DLR's Dual-Polarized Offset Reflector Antenna with Digital Feed Array for Synthetic Aperture Radar

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***Abstract*—The German Aerospace Center (DLR) is currently developing a ground-based Synthetic Aperture Radar (SAR) with digital beamforming (DBF) capabilities for versatile scientific use. Primary focus of the project is on the reflector antenna and on the implementation of onboard DBF pre-processing concepts & data reduction in real-time. This paper describes the innovative contributions and challenges during the X-band offset reflector antenna design with 4x32 dual-polarized feed elements at a center frequency of 9.6 GHz.**

Keywords—synthetic aperture radar, offset reflector antenna, patch excited cup, digital beam-forming

I. Project's Purpose and Scientific Challenges

Under the framework of DLR's scientific contributions to environmental monitoring for climate research, there is stronger need for SAR in lower frequency bands with greater flexibility than state-of-the-art systems. Especially the L-band at approx. 1.2 GHz promises deeper knowledge of environmental parameters, like soil moisture, biomass classification, glacier melting processes, and many more. Based on proposals and contributions for L-band spaceborne SAR missions, like Tandem L [1], NISAR [2], ROSE-L [3], or Sentinel-1 NG, the Microwaves and Radar Institute of DLR is currently developing a ground-based experimental SAR. Since the structures become very large at these wavelengths, the system is scaled to X-band at 9.6 GHz for more convenient use on ground.

Main characteristics of the new SAR system are:

- Real-time processing capabilities
- 32 digital channels
- Dual-polarization
- RF-frequency: 9.6 GHz
- IF-frequency: 1.2 GHz
- IF-bandwidth: >80 MHz
- Integrated hardware design
- Offset reflector antenna with DBF

This radar is designed for versatile scientific use to verify the measurement possibilities of environmental parameters on the one hand side, and to verify advanced digital signal processing and the use of a DBF reflector antenna in SAR on the other side. For example, the Scan-On-Receive (SCORE) technique with a reflector antenna shall be investigated [4]. With respect to the typical side-looking geometry of a SAR, the radar echo is received with a certain relation between time-of-arrival and angle-of-arrival. Based on this known correlation, the highly focused frequency-variant receive antenna beam is steered in real-time to follow the radar echo signal on ground. This requires an adaptive partial illumination of the reflector and a high computational power.

While this paper concentrates on the antenna concept, we only briefly describe the overall system concept: The pulsed transmitter consists of two transmit channels (one for each polarization) at a center frequency of 9.6 GHz. The transmit power can be adjusted flexibly within the range of 0 dBm – 50 dBm and for signal generation an arbitrary waveform generator with 300 MHz bandwidth is used. Standard gain horn antennas serve as transmit antennas. On receive, the reflector antenna receives the backscattered radar signal with its 4x32 dual-polarized feed elements. Each DBF channel combines 4 azimuth elements with an analogue microstrip power combiner. The remaining 32 elevation channels pass an LNA- and down-conversion unit from 9.6 GHz to 1.2 GHz. The 32 L-band IF signals are then directly sampled and pass a data reduction unit for real-time processing for DBF. Initially, the full system is characterized in an anechoic chamber. Later, to conduct true SAR measurements in the field, the system is mounted in 7 m height on a motorized wagon driving along rails. In the following, we describe the receive antenna system in detail.

II. Antenna System

The receive antenna system consists of three major parts: reflector & boom, antenna feed array with 4x32 dual-polarized elements, and 2x32 azimuth power combiners, which implement a fixed analog beamforming of the four azimuth channels per polarization (cf. Fig. 1). The whole antenna was designed and optimized in a stepwise approach via a hybrid simulation setup consisting of IE and FEM solver in ANSYS HFSS. In view of the large differences in size, the reflector and the boom were solved via IE solver. The setups of the feed array and azimuth power combiner in microstrip technology were set up via the FEM method.

