TERRASAR-X: A NEW PERSPECTIVE FOR APPLICATIONS REQUIRING HIGH RESOLUTION SPACEBORNE SAR DATA

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ABSTRACT:

TerraSAR-X is a new German radar satellite that shall be launched in mid 2005. It's planned lifetime is 5 years. It carries a high frequency X-band SAR sensor that can be operated in three different modes and polarisation. The Spotlight-, Stripmap- and ScanSAR-modes provide high resolution images for detailed analysis as well as wide swath data whenever a larger coverage is required. Imaging will be possible in single, dual and, on an experimental basis even quad-polarisation. The TerraSAR system consists of the Space and the Ground Segments and the User Infrastructure. DLR is responsible for the scientific use while the commercial sector will be handled by the Infoterra GmbH. TerraSAR-X will be an operational SAR-system for scientific and commercial applications.

1. INTRODUCTION

TerraSAR-X is an operational, advanced SAR-satellite system for scientific and commercial applications. It is realised in a close co-operation between the German Ministry of Education and Science (BMBF), the German Aerospace Centre (DLR) and the Astrium GmbH. DLR will implement the satellite control system as well as the payload ground segment for receiving, processing, archiving and distribution of the X-band SAR data. DLR is also responsible for the instrument calibration, the 5 years of operation and the scientific use of the TerraSAR-X data. Astrium will develop, build and launch the satellite under DLR contract. Astrium will set up a distribution system for the commercial use of the TerraSAR-X data and products on its own cost. Distribution and value adding will be the task of the Infoterra GmbH.

TerraSAR-X is a new high resolution satellite operating in the X-band at 9.65 GHz. The launch is planned for mid 2005. More information about the satellite and the sensor is provided in (M. Suess, 2002).

The mission will serve two main objectives:

- to provide the scientific community with high-quality, multi-mode X-band SAR-data for scientific research and applications; and
- to support the establishment of a commercial EO-market and to develop a sustainable EO-service business, based on TerraSAR-X derived information products.

2. SENSOR PARAMETERS

TerraSAR-X is a side-looking synthetic aperture radar (SAR) based on active phased array antenna technology. It is capable to transmit pulses in X-Band in two polarisation - H and V - to the Earth, which will be reflected back to the instrument and received again by the radar.

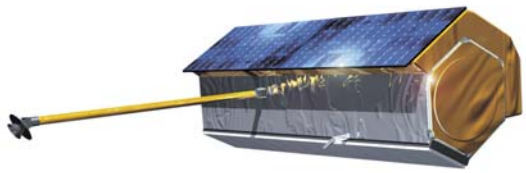

Figure 1. Artist view on TerraSAR-X:

Figure 1 shows an artist view on the TerraSAR-X satellite. The solar panel is mounted on top of the satellite bus. The SAR antenna is visible on the bottom side. The X-band downlink antenna is mounted on a small boom in order to avoid interference with the SAR-antenna.

Polarisation	HH, VH, HV, VV
Wavelength	3.1 cm
Pulse Repetition Frequency (PRF)	3 kHz – 6.5 kHz
Range Bandwidth	nominally 150 MHz
Number of beams in elevation in SM/SC	ca. 12
Number of beams in elevation in SL/HS	ca. 95
Nominal antenna look direction	right
Yaw steering	yes

Table 1: TerraSAR-X System Parameters

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The instrument is designed for multiple imaging modes like StripMap, SpotLight and ScanSAR operating with either single- or dual-polarisation. The nominal range bandwidth is 150 MHz. In addition it allows for an experimental high-resolution 300 MHz mode as well as for the so-called Dual-Receive-Mode, which is based on the usage of the antenna in two azimuth halves and utilises the redundant electronics set as a second receiver channel. The Dual-Receive-Mode will enable along-track interferometry, e.g. for velocity measurements and traffic control, and a full polarimetric mode, by simultaneously receiving H and V with the two sub-apertures. The system parameters are summarised in Table 1.

