OUTDOOR RCS MEASUREMENT RANGE FOR SPACEBORNE SAR CALIBRATION TARGETS

Björn J. Döring, Marco Schwerdt, Robert Bauer

Microwaves and Radar Institute, German Aerospace Center (DLR)
D-82234 Wessling, Germany

Phone: +49 8153 28-2246
bjoern.doering@dlr.de

Abstract

The Microwaves and Radar Institute regularly performs calibration campaigns for spaceborne synthetic aperture radar (SAR) systems, among which have been X-SAR, SRTM, and ASAR. Tight performance specifications for future spaceborne SAR systems like TerraSAR-X and TanDEM-X demand an absolute radiometric accuracy of better than 1 dB. The relative and absolute radiometric calibration of SAR systems depends on reference point targets (i. e. passive corner reflectors and active transponders), which are deployed on ground, with precisely known radar cross section (RCS).

An outdoor far-field RCS measurement facility has been designed and an experimental test range has been implemented in Oberpfaffenhofen to precisely measure the RCS of reference targets used in future X-band SAR calibration campaigns. Special attention has been given to the fact that the active calibration targets should be measured under the most realistic conditions, i. e. utilizing chirp impulses (bandwidth up to 500 MHz, pulse duration of 2 µs for a 300 m test range).

Tests have been performed to characterize the test range parameters. They include transmit/receive decoupling, background estimation, and two different amplitude calibrations: both direct (calibration with accurately known reference target) and indirect (based on the radar range equation and individual characteristics). Based on an uncertainty analysis, a good agreement between both methods could be found.

In this paper, the design details of the RCS measurement facility and the characterizing tests including amplitude calibration will be presented.

Keywords: RCS Measurements, Far-Field Range, SAR (Synthetic Aperture Radar)

1. Introduction

This paper describes the design and experimental setup of an outdoor RCS measurement facility, which is centered on measuring the radar cross section of point targets as used during calibration campaigns of spaceborne SAR systems.

The Microwaves and Radar Institute regularly performs calibration campaigns for spaceborne SAR systems, among which have been X-SAR, SRTM, and ASAR. The most current SAR instrument to be calibrated is the German SAR satellite TerraSAR-X, which was launched in June 2007. Before a SAR system is ready for scientific and/or commercial use, the instrument has to be calibrated to ensure highly accurate data products. Over the years, the specifications for the absolute radiometric accuracy were tightened. For TerraSAR-X, an accuracy better 1 dB is required.

The relative and absolute radiometric calibration of SAR systems depends on reference point targets (i. e. passive corner reflectors and active transponders) with precisely known RCS. During a calibration campaign, these reference targets are being deployed in the field.

Prior to utilizing the reference targets, their RCS must be precisely determined. For (idealized) corner reflectors, simple formulas for computing the RCS exist. For active targets (transponders), on the other hand, measurements are required.

The RCS σ of transponders can be determined by two methods. The first one combines several independent measurements mathematically according to

$$\sigma = \frac{\lambda^2 G_r G_e G_t}{4\pi}, \tag{1}$$

where λ is the wavelength, G_r and G_t the antenna gains of receive and transmit antenna, and G_e the electronic amplification of the active target [1]. This approach allows comparably simple antenna gain measurements, and the electronic amplification can be conveniently determined in the laboratory. If a temperature chamber is used, the electronic amplification can even be determined over temperature to ensure good and uniform performance under all outdoor conditions. Uncertainties might be introduced at the antenna/device interface due to mismatches, and by antenna coupling, which can inherently not be taken into account.

