# Linearity Measurements of an Accurate Transponder for Calibrating Future Spaceborne SAR Systems

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## Abstract

The requirements on new spaceborne synthetic aperture radar (SAR) missions are always pushed towards better image quality with respect to signal-to-noise ratio, radiometric accuracy, and spatial resolution. Therefore an accurate calibration of the SAR system and the final product is essential. The quality of the calibration depends on the utilized reference target. In this paper a new active calibration target (transponder), currently under development at DLR [1], and measurement results of the linearity of the high frequency section is presented.


## 1 Introduction

The intention of an imaging synthetic aperture radar (SAR) instrument is to record a high resolution backscattering map of the observed scenario. Therefore, the measured digital backscattered values needs to be converted into geophysical units, like the backscattering coefficient of a distributed target or the radar cross section (RCS) of a point target.

For this purpose systematic error contributions throughout the complete SAR system has to be estimetd and compensated for. This so called radiometric calibration process is performed in two steps: at first relative and afterwards absolute radiometric calibration.

Relative radiometric calibration is based on an accurate internal calibration facility, integrated within the radar instrument for monitoring and compensating for drift effects [2], and on a precise antenna model [3] for providing the antenna patterns, which are required to correct the gain drop across the swath during SAR data processing.

In the final step, these relatively calibrated SAR images are converted to RCS maps. This so called absolute radiometric calibration is based on an accurate reference target with well known backscattering characteristics.

For spaceborne SAR missions like TerraSAR-X or TanDEM-X this calibration is performed during a commissioning phase [4] and for later recalibration phases [5].

In order to keep up with the growing demand on SAR data products of high quality, a new transponder is currently under development being well prepared for future spaceborne SAR systems.

The focus of the transponder development is set on a very accurate and stable RCS value. To furthermore disregard the clutter and sidelobe effects of other targets nearby the RCS value should be in the order of 60 $dBm^2$. Furthermore, the transponder will be operated autonomously in a remote mode on a two axis positioner in a low clutter environment.

However, due to the cumulative frequency response of all devices within the transponder chain and non linearity effects especially of the final transmitting amplifier, the RCS for the same transponder differs for different instrument modes and observation angles because of variable receive power and possible frequency range at the transponder input. So, special attention on a highly linear RF-part with low variation over frequency is recommended [6].

The paper decsribes the transponder design and first measurements of important paremeters of the RF chain in order to achieve an accurate and stable RCS.

## 2 Transponder design and requirements

To fulfill the needs mentioned above, the requirements for an active transponder with a radar cross section of 60 $dBm^2$ at X-band are challenging. The major parameters are as follows:

- Radar cross section: 60 $dBm^2$
- Transponder bandwidth: > 600 MHz
- Center frequency: 9.65 GHz
- Radiometric stability: < 0.2 dB ($1\sigma$)
- Radiometric accuracy: < 0.2 dB ($1\sigma$)
- 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

The high bandwidth and the recording requirement results in a FPGA based digital design. The basic block diagram of the transponder is shown in Fig. 1. The signal is received by a Potter horn antenna [1] and fed to the receiver chain. The signal is filtered and amplified. A variable attenuator adjusts the power to a suitable level for the subsequent units. The signal is down-converted and lowpass filtered before analog to digital conversion. The FPGA allows almost any digital signal processing and storage of sampled pulses of the received signal. In the transmit part the signal is coherently up-converted and adjusted to the desired RCS value by a second variable attenuator before it is amplified by a high power amplifier (HPA) and transmitted via a second Potter horn. An internal calibration loop guarantees in conjugation with the digital board and the variable attenuators a very stable RCS of the transponder, having very few passive and temperature stable components outside the calibration loop that are not compensated for [1].

