Current status of DLR's new F-SAR sensor.

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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 F-SAR, which is planned to fully replace the older E-SAR system in the next years. The development of F-SAR was triggered by the demand for data being simultaneously acquired at different wavelengths and polarisations as well as by the demand for very high range resolution, which could not anymore be fulfilled in all cases by the E-SAR. Currently, even though the system is still under heavy development, parts of the instrument are reaching a pre-operational stage. This paper should give an overview over the current status and performance of the system, including results from various flight campaigns during the last couple of months. In particular, this paper focuses on the newly integrated real-time processing unit for SAR and GMTI modes and F-SAR's real-time down-link capabilities over a laser transmission line. Additionally, new results of X-band step-frequency mode with 750MHz chirp bandwidth will be shown.

1 DLR's new airborne SAR

1.1 General system design features

F-SAR is currently designed to operate in X-, C-, S-, L- and P-bands with

- simultaneous full polarimetry at all wavelengths
- simultaneous data acquisition in up to 4 wavelengths (multispectral SAR)
- single-pass polarimetric interferometric capability (XTI) in X- and S-band
- single-pass polarimetric interferometric capability (ATI) in X- band

Repeat-pass Pol-InSAR is a standard measurement mode [3]. Range resolution is determined by the available system bandwidth and reaches 760MHz at X-band step-frequency operation. However, up to now only the X-, C- and S-band subsystems are finished, and XTI single-pass interferometry is not yet possible.

1.2 System design overview

The F-SAR system comprises a basic system control and data acquisition sub-system to which individual RF sub-system modules are connected. System control is based on an Extended CAN bus and Ethernet concept. This gives the necessary flexibility and the degrees of freedom to configure the system optimally for carrying out the desired measurements and experiments like bistatic SAR for instance. The main F-SAR technical parameters are given in Table 1.

A special antenna mount, designed to fix planar array antennae to the aircraft is under development. Fully-fledged in multi-frequency configuration it holds seven right-looking dual polarised antennae: three in X-band, one in C-band, two in S-band and one in L-band. The P-band antenna is mounted under the nose of the aircraft. The antenna mount has the one important advantage that it makes it easy to change antenna configuration and to mount other antennae while avoiding individual airworthiness certification procedures at the same time.

Table 1: F-SAR technical characteristics.

	X	C	S	L	P
RF [GHz]	9.6	5.3	3.25	1.325	0.35/0.45
Bw [MHz]	800	400	300	150	100
PRF [kHz]	5	5	5	10	10
PT [kW]	2.5	2.2	2.2	0.9	0.9
Rg res. [m]	0.2	0.4	0.5	1.0	1.5
Az res. [m]	0.2	0.3	0.35	0.4	1.5
Rg cov. [km]	12.5 (at max. bandwidth)				
Sampling	8 bit real, 1000MHz				
Channels	4	2	2	1	1
Data rate	247 MByte/s (per channel)				

1.3 On-board real-time processing / GMTI

Recently, the F-SAR has been extended by an on-board real-time processing unit. It is using PC-based processor cards with standard dual-core CPUs. The real-time processing unit is connected to the radar's digital unit via a fibre-optic link and can equally work in real-time using currently received data or offline on already recorded data. The on-board processor is capable of handling 4 independent channels and can easily be extended by additional processor cards if additional performance is required. A photo of the unit is shown in Fig. 2, a block diagram can be found in Fig. 1.

A special capability of the new on-board processor is the processing of GMTI results in real-time. Since F-SAR can be equipped with 4 X-band antennas in ATI configuration, operational near real-time traffic monitoring is possible. In order to promptly supply task forces on ground with the necessary information, a laser down-link terminal will be used, having a typical range of about 80km and a specified data rate of about 50Mbs. In a subsequent stage, it is planned to replace this laser terminal by a microwave link in order to become independent of weather conditions. Up to now, it was not yet possible to test one of these two down-link options in flight together with the F-SAR. However, separate flight and ground tests are currently ongoing and it is planned to demonstrate F-SAR's real-time downlink capabilities within the next months.

