inc}}} \qquad (6)$$

None of the calculated conversion gains shall be outside the limits specified in clause 7.2.3.

9.3.3 Conducted measurement

The test procedure shall be as follows:

1) Prepare the test site according to clause A.5.4.1. The gain of the OBU's receive and transmit antenna for the initial alignment of the OBU as needed in step 4 is assumed to be according to direction M0 in figure 1.

2) Tune the frequency of the MSS1's output signal to the carrier frequencies f_{Tx} defined for channel 1 according to table 2 and clause 6.6.

3) Replace the OBU receiver by the power meter PM1.

4) Adjust the output power of the MSS1 such that the power measured by the power meter PM1 matches the minimum allowed incident signal power level $P_{\text{inc,dBm}} = P_{\text{D11b}}$ = -43 dBm (given by the OBU sensitivity limit) increased by the maximum gain $G_{\text{OBU,Rx}}(\text{Mi})$ of the OBU receive antenna, i.e. in direction Mi, i = 0…4, according to figure 1, as declared by the provider.

5) Replace the power meter PM1 by the OBU receiver.

6) Set the OBU to a test mode such that it re-transmits test signal TS2 as specified in table A.1 in clause A.2 with sub-carrier frequency f_{s}.

7) Measure the smaller of the power levels P_{ssb} within the two side bands by the RD with a RBW of 100 kHz considering all losses the signal suffers between the output connector of the OBU and the input connector of the RD and report this value together with the value of f_{s} and f_{Tx}.

8) The retransmitted power P_{reTx} of the OBU shall be calculated by:

$$P_{\text{reTx}}(\text{Mi}) = P_{\text{ssb}} \times G_{\text{OBU,Tx}}(\text{Mi}) \quad (7)$$

where $G_{\text{OBU,Tx}}(\text{Mi})$ is the OBU's transmit antenna gain in the direction Mi.

9) Repeat steps 7 and 8 for the other value of the sub-carrier frequency f_{s}.

10) Repeat steps 3 through 9 for the carrier frequency f_{Tx} defined for channel 4 according to table 2 and clause 6.6.

11) Repeat steps 2 through 10 for all remaining OBU orientations Mi as indicated in figure 1.

12) The conversion gain $G_c(\text{Mi})$ of the OBU shall be calculated by:

$$G_c(\text{Mi}) = \frac{P_{\text{reTx}}(\text{Mi})}{P_{\text{inc}}} \quad (8)$$

None of the calculated conversion gains $G_c(\text{Mi})$ shall be outside the limits specified in clause 7.2.3.

Annex A (normative): Basics of testing

A.1 General conditions

A.1.1 Environment

Tests defined in the present document shall be carried out at representative points within the boundary limits of the mandatory environmental conditions as defined in clause 4.2.2.

Where technical performance varies subject to environmental conditions, tests may also be carried out under conditions as declared by the provider and being within the boundary limits of the declared operational environmental profile in order to give confidence of compliance for the affected technical requirements.

A possible provider declaration can be based on the extreme categories I, II, III as defined in clause 4.2.3.

A.1.2 Power source

For testing the equipment, it shall be powered by a test power source, capable of producing test voltages as declared by the provider.

For battery operated equipment the battery shall be removed when possible, and an external test power source shall be suitably decoupled. For radiated measurements any external power leads shall be arranged so as not to affect the measurements. If necessary, the external test power source may be replaced with the supplied or recommended internal batteries at the required voltage, or a battery simulator. This shall be stated on the test report. For radiated measurements on portable equipment, fully charged internal batteries shall be used. The batteries used shall be as supplied or recommended by the provider of the EUT.

During tests the external test power source voltages shall be within a tolerance of ±1 % relative to the voltage at the beginning of each test. The value of this tolerance can be critical for certain measurements. Using a smaller tolerance provides a better uncertainty value for these measurements. If internal batteries are used, at the end of each test the voltage shall be within a tolerance of ±5 % relative to the voltage at the beginning of each test.

The internal impedance of the external test power source shall be low enough for its effect on the test results to be negligible. The voltage of the external test power source shall be measured at the input terminals of the equipment.

A.1.3 Thermal balance

Before measurements are made the equipment shall have reached thermal balance in the test chamber.

The equipment shall be switched off during the temperature stabilizing period.

In the case of equipment containing temperature stabilization circuits designed to operate continuously, the temperature stabilization circuits shall be switched on for a time period as declared by the provider such that thermal balance has been obtained, and the equipment shall then meet the specified requirements.

If the thermal balance is not checked by measurements, a temperature stabilizing period of at least one hour, or such period as may be decided by the test laboratory, shall be allowed. The sequence of measurements shall be chosen and the relative humidity content in the test chamber shall be controlled so that condensation does not occur.

A.2 Test signals

Test signals and test messages are defined in table A.1.

Table A.1: Test signals and messages

Test signal/message	Description
Test Messages (TM1)	Set of DSRC messages supporting initialization and ECHO command compliant to EN 12795 [i.6], EN 12834 [i.7] and ISO 14906 [i.4].
Test Signal (TS1)	Properly modulated and coded DSRC signal where the data is a continuously repeated maximum length pseudo-random sequence generated by a linear feedback shift register. The period of the pseudo-random sequence shall be 511 bits.
Test Signal (TS2)	Continuous DSRC up-link signal with unmodulated sub-carrier. The sub-carrier frequency shall be settable to f_s = 1,5 MHz and f_s = 2,0 MHz, respectively.

Data coding and bit rates in down-link and up-link shall be according to parameters D7, U7 and D8, D8a, U8, U8a of EN 12253 [1], respectively.

A.3 Test sites

A.3.1 Test sites overview

All tests specified in the present document can be performed in a shielded anechoic chamber or at an open area test site.

The modulation index test can alternatively also be done in a test fixture.

Basics on test sites are specified in the following clauses. More details on test sites can be found in ETSI TS 103 052 [i.10].

A.3.2 Shielded anechoic chamber

A typical anechoic chamber is shown in figure A.1. This type of test chamber attempts to simulate free space conditions.

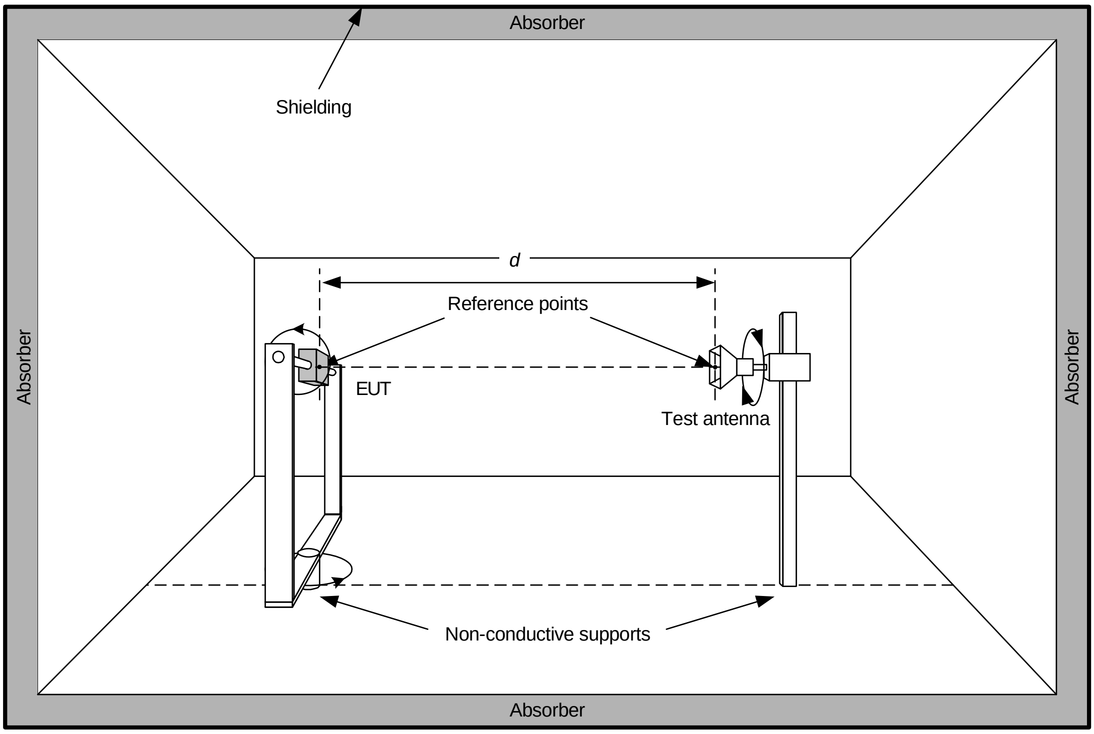

Figure A.1: Typical anechoic chamber

The chamber contains suitable antenna supports on both ends.

The supports carrying the test antenna and EUT shall be made of a non-permeable material featuring a low value of its relative permittivity.