The spacecraft will be launched into a sun-synchronous dusk-dawn orbit with a nominal orbit height at the equator of 514 km. The inclination will be 97.44°. The satellite will circle around the earth $15^2/_{11}$ times per day leading to a revisit time of 11 days. The spacecraft's orbit will be controlled in order to maintain a ground track repeatability within ±500 m per repeat cycle for nominal mapping and ±250 m for interferometry.

3. IMAGING MODES

The four imaging modes of TerraSAR-X High Resolution SpotLight Mode, Spotlight Mode, StripMap Mode and ScanSAR Mode will be described in more detail in the following chapters.

3.1 High Resolution SpotLight Mode (HS)

The SpotLight modes provide the highest geometrical resolution. Therefore the size of the observed area on ground is smaller than the one in all other modes. During the observation of a particular ground scene the radar beam is steered like a spotlight so that the area of interest is illuminated longer and hence the synthetic aperture becomes larger. The Maximum azimuth steering angle range is ±0.75°.

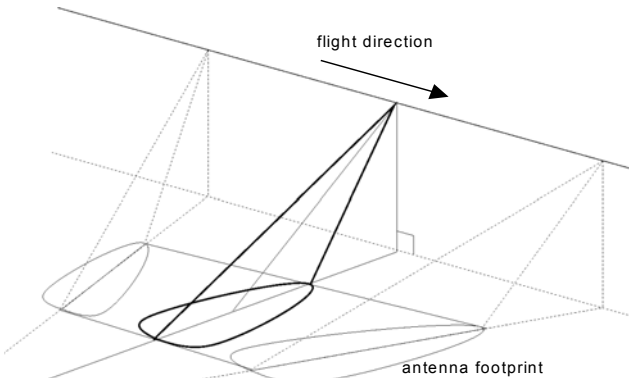

Figure 2. SpotLight Geometry

3.2 SpotLight Mode (SL)

HS and SL modes are very similar. In SL mode the geometric azimuth resolution is reduced in order to increase the azimuth scene coverage. The SpotLight geometry (HS and SL) is depicted in Figure 2. Characteristic parameters of the SpotLight (SL) and High Resolution SpotLight (HS) modes are listed in Table 2.

Parameter	Value HS	Value SL
Scene extension (azimuth x ground range)	5 km x 10 km	10 km x 10 km
Incidence angle range (full performance)	20° - 55°	20° - 55°
Azimuth resolution	1 m	2 m
Ground range resolution (55°-20° incidence angle)	1.5 m - 3.5 m	1.5 m - 3.5 m

Table 2: Parameters of SpotLight and High Resolution SpotLight Modes

3.3 StripMap Mode (SM)

The ground swath is illuminated with a continuous sequence of pulses while the antenna beam is fixed in elevation and azimuth. This results in an image strip with continuous image quality in azimuth. In Figure 3 the StripMap mode geometry is illustrated. The StripMap mode (SM) parameters are listed in Table 3.

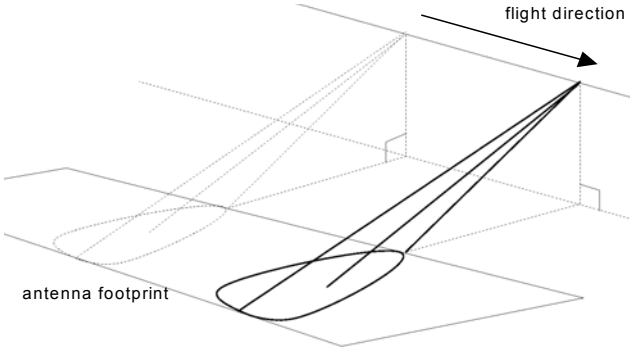

Figure 3. StripMap Geometry

Parameter	Value SM	Value SC
Number of sub-swaths	na	4
Swath width (ground range)	30km (polarimetric mode: 15–30 km)	100 km
Acquisition length	≤ 1650 km	≤ 1650 km
Incidence angle range	20° - 45°	20° - 45°
Azimuth resolution	3 m	16 m
Ground range resolution (45°-20° incidence angle)	1.7 m - 3.5 m	1.7 m - 3.5 m

