ETSI GS RIS 008 V1.1.1 (2026-02)

GROUP SPECIFICATION

Reconfigurable Intelligent Surfaces (RIS); Standardized Testing Test Standards for Reconfigurable Intelligent Surfaces

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Foreword

This Group Specification (GS) has been produced by ETSI Industry Specification Group (ISG) Reconfigurable Intelligent Surfaces (RIS).

Modal verbs terminology

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Executive summary

The present document from ETSI ISG RIS provides a framework for assessing the performance of Reconfigurable Intelligent Surfaces (RIS) against an initial set of defined characteristics and measurable parameters.

Introduction

Reconfigurable Intelligent Surfaces (RIS) are considered a foundational technology in future communication systems. They offer significant potential to enhance signal control, coverage, energy efficiency, and overall network efficiency and performance.

To ensure the effective deployment and integration of RIS in real-world scenarios, standardized and comparable approaches to quantifying RIS behaviour parameters are needed. These parameters will allow RIS end-users to compare how the RIS performs against each other in a defined measurement context early on.

The present document objective is to define standardized testing procedures and relevant RIS parameters. It selects parameters and defines how to measure them, enabling assessment of RIS performance. Standardized testing is critical to guaranteeing that displayed results are consistent, reliable, comparable, and aligned with industry norms.

It is important to understand that, given the diversity of RIS solutions, many other parameters may also be critical for the ultimate performance and functioning of a RIS. However, these other parameters are outside the scope of the present document.

As RIS technology becomes a vital component in shaping future communication systems, including sixth-generation (6G) networks, reliable methods to assess and characterize RIS performance become increasingly important.

1 Scope

The present document defines test methods and relevant RIS characteristics and parameters to be measured by the methods to capture RIS functionality and performance.

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.

Referenced documents which are not found to be publicly available in the expected location might be found in the ETSI docbox.

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

[1] ETSI TS 103 789 (V1.1.1): "Short Range Devices (SRD) and Ultra Wide Band (UWB); Radar related parameters and physical test setup for object detection, identification and RCS measurement".

[2] 3GPP TS 38.141-2 (V19.0.0): "NR; Base Station (BS) conformance testing Part 2: Radiated conformance testing".

[3] ETSI TS 138 104: "5G; NR; Base Station (BS) radio transmission and reception (3GPP TS 38.104)".

2.2 Informative references

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[i.1] Yu A., Yang F., Elsherbeni A.Z., Huang J. and Rahmat-Samii Y.: "Aperture efficiency analysis of reflectarray antennas", in Microw. Opt. Technol. Lett., 52: 364-372., 2010.

[i.2] F. T. Bette, T. M. Gemmer, S. v. Wnuck-Lipinski, H. Bartko, B. Derat, S. Otto, M. Willemsen und W. Keusgen: "Monostatic Measurement Setup and Transformation Method to Obtain Bistatic Reflection Patterns of Reconfigurable Intelligent Surfaces", in Antenna Measurement Techniques Association Symposium (AMTA), 2024.

[i.3] ETSI, TP to DGS RIS 008 on Test Methodology for Bistatic Measurement Setup, RIS(25)019008, 2025.

[i.4] F. T. Bette, O. Kasap, T. M. Gemmer, F. X. Muhr, F. X. Röhrl, H. Bartko, B. Derat and W. Keusgen: "Extension of Falconer's Monostatic to Bistatic Equivalence Theorem with Respect to Reconfigurable Intelligent Surface Testing" Accepted for AP-S/URSI 2025 conference.

[i.5] F. T. Bette, O. Kasap, T. M. Gemmer, H. Bartko, B. Derat and W. Keusgen: "Monostatic to Bistatic Equivalence Theorem for 2-Dimensional Reflection Pattern Measurements of Reconfigurable Intelligent Surfaces", 2025.

[i.6] A. Díaz-Rubio, S. Kosulnikov and S. A. Tretyakov: "On the Integration of Reconfigurable Intelligent Surfaces in Real-World Environments: A Convenient Approach for Estimation Reflection and Transmission", in IEEE Antennas and Propagation Magazine, vol. 64, no. 4, pp. 85-95, August 2022.

[i.7] R. Liu, J. Dou, P. Li, J. Wu and Y. Cui: "Simulation and Field Trial Results of Reconfigurable Intelligent Surfaces in 5G Networks," in IEEE™ Access, vol. 10, pp. 122786-122795, 2022.

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

RIS Parameters: parameters from the RIS that can be measured

3.2 Symbols

Void.

3.3 Abbreviations

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

2D	Two Dimensional
3D	Three Dimensional
3GPP	3G (mobile) Partnership Project
5G	Fifth generation cellular network
6G	The Sixth Generation
CATR	Compact Antenna Test Range
CW	Continuous Wave
DFF	Direct Far Field
DUT	Device Under Test
EVM	Error Vector Magnitude
GS	Group Specification
IFBW	Intermediate Frequency BandWidth
IFF	Indirect Far Field
ISG	Industry Specification Group
LoS	Line-of-Sight
MBET	Monostatic-to-Bistatic-Equivalent Theorem
NF	Near Field
NR	New Radio
OTA	Over-The-Air
QAM	Quadrature Amplitude Modulation
QZ	Quiet Zone
RCS	Radar Cross Section
RF	Radio Frequencies
RIS	Reconfigurable Intelligent Surfaces
SLL	SideLobe Level
SNR	Signal-to-Noise Ratio
TS	ETSI Technical Specification
UE	User Equipment
VNA	Vector Network Analyser
VSA	Vector Signal Analyser

VSG	Vector Signal Generator

4 Selection of RIS Parameters

4.0 General

The list of selected RIS parameters is not meant to be exhaustive. These parameters are introduced and defined in clause 4 so that measurement methodologies can be introduced in clause 5. To evaluate RIS performance in practical networks comprehensively, system-level trials such as the ones in [i.7] are beneficial.

4.1 RIS Operating Frequency Range

The operating frequency range refers to the range of frequencies over which the RIS is designed to perform its intended function. The RIS vendor may specify a specific range in terms of [Hz], e.g. 1,8 GHz to 2,0 GHz, or refer to standardized frequency bands, e.g. 3GPP NR frequency bands (e.g. band n81) or ITU frequency band allocations (e.g. C-band).

4.2 RIS Maximum Operating Bandwidth

The maximum instantaneous bandwidth over which the RIS surface can operate with no unintended harm to the impinging signals quality according to clause 4.6. In other words, it defines the maximum allowed continuous bandwidth of an impinging modulated signal, e.g. a 3GPP 5G NR signal.

4.3 Radar Cross Section

4.3.0 General

The RIS' surface characteristic to reflect/ refract radio waves at a given cross-section. RIS surface is configured to give an expected 'radiated angle' azimuth θn (degrees) and elevation ϕn (degrees). A uniform plane wave of known power (dBm) is incident onto the RIS surface at a given 'incident angle' of (θ_i, ϕ_i)(degrees).

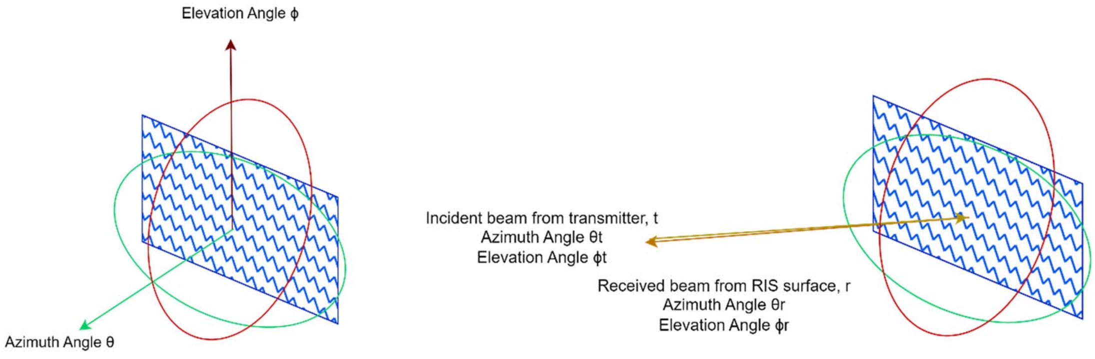


Figure 4.3.0-1

Measure the total radiated power (dBm) sent towards the receiver from the whole RIS surface. Calculate the RCS (dBm^2) as relative power received (dB) across the RIS surface (m^2).

For an expected 'radiated angle' angle' θn and ϕn (degrees), the 'total power' from the radiating surface is measured at the receiver whilst it is moved across a hemispherical plane (e.g. azimuth or elevation plane) angle θ_r, ϕ_r (degrees).

The transmitter source and receiver are co-located, such that θ_i, ϕ_i are equal to θ_r, ϕ_r respectively.

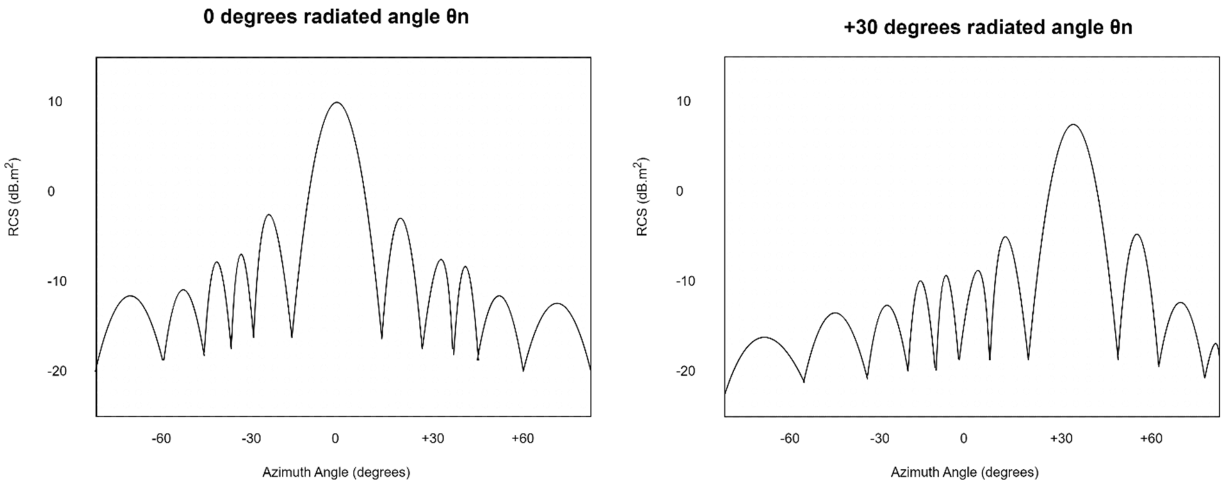


Figure 4.3.0-2

4.3.1 Background for RCS measurement

The measurement of RCS is used to evaluate a RIS' surface characteristic to reflect/ refract radio waves at a given cross-section. The RIS surface is configured to give an expected 'radiated angle' azimuth θn (degrees) and elevation ϕn (degrees), using the coordinate system given in Figure 4.3.1-1. A uniform plane wave of known power (dBm) is incident onto the RIS surface at a given 'incident angle' of θ_i, ϕ_i (degrees).