The anechoic chamber shall be shielded. Internal walls, floor and ceiling shall be covered with radio absorbing material. The shielding and return loss for perpendicular wave incidence versus frequency as detailed in figure A.2 shall be met by anechoic chambers used to perform tests.

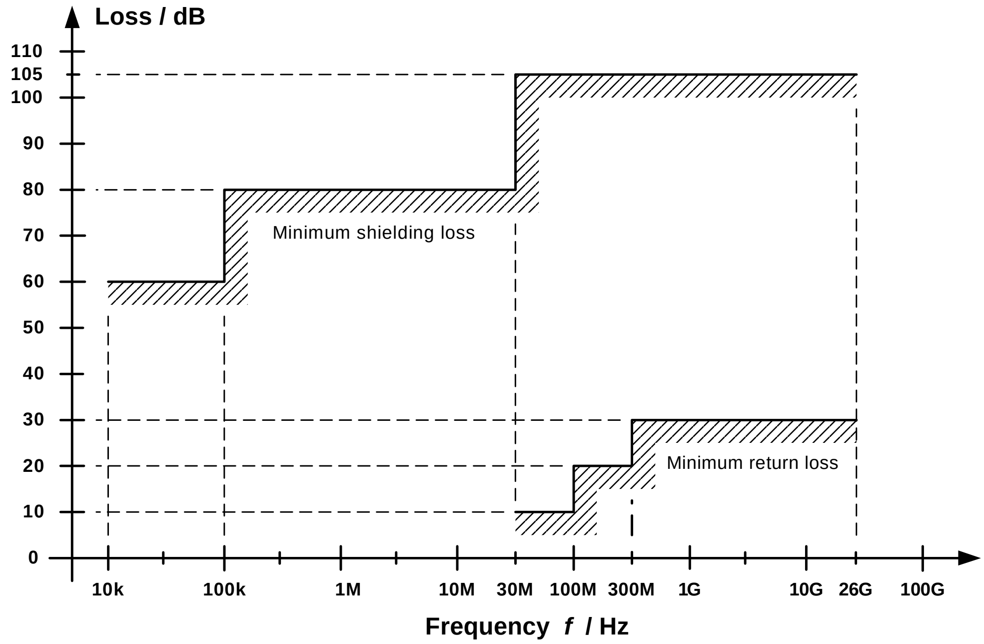

Figure A.2: Minimal shielding and return loss for shielded anechoic chambers

Both absolute and relative measurements can be performed in an anechoic chamber. Where absolute measurements are to be carried out the chamber shall be verified.

The shielded anechoic chamber test site shall be validated for the frequency range being applicable.

A.3.3 Open area test site

A typical open area test site is shown in figure A.3.

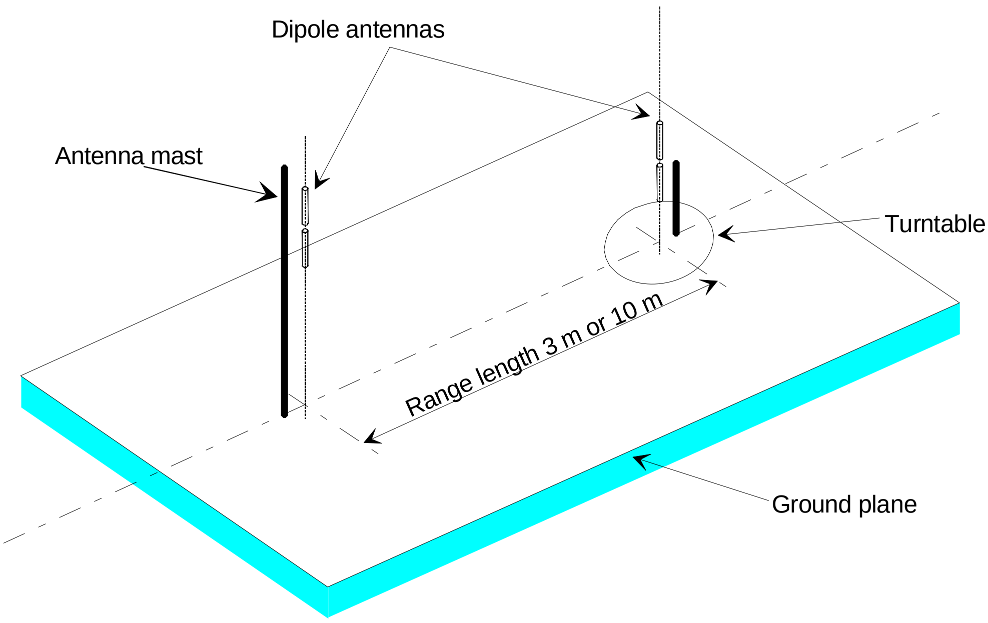

Figure A.3: Typical open area test site

The ground plane shall provide adequate size, such as to approximate infinite size. Relevant parts of the ground plane shall be covered by absorbing material.

Measurements performed in open area test sites follow the same procedures as detailed for radiated measurements performed in shielded anechoic chambers.

The open area test site shall be calibrated and validated for the frequency range being applicable.

A.3.4 Test fixture

A test fixture is a device that allows for conducted measurements of an EUT that does not provide antenna connectors itself. The EUT can be either an OBU or an RSU. A test fixture consists of at least one RF connector featuring a characteristic impedance of 50 Ω, subsequently called 50 Ω RF connector, and a device for electromagnetic coupling to the EUT. It incorporates a means for repeatable positioning of the EUT. The following figure A.4 illustrates a typical test fixture.

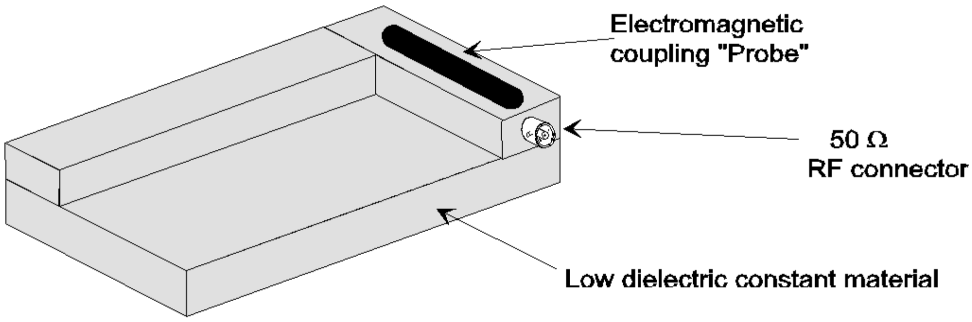

Figure A.4: Typical test fixture

The coupling device usually comprises a small antenna that is placed, physically and electrically, close to the EUT. This coupling device is used for sampling or generating the test fields when the EUT is undergoing testing. Figure A.5 illustrates an EUT mounted on a test fixture.

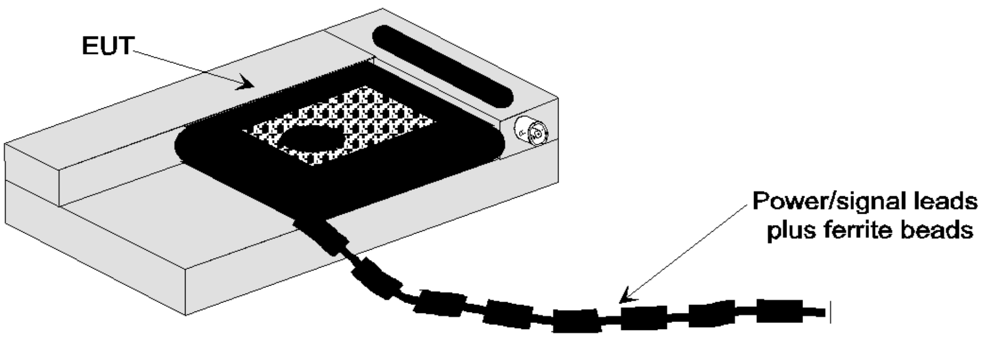

Figure A.5: EUT mounted in a typical test fixture

The entire assembly of test fixture plus EUT is generally compact and it can be regarded as a EUT with antenna connector. Its compactness enables the whole assembly to be accommodated within a test chamber, usually a climatic facility. The circuitry associated with the RF coupling device should contain no active or non-linear components and should present a VSWR of better than 1,5 to a 50 Ω line.

Absolute measurements shall not be made in a test fixture. Since the antennas of the EUT and the test fixture might be mutually in the near-field of each other. Hence, only relative measurements shall be performed that have to be related to results taken on a verified free field test site.

The way to relate the results is by a process, referred to as field equalization, in which the relevant parameter, e.g.: effective radiated power, receiver sensitivity, etc. is initially measured on a free field test site under normal environmental conditions and then subsequently re-measured using the test fixture under the very same environmental conditions. The relation between the two results is termed the coupling factor of the test fixture and provides the link between all the results of EUT tests carried out in the test fixture and its performance on a verified free field test site. Generally, the coupling factor should not be greater than 20 dB.

