Development of DLR's Innovative Remote Controlled Calibration Targets - Potential of Polarization Sensitive Measurements

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Abstract

For the radiometric calibration of a spaceborne synthetic aperture radar (SAR) system active and passive point targets with well known backscatter properties are used. The permanent advancement of upcoming SAR satellite missions regarding complexity, multiple operational modes, and accuracy lead to novel challenges for these reference targets. Full polarimetric SAR systems play an important role and the calibration of these systems requires reference targets with polarimetric backscattering properties. This paper gives an overview about the DLR activities concerning the development of accurate and innovative reference target including a presentation of results from polarization sensitive measurements.

1 Introduction

Present and future SAR missions like Tandem-L [1] or Biomass [2] will provide comprehensive imaging modes using polarimetric SAR systems with an increased complexity. The rising geometric and radiometric requirements demand precise and accurate in-orbit calibration. Therefore active and passive calibration targets (transponders and e. g. trihedral corner reflectors), which act as an absolute reference, are used. In order to comply with the increased calibration requirements a continuous development of these reference targets is required. By means of full polarimetric transponders, which record and retransmit the radar signal simultaneously, a backscattering reference is available, allowing to characterize the SAR system's polarization properties.

This paper presents an overview about DLR's reference target development activities (Section 2) and shows the potential of polarization sensitive measurements with DLR's state-of-the-art transponders (Section 3). By means of several acquisitions with ESA's Sentinel-1A (S-1A) satellite the measurement uncertainty is evaluated for the receive power determination independent of the polarization orientation of the transponder's receiving antenna. Additionally the cross-talk on transmit path for S-1A's SAR instrument is derived.

2 Reference Target Development

The DLR has experiences of more than 25 years in developing active (transponders) and passive (e. g. trihedral corner reflectors) reference targets which were used for several calibration campaigns [3] [4]. In **Figure 1** DLR's innovative multi-mission reference targets are presented. Three C-Band transponders, called Kalibri, and three 2.8 m trihedral corner reflectors are deployed in South Germany. These targets have been successfully used for an independent calibration of ESA's Sentinel-1A (S-1A) and Sentinel-1B (S-1B) satellites [5] [6] and are currently operated for the ongoing mission routine support of both satellites.

Figure 1: DLR's remote-controlled multi-mission calibration point targets. Left: 2.8 m trihedral corner reflector (passive). Right: C-Band transponder (active).

The specifications of the novel DLR reference targets, shown in **Figure 1**, are listed in **Table 1**. All six installed targets are operated remote controlled. The Kalibri transponder is based on a two antenna concept with an individual receiving (RX) and transmitting (TX) path including two separated antennas [7].

For the upcoming Radarsat Constellation Mission (RCM) [8], to be launched in 2018, DLR has developed and delivered two transponders to the Canadian Space Agency (CSA). These systems represent a further development of the Kalibri transponders with some adaptions related to RCM.

	Corner Reflector	C-Band Transponder
RCS	49.2 dBm^2	60 dbm^2
Absolute Rad. Accuracy	0.2 dB	$\leq$0.2 dB
Mechanical Tolerance	$\leq$1.0 mm	
Radiometric Stability		<0.1 dB

Table 1: DLR Reference target specifications for C-Band.

The Kalibri and RCM transponders provide a flexible polarization adjustment technology using rotatable horn antennas [9]. By a separate rotation of the receiving and transmitting antenna a reference target is provided enabling to characterize all four possible polarization channels (Transmit/Receive) of a SAR instrument:

- Vertical/Vertical (V/V),
- Vertical/Horizontal (V/H),
- Horizontal/Vertical (H/V),
- Horizontal/Horizontal (H/H).

Besides operation as a backscattering target the DLR transponder records simultaneously the transmit pulses of a SAR instrument during an overpass by means of an implemented Digital-Sub-System (DSS). This functionality can be used in order to characterize the azimuth antenna pattern of a SAR instrument which is needed to verify an antenna model applied during SAR data processing.

In the following such polarization sensitive measurements performed for a spacebore SAR system by means of two DLR transponders are presented and discussed.