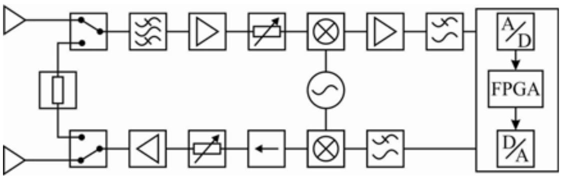


**Figure 1** Block diagram of the transponder.

This principle design with two linear polarized rotatable antennas, one for receiving and one for transmitting the radar signal, allows a very flexible operation especially for calibration of different polarizations. This constellation also guarantees a good isolation between the receive and the transmit path.
The required accurate knowledge of the RCS for different polarization constellation recommends a design with rotatable antennas in a temperature stabilized housing. A sketch of the transponder with the two round radoms covering the two antennas is shown in Fig. 2. Considering the theoretical RCS of a transponder

$$\mathrm{RCS}_{\mathrm{Transponder}} = \frac{G_{RX}\, G_{TX}\, G_E\, \lambda^2}{4\pi}$$

and an antenna gain of 18 dBi for receive $G_{RX}$ and for transmit $G_{TX}$, a RCS of 60 dBm$^2$ requires an electrical transponder gain $G_E$ of 65 dB. With a maximum radar signal level of -52 dBm at the transponder receive antenna a HPA output level of 35 dBm is required [7]. A linear operation of the whole transponder loop as recommended above demands a considerate view on devices with a quadratic characteristic like the mixers and the amplifiers and especially the HPA.

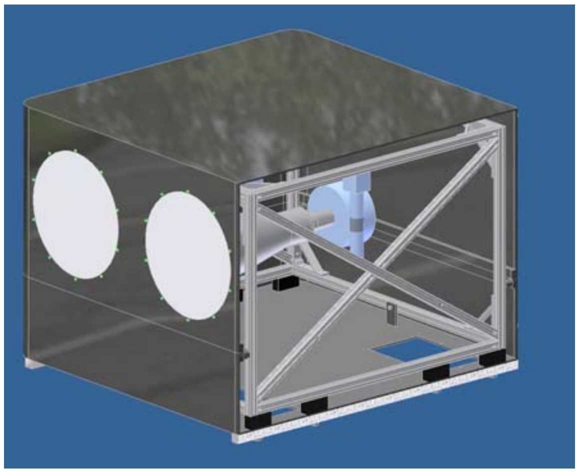

**Figure 2** Sketch of the transponder housing with the frame and antennas.

The requirement of a radiometric accuracy below 0.2 dB results in a linearity requirement below 0.1 dB for the whole transponder. First measurements of this important parameter are presented next.

# 3 Measurement of the linearity

The linearity is one major parameter for a dependable transponder design. Because of the digital FPGA part of the transponder and the internal calibration loop small variations in power linearity can be compensated for. The disadvantage is the higher delay caused by the digital signal processing on the FPGA chip. Therefore a high linearity with deviation below 0.1 dB enables an operation with the lowest delay.
The measurement of the whole transponder except the antennas and the digital part, which was replaced by a cable, was performed with a network analyzer (NWA). To protect the NWA and to shift the power to the most sensitive range additional 30 dB attenuation at the input and 50 dB at the output of the transponder are added. Fig. 3 shows the gain (blue curve almost horizontal; plus 80 dB total attenuation) and the output power (green curve diagonal; plus 50 dB output attenuation) both as function of input power and for three different frequencies: 9.35, 9.65, and 9.95 GHz. The result shows a deviation below 0.1 dB to an output power greater than 35 dBm. As shown in Fig. 4, the variation of the amplitude and the group delay of the transfer function (in the used frequency range) are less than 2.3 dB and 3 ns respectively. The mean electrical transponder gain $G_E$ can be calculated to 66 dB.
The deviation from an ideal transponder transfer function can be compensated for, e.g. by an appropriated DSP implementation on the FPGA but at the cost of time delay due to additional processing time.

