

### **Abstract**

Future SAR missions like SIR-C with the German X-band radar will acquire multi-frequency and multipolarisation data with various incidence angles. In order to exploit the mission's full scientific potential DFVLR is going to calibrate both its 'Intelligent SAR Processor' ISAR and the final image products. The idea of the EXAS proposal is to use extra data gained from an independent Doppler measurement. These data will be gathered at a geolocated receiver in order to tune and finally to calibrate the ISAR processor. The receiver will be adjusted to the sensor carrier frequency, the signals will be mixed down to baseband, be digitised and transferred to the ISAR hardware system. This can be performed in parallel for three frequencies with two different polarisations. Immediately after the fly-over the data will be analysed. The azimuth antenna pattern will be computed and fed back into the processing chain. The replica of the chirps radiated by the sensor will be recorded by the ground receiver. Therefore, the exact range reference function is known and can be used for the processing. The calibrated processor will produce images with a very accurate absolute pixel location. In order to verify this, a cluster of geolocated point reflectors shall be positioned over the swath and the SAR image will be compared with a cartographic map. The paper describes the experiment plan and the contributions of three institutes.

### **Keywords:**

SAR, SIR-C, X-SAR, ERS-1, ISAR, Calibration, Multifrequency, Multipolarisation

## 1. Introduction

The combined SIR-C/X-SAR mission will be the first spaceborne Synthetic Aperture Radar System to acquire high quality radar data from earth using multifrequency, multipolarisation sensors with variable incidence angles. Furthermore, the european ERS-1 satellite will be an operational SAR sensor with an expected lifetime of about three years. In order to contribute to the achievement of the scientific goals of these missions, the resulting data products have to be calibrated. This is all the more true if one also attempts to compare data resulting from different radar channels with optically acquired data such as that from SPOT. Therefore, the main goal of this experiment is to install a closed calibration loop for the processing system. For this purpose several research institutions will start a cooperative effort which combines knowledge and experience from different research and application areas.

If the calibration of a Synthetic Aperture Radar imaging system is considered, the whole data acquisition and processing chain must be understood as an end-to-end system.

The different components are:

- the target itself,
- the electromagnetic interaction with the target,
- the atmospheric propagation effects,
- the sensor platform,
- the sensor itself,
- the SAR signal processor, and
- the SAR post-processor for geocoding.

This proposal is aimed at calibrating one part of this chain, namely, the SAR signal processor and especially, some modules which estimate various key processor parameters, like the Doppler Centroid and the PRF Ambiguity Band. In order to accomplish this, extra and independent reference measurements, which are supposed to be more accurate, will be performed for data takes at a test site.

A ground microwave receiver and a signal processor shall be used to perform high precision Doppler frequency measurements, which will then be used to calibrate the SAR processor modules. Furthermore, it is shown that the proposed receiver has more benefits for SAR missions. It turns out that deterministic error sources like the antenna pattern can be corrected in the SAR processor on a routine basis. Another goal of the experiment is to use the receiver to collect reference data from all sensor fly-overs in order to contribute to a long term sensor performance assessment.

## 2. Experiment Plan

### 2.1 The ISAR Processor

The 'Intelligent SAR Processor' ISAR, currently under development at DFVLR's Data Processing Division (WT-DA) will be used to generate high precision SAR images from future SAR missions. These are in particular the European ERS-1 satellite and the NASA SIR-C mission with the German X-band radar. The design goals of the processor are high throughput and high precision. The generated images shall have high geometric and radiometric resolution as well as high map projection fidelity [1, 2]. Figure 1 depicts the ISAR hardware configuration with a high performance array processor, a host computer, various workstations, the Corner Turn Memory (CTM), the Real Time Input Facility and the EXAS receiver with an interface to the CTM.

