Variations of the Transponder's RCS Due to Environmental Impacts on the Antennas

Philipp Looser, Björn J. Döring, Matthias Jirousek, Marco Schwerdt
German Aerospace Center (DLR), Microwaves and Radar Institute, Oberpfaffenhofen, Germany

Abstract

Transponders for synthetic aperture radar (SAR) need to be extremely precise in order to qualify as absolute calibration references for the increasingly demanding new SAR systems. To guarantee highest accuracy and stability even components which normally are considered ideal, have to be be taken into account. This paper shows the environmental influence on the antenna gain and thus on the overall transponder gain, compares two different housing designs and explains why this particular design has been chosen for the new transponder currently being developed at the DLR.

1 Introduction

A synthetic aperture radar (SAR) maps the reflectivity of the illuminated scene. Like every measurement instrument, the system dependent output has to be absolutely calibrated in order to obtain consistent and comparable physical quantities. SAR satellites are usually absolutely calibrated in a dedicated commissioning phase before starting normal operation and verified periodically during their lifetime. Driven by the rising demand for high quality SAR products, new increasingly precise transponders are needed, like the new generation transponder currently under development at the DLR [1]. It is designed for future C- and X-band SAR missions that will exceed the already outstanding performance of TerraSAR-X and TanDEM-X in terms of their radiometric accuracy and geometric resolution [2]. The resulting demands on the future calibration references thus are:

- Radiometric accuracy: < 0.2 dB (over 15 years)
- Radiometric stability: < 0.2 dB (over 15 years)
- Bandwidth: ≥ 600 MHz
- Individual polarization for receive and transmit
- Remote operation and low maintenance
- Record coherently sampled pulses

In order to fulfill these requirements, a different transponder design is required compared with the one used for calibrating current SAR satellites like TerraSAR-X and TanDEM-X [3] and older systems like ESR-1 [4].

2 Transponder Design

The transponder contains of several subsystems completely integrated inside a temperature controlled and sealed housing.

2.1 RF Circuit

A block diagram of the rf circuit is shown in Fig. 1. The main signal path contains of a receiver chain, transmitter chain, and a digital sub-system (DSS) to record and process the radar pulses. As the transfer characteristics of active devices (especially amplifiers) are known to be highly temperature sensitive, an internal calibration (ICAL) loop is incorporated into the main signal path.

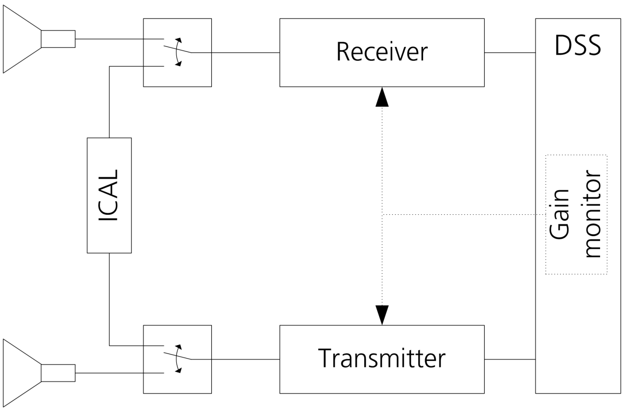

Figure 1: General functional rf block diagram.

The basic principle of this internal calibration strategy is to generate a test pulse inside the DSS which shall experience the same changes as the radar pulse while propagating through the transmitter and receiver chain. If a variation of the transfer characteristic is detected, either the digital attenuators within the receiver and transmitter chains are readjusted accordingly to compensate for the gain variations or digital filters inside the DSS are applied to restore the initial transfer characteristic. This strategy implies, that the calibration signal follows the main signal path as far as possible and covers at least all sensitive components. Gain variations of components used only by the calibration signal (i.e. ICAL components) or only by the radar signal (i.e. antennas and feeds) can not be detected or compensated with this ICAL strategy. Therefor the ICAL path only contains a minimum amount of highly stable, passive devices with very low temperature coefficients in the order of few thousands of a decibel [5]. To further minimize the influence of temperature variations on the transponder gain, the whole circuit is mounted in a hermetically sealed and temperature regulated housing. This guarantees highest stability of the ICAL components, prevents premature wearing of all components due to temperature cycles and excessive relative humidity, and provides stable ambient conditions during the overflight. Hence, any variation of the receiver's or transmitter's transfer characteristic is monitored by the ICAL loop and can be readjusted up to the high degree of the ICAL components' stability itself.