3 Polarimetric Measurements with Calibration Transponders

The RCM transponders with flexible polarization adjustment technology have been operated for several overpasses of ESA's Sentinel-1A (S-1A) satellite. **Figure 2** shows the convention for the three possible orientations of the antenna polarization allowing to operate transponder either with:

- Vertical/Horizontal (V/H),
- Diagonal/Diagonal (D/D), or
- Horizontal/Vertical (H/V)

configuration during an overpass.

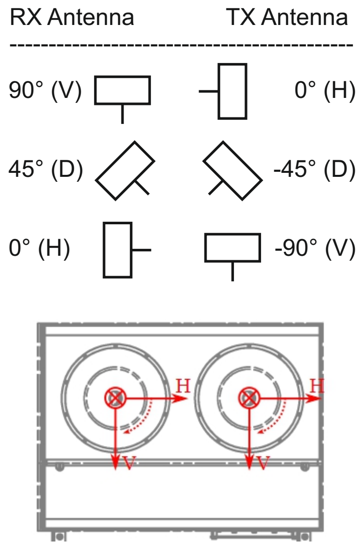

Figure 2: Definition of antenna polarization angles: The bottom drawing shows a front view of the transponder. Sketches of the antenna waveguide and the feed pin for all three nominal antenna positions are provided on the top.

In the diagonal position (D/D) both polarization will be retransmitted simultaneously with one antenna providing a reference signal for both receiving polarization channels of the SAR instrument. In case of a vertical/horizontal (V/H) or horizontal/vertical (H/V) orientation for RX/TX antennas the corresponding cross-polarized signal is retransmitted.

3.1 Measurement Execution

For the measurements with S-1A both RCM transponders, installed in Canada, have been used. The systems are located in a distance of approximately 2 km so that both targets are within the same scene of a radar acquisition. For all acquisitions presented in this paper Sentinel-1A is operated in the Interferometric Wide Swath (IW) mode with V-polarization on transmit. **Table 2** shows a list of all executed overpasses with the corresponding antenna polarization settings of both transponders and acquisition geometry.

All acquisitions were executed in two different alignment geometries between satellite and transponder. For overpasses of the same geometry the incident angle of the radar signal and the alignment position of the transponder are equal. For S-1A the acquisition geometry will be repeated after satellite's duty cycle of 12 days. Both geometries differ in incident and transponder alignment angle, yielding to different distances between satellite and reference target and consequently to an individual free space loss. This loss can be derived from corresponding slant range parameters (not shown in this paper) and differ between the two geometries around 1 dB.

Overpass Nr.	Geometry Nr.	Trsp. 1 Ant. settings (Rx/Tx)	Trsp. 2 Ant. Settings (Rx/Tx)
1	1	D/D	D/D
2	1	D/D	D/D
3	2	D/D	D/D
4	1	D/D	H/V
5	2	H/V	D/D
6	1	V/H	D/D
7	2	D/D	V/H
8	1	V/H	D/D
9	2	D/D	—
10	1	—	V/H

Table 2: List of all S-1A overpasses including acquisition geometry and transponders' antenna orientation settings. H: horizontal polarized; V: vertical polarized; D: diagonal polarized, see **Figure 2** for further details. Two overpasses were executed with only one transponder.

Figure 3 shows the azimuth antenna patterns recorded by both transponders for the two acquisition geometries. Each diagram corresponds to one overpass and includes the recorded antenna patterns of both transponders. The different acquisition geometries are clearly visible by the individual appearance of the corresponding recorded antenna pattern. In both diagrams further main beams with reduced power level are visible beside the corresponding main lobe. This results from switching the beam between three different sub-swaths in the IW mode of S-1A which is realized by the novel Terrain Observation by Progressive Scans (TOPS) mode [10]. The main lobe represents the sub-swath beam which illuminates the ground area where the transponder is located. Consequently the adjacent beams (where the transponder is not positioned) were detected with reduced power. Hence, by means of the DLR transponders (equipped with a recording unit) the azimuth antenna patterns of all sub-swaths in TOPS operation can be detected during one overpass. More details on recording azimuth patterns of TOPS acquisition can be found in [11].