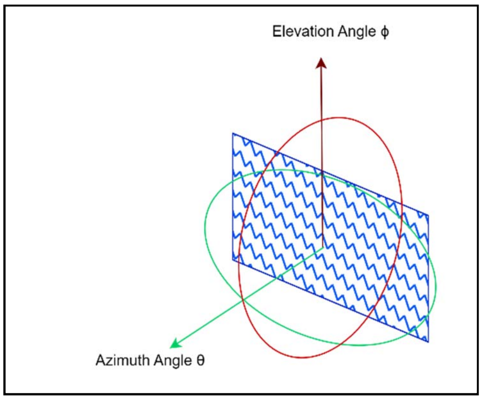


Figure 4.3.1-1: RCS coordinate system

Measure the total radiated power (dBm) sent towards the receiver from the whole RIS surface. Calculate the RCS (dBm^2) as relative power received (dB) across the RIS surface (m^2). For an expected 'radiated angle' angle' θn and ϕn (degrees) configured for the RIS, the 'total power' from the radiating surface is measured at the receiver whilst it is moved across a hemispherical plane (e.g. azimuth or elevation plane) of 'received angle' θ_r, ϕ_r (degrees). In a monostatic configuration, the transmitter source and receiver are collocated, such that θ_i, ϕ_i are equal to θ_r, ϕ_r, respectively, as given in Figure 4.3.1-2. In a bistatic configuration, the transmitter source and receiver are independently located, such that θ_i, ϕ_i are different from θ_r, ϕ_r, respectively, as given in Figure 4.3.1-3.

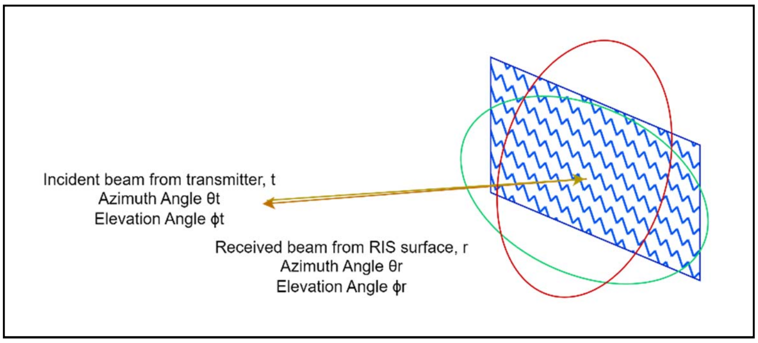


Figure 4.3.1-2: Monostatic RCS measurement

Suitable measurement methods for RCS have previously been defined by ETSI TS 103 789 [1]. The methodology given is based on a mono-static configuration, and the measurement set-up described (including implementation with 2 2-port VNA) is based on a mono-static configuration (and a mono-static VNA). For the application to RIS, the configuration is generically defined to be bi-static, as the mono-static use case for the RIS surface to reflect signals back to the transmitter is not considered a specific use case. So, the following text describes an extension of the established RCS test methodology described in ETSI TS 103 789 [1] from mono-static to bi-static use cases to align with ETSI ISG RIS use cases, and the corresponding implementation using a bi-static VNA.

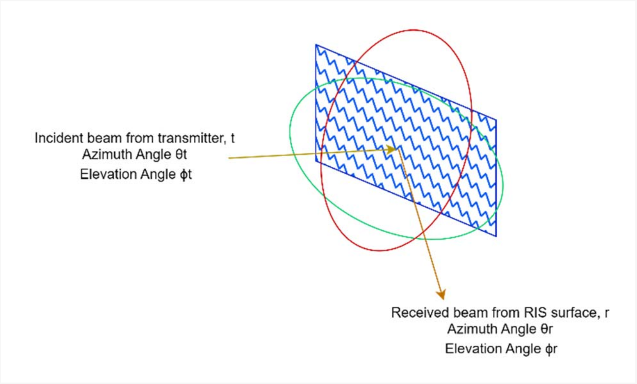


Figure 4.3.1-3: Bi-static RCS measurement

The bistatic RCS can be used to characterize the Peak Reflected/Refracted Power (PRRP) from a reflective RIS in the direction of the receiver, and it is independent of the distance terms. It is not possible to obtain the exact measurement of the bistatic RCS, but it can be estimated with the following procedure:

1) Consider a reflective RIS illuminated by a transmitter at a distance d_{Tx-RIS} and observed by a receiver at a distance d_{RIS-Rx}. The incident power density $S_{inc}(\theta_i)$ at the RIS surface area is defined as:

$$S_{inc}(\theta_i) = P_{Tx} + G_{Tx} - L_{Tx} + 10\log_{10}\left(\frac{1}{4\pi\, d_{Tx-RIS}^2}\right) + 10\log_{10}(\theta_i)$$

where P_{Tx} is the transmit power, G_{Tx} is the transmitter antenna gain, L_{Tx} is the loss factor for the transmitter, and θ_i is the polar incidence angle (measured from the surface normal of a RIS).

2) Similarly, the measured PRRP from the RIS is defined in the direction of the programmed anomalous reflection (θ_r, ϕ_r) as:

$$PRRP(\theta_r, \phi_r) = P_{Rx}(\theta_r, \phi_r) - G_{Rx} + L_{Rx} - 20\log_{10}\left(\frac{\lambda}{4\pi\, d_{RIS-Rx}}\right)$$

where P_{Rx} is the received power at the VNA port for RIS configured at (θ_r, ϕ_r), G_{Rx} is the receiver antenna gain, and L_{Rx} is the loss factor for the receiver. Typically, antenna gains and losses are calibrated out in the VNA before the measurement. Additionally, a time delay gating is applied to remove the direct coupling path between the antennas.

3) Then, from the remaining path loss terms, the bistatic RCS (σ_{RIS}) of the RIS at the programmed anomalous reflection angle (θ_r, ϕ_r) can be estimated as:

$$\sigma_{RIS}(\theta_r, \phi_r) = PRRP(\theta_r, \phi_r) - S_{inc}$$

All quantities are expressed in decibel units: P_{Tx} and P_{Rx} in dBm, gains G_{Tx} and G_{Rx} in dBi, and σ_{RIS} in dBsm.

4.3.2 Bi-static RCS test set-up

For a bi-static measurement, fixed incident angles θ_i, ϕ_i (degrees) need to be defined and then measure the RCS across a range of received angles θr and ϕr, respectively. During a measurement campaign, one of the received angles, θr and ϕr, may be fixed (e.g. to zero) and then measured only across the variable received angle. When considering an active RIS surface, then the 'radiated angle' θn and ϕn should be set to a known condition. Depending on the RIS surface and RIS controller, it may also be necessary to configure the RIS surface incident angle θ_i, ϕ_i.

4.3.3 Bi-static RCS measurement

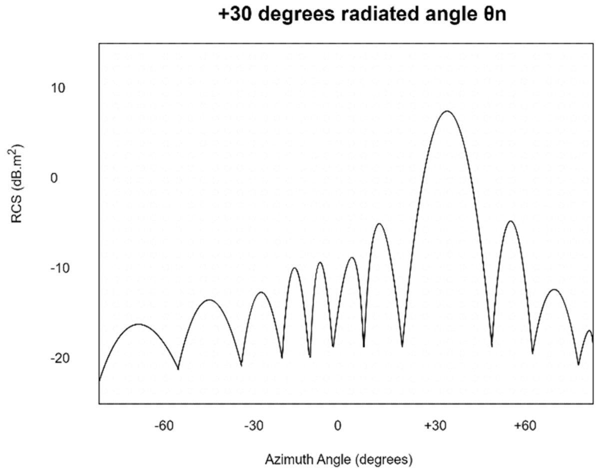


Figure 4.3.3-1: RCS Measurement example +30°

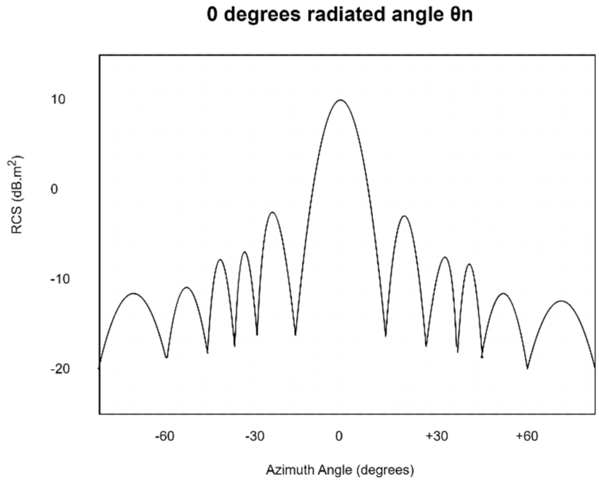


Figure 4.3.3-2: RCS Measurement example 0°

4.4 Reflected/Refracted beam spatial characteristics

4.4.1 Definition

The properties of the beam reflected by the RIS surface include directivity, peak re-radiated isotropic power, and the radiation pattern. It analyses the spatial properties of reflected/refracted beams across a specified angular range (elevation and azimuth).

It can also be shown that the RCS of a reflective RIS follows closely the specular reflector model [i.6] and can be accurately described by the $\cos^2(angle°)$ function, where the four possible incident and reflected angle combinations are $(\theta_i, \phi_i, \theta_r, \phi_r)$. This relationship can be expressed similarly to the RCS expression for a flat metal plate:

$$\sigma_{RIS}\,(\theta_i, \phi_i, \theta_r, \phi_r) \approx \frac{4\pi\, A_{RIS}^2}{\beta_{RIS}\,\lambda^2} \cos^2(\theta_i) \cos^2(\theta_r)$$

$$\operatorname{sinc}^2\left(\frac{\pi X}{\lambda}(\sin\theta_r \cos\phi_r + \sin\theta_i \cos\phi_i)\right) \operatorname{sinc}^2\left(\frac{\pi Y}{\lambda}(\sin\theta_r \sin\phi_r + \sin\theta_i \sin\phi_i)\right),$$

where A_{RIS}^2 is the $X \times Y$ area of RIS, and β_{RIS} is the design-specific loss term that differentiates RIS from a flat perfect electric conductor (PEC) plate, and sinc^2 terms account for tangential phase-mismatch components between (θ_i, ϕ_i) and (θ_r, ϕ_r) along the RIS's X and Y axes. In this expression, $\cos^2$ terms define the amplitude of the peak, and sinc^2 terms define the beamwidth of the reflected wave. However, for the peak (specular) RCS, with spherical coordinates aligned to the RIS normal, the azimuthal dependence drops out, and the sinc^2 terms become equal to 1. Then, the expression reduces to:

$$\sigma_{RIS}\,(\theta_i, \theta_r) \approx \frac{4\pi\, A_{RIS}^2}{\beta_{RIS}\,\lambda^2} \cos^2(\theta_i) \cos^2(\theta_r)$$

One implication of this equation is that the peak RCS of RIS at the specular reflection angle (when incidence and reflection angles are equal) is always less than that of a PEC of the same size. However, a RIS can have a higher RCS peak than a PEC when $\theta_i \neq \theta_r$. This is shown in Figure 4.4.1-1.