A. *Reflector Antenna & Boom*

The elliptically-shaped offset reflector antenna has a diameter of approx. 1.7 m and a focal length of 1.8 m leading to a maximum gain of 38 dBi (cf. Fig. 2). Via the digital feed array it allows scanning in elevation within a range of -9.2° to +8.4° from boresight. While in a spaceborne scenario a deployable reflector will be used, in this ground-based hardware a solid type manufactured out of carbon fiber with conductive surface treatment is used.

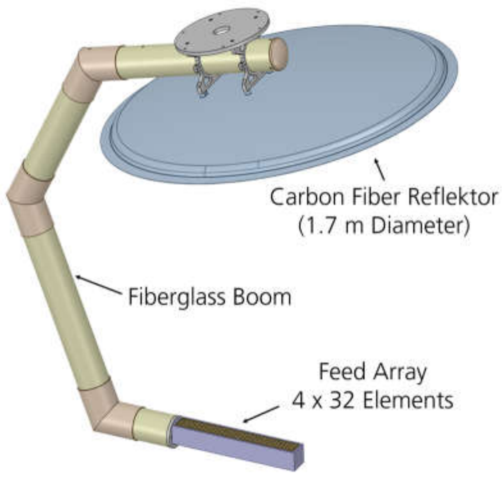

Fig. 1: Full Assembly of the offset reflector antenna.

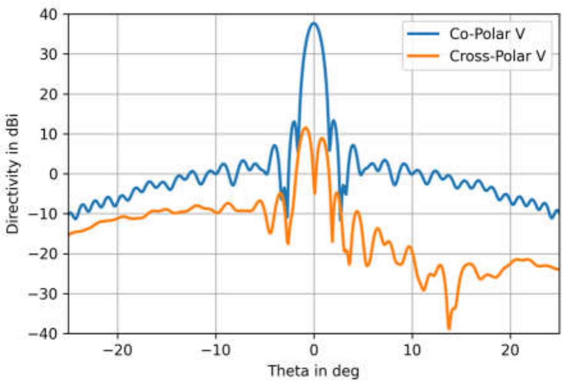

Fig. 2: Simulated antenna pattern (main cut, reflector far-field) in azimuth co- and cross-polar.

For the underlying measurement scenarios an absolute pointing accuracy is not of high importance since the full setup can be adjusted and will be calibrated properly. However, with respect to the relatively narrow half-power beam-width of 0.7°, during a measurement series the antenna pointing must be stable. Therefore, a stress analysis was conducted during the engineering phase of the reflector and boom. Especially the mounting case in the anechoic chamber for antenna measurements led to the most critical cases. For the antenna pattern characterization, the whole antenna, including the 15 kg feed array, is rotated over the full hemisphere. Occurring deformations during the measurement due to gravity would lead to a wrong adjustment of the beam-forming weights and, in turn, to mis-pointing effects and errors in null-steering techniques. The preceding stress analysis led to a special sandwich structure of the carbon fiber for the reflector, and resulted in a glass fiber tube for the boom. This guarantees a dynamic deformation of less than 0.4 mm at the outer tips of the system and to an absolute manufacturing accuracy of less than 5 mm.

The reflector and the boom are finalized in hardware and are currently waiting for integration.

B. *Feed Array & Single Antenna Element*

A significant new contribution is the feed antenna array consisting of Patch Exited Cup (PEC) antennas (pending patent). This special antenna type is space applicable and consists of a resonator (cup) with two circular plates as radiator within the cup (cf. Figs. 3, 4). The metallic cup provides a quite high isolation to neighboring elements of

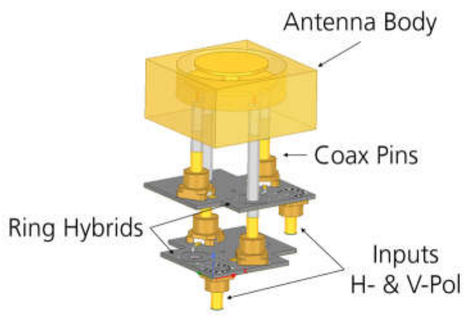

Fig. 3: CAD drawing of the PEC antenna element, showing the element body, feeding pins and the two ring hybrids for symmetrical feeding.