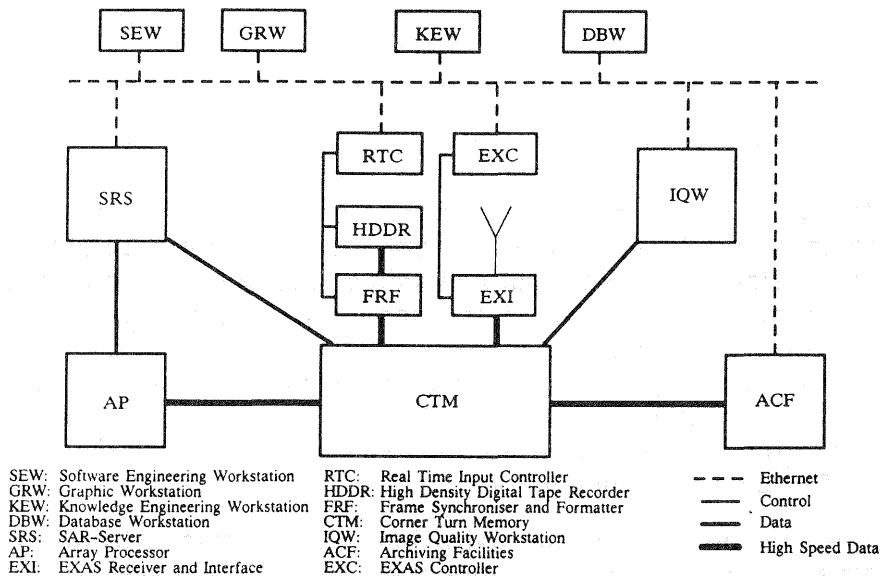


Fig. 1: The ISAR Processor Hardware Configuration

### 2.2 ISAR Product Validation

In order to assure the delivery of good products to the user community various image quality checks and processor validations are planned. In particular the geolocation accuracy will be verified by means of active reflectors, which receive, amplify and retransmit the signals back to the sensor. It is assumed that these reflectors are much more visible in the SAR image than passive corner reflectors. They will be delivered by the University of Stuttgart's Institute for Navigation and will be deployed over the swath at a test site [3]. The position of the reflectors will be determined very precisely, with the possible use of the Global Positioning System GPS. The remote sensing laboratories of the University of Zurich will use these spots as Ground Control Points and verify the geometric fidelity of the ISAR processor products.

## 2.3 Calibration of the ISAR Processor

The geometric and radiometric resolution of a SAR image is mainly determined by a proper Range and Azimuth filter generation, which in turn needs precise attitude and orbit data. Unfortunately, the sensor attitude is by far not as precisely known as it should be. A very dramatic example is the yaw angle of the SIR-C sensor which can vary in a range of  $\pm 1^\circ$ . In the case of the X-band this is equivalent to approximately 4 km on the ground. Nevertheless, a map projection fidelity of about one resolution cell of 30 m is desired.

The main contributory factor towards the error in the geolocation of an image pixel is the uncertain estimation of the sensor look-direction. As sensor attitude data cannot be used, the sensor look-direction must be determined by using the SAR data itself, knowing that the Doppler frequency shift changes with the variation of the look-direction. By analysing the Doppler frequency, the sensor attitude and the antenna look-direction can be reconstructed [4]. Within one PRF-band a so called 'Doppler Centroid' routine can be used [5] and in order to determine the valid PRF-band a 'PRF Ambiguity Resolver' may be used [6].

A common method of determining the Doppler Centroid is a clutter lock technique, where several power spectras of azimuth lines are averaged and then correlated with the antenna pattern. This method has some inherent drawbacks because a large array of data has to be analysed. Therefore, scatterers with many different Doppler shifts are involved in the measurement. Furthermore, bright targets which are partially covered by the spectral analysis or scene inhomogeneities like a contrast edge, orthogonally oriented to the sensor flight track, can lead to a severe estimation error [7]. It does not matter which Doppler Centroid algorithm is used, the designer always faces the problem of not knowing the exact and actual Doppler Centroid value when he wants to tune and finally to calibrate its estimation algorithm. In addition, the 'PRF Ambiguity Resolver' can only be calibrated with exact absolute Doppler reference values.

The idea of the EXAS proposal is to use extra information gained from an independent measurement. This will be accomplished by a geolocated microwave antenna connected to a receiver and a data storage device. This passive receiver chain acquires a signal which is identical to the radar return of the particular spot on the earth's surface where the antenna is mounted. The received pulses from the SAR system will be analysed and used to tune and calibrate the ISAR processor Doppler Centroid and PRF Ambiguity Resolver Modules. These ISAR modules will be applied on SAR raw data as well as on EXAS received data in order to compare the results. The parameters estimated from the EXAS measurement are expected to be much more accurate because:

- A data set acquired with the EXAS receiver is the two-dimensional point spread function of only one particular target on the ground.<sup>1)</sup> In contrast the SAR raw data which are normally used for the parameter estimation are a superposition of an infinite number of ground reflectors. Most of the infinite number of reflectors have a different relative motion to the sensor and therefore, different Doppler shifts. If SAR raw data are used for the measure-

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<sup>1)</sup> The only difference between this and real SAR raw data is that only a one-way Doppler shift has appeared.

ment of the absolute Doppler frequency and the determination of the PRF-band, the result will always be uncertain.