Emission tests are limited to the nominal frequencies, for which the performance of the test fixture has been verified.

Only after it has been verified that the test fixture does not affect performance of the EUT, the EUT can be confidently tested.

The test fixtures shall be calibrated and validated for the frequency range they are used for.

A.4 General requirements for RF cables

All RF cables including their connectors at both ends used within the measurement arrangements and set ups shall be of coaxial type featuring within the frequency range they are used:

- a nominal characteristic impedance of 50 Ω;
- a VSWR of less than 1,2 at both of their ends, preferably better;
- a shielding loss exceeding 60 dB, preferably better.

All RF cables exposed to radiation shall be loaded with ferrite beads spaced with a gap of D_{fb} between each other along the entire length of the cable. Such cables are referred to as FCCA. The gap D_{fb} shall be smaller than half of the signal's wavelength under test.

All RF cables shall be routed suitably in order to reduce impacts on antenna radiation pattern, antenna gain, antenna impedance.

A.5 Conducted measurements

A.5.1 One antenna connector arrangement

Figure A.6 shows the measurement arrangements that shall be used in case of a single antenna connector at the EUT.

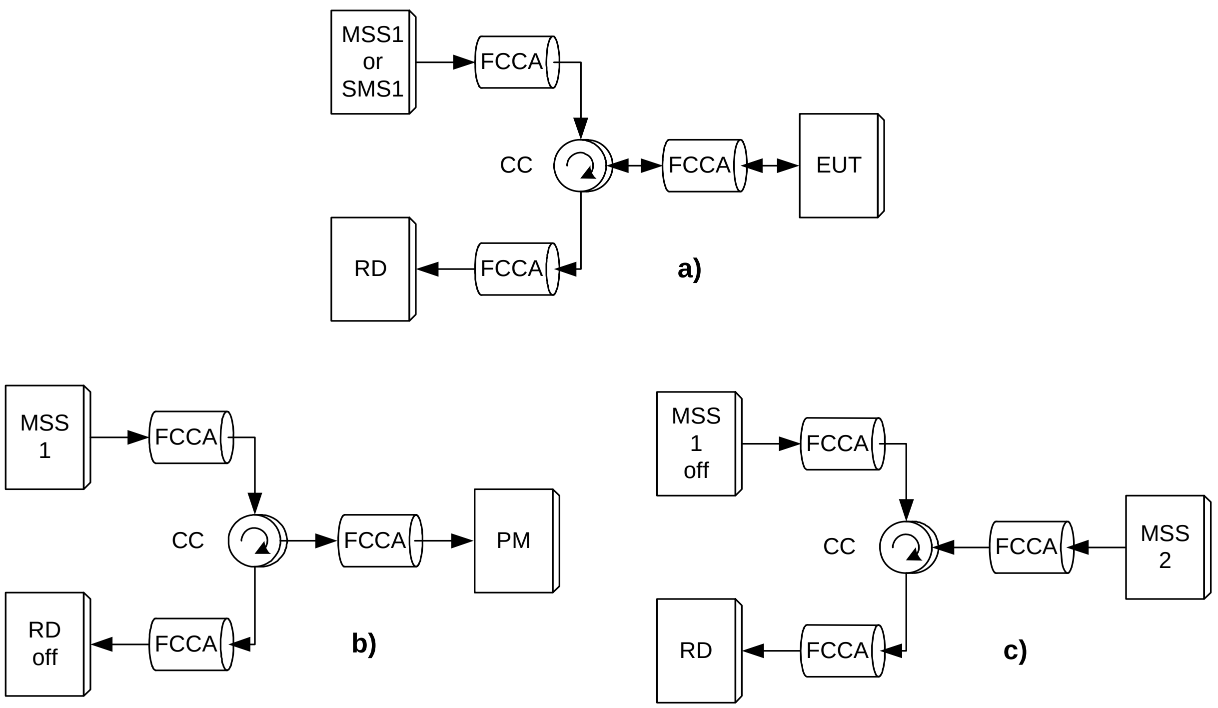

Figure A.6: Measurement arrangement with one antenna connector:
a) for measurement of EUT parameters
b) for adjusting input power to EUT
c) for substitution measurements

A.5.2 Two antenna connectors arrangement

Figure A.7 shows the measurement arrangements that shall be used in case of a two antenna connectors at the EUT.

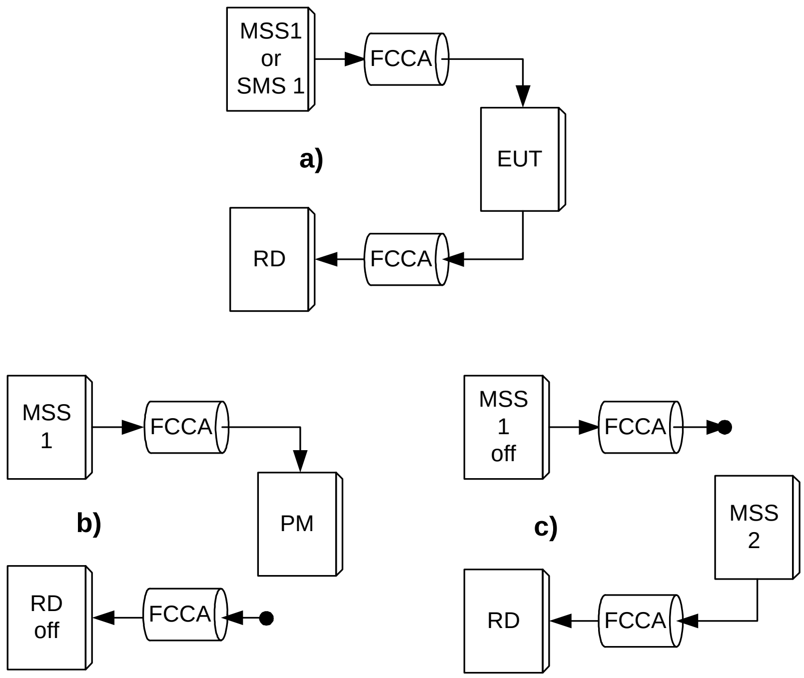

Figure A.7: Measurement arrangement with two antenna connectors:
a) for measurement of EUT parameters
b) for adjusting input power to EUT
c) for substitution measurements

A.5.3 Test site requirements

Conducted measurements shall be performed at the antenna connector(s) of the EUT.

A.5.4 Site preparation

A.5.4.1 Monochromatic signals

If the measurement arrangement with one antenna connector is used, the measurement set up depicted in figure 6 applies and the site preparation is as follows:

1) The calibrated MSS1 shall be connected to the antenna connector of the EUT via the calibrated CC providing three terminals.

2) The RD shall be connected to the antenna connector of the EUT via the remaining third terminal of the calibrated CC.

If the measurement arrangement with two antenna connectors is used, the measurement set up depicted in figure A.7 applies and the site preparation is as follows:

1) The calibrated MSS1 shall be connected to the receive antenna connector of the EUT.

2) The RD shall be connected to the transmit antenna connector of the EUT.

A.5.4.2 Modulated signals

If the measurement arrangement with one antenna connector is used, the measurement set up depicted in figure A.6 applies and the site preparation is as follows:

1) The calibrated SMS1 shall be connected to the antenna connector of the EUT via the calibrated CC providing three terminals.

2) The RD, i.e. either an RSU receiver or a measurement receiver, shall be connected to the antenna connector of the EUT via the remaining third terminal of the calibrated CC.

If the measurement arrangement with two antenna connectors is used, the measurement set up depicted in figure A.7 applies and the site preparation is as follows:

1) The calibrated SMS1 shall be connected to the receive antenna connector of the EUT.

2) The RD, i.e. either an RSU receiver or a measurement receiver, shall be connected to the transmit antenna connector of the EUT.

A.6 Radiated measurements

A.6.1 One antenna arrangement

Figure A.8 shows the measurement arrangements that shall be used in case one test antenna TA for transmitting and receiving signals are selected for testing the EUT.

