Status of DLR's C-band Calibration Transponders and Outlook on an Upgrade for future SAR Missions

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Abstract

For more than 25 years, DLR's SAR Calibration Center has supported the calibration of a large number of spaceborne SAR missions. For ESA's Sentinel 1 mission, launched in 2014, three active reference targets, called "Kalibri" transponders, were developed and manufactured in-house. These transponders were used for an independent calibration of the Sentinel-1A and -1B satellites. Since then, the radiometric and polarimetric calibration of both SAR instruments has been monitored by routine overpasses with all three targets.
In order to ensure the availability of the C-band transponders until the end of the mission and to be well prepared for follow-on missions such as Sentinel-1 Next Generation, DLR has already started with the design of a comprehensive facelift of these "Kalibri" transponders. This paper provides an outlook on the planned transponder upgrade and gives an overview of the current status of DLR's C-band transponder activities.

1 Introduction

Due to the technical enhancement geometric and radiometric requirements for a spaceborne Synthetic Aperture Radar system (SAR) have constantly risen. This also demands highly precise and accurate geometric and radiometric calibration. For this external calibration process, passive (corner reflectors) and active (transponders) reference targets are used [1]. By recording their known backscatter with the SAR instrument, the calibration parameters can be derived. Accurate and stable target operation is a prerequisite for a high product quality of the delivered SAR data.
The DLR SAR Calibration Center has many years of experience in the calibration of spaceborne SAR systems [1][2] and operates a calibration field with more than 30 reference targets [3]. An overview of the existing DLR calibration facility is given in Chapter 2.
For the Sentinel-1 mission (S1) of the European Space Agency (ESA), three C-band transponders, called "Kalibri", have been developed, manufactured and operated since the launch of the first satellite S-1A in April 2014 [4]. These targets have been used for the calibration and monitoring process of the S-1A and S-1B satellites [2][5] and are also planned for the upcoming S-1C and S-1D satellites.
In addition, two similar C-band transponders were manufactured for the RADARSAT Constellation Mission (RCM) and delivered to the Canadian Space Agency (CSA) in 2017. Details of all C-band transponder activities are described in Chapter 3.
To ensure the availability of the "Kalibri" transponder until the end of the Sentinel-1 mission and to be well prepared for future SAR missions, e.g. Sentinel-1 Next Generation (S1-NG), continuous transponder development activities are necessary. For this purpose, DLR has already started the design phase of a transponder upgrade, called "Kalibri Facelift" (KFL). An outlook on the planned transponder upgrades is given in Chapter 4.

2 DLR's Calibration Facility

In 2014, the DLR SAR Calibration Center extended its existing calibration field by six novel reference targets. In addition to the "Kalibri" transponders, which were completely developed and manufactured in-house, three remote-controlled corner reflectors with an inner leg length of 2.8 m were installed in southern Germany [3]. All new targets can be operated completely remote-controlled from the office. This fact provides a big improvement compared to previous calibration activities, where each target had to be aligned manually for every overpass. Each type of new calibration target is shown in **Figure 1** and the specification parameters are listed in Table 1.

Figure 1: "Kalibri" transponder and 2.8 m corner reflector.

With the expansion, the DLR calibration site currently includes approximately 30 reference targets [6]:

- Three remote-controlled C-band transponders,
- three 2.8 m remote-controlled corner reflectors,
- six 3.0 m corner reflectors,
- more than 20 1.5 m corner reflectors,
- one X-band transponder.

All targets are located in an area of 120 x 40 km^2 in southern Germany.

Parameter	„Kalibri“ Transponder	2.8 m corner reflector
Center frequency	5.405 GHz	-----
Bandwidth	100 MHz	-----
RCS (C-band)	ca. 60 dBm^2	49.2 dBm^2
Mech. form tolerance	-----	≤ 1.0 mm
Rad. stability	≤ 0.1 dB	-----
Rad. Accuracy (1 σ)	0.2 dB	0.2 dB

Table 1: Specification parameters of DLR's remote controlled C-band transponders and 2.8 m corner reflectors.

