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X-SAR

THE X-BAND SYNTHETIC APERTURE RADAR ON BOARD THE SPACE SHUTTLE

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Introduction

X-SAR is the German/Italian contribution to the NASA/JPL Shuttle Radar Lab missions as part of the preparation for the Earth Observation System (EOS) program. The Shuttle Radar Lab is a combination of several radars: an L-band (1.2 GHz)and a C-band (5.3 GHz) multipolarisation SAR known as SIR-C (Shuttle Imaging Radar) and an X-band (9.6 GHz) vertical polarised SAR which will be operated synchronously over the same target areas to deliver for the first time calibrated multifrequency and multipolarisation SAR data at multiple incidence angles from space.

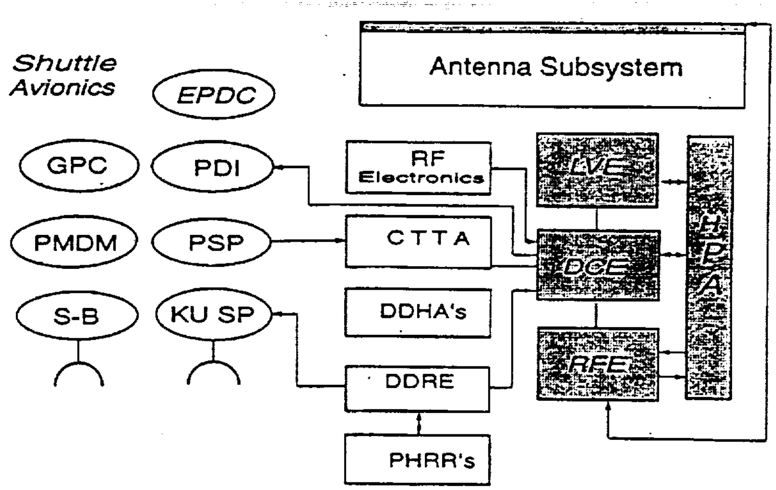
A joint German/Italian project office at DARA (German Space Agency) is responsible for the management of the X-SAR project. The space hardware has been developed and manufactured under industrial contract by Dornier and Alenia Spazio. Besides supporting all the technical and scientific tasks, DLR, in cooperation with ASI (Agenzia Spaziale Italiano) is responsible for mission operation, calibration and high precission SAR processing. In addition, DLR developed an airborne X-band SAR to support the experimenters with campaigns to prepare for the missions.

The main advantage of adding a shorter wavelength (3 cm) radar to the SIR-C radars is the X-band radar's weaker penetration into vegetation and soil and its high sensitivity to surface roughness and associated phenomena. The performance of each of the three radars is comparable with respect to radiometric and geometric resolution.

Instrument development

As of about one year before the first mission, the flight hardware has been manufactured, and the integrated X-SAR instrument is undergoing a phase of thorough testing and characterization of its performance. Following to these tests, the X-SAR has been delivered to the U.S.A. and will be integrated in the SIR-C radars and subsystems at JPL (Jet Propulsion Laboratories in Pasadena). After the three X-SAR slotted waveguide array antenna panels are mounted on to the common mechanical antenna structure the antenna will become for the first time a full 12 m in length. The X-band antenna will be mechanically pointed to its targets while the SIR-C antennas have the capability to point electronically to the same target area on ground. The passive X-SAR antenna is connected to its high power transmitter and its low noise receiver via a quite long waveguide running from the electronic boxes down in the pallet bay up to the top of the antenna structure. The three panels are fed via a rotary joint and a three-way power devider. The predicted mechanical loads and stresses, up to 15 g during launch and landing, are a challenge to the design of this waveguide, which has to be built out of special rigid and flexible pieces to take care of the dynamic and static deflections between the pallet-mounted equipment and the antenna as well as between the movable X-SAR structure and the core structure.