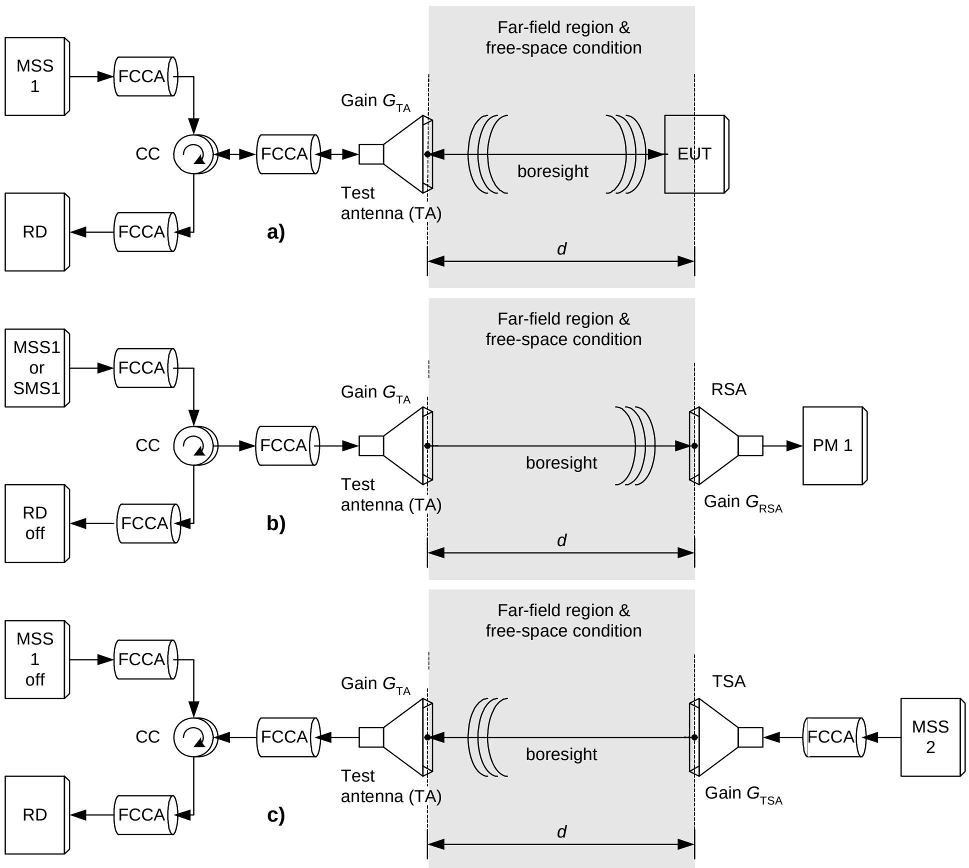

Figure A.8: Measurement arrangement with one test antennas:
a) for measurements of EUT parameters
b) for adjustment of the incident power to the EUT
c) for measurement steps using the substitution antenna

A.6.2 Two antennas arrangement

Figure A.9 shows the measurement arrangements that shall be used in case two test antennas, i.e. TTA and RTA, are selected for testing the EUT.

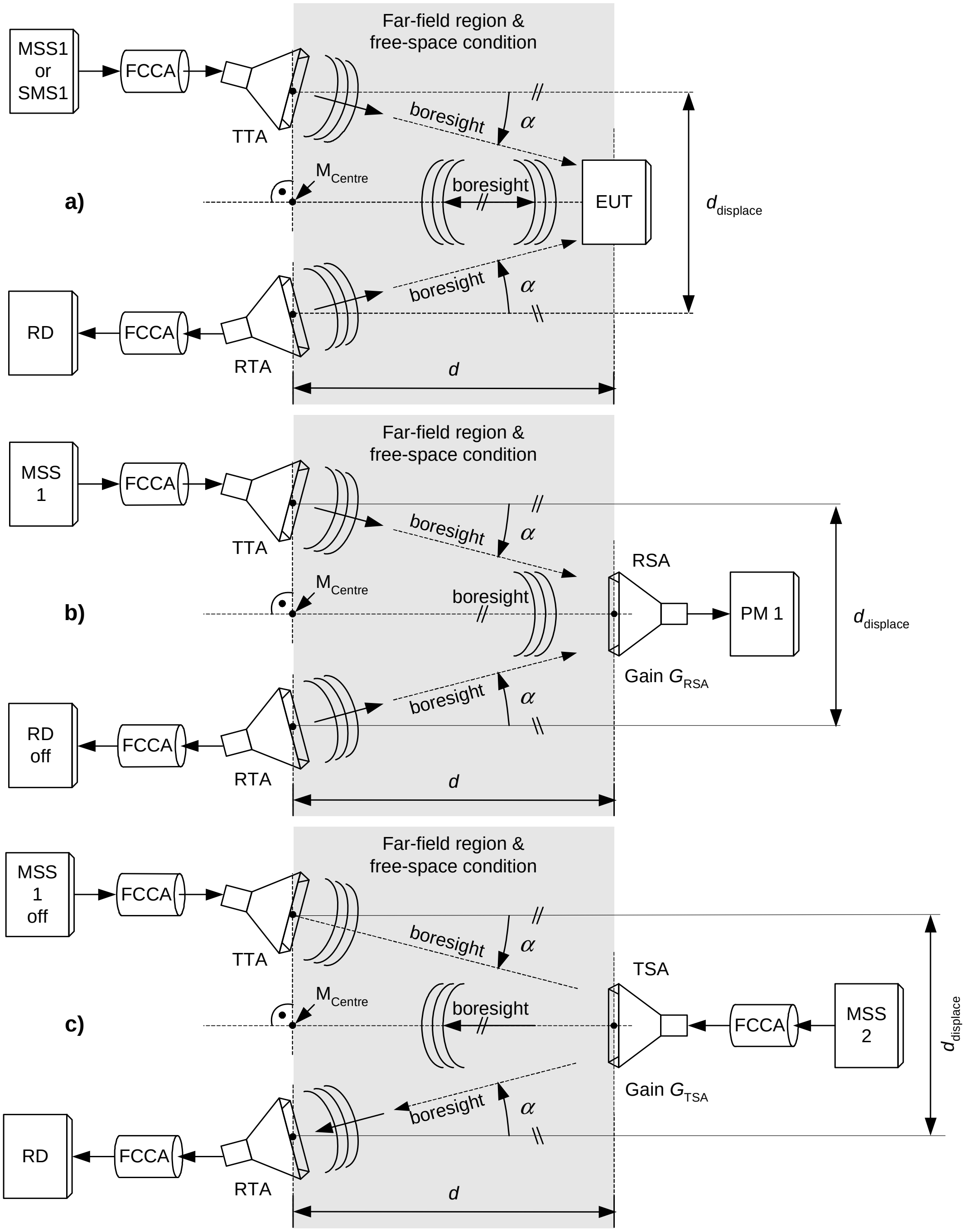

Figure A.9: Measurement arrangement with two test antennas:
a) for measurements of EUT parameters
b) for adjustment of the incident power to the EUT
c) for measurement steps using the substitution antenna

A.6.3 Test site requirements

A.6.3.1 Measurement distances

Within an open area test site or a shielded anechoic chamber the measurement distance or range length *d* depicted in figures A.8 and A.9 shall be such, that the antennas on both sides of the radio link are mutually in the far field of each other, i.e. *d* shall be according to the most stringent of the following three equations:

$$d > \frac{2\times\left(D_{0,\mathrm{TA}}+D_{0,\mathrm{EUT}}\right)^2}{\lambda},\ d > 5\times\left(D_{0,\mathrm{TA}}+D_{0,\mathrm{EUT}}\right) \text{ and } d > 2\times\lambda, \qquad \text{(A.1)}$$

where $D_{0,\mathrm{TA}}$, $D_{0,\mathrm{EUT}}$ and λ denote the largest dimension of the test antenna, the EUT antenna, and the wavelength, respectively.

This distance *d* shall be measured between:

- the centre of aperture of the test antenna TA, in case of a horn antenna, or the feeding point in case the TA is of another type; and
- the feeding point of the EUT antenna if the location of the EUT antenna is known, or the volume centre of the EUT if the location of its antennas is unknown.

A.6.3.2 Free-space wave propagation

Within an open area test site or a shielded anechoic chamber, a radio path between a transmitting and receiving antenna requires a certain amount of clearance around the central or direct ray if the signal expected from free-space propagation is to be received.

The clearance is usually quoted in terms of Fresnel zones. As depicted in figure A.10 the first Fresnel zone encloses all radio paths from the transmitting to the receiving antenna for which the detour path length $d_{F1} + d_{F2}$ relative to the length *d* of the direct radio path does not exceed half of the wavelength λ, i.e. a phase change of 180°, of the radiated signal in air:

$$d_{F1} + d_{F2} - d \leq \lambda/2. \qquad \text{(A.2)}$$

Disregarding the non-conductive, dielectric supports of the EUT and the test antenna(s) the clearance around the LOS path between the transmitting and receiving antenna shall be such that at least the first Fresnel zone is free of any obstacles.