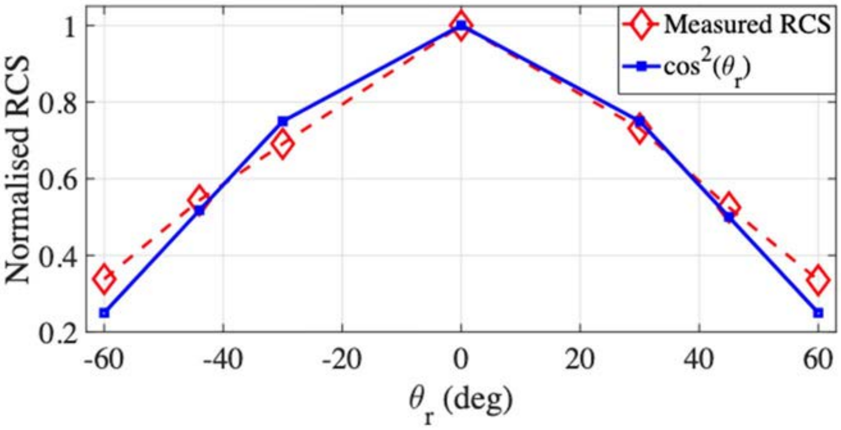


Figure 4.4.1-1: Illustration of the measured and normalized RCS for a reflective RIS vs $\cos^2(\theta_r)$ function

This observation is significant because it means that the RCS values for all reflection angles of a RIS can be approximated by measuring just a handful of $PRRP(\theta_r, \phi_r)$ values and fitting the rest against $\cos^2(\theta_i)$, $\cos^2(\theta_r)$ curves, thereby drastically reducing the number of required measurements as well as the overall measurement time.

Similar to the RCS of a reflective RIS, a refractive/transmissive RIS can be characterized in terms of its main lobe diffraction efficiency (η_{RIS}) i.e. the fraction of incident power steered into the programmed transmitted lobe for a given incidence and refraction angles (θ_i, θ_r):

$$\eta_{RIS}\,(\theta_i, \theta_r) \approx \frac{\lambda^2\, PRRP(\theta_r, \phi_r)}{4\pi\, S_{inc}\, A_{RIS}^2 \cos(\theta_i) \cos(\theta_r)}$$

Therefore, its estimated value can also be obtained from the $PRRP(\theta_r, \phi_r)$ measurement of S21 with a VNA.

4.4.2 A uniform plane wave is incident onto the RIS surface

Definition of incident plane wave beam such as:Absolute power (dBm), angle of incidence (degrees) (θ_i, ϕ_i).

Configure the RIS to reflect/refract at a nominal beam angle azimuth θn (degrees) and elevation ϕn (degrees).

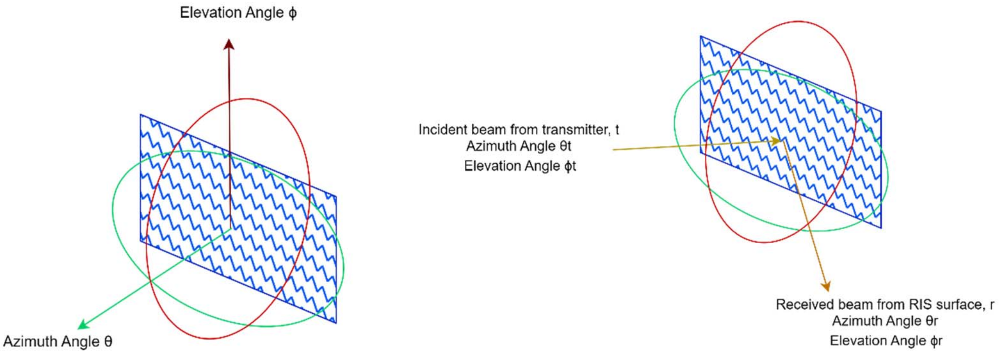


Figure 4.4.2-1

Measure absolute characteristics of radiated beam coming from RIS surface:

- 3 dB beam width (degrees) in azimuth and elevation.
- Peak reflected/refracted power (dBm).

Angular received beam pattern (hemispherical) θ_r, ϕ_r, from the radiating surface.

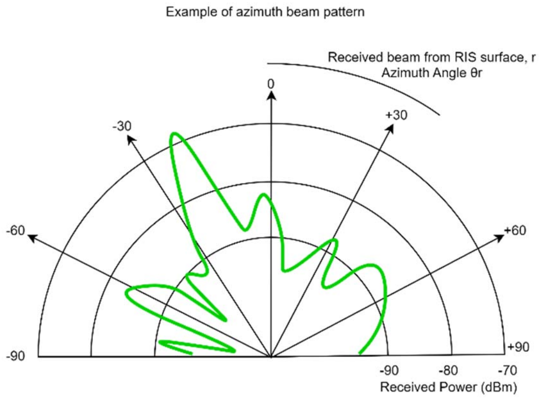


Figure 4.4.2-2

4.4.3 A narrow beam is incident onto the RIS surface

Definition of incident narrow beam such as:

- 3 dB beam width (degrees), peak reflected/refracted power (dBm), absolute power (dBm), sidelobe levels (dB), angle of incidence (degrees).
- Measure relative change in characteristics (relative to incident beam) of radiated beam coming from RIS surface.
- 3 dB beam width (degrees) in azimuth and elevation.
- Peak reflected/refracted power (dBm), Angular beam pattern (hemispherical) from the radiating surface.

4.5 Total Reflected/Refracted Power

Specification of the overall spatial power radiated from the RIS while it is programmed at a specific reflection/refraction angle (elevation and azimuth) as stated by the vendor. If the RIS is designed to scatter energy uniformly or provide a multi-beam pattern, such as STAR, these configurations will also be considered. The present document provides a metric for the analysis of angular interference caused by the RIS and its spatial EMF intensity.

The characterization of directivity and the Total Reflected/Refracted Power (TRRP) allows the evaluation of side lobe levels (SLLs) created by the RIS and their impact. Following the measurement of PRRP for each RIS configuration angle (θ_r, ϕ_r), its directivity and the TRRP at this angle can be expressed as:

$$D_{RIS}(\theta_r, \phi_r) \;=\; \frac{PRRP_i(\theta\prime, \phi\prime)}{\left(\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} PRRP_{\vartheta,\varphi}\, sin\,\vartheta\; d\vartheta\; d\varphi\right)} \;=\; \frac{PRRP_i(\theta\prime, \phi\prime)}{TRRP_{RIS}(\theta, \phi)},$$

where (ϑ, φ) are the sampled values obtained from a spherical measurement of the spatial re-radiation pattern of the RIS configured with a reflection/refraction angle that corresponds to the power density of a hypothetical isotropic radiator $PRRP_i(\theta', \phi')$ with the same isotropic reflected/refracted power as the PRRP (θ_r, ϕ_r). In other words, although $PRRP_i(\theta', \phi')$ and $PRRP\;(\theta_r, \phi_r)$ are equal in magnitude, the former is isotropic (constant for all (θ', ϕ')), whereas the latter is directional and determined by the programmed reflection/refraction angle (θ_r, ϕ_r). Consequently, the value of $PRRP_i(\theta', \phi')$ is implicitly dependent on the programmed (θ_r, ϕ_r).

This expression equates to the ratio of the power density radiated in the far field at (θ_r, ϕ_r) with (ϑ, φ) sampled values relative to the power density assumed to be from a hypothetical isotropic reflection/refraction source. Re-arranging the terms in this equation allows to obtain a simplified expression for the $TRRP(\theta_r, \phi_r)$:

$$TRRP_{RIS}(\theta_r, \phi_r)\;(dBm) \;=\; PRRP(\theta_r, \phi_r)\;(dBm) \;-\; D_{RIS}(\theta_r, \phi_r)\;(dBi)$$

This formulation means that the PRRP (θ_r, ϕ_r) value, that is driven by σ_{RIS} in the reflective RIS case or the diffraction efficiency (η_{RIS}) in the refractive RIS case, is multiplied by the D_{RIS} value that is different for each RIS configuration angle (θ_r, ϕ_r), and can be considered as the most accurate definition of RIS gain. However, it requires measuring the peak power for each side lobe of the RIS, and since the RIS pattern typically has many side lobes, this task is particularly challenging. To do that, the TRRP (θ_r, ϕ_r) of the RIS can be numerically approximated from a set of sampled PRRP (ϑ, φ) values in a sphere, by applying the following formula and considering both polarizations:

$$TRRP_{RIS}^{full}(\theta_r, \phi_r) \;\approx\; \frac{\pi}{2NM}\sum_{n=1}^{N}\sum_{m=0}^{M}\Big(PRRP_{\vartheta}(\vartheta_n, \varphi_m) \;+\; PRRP_{\varphi}(\vartheta_n, \varphi_m)\Big)\, sin\,\vartheta_n,$$

where N is the number of elevation (ϑ) samples and M is the number of azimuth (φ) samples, for a total of $N \times M$ sample points over the full sphere.

NOTE: This formula only works for a constant angular spacing or under the trapezoidal approximation, as the integral cannot otherwise be reduced to this form. Where appropriate, the full-sphere measurement of $TRRP_{RIS}^{full}$ can be restricted to a hemisphere. For example, when measuring reflective RIS devices mounted above a solid ground plane (acting as a PEC boundary), the $TRRP_{RIS}^{hemi}$ can be expressed as:

$$TRRP_{RIS}^{hemi}(\theta_r, \phi_r) \;\approx$$

$$\frac{\pi}{NM}\sum_{n=1}^{N}\sum_{m=0}^{M}\Big(PRRP_{\vartheta}(\vartheta_n, \varphi_m) \;+\; PRRP_{\varphi}(\vartheta_n, \varphi_m)\Big)\, sin\,\vartheta_n + \frac{1}{2}\sum_{m=0}^{M-1}\Big(PRRP_{\vartheta}(\vartheta_0, \varphi_m) + PRRP_{\varphi}(\vartheta_0, \varphi_m)\Big)$$

Also note that M samples are still taken across the fully spherical azimuth range, since φ ∈ [0, 2π].

4.6 Reflected/Refracted Beam Modulated Signal Quality

This metric quantifies the impact of the RIS on the fidelity and integrity of modulated signals as they pass through (refraction) or reflect off the surface. This metric is assessed using the Error Vector Magnitude (EVM), which measures the deviation between the transmitted and received signals in terms of amplitude and phase. A lower EVM indicates higher signal quality and minimal distortion caused by the RIS.

In the context of RIS, this metric assesses how effectively the surface preserves the key characteristics of the modulated signal, including amplitude, phase, and timing, while also accounting for any unintended distortions or degradations introduced during beam manipulation. It is crucial to ensure that the RIS does not compromise signal performance in scenarios requiring high data rates or robust communication integrity. Metrics such as EVM provide a direct means to assess signal quality. Still, additional considerations, such as Signal-to-Noise Ratio (SNR) and spectral efficiency, may complement the evaluation for a holistic understanding of RIS performance.

