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Short Range Devices (SRD) and Ultra Wide Band (UWB); Radar related parameters and physical test setup for object detection, identification and RCS measurement

Reference
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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

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1 Scope

The purpose of the present document is to summarize Radar related parameters for object detection, identification and RCS measurement and to develop a physical test setup (e.g. based on fixed and moving targets with specified RCS) to provide a simplified test for the assessment of RBS and RBR requirements. Therefore, a clear specification is necessary to provide all necessary information to test houses to run "reproducible" and "comparable" tests.

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

[i.1] J. Fortuny-Guasch, J.M. Chareau: "Radar Cross-Section Measurements of Pedestrian Dummies and Humans in the 24/77 GHz Frequency Bands. Establishment of a Reference Library of RCS Signatures of Pedestrian Dummies in the Automotive Radar Bands", JRC Scientific and Policy Report EUR 25762 EN, 2013.

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[i.7] Application Note; ROHDE&SCHWARZ: "Antenna Measurements, RCS Measurements and Measurements on Pulsed Signals with Vector Network Analyzers R&S ZVM, R&S ZVK".

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[i.26] EN 50131-2-3:2008: "Alarm systems - Intrusion and hold-up systems - Part 2-3: Requirements for microwave detectors" (produced by CENELEC).

NOTE: A newer version is available as per EN 50131-2-3:2021.

[i.27] EN 50131-2-4:2020: "Alarm systems - Intrusion and hold-up systems - Part 2-4: Requirements for combined passive infrared and microwave detectors" (produced by CENELEC).

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

assessment area/volume: area/volume the target could move based on the test set-up and specified based on the intended use

supporting structure: to realize larger distances for simulating the intended use and positioning the object/target in the assessment spot (area of the intended use)

target: object that scatters energy back to the EUT

target retainer: mechanical structure to position the target/object and simulate small movements within the assessment spot (area of the intended use)

NOTE: Target retainer is also within the "beam" of the EUT.

3.2 Symbols

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

A_{eff}	effective area of the receiving antenna [m²]
c	speed of light: 299 792 458 [m/s]
D	distance between EUT and target [m]
D_T	maximal distance between EUT and target for the use-case
D_{wp}	maximum distance to the target based on the wanted technical performance, use-case; in [m]
D_{conf}	distance for the conformance test [m]
D_{max}	maximum detection distance (between EUT and target)
dB	decibel
f	frequency in [Hz]
G	gain of the transmit antenna [dimensionless]
G_{RX}	gain of the receiving antenna [dimensionless]
g_{RX}	gain of the receiving antenna in [dBi]
G_{TX}	gain of the transmit antenna [dimensionless]
g_{TX}	gain of the transmit antenna in [dBi]
L	edge length of corner reflector
$P_{@EUT}$	received power at the EUT in [dBm]
P_{RX}	power received back from the object by the EUT, either in [W], [dBW] or [dBm]
P_{TX}	transmitter power of the EUT, either in [W], [dBW] or [dBm]
P_{RTX}	radiated transmitted power of the EUT, either in [W], [dBW] or [dBm]
P_{sen}	received power at the EUT if the receiver is at his sensitivity in [dBm]
r_{sphere}	radius of the conducting sphere
r_T	radius of a specified target around a rotating axis, in [m]
RCS	Radar CrossSection [m²]
rcs	radar cross-section [dBm²]
RCS_{conf}	RCS of the object for the conformance test [m²]
RCS_{sphere}	Radar Cross-Section (RCS) of the conducting sphere [m²]
RCS_{square}	Radar Cross-Sections of trihedral square shaped corner reflector in boresight direction, in [m²]
RCS_T	minimal RCS of the related target for the use-case; specified in related standard, in [m²]
rcs_T	minimal RCS of the related target for the use-case specified in related standard, in [dBm²]
$RCS_{triangular}$	Radar Cross-Sections of trihedral triangular shaped corner reflector in boresight direction, in [m²]
RCS_{wp}	RCS of the object based on the wanted technical performance, use-case; in [m²]
rcs_{wp}	RCS of the object based on the wanted technical performance, use-case; in [dBm²]
λ	wavelength of the radio signal [m] and $\lambda = \frac{c}{f}$

Δ	delta difference of a distance, in [m]
ω_T	rotation speed of a specified target, in [cps]

3.3 Abbreviations

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

AFR	Alias Free Range
CAN	Controller Area Network
CPD	Child Presence Detection
e.i.r.p.	equivalent isotropically radiated power
EURAD	European Radar Conference
EUT	Equipment Under Test
FAR	False Alarm Rate
HPBW	Half Power Beamwidth
IRS	International Radar Symposium
LPR	Level Probing Radar
NARCAP	National Aviation Reporting Center on Anomalous Phenomena
OFR	Operating Frequency Range
OSM	Open-Short-Match
OTA	Over-The-Air
RBR	Receiver Baseline Resilience
RBS	Receiver Baseline Sensitivity
RCS	Radar Cross-Section [m^2]
RX	Receiver
SPEAG	Schmid & Partner Engineering AG
TGUWB	Task Group Ultra Wide Band
TX	Transmitter
UWB	Ultra Wide Band
VNA	Vector Network Analyser

4 Object and Radar Cross-Section

4.1 Radar Cross-Section (RCS)

4.1.1 General

Informally, the RCS of a target is the cross-sectional area of a perfectly reflecting sphere that would produce the same strength reflection as would the target in question. (Bigger sizes of this imaginary sphere would produce stronger reflections.) Thus, RCS is an abstraction: the Radar Cross-Sectional area of an object does not necessarily bear a direct relationship with the physical cross-sectional area of that object but depends upon other factors.

Somewhat less informally, the RCS of a radar target is an effective area that intercepts the transmitted radar power and then scatters that power isotopically back to the radar receiver.

Radar Cross-Section (RCS) is a measure of how detectable a target is by radar sensor. Therefore, it is often referred to as the electromagnetic signature of the target. A larger RCS indicates that a target is more easily detected.

While important in detecting targets, strength of transmitter and distance are not factors that affect the calculation of an RCS because RCS is a property of the target's reflectivity.

In radar sensor measurements power is transmitted towards a target which reflects a portion of the power back to a receiver. The received power depends - among other factors - on the Radar Cross-Section (RCS) of the object:

$$P\_Rx \propto RCS \quad (1a)$$

The Radar Cross-Section (RCS) of a target depends on several parameters:

- Frequency of radar signal.

- Target material.
- Target shape.
- Target size.
- Direction of the incident and reflected waves relative to the target.
- Target movement:
  - If a target moves it may change its orientation (direction of the incident and reflected waves relative to the target), or its shape (e.g. a human moves inside the same range gate) or the distance to the TX and RX. Movement on its own (translation or rotation), without change of shape or size, does not change the angle dependent RCS of a target if viewed from the coordinate system of the target.
- Target illumination:
  - RCS of a target is different for different directions/illumination angles (incident and reflected may be different directions in case of multi-static radar). Inhomogeneity in the material of a target may cause angle-dependent RCS.

4.1.2 Radar equation

The RCS of a radar target is the hypothetical area required to intercept the transmitted power density at the target as if the total intercepted power were re-radiated isotopically. This is a complex statement that can be understood by examining the monostatic radar (radar transmitter and receiver co-located, see figure 1).

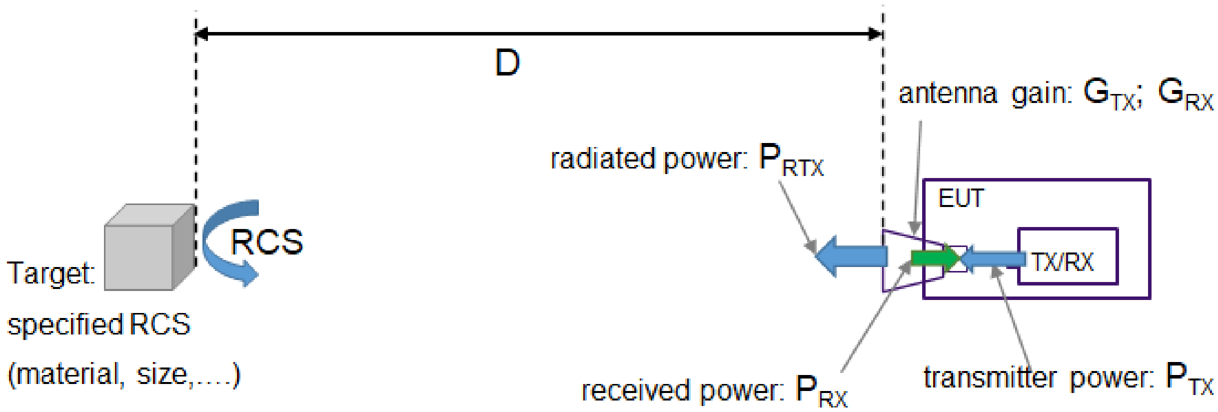


Figure 1: Scenario to show connection between RCS, Distance (D) and Power

The related radar equation (see equation (1b)) could be written as:

$$P_{RX} = \frac{P_{TX} \times G_{TX}}{4 \times \pi \times D^2} \times RCS \times \frac{1}{4 \times \pi \times D^2} \times A_{eff} \tag{1b}$$

with:

- P_{TX}: transmitter power [W]
- G_{TX}: gain of the transmit antenna [dimensionless]
- D: distance between EUT and target [m]
- RCS: Radar Cross-Section [m²]
- P_{RX}: power received back from the object by the EUT [W]
- A_{eff}: effective area of the receiving antenna [m²], see equation (2):

$$A_{eff} = \frac{G_{RX} \times \lambda^2}{4 \times \pi} \tag{2}$$

with:

- G_{RX}: gain of the receiving antenna [dimensionless]
- λ: wavelength of the radio signal [m] and $\lambda = \frac{c}{f}$
  - c: speed of light: 299 792 458 [m/s]
  - f: frequency in [Hz]

and provided that the transmitter and the receiver are co-located, and the same antenna is used for transmitting and receiving ($G_{TX} = G_{RX} = G$), see equation (3):

$$P_{RX} = \frac{P_{TX} \times G^2 \times \lambda^2}{(4 \times \pi)^3 \times D^4} \times RCS \quad (3)$$

with:

- P_{TX}: transmitter power [W]
- G: gain of the transmit antenna [dimensionless]
- D: distance between EUT and target [m]
- RCS: Radar Cross-Section [m²]
- P_{RX}: power received back from the object by the EUT [W]

A radio determination device (EUT) is only able to detect a signal reflected from an object (target) if the signal is above the sensitivity level of the EUT receiver. The level "above" the sensitivity is necessary to guarantee an object detection (detection probability), see equation (4):

$$P_{RX} \geq \text{Sensitivity of RX} = P_{sen} \quad (4)$$

For the RBS requirement (sensitivity) for radiodetermination in a harmonised standard it is therefore sufficient to specify:

- the target (kind of) or a representative RCS (which could be realized by e.g. triple mirror, see trihedral in clause A.1);
- a minimum distance of the object to the EUT; and
- a wanted technical performance criteria: e.g. detection probability.

The antenna gain and transmit power is given by the TX-requirements in the harmonised standard (part of the radio regulation).

With these specified requirements/parameters in the related standard each EUT has to fulfil a clear minimum level of sensitivity to guarantee a level of detection.

4.1.3 Maximum detection distance

The maximum detection distance for a EUT is if the received signal is equal to the sensitivity level of the receiver P_{sen}, (see clause 4.1.2, equation (4)). Together with equation (4) and equation (3) (see clause 4.1.2) the maximum detection distance D_{max} for a EUT with the same antenna gain for the transmitting and receiving path is shown in equation (5). If the antenna gains for the transmitting and receiving path are not equal, see equation (6).

$$D_{max} = \sqrt[4]{\frac{P_{TX} \times G^2 \times \lambda^2 \times RCS}{(4 \times \pi)^3 \times P_{sen}}} \quad (5)$$

$$D_{max} = \sqrt[4]{\frac{P_{TX} \times G_{TX} \times G_{RX} \times \lambda^2 \times RCS}{(4 \times \pi)^3 \times P_{sen}}} \quad (6)$$

4.1.4 Scaling distance and RCS

4.1.4.1 General on scaling

In equation (6) the EUT related parameter and the frequency are constant, the maximal distance the EUT is able to detect an object is only relating to the RCS of the object, see equation (7).

$$D_{max} = \sqrt[4]{\frac{\mathrm{P_{TX}} \times \mathrm{G}^2}{P_{sen}} \times \frac{\lambda^2}{(4\times\pi)^3} \times RCS} = \sqrt[4]{constant \times RCS} \quad (7)$$

If the maximum detection distance D_{wp} according to the wanted technical performance of the EUT can not be realized in a test scenario (e.g. due to limited size of test site), then the distance for the conformance test D_{conf} can be scaled down by choosing another RCS_{conf} (see equation (8)).

$$D_{conf} = \sqrt[4]{\frac{\mathrm{RCS_{conf}}}{\mathrm{RCS_{wp}}}} \times D_{wp} \quad (8)$$

with:

- D_{conf}: distance for the conformance test [m]
- RCS_{conf}: RCS of the object for the conformance test [m²]
- RCS_{wp}: RCS of the object based on the wanted technical performance, use-case; in [m^2]
- D_{wp}: maximum detection distance to the object based on the wanted technical performance, use-case; in [m]

If the distance for the conformance test D_{conf} can be fixed, then the necessary RCS_{conf} for the conformance test can be calculated based on formula (9).

$$RCS_{conf} = \left(\frac{D_{conf}}{D_{wp}}\right)^4 \times RCS_{wp} \quad (9)$$

4.1.4.2 Scaling limitations for considering in related standard

There are limitations to the RCS vs. distance scaling approach. The related standard shall consider the following points in context with the use-case, wanted technical performance and restrict the scaling as necessary, if one of the conditions below would apply:

- the detection algorithm of the EUT is configured for a certain absolute distance or for a min/max range (e.g. reflections from objects below a minimum distance and/or above a maximum distance are omitted):
  - therefore, scaling can only be applied within the operating range of the detection algorithm. This operating range can be specified in the related standard by e.g. different wanted technical performance criteria or different EUT categories;
- the EUT is implementing full-duplex operation and the detection "sensitivity" is dominated by cross-coupling of the TX signal into the RX path ("spill-over"):
  - therefore, scaling can only be applied as long as thermal noise in the RX is the limiting factor for the detection distance.

4.1.5 Receiving power based on distance and RCS (in dB)

Based on clause 4.1.2, equation (3) and the case that the antenna gain for the transmitting and receiving path will be considered separately. This would lead to:

$$\mathrm{P_{RX}} = \frac{\mathrm{P_{TX}} \times G_{TX} \times G_{RX} \times \lambda^2}{(4\times\pi)^3 \times \mathrm{D}^4} \times \mathrm{RCS} \quad (10)$$

With the mathematical consideration:

$$\mathrm{P[dBW]} = 10\log(\mathrm{P[W]}) \quad (11)$$

The received power P_{RX} in [dBW] can be calculated (equation (11) within equation (10)).

$$P_{RX}[\mathrm{dBW}] = 10\log(P_{TX}) + 10\log(G_{TX}) + 10\log(G_{RX}) + 20\log(\lambda) - 30\log(4\pi) - 40\log(D) + 10\log(RCS) \quad (12)$$

with the considerations of:

- 10 log (G) = antenna gain in [dBi] = g
- 30 log (4π) = 32,98
- 10 log (RCS) = rcs [dBm^2]

A simplified equation for the received power P_{RX} in [dBW] can be written as:

$$P_{RX}[\mathrm{dBW}] = P_{TX}[dBW] + g_{TX} + g_{RX} + 20\log(\lambda) - 32{,}98 - 40\log(D) + \mathrm{rcs} \quad (13)$$

The equation for received power P_{RX} in [dBW] could be further simplified as:

$$P_{RX}[\mathrm{dBW}] = P_{TX}[dBW] + g_{TX} + g_{RX} + 20\log(c) - 20\log(f) - 32{,}98 - 40\log(D) + \mathrm{rcs} \quad (14)$$

With the consideration of:

- $20\log(c) = 169{,}54$
- and equation (14)

$$P_{RX}[\mathrm{dBW}] = P_{TX}[dBW] + g_{TX} + g_{RX} + 169{,}54 - 20\log(f) - 32{,}98 - 40\log(D) + \mathrm{rcs} \quad (15)$$

with a final consideration of:

- $P[dBm] = \mathrm{P}[\mathrm{dBW}] + 30$

a final simplification would lead to equation (16); received power P_{RX} in [dBm]:

$$P_{RX}[\mathrm{dBm}] = P_{TX}[dBm] + g_{TX} + g_{RX} - 20\log(f) - 40\log(D) + \mathrm{rcs} + 166{,}56 \quad (16)$$

For most of the EUTs the radiated power (e.i.r.p.) is regulated and the EUTs are highly integrated (no antenna connector, etc.) so that only the received power at the EUT (see figure 2) can be assessed, therefore based on (16) and figure 2.

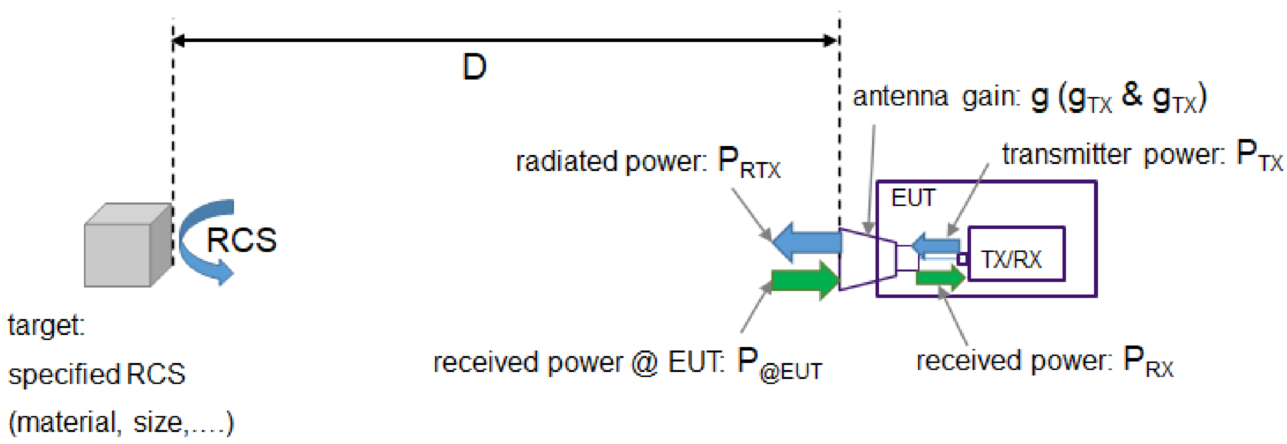


Figure 2: Scenario to show connection between RCS, Distance (D) and Power@EUT

and considering that:

- $P_{RTX}[\mathrm{dBm}] = P_{TX}[\mathrm{dBm}] + g_{TX}$; radiated power in [dBm]
- $P_{@EUT}[\mathrm{dBm}] = P_{RX}[\mathrm{dBm}] - g_{RX}$; received power @ the EUT in [dBm]

The received power @ the EUT ($P_{@EUT}$) in [dBm] can be given with:

$$P_{@EUT}[\mathrm{dBm}] = P_{RTX}[dBm] - 20\log(f[Hz]) - 40\log(\mathrm{D}[\mathrm{m}]) + \mathrm{rcs} + 166{,}56 \quad (17)$$

For the sensitivity case:

$$P_{sen}[\mathrm{dBm}] = P_{RTX}[dBm] - 20\log(f[Hz]) - 40\log\left(D_{wp}[\mathrm{m}]\right) + rcs_{wp} + 166{,}56 \quad (18)$$

Based on equation (18) a related standard has to specify the:

- D_{wp}: minimum distance to the object based on the wanted technical performance, use-case; in [m]
- rcs_{wp}: rcs of the object based on the wanted technical performance, use-case; in [dBm^2]

Summary: based on clause 4.1.4 and the case that the RCS of an object is fixed a related standard could cover several use-cases only by adjusting the distance between EUT and target. Based on this case the usage of available "radar targets" from the market with specified RCS would simplify and make testing more reproduceable.

The purpose of this case is to justify and simplify an argument for adjusting the power at the EUT. For situations when the movement of the target is relevant to determining the function of the EUT, see some possible setups in clause 6. If only the distance needs to be adjusted to adjust the power, this would make a test setup easier, and there are some parameters, e.g. rotation speed, that can change and not present a complication for the tests in the end.

4.2 Direct Object Reflectors

Summary mechanical objects, details inside a specific Annex A.

The shape and size of radar targets depend on the desired Radar Cross-Section (RCS). Conducting spheres as well as square or triangular shaped corner reflectors of different sizes are most suitable for this purpose. The equations for the Radar Cross-Sections of these different reflectors in the boresight direction are simple and can be found throughout the radar literature.

The Radar Cross-Section of a conducting sphere is independent of the wavelength and angle of incidence of the reflected radar signal. It is defined as:

$$RCS_{sphere} = \pi \cdot r_{sphere}^2 \quad (19)$$

- RCS_{sphere}: Radar Cross-Section (RCS) of the conducting sphere.
- r_{sphere}: radius of the conducting sphere.

The Radar Cross-Sections in boresight direction of the two different trihedral corner reflectors (RCS_{square} and $RCS_{triangular}$) illustrated in figure 3 can be calculated as follows:

$$RCS_{square} = 12\frac{\pi \times L^4}{\lambda^2} \quad (20)$$

$$RCS_{triangular} = \frac{4}{3}\frac{\pi \times L^4}{\lambda^2} \quad (21)$$

- RCS_{square}: Radar Cross-Sections of trihedral square shaped corner reflector in boresight direction (in m^2), see figure 3 left.
- $RCS_{triangular}$: Radar Cross-Sections of trihedral triangular shaped corner reflector in boresight direction (in m^2), see figure 3 right.
- L: edge length of corner reflector (compare figure 3).
- λ: wavelength of incident wave.

However, the validity of these simple RCS equations is subject to some constraints which are treated in detail in Annex A.

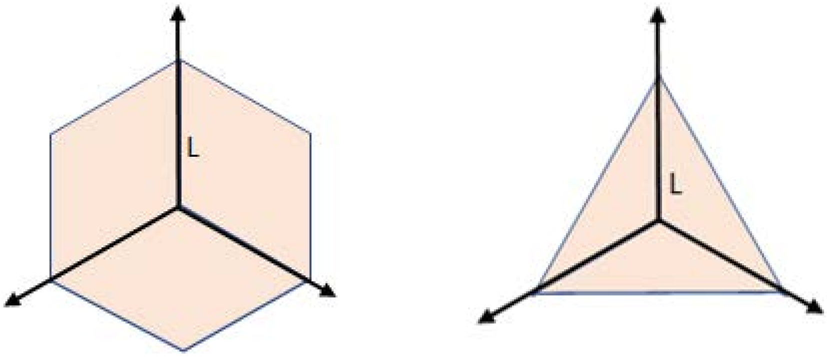


Figure 3: Different corner reflectors (left-hand side: trihedral square shaped, right-hand side: trihedral triangular shaped)

For such corner reflectors the RCS is very limited to a small angular range, see as an example for a trihedral triangular shaped corner reflector in figure 4.

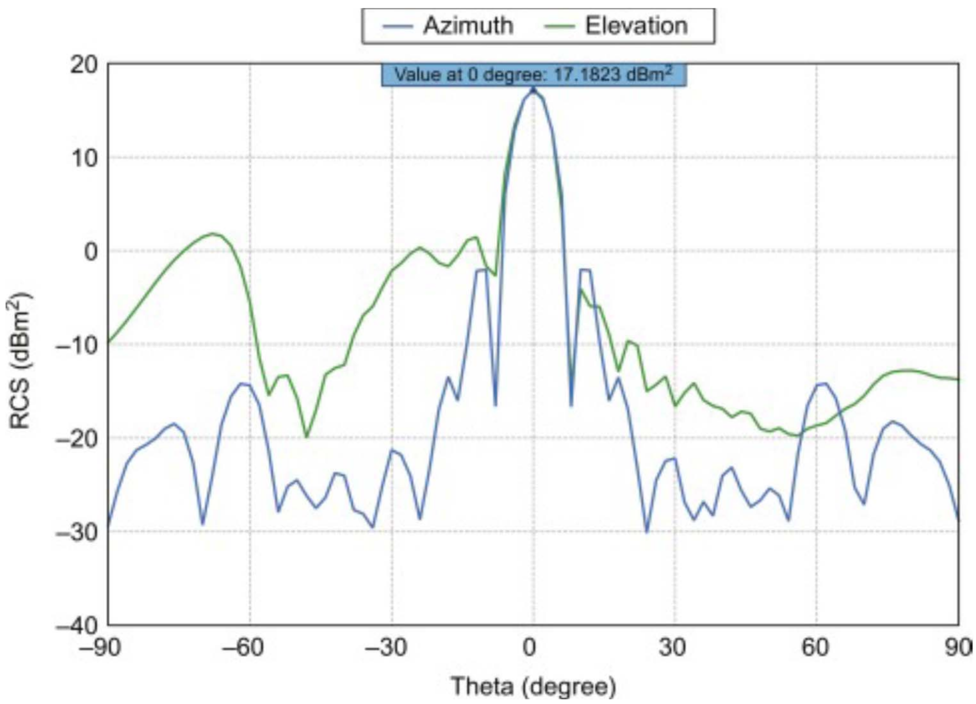


Figure 4: General Radiation pattern for a trihedral triangular shaped corner reflector

There is also the possibility to combine the corner reflectors to a 3-dimensional structure (see figure 5).

This would allow a relatively more constant RCS of the angle around the target, see figure 6.