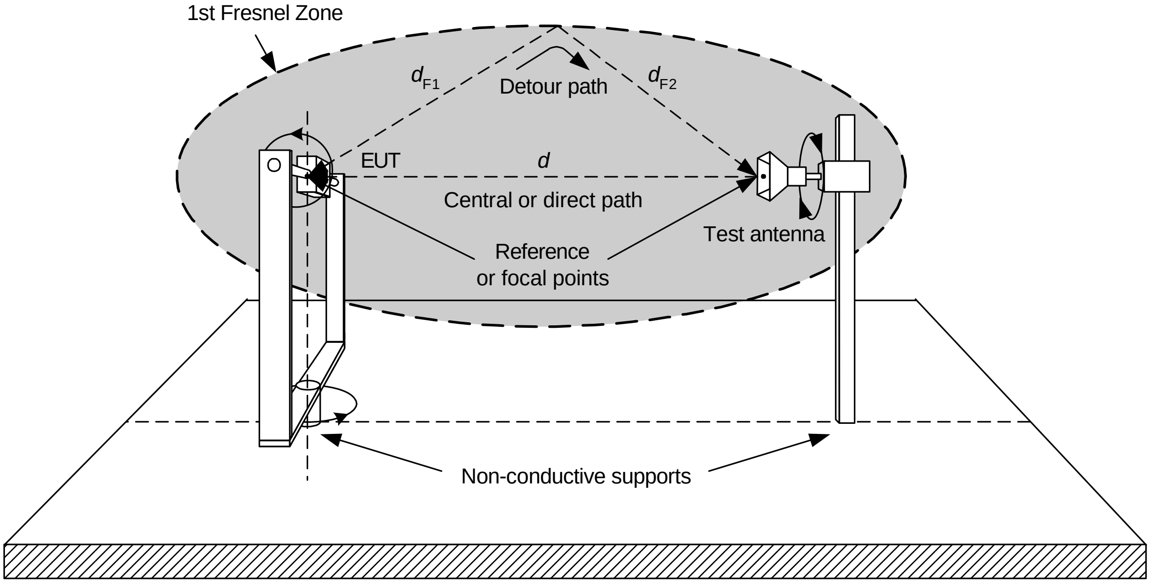

Figure A.10: First Fresnel zone with direct and detour radio path

A.6.4 Test and substitution antennas

Test antennas are used to detect the radiation from the EUT or to transmit a signal towards the EUT while substitution antennas together with signal generators are used to replace the EUT and its antenna in substitution measurements.

The test or substitution antenna shall be either LHCP, LP, or XP, whichever is required in the test procedure of the respective EUT parameter. Cross-polarized test or substitution antennas require a XPD > 25 dB within their specified frequency range.

Preferably test or substitution antennas with pronounced directivities shall be used. However, their directivities D_i relative to an isotropic radiator shall be such that the antennas on both sides of the radio link are mutually in the far field region of each other.

If the symmetry of the test or substitution antenna does not match the one of its feeding cables, a symmetry matching circuit (balun) shall be inserted between the antenna output and the input of its feeding RF cable.

The return loss at the terminal of the test or substitution antenna shall exceed 15 dB within its specified frequency range.

When measuring signals in the frequency range up to 1 GHz the test or substitution antenna shall be either:

- a half wavelength dipole, resonant at the operating frequency; or
- a shortened dipole, calibrated to the half wavelength dipole; or
- a biconical antenna.

For measurements between 1 GHz and 4 GHz either:

- a half wavelength dipole; or
- a biconical antenna; or
- a horn radiator may be used.

When measuring signals in the frequency range above 4 GHz a horn antenna shall be used.

The type of test or substitution antenna used in the tests shall be stated in the test report.

A.6.5 Site preparation for OBU measurements

A.6.5.1 Monochromatic signals

If the measurement arrangement with one test antenna is used, the measurement set up depicted in figure A.8 applies and the site preparation is as follows:

1) The LHCP calibrated Test Antenna (TA, TTA: transmit path, RTA: receive path) shall be suited for the range of carrier frequencies f_{Tx} in accordance with clause 6.6. It shall be mounted in a shielded anechoic chamber on a vertical pole. The distance between any part of this TA and the ceiling, floor or walls shall be at least 0,5 m (see also clause A.6.3.2). The height of the phase centres above floor of the TA and the CA shall be equal. The CA is either the OBU antenna (EUT) or the RSA. The bore sight of the TTA shall point towards the phase centre of the CA.

2) The TA shall be connected via a CC featuring three terminals to a calibrated MSS1 using calibrated FCCAs. The remaining third terminal of the circulator shall be connected via a calibrated FCCA to the input of a calibrated RD, i.e. spectrum analyser or measuring receiver, calibrated at the frequencies of the monochromatic signals under consideration. Appropriate precautions shall be taken to prevent overloading the input of the RD.

3) The LHCP calibrated RSA of gain G_{RSA} shall be suited for the range of carrier frequencies f_{Tx} in accordance with clause 6.6. It shall be mounted on a vertical pole within the "quiet zone" at the other end of the shielded anechoic chamber. This pole shall be mounted on a turntable allowing rotating the RSA's phase centre around a vertical axis. The distance between any part of the RSA and the ceiling, floor or walls shall be at least 0,5 m (see also clause A.6.3.2). Further, the distance *d* between the TTA and the RSA shall be such that the two antennas are mutually in the far field of each other, see clause A.6.3.1. The bore sight of the RSA shall point towards the phase centre of the TA. The output of the RSA shall be connected directly to the power sensor of power meter PM1 that shall be calibrated to the frequency of the monochromatic signal under consideration.

If the measurement arrangement with two test antennas is used, the measurement set up depicted in figure A.9 applies and the site preparation is as follows:

1) The LHCP calibrated TTA and the LHCP calibrated RTA shall each be suited for the range of carrier frequencies f_{Tx} in accordance with clause 6.6. They shall be mounted in a shielded anechoic chamber on a vertical pole. These two antennas shall be displaced either horizontally or vertically such as to minimize the coupling between them. Vertically polarized TTA and RTA shall be displaced vertically whilst horizontally polarized TTA and RTA shall be displaced horizontally. Additionally, the phase centre of the TTA shall be displaced from the phase centre of the RTA by a distance d_{displace} such that the coupling loss between the two antennas becomes larger than 30 dB and the overall uncertainty of the measurement set-up shall comply with the requirements specified in table B.1. The actual coupling loss and the distance d_{displace} between the TTA and the RTA shall be stated in the test report together with a unique identification of the TTA and the RTA used. The position between both phase centres is denoted M_{centre}. The distance between any part of the TTA and the RTA with respect to the ceiling, floor or walls shall be at least 0,5 m (see also clause A.6.3.2). The height of M_{centre} and the phase centre of the CA above floor shall be equal. The CA is either the OBU antenna or the RSA. The bore sight of the TTA and the RTA shall point towards the phase centre of the CA.

2) The TTA shall be connected to the calibrated MSS1 using calibrated FCCAs.

3) The RTA shall be connected to the input of the calibrated RD, i.e. a spectrum analyser or a measuring receiver, using calibrated FCCA. The RD shall be calibrated at the frequencies of the monochromatic signals under consideration. Appropriate precautions shall be taken to prevent overloading the input of the RD.

4) The LHCP RSA of gain G_{RSA} shall be suited for the range of carrier frequencies f_{Tx} in accordance with clause 6.6. It shall be mounted on a vertical pole within the "quiet zone" at the other end of the shielded anechoic chamber. This pole shall be mounted on a turntable allowing to rotate the RSA's phase centre around a vertical axis. The RSA shall be positioned close to the middle between the ceiling and the floor. Its bore sight shall point to the centre between the phase centres of the TTA and the RTA. The distance between any part of the RSA and the ceiling, floor or walls shall be at least 0,5 m (see also clause A.6.3.2). Further, the distance *d* between the TTA and the RSA as well as between the RTA and the RSA shall be such that the two antennas on both sides of the radio link are mutually in the far field region of each other, see clause A.6.3.1. Additionally, the distance *d* between CA and the position M_{centre} shall be such that the displacement angle α_{displace} between TTA and RTA as observed from the CA complies with:

$$\alpha_{\text{displace}} = 2 \times arctan\left(\frac{d_{\text{displace}}}{2 \times d}\right), \quad \text{(A.3)}$$

$$\alpha_{\text{displace}} \leq 2^{o} \text{ for horizontally displaced antennas,} \quad \text{(A.4)}$$

$$\alpha_{\text{displace}} \leq 6^{o} \text{ for vertically displaced antennas.} \quad \text{(A.5)}$$

The output of the RSA shall be connected directly to the power sensor of power meter PM1 that shall be calibrated at the frequencies of the monochromatic signals under consideration.

A.6.5.2 Modulated signals

If the measurement arrangement with one test antenna is used, the measurement set up depicted in figure A.8 applies and the site preparation is as follows:

1) The LHCP calibrated test antenna (TA, TTA: transmit path, RTA: receive path) shall be suited for the range of carrier frequencies f_{Tx} in accordance with clause 6.6. It shall be mounted in a shielded anechoic chamber on a vertical pole. The distance between any part of this TA and the ceiling, floor or walls shall be at least 0,5 m (see also clause A.6.3.2). The height of the phase centres above floor of the TA and the CA shall be equal. The CA is either the OBU antenna (EUT) or the RSA. The bore sight of the TTA shall point towards the phase centre of the CA.