From the main lobe peak of every recorded antenna pattern the maximal receive power density can be derived. This was done for all overpasses with different antenna polarization alignment constellations listed in **Table 2**, in order to:

- estimate the error contribution for the receive power detection due to the antenna polarization orientation (Subsection 3.2).
- derive the cross talk of the SAR instrument on transmit path (Subsection 3.3).

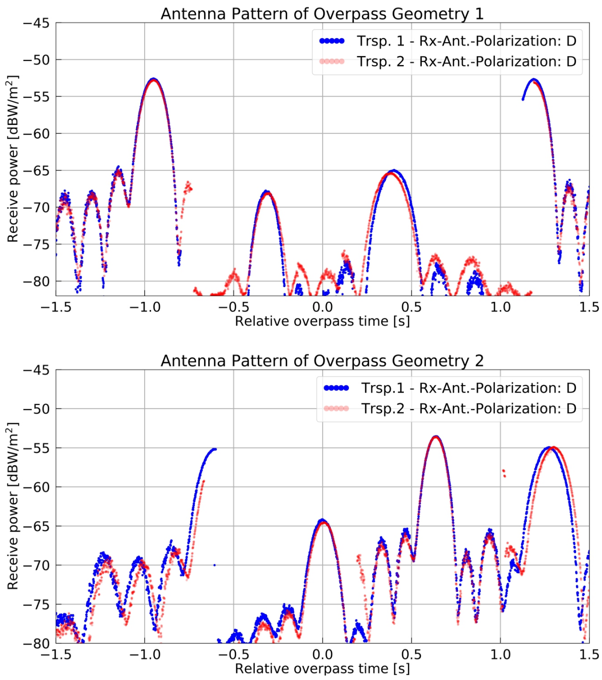

Figure 3: S-1A azimuth antenna patterns for both alignment geometries recorded by two transponders: Each diagram corresponds to one S-1A overpass in IW mode with V polarization on transmit. The top plot shows the satellite's azimuth antenna pattern for geometry 1 where both transponders are illuminated by sub-swath 3. The bottom plot represents an overpass in geometry 3 where both transponders are illuminated by sub-swath 1. For both acquisitions the polarization orientation of both transponders was diagonal.

For analyzing the error contribution transponder data, recorded with V- and D-orientation (on receiving antenna) are used.Fr om the overpasses executed with H-orientation the SAR instrument's cross-talk is determined. **Figure 5** illustrates the analysis principle.

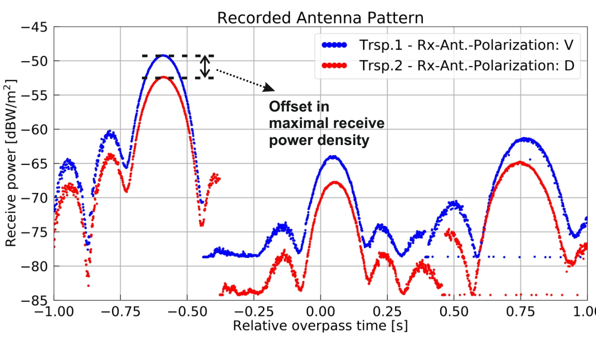

Figure 4: Azimuth antenna patterns for one S-1A acquisition in IW mode recorded by two transponders: The receiving antenna polarization orientation differs between both transponders (vertical polarized in blue, diagonal polarized in red).

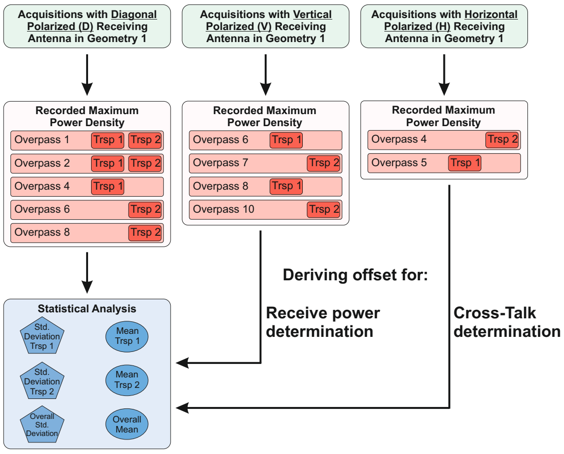

Figure 5: Principle of data analysis for all acquisitions within one geometry (exemplary for geometry 1).

