Polarimetric Measurements for Sentinel-1 and Radarsat Constellation Mission using Reference Point Targets

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The paper focuses on polarimetric measurements executed for two C-Band SAR missions: Sentinel-1 (S1) and Radarsat Constellation Mission (RCM). RCM is able to operate as a quad-pol system which transmits alternatingly H and V polarization pulses and receives H and V simultaneously. In contrast to this, S1 is implemented as dual-polarization system which transmits either H or V polarization for a specific acquisition and receives both H and V polarization simultaneously. For this purpose, reference point targets have been used to allow a comparison of the impulse response function derived from the different polarization channels. While trihedral corner reflectors allow to compare co-polarized channels only, transponders are used for analyzing all four polarization channels (HH, VV, HV and VH). In order to enable a comparison of all four polarization channels also for S1, longer time series of acquisitions over stable reference targets have been acquired. The results show that the polarization channels are well balanced for both SAR missions. The channel imbalance between the polarization channels is low for all pairs in particular between co-polarized channels (HH-VV) but also for cross-polarized channels (HV-VH).

1 Introduction

Well calibrated SAR data products with accurately measured radar brightness are required for a number of applications and compose the basis for the quality of higher-level products. The measured radar brightness can be exploited for various scientific applications i.e. to classify or even quantify the observed target area, e.g., ice areas, forests or other kinds of vegetation, soil moisture of wetland and grassland, as well as ocean currents or wind speeds.

Modern spaceborne synthetic aperture radar (SAR) systems used for earth observation are capable of acquiring high resolution data while using polarimetry. To ensure the data quality, the various polarimetric channels must be calibrated as accurately as possible **[1]** by using passive and active reference targets (for example corner reflectors and transponders) with well-known backscattering properties.

The Sentinel-1 (S1) mission consists of a SAR constellation with S-1A and S-1B. Since the failure of S1B in December 2021, only S1A is currently in operation. S1 is able to operate with dual-polarization capability, i.e. the instrument can transmit either H or V polarization for a certain acquisition and receive H and V polarization simultaneously **[2]**. Consequently, in dual-pol operation mode there are two SAR products available for the same acquisition area: either VV and VH or HH and HV polarization products.

The Radarsat Constellation Mission (RCM) consists of three identical radar satellites flying in a sun-synchronous orbit with each satellite de-phased by 120° **[3]**. The C-band radar instruments are capable of operating in quad-polarization mode, i.e. it is possible to transmit and receive an electromagnetic signal in vertical (V) and horizontal (H) polarization. This allows to acquire SAR data in all four polarization channels (VV, VH, HH, HV) during an overpass.

2 Data and Method

2.1 Reference Point Targets

Reference point targets create specific impulse response functions in the complex SAR data which can be compared between different polarization channels and enables evaluating polarimetric SAR measurements. In this study the following reference target types have been utilized:

- trihedral corner reflectors as passive targets, and
- transponders as active targets.

While trihedral corner reflectors generate impulse responses in co-polarized products (HH and VV) only, transponders are more flexible and allow analyzing all combinations of polarizations.

The transponders used in this study were designed and manufactured by DLR **[4, 5]**. The DLR transponder design allows a specific adjustment of the separated receiving (RX) and transmitting (TX) antennas in line of sight which account for polarization channels H and V. For this study the 45° operation mode was selected i.e. RX and TX antennas were adjusted with diagonal antenna positions (DD) **[6]**. For this mode, the incoming signal from the SAR instrument is received and retransmitted by the transponder in both polarizations (H and V) simultaneously. As a result, the transponder's impulse responses are visible for all polarization channels, expecting the same radar cross section (RCS) in related SAR data products.

2.2 Channel Imbalance

The channel imbalance has been analyzed as the difference of the target response between given polarization channels. For this study we focus on channel imbalance in amplitude expressed as the ratio between derived RCS values from different polarization channels. This ratio is expected to be one (or zero in dB for the gain difference) under the assumption that the derived RCS from point target is polarization independent.

For dual-pol systems like Sentinel-1 only two polarization channels are available for a single acquisition. In order to allow comparisons between all four polarization channels also for S1, longer time series of acquisitions over stable reference targets have been acquired and averaged.

For quad-pol systems like RCM all four polarization channels (HH, HV, VV, VH) are available for a single acquisition. Then, the channel difference can be evaluated between each pair. From particular interest is the channel imbalance between co-polarized channels (HH and VV) and the imbalance between cross-polarized channels (HV and VH).

2.3 Sentinel-1 Acquisitions

For S1 evaluations the following calibrations sites and reference target types have been used:

- DLR calibration site in Southern Germany with three CRs (2.8 m leg length) and three C-band transponders,
- Australian calibration site (Surat) with six CRs (~2.5m),
- Canadian calibration site (near Montreal) with two transponders (DLR design).