3 Current Status of C-band Calibration Activities

3.1 Sentinel-1 Mission

All six remote-controlled targets, described in Chapter 2, have been successfully operated for ESA's Sentinel 1 mission since April 2014. Following the launch of the S-1A (2014) and S-1B (2016) satellites, the associated radar instrument was calibrated during the commissioning phase by means of overpasses with both target types [2][5]. Since then, the performance of both Sentinel-1 satellites has been monitored by further routine acquisitions over these reference targets during mission operations [7]. Since the launch of S-1A in 2014, each target has been aligned towards the S-1 satellites approximately every second day.
All targets are permanently installed at separate sites in southern Germany and are exposed to the weather condition all year around. This fact is a big challenge for the hardware design, especially for the transponders. To protect the hardware from the climatic conditions, all components, including both antennas, are integrated into an insulated housing. This design has proven itself so far. Up to now each transponder is fully operational and there has been no major downtime, except for planned maintenance.
Figure 2 shows a S-1A SAR image showing the impulse response of two C-band transponders.

Before using the “Kalibri” transponders as a reference, the backscattering properties of each device had to be determined [8][9][10]. An accurate knowledge of the RCS is essential for SAR system calibration because the quality of the computed calibration parameters depends on the quality of the deployed transponders. They serve as an external, absolute reference during instrument calibration and for long-term system monitoring. Thus, during routine operation the radiometric backscatter of the transponders should be also as stable as possible.

Figure 3 shows the radiometric performance of S-1A over several years. The absolute calibration factor was derived from the impulse response of the three “Kalibri” transponders within the SAR image.

The mean value can be estimated to be approximately 0.0 dB. This indicates a very good radiometric stability not only of the entire S-1A system over the entire acquisition time, but also implies the high radiometric stability of the reference targets used, namely the three “Kalibri” transponders.

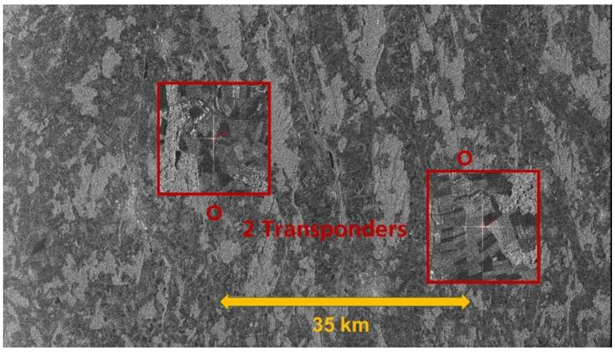

Figure 2: S1-A SAR image over two “Kalibri” transponder sites. By zooming in the impulse response of both transponders become visible.

Since the launch of the mission until the end of 2022, approximately 1400 overpasses with more than 7100 target alignments were executed with a target reliability of more approximately 95%. On behalf of ESA, it is planned to continue this service for the upcoming S-1C and S1-D satellites planned for 2024 and 2025.

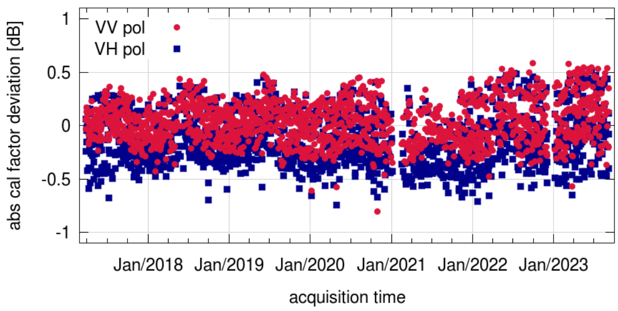

Figure 3: Radiometric stability of ESA's S1-A satellite in VV and VH polarization over mission time by means of measurements with DLR's “Kalibri” transponders.

3.2 RCM-Transponders

DLR's SAR Calibration Center has designed and has manufactured two transponders for RCM and both systems were delivered to CSA in 2017. Their design is based on the “Kalibri” transponder concept, but was adapted to the harsher weather conditions in Canada.
Figure 4 shows an RCM transponder installed in a dome in front of CSA's headquarter. Since installation, both targets have been operated for RCM and RADARSAT-2.

Figure 4: RCM transponder installed in a dome in front of CSA’s headquarter in Saint-Hubert, Canada.

