Highly Accurate Calibration Target for Multiple Mode SAR Systems

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Abstract

The product quality with respect to radiometric accuracy of current and future space-borne synthetic aperture radar (SAR) systems depends on the grade of the utilized external calibration targets. This paper presents the first steps taken in designing and building a highly accurate active target (transponder), which exhibits high radar cross section stability (in the order of a tenth of a decibel) over its lifetime even for future multiple mode SAR systems. Furthermore, the transponder allows the recording of the azimuth pattern and fully sampled pulses.

1 Introduction

The main objective of a space-borne synthetic aperture radar (SAR) system is to acquire a georeferenced backscatter coefficient for each image element.

Absolutely calibrated data can only be achieved after considering and incorporating many different influences. The instrument's state needs to be closely monitored and adjusted, and the respective impacts on the recorded data need to be compensated during SAR data processing. This is referred to as internal calibration.

The internal calibration and subsequent data processing lead to a *relatively* calibrated SAR image. The data processing includes the antenna model, based on which the impact of the antenna characteristics are compensated [1]. In the last step, the image intensity (i. e. gray level) is bound to a backscatter coefficient by means of absolute radiometric calibration. Not until then can a physical meaning be attached to the measured amplitudes.

In practice, absolute radiometric calibration is being achieved as for all measurement instruments: The instrument's output is related to a known measurement standard. For highly accurate systems (1σ uncertainty below 1 dB), distributed targets are ruled out and only point targets (passive or active) are used.

The initial absolute calibration of the SAR system is usually carried out during a dedicated and concentrated commissioning phase. Later on, the derived absolute calibration factor needs to be monitored and possibly corrected over the system lifetime.

This paper presents the first steps taken in developing and building an active calibration target (a transponder) for future space-borne multiple mode SAR systems. The experience gained from calibrating TerraSAR-X [2] and the planning for the upcoming TanDEM-X calibration campaign is incorporated in the design process. The focus is set on a highly accurate and stable radar cross section (RCS), and autonomous operation which facilitates continuous long-term system monitoring. In contrast to a passive target like a corner reflector, a much larger RCS can be realized at smaller physical dimensions. Also, thanks to the polarization of the utilized receive and transmit antenna, it can be used for calibrating co- and cross-polarization modes (a trihedral corner reflector has only a co-polar return). Furthermore, it will be able to record the phase-coherent received signal for later analysis.

The transponder will accommodate for future requirements with respect to accuracy (order of a tenth of a dB, 1σ) and bandwidth ($\geq$ 600 MHz). A new internal calibration approach will ensure a constant transponder RCS even for multiple mode (including split-bandwidth) SAR systems over the whole lifetime of the transponder.

2 Requirements

The requirements for the transponder design can be summarized as follows:

- Radar cross section: 60 dBm^2
- Transponder bandwidth: $\geq$ 600 MHz
- Frequency: X-band
- Radiometric stability: < 0.2 dB (1σ)
- Radiometric accuracy: < 0.2 dB (1σ)
- Record UTC synchronized azimuth pattern for later analysis
- Record coherently sampled pulses
- Remote controlled alignment by positioner
- Polarization: H and V in receive and transmit

Especially the requirements in terms of accuracy and stability represent a step forward with respect to transponders which were operated during the TerraSAR-X commissioning phase [3].

3 Transponder Design

The basic units of the transponder are shown in Fig. 1. The radar signal is received and down-converted, digitally sampled, delayed and possibly modified, and re-generated by the digital sub-system (DSS), up-converted, and finally retransmitted to the satellite. In the DSS a gain stabilization system is included which ensures a very stable RCS over the transponder lifetime.