Such possibilities and impact shall be considered in the related standard if specifying the target based on the intended use. More details are provided in [i.17], [i.18] and [i.21].

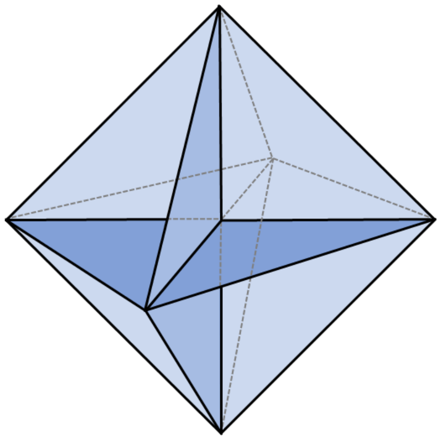
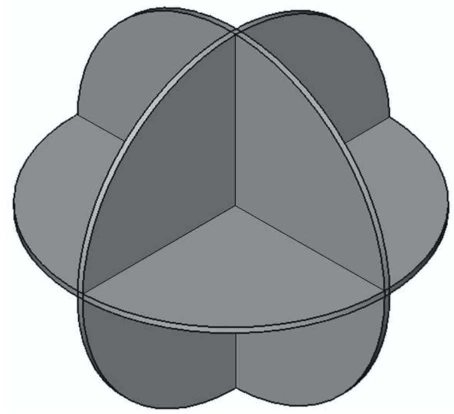
 Trihedral triangular, [i.18]	 Trihedral quarter-circle trihedral, [i.19]

Figure 5: Octahedral reflector

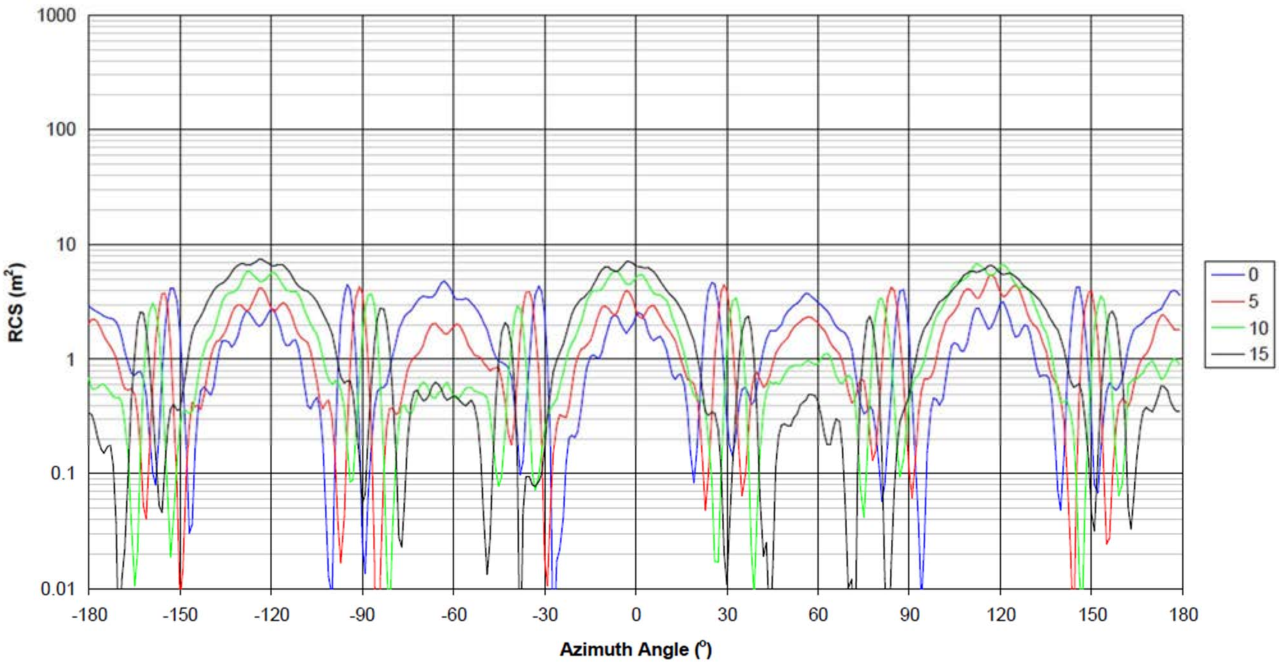


Figure 6: RCS of a 3-D trihedral triangular shaped target (left-hand in figure 5)

5 RCS of targets

The present document provides the following information on Radar Cross-Section (RCS) and targets:

- In clauses 4.2 and A.1 are information on typical simplified mechanical test targets. More information on mechanical targets are also available in [i.16].
- Clause A.2 of the present document provides guidance to find an equivalent RCS for a dielectric surface in relation to a specified use-case (intended use) in a standard.
- Annex D of the present document provides a list of rcs in [dBm^2] for scenarios with living object (or parts of) as the target.

6 Test Set-up

6.1 General points and points to be considered in related standard

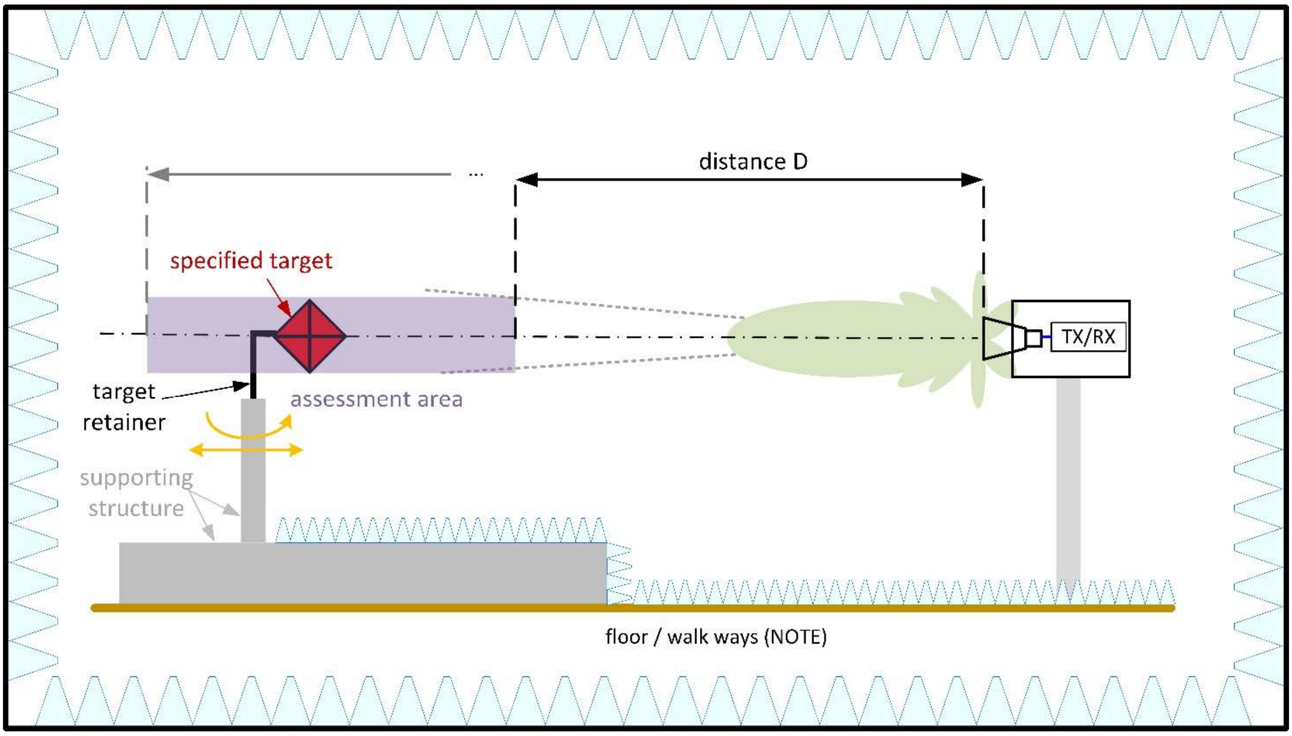
The proposed replacement of a human or parts of could be done by a mechanical radar target (reflector). This simplification was used in test and presented in several publications, see clause 2. For most of the assessed use-cases and applications there is in addition the need to move the radar target. This movement (distance, speed and direction) is directly related with the real scenario and the object which shall be tested. Therefore, in the following clauses (see clauses 6.3 to 6.5) four test setups are described with which most of the use-cases could be "simulated" and replaced.

General points for consideration for the mechanical realization of the target for the testing (The related standard could provide guidance and a proposal for the set-up realization):

- Each kind of engine and oscillator (to simulate the wanted technical performance, e.g. for rotation of radial movement) will add reflections and the related standard shall make clear if this parts shall be considered as part of the target or as part of the target retainer (see different requirements on the RCS of these parts, see clause 6.2. The different reflections (RCS) could be assessed based on the justification tests in clause 7.

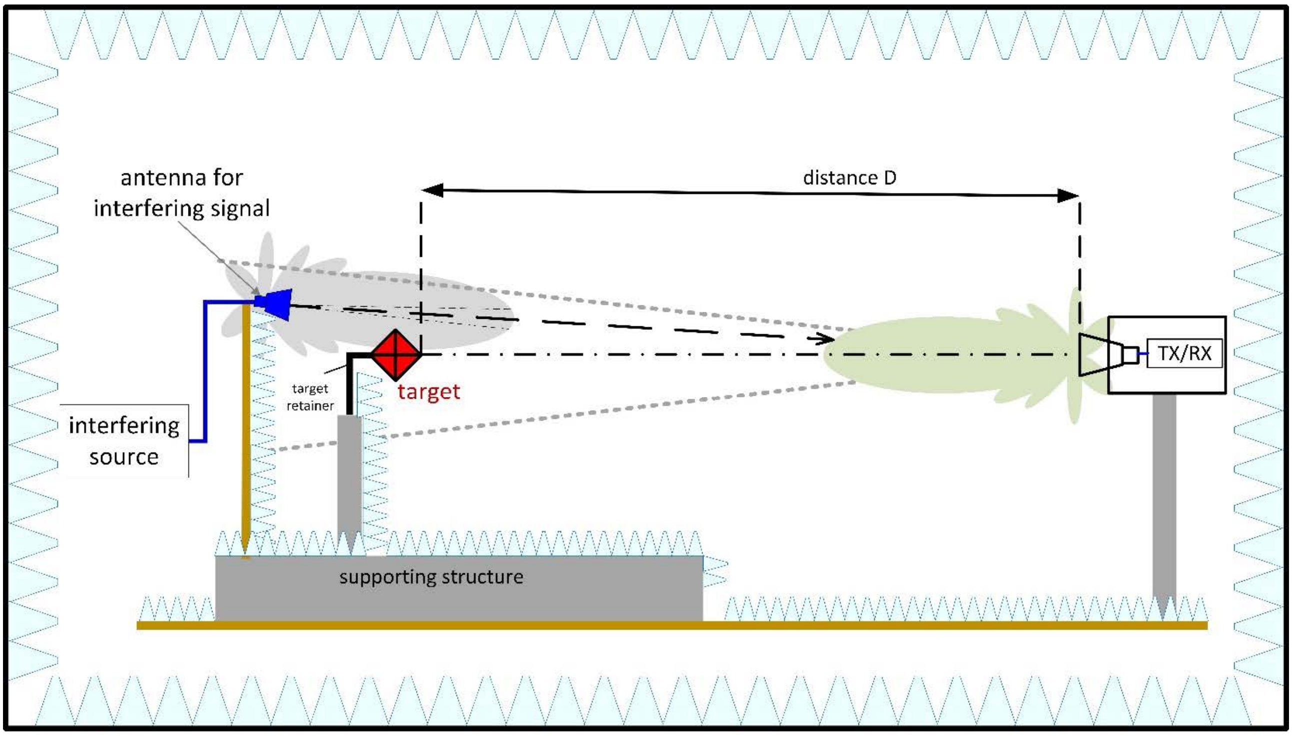
NOTE: RCS of the target should be at least 20 dB larger than the RCS of supporting structure/target retainer. The RCS value of the target is specified in the related standard to "simulate" the intended use and the wanted technical performance criteria. To assess the different RCS parameters, see clause 7.

- For manufacturing of the target and target retainer for testing, considerations of the minimum size and possible kinds of materials necessary to enable the target to reach the specified RCS shall be included in the related standard (e.g. size in relation of RCS in Annex A).
- In addition, for the mechanical realization of the test set-up it is necessary to consider the maximum movements (speed) in relation to the size and weight of the target (to avoid damages of the test system based on kinetic energy) and the wanted technical performance specified in the related standard.
- In the related standard it is necessary to be specified based on the intended use and the wanted technical performance (e.g. time necessary for the EUT (measurement time) to detect the target). This "measurement time" has an impact to the measurement distance (number of samples) this needs to be specified in the related standard.
- The related standard has to consider if there would be a need to use an interface/test jig to read out the necessary information out of the EUT to decide on the minimum wanted technical performance (use-case), (Manufacturer has to supply suitable means to monitor if the EUT has detected the target (to operate as intended, as specified in related standard; within the specified scenario).
- The related standard needs to consider: if the "real" scenario the EUT has to deal with multipath reflections (e.g. inside a vehicle) or such multipath effects are less critical (e.g. outdoor use-cases). For the related standard: to avoid "multipath" or reflections from test supporting structure (and from additional parts e.g. for interferer signal handling tests (see ETSI EN 303 883-2 [i.20]) which could heavily have an impact on the RCS (see RCS assessment in clause 7) the space between target and EUT and the supporting structure and additional parts could be coated with absorbing material, see figure 7 and figure 8.



NOTE: floor based on radio invisible material (e.g. wood) and/or floor and „walk ways" shall covered by „absorbing" material (absorbers) to „reduce" unwanted multipath effects and reflection effects to a minimum.

Figure 7: General test set-up within an anechoic chamber



NOTE: all mechanical parts (holders/retainers) which are in addition to the target and the floor / the „walk ways" shall covered by „absorbing" material (absorbers) to „reduce" unwanted multipath effects and reflection effects to a minimum.

Figure 8: General test set-up with interferer signal handling option within an anechoic chamber

In addition to the general points (listed above) which shall be considered in the related standard, the present document provides additional information and proposals for simplified test set-ups and additional information which could help in the definition of a test scenario in the related standard. The proposed simplified test set-ups are only examples and propose the concept to realize a test scenario. The related standard shall specify the test-set-up more in detail to cover the intended use that is possible to assess the specified wanted technical performance during the tests. Therefore, in the related standard another simplified solution could be specified and justified (e.g. test set-up with specific dummy).

The present document proposes and explains the following simplified test set-ups:

- Set-up 1: rotating target, RCS varies within a range, see clause 6.3.
- Set-up 2: rotating target, RCS fixed to the EUT, see clause 6.4 and Annex F.
- Set-up 3: fixed RCS with small movement, see clause 6.5.
- Set-up 4: fixed RCS with large movement, see clause 6.6.

And provides additional information on:

- Possible kinds of simple mechanical radar target and related RCS and boundary conditions of the RCS equations, see clauses 4.2 and A.1.
- Background info to transfer an RCS based on material parameter to a mechanical target, see clause A.2.
- Boundary conditions for radiated measurement scenarios using artificial radar targets, see Annex B.
- Friis transmission equation, see Annex C.
- Summary of values for RCS of living objects, see Annex D.

6.2 Radar Target

Based on Annex A there are several technical solutions possible to realize a mechanical radar target. Based on the required RCS in dBm^2 (provided by the use-case in the related standard) there may be a mechanical limitation (in size) to use one or the other mechanical solution. For that reason, the kind and size of the radar target need to be specified in the related standard.

The dominant part of the RCS shall be the target specified in the related standard. The RCS of the target retainer and supporting structure (see figure 7, figure 8, etc.) shall be at least 20 dB below the RCS of the specified RCS of the target. This could be reached by using "less reflective" material (e.g. low dielectric plastics) or shield parts with absorbing materials.

In addition, the target dimensions shall be specified in such a way that the RCS is within -3 dB azimuth and elevation angles of the antenna beam dimensions of the EUT (if nothing different is specified in the related standard)

6.3 Set-up 1: rotating Target, RCS varies within a range

Within this setup the specified object is rotating around an axis. The RCS varies within a range. This depends on the orientation of the object in relation to the EUT. The relative movement (delta in the distance and in speed) of the object to the EUT could be specified with an arm between the rotating axis and the object. There are two basic set-ups possible:

1) With a shaft and an arm as the target retainer, see figure 9.
2) Target is mounted on a rotating plate, see figure 10.

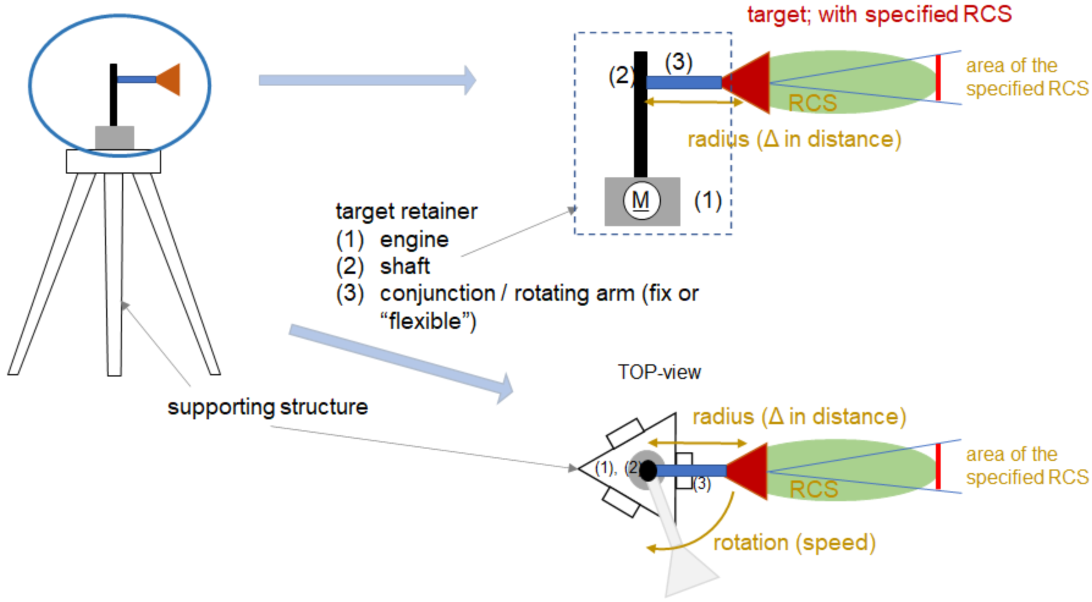


Figure 9: Principal solution for a rotating target, RCS varies within a range

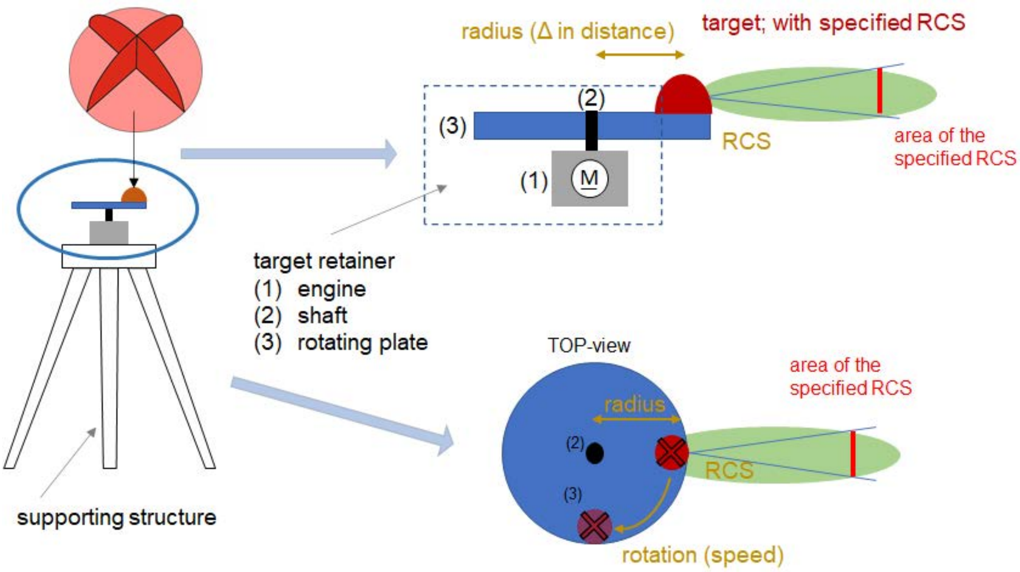


Figure 10: Second principal solution for a rotating target, RCS varies within a range

The mechanical set up and the materials of the parts shall be specified within the related standard.

The related standard shall consider following points in context with the use-case; wanted technical performance if considering such set-ups as shown in figure 9 and figure 10.

Table 1: Considerations for set-ups with a rotating target, RCS varies within a range

Parameter	Description	Unit	Note
Distance to the EUT D_T	Maximal Distance between EUT and Object for the use-case	[m]	If necessary, scaling to reach usable and practical test distance
Radar Cross-Section target RCS_T/rcs_T	Minimal Radar Cross-Section of the related Object for the use-case	[m^2] or [dBm^2]	If necessary, scaling is possible to group more use-cases together, see clause 4.1.5 Eq. (18)
Rotation speed ω_T	Relative movement, depending on the use-case it could be minimum or maximum	[cps]	To generate a necessary doppler signal Tangential speed $v_{WP} = 2 \times \pi \times r_{WP} \times \omega_{WP}$
Radius around the rotating axis r_T	Delta in the distance	[m]	Which minimum or typical change in the distance the EUT shall be able to detect. If the "arm", see figure 3 will be realized in a flexible way this will also generate a range in the delta of the distance and in the "speed"
Material/kind of	Material of the target and kind of the target		See for example Annex A
	Material of the target retainer and supporting structure		RCS of the target retainer/supporting structure shall be in minimum 20 dB lower than the rcs of the target, see clause 7

EXAMPLE 1: Such set-ups have been used for testing of:

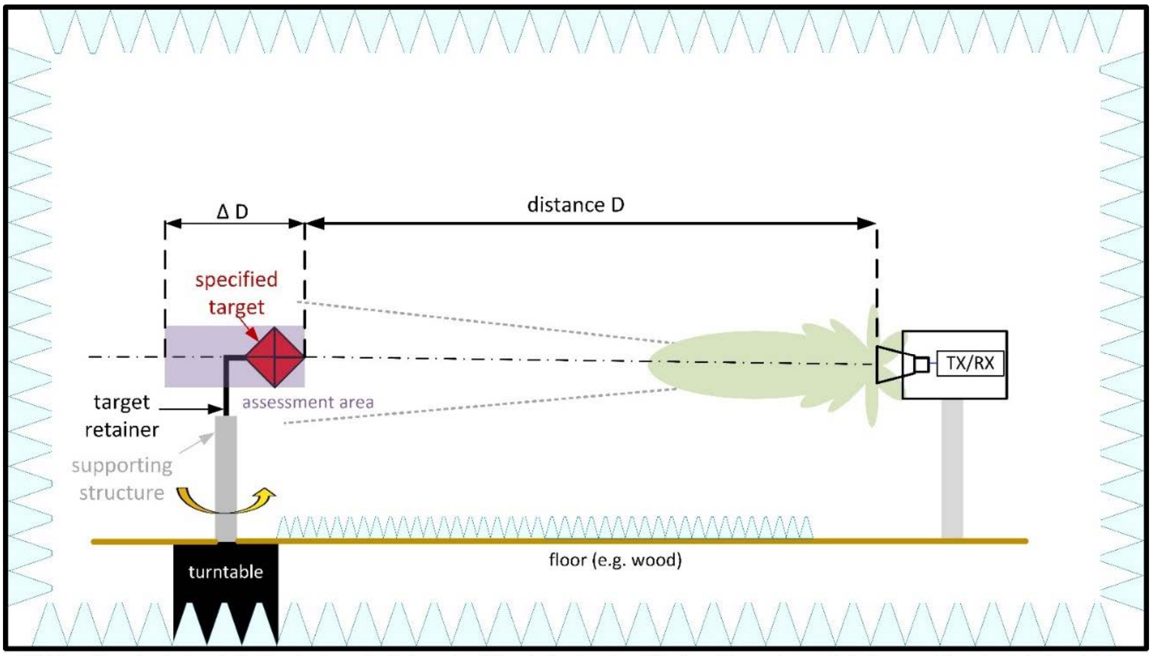
- intrusion detection radar at 10 GHz;
- presence detection and vital sign measurement devices based on UWB technology < 10 GHz.

EXAMPLE 2: As a summary of the parameter is provided in table 2.

Table 2: Necessary parameter for presence detection and vital signs monitoring based on Set-up 1

	Breathing	Heartbeat
Distance between EUT and target for the use-case	See related standard	See related standard
Minimal Radar Cross-Section of the related target for the use-case Rotation speed	See table D.1, table D.2 with RCS 20	See table D.1, table D.2 with RCS 80
Radius around the rotating axis	5 mm	5 mm

Instead, a separate engine and if a turntable within an anechoic chamber allows such rotating speeds, a setup as shown in figure 11 could be realized. On space between target and EUT the "floor" shall be filled with absorbing material to reduce reflections (impact) from the floor (see figure 11).



NOTE: all mechanical parts (holders/retainers) which are in addition to the target and the floor / the „walk ways“ shall covered by „absorbing“ material (absorbers) to „reduce“ unwanted multipath effects and reflection effects to a minimum.

Figure 11: Solution for a rotating target, RCS varies within a range (within an anechoic chamber)

6.4 Set-up 2: rotating Target, constant RCS to the EUT

In this set-up the object/RCS is realized in such a way that the visible RCS for the EUT is constant but there would be a change in the distance.

Technical possibilities to realize such set up is shown in Annex F.

