Innovative Antenna Concepts for DLR's Fully Polarimetric Low-Frequency Transponders

Klaus Weidenhaupt, German Aerospace Center (DLR), klaus.weidenhaupt@dlr.de, Germany
Sebastian Raab, German Aerospace Center (DLR), sebastian.raab@dlr.de, Germany
Daniel Rudolf, German Aerospace Center (DLR), daniel.rudolf@dlr.de, Germany
Marco Schwerdt, German Aerospace Center (DLR), marco.schwerdt@dlr.de, Germany

Abstract

With the *Kalibri* project [1], DLR has designed, manufactured and operated transponder systems tailored to the in-orbit calibration of modern spaceborne SAR systems. With upcoming SAR instruments, low frequencies (L and P-band), high bandwidths and fully polarimetric acquisitions come into play and introduce new challenges to the design of calibration transponders. We introduce DLR's recently launched *Kalibri Next Generation* project and its transponder concepts aiming at future missions. Furthermore, the development of dual-polarization and low-frequency antenna concepts for calibration transponders and the application of innovative antenna manufacturing techniques is presented.

1 Introduction

Since more than 25 years, DLR has been conducting the calibration of spaceborne SAR systems. For this purpose, DLR has established the DLR SAR calibration center composed of a large number of reference targets as well as analysis and evaluation tools. Recently, DLR's novel generation of C-band transponders called *Kalibri* were used for independent system calibration of ESA's Sentinel-1A [2] and Sentinel-1B satellites [3] in the framework of the European Copernicus program. Their remote-controlled operation permits regular short-interval calibration measurements as currently performed within the scope of routine operation support of Sentinel-1.
Besides innovative reference targets, DLR develops new calibration strategies with focus on complex systems such as Tandem-L [4], which foresees multiple acquisition modes and beamforming techniques. An advantage is thus that hardware development can be adapted to calibration strategies and vice versa.

2 Next Generation Calibration Transponders

Towards future SAR missions DLR has identified the following additional key aspects of new calibration hardware, all of which are covered within the 'Kalibri Next Generation' project.

1. Support of **low frequencies**, that is L-band aiming at the Tandem-L mission [5] and P-band for Biomass [6].
2. Processing of **high bandwidths** up to 1.2 GHz as envisaged by HRWS [7] at X-band.
3. **Fully polarimetric** capabilities as foreseen by Tandem-L and Biomass.

Besides these additional demands, DLR's next generation transponder systems will inherit the successful concept of the *Kalibri* C-band transponders. The photograph of Fig. 1 shows the latest stage of development of these systems which have been installed at sites of the Canadian Space Agency (CSA) to support the Radarsat Constellation Mission [8].

Figure 1: DLR's C-band transponder system consisting of an indoor unit (left) and the fully remote controllable outdoor unit (right) developed for the Canadian Radarsat Constellation Mission (RCM).

The transponder is part of an outdoor unit which is designed for all-season autonomous outdoor operation. It is remotely aligned towards the satellite by a two-axis positioner. An indoor unit hosts the power electronics and the main control computer.
The transponder's transmit and receive antennas are embedded in a temperature stabilized housing together with the HF analog circuit. The superior radiometric stability of below 0.1 dB is maintained by an internal calibration loop. An FPGA-based sub-system allows for a digital recording of radar chirps. The configuration of satellite overpasses and the corresponding data acquisitions are conducted in an automated fashion and can be conveniently scheduled and monitored by a web interface.
Towards upcoming missions, this concept will be adapted to X, L and P-band frequencies and enhanced by dual-polarization capabilities to allow for fully polarimetric measurements. This requires new antenna concepts which are currently being investigated by DLR.

3 Antenna Concept

Antennas suitable for SAR calibration transponders have to fulfill a multitude of electrical and environmental demands. The most important ones have been identified as:

- Relatively broad main lobe region maintaining an axial symmetry and stable gain over the desired bandwidth
- Low side lobe ratio
- High cross-polarization isolation (XPI)
- Dual-polarization capabilities
- Compact and lightweight design
- Robust structure for long term all-season operation

Main challenge is the unification of the above electric demands with a compact design suitable for DLR's remote controlled transponder concept. Extensive in-house R&D resulted in an innovative antenna design based on a chocked Gaussian horn antenna which was named *VeGA* (German for *Verkürzte Gauß Antenne*).

3.1 The *VeGA* Antenna

The design of the *VeGA* antenna depicted in Fig. 2 features 3 functional sections. The lower section constitutes a planar Orthomode Transducer (OMT), basically a circular waveguide with four metallic probes arranged on a thin dielectric disc. Opposite probes are fed with waves having a 180° phase shift to predominantly produce a TE_{11} mode. A stepped cylindrical tuning stub improves matching and expands the operational bandwidth. The middle section has vertical corrugations and acts as a mode converter to transform from TE_{11} mode to a HE_{11} hybrid mode. The upper 'flare' section with its Gaussian curvature and horizontal corrugations couples the hybrid mode into free space. The entire antenna including the dual-feed has a total length of 3 λ (76 cm at L-band) only.
Simulations of the *VeGA* (see Fig. 2) predict a smooth gain pattern with nominal gain of about 15 dBi while maintaining a cross-polarization isolation of better than 30 dB.

