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HRWS: The upcoming German X-Band Spaceborne SAR Mission

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Abstract

This paper presents the High-Resolution Wide-Swath (HRWS) mission as the next German civilian spaceborne Synthetic Aperture Radar (SAR) system for earth observation in X-Band. Following the successful path of the TerraSAR-X and TanDEM-X missions, HRWS is designed to guarantee the X-band data and service continuity for institutional, scientific and commercial users well beyond the year 2030. HRWS is a very innovative multistatic SAR mission exploiting the formation flight of one active main satellite and three smaller passive companion satellites. With HRWS the novel MirrorSAR concept will be implemented in space for the first time. The HRWS mission has been approved for realization in December 2020 and, as for the current planning, the launch is expected in the time frame of 2026/2027. This paper presents an overview of the outstanding capabilities and new technologies of HRWS, including F-SCAN, digital beam-forming, hybrid agility, and single-pass dual-baseline interferometry, as well as the various fields of applications.

1 Introduction

Since 2007 and 2010 respectively, the TerraSAR-X (TSX) and TanDEM-X (TDX) missions have provided X-Band data on a reliable operational basis including the unrivalled global WorldDEM coverage [1, 2]. The next significant milestone in the German X-Band SAR roadmap will be the HRWS mission. The mission is designed to deliver the next levels of data quality, quantity and availability, fully meeting the requirements of the upcoming decade, while ensuring seamless X-Band data and service continuity for scientific, public institutional and commercial users beyond the year 2030.

2 Mission Concept

The HRWS mission is to be flown in the same orbit as TSX, at ca. 514 km altitude in a sun-synchronous dusk-dawn orbit with a repeat ground-track cycle of 11 days.
The HRWS space segment consists of a master satellite with a highly performant phased array SAR instrument, and three companion satellites flying in a close helix formation, ca. 15 km ahead of the main satellite (**Figure 1**). This challenging formation was chosen in order to implement the novel MirrorSAR concept developed by the DLR Microwaves and Radar Institute [3].
The master and the companions are interconnected by an RF inter-satellite link for exchange of phase synchronization pulses and radar raw signals. The companions host a transponder-like receive-only sensor. As will be discussed below, the superior imaging characteristics will be achieved by means of digital beam forming and fractionated radar architecture. In addition, using the new ITU frequency allocation in X-band (allowing a bandwidth of up to 1200 MHz), a frequency scanning functionality (F-SCAN) for the main satellite was developed and proposed by Airbus during the phase A study [4] and approved by the DLR Space Administration for implementation.

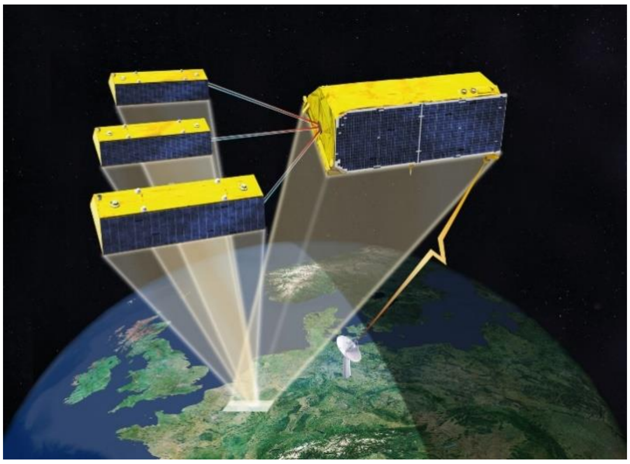

Figure 1 HRWS space segment.

2.1 HRWS Main Satellite

In stand-alone mode, the HRWS master instrument is a classical monostatic SAR sensor. The great variety of required SAR products, ranging from high-resolution spotlight modes via medium-resolution strip-map modes to low-resolution Scan-SAR modes, clearly leads to the phased array technology.
In single-pass interferometry mode, the HRWS master instrument will take the role of the illuminator, digitizer and data collector within the multistatic formation. This is made possible by the inter-satellite link, which directly connects to the RF electronics of the instrument.