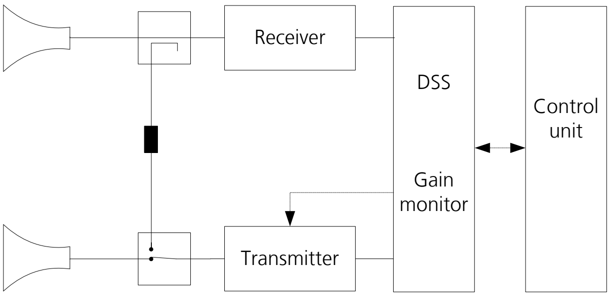

Figure 1: General functional transponder block diagram.

The remote control and storage of received data is accomplished by the control unit. The transponder will be mounted on a positioner, see Fig. 2, and will be installed in a location which exhibits low multipath effects, i. e. on a field with no other disturbing point targets. The transponder control unit also communicates with a positioner controller, which is required to autonomously align the transponder with the satellite's line of sight before an overpass.

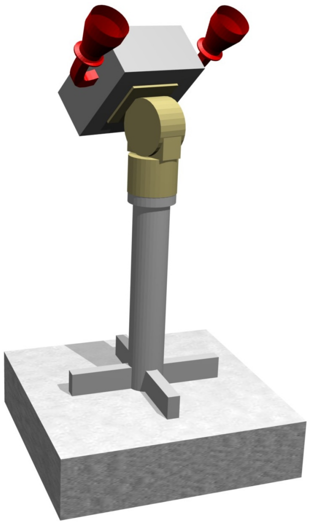

Figure 2: Sketch of the mechanical transponder setup.

As the transponder is used to absolutely calibrate the SAR system, it is essential to precisely and absolutely calibrate the transponder as well. Only under these conditions the transponder is useful for calibration campaigns and subsequent ongoing system monitoring.

4 Calibration

As the transponder is used as a calibration standard, it must itself be accurately characterized, its performance monitored during operation and, if necessary, its loop gain automatically corrected. This is achieved by the internal and external transponder calibration, comparable to the internal SAR instrument calibration and on-ground characterization.

4.1 Internal Transponder Calibration

The internal calibration constantly monitors the transponder gain. The gain (mostly of active RF devices) could vary due to temperature variations or aging. If a gain variation is detected, it will be compensated.

Traditional transponder gain controls are simple: Either they compensate a previously calibrated temperature drift by means of temperature sensing [4], or they measure the loop gain at a single (the center) frequency [5]. In contrast, the proposed new transponder design incorporates the capabilities of the digital sub-system by generating mode-dependent test pulses. These mode dependent test pulses do not only monitor the transponder's gain at one frequency but at a frequency band. Also, a variable center frequency can be chosen which is useful to adapt the internal calibration to match the respective SAR mode. This approach is also better suited to transponders with a larger bandwidth as the complete transfer function can be taken into account. Due to this approach, the requirements on amplitude ripple over the complete operational bandwidth can be relaxed. Also, changes in the complex transfer function which cannot be described by a simple gain offset can be modeled.

One challenge in designing a stable and precise internal calibration loop is that not all components can be incorporated into a compensation. This holds true for the feedback loop which couples the transmit signal back into the receive path (see Fig. 1). Should the attenuator or the cable connectors change their transmission coefficients over time or temperature, then this change could not be distinguished from a gain variation of one of the active components, for instance. Therefore, the internal calibration loop incorporates as few components as possible since each additional component can contribute to the overall calibration uncertainty. The internal calibration components (e. g. coupler and attenuator) are all passive devices and expected to be highly stable over temperature and time. In the course of this work, the characterization of those internal calibration loop components will play an important role.

The proposed internal calibration setup and the utilization of the capabilities of the digital sub-system result in an improved long-term RCS stability and accuracy in comparison to previous designs.

4.2 External Transponder Calibration

An external transponder calibration is necessary in order to determine the precise *total* transponder gain after manufacture. The absolute transponder calibration has a direct impact on the absolute radiometric accuracy of the SAR system and therefore is of major concern.

