EARTH STATION VERIFICATION ASSISTANCE

ESOG 130 – ISSUE 4

June 2024

EUTELSAT GROUP

Earth Station Verification Assistance (ESVA)

ESOG 130 – Issue 4

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Earth Station Approval Office

Contents

FOREWORD

The Eutelsat S.A. Systems Operations Guide (ESOG) is published to provide all Eutelsat S.A. space segment users with information that is necessary for successful operation of earth stations within the Eutelsat S.A. satellite system.

The ESOG consists of 2 Volumes. They contain, in modularised form, all the necessary details, which are considered important for the operations of earth stations.

Volume I focus on Earth Station and Antenna Approvals, System Management and Policy aspects.

Volume II describes the initial line-up of satellite links between earth stations and the commissioning of earth stations for Eutelsat S.A. services. The modules which are contained in this Volume relate to the services provided via Eutelsat S.A. satellites.

The ESOG can be obtained either by requesting a printed version from Eutelsat S.A. or by downloading it in PDF from the Eutelsat S.A. Website:

http://www.Eutelsat.com/en/support/earth-stations/esog.htm

1 OVERVIEW ESOG MODULES

1.1 VOLUME I: Eutelsat S.A. SYSTEM MANAGEMENT AND POLICIES

Earth Station Standards	Module 100
Earth Station Access and Approval Procedures	Module 110
Earth Station Type Approval	Module 120
Earth Station Verification Assistance (ESVA)	Module 130
Operational Management, Control, Monitoring & Coordination	Module 140
VSATs’ ODUs Type Approval	Module 160

1.2 VOLUME II: Eutelsat S.A. SYSTEMS OPERATIONS AND PROCEDURES

Digital Services Handbook	Module 210
VSAT Handbook	Module 230
Manual and auto-deploy terminals Handbook	Module 260

2 INTRODUCTION

Eutelsat Group approval procedures require the submission of technical earth station data to demonstrate compliance with the relevant specifications (ESOG Vol. I, Module 100 and Module 110 refer).

In general, this can be achieved by the following means:

- **Satellite-Based ESVA (SB-ESVA)**
    - Eutelsat ESVA facilities: are generally conducted between a Eutelsat Reference Station (ERS)
    - Third-party satellite-based measuring facilities, under the exclusive discretion of Eutelsat Earth Station Approval Office
- **Drone-Based ESVA (DB-ESVA)**
    - Eutelsat approved drone-based measuring systems
- **Facilities agreed by Eutelsat** such as:
    - far field test ranges, compact ranges, near field ranges, etc.
- Some combination of these facilities

The purpose of conducting verification tests is to prove that the Station Under Test (SUT) and/or associated equipment will comply in all respects with the mandatory performance characteristics as set forth in the relevant specifications.

Verification testing involving the use of a Eutelsat satellite shall be conducted in coordination with the Eutelsat ESVA team and/or a qualified corresponding earth station.

ESVA testing may be required upon request from Eutelsat or the earth station owner. The ESVA testing may generally be required:

- for new earth stations prior to commencement of service.
- for existing earth stations after major modifications (especially of the RF front end).

Typical parameters which shall be measured during a Eutelsat ESVA test and included in the standard program presented in this Module are:

1. Earth Station EIRP
2. Transmit Gain
3. Transmit Sidelobes
4. Transmit Polarisation Isolation
5. Receive Gain
6. G/T
7. Receive Polarisation Isolation
8. Receive Sidelobe Patterns

For small earth stations (aperture <2 m), such as VSAT or SNG terminals, which are furnished with manual antenna pointing, the pattern measurements may be very time consuming and inaccurate if conducted from a remote site. Such stations may therefore be more conveniently Type Approved or Characterised following ESOG 120 guidelines.

3 ESVA REQUIREMENTS

This section includes the conditions which ensure smooth implementation of ESVA, namely:

- prevention of interference to existing traffic,
- consistency of measurement results,
- efficient coordination of testing.

The rules given hereafter apply to **all** ESVA activities, including full scale ESVA programmes or parts of it and repetitions, and for both Satellite-based and Drone-based testing.

3.1 Earth Station Preparation

The correct function of all relevant earth station equipment must be verified by preliminary in-station testing in order to avoid delay of ESVA and interference to existing traffic during the initial space segment access. As far as possible, the in-station test shall prove compliance of the equipment with the Eutelsat specification. Additional parameters which are required for ESVA such as:

- antenna slew speed for azimuth and elevation,
- power meter coupling factor and post coupler loss for each TX chain,
- receive coupling factor and receive feed loss if applicable

shall be measured during the preparational phase and results shall be communicated to Eutelsat.

Before the commencement of the ESVA, the SUT must be already configured for the forthcoming measurements as shown in Figure 5.1. The station shall acquire and track the satellite foreseen for testing and the equipment shall be set to parameters defined in the Eutelsat test plan.

To eliminate eventual problems at this stage, it is strongly recommended to perform a G/T and a receive sidelobe pattern test, using the satellite beacon.

3.2 Test Coordination

Planning of ESVA activities is based on the initial ES registration sent by the applicant responsible for the ES operations to the ES approval Office of Eutelsat:

1. online through the Eutelsat extranet portal (https://services-cas.eutelsat.fr/cas/login) or
2. by mail at esapproval@eutelsat.com, by completion of the procedures reported in the ESOG Module 110, and the form reported in its Annex A. The form may be used for already approved stations.

The completion of the ESVA questionnaire reported in Annex B is then required in preparation for the ESVA.

An advance notice of normally 2 weeks prior to the tentative ESVA date, should be given to ensure smooth implementation. Eutelsat issues a test plan which includes the confirmation of the availability of the ESVA facility (i.e. space segment and reference station). It must be born in mind that, due to operational needs, the test plan may be subject to changes at any time on short notice. The test plan contains the time schedule, technical and geographical parameters, contact points and notes required for preparation and execution of the subject test.

Immediately after conclusion of testing, the ERS operator forwards to the applicant a provisional test report to the test manager of the SUT. Nevertheless, all data is subject to confirmation by Eutelsat who will issue the final test report with the conclusions usually within 4 weeks. In case of heavy non-compliances, a summary report is delivered faster to allow discussions between the responsible of the ES and the Eutelsat Approval Office.

This final report comprises results and parameters in detail and, will be forwarded to the applicant for ESVA.

3.3 Space Segment Access

Prior to commencement of any test programme, the Station Under Test (SUT) must contact the Eutelsat Reference Station (ERS). The contact of the ERS operator is provided by Eutelsat ES approval team. The reference station will then coordinate with the Eutelsat CSC the forthcoming test activities. The reference station must obtain the approval of the CSC for space segment access before the start of testing and report to the CSC when testing is terminated or in case of significant interruptions.

Note: the ERS operator shall double check with the CSC the exact nominal uplink EIRP before starting any transmission.

Furthermore, each space segment access by a station under test must be endorsed by the ERS. When transmitting, the SUT must maintain contact with the reference station at all times. In particular, the SUT must ensure permanent presence of staff at the phone to guarantee instant reaction on ERS directives. If the communication link fails, the Station Under Test must immediately cease transmissions and attempt to re-establish contact with the reference station. It is therefore essential that suitable telephone equipment is available and accessible at all relevant sites (e.g.: antenna hub, control room etc.) throughout the testing.

If other means of communication are preferred by the SUT, e.g. videoconferencing tools, they must be agreed with the ERS in advance and tested before the ESVA begin to ensure the respect of the test schedule. The detailed procedures compulsory to each space segment access are prescribed in paragraph 4.1 of this document.

3.4 Weather Conditions

Atmospheric attenuation and wind may considerably degrade the accuracy of measurements. It is therefore preferable to conduct ESVA testing during clear sky conditions with light wind-speeds. If, due to operational needs, testing must be performed during deteriorated weather conditions, special consideration will be given during results evaluation. In case of discrepancies, partial or complete repetition of the test programme will be agreed.

3.5 Antenna Alignment

All ESVA tests are based on the perfect initial alignment of the antenna under test. Great care must be taken by the SUT when optimizing the antenna pointing, i.e. peaking.

Peaking must be performed initially, i.e. prior to testing,

1. after each antenna movement (e.g. during G/T, antenna sidelobe measurements etc...),
2. after interruption of the test programme.

The SUT must ensure that optimized pointing is achieved before all measurements. On request, the ERS will provide assistance and guide the SUT.

3.6 Check List

Completion of the following checklist by the SUT, before the start of an ESVA activity will prevent delays.

- Earth Station equipment functions compliant to specifications:
    - Antenna, drive and tracking system,
    - HPA,
    - LNA (LNB, LNC),
    - Up and Down-Converters,
    - Station control and waveguide switching,
    - TX chains have been checked for spurious emissions;
- Test equipment is available, calibrated and warm-up period respected:
    - RF synthesizer (frequency drift measured),
    - RF power meter (auto-zero, calibration factor set),
    - Spectrum Analyser (calibration procedure completed),
    - Plotter (connected, calibrated);
- TX power meter coupling factors and post coupler losses measured for each TX-chain, results sent to Eutelsat;
- Satellite as per test plan acquired, antenna pointing optimized (peaking);
- Polarization alignment optimized;
- Appropriate means for communication during the test are available;
- [optional] G/T and antenna RX-pattern;

4 TEST EQUIPMENT

The measurement equipment which must be available at the SUT during ESVA, is summarized hereafter. The lack of measurement equipment could lead to incomplete results. Prior to the start of ESVA, the station operator shall ensure that all test equipment:

- functions correctly,
- warm-up periods are respected,
- calibration procedures and timing have been respected.

For completion of test records, the test equipment types shall be reported to Eutelsat.

4.1 RF Power Meter

The RF power meter is required for the measurement of the transmit power and calibration of the station EIRP. At SUT equipped for pilot injection, the power meter is furthermore required for measurement of the pilot level. Generally, the dynamic range of the power sensor should be dimensioned to include the full range of transmit power required during operations and ESVA. Before measurements, the operator shall set the appropriate calibration factor and execute an "Auto-Zero" cycle to ensure accurate results.

4.2 RF Spectrum Analyser

The spectrum analyser is required for execution of the space segment access test, the measurement of the G/T ratio and the antenna receive sidelobe pattern. Furthermore, it is used for monitoring of the receive frequency range and the HPA output. To facilitate the G/T measurement, it is preferable to use an analyser which permits a direct noise level readout (noise marker) in dBm/Hz. Both RF and IF frequency bands of the SUT should be covered by the analyser.

The spectrum analyser shall have the possibility to store the captured spectrum and measurement into digital files that will be exported and shared with Eutelsat.

4.3 Signal Source

For the assessment of transmit parameters, a stable signal source is required at the station under test. To prevent interference when testing is conducted via transponders bearing traffic, to obtain a maximum dynamic range and accuracy, the frequency drift, residual modulation and level variation must be kept at a minimum.

The short-term frequency drift measured at RF level (e.g. 14 GHz), should be less than 10 Hz per 30 minutes (typical figure: 5 x 10^{-10}/day ageing rate). Therefore, a synthesized source is required for generation of the test signal. Alternatives like the operational modulator (preferably with clock locked to an external high stability reference) require prior endorsement by Eutelsat and should be considered only in exceptional case.

4.4 Temporary Approval or Modification of an Existing Authorisation to Operate

Earth stations are sometimes used to enable operators to utilise satellites for unforeseen ad-hoc events, requiring urgent access to the space segment.

Eutelsat S.A. may extend or modify an existing authorisation for operation at a different location, or to grant temporary approval for the provision of commercial service of an ad-hoc nature (e.g. Emergency Telecommunication Services) for a single short duration purpose and within established Eutelsat S.A. policies.

5 SPACE SEGMENT ACCESS TEST

5.1 Test Objectives

1. Ensure the correct alignment with parameters set by the Eutelsat test plan.
2. Prevent any interference to existing services.
3. Evaluate basic carrier parameters as frequency drift and EIRP fluctuation in order to estimate possible impairments to test results and to adapt instrument settings at ERS accordingly.

5.2 Principle

Initially, the ERS transmits a marker carrier which shall be identified by the SUT to prove correct pointing. Upon authorization by the ERS, the SUT transmits at low EIRP. The ERS will check value and fluctuation of carrier level and frequency.

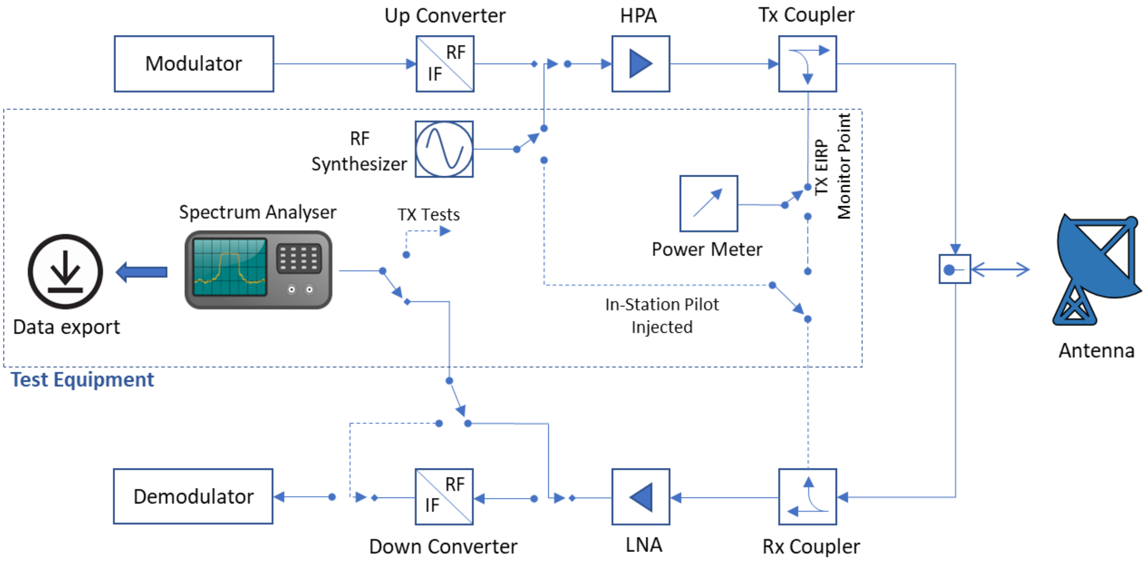


Figure 5.1: SUT Configuration during ESVA.

5.3 Step-by-Step Procedure

A. ACQUISITION OF SATELLITE

Step 1: Upon successful completion of the independent in-station tests as described under Section 3.1 above and **PRIOR** to the transmission of **ANY** signal, the SUT shall identify, acquire and track the specified satellite.

Step 2: SUT set the polarization angle according to the parameter provided in the Eutelsat test plan. For further optimization, SUT shall monitor the cross-polar component of the satellite beacon signal. The SUT shall slowly rotate the polarization plane until the level reaches a minimum.

NOTE: Where this procedure is not applicable (e.g. for transmission on X polarization from SUT equipped with a 2-port feed), another suitable signal on the satellite may be used.

B. ACCESS COORDINATION

Step 3: Immediately prior to the scheduled commencement of ESVA (i.e. ~ 5 minutes) the SUT shall establish and maintain phone contact with ERS. SUT shall communicate sky and wind conditions and information on all details which may impair testing.

Step 4: ERS shall contact the Eutelsat CSC to obtain authorization for space segment access and confirmation of the nominal uplink EIRP to be used during the tests

Step 5: In accordance with parameters of the Eutelsat test plan, ERS transmit a marker carrier.

Step 6: On request of ERS, SUT monitor the allocated down-link frequency range. SUT reconfirm presence of the marker carrier to ERS.

Step 7: ERS double-checks identification of marker carrier by SUT. Proceed to Step 9 only if identification is affirmative.

C. TRANSMISSION BY SUT

Step 8: Under direction of the ERS, SUT transmit a carrier at the assigned frequency and EIRP. (The initial EIRP is in general in the order of 50 dBW and it must never exceed 55 dBW).

NOTE: The SUT must **CEASE** transmissions immediately if the communications link to the ERS fails or if the presence of staff at the SUT phone is interrupted. This rule applies to this and all following tests where the SUT transmits.

Step 9: SUT notify the ERS of the activation of its carrier.

Step 10: If the ERS does not detect the carrier under test within the allocated frequency range, the SUT shall CEASE transmissions. The SUT shall again verify its set-up on:

- correct satellite acquisition,
- polarization plane alignment,
- transmit frequency and
- transmit EIRP

and return to Step 8.

Step 11: SUT monitor the receive level of its own transmitted carrier. ERS request SUT to slew SUT antenna first in azimuth and then in elevation to reconfirm correct pointing.

Step 12: SUT report TX power meter reading to ERS and maintain frequency setting throughout following tests.

5.4 Example for Spectrum Analyser Setting

Reference level	: As applicable
Attenuator	: As applicable
Scale	: 1 dB/Division
Centre frequency	: SUT down-link frequency as per
	: test plan (11 or 12 GHz range)
Span	: 200 Hz
Resolution bandwidth	: Auto
Video bandwidth	: Auto
Video averaging	: OFF
Sweep time	: Auto
Marker noise	: OFF
D-Marker	: OFF
Trace	: Clear write A
	: Max. Hold BDisplay line : OFF

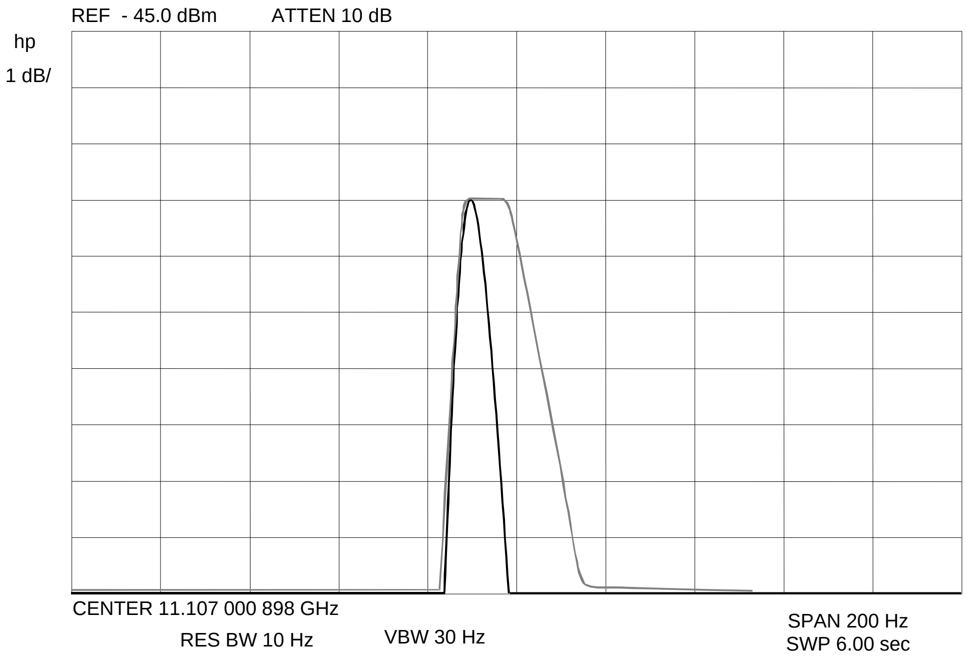


Figure 5.2: Spectrum Analyser Display at ERS during Space Segment Access Test (Verification of frequency stability).

6 POLARIZATION ALIGNMENT

6.1 Test Objectives

To accomplish optimum alignment of the polarization plane of the SUT antenna with the receive antenna of the satellite, in order to guarantee accurate ESVA measurement results.

For SUT equipped with 4-port feed, to evaluate isolation of transmit polarization planes (X and Y for linear polarization or LH and RH for circular polarization).

6.2 Principle

The SUT transmits a carrier via the co-polar channel while the ERS monitors the residual carrier level in the cross-polar channel. Under control of the ERS, the SUT slowly rotates its polarization plane. The ERS records the variation of the cross-polar level and guides the SUT to the angular position where the minimum level is detected (nulling).

The following configurations must be considered:

1. the down-link frequency bands of the co-polar and cross-polar channel are different.
2. the co-polar channel is set to minimum gain and the cross-polar channel is set to maximum gain

For SUT equipped with a 4-port feed, and in order to verify the isolation of the polarization planes, the alignment procedure is executed via both polarizations (X and Y, LH and RH). For linear polarizations, the angle indications for the optimum positions are read for X and Y polarization and then compared.

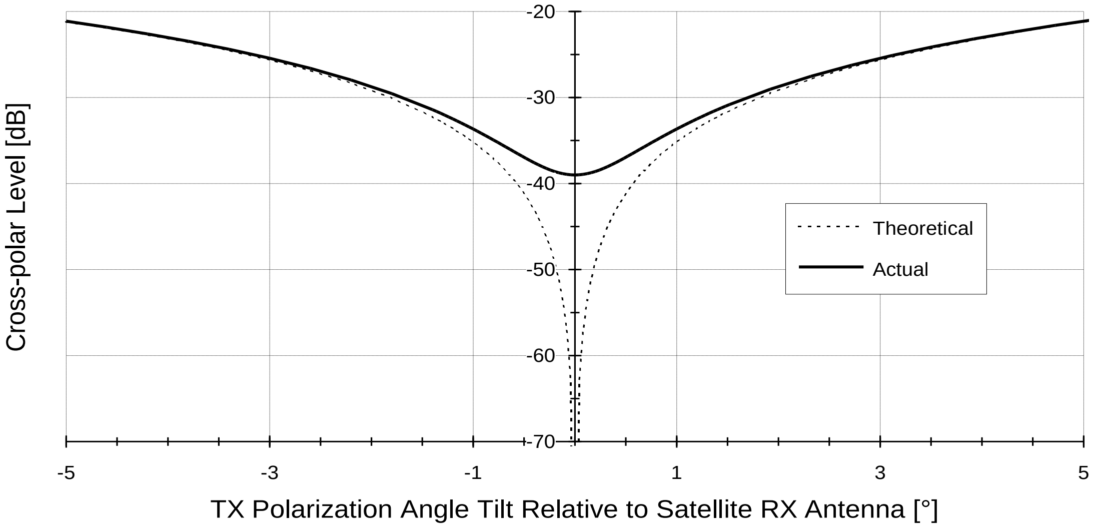


Figure 6.1: Cross-polar Signal Level as Function of Polarization Plane Alignment.

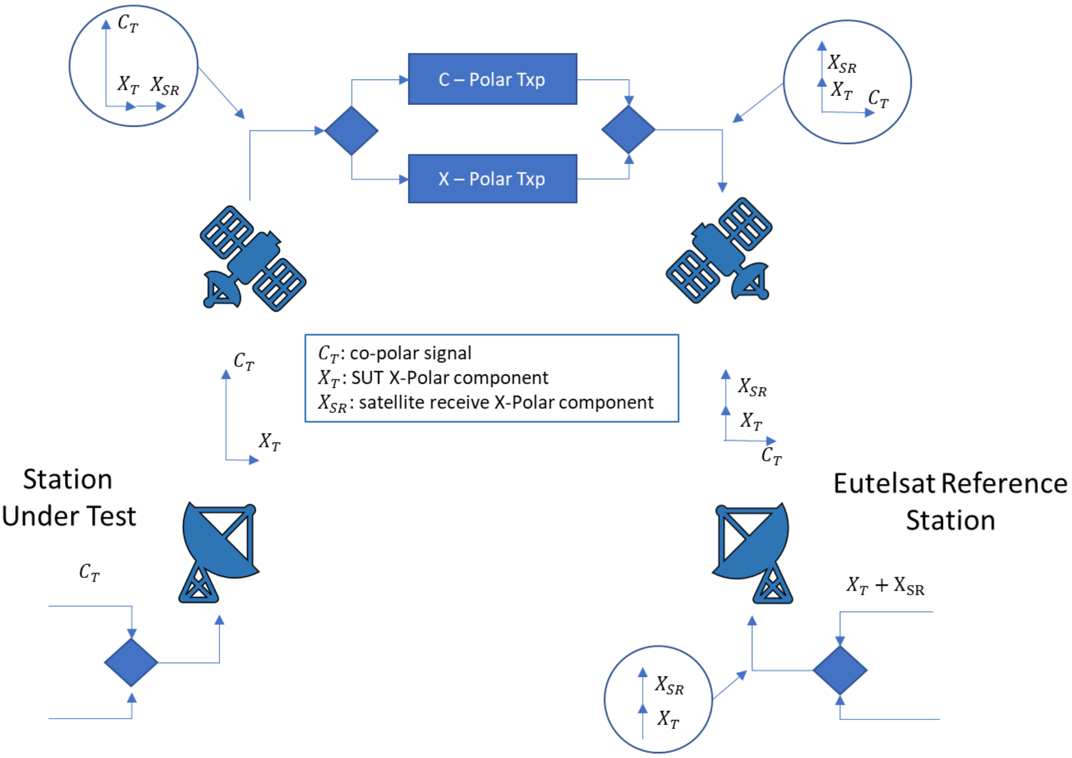


Figure 6.2: Schematic Representation of Polarization Alignment for linear polarization.

6.3 Step-by-Step Procedure

[Linear and circular polarizations]

Step 1: SUT set antenna tracking system to manual mode.

Step 2: Under direction of ERS, SUT transmit a carrier at the frequency as established during the Satellite Access Test and set the EIRP as per test plan.

Step 3: ERS record the level of the cross-polar component of the carrier under test.

[Linear polarization only]

Step 4: In coordination with the ERS, SUT rotate slowly the polarization plane in the following way:

1. Rotate towards the anti-clockwise limit. (e.g.: –5° relative to start position).
2. Rotate via the optimum to the clockwise limit. (e.g.: +5° relative to start position).

NOTE: Values of angles are positive if the rotation is clockwise as seen from the earth station towards the satellite.

Step 5: ERS guide SUT to acquire the optimum position (i.e. where polarization plane of SUT and satellite receive antenna match and a minimum in cross-polar level is observed).

Step 6: SUT secure feed position. ERS verify that the optimum is maintained.

Step 7: SUT report the polarization angle indication to the ERS. If the SUT is not equipped with indicators, the feed position shall be marked.

6.4 Example for Spectrum Analyser Setting

Reference level: : As applicable
Attenuator: : As applicable
Scale: : 5 dB/Division
Centre frequency: : SUT down-link frequency as per
: test plan (11 or 12 GHz range)
Span: : 0 Hz
Resolution bandwidth: : 100 Hz
Video bandwidth: : 3 Hz
Sweep time: : 100 s or a appropriate
Marker noise: : OFF
∆-Marker: : Disabled
Trace: : Clear write ADisplay line: : Set to
minimum

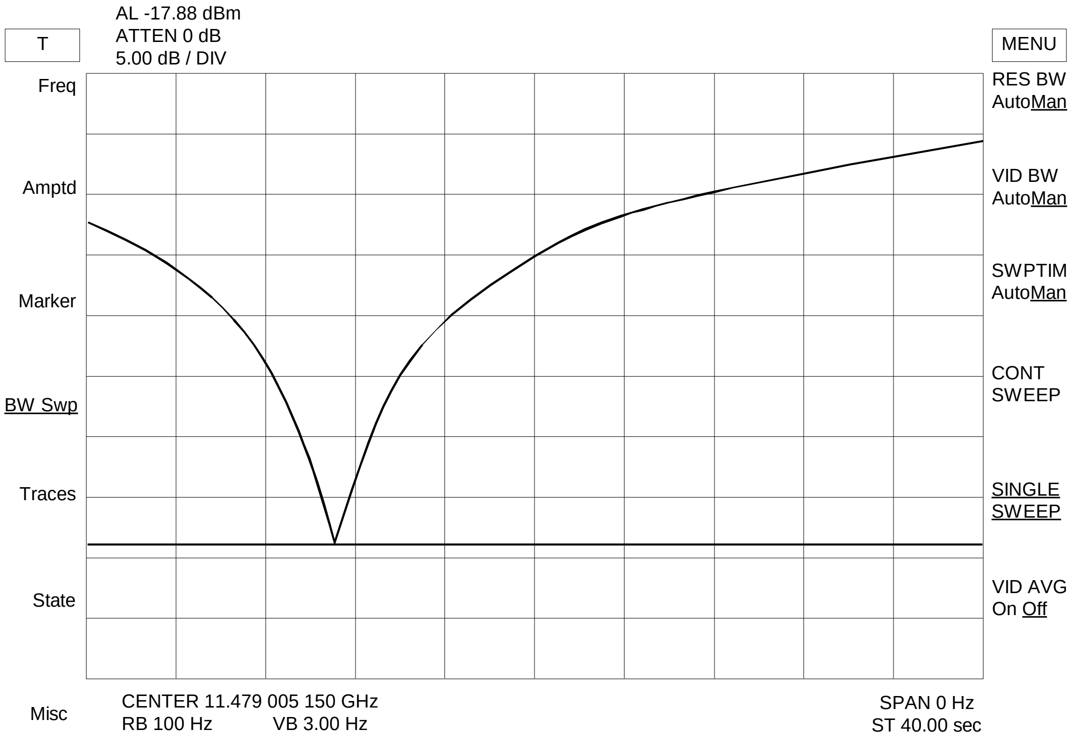


Figure 6.3: Spectrum Analyser Display during Polarization Plane Alignment.