The related standard shall consider following points in context with the use-case; wanted technical performance if considering such mechanical solution as shown in Annex F (or similar).

Table 3: Considerations for Set-ups with a rotating target, constant RCS to the EUT

Parameter	Description	Unit	Note
Distance to the EUT D_T	Maximal Distance between EUT and Object for the use-case	[m]	If necessary, scaling to reach usable and practical test distance
Radar Cross-Section target RCS_T/rcs_T	Minimal Radar Cross-Section of the related Object for the use-case	[m^2] or [dBm^2]	If necessary, scaling is possible to group more use-cases together, see clause 4.1.5 Eq. (18)
Rotation speed ω_T	Relative movement, depending on the use-case it could be minimum or maximum	[cps]	To generate a necessary doppler signal Tangential speed $v_{WP} = 2 \times \pi \times r_{WP} \times \omega_{WP}$
Radius around the rotating axis r_T	Delta in the distance	[m]	Which minimum or typical change in the distance the EUT shall be able to detect
Material/kind of	Material of the target and kind of the target		See for example Annex A
	Material of the target retainer and supporting structure		RCS of the target retainer/supporting structure shall be in minimum 20 dB lower than the rcs of the target, see clause 7

EXAMPLE: Such set-ups have been used for testing of:

- gesture detection/face recognition @ 60 GHz

6.5 Set-up 3: constant RCS to the EUT with small movement

Within this setup the RCS as seen by the EUT is constant and the movement/delta in the distance is small. A solution for such could be realized based on an actuator (e.g. loudspeaker), see figure 12.

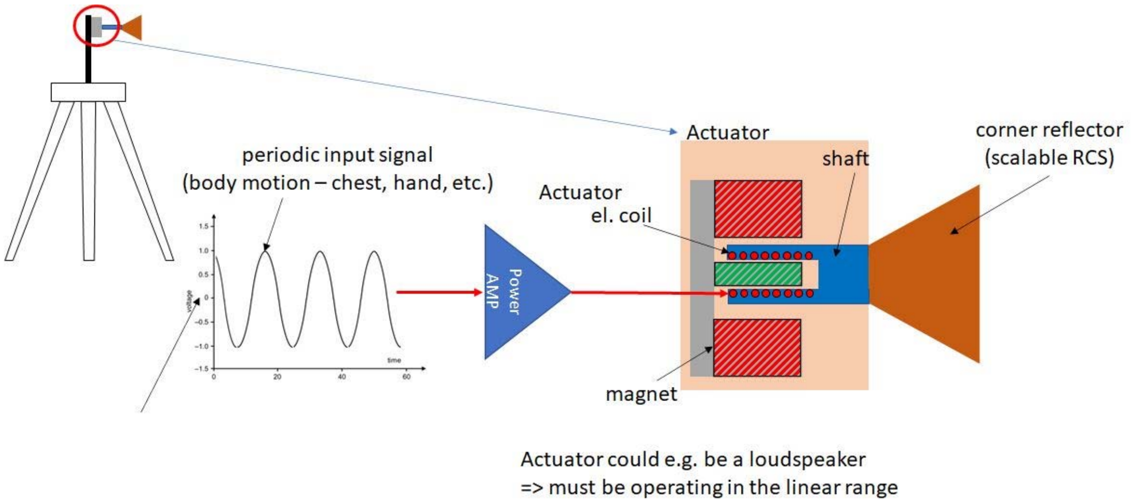


Figure 12: Principal solution to realize a fixed RCS with a small delta in the distance

The related standard shall consider following points in context with the use-case; wanted technical performance if considering such set-ups as shown in figure 12.

Table 4: Considerations for set-ups with a fixed RCS relative to the EUT with a small delta in distance

Parameter	Description	Unit	Note
Distance to the EUT D_T	Maximal Distance between EUT and Object for the use-case	[m]	If necessary, scaling to reach usable and practical test distance
Radar Cross-Section target RCS_T/rcs_T	Minimal Radar Cross-Section of the related Object for the use-case	[m^2] or [dBm^2]	If necessary, scaling is possible to group more use-cases together, see clause 4.1.5 Eq. (18)
Frequency of input signal v_T	Relative movement, depending on the use-case it could be minimum or maximum	[Hz]	To generate a necessary doppler signal; the related standard shall define the exact waveform of the periodic input signal (sinewave, rectangle, sawtooth, etc.)
Amplitude of periodic input signal ΔD_T	Delta in the distance of the relative movement	[m]	Which minimum or typical change in the distance the EUT shall be able to detect
Material/kind of	Material of the target and kind of the target		See for example Annex A
	Material of the target retainer and supporting structure		RCS of the target retainer/supporting structure shall be in minimum 20 dB lower than the rcs of the target, see clause 7

EXAMPLE: Such set-ups have been used for testing of:

- possible breathing and motion movements (e.g. child detection) @ 60 GHz

6.6 Set-up 4: constant RCS to the EUT with large movement

Within this setup the RCS is constant as seen by the EUT and the movement/delta in the distance could be realized over a larger range. A solution for such could be realized based on a linear actuator, see figure 13.

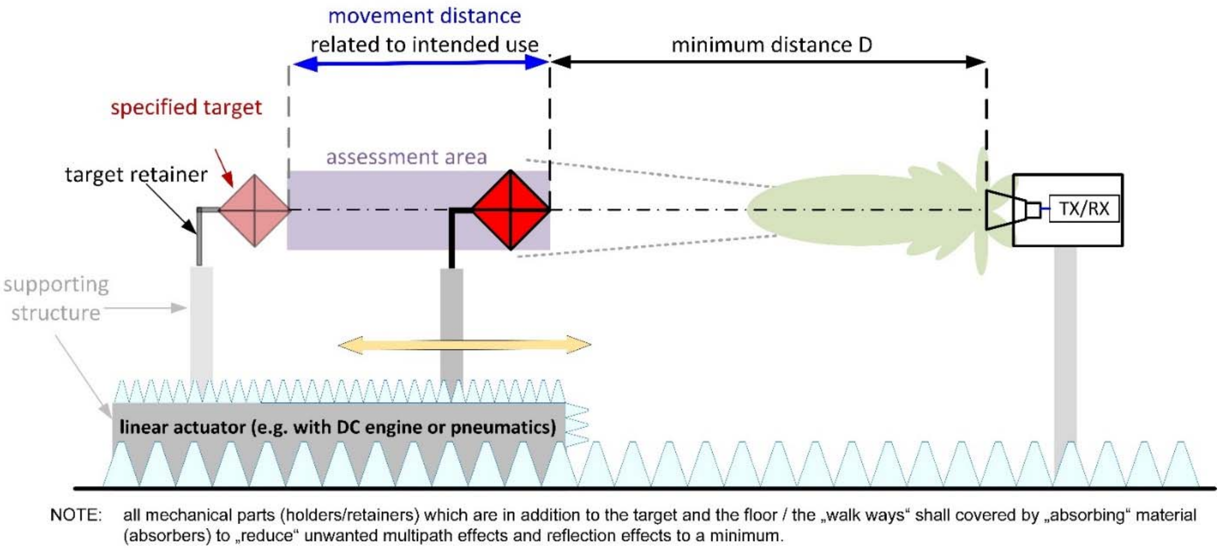


Figure 13: Principal solution to realize a fixed RCS with a larger delta in the distance

The related standard shall consider following points in context with the use-case; wanted technical performance if considering such set-ups as shown in figure 13.

Table 5: Considerations for set-ups with a fixed RCS to the EUT with a larger delta in distance

Parameter	Description	Unit	Note
Distance to the EUT D_T	Maximal Distance between EUT and Object for the use-case	[m]	If necessary, scaling to reach usable and practical test distance
Radar Cross-Section target RCS_T/rcs_T	Minimal Radar Cross-Section of the related Object for the use-case	[m^2] or [dBm^2]	If necessary, scaling is possible to group more use-cases together, see clause 4.1.5 Eq. (18)
Movement speed of the target v_T	Relative movement, depending on the use-case it could be minimum or maximum	[m/s]	To generate a necessary doppler signal
Delta distance ΔD_T	Delta in the distance	[m]	Which minimum or typical change in the distance the EUT shall be able to detect
Material/kind of	Material of the target and kind of the target		See for example Annex A
	Material of the target retainer and supporting structure		RCS of the target retainer/supporting structure shall be in minimum 20 dB lower than the rcs of the target, see clause 7

EXAMPLE: Such set-ups have been used for testing of:

- for intrusion detection radars @ 60 GHz and 10 GHz, a target assessment as example, see clause G.2.

NOTE: Depending on the use-case this set-up could be combined with the other three setups, but this would lead to a very complex set-up.

6.7 Measurement uncertainty of the radar target

A typical uncertainty for a mechanical targets/target set-up is around: ±2 to ±3 dB.

7 RCS measurement

7.1 Justification for RCS measurement with VNA

Radar Cross-Section (RCS) is the measure of a target's ability to reflect a radar signal in the direction of the radar receiver i.e. it is the measure of the ratio of backscatter per steradian in the direction of the radar (from the object) to the power density that is intercepted by the target, see clauses 4.1 and 4.2. Background information, literature for RCS measurement is available in [i.7], [i.8], [i.9] and [i.10].

A Vector Network Analyser (VNA) with Time Domain Gating can be used to measure the RCS of the test object. The RCS of an object can be visualized as a comparison of the power of the reflected signal from this object to the reflected signal from a perfectly conducting smooth sphere of specified RCS area.

The RCS of a sphere is independent of frequency (see clause A.1.4) provided that the sphere shall be placed in the far field of the measurement antenna (see clause B.2) and the effective sphere radius r shall be as specified in clause A.1.11.

The radar equation (4) could also be described based on a block diagram, see figure 14.

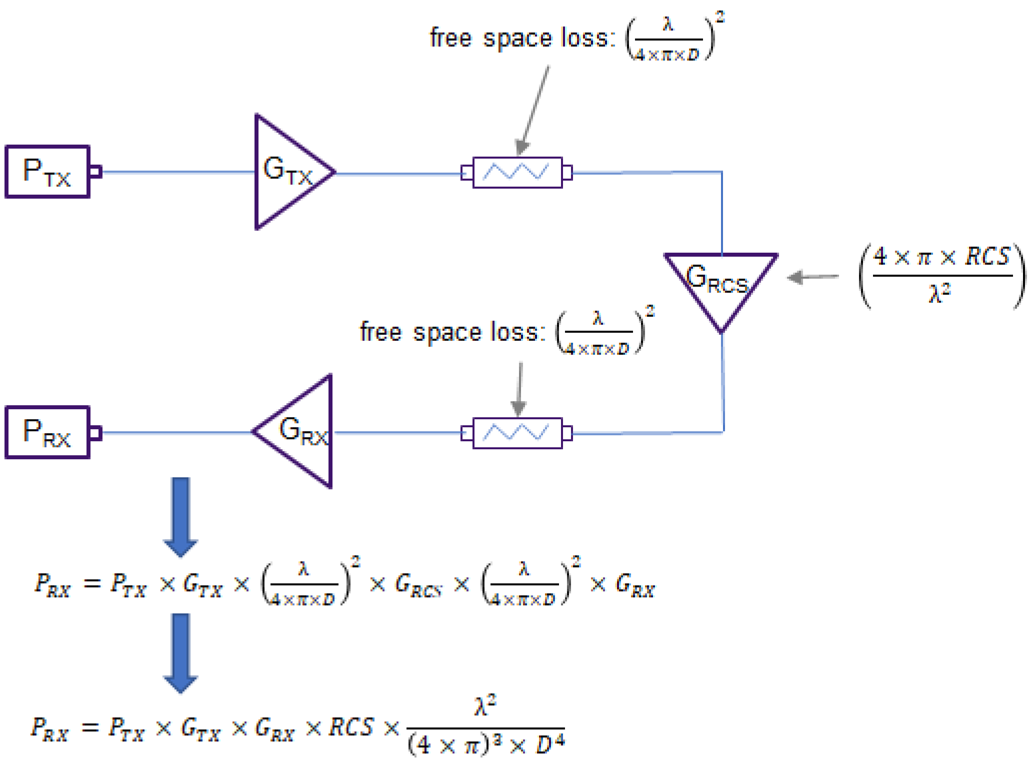


Figure 14: Circuit Block Diagram for the RCS measurement

Based on figure 14 and equation (4) the RCS is given as:

$$RCS = \frac{P_{RX}}{P_{TX}} \times \frac{(4\times\pi)^3 \times D^4}{G_{TX} \times G_{RX} \times \lambda^2} = k \times \frac{P_{RX}}{P_{TX}} \qquad (22)$$

A S21 measurement with an VNA system has the same equivalent circuit description than in equation (22). With a VNA system the frequency domain response S21 of the system will be measured. Therefore, port 1 of the VNA is connected to a transmit antenna and port 2 is connected to a receive antenna.

A summary of the two-port measurement setup is shown in figure 15.

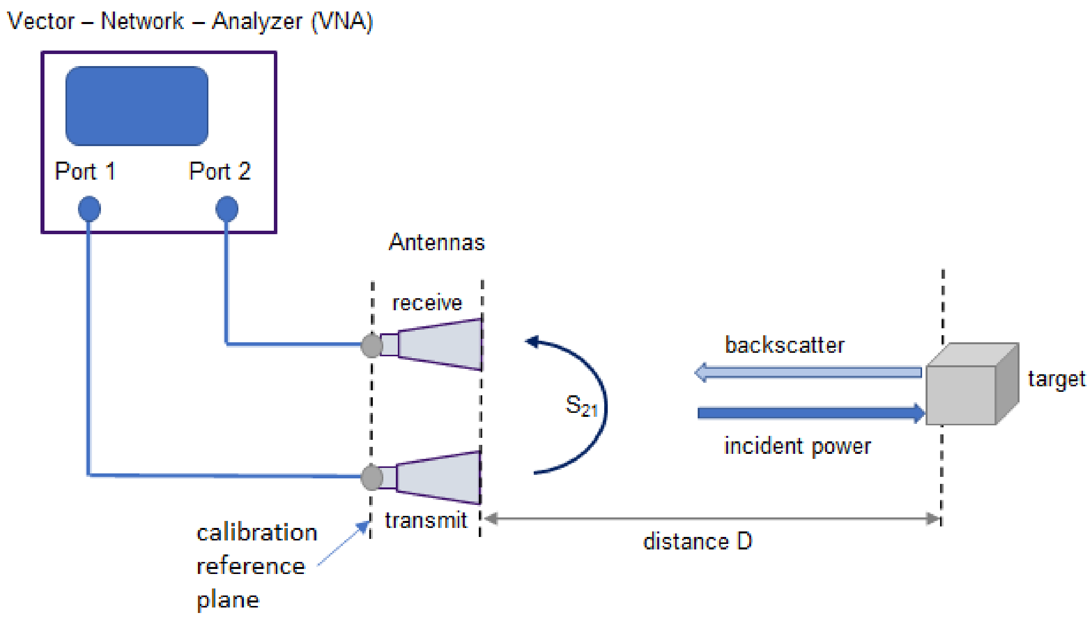


Figure 15: Principle of a two-port test set-up for RCS measurement with VNA

The S21 measurement (two-port) set-up shown in figure 15 shall be used for complex targets. The main reason huge effort in the necessary arrangement and adjustment in the mechanical set-up, for more details see Annex E.

For the more simplified targets (see clause 5 and clause A.1) which are expected to be used in the related standards for receiver tests a VNA test-up using only one-port is possible as well. The underlying basis is similar to the RCS justification in clause 4.1. The summary of the one-port measurement setup is shown in figure 16.

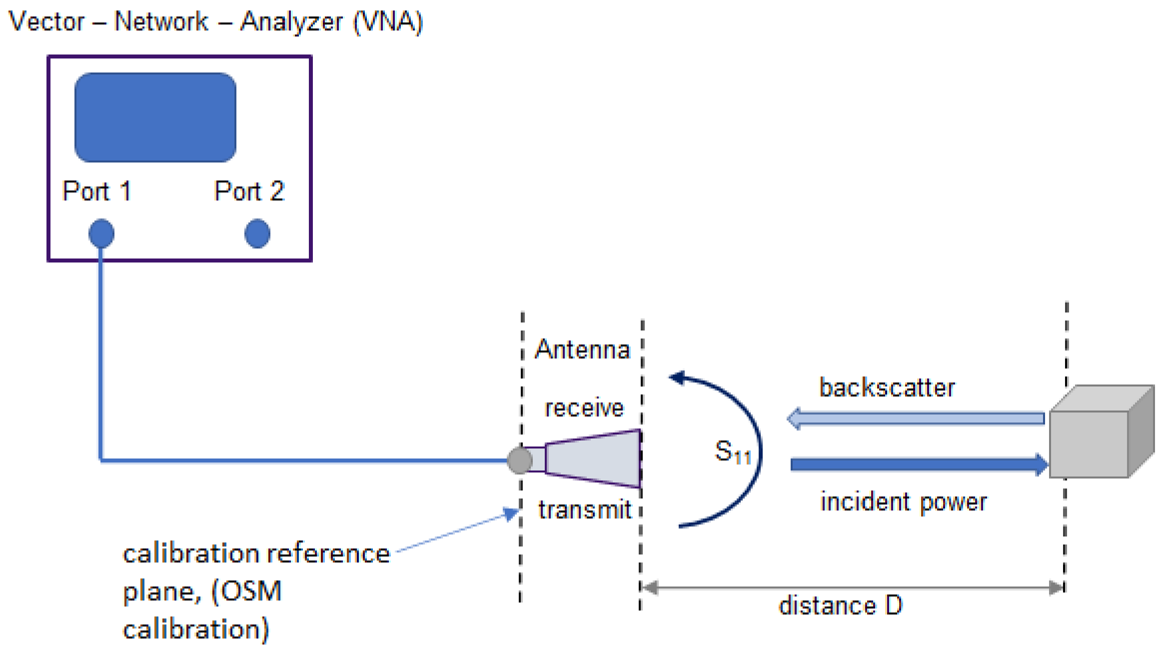


Figure 16: Principle of a one-port test set-up for RCS measurement with VNA

Equation (22) using the one-port setup could be expressed in logarithmic form as shown in following equation (23)

$$rcs\ [dBm^2] = 10 \times log\ RCS\ [m^2] = P_{RX}[dBm] - P_{TX}[dBm] - 2 \times g[dB] - 20\ log\ \lambda + 40\ log\ D + 33\ dB \quad (23)$$

With: $P_{RX}[dBm] - P_{TX}[dBm]$ equals the measured S11-parameter.

This leads to the following equation (24):

$$rcs\,[dBm^2] = \mathrm{S11[dB]} - 2 \times g[dB] - 20\log\lambda + 40\log D + 33\,dB \qquad (24)$$

7.2 Preparation set-up

7.2.1 Vector Network Analyser (VNA)

The VNA shown in figure 15 and figure 16 measures the S-parameters in the frequency domain. The VNA shall be able to operate over the OFR of the EUT in the related standard. The time domain function of the VNA will transform the S-parameter frequency domain measurement (S11/S21 vs. frequency) to the time domain (S11/S21 vs. time or distance). In addition, the VNA shall have a time gating function in the time domain measurement.

7.2.2 Test antennas

The measurement antenna shown in figure 15 and figure 16 shall be able to operate over the OFR of the EUT in the related standard and shall have the same kind of polarization as the EUT. If the EUT polarization is not known the RCS of the object/target could be assessed in horizontal and vertical polarization planes (e.g. E-plane and H-plane) by using linear polarized antennas, (see figure 17 for the orientation of polarization for the one-port set-up).

7.2.3 Test set-up arrangement

For the assessment of the maximum measurement range D the transform process is the Alias Free Range (AFR). The transform is a circular function and repeats itself periodically outside of its inherent time range that is:

t = 1/(Frequency Step Size)

The frequency step size is proportional to the frequency span and inversely proportional to the number of data points. Inherent time range:

t = (N-1)/(Frequency Span)

For example, at K-band (16,5 GHz - 28 GHz) using a 11,5 GHz frequency span and 801 data points, the (AFR) is: 800/11,5 GHz = 69,6 nanoseconds corresponding to a 20,8 m alias free range. The 20,8 m range is the round-trip time thus the target should not be placed more than 10,4 m from the VNA.

Both antennas, in case the two-port test setup is used (see Annex E), are located as close as possible but it shall be considered that the target shall be within the far field of the measurement antenna (see clause B.2), in either the vertical or horizontal plane (measurement distance D). The target should be located at a distance less than AFR/2 but far enough from the antenna to ensure that the entire target is within the main beams of the antennas, see figure 18 and figure 1.

Before starting the radiated RCS measurement, an Open-Short-Match (OSM) calibration shall be performed in the VNA at the output of the coaxial cables to establish the reference plane for the RCS measurements.

Ensure that distance for the measurement distance D is fulfilled that the target dimensions are within -3 dB azimuth and elevation angles of the measurement antenna main beam, see figure 18.

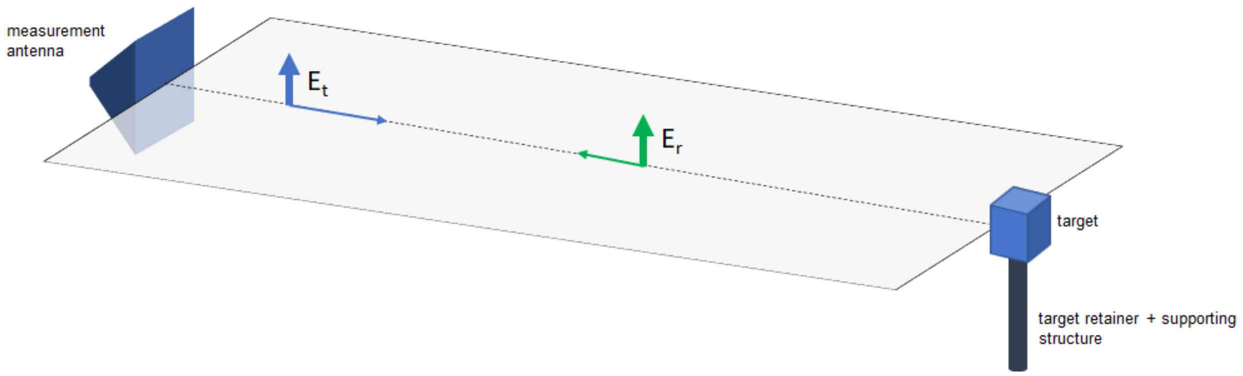


Figure 17: Consideration of the polarization in the one-port test set-up

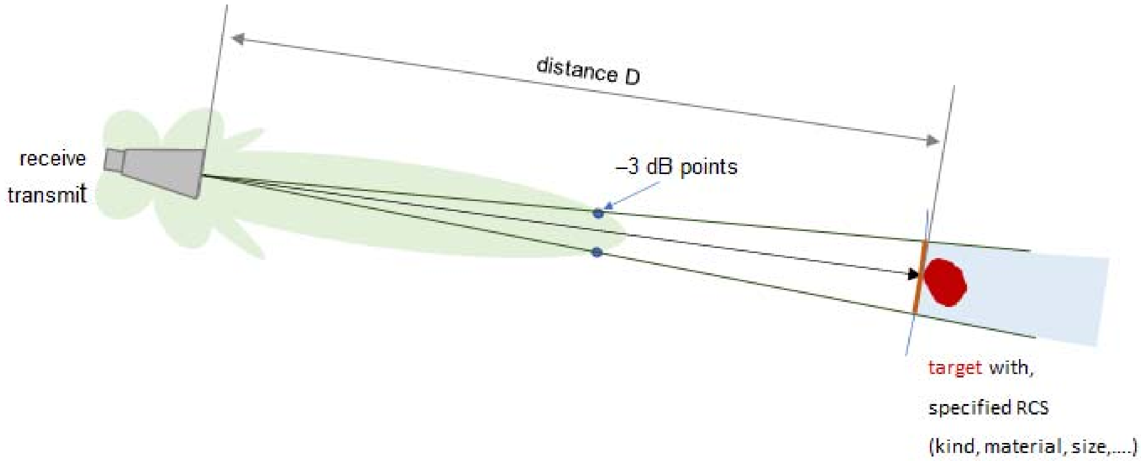


Figure 18: Arrangement of the measurement target in front of the measurement antenna (one-port test set-up)

If a target retainer and support structure is used (e.g. to move the target), measure $S11_{trss}$ of the target retainer and support structure with the target removed. The measured value should be at least 20 dB lower than that of the estimated target rcs ($S11_{target}$). If not, add additional microwave absorbing material around the support structure to reduce its RCS to the acceptable value. It should be ensured that there are no other targets at the same distance from the antenna to avoid confusion.

7.3 RCS assessment

7.3.1 Antenna System Calibration

The RCS of known target geometries and their corresponding Radar Cross-Section (RCS) are shown in clause A.1. The ideal standard to use is a conducting sphere of a known diameter.

For example, a 1,13 m diameter sphere has an RCS of 1 m^2 that is independent of frequency. The diameter of the sphere whose RCS corresponds to the expected RCS can be chosen. But any other geometry could be specified in the related harmonised standard.

NOTE: To calculate the RCS_{cal} based on the mechanical dimensions for simple mechanical target, see clause A.1.

7.3.2 RCS assessment procedure

For the RCS assessment use the following steps:

Step 1: Run an OSM calibration of the VNA (including the necessary cables), see figure 19 (and figure 16).

