The DLR High Altitude Platform Synthetic Aperture Radar Instrument HAPSAR

Matthias Jirousek[a], Markus Peichl[a], Simon Anger[a], Stephan Dill[a], Markus Limbach[a]
[a] German Aerospace Center DLR, Muenchener Str. 20, 82234 Wessling, Germany,

Abstract

Amidst ever-evolving challenges and simultaneously emerging technological opportunities, the German Aerospace Center (DLR), is actively engaged in the development of a stratospheric aircraft named High-Altitude Platform α (HAP-α) [1, 5]. Such a HAP provides the capability to remain stationed at altitudes ranging from 15 km to 25 km for months on end. This facilitates continuous monitoring of a specific region of interest for a multitude of applications, particularly in the realms of climate research and security.
To achieve this goal, various remote sensing sensors tailored to the environmental and operational conditions of a HAP need to be developed. In its foundational configuration, these encompass a high-resolution optical camera (MACS) [2] and the Synthetic Aperture Radar (SAR) system known as HAPSAR. In this article, we provide a more detailed description of the HAPSAR instrument [9], currently under construction. We delve into the fundamental concept, structural design, and individual components of this system.

1 Motivation for Observation with High-Altitude Platforms

An essential aspect of observation using High-Altitude Platforms (HAPs) is the continuous monitoring of specific target areas. This is particularly crucial in climate research to observe changes over extended periods, in crisis zones to assess the aftermath of natural disasters, or in maritime contexts for tracking ship routes. Satellites in low Earth orbit, primarily employed in global remote sensing, offer only brief dwell times in target areas, typically just a few seconds. Similarly, conventional manned or unmanned aircraft also have limited dwell times and range for sustained observation. It's this very gap that various HAP platforms aim to address [4].
In the realm of HAP platforms, heavier-than-air glider systems, in contrast to stationary balloons or airships, emerge as standout candidates due to their capacity to swiftly cover extensive areas. Furthermore, these glider systems possess the critical advantage of relative motion above the Earth's surface, a prerequisite for effective Synthetic Aperture Radar (SAR) imaging. However, addressing the unique demands and enduring the rigorous environmental conditions encountered at HAP altitudes necessitates the development of a tailor-made radar system.

2 The DLR HAP Aircraft

The HAP-α aircraft, developed by the German Aerospace Center (DLR), is an unmanned solar-powered aircraft with a 27-meter wingspan, a 136-kilogram takeoff weight (including a 5-kilogram payload), and is designed to operate at 20 kilometers altitude for research above weather turbulence and air traffic.

Figure 1 Artist view of DLR's HAP-α with HAPSAR integrated in the aircraft nose.

In addition to the aircraft itself, deploying a HAP in the stratosphere requires the establishment of a mobile ground station (as depicted in Figure 2) and the programming of a flight controller. The ground station serves as a hub for controlling, monitoring, and transmitting data from both the platform and the installed payload. This is achieved through two radio links [3]:

- Control and Command (C2) Link: A bidirectional S-band link is employed for flight control.
- Data Transmission Link: A unidirectional X-band link with a theoretical transmission rate of up to 100 Mbit/s is used for transmitting high volumes of payload data to the ground.

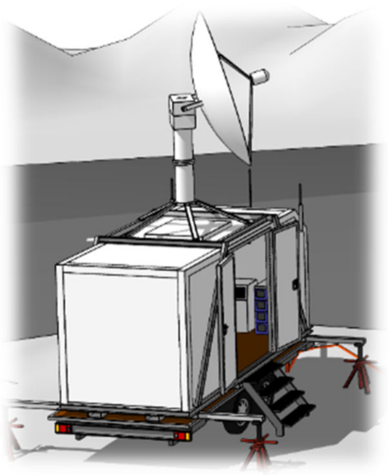

Figure 2 Artist view of DLR's HAP-α ground station.

DLR develops in addition to a flight recorder, two payload sensor system, a high-resolution wide area optical camera, known as MACS. Furthermore, a high-resolution and adaptable radar system is currently under development. The primary challenge is to maintain the HAPSAR system's weight under 5 kilograms and power consumption below 250 watts while ensuring reliable operation over extended distances, up to 30 km from the target area.
To achieve the required weight reduction for the active radar system, an innovative design is essential. The radar system is situated in the fuselage's nose of HAP, with a specially tailored compartment for payloads, as seen in Figure 3. This design incorporates a microwave-transparent radome seamlessly, eliminating the need for additional struts, thus preserving the antenna's directional performance.
The remaining compartment is covered by a tent-like fabric stretched over a CFRP (carbon-fiber-reinforced polymer) sandwich support structure, located outside the antenna beam. The transparent cover, shown in Figure 3, provides a view of the radome's interior. The grey antennas are mounted on a CFRP support structure, while the radar's electronic components are positioned at the rear. To prevent excessive cooling during standby mode, the radar is encased in an insulating green cover. An inlet-controlled airflow is directed into the compartment to cool vital components in the upper ochre unit.

