The Sentinel-1 C-SAR Instrument Design & Performance

F. Rostan, EADS Astrium GmbH, Germany
S. Riegger, EADS Astrium GmbH, Germany
M. Huchler, EADS Astrium GmbH, United Kingdom
R. Croci, Thales Alenia Space Italia S.P.A., Italy
R. Torres, European Space Agency, The Netherlands
P. Snoeij, European Space Agency, The Netherlands.

Abstract

The ESA Sentinels constitute the first series of operational satellites responding to the Earth Observation needs of the EU-ESA Global Monitoring for Environment and Security (GMES) programme. The GMES space component relies on existing and planned space assets as well as on new complementary developments by ESA. This paper describes the Sentinel-1 mission, an imaging synthetic aperture radar (SAR) satellite constellation at C-band. It provides an overview of the mission requirements, its applications and the technical concept for the system.

1 Introduction

'Global Monitoring for Environment and Security (GMES)' is a joint initiative of the European Commission (EC) and the European Space Agency (ESA), designed to support Europe's goals regarding sustainable development and global governance of the environment by providing timely and quality data, information, services and knowledge.
In the frame of the GMES programme, ESA is undertaking the development of the European Radar Observatory Sentinel 1, a European polar orbiting multi-satellite system for the continuation of SAR operational applications. Sentinel-1 is an imaging radar mission in C-band, aimed at providing continuity of data for user services, in particular with respect to the ESA ERS and Envisat missions.

2 The Sentinel-1 System

Sentinel-1 is an imaging Synthetic Aperture Radar mission at C-band. The design of its system has been driven by the need for continuity of ERS/Envisat class data provision with improved revisit, coverage, timeliness and reliability of service. Its main technical characteristics are listed below. Sentinel-1 is being realized by an industrial consortium lead by Thales Alenia Space Italy as Prime Contractor, with Astrium Germany being responsible for the C-SAR payload, incorporating the central radar electronics sub-system developed by Astrium UK.

Figure 1. Artist impression of Sentinel-1A

3 C-SAR Instrument Design

The Sentinel-1 mission requirements ask for data products with different image characteristics, which require the implementation of four different measurement modes:

- Interferometric Wide Swath Mode
- Wave Mode
- Strip Map Mode
- Extra Wide Swath Mode

Except for the Wave Mode, which is a single polarization per vignette mode (HH or VV), the SAR instrument has to support operation in dual polarisation (HH-HV, VV-VH), which requires the implementation of one transmit chain (switchable to H or V) and two parallel receive chains for H and V polarisation.

The specific needs of the four different measurement modes with respect to antenna agility require the implementation of an active phased array antenna.

To meet the ambitious image requirements, the Interferometric Wide Swath mode has to be implemented as a ScanSAR mode with progressive azimuth scanning. This requires a fast antenna beam steering in elevation for ScanSAR operation, i.e. transmitting a burst of pulses towards a sub swath. In addition, fast electronic azimuth scanning has to be performed per sub swath (TOPS operation [1]) in order to average the performance in along track direction (reduction of scalloping). Hence, the Interferometric Wide Swath mode will allow combining a large swath width (250 km) with a moderate geometric resolution (5 m x 20 m). Interferometry has to be ensured by sufficient overlap of the Doppler spectrum (in the azimuth domain) and the wave number spectrum (in the elevation domain).

The Wave mode data product is composed of single stripmap operations with an alternating elevation beam (between 23 and 36.5 mid incidence angle) and a fixed on/off duty cycle, which results in the generation of vignettes of 20 km x 20 km size in regular intervals of 100 km.

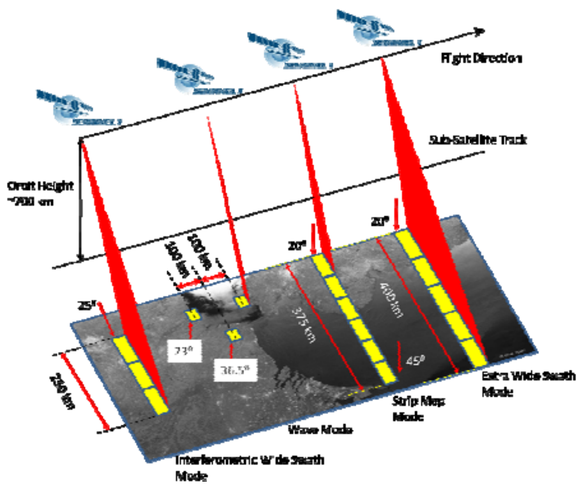

Figure 2. Sentinel-1 Operational Modes

Extra Wide Swath mode and Wave mode complement the SAR data products. In Extra Wide Swath mode a huge swath width of 400 km has to be covered with low resolution (20 m x 40 m), which can be met by the implementation of a ScanSAR mode with a fast beam scanning capability in elevation. As the Interferometric Wide Swath mode also the Extra Wide Swath mode is implemented with a progressive azimuth scanning (TOPS operation).

In Strip Map mode the instrument has to provide an uninterrupted coverage with a high geometric resolution (5 m x 5 m) at a medium swath width of 80 km. Six overlapping swathes cover the required access range of 375 km. For each swath the antenna has to be configured to generate a beam with fixed azimuth and elevation pointing. Appropriate elevation beam forming has to be applied for range ambiguity suppression.

