First Interferometric Trials with the Airborne Digital-Beamforming DBFSAR System

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Abstract

The Microwaves and Radar Institute of the German Aerospace Center (DLR) is known for its consistent work on the field of airborne Synthetic Aperture Radar and its application. Currently, the Institute is developing a new advanced airborne SAR system, the DBFSAR, which is planned to supplement its operational F-SAR system in near future. The development of DBFSAR was triggered by the various evolving digital beamforming (DBF) techniques for future space-borne SAR systems and the need for an airborne experimental platform for preparation of such missions. Additionally, there is a demand for very high resolution SAR imagery, which cannot anymore be fully satisfied with the existing F-SAR system. This paper should give an overview over the current status and performance of the DBFSAR system, including interferometirc results from test flights performed in spring 2017.

1 Introduction

One challenge for future spaceborne SAR systems is to optimise the performance/cost ratio as much as possible so that large-scale imaging with fast repeat intervals becomes possible. This requires innovative concepts with bistatic and multistatic system configurations. Digital beamforming for transmit and/or receive will solve the contradiction posed by the antenna size in traditional SAR systems that prohibits the SAR sensor from having high azimuth resolution and a large swath width at the same time. Digital beamforming is therefore a key technology for future systems, allowing enormous flexibility in the sensor imaging mode, sensor calibration, interference removal and ambiguity suppression [2, 4, 5].
Airborne SAR sensors with digital beamforming capabilities are important tools to prepare such missions [3]. They allow to research the key aspects of digital beamforming and to establish the necessary technology for later implementation on a satellite. Because of that, DLR's Microwaves and Radar Institute initiated in 2014 the development of a DBF extension of its airborne F-SAR sensor [1], the so-called DBFSAR. The system's maiden flight was successfully performed in autumn 2016, followed by some interferometric trials in spring 2017. In the following, sensor details and the first experimental results are presented.

2 DBFSAR instrument design

The DBFSAR system comprises of three main components:

- Digital subsystem: the digital backend includes data sampling and recording for 12 receive channels with 2 GHz bandwidth each, as well as the complete system control and a user console for the flight operator.
- X-band subsystem: the frontend contains all RF components, including the X-band high power amplifier. It features 12 simultaneous receive and 4 sequential transmit channels.
- DBF antennas: the antenna configuration consists of a dedicated antenna carrier, carrying 4 single-pol X-band transmit antennas, aligned in H and V direction forming wide or narrow beams, and 12 receive antennas, which can be arranged in various configurations.

2.1 The digital subsystem

In the digital rack, all components for the central system control and in-flight operations are integrated. This includes the radar display, the navigation display, the console, and the components for 12-channel data acquisition and on-board real-time processing. System control and data acquisition units are designed in a way, that they can drive both the new digital-beamforming X-band subsystem of DBFSAR (using Ethernet), and the existing older F-SAR RF racks (using CAN bus). The data acquisition unit (DR2 in Fig. 1) possesses 12 analogue-digital converters (ADC) with 4 GHz and 8 bits and integrated FPGA for data pre-processing. For real-time processing, the data stream of all ADC can be connected to 3 high-performance CPUs. The radar control unit (DR5 in Fig. 1) is responsible for driving and monitoring the radar operations. It includes a 20″ flight-certified display and rugged keyboard. The control computer uses Linux as operating system and runs either a new DBFSAR control software, or an adapted version of the FSAR control software. On its 10 GbE Ethernet interface, an additional GPU module can be connected for en-

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hanced real-time processing (not realised at the moment).

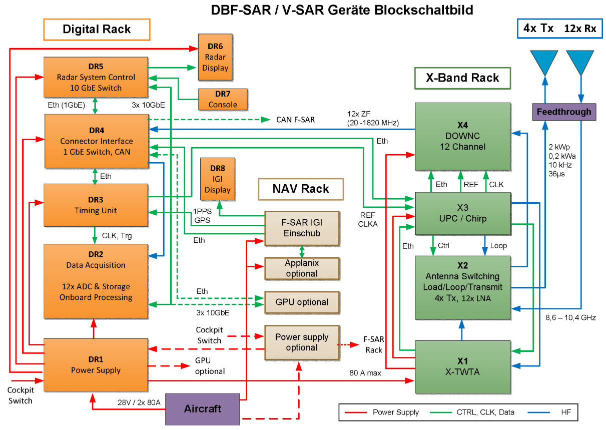

Figure 1: Block diagram of DBFSAR's digital and X-band subsystems.