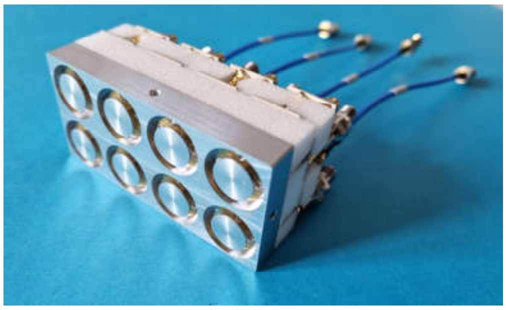

Fig. 4: Photo of the PEC element prototype array consisting of 4x2 elements.

approx. 30 dB at an element size of only 0.6 λ (2.0 cm). Two ring hybrids are arranged in two individual layers with half-wavelength separation (one for each polarization) at the backside of the antenna in order to feed both polarizations of the antenna symmetrically. This innovative feeding concept provides symmetrical and identical pattern in the E- and H-plane of 70° HPBW. According to the FEM simulation results, a cross-polar suppression within the main-lobe of better than 32 dB could be achieved.

The final feed array consists of 4x32 PEC antenna elements which are supported by an aluminum frame. At the current status the pre-series elements are measured with promising results and the series manufacturing has been started.

C. *Azimuth Power Combiner*

It is known that an offset reflector antenna shows typically a poor cross-pol performance [5]. In the underlying case, the cross-pol level of the far-field secondary pattern are 23 dB. This result is absolutely sufficient for the first and all foreseen tests can be done, but we are looking for ways for improvement. Thus, in a later development step, cross-pol cancellation feeding networks are designed, which couple out a part of the parasitical polarization and feed the energy inversely into the intended polarization to achieve a compensation. A first prototype of this network already exists and led to an improved cross-pol level by ~10 dB [6].

In this initial development step, we use an uncompensated power combiner solution to reduce any risks. Each four elements in azimuth direction are combined via analogue beam-forming. This is done for each polarization state individually. The weight coefficients were obtained via the MVDR algorithm [7] based on the simulated secondary pattern to optimize the gain in the azimuthal center direction.

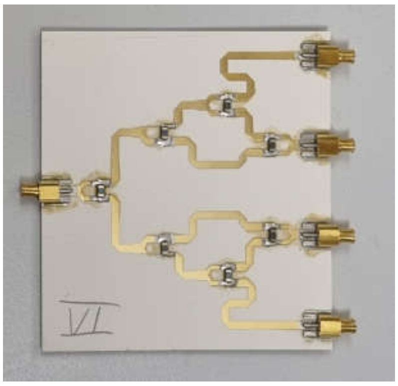

Fig. 5: Photo of one azimuth power combiner consisting of cascaded Wilkinson power combiners (division ratio: 6.7 dB).

Theoretically, for each row an individual set of weights is required, since the individual reflector illumination differs. But due to the robustness of the design, margins of 1.5 dB in amplitude and 22° in phase can be tolerated without visible changes in performance. Based on this knowledge six power combiners with slightly different weights but of same type and structure have been designed (cf. Fig. 5).

With amplitude weights ranging between 4.5 dB and 7.7 dB, it is not possible to use a power divider or a coupler directly. Thus, a cascaded design of Wilkinson power divider with three stages was chosen. The microstrip PCBs are plugged via SMP connectors to the PEC elements.

All azimuth power combiner developments are finalized and the hardware is already manufactured.

III. Outlook

Besides the series production of the PEC antenna elements, all main components are finished and prepared for integration. After the full assembly the measurements in the Institutes anechoic chamber (CTR) [8] with deep analysis and comparison to the simulations will be performed. Then, the receive antenna system is integrated in the full radar setup for further characterizations and first SAR measurements.

As previously mentioned, at later point of time, the current configuration of azimuth power combiner will be replaced by cross-pol compensation networks to improve the cross-pol level. Also studies on deformed reflectors shall follow and the frequency selective and time-variant DBF algorithms shall be optimized.

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