This leaves the antennas as only unknown error sources, as they are not covered by the ICAL. While it was sufficient for traditional transponders to consider them as ideal and only compensate for the variations caused by active devices, this is not enough to meet the tight error budget of this transponder. In fact, variations of the antenna gain (due to changing temperature or humidity) influence both the received and transmitted signal and therefore directly contribute to the overall stability of the transponder by a factor of two.

2.2 Housing Design

Based on the location of the antennas, two different housing designs can be distinguished - either to place them inside the hermetically sealed and temperature controlled housing or outdoor only covered with a radome to protect them from environmental contamination like dirt, rain, or snow. While in the first case the antennas are always operated in a controlled ambient, in the latter case they may suffer of substantial temperature and humidity variations as they occur outdoors during a day. Due to temperature fluctuations a pressure difference results between the inside and outside of the antennas, which eventually causes slight amounts of gas exchange and thus water vapor to enter the antennas. When the air temperature falls below it's dew point, the humidity - either being induced at the time of mounting or later due to gas exchange and diffusion through the radome - begins to condensate inside the antennas. This lowers the efficiency of the antenna partially due to its higher dielectric constant of water vapor compared to air and partially because the condensation alters the impedance of the antenna generating a mismatch and thus a decrease of the overall transponder gain. The only practical way to prevent the accumulation of moisture in the antenna over the whole lifetime of the transponder of 15 years is by using a dehumidifying system with pressurized air inside the antenna. This requires additional, external power supplies and depending on the type of air dehumidifier system also a compressors, membrane cartridges or coolant, which would nullify the advantages of a smaller housing and lower weight and most likely demand for a shorter maintenance intervals, too. Additional mounting difficulties may arise from the individually rotary antennas. Due to these reasons a dehumidifying system has not been considered as promising alternative and therefore not investigated further in this paper.

Even though the limitation regarding airtight sealing applies the same for a transponder with the antennas mounted inside the housing, the penetration of water vapor doesn't affect the antennas. Due to the electronics' waste heat, the temperature inside the housing is always higher than the one of the infiltrated water vapor, prevent it from condensing. Secondly, before a critical relative humidity can be reached inside the housing, the water vapor will condensate at the heat exchanger, as this is always the coldest spot.

To decide whether the antennas need to be placed inside the housing or can be mounted outside without causing errors in the order of a tenth of a decibel, measurements are performed.

3 Measurements

3.1 Antenna

The goal of the measurement is to quantify the influence of small amounts of condensed water inside the antennas.

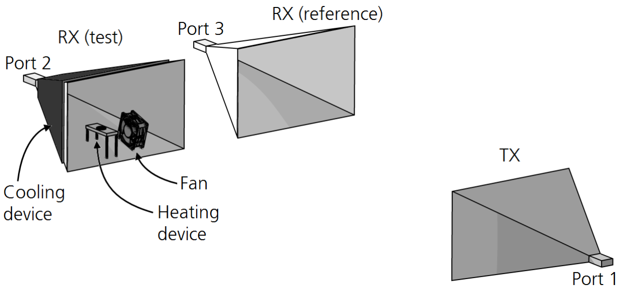

Figure 2: Differential antenna measurement using a common transmit antenna (TX), the antenna to be measured (RX test) and an identical reference antenna (RX reference). Water is vaporized inside the antenna using a power resistor while the antenna is cooled below ambient temperature with a peltier element.

To compensate for the network analyzer's (NWA) drift a differential antenna measurement setup is used as shown in Fig. 2. Due to practical reasons, pyramidal horn antennas are used for the measurement instead of the actual transponder's pottern horn antennas.

To measure the influence of a certain amount of water, a well defined amount is placed inside the test antenna on top of a heating device (i.e. power resistor). After sealing the antenna aperture with a polythene film, the inserted water is vaporized by heating up the resistor. To ensure the water vapor to condensate only at the antenna (instead of the cover sheet or antenna feed), the antenna is cooled down by a few kelvin below ambient temperature using a peltier element attached on the outside of the antenna. After all the water had condensed inside the antenna, the polythene cover, heating device, and fan are removed and both antennas are remeasured. This differential measurement setup greatly reduces any unwanted influences and thus enables an extremely precise measurement of the antenna gain drop as a result of condensed water on the inside of the antenna (Fig. 3).

