

# The next Generation of DLR’s C-band Transponders for Calibrating future SAR Systems – Status and Outlook

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## Abstract

Since more than 30 years the DLR SAR Calibration Center is active in the calibration of spaceborne SAR Systems. Three C-band transponders, named „Kalibri, and three remote-controlled corner reflectors were commissioned in 2014 and have been used as central calibration field for ESA’s Sentinel-1 mission. In order to be well prepared for the future, DLR intensifies its development activities for novel C-band transponders. The increasing complexity of modern SAR missions requires for suitable reference targets with state-of-the-art hardware. In this paper the current status of DLR’s C-band transponder development including a roadmap is presented. Within the next years a new generation of innovative C-band transponders will be developed, in order to be well prepared for the calibration of future SAR missions.

## 1 Introduction

Modern spaceborne Synthetic Aperture Radar (SAR) systems used for Earth observation are capable of acquiring high-resolution data. To ensure high quality data, the SAR system must first be calibrated. DLR’s SAR Calibration Center has been involved in the calibration of various spaceborne SAR missions for more than 30 years [1][2.] A key activity is the development, production and operation of active (transponder) and passive (corner reflector) reference targets for different frequency bands [3][4].

Since the launch of ESA’s first Sentinel-1 satellite in 2014, six remote-controlled reference targets (three corner reflectors and three transponders) located in southern Germany have been successfully operated for more than 10 years [5][6].

The three transponders, referred to as “Kalibri” transponders, were developed and manufactured entirely in-house in accordance with the requirements applicable prior to 2014. In order to be well prepared for future C-band SAR missions (e.g. Sentinel-1 Next Generation) and considering the age of the Transponders, too, DLR has already started the development for the next generation of C-band transponders which will replace the “Kalibri” transponders in the near future.

This paper will outline the current development status and present especially the improvements of DLR’s novel C-band transponder in more detail.

### 1.1 Motivation for novel C-Band Transponders

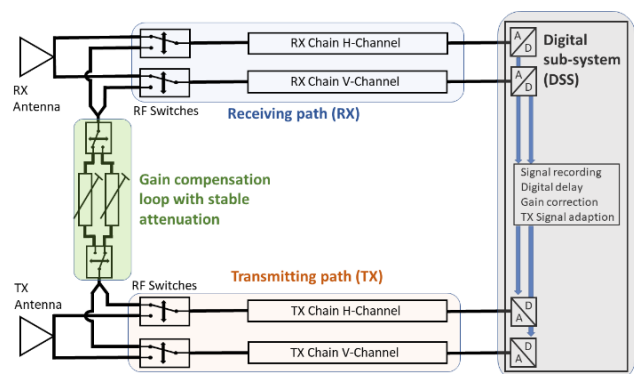
Although DLR’s Kalibri transponders have been in successful and uninterrupted operation since 2014, with more than 1700 executed overpasses and a reliability of approximately 93%, the nominal life cycle of several hardware components has been exceeded and the maintenance effort has increased in recent years.

In order to maintain the high reliability and to minimize the risk of longer outages, and to be well equipped for future

C-band SAR missions with full polarisation and novel operation modes such as digital beamforming, the existing transponders will be replaced within the next years without interruption of the continuous operation. Thus, the availability of novel C-band Transponders with state-of-the-art hardware can be ensured for future SAR missions.

## 2 DLR’s novel C-Band Transponder

The new generation of DLR’s C-band transponder will be based on a 2-channel system being able to receive and re-transmit both polarisation signals independently from each other and therefore well suitable for calibrating full polarimetric spaceborne SAR systems. This new concept is shown in **Figure 1**. With this dual-channel system, separate signals for each polarization are processed by the new digital processing unit with increased processing capacity.



**Figure 1:** Concept of the dual-channel architecture for individual handling of the RF-signal for H- and V-polarization.