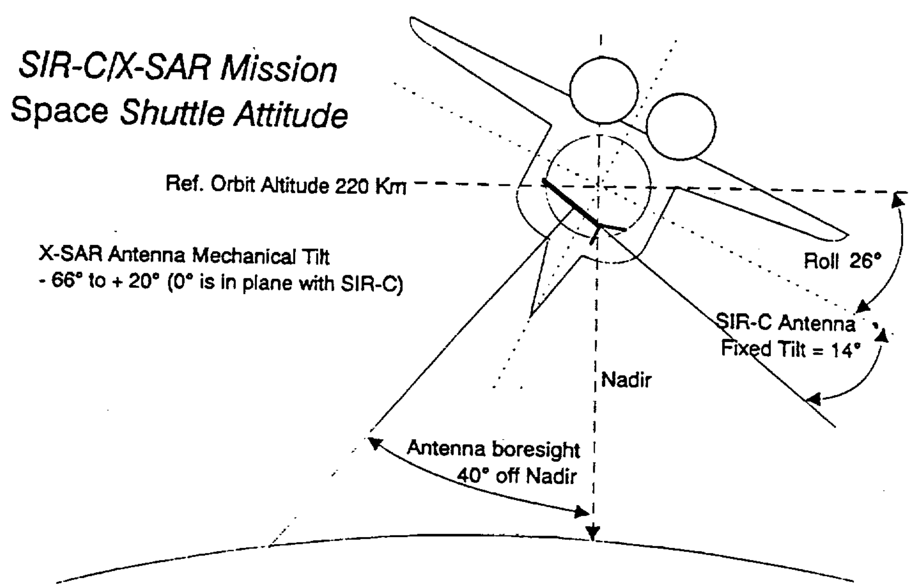
X-SAR/SIR-C Blockdiagram



Although it is planned to operate X-SAR and SIR-C synchronously, each radar is also capable of autonomous operation. To insure proper synchronism SIR-C acts as the master for all timing signals as well as for the local oscillator, which is the basis for the common frequency generation. Also part of the telemetry and command subsystems and the high rate data handling, recording and switching is under SIR-C control. Therefore, in addition to the testing of the subsystems itself, careful testing of this interfaces and the compatibility of both systems running, has to be verified before delivery to the Kennedy SpaceFlight Center for integration with the orbiter. The antenna will cover about 60 % of the whole cargo bay and is mounted with a fixed tilt of 14 degrees. All electronic boxes are installed on coldplates under the antenna structure on a spacelab pallet. Inside the shuttle cabin one of the three high rate data cassette recorders will be dedicated to record X-SAR data.

Mission operations

The three radars will be operated during the ten day missions synchronously over selected target areas based on the mission plan, worked out by the SIR-C/X-SAR science team in collaboration with the principal investigators.Highest priority is given to the so-called super test sites in which ground calibration and insitu measurements are made. In total, about 50 hours of X-SAR raw data are expected which will be recorded on board. A part of this data can in addition be transmitted to the ground in real time. The orbit altitude is planned to be 220 km and the inclination will be 57°. The orbiter will fly in a 26° roll and a 180° pitch angle which makes the radars looking 40° off nadar when no beam pointing is commanded.



To carry out the ambitious mission plans, a powerful and flexible mission operations and planning tool is being developed which is capable of performing joint, coordinated operations with SIR-C.

The main elements of the MPOS (mission planning and operations system) are the mission planning and analysis system, the telemetry system, the command system and the SAR real time quicklook processing system. While the mission planning software tools such as the mission timeline planning, the data-take selection, the performance estimator and the command plan generator are also necessary for pre-mission preparation, these and the hardware elements mentioned above will all be integrated into the JSC POCC (payload operation and control center at the Johnson Space Flight Center) in Houston.

The flow of the mission planning is normally the following: Input data provide latest information about the sites, the attitude timeline and the orbit state vectors. The mission planning software then calculates and displays the data take opportunities, which are then checked against the requirements and mission rules by the data-take selection software. To determine the optimum and jointly coordinated radar parameter settings, a performance estimator calculates radar parameters and the predicted image performance using known instrument characteristics for each target or data-take. These radar settings are then transformed by the command plan generator into commands which are tagged with the appropriate times for execution in the instrument. Up to 256 command blocks may be sent to the onboard instrument sequencer memory, enough for a whole day of automatic operation if no updates would be necessary.

Real time commanding is possible and might be necessary during the mission when the performance analyser system shows the operator improper radar parameters, or if the parameters are no longer optimum. This might happen because the Space Shuttle is not a very stable platform for a SAR and the attitude and orbit data avaiable during mission are not very accurate. The monitoring of the on-board instrument is performed with the telemetry system which shows the status and health of the X-SAR instrument as well as with the SAR processing system when realtime data transmission is scheduled for X-SAR. The real time data will be recorded on ground and in parallel routed to the deformatter and quicklook SAR processor, which show the processed image of the scene in a waterfall display. This will permit the monitoring of the performance of the instrument, the proper timing of the receive window and the pointing of the antenna to support the control of the test-site coverage.