4.7 Static Configuration Power Consumption

This metric quantifies the total power a RIS consumes when operating in a static configuration. It encompasses the power usage of all integral components required to maintain the RIS's functionality in this state, including, but not limited to, the RIS controller, signal processing units, and any auxiliary systems. A static configuration refers to a fixed operational mode where the RIS elements are configured to remain in a predetermined state, without dynamic adjustments or active reconfiguration during operation.

This parameter differentiates between active and inactive processes, explicitly accounting for:

- Active static processes: Components or subsystems actively consuming power to sustain the static configuration (e.g. maintaining voltage bias on tunable elements).
- Inactive static processes: Standby power consumption by components that are not actively performing a function but are essential for system readiness or state preservation.

4.8 RIS Reconfiguration Time

Measures the time interval experienced from the moment when the RIS controller receives the desired/new RIS configuration command, till the moment when the configuration update (e.g. such as phases, amplitudes, or other reconfigurable properties of various RIS elements) of a RIS surface is effective/measurable. This may include the switching time of RF components and the speed of the RIS controller hardware.

Specification of the RIS reconfiguration time is useful guidance for RIS's usage in an appropriate scenario in terms of supported UE mobility, and targeted improvement goal (e.g. coverage improvement, or capacity/QoS improvement). For example, in a scenario with slow moving/static UEs and targeting coverage improvement longer RIS reconfiguration times might be acceptable. On the other hand, when considering supporting moving UEs and targeting capacity/QoS improvements then short (e.g. shorter than a TTI) RIS reconfiguration times are required.

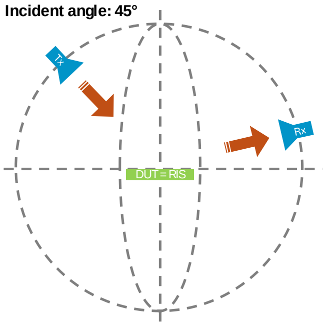
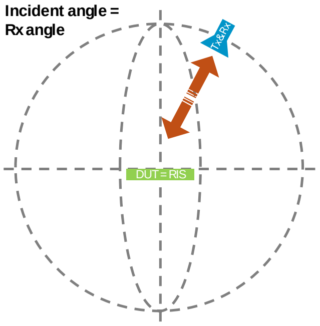
5 Measurement Setups and Methodologies

5.0 General

This clause describes all the information needed to measure the RIS parameters. It includes the physical environment in which the measurements are conducted, the tools to be used, and the instruments and equipment used to perform the measurements. This clause outlines the step-by-step measurement procedure, including calibration where needed. It also includes instructions for configuring the RIS.

Table 5.0-1 compares the bistatic with the monostatic RIS test approach.

Table 5.0-1: Comparison of bistatic and monostatic RIS test approach

	Bistatic RIS test approach	**Monostatic RIS test approach**
Sketch of setup		
Test scenario	Corresponds to RIS use case scenario → No post-processing required	Different test scenario than RIS use case scenario → Post-processing required.
Measurement uncertainty	Exact measurement of full pattern	Transformation formula uses assumptions → RIS main lobe assessment method.
Setup complexity/footprint	Very high: As RIS characterization requires far field conditions in both signal paths (illumination path and probing path)	Extremely reduced compared to bistatic setup as commercial off the shelf CATR chambers can be easily used.
Blockage/shadowing problem	Probe antenna is shadowed by illumination antenna → Certain pattern range can therefore not be measured	No shadowing/blockage as only one antenna is part of the setup.
Measurement duration		Tremendously reduced as less degrees of freedom → All bistatic patterns for various incident angle combinations can be calculated during post-processing. No need for repeating the bistatic measurement for different incident angles.
Amount of data		Much less as in monostatic scenario incident angle = probing angle holds.

5.1 Bistatic Measurement Setup

5.1.1 General Method

RIS OTA requirement testing may be conducted in a controlled anechoic chamber to evaluate signal propagation and performance. This test methodology follows a "black box" approach, ensuring the Device Under Test (DUT) is centrally positioned within the test zone for accurate and repeatable measurements.

Testing is performed under a fixed mechanical positioning mode, with both vertical and horizontal polarizations measured independently. A Compact Antenna Test Range (CATR) setup is used, incorporating Near-Field (NF) and Indirect Far-Field (IFF) probing techniques.

RIS OTA requirement testing may also be conducted Directly in a Far Field (DFF) condition, where the RIS is placed in an open space, or a controlled anechoic chamber, and the measurements are made in far field conditions. This test methodology follows a "black box" approach, ensuring the Device Under Test (DUT) is centrally positioned within the test zone for accurate and repeatable measurements. Testing is performed under a fixed mechanical positioning mode, with both vertical and horizontal polarizations measured independently. Both the position/orientation of the DUT and the position/orientation of the measurement sensors may be adjusted to provide the required range of measurement angles.

5.1.2 Compact Antenna Test Range (CATR)

5.1.2.1 System setup

The test setup is based on a Multi-Probe CATR anechoic chamber, integrating NF and IFF measurement capabilities. The DUT is positioned at the centre of a motorized rotation platform, enabling precise angular adjustments. Two fixed rotation axes below the DUT's centre allow for multiple degrees of freedom, facilitating both NF and IFF illumination. The DUT can rotate at 90° in both the azimuth and elevation planes to capture the full reflection pattern.

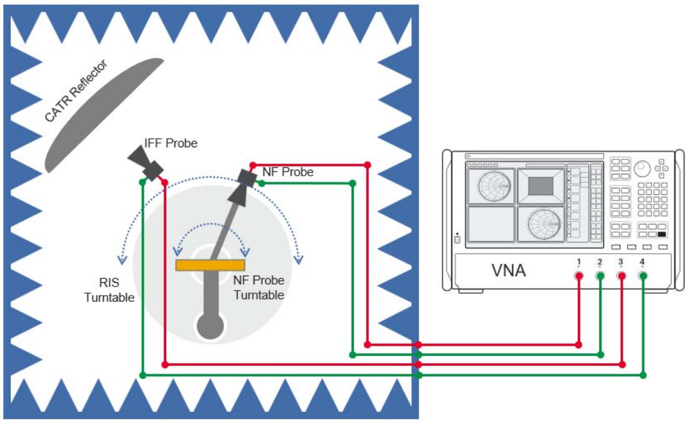


Figure 5.1.2.1-1: Top view of CATR system layout for RIS OTA testing

The system employs a NF probe and a CATR reflector with suitable edge treatments, such as rolled, serrated, or other commonly used edge treatments, in CATR systems, to minimize diffraction and generate the IFF. The NF probe and the IFF feed horn are dual-polarized, with separate horizontal and vertical polarization connections. The measurement system is configured to analyse both polarizations, ensuring comprehensive data collection. The elevation and azimuth plane can be evaluated by rotating the DUT around the Boresight axis. The coordinate system used for the notation is defined as the base station conformance testing system (3GPP TS 38.141-2 [2]).

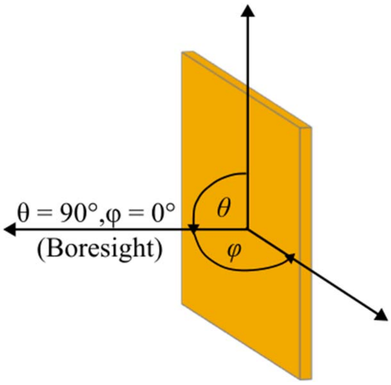


Figure 5.1.2.1-2: Side view of CATR system layout for RIS OTA testing

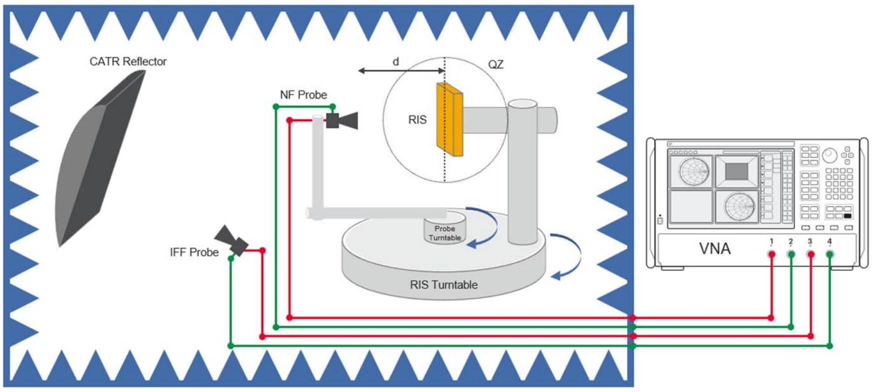


Figure 5.1.2.1-3: Side view of CATR system layout for RIS OTA testing

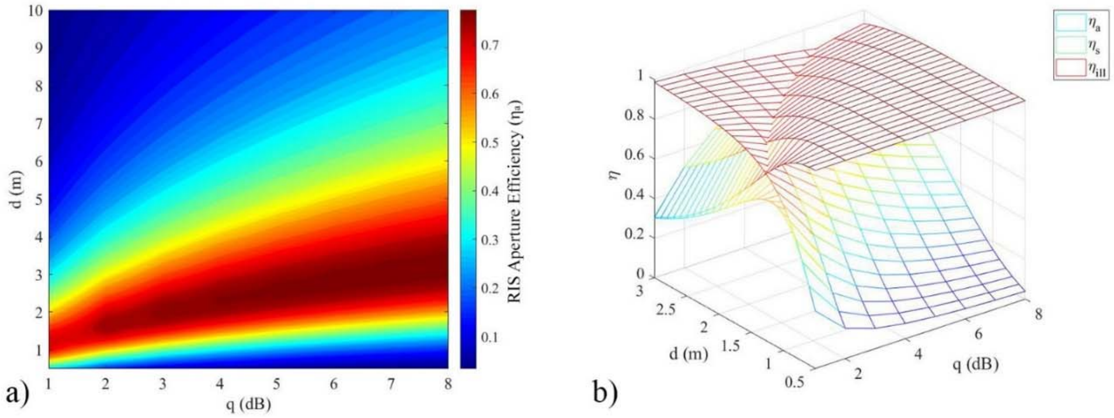
5.1.2.2 Minimum Range Length

The size of the Quiet Zone (QZ) generated by the CATR should be larger than the aperture of the DUT to ensure uniform field exposure. The NF probe should be positioned at a spherical coordinate (d, θ, ϕ) relative to the centre point of the RIS. The RIS codebook should be configured to generate a distance-based beam pattern directed explicitly toward this location. Any misalignment between the programmed beam direction and the actual probe position, whether in distance or angular coordinates, can result in invalid measurement data. The required phase distribution for NF focusing on RIS can be mathematically expressed as:

$$\Phi(x, y) = -\frac{2\pi}{\lambda}\left(\sqrt{\left(x - x_f\right)^2 + \left(y - y_f\right)^2 + d^2} - d\right),$$

where λ is the wavelength, (x, y) are the 2-D coordinates of a RIS unit cell, and (x_f, y_f, d) represent the NF probe location, with both expressed in a Cartesian coordinate system. This formulation ensures that the RIS elements induce the appropriate phase shifts to converge the wavefront at the desired NF focal point, deviating from conventional plane-wave approximations. It is important to note that not all RIS architectures can support distance-based NF beam focusing. This capability should be verified before testing. While conventional RISs are often configured with a linear phase gradient codebook for FF conditions, such a codebook would not be adequate for the NF-probe, described in this test methodology.