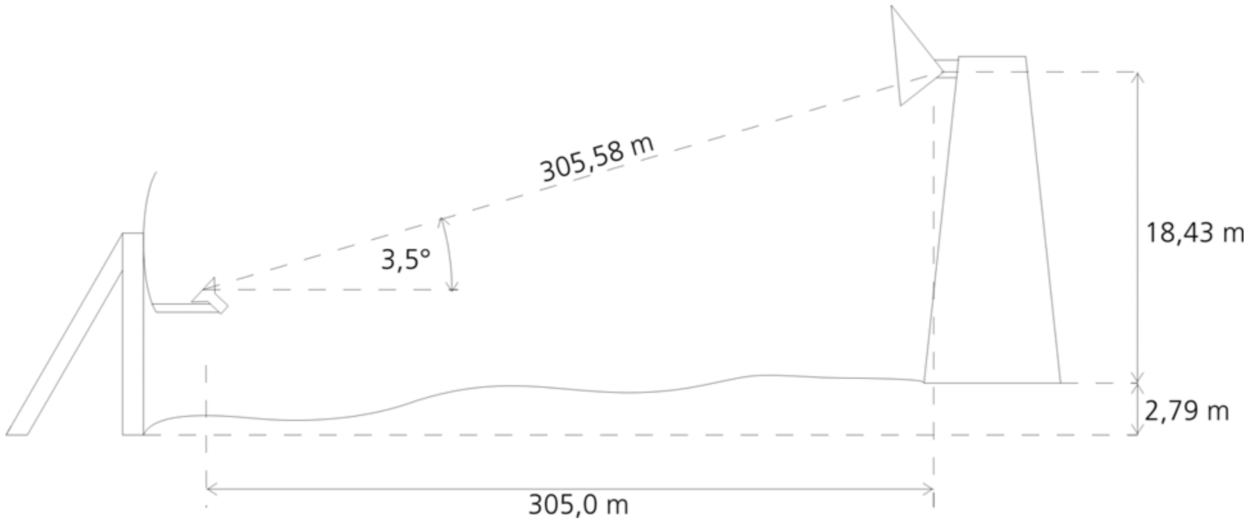

Figure 1 – Test range geometry.

The second method involves the direct measurement of the transponder RCS under the most realistic conditions in an outdoor far-field RCS range. The advantages are the treatment of the system as a whole including possible influences from antenna coupling, mismatches, and transponder mount and housing.

The design and experimental implementation of such an RCS range will be discussed in the following sections.

2. Design Goals

The design goals are tailored towards the test implementation which has been built up on the DLR site in Oberpfaffenhofen. Later, it is thought to move the RCS measurement facility to a new location, mainly in order to allow for a better suited target mount (tower). The specifications are:

- Frequency: 9.4 GHz to 9.9 GHz
- Quasi-monostatic setup (two parabolic-reflector antennas)
- Signal: pulsed chirp signal, usually 2 µs, 300 MHz (comparable to SAR signal)
- Target RCS: > 40 dBm² (limited by RCS of tower)
- Measurement uncertainty: 1-sigma < 0.5 dB
- Target weight: Up to 60 kg

3. Mechanical Setup

The radar target is mounted on the outer side of a metal tower on a lift. It can be lowered to the ground to allow convenient and relatively fast substitution of reference target and target under test. Mechanical fixtures exist for transponders and corner reflectors featuring an inner leg length of up to 1.5 m.

The tower is about 20 m high. The two radar antennas for transmit and receive are located about 300 m away on ground (see Fig. 1 and 2) and are mechanically fixed to a concrete base. The distances as stated in Fig. 1 were independently measured by using a tachymeter. The two 1.2 m parabolic antennas featuring a gain of about 40 dBi are set up next to each other, which results in a quasi-monostatic design.

In order to direct the main beams of the parabolic antennas exactly towards the target position on the tower, the target was substituted by a horn antenna connected to a CW generator. Each parabolic antenna was aligned separately until the receive power reached its respective maximum.

4. Calibration and Uncertainties

The analysis of sources of uncertainties was adapted from [2], which gives a good overview of determining the uncertainty for RCS measurements.

4.1 Transmit/Receive Decoupling

The transmit/receive antennas feature a high decoupling of 88 dB. For the given range geometry and a target RCS ≥ 40 dBm², this results in a maximal uncertainty due to transmit/receive coupling of less than 0.1 dB.