The specification parameters for the novel transponder are listed in **Table 1**. The new design of the transponders enables the following features:

- Design to a fully polarimetric system with individual channels in receive and transmit for horizontal (H) and vertical (V) polarization,
- Bandwidth increase up to 320 MHz,
- Integration of fully polarimetric receiving and transmitting corrugated horn antennas with dual-channel feeding system,
- Adaption of decoupling concept between receiving and transmitting antenna,
- New digital unit with increased computing power for individual processing of H- and V-channel,
- Implementation of an active cooling system for temperature management improvement.

All these modifications allow a wide range of applications for full polarimetric operation of the transponder.

Specification parameters of novel C-band transponder	
Center frequency	5.405 GHz
Bandwidth	320 MHz
Polarization	Quad-pol.
RCS (C-band)	ca. 65 dBm <sup>2</sup>
Radiometric stability (expected)	≤ 0.05 dB (1σ)
Radiometric accuracy (expected)	≤ 0.1 dB (1σ)

**Table 1:** Specification parameters of DLR’s novel C-band transponders.

## 2.1 Antenna design

A fully polarimetric transponder with a dual-channel design demands the development of a new antenna design concept. Due to the high intrinsic amplification (60dB) sufficient decoupling between RX and TX antennas is essential in order to fulfil the transponder requirements.

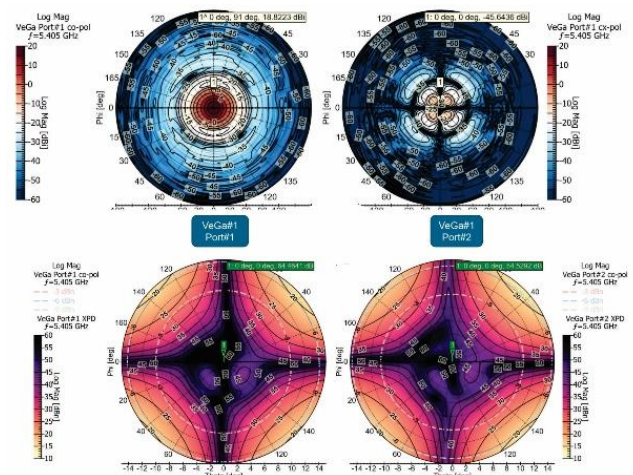
After an intensive analysis, a new design of a dual-polarized antenna was developed, based on a choked Gaussian horn antenna (VeGA) with additional choke rings to increase the decoupling effects and including a corresponding feeding system. In **Figure 3** the new C-band VeGA horn antenna is shown.



**Figure 3:** C-band choked Gaussian horn antenna (VeGA).

The performance of the newly developed antenna and feeding system was verified by measurements in DLR’s in-

house Compact Test Range (CTR). The results are presented in **Figure 4**.



**Figure 4:** Results of CTR measurements for one VeGA antenna. Top: measured gain pattern for co- (left) and cross- (right) polarization. Bottom: cross-polarization discrimination for H-port (left) and V-port (right) of one antenna.

The top diagram represents the measured antenna gain pattern in co- and cross-polarization and verifies the antenna performance regarding absolute gain, pattern symmetry and functionality of the feeding system.

The bottom diagram shows the measured results for cross-polarization discrimination in H- and V-polarization. The strong requirement for discrimination of +45 dB has been achieved by the new antenna design and successfully verified by DLR’s Compact Test Range (CTR).