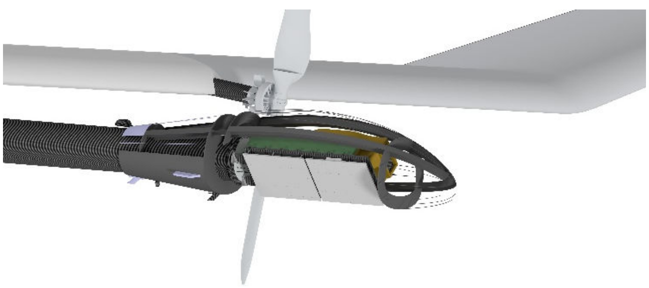

Figure 3 HAPSAR in a transparent compartment at the nose of the fuselage.

3 Developing a Dedicated Pulse Radar for HAP

In order to cater to the versatile SAR modes outlined in the previous section and to align with the unique requirements of High-Altitude Platforms (HAPs), a specialized pulse radar was meticulously crafted. After evaluating power and aperture size considerations, along with scene size specifications, it was decided to employ an S-band radar equipped with two antennas for transmit (TX) and receive (RX) functions, boasting a maximum transmit power of 20 W. The schematic structure of the sensor is depicted in Figure 4 and comprises five core components, Central Processing Unit (CPU), digital unit, Integrated Radar Electronic (IRE), the transmit power amplifier (TX HPA) and the Antennas. These components are described in more detail.
The interface to both the platform and the ground station is established through LAN connections, as detailed earlier. Additionally, crucial information from the HAP is received via a CAN bus.

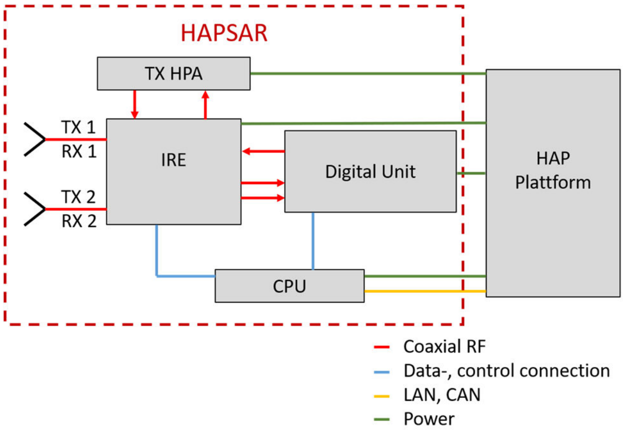

Figure 4 HAPSAR instrument block diagram with the main parts.

Notably, the radar system's key parameters are summarized in Table 1, emphasizing the favourable weight-to-output power ratio and performance values, particularly the Noise Equivalent Sigma Zero (NESZ). This is achieved by employing a high Pulse Repetition Frequency (PRF) in combination with extended pulse durations, capitalizing on the platform's low speed and the expansive synthetic aperture facilitated by the high altitude and broad azimuth antenna pattern. The blocks contributing to the performance are described next.

Tabel 1: HAPSAR instrument main specification

Specification	**Value**
Frequency	3.25 GHz
Bandwidth	300 MHz
Range	> 30 km
Incident angle	45° nominal
Swath width	> 5 km – 10 km
Resolution	< 0.7 m
NESZ	< -20 dB

Max transmit power	20 W
Max PRF	2.5 kHz
Max pulse duration	150 µs
Antenna concept	2x TX, 2x RX
Weight of whole system	≈ 5 kg
Electric Power	< 250 W
Max operating Temperature	40°C
Min operating Temperature	-20°C
Air pressure min	15 mbar

3.1 Radar sub-components

Starting with the heart of HAPSAR, the CPU situated on a specially designed carrier board. This CPU carrier board serves as the central hub for HAPSAR, handling responsibilities such as communication with the ground station, image control, and peripheral tasks like temperature management and power control. The power supply for HAPSAR is managed through the HAP power distribution unit, which delivers power from either the onboard batteries or the solar generator. The CPU itself is a COM Express (COMe) module featuring an 11th generation Intel i7 processor, 48 GB of DDR4 RAM. The carrier board is equipped with SATA and NVMe memory, a LAN switch, and VPX support, as depicted in Figure 5. The COMe Module is equipped with a heat spreader on the central left side, while the VPX connection to the digital unit is located on the right, demonstrating a backplane configuration.