The distance d between RIS and the NF probe should be carefully selected to ensure that the RIS has a favorable aperture efficiency for the measurement. In line with reflect-array antenna design principles, d should be chosen to yield an aperture efficiency of 60 % to 80 %, as shown in Figures 5.1.2.2-1 a) and b). The selection of this distance depends on a) the RIS's physical dimensions, b) operating frequency, and c) the q-factor of the NF probe (Rx), which relates to its directivity and gain. From these figures, it can be observed that if the NF probe is placed too close to the RIS or too far from the RIS, the aperture efficiency drops rapidly due to either low illumination efficiency (too close) or high spillover efficiency (too far). Therefore, based on DUT and chamber characteristics, d should be selected in accordance with reflect-array antenna design principles for the focal point derivation, described in [i.1].



a) the theoretical aperture efficiency (ηa)

b) spillover (η_s) and illumination (η_{ill}) efficiencies

Figure 5.1.2.2-1: For a 1m x 1m RIS operating at 26 GHz

5.1.3 Direct Far Field (DFF) Test Range

5.1.3.1 System setup

The test setup is based on Direct far-field measurement capabilities. The DUT is positioned at the centre of a mounting platform, which may be motorized to enable precise angular adjustments. Two fixed rotation axes below the DUT's centre may allow for multiple degrees of freedom, facilitating a full range of measurement angles for the RCS/antenna pattern. The DUT can rotate at 90° in both the azimuth and elevation planes to capture the full reflection pattern. Both the TX and RX locations may be moved along the axis of measurement, enabling the arbitrary, independent selection of both the incidence and reflection angles.

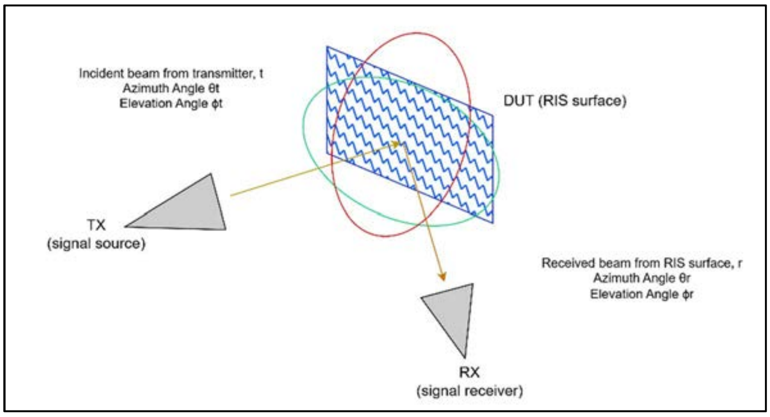


Figure 5.1.3.1-1

The TX and RX may use modulated signals (e.g. for the purpose of Beam Signal Quality measurement EVM) or Continuous Wave (CW) signals (for the purpose of other power-based measurements).

The TX and RX can be independently located to provide the required geometric configuration for the test being performed (i.e. incident beam angles (θ_i, ϕ_i), and reflected beam angles (θ_r, ϕ_r). Where required, the TX or RX equipment may be placed onto a mechanical assembly (e.g. gantry, robot arm, AGV) to automate the positioning and measurement locations. In addition, the TX and RX locations may be fixed during a test, and the DUT may rotate on the mounting platform.

The system may use antennas on both TX and RX ports to provide sufficient directionality and link budget to the system so that measurements can be made with the required signal-to-noise ratio that meets uncertainty requirements. The antennas may be single or dual polarized to provide flexibility in the choice of the polarization modes to be measured during each test.

5.1.4 DUT positioning

The DUT shall fit fully into the quiet zone of the IFF and shall be aligned to the centre of rotation, keeping the distance of the NF probe constant to the centre. Any additional hardware shall be removed or padded with absorber material.

5.2 Monostatic Measurement Setup

5.2.1 General Method

One of the most important RIS test scenarios involves validating the beamforming capabilities of a Reconfigurable Intelligent Surface. As stated in [i.3] this kind of test corresponds to a bistatic Radar Cross Section pattern measurement. The conventional measurement technique employs two antennas positioned at different angles to capture the bistatic RIS reflection pattern for various incident angles and RIS configurations. In bistatic RIS test setups, meeting the far-field condition poses challenges, and due to the extensive parameter set, the measurements are highly time-consuming, as the reflection pattern shall be measured for each incident angle and RIS configuration in the three-dimensional space. Therefore, in [i.3], a setup and test methodology is proposed, where one of the two antennas is in the near field and the other one in the indirect far field (Compact Antenna Test Range (CATR) arrangement). However, this setup assumes that the RIS supports near-field operation, which does not hold for many RIS prototypes discussed in the literature. Therefore, this contribution proposes an alternative measurement methodology that allows far-field measurements within a commercial off-the-shelf monostatic CATR test chamber, normally used for antenna measurements. After the monostatic RIS reflection pattern is acquired for each individual RIS configuration, the bistatic patterns are mathematically calculated by employing a monostatic to bistatic transformation formula. With this approach, the measurement shall be carried out for one incident angle configuration only, as the incident angle can be arbitrarily chosen within the subsequent post-processing transformation step. This approach significantly reduces the overall measurement time and simplifies the measurement process.

5.2.2 Monostatic RIS test setup and approach

Figure 5.2.2-1 illustrates the basic test setup and the corresponding measurement procedure. The configuration features a CATR chamber, which is equipped with a 3D positioner system, where the RIS is mounted. To perform the evaluation under far-field conditions, it is essential to position the DUT within the designated quiet zone of the CATR reflector. With an e.g. vector network analyser, the magnitude of the reflection S-parameter (S11) is measured. This process is repeated for various angles of the positioner to capture the pattern of the complete upper hemisphere around the RIS and for the two different linear polarizations. As an optional extension, a dual-polarized feed antenna can be used to reduce the measurement time even further, as both linear polarizations can be measured simultaneously. To extract the RIS reflection from other unwanted additional reflections (e.g. antenna mismatch, standing wave, multiple RIS reflections), time gating is employed. As an alternative setup implementation, a quasi-monostatic setup can also be employed. Up to this point, the evaluation corresponds to a regular monostatic RCS measurement of a RIS.

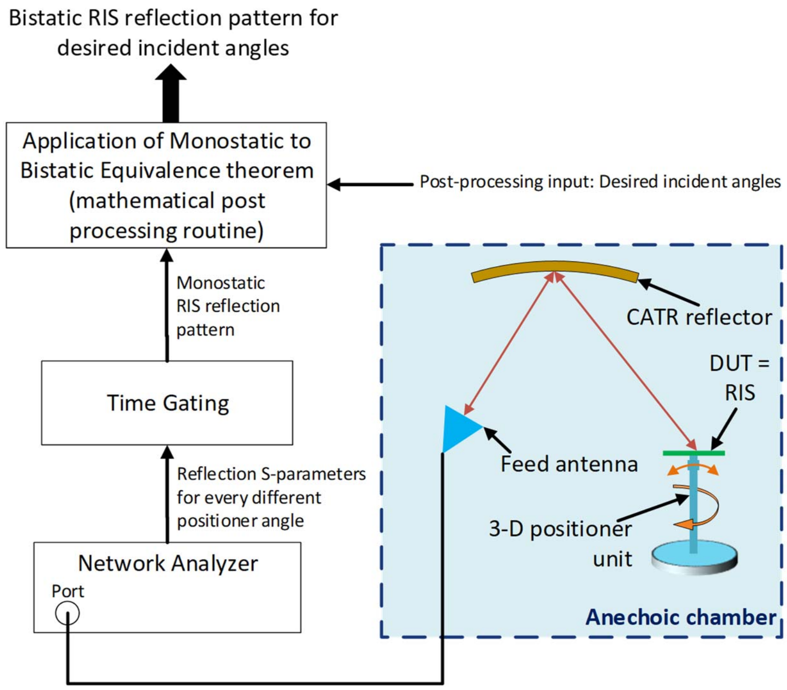


Figure 5.2.2-1: Monostatic RIS test setup and methodology

As the RIS beamforming capabilities in bistatic environments are of interest, the monostatic RIS reflection pattern is not sufficient. Therefore, in [i.2], [i.4] and [i.5] a post-processing method is proposed that employs and extends Falconer's RCS Monostatic to Bistatic Equivalence Theorem (MBET) in view of RIS testing. With this MBET, the monostatic RIS reflection pattern can be transformed into bistatic patterns for any arbitrary desired bistatic incident angle configuration. The validity of this monostatic RIS test approach is proven and the accuracy is assessed in [i.2], [i.4] and [i.5]. For this purpose the deviation of the transformed monostatic pattern with its bistatic reference pattern is evaluated around the RIS main beam for various different RIS configurations within an angular range of -60° to 0° for the incident angle and 0° to +60° for the RIS reflection angle. Depending on a specific angle configuration the uncertainty is given in Figure 8 of [i.4].

6 Measurement Methodologies

6.0 General

This clause outlines standardized procedures for acquiring various RIS parameters listed in clause 4, based on measurement setups described in clause 5.

6.1 First Considerations

6.1.1 Environmental Conditions, Safety, and Responsibilities

Before calibration, the VNA's measurement stability should be ensured according to the manufacturer's specification (e.g. warm-up time, temperature stability, etc.). Adhere to all essential ESD precautions and handle connectors carefully to prevent damage or misalignment. The technician or engineer conducting the calibration is responsible for following this procedure. The equipment should be in optimal working condition and operated by qualified personnel.

6.1.2 Through Response Calibration Procedure

1) Initialization:
    a) Power on the VNA and allow it to warm up for a minimum of 30 minutes.
    b) Clean and inspect all VNA ports, cables, adapters, and calibration standards.
    c) Connect four test cables to VNA ports 1 through 4.
    d) Load the correct calibration kit definition on the VNA.
2) Configure Measurement Settings:
    a) Set the desired frequency range.
    b) Select the number of sweep points (e.g. 201, 401).
    c) Configure other measurement parameters: IF bandwidth and Source power level.
    d) Perform full 4-Port Calibration.
    e) Choose the correct calibration kit definition.
3) Performing Calibration Steps.

Perform Open, Short, and Load on each port, and Thru connections for every unique port pair. Reflection Standards (Single-Port). Repeat for all four ports. Transmission Standards (Thru Pairs) and perform Thru calibrations for all unique port pairs:

- Port 1 ↔ Port 2
- Port 1 ↔ Port 3
- Port 1 ↔ Port 4
- Port 2 ↔ Port 3
- Port 2 ↔ Port 4
- Port 3 ↔ Port 4

For each pair: Connect the Thru standard or cable between the two ports and then press the corresponding "Thru" prompt on the VNA.

4) Complete Calibration:
    a) Once all standards have been measured, execute Calibration Solve or Calculate.
    b) Apply the calibration correction data.
    c) Confirm that the correction is active.