4 Instrument Architecture and Functionality

The radar signal is generated at baseband by the chirp generator and up-converted to C-band within the SAR electronics. This signal is distributed to the High Power Amplifiers inside the Transmit/Receive Modules via the beam forming network of the SAR antenna. Signal radiation and echo reception is realized with the same antenna using slotted waveguide radiators. In receive, the echo signal is amplified by the low noise amplifiers inside the Transmit/Receive Modules and summed up using the same network as for transmit signal distribution. After filtering and down conversion to baseband inside the SAR Electronics, the echo signal is digitised and formatted for recording. Table III provides a brief overview on the instrument key parameters.

The key design aspects of the C-SAR Payload can be summarized as follows:

- Active phased array antenna providing fast scanning in elevation (to cover the large range of incidence angle and to support ScanSAR operation) and in azimuth (to allow use of TOPS technique to meet the required image performance)
- Dual channel Transmit & Receive Modules and H/V-polarised pairs of slotted waveguides (to meet the polarisation requirements)
- Internal Calibration scheme, where transmit signals are routed into the receiver to allow monitoring of amplitude/phase to facilitate high radiometric stability
- Metallised Carbon Fibre Reinforced Plastic radiating waveguides to ensure good radiometric stability even though these elements are not covered by the internal calibration scheme
- Digital Chirp Generator and selectable receive filter bandwidths to allow efficient use of on board storage considering the ground range resolution dependence on incidence angle
- Block Adaptive Quantisation to allow efficient use of on-board storage and minimise downlink times with negligible impact on image noise

A three dimensional view of the SAS Tile, which is the elementary building block of the SAR Antenna Subsystem, is given in Figure 3.

TABLE I. INSTRUMENT KEY PARAMETERS

Parameter	Value
Centre Frequency	5.405 GHz
Instrument Mass	945 kg
DC-Power Consumption	4075 Watt (Interferometric Wide Swath Mode, two polarisations)
Bandwidth	0 … 100 MHz (programmable)
Polarisation	HH-HV, VV-VH
Antenna Size	12.3 m x 0.821 m
RF Peak Power (sum of all TRM, at TRM o/p)	4368 W
Pulse Width	5-100 us (programmable)
Transmit Duty cycle	
• max	12%
• Strip Map	8.5 %
• Interferometric Wide Swath	9 %
• Extra Wide Swath	5 %
• Wave	0.8%
Receiver Noise Figure at Module input	3 dB
Pulse Repetition Frequency	1000- 3000 Hz (programmable)
ADC Sampling Frequency	260 MHz (real sampling) (Digital down-sampling after A/D conversion)
Sampling	10 bits
Data Compression	Selectable according to FDBAQ

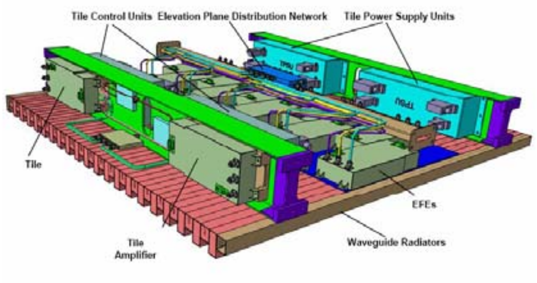

Figure 3. Three-Dimensional View Of The SAS Tile Layout

Important to mention is also the roll steering mode of the spacecraft. This continuous roll manoeuvre around orbit (similar to yaw steering in azimuth) compensates for the altitude variation such that it allows usage of continuous pulse repetition frequency (PRF) and a minimal number of different sample window lengths (SWLs) round the orbit. In addition, the update rate of the sampling window position around orbit is minimised (< 1 /2.5 min), which simplifies instrument operations significantly. Since the instrument can work with a single fixed beam for each swath/sub-swath over the complete orbit, also the number of elevation beams is minimised. The roll steering rate has been fixed to 1.6 deg/ 27 Km altitude variation. The roll applied to the sensor attitude depends linearly on altitude and varies within the interval -0.8 deg (minimum sensor altitude) to 0.8 deg (maximum sensor altitude).

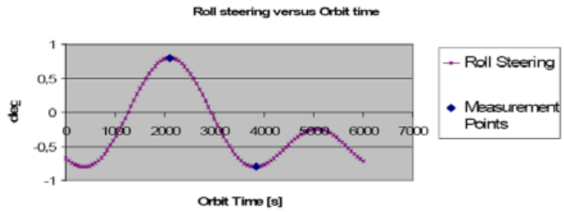

Figure 4. Variation of the roll angle along the orbit

5 Conclusions

The Sentinel-1 synthetic aperture radar (SAR) constellation represents a completely new approach to SAR mission design by ESA in direct response to the operational needs for SAR data expressed under the EU-ESA Global Monitoring for Environment and Security (GMES) programme. The mission ensures continuity of C-Band SAR data to applications and builds on ESA's heritage and experience with the ERS and ENVISAT SAR instruments, notably in maintaining key instrument characteristics such as stability and accurate well-calibrated data products. At the same time a number of mission design parameters have been vastly improved to meet major user requirements collected and analysed through EU Fast Track and ESA GSE activities, especially in areas such as reliability, revisit time, geographical coverage and rapid data dissemination. As a result, the Sentinel-1 constellation is expected to provide near daily coverage over Europe and Canada, global coverage all independent of weather with delivery of radar data within 1 hour of acquisition – all vast improvements with respect to the existing SAR systems.

References

[1] De Zan, F., Monti Guarnieri, A.M., "TOPSAR: Terrain Observation by Progressive Scans", IEEE Transactions on Geoscience and Remote Sensing, Volume 44, Issue 9, Sept. 2006 Page(s): 2352 – 2360.