For the DLR calibration site mainly dual-pol acquisitions are available for DV-polarization (VV and VH) for the long-lasting observation period since 2017. DH-polarization SAR images had been acquired only for short measurement campaigns in 2015/2016 and early 2021 over this site. However, these targets have been used for the calibration of S1A and S1B during the commissioning phase **[7, 8]** as well as for long-term monitoring **[9, 10]**.

For the large six CRs of the Australian calibration site single-polarization S1A acquisitions (HH or VV) are acquired since early 2023 alternating between consecutive orbit cycles (every 12 days).

For the Canadian calibration site, only a limited number of 22 measurements are available since June 2023 with alternating dual-polarized acquisitions (DV or DH) for S1A.

2.4 RCM Acquisitions

DLR's SAR Calibration Center has designed and manufactured two transponders with flexible polarization settings for the RADARSAT Constellation Mission (RCM). Both systems were delivered to the Canadian Space Agency (CSA) in 2017 **[6]**. They are used to support the radiometric and polarimetric calibration of RCM.

For this study, only a limited number of RCM quad pol acquisitions acquired since June 2023 over the CSA Montreal site in Canada were available. These 22 acquisitions cover all three RCM units (RCM-1, RCM-2, and RCM-3) with four different acquisition geometries for ascending and descending orbit at near and far range.

3 Results

3.1 Channel Imbalance of Sentinel-1

In the first part, the S1A channel imbalances in amplitude have been derived for the dual-polarization channels (DH and DV), i.e. each pair of polarization channels is related to a given transponder covered by a single acquisition. All channel imbalances are plotted as a function of elevation angle to account for potential impacts from the elevation antenna pattern of the SAR instrument.

The DH imbalance in amplitude (HH-HV) is depicted in **Figure 1**; the DLR transponder results are shown in red, the CSA transponder in blue. The DV imbalance (VV-VH) is shown in **Figure 2** with the same color code. Symbols (crosses) present the mean values, error bars the standard deviations; thin vertical lines indicate the coverage of the related sub-swath IW1, IW2, and IW3.

For these both channel combinations (HH-HV and VV-VH) the imbalance is below 0.2 dB. In particular for the DLR site transponders (red) in **Figure 2** the statistics for each acquisition geometry is based on more than hundred data points. The low standard deviations indicate stable conditions for S1A over the six years observation time.

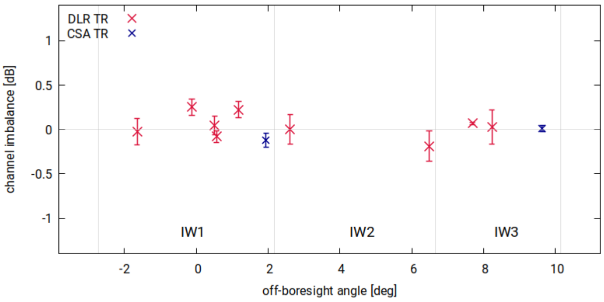

Figure 1 S1A channel imbalance (HH-HV) in amplitude for DLR transponders (red) and CSA transponders (blue).

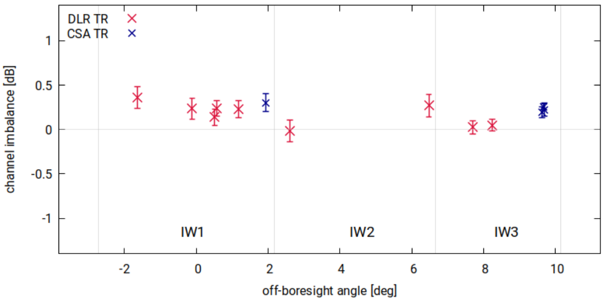

Figure 2 S1A channel imbalance (VV-VH) in amplitude for DLR transponders (red) and CSA transponders (blue).

In the next step, channel combinations are evaluated which are not available for a single S1A dual-pol acquisitions. For this purpose, time series of the RCS derived for a given target - acquired under a certain look angle - have been averaged for a given polarization channel. Assuming stable radiometric conditions, a deviation of the averaged RCS between polarization channels is a measure for their channel imbalance. In addition to transponder measurements, we can also use derived RCS over corner reflectors which are available for channel difference between co-polarized channels (HH and VV).

The co-polarized channel imbalance (HH-VV) for S1A is depicted as function of elevation angle in **Figure 3**. In addition to the transponders from the DLR calibration site (red squares) and CSA site (blue squares), also (large) corner reflectors are considered, in particular from the DLR calibration site (red triangles) and the Australian calibration site (green triangles). Note that Australian corner reflectors are only available for IW2 while DLR targets cover IW1, IW2 and IW3. CSA transponders are located at the edges of IW1 and IW3.