3.2 Uncertainty Estimation of Receive Power Determination

The receive power can be determined from transponder measurements independent of the polarization orientation of the receiving antenna. For an uncertainty assessment two points are analyzed in the following: how is the repeatability and what is the potential error contribution due to misalignment by the polarization orientation of the receiving antenna?

Table 3 presents the standard deviation of the detected maximum power as indicator for measurement repeatability for all transponder overpasses with diagonal polarized receiving antenna, distinguished in alignment geometries and transponders. From the presented results a measurement repeatability of about 0.1 to 0.2 dB can be derived.

	Geometry 1		Geometry 2	
	Trsp. 1	Trsp. 2	Trsp. 1	Trsp. 2
Std. deviation for each transponder in dB	0,15	0,18	0,09	0,2
Std. deviation for geometry in dB	0,16		0,15	

Table 3: Derived standard deviations, distinguished in alignment geometry and transponder, for all acquisitions with diagonal polarized (D) receiving antenna. The measurement precision is always better than two tenth of a dB.

For estimating the error contribution due to misalignment of the polarization orientation the maximum power is derived from different antenna patterns: one recorded with vertical and one with diagonal polarized receiving antenna. Hence, an offset of 3 dB is expected due to the different polarization orientation of both transponders. The radar signal transmitted by the SAR instrument has a vertical polarization and is received by the diagonal polarized antenna with reduced signal power. This is exemplary shown in **Figure 4** for one overpass. This offset has been derived for three different cases by relating the maximum power to:

1. case 1: the maximum power measured by the other transponder in the same overpass with D-orientation on RX antenna.
2. case 2: the maximum power of the other transponder averaged over all acquisitions in D-orientation (of the receiving antenna) and in the same geometry.
3. case 3: the maximum power averaged over both transponders for all acquisitions in D-orientation (of the receiving antenna) and in the same geometry.

The results for the different cases of offset determination are shown in **Table 4**.

		Detected power offset between V- and D-oriented receiving antenna [dB]		
Overpass Nr.	Alignment of RX antenna (Trsp.1 - Trsp.2)	Case 1	Case 2	Case 3
6	V - D	-2,97	-3,06	-3,07
7	D - V	-2,72	-2,68	-2,72
8	V - D	-3,17	-3,40	-3,41
10	x - V	---	-2,67	-2,66
Mean value:		-2,95	-2,95	-2,97
Standard deviation:		0,35	0,35	0,35

Table 4: Detected power offset between V- and D-oriented receiving antenna for cases 1 to 3. During one overpass, labeled with 'x - V', only one transponder was active.

As expected an offset of approximately -3 dB between vertical polarized and diagonal polarized azimuth antenna patterns can be observed for all three offset determination cases. The transponder with diagonal polarized receiving antenna receives half of the signal power regarding to the measured pattern recorded by the other transponder with co-polarized (with respect to the transmitted SAR signal) receiving antenna. The mean values are almost identical and deviate less than 0.1 dB from the theoretical expected -3 dB. From this fact it can be seen that the maximum power density in the recorded antenna patterns can be determined from transponder measurements independent of the polarization orientation of the transponders receiving antenna with a mean error contribution of less than one tenth of a dB. As anticipated the standard deviation of the three derived offsets is equal (0.35 dB), because only the corresponding constant reference value, to which all derived maximum power densities are related, is changed between the three different cases. However, the standard deviation as indicator for the repeatability is higher, meaning that at least three overpasses are necessary in order to reach the determined measurement uncertainty for maximum receive power of smaller than 0.1 dB.

3.3 Cross-Talk Determination

The second analysis discussed in this paper concerns the cross-talk estimation of the SAR instrument on transmit path. By means of two overpasses, each executed with both transponders, one with horizontal and one with diagonal polarized receiving antenna, an upper limit for the cross-talk of S-1A is derived. In **Figure 6** the recorded antenna patterns for one acquisition are presented. The transponder with diagonal polarized antennas received the transmit signal of the SAR instrument (blue plot), whereas the transponder with horizontal polarized receiving antenna did not receive any signal power over noise level (red plot) - only in main beam direction a remaining signal power level was detected.