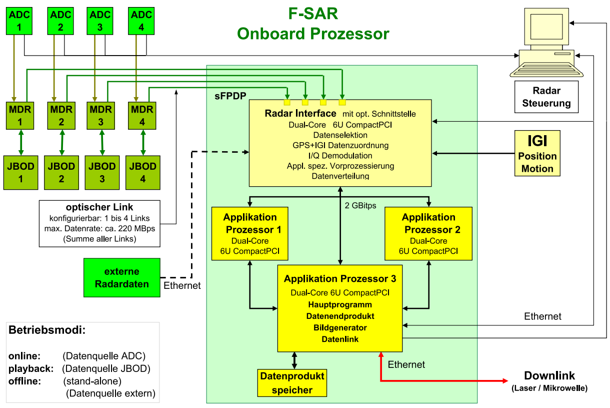

Figure 1: Block diagram of F-SAR's new real-time processing unit

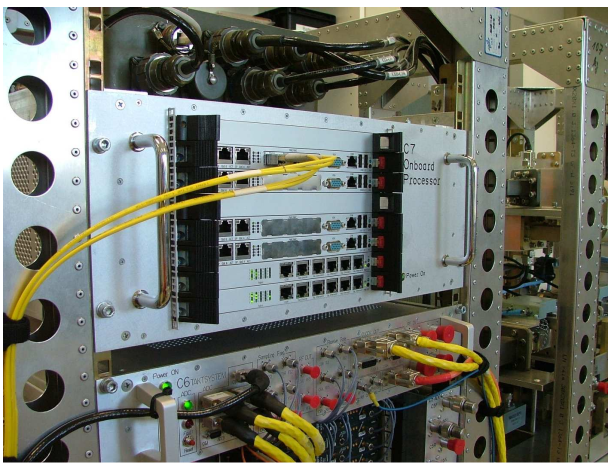

Figure 2: Photo of F-SAR's new real-time processing unit.

1.4 Step-frequency operation

Standard operation of F-SAR at X-band is limited to 384MHz bandwidth, corresponding to a slant-range resolution of about 40cm. In the recently implemented step-frequency mode, the range bandwidth is increased by subsequently transmitting two pulses with shifted centre frequencies. For off-line recombination of the pulses, a certain spectral overlap of at least 10MHz is needed, resulting in a total bandwidth of about 760MHz, corresponding to 20cm slant-range resolution.

One disadvantage of 2-pulse step-frequency operation is that the effective PRF of the system is divided by two. Also fully polarimetric data acquisition requires the use of two pulses, in case of a dual-channel system, to record all elements of the scattering matrix. However, due to the maximum available PRF of 5kHz at X-band, step-frequency operation can still be combined with fully polarimetric data acquisition.

If the enhanced spatial resolution of the X-band step-frequency mode is not required, alternatively 2-look data can be generated at the standard resolution, with increased radiometric quality and better SNR.

1.5 Multispectral radar operation

F-SAR is capable of simultaneous data acquisition in several frequency bands. This reduces the operation time / costs when multi-frequency acquisition is desired and allows to record data sets at precisely the same moment in time. During multi-frequency operation, the available PRF has to be shared among the different bands if more than two polarisations or bands have to be recored, since the sensor currently offers only a dual-channel receiver. Additionally, chirp generation is common for X-/C- and S-band and cannot be altered from pulse to pulse. Finally, the S-/C-band subsystem is shared and cannot be operated at the same time in both bands.

Considering these restrictions, currently fully polarimetric joint data acquisitions at X- and C-band are possible at maximum resolution, as well as fully polarimetric acquisitions at X- and S-band with 300MHz bandwidth. In both cases, the X-band can be operated in step-frequency mode if needed, roughly doubling the available bandwidth, i.e. to 760MHz or 590MHz, respectively

Once the L-band subsystem is finished, which is scheduled for the second half of 2010, combinations with any of the other bands will be possible. Since a separate chirp generator is used for L-band, X-/C- or S-band can be operated at maximum resolution, while L-band stays limited to 150Mhz. Theoretically possible is also a simultaneous operation of 3 bands, like X-, S- and L-band. The same as for L-band holds for the P-band subsystem, which is scheduled to be finished in 2011.