2.1.1 Antenna Architecture

The antenna architecture in the current baseline design, including the partitioning into leaves and IFETs, is sketched in **Figure 2**. The antenna is sub-divided into four leaves. Every leaf consists of 3 x 4 integrated front-end tiles (IFETs). The IFET represents a fully functional phased array tile and forms the smallest functional entity of the X-band SAR antenna front-end, encompassing all

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functions necessary to ensure beam steering and beam shaping of the phased array antenna. Electrically, the IFET comprises TEM radiators, T/R modules, switchable true time delay lines (TTDLs), and a power and control unit.

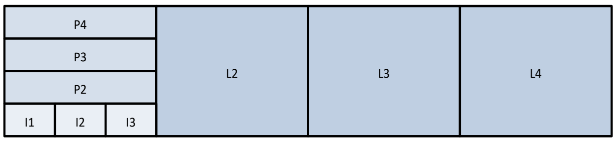

Figure 2 HRWS master antenna architecture.

2.1.2 Digital Beamforming

All monostatic SAR modes make use of digital beamforming (DBF) using the Multiple Aperture Phase Centers (MAPS) approach [5]. The HRWS master instrument comprises four receiver channels, each capable of handling the entire signal bandwidth of 1200MHz. The allocation of these receiver channels on sub-apertures and on both polarizations is quite flexible, which is exploited by SAR mode design. The summation stage of the digital beam former is implemented within the SAR processor in the ground segment and not on-board the spacecraft. For MAPS, this is no disadvantage, since the signal information (and thus the data rate) before and after the MAPS processing stage remains almost constant.

2.1.3 F-SCAN

The HRWS master instrument allows for controlling the beam dispersion in azimuth or elevation direction.

F-SCAN is an analogue beamforming technique that can be implemented with much less hardware complexity than a full digital beamforming system by using an analogue frequency scanning approach in elevation [4] (**Figure 3**).

Usually, e.g. in high-resolution spotlight modes, beam dispersion is not desired, and hence minimized by controllable TTDLs. In this case the TTDLs, which are distributed across the entire antenna, are configured such that a plane wave front impinging from the scene onto the phase centers of the receive aperture experiences a uniform time delay until the final beam summation stage. In transmit direction, the principle is the same.

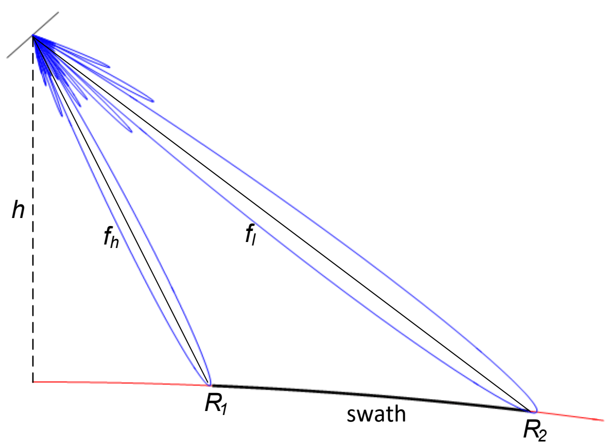

Figure 3 Active phased array antenna at altitude h. Highest frequency f_h, lowest frequency f_l.

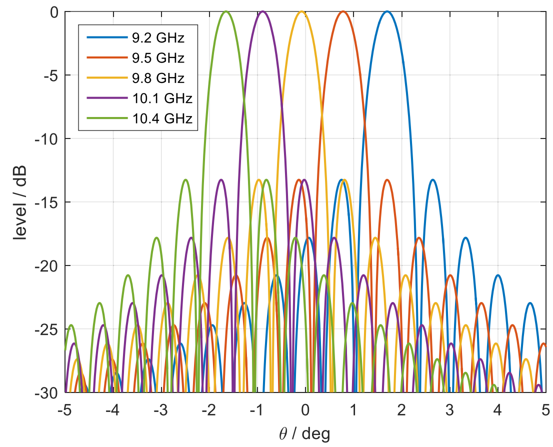

Figure 4 Antenna pattern for dispersive elevation beam.