7 EIRP (INCLUDING TRANSMIT GAIN)

7.1 Test Objectives

1. Reconfirm the SUT EIRP calibration prior to commencement of operations,
2. Assess the linearity of the EIRP indication at the SUT,
3. Evaluate the transmit gain of the antenna at the SUT,
4. Measure the maximum EIRP capability of the SUT.

7.2 Principle

7.2.1 Power Balance

The EIRP measurement is based on the up-link power balance technique where the EIRP of the SUT is compared against an accurately calibrated EIRP radiated from the ERS. Corrections for the satellite antenna receive gain (off-axis loss), path loss and atmospheric loss due to the distant location of both stations are applied to obtain the value of the SUT EIRP. To minimize the influence of amplitude-frequency response of the satellite transponder and ERS, the difference of carrier frequencies of SUT and ERS is small (generally < 100 kHz). Carrier levels of both SUT and ERS are equal or differ by no more than 0.2 dB to avoid inaccuracies due to the non-linearity of the satellite TWT.

The following formula applies:

$$\begin{aligned} EIRP_{SUT} = EIRP_{ERS} + &\left(L_{oa,SUT} - L_{oa,ERS}\right) \\ &+ \left(L_{at,SUT} - L_{at,ERS}\right) \\ &+ \left(L_{fs,SUT} - L_{fs,ERS}\right) - \Delta \end{aligned}$$

Equation 7-1

where:

L_{oa}	: Off-axis Loss	[dB]
L_{fs}	: Free space Loss	[dB]
L_{at}	: Atmospheric Loss	[dB]
Δ	: Small difference between EIRP of carriers	[dB]

Δ is positive when: $EIRP_{SUT} < EIRP_{ERS}$

Δ is small when: $|\Delta| < 0.2\ dB$

L_{at} is measured at the ERS by radiometer during the test. For SUT where no radiometer is available, 0.3 dB shall be assumed for clear sky conditions.

The values of free-space loss (L_{fs}) and off-axis loss (L_{oa}) will be indicated in the relevant Eutelsat test plan.

7.2.2 EIRP Calibration

At power balance condition, the SUT reads the transmit power meter. This value which corresponds to a (now) accurately known EIRP, shall be noted and used as reference for future operations.

In cases where the power reading during operations will not be derived from the same test point, it is essential to include the operational test point in the calibration procedure.

7.2.3 Linearity of EIRP Indication

EIRP calibration is repeated at several (e.g. 4) different EIRP levels. The range shall include the future operational EIRP of the SUT. It shall thus provide a reliable base for determination of any EIRP value required during forthcoming SUT operations

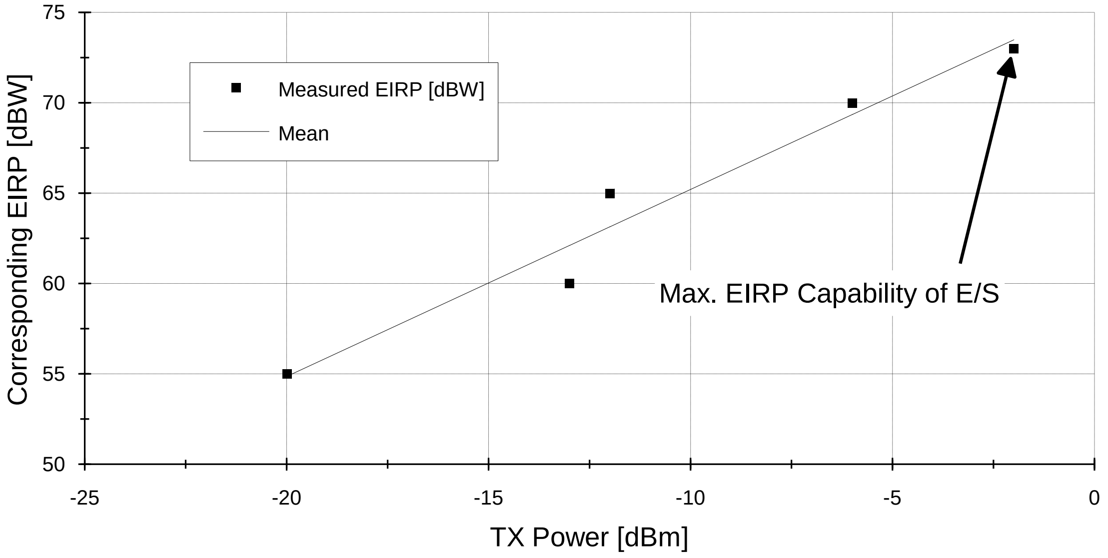


Figure 7.1: Linearity of TX Power Indication.

7.2.4 Transmit Gain

At known station EIRP the antenna Transmit gain of the SUT may be calculated. During ESVA preparation, transmit power meter coupling factor and loss between transmit coupler and antenna flange (or interface where antenna gain is defined) have to be obtained by in-station measurements.

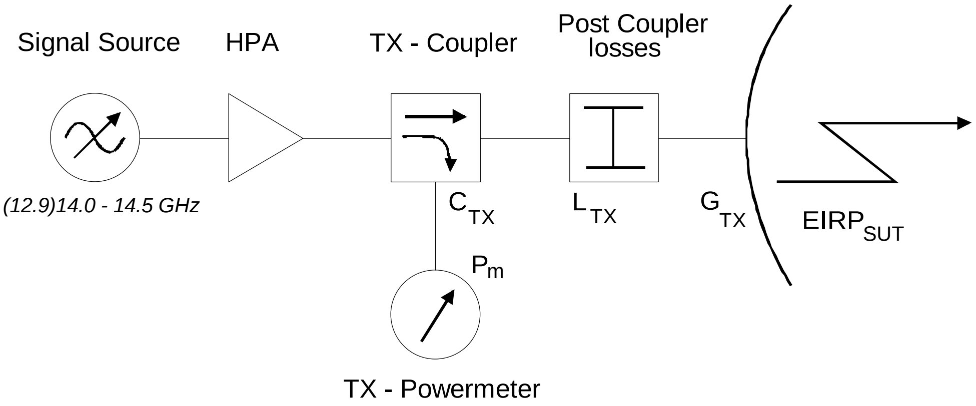


Figure 7.2: Schematic Diagram of SUT TX-Chain.

Using the value of $\mathrm{EIRP}_{\mathrm{SUT}}$ from Equation 7-1 above, the TX gain is given by:

$$G_{TX} = EIRP_{SUT} - P_m + 30 - C_{TX} + L_{TX} \qquad \text{Equation 7-2}$$

where:

P_m	: Transmit power meter reading	[dBm]
C_{TX}	: Transmit coupling factor	[dB]
L_{TX}	: Post coupler Losses	[dB]
30	: Conversion dBW => dBm	[dB]

To appreciate the measurement result, it is compared to the expected value which may be computed as follows:

$$G = 10\log_{10}\left[\eta \cdot a \cdot b \cdot \left(\frac{\pi \cdot f}{c}\right)^2\right] \qquad \text{Equation 7-3}$$

where:

G	: Antenna gain	[dBi]
η	: Efficiency (assumed at 0.65)	[1]
a, b	: Major, minor axis of antenna reflector aperture	[m]
f	: Frequency	[Hz]
c	: Speed of Light (i.e. ~$3\text{x}10^8$)	[m/s]

7.2.5 Maximum EIRP Capability of SUT

Under close control of the ERS, the SUT increases its TX EIRP to the maximum value defined as per test plan or until the saturation of the SUT HPA, whichever is reached first. If applicable, 2 HPAs and phase combiner shall be used during this test. The ERS conducts a power balance and logs the maximum EIRP capability of the SUT as reference for Eutelsat records.

7.3 Step-by-Step Procedure

A. PREPARATION

Step 1: SUT forward the following information to Eutelsat prior to commencement of ESVA:

- Type of feed (2-port, 4-port),

- No of TX-chains,
- Coupling factor (C_{TX}) for each TX chain,
- Post coupling Loss (L_{TX}) for each TX chain.

B. POWER BALANCE

Step 2: ERS transmits the reference carrier at the frequency and EIRP as specified by the ESVA test plan.

Step 3: SUT adjust the EIRP setting to obtain the value specified in the ESVA test plan. Under the direction of the ERS, SUT commence transmission at the frequency established during the Satellite Access Test.

Step 5: If necessary, SUT adjust the EIRP under control of ERS to balance the reference carrier. The difference in level of both carriers as monitored by the ERS shall not exceed 0.2 dB.

Step 6: ERS confirm balance condition.

Step 7: SUT read the TX power meter and report the value to ERS.

C. LINEARITY

Step 8: If required by the test plan, ERS increase the EIRP of the reference carrier. Under control of ERS, SUT increase the EIRP of the carrier under test.

Step 9: Repeat Steps 5 through 7 for each EIRP level to be calibrated.

NOTE: In general, the EIRP calibration is performed for the following levels:

1. Start EIRP.
2. Start EIRP – 5 dB.
3. Start EIRP – 10 dB.
4. Start EIRP – 15 dB.

The start EIRP is specified in the ESVA test plan.

D. MAXIMUM EIRP CAPABILITY

Step 10: Carry out this step only if required by the ESVA test plan, otherwise proceed to Step 12.

Step 11: Under close control of the ERS, SUT increase slowly the EIRP. The increase shall in no case exceed the limits given in the ESVA test plan to avoid interference to traffic or over saturation of the transponder. Below the specified limits, the SUT EIRP may be increased until the SUT HPA or, in case of phase combiner, the two SUT HPAs are saturated. SUT report the TX power reading to ERS. If the SUT Tx chain is equipped with several couplers, the calibration is performed using the coupler which is the nearest to the antenna feed. For cross-reference, at least 1 measurement shall be performed for each Tx chain using another coupler(s) (e.g. HPA RF power meter).

Step 12: If the SUT EIRP capability is superior to the limit stated as per test plan, the ERS will request to commute the SUT TX-chain to dummy load and/or to de-point the SUT antenna far off the geostationary arc. Then, the SUT increases its power to its maximum. The corresponding power meter reading is communicated to the ERS, which will compute the maximum SUT EIRP capability. The SUT reduces its EIRP to the nominal level and ceases transmissions. To proceed with testing, the SUT re-acquires the satellite as previously defined.

Step 13: From the results of the previous power balance, ERS evaluate the maximum EIRP capability of the SUT and the SUT antenna TX gain, and if available, other power indications (e.g. output-power display of HPA).

7.4 Example for Spectrum Analyser Settings

Reference level : As applicable
Attenuator : As applicable
Scale : 1 dB/Division
Centre frequency : SUT down-link frequency as per test plan (11 or 12 GHz range)
Span : 200 kHz
Resolution bandwidth : 30 kHz
Video bandwidth : Auto
Video average : 20
Sweep time : Auto
Marker noise : OFF
Marker : Peak search
Δ-Marker : Δ-peak search
Trace : Clear write A
Display line : OFF

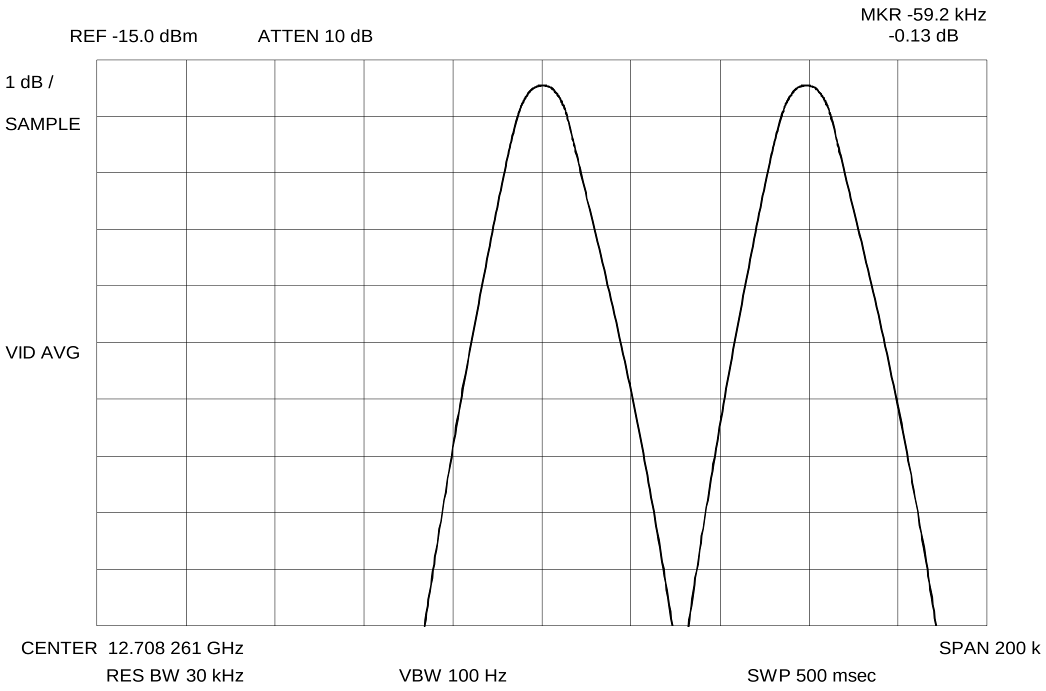


Figure 7.3: Spectrum Analyser Display during Power Balance.

8 TRANSMIT POLARIZATION DISCRIMINATION

8.1 Objectives

To measure the transmit polarization isolation of the Station Under Test at optimized TX polarization alignment. The measurement is carried out at boresight and at 8 samples within the 1 dB contour of the co-polar antenna TX pattern.

8.2 Principle

To measure the EIRP of the SUT, a power balance is carried out via the co-polar channel. Then, the ERS transmits a reference carrier (e.g. 20, 30 or 40 dB below the co-polar level) via the cross-polar transponder. From the difference in level of the reference carrier and the cross-polar component of the carrier under test, the transmit XPD of the SUT is computed. Then in order to verify the performance within the co-polar -1 dB TX contour, the SUT antenna is depointed in azimuth and elevation as described in the figure below:

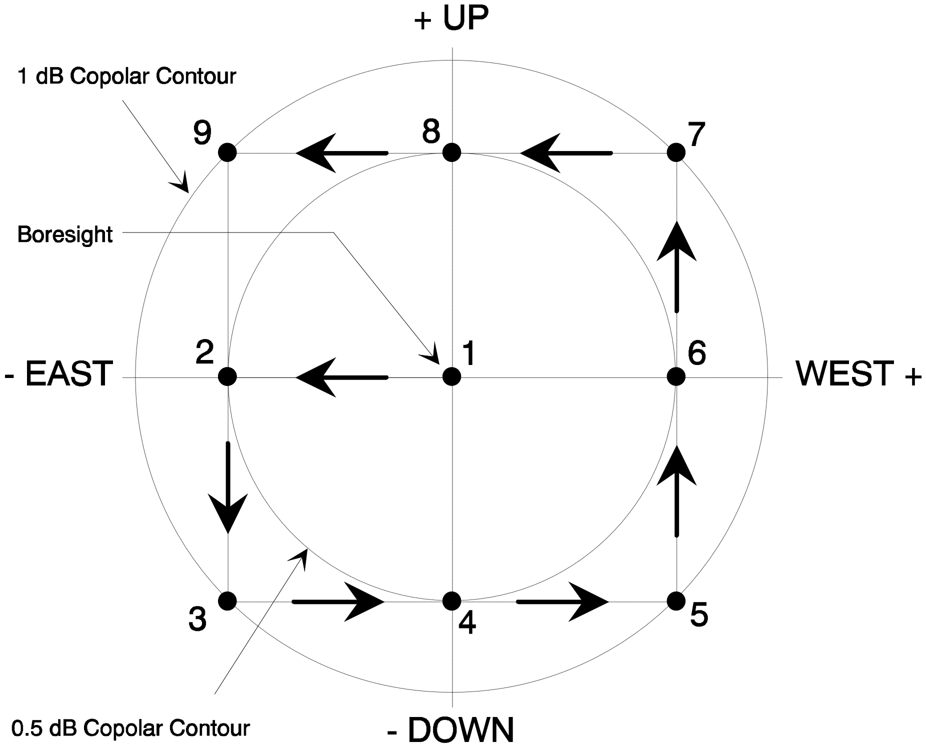


Figure 8.1: Antenna Depointing Sequence during XPD Measurements.

The angular increment for antennas with circular aperture may be estimated by the following expression:

$$AI = \frac{3.978}{d \cdot f}$$

Equation 8-1

where: d : Antenna diameter [m]
f : Frequency [GHz]

(Ref.: CCIR Handbook on Satellite Communications).

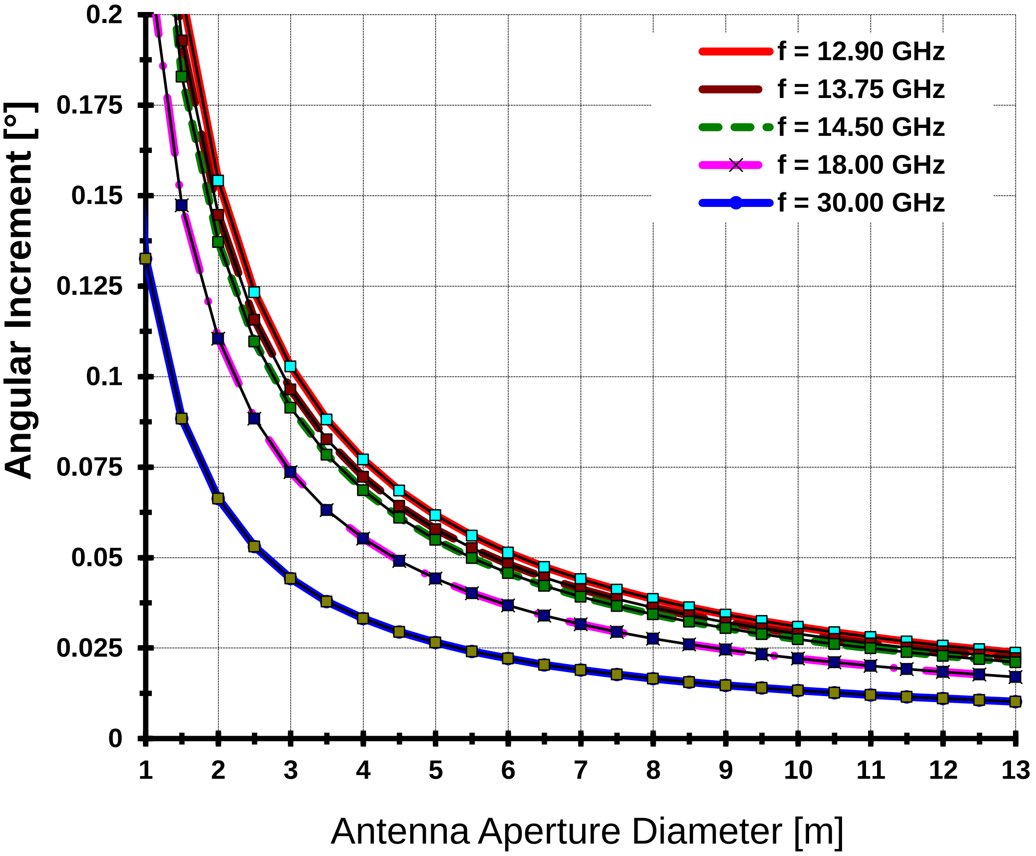


Figure 8.2: Angular Increment (AI) for TX-XPD Measurements.

While the SUT is depointing its antenna, the ERS monitors the variation of the co-polar carrier level and guides the SUT through the defined measurement pattern.

Nine measurements of the difference between the cross-polar component of the carrier under test and the cross-polar reference carrier are taken. Then the test configuration is reversed (i.e. the cross-polar channel becomes co-polar, etc...) and the measuring sequence is repeated. A correction for differences in the up-link off-axis loss between co-polar and cross-polar channel is applied and the XPD of the SUT is computed.

$$XPD = C_{SUT} - X_{SUT}$$

Equation 8-2

$$XPD = (C_{ERS} - X_{ERS}) - L_{OA,ERS,C} + L_{OA,ERS,X} + L_{OA,SUT,C} - D_C + D_X$$ Equation 8-3

Where:

$(C_{ERS} - X_{ERS})$: Difference in EIRP of co-polar and cross-polar reference carrier [dB]

D_C : Difference between co-polar reference carrier and co-polar carrier under test [dB]

D_X : Difference between cross-polar reference carrier and cross-polar component of carrier under test [dB]

L_{OA} : Off axis-Loss [dB]

Index SUT:	Station Under Test
Index ERS:	Eutelsat Reference Station
Index C:	Co-polar
Index X:	Cross-polar

NOTE: D_C, D_X is positive if the level of the reference is greater than the level of the signal under test.

In case of a perfect power balance via the co-polar channel (i.e. D_C = 0 at boresight), the values of D_C are as follows:

Point Nr.	D_C [dB]
1	0
2, 4, 6, 8	0.5
3, 5, 7, 9	1

Table 8.1: Variation of co-polar carrier level during depointing sequence.

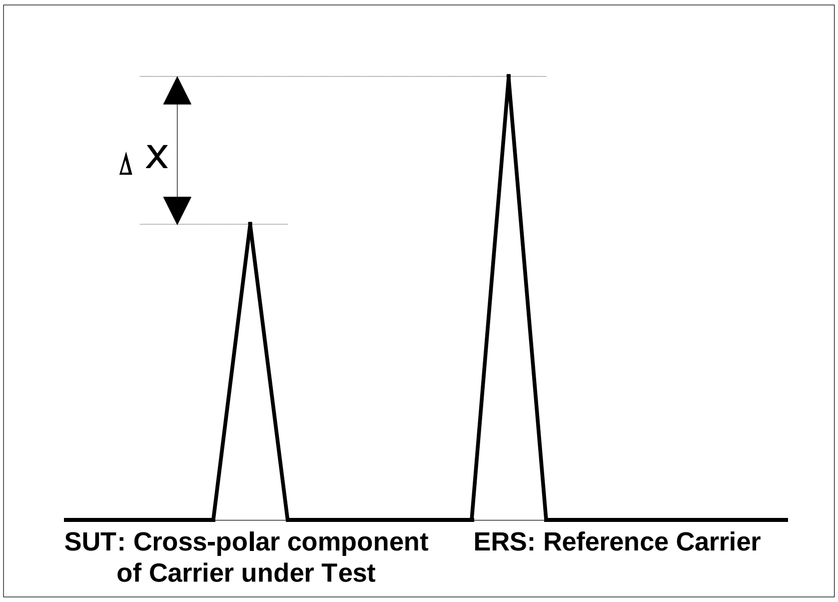


Figure 8.3: Carrier Configuration during XPD Measurements.

8.3 Step-by-Step Procedure

Step 1:	ERS transmit the reference carrier via the co-polar channel at the frequency and EIRP as specified in the Eutelsat test plan.
Step 2:	SUT adjust the EIRP setting to obtain the value specified in the Eutelsat test plan. Under direction of the ERS, SUT commence transmission at the frequency established during the satellite access test.
Step 3:	If necessary, SUT adjust the EIRP under control of ERS to balance the reference carrier.
Step 4:	ERS confirm balance condition.
Step 5:	ERS transmit the reference carrier via the cross-polar channel at EIRP (generally 20 to 40 dB below co-polar) and frequency as specified in the Eutelsat test plan. If needed carrier can be moved closer to test carrier.
Step 7:	ERS measure the difference in level between the reference carrier and the cross-polar component of the carrier under test. ERS compute the value of the TX-XPD of the SUT.
Step 8:	In coordination with the ERS, SUT move the antenna off-boresight according to Figure 8.1. The angular increment (AI) is given in the Eutelsat test plan. ERS monitor the variation of the co-polar level of the carrier under test. If necessary, guide the SUT to the required antenna positions.
Step 9:	Repeat Step 7.
Step 10:	Repeat Steps 8 and 9 for the remaining points.

8.4 Example for Spectrum Analyser Settings

Co-polar Signal:

Reference level : As applicable
Attenuator : As applicable
Scale : 1 dB/Division
Centre frequency : SUT down-link frequency as per test plan (11 or 12 GHz range)
Span : 200 kHz
Resolution bandwidth : 10 kHz
Video bandwidth : 3 kHz
Video average : ON (10 samples)
Sweep time : Auto
Marker noise : OFF
∆-Marker : ON (Marker peak search at boresight)
Trace : Clear write A

Display line : ON (Set to level at boresight)

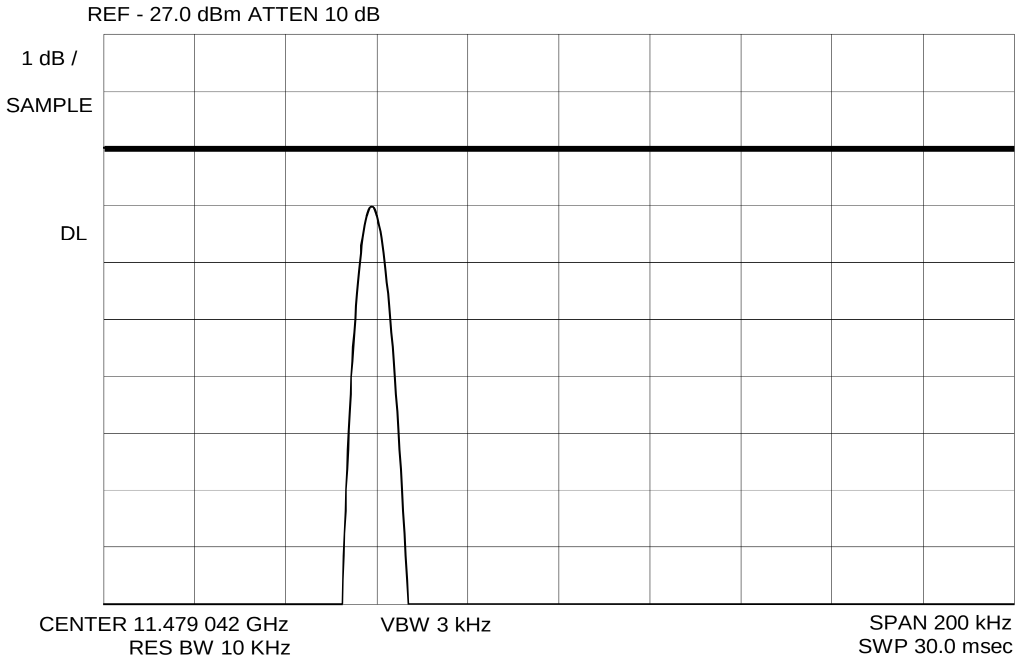
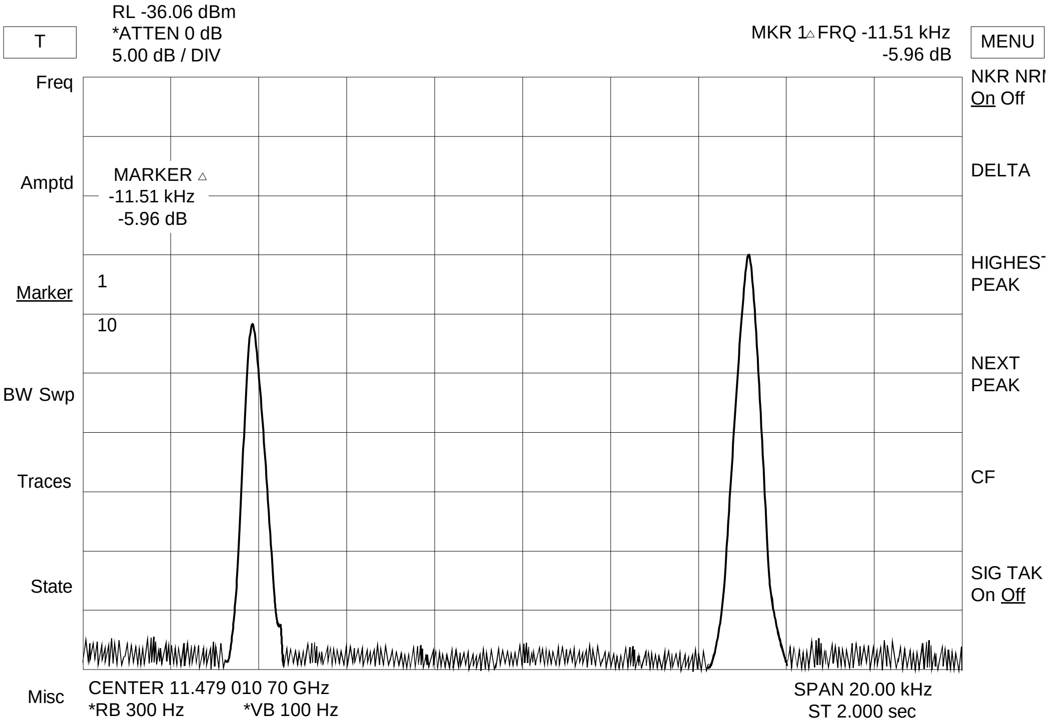


Figure 8.4: Spectrum Analyser Display during TX-XPD Measurement (Co-Polar Signal).

