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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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Keywords

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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.8] Application Note; ANRITSU: "Measurement of Radar Cross-Section Using the "VNA Master" Handheld VNA".

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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 [m²]
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).

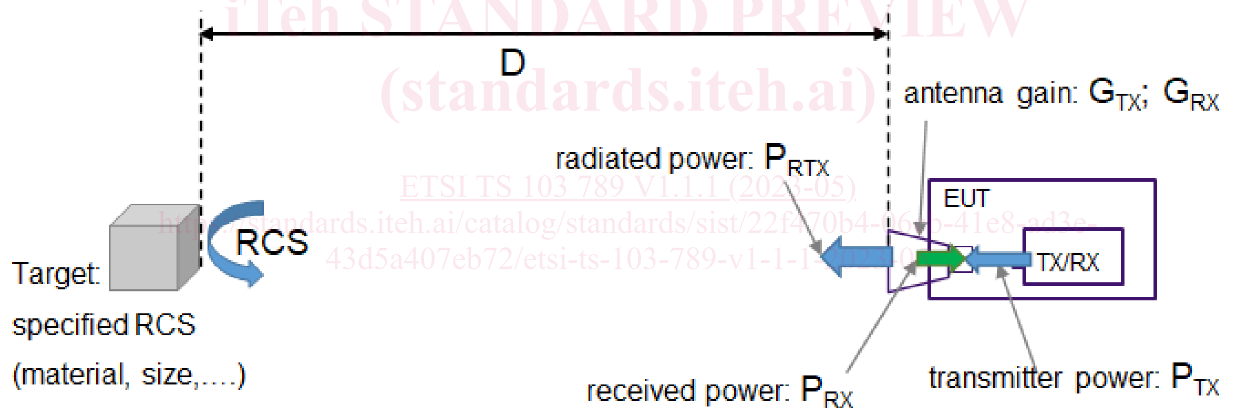

Figure 1: Scenario to show connection between RCS, Distance (D) and Power

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

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

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):

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

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)).

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

with the considerations of:

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

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

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

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

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

With the consideration of:

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

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

with a final consideration of:

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

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

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

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.

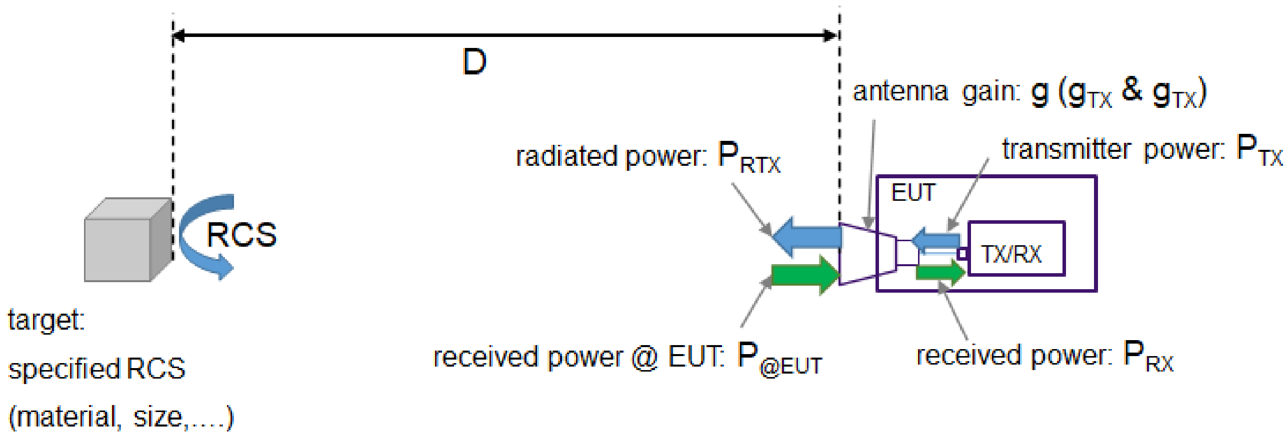

Figure 2: Scenario to show connection between RCS, Distance (D) and Power@EUT

and considering that:

- $P_{\mathrm{RTX}}[\mathrm{dBm}] = P_{TX}[\mathrm{dBm}] + g_{TX}$; 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:

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

For the sensitivity case:

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

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.