2.2 The X-band subsystem

In the X-band front-end, transmitter, signal generation and the 12-channel receiver of the radar are integrated. The transmit-/receiver frequency range lies between 8.6 and 10.4 GHz, the pulse modulation is freely programmable.The X-band subsystem can be connected to 12 receive and 4 transmit antennas, where the first are operated simultaneously and the latter sequentially. As high-power amplifier (X1 in Fig. 1), an air-cooled wide-band travelling wave tube (TWTA) is used, allowing for transmit powers of around 2 kW peak with a maximum duty cycle of 12%. The antenna switching matrix (X2 in Fig. 1) is a high-power transmit matrix in wave-guide technology with 12 integrated LNAs and bandpass filters on receive side. Via a coupler, fast switches and a power divider, each LNA input can be connected to a calibration signal. The chirp generator is an arbitrary waveform generator (AWG), which is capable of generating transmit signals of up to 1.8 GHz bandwidth. The waveform is freely programmable up to a maximum duration of 250 ms.

2.3 The DBF antenna configuration

The DBFSAR antenna system consists of four single polar transmit horn antennas, which are designed for high average power (10% duty cycle), and 12 DBF receive antennas in microstrip-patch technology. Important general design parameters are 2 GHz bandwidth at 9.5 GHz center frequency. On transmit side, the 3 dB beamwidth lies around 30 deg in both azimuth and elevation; an alternative pair of antennas is foreseen to generate a narrower beam with 16 deg beamwidth. On receive side, base DBF modules containing 1x4 individual patches are used, denoted as DBFRAM (DBF Receive Antenna Modules). They feature high efficiency (>75%) and constant amplitude and phase tapering for minimising noise figures. A flexible antenna backplane allows various combinations of DBFRAM modules (see Fig. 3) in along-track, across-track or a mix of both of them.

Figure 2: DBFSAR mounted in the cabin of DLR's Do228 aircraft: digital backend in the back, RF frontend in the front and X-band wave-guide connections on the very right of the image.

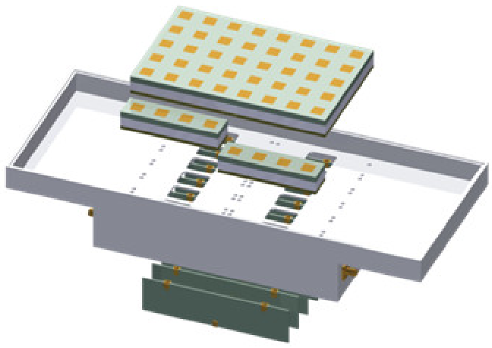

Figure 3: Schematic representation of the DBFSAR antenna backplane, constructed to realise various DBF configurations out of a large number of DBFRAM modules.

3 Test flight & calibration results

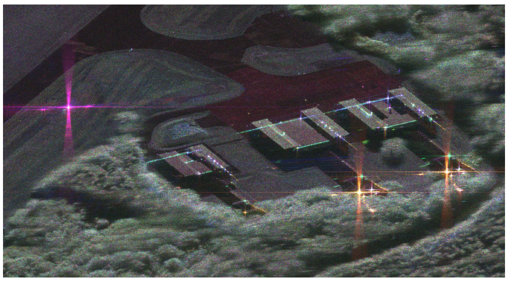

Figure 4: Zoom into the first DBFSAR image to illustrate the high resolution capabilities. HH=blue, VV=red, HV=green.

The maiden flight of the DBFSAR system took place on November 29th, 2016 over the calibration test-site Kaufbeuren in southern Germany. This test-site is perma-

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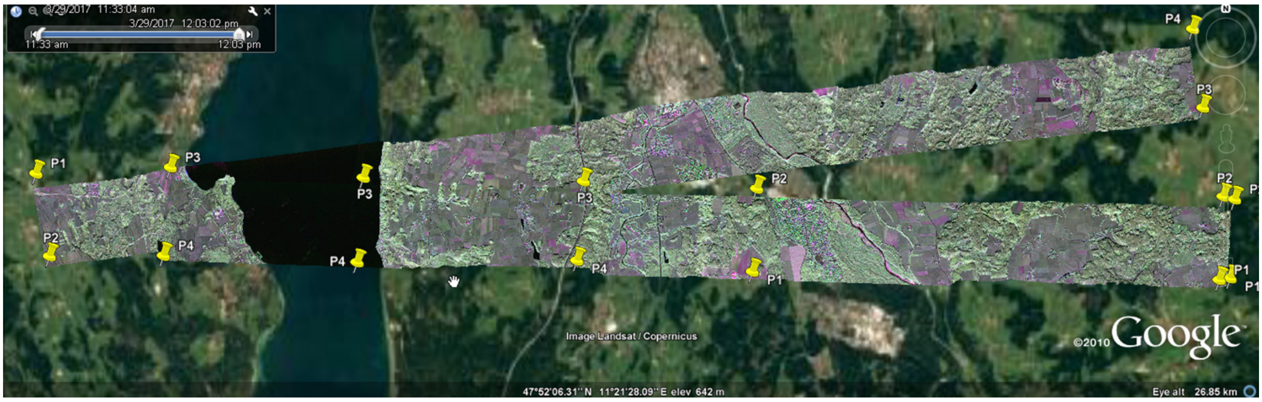