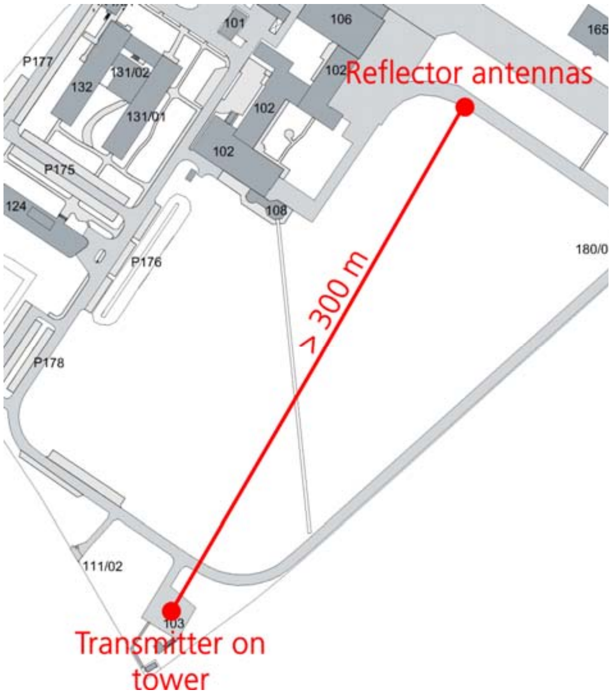

Figure 2 – Experimental measurement site at the DLR in Oberpfaffenhofen.

4.2 Background Estimation

Even if no target is present, the radar receives a signal from the background and the tower. Due to at least some background-target interaction once the target is mounted again, the received background signal cannot easily be subtracted from the receive signal. The worst case RCS uncertainty introduced by the background is given by

$$\Delta\sigma = -20\log(1-10^{-SNR/20}), \qquad (2)$$

where the SNR is the signal-to-noise (-background) ratio. On different days, a SNR of 34 dB to 40 dB was measured for a target RCS of 50 dBm². This results in a maximal uncertainty of 0.2 down to 0.1 dB. For targets featuring a smaller RCS, the smaller SNR results in higher uncertainties of up to 0.6 dB for a target RCS of 40 dBm².

This shows that improvements are necessary for a final setup in order to minimize errors due to the tower/background.

4.3 Ground Reflections/Multipath

It was analyzed if possible reflections from the grassy ground and nearby obstacles (buildings) affect the measurements. This was done by using a corner reflector as the reference target and operating the radar with a CW signal. The frequency was slightly changed, and a periodic amplitude variation was expected should reflections occur. Since no amplitude variation could be detected, the influence of reflections can be neglected**.**

4.4 Indirect Amplitude Calibration

The indirect amplitude calibration is based on the radar equation (as given for instance in [3])

$$\sigma = \frac{P_r \cdot (4\pi)^3 \cdot R^4}{P_t \cdot G_t G_r \cdot \lambda^2}. \qquad (3)$$

If the individual parameter like receive/transmit power P_r/P_t (losses already accounted for), the transmit/receive radar antenna gains G_t and G_r, the range R (one-way), and the wavelength λ are known, the RCS of the unknown target can be computed. This approach gives a simple first impression on the overall performance of the range setup, if a known target is used and the computed value is compared with the known target RCS.

In a first test (CW signal), a known target (trihedral corner reflector, ideal RCS equals 43.42 dBm²) was used and a closure determined. The (ideal) corner reflector RCS was 1.1 dB above the value determined by Eq. (3). The difference can be explained by examining the estimated contributions to the overall uncertainty (all uncertainties are 1-sigma values) as proposed in [2]:

Misalignment of radar antennas, antenna gain	> 0.6 dB
Target-background interaction	0.1 dB
Clutter	0.39 dB
Reference target	0.3 dB
Near-field (field taper)	0.1 dB
Cross-polarization	0.2 dB
Range	0.05 dB
Drift	0.2 dB
Combined uncertainty (RSS)	0.88 dB

The combined uncertainty was determined by computing the root-sum-square (RSS). The largest uncertainty was certainly introduced by slight misalignment of the radar antennas since they feature a high directivity and therefore are sensitive to misalignment. This shows well the limitation of the indirect amplitude calibration, which depends on the knowledge of the previously determined parameters.