Cross-polar Signal:

Reference level : As applicable
Attenuator : As applicable
Scale : 5 dB/Division
Centre frequency : Centre between down-link frequencies of SUT and ERS (11 or 12 GHz range)
Span : As applicable
Resolution bandwidth : As applicable
Video bandwidth : As applicable
Video average : ON (10 samples)
Sweep time : Auto
Marker noise : OFF
Δ-Marker : ON (Marker set to ERS carrier, Δ-Marker to SUT cross-polar signal)
Trace : Clear write A
Display line : OFF



RL -36.06 dBm
*ATTEN 0 dB
5.00 dB / DIV

MKR 1△FRQ -11.51 kHz
-5.96 dB

MARKER △
-11.51 kHz
-5.96 dB

CENTER 11.479 010 70 GHz
*RB 300 Hz *VB 100 Hz

SPAN 20.00 kHz
ST 2.000 sec

Figure 8.5: Spectrum Analyser Display during TX-XPD Measurement (Cross-Polar Signal).

9 TRANSMIT SIDELOBES

9.1 Test Objectives

To record the co- and cross-polar radiation diagrams of the antenna of the station under test, the result shall enable Eutelsat to determine the maximum permissible EIRP limits of the SUT.

9.2 Principle

9.2.1 General

While transmitting a carrier the SUT slews its antenna in azimuth or elevation and communicates continuously the antenna position readout to the ERS. The ERS records the level of the co- and cross-polar components of the received carrier. Prior to the antenna measurement, the ERS performs a calibration to compensate inaccuracies which may be caused by non-linearity of the satellite transponder or the ERS RX chain. The ERS processes angular information, calibration data and the recorded level to produce the antenna pattern. For azimuth cuts, the following correction is applied to compute the true angle from the azimuth readout.

$$\sin\left(\frac{Az'}{2}\right) = \sin\left(\frac{Az}{2}\right)\cdot\cos(El) \qquad \text{Equation 9-1}$$

Where:
Az': Real angle from boresight.
Az : Azimuth as read from encoders.
El : Elevation under which the test is performed.

To facilitate the evaluation the following envelope is given in Figure 9.2.

Co-polar:

$$\begin{cases} 29 - 25\cdot log_{10}\theta & dBi & for & 1^\circ < \theta \le 7^\circ \\ +8 & dBi & for & 7^\circ < \theta \le 9.2^\circ \\ 32 - 25\cdot log_{10}\theta & dBi & for & 9.2^\circ < \theta \le 48^\circ \\ -10 & dBi & for & 48^\circ < \theta \end{cases} \qquad \text{Equation 9-2}$$

Cross-polar:

$$\begin{cases} 19 - 25\cdot log_{10}\theta & dBi & for & 1.8^\circ < \theta \le 7^\circ \\ -2 & dBi & for & 7^\circ < \theta \le 9.2^\circ \end{cases} \qquad \text{Equation 9-3}$$

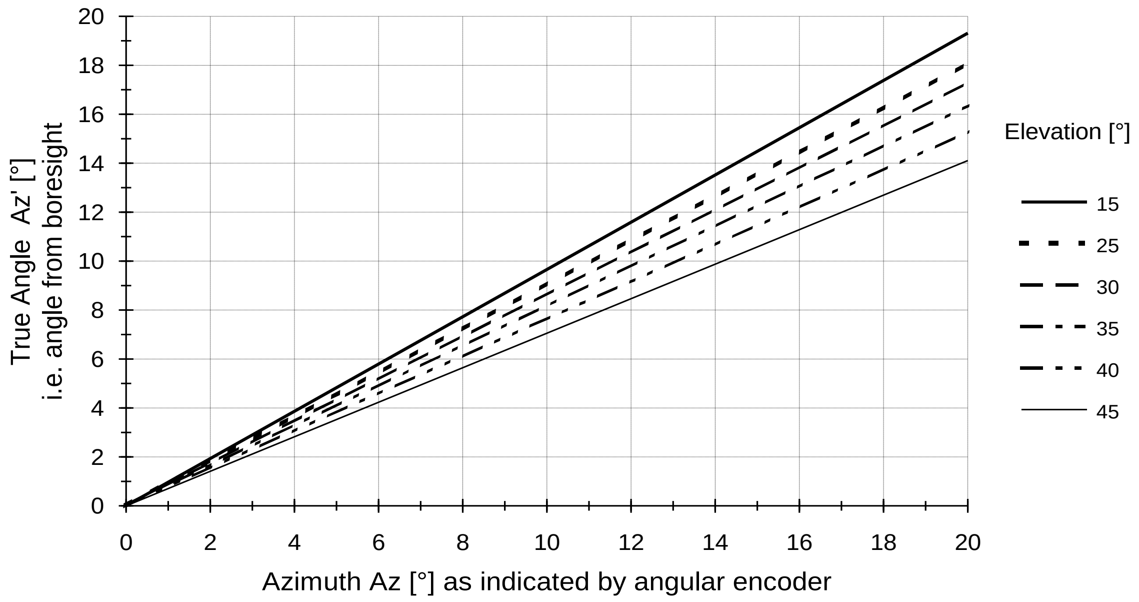


Figure 9.1: True Angle (Az') as Function of Azimuth (Az).

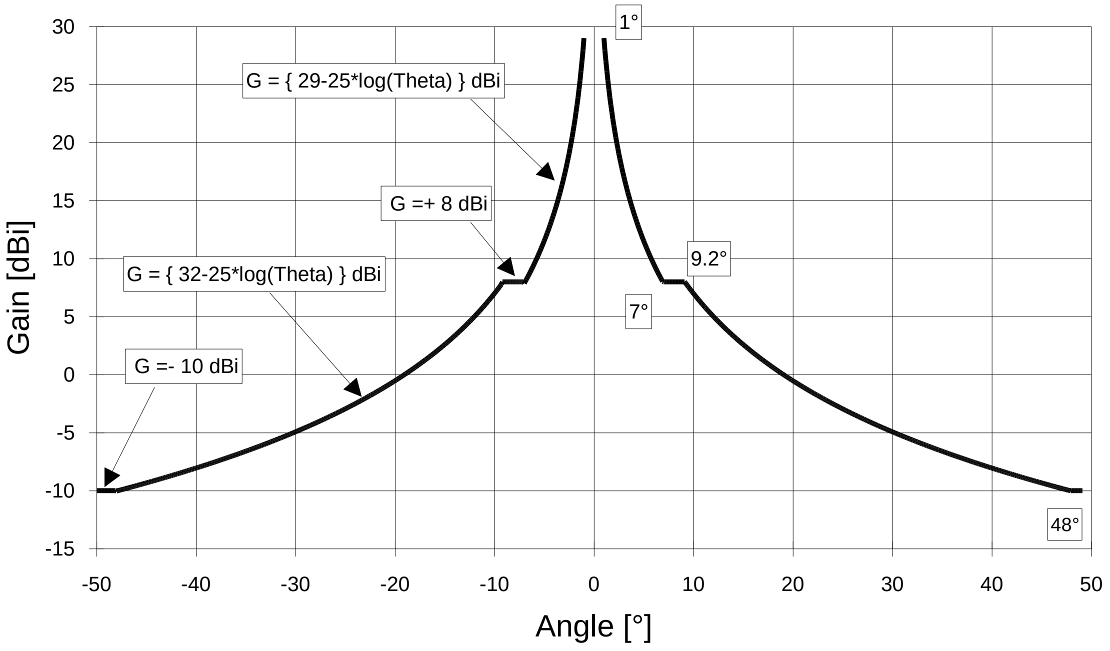


Figure 9.2: Envelope for Co-polar TX Sidelobe Pattern.

9.3 Step-by-Step Procedure

This procedure is applicable to earth stations equipped with motorized antenna drives.

A. PREPARATION

Step 1: During ESVA preparation, prior to commencement of testing, SUT investigate the slew speed for azimuth and elevation antenna movement and forward the values to Eutelsat. If various settings are available (e.g. SLOW and FAST), all speeds should be communicated to Eutelsat. If these parameters are not provided by the station manufacturer, the slew speed should be measured by the method described hereafter (Steps 1.1 through 1.9)

No signals shall be transmitted during this part of the test.

Step 1.1: Acquire the beacon of the satellite specified in the test plan. Optimize the antenna pointing for maximum receive signal level.

Step 1.2: Move the antenna in azimuth 5° counter-clockwise.

Step 1.3: Measure the time of the azimuth movement from –5° via beamcentre to +5° (i.e. clockwise antenna motion from East to West). Calculate the azimuth slew speed in degrees per second.

Step 1.4: For motorized antennas which are not equipped with angular encoders, Steps 1.1 through 1.3 shall be repeated at least 3 times and results shall be averaged.

Step 1.5: Repeat Step 1.1.

Step 1.6: Move the antenna in elevation 5° down.

Step 1.7: Measure the time of the elevation movement from –5° via beamcentre to +5° (i.e. ascending antenna motion). Calculate the elevation slew speed in degrees per second.

Step 1.8: If applicable, repeat Step 1.4.

Step 1.9: Report results prior to commencement of ESVA to the Eutelsat System Verification Test Section.

B. POWER BALANCE

Step 2: ERS transmit the reference carrier at the frequency and EIRP as specified in the Eutelsat test plan.

Step 3: ERS perform a calibration of the satellite loop by recording the ERS carrier for an EIRP range of 60 dB below the initial value in 10 dB steps. Proceed with step 6 if co-polar patterns only are recorded.

Step 4: ERS transmit the reference carrier via the cross-polar channel at EIRP (generally from 20 to 40 dB below co-polar) and frequency as specified in the Eutelsat test plan.

Step 5: ERS measure the difference in level between the reference carrier and the cross-polar component of the carrier under test. ERS compute the cross-polar antenna gain of the SUT.

Step 6: SUT adjust the EIRP setting to obtain the value specified in the Eutelsat test plan. Under direction of the ERS, SUT commence transmission at the frequency established during the satellite access test.

Step 7: If necessary, SUT adjust the EIRP under control of ERS to balance the reference carrier.

Step 8: ERS confirm balance condition.

Step 9: ERS cease transmission of the reference carrier.

C. AZIMUTH PATTERN

Step 10: Considering the outcome of the Satellite Access Test, ERS optimize spectrum analyser settings for reception of the SUT carrier.

Step 11: Upon request by the ERS, SUT interrupt transmission for a short interval. ERS proceed with optimization of analyse settings. SUT activate carrier on request of ERS.

Step 12: Under direction of the ERS, SUT move the antenna starting from boresight to the "counter clockwise" limit (i.e.: to the East). The value of the East limit (e.g. –25° off beamcentre) is stated in the test plan. ERS verify the antenna slew speed.

Step 13: In close coordination with the ERS (Figure 9.3), SUT move the antenna to the "clockwise" limit (i.e.: from the start position via boresight to the West). The value of the West limit (e.g. 25° off beam centre) is stated in the test plan. ERS record the co- and cross-polar patterns.

Step 14: SUT switch off the carrier and return to boresight. Under the direction of the ERS, SUT recommence transmission and optimise antenna pointing for maximum receive level. SUT cease transmission if no further antenna measurements follow.

Step 15: Process measurement data and produce plots of co-polar azimuth and elevation antenna TX diagrams including the appropriate masks. In case major anomalies in the patterns are identified, the results are reviewed internally. A suspension of the ESVA may be decided in case non-compliances with respect to Eutelsat standards are detected.

D. ELEVATION PATTERN

Step 16: Under direction of the ERS, SUT move the antenna starting from boresight to the "lower" limit (i.e. from start position via boresight down). The value of the lower limit is stated in the test plan (e.g. –15° off beam centre). ERS verify the antenna slew speed.

Step 17: In close coordination with the ERS (Figure 9.3 refers), SUT move the antenna from the “lower” limit via boresight to the "upper" limit (e.g. +15° off beam centre). The value of the upper limit is stated in the test plan. ERS record the co- and cross-polar patterns.

Step 18: SUT switch off the carrier and return to boresight. Under direction of the ERS, SUT recommence transmission and optimize antenna pointing for maximum receive level. SUT cease transmission if no further antenna measurements follow.

Step 19: Process measurement data and produce plots of co-polar azimuth and elevation antenna TX diagrams including the appropriate masks. In case major anomalies in the patterns are identified, the results are reviewed internally. A suspension of the ESVA may be decided in case non-compliances with respect to Eutelsat standards are detected.

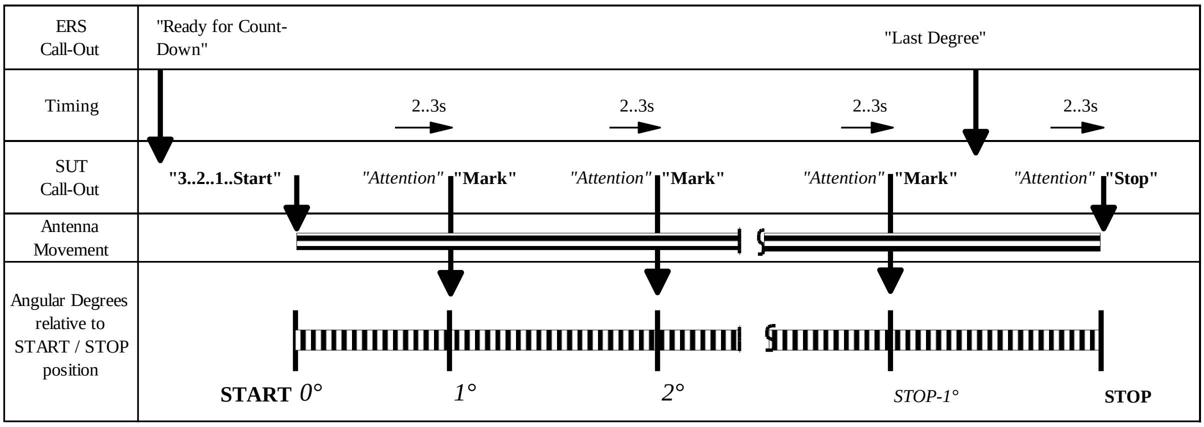


Figure 9.3: Coordination Scheme during Antenna Pattern Measurements.

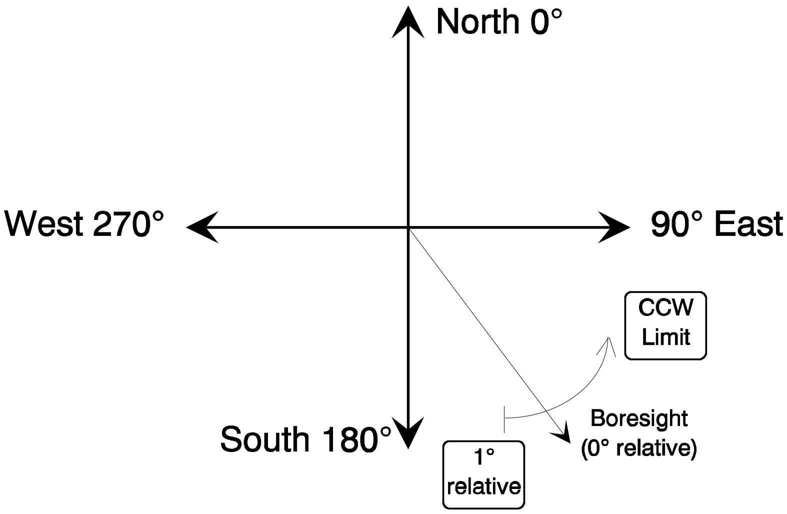


Figure 9.4: Terminology for Azimuth Antenna Movement.

Cut Nr.	Azimuth/Elevation	Antenna Movement	Direction
1	Az	+1° to CCW limit	Towards East
2	Az	-1° to CW limit	Towards West
3	El	+1° to lower limit	Down
4	El	-1° to upper limit	Up
CCW : Counter-clockwise CW : Clockwise			

Table 9.1: Summary of Antenna Pattern Measurement.

Note 1: Relative azimuth angles are not corrected for non-orthogonality. They are therefore equivalent to angular encoder readout at the earth station.

Note 2: To achieve constant slew speed during the measurement and thus avoiding errors due to acceleration, the actual start position is offset from de first-degree mark. The offset depends on the antenna slew speed and it is typically between 0.5° and 1°. The SUT may propose a suitable value.

9.4 Example for Spectrum Analyser Settings

Reference level:	: As applicable
Attenuator	: 0 dB
Scale	: 10 dB/Division
Centre frequency	: SUT down-link frequency as per test plan (11 or 12 GHz range)
Span	: 0 Hz
Resolution bandwidth	: 30 Hz (or 10 Hz)
Video bandwidth	: 1 Hz
Sweep time	: According to antenna slew speed e.g. 500 sec.
Marker noise	: OFF
D-Marker	: OFF

Trace	: Clear write
Display line	: Position to noise floor

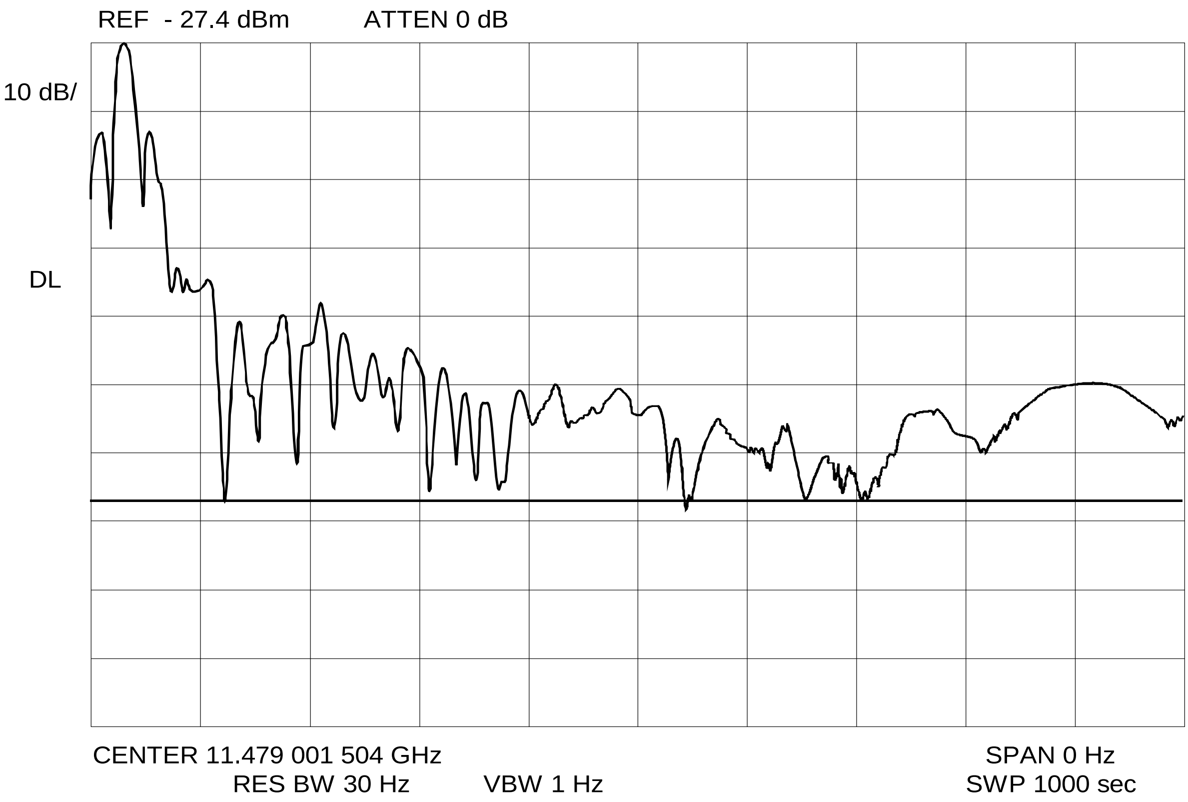


Figure 9.5: Spectrum Analyser Display during Antenna Pattern Measurement.

10 G/T

10.1 Test Objectives

To measure the gain-to-equivalent noise temperature ratio (G/T) of the earth station receive section.

Verification of correct function of the receive chain(s) by confirmation of the expected G/T value at IF interface.

10.2 Principle

In contrast to separate evaluation of antenna gain and system noise temperature, the following procedure implies the direct measurement of the G/T. Therefore, it is required to measure the receive level (P_C) of a reference carrier at the station under test. Then, the antenna under test is pointed to the cold sky and the noise level (P_N) is measured in a defined bandwidth. From these two values, the G/T is computed.

$$G/T_{SUT} = L_{fs,SUT} + L_{at,SUT} + B + K - EIRP_{SAT,SUT} + R \qquad \text{Equation 10-1}$$

$$R = 10 \cdot log_{10}\left[10^{(P_C - P_N)/10} - 1\right] \qquad \text{Equation 10-2}$$

If

$$P_C - P_N > 20, \qquad \text{Equation 10-3}$$

the expression Equation 10-2 may be simplified to:

$$R \cong P_C - P_N \qquad \text{Equation 10-4}$$

Where:

G/T_{SUT}	: Gain to equivalent noise temperature ratio of SUT	[dB/K]
$L_{fs,SUT}$	: Free space loss towards SUT= 20*log(4.B.d.f / c) f = frequency (Hz) d = distance (m) c = 299792458 (m/s)	[dB]
$L_{at,SUT}$	: Atmospheric attenuation at SUT	[dB]
B	: Equivalent noise bandwidth [dBHz]	
K	: Boltzmann’s constant: (1.38051·10^{-23} Ws/K ≅ – 228.60 dBWs/K)	[dBWs/K]
$EIRP_{SAT,SUT}$	: Satellite EIRP towards SUT	[dBW]
P_C	: Carrier level (C + N)	[dBm]
P_N	: Noise level (N)	[dBm]
R	: Power ratio $\left(\frac{C+N}{N}\right)$	[dB]

NOTE: For the atmospheric attenuation, the following values are assumed under clear sky conditions:11 GHz range: 0.20 dB12 GHz range: 0.25 dB

NOTE: For spectrum analyser measurements, Equation 10-3 must be valid at resolution bandwidth even if readout is normalized to 1 Hz.

The satellite EIRP towards the SUT is computed from the measured value of satellite EIRP towards the ERS.

$$EIRP_{SAT,SUT} = EIRP_{SAT,ERS} + L_{OA,ERS} - L_{OA,SUT}$$ Equation 10-5

where:

$EIRP_{SAT,ERS}$	: Satellite EIRP towards ERS	[dBW]
$L_{OA,ERS}$	: Off-axis loss towards ERS	[dB]
$L_{OA,SUT}$	: Off-axis loss towards SUT	[dB]

As the measurement is generally carried out by a spectrum analyser, corrections of the displayed noise level for bandwidth and detection must be applied. In modern analysers this correction is achieved by an internal routine which provides a direct readout of the normalized noise level (noise marker). Where this facility is unavailable, the operator must refer to the relevant instrument application notes (e.g. HP 8-series) to obtain the applicable values.

The following figures for correction of the displayed noise level are typical:

Translation from resolution bandwidth to noise bandwidth:	–0.8 dB
Combined correction for detector characteristics and logarithmic shaping:	+2.5 dB
The total typical correction is therefore:	**+1.7 dB**.

In this case, the actual noise level is 1.7 dB higher than the displayed figure. Therefore the "displayed" C/N is 1.7 dB better than the actual value of C/N.

Care must be taken to avoid inaccuracy of the noise level measurement due to the contribution of the spectrum analyser. To confirm correct function of the whole receive chain, it is recommended to carry out the measurement at RF and IF level.

10.3 Step-by-Step Procedure

A. TRANSMISSION OF REFERENCE CARRIER

Step 1: ERS transmit the reference carrier at the frequency and EIRP as specified in the Eutelsat test plan.

NOTE: Disregard Step 1 if the G/T measurement is performed using the satellite beacon.

B. MEASUREMENT OF CARRIER LEVEL

Step 2: ERS measure the satellite EIRP of the reference carrier and compute the corresponding EIRP towards the SUT.

Step 3: With the antenna at boresight, SUT measure the reference carrier level at RF and IF interfaces in dBm/Hz. For beacon measurements, the applicable resolution bandwidth shall be agreed between ERS and SUT. Examples are reported in Figure 10.1 and Figure 10.2. SUT report the value to the ERS.

C. MEASUREMENT OF NOISE LEVEL

Step 4: At a small frequency offset (e.g. 100 kHz), SUT measure the noise level in dBm/Hz.

Step 5: SUT move the antenna off to the satellite, preferably in azimuth by at least 5°. While slewing the antenna, SUT monitor the noise level. The antenna movement may be stopped when the noise level does no longer decrease.

Step 6: SUT terminate the spectrum analyser input and read the noise level. Report the value to the ERS.

Step 7: SUT connect the spectrum analyser to the RF interface. With identical settings of Steps 5, 6 above, SUT measure the noise level (Figure 10.3). SUT reports the value to the ERS.

Step 8: Repeat Step 7 with the analyser connected to the IF interface.

D. EVALUATION

Step 9: If applicable, SUT report the relevant correction factors and the bandwidth to ERS. SUT return the antenna to boresight.

Step 10: ERS communicate value of the satellite EIRP to SUT and calculate the value of the G/T.

NOTE: Given the measured parameter are not constant over time the whole procedures shall be performed at once in the shortest possible timeframe to ensure meaningful results.

10.4 Example for Spectrum Analyser Settings

Measurement of Carrier Level (Note: ERS may advice to apply different settings)

Reference level:	: 5 dB above level of reference carrier
Attenuator	: 0 dB
Scale	: 10 dB/Division
Centre frequency	: ERS down-link frequency as per test plan (RF or IF range)
Span	: 100 kHz
Resolution bandwidth	: 3 kHz
Video bandwidth	: 100 Hz
Video average	: ON (10 samples)
Sweep time	: Auto (typically 1.5s)
Marker noise	: OFF
∆-Marker	: OFF, Marker peak search
Trace	: Clear write A

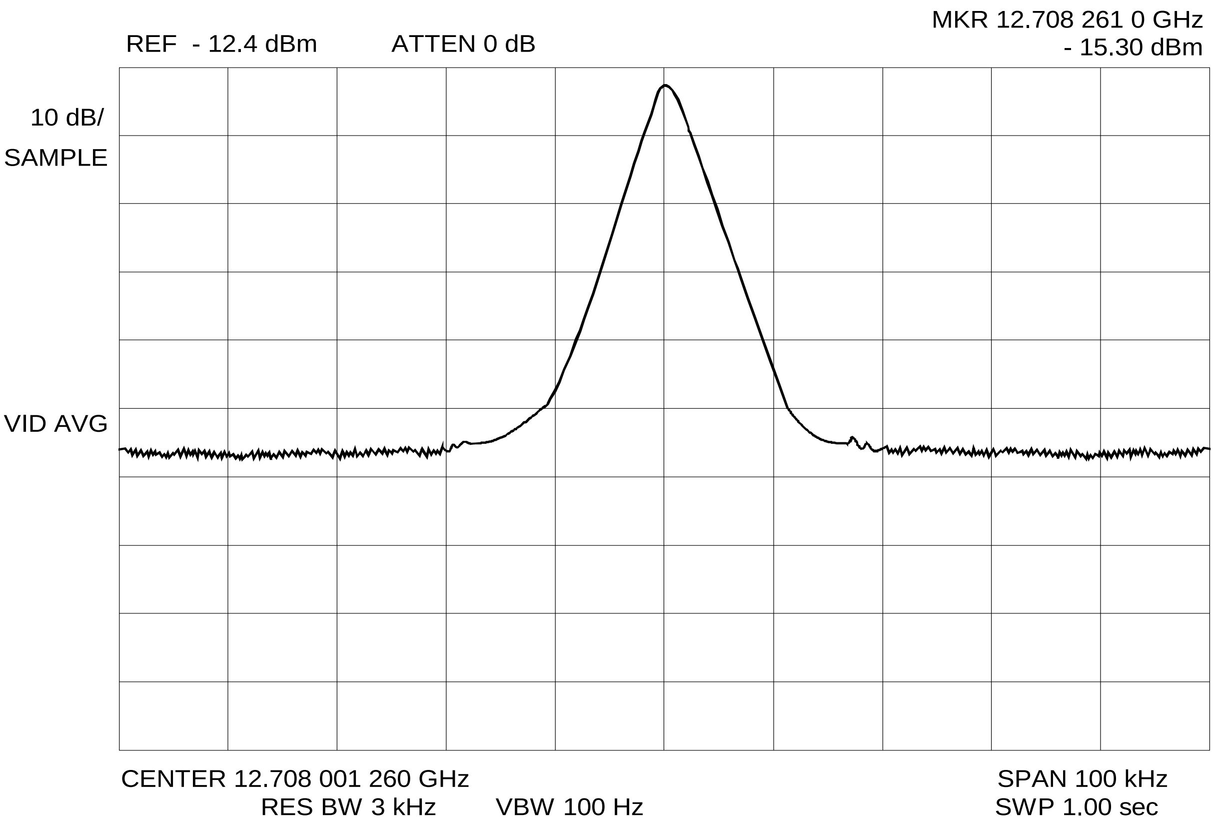


Figure 10.1: Spectrum Analyser Display during G/T Measurement (Carrier level).