Figure 5: DBFSAR images, testsite Starnberg lake / Germany, geocoded polarimetric data.

nently equipped with an array of trihedral corner reflectors for calibration purposes. As mentioned above, at the time of the flights the DBFSAR antenna carrier was not yet available. Therefore, for all flight tests the existing F-SAR antenna carrier together with the existing F-SAR antennas have been used. This implied a number of limitations with respect to the full potential of DBFSAR:

- Only three F-SAR antennas have been mounted in an interferometric XTI configuration. Consequently, no DBF modes have been tested yet. However, all antennas are dual-pol, so that simultaneous reception on 6 channels could be demonstrated.
- The F-SAR X-band antennas are designed for 300 MHz bandwidth only. They have been, however, successfully used with 760 MHz bandwidth in the past. For this experiment it has been decided to limit the bandwidth to 800 MHz in order in order to ensure a satisfactory SNR and image quality.

The first flights were completed very successfully and raw data in various modes were collected and processed. Fig. 4 shows a zoom into the area, containing a trihedral corner reflector in the left and several strong target echoes in the right of the image. No spectral weighting has been applied in this case to reach maximum resolution.
Further flights, this time including interferometric XTI / ATI configuration were performed in April 2017. Fig. 5 shows an overview of the test-site of Starnberg lake / Germany. Several image strips were successfully processed and geo-coded. Fig. 6 shows the differential XTI phase relative to the TanDEM-X DEM. Basically, no significant trends can be observed, except some edge effects due to the much higher spatial resolution of the DBFSAR images. Fig. 7 again shows interferometric results, this time over the calibration site of Kaufbeuren, Germany. The differential XTI phase is this time calculated relative to a airborne laser scanning (ALS) DEM. In forested areas, the ALS DEM corresponds to ground level, while the DBFSAR inherently measures the canopy level. This explains the rather large phase differences in these areas. Apart from that, no dominant phase trends are visible, both in XTI and ATI phase, demonstrating the excellent phase calibration of the system.

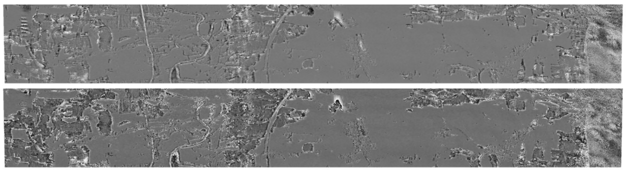

Figure 6: DBFSAR XTI mode. Top: differential phase, half-baseline mode, VV. Bottom: differential phase, full-baseline mode, HH.

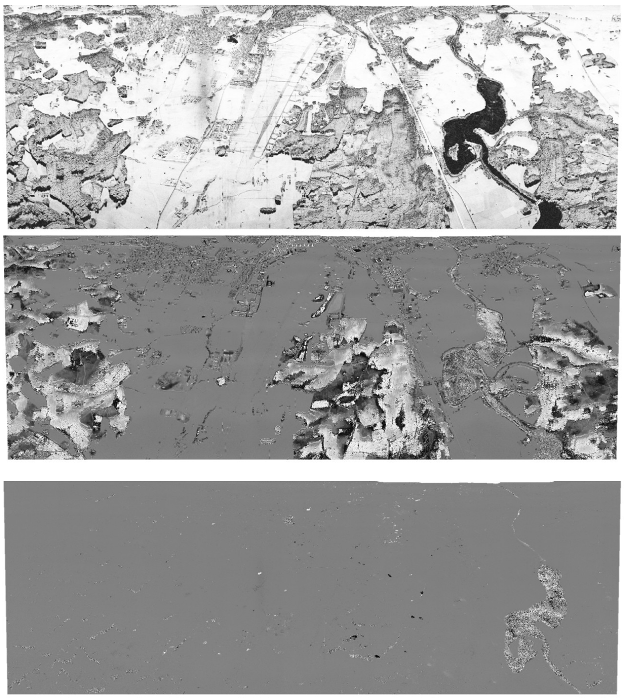

Figure 7: Top: DBFSAR XTI full-baseline mode, interferometric coherence. Middle: DBFSAR XTI full-baseline mode, residual phase relative to ALS DEM. Bottom: DBFSAR ATI half-baseline mode, differential phase.

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4 Conclusion & Outlook

Digital beamforming is a key technology for future satellite missions, as they allow to circumvent the limitation of traditional SAR systems not being able to have high azimuth resolution and a large swath width at the same time. Airborne SAR sensors with digital beamforming capabilities are essential tools to prepare such missions, as they allow to experimentally establish the necessary technology for later implementation on a satellite.
The newly developed DBFSAR system will help prospering research in the area of digital beamforming SAR. The system has now successfully conducted its maiden flight and showed an excellent performance during its very first data takes. Further development will concentrate on adding the final digital beamforming antennas and another dedicated antenna for ground moving target indication (GMTI) and situation monitoring.

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