6.1.3 Source Power Calibration Procedure

1) Initialization:
    a) Set up your measurement (sweep type, frequency range, IFBW).
    b) Connect the coax cable, GPIB cable, and power sensors to the VNA.
    c) Apply power to the power meter and allow for warm-up time before beginning calibration.

2) Performing Calibration Steps:
    a) Complete the Source Power Cal , including Loss Compensation and Power Sensor Settings, as needed.
    b) Connect the sensors as required.
    c) Change the Source Port setting and perform a Source Power Cal on a different port.
    d) The calibration is finished.
3) Complete Calibration:
    a) Remove sensor.
    b) Perform a S-parameter calibration, which would use the corrected stimulus power levels for the relevant ports.

6.2 RIS Operating Frequency Range Measurement Methodology

6.2.1 Measurement Setup

The measurement setup required for this parameter is described in clause 5.1. Perform the steps mentioned in clause 6.1.2.

6.2.2 Measurement Procedure

1) RIS Initialization:
    a) Mount RIS on the platform.
    b) Ensuring centre alignment with the CATR or DFF coordinate system.
    c) Connect the RIS controller and verify software access.
2) Incident Wave Setup:
    a) Set incident wave parameters through positioning of the CATR or DFF (θ_i, ϕ_i).
    b) Program RIS to generate a beam toward the desired radiated direction (θ_r, ϕ_r).
3) Measurement Execution:
    a) Sweep across the desired frequency ranges:
        i) Frequency Sweep with ideally 50 MHz or smaller steps.
    b) Record received power.
4) Data Post-processing:
    a) Generate a plot of the measured gain magnitude (e.g. |S21| in dB) as a function of frequency for that specific angle combination.
    b) Identify the frequency at which peak gain occurs.
    c) Determine the operating frequency range by identifying the frequency points at which the gain drops by a predefined amount (e.g. 3 dB) from the peak value. The range between these lower and upper frequency points defines the RIS operating frequency range.

6.2.3 Notes and Considerations

Several factors are crucial for obtaining accurate and repeatable RIS frequency measurements. Ensuring measurement environment integrity is crucial, including suppressing chamber reflections and removing interfering signals. Using time-gating, if available, helps isolate direct signals and reduce reflections. A single measurement may not fully represent the device's usual performance. Repeating measurements with multiple RIS codebooks enables statistical evaluation, providing a better understanding of the frequency range across states.

6.3 RIS Maximum Operating Bandwidth Measurement Methodology

6.3.1 Measurement Setup

The measurement setup required for this parameter is described in clause 5.1. Perform the steps mentioned in clauses 6.1.2 and 6.1.3.

6.3.2 Measurement Procedure

1) RIS Initialization:
    a) Mount RIS on the rotary platform.
    b) Ensuring centre alignment with the CATR or DFF coordinate system.
    c) Connect the RIS controller and verify software access.
2) Incident Wave Setup:
    a) Set incident wave parameters through positioning of the CATR or DFF (θ_i, ϕ_i).
    b) Program RIS to generate a beam toward the desired radiated direction (θ_r, ϕ_r).
3) Equipment Initialization:
    a) Power on the Vector Signal Generator (VSG) and Vector Signal Analyser (VSA).
    b) Allow sufficient warm-up time to ensure stable operation.
    c) Verify connections, power levels, and synchronization between instruments.
4) Measurement Execution:
    a) Configure the VSG to generate the reference modulated signal (e.g. 64-QAM, 5G NR) at the defined centre frequency and power level.
    b) Set the initial signal bandwidth (e.g. 20 MHz).
    c) Use the VSA to capture the reflected signal and measure the EVM. Average results over N captures (e.g. N = 10) to reduce statistical variability.
    d) Incrementally increase the signal bandwidth in steps fine enough to capture the EVM degradation (e.g. 5 to 20 MHz). For each step:
        i) Generate a broader-band signal.
        ii) Measure and record the EVM (averaged over N captures).
        iii) Log the bandwidth and the corresponding average EVM value.

5) Data Post-processing:
    a) Plot EVM as a function of signal bandwidth.
    b) Define the RIS Maximum Operating Bandwidth as the highest bandwidth at which the measured EVM remains within the defined threshold.
        i) The threshold shall be: An absolute EVM requirement specified by the relevant communication standard (e.g. ETSI TS 138 104 [3]) or a relative degradation limit (e.g. not exceeding X% above baseline EVM).
    c) Report the result together with:
        i) The applied threshold definition.
        ii) Bandwidth step size.
        iii) Measurement averaging method.
        iv) Estimated measurement uncertainty.

6.3.3 Notes and Considerations

The pass/fail EVM threshold is critical and shall be clearly defined. It should be based on the requirements of the target application or relevant communication standards (e.g. 3GPP). RIS's bandwidth performance can vary across its operating frequency range, so it is recommended to perform this test at multiple centre frequencies (e.g. at the low, mid, and high points of the operating range) to ensure comprehensive characterization as well as different angle configurations.

6.4 Radar Cross Section Measurement Methodology

6.4.1 Bistatic (CATR) Measurement Setup

6.4.1.0 General

The measurement setup required for this parameter is described in clause 5.1. Perform the steps mentioned in clause 6.1.2.

6.4.1.1 Measurement Procedure

1) RIS Initialization:
    a) Mount RIS on the rotary platform.
    b) Ensuring centre alignment with the CATR coordinate system.
    c) Connect the RIS controller and verify software access.
2) Incident Wave Setup:
    a) Set incident wave parameters through positioning of the CATR (θ_i, ϕ_i).
    b) Program RIS to generate a beam toward the desired radiated direction (θ_r, ϕ_r).
3) Measurement Execution:
    a) Sweep receiver across the desired angle and frequency ranges:
        i) Angular Sweep with ideally 0,5º or smaller steps.
        ii) Frequency sweep should be at least the RIS operational frequency range.
    b) Record received power.

   c) Log measurement metadata (angles, polarization, frequency).

4) Data Post-processing:
   a) Generate RCS plot over (ϑ_n, φ_m) hemispherical scan.
   b) Identify peak RCS value for each RIS configuration.
   c) Analyse beam direction accuracy and side lobe levels.

6.4.1.2 Notes and Considerations

To ensure environmental isolation, it is imperative to suppress chamber reflections and eliminate illegitimate sources. Before conducting scans verify the probe's alignment. If available, employ time-gating to effectively isolate the direct path. It is advisable to repeat measurements using multiple RIS codebooks to facilitate statistical evaluation. Regarding NF beam targeting, ensure that the codebook can support the necessary focusing requirements.

6.4.2 True bi-static (DFF) Measurement Setup

6.4.2.0 General

The test configuration consists of a 2 port VNA that is operating in true far field conditions, and has VNA measurement port locations that can be moved to different locations as a true bi-static configuration. To enable this, a suitable test range shall be used to enable far field conditions without introducing unwanted reflections. In addition, a mounting structure for the DUT and for the reference calibration plate is required, and this may also include a turntable to adjust the apparent angle of the DUT to the antenna ports.

A reference calibration plate is used, of metal construction. The plate may be rectangular, with frontal dimensions D_1 and D_2, or may be square such that $D_1=D_2$. The plate is of thickness D_T, such that it can maintain mechanical rigidity and flat surface when mounted using a rear attachment supporting structure to prevent any blockage of the reflecting surface.

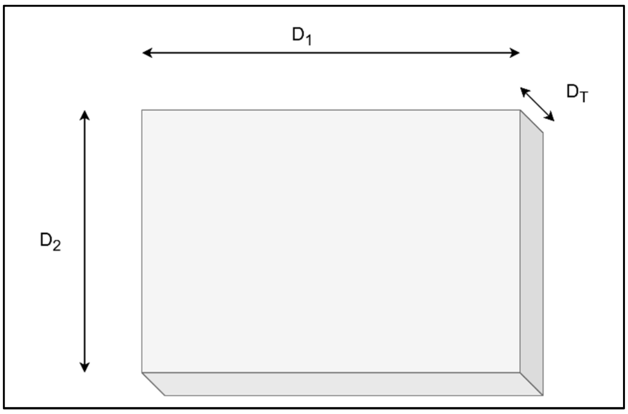


Figure 6.4.2.0-1

The measurement of RCS of the RIS device (DUT) is established using a three step process, as described in the following sections:

1) Configuration of equipment and measurement site.
2) Measurement of Reference Plate.
3) Measurement of DUT.

6.4.2.1 Configuration of Test Equipment

1) Two ports of VNA:

    i. The 2 ports of VNA can be configured either symmetrically or asymmetrically distant from the DUT. If the DUT is large, the Tx antenna far field is generally << than the DUT far field (R_{FF}), in which case the Tx antenna (R_T)can be much closer to the DUT. In such configurations, the Tx pathloss is minimized such that Rx dynamic range is maximized:

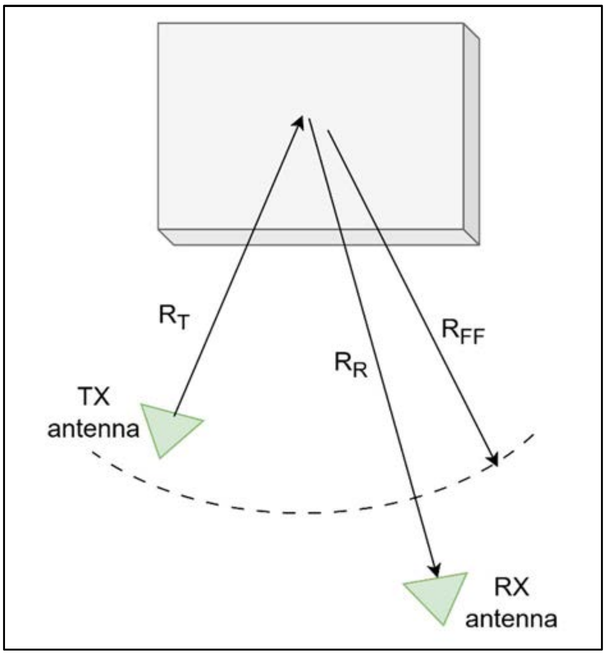


Figure 6.4.2.1-1

2) VNA calibration kit.

3) Two appropriate antennae (including mounting tripods) with Gain = G (dBi).

4) Reference target (including mounting equipment).

5) DUT (including mounting equipment).

6) Appropriately sized range for far field measurements (far field = $2D_1^2/\lambda$), for a rectangular RIS target with the largest dimension D_1, and a RIS system operating wavelength of λ.

NOTE: It is necessary to consider the far field distance for both the Tx antenna that is illuminating the DUT, and the reference target/DUT (which itself is acting as an antenna/radiator).

6.4.2.2 VNA Calibration

Power on the VNA system and allow sufficient warm-up time in the desired sweep configuration (as described by the manufacturer's operation manual). Perform a 2-port twelve-term calibration (as described by the manufacturer's operation manual), in line with the procedure described in clause 6.1.2.