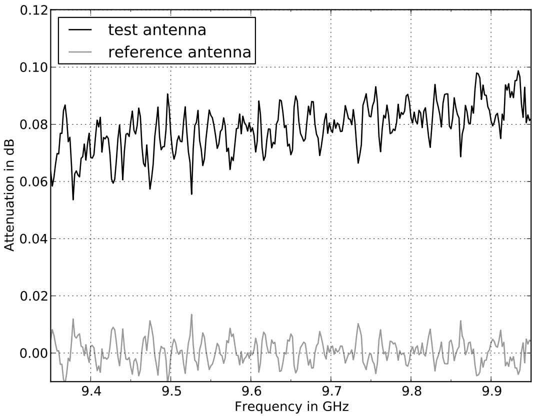

Figure 3: Decrease of the test antenna's gain resulting from 1.2 g of condensed water (—) and the corresponding reference antenna measurement (—).

This measurement is repeated for different amounts of water ranging from 0.2 g to 1.2 g showing a considerable decrease of the one-way antenna gain up to 0.08 dB (Fig. 4).

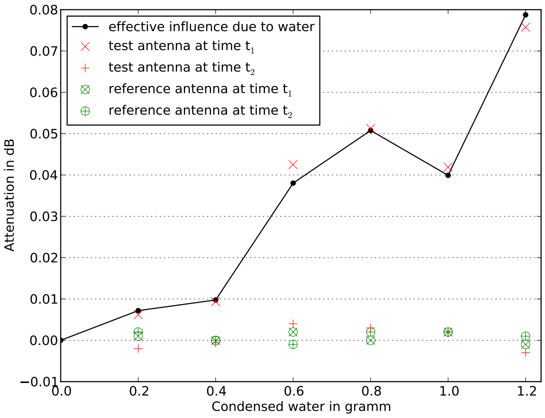

Figure 4: Mean antenna gain between 9.35 ghz and 9.95 ghz due to different amounts of condensed water inside the antenna. t_1 indicates the time when the biggest gain variation of the test antenna occurred, t_2 the time, after all the water of the test antenna has evaporated again.

Based on these results, a transponder with outdoor antennas suffers from total gain variations up to 0.16 dB due to the equal influence on receive and transmit antenna (i.e. two-way antenna gain), hence almost consuming the overall error budget of the transponder of 0.2 dB.

3.2 Waveguide

The error budget of a transponder with outdoor antennas must also account for environmental impacts on the cables / waveguides that feed the antennas. High quality coaxial cable normally show a temperature dependency of around 0.003 dB/(m·K) [5]. Assuming antenna cable lengths of one meter each, and an outside temperature range from -15 °C to +35 °C, already adds up to a variation of 0.3 dB by the cables alone. Alternatively waveguides can be used to feed the antennas. They don't suffer from temperature change, but are – like antennas – susceptible to condensing water.

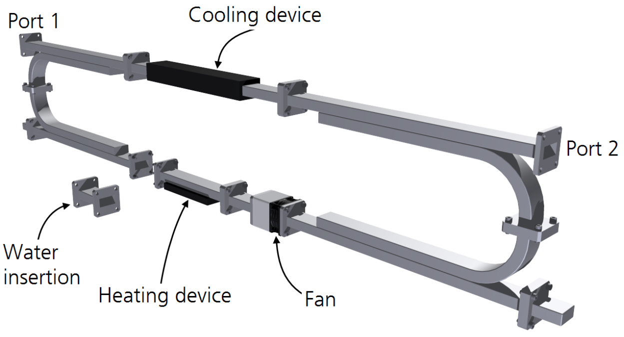

Figure 5: A controlled amount of water is inserted in the lower part of the waveguide. After heating, the water vapor condensates in the top section. Variations of the attenuation between port 1 and port 2 are compared against a reference cable in order to compensate for a possible NWA drift.

Fig. 5 shows the measurements setup for the characterization of the waveguide. Port 1 and port 2 represent the corresponding ports of the network analyzer (NWA), hence the attenuation of the waveguide in between is measured. The lower part of the loop is only used to insert, evaporate, and circulate the water vapor inside the waveguide. Due to the low coupling between lower and upper section, small variations caused during mounting and dismounting for water insertion doesn't significantly affect the measurement. By heating up the lower part of the waveguide while simultaneously cooling down the upper section by a few kelvin, the inserted water will vaporize and eventually condensate inside the cooled waveguide. Fig. 6 shows the effect caused by 0.6 g of condensed water over a length of 15 cm to 20 cm.