In HRWS the goal of F-SCAN is to illuminate the entire swath width with a scanning pencil beam both in transmit and in receive direction (**Figure 3**). The swath width should be large compared to the elevation pencil beam. Another pre-condition is that sufficient excess bandwidth is available (**Figure 4**). Under these conditions F-SCAN improves the NESZ of the SAR mode similar to SCORE [6] (i.e. DBF in elevation). Furthermore, due to the characteristics of the 2-way pencil beam pattern, F-SCAN ameliorates the range ambiguity ratio (RAR) in relation to SAR modes that are based on widened elevation beams.

2.1.4 Hybrid Agility

Hybrid agility is a concept that combines the three axes platform agility (roll, pitch, and yaw) provided by the control momentum gyro (CMG) actuators, and the two-dimensional electronic beam agility (u,v) of the SAR instrument during and in between acquisitions.

Thanks to the hybrid agility of HRWS, the so-called theatre mode will be able to acquire up to eight staring spotlight regions with 7.5 x 7.5 km^2 coverage and 25cm resolution within an area of interest of 100 x 100km^2 (**Figure 5**).

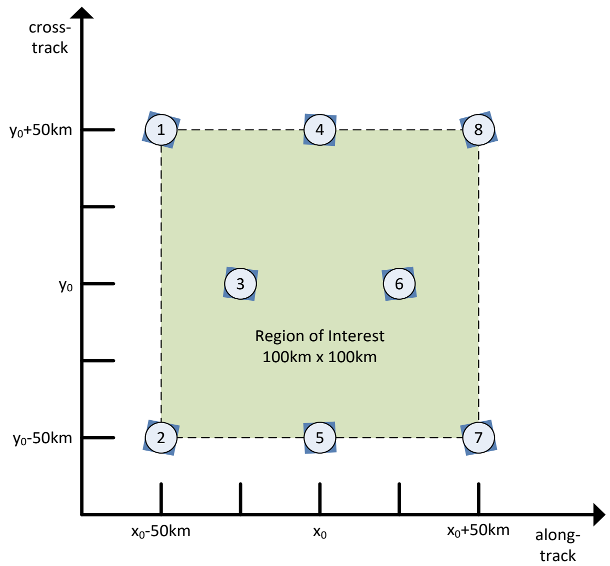

Figure 5 HRWS theatre mode scenario.

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Such a scenario would not be possible without platform agility, since the electronic steering angle of a space-borne phased array SAR is in general very limited in azimuth dimension.

2.2 HRWS Companions

The HRWS companions are passive SAR sensors (see **Figure 1)**. The received SAR echo signals are low-noise amplified, frequency-shifted to one of the Mirror-Link frequency bands, and transmitted via the Mirror-Link to the HRWS master instrument. For phase synchronization, the master instrument regularly transmits radar pulses via the Sync-Link, which are mirrored by the companion instruments back to the master instrument.
Due to the simplicity of this concept, the hardware and thermal design of the companion satellites is considerably reduced. The companion instrument requires no mode timing, no ADC, no mass memory, and no payload data downlink, which lowers their mass, size and power demand. Thanks to the three companions, single-pass dual-baseline interferometry is provided, which offers significant benefits to interferometric processing compared to sequential single-baseline acquisitions.

2.3 Multistatic operation using MirrorSAR

The HRWS multistatic acquisitions are based on the MirrorSAR concept, as depicted in **Figure 1**.
Since the companion spacecrafts will fly in a dual helix with ca. 15 km mean distance to the main satellite, and considering their very different ballistic properties with respect to the main satellite, it has been decided that the HRWS main satellite follows the companions in order to allow for passive security.
In the multistatic mode the main satellite will illuminate the area of interest and at the same time transmit direct Tx pulses to the companions. The companions receive the ground reflected SAR signal and the direct Tx pulses which will be inserted in the SAR signals. Both are then transmitted (mirrored) back to the main satellite where the actual SAR signal processing, on-board storage and down link to the ground station network is performed.
The HRWS multistatic mode will primarily be used for the flexible generation of high-quality Digital Elevation Models (DEMs) from local to regional to global scales. For DEM acquisition a dedicated multistatic Stripmap mode will be utilised. The regional DEMs will provide a plot spacing of 4m and a relative vertical accuracy, defined as the uncertainty in height between two points caused by random errors and specified as linear errors at a 90% confidence interval, of 2 m for low to medium relief areas (predominant slope from 0 to 20 %) within the data cell and 2.8 m for areas where the predominant slope exceeds 20 %.
Main advantages of the multistatic configuration with three companions are that the high-quality regional DEMs can be ordered on demand since the required data can be generated in just one pass, thus reducing the latency from ordering to product delivery significantly.