A comparison between the overall 1-sigma uncertainty and the ideal RCS of the known target shows good agreement for the given uncertainty interval. The measurement was repeated on different days to assess the repeatability (uncertainty due to drift taken into account), and the results were in agreement with the stated uncertainty.

4.5 Direct Amplitude Calibration

The direct amplitude calibration relates the receive power from a known target to the receive power of the device under test. The advantage here is that losses (range, cables, antenna misalignment) are inherently being taken care of, but the need for a highly precise calibration target remains. Also, by repeated calibration of the RCS range, uncertainties introduced by instrument drift can be diminished.

Several measurements were performed, all based on the 1.5 m corner reflector as a reference target. The largest (with respect to RCS) target under test was another 1.5 m corner reflector, for which the RCS was reduced by 0.6 dBm² with respect to the expected (ideal) RCS of the corner reflector. The uncertainty analysis is somewhat simplified as there are fewer contributions:

Target-background interaction	0.1 dB
Clutter	0.39 dB
Reference target	0.3 dB
Near-field (field taper)	0.1 dB
Cross-polarization	0.2 dB
Drift	0.2 dB
Combined uncertainty (RSS)	0.61 dB

This shows that the good closure between the measured RCS and the expected measurement result can be well explained by the uncertainty analysis.

4.6 Instrument Drift/Repeatability

It is anticipated to calibrate the final setup of the RCS range by (repeated) direct amplitude calibrations. For this, a good mechanical reproducibility (with respect to position and alignment of the reference target on the lift) and low instrument drift must be ensured. This is why tests (CW signal) were performed over several hours while moving the lift, re-mounting the reference target, and observing instrument drift and clutter fluctuations.

Fig. 3 shows that the lift itself (first measurement) does not introduce any additional uncertainties. The drift, due to the instruments and background fluctuations, is about 0.2 dB. The effect can later on be diminished by regularly performing calibration measurements in between measurements of unknown targets.

5. Chirp Impulse Measurements

First measurements were performed by utilizing chirp impulses (2 µs, 300 MHz bandwidth, 9.65 GHz center frequency). The main advantage of using chirp impulses is that active targets are being measured under the most

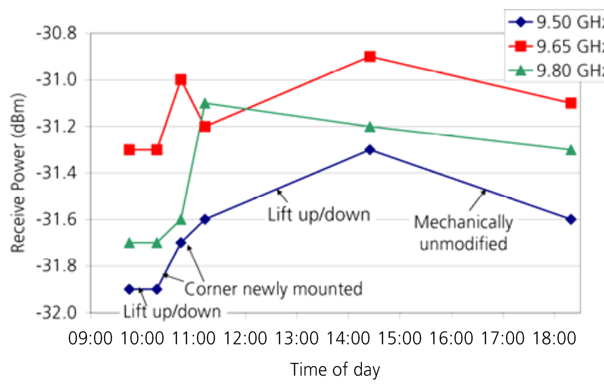

Figure 3 – Mechanical reproducibility and drift.

realistic conditions. The radar signal is virtually equivalent to the (chirp impulse) satellite radar signal, and the active target is fully assembled (in contrast to laboratory measurements of the separate parts.)

The measurements showed that the setup is operational. The measured RCS of the active target was less than expected though, and this was attributed to the alignment of the active target with the radar beam. For this experimental setup, the alignment had to be performed manually, and, once the lift was up, could not be verified anymore. Therefore, slight misalignments result in a reduced target RCS.

6. Conclusion and Improvements

The design and implementation of an experimental setup of a far-field RCS test range for spaceborne SAR calibration targets was presented. In the final setup, the RCS of SAR calibration targets will be measured under the most realistic conditions utilizing chirp impulses.

An uncertainty analysis for the implemented test range was shown. A good agreement between direct and indirect calibration of the measurement facility was presented, which represents a good starting point for future work.

In an improved setup, two major factors should be worked on. First, a tower with a lower RCS should be chosen, which entails relocation of the measurement facility. This will result in a reduced clutter contribution and would also allow to measure targets featuring a lower RCS. Second, a target positioner is necessary to minimize uncertainties due to target misalignment. A lightweight high-precision positioner is currently under development.

7. References

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