Figure 5 CPU carrier board with COMe Modul, VPX and periphery connection.

The VPX digital unit, as shown in Figure 6, is tasked with GNSS synchronized signal generation and recording, encompassing digital up/down conversion directly to the S-band and precise timing control. Real-time functionality is executed through an FPGA, connected to the COMe CPU via PCIe. Within this setup, a DAC operating at 12 GS/s and a dual-channel ADC operating at 6.4 GS/s, both located on a daughter card, handle the generation and sampling of RF signals. Subsequently, the data is stored in onboard RAM and subjected to pre-processing to facilitate data reduction.

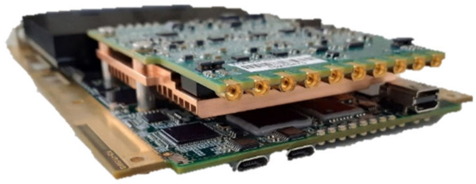

Figure 6 Digital unit, FPGA based processing and daughter card with ADC and DAC circuits.

The relative slow speed of the HAP and resulting long integration time requiring a stable and low phase noise oscillator in a small and lightweight package. The Global Positioning System Disciplined Oscillator (GNSSDO) offers in conjunction with double oven-controlled crystal oscillator an excellent base clock signal (Figure 7).

Figure 7 Small lightweight Global Positioning System Disciplined Oscillator (GNSSDO) with a double oven-controlled crystal oscillator (OCXO).

The radar frontend is housed within the IRE. The IRE primarily consists of filters, amplifiers, and variable attenuators to condition signals for both the TX HPA on the transmission side and ADC on the reception side. Within the modular RF design, the various paths, including TX, two RX, and antenna connection module, are integrated into separate aluminum-shielded enclosures. These enclosures are assembled into two towers and mounted on a plate, as depicted in Figure 8. This distinctive appearance is a result of weight constraints. In addition to the radar electronics, the TX HPA is housed in a separate enclosure (Figure 9), with the specific aim of achieving thermal and electrical isolation. The pulsed amplifier boasting an output power exceeding 20 W while maintaining a remarkably light weight of only 150 grams.

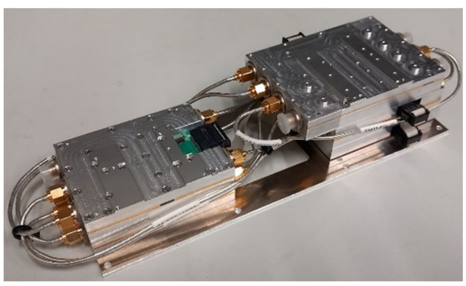

Figure 8 IRE (Integrated Radar Electronics) processes RF-signals to the required level.

Figure 10 HPA: pulse amplifier with more than 20 W pulsed output power and only 150 g weight

Signals can be alternately radiated on either of the two antennas to serve the several modes including strip map, video SAR, GMTI/MMTI [6, 7, 8], which requires multiple phase centers. The antennas, shown in Figure 10, are in-house designed very lightweight 260 g single polarized dual-stacked patch antennas with 20 elements, 4 rows @ 5 patches. The design and feeding network on the back side of the antenna, shown in gold, includes a tapering and enables an 18 dBi gain with almost 30 dB sidelobe suppression. The 3D antenna diagram of the compact test range CTR measurement is shown in Figure 11. The beamwidth is adapted to the HAPSAR requirements to compensate in azimuth for the platform yaw angle and in elevation for the pitch angle and the ground range projection.

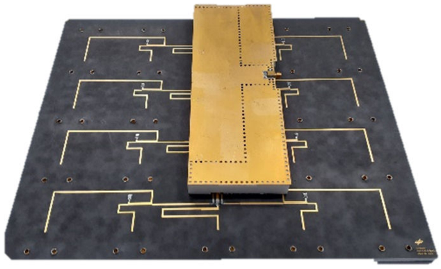

Figure 10 Antenna: 260 g dual-stacked patch antenna.