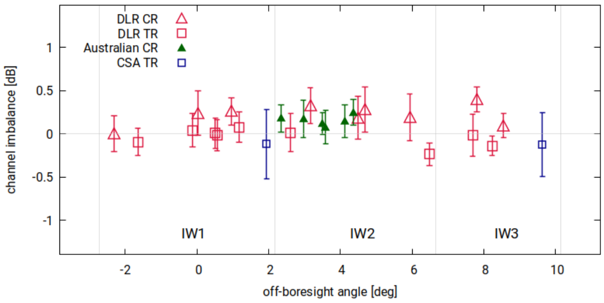

Figure 3 S1A channel imbalance between co-polarized channels (HH-VV).

The cross-polarized channel imbalance (HV-VH) for S1A is depicted in **Figure 4**. In this plot transponder evaluations from the DLR calibration site (red crosses) and CSA site (blue crosses) are visible.

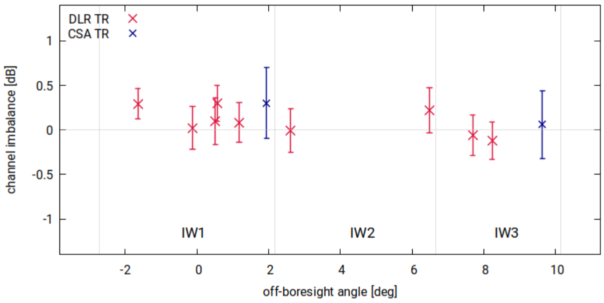

Figure 4 S1A channel imbalance between cross-polarized channels (HV-VH).

It can be concluded that the S1A channel imbalance shown in **Figures 1-4** is consistent and independent from the calibration site. Furthermore, the channel imbalance is found to be low. A slight variation over elevation angle is visible which is thought to be related with the used elevation antenna pattern. For the CSA transponders higher variations in the order of 0.3 dB have been found for HH/VV and HV/VH channel imbalances compared to other targets (see **Fig 3 and 4**) but also for the same target but other channel combinations (compare with **Fig 1 and 2**). These finding will be further investigated by evaluating more CSA transponder measurements using S1A acquisitions.

3.2 Channel Imbalance of RCM

RCM acquisitions were only available for the transponders at the CSA site in Montreal. The transponders are covered by four different acquisition geometries w.r.t. the SAR instrument at near and far range and with ascending and descending orbits. The look angles at near range are at 23.8°, at far range at 34.5°.

Analog to the S1 analysis, four different combinations of polarization channels have been evaluated for the channel imbalance in amplitude which is depicted in **Figure 5**. The channel imbalance is found to be below 0.4 dB. In particular the channel imbalance between cross-polarization channels (HV-VH) but also the combination VV-VH is very low (below 0.1 dB) for all four different acquisition geometries.

The channel imbalance including HH polarization channel is always below 0 dB (HH-VV and HH-HV) indicating that the RCS derived from the HH channel is lower compared to the other three channels (VV, HV, VH). It is planned to analyze this finding in future, e.g. with measurements over corner reflectors.

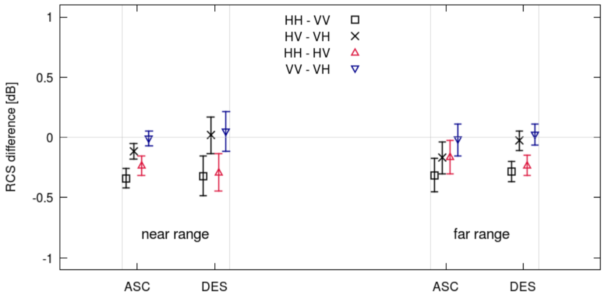

Figure 5 RCM channel imbalances for four different combinations of polarization channels.

3.3 Discussion

All results for the derived channel imbalance of S1A and RCM are summarized in **Table 1**. In particular for S1A the channel imbalances (mean values) are very low (below 0.2 dB). The standard deviation for S1A is lower for the channel imbalance of the dual-polarization products (HH-HV and VV-VH) compared to co-polarized (HH-VV) and cross-polarized channels (HV-VH). For the latter both, the standard deviation is slightly higher due to the channel combinations (DH or DV) acquired from different S1A acquisitions.

Table 1 Summary of the derived channel imbalance in amplitude for different combinations of polarization channels of S1A and RCM.