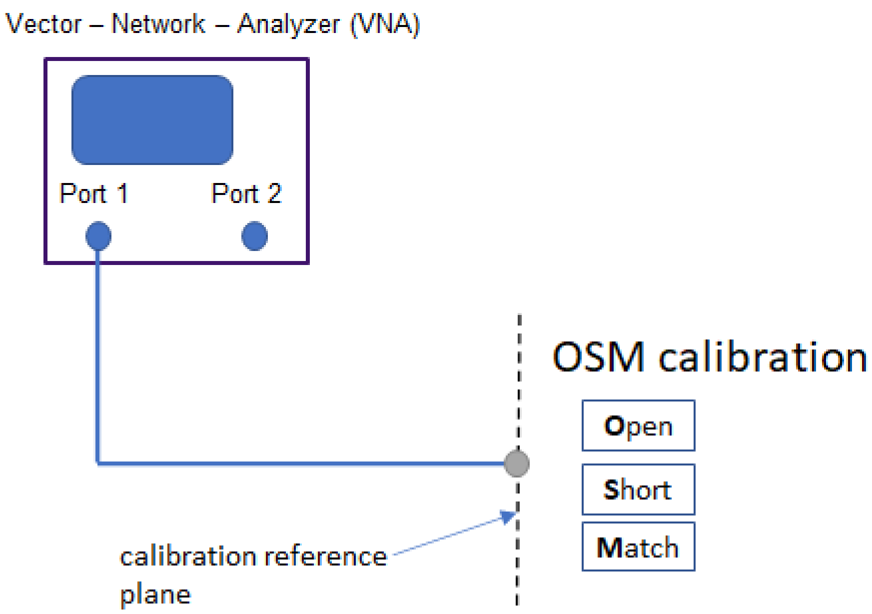


Figure 19: OSM calibration for one-port test set-up

Step 2: Connect one port of the VNA to the measurement antenna.

Step 3: Assess the measurement distance (see clause 7.2.3) and area (see figure 18, figure 1).

Step 4: Measure the RCS of the target retainer + supporting structure and store the data ($S11_{trss}$):

Sub-Step 4.1: Set-up in frequency domain the frequency range over which the RCS shall be measured.

Sub-Step 4.2: Switch to time domain function and measure within the time domain mode of the VNA, for an example see figure 20.

Sub-Step 4.3: Place a time gate centred at the highest peak (at the distance D) to the target and set time gate width greater than the observed "size" of the target in time domain, for an example see figure 21.

Sub-Step 4.4: Step back to the frequency domain.

Sub-Step 4.5: Read out S11 [dB] over the measured range and store the data ($S11_{trss}$), for an example see figure 22.

Sub-Step 4.6: Calculate the RCS based on equation (24):

$$\mathrm{rcs}_{\mathrm{trss}}\,[dBm^2] = \mathrm{S11}_{\mathrm{trss}}[\mathrm{dB}] - 2 \times g[dB] - 20\log\lambda + 40\log D + 33dB \qquad (25)$$

Step 5: Measure now the target together with the target retainer + supporting structure and store the data as well ($S11_{target}$):

Sub-Step 5.1: Set-up in frequency domain the frequency range over which the RCS shall be measured.

Sub-Step 5.2: Switch to time domain function and measure within the time domain mode of the VNA, for an example see figure 20.

Sub-Step 5.3: Place a time gate centred at the highest peak (at the distance D) to the target and set time gate width greater than the observed "size" of the target in time domain, for an example see figure 21.

Sub-Step 5.4: Step back to the frequency domain.

Sub-Step 5.5: Read out S11 [dB] over the measured range and store the data ($S11_{target}$), for an example see figure 22.

Sub-Step 5.6: Calculate the RCS based on equation (24):

$$\mathrm{rcs_{target}}\ [\mathrm{dBm^2}] = \mathrm{S11_{target}}[\mathrm{dB}] - 2 \times \mathrm{g}[\mathrm{dB}] - 20\log\lambda + 40\log\mathrm{D} + 33\mathrm{dB} \quad (26)$$

Step 6: Check if the measured RCS value of the target retainer + supporting structure in sub-step 4.5 is at least 20 dB lower than that of the estimated target rcs in sub-step 5.5, see clause 7.3.2.

Step 7: Measure the calibration standard target (as specified in the related standard, see clause 7.3.1):

Sub-Step 7.1: Set-up in frequency domain the frequency range over which the RCS shall be measured.

Sub-Step 7.2: Switch to time domain function and measure within the time domain mode of the VNA, for an example see figure 20.

Sub-Step 7.3: Place a time gate centred at the highest peak (at the distance (D) to the target and set a time gate width greater than the observed "size" of the target in time domain, for an example see figure 21.

Sub-Step 7.4: Step back to the frequency domain.

Sub-Step 7.5: Read out S11 [dB] over the measured frequency range and store the data ($S11_{cal}$), for an example see figure 22.

Sub-Step 7.6: Calculate the RCS based on equation (24):

$$\mathrm{rcs_{cal,measured}}\ [\mathrm{dBm^2}] = \mathrm{S11_{cal}}[\mathrm{dB}] - 2 \times \mathrm{g}[\mathrm{dB}] - 20\log\lambda + 40\log\mathrm{D} + 33\mathrm{dB} \quad (27)$$

NOTE: In addition, the RCS of the used calibration standard target could be calculated based on the theoretical equations (mechanical dimensions; $RCS_{cal,theoretical}$), see Annex A or could be taken from the corresponding datasheet.

Step 8: The corrected RCS of the target could now be calculated using the VNA trace math following derivation from the Radar equation.

$$RCS_{target,corrected}[m^2] = RCS_{cal,theoretical}[m^2] \times 10^{\left(\frac{S11_{target}[\mathrm{dB}] - S11_{cal,measured}[dB]}{10}\right)} \quad (28)$$

or could be calculated based on the already calculated RCS and measured S11 values

$$rcs_{target,corrected}\ [dBm^2] = rcs_{cal,theoretical}\ [dBm^2] + S11_{target}[dB] - S11_{cal,measured}[dB] \quad (29)$$

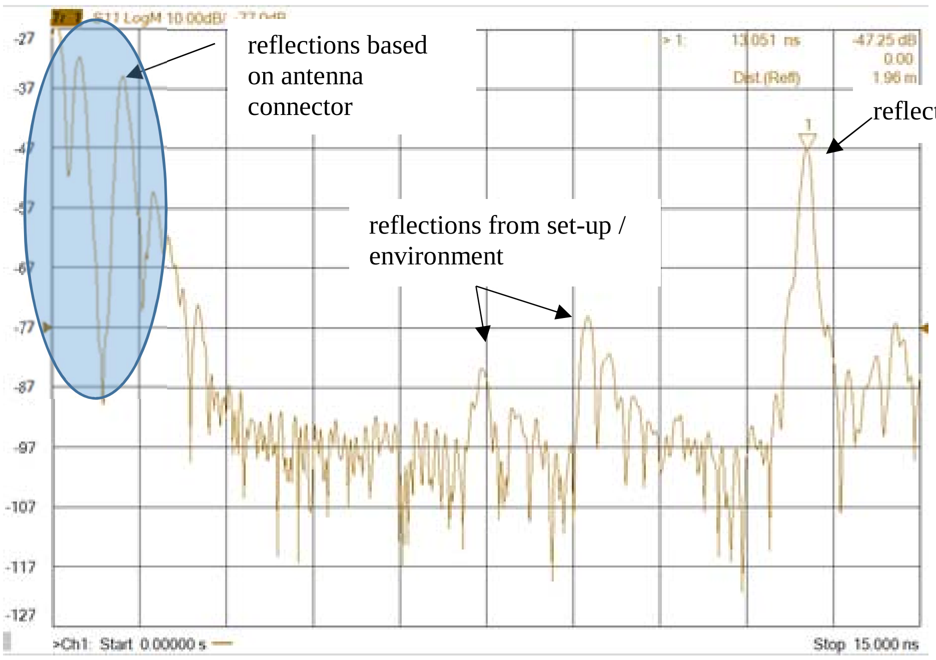


Figure 20: Example for an RCS measurement (S11) in time domain mode for the one-port test set-up

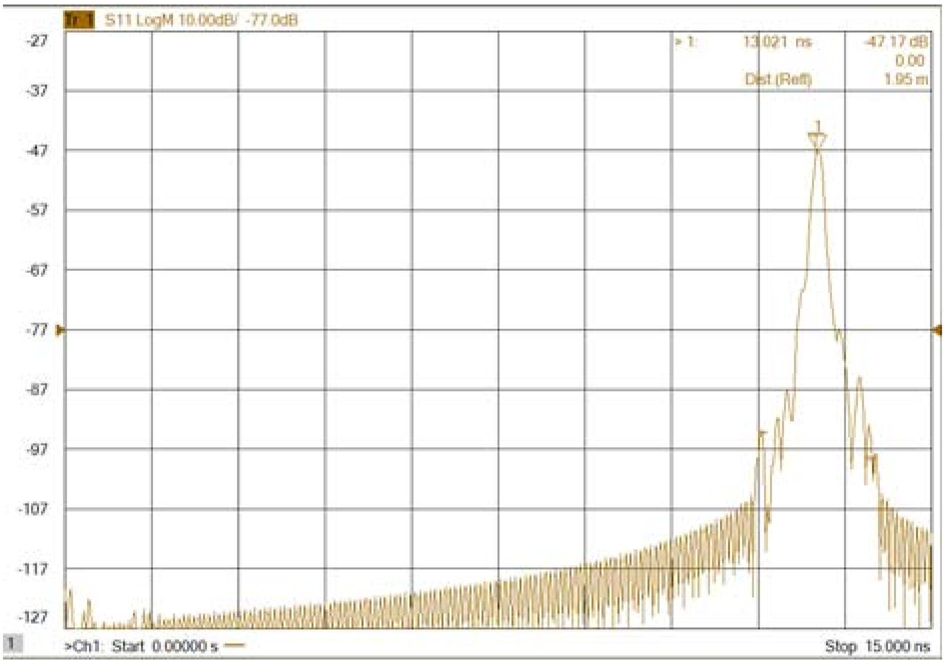


Figure 21: Example for a time gated RCS measurement (S11) in time domain mode for the one-port test set-up

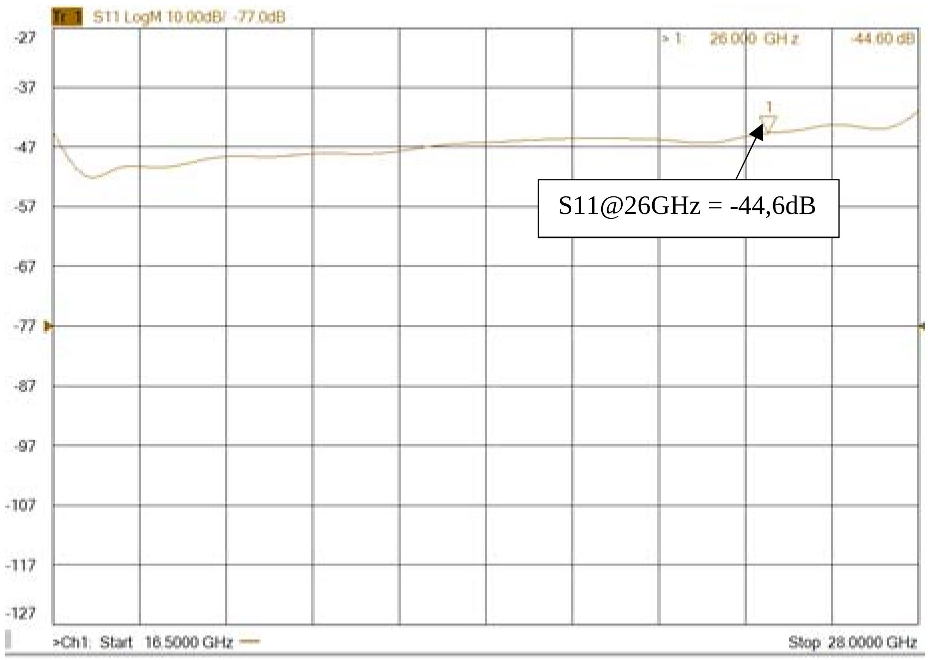


Figure 22: Example for S11 of the single antenna measurement (one-port test set-up) in frequency domain (over frequency range 16,5 GHz to 28 GHz) using a gating window in time domain

Annex A (informative): Kind of radar target and related RCS

A.1 Mechanical radar target

A.1.1 Trihedral, Triangular corner target (made from triangular plates)

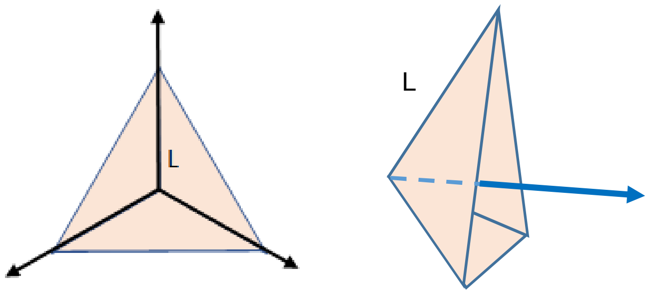


Figure A.1: Triangular corner target

RCS
In the main direction/maximum direction: $$\mathrm{RCS_{max}} = \frac{4 \times \pi \times L^4}{3 \times \lambda^2}$$ With: • L: side edge length • λ: wavelength of the radar More information provided in [i.17] and [i.18] NOTE: RCS if far field condition applies, see clause B.2.

A.1.2 Trihedral, Square corner target (made from square plates)

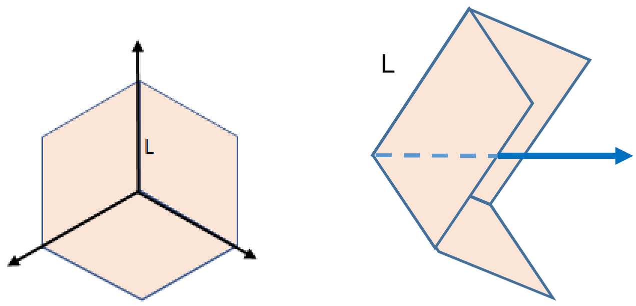


Figure A.2: Square corner target

RCS
In the main direction/maximum direction: $$\mathrm{RCS_{max}} = \frac{12 \times \pi \times L^4}{\lambda^2}$$ With: • L: side edge length • λ: wavelength of the radar More information provided in [i.17] and [i.18] NOTE: RCS if far field condition applies, see clause B.2.

A.1.3 Trihedral, Round corner target (made from quadrant plates)

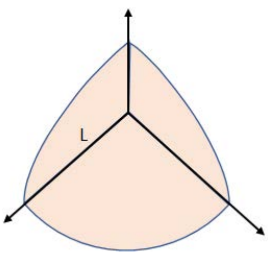


Figure A.3: Round corner target

RCS
In the main direction/maximum direction: $$\mathrm{RCS_{max}} = \frac{15{,}6 \times \pi \times L^4}{3 \times \lambda^2}$$ With: • L: side edge length • λ: wavelength of the radar More information provided in [i.19] NOTE: RCS if far field condition applies, see clause B.2.

A.1.4 Sphere, spherical target

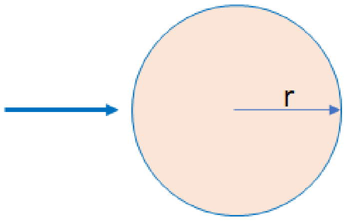


Figure A.4.1: Spherical target

RCS
Any direction $$\mathrm{RCS_{max}} = \pi \times r^2$$ With: • r: radius NOTE: RCS if far field condition applies, see clause B.2.

Rayleigh Region ($\lambda \gg r$)

$$\boldsymbol{RCS = (\pi \times r^2)(7{,}11 \times (k \times r)^4)}$$

with: $k = \frac{2\times\pi}{\lambda}$

Mie / Resonance Region

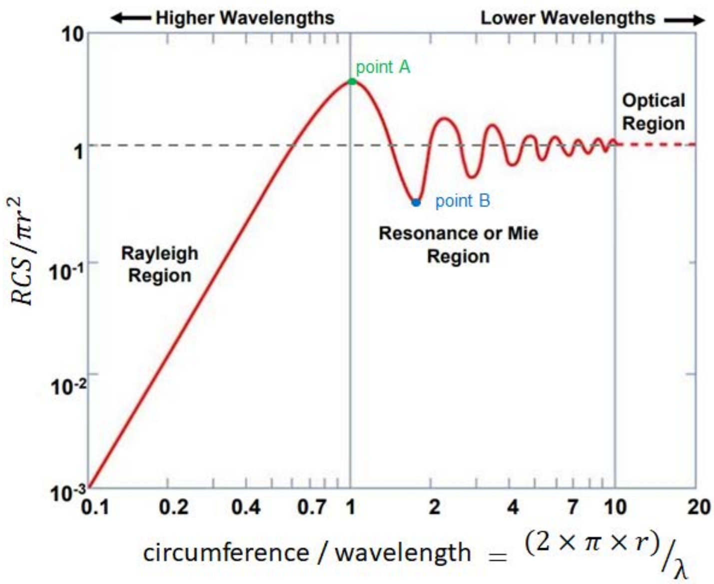
Oscillations backscattered wave interferes with creeping wave

$$RCS = 4 \times \pi \times r^2 \ \ (maximum; point\ A)$$
$$RCS = 0{,}26 \times \pi \times r^2 \ \ (minimum; point\ B)$$

Optical Region ($\lambda \ll r$)

Surface and edge scattering occur; RCS of a sphere is independent of frequency

$$RCS = \pi \times r^2$$



NOTE: More information on spherical targets, see [i.22].

Figure A.4.2: RCS of a sphere

A.1.5 Ellipsoid, elliptical target

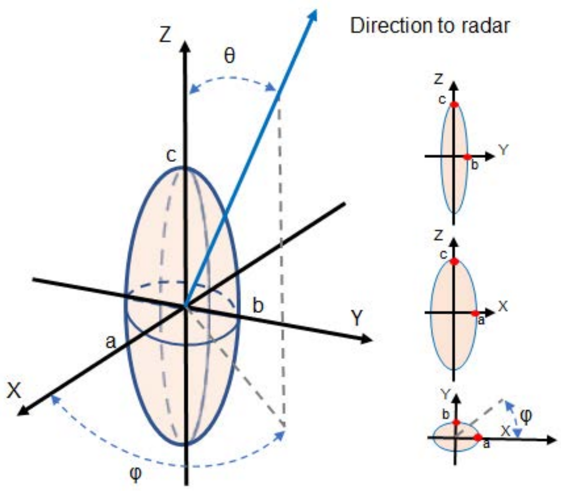


Figure A.5: Elliptical target

RCS
In direction to the radar $$\mathrm{RCS_{max}} = \frac{\pi \times a^2 \times b^2 \times c^2}{(a^2 sin\theta^2 \cos\varphi^2 + b^2 sin\theta^2 \sin\varphi^2 + c^2 \cos\theta^2)^2}$$ With: • a = ellipsoid a-radius • b = ellipsoid b-radius • c = ellipsoid c-radius NOTE: RCS if far field condition applies, see clause B.2.

A.1.6 Plate, flat target

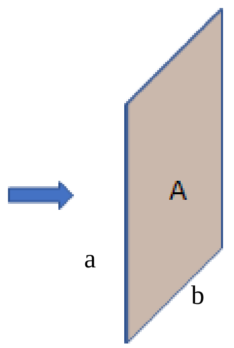


Figure A.6.1: Flat plate target

RCS
In the main direction/maximum direction: $$RCS_{max} = \frac{4 \times \pi \times A^2}{\lambda^2}$$ with: • A: area of the plate (A = a x b) • a: length side 1 • b: length side 2 • λ: wavelength of the radar NOTE: RCS if far field condition applies, see clause B.2.

Sub-case1: with angle θ from the main direction

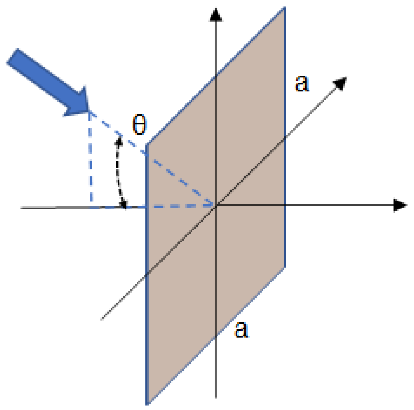


Figure A.6.2: Square plate target

RCS
In direction of angle θ (angle to the normal) $$RCS = \frac{4 \times \pi \times a^4}{\lambda^2} \times \left[\frac{\sin(k \times a \times \sin\theta)}{k \times a \times \sin\theta}\right]$$ With: • a: length of side • k: wave vector $k = \frac{2\times\pi}{\lambda}$ • λ: wavelength of the radar NOTE: RCS if far field condition applies, see clause B.2.

A.1.7 Dihedral, dihedral corner target

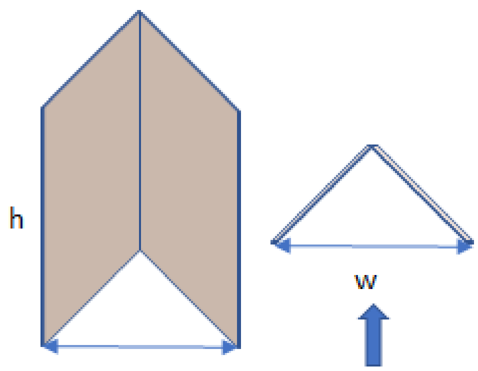


Figure A.7: Dihedral target

RCS
In main direction: $$RCS_{max} = \frac{8 \times \pi \times h^2 \times w^2}{\lambda^2}$$ With: • h: height • w: visible width • λ: wavelength of the radar NOTE: RCS if far field condition applies, see clause B.2.

A.1.8 Cone, conic corner target

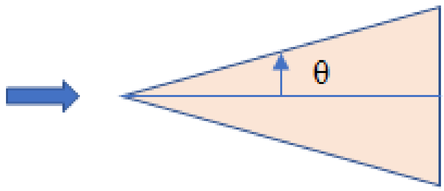


Figure A.8: Conic target

RCS
In axial direction: $$\mathrm{RCS_{max}} = \frac{\lambda^2}{16 \times \pi} \times \tan^4 \theta$$ With: • θ: Cone half angle • λ: wavelength of the radar NOTE: RCS if far field condition applies, see clause B.2.

A.1.9 Cylinder, cylindrical corner target

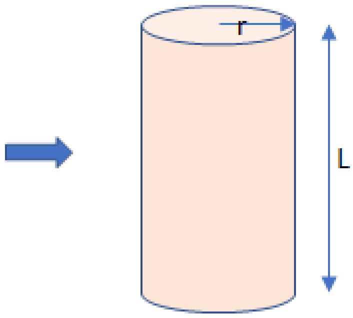


Figure A.9: cylindrical target

RCS
In main direction $$RCS = \frac{2 \times \pi \times r \times L^2}{\lambda}$$ With: • r: Radius • L: Length • λ: wavelength of the radar NOTE: RCS if far field condition applies, see clause B.2.

A.1.10 Consideration of target speed

By adding motion to a direct object reflector, the occurring Doppler effect causes the reflected power to be shifted in frequency ($f_C + f_D$):

$$f_D = \frac{2 \times v_T}{\lambda} \quad \text{(A.1)}$$

Motion towards (v_T) the radar sensor gives a positive frequency shift while motion away from the radar sensor gives a negative frequency shift.

A.1.11 Boundary conditions of the RCS equations

The basis for the derivation of the Radar Cross-Section (RCS) equations is based on a geometric optics model. This model assumes that the wavelength is small with respect to the physical dimensions of the individual target reflector. And therefore, the formulas in clauses A.1.1 to A.1.9 consider this model for calculation of the Radar Cross-Section are the formulas are valid under the condition of optical, i.e. frequency-independent reflection at bodies that are much further away (within the far filed of the EUT/measurement antenna) and from the wavelength of the transmitter signal which is much larger than the used wavelength of the device.

In particular, the equation used for the Radar Cross-Section of the conducting sphere RCS_{sphere} is only valid, if the following condition is fulfilled (see clause A.1.4):

$$\frac{2\pi \cdot r_{Sphere}}{\lambda} \geq 5 \quad \text{(A.2)}$$

Based on the requirement for a sphere equation (A.2) and that the RCS depends on the apparent area of the target and the optical model it is proposed to consider the size of the target compared to the wavelength of the signal. Therefore, for the Radar Cross-Sections of the two corner reflectors RCS_{square} and $RCS_{triangular}$, respectively, the requirement in equation (A.3) has to be considered. If based on the use-case very low RCS values are necessary and the requirement in equation cannot be fulfilled, the RCS of the target could be justified by the measurements in clause 7 or if the manufacturer of the target provides the RCS value for the assessed frequency range

$$\frac{2\pi\frac{\sqrt{6}}{3}L}{\lambda} \geq 5 \qquad \text{(A.3)}$$

These two conditions (equations A.2 and A.3) lead to minimum sphere radius and minimum edge lengths with respect to the frequency of the incident wave. Table A.1 shows these minimum dimensions as a function of frequency for selected frequencies in the permitted frequency ranges.

Table A.1: Minimum physical dimensions of the radar targets as a function of frequency

Frequency range [GHz]	Assumed centre frequency of incident wave [GHz]	Minimum sphere radius r_{sphere} (mm) based on equation A.2	Mechanical limitation radius sphere (note)	Minimum corner reflector edge length L (mm) based on equation A.3	Minimum mechanical limitation (L) (note)
3,1 to 4,8	4,8	**50 mm**	10 mm	**70 mm**	20 mm
6 to 8,5	7	**35 mm**	10 mm	**50 mm**	20 mm
9 to 10	9,5	**26 mm**	10 mm	**40 mm**	20 mm
24,05 to 26,5	25	**10 mm**	10 mm	12 mm	**20 mm**
57 to 64	61	4 mm	**10 mm**	5 mm	**20 mm**
75 to 85	80	3 mm	**10 mm**	4 mm	**20 mm**
122 to 123	123	2 mm	**10 mm**	3 mm	**20 mm**
116 to 148,5	132,25	1,8 mm	**10 mm**	3 mm	**20 mm**
167 to 190	178,5	1,4 mm	**10 mm**	2 mm	**20 mm**
231,5 to 250	240,75	1 mm	**10 mm**	1,5 mm	**20 mm**
NOTE: Mechanical dimensions which were publicly purchasable (with datasheet).					