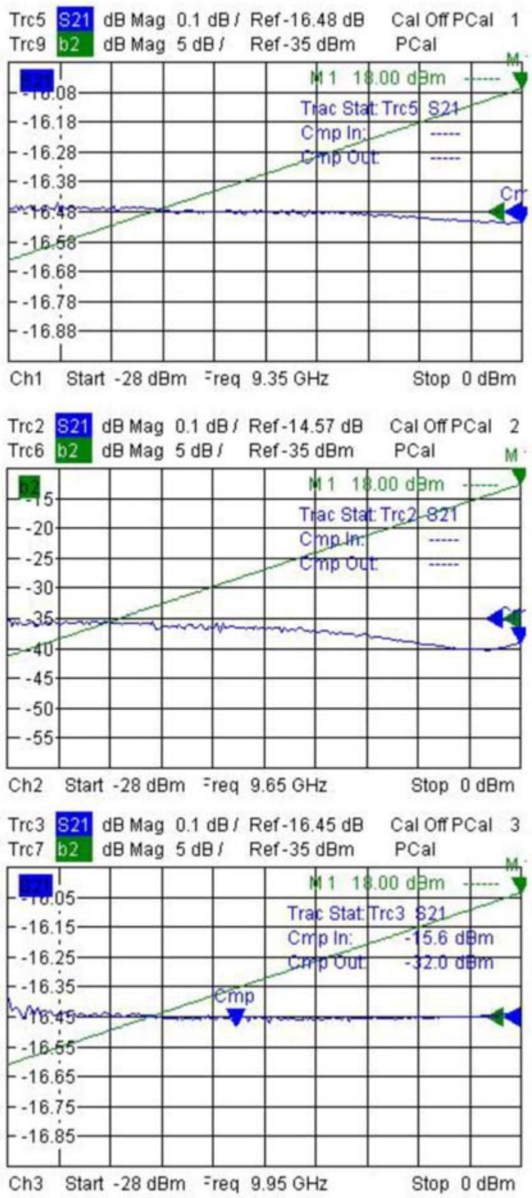


**Figure 3** Linearity measurements with a network analyzer of the whole transponder chain (additional 30 dB attenuation at the input, 50 dB at the output) for 9.35, 9.65, and 9.95 GHz: blue curve: gain over input power; green curve: output power over input power.

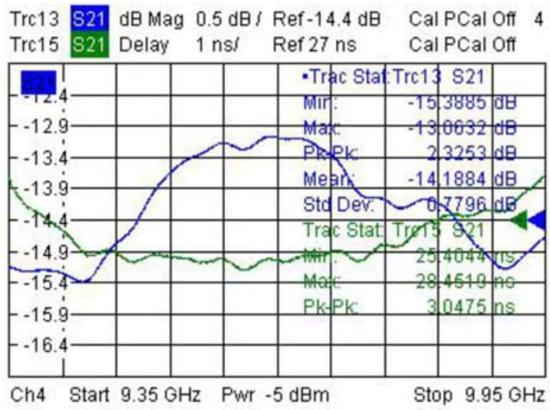


**Figure 4** Magnitude and group delay of the transfer function of the whole transponder chain measured with a network analyzer (additional 30 dB attenuation at the input, 50 dB at the output).

The focus of the transponder development is the radiometric calibration of a SAR-system. Therefore the linearity in magnitude is the main performance parameter. Also the linearity in phase and group delay is a system parameter but of minor priority. The measurement of the phase deviation and the group delay at the 0.1 dB deviation point (0 dBm input level plus 30dB attenuation) relative to the linear case (-15 dBm input level plus 30dB attenuation) is shown in Fig. 5. The maximum deviation is less than 4° in phase and below 0.1 ns in group delay. If the transponder will be used for an interferometric calibration in future this factor can be of interest, but for the radiometric calibration the deviation is below a reasonable value that affects the RCS value.

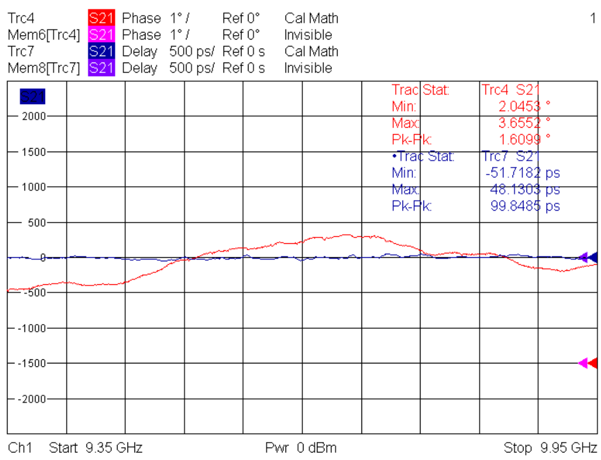


**Figure 5** Phase and group delay deviation at the 0.1 dB deviation point relative to the linear case of the transfer function of the whole transponder chain.

# 4 Conclusion

The development of a highly accurate X-band active calibration target for the calibration and long-term system monitoring of future SAR systems is preceded so far that first measurements of the important instrument parameter, the gain linearity, are conducted. The results show a deviation form linear gain of less than 0.1 dB up to the required RCS value in a worst case scenario. So the error contribution by this hardware to the overall calibartion budget, relevant for the accuracy requirement, is accetable.

# References:


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