__NOTE__: The example applies to measurements where the spectrum analyser is connected to the LNA output. In case of measurements at IF, the alternator has to be set according to the actual level (in order to avoid over drive).

Measurement of Beacon Level (Note: ERS may advice to apply different settings)

Reference level: : 5 dB above beacon level
Attenuator : 0 dB
Scale : 10 dB/Division
Centre frequency : Beacon frequency as per test plan (RF or IF range)
Span : 1 MHz
Resolution bandwidth : 3 kHz
Video bandwidth : 30 Hz
Video average : ON (10 samples)
Sweep time : Auto (typically 1.5s)
Marker noise : OFF
Δ-Marker : OFF, Marker peak search
Trace : Clear write A

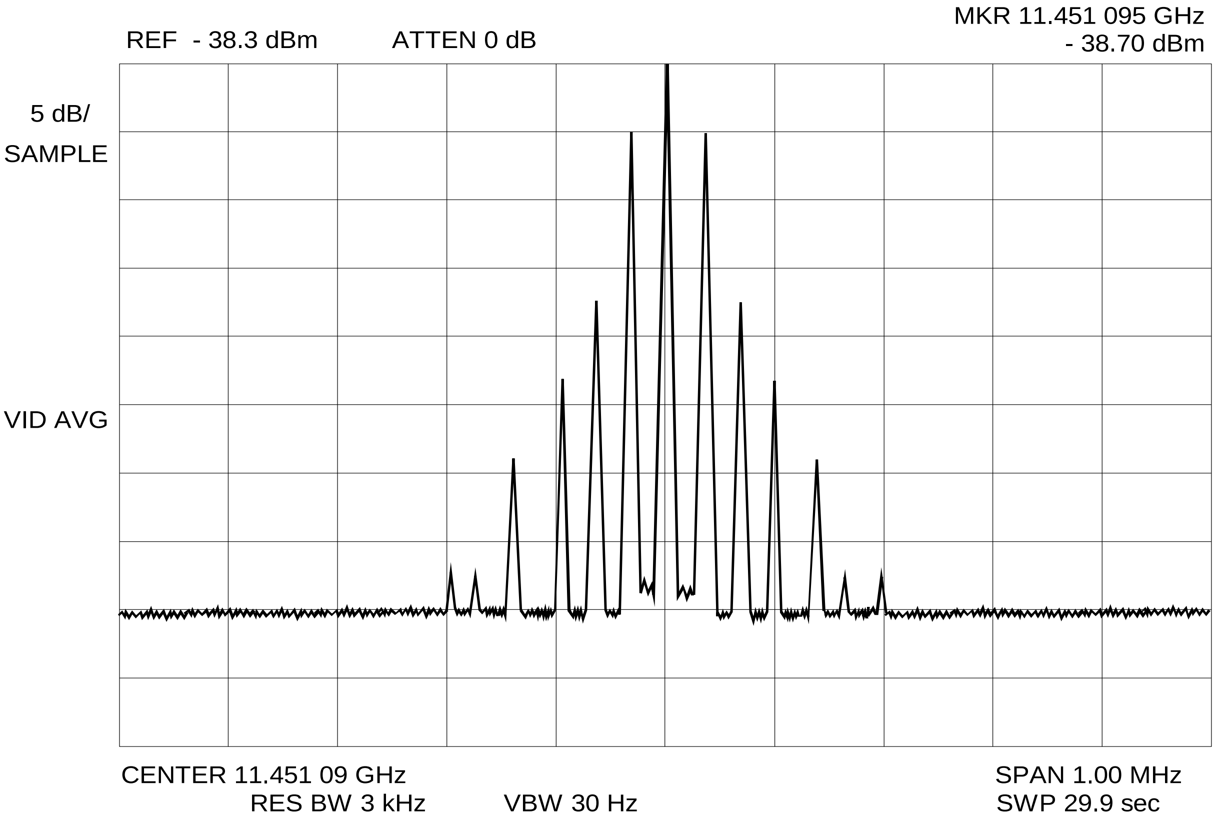


Figure 10.2: Spectrum Analyser Display during G/T Measurement (Carrier Level).

Measurement of Noise Level (Note: ERS may advice to apply different settings)

Reference level: : 5 dB above noise floor
Attenuator : 0 dB
Scale : 10 dB/Division
Centre frequency : Beacon frequency as per
(RF or IF range)
Span : 100 kHz
Resolution bandwidth : 3 kHz
Video bandwidth : 100 Hz
Video average : ON (10 samples)
Sweep time : Auto (typically 1.5s)
Marker noise : ON
Marker Frequency : 200 kHz below carrier beacon frequency
Δ-Marker : OFF
Trace : Clear write A
Display line : ON

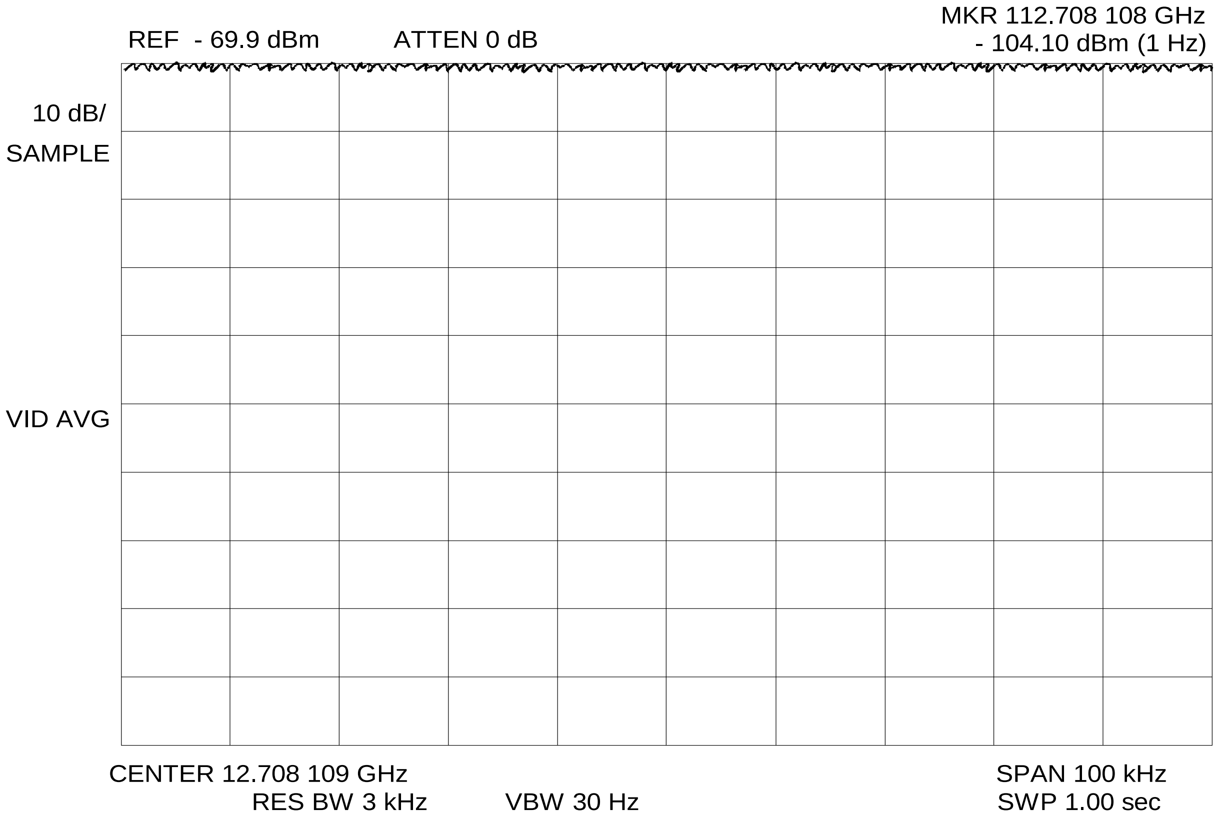


Figure 10.3: Spectrum Analyser Display during G/T Measurement (Noise Level).

NOTE: The above (para. 10.4) are generally applicable if the spectrum analyser is connected to an LNA output. The attenuator setting to 0 dB may be inappropriate in case of connection to the output of a down-convertor, line-amplifier, etc. In any case, the carrier level indicated must be independent of the attenuation setting, i.e. when changing the attenuator, no change of carrier level should be observed.

11 RECEIVE POLARIZATION DISCRIMINATION

11.1 Test Objectives

To measure the receive polarization isolation of the station under test at optimized TX polarization alignment. The measurement is carried out at boresight and at 8 samples within the 1 dB contour of the co-polar antenna RX pattern.

Although the measurement is not mandatory, it is recommended and it will provide additional aspects for the evaluation of the overall antenna performance.

11.2 Principle

The ERS transmits a carrier via a Eutelsat satellite and maintains a constant flux. Then at optimum TX polarization alignment (Chapter 6 refers), the Station Under Test measures the co-polar and the cross-polar component of the reference carrier by comparison to an injected signal. From the difference in level, the RX-XPD of the SUT is computed.

Possible inaccuracies can be due to the up-link (i.e. ERS, TX-XPD, satellite RX-XPD).

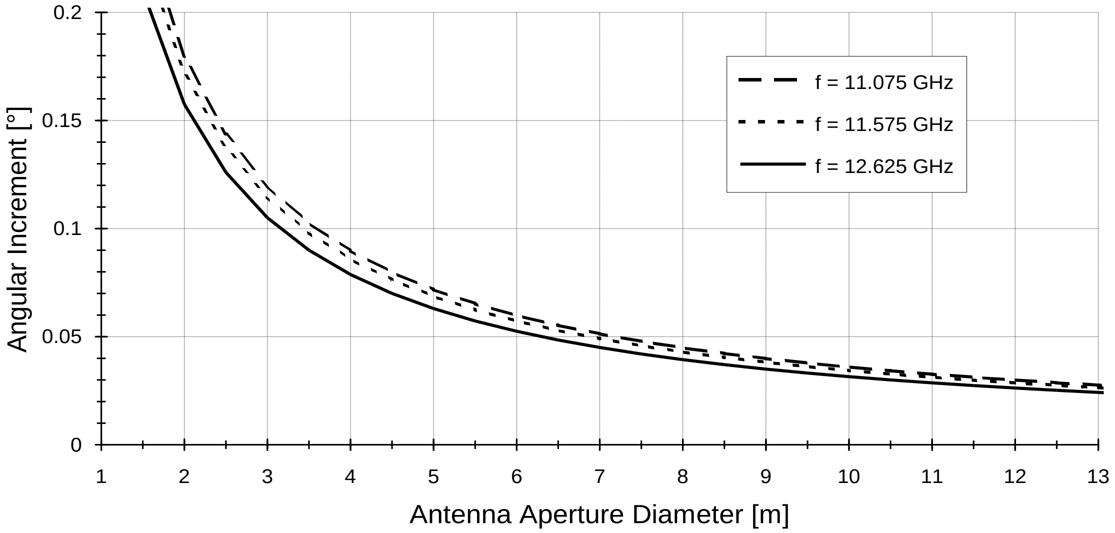


Figure 11.1: Angular Increment (AI) for RX-XPD Measurements.

To verify the performance of the SUT antenna within the co-polar -1 dB RX contour, the SUT antenna is depointed in azimuth and elevation as described in Figure 8.1 and the measurement is conducted at each point (boresight and 8 samples). The angular increment (AI) may be estimated by formula (1) of paragraph 11.2.

To ensure accurate positioning of the antenna, a SUT equipped with a 4-port feed monitors the variation of the co-polar RX level of the reference carrier. For SUT equipped with a 2-port feed, the reference carrier shall be transmitted via X polarization (i.e. received via Y polarization). Hence, the SUT measures the cross-polar component of the reference carrier and monitors the variation of the satellite beacon level via the same (X) polarization.

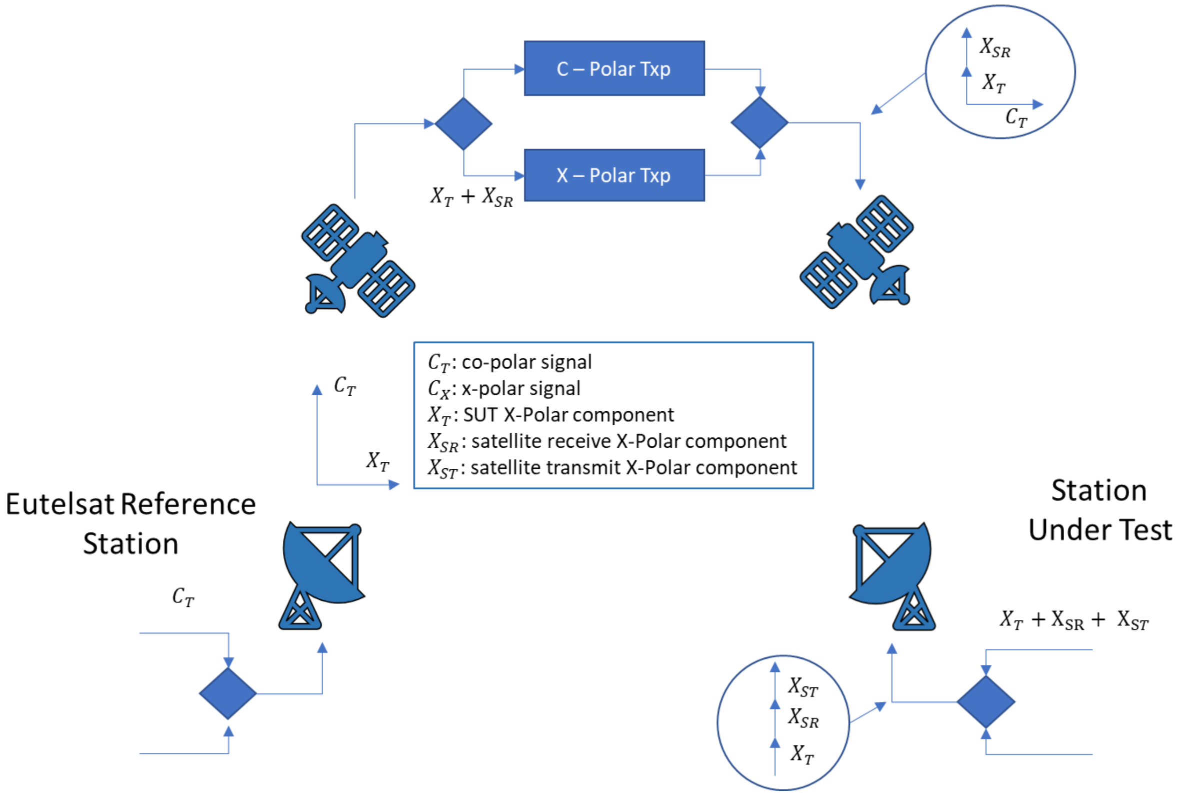


Figure 11.2: Schematic Representation of the RX-XPD Measurement.

11.3 Step-by-Step Procedure

NOTE: Optimum TX-polarization alignment must be assured prior to this test. For SUT equipped with a 4-port feed the alignment of para. 6.3 remains unchanged and commutation from X to Y polarization is done by switching.

NOTE: For SUT equipped with a 2-port feed, the optimum polarization alignment must be established for the Y-plane. If this has not been accomplished, test 5.2 must be repeated prior to the following measurements.

Step 1: During ESVA preparation and prior to commencement of ESVA testing, SUT check the linearity of the RX-chain(s) as follows:

A test signal at stable amplitude and frequency (i.e. the in-station pilot) is injected at the input of the LNA. By means of a microwave attenuator, the pilot level is reduced in 10 dB steps and the corresponding power levels displayed on the spectrum analyser are recorded. This establishes a reference scale and a check of the linearity of the RX-chain(s) including the analyser display.

Step 2: SUT equipped with 2-port feed proceed with Step 5.

Step 3: SUT inject the pilot into one of the RX chains and measure its level.

Step 4: Under consideration of differences in the RX coupling factors, inject the same pilot level into the second RX chain and measure the difference relative to the value obtained in Step 3 above. The result is the correction factor (i.e. the RX gain difference) for the following RX-XPD measurements.

Step 5: ERS transmit the reference carrier at frequency and EIRP as specified in the Eutelsat test plan.

Note: If the SUT is equipped with a 2-port feed, the test plan shall provide a channel with X polarization in up-link and Y polarization in down-link.

Step 6: SUT receive the co-polar component of the reference carrier. Set the pilot frequency close to the RX-frequency of the reference carrier (e.g. $f_{PILOT} = f_{REF}$ - 200 Hz).

Step 7: ERS transmit the reference carrier via the co-polar channel at the frequency and EIRP as specified in the Eutelsat test plan.

SUT equipped with 4-port feed proceed with Step 9.

Step 8: SUT rotate the antenna feed by 90° and ensure that this position corresponds to the optimum TX polarization alignment established during test 4.2 (compare angular readout and/or marks on feed).

SUT equipped with 2-port feed proceed with Step 10.

Step 9: SUT switch to orthogonal channel.

Step 10: SUT lock to the cross-polar component of the reference carrier and measure the difference in level between the pilot and the cross-polar component of the reference carrier. If necessary, apply a correction (Step 4 above) and determine the XPD.

Step 11: SUT lock to the co-polar component of the reference carrier (the satellite beacon for SUT equipped with 2-port feed). Move the antenna off boresight according to Figure 8.1. While moving the antenna, SUT monitor the variation of the RX level and control the movement accordingly, (Table 8.1 refers).

Step 12: Repeat Steps 11 and 12 for each point of the sequence described in Figure 8.1.

Step 13: SUT report results to Eutelsat.

11.4 Example for Spectrum Analyser Settings

Co-polar Reception

Reference level:	: As applicable
Attenuator	: 0 dB
Scale	: 5 dB or 10 dB/Division
Centre frequency	: ERS down-link frequency as per test plan (11 or 12 GHz range)
Span	: 2 kHz
Resolution bandwidth	: 30 Hz
Video bandwidth	: 30 Hz
Video average	: OFF
Sweep time	: Auto
Marker noise	: OFF
∆-Marker	: activated
Trace	: Max. Hold A
Display line	: OFF

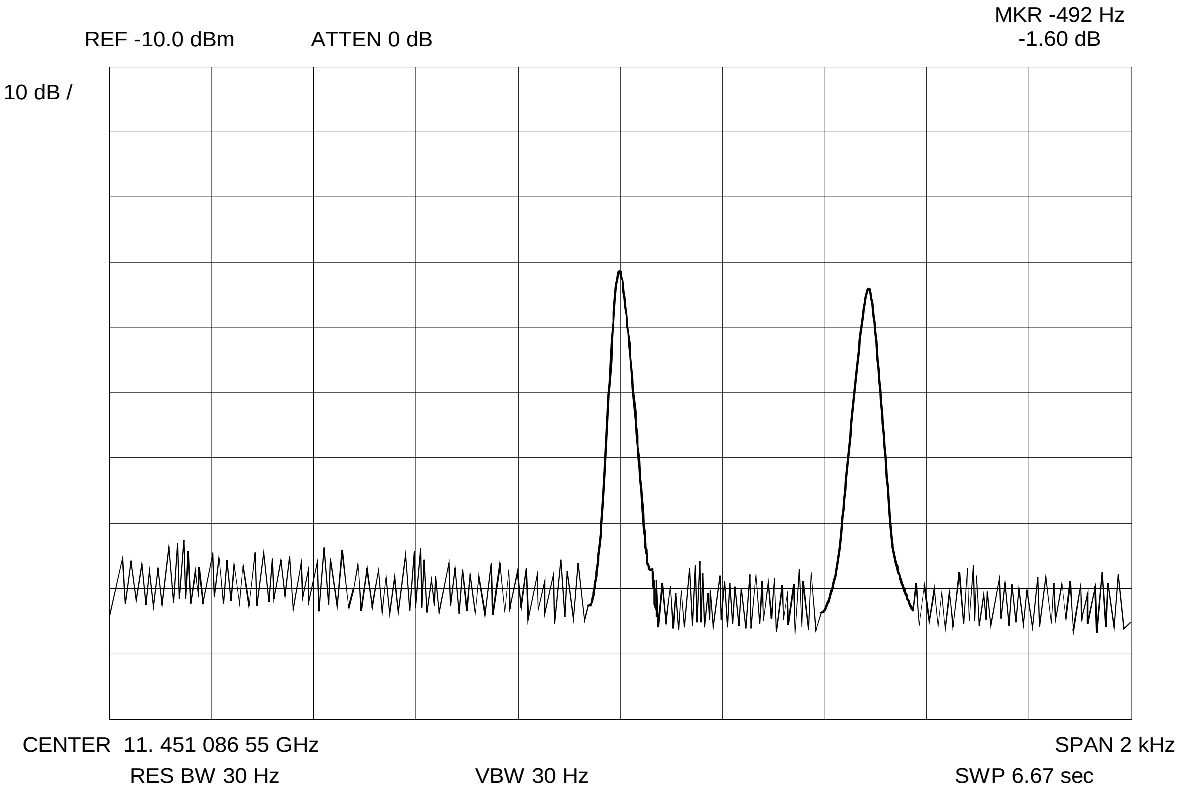


Figure 11.3: Spectrum Analyser Display during RX-XPD Measurement Co-Polar Reception.

Cross Polar Reception

Reference level: : As applicable
Attenuator : 0 dB
Scale : 5 dB or 10 dB/Division
Centre frequency : ERS down-link frequency as per test plan (11 or 12 GHz range)
Span : 2 kHz
Resolution bandwidth : 30 Hz
Video bandwidth : 30 Hz
Video average : OFF
Sweep time : Auto
Marker noise : OFF
Δ-Marker : activated
Trace : Max. Hold A
Display line : OFF

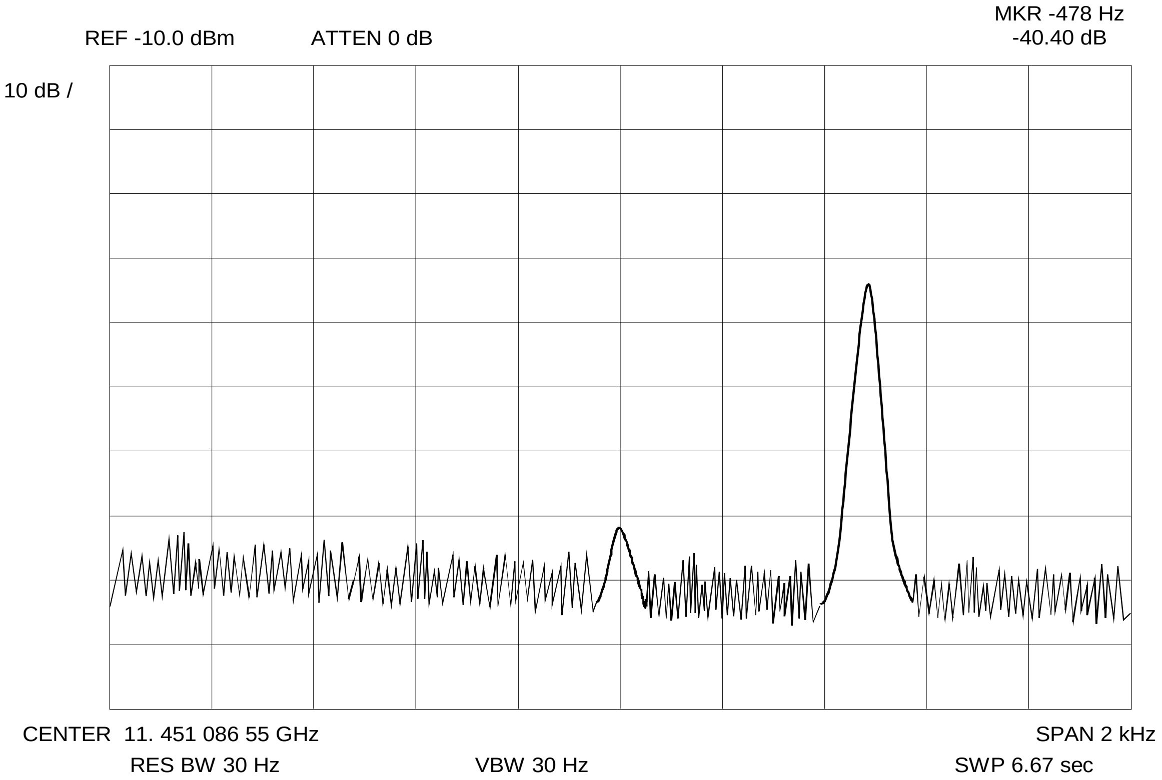


Figure 11.4: Spectrum Analyser Display during RX-XPD Measurement.

12 RECEIVE SIDELOBES (INCLUDING RECEIVE GAIN)

12.1 Test Objectives

To record the receive antenna diagram of the station under test. Although the measurement is not mandatory, it is recommended and it will provide additional aspects for the evaluation of the overall antenna performance.

12.2 Principle

12.2.1 Antenna Pattern

The ERS transmits a carrier via an Eutelsat satellite and maintains a constant flux. Alternatively, the station under test may lock to a satellite beacon signal. Then, the station under test records the receive level as function of the slewing angle in azimuth and elevation. Due to the non-orthogonality of the rotational axes, the azimuth angle is corrected according to formula 1 of paragraph 9.2.1. For evaluation of the antenna performance, the envelope of Figure 9.2 is applied.

12.2.2 Receive Gain

If the station under test is equipped with a receive coupler, the antenna receive gain may be calculated at known satellite EIRP. During ESVA preparation, the values of the RX coupling factor and the loss between the RX coupler and the antenna flange (or interface where the antenna gain is defined) have to be obtained by in-station measurement.

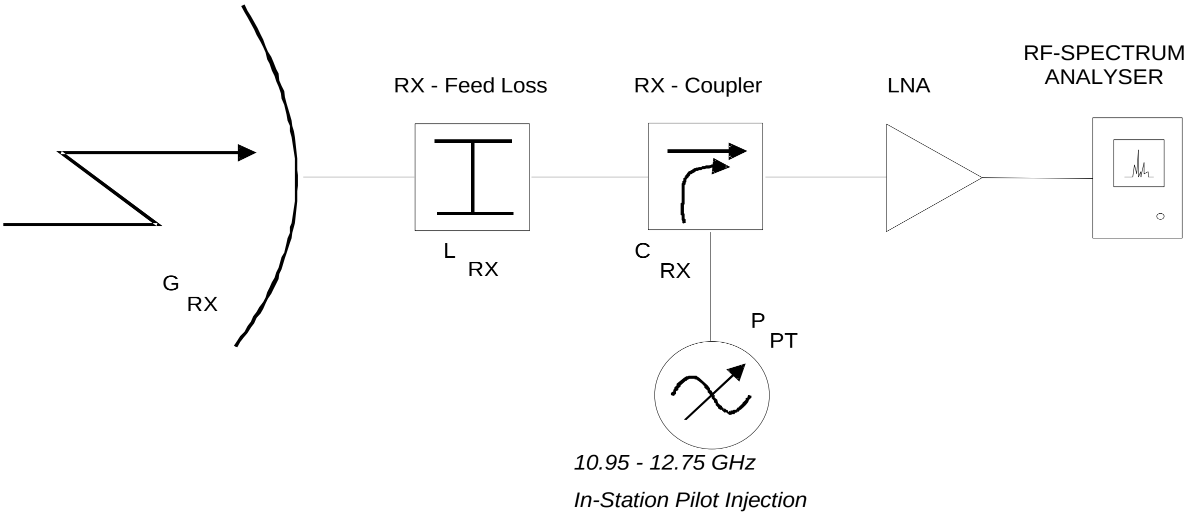


Figure 12.1: Block Diagram of SUT RX-Chain.