The correlation between the Radar Cross-Section (RCS) of the target and the physical dimension; sphere radius r_{sphere} or edge length (L) of the two corner reflectors (trihedral triangular and trihedral square) is illustrated in dBm²-values. In addition, the boundary conditions and the mechanical limitations given in table A.1 and equations A.2 and A.3 were considered:

- for the frequency range 3,4 to 4,8 GHz (@ 4,8 GHz: ~62,4 mm wavelength) in figure A.10.
- for the frequency range 6 to 8,5 GHz (@ 7 GHz: ~42,8 mm wavelength) in figure A.11.
- for the frequency range 9 to 10 GHz (@ 9,5 GHz: ~31,5 mm wavelength) in figure A.12.
- for the frequency range 24,05 to 26,5 GHz (@ 25 GHz: ~12 mm wavelength) in figure A.13.
- for the frequency range 57 to 64 GHz (@ 61 GHz: ~4,9 mm wavelength) in figure A.14.
- for the frequency range 75 to 85 GHz (@ 89 GHz: ~3,75 mm wavelength) in figure A.15.
- for the frequency range 122 to 123 GHz (@ 123 GHz: ~2,4 mm wavelength) in figure A.16.
- for the frequency range 116 to 148,5 GHz (@ 132,25 GHz: ~2,3 mm wavelength) in figure A.17.
- for the frequency range 167 to 190 GHz (@ 178,5 GHz: ~1,68 mm wavelength) in figure A.18.
- for the frequency range 231,5 to 250 GHz (@ 240,75 GHz: ~1,24 mm wavelength) in figure A.19.

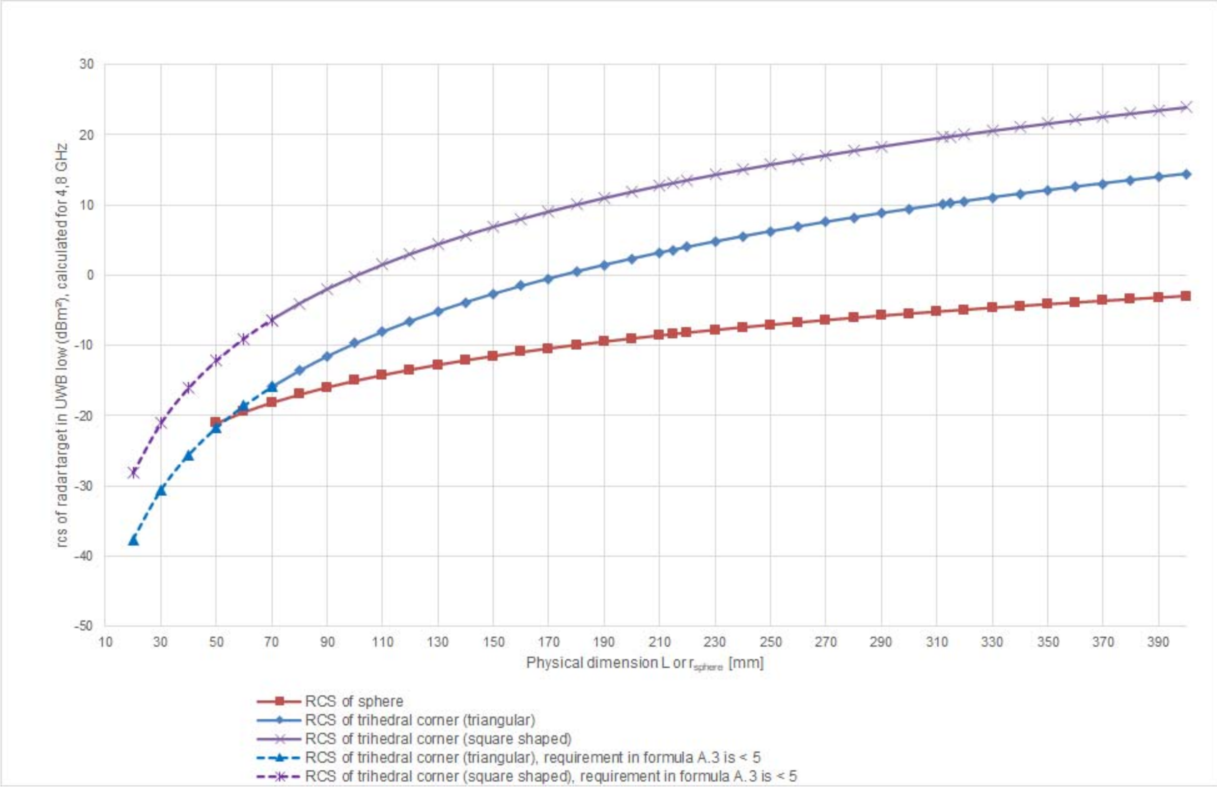


Figure A.10: Radar Cross-Sections as a function of the physical dimensions of different targets for the frequency range 3,4 to 4,8 GHz (wavelength ~62,4 mm)

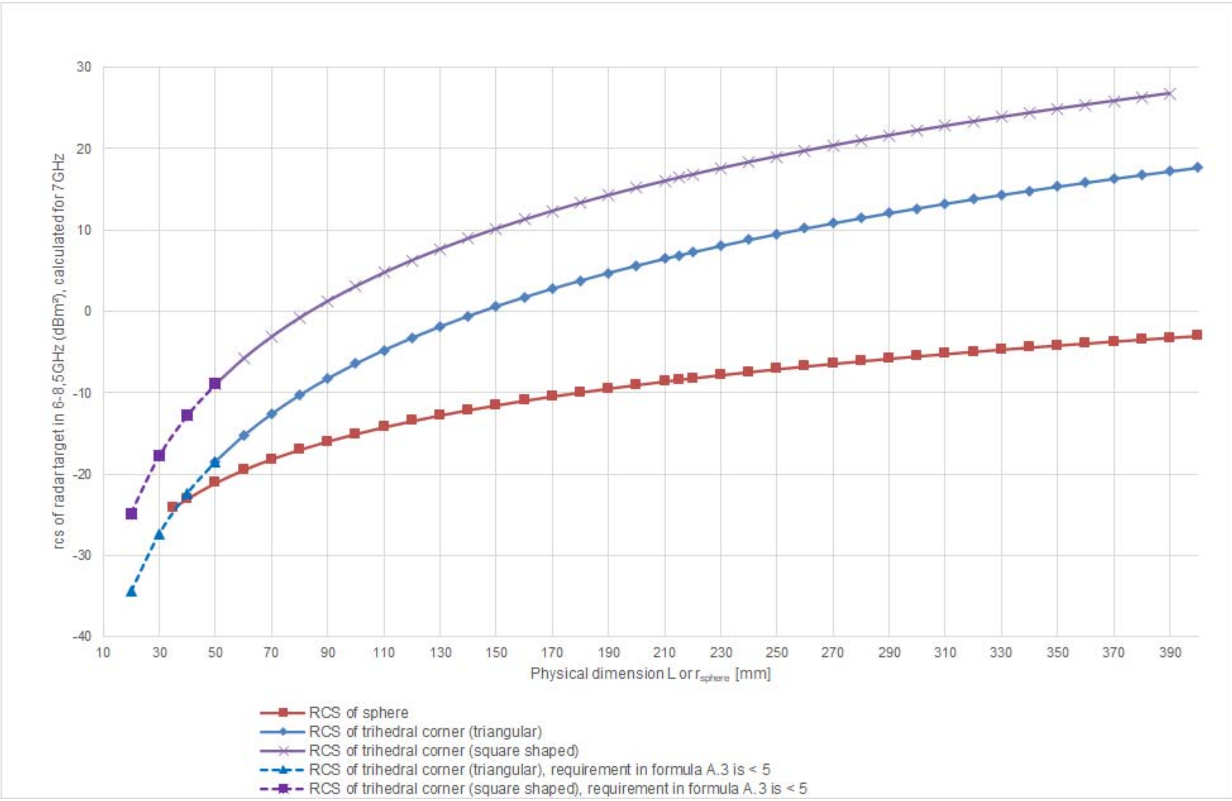


Figure A.11: Radar Cross-Sections as a function of the physical dimensions of different targets for the frequency range 6 to 8,5 GHz (wavelength ~42,8 mm)

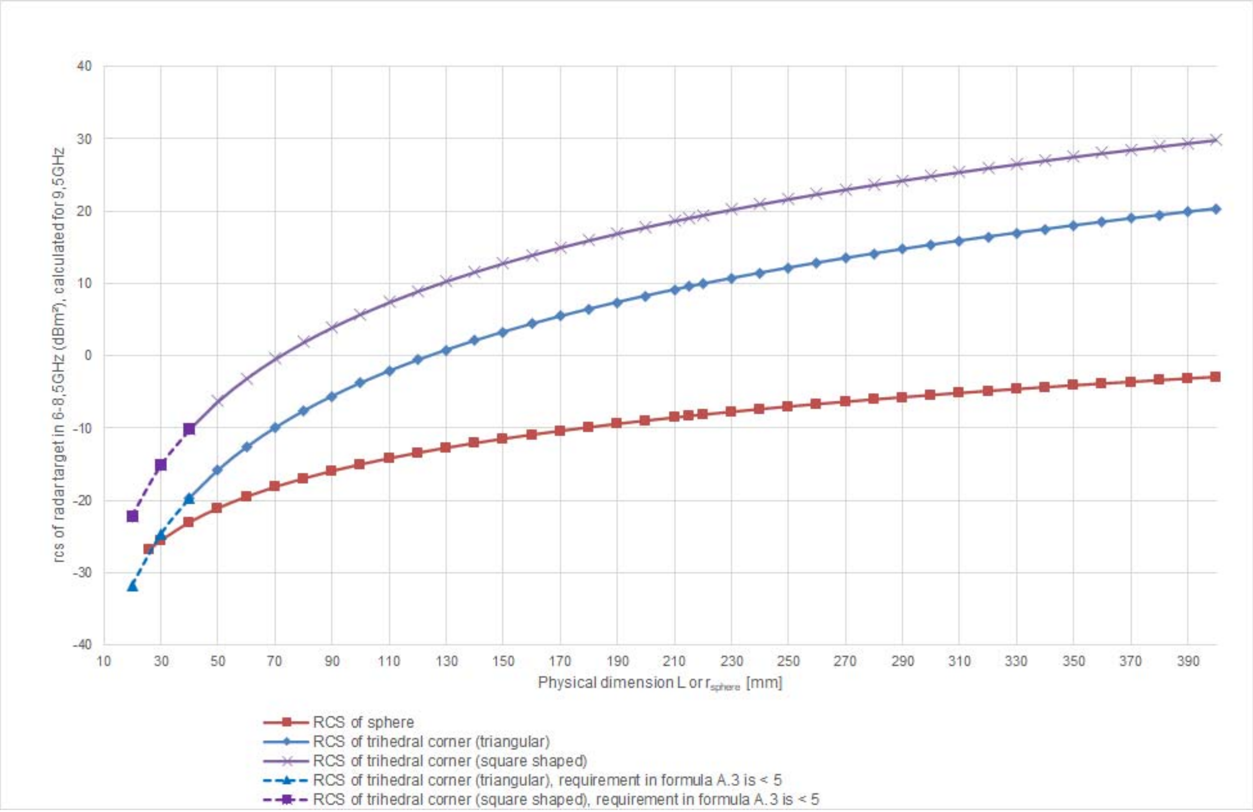


Figure A.12: Radar Cross-Sections as a function of the physical dimensions of different targets for the frequency range 9 to 10 GHz (wavelength ~31,5 mm)

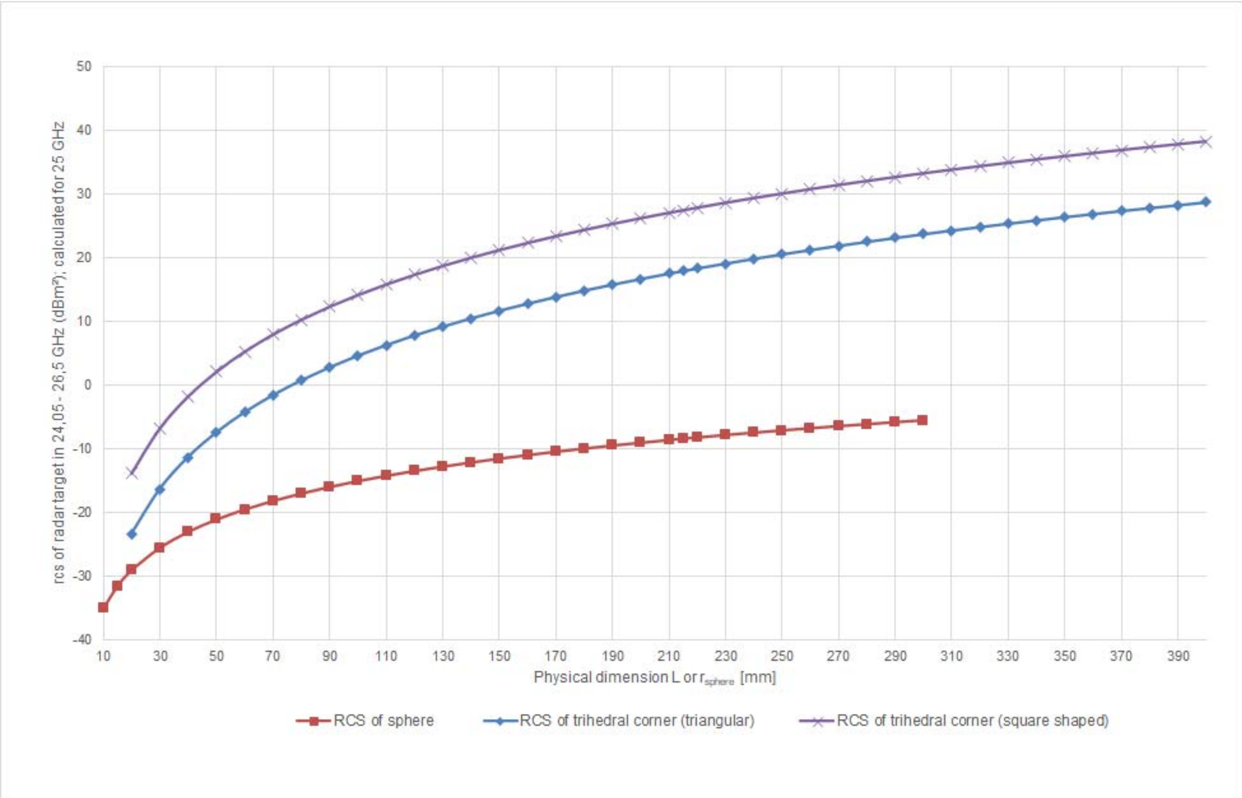


Figure A.13: Radar Cross-Sections as a function of the physical dimensions of different targets for the frequency range 24,05 to 26,5 GHz (wavelength ~12 mm)

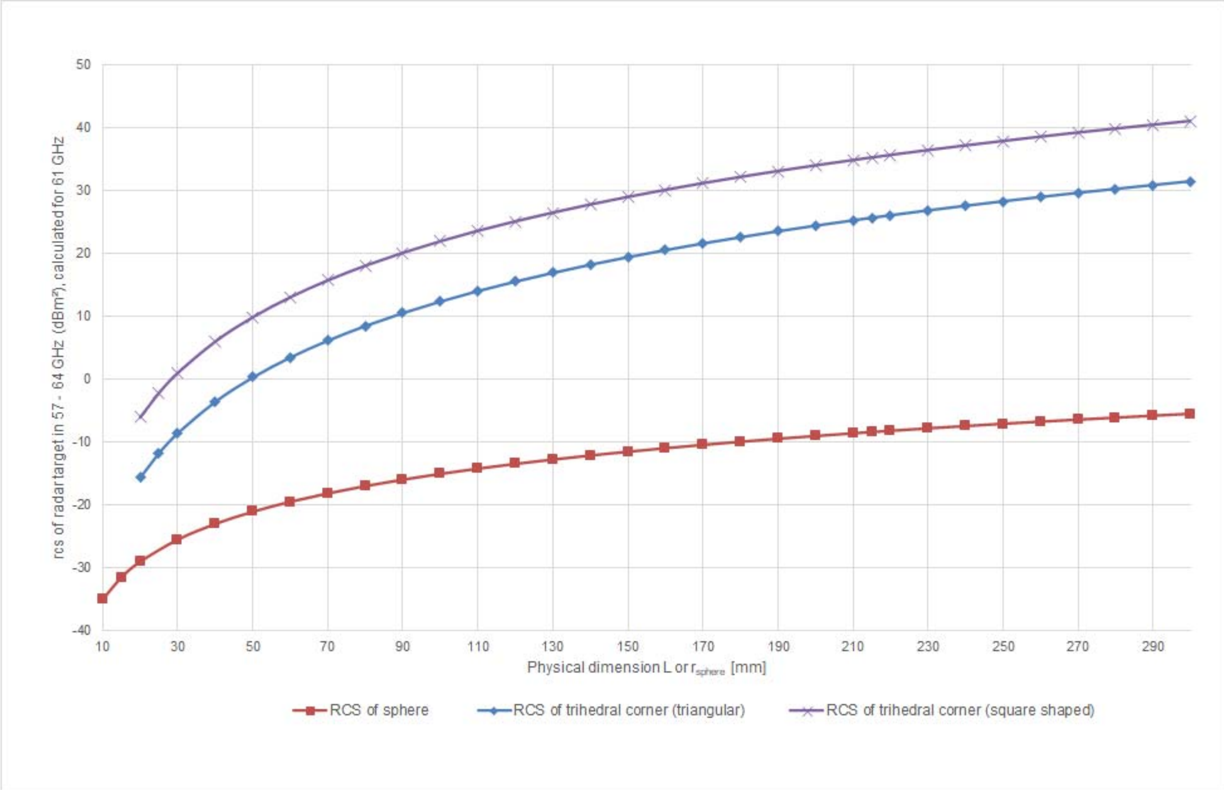


Figure A.14: Radar Cross-Sections as a function of the physical dimensions of different targets for the frequency range 57 to 64 GHz (wavelength ~4,9 mm)

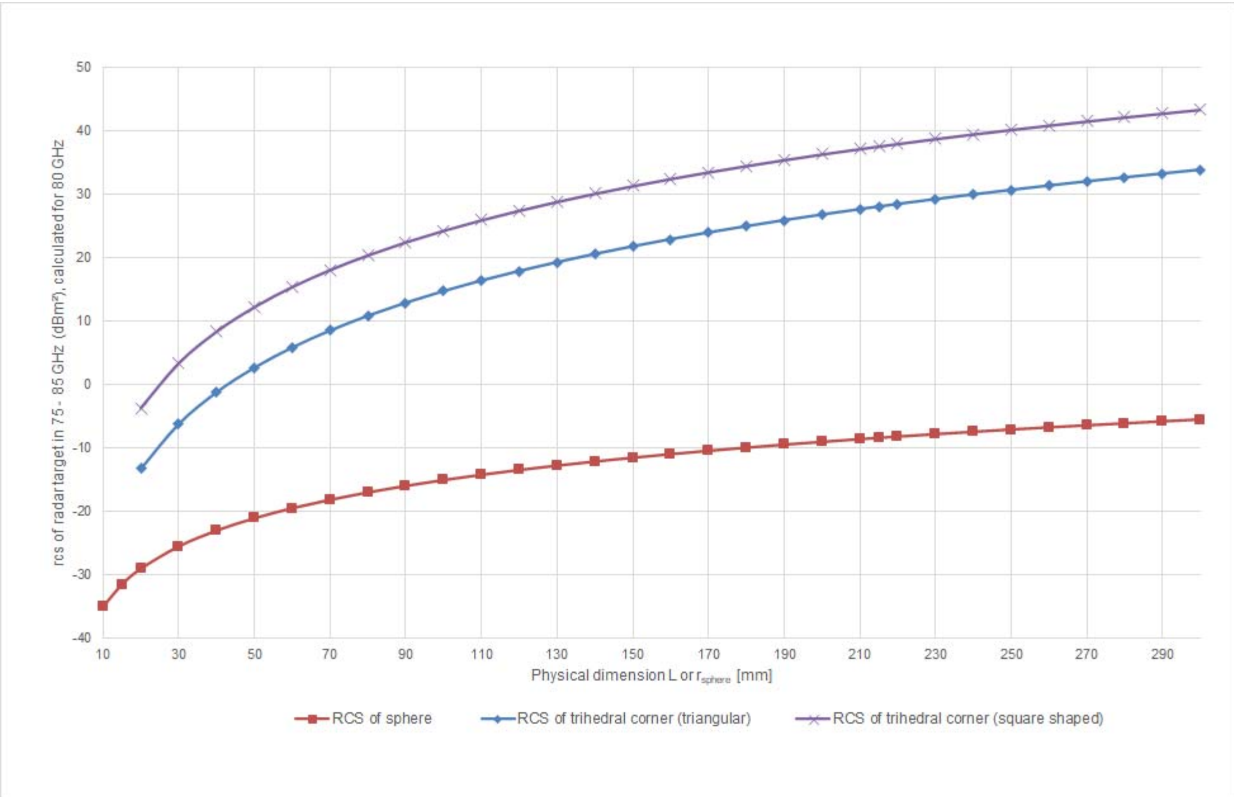


Figure A.15: Radar Cross-Sections as a function of the physical dimensions of different targets for the frequency range 75 to 85 GHz (wavelength ~3,75 mm)

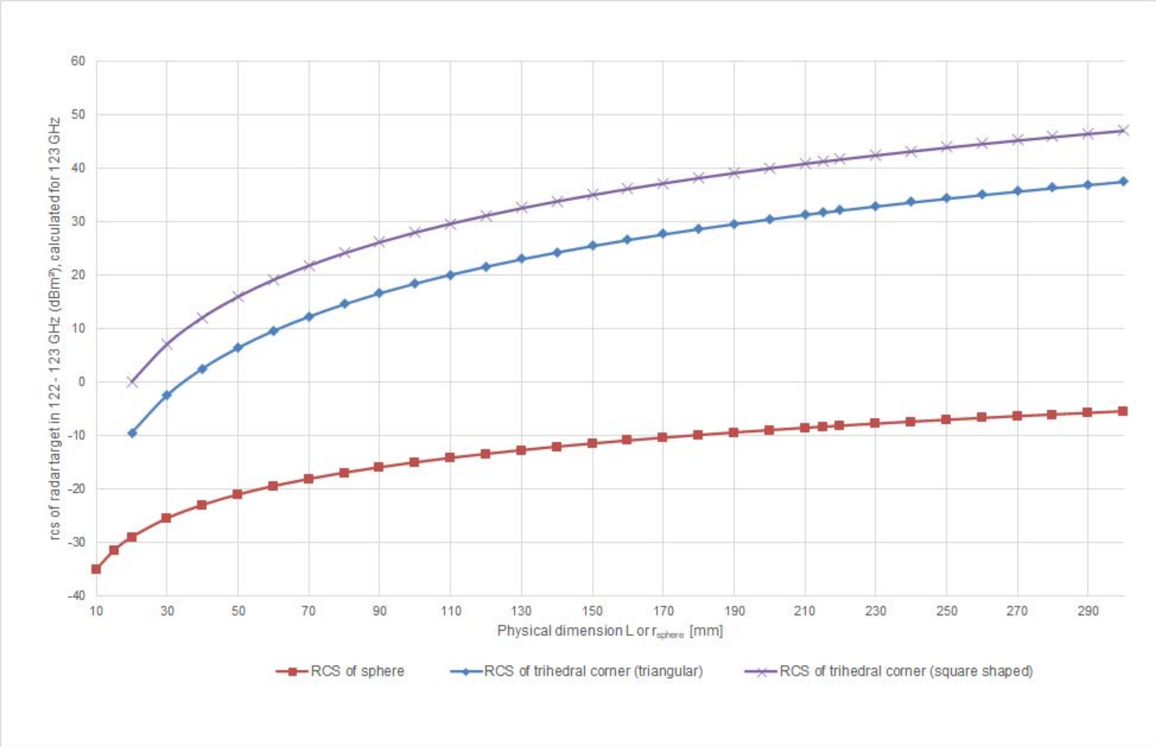


Figure A.16: Radar Cross-Sections as a function of the physical dimensions of different targets for the frequency range 122 - 123 GHz (wavelength ~2,4 mm)