Several external calibration strategies exist. One of them is to measure the RCS on an outdoor RCS measurement range [6]. Another approach follows [5]. For this approach, the transponder itself generates a transmit signal. The radiated signal is reflected by an adequately shaped metallic plate of known size at a known distance, and received again by the transponder. The difference between transmit and receive power is utilized to determine the total transponder gain, assuming that the plate RCS can be computed with sufficient precision, the distance is known, and that the orientation of the plate with respect to the line of sight is sufficiently accurate.

The RCS uncertainty of the reference plate is an important contribution to the transponder RCS uncertainty. Therefore, first numerical simulations have been conducted in order to determine the permissible plate imperfections (slight surface roughness, plate alignment). More work needs to be performed to complete the study.

5 Antenna Design

The antenna needs to be designed with several, sometimes diverging, constraints in mind:

Gain stability: Since the antenna gain is not covered by the internal calibration loop, a gain variation (over temperature, time, humidity) directly results in an RCS variation. This can be positively influenced by choosing an appropriate aperture cover and installing the antennas together with the RF electronics *inside* of a thermally controlled housing.

Gain flatness: The gain flatness around the main beam direction is important in order to minimize the angular dependent RCS reduction during one overpass.

Gain: A higher antenna gain reduces the requirement on the RF amplifier chain. This is especially important for high RCS ($> 60\,\mathrm{dBm}^2$) devices.

Low cross-polarization: The transponder cross-polarization suppression defines the transponder performance for multiple polarization measurements. It is given by the limited cross-polarization suppression of the antenna and the mechanical misalignment (rotation) during operation.

Sufficient side-lobe suppression: Low side-lobes help to reduce the multipath effect, which is due to ground reflections in the vicinity of the transponder. A superposition of multipath and direct receive or transmit waves can otherwise influence the effective transponder RCS.

A smooth-walled Potter horn design based on [7] was chosen. It promised to be the best compromise between antenna size, ease of manufacture, main-lobe shape, side-lobe suppression, and cross-polarization suppression.

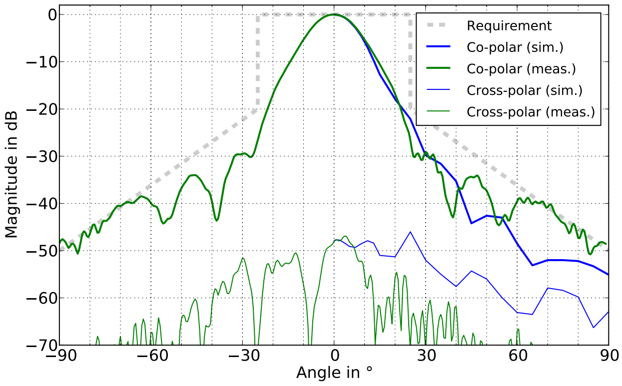

Figure 3: Normalized cut through the E-plane of the simulated (for pos. angles only due to symmetry) and measured Potter horn.

The antenna pattern was simulated using FEKO before the horn was built in-house. The horn is about 40 cm long and weighs 2,7 kg, which is still acceptable for mechanical integration and mounting of the transponder on a target positioner.

The normalized power pattern was measured at DLR's new compact range in Oberpfaffenhofen [8]. The antenna pattern and the simulation results are shown in Fig. 3. The side-lobe suppression is better 20 dB for angles which are 25° or further off the main-beam direction. A beam shape which is narrower was not chosen as it would limit the gain flatness in the main-lobe direction. The measured cross-polarization suppression is about 48 dB and therefore surpasses alternative and more compact antenna designs like patch antennas.

6 Conclusion

First steps have been conducted in designing and building a highly accurate active calibration target, which can be utilized during commissioning and long-term system monitoring of future SAR missions. Based on the proposed design, the required accuracy of the transponder can be achieved by considering the impact of each component on the absolute radiometric uncertainty. This is aided by a new and compact internal calibration strategy, which allows the operation in multiple mode SAR systems. A suitable antenna design for this project was presented and measurement results confirmed the antenna's applicability especially with respect to cross-polarization and side-lobe suppression.

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