4 Upgrade of C-band Transponders

As described in Chapter 2, the three C-band transponders have been in operation since 2014 without any longer outage. To ensure continuous transponder operation, maintenance activities have been executed at frequent intervals. In order to provide the transponder availability until the end of the Sentinel-1 mission and to be well prepared for further SAR missions in C-band, an upgrade of the three “Kalibri” transponders is planned. DLR has already started to design a transponder facelift, called “Kalibri Facelift” (KFL).

Due to enhancement of follow-on missions such as Sentinel 1 Next Generation (S1-NG), the reference target hardware and software must evolve to fulfil the increased requirements. Among others the following upgrade requirements for the KFL transponder can be derived from the S1-NG mission specification:

- Upgrade to a fully polarimetric dual-channel system. This concerns the RF chain in receive and transmit (RX and TX) and the digital unit.
- Bandwidth increase to 320 MHz.
- Adaptation of the antenna feeding system for dual-channel operation.
- New digital unit with increased processing power (i.e. higher sampling rate of AD converters).
- Enhanced cooling system for improved temperature management.
- Redesign of the transponder housing.

Within the next years, it is planned to develop an additional C-band transponder device based on new hardware components and with the new features mentioned above. After an extensive test phase, followed by an external calibration, this novel transponder is ready for operation. By means of a circular exchange (upgrade of one device in the laboratory and subsequent replacement of an “old” transponder), all transponders can be upgraded without interrupting the routine operation of all three devices.

Figure 5 shows the CAD concept of the upgraded transponder. Visually, this new generation is similar to the existing “Kalibri” targets, but most of the integrated hardware components will be upgraded.

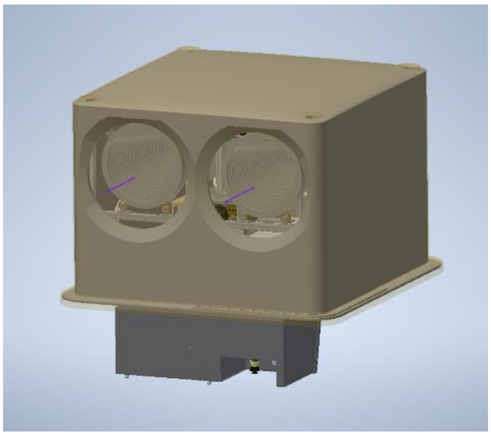

Figure 5: CAD model of the upgraded C-band transponder.

A key modification is the development of a dual-channel system. The existing C-band transponders are capable of receiving and transmitting a radar signal in H and V polarization by rotating the antennas. In 45° position, both polarizations can be handled simultaneously with half of the power, but internally only one RF signal is received, sampled and amplified. With the planned dual-channel system, separate signals for each polarization are processed by a new dual-channel digital subsystem. This provides a separate receive and transmit chain for H and V polarization. This modification allows a wide range of applications for polarimetric operation of the transponder. **Figure 6** shows the block diagram of the internal signal routing including the internal gain compensation path.

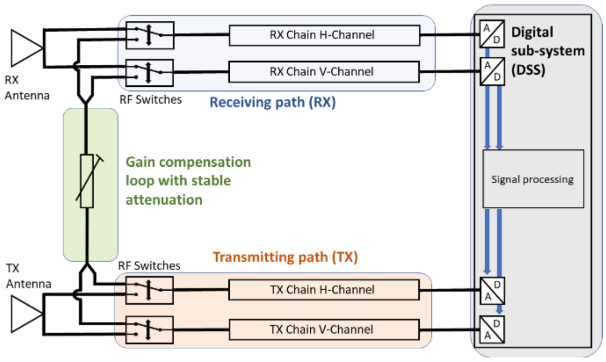

Figure 6: Block diagram of the upgraded transponder.

5 Conclusion

This paper describes DLR's activities in the development and operation of calibration transponders for spaceborne SAR missions in C-band.

Since 2014, the three “Kalibri” transponders have been in operation for the Sentinel-1 mission and form the backbone of the system calibration and monitoring. Based on this successful concept two similar transponder were developed for CSA's RCM and are in operation since 2017.

The increased requirements derived from future SAR missions demand a technological transponder enhancement. In order to be well prepared, DLR intensifies its development activities for C-band transponders. For this purpose, a concept for a comprehensive upgrade will be presented. With the planned development, DLR's SAR Calibration Center aims to ensure that suitable C-band calibration transponders are also available for future SAR missions such as S1-NG.

6 Literature

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