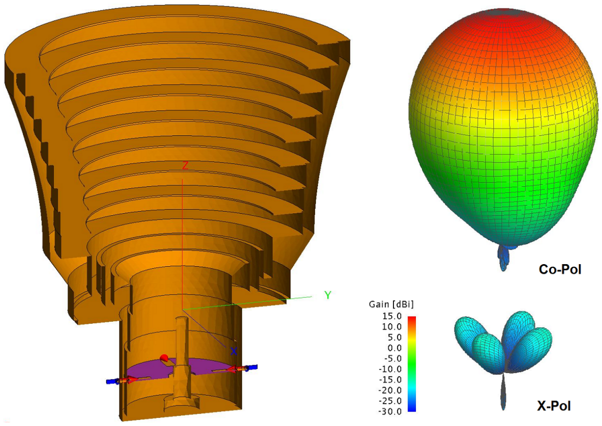

Figure 2: Cross section of the *VeGA* antenna and simulated gain pattern for co and cross-polarization.

3.2 The *VeGA* Orthomode Transducer

The TE_{11} mode generated by the OMT evolves from the superposition of two waves coupled into opposite feed probes of the OMT. For the nominal operation of the OMT, these waves are required to have an equal amplitude and a phase offset of exactly 180°. This configuration is realized by means of hybrid couplers, passive microwave components which split the feed RF signal into two signals of half power and introduce the desired phase shift at the same time. However, even high precision narrow-band hybrid couplers introduce a certain amplitude and phase imbalance between the two output channels which potentially 'detune' the feeding of the OMT. To study the impact of such a detuned feeding on the antenna performance, three different feed configurations have been simulated:

- Nominal configuration: waves of equal magnitude and 0° and 180° phase, respectively, are coupled into opposite feed patches.
- 10° phase offset configuration: waves of equal magnitude and 0° and 170° phase, respectively, are coupled into opposite feed patches.
- 20% magnitude offset configuration: waves of 20% difference in magnitude and 0° and 180° phase, respectively, are coupled into opposite feed patches.

The co-polar and cross-polar gains resulting from these configurations are compared in Fig. 3 and Fig. 4. For the co-polar gain, the effect of the detuning manifests as an asymmetry in theta and a slight reduction of the gain. Focusing on the main lobe region between $-15°$ and $15°$,

which is of primary interest for the application in calibration transponders, a maximum deviation of 0.12 dB is observed. For the Cross-polar component, a similar asymmetry is visible.
The simulations thus predict that the *VeGA* is sensitive to a detuning of the feeding of the OMT. However, the simulated offsets have been chosen rather large to emphasize the detuning effect. The actually used hybrid couplers have a maximum phase imbalance of $\pm 2°$ and an maximum amplitude imbalance of ± 0.2 dB. To further reduce the phase imbalance, passive phase trimmers are employed to the feed network during measurements and operation of the *VeGA*.

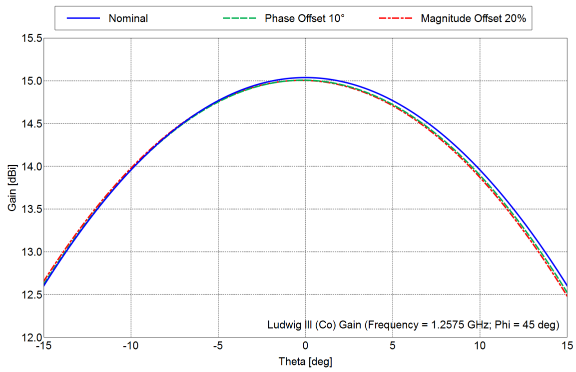

Figure 3: Influence of a detuned feed of the *VeGA* to the co-polarization gain in the main lobe region. See text for details of the different feed configurations.

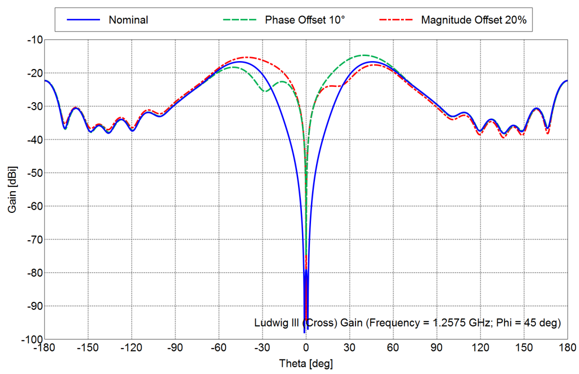

Figure 4: Influence of a detuned feed of the *VeGA* to the cross-polarization gain. See text for details of the different feed configurations.