At known satellite EIRP, the RX gain is given by:

$$G_{RX} = P_{Pt} + L_{RX} - C_{RX} - (EIRP_{SAT,SUT} - L_{fs,SUT} - L_{at,SUT} + 30) \qquad \text{Equation 12-1}$$

where:

G_{RX} : Antenna receive gain of SUT[dBi]
L_{RX} : RX feed Loss [dB]
P_{Pt} : Level of in-station pilot at injection point [dBm]
C_{RX} : RX coupling factor [dB]
$EIRP_{SAT,SUT}$T : Satellite EIRP towards SUT[dBm]
$L_{fs,SUT}$: Free space loss towards SUT [dB]
$L_{at,SUT}$: Atmospheric loss for reception at SUT [dB]
30 : Conversion dBW ==>dBm[dB]

The satellite EIRP towards the SUT is computed from the measured value of satellite EIRP towards the ERS.

$$EIRP_{SAT,SUT} = EIRP_{SAT,ERS} + L_{OA,ERS} - L_{OA,SUT}$$ Equation 12-2

where:

$EIRP_{SAT/ERS}$: Satellite EIRP towards ERS [dBW]
$L_{OA/ERS}$: Off-axis loss towards ERS [dB]
$L_{OA/SUT}$: Off-axis loss towards SUT [dB]

To appreciate the measurement results, the theoretical expected value of the receive gain may be calculated according to Equation 7-3 of para. 7.2.4.

12.3 Step-by-Step Procedure

A. Transmission of Reference Carrier

Step 1: ERS transmit the reference carrier at the frequency and EIRP as specified in the Eutelsat test plan.

NOTE: Disregard Step 1 if the antenna measurement is performed using the satellite beacon.

B. Calibration of Receive Chain

Step 2: With the SUT antenna at boresight, SUT adjust the spectrum analyser and confirm linearity of receive and test equipment. If the SUT is not equipped with a receive coupler go to Step 6.

Step 3: Verification of linearity may be achieved by injection of an in-station pilot via a coupler prior to the LNA input. The pilot level shall be equal to the received carrier at frequency which is approximately 10 kHz apart.

Step 4: SUT communicate receive coupling factor and receive feed loss to ERS. ERS evaluate satellite EIRP towards SUT and calculate antenna receive gain.

Step 5: SUT report the in-station pilot level at the LNA output and reduce the pilot in 10 dB steps from relative 0 dB to –50dB.

C. Azimuth Pattern

Step 6: SUT remove the in-station pilot and lock to the reference carrier. Except for the centre frequency, all analyser settings must remain unchanged from Step 5.

Step 7: SUT move the antenna counterclockwise (i.e. to the East) in azimuth until the receive level is in the order of the noise floor (e.g. to –20°).

Step 8: While recording the receive level, SUT slew the antenna in azimuth via boresight to the corresponding clockwise (i.e. West) position (e.g. +20°).

Step 9: SUT slew the antenna to beam centre and optimize pointing for maximum receive level.

D. Elevation Pattern

Step 10: SUT descend the antenna in elevation until the receive level is in order of the noise floor (e.g. –15°).

Step 11: While recording the receive level, SUT rise the antenna in elevation via boresight to the corresponding upper position (e.g. +15°).

Step 12: SUT slew the antenna to beam centre and optimize pointing for maximum receive level.

Step 13: SUT process measurement data and produce plots of the co-polar azimuth and elevation antenna receive diagrams including the appropriate envelopes.

Step 14: SUT inform ERS of measurement conclusion and forward results to Eutelsat.

12.4 Example of Spectrum Analyser Settings

Reference level: : As applicable
Attenuator : 0 dB
Scale : 10 dB/Division
Centre frequency : SUT down-link frequency as per test plan (11 or 12 GHz range)
Span : 0 Hz
Resolution bandwidth : 30 Hz (or 10 Hz)
Video bandwidth : 1 Hz
Sweep time : According to antenna slew speed, e.g. 500 sec.
Marker noise : OFF
Δ-Marker : OFF
Trace : Clear write
Display line : Position to noise floor

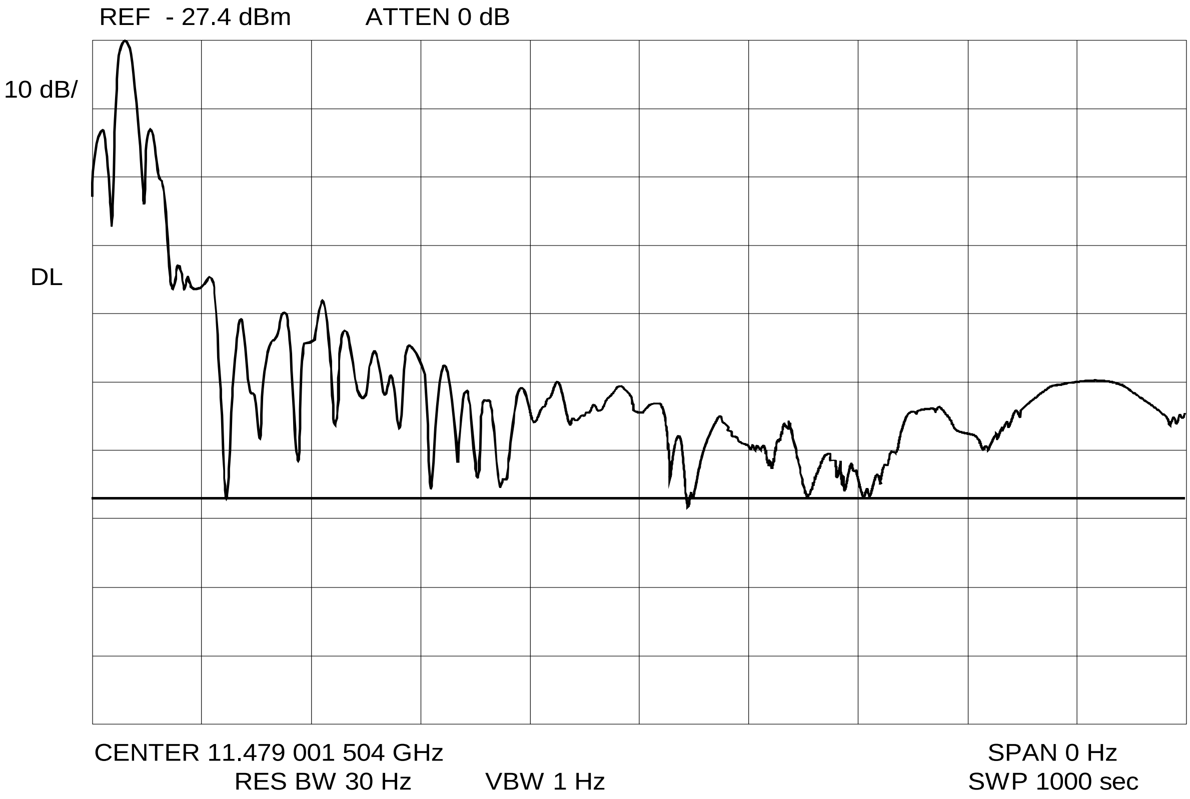


Figure 12.2: Spectrum Analyser Display during Antenna Pattern Measurement.

Annex A - Questionnaire

The form on the next page is used to provide Eutelsat with specific data relevant to any forthcoming ESVA or Earth Station Test activity. This information is required to ensure smooth implementation of measurements and is normally not part of the Eutelsat Earth Station database. With submission of the completed form, the station operator re-confirms and guarantees his adequate preparation and readiness for test activities.

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32, boulevard Gallieni – 92130 Issy-les-Moulineaux, France
Phone : +33 (1) 5398-3925/4613/3863 - E-Mail : esapproval@eutelsat.com

ESVA Test: __/____

Date: __ / __ / ____

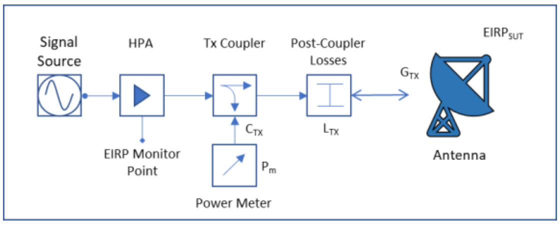
ESVA Questionnaire for E/S: _________

1. Availabilities

Preferred date(s) for the test: ______________________________ (TBC by ERS) Preferred start time (UTC): __________

Remarks: ____

2. E/S Parameters



Station reference gain:

G_{TX} : ______________________ [dBi]

At frequency: ______________ [GHz]

Note: Unless stated otherwise, antenna diagrams will be normalized to typical antenna gain, i.e. 65% efficiency, at test frequencies.

EIRP calibration performed via monitor points applicable to forthcoming operations: Yes ☐ No ☐

TX Chain Designation	HPA 1	HPA 2	Other: ________
TX Coupling Factor C_{TX} [dB]			
Post Coupler Loss L_{TX} [dB]			

Receive pattern is attached Yes ☐ No ☐ **Earth station block diagram is attached** Yes ☐ No ☐

3. E/S Configuration

Usable Frequency Range for ESVA

Up-Link: _________-_________GHz

Down-Link: _________-_________GHz

Antenna Motorisation None ☐ Mechanic (Handwheel/Leadscrew) ☐ Electrical ☐

Az/El Encoding None ☐ Phisical Marks ☐ Digital ☐

Geostationary Visibility (Longitude From-To) _______° - _______°

Test Equipment Type

Signal Source ____
Power Meter ____
Spectrum Analyzer ____

Feed Type

2-Port ☐ 4-Port ☐

Polarization

Linear ☐ Circular ☐

Polarization Plane Adjustment Range

+ / -: ___________________ °

Antenna Slew Speed
(if motorised and at lowest speed settings)

Azimuth: __________________ °/s
Elevation: __________________ °/s

Antenna Coordinates

(for transportable E/S indicates location of test)

Latitude: _________ ° N ☐ S ☐
Longitude: _________ ° E ☐ W ☐

4. Contact Points

Station Manager Name: _________________ Phone: _______________ e-mail: ______________________
Contact during ESVA Name: _________________ Phone: _______________ e-mail: ______________________

5. Remarks (for missing information please specify reason)

Annex B - List of Abbreviations

AI	Angular Increment
C/N	Carrier to Noise Ratio
CCIR	International Radio Consultative Committee (Comité Consultatif International de Radiocommunications)
CCW	Counter-Clockwise
CSC	Eutelsat Communications System Control Centre
CW	Clockwise
CW	Continuous Wave (clean carrier)
E/S	Earth Station
EIRP	Equivalent Isotropic Radiated Power
ERS	Eutelsat Reference Station
ESOG	Eutelsat System Operations Guide
ESVA	Earth Station Verification Assistance
G/T	Gain to Equivalent Noise Temperature Ratio
HPA	High Power Amplifier
IF	Intermediate Frequency
IPFD	Input Flux Density
LNA	Low Noise Amplifier
LNB	Low Noise Block Converter
LNC	Low Noise Converter
RF	Radio Frequency
RX	Receive
SUT	Station Under Test
TX	Transmit
UTC	Universal Time Coordinate
XDR	Transponder
XPD	Cross-Polarization Discrimination

Annex C - Measurement of Spurious Radiation

C.1 Test Objectives

- Confirm compliance with spurious radiation specifications.
- Prevent any interference to existing services.

C.2 Principle

The SUT transmits at nominal power to dummy load or clear sky (i.e. far off the geostationary arc) at operational configuration. Using a calibrated measurement point of the station transmit (TX) chain, the output signal is examined within a suitable frequency range for the presence of spurious and intermodulation products.

The following procedure is intended to provide enough indication of presence of spurious emissions. Further investigation (e.g.: zooming into the frequency band where a suspect spurious signal occurs) will be required if spurious signals are detected during this measurement.

C.3. Summary of Requirements

Although the specifications vary following E/S standard, a reasonably simple way to check compliance is to take spectrum analyser dumps of the frequency range of interest. It is however required that SUT provides at least a way to keep a copy of the trace (plotter, screen snapshot, computer file), copy which shall be forwarded (fax or e-mail) to ERS/Eutelsat for evaluation.

Furthermore, the SUT shall record the relevant levels observed using the spectrum analyser marker functions.

Eutelsat Specification	E/S standard	Spurious excluding Intermodulation				Intermodulation Products		Spectral Sidelobes	
		Outside alloc. BW		Inside alloc. BW					
		Level (dBW)	Meas. BW (kHz)	Level (dBW)	Meas. BW (kHz)	Level (dBW)	Meas. BW (kHz)	Level (dBW)	Meas. BW (kHz)
EESS 200	T-2	4	4	N/A	N/A	12	4		
EESS 203	I	4	4	TX carrier -50 dB	4	12	4		
EESS 400	L	4	4			7	4		
						12	4	12	4
						42	12500	42	12500
EESS 500	S	4	4	TX carrier -50 dB					
EESS 502	M	4	4	TX carrier -50 dB		12		TX carrier -50 dB	

C.4. Test conditions

- HPA to dummy load or antenna pointed to clear sky.
- Signal generated by the operational modulator, routed through the operational up-converter.(SUT in operational configuration).
- SUT HPAs to operate at standardized input back off.
- Test Equipment (S.A.) connected to a test point which has been calibrated during ESVA.
- HPA power set using a power meter at the calibrated test point. (Use of the S.A. would be inaccurate since it is usually connected through an uncalibrated cable).

C.5. Potential Pitfalls

Linearity of S.A. log amplifier, as a wide dynamic range is used.

Noise floor of S.A.: with the typical levels observed in most stations, this will not usually cause trouble.

Noise response of S.A log amplifier/detector: see point 1.9 below.

Long sweep time (15s) for 4kHz measurements: some brief events may be lost possible remedy: let at least 10 sweeps accumulate data in max. hold mode.

Limited 1000 or 400 points frequency resolution (4kHz measurements).

Position of the measurement point in the up-link chain (if an up-link bandpass filter is present).

SUT signal modulation may be incompatible with the above S.A. settings.

The actions to take here depend obviously upon the modulation spectral characteristics and are to be solved on a case by case basis.

C.6. Step by Step Procedure

Step 1:	SUT switches to dummy load or depoints the antenna to cold sky (SUT to consider potential danger when commuting switches at high EIRP settings).
Step 2:	SUT configures the signal path as for operational transmission, i.e.: The signal is generated by the operational modulator and routed through the operational upconverter. No modulation is applied (see test conditions below).
Step 3:	SUT adjusts the EIRP to obtain the nominal transmit EIRP value, using the calibrated test point (see EIRP test). SUT records the EIRP and level readings.
Step 4:	Keeping the HPA power constant, SUT substitutes the spectrum analyser cable to the power sensor and sets the spectrum analyser (refer to recommended settings below).
Step 5:	SUT records the peak signal level on the analyser and deduces the cable loss (which should typically not exceed 5 dB).
Step 6:	SUT sets the spectrum analyser following the guidelines of table 1.7.1 below then activates the max. hold mode. After at least 10 sweeps, SUT freezes (‘view’) and records the trace (plotter / printer).
NOTE:	Assuming a 1000-point plot, each point represents a 500 kHz slice of the spectrum, which is 50 times larger than the resolution bandwidth. It is therefore recommended to zoom on visible spurious using a 10 MHz span, keeping same reference level, RBW and VBW.
Step 7:	Maintaining the above analyser settings, the SUT disconnects the spectrum analyser and records the level of the noise floor.
Step 8:	As step 6 but SUT uses the settings defined by table 1.7.2 below (The required data accumulation time will exceed 2 minutes).
Step 9:	SUT ceases transmission and forwards the results (copy of spectrum plots including corresponding EIRP levels of spurious signals and noise floor) to Eutelsat and ERS.

C.7. Spectrum Analyser Settings

Measurements for Detection of Spurious within 4 kHz Bandwidth:

Frequency	: 14.25 GHz	(Centre of the transmit band of interest or SUT carrier frequency)
Span	: 500 MHz	
Resolution Bandwidth	: 10 kHz	(For HP S.A. equivalent Noise Bandwidth equals 10 x 1.2 = 12 kHz). See note*
Video Bandwidth	: 10 kHz	See note*
Sweep Time	: 15 sec	Automatic (coupled)
RF Attenuator	: 10 dB	(Depends on level at nominal power. To optimize the dynamic range, it is recommended to set the attenuator to 0dB at test points with low level)
Max. Ref level	: 0 dBm	(Depends on RF attenuation)
Max. hold	: On	
Max. hold noise	: -73 dBm	(With HP8566A/B and 10dB RF input attenuation. At 0dB input attenuation: -83)

DRONE-BASED ESVA

13 Drone-Based ESVA Procedure

13.1 Drone-Based ESVA test sequence

In the following chapters, the official procedure for a Drone-Based ESVA testing is reported, including the requirement, type and procedures of each measurement and the contact of Eutelsat approved testing entities.

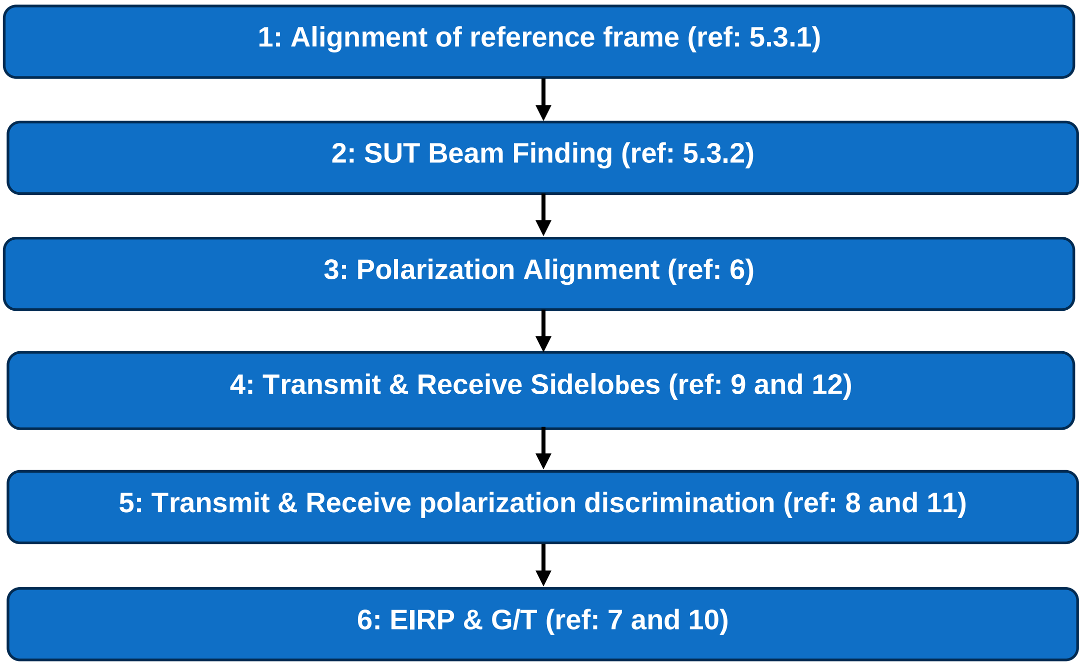


Figure *3: Optimal Quadsat ESVA test sequence*

14 ESVA Requirements

This section includes the conditions which ensure smooth implementation of ESVA using the Quadsat system, namely:

- *Prevention of interference to existing communications traffic*
- *Consistency of measurement results*
- *Efficient coordination of testing*

The rules given hereafter apply to all ESVA with the Quadsat methodology.

14.1 Obtaining flight license

A drone flight license might be required depending on the location of the SUT and the conditions of the test; this can be obtained from the local aviation regulator, e.g. DGAC in France, FAA in the USA or CAA in the UK. All professional UAV operators should follow the applicable regulations. A comprehensive list of global aviation regulators can be found here.[1]

As it is the UAV operator that are flying the drone from a legal and safety point-of-view, it is also his/her responsibility to obtain a flight license when needed. The UAV operator's operational procedures, and any extra risk mitigation efforts applied, are typically evaluated.

Depending on the complexity of the flight, and the internal procedures and workload of the local aviation regulator, the flight license process can course a delay, typically in the range from 1 day

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[1] https://en.wikipedia.org/wiki/Civil_aviation_authority

to 6 months. It is advised to contact the regulator for more information on local requirements and expected timelines at an early stage.

14.2 Obtaining transmit license

An RF transmit licence might be required depending on the location of the SUT and the conditions of the test. This can be obtained from the local telecommunications regulator, e.g. ANFR in France, FCC in the USA or OFCOM in the UK. A comprehensive list of global telecommunications regulators can be found here.[2]

The RF transmit license can either be obtained by the SUT operator or be provided by the UAV operator as an added service. Due to the expected ongoing relationship between the SUT operator and the local telecommunications regulator, the former is often the most efficient.

Depending on the complexity of the operation, and the internal procedures and workload of the local telecommunications regulator, the RF transmit license process can course a delay, typically in the range from 1 day to 30 days. It is advised to contact the regulator for more information on local requirements and expected timelines at an early stage.

14.3 Weather Conditions

Quadsat ESVA is not sensitive to atmospheric attenuation since the measurement is done at relatively low altitude, between the UAV and the SUT. Measurements in heavy rain, a scenario that potentially could influence the data, is not relevant as the system would not be operational under those conditions, see below rain limits.

However, wind and temperature are important factors to consider when planning and executing UAV operations, and the limits specified in the System User Manual must always be respected.

Here are some approximate limits:

Wind: max 15 m/s

System operating temperature: -15 °C to +40 °C

Battery operating temperature: +10 °C to +45 °C

Battery start temperature: min +10 °C

Rain: No more than light rain (Payload and Drone rated IP42, GCS rated IP20)

14.4 Antenna Alignment

With the Quadsat methodology, the antenna alignment, position, and centre of the main beam shall be identified. This ensures the accuracy of the following measurement. The necessary procedures to obtain this information are described in section 18.

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[2] https://en.wikipedia.org/wiki/List_of_telecommunications_regulatory_bodies

14.5 Check List

In Annex E , a simplified checklist summarizes the most important things to check/remember prior to starting a measurement.

15 Test Equipment

The measurement equipment which must be available at the SUT during ESVA, is summarized hereafter. The lack of any part from the measurement equipment could lead to incomplete results. Prior to the start of ESVA, the test operator shall ensure that all test equipment, and the SUT operator ensure that the SUT:

- functions correctly,
- it’s warm-up periods are respected,
- it’s calibration procedures and timing have been respected,

For completion of test records, the test equipment types shall be reported to Eutelsat.

16 Measuring system kit

The measurement kit is usually composed of:

- RF payload,
- a UAV,
- a Ground Control Station (GCS),
- other positioning equipment

Figure 4: Example of a drone measuring system kit (courtesy of QuadSat).

16.1 Measuring System Components and Certified Equipment

16.1.1 Payload

The payload is defined as the RF frontend installed on the UAV. It is needed to assess the transmit and receive parameters of the SUT.

The authorised payload to performed a DB-ESVA’s up to date are:

- **QS 6-24 DL** (manufacturer: Quadsat (Denmark)): it comprises a dual-channel signal source, a probe, a 10MHz GPSDO frequency reference, a stabilization system, and a microcomputer. The used probe in QS 6-24 DL is a dual-polarized linear horn operating from 6 – 24 GHz. The payload transmits a continuous wave (CW) to or from the SUT at its test frequency. The probe is mounted on a 3-axis stabilized gimbal and its orientation and polarization alignment are maintained precisely during the measurement. Additionally, the precise position of the drone and RF payload is obtained with the help of the RTK GNSS reference system.

16.1.2 Unmanned Aerial Vehicle (UAV)

The payload is mounted on a drone which is selected based on Quadsat’s specifications such as flight characteristics, stability, durability, country of origin, and other parameters. The currently available types of drones that are compatible Quadsat system and relevant for ESVA are listed as follows:

- Videodrone 7 X4S (manufacturer: Nordic Drones (Finland))

The average flight time of the drones is approximately 25-30 minutes. With the support of a precise positioning system at the GCS.

16.1.3 Ground Control Station

GCS comprises a main computer, a spectrum analyser and various connectivity modules. The Quadsat's purpose-built software, FANG, is installed in the main computer and support flight planning, flight execution and data post-processing.

The main computer controls a spectrum analyser and collects measurement data of SUT via external software during the mission.

After the flight, the measurement data from the spectrum analyser and the drone navigation data are processed as a mission dataset at FANG. The final test results are presented in various formats. The results can be stored locally or shared via Quadsat's cloud service.

16.1.4 Real Time Kinematics (RTK) Base Station

The RTK base station provides positioning error corrections to the drone through the main computer and communication module in the GCS. Together with the information from the GPS receiver on the drone, the determination accuracy of the positioning is achieved in the order of a few centimetres (+/-2 centimetres) in all directions of a 3D space.

The corrected GPS positions are used during the data post-processing.

16.1.5 Reference antenna or Standard Gain horn

Reference measurements are needed for EIRP and G/T measurements. For this, a calibrated standard gain horn (SGH) or a compact reference antenna (RA) is necessary to guarantee the necessary precision.

16.1.6 Vector Network Analyser (VNA)

For EIRP measurement a VNA can be used, as described in section 20. If this method is preferred, a separate VNA is part for the required test equipment list.

17 Eutelsat Certified Test Entities

The Drone-Based ESVA requires specific competencies in order to ensure that the measurements are taken following the present procedure and are provided with the right level of accuracy.

For this, Eutelsat will validate the quality of the measurement for any entities that wishes to be eligible to provide such service.

In this section are reported the contact details of the certified entities that are allowed to perform a Drone-Based ESVA test.

- **QuadSAT ApS**
  Joakim ESPELAND
  CEO
  Lufthavnvej 151
  DK-5270 Odense N
  Phone: +45 53 57 49 43
  E-mail: je@quadsat.com
  WebSite: https://www.quadsat.com

18 System setup and alignment

18.1 Test Objectives

1. *Ensure the correct positioning of the SUT relative to the detailed local GPS reference frame.*
2. *Localisation of the main beam of the SUT.*

18.2 Beam Localisation Principle

Initially, the precise position of SUT is confirmed to create a local reference frame by using GPS information.
One of the two methods are considered for the localization of SUT depending on the scenario:

- **Scenario 1**: The aperture of SUT is less than approximately 4 metres and the SUT is easily accessible. In this scenario, the antenna locator, which is part of the GCS can measure the position of SUT directly.
- **Scenario 2**: The aperture of SUT is larger and the antenna locator does not reach the feed of SUT or the antenna is not easily accessible, e.g. mounted in a mast. In this scenario, the SUT feed is located by using the drone.

Once the antenna location is determined, the pointing angle of the SUT is estimated using e.g. the mechanical direction display from the SUT, compass readings and/or visual estimation.
Afterwards, the pointing angle is validated with a SUT beam finding flight. During SUT beam finding, the drone will fly on a spherical surface centred at the identified SUT position and execute a raster scan around the estimated beam centre at far-field to localize the boresight angle of the main beam more precisely.
The raster scan consists of multiple horizontal cuts along a certain elevation range. During the raster scan, the payload on the drone transmits CW signal toward the SUT at operation frequency and the received signal strength is measured at SUT. Due to the antenna reciprocity, it is valid to localize the beam centre based on the received signal at the SUT. This process is iterated several times with higher resolution in smaller ranges until the estimated centre converges.
The resolution of raster scan is defined by the step size between elevation cuts in Quadsat method. Assuming that the smaller raster scan is defined by $\pm 2°$ range in azimuth and elevation direction and the beam is arbitrary placed within $\pm 1°$around the origin of the area, the figure below shows the simulation result which links between the beamwidth, elevation step and beam localization accuracy after 1000 times trials.