From the measured maximum power densities in main beam direction the offsets are derived for both overpasses according to the three cases described in Subsection 3.2. The results are presented in **Table 5**. It should be mentioned that an additional gain of -3 dB must be considered for the cross talk estimation between horizontal and vertical polarization channel because one transponder was operated with diagonal polarized receiving antenna. This additional gain is already included in the specified offsets in **Table 5**.

Due to the fact that a possible unknown misalignment in the polarization orientation of the transponder receiving antenna can cause a considerable error contribution for the power measurements the derived offset must be considered as an upper limit for the SAR instrument's cross-talk. Any misalignment leads to a decreased magnitude of the derived power offset (due to non-orthogonality of detected power levels for H- and V-channel) and thus to an inaccurate and reduced cross-talk determination. Hence, by considering an antenna alignment uncertainty for the transponder, an upper limit for S-1A's cross-talk of almost -30 dB can be determined.

		Determined power offset between H- and V-channel (including additional gain of -3 dB) [dB]		
Overpass Nr.	Alignment of RX-Antenna (Trsp.1 - Trsp.2)	Case 1	Case 2	Case 3
4	D - H	-30,82	-31,03	-31,04
5	H - D	-28,42	-28,56	-28,62
Mean value:		-29,62	-29,80	-29,83
Standard deviation:		1,70	1,75	1,71

Table 5: Determined power offset between H- and V-channel (including additional gain of -3 dB) of the SAR instrument for cases 1 to 3.

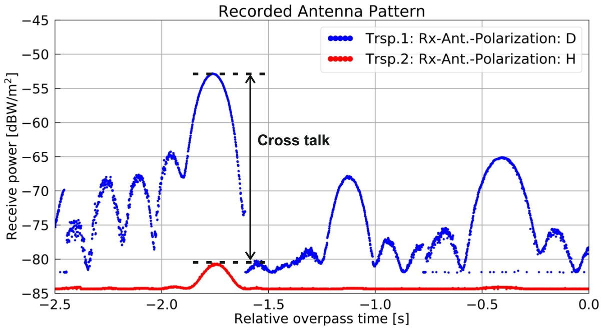

Figure 6: Recorded azimuth antenna patterns for one S-1A acquisition in IW mode with two transponders: the blue plot represents the antenna pattern recorded by one transponder with diagonal polarized receiving antenna and the red plot the antenna pattern recorded by the second transponder with horizontal polarized receiving antenna.

A corresponding SAR image for the SAR instrument's V/H channel (TX/RX) is shown in **Figure 7**. The visible impulse response (in the bottom right corner) represents the backscattering of the transponder with diagonal polarized antennas. The second point target (with H/V polarized antennas), located in the white circle, is not visible because the cross polarized receiving antenna detects only the cross-polarized part of the instrument which is almost 30 dB below the co-polarized channel (shown in **Figure 6**).

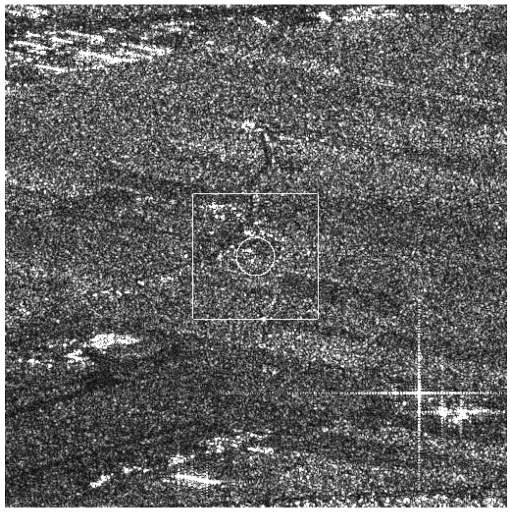

Figure 7: S-1A SAR image for the V/H channel (RX/TX) across the two RCM transponders : In the bottom right corner the impulse response of the transponder with diagonal polarized antennas is clearly visible, whereas the second transponder with H/V polarized antennas (receive/transmit), located in the white circle, is not visible.