2) The TA shall be connected via a CC featuring three terminals to the calibrated SMS1 using calibrated FCCAs. The remaining third terminal of the circulator shall be connected via a calibrated FCCA to the input of the calibrated RD, i.e. RSU receiver or measuring receiver, calibrated at the frequencies of the modulated signals or messages under consideration. Appropriate precautions shall be taken to prevent overloading the input of the RD.

3) The LHCP calibrated RSA of gain G_{RSA} shall be suited for the range of carrier frequencies f_{Tx} in accordance with clause 6.6. It shall be mounted on a vertical pole within the "quiet zone" at the other end of the shielded anechoic chamber. This pole shall be mounted on a turntable allowing to rotate the RSA's phase centre around a vertical axis. The distance between any part of the RSA and the ceiling, floor or walls shall be at least 0,5 m (see also clause A.6.3.2). Further, the distance d between the TTA and the RSA shall be such that the two antennas are mutually in the far field of each other, see clause A.6.3.1. The bore sight of the RSA shall point towards the phase centre of the TA. The output of the RSA shall be connected directly to the power sensor of power meter PM1 that shall be calibrated at the frequencies of the signals under consideration.

If the measurement arrangement with two test antennas is used, the measurement set up depicted in figure A.9 applies and the site preparation is as follows:

1) The LHCP calibrated TTA and the LHCP calibrated RTA shall each be suited for the range of carrier frequencies f_{Tx} in accordance with clause 6.6. They shall be mounted in a shielded anechoic chamber on a vertical pole. These two antennas shall be displaced either horizontally or vertically such as to minimize the coupling between them. Vertically polarized TTA and RTA shall be displaced vertically whilst horizontally polarized TTA and RTA shall be displaced horizontally. Additionally, the phase centre of the TTA shall be displaced from the phase centre of the RTA by a distance $d_{displace}$ such that the coupling loss between the two antennas becomes larger than 30 dB and the overall uncertainty of the measurement set-up shall comply with the requirements specified in table B.1. The actual coupling loss and the distance $d_{displace}$ between the TTA and the RTA shall be stated in the test report together with a unique identification of the TTA and the RTA used. The position between both phase centres is denoted M_{centre}. The distance between any part of the TTA and the RTA with respect to the ceiling, floor or walls shall be at least 0,5 m (see also clause A.6.3.2). The height of M_{centre} and the phase centre of the CA above floor shall be equal. The CA is either the OBU antenna or the RSA. The bore sight of the TTA and the RTA shall point towards the phase centre of the CA.

2) The TTA shall be connected to a calibrated SMS1 using calibrated FCCAs.

3) The RTA shall be connected to the input of the calibrated RD, i.e. an RSU receiver or a measuring receiver, using a calibrated FCCA. The RD shall be calibrated to the frequency of the modulated signal or message under consideration. Appropriate precautions shall be taken to prevent overloading the input of the RD.

4) The LHCP RSA of gain G_{RSA} shall be suited for the range of carrier frequencies f_{Tx} in accordance with clause 6.6. It shall be mounted on a vertical pole within the "quiet zone" at the other end of the shielded anechoic chamber. This pole shall be mounted on a turntable allowing to rotate the RSA's phase centre around a vertical axis. The RSA shall be positioned close to the middle between the ceiling and the floor. Its bore sight shall point to the centre between the phase centres of the TTA and the RTA. The distance between any part of the RSA and the ceiling, floor or walls shall be at least 0,5 m (see also clause A.6.3.2). Further, the distance *d* between the TTA and the RSA as well as between the RTA and the RSA shall be such that the two antennas on both sides of the radio link are mutually in the far field region of each other, see clause A.6.3.1. Additionally, the distance *d* between the CA and the position M_{centre} shall be such that the displacement angle α_{displace} between the TTA and the RTA as observed from the CA complies with:

$$\alpha_{\text{displace}} = 2 \times arctan\left(\frac{d_{\text{displace}}}{2 \times d}\right), \quad \text{(A.6)}$$

$$\alpha_{\text{displace}} \leq 2^{o} \text{ for horizontally displaced antennas,} \quad \text{(A.7)}$$

$$\alpha_{\text{displace}} \leq 6^{o} \text{ for vertically displaced antennas.} \quad \text{(A.8)}$$

The output of the RSA shall be connected directly to the power sensor of the power meter PM1 that shall be calibrated at the frequencies of the signals under consideration.

A.6.6 Site preparation for RSU measurements

A.6.6.1 Arrangement for transmit parameters

Figure A.11 details the arrangement used for measurement of the modulation index.

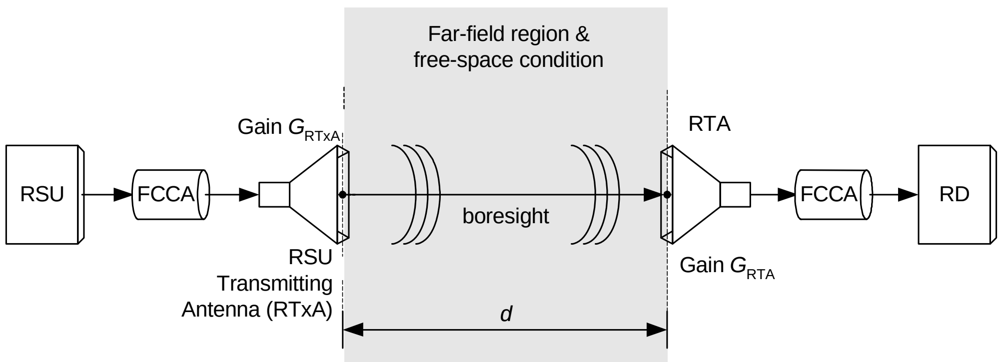

Figure A.11: RSU transmit parameter measurement arrangement

1) The LHCP RTxA shall be mounted on a vertical pole within the "quiet zone" of the shielded anechoic chamber. The distance between any part of the RTxA and the ceiling, floor or walls shall be at least 0,5 m (see also clause A.6.3.2).

2) The RTA shall be suited for the range of carrier frequencies f_{Tx} in accordance with table 2 in clause 5.2. It shall be mounted on a pole at the other end of the shielded anechoic chamber. The distance between any part of the RTA and the ceiling, floor or walls shall be at least 0,5 m (see also clause A.6.3.2). The RTA shall be LHCP if not stated otherwise in the test procedures.

3) The distance *d* between the RTxA and the RTA shall be such that the two antennas are mutually in the far field of each other, see clause A.6.3.1.

4) The phase centres of the RTxA and the RTA shall be at the same height above floor.

5) The bore sight of the RTA shall point towards the phase centre of the RTxA. The bore sight of the RTxA shall point towards the phase centre of the RTA.

6) Connect the RSU transmitter to the RTxA via an FCCA.

7) Connect the RTA to the RD via an FCCA.

A.6.6.2 Arrangement for receive parameters

Figures A.12 and A.13 detail the arrangements used for measuring the intermodulation immunity. Figure A.12 is related to an RSU with separate antenna connectors for receive and transmit path.

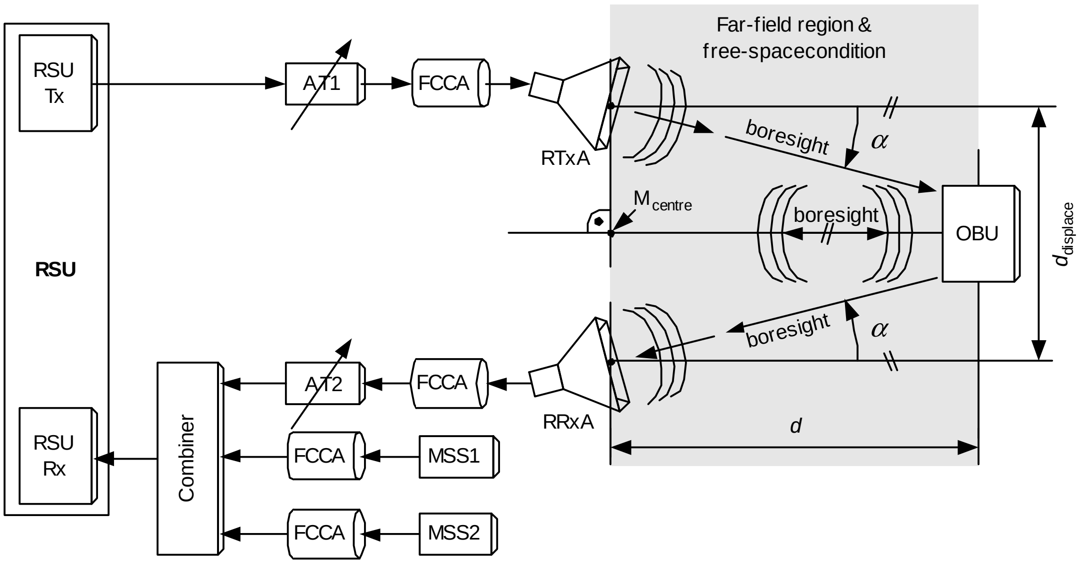

Figure A.12: RSU receive parameter measurement arrangement for horizontally separated antennas

In case the RSU under test provides only a single antenna connector for both, the transmit and receive path, a CC shall be used in order to split up the single antenna connector into two antenna connectors, one for the receive path and one for the transmit path; see figure A.13.