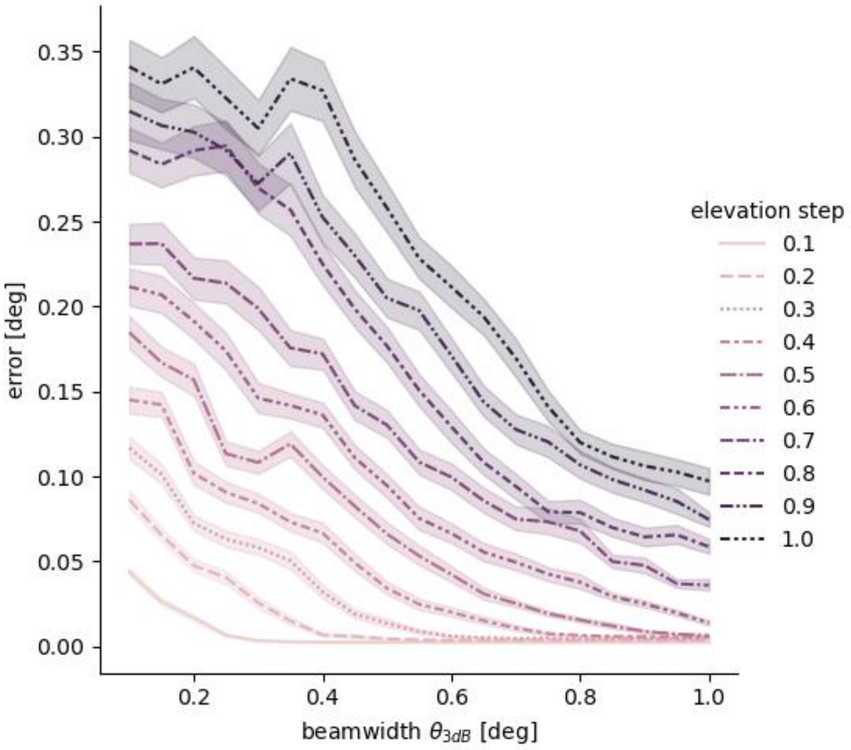


Figure 5: Beam localization accuracy linked with beamwidth and elevation step size on raster scan (courtesy of QuadSat)

From the simulation result, the relationship between maximum elevation step (, therefore the shortest flight path) and beamwidth by maintaining the beam localization accuracy below $0.05°$ is formulated as equation:

$$elevation\ step = -1.251\theta_{3dB}^3 + 1.914\theta_{3dB}^2 + -0.047\theta_{3dB} + 0.093$$ Equation 1

The beamwidth is typically estimated by equation:

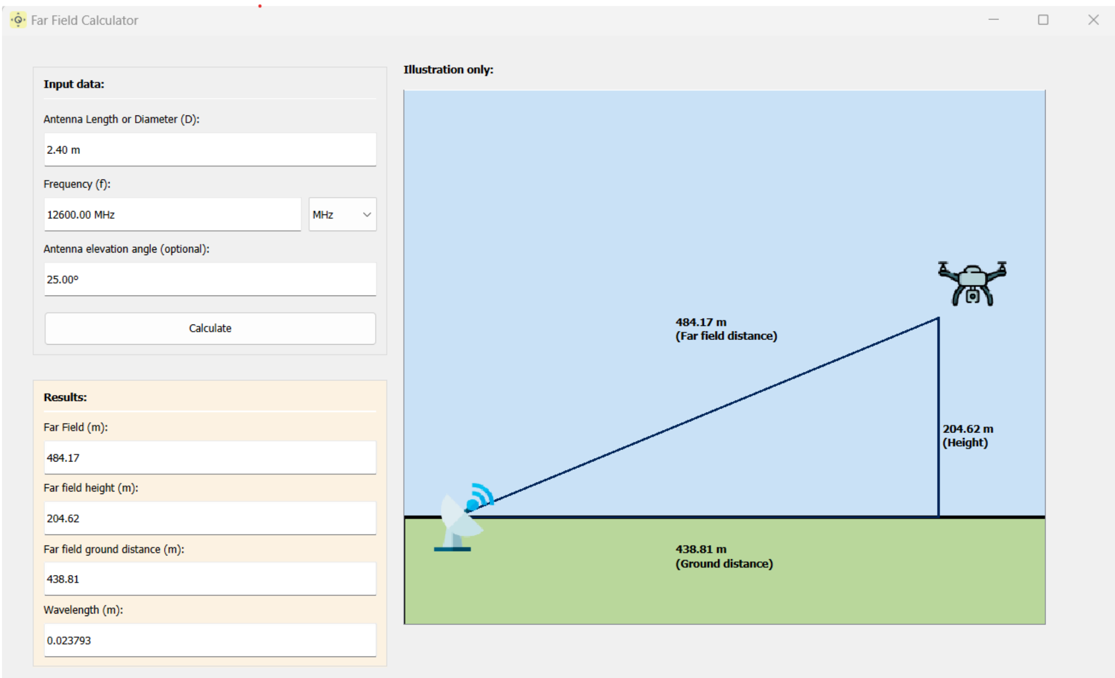
$$\theta_{3dB} = 70\lambda/D$$ Equation 2

Where:
λ is wavelength and D is the diameter of the antenna.

The distance between SUT and the payload is fixed during the raster scan. Under normal circumstances, the minimum distance is determined by the SUT far field distance which is obtained by equation.

$$d_F = (2D^2)/\lambda$$ Equation 3

Where:
D : the diameter of SUT
λ : wavelength



Input data:

Antenna Length or Diameter (D): 2.40 m

Frequency (f): 12600.00 MHz MHz

Antenna elevation angle (optional): 25.00°

Calculate

Results:

Far Field (m): 484.17

Far field height (m): 204.62

Far field ground distance (m): 438.81

Wavelength (m): 0.023793

Figure 6: Far field calculation and visualization in FANG (courtesy of QuadSat)

It is preferred to perform measurements by maintaining the maximum signal-to-noise ratio at the beam peak to obtain the accurate measurement. The transmit power at the payload is determined based on link budget calculation for the initial measurements with the available gain of the probe so that the input power to SUT and spectrum analyser does not exceed its limit by assuming that the gain of the earth station is obtained by equation.

$$G = 20\log_{10}\left(\frac{\pi D}{\lambda}\right) - 1.5\ [dBi]$$

Equation 4

Once the direction and polarization of the main beam are known (see section 18 and 19), the transmission power is reconsidered by examining the linearity of the received power level. The transmission power is changed from minimum to maximum at the beam peak while maintaining accurate polarization alignment. The linearity of the received power level is evaluated, and the transmission power is reconfigured at near the saturation level without risking damaging the SUT and the spectrum analyser for the rest of the measurements. The system setup once completed can be visualised like this:

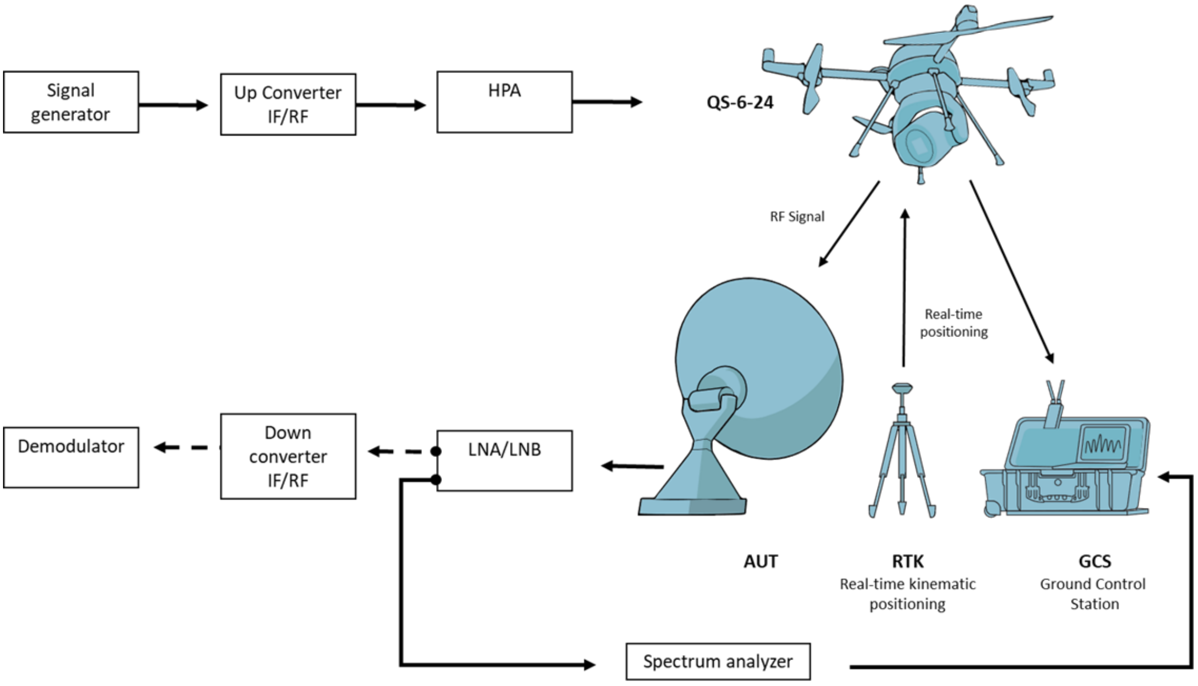


Figure 7: Main drawing of the Quadsat system and interface with the SUT in a Rx/Downlink scenario (courtesy of QuadSat)

18.3 Step-by-Step Procedure

Alignment of reference frame

The Quadsat methodology requires that a local reference frame is established to enable high-precision measurements. Also, the exact position of the SUT must be determined. For this, two methods are available.

Method A

For smaller aperture antennas (approximately up to 4 metres), the exact antenna position can be determined with the help of the antenna locator which is part of the Ground Control Station.

Step 1: Determine the best direction of the planned measurement. There should be no interference and objects on the line-of-sight between the UAV and SUT for the whole measurement. Take into consideration the required Az and El angles, the desired radius from the SUT, and generated flight area, when determining this.

Step 2: The antenna locator is connected to the GCS laptop and FANG software is opened.

Step 3: With the SUT pointing in the approximate direction of the planned measurement, the antenna locator is placed as close to the SUT feed as safely possible. Adjust for the SUT rotational axis.

Step 4: Record the SUT position in FANG via the automatic record button (Get GPS position from antenna locator).

Step 5: Finish the configuration of the antenna meta data in FANG, e.g. test frequency, signal power etc.

Method B

For larger aperture SUTs, the antenna locator cannot be used since it is not possible to manually reach the SUT feed. For these scenarios, another method can be used:

Step 1: Evaluate the best direction of the planned measurement. There should be no interference and objects on the line-of-sight between the UAV and SUT for the whole measurement.

Step 2: The drone is flown above the antenna, as close to the phase centre position as possible. The SUT longitude and latitude is recorded via the automatic record button (Get GPS position from drone).

Step 3: The drone is flown at the height of the SUT feed, but at a safe distance. The camera feed from the payload can be used to increase the accuracy. The SUT altitude is recorded.

Step 4: For verification, the drone is flown further away, and the gimbal should point towards the previously defined SUT centre point.

Step 5: The coordinate system is an Elevation over Azimuth coordinate system, and the gimbal always points towards the centre of the coordinate system.

Step 6: Finish the configuration of the antenna meta data in FANG, e.g. test frequency, signal power etc.

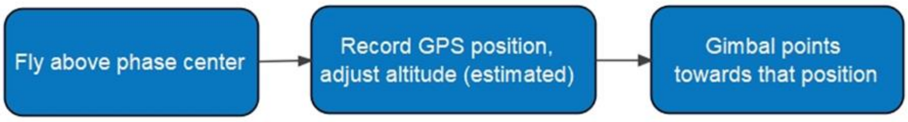


Figure 8: Flowchart of Alignment of reference frame process with method B.

The direction of the main beam of the SUT is estimated:

Step 1: Configure raster scan and flight trajectory in FANG. Namely, define the distance between the SUT and the payload and raster scan by selecting a range of azimuth and elevation defined by the currently estimated beam centre and step size between horizontal cuts.

Step 2: Execute the raster scan in accordance to operational procedure. The drone automatically performs a raster scan in a defined angular range around that region.

Step 3: Estimate beam centre using flight data and RF data at FANG by matching the measurement data files from the AUV and the UAT. FANG's analysis tool gives the offset from originally estimated beam centre.

Step 4: This position is used as the new central reference position (Az, El) = (0º, 0º) and a new raster scan is performed to verify the estimation of the beam centre. Optionally, the angular scope and steps between horizontal lines can be narrowed to focus on a specific area of interest.

18.4 Screenshot examples

Reference level : 0 dB (Advise to set 5 dB above level of reference carrier)

Attenuator : Auto

Scale : 10 dB/Division

Centre frequency : 2.000007 GHz

Span : 10 kHz

Resolution bandwidth : 100 Hz

Video bandwidth : 100 Hz

Video average : On

Sweep time : 7 ms

Marker : Peak search, To centre

Trace : One, Clear &Write

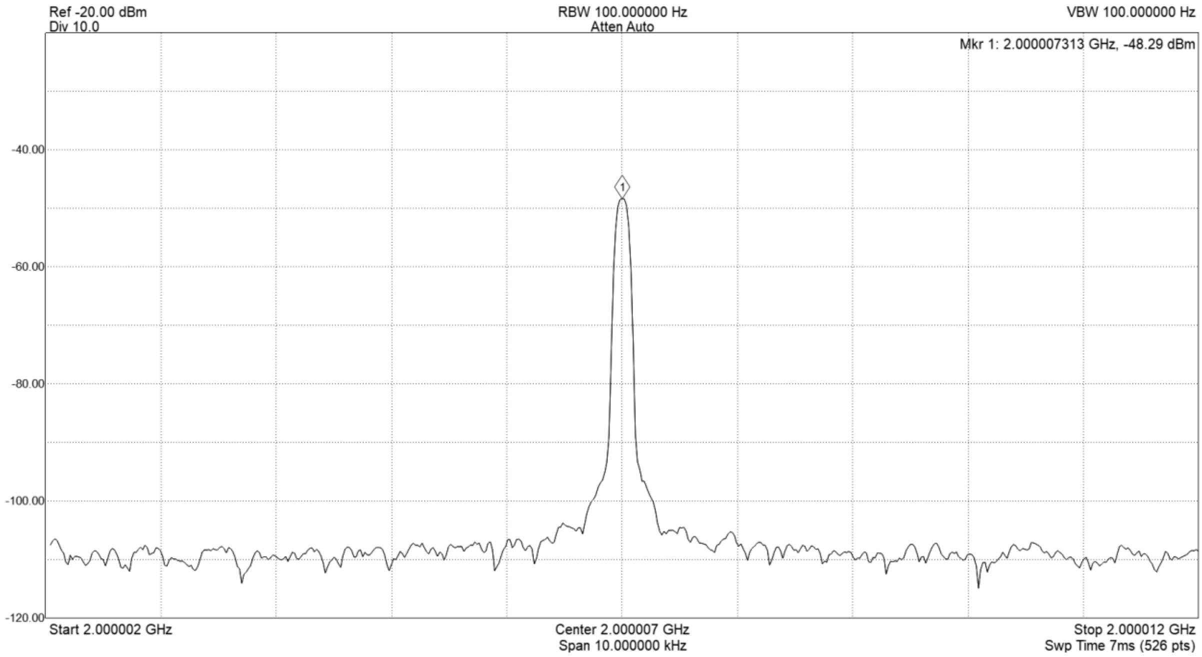
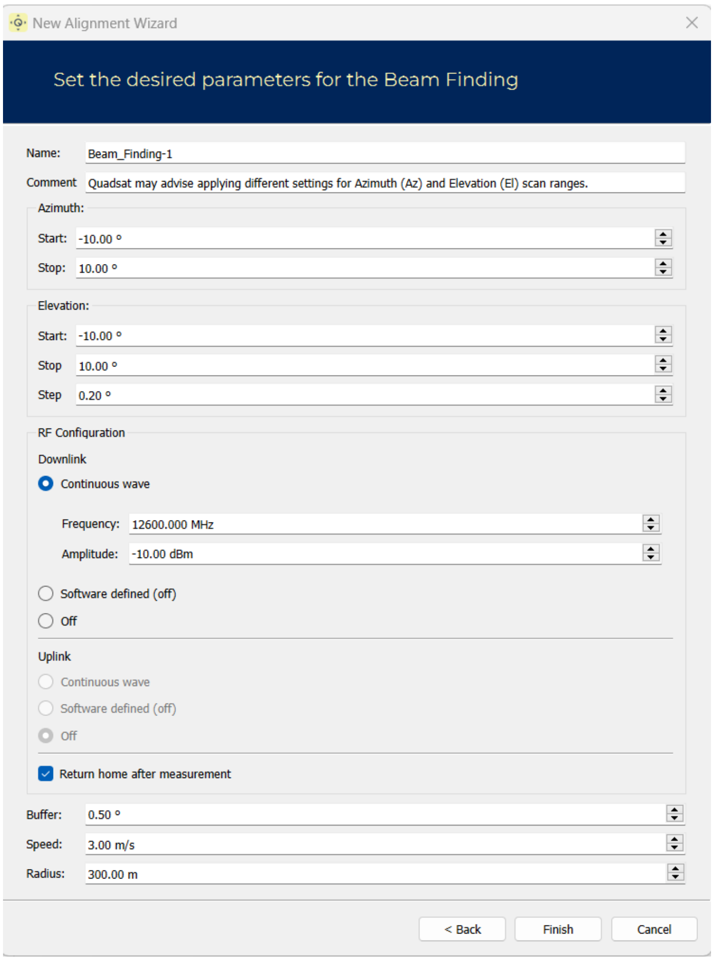


Figure 9: Spectrum analyser display during SUT beam localisation test.


New Alignment Wizard

Set the desired parameters for the Beam Finding

Name: Beam_Finding-1

Comment: Quadsat may advise applying different settings for Azimuth (Az) and Elevation (El) scan ranges.

Azimuth:

Start: -10.00 °

Stop: 10.00 °

Elevation:

Start: -10.00 °

Stop: 10.00 °

Step: 0.20 °

RF Configuration

Downlink

● Continuous wave

Frequency: 12600.000 MHz

Amplitude: -10.00 dBm

○ Software defined (off)

○ Off

Uplink

○ Continuous wave

○ Software defined (off)

● Off

☑ Return home after measurement

Buffer: 0.50 °

Speed: 3.00 m/s

Radius: 300.00 m

Figure 10: Beam finding settings in Flight Assistant- Next Generation (FANG) (courtesy of QuadSat).

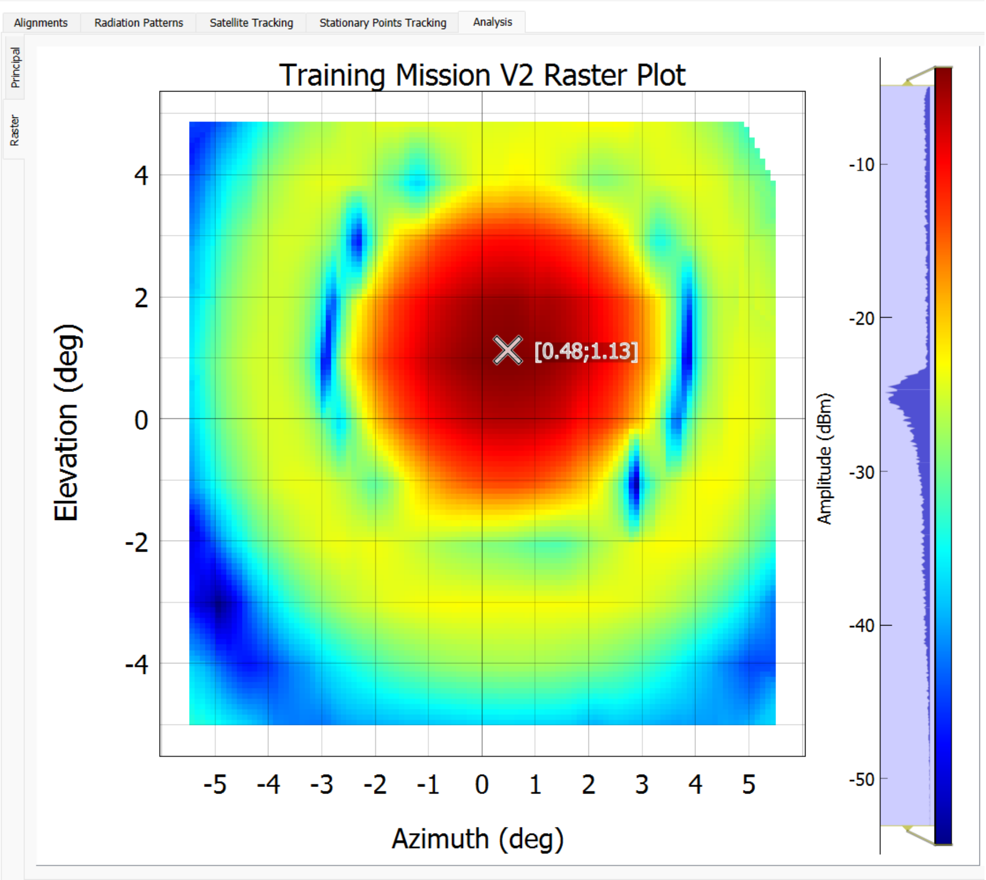


Figure 11: Beam finding visualization: Beam with offset value (Az 0.48, El 1.13) (courtesy of QuadSat).

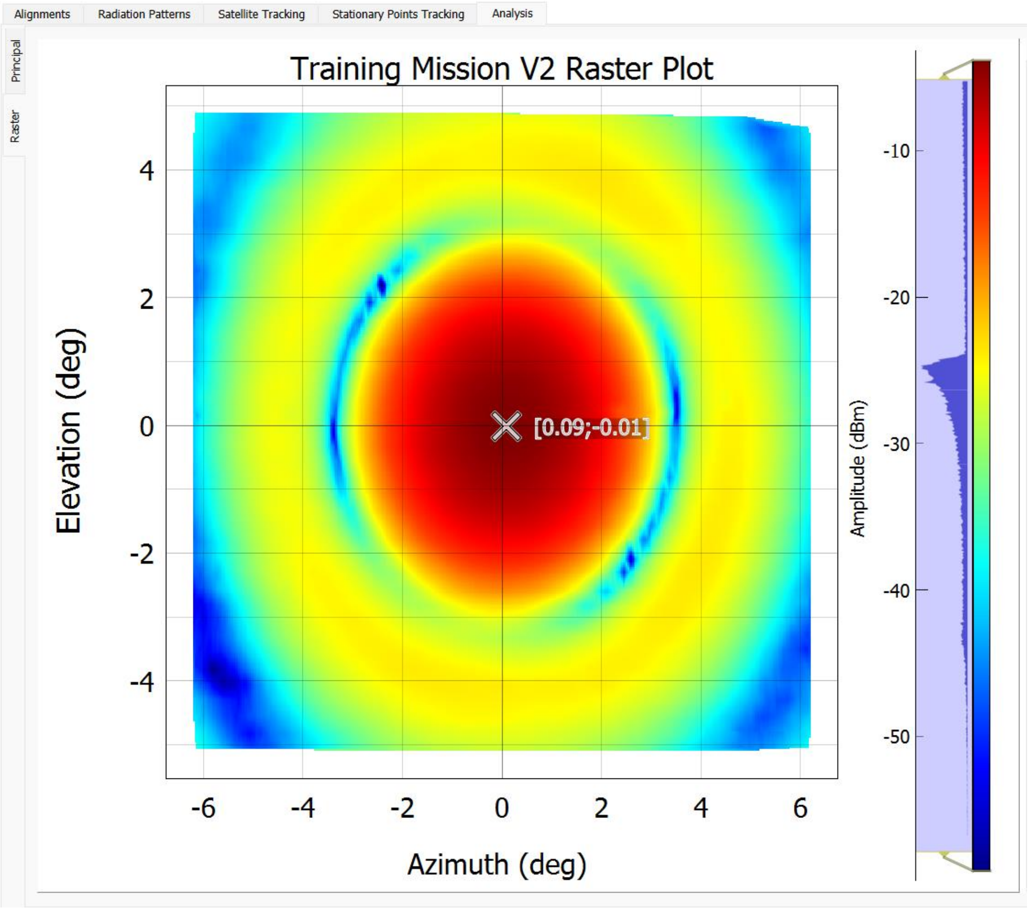


Figure 12: Visualisation of Raster scan of measurement with applied offset (courtesy of QuadSat).

19 Polarization Alignment

19.1 Test Objectives

To accomplish optimum alignment of the polarization plane between the SUT and the Quadsat payload, in order to guarantee accurate Quadsat ESVA measurement results.

19.2 Principle

After the peak of the main beam is defined according to the procedure described in 18.2, the drone is flown to the centre of the main beam. The payload is set to transmit a CW signal towards the SUT at the operation frequency via the co-polar channel. The polarization angle of the payload is tilted gradually, and the received signal strength is recorded to identify the angular position where the minimum level is detected (nulling).

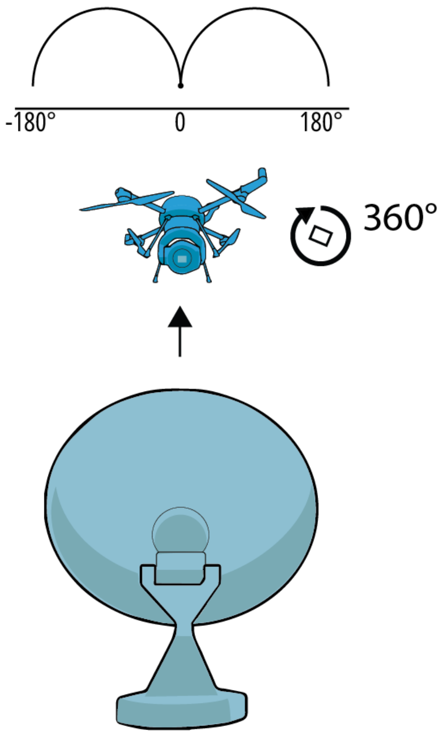


Figure 13: Illustration of polarization alignment with UAV (courtesy of QuadSat).

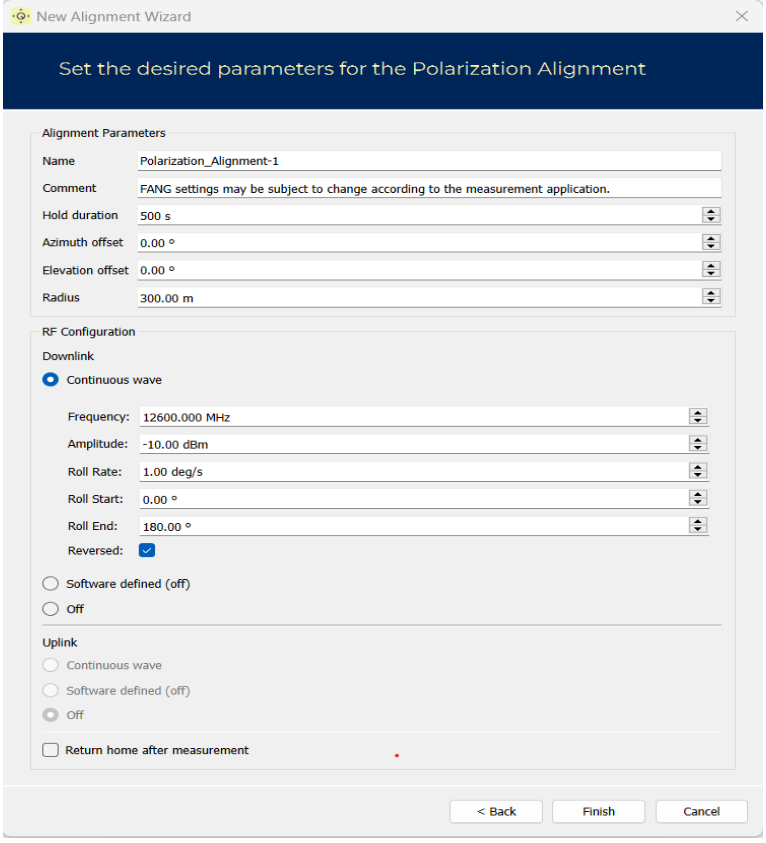
19.3 Step-by-Step Procedure

Step 1: The drone is flown to the centre of the (Az, El) = (0º, 0º) coordinates and points towards the SUT.

Step 2: The polarization axis ϕ at Quadsat payload is rotated by 360º while data is recorded. The origin position ϕ = 0º is set where the recorded value is maximum for the rest of the measurements.

NOTE: Values of angles are positive if the rotation is clockwise as seen from SUT.

19.4 Screenshot examples



Set the desired parameters for the Polarization Alignment

Alignment Parameters

Name: Polarization_Alignment-1
Comment: FANG settings may be subject to change according to the measurement application.
Hold duration: 500 s
Azimuth offset: 0.00 °
Elevation offset: 0.00 °
Radius: 300.00 m

RF Configuration

Downlink

● Continuous wave

Frequency: 12600.000 MHz
Amplitude: -10.00 dBm
Roll Rate: 1.00 deg/s
Roll Start: 0.00 °
Roll End: 180.00 °
Reversed: ☑

○ Software defined (off)
○ Off

Uplink

○ Continuous wave
○ Software defined (off)
● Off

☐ Return home after measurement

Figure 14: Polarization adjustment settings in Flight Assistant- Next Generation (FANG) (courtesy of QuadSat).