Table 3: Parameters of StripMap and ScanSAR Modes

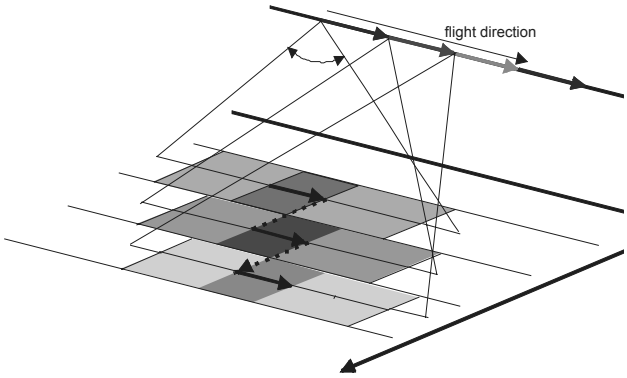

Figure 4. ScanSAR Geometry

3.4 ScanSAR Mode (SC)

The ScanSAR mode provides a large area coverage. The wider swath is achieved by scanning several adjacent ground sub-swaths with simultaneous beams, each with a different incidence angle. Due to the reduced azimuth bandwidth the azimuth resolution of a ScanSAR product is lower than in StripMap mode. In Figure 4 the ScanSAR geometry is illustrated. The ScanSAR beams will be composed from the calibrated StripMap beams. The corresponding parameters are listed in Table 3.

4. POLARISATION

Each pulse can be transmitted either vertically (V) or horizontally (H) polarised. The back-scattered signal can be received with either vertical or horizontal polarisation, independent from the transmit polarisation.

4.1 Single Polarisation

The radar transmits either H or V polarised pulses and receives in H or V polarisation. The resulting product will consist of one polarimetric channel in one of the combinations HH, HV, VH or VV. It can be operated in all different modes HS, SL, SM and SC.

4.2 Dual Polarisation

In this mode the radar toggles the transmit and/or receive polarisation on a pulse to pulse basis. The effective PRF in each polarimetric channel is half of the total PRF, which means that the azimuth resolution is slightly reduced. The polarimetric phase between both channels can be exploited, e.g. for interferometry or classification purposes. The product consists of two layers that can be selected out of the possible combinations. Dual polarisation is possible for all image modes as well.

4.3 Quad Polarisation

Quad polarisation is possible in the experimental dual receive antenna mode as the signal can be received simultaneously in H and V polarisation. By sending alternating H and V pulses, the full polarimetric matrix can be obtained. Currently quad-polarisation is not operationally foreseen.

5. PRODUCTS

The data acquired in the four imaging modes are provided as four different product types:

5.1 Single Look Slant Range Complex (SSC)

The SSC is the basic single look product of the focused radar signal. The pixels are spaced equidistant in azimuth and in slant range. The data are represented complex, i.e. each sample consists of a real and an imaginary part. The product contains all spectral information and phase information so that any other product can be generated at a later time.

5.2 Multi Look Ground Range Detected (MGD)

The MGD is a multi-look product with reduced speckle and approximately square ground resolution cells. The image co-ordinates are oriented along flight direction and along ground range. The pixel spacing is equidistant in azimuth and in ground range. A simple polynomial projection is performed in range to an ellipsoid in order to achieve approximately quadratic pixels.

5.3 Geocoded Ellipsoid Corrected (GEC)

The GEC is a multi-look detected product. It is projected and re-sampled to either UTM or UPS with WGS84 as reference and assuming one average terrain height. The pixel spacing is equidistant in northing and easting.