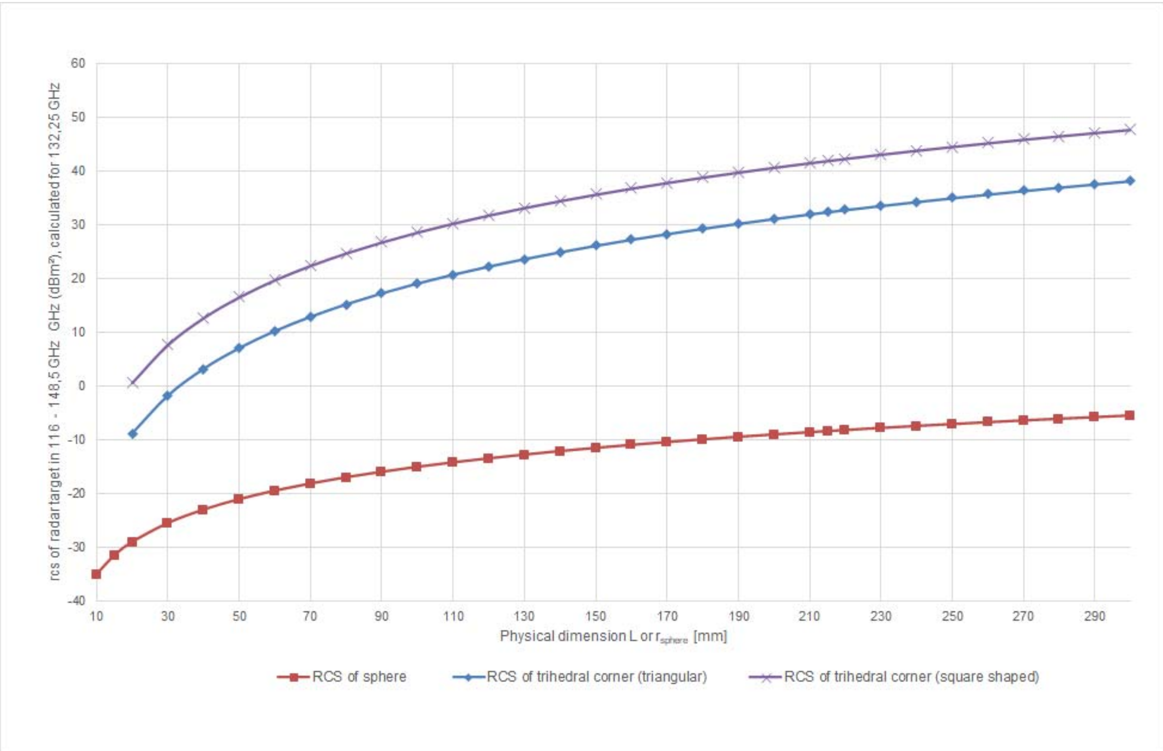


Figure A.17: Radar Cross-Sections as a function of the physical dimensions of different targets for the frequency range 116 - 148,5 GHz (wavelength ~2,3 mm)

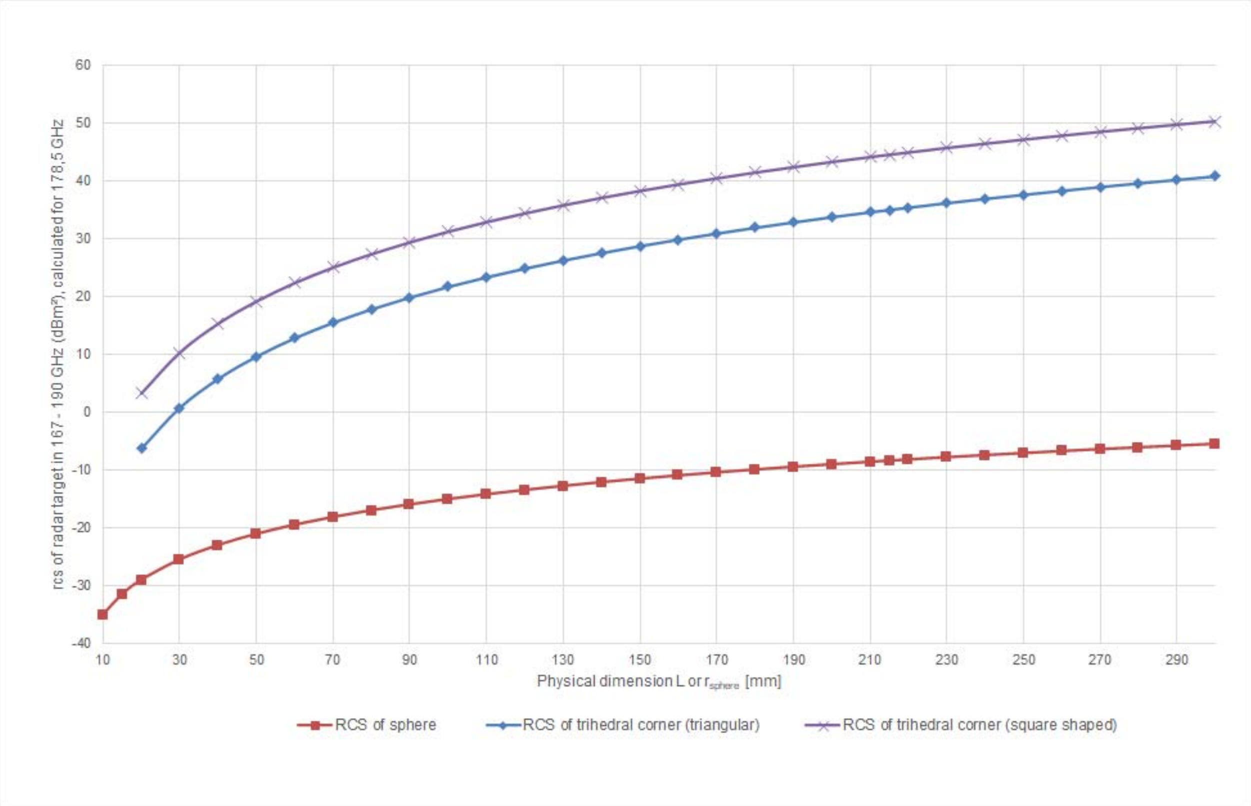


Figure A.18: Radar Cross-Sections as a function of the physical dimensions of different targets for the frequency range 167 - 190 GHz (wavelength ~1,64 mm)

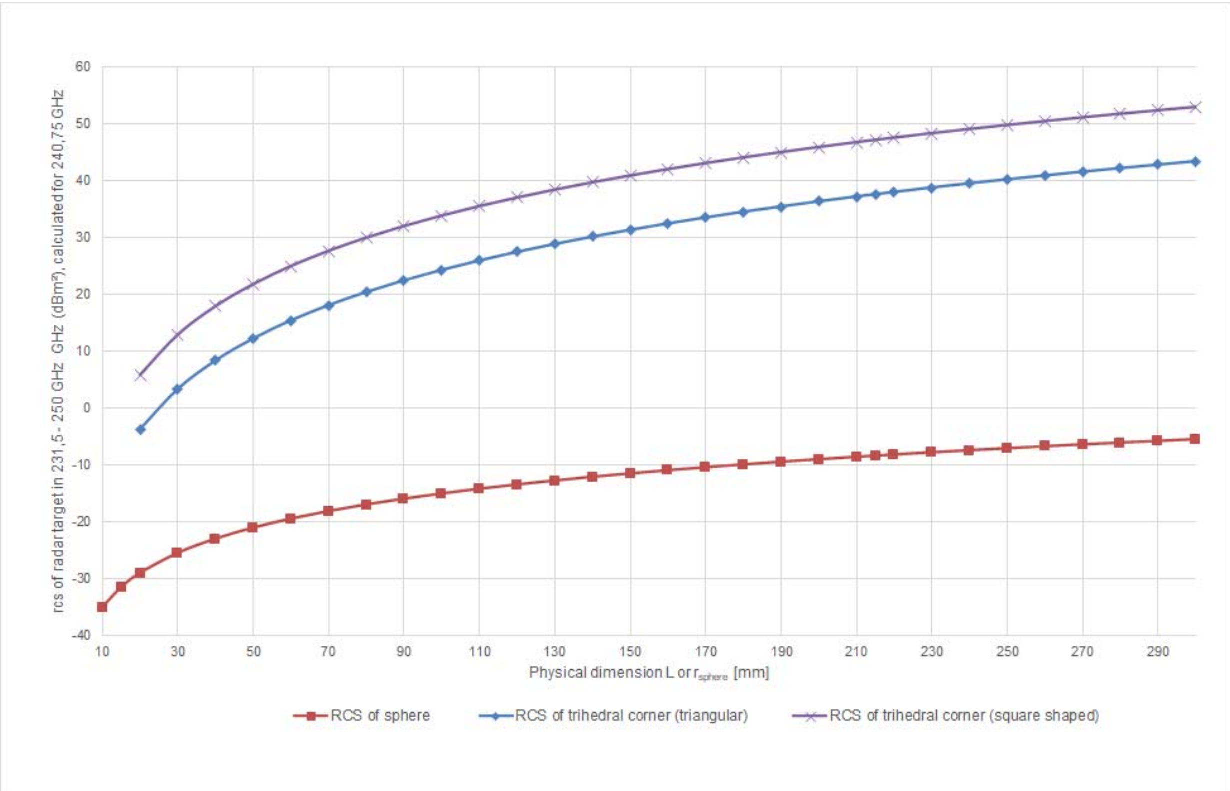


Figure A.19: Radar Cross-Sections as a function of the physical dimensions of different targets for the frequency range 231,5 - 250 GHz (wavelength ~1,24 mm)

To show the RCS of a trihedral triangular corner via the frequency ranges, see figure A.20.

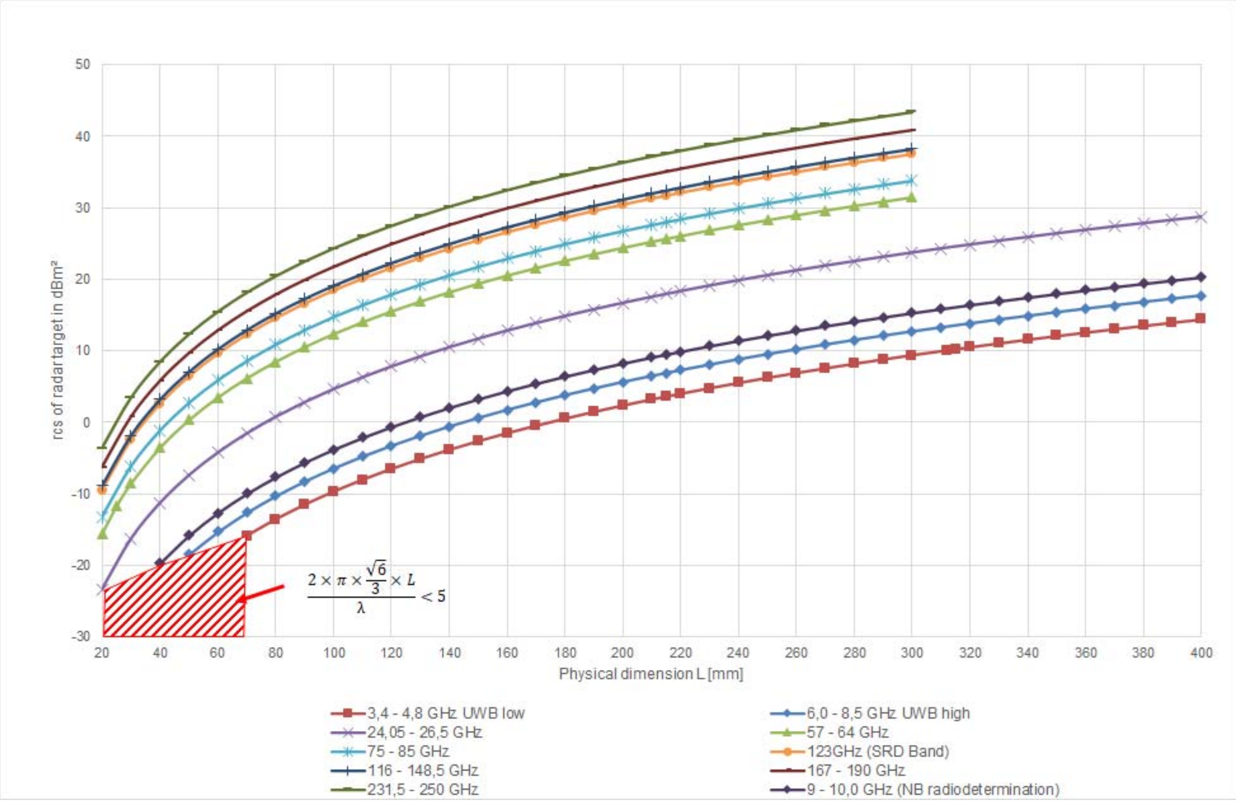


Figure A.20: Reachable Radar Cross-Sections of a trihedral triangular corner in the different frequency ranges and the consideration in table A.1 and of equation (A.3)

A.2 RCS based on material parameter/material surfaces

A.2.1 General

Some use-cases consider material as a target (e.g. (Tank) Level Probing Radar ((T)-LPR) or Ground Based Synthetic Aperture Radar (GB-SAR)). Most of the materials can be seen as dielectrics and are non-magnetic with a relative permittivity ε_r.

A.2.2 Theory reflections on dielectric surfaces

Reflections on surfaces/materials happen when radar waves have to pass through dielectrics such as e.g. window glass. Snell's law and the Fresnel equations describe the behaviour of electromagnetic waves when they encounter these surfaces/materials.

Snell's law describes the relationship between the angle of the incident wave and the angle of the transmitted wave, as shown in figure A.12. The incident wave has an angle of θ_i to the normal angle of the surface between two materials. The resulting transmitted wave will have an angle of θ_t to the normal angle.

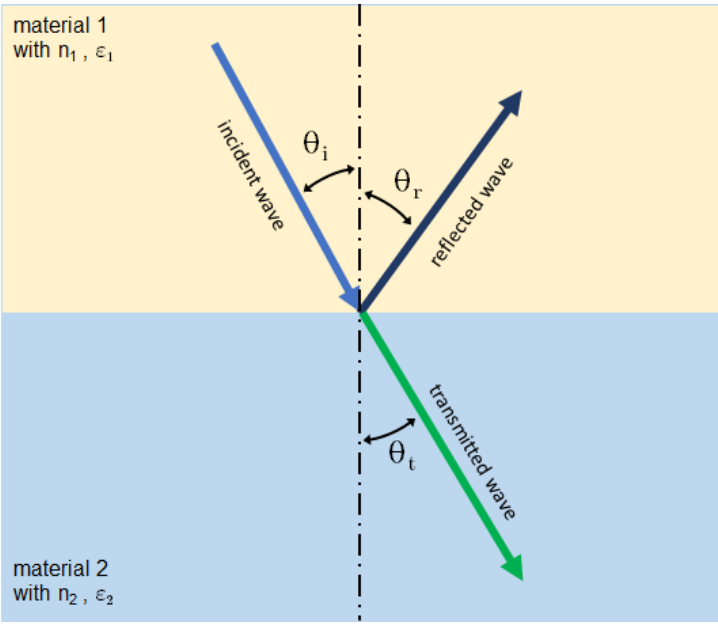


Figure A.21: Illustration of Snell's law

The material (material 1) on the incident wave side has a relative permittivity $\varepsilon_r = \varepsilon_1$, and the material on the transmitted side has a relative permittivity $\varepsilon_r = \varepsilon_2$. As most dielectrics are non-magnetic (μ_r=1), the refractive index of a material is defined as the square-root of the relative permittivity, see (A.4):

$$n = \sqrt{\varepsilon_r} \qquad \text{(A.4)}$$

The wavelength in the material is defined as (see (A.5)):

$$\lambda_{material} = \frac{\lambda_{vacuum}}{n} \qquad \text{(A.5)}$$

Snell's law states that the product of the refractive index and the sine of the angle are constant at a surface. Therefore, it can be written as (see (A.6)):

$$n_1 \times sin\,\theta_1 = n_2 \times sin\,\theta_2 \qquad \text{(A.6)}$$

where n_i and θ_i are the refractive index and the ray's angle in the material with relative permittivity ε_i. With this law, it is possible to compute the direction of the angle of the transmitted wave with a known angle of incidence and known refractive indices (permittivity) at the surface.

NOTE: The shape of the surface of the dielectric material is also crucial. The equations in this clause assume a flat surface. If the material in the use-case scenario has a curved or rough surface, it might be necessary to consider a small section of the surface and approximate it as being flat. Typically, a roughness of below one thirtieth of the wavelength can be ignored, and the surface treated as flat.

In order to calculate how much of the incident wave is reflected and how much is transmitted, this could be calculated by using the Fresnel equations.

There is a need to distinguish between the polarization of the wave. There are two polarizations; P- and S-polarization: S-polarization is the polarization parallel to the surface (wave's electric field normal to the plane of incidence; parallel to the surface, see figure A.22; E-field vector $E_{(s)}$). The P-polarization would be perpendicular to the wave's directions of travel in the incidence plane shown in figure A.22 (wave's electric field in the plane of incidence). All polarizations are superpositions of P- and S-polarization. In addition, it is assumed that the angle of incidence is equal to the angle of reflection $\theta_i = \theta_r$ (see figure A.22).

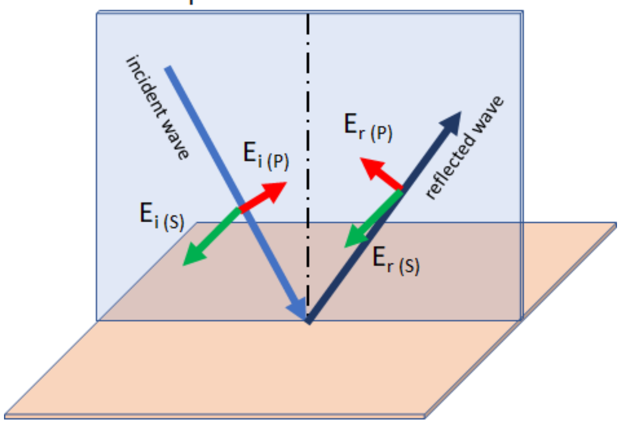


Figure A.22: Illustration of the wave polarization

For S-polarized waves (also named TE-component of a wave) at the surface:

$$\left(\frac{E_t}{E_i}\right) = t_s = \frac{2 \times n_1 \times cos\,\theta_i}{n_1 \times cos\,\theta_i + n_2 \times cos\,\theta_t} \quad \text{(A.7)}$$

$$\left(\frac{E_r}{E_i}\right) = r_s = \frac{n_1 \times cos\,\theta_i - n_2 \times cos\,\theta_t}{n_1 \times cos\,\theta_i + n_2 \times cos\,\theta_t} \quad \text{(A.8)}$$

And for considering the power coefficient with: $\frac{P_{t;r}}{P_i} = \left|\frac{E_{t;r}}{E_i}\right|^2$

$$T_s = \left|\frac{2 \times n_1 \times \cos\theta_i}{n_1 \times \cos\theta_i + n_2 \times \cos\theta_t}\right|^2 \quad \text{(A.9)}$$

$$R_s = \left|\frac{n_1 \times \cos\theta_i - n_2 \times \cos\theta_t}{n_1 \times \cos\theta_i + n_2 \times \cos\theta_t}\right|^2 \quad \text{(A.10)}$$

For P-polarized waves (also named TM-component of a wave) at the surface:

$$\left(\frac{E_t}{E_i}\right) = t_p = \frac{2 \times n_1 \times \cos\theta_i}{n_2 \times \cos\theta_i + n_1 \times \cos\theta_t} \quad \text{(A.11)}$$

$$\left(\frac{E_r}{E_i}\right) = r_p = \frac{n_2 \times \cos\theta_i - n_1 \times \cos\theta_t}{n_2 \times \cos\theta_i + n_1 \times \cos\theta_t} \quad \text{(A.12)}$$

And for considering the power coefficient with: $\frac{P_{t;r}}{P_i} = \left|\frac{E_{t;r}}{E_i}\right|^2$

$$T_P = \left|\frac{2 \times n_1 \times \cos\theta_i}{n_1 \times \cos\theta_i + n_2 \times \cos\theta_t}\right|^2 \quad \text{(A.13)}$$

$$R_P = \left|\frac{n_2 \times \cos\theta_i - n_1 \times \cos\theta_t}{n_2 \times \cos\theta_i + n_1 \times \cos\theta_t}\right|^2 \quad \text{(A.14)}$$

As a consequence of conservation of energy, one can find the transmitted power (or more correctly, irradiance: power per unit area) simply as the portion of the incident power (power coefficient) that is not reflected:

$$T_S = 1 - R_S \quad \text{(A.15)}$$

and

$$T_P = 1 - R_P \quad \text{(A.16)}$$

A.2.3 Special cases

A.2.3.1 Normal incidence

For the case of normal incidence, $\theta_i = \theta_t = 0$, and there is no distinction between S and P polarization. Thus, the reflectance simplifies to:

$$R = \left|\frac{n_1 - n_2}{n_1 + n_2}\right|^2 \quad \text{(A.17)}$$

For common glass ($n_2 \approx 1{,}5$) surrounded by air ($n_1 = 1$), the power reflectance at normal incidence can be seen to be about 4 %, or 8 % accounting for both sides of a glass pane.

A.2.3.2 Brewster's angle

At a dielectric interface from n_1 to n_2, there is a particular angle of incidence at which R_p goes to zero and a P-polarized incident wave is purely refracted, thus all reflected light is S-polarized. This angle is known as Brewster's angle, and is around 56° for $n_1 = 1$ (air) and $n_2 = 1{,}5$ (typical glass).

A.2.3.3 Total internal reflection

When a wave is travelling in a denser medium strikes the surface of a less dense medium (i.e. $n_1 > n_2$), beyond a particular incidence angle known as the critical angle, all energy is reflected and $R_s = R_p = 1$. This phenomenon, known as total internal reflection, occurs at incidence angles for which Snell's law predicts that the sine of the angle of refraction would exceed unity (whereas in fact $\sin\theta \leq 1$ for all real θ). For glass with $n = 1{,}5$ surrounded by air, the critical angle is approximately 42°.

A.2.3.4 Power coefficient diagrams

Figure A.23 and figure A.24 show power coefficient diagrams for an example of the two materials: air/glass.

Figure A.23 shows the air to glass, figure A.24 shows glass to air.

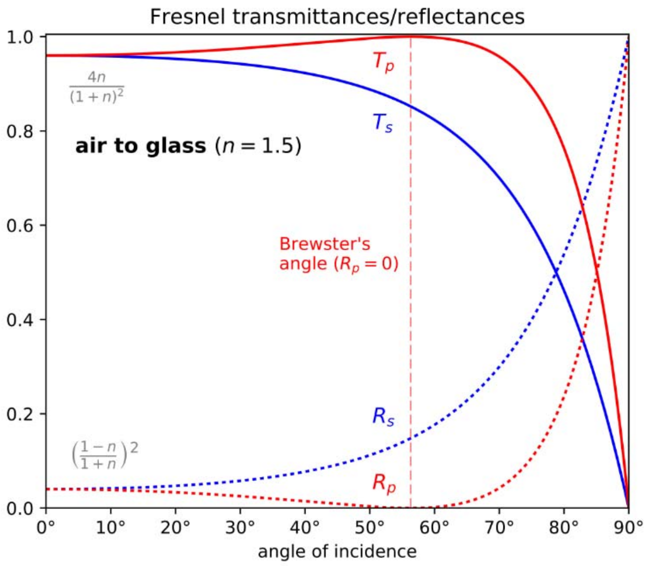


Figure A.23: Power coefficients: air to glass

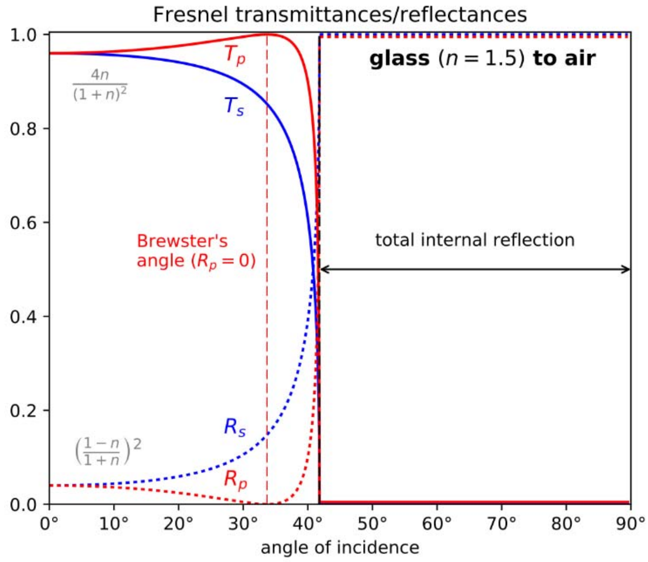


Figure A.24: Power coefficients: glass to air

A.2.4 From use-case with material to equivalent test scenario with target and specified RCS

In a typical real scenario, outlined in the upper part of Figure 15, a reference device is measuring against a material surface in a distance D_{meas}. Assuming a specular reflection at this smooth and flat material surface, this typical real scenario can be translated into a radiated equivalent scenario using an artificial radar target (e.g. sphere, corner reflector, etc.) located in an arbitrary distance D_T which produces exactly the same Rx power at the EUT's receiver (see lower part of Figure A.25).

The aim of the equivalent test scenario is to enable the possibility to carry out the radiated measurements in the limited space provided e.g. in an anechoic chamber (described for example in ETSI EN 303 883-1 [i.24], clause B.2.2.2) at a much shorter measurement distance $D_{T,}$ i.e. $D_T < D_{meas}$ and thus to facilitate testing.