2 Test flight results and experiments

Flight testing of the F-SAR X-band system is ongoing since 2007. These tests included GMTI experiments [1], TS-X under-flights and calibration test flights. Since 2009, the S- and C-band subsystems have been extensively tested, as well as the X-band step-frequency mode and multispectral operation. In the following, some representative results of the campaigns will be shown.
Fig. 3 shows a radar image acquired during one of the last calibration campaigns in summer 2009 in X-band step-frequency mode over the calibration test site of Kaufbeuren / Germany. In the depicted crop of the full scene, a rural area with a small farm house in the middle is found. The sensor shows an excellent performance, allowing to distinguish different surface types not only based on their polarimetric signature, but also on their surface texture, which gets very pronounced at this level of detail.

Figure 3: Fully polarimetric X-band image acquired by F-SAR in step-frequency mode. Full swath is about 5km from 3km platform altitude.

The second example, shown in Fig. 4, is again a agricultural scene, this time located in Wallerfing / Lower Bavaria and imaged in fully polarimetric C-band mode. A very distinct and variable polarimetric response is obvious in this image, acquired in the middle of the vegetation period in late May 2009. Also at C-band, the spatial resolution is high enough to observe surface textures on several of the fields of the scene.
Finally, Fig. 5 shows a fully polarimetric S-band image, acquired with a bandwidth of 300MHz of the test-site of Kaufbeuren.

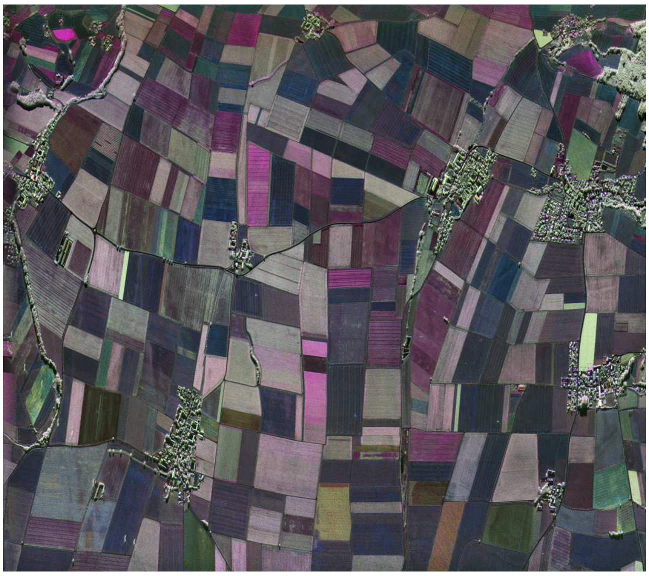

Figure 4: Fully polarimetric C-band image acquired by F-SAR at 384MHz bandwidth. Agricultural areas show a very diverse polarimetric backscattering at this wavelength.

Figure 5: Fully polarimetric S-band image acquired by F-SAR at 300MHz bandwidth. Despite the relatively long wavelength, very high spatial resolution and good SNR could be achieved.

Multispectral operation was successfully tested in several campaigns. All possible X-/S-band combinations have been tested, while for X-/C-band it was only possible to test the combination of fully polarimetric X-band with copolar C-band (HH or VV). The reason here are size restrictions in the currently used temporary antenna hold. When the final antenna hold is available, this limitation will disappear.

The newly implemented real-time processing capabilities have undergone first tests in 2009. Up to now, it was not possible to test the on-board processor in flight, due to the unfinished air-worthiness certification process. Instead, the recorded SAR data has been processed on ground with the real-time processor. Fig. 6 shows an example of a X-band scene, where a quicklook image was generated on the on-board processor an mapped into Google-Earth. Processing times for quicklook images is much faster than real-time. For full resolution images, currently the processing speed is around the time needed for the data acquisition time itself, further optimisations are ongoing to enable real-time processing in all modes.