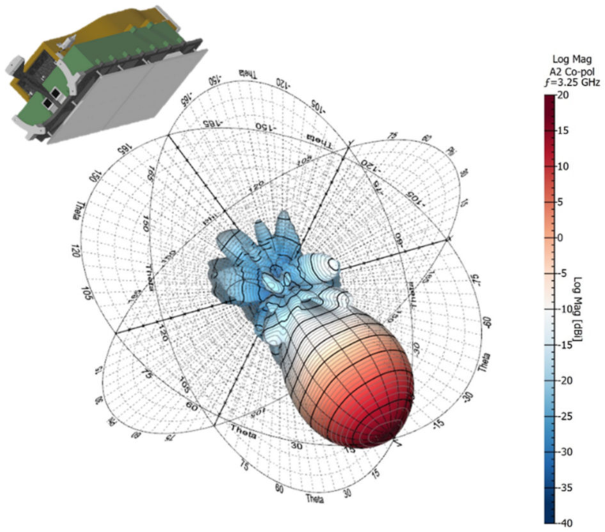

Figure 11 3D antenna diagram of the CRT measurement.

In addition to the GNSSDO module, a High-Performance Inertial Navigation System (HPINS) is employed to acquire precise spatial and orientation data, which is indispensable for achieving precise processing and SAR focusing. This unit combines an Epson Inertial measurement unit (IMU) with a dual-antenna Novatel GNSS receiver to deliver top-tier performance (Figure 12).

Figure 12 HPINS based on Novatel dual antenna GNSS receiver and Epson IMU

Conversely, this necessitates a stringent weight limitation to meet the prescribed parameters for weight and cooling performance. Figure 13 illustrates the initial unit, constructed using CFRP sandwich plates arranged in a T-configuration as the load-bearing structure. This structure is later fixed to the HAP through three attachment points. In the figure, an aluminium structure is utilized as a support for laboratory purposes. The structure is designed to withstand forces up to 2g acceleration, incorporating a double safety factor.
The five major units of the HAPSAR instrument can be observe on the base plate. The digital components are situated on the left side, and due to the radar's side-view configuration, they are positioned above the analog components. In the digital section, the CPU board is mounted near the HAP spars' connection to ensure the shortest possible cable routing. The FPGA board, is attached to the board via a tailored VPX backplane. On the analog side, you'll find the high-frequency components and the HPINS. To minimize cable lengths, the radar electronics are positioned in close proximity to the FPGA board, with the HPA and HPINS situated towards the rear.

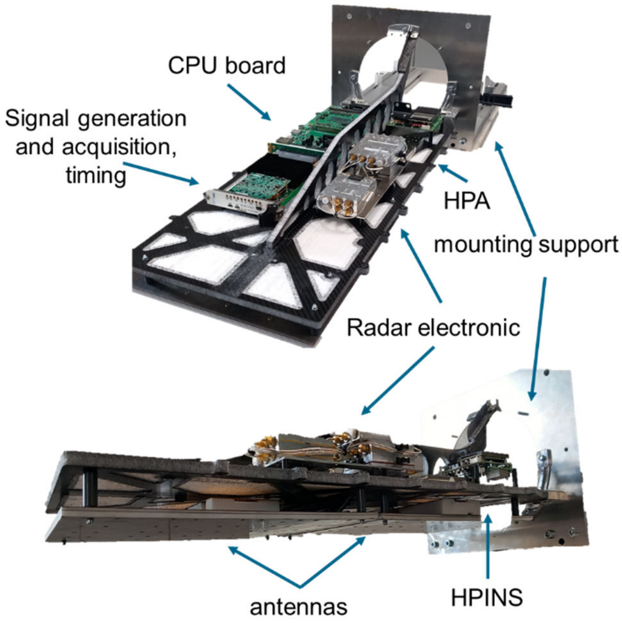

Figure 13 HAPSAR components mounted on the structure in the laboratory holder

4 Conclusion

High altitude platforms serve as a bridge between conventional aircraft and satellite-based observation systems. They provide the capability for uninterrupted monitoring spanning several months and possess the adaptability to traverse extensive distances, allowing them to access diverse regions across the globe. Achieving this, however, necessitates the development of specialized sensors that align with the platform's unique parameters and can endure the challenging atmospheric conditions. The flexible HAPSAR radar system enables data acquisition independently of weather conditions and time of day. Furthermore, the high-resolution instrument, in conjunction with the dual TX/RX antennas, offers a range of operational modes suitable for various mission scenarios. Coping with the substantial data volumes, the system conducts onboard data reduction using diverse techniques to conform to the 100 Mbit/s data link restriction. The thermal and structural design is presently in the finalization stage. Preliminary testing of HAPSAR on the ground is scheduled for the middle of 2024, with subsequent evaluations on an airborne platform and integration into HAP-α.

5 Literature

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