6.4.2.3 Site Calibration

Perform a pseudo-bistatic measurement of a reference target. A maximum Reference Plate width shall be used that guarantees the reflection received from the Reference Plate is in the Far Field with respect to the receiver antenna (distance R_R). The Reference Plate should be larger than the DUT to ensure the DUT is also in the Far Field, and the Reference Plate should completely cover the DUT if the DUT were placed behind it.

$$W_{max}=(R_R\times\lambda/2)\hat{}(1/2)$$

Where W_{max} is the maximum width of the square reference plate at R_R distance, given by the greater of D_1 and D_2.

Figure 6.4.2.3-1

The pseudo bi-static configuration is defined as the scenario where the Tx and Rx antennas are co-located. This gives the Tx and Rx antennas the same view of the Reference plate (or DUT), at the same distance ($R_R = R_T$) and angle ($\theta_i, \phi_i = \theta_r, \phi_r$), and the distance is selected to fulfill the far-field criteria for both the Tx antenna (R_T) and the Reference plate (or DUT) (R_R).

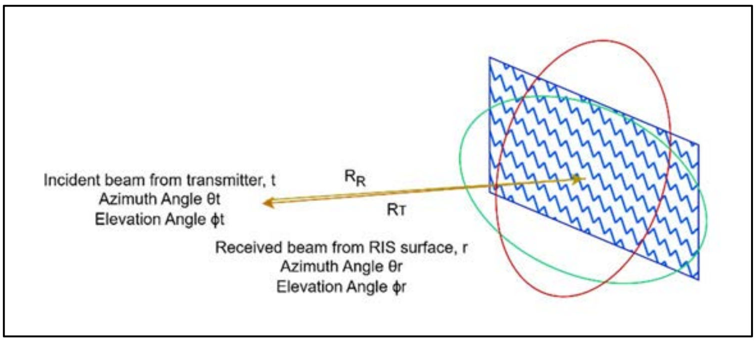


Figure 6.4.2.3-2

The Antenna to Target angle (θ_R) is given by the following equation (this is assuming that the Antenna is pointing upwards, and correspondingly, the Target is pointing downwards):

$$\theta_R=\text{asin}((H_A+H_R)/R_R)$$

It is recommended to ensure that the height of the antenna and reference plate is above the level where ground reflections may cause interference to the measurement by calculating the Fresnel zone radius of the site. The 5th Fresnel zone is recommended to be used to ensure suppression of interference. The Safe area below the Nth Fresnel zone at $R_R/2$ distance is given by:

$$r_N=((N\times R_R/4)\times\lambda)^{½}$$

The height of the antenna (H_A), and the height of the lower edge of the target (DUT or reference plate) given by (H_R-D_2/2), should be greater than r_N for a value of N=5.

Example Site Configuration:

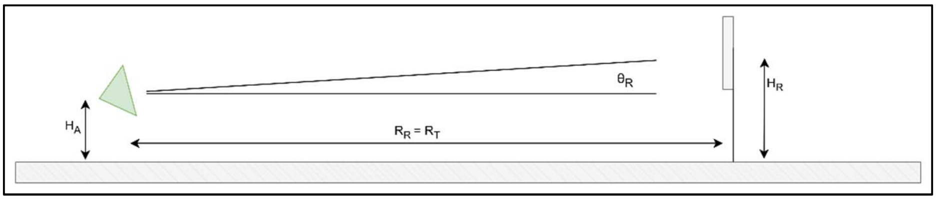


Figure 6.4.2.3-3

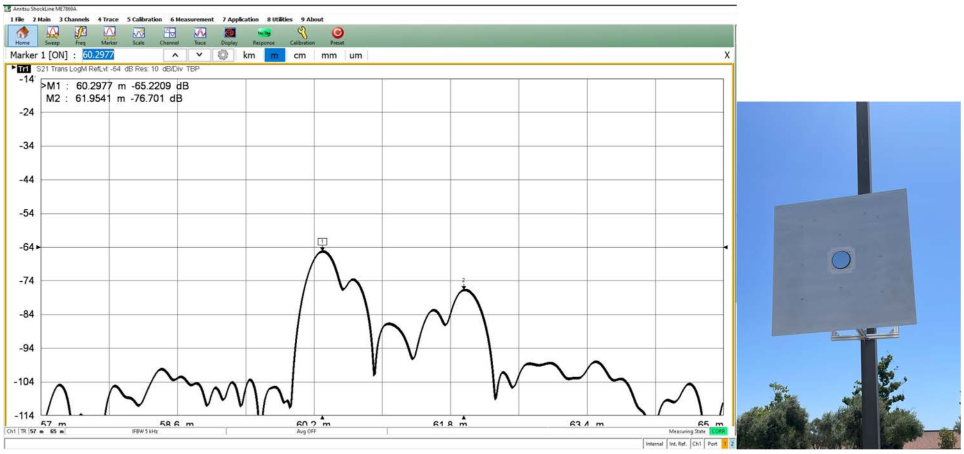
In the above example, the following characteristics of the test site are defined as:

- Operating frequency F(GHz) = 4,5
- R_T: Tx Antenna to Reference Plate Line of Sight (LoS) Distance(m) = 30,0
- R_R: Rx Antenna to Reference Plate Line of Sight (LoS) Distance(m) = 30,0
- R_{FF}: Reference Plate Re-radiated Far Field Distance(m) < 30,0
- (H_A): Antenna height(m) = 1,0
- (H_R): Centre of Reference Plate height(m) = 3,6
- Tx & Rx Antenna: Reference Plate LoS angle θ_R (degrees) = 4,97
- Reference Plate Width D_1 (m) = 1,0000
- Above ground Fresnel Safe Zone(m) = 0,47

EXAMPLE: Target Summary (theoretical): Align the antennas (by adjusting antenna(s) boresight) to the DUT/Reference plate, which is confirmed by matching to the ideal S21(pseudo-bistatic) reading as calculated above.

NOTE: Any difference, within a few dB, can be due to antenna gain deviation from published specifications, inaccurate antenna to target distance, too narrow antenna beam width, or stray Fresnel reflections. The peak achievable value of S21 should be the reference reading. This measured S21(pseudo-bistatic) is now the reference reading used for further unknown RCS measurements compared to the reference plate.

When measuring the S21 response of the VNA, 'time gating' may be used to isolate the reflection of the DUT from any mounting pole or similar test environmental objects that may also cause reflections. As the Distance R_R from the antenna to the DUT is known, then the S21response may be time gated to the precise distance (time of flight) to the DUT. Any other structures behind the DUT (such as a mounting pole) can then be isolated due to the different time of flight.



Marker 1 [ON] : 60.2977

S21 Trans LogM RefLvl: -64 dB Res: 10 dB/Div TBP

```
>M1 :  60.2977  m  -65.2209  dB
 M2 :  61.9541  m  -76.701  dB
```

NOTE 1: Marker 'M1' is set to the Reference Plate distance 2*RR (2 x 30 metres, round trip time is 60 metres).
NOTE 2: Marker 'M2' is set to the support pole behind the Reference Plate (round trip of 62 metres).

Figure 6.4.2.3-4: Shows a Reference Plate mounted on a pole, together with a corresponding S21 trace

6.4.2.4 Measurement of the reference plate (true-bistatic)

Figure 6.4.2.4-1: Example of true bi-static range

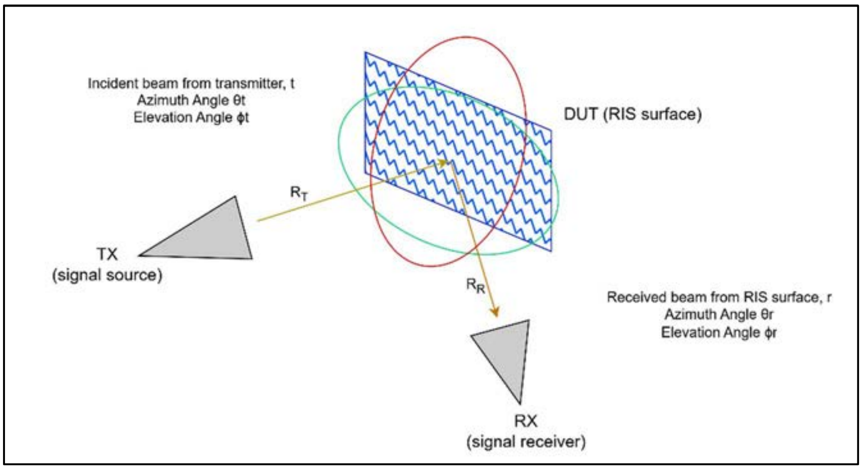


Figure 6.4.2.4-2: Definitions of true bi-static configuration

6.4.2.5 Measure S21 of the Reference Plate

The Tx and Rx antenna should be located at angles such that the desired angular response of the DUT will be measured. Time Gating may be used in the VNA to isolate the reflection of the DUT from other reflections that may be present in the test site.

NOTE: The reference target/plate RCS true bi-static measurement value is expected to be less than pseudo-bistatic measurement because its apparent size is reduced due to the geometric reduction in the size ($D1_{off}$) of the plate (size D1) when viewed from an offset angle (θ_{off}), see Figure 6.4.2.5-1. This nominal RCS of the reference plate can be calculated from the angular trigonometry, using equation:

$$\mathbf{D1_{off} = D1 \times Cos(\theta_{off})}$$

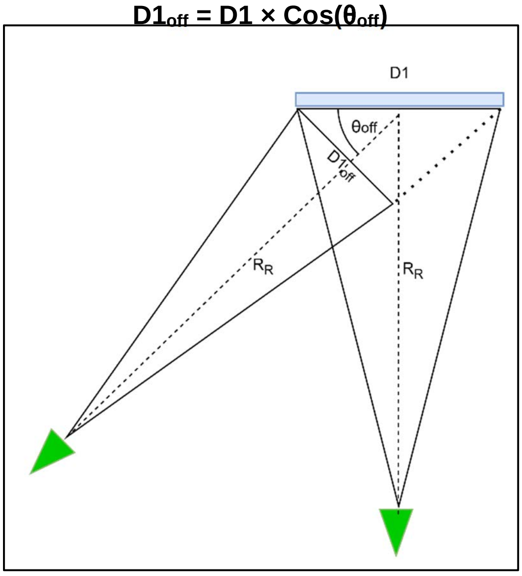


Figure 6.4.2.5-1

6.4.2.6 Calculate RCS of Reference Plate

RCS(m^2) is obtained by the formula (the standard RCS of a measured square plate (D_1^2) given in clause 4.3.1. RCS(dBm^2) is given by the formula given in clause 4.3.1. The measured VNA reflection response S21 of a Theoretical plate under the above conditions (using the Radar Range equation). Using the above example, the following RCS related parameters can be calculated:

- Transmit/Receive Antenna Gain G(dBi) = 10,1.
- Square Reference Plate ideal S21(pseudo-bistatic) dB = -60,87 (theoretical).
- Square Reference Plate RCS(m^2) = 2 827,4.
- Square Reference Plate RCS(dBm^2) = 34,51.

6.4.2.7 Measurement of the DUT

1) Replace the reference plate with the DUT.
2) Perform a true-bistatic S21 measurement with the same method as described with the reference plate.
3) Calculate the resulting DUT RCS with the same method as described with the reference plate.