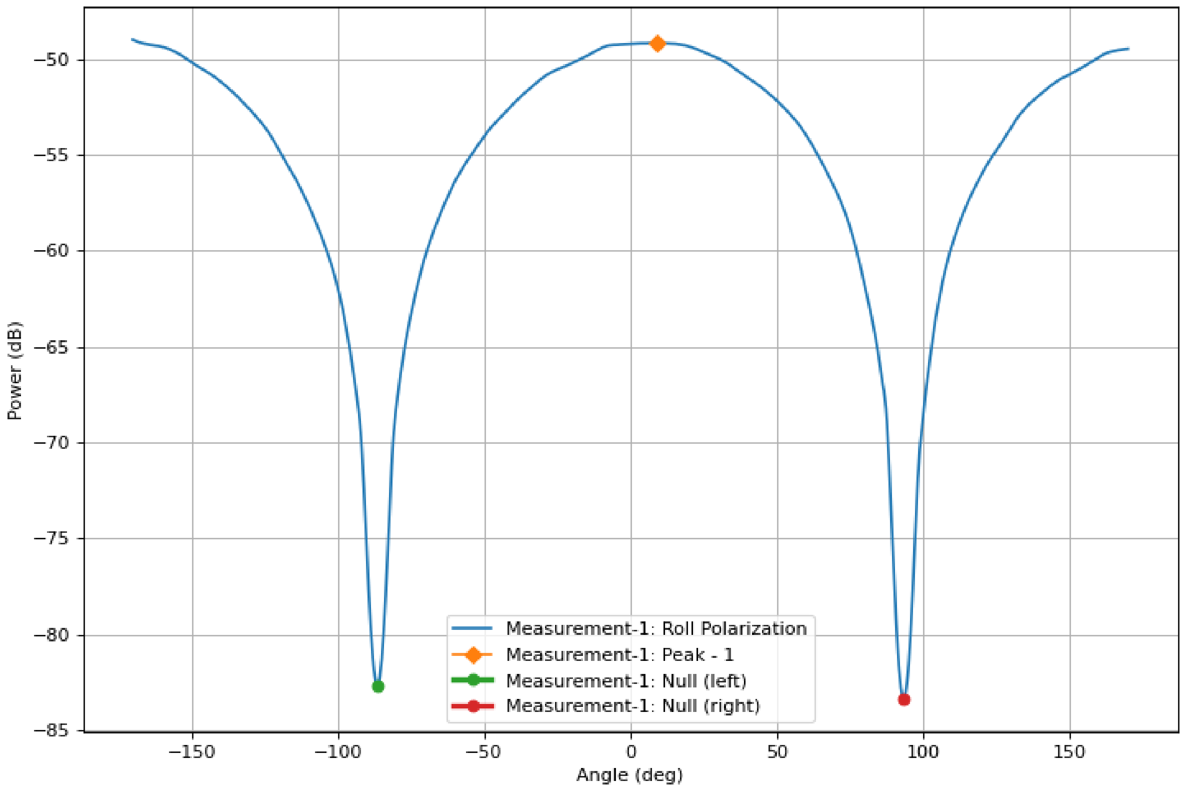


Figure 15: Alignment profile incl. roll offset (courtesy of QuadSat).

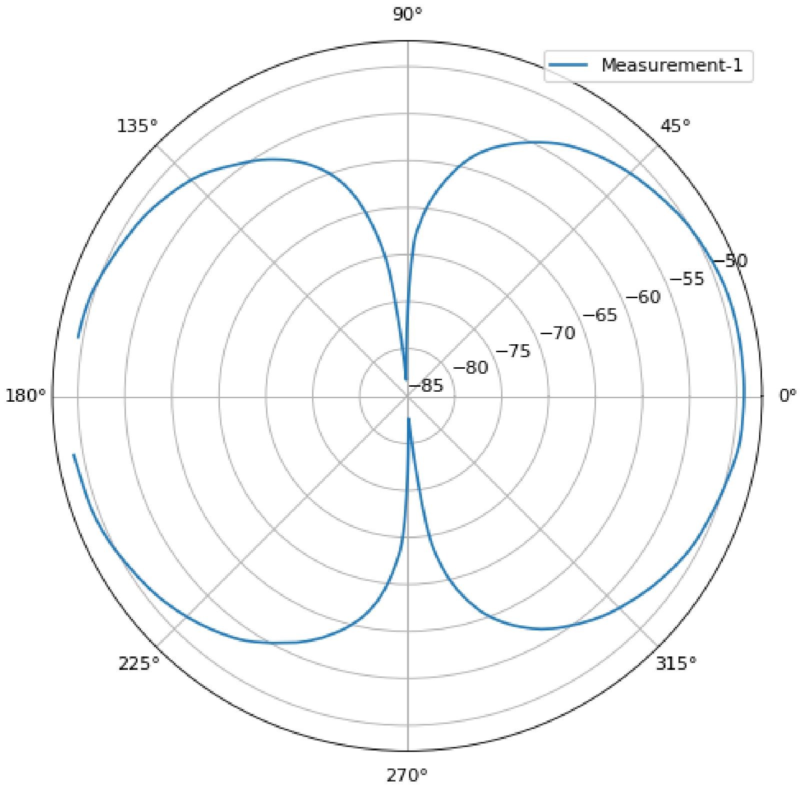


Figure 16: Alignment profile power over angles (polar) visualization (courtesy of QuadSat).

20 EIRP and transmission gain measurements

20.1 Test Objectives

- Reconfirm the SUT EIRP calibration prior to commencement of operations,
- Assess the linearity of the EIRP indication at the SUT,
- Evaluate the transmit gain of the SUT,
- Measure the maximum EIRP capability of the SUT.

20.2 Principle

To calculate EIRP, the gain of the SUT is measured first. Together with the obtained gain, EIRP is acquired by measuring the transmitted power at the SUT with either VNA, Spectrum analyser or power meter.

20.2.1 Gain measurement using a SGH

The gain of SUT is obtained by using the substitution method. The signal levels are measured at the standard gain horn (SGH) and the SUT while the drone hovers at each beam centre and transmits the signal. The configuration of the signal path should be assumed to be the same and hence, the gain is calculated from the measured value at each position and the known gain of SGH by equation:

$$G_{SUT}(dBi) = E_{max,SUT}(dB) - E_{max,SGH}(dB) + G_{SGH}(dBi)$$

Equation 20-1

Where:

G_{SUT}, G_{SGH}: the gain of SUT and SGH

$E_{max,SUT}$, $E_{max,SGH}$: The field value measured at the maximum of the main beam of SUT and SGH.

The accurate antenna position, the angular position of the beam centre, and the polarization plane are known from the previous measurements for SUT. To perform the substitution method, the information with respect to SGH should be collected by following the same methods described in section 18 and 19. To further ensure the alignment of the beam and the polarization between AUT and SGH, the received signal level at SGH $E_{max,SGH}$ is compared to the expected value $\hat{P}_{RX,SGH}$ which is obtained by link budget calculation as follows:

$$\hat{P}_{RX,SGH} = EIRP - L_{tot} + G_{SGH}$$

Equation 20-2

Where:

$EIRP$: EIRP of payload which will be provided by the drone system

L_{tot}: all losses and gains on the path e.g., free space loss, cable loss, LNB gain

G_{SGH}: Known gain of SGH

The field value should ideally be measured at the maximum of the main lobe. To mitigate the effect of the motions of the drone and payload, the drone hovers for a certain period at the estimated beam centre to collect samples to be averaged. The required number of samples depends on the beam width of the SUT. The number of samples and hovering time for gain measurement are calculated based on stochastic analysis to guarantee the measurement accuracy.

20.2.2 EIRP measurement

EIRP is obtained by measuring the transmitted power at the SUT using either a VNA, a Spectrum Analyser, or Power Meter.

The signal is transmitted at set power levels and frequencies at the SUT. Then, the generated power level is measured before the port by using coupler. Based on the measurement, EIRP is calculated by equation:

$$EIRP_{SUT} = G_{TX} + P_m - 30 + C_{TX} - L_{TX}$$

Equation 20-3

Where:

P_m: transmit power reading (dBm)

C_{TX}: transmit coupling factor (dB)

L_{TX}: post coupler losses (dB)

30 : conversion from “dBm” to “dBW”

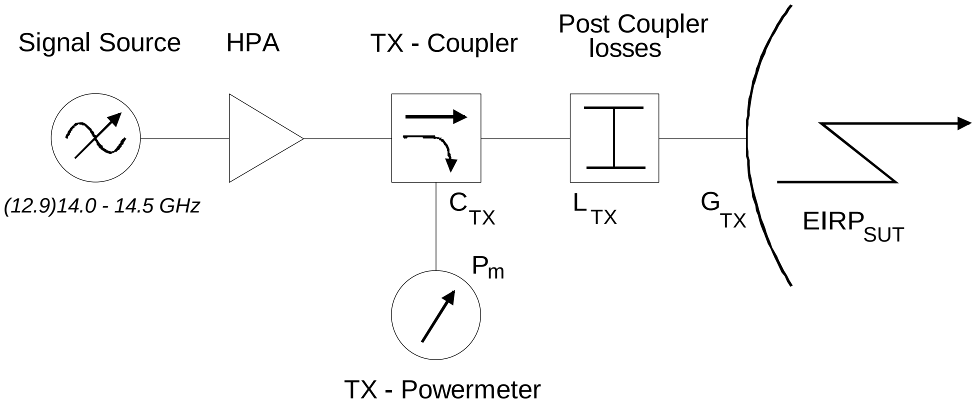


Figure 17: Schematic diagram of SUT TX-chain for EIRP measurement.

20.3 Step-by-Step procedure

20.4 Gain measurement

Step A1: Plan the flight by configuring the distance, frequency, transmit power level, hovering period, and alignment information (i.e., antenna location, beam centre, polarization plane) for the payload.

Step A2: Execute the flight and collect measurement data. The drone should hover at the boresight of SUT for the certain period while the payload tries to keep pointing and polarization of its antenna.

Note: the following steps should be executed quick enough after Step A2 so that the condition of the measurement environment does not drastically change.

Step A3: Place SGH close to SUT and point toward approximately the same direction of SUT.

Step A4: Connect SGH by replacing SUT with SGH. To execute substitution method, the signal path should be the same. Thus, the same cable, GCS and Low Noise Block(LNB) should be used.

Step A5: Collect alignment information of SGH.

- SUT localization (section 18)
- Beam localization (section 18)
- Polarisation alignment (section 19)

Step A6: Plan the flight on FANG to measure by configuring the same distance, frequency, transmit power level as Step 1, and hovering period and alignment information (i.e., antenna location, beam centre, polarization plane) for the payload.

Step A7: Execute the flight and collect measurement data. The drone should hover at the boresight of SGH for the certain time while the payload tries to keep pointing and polarization of its antenna.

Step A8: Calculate Gain of SUT.

20.5 EIRP measurement

Note: this measurement does not involve the drone.

Step B1: Generate signal at SUT.

Step B2: Read the values of transmitted power at the used test equipment (VNA/spectrum analyser/ power meter). IF VNA is used, the cable loss between the coupler and the VNA could be calibrated before the measurement.

Step B3: Calculate EIRP.

Step B4: Repeat this process to complete all frequency and transmit power to be evaluated.

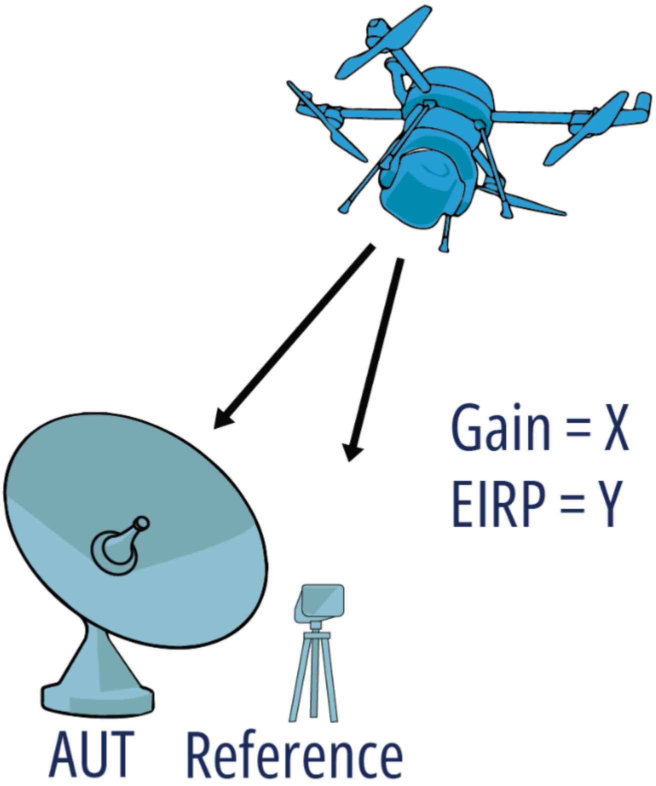


Figure 18: Illustration of Gain measurements with UAV with a SGH deployed next to the SUT in order to measure the absolute gain using the substitution method (courtesy of QuadSat).

20.6 Screenshot examples

Reference level	: 0 dB (Advise to set 5 dB above level of reference carrier)
Attenuator	: Auto
Scale	: 10 dB/Division
Centre frequency	: N/A
Span	: 500 MHz (Subject to change)
Resolution bandwidth	: 300 Hz
Video bandwidth	: 300 Hz
Sweep recording	: On
Frequency step size	: 10 MHz (Subject to change)
Sweep time	: 100 ms (Subject to change)

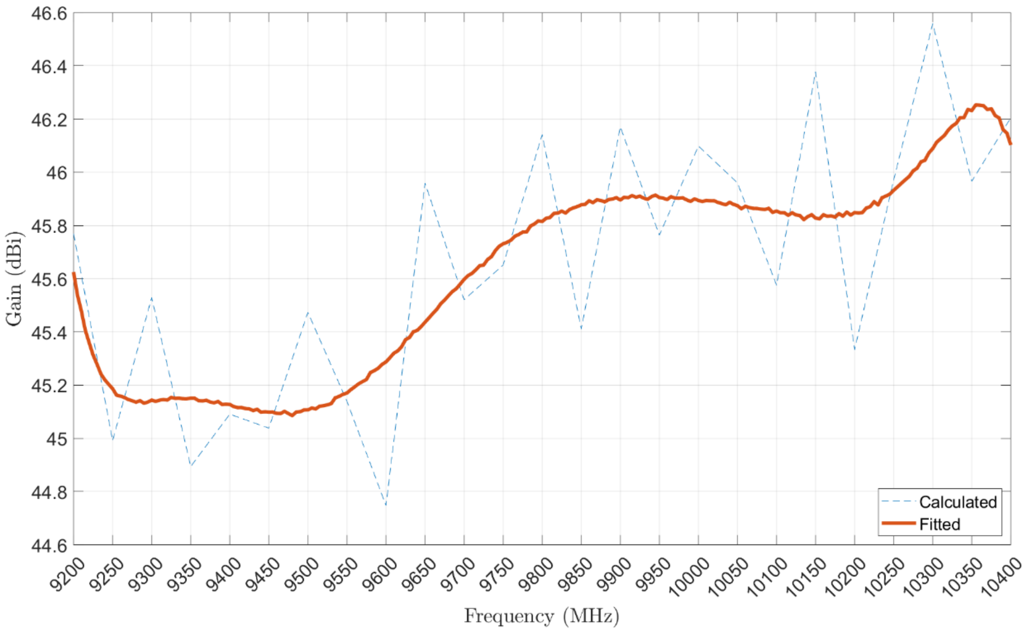


Figure 19: SUT Absolute Gain (courtesy of QuadSat).

21 Transmit Polarization Discrimination

21.1 Test Objectives

To measure the transmit polarization isolation of the SUT at optimized polarization alignment.

21.2 Principle

The measurement is carried out the co- and cross- radiation pattern using the obtained alignment information in section 18 and section 19.

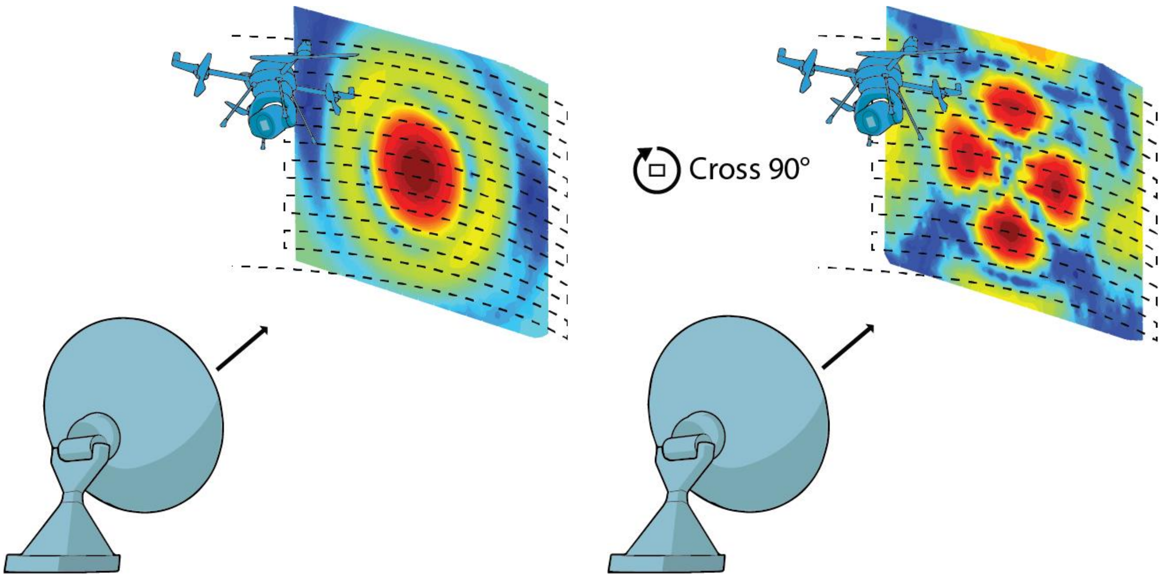


Figure 20: Illustration of first a Co-pol raster (left) and then a Cx-pol raster (right) of an SUT (courtesy of QuadSat).

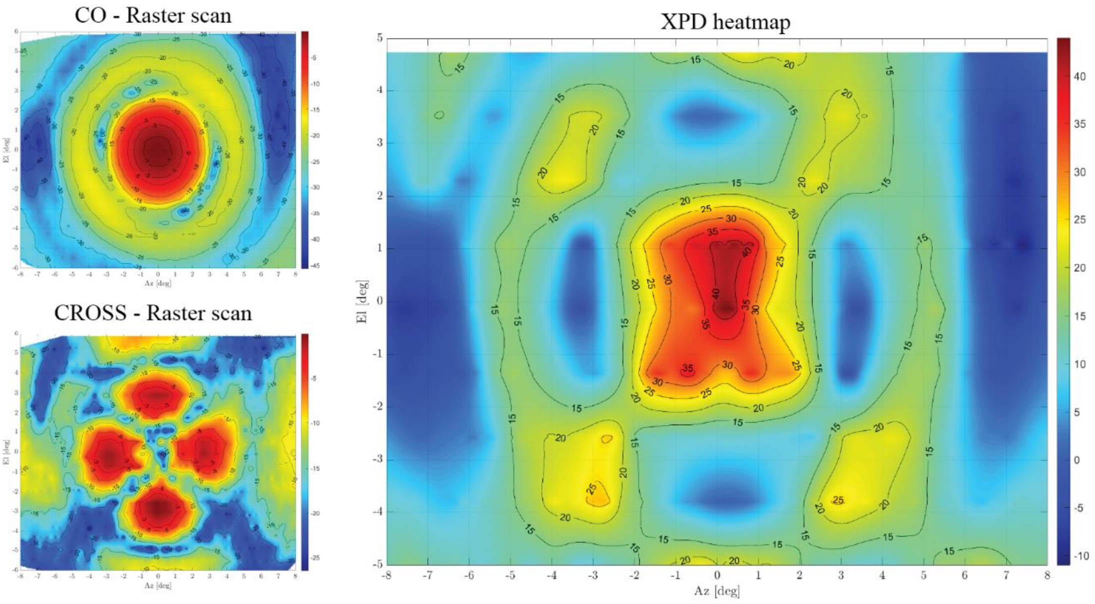
To calculate the Cross-Polar Discrimination (XPD), the value measured for the Cx component at a certain angular point is subtracted to the value measured for the Co component as equation:

$$XPD = C_o - C_x$$

Equation 21-1

While this value is typically defined at boresight, an assessment of how the XPD changes around the peak of the main beam is necessary to take a possible pointing error, or depointing, into account.

In the Quadsat ESVA, a Co-pol raster scan and a Cx-pol raster scan is conducted on the main beam (see section 18) to create a XPD heatmap. This gives a comprehensive understanding of the XPD characteristics, all around the main beam of the SUT.



CO - Raster scan

CROSS - Raster scan

XPD heatmap

Figure 21: XPD heatmap generated in FANG (QuadSat) from Co and Cx raster scans.

The XPD heatmap forms the basis for evaluating the antennas worst performing areas within the -1dB contour. Any point of interest within that area can be further analysed by a polarization alignment measurement at each desired position as described in section 19 Polarization Alignment.

The XPD at each point is displayed as the Delta-value in the Alignment profile visualisation in FANG, see Figure 21 and, in more detail, Figure 22.

21.3 Step-by-Step Procedure

Step 1: Conduct a beam finding measurement with radius of min 125m in order to secure angular accuracy of minimum 0.05 degrees and determine the boresight.

Step 2: Conduct a polarization alignment in boresight.

Step 3: Conduct a raster scan in Co with the applied polarization alignment.

Step 4: Conduct a raster scan in Cx

Step 5: Create a XPD raster scan from the delta between step 3 and step 4.

Step 6: Analize the heatmaps with contour of 0.5 dB steps and find the worst antenna performance in the -1dB gain contour.

Step 7: Extract positions in 1.0 dB contour based on step 6.

Step 8: Perform polarization measurement in all chosen positions with 1deg/s speed.

Step 9: Extract the XPD value from all polarization measurements.

21.4 Screenshot examples

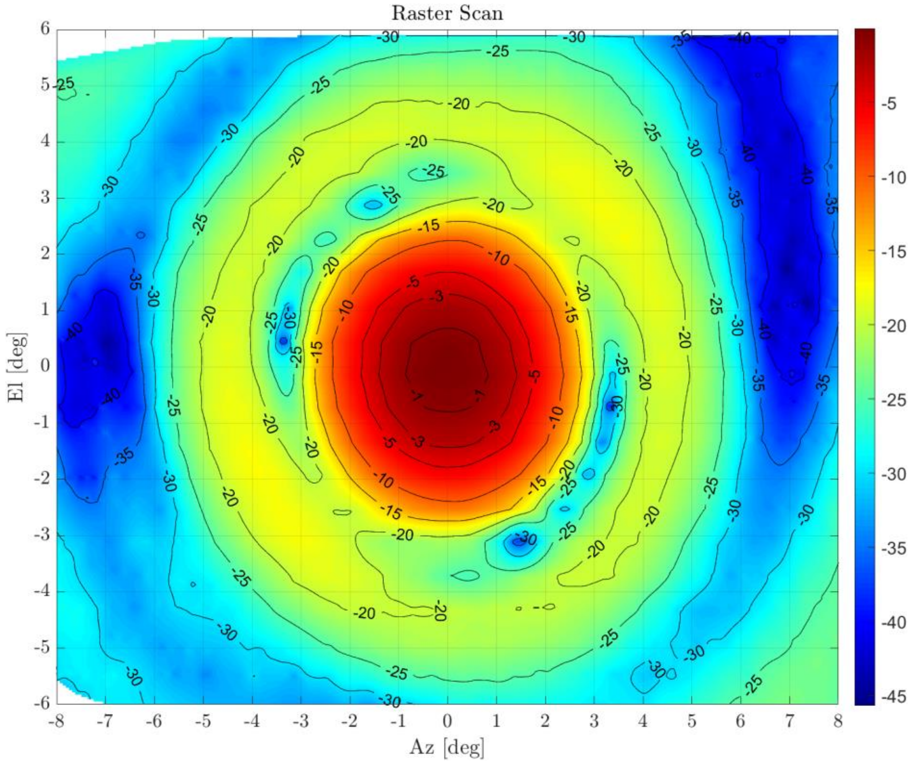


Figure 22: Heatmap from raster scan in Co with contours (courtesy of QuadSat).

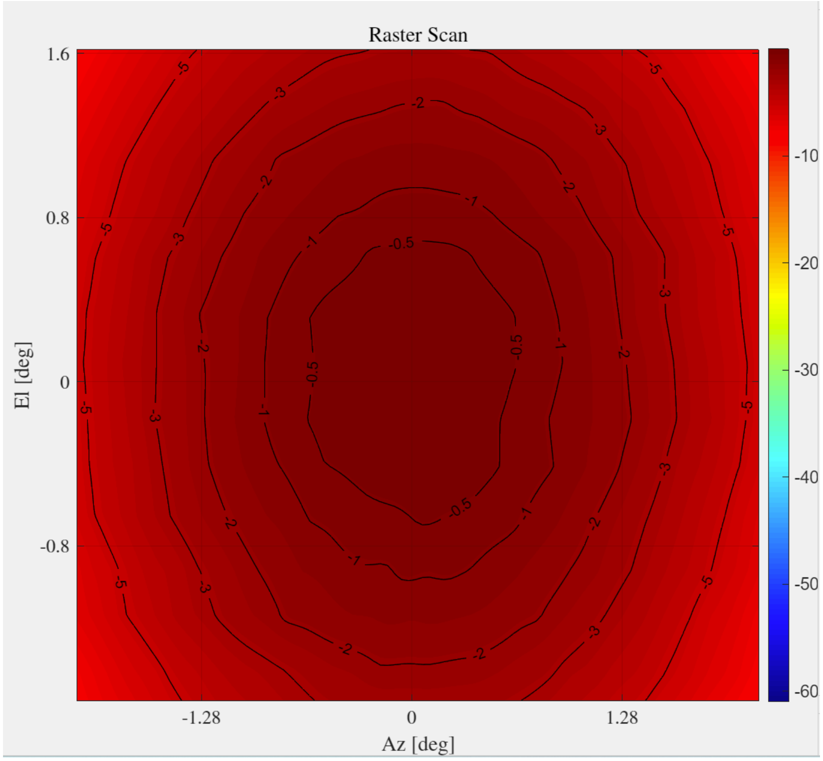


Figure 23: Zoomed heatmap to evaluate -1dB contour position (courtesy of QuadSat).

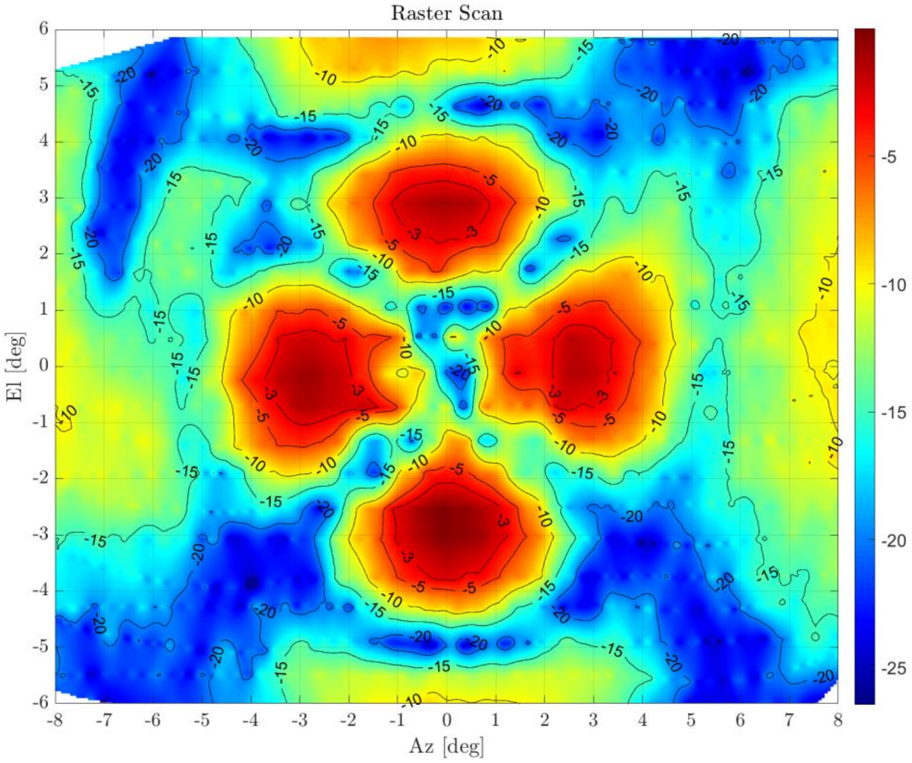


Figure 24: Heatmap from raster scan in Cx with contours.