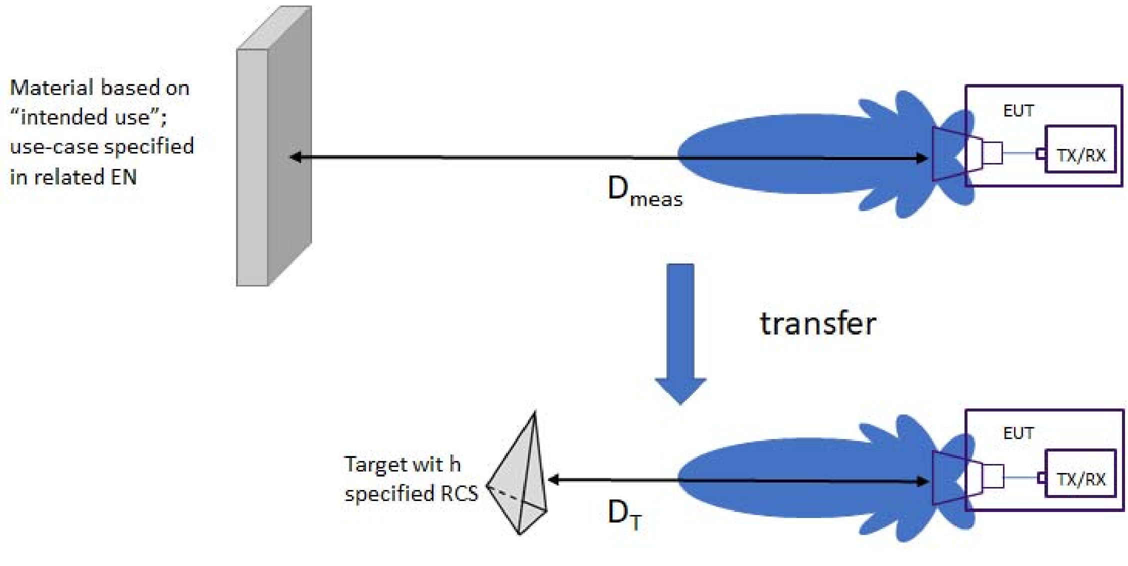


Figure A.25: Transfer from use-case scenario with material to equivalent scenario with target

The related standard has to specify the technical parameters of the reference target and the related kind of material which has to be detected.

The received power P_{r_real} fed back into the receiver of the reference device (see upper part of figure 15) can be calculated according to the following equation (refer to equation (3)), assuming a specular reflection at the material surface:

$$P_{r\_real} = \frac{P_{t\_ref} G_{ref}^2 \lambda^2 |r|^2}{(8\pi D_{meas})^2} \quad \text{(A.18)}$$

With:

P_{r_real} : received power in the real measurement scenario [W], specified in related standard.

P_{t_ref} : transmitter output power of the reference device; specified in related standard [W].

G_{ref}: antenna gain of the reference device; specified in related standard [dimensionless].

λ: wavelength of the transmit signal at centre frequency f_c [Hz].

D_{meas}: measurement distance in the real use-case scenario [m], specified in related standard.

r: reflection coefficient of the reference material (e.g. ε_r = 2,0) and wave polarization (r_P or r_S), angles in the scenario θ_i, as specified in related standard.

For the equivalent scenario the radar equation in (3) would lead to:

$$P_{r\_equivalent} = \frac{P_{t\_EUT}\, G_{EUT}^2\, \lambda^2 RCS}{(4\pi)^3 D_T^4} \quad \text{(A.19)}$$

with:

$P_{r\_equivalent}$: received echo power in the equivalent measurement scenario [W].

P_{t_EUT}: transmitter output power of the EUT [W].

G_{EUT}: gain of the EUT antenna (dimensionless).

D_T: distance between EUT and radar target in the equivalent scenario [m], measurement distance based on specified test environment in related standard.

RCS: Radar Cross-Section (RCS) of the artificial radar target [m²].

To find the equivalent RCS for the measurement target it is now necessary to set equal equations (A.18) and (A.19):

$$P_{r\_real} = P_{r\_equivalent} \quad \text{(A.20)}$$

Of course, it is valid to use targets with smaller Radar Cross-Sections (based on available certified test targets) for convenience to conduct the actual radiated tests. This would result in a smaller echo signal and thus in a smaller signal-to-noise ratio in the EUT receiver, i.e. $P_{r\_real} \geq P_{r\_equivalent}$.

The resulting equation in logarithmic form (A.21):

$$\text{rcs} \leq P_{t\_ref} - P_{t\_EUT} + 2 \cdot g_{ref} - 2 \cdot g_{EUT} + 40 \cdot \log D_T - 20 \cdot log D_{meas} + 20 \cdot log|r| + 5dB \quad \text{(A.21)}$$

with:

rcs: Radar Cross-Section (RCS) of the radar target [dBm²].

P_{t_ref} transmitter output power of the reference device [dBm].

P_{t_EUT}: transmitter output power of the EUT [dBm].

g_{ref}: antenna gain of the reference device [dBi].

g_{EUT}: gain of the EUT antenna [dBi].

Annex B (normative): Boundary conditions for radiated measurement scenarios using artificial radar targets

B.1 General

For the derivation of the radiated equivalent scenario (see clause 4.1.2) the simple form of the radar equation (see clause 4.1.2, equation (1) has been applied. The radar equation, however, is subject to the two boundary conditions specified in the following clauses B.2 and B.3 in order to ensure its accuracy and validity. These conditions shall therefore apply to the related radiated test scenarios.

B.2 Far-field condition

The simple form of the radar equation, introduced in clause 4.1.2, is only valid if the radar target is located in the far-field region of the EUT antenna.

A good measure for the far-field distance of electrically large antennas can be deduced from ETSI EN 303 883-1 [i.24] clause B.2.3.5. Consequently, the antenna dimension d_2 in ETSI EN 303 883-1 [i.24] equation (B.3) could be set to zero as a second antenna (test antenna) is not present in this case. This leads to the following equation for the far-field region:

$$d_{ff} = \frac{2d_1^2}{\lambda} \tag{B.1}$$

d_{ff}: distance from the EUT antenna to the inner boundary of its far-field region.

d_1: largest dimension of the physical aperture of the EUT antenna.

λ: wavelength of the transmit signal at centre frequency f_c.

That means the following requirement ensures far field conditions in radiated measurement scenarios using artificial radar targets:

$$R_T \geq d_{ff} \tag{B.2}$$

R_T: distance between EUT and radar target in a radiated scenario using an artificial radar target.

Figure B.1 shows the correlation between the distance to the inner boundary of the far-field region d_{ff} and the largest dimension of the antenna aperture for the different permitted frequency ranges of the EUT.

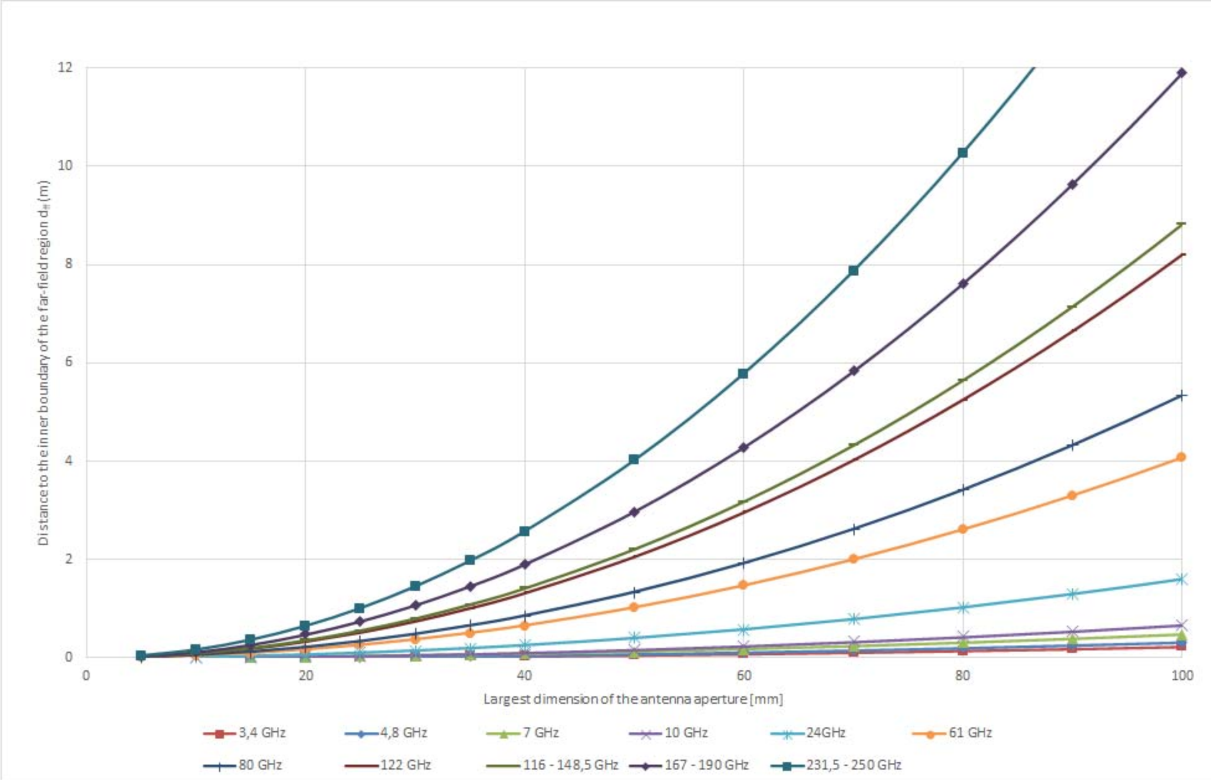


Figure B.1: Correlation between far-field distance and antenna aperture size up to 100 mm for the different frequency bands

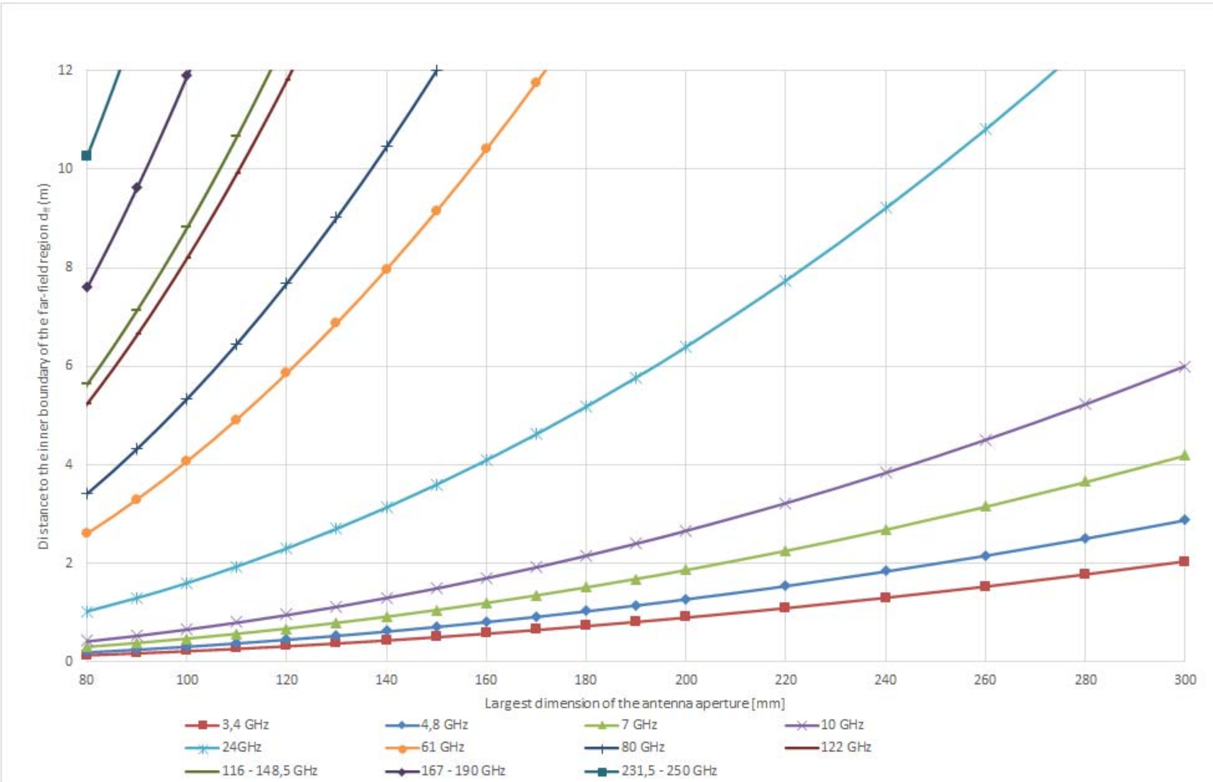


Figure B.2: Correlation between far-field distance and antenna aperture size between 80 and 300 mm for the different frequency bands

B.3 Point target condition

The simple form of the radar equation, introduced in clause 4.1.2, is only valid for point targets. That means the radar target should be either small enough or located far enough from the EUT in order to behave as a point target compared to the extent of the EUT's resolution cell in cross-range at the location of reflection.

Figure B.3 shows a simplified and normalized radiation pattern of a potential EUT antenna in one plane. The extent of the resolution cell in cross-range (angular resolution) is the same as the extent of the main lobe of the antenna pattern at the location of reflection in slant distance R_T. Thus, from the antenna pattern in figure B.3 the angular resolution can be approximated as follows:

$$d = 2\ R_T\ \sin\left(\frac{\vartheta_{3dB}}{2}\right) \qquad \text{(B.3)}$$

d: extent of the main lobe in slant distance R_T.

ϑ_{3dB}: half power beamwidth (HPBW) or opening angle of the antenna pattern.

R_T: slant distance between EUT and target.

An object can be considered a point target if its largest extent is at least 5 times smaller than the extent of the antenna main lobe (angular resolution) at the location of reflection in slant distance R_T (see figure B.3).

Thus, a sphere can be considered as a point target if the following condition is fulfilled:

$$\frac{d}{2\ r_{sphere}} \geq 5 \qquad \text{(B.4)}$$

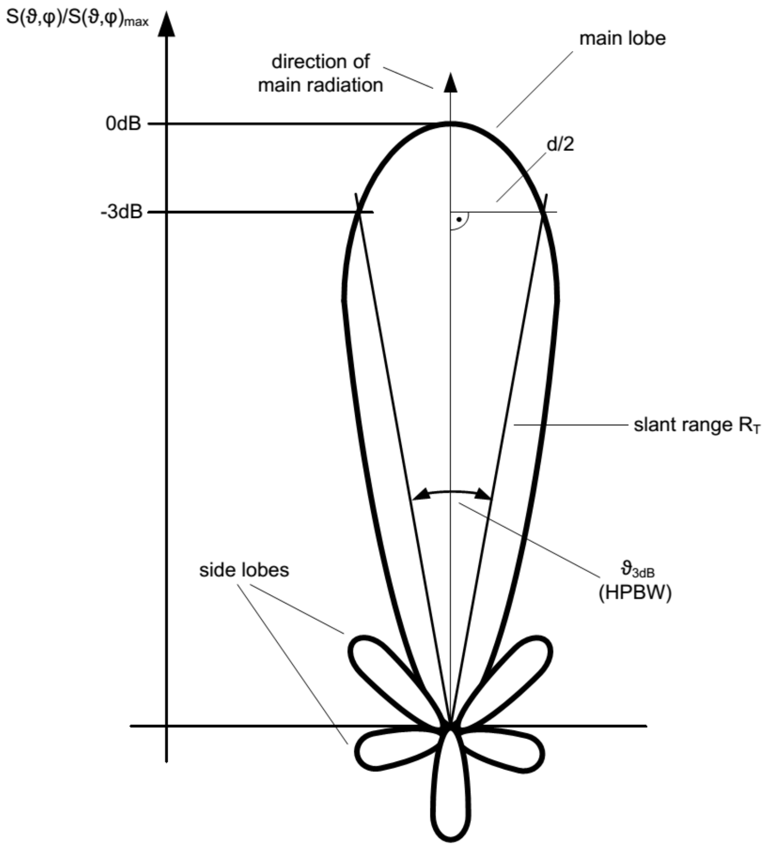


Figure B.3: Simplified and normalized radiation pattern of a highly directive EUT antenna

And corner reflectors can be considered as point targets if the following condition is fulfilled:

$$\frac{d}{L\sqrt{2}} \geq 5 \tag{B.5}$$

L: edge length of corner reflector (refer to clause A.1.1).

Annex C (normative): Friis transmission equation

The transmitted power level of the interfering signal $P_{t\_interferer}$ which shall be fed into the test antenna during the receiver baseline resilience test in order to generate the wanted interferer power level $P_{r\_interferer}$ at the EUT receiver can be determined using the well-known Friis transmission equation.

$$\frac{P_{r\_interferer}}{P_{t\_interferer}} = G_t G \left(\frac{\lambda_{interferer}}{4\pi R}\right)^2 \qquad \text{(C.1)}$$

Expressed in a logarithmic form and resolved for the transmitted interferer power leads to the following equation:

$$P_{t\_interferer}^{dBm} = P_{r\_interferer}^{dBm} - 10\log G_t - 10\log G - 20\ log\ \lambda_{interferer} + 20\ log\ R + 22dB \qquad \text{(C.2)}$$

$P_{r\_interferer}$ $(P_{r\_interferer}^{dBm})$: received interferer power at the location of the EUT in watts (in dBm).

$P_{t\_interferer}$ $(P_{t\_interferer}^{dBm})$: transmitted (needed) power (generated by the signal generator) in watts (in dBm).

G : gain of the EUT antenna in the direction of main radiation (main lobe axis).

G_t : gain of the test antenna in the direction of main radiation (main lobe axis).

$\lambda_{interferer}$: wavelength of the interfering signal.

R : distance between EUT and test antenna.

The Friis transmission equation is only valid if far-field conditions are applied in the radiated measurement setups illustrated in Figure 11 and Figure 12. That means the EUT antenna shall be located in the far-field region of the test antenna and vice versa. From ETSI EN 303 883-1 [i.24], clause B.2.3.5 can deduce that the range length (in the test setup illustrated in Figure 11 and Figure 12 the range length is identical to the distance R) between the two antennas shall meet the following condition:

$$R \geq \frac{2(d_1+d_2)^2}{\lambda_{interferer}} \qquad \text{(C.3)}$$

$d_1,\ d_2$: largest dimensions of the physical aperture of the test antenna and the EUT antenna

If this condition cannot be fully met, the uncertainty contributions described in ETSI EN 303 883-1 [i.24], table B.4 could be considered in addition.

Annex D (informative): RCS of Living Objects

List of rcs in [dBm^2] in scenarios with living objects; frequency in [GHz].

Table D.1: List of RCS in scenarios with living objects (RCS dominated by the "human - (parts of)")

	RCS in dBm^2 or in m^2						
Kind of target	**3,4 - 4,8 GHz**	**6 - 8,5 GHz**	**8,5 - 10,5 GHz**	**24 GHz**	**57 - 64/71 GHz**	**76 - 81 GHz**	**> 116 GHz**
Human/adult	-4 dBm^2 to -1,54 dBm^2 [i.14]	-0,71 dBm^2 [i.5]	-0,71 dBm^2 [i.5]	-4,5 dBm^2 [i.1] From -5,5 dBm^2 to -2,2 dBm^2 [i.11]		Average between -5,44 dBm^2 and -7,12 dBm^2 [i.1]	
Human/child				-10 dBm^2 [i.1]		Average -11,4 dBm^2 [i.1]	
Humans/baby					-15 dBm^2		
"hand" (with arm)	Average -17 dBm^2 [i.11]	Average -21 dBm^2 [i.11]	Average -22 dBm^2 and -50 dBm^2 minimum [i.11]		For hand/gesture between -45 dBm^2 and -20 dBm^2 [i.3]	For hand/gesture between -45 dBm^2 and -20 dBm^2 [i.3]	
"foot" and/or "leg"	Average -20 dBm^2 [i.11]	Average -23 dBm^2 [i.11]	Average -23 dBm^2 [i.11]			Average -15 dBm^2 [i.6]	
"face"/"head"							
"chest/thorax" for adult		Between -15 dBm^2 to -4 dBm^2 [i.13]					
"chest/thorax" for baby		Between -22 dBm^2 to -11 dBm^2 [i.12] [i.15]			-20 dBm^2		

Table D.2: List of RCS in vital sign measurement scenarios

	RCS in dBm^2 or in m^2						
Kind of target	**3,4 - 4,8 GHz**	**6 - 8,5 GHz**	**8,5 - 10,5 GHz**	**24 GHz**	**57 - 64/71 GHz**	**76 - 81 GHz**	**> 116 GHz**
Adult "with respiration/heartbeat	-40 dBm^2 [i.2] for heartbeat -30 dBm^2 [i.2] for respiration	-30 dBm^2 [i.2] and [i.4] for heartbeat -10 dBm^2 [i.2] and [i.4] for respiration	-30 dBm^2 [i.2] and [i.4] for heartbeat -10 dBm^2 [i.2] and [i.4] for respiration		Respiration adult: -14 dBm^2 Heartbeat: -50 dBm^2 [i.2]		
Baby/Child Heartbeat/ respiration		Respiration child -18 dBm^2			Respiration child: -20 dBm^2		

Annex E (normative): RCS measurement with 2-port VNA solution

E.1 General

The 2-port RCS assessment procedure is necessary if the EUT has a nonlinear antenna, or the target could generate reflection in different directions (complex targets), see figure 15.

The theory behind: The polarization of the electric field vector of the reflected signal can be different than that of the transmitted signal, see [i.23].

The shape and surface of the target is responsible for the depolarizing characteristics (angular difference $\gamma_t - \gamma_r$) as described in figure E.1. To correct for the depolarization, full polarization matrix imaging is utilized by measuring both the vertical and horizontal components of the electric field independently. This will require two transmit and two receive polarizations (horizontal H and vertical V).

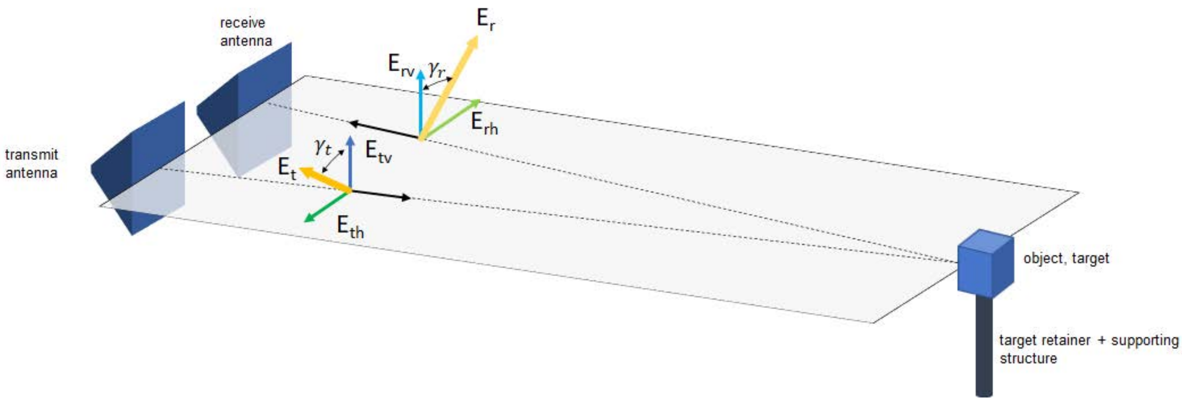


Figure E.1: Consideration of the polarization in the two-port test set-up

Necessary measurements:

Table E.1: RCS of a target in relation to the polarization of the incident transmitting signal

Transmitting Signal	Receiving Signal	
vertical polarization	1. vertical polarization to get the S_{vv} of the RCS	2. horizontal polarization to get the S_{vh} of the RCS
horizontal polarization	3. vertical polarization to get the S_{hv} of the RCS	4. horizontal polarization to get the S_{hh} of the RCS
With: S_{xx} is a complex number defining the 4 possible measurement conditions for S21 (see figure 15).		

From the above measurements a polarization matrix is generated to describe the effect of the polarization to correct for the depolarization.

$$E_t = E_{tv} \times \cos(\gamma_t) + E_{th} \times \sin(\gamma_t) \quad (E.1)$$

$$E_r = E_{rv} \times \cos(\gamma_r) + E_{rh} \times \sin(\gamma_r) \quad (E.2)$$

E_t and E_r are decomposed to:

$$E_{rv} = S_{vv} \times E_{tv} + S_{hv} \times E_{th} \quad (E.3)$$

$$E_{rh} = S_{vh} \times E_{tv} + S_{hh} \times E_{th} \quad (E.4)$$

Based on the complex S_{21} for a RCS assessment based on the two-port measurement could be given as:

$$S_{21} = \begin{matrix} S_{vv} & S_{hv} \\ S_{vh} & S_{hh} \end{matrix} \tag{E.5}$$

E.2 Preparation set-up

E.2.1 Vector Network Analyser (VNA)

Similar to the one-port measurement in clause 7.1 the VNA shown in figure 15 measures the S-parameters in the frequency domain. The VNA shall be able to operate over the OFR of the EUT in the related standard. The time domain function of the VNA will transform the S-parameter frequency domain measurement (S11/S21 vs. frequency) to the time domain (S11/S21 vs. time or distance). In addition, the VNA shall have a time gating function in the time domain measurement.

E.2.2 Test antennas

The antennas shown in figure 15 shall be able to operate over the OFR of the EUT in the related standard and shall have the same kind of polarization than the EUT. If the EUT polarization is not known the RCS of the object/target could be assessed by using linear polarized antennas and assess the RCS two times (turning the antennas by 90 degrees in the horizontal plane), see figure E.1. For the test the transmitting and receiving antenna shall be oriented with the right polarization, see clause E.1.

E.2.3 Test set-up arrangement

The test set-up arrangement is similar to the one-port measurement in clause 7.2.3. The only complicating point is that both antenna patterns need to be considered for positioning the target, see figure E.2.