5.4 Enhanced Ellipsoid Corrected (EEC)

Like MGD and GEC, the EEC is a multi-look detected product. However it is projected and re-sampled to either UTM or UPS using the WGS84 reference and a Digital Elevation Model (DEM). The pixel spacing is equidistant in northing and easting. Terrain induced distortions are corrected and the pixel location of these products is very accurate. The best available DEM will be compiled from different sources. The backbone will be SRTM/X-SAR with 30 m resolution supplemented with elevation data of similar quality from other sources. Areas where no better elevation data can be acquired will be filled with the 1km GLOBE data set.

Two resolution variants will be offered for each of the detected products MGD, GEC and EEC. One is optimised with respect to the spatial, the other with respect to radiometric resolution. The spatially enhanced product is designed for the highest possible ground resolution while the radiometrically enhanced variant improves the radiometry by multi-looking.

6. APPLICATION POTENTIAL

The potential of TerraSAR-X is based on a combination of new features of the SAR instrument not being operationally available from space before:

- High geometric and radiometric resolution with an experimental very high resolution 300 MHz mode,
- single-, Dual- and Full- Polarisation modes
- new imaging modes like ScanSAR and Spotlight Mode,
- the possibility of Repeat-pass as well as Along Track Interferometry (ATI) (R. Romeiser, 2002) for moving target indication, and
- the highly flexible active phased array antenna enabling the realisation of new imaging modes (like Along-track interferometry, Moving Target Identification, etc.).

These features in conjunction with

- the precise attitude and orbit control and determination as well as phase stability e.g. for Repeat-Pass interferometry,
- the high synergy potential with other frequency bands and
- the long term observation with the opportunity for multi-temporal imaging

provide unique capabilities for a broad spectrum of applications like environmental and disaster monitoring, hydrology, geology, oceanography as well as cartography.

The very high resolution, the multi-polarization and multi-incidence angle capability of TerraSAR-X open very interesting perspectives for the mapping and monitoring of urban areas (F. Henderson, 1999; A. Bennet, 2003; M. Karjalaiinen, 2003). It also provides new capabilities for topographic mapping (U. Wegmüller, 2003), DEM generation (T. Toutin, 1999) and road network detection (F. Tupin, 1998). Disaster assessment requires the availability of high resolution data as well.

Interferometric applications like coherence analysis (T. Strozzi, 1998), differential interferometry and permanent scatterer technique (A. Feretti, 2001; M. Kircher, 2003) can be applied.

7. GROUND SEGMENT

The major elements of the TerraSAR-X Ground Segment are

- the space segment consisting of platform and SAR instrument,
- the overall ground segment and
- the user segment with two the categories science and commercial users.

The TerraSAR-X ground segment and it's service infrastructure act as the interface between the user services and the spacecraft. It controls and operates the TerraSAR-X satellite platform as well as the SAR sensor, performs all issues required for the instrument calibration, acquires and archives the SAR data and generates the basic products. The ground segment is provided and operated by DLR while Infoterra coordinates the exploitation and service infrastructure.

The DLR Ground Segment is composed of three major elements (S. Buckreuss, 2003),

- the Mission Operations Segment (MOS),
- the Instrument Calibration Segment (IOCS) and
- the Payload Ground Segment (PGS).

The PGS is additionally provides the order interface and product provision facility for the scientific user community.

The TerraSAR-X Ground Segment is in the development phase. It is based on experience and systems from previous missions like SIR-C/X-SAR, SRTM and ERS/Envisat. The development phase will end after the commissioning phase which is planned for October 2005.

8. CONCLUSION

TerraSAR-X will provide for the first time from space very high resolution SAR data in different polarization. The satellite control and commanding, the instrument calibration, the data acquisition, archiving and processing will be performed by DLR. DLR will also provide the user segment for scientific applications while the commercial sector will be coordinated through the Infoterra GmbH.

Three different modes will be available providing different resolutions. Operationally the TerraSAR-X antenna will operate in single and dual polarisation mode. The experimental dual receive antenna mode enables full polarisation and along track interferometry capability. A variety of SAR products will be offered ranging from the single look complex product to the enhanced ellipsoid corrected and geocoded data set, where SRTM and other DEM sources will be utilised for terrain correction of the SAR data.

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