- Data acquired by the EXAS receiver will be less noisy than SAR raw data, because the signals have travelled only once from the sensor to the ground. Furthermore, they are not overlaid with background clutter.
- In the EXAS receiver a much better analogue to digital conversion can be performed than by the sensor. The signals may be sampled with up to 150 MHz or with a resolution of up to 10 bits.

## 2.4 The Data Receiving and Recording System

The reception and recording chain for the EXAS experiment consists of an antenna, a microwave receiver, a digitiser and the Corner Turn Memory to store the received pulses. This is depicted in Figure 2. The system can be enlarged to acquire data from different frequency channels or different polarisations at the same time (Figure 3).

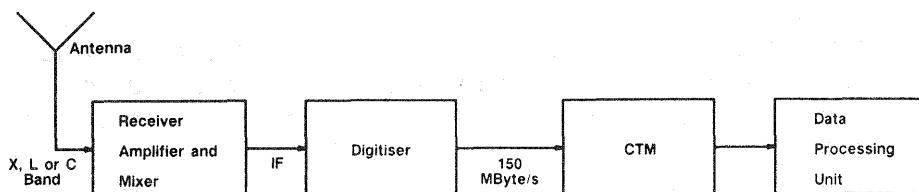


Figure 2: The Data Acquisition Chain

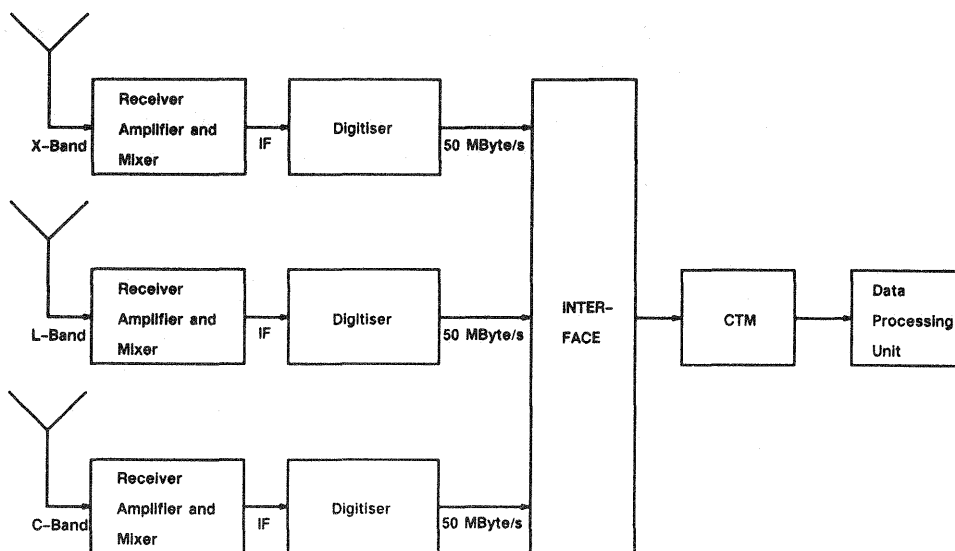


Figure 3: A Three Channel Receiver

In order to avoid an antenna steering mechanism, an antenna with an omnidirectional characteristic could be used. Therefore, the receiving angle of the antenna does not need to be adapted for each fly-over. It may turn out that the noise from other microwave sources is too high and an antenna with a narrower opening angle must be used. In any case it will be valuable for the SIR-C mission to use horizontally and vertically polarised antennas.

The receiver must have a high sensitivity and low noise level in order to be able to detect the signals coming from the SAR platform in space. The receiver must have a narrow input bandwidth so that noise from other microwave sources can be suppressed. The receiver shall be tuneable to adjust it to the three frequency bands of SIR-C, X, L and C and the C-band of ERS-1. The receiver's amplifier must be capable of precise adjustments, because this equipment will in turn be used for calibration. The IF stage of the amplifier must have a bandwidth of 20 MHz because of the high X-SAR chirp bandwidth of 19 MHz.

The industry offers digitisers with a sampling rate of up to 200 MHz and a resolution of 10 bits. For the Corner Turn Memory a standard 3-channel interface with a sampling rate of 50 MHz per channel and a resolution of 8 bits is available.