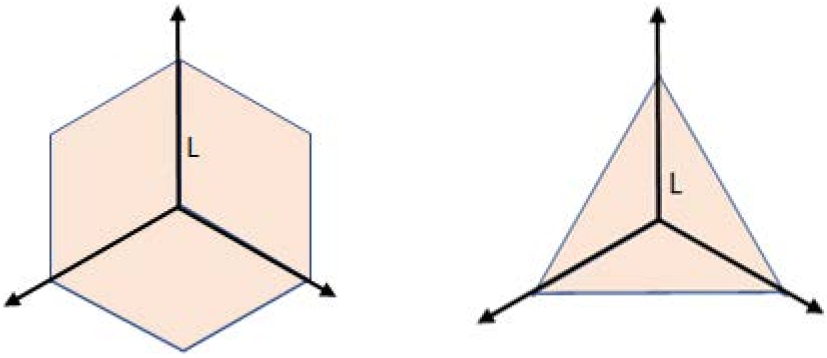

**Figure 3: Different corner reflectors
(left-hand side: trihedral square shaped, right-hand side: trihedral triangular shaped)**

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.

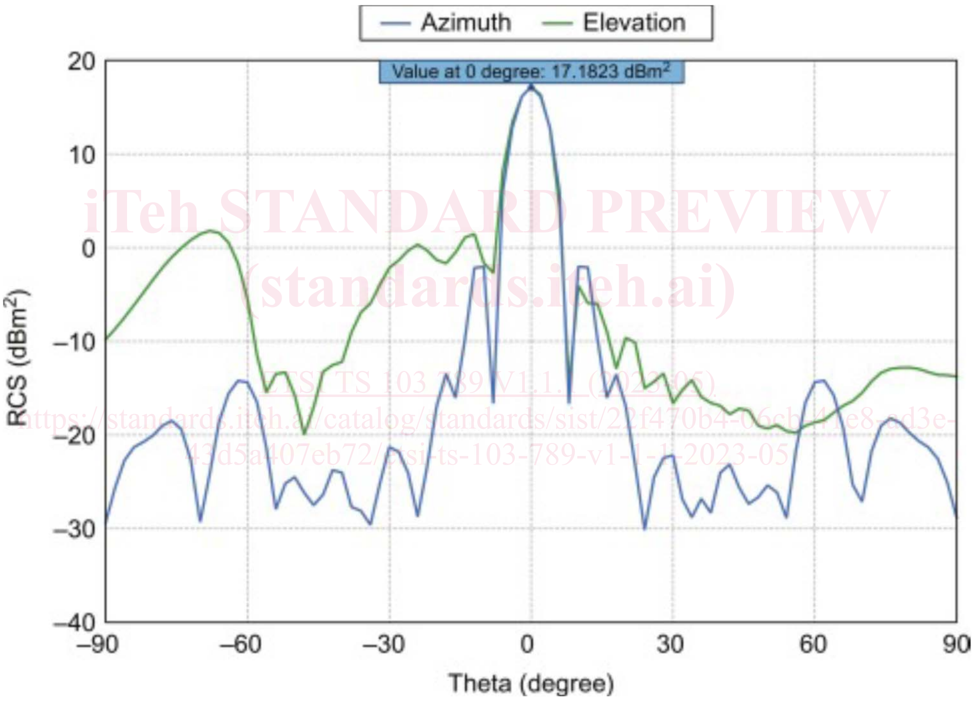

Figure 4: General Radiation pattern for a trihedral triangular shaped corner reflector

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].