3 Fields of Application

Based on a survey of the HRWS user needs, several geo-information products and services have been identified for implementation in the HRWS service segment: i) surface movement mapping, ii) ground control point generation, iii) change detection product generation, iv) maritime surveillance, v) radargrammetry and vi) digital elevation model generation.
Furthermore, the multistatic capabilities of HRWS will also foster new, innovative applications such as 3D/4D volumetric change detection, sea ice topography, SAR tomography over urban areas, ground moving target indication (GMTI), as well as, a large variety of scientific applications.

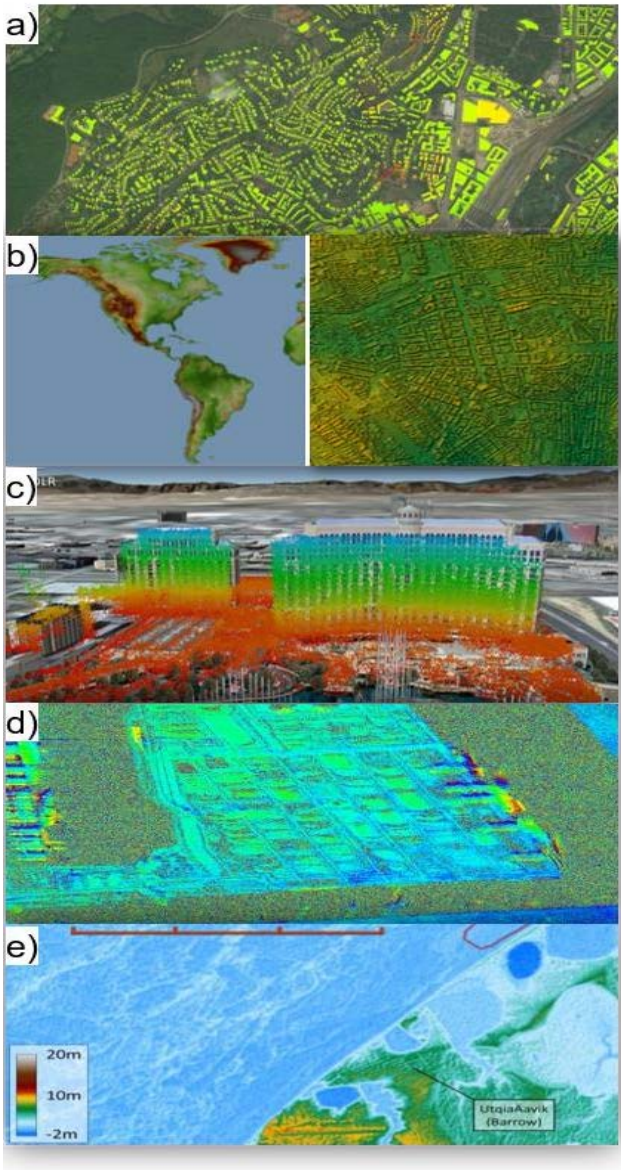

Figure 6 HRWS interferometric and multistatic capabilities: a) Surface motion detection with millimetric precision; b) Global, local and regional on-demand high-resolution DEMs; c) 3D reconstruction using SAR tomography; d) 3D/4D change detection; e) Sea ice topography monitoring.

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4 Conclusions and Outlook

The innovative SAR System HRWS will provide continuity to the German spaceborne SAR program in X-band after the TerraSAR-X and TanDEM-X missions. New imaging technologies and an innovative multistatic mission concept allow the fulfillment of the demanding user requirements in scientific, commercial, institutional and security related applications. The use of digital beamforming by means of MAPS (multiple phase centers in azimuth) in connection with F-SCAN (frequency scanning in elevation) offers a less complex SAR instrument implementation for high-resolution, wide-swath imaging. In addition, a new class of DEM will be generated by the MirrorSAR concept with a fractionated radar architecture. The phase B of the HRWS mission is expected to start later this year and the launch is currently planned for 2026/2027 timeframe.

5 Literature

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