After the mission an as-run timeline and a mission operations report evaluating the instrument functional performance will be supplied, together with a duplicate of all recorded data for the off-line processing systems.

Performance critical areas

A key instrument parameter for the performance is the in flight antenna pattern, but its prediction has a high uncertainty. Each of the three 4 m long antenna panels had to be measured seperately on a far-field test range. An ideal reconstruction of the full 12 m antenna performed using software tools showed excellent performance.

The inflight antenna pattern will be more or less degraded by the mechanical performance of the antenna truss with its static deflections and temperature effects but also due to the presence of the SIR-C antenna and the orbiter elements. A further problem area is the knowledge of the pointing of the antenna to the target which is depending on the attitude measurement accuracy and the alignement accuracy of the antennas with respect to the orbiter coordinate system. Main regions of concern are the 1. sidelobe levels (up to -8.3 dB in a worst case) of the azimuth pattern which impacts on the ambiguity ratio and the peak gain variation (up to 0.9 dB in worst case) which impacts on the gain stability and calibration accuracy. A verification of the inflight antenna pattern and its pointing will be measured with ground receivers distributed over the swath at least over the calibration test site.

Gain variation of the transmitter and receiver chain over the temperature range is an other critical area which directly impacts on the radiometric accuracy or at least complicates the calibration. X-SAR was not successfull in implementing an automatic compensation of the gain variation over the temperature range of about 40 degrees Celsius. But for the postmission data processing a careful characterisation of the gain versus temperature under thermal vaccum conditions has been done resulting in a set of curves which have to be used together witch the temperature housekeeping recorded during the mission. The measured gain variation is about 0.2 dB per degree Celsius which should not be too bad taking into account the excellent temperature stability of the coldplates in earlier missions.

Performance prediction

Based on jointly agreed upon definitions, X-SAR and SIR-C calculate their predicted performance with validated system perfomance software tools. The performance models use algorithms which transform the instrument parameters and assumptions about the platform, the processor and the target into image performance parameters. The instrument parameters used were taken from the latest measurements of the flight hardware. The performance is calculated for point targets, providing geometric resolutions. For distributed targets radiometric resolution, ambiguity levels, signal-to-noise ratios and the performance swath width are calculated. The following table shows the performance for four typical incidence angles.

Requirement	for point targets				distributed targets			
Incidence angle	20°	30°	40°	50°	20°	30°	40°	50°
Range resolution								
fine < 10 m	9.6	9.8						
coarse < 20 m			17.7	18.0				
Range ISLR >11 dB	12.1	12.1	12.2	12.2				
Range PSLR >20 dB	21.9	21.9	21.9	21.9				
Azimuth resol. 30	27.5	27.5	27.4	27.4				
Azimuth ISLR >11dB	15.47	15.45	15.51	15.51				
Azimuth PSLR >20dB	21.9	21.9	21.9	21.9				
Ambiguity Azimuth					19.4	19.4	20.0	19.4
Ambiguity Range					>40	>40	>40	>40
Total > 18 dB					19.4	19.4	20.0	20.0
Radiom. Res.<2.75					<2.1	<2.8	<2.0	<2.1
Image SNR					>8.7	>8.4	>10.2	>7.7
Dynamic > 20 dB					32.9	34.7	36.7	36.8
Swath width>15 km					30.4	20.7	36.6	32.0

SAR Data Processing

The processing of the X-SAR raw radar data will be performed in two processing and archiving centers one at ASI in Matera Italy (I-PAF) and one at DLR in Oberpfaffenhofen Germany (D-PAF). ASI will be responsible for processing the survey products of all X-SAR data within three months after the mission for the selection of the test sites for which high precision calibrated products will be processed. The processing of the high precision products will be shared between ASI and DLR. The calibration testsites will be processed first, so that the calibration team can determin the calibration factors to be used from both PAF's for the precision processing. Several data products like single look, multilook, geocoded and several product media can be selected by the data users which place their orders via the science team to the PAF's. All three processing centers JPL, ASI and DLR have jointly agreed on the data products, quality and the formats. The main challenge for the X-SAR data processing is the relative unstable Shuttle plattform and the low precision of the orbit and attitude data. To find the correct doppler and dopplerband a new algorithm to solve the doppler ambiguity problem in the X-SAR data has been developed and will be applied during the screening process of the data. The processor hardware and software development is in good progress and converted ERS-1 and simulated test data have been processed successfully.

As an example for the SAR processing the D-PAF block diagram is shown.

PAF Environment