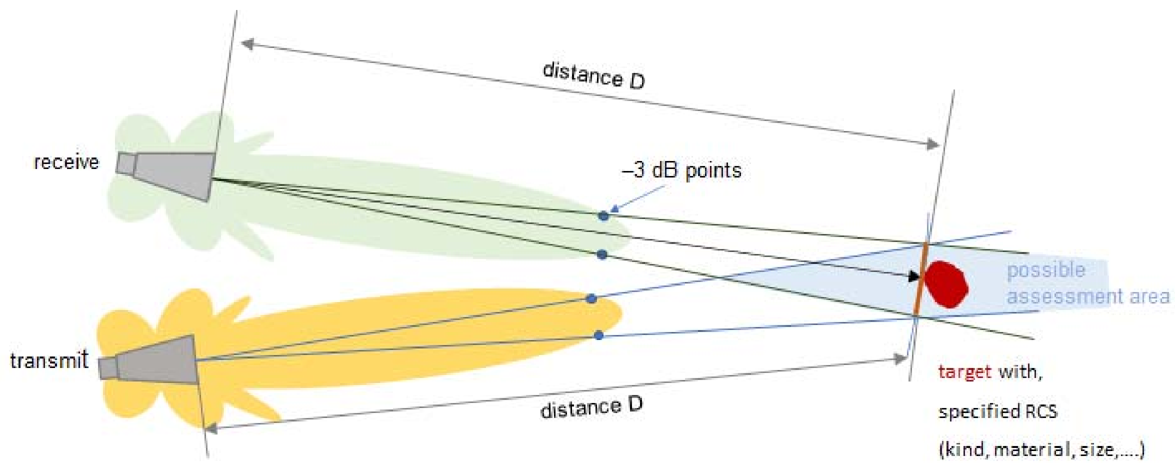


Figure E.2: Arrangement of the measurement target in front of the measurement antenna (two-port test set-up)

E.3 RCS assessment

E.3.1 Antenna System Calibration

The Antenna System Calibration would be the same as for the one-port measurement in clause 7.3.1.

E.3.2 Measurement cases

E.3.2.1 General

For the measurement cases it needs to be considered if:

- the target retainer + supporting structure; or
- the calibration standard target has a depolarization effect as well.

E.3.2.2 Case: linear polarized incident transmitting signal/target with depolarization effect

The RCS assessment for a target if the incident transmitting signal is linear polarized and the target itself has a depolarization effect, the assessment could be reduced to the two following cases, see table E.2.

Table E.2: Assessment cases for a linear polarized incident transmitting signal and a target with depolarization effects

Transmitting Signal	Receiving Signal	
linear polarization	1. vertical polarization to get the S_{lv} of the RCS	2. horizontal polarization to get the S_{lh} of the RCS
With: S_{xx} is a complex number defining the 4 possible measurement conditions for S21 (see figure 15).		

E.3.2.3 Case: incident transmitting signal with two polarization/target with no depolarization effect

The RCS assessment for a target if the incident transmitting signal has two polarizations and the target itself has no depolarization effect, the assessment could be reduced to the following two cases, see table E.3.

Table E.3: Assessment cases for a dual polarized incident transmitting signal and a target with no depolarization effects

Transmitting Signal	Receiving Signal
vertical polarization	1. vertical polarization to get the S_{vv} of the RCS
horizontal polarization	2. vertical polarization to get the S_{hh} of the RCS
With: S_{xx} is a complex number defining the 4 possible measurement conditions for S21 (see figure 15).	

E.3.2.4 Case: incident transmitting signal with two polarization/target with depolarization effect

The RCS assessment for a target if the incident transmitting signal has two polarizations and the target itself has a depolarization effect, the assessment has to consider four cases, see table E.1.

E.3.3 RCS assessment procedure

For the RCS assessment use the following steps:

Step 1: Run a 12-term calibration of the VNA (including the necessary cables), see figure 13.

Step 2: Connect port 1 of the VNA to the transmit antenna and port 2 to the corresponding receive antenna. The polarization shall be known and adjusted, and considered as described in clause E.1.

Step 3: Assess the measurement distance (see clause 7.2.3) and area (see figure E.2).

Step 4: Assess the relevant case as specified in clause E.3.2.

Now all steps need to be repeated in the combination (orientation) depending on the case identified in step 4.

Step 5: Measure the RCS of the target retainer + supporting structure and store the data ($S21_{trss}$):

Sub-Step 5.0: Assess the depolarization effect of the target retainer + supporting structure.

NOTE 1: If not known measure all necessary combinations, see clause E.3.2.2 or clause E.3.2.4.

Sub-Step 5.1: Set-up in frequency domain the frequency range over which the RCS shall be measured.

Sub-Step 5.2: Switch to time domain function and measure within the time domain mode of the VNA, for an example see figure 20.

Sub-Step 5.3: Place a time gate centred at the highest peak (at the distance D) to the target and set time gate width greater than the observed "size" of the target in time domain, for an example see figure 21.

Sub-Step 5.4: Step back to the frequency domain.

Sub-Step 5.5: Read out S21 [dB] over the measured range and store the data ($S21_{trss}$), for an example see figure 22.

Sub-Step 5.6: Calculate the RCS based on equation (24):

$$\mathrm{rcs_{trss}}\ [dBm^2] = \mathrm{S21_{trss}}[\mathrm{dB}] - 2 \times g[dB] - 20\log\lambda + 40\log D + 33dB \quad \text{(E.6)}$$

Step 6: Measure now the target together with the target retainer + supporting structure and store the data as well ($S21_{target}$). Consider the right orientation of the target based on the identified case (step 4):

Sub-Step 6.1: Set-up in frequency domain the frequency range over which the RCS shall be measured.

Sub-Step 6.2: Switch to time domain function and measure within the time domain mode of the VNA, for an example see figure 20.

Sub-Step 6.3: Place a time gate centred at the highest peak (at the distance D) to the target and set time gate width greater than the observed "size" of the target in time domain, for an example see figure 21.

Sub-Step 6.4: Step back to the frequency domain.

Sub-Step 6.5: Read out S21 [dB] over the measured range and store the data ($S21_{target}$), for an example see figure 22.

Sub-Step 6.6: Calculate the RCS based on equation (24):

$$\mathrm{rcs_{target}}\ [\mathrm{dBm^2}] = \mathrm{S21_{target}}[\mathrm{dB}] - 2 \times \mathrm{g}[\mathrm{dB}] - 20\log\lambda + 40\log\mathrm{D} + 33\mathrm{dB} \quad \text{(E.7)}$$

Step 7: Check if the measured RCS value of the target retainer + supporting structure in sub-step 5.5 is at least 20 dB lower than that of the estimated target rcs in sub-step 6.5, see clause E.3.3.

Step 8: Measure the calibration standard target (as specified in the related standard, see clause 7.3.1):

Sub-Step 8.0: Assess the depolarization effect of calibration standard target.

NOTE 2: If not known measure all necessary combinations, see clause E.3.2.2 or clause E.3.2.4.

Sub-Step 8.1: Set-up in frequency domain the frequency range over which the RCS shall be measured.

Sub-Step 8.2: Switch to time domain function and measure within the time domain mode of the VNA, for an example see figure 20.

Sub-Step 8.3: Place a time gate centred at the highest peak (at the distance (D)) to the target and set a time gate width greater than the observed "size" of the target in time domain, for an example see figure 21.

Sub-Step 8.4: Step back to the frequency domain.

Sub-Step 8.5: Read out S21 [dB] over the measured frequency range and store the data ($S11_{cal}$), for an example see figure 22.

Sub-Step 8.6: Calculate the RCS based on equation (24):

$$\mathrm{rcs}_{\mathrm{cal,measured}}\,[\mathrm{dBm}^2] = \mathrm{S21}_{\mathrm{cal}}[\mathrm{dB}] - 2 \times \mathrm{g}[\mathrm{dB}] - 20\log\lambda + 40\log\mathrm{D} + 33\mathrm{dB} \qquad \text{(E.8)}$$

In addition, the RCS of the used calibration standard target could be calculated based on the theoretical equations (mechanical dimensions; $RCS_{cal,theoretical}$), see Annex A or could be taken from the corresponding datasheet.

Step 9: The corrected RCS of the target could now be calculated using the VNA trace math following derivation from the Radar equation.

$$RCS_{target,corrected}[m^2] = RCS_{cal,theoretical}[m^2] \times 10^{\left(\frac{S21_{target}[\mathrm{dB}] - S21_{cal,measured}[dB]}{10}\right)} \qquad \text{(E.9)}$$

or could be calculated based on the already calculated RCS and measured S21 values

$$rcs_{target,corrected}\,[dBm^2] = rcs_{cal,theoretical}\,[dBm^2] + S21_{target}[dB] - S21_{cal,measured}[dB] \qquad \text{(E.10)}$$

Step 10: Note the RCS based on the assessed orientation/polarization case, as identified in step 4.

Final Step: After measuring "all" combinations/cases and calculate the RCS as in equation (E.5).

Annex F (informative): possible technical solutions for target in Set-up 2 with fixed RCS

Figure F.1 provides an example to realize a rotating target with a fixed specified RCS to the EUT.

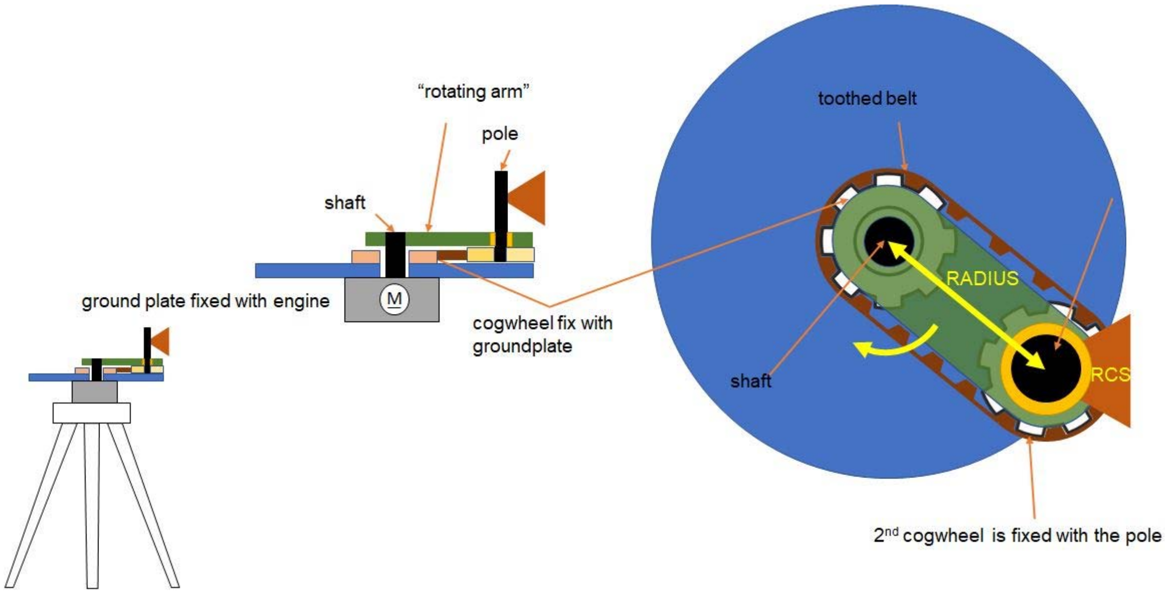


Figure F.1: Proposal for a mechanical solution to create a target which has a constant RCS to the EUT but provides a small movement (doppler) in the distance

Annex G (informative): Example for clause 6 set-ups

G.1 Example for clause 6.5 set-up; RX conformance test for Child Presence Detection applications in vehicles

This annex provides an example how the content of the related standard would be used for defining a receiver conformance test setup for UWB sensors of "Child Presence Detection" (CPD) applications in vehicles.

"Child Presence Detection" (CPD) aims to detect scenarios where babies or children are left (unintentionally) in the cabin after locking the car, in order to inform or alarm the user.

UWB sensors - operating in a monostatic radar mode - can greatly support this CPD function as they can detect characteristic signals of living objects (like breathing or heartbeat) and therefore work successfully in scenarios where other technologies may fail (e.g. sleeping baby covered by blanket, which is not detected by cameras).

For the scope of a standard conformance test the **UWB sensor is the Equipment Under Test** (EUT) and the **intended use is the detection and classification of characteristic signals from living objects**.

The final decision about alarming the user may involve additional sensors (further UWB sensors, camera, etc.) as well as sensor fusion techniques, residing in different control units, and is therefore out of scope for the EUT conformance test.

The following steps sketch the approach how a conformance test setup for receiver tests could be defined, using guidance from the related document and how wanted performance criteria and limits would be derived.

Table G.1

Approach	*Examples for CPD use case*
1. Selection of test setup from ETSI TS 103 789 (the present document), which represents the intended use	*Set-up 3 in clause 6.5; constant RCS to the EUT with small movement.* *Represents breathing of a child*
2. Definition of target parameters (material, RCS, movement) related to selected test setup	*Target = metallic corner reflector* rcs_T*=-18 dBm² (see table D.2, frequency range 6 - 8,5 GHz)* *Periodic input signal: sinewave.* *Motion frequency* v_T*= 0,5 Hz, amplitude* ΔD_T*= 3 mm*
3. Definition of "detection": Figure of merit that is observable at the EUT output during the conformance test (detection parameters like motion frequency, or decision on presence of target motion). EUT output has to be made available to the test house with an interface/test jig provided by the manufacturer (e.g. converting EUT CAN bus data into a binary decision signal; no specific test mode!)	*Figure of merit: detect characteristic target motion* *EUT output: motion with frequency below 2 Hz present (yes/no)*
4. Definition of (max.) observation time and (min.) EUT decision update rate	*max. observation time = min.* *EUT decision update rate = 10 s*
5. Definition of what is a "correct detection" and related acceptance criteria (Success Rate/False Alarm Rate (FAR)) for the RX conformance tests	*Definition: A "correct detection" is indicated, if the EUT decides "motion present: yes" for a target with motion frequency < 2 Hz.* *The ratio of "correct detections" to the total number of EUT decisions is called "Success Rate"* *Definition: A "false alarm" is indicated, if the EUT decides for "motion present: yes" without target or for a target with motion frequency > 2 Hz.* *The ratio of "false alarms" to the total number of EUT decisions is called "False Alarm Rate (FAR)".* *Success Rate and False Alarm Rate has to be derived from (at least) 20 EUT decisions* *Acceptance criteria:* *FAR (no target) < 1 %* *FAR (target present, motion frequency = 5 Hz) < 1 %* *Success rate (target present, motion frequency = 0,5 Hz) > 90 %*
6. Definition of distance D_{wp} that is minimum required for the intended use	*CPD requires an assessment distance of min. 2 m:* $D_{wp} = 2\ m$
7. Show justification why target, setup, acceptance criteria and limits ensure minimum performance for the intended use	*Detecting shallow breathing is the most difficult task for the UWB sensor; shallow breathing converts to motion with low frequency - spectral components typically below 2 Hz - and small amplitude* *The distance limit* D_{wp} *ensures that a UWB sensor is able to detect breathing within the vehicle cabin, which is a basic feature for Child Presence Detection*
8. Apply RCS scaling, if appropriate, to derive the distance D_{conf} for the conformance test	*RCS scaling according to clause 4.1.4* *measurement distance should be between 2 m and 4 m* *Scaling only applicable, if* D_{conf} *is within the operating range of the EUT*

G.2 Example for clause 6.6 set-up; RX conformance test for Intrusion detection applications

This annex provides an example how the content of the related document would be used for defining a receiver conformance test setup for sensors of Intrusion Detection applications for alarm systems.

Wanted technical performance criteria and considered use-case:

The use-case covers the detection of persons within an "observation" area to trigger an alarm with an intrusion/alarm system, see figure G.1.

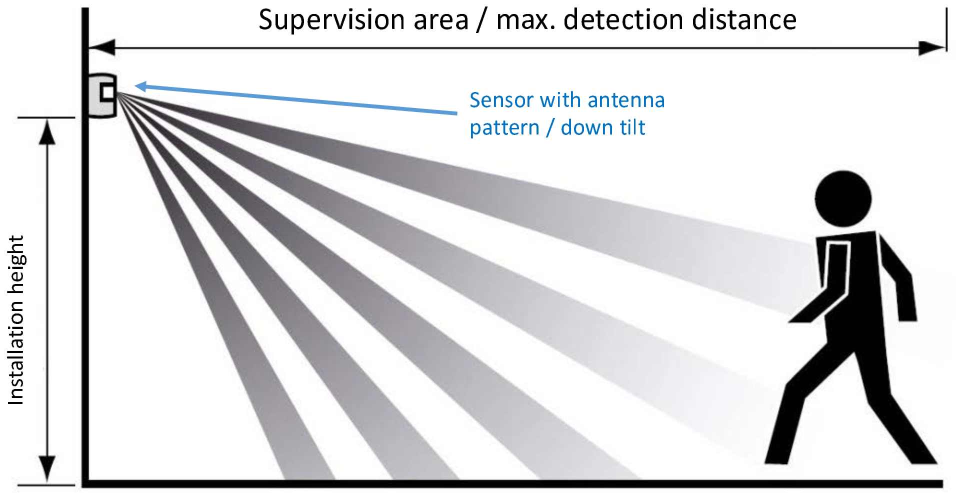


Figure G.1: Principal figure for a intrusion detection application

There are lot of similar use-cases but the "wanted technical performance" could be different. There could be a need to differentiate between:

- Detection range
- Professional or non-professional system
- In cooperation into an alarm system
- Simple movement sensor to activate e.g. lights, etc.

For this example, assessment of the wanted technical performance for a device which is able to operate as part of an alarm system.

For an alarm system and the integrated intrusion and hold-up function there is an application specific EN family specified by CENELEC; CLC/TC 79 - Alarm systems.

- EN 50131-1 [i.25]; Alarm systems - Intrusion and hold-up systems

For the radio parts in such system are two specific sub-parts:

- EN 50131-2-3 [i.26]: Intrusion detectors - Microwave detectors
- EN 50131-2-4 [i.27]: Intrusion detectors - Combined passive infrared/Microwave detectors

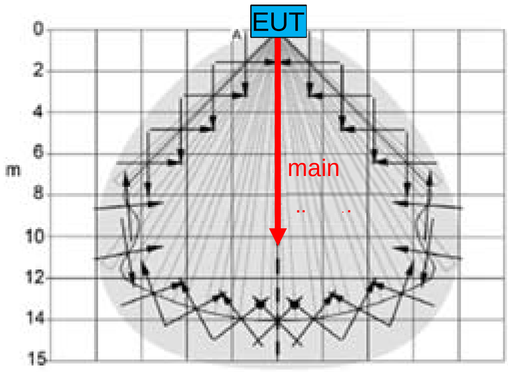
For such intrusion sensor incorporated into an alarm system (covered under EN 50131 [i.25]) it is proposed to use the following object for the receiver test:

Within the EN 50131-1 [i.25] a "real" human as object is specified:

- See clause 6.2.5.1 General

And the test is descripted in the following way:

- the "test person" has to have the physical dimensions of 1,60 m to 1,85 m in height, and a weigh of 70 kg ± 10 kg. The "test person" wear close-fitting clothing during the test with a recommended emissivity of at least 80 % between 8 µm and 14 µm wavelength. Any kind of metallic objects worn or carried by the "test person" must be avoided or incorrect microwave reflection will adulterate the measurement results; and
- the detections test has to be made at several points and direction, see walking matrix in Annex B and Annex C of EN 50131-2-4 [i.27], see figure G.2;
- the detection probability of the "test person" during the test has to be in minimum of 95 % of the test cycles (measurement cycles) of the EUT.



a) Detection across the claimed detection boundary for detectors with a coverage angle less than or equal to 180° (6.4.3.2)

Figure G.2: Walking test diagram for devices under EN 50131-2-4 [i.27] Annex C and main direction of the EUT in the horizontal plane

Based on the assessment of the application requirements for such EN 50131-2-4 [i.27] it is proposed to use set-up 4 in clause 6.6, linear movement and the linear movement has to be in the "main" direction of the EUT see figure G.2.

For the movement of the target, the proposed parameters are based on EN 50131-2-4 [i.27]. The parameters for the movement of the target therefore are as follows:

- target is moving with a speed of 0,7 m/s moving towards the EUT;
- and the delta in distance, travel distance of 1 m (from "far" to "close");
- the starting distance will be fixed in the related standard/use-case sub-category (detection range (e.g. short or long range). The specified distance could also be different based on the used regulation/possible usable transmit power).

Based on the specified human in EN 50131, see above, the specification is not as specific as and "clear" as requested for an ETSI EN. Therefore, literature on RCS of humans was assessed, see summary overview in Annex D.

And in addition, for the height of the target for the test the "largest" test person in EN 50131-2-4 [i.27] will be considered (1,85 m). Therefore, the centre of the target is placed at a height which is equal in the middle of the specified test person (1,85 m height) which will be 0,925 m.

For this example: EUT operating within the range 6 - 10,6 GHz.

And based on Annex D a triple mirror with a RCS of 0,85 m^2 for EUT operating in the range 6 - 10,6 GHz is used.

For the related standard there is a need to specify in addition the measurement uncertainty, therefore an uncertainty for the rcs of ±2 dB is proposed (see clause 6.7).

Summary

- Considered Operating Frequency Range (OFR): within 6 - 10,6 GHz.
- For depending permitted range and related regulation (+ TX-power, etc.), see related EN.
- Target: RCS of 0,85 m^2; rcs: -0,71 dBm^2, mechanical dimension of a triple mirror, see clause A.1.1.
- Linear movement to EUT: with 0,7 m/s and 1 m delta in distance (ETSI TS 103 789, clause 6.6) in the main measurement direction of the EUT.
- Installation height of the target over ground: 0,925 m.
- Starting distance (maximum detection distance): see related EN (e.g. specification of sub-categories, like short range, mid-range, long range).
- Wanted technical performance: 95 % detection probability. The related standard has to specify the number of test repetitions.

Annex H (informative): Bibliography

- For information from company SPEAG on their OTA PHANTOMS. Link (11/2022): OVERVIEW » SPEAG, Schmid & Partner Engineering AG.
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- Novel Heart Rate Detection Method Using UWB Impulse Radar; Hui-Sup Cho & Young-Jin Park Hong-Kun Lyu1 & Jin-Ho Cho; Springer Science+Business Media New York 2016; Published online: 3 September 2016.
- On Indoor Human Sensing Using Commodity Radar; On Indoor Human Sensing Using Commodity Radar | Proceedings of the 2018, International Joint Conference and 2018 International Symposium on Pervasive and Ubiquitous Computing and Wearable Computers.
- ETSI contribution: ERMTGUWB(21)059028_Proposal_for_EN_305_550-4_and_TS_103_789_for_use-case_incabin.
- ETSI contribution: ERMTG28(21)060005_Robert_Bosch_contribution_for_EN_300_440-3_work.
- ETSI contribution: ERMTGUWB(20)0RT002_Suggested_additional_methods_for_measuring_the_sensitivity_of_Radio Determination Devices.
- ETSI contribution: ERMTGUWB(20)RT2008_Rotating_sphere_for_human_RCS_simulation.
- ETSI contribution: ERMTGUWB(20)RT2010_Lit_Reference-Doc.
- ETSI contribution: ERMTGUWB(20)RT2004_Lit_ArticlePDF_Available_Polarimetric_Radar_Cross-Sections_of pedestrians at automotive radar frequencies.
- Report by QinetiQ: "Performance Investigation of Marine Radar Reflectors on the Market", from Marine Accident Investigation Branch - GOV.UK (www.gov.uk) Radar Detection of Spherical Targets, Martin L. Shough* NARCAP Research Associate (United Kingdom)© 2009.

Annex I (informative): Change History

Date	Version	Information about changes
December 2020	1.1.1_0.0.1	Initial draft
January 2021	1.1.1_0.0.2	With notes from TGUWB#57
May 2021	1.1.1_0.0.3	New draft based on discussions during TG UWB#58
December 2021	1.1.1_0.0.4	New working draft
December 2021	1.1.1_0.0.5	New working draft; outcome rapporteur meeting 7th December 2021
February 2022	1.1.1_0.0.6	Comments during TGUWB#60 + new content based on TGUWB#60 discussions
March 2022	1.1.1_0.0.7	New clause 7 "RCS assessment"
March 2022	1.1.1_0.0.8	Implementing received comments during TGUWB#60 + additional editorials based on editor notes
March 2022	1.1.1_0.0.9	New version
April 2022	1.1.1_0.0.10	Version 0.0.10 outcome rapporteur meeting
April 2022	1.1.1_0.0.11	Clean version based on 0.0.10 + editorial amendments (target and dBm^2 all over the document)
April 2022	1.1.1_0.0.12	Update Figure 1, 2, 7, 8, 9, 10, 12, 14 and 16
May 2022	1.1.1_0.0.13	revision Annex A.1 with subclauses to allow reference to a specific mechanical target + transfer human target info into a new Annex D + outcome rapporteurs meeting @ 30th of June
July 2022	1.1.1_0.0.14	Change of the title based on changed WI + transfer two-Port RCS assessment to a new Annex (Annex E) + add text for one-Port RCS assessment test procedure + include all changes/proposal from ERMTGUWB(22)000022 + add text to assess a RCS of an equivalent target based on material parameter
July 2022	1.1.1_0.0.15	Clean version of 0.0.14 + corrections in formatting, + adding equation numbers and figure titles Deletion of still solved comments (until 0.0.13 version)
August 2022	1.1.1_0.0.16	Outcome Rapporteur Meeting 31st of August
August 2022	1.1.1_0.0.17	Revised document based on tasks for rapporteur from meeting 31st of August
September 2022	1.1.1_0.0.18	Revised document based on discussions during rapporteur meeting#6 14th of September
October 2022	1.1.1_0.0.19	Updated draft
November 2022	1.1.1_0.0.20	Editorial revision of figures 7, 8, 11 and 13 and editorial work in Annex E
November 2022	1.1.1_0.1.0	Outcome rapporteur meeting#7 (18th November)
November 2022	1.1.1_0.1.1	Some editorial corrections in Annex B and C + adding contribution RT8001 + update Bibliography
December 2022	1.1.1_0.1.2	Some editorial and grammatical corrections provided by Bosch
December 2022	1.1.1_0.1.3	Outcome rapporteur meeting#8
January 2023	1.1.1_0.1.4	editHelp clean-up
February 2023	1.1.1_0.1.5	Some editorial corrections + adding new clause G.2
February 2023	1.1.1_1.0.0	Clean and approved version during TGUWB#63

History

Document history		
V1.1.1	May 2023	Publication