4 Conclusion

This paper gives an overview about DLR activities in reference target development for SAR system calibration.

Due to the demand on increasing requirements current transponders must be enhanced for future SAR missions in order to ensure a high precise and accurate calibration. DLR transponders provide a flexible polarization adjustment technology and allows consequently the calibration of full polarimetric SAR systems. The presented results of polarimetric sensitive measurements show the potential of transponders with a two antenna concept and an implemented recording unit. The maximum receive power of the transponder can be determined from measurements independent of the polarization orientation of the rotatable receiving antenna. Three overpasses with the DLR transponders are sufficient in order to reach a mean error contribution of less than one tenth of a dB. Furthermore, the upper limit for the cross-talk can be determined by the receive power measurements and is almost -30 dB for S-1A.

References

[1] A. Moreira, G. Krieger, I. Hajnsek, K. Papathanassiou, M. Younis, P. Lopez-Dekker, S. Huber, M. Villano, M. Pardini, M. Eineder, F. De Zan, A. Parizzi: *Tandem-L: A Highly Innovative Bistatic SAR Mission for Global Observation of Dynamic Processes on the Earth's Surface*, IEEE Geoscience and Remote Sensing Magazine, Volume: 3, Issue: 2, Pages: 8 - 23, 2015.

[2] F. Heliere, F. Fois, M. Arcioni, P. Bensi, M. Fehringer, K. Scipal: *Biomass P-band SAR interferometric mission selected as 7th Earth Explorer Mission*, Proceedings of European Conference of Synthetic Aperture Radar (EUSAR), 2014.

[3] M. Schwerdt, B. Braeutigam, M. Bachmann, B. Doering, D. Schrank, J. Hueso Gonzalez: *Final TerraSAR-X Calibration Results Based on Novel Efficient Methods*, IEEE Transactions on Geoscience and Remote Sensing Magazine, VOL. 48, NO. 2, 2010.

[4] M. Schwerdt, J. H. Gonzalez, M. Bachmann, D. Schrank, B. Doering, N. T. Ramon, J. W. Antony: *In-Orbit Calibration of the TanDEM-X System*, IEEE International Geoscience and Remote Sensing Symposium, pp. 2420-2423, 2011

[5] M. Schwerdt, K. Schmidt, N. Tous Ramon, G. Castellanos Alfonzo, B. Doering, M. Zink, P. Prats-Iraola: *Independent Verification of the Sentinel-1A System Calibration*, IEEE Journal of Selected Topics in Applied Earth Observation and Remote Sensing, VOL. PP, NO.99, pp.1-14, 2015.

[6] M.Schwerdt, K. Schmidt, N. Tous Ramon, P. Klenk, N. Yague-Martinez, P. Prats-Iraola, M. Zink, D. Geudtner: *Independent System Calibration of Sentinel-1B*, MDPI Special Issue "Calibration and Validation of Synthetic Aperture Radar", 2017.

[7] M. Jirousek, B. Doering, D. Rudolf, S. Raab, M. Schwerdt: *Development of the Highly Accurate DLR "Kalibri" Transponder*, Proceedings of European Conference of Synthetic Aperture Radar (EUSAR), 2014.

[8] D. De Lisle and S. Iris: *RADARSAT Constellation Mission Status Update*, Proceedings of European Conference of Synthetic Aperture Radar (EUSAR), 2016.

[9] D. Rudolf, B. Doering, M. Jirousek, J. Reimann, M. Schwerdt: *A Compact Antenna Rotation Concept for Precise Polarimetric SAR Calibration Transponders*, Proceedings of European Conference of Synthetic Aperture Radar (EUSAR), 2016.

[10] F. D. Zan, A. M. Guarnieri: *TOPSAR: Terrain Observation by Progressive Scans*, IEEE Transactions on Geoscience and Remote Sensing, VOL. 44, NO. 9, 2006.

[11] G. Castellanos Alfonzo, M. Schwerdt, S. Wollstadt, M. Bachmann, B. Doering, and D. Geudtner: *First TerraSAR-X TOPS mode antenna pattern measurements using ground receivers*, International Journal of Antennas and Propagation, Volume 2013, Article ID 635069.