The Corner Turn Memory (CTM) of the ISAR processor hardware system will be used for data recording. It is a huge semiconductor bulk memory of 512 Megabytes and able to provide a high speed memory access in the row and column direction of a matrix. It has interfaces to the ST-100 array processor and the host computer. Therefore, the gathered data can be easily processed as soon as they are in the CTM. The achievable data rate of the CTM is 40 Mbytes/s for both row and column access of a data matrix. In a sequential data acquisition mode the memory can run with a speed of 150 Mbytes/s. With an input data rate of 150 Mbytes/s and 512 Mbyte storage capacity the data take can be as long as 3.4 seconds.

In order to obtain a time reference, a high precision time code receiver shall be used. It is sufficient to store only one time sample at one data take, because the sampling frequency of the digitiser is controlled very precisely. Therefore, the exact timing for each sample is determined.

If it is desired that the SAR azimuth reference function be obtained with the ground equipment, the received pulses must be aligned very precisely. In order to accomplish this, a stable oscillator may be synchronised with the sensor on-board oscillator and the received signals can be I/Q detected.

The data acquisition unit shall be equipped with an automatic trigger function. This will enable the unattended use of the calibration facility. It would be misleading to trigger only on the amplitude of the incoming signal because alien microwave sources could easily cause a triggering. Therefore, the incoming data stream shall be recorded continually anyway, but if SAR data are detected a 'post triggering' shall be performed as soon as the CTM is filled with useful data. The post triggering unit may also initialise the recording of an actual time sample from the time reference unit.

In order to detect whether the received signals are SAR data or alien signals, the pulses may be correlated with the nominal sensor chirp replica. This can be performed by a simple real time hardware correlator or with the ST-100 array pro-

cessor. Because of its 100 MFLOPS performance, the array processor can correlate a signal with a chirp replica of 1k samples in the timeframe of only 1ms.

## **2.5 Choice of the Test Site**

Data acquisition with the ground receiver requires a data recording facility of at least 40 MSamples per second. This high data rate can only be achieved with a fast semiconductor memory, like the 'Corner Turn Memory' of the ISAR hardware system.

However, the ISAR processor is located at DFVLR in Oberpfaffenhofen and is not portable. Therefore, the receiver must also be placed in Oberpfaffenhofen, very close to the ISAR processor. This is a benefit for a SAR mission because the received signals can already be analysed during the campaign and eventual sensor malfunctions can be detected. Furthermore, DFVLR owns equipment for high precision orbit tracking and determination, which can provide a very precise state vector required for the processor calibration. In addition, DFVLR's Institute for Radio Frequency Technology can supply extensive facilities for radiometric and geometric SAR calibration.

## **3. Benefits of the Experiment**

The original idea of the EXAS proposal was to gain absolute Doppler frequency measurements for the calibration and tuning of key SAR processor modules. However, it turned out that the system has several more benefits for a SAR mission.

- The exact replica of the chirps radiated by the sensor can be recorded, therefore, the exact range reference function is known. From our experience with the Convair-580 experiment in 1981 this can be extremely helpful, if the range chirp is distorted for any reason. The range chirp will be extracted and compared with a nominal chirp. Furthermore, it will be saved on a disk file and used when the particular scene of raw data is processed later.
- The exact azimuth antenna pattern can be measured and fed back into the processing chain for calibration purposes. If three receivers are used, the X, L and C-band antenna pattern can be obtained in parallel and the difference between the pointing angles between the three antennas can be determined.
- If two receivers and two suitable antennas are used, pulses with different polarisation can be received and stored for further analysis.
- The EXAS receiver chain can record all data from three channels for a timeframe of 3.4 seconds. This covers the SAR pulses themselves and the gaps between the pulses. In these gaps, the pulses from alien microwave sources can easily be detected and analysed. From the experiences with SIR-B, this jamming can be very extensive and may influence the final SAR image.

- The data set received with the EXAS system can be used to verify the output of a SAR simulator. If the simulator is set up with the conditions of the EXAS data take, the measured two-dimensional point spread function and the simulated one should be equal in their main parameters.
- All actions mentioned above can be performed immediately after the satellite fly-over. The data are stored for online access to the ISAR processor, including advanced engineering workstations, the ST-100 array processor, the ISAR knowledge base and the SAR simulator.

#### **4. Future Prospects**

The measurement results like absolute Doppler frequency, azimuth antenna pattern and the range chirp replica, can be fed directly into the ISAR processing chain for immediate analysis. The aim is to calibrate key SAR processor modules autonomously and on an operational basis. However, this requires a regular fly-over of the sensor.

It is believed that it would be worthwhile thinking about a cheaper and portable version of the receiver and data recording system described in this paper. Several of these compact systems could be deployed in the field at test sites along or across the swath. The EXAS proposal will be a first step in the direction of a long term and autonomous SAR processor calibration.



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