3.3 Innovative Antenna Manufacturing Techniques

When aiming at a compact transponder design where the antennas can be aligned towards the satellite, the antenna weight becomes an important factor already at L-band frequencies. To realize a mobile P-band antenna, even when exploiting the compact *VeGA* design, becomes a challenge in terms of engineering. Modern, weight optimized manufacturing techniques are thus investigated by DLR besides the conventional design using aluminum. Most promising is the use of composite techniques (glass and carbon fiber) and 3D-printing techniques. A composite/aluminum hybrid approach of the L-band *VeGA* is currently under construction as well as a conventional aluminum version. A 3D-printed *VeGA* at L-band was already build and first measurements are discussed below. A detailed performance benchmark of all three versions (3D-printed, composite and aluminum) of the *VeGA*, utilizing DLR's antenna compact test range is scheduled for summer 2018.

3.4 Performance of 3D-printed *VeGA*

To examine the potential of additive 3D-printing techniques, the L-band *VeGA* antenna was printed out of plastic using an industrial 3D printer. Due to the size limitations of the 3D printer, the antenna is assembled out of multiple segments. A stiff structure and significant weight reduction compared to conventional aluminum design is mainly achieved by the integration of cavities. The conductivity of the antenna surface is realized with a conductive carbon based paint. The electrical performance was measured in DLR's Compact Test Range (CTR). A photograph of the printed *VeGA* during the measurement is presented in Fig. 5.

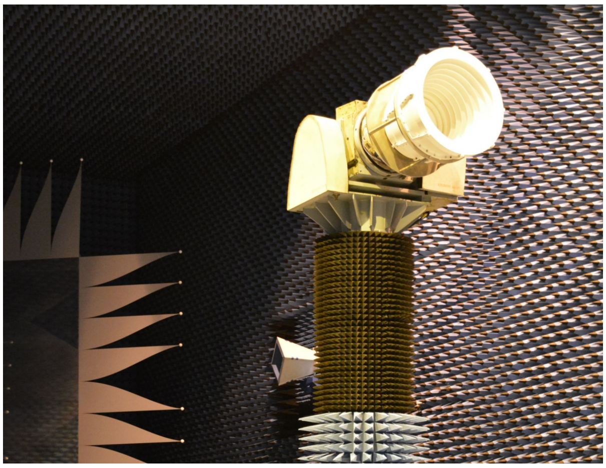

Figure 5: Printed *VeGA* antenna mounted on a positioner in DLR's compact test range.

The measured gain in comparison to simulations is summarized in Fig. 6. The main performance requirements for an application in DLR's calibration transponders are met with the printed version of the *VeGA*. That is, the main lobe region shows the smooth shape predicted by the simulations and a cross-polarization isolation of better than 30 dB is observed. This accounts for both channels of the dual-feed antenna. However, a significant gain reduction of about 4.4 dBi compared to the simulations is measured which can be mainly attributed to losses within the antenna structure. The exact cause is currently under investigation.
The manufacturing technique most suitable for our

transponder applications will be determined in a detailed comparison of the 3D-printed version with a composite as well as an aluminum version of the *VeGA* of identical geometry.

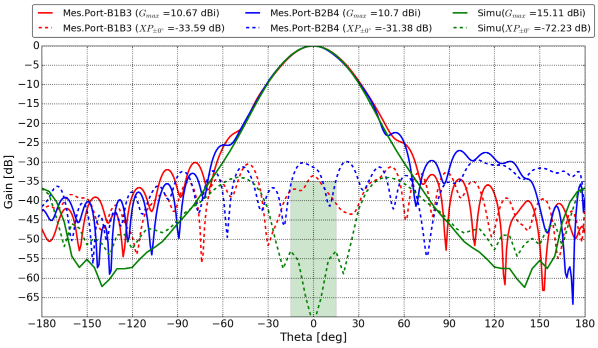

Figure 6: Measured and simulated gain of the printed *VeGA* antenna as a function of the θ angle (vertical plane), normalized to the maximum gain. Solid lines denote the co-polarization component, dashed lines the cross-polarization. For the measurements, the results from both orthogonal channels (Port-B1B3 and Port-B2B4) of the antenna are shown. From [9].

4 Conclusions

With the *Kalibri Next Generation* project, DLR has already launched the development of transponder systems for the calibration of future SAR missions. The main challenges such as low frequency support, high bandwidths and fully polarimetric systems have been identified and hardware solutions are being developed.
The design of antennas for calibration transponders becomes demanding especially due to the vast dimensions at L and P-band frequencies. With the VeGA antenna, a compact antenna design has been developed and optimized by means of detailed simulations. With regard to weight reduction and long term use, innovative manufacturing techniques such as 3D-printing and composite techniques are currently being probed. First measurements with a 3D-printed dual-polarized antenna yield promising performance results and their optimization is ongoing.

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