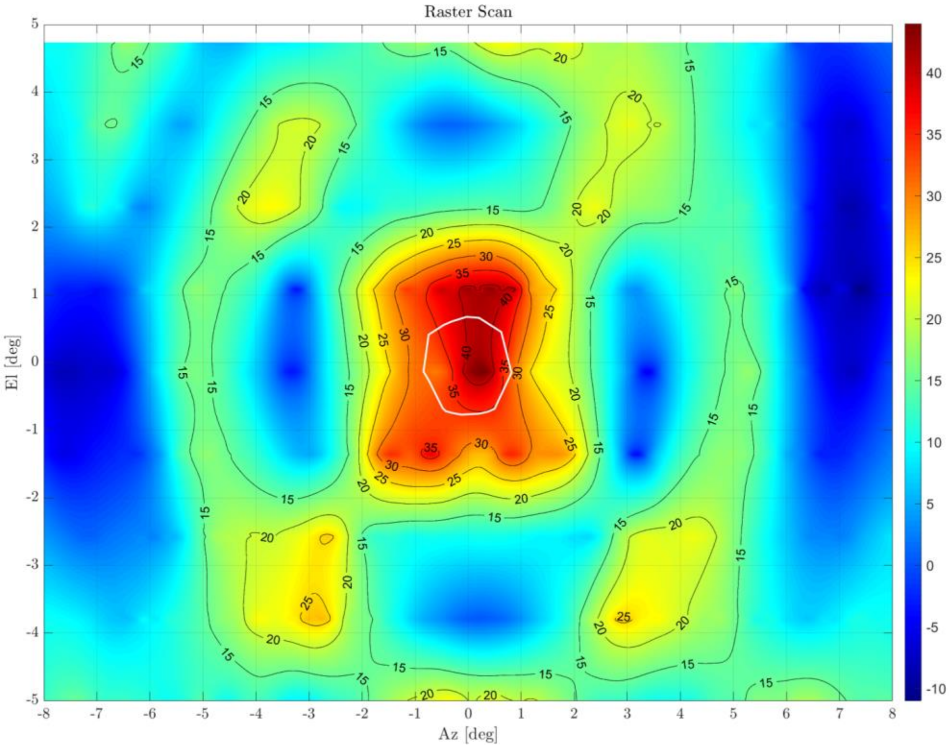
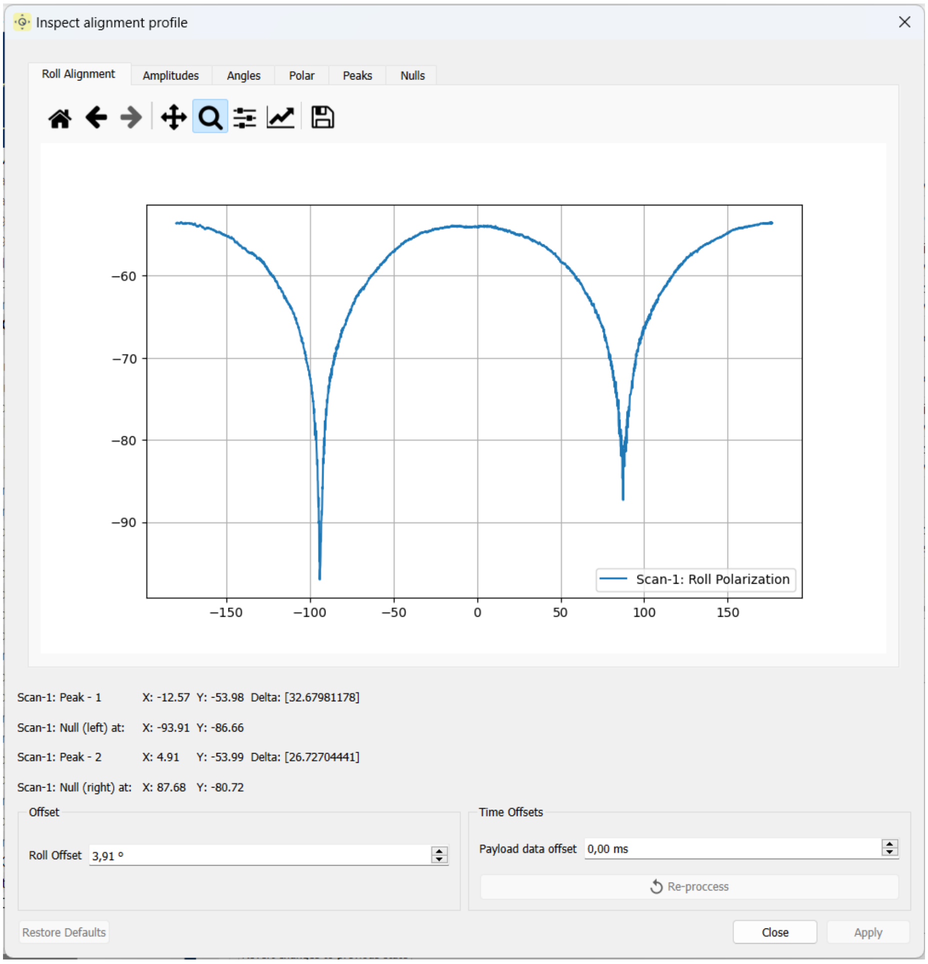


Figure 25: Heatmap XPD as Delta between Co and Cx Raster scans, with white label outlining -1dB from Co.



```
Scan-1: Peak - 1          X: -12.57  Y: -53.98  Delta: [32.67981178]
Scan-1: Null (left) at:   X: -93.91  Y: -86.66
Scan-1: Peak - 2          X: 4.91    Y: -53.99  Delta: [26.72704441]
Scan-1: Null (right) at:  X: 87.68   Y: -80.72
```

Roll Offset: 3,91 °

Payload data offset: 0,00 ms

Figure 26: Alignment profile incl. Delta value (XPD value of 32,67).

22 Transmit Sidelobes

22.1 Test Objectives

To record the co- and cross-polar radiation diagrams of the antenna of the station under test and compare it against the EESS502 gain mask.

22.2 Principle

After the peak of the main beam is defined according to the procedure described in Section 18, and the signal polarization is aligned according to the procedure described in 19 Polarization Alignment, the drone flies in front of the SUT at far-field, keeping a specified distance from the SUT while the CW signal at operation frequency is transmitted and the level of the co- and cross-polar signal are recorded at SUT.

The standard Azimuth and Elevation principal cuts are planned in FANG as a default. However, if other directional cuts are of interest, a diagonal principal cut can be made by specifying an angle during the flight planning process. With these settings, the measurement will be a cut through boresight but at the specified off angle, thus it reveals other sections of the radiation pattern.

The rotations of the payload that complies with the so-called Ludwig 3 reference plane definition shall be automatically performed by the measuring system.

By collecting information of alignment in 18and 19, the cross-polar (Cx) component is generated by:

- Linearly polarized SUTs (LP): rotating the polarization axis by 90º relative to the aligned Co-pol.
- Circularly polarized SUTs (CP): modifying the phase shift between both channels of the source so that the CP is generated in the opposed sense.

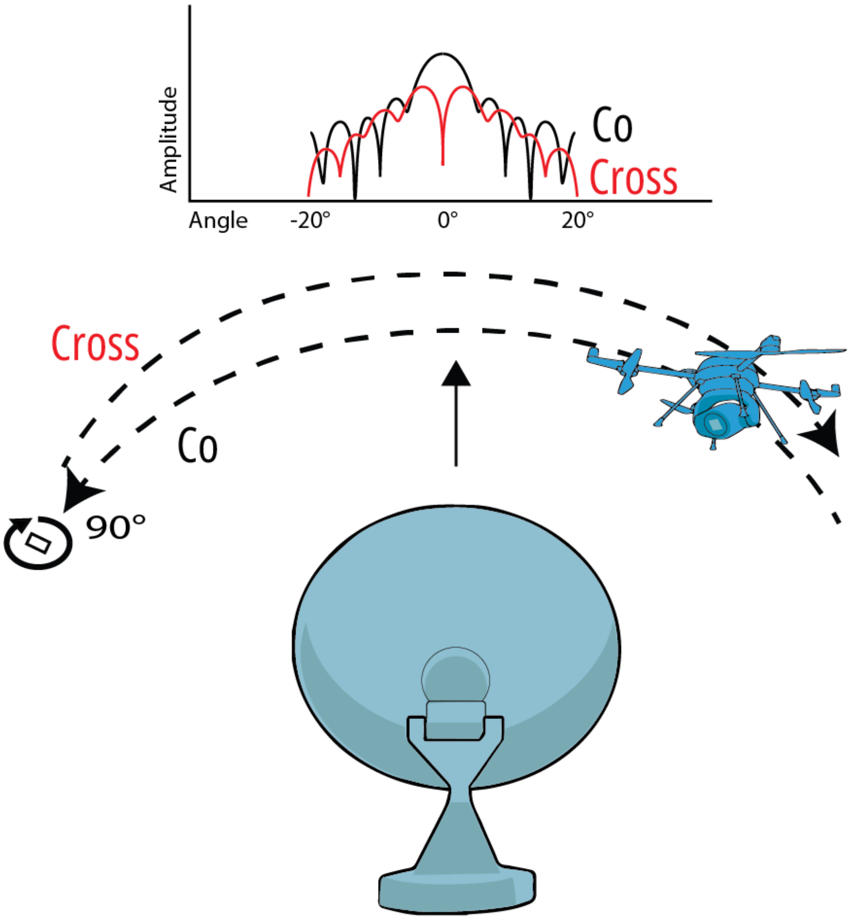


Figure 27: Illustration of an Azimuth principal cut using a UAV (courtesy of QuadSat).

The sidelobe characteristics are evaluated by following the envelopes given in the EESS502 and visualised in . The envelopes are standard overlays in FANG’s analysis tools

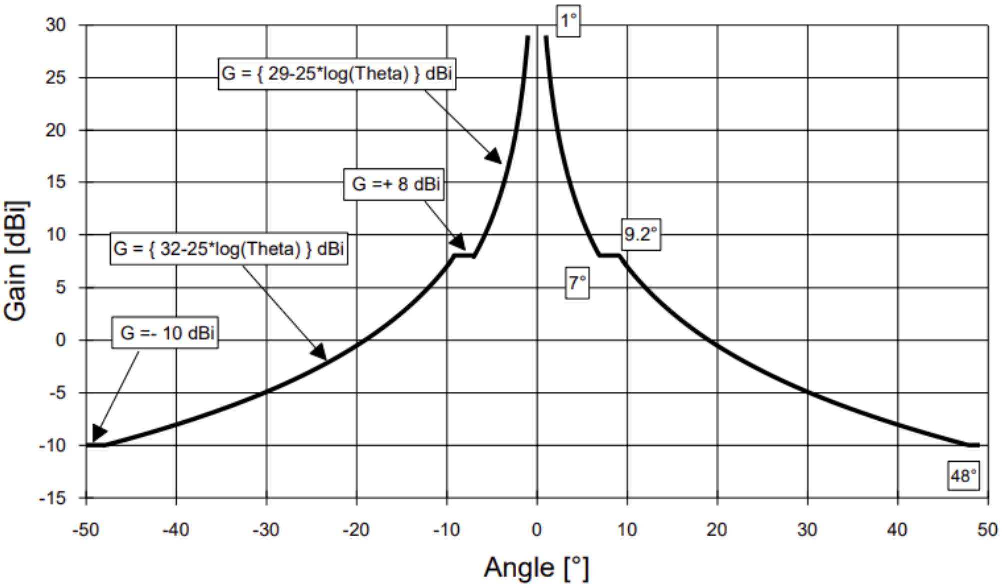


Figure 28: Envelope for Co-polar TX Sidelobe Patterns (EESS502).

22.3 Step-by-Step Procedure

Step 1: Configure principal cut in FANG (measurement angle, polarisation alignment etc,) based on previous.

Step 2: Execute the measurement.

Step 3: Process measurement data and produce plots including the appropriate masks.

22.4 Screenshot examples

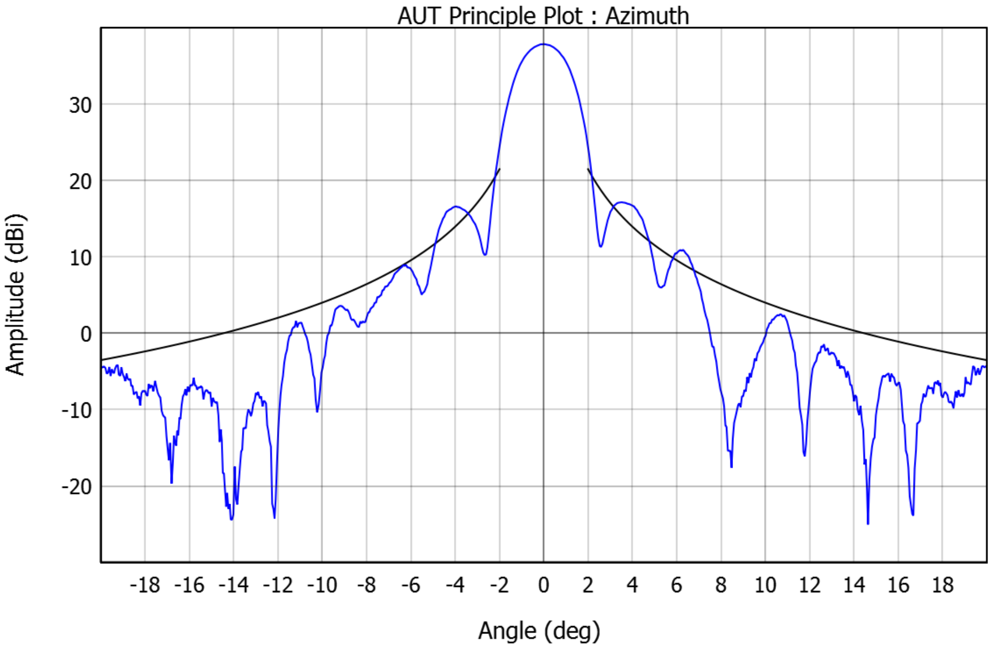


Figure 29: Visualisation of Principal cut including envelope from FANG: ITU-R S.580 mask.

23 G/T

23.1 Test Objective

To measure the gain-to-equivalent noise temperature ratio (G/T) of the earth station receive section.

23.2 Principle

Instead of separate measurement of antenna gain and system noise temperature, “direct measurement” is taken and the procedure is described. The direct measurement derives G/T value without independent analysis of gain and system noise temperature.

From the basic formula of link budget calculation, Equation 23-1 is available.

$$G/T = C/N_0 - EIRP + L_{fs} + K \quad [dB/K] \qquad \text{Equation 23-1}$$

Where:

$C\ /\ N_0$: carrier power-to-noise power spectral density ratio [dB]

$EIRP$: effective isotropic radiated power [dBW]

L_{fs}: free space loss [dB]

K: Boltzmann’s constant - 228.60 [dBWs/K].

The approximated free space loss is calculated by:

$$L_{fs} = 20\log_{10} 4\pi df/c\,[dB]$$ Equation 23-2

Where:

d: distance between the SUT and the drone [m]

f: test frequency [Hz]

c: speed of light 299 792 458[m/s].

$C\,/\,N_0$ in the equation # is obtained from two measurements which are carrier level and the noise power spectral density under clear sky conditions by:

$$C/N_0 = P_c - P_{N_0}[dBHz]$$ Equation 23-3

Where:
P_c: the measured carrier level [dBm] with normal marker when the drone transmits CW signal at the beam center
P_{N_0}: the noise power spectral density [dBm/Hz] with noise marker when the transmission is off at the drone payload

Although the carrier level is affected by the existing noise (namely, $P_c = C + P_N$, where P_N is noise level [dBm]), the effect on the result becomes negligible (below 0.05 dB) by keeping the difference of them more than 20 dB. As EIRP and distance are adjustable on the UAV device, this condition is easily satisfied.
The EIRP of UAV payload will be provided with the system for corresponding frequencies and set transmit power values. In general, the stable power level to be set is between -10 dBm to 10 dBm. To ensure that the contribution of the spectrum analyser is negligible to the measurement results, the noise value with and without connecting the spectrum analyser to the receiver system should be kept more than 20 dB.

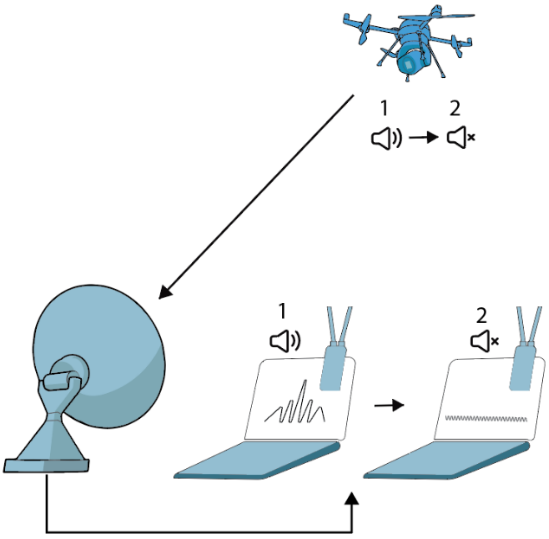


Figure 30: Visualisation o G/T measurement (Courtesy of QuadSat).

23.3 Step-by-Step Procedure

Step 1:	Ensure that the is no interference at the test frequency.
Step 2:	Warm up the payload for 10 minutes on the ground before making measurements.
Step 3:	Plan the flight by configuring the distance, frequency, transmit power level, hovering period, and alignment information (i.e., antenna location, beam center, polarization plane) for the payload.
Step 4:	Execute flight and record the measured carrier level P_c at the spectrum analyser with a normal marker.
Step 5:	Stop transmission and, by a noise marker, measure noise levels with and without connecting the spectrum analyser to the receiver system to confirm that the spectrum analyser's contribution is negligible. Adjust reference level at spectrum analyser to acquire the condition if it is necessary. Record the noise value P_{N_0}.
Step 6:	Calculate G/T.

23.4 10.4 Screenshot Examples

Carrier level measurement:

Reference level:	5 dB above carrier level
Attenuator:	Auto
Scale:	10 dB
Center frequency:	IF frequency
Span:	10k Hz
Resolution bandwidth:	1000 Hz
Video bandwidth:	10 Hz

Sweep time:	Auto
Marker type:	Normal
Trace:	Average
Average count:	10

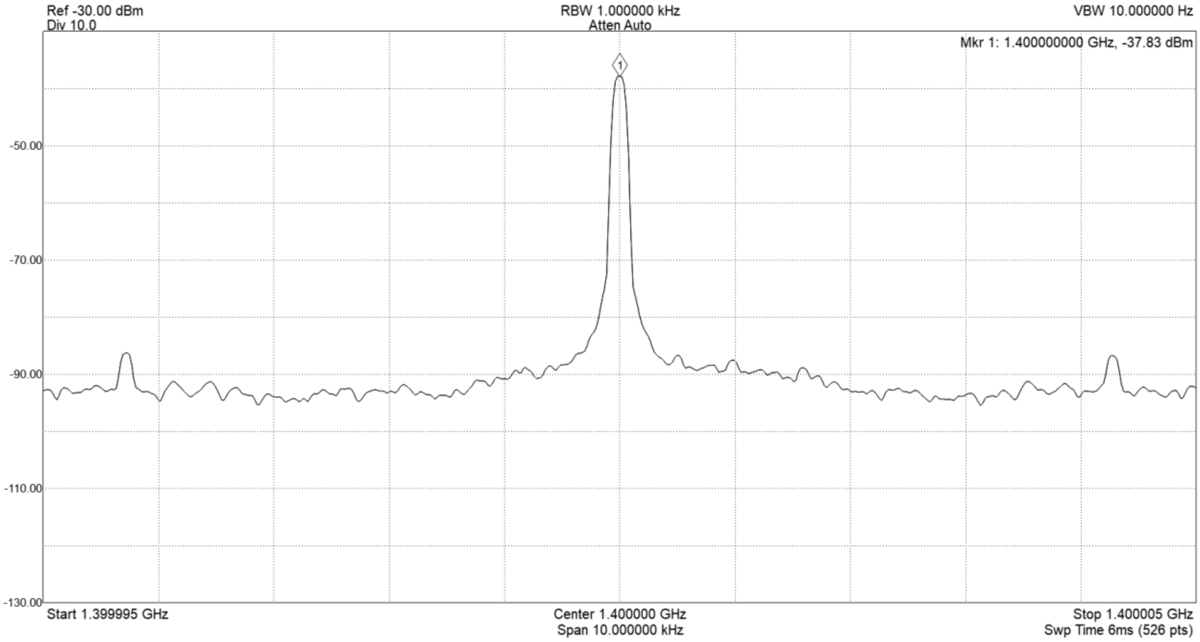


Figure 31: The measured carrier level P_c [dBm] with normal marker (Mkr1) when the drone transmits CW signal at the beam center.

Noise level measurement:

Reference level:	the level where 20 dB difference is observed in the noise measurements with and without connecting to receiver system
Attenuator:	Auto
Scale:	10 dB
Center frequency:	IF frequency
Span:	10k Hz
Resolution bandwidth:	1000 Hz
Video bandwidth:	10 Hz
Sweep time:	Auto
Marker type:	Noise
Trace:	Average
Average count:	10

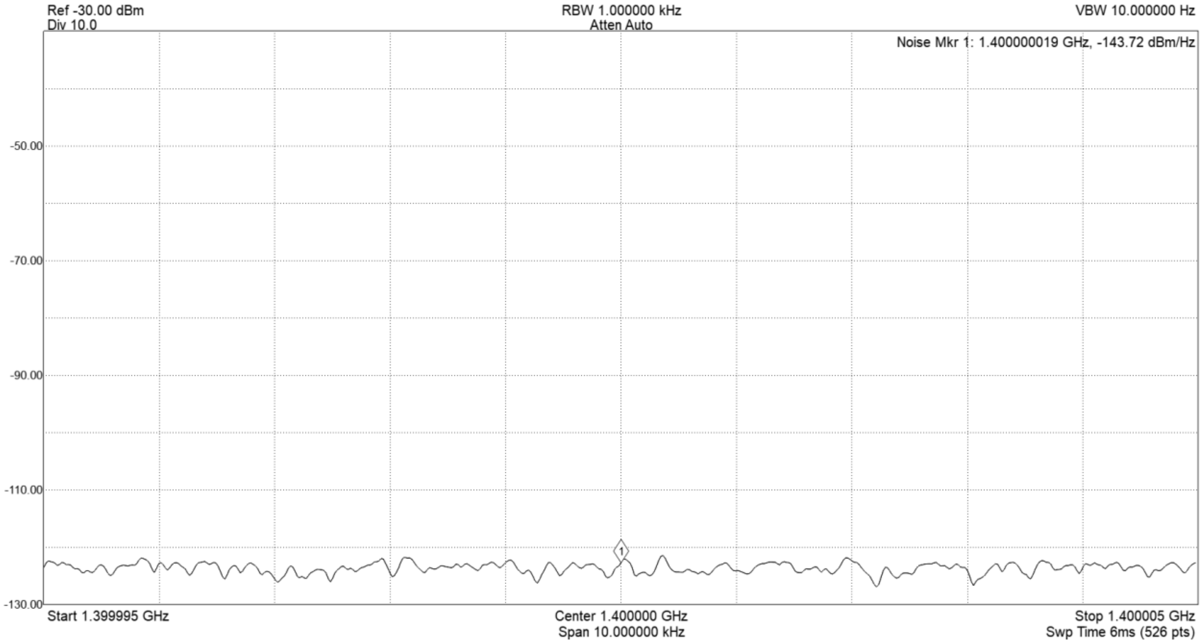


Figure 32: The measured noise level (Noise Mkr 1) without connecting Spectrum Analyser.

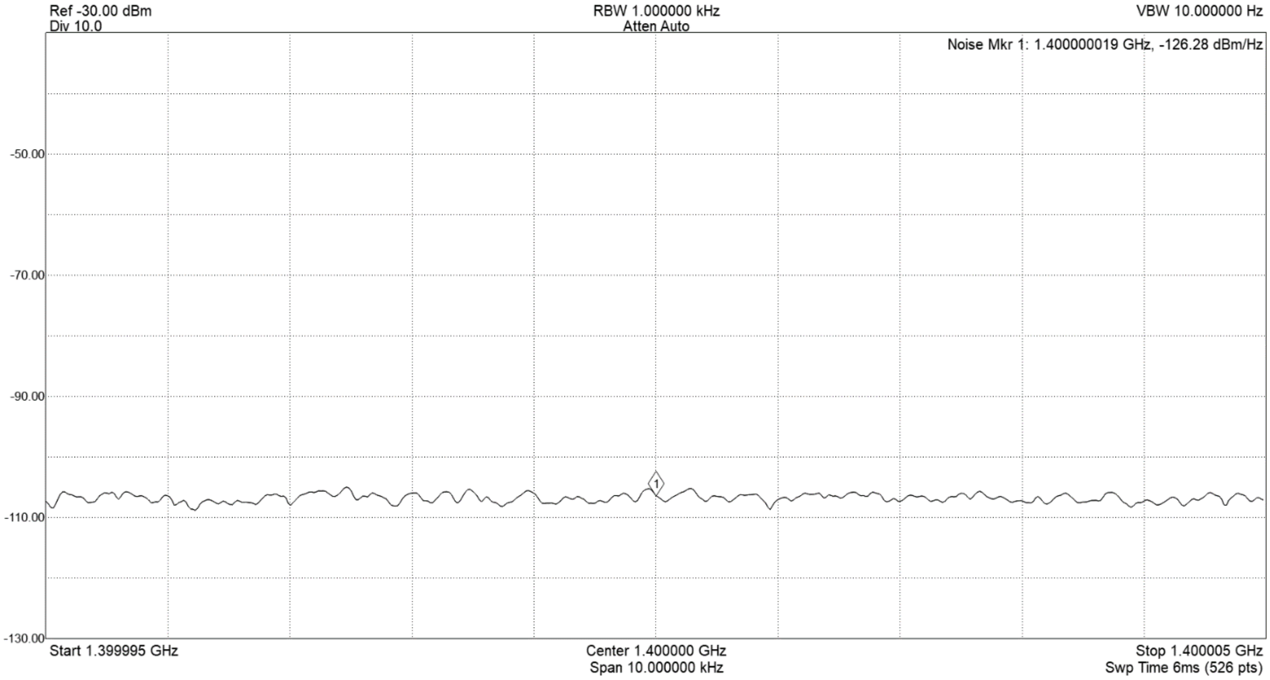


Figure 58: The measured noise level (Noise Mkr 1) after connecting Spectrum Analyser.

24 Receive Polarization Discrimination

24.1 Test Objectives

To measure the receive polarization isolation of the station under test at optimized TX polarization alignment. The measurement is carried out at boresight and at 8 samples within the 1 dB contour of the co-polar antenna RX pattern.

Although the measurement is not mandatory, it is recommended, and it will provide additional aspects for the evaluation of the overall antenna performance.

24.2 Principle

Based on the principle of reciprocity, the Receive Polarization Discrimination determined the same way as for Transmit, see section 21.

24.3 Step-by-Step Procedure

The procedure is the same as previously covered in section 21.

25 Receive Sidelobes

25.1 Test Objectives

To record the receive antenna diagram of the station under test. Although the measurement is not mandatory, it is recommended, and it will provide additional aspects for the evaluation of the overall antenna performance.

25.2 Principle

Using the principle of reciprocity, receive/downlink radiation characteristics are the same as transmit/uplink characteristics. The principle is therefore covered in section 22.

25.3 Step-by-Step Procedure

The procedure is the same as previously covered in section 22.

25.4 Screenshot Examples

N/A

Annex D – Abbreviations

CW	Continuous wave
EIRP	Effective Isotropic Radiated Power
ESVA	Earth Station Validation Assistance
G/T	Gain to Equivalent Noise Temperature Ratio
RA	Reference Antenna
SGH	Standard Gain Horn / Standard Gain Antenna
SNR	Signal to Noice Ratio
SUT	Station Under Test. Synonymous with Antenna Unter Test
UAV	Unmanned/Uncrewed Airial Vehicle
VNA	Vector Network Analyser
XPD	Cross-Polar Discrimination

Annex E – Preparation Checklist

The following is a summarised list of the most important things to check/remember prior to starting a measurement.

SUT:	
Position, farfied distance, minimum elevation angle	
Test frequency determined and SUT prepared	
It transmit license needed (and obtained)?	
SUT calibrated and at operational temperature	
UAV Operation	
Define operational volume – is flight permission needed (and obtained)?	
Ensure access to the mission area. Ground restrictions. Air restrictions.	
Access if weather conditions are acceptable (visibility, wind, rain etc.)	
Take-off & Landing areas established	
Drone and Payload	
Inspect UAV for abnormalities before flight (chassis, propellers, lights, battery etc.)	
Inspect Payload for abnormalities before flight (free rotating axis, connectivity etc.)	
Personnel:	
Ascertain the necessary competencies and number of crewmembers needed	
Is involved crewmembers trained, informed and fit for the assignment?	

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