For the given angular configuration, the following example is given:

Measurement of the VNA response of the DUT (S21 true-bistatic) dB:

- -62,25.

From this measurement, the calculated RCS can be derived as follows:

- RCS (m^2) = 2 120,28
- RCS (dBm^2) = 33,26

6.5 Reflected/ Refracted Beam Spatial Characteristics Measurement Methodology

6.5.1 Measurement Setup

The measurement setup required for this parameter is described in clause 5.1. Perform the steps mentioned in clause 6.1.2.

6.5.2 Measurement Procedure

1) RIS Initialization:
    a) Mount RIS on the rotary platform.
    b) Ensuring centre alignment with the CATR or DFF coordinate system.
    c) Connect the RIS controller and verify software access.
2) Incident Wave Setup:
    a) Set incident wave parameters through positioning of the CATR or DFF (θ_i, ϕ_i).
    b) Program RIS to generate a beam toward the desired radiated direction (θ_r, ϕ_r).
3) Measurement Execution:
    a) Program the RIS for the desired configuration.
    b) Perform an angular scan with the receive antenna across a spherical range (ϑ_n, φ_m) that covers the main beam and sidelobes.
    c) For each angular point, measure and record:
        i) Absolute received power (dBm).
        ii) Angular radiation pattern.
        iii) 3 dB beamwidth (azimuth and elevation).
        iv) Sidelobe levels (relative to main lobe).
    d) Repeat for additional RIS configurations.

6.5.3 Notes and Considerations

Parameters such as directivity can be extrapolated. All RIS results shall be expressed relative to the baseline incident beam characteristics to isolate RIS effects. The angular step size in the scan shall be sufficiently fine to resolve the main lobe and sidelobes (e.g. ≤ 0,5°). Maintain consistent transmit/receive polarization during baseline and RIS measurements. If the RIS supports polarization conversion, measure both co- and cross-polarized components. Ensure the receive system dynamic range is sufficient to capture sidelobe levels accurately. Repeat scans for each configuration multiple times and average results to reduce variability. Report standard deviation.

6.6 Total Reflected/Refracted Power Measurement Methodology

6.6.1 Measurement Setup

The measurement setup required for this parameter is described in clause 5.1. Perform the steps mentioned in clause 6.1.2.

6.6.2 Measurement Procedure

1) RIS Initialization:
    a) Mount RIS on the rotary platform.
    b) Ensuring centre alignment with the CATR or DFF coordinate system.
    c) Connect the RIS controller and verify software access.
2) Incident Wave Setup:
    a) Set incident wave parameters through positioning of the CATR or DFF (θ_i, ϕ_i).
    b) Program RIS to generate a beam toward the desired radiated direction (θ_r, ϕ_r).
3) Measurement Execution:
    a) Program the RIS to the test configuration.
    b) Using the receive antenna, perform an angular scan over the defined azimuth/elevation range.
    c) For each angular position, measure and record the received power (dBm).
    d) Sum the received power contributions across all angular positions in a spherical range (ϑ_n, φ_m) (accounting for antenna gain and calibration) to compute **total radiated power**.
    e) Repeat measurements for all RIS configurations under test.
4) Data-Post Processing:
    a) Integrate the measured power pattern over the scanned angular space to estimate the **total radiated/reflected/refracted power**.
    b) Normalize results against the baseline incident power to determine RIS efficiency.
    c) Report for each RIS configuration:
        i) Total radiated power (absolute, dBm).
        ii) Normalized power relative to incident beam (% or dB).
        iii) Spatial distribution (polar or Cartesian plots).
        iv) Peak vs sidelobe contributions.
        v) Uncertainty estimates from repeated measurements.

6.6.3 Notes and Considerations

For RIS programmed to generate multiple beams or scattering distributions, integrate across the entire angular radiation pattern to capture the complete power budget. Ensure scanning resolution is fine enough to capture narrow beams and sidelobe variations (e.g. ≤ 0,5°). If the RIS supports polarization control or conversion, measure both co-polarized and cross-polarized power contributions. The receiver system shall have sufficient dynamic range to capture both strong main beams and weak sidelobes without saturation or clipping.

6.7 Reflected/Refracted Beam Modulated Signal Quality Measurement Methodology

6.7.1 Measurement Setup

The measurement setup required for this parameter is described in clause 5.1. Perform the steps mentioned in clauses 6.1.2 and 6.1.3.

6.7.2 Measurement Procedure

1) RIS Initialization:

    a) Mount RIS on the rotary platform.

    b) Ensuring centre alignment with the CATR or DFF coordinate system.

    c) Connect the RIS controller and verify software access.

2) Incident Wave Setup:

    a) Set incident wave parameters through positioning of the CATR or DFF (θ_i, ϕ_i).

    b) Program RIS to generate a beam toward the desired radiated direction (θ_r, ϕ_r).

3) Equipment Initialization:

    a) Power on the Vector Signal Generator (VSG) and Vector Signal Analyser (VSA).

    b) Allow sufficient warm-up time to ensure stable operation.

    c) Verify connections, power levels, and synchronization between instruments.

4) Measurement Execution:

    a) Configure the VSG to generate a reference modulated signal with the following defined parameters.

EXAMPLE: 64-QAM, 5G NR waveform, 100 MHz bandwidth, specified subcarrier spacing, centre frequency in the FR1/FR2 band, and a defined output power.

    b) Measure and record the EVM at the VSA.

    c) Average over N captures (e.g. N = 10) to reduce statistical variability.

5) Measurement Execution:

    a) Configure the RIS for the intended reflection or refraction state, pointing at the NF probe placed at the minimal focal distance of the RIS.

    b) Measure the reflected/refracted signal with the VSA.

    c) Record the EVM and corresponding SNR at the receiver.

    d) Average over N captures for each RIS state.

    e) Repeat the measurement across a representative set of RIS configurations (e.g. multiple beam steering angles, beam focusing states, or codebook entries).

6) Data Post-Processing:

    a) For each RIS configuration, compute the EVM degradation relative to the baseline:

        i) Absolute: $\Delta EVM = EVM_{RIS} - EVM_{In}$

        ii) Relative: Degradation (%) = $\frac{EVM_{RIS}-EVM_{In}}{EVM_{In}} \times 100$

    b) Summarize the results as a set of EVM values and degradations for each RIS configuration.

    c) Plot EVM vs RIS configuration (e.g. beam angle).

    d) Report results together with:

        i) Baseline EVM value.

        ii) Signal parameters (modulation, bandwidth, frequency, power, subcarrier spacing).

        iii) RIS configuration identifiers.

        iv) Averaging method and number of captures.

        v) Estimated measurement uncertainty.

6.7.3 Notes and Considerations

The baseline EVM is mandatory. Report only the difference between RIS-influenced and baseline values. Ensure the received power is sufficiently high to avoid noise-limited EVM. Record both EVM and SNR for traceability. Evaluate multiple RIS states to ensure results reflect the full operational space (e.g. beam steering range, focusing, polarization). Higher-order schemes (e.g. 1024-QAM) are more sensitive to distortion and provide stricter evaluation of RIS performance.

6.8 Static Configuration Power Consumption Measurement Methodology

6.8.1 Measurement Setup

The measurement setup required for this parameter is described in clause 5.1. Perform the steps mentioned in clause 6.1.2.

6.8.2 Measurement Procedure

1) RIS Initialization:
    a) Mount RIS on the rotary platform.
    b) Connect the RIS controller and verify software access.
2) Incident Wave Setup:
    a) Set incident wave parameters through positioning of the CATR or DFF (θ_i, ϕ_i).
    b) Program RIS to generate a beam toward the desired radiated direction (θ_r, ϕ_r).
3) Measurement Execution:
    a) Measure the steady supply voltage and current for a moderate duration to capture a stable baseline.
    b) Record environmental conditions and device state (firmware version, configuration).
    c) Repeat the measurement for a small set of representative static configurations. Include any known worst-case biasing states.
4) Data Post-Processing:
    a) For every measured condition, record: averaged voltage and current, the device configuration identifier, ambient temperature, and firmware/build tag.
    b) Report results as clear, labelled numbers for: static for each configuration, and any observed worst-case condition.

6.8.3 Notes and Considerations

Ensure the RIS is not actively switching states during the measurement. Some devices periodically refresh internal settings, which shall be disabled. The official parameter should be measured at the RIS input connector, so the figure represents what the product draws from its supply. If the measurements are done upstream, report the measurement point and any cable or injector losses separately. Background communication, logging, or debug features can add measurable power. Put the controller in the mode representative of real-world static operation. Power can change slightly as the board and regulators warm up. Either stabilize the temperature before the final reading or report both initial and stabilized values. Use a measurement window that is long enough to smooth out occasional housekeeping or telemetry bursts. If the device produces periodic activity, ensure the window captures several cycles.

6.9 RIS Reconfiguration Time Measurement Methodology

6.9.1 Measurement Setup

The measurement setup required for this parameter is described in clause 5.1. Perform the steps mentioned in clause 6.1.2.

6.9.2 Measurement Procedure

1) RIS Initialization:
    a) Mount RIS on the rotary platform.
    b) Ensuring centre alignment with the CATR or DFF coordinate system.
    c) Connect the RIS controller and verify software access.
2) Incident Wave Setup:
    a) Set incident wave parameters through positioning of the CATR or DFF (θ_i, ϕ_i).
    b) Program RIS to generate a beam toward the desired radiated direction (θ_r, ϕ_r).
3) Measurement Execution:
    a) Record the received power in the initial configuration until it stabilizes.
    b) Command the RIS to switch to a different beam direction. Observe and record the change in received power.
    c) Command the RIS to switch back to the original configuration used in step (a).
    d) Measure the time taken for the received power to return to the previously recorded stable level.
    e) Repeat the switching process across several representative pairs of configurations (e.g. small angular changes, large angular changes, and worst-case configurations).
4) Data Post-Processing:
    a) For each switching event, log:
        i) Initial configuration (beam ID, target direction).
        ii) Final configuration (beam ID, target direction).
        iii) The observed reconfiguration time.
        iv) Average the results across multiple repetitions to ensure repeatability.
        v) Summarize the results in a table showing typical, minimum, maximum, and worst-case reconfiguration times.

6.9.3 Notes and Considerations

Clearly state whether it is measured from the moment the control command is issued, from when the controller begins switching, or from when the output beam reaches a defined percentage of the new steady state. Ensure this definition is consistent across tests. Use instruments with a time resolution significantly smaller than the expected switching time. Define what "stabilized power" means (e.g. within a small percentage of the final level for a defined duration).

The reported time may include both controller communication delays and RIS hardware switching delays. If possible, separate them for diagnostic purposes. Perform multiple measurements of the same transition to account for jitter and variability. Present results as a range (minimum, maximum, average) and indicate the test conditions, configurations, and instruments used.

7 Considerations for Future Testing and Validation

This normative document has defined measurement methods for a very limited set of RIS parameters by design. However, additional RIS parameters can be defined and measured.

History

Version	Date	Status
V1.1.1	February 2026	Publication