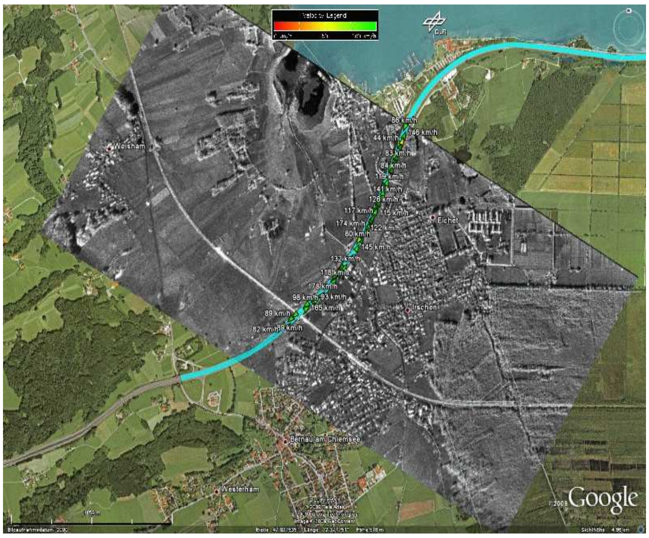

Figure 6: X-band SAR quicklook image, processed in real-time on the F-SAR on-board processor and mapped onto Google-Earth, together with extracted GMTI targets.

In addition to standard SAR processing, the on-board processor is also capable of GMTI processing using an aperture-switched 4-channel mode in X-band with a bandwidth of 100MHz. An a-priori knowledge based GMTI algorithm is adopted [2], which uses pre-recorded digital road network information. In GMTI mode, processing times are currently slower than real-time by a factor of 5, because un-optimised code is used. However, the output of the GMTI processing are very small xml files, containing only the extracted information about the GMTI target (see Fig. 7. Such data can easily be submitted through even a relatively slow real-time down-link. An in-flight demonstration of near-real-time traffic monitoring using the laser down-link is planned for mid-2010.

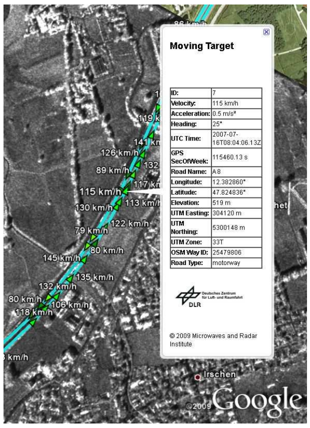

Figure 7: GMTI target information extracted in near-real-time.

3 Conclusions

Currently, the X-, C- and S-band subsystem of F-SAR are finished and operational so far. Various flight tests in 2009 demonstrated the excellent performance of the system in all available bands. Fully polarimetric data acquisition is possible in all bands and at maximum resolution. Additionally, simultaneous data acquistion in two frequency bands and step-frequency mode at X-band are available. Even though the system is not yet fully finished, F-SAR is so far able to deliver data to scientific and commercial customers in these modes. A first commercial campaign was accomplished in autumn 2009.
XTI interferometry at X- and S-band are currently not possible, this requires the completion of the new multi-antenna hold, planned for the second half of 2010. The L-band subsystem of F-SAR is close to completion and first flight tests are also planned for the second half of 2010. P-band is intended to follow in 2011. The first in-flight tests of the real-time processor together with the laser down-link are expected for second half of 2010, up to now only ground tests could be performed.

References

[1] S. Baumgartner, M. Gabele et al.: "Digital Beamforming and Traffic Monitoring Using the new F-SAR System of DLR". Proceedings International Radar Symposium, Berlin, Germany, 2007.

[2] S. Baumgartner, G. Krieger: "A Priori Knowledge Based GMTI Algorithm For Traffic Monitoring Applications". Proceedings of EUSAR'10, Aachen, Germany, 2010.

[3] J. Fischer, S. Baumgartner et al.: "Geometric, Radiometric, Polarimetric and Along-Track Interferometric Calibration of the new F-SAR system of DLR in X-Band". Proceedings EUSAR, Friedrichshafen, Germany, 2008.