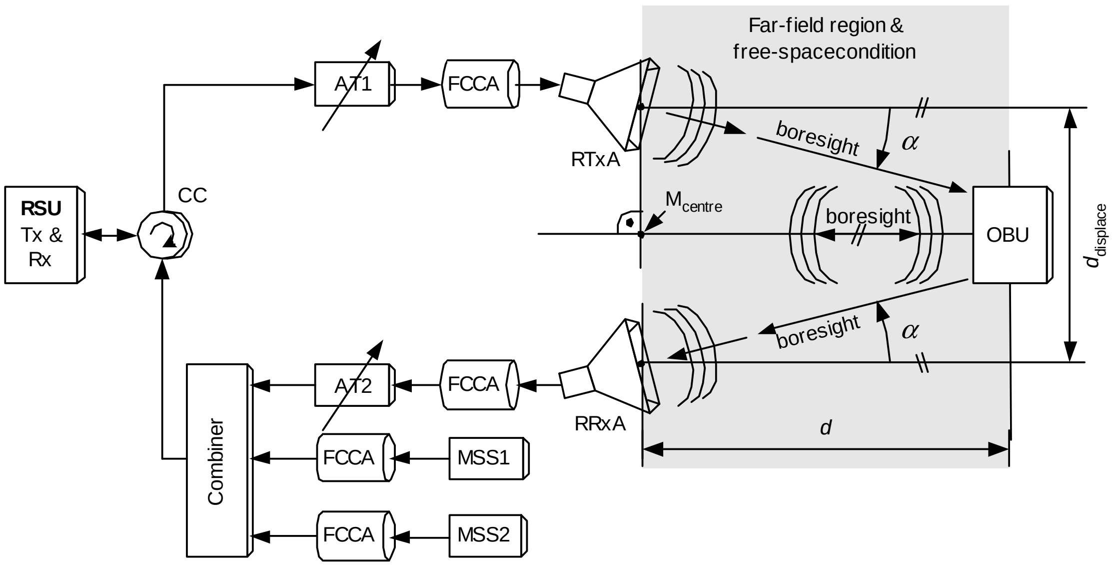

Figure A.13: RSU receive parameter measurement arrangement with CC for horizontally separated antennas

1) The RTxA shall be mounted on a vertical pole within the "quiet zone" of the shielded anechoic chamber. The distance between any part of the RTxA and the ceiling, floor or walls shall be at least 0,5 m (see also clause A.6.3.2).

2) The RRxA shall be mounted on a vertical pole within the "quiet zone" of the shielded anechoic chamber. The distance between any part of the RRxA and the ceiling, floor or walls shall be at least 0,5 m (see also clause A.6.3.2).

3) The phase centre of the RTxA shall be displaced from the phase centre of the RRxA by d_{displace}. The position between both phase centres is denoted M_{centre}.

4) The displacement shall either be horizontally or vertically such as to minimize the coupling between these antennas. The distance d_{displace} shall be such that the coupling loss between the two antennas exceeds 30 dB. The actual coupling loss and the distance d_{displace} shall be stated in the test report together with the unique identification of the RTxA and RRxA used.

5) The OBU shall be mounted on a vertical pole at the other end of the shielded anechoic chamber, such that its bore sight points towards M_{centre}.

6) The height of the phase centres above floor of the RTxA, RRxA and the OBU antenna shall be equal.

7) Bore sight of the RTxA shall point towards the phase centre of the OBU antenna.

8) Bore sight of the RRxA shall point towards the phase centre of the OBU antenna.

9) The OBU antenna(s) shall be mutually in the far field of RTxA and RRxA, see clause A.6.3.1.

10) Connect the RSU transmitter to the RTxA via an adjustable attenuator AT1 and an FCCA.

11) Connect the RRxA to the RSU receiver via a combiner with four terminals, an isolator, an adjustable attenuator AT2 with attenuation ATN_{AT2} and an FCCA.

12) Connect a MSS1 via a FCCA to one of the remaining terminals of the combiner.

13) Connect a MSS2 via a FCCA to the remaining terminal of the combiner.

A.7 Instruments

A.7.1 Receiving device

The RD shall be either a spectrum analyser or a measurement receiver. The subsequent requirements shall apply for a spectrum analyser:

1) The level of the superposition of all RF signals simultaneously fed to the input of the spectrum analyser shall be within its range of specification applying for its calibrated operational mode of operation.

2) The RD shall be operated only within modes for which the instrument has been calibrated.

3) For any frequency to be measured, the noise floor of the RD shall be at least 10 dB below any power value intended to be measured.

4) The DC voltage fed to the input of the spectrum analyser shall be within its range of specification applying for its calibrated operational mode of operation.

5) The frequency error of the spectrum analyser shall be compliant with table B.1.

6) The nominal characteristic impedance of the spectrum analyser's input connector shall match the nominal characteristic impedance of the device connected to this input connector. The VSWR shall be smaller than 2,0. If this cannot be met, an attenuator or an isolator featuring a VSWR smaller or equal to 2,0 within the frequency range of the measurement shall be attached to the input of the spectrum analyser and the EUT shall be connected to the input of this attenuator or isolator.

7) The Video BandWidth (VBW) shall always be equal to or larger than the Resolution BandWidth (RBW) selected. The RBW will also be referred to as the reference or equivalent bandwidth.

8) Signal power measurements performed using the spectrum analyser's CW mode shall equal to the arithmetic average of the largest and smallest signal level measured during the observation time.

9) The spectrum analyser shall be used only after the instrument has warmed up. The minimum warm up duration is usually specified in the manual of the spectrum analyser. If this is not the case, a warmup time of at least half an hour shall be considered.

10) The spectrum analyser shall be calibrated before usage.

11) If the dynamic range of the spectrum analyser in conjunction with the required setting of the RBW is not sufficient to measure relevant weak signals in the presence of irrelevant strong signal components appropriate measures to suppress the irrelevant strong signal components shall be applied in agreement between provider and test laboratory and shall be described in the test report.

12) The rms detector shall be used.

For the usage of a measurement receiver the above requirements shall apply as well with the exception, where requirements are not applicable, like the VBW.

A.7.2 RF power sensor

The subsequent requirements shall apply for RF signal power measurements.

1) RF signal power measurements shall not be performed before warmup of the RF power sensor and the RF power meter. The warmup duration is usually specified in the manual of the instrument. If this is not the case the instrument shall be allowed for a warmup time of at least half an hour.

2) The RF power sensor and RF power meter shall be calibrated and zeroed before usage according to the requirements and the procedure specified in the manual of the instrument.

3) The RF power sensor shall be kept within a small enough temperature range such as to keep the measurement uncertainty of the measurement set up within the range specified in clause B.2.

4) The VSWR at the input of the RF power sensor shall be less than 1,5 within the frequency range of the measurement under investigation.

5) The level of the superposition of all signals simultaneously fed to the input of the RF power sensor shall be within the dynamic range of the RF power sensor as stated by its provider for its operational mode.

6) The power sensor shall be dedicated for the signal waveform under consideration.

A.7.3 Combiner

All RF combiners used within the measurement arrangements and set ups shall provide coaxial connectors at all ports and feature within the frequency range they are used:

- a nominal characteristic impedance of 50 Ω at each port;
- a VSWR of less than 1,5 at each port;
- an isolation between the input ports of at least 10 dB; and
- an amplitude balance between each of the input ports and the output port of less than 1 dB.

A.8 Power level of modulated RSU carrier

Figure A.14 illustrates as an example the basic time-dependent sequence of unmodulated and modulated RSU transmit signals for a case of a modulation index $m = 0{,}5$, where the transmit signal power P_{mod}, and P_{CW}, respectively, of the modulated, and unmodulated signal parts are equal. The condition of equal power levels $P_{\mathrm{mod}} = P_{\mathrm{CW}}$ is not required by the present document.

NOTE: Figure A.14 does not allow extracting valid timing relations between carrier frequency and bit rate.