## 2.2 RCS Determination

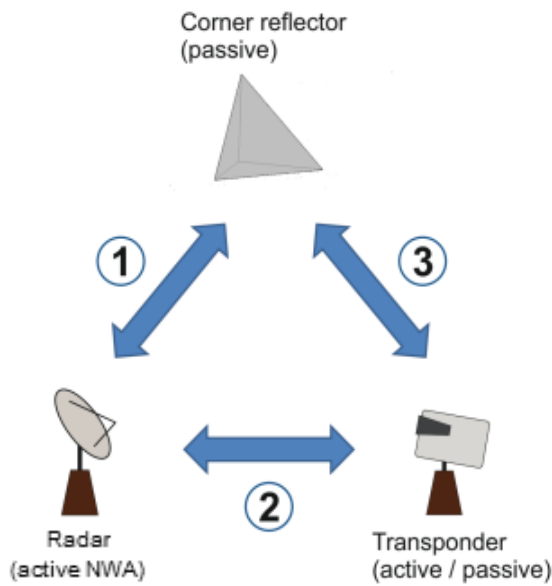
Before a transponder can be used as reference target, its radar backscattering characteristics, especially the RCS, must be determined as accurately as possible [7]. This absolute radiometric calibration of a reference targets is an important point because it directly affects the accuracy with which the SAR system can be calibrated.

DLR has performed a lot of effort to fully and precisely characterize their transponders. So at the end, the innovative “Three Transponder Method“ (3TM) was developed by DLR and patented [8]. With this method the individual RCS for each transponder can be determined with high precision. No knowledge of an additional absolute reference is necessary.

It is not necessary to use three transponders, as mentioned in the name. Also, it can be executed with one transponder, an external radar and any kind of radar target, as shown in **Figure 5**. From three independent measurements the transponder RCS can be derived by measuring the power ratio of radar and target for each device combination and the corresponding distance.

From an uncertainty analysis in X-band, based on GUM, an overall absolute radiometric accuracy of better than 0.1 dB (1 σ) was achieved for DLR’s new X-band transponder

[9][10]. A similar accuracy is expected for new C-band transponder as well.



**Figure 5:** Measurement principle for the Three Transponder Method.

### 2.3 Digital Electronics

The digital unit can be seen as the heart of the transponder. It is used to digitize, process, and retransmit the incoming radar pulses. For the novel transponder a complete new digital electronic with following features is foreseen:

- dual-channel FPGA Transceiver with 6.4 GSPS,
- full sampling of received chirps,
- support of the full 320 MHz bandwidth,
- dual-channel operation for polarimetric calibration purposes,
- GPS synchronized timestamps,
- adjustable delay of impulse response,
- internal gain compensation for fine tuning of RCS,
- FIR filtering for compensation of frequency response variations.

The implementation of a FIR filter allows to compensate the magnitude and phase variations over frequency in real-time. This feature is becoming more and more important for future SAR missions with higher bandwidths and in the end helps to improve the calibration accuracy.

## 3 Roadmap for the development of the novel C-Band Transponder

The new C-band transponder has been developed since 2024. The integration of the first device will be finished in 2026. After an extensive test phase, followed by an external calibration for accurate RCS determination, the new transponder is ready for operation.

Within the next years it is foreseen to replace all three existing Kalibri transponders by means of a circular exchange (development & test of one new device in the lab and sub-

sequent replacement of an “old” transponder on site) without interrupting the routine operation for all three devices. After the replacements, at the end an additional transponder will be available for further developments, experiments, and as test device for maintenance activities.

## 4 Conclusion

The DLR SAR Calibration Center has been established since more than 30 years and provides a facility of several active and passive reference targets for different frequency bands.

The Kalibri C-band transponders have been in operation since 2014 and provide the backbone of SAR system calibration and monitoring for the Sentinel-1 Mission. In order to ensure C-band transponder availability for the next decade, an upgrade of the existing transponder is essential. Moreover, a completely new C-Band transponder has been designed to meet the challenges of future SAR missions, and is currently under development. The concept and status are presented in this paper.

The radiometric transponder accuracy is expected  $\leq 0.1$  dB by means of the innovative Three Transponder Method, which defines a milestone for absolute radiometric calibration of reference targets.

The replacement of the transponders will be executed without interrupting the transponders’ routine operation.

With the planned development, DLR’s SAR Calibration Center aims to ensure that suitable C-band transponders are also available within the next decade for present and future SAR missions such as Sentinel-1, Sentinel-1 Next Generation and even, depending on the bistatic angle, for satellite constellations, such as ESA’s planned Harmony mission.

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