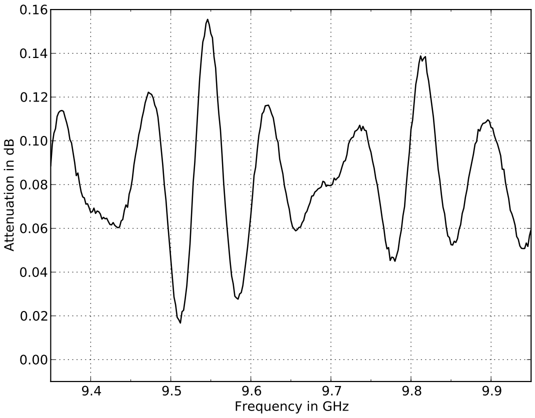

Figure 6: Increased attenuation due to condensed water (0.6 g) within 15 cm to 20 cm.

Fig. 7 shows the influence for different amounts of condensed water on a waveguide's attenuation. Due to the roughly linear dependency between the amount of water and the resulting degradation in dB, the length has no influence. Hence, by using a waveguide of twice the length, the resulting degradation from the same amount of moisture is only half as big per unit length, but is equalized again due to the doubled length.

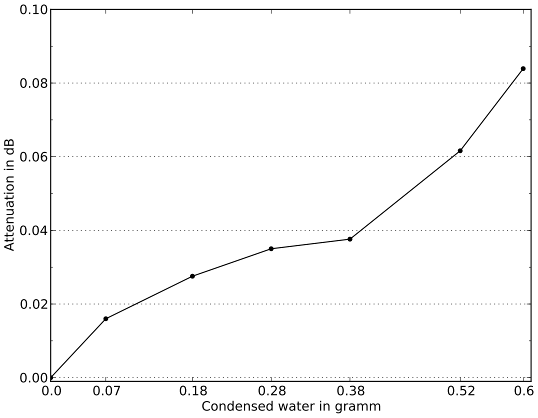

Figure 7: Mean increase of waveguide's attenuation between 9.35 ghz and 9.95 ghz due to different amounts of condensed water.

Based on these measurements, serious degradation of the transponder's stability (> 0.1 dB) can already occur for amounts of water in the waveguides as low as 0.45 g, due to the equal influence on the receive and transmit antenna gain. This equals for example the amount of water stored in 0.01 m^3 saturated air at 38 °C, which is likely to penetrate the antenna over several years.

4 Conclusion

An important design choice is whether to operate the antennas in a hermetically sealed and thermally controlled environment or outdoor. While the first approach has mechanical drawbacks due to the larger size of the housing, in the latter case the antennas and their feeding cables / waveguides are exposed to all kind of environmental and climatic influences over the years. Even though for traditional transponders with accuracies in the order of 1 dB these influences can be ignored, they start to count for new transponder generations with accuracies in the order of a tenth of a decibel and may jeopardize the desired accuracy goal if not taken into account.

Therefore, the influence of condensation inside a pyramidal horn antenna has been measured for different amounts of water. Due to the required measurement sensitivity below 0.01 dB, a differential measurement setup has been used. In a further step the environmental influences on coaxial cables and waveguides has been analyzed. While coaxial cables are not suitable to feed outdoor antennas due to their inherent temperature dependency, waveguides suffer from condensing water. Finally it has been shown, that even small amounts of water below 0.5 g render a transponder useless as high precision calibration target due to the high influence of the transponder's RCS by a factor of two. Resulting from these measurements, the antennas of a high precision transponder should be mounted inside the temperature controlled and sealed housing together with the other rf components.

References

[1] B. Döring, P. Looser, M. Jirousek, M. Schwerdt, M. Peichl: *Highly Accurate Calibration Target for Multiple Mode SAR Systems*, Proceedings of the European Conference on Synthetic Aperture Radar (EUSAR), Aachen, Germany, 2010.

[2] M. Schwerdt, B. Bräutigam, M. Bachmann, Döring, D. Schrank, J. H. Gonzales: *Final TerraSAR-X Calibration Results Based on Novel Efficient Calibration Methods*, IEEE Transactions on Geoscience and Remote Sensing, vol. 48, no. 2, pp. 677–689, February 2010.

[3] R.Lenz: *Hochpräzise, kalibrierte Transponder und Bodenempfänger für satellitengestützte SAR-Missionen*, Ph.D. dissertation, Institut für Hochfrequenztechnik und Elektronik (IHE), Universität Karlsruhe, 2007.

[4] H.D.Jackson and A.Woode: *Development of the ERS-1 active radar calibration unit*, IEEE Transactions on Microwave Theory and Techniques, vol. 40, no.6, 1992.

[5] P. Looser: *HF-Design eines Transponders zur Kalibrierung satellitengestützter SAR-Systeme*, Master Thesis, DLR, 2010.