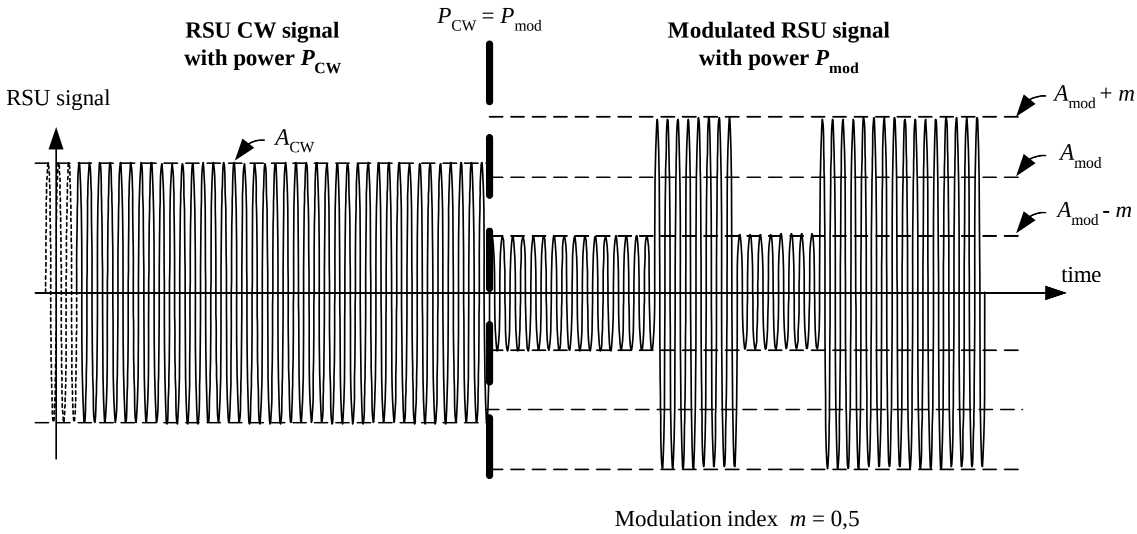

Figure A.14: RSU transmit signal

An RSU normally allows for a transmit mode "send unmodulated carrier", i.e. continuous transmission of the unmodulated carrier. Thus it is possible to measure the power of the unmodulated signal in figure A.14, $P_{\mathrm{CW}} = \frac{1}{2}A_{\mathrm{CW}}^2$, by means of a thermal power sensor or a spectrum analyser.

An RSU does normally not allow for continuous transmission of the modulated carrier. Modern test equipment can do a gated power level measurement in time domain to overcome this problem.

Following procedure allows to estimate the power $P_{mod} = \frac{1}{2}A_{\mathrm{mod}}^2(1 + m^2)$ of the modulated carrier without doing gated power level measurements:

1) Set the RSU in a mode that it transmits an unmodulated carrier. Measure P_{CW}.

2) Set the RSU in a mode that it transmits BSTs of maximum possible duration T_{mod} with a repetition period as close as possible to twice of the duration of a BST transmission. The gap between subsequent BST transmissions has duration T_{CW}. The duration T_{mod} and T_{CW} shall be constant within the following test.

3) Measure the average signal power level P_{avg} of the signal transmitted according to step 2 with a measurement duration of at least ten times the repetition period $T_{\mathrm{CW}} + T_{\mathrm{mod}}$.

4) Measure the duration T_{mod} and T_{CW}.

5) Calculate $P_{mod} = P_{avg} + \frac{T_{CW}}{T_{mod}}\left(P_{avg} - P_{CW}\right)$.

A.9 Bit error ratio measurements

A.9.1 Basics

The required BER for communication is referred to as parameters D9a and U9a in EN 12253 [1].

BER measurements shall be conducted either in a direct or indirect way.

The direct way requires the possibility to generate and receive a continuous bit stream of significant length. The fraction of erroneous bits out of the total number of received bits is the BER. This approach uses standard laboratory equipment for BER measurement and requires a modification of the EUT.

The indirect way is based on generating and receiving frames of limited length where any bit errors in the frame can be detected by means of a CRC. The fraction of erroneous frames out of the total number of frames, which is called the FER, allows to estimate the BER assuming that bit errors are equally distributed. Precautions shall be taken to prevent drops of error-free received frames caused by specific implementation of upper layers.

A.9.2 BER measurement

BER may be measured indirectly, see clause 9.3.

A.9.3 FER measurement

A.9.3.1 Mathematical expressions

Assuming equally distributed and statistically independent occurrence of erroneous bits the following relations between *FER*, *BER*, and total number *N* of transmitted bit within a single frame apply:

$$FER = 1 - (1 - BER)^N, \tag{A.9}$$

$$BER = 1 - 10^{\frac{lg(1-FER)}{N}} = 1 - \sqrt[N]{1 - FER}. \tag{A.10}$$

The minimum number C_F of frames together with the frame size shall be reported.

EXAMPLE 1: With $BER = 10^{-6}$ and frame length N = 1 000 the equivalent *FER* amounts to approximately $1{,}0 \times 10^{-3}$. A reasonable number C_F of frames to be transmitted is 10 000, i.e. 10 frames may be lost on average.

EXAMPLE 2: For a large value of FER, e.g. 0,9999 which results from a BER = $9{,}2 \times 10^{-3}$ and a frame length N = 1 000, a reasonable number C_F of frames to be transmitted is 100 000, i.e. 10 frames may be error-free on average. The very large number of frames to be transmitted is necessary to estimate the BER, since a small variation in erroneous frames may cause a significant change of the corresponding estimated BER.

A.9.3.2 Equipment

FER measurements can be easily conducted using the set of test messages TM1 as specified in table A.1 in clause A.2. Thus, standard DSRC equipment might be used if the following software configuration has been implemented:

- initialization with BST and VST is implemented; see EN 12795 [i.6] and EN 12834 [i.7];
- the EFC command ECHO is implemented; see ISO 14906 [i.4].

In case of a bit error performance measurement of the RSU receiver, the following additional configuration requirements apply:

- An ECHO.request transmitted by the RSU and not responded by the OBU shall be treated as "never transmitted", as in this case the ECHO.request was received erroneous.
- An erroneous ECHO.response received shall not result in a retransmission of the related ECHO.request as normally required by the DSRC protocol. It shall just lead to an increment of the frame error counter.

In case of a bit error performance measurement of the OBU receiver, the following additional configuration requirements apply:

- An ECHO.request transmitted by the RSU and not responded by the OBU shall not result in a retransmission of the related ECHO.request as normally required by the DSRC protocol. It shall just lead to an increment of the frame error counter.

- An erroneous ECHO.response received shall not result in a retransmission of the related ECHO.request as normally required by the DSRC protocol, it shall just be ignored, as in this case the ECHO.request was received error free at the OBU.

A.9.3.3 Procedure

1) The RSU shall perform initialization with the OBU by exchanging BST and VST. The signal level at the receiver input relevant for BER measurement shall be set to the level required for the test. The signal level at the other receiver input shall be set at a reasonable high value as declared by the provider such that error free reception is very likely. In the unexpected case of transmission errors, the initialization attempt shall be repeated. During initialization any additional interfering signals as requested by a specific test procedure shall be switched off.

2) The RSU shall transmit a single ECHO command of maximum length. Reception of the corresponding response from the OBU is expected to be error free. In case of errors, repetitions of the ECHO command according to the DSRC protocol shall happen. This finalizes initialization.

In case of a bit error performance measurement of the RSU receiver, the following additional procedural steps shall be processed:

3) Repeat step 2 C_F times, C_F see clause A.9.3.1, and report the total number C_E of erroneous ECHO.response frames received by the RSU. Calculate the actual Frame Error Ratio $FER = C_E / C_F$. Continue with step 5.

In case of a bit error performance measurement of the OBU receiver, the following additional procedural steps shall be processed:

4) Repeat step 2 for C_F times, C_F see clause A.9.3.1, and report the total number C_E of ECHO.response frames not received by the RSU. Calculate the actual Frame Error Ratio $FER = C_E / C_F$.

5) Calculate *BER* out of *FER* according to clause A.9.3.1.

Annex B (normative): Interpretation of results and measurement uncertainty

B.1 Interpretation of results

The interpretation of the results recorded in the test report for the measurements described in the present document shall be as follows:

- the measured value related to the corresponding limit shall be used to decide whether an equipment meets the requirements of the present document;
- the measurement uncertainty value for the measurement of each parameter shall be included in the test report.

B.2 Measurement uncertainty

Table B.1 shows the recommended values for the maximum measurement uncertainty figures.

Table B.1: Maximum measurement uncertainty

Parameter	Uncertainty
RF power (conducted)	±1,5 dB
RF frequency, relative	$\pm 1 \times 10^{-7}$
Radiated emission of transmitter, valid to 40 GHz	±6 dB
Sensitivity	±3 dB
Two and three signal measurements	±4 dB
Two and three signal measurements using radiated fields	±6 dB
Radiated emission of receiver, valid to 40 GHz	±6 dB
Temperature	±1 K
Relative humidity	±5 %

History

Document history		
V1.1.1	June 2024	Publication