Channel Imbalance	**S1A**	**RCM**
HH – HV	0.01 dB ± 0.18 dB	-0.22 dB ± 0.09 dB
VV – VH	0.16 dB ± 0.16 dB	0.01 dB ± 0.08 dB
HH – VV	0.09 dB ± 0.20 dB	-0.30 dB ± 0.10 dB
HV – VH	0.11 dB ± 0.26 dB	-0.08 dB ± 0.10 dB

The results for RCM (**Table 1**, right column) confirm the findings depicted in **Figure 5**: the channel imbalance is in particular low (<0.1 dB) for the cross-polarized channels (HV-VH) and the combination VV-VH and slightly higher for the combinations HH-VV and HH-HV. Furthermore, lower standard deviations are derived for RCM compared to S1A which might be related to less particular points for different elevation angles.

Additional investigations are planned to analyze the impact from other external factors on channel imbalance, such as the ionosphere (e.g. due to faraday rotation) and mis-pointing (e.g. due to antenna steering during TOPS mode).

4 Conclusion

The channel imbalance for different combinations of polarimetric channels has been investigated for two spaceborne C-band SAR system: S1A with dual pol capability and RCM as a quad-pol system. The channel imbalance has been derived using trihedral corner reflectors and transponders from different calibration sites: the DLR calibration site in Germany, the Australian corner reflector array, and the CSA calibration site in Canada. While corner reflectors are sensitive for co-polarized polarization channels (HH and VV) only, transponders allow to analyze all four polarizations (HH, HV, VV, VH).

Despite the available channel combinations for the dual-pol S1 system (HH/HV and VV/VH) also other combinations have been evaluated by using averaging over longer timelines. In particular the co-polarization imbalance (HH/VV) and the cross-polarization imbalance (HV/VH) has been analyzed.

The derived channel imbalances (mean values) for both SAR systems are found to be low - for S1A below 0.2 dB, for RCM below 0.3 dB. In particular differences between cross-polarized channels (HV-VH) are in the order of 0.1 dB for both SAR systems. For RCM, slightly higher offsets are found for combinations with the HH channel indicating a slight negative bias in the order of 0.3 dB for the HH calibration factor. It is planned to validate these results using further RCM measurements with corner reflectors.

5 Acknowledgements

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6 Literature

[1] Kumar, S.; Babu, A.; Agrawal, S.; Asopa, U.; Shukla, S.; Maiti, A. “Polarimetric calibration of spaceborne and airborne multifrequency SAR data for scattering-based characterization of manmade and natural features”, *Advances in Space Research*, 69 (4), 1684-1714; **2022**.

[2] Torres, R. et. al., “GMES Sentinel-1 Mission”, *Remote Sensing of Environment*, (120), 9–24, **2012**.

[3] Cote, S.; Lapointe, M.; Vezina, P.; Arsenault, E.; Casgrain, C., and Boyer, A. "Status of the RADARSAT Constellation Mission in the Third Year of Operation," *Proceedings of EUSAR 2022*, Leipzig, Germany, **2022**.

[4] M. Jirousek, B. Doering, D. Rudolf, S. Raab, M. Schwerdt: “Development of the Highly Accurate DLR ‘Kalibri’ Transponder”, *Proceedings of EUSAR 2014*, Berlin, Germany, **2014**.

[5] D. Rudolf, B. Doering, M. Jirousek, J. Reimann, M. Schwerdt: “A Compact Antenna Rotation Concept for Precise Polarimetric SAR Calibration Transponders”, *Proceedings of EUSAR 2016*, Hamburg, Germany, **2016**.

[6] Raab, S.; Rudolf, D.; Weidenhaupt, K. and Schwerdt, M., "Development of DLR's innovative remote-controlled calibration targets - potential of polarization sensitive measurements", *Proceedings of EUSAR 2018*; Aachen, Germany, **2018**.

[7] Schwerdt, M.; Schmidt, K.; Tous Ramon, N.; Castellanos Alfonzo, G.; Döring, B.; Zink, M.; Prats, P., “Independent Verification of the Sentinel-1A System Calibration”, *IEEE Journal of Selected Topics in Applied Earth Observation and Remote Sensing*, 9, 994–1007, **2016**.

[8] Schwerdt, M.; Schmidt, K.; Ramon, N.T.; Klenk, P.; Yague-Martinez, N.; Prats-Iraola, P.; Zink, M.; Geudtner, D. “Independent System Calibration of Sentinel-1B”, *Remote Sensing*, 9, 511, **2017**.

[9] Schmidt, K.; Tous Ramon, N.; Schwerdt, M. “Radiometric Accuracy and Stability of Sentinel-1A Determined using Point Targets”, *IJMWT* (10) 538–546, **2018**.

[10] Schmidt, K.; Schwerdt, M.; Ramon, N.T.; Klenk, P.; Miranda, N.; Reimann, J. “Radiometric Comparison within the Sentinel-1 SAR Constellation over a Wide Backscatter Range”, *Remote Sensing*, 12 (5), **2020**.