PanelSAR: a smallsat radar instrument

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ABSTRACT

This paper presents the background, capabilities and opportunities of a smallsat miniSAR, a novel and low-cost solution for Synthetic Aperture Radar from space.

The paper focuses on a solution based on low power SAR principles (FMCW/iFMCW), already proven in airborne SAR applications, that can be embarked on a commercially affordable small satellite. The system architecture is presented, showing how features such as modularity, reliability, low power and low mass are achieved to provide a low-cost end-to-end solution. Also the "new space" approach adopted in the development of the smallsat miniSAR is addressed.

INTRODUCTION

The SSBV Aerospace and Technology Group is a Dutch-owned group of SME's with 28 years of experience in the space industry. SSBV adopts a product-based engineering and development approach to design and provide component, subsystem and system solutions. The SSBV portfolio covers a full scope of EGSE, TTC and High-Rate Ground Station Solutions, smallsat sensors and subsystems and, since 2011, the development of an X-Band miniSAR instrument suitable for smallsat deployment.

Synthetic Aperture Radar (SAR) is generally considered one of the most powerful means for Earth Observation, thanks to the wide range of applications and associated downstream specialisations that can be deployed on the basis of SAR data. Nevertheless, due to its complexity and the resource demands (e.g. size, power, cost) imposed on a satellite for a SAR mission, it is not (yet) a commonplace sensor. For this reason, SAR is mainly associated with large, complex, expensive and primarily institutional or military satellites.

The SSBV smallsat miniSAR intends to break this belief by specifically focusing on a combination of proven airborne SAR technology, low-power SAR principles (FMCW / iFMCW) and the use of a mix of commercial and next generation space technology to implement a capable, yet affordable SAR sensor and an equivalent end-to-end smallsat solution.

SSBV initiated the miniSAR R&D activities back in 2011. Following the initial design and assessment, further critical technology research and development of the miniSAR continued with support from the Netherlands Space Office (NSO) through a national technology development programme. The building and integration activities for the in-orbit demonstrator will take place under the PRODEX instrument programme of the European Space Agency (ESA) during the period 2013-2015.

The first in-orbit technology demonstration mission is planned for end 2015. During this mission, calibration/validation of the instrument in a complete end-to-end environment will be performed, including a comprehensive scientific work plan, defined and executed in co-operation with the Technical University of Delft, to generate and validate datasets related to the specific inSAR features of the instrument.

MiniSAR AND THE 'NEW SPACE' APPROACH

The initial work on the miniSAR started in 2011 by means of an early technology review, followed by a Concurrent Design phase in which the feasibility, high-level requirements and overall instrument, smallsat concept and commercial aspects (design-to-cost target) were addressed.

From the very start, re-use of existing technology from the airborne FMCW SAR domain was baselined and the requirements were drawn up against a challenging cost versus performance budget. However, not only the technical approach plays a role in achieving some of the challenging objectives. Also the overall approach to the project, involvement of R&D and industrial partners, as well as the Design, Development and A.I.T. play an important role in minimising overheads, costs and risks.

This is especially relevant in a time where budget constraints, as well as the demands for lower-cost yet capable space solutions, are increasing. This applies even more to the Synthetic Aperture Radar domain. For reasons of experience, as a flexible and small-medium size organisation, as well as to address the challenges mentioned before, SSBV applies a "New Space" approach to the miniSAR product development.

Overall, the objective is to achieve "industry standard" design/execution to plan and cost without compromising quality and flexibility.

This is done by applying a philosophy and working concept which takes into account the following factors:

- Reduction of overheads through a high level of integration at team/industrial consortium level, without applying the traditional prime-subco-supplier relationship (=partnership)
- Making use of modern engineering & simulation approaches
- Making use of space- and commercial technology with targeted developments for new technology only if they provide a clear benefit and form an essential building block or 'enabler'
- Design and implementation of the system in a building block manner (both from an electronics and functional/operational point of view)
- Ensure that all efforts related to the project/product/mission remain within their pre-agreed scope, without the ambition to grow beyond or consider aspects that do not fall within the pre-defined commercial and technical constraints
- Applying an integrated team concept with shared responsibilities
- Allowing and imposing short lines of communication and short decision cycles
- Applying a product-driven design, engineering, implementation and test philosophy
- Imposing clear cost- and functional constraints that are known and consequently applied throughout the different phases and known at all levels within the team
- Continuously take feedback from commercial, engineering, AIT and operations point of view into account

A special consideration within the miniSAR activities is related to the fact that ultimately the tight integration of the miniSAR instrument and an agile smallsat platform that is optimised for this purpose is a true enabler for low-cost smallsat SAR missions.

Based on the size, shape and configurable aspects of the overall system, the SAR and smallsat elements are referred to as PanelSAR and PanelSAT respectively.

HIGH-LEVEL OVERVIEW: PanelSAT AND PanelSAR

The overall architecture is based on single products combined together to increase the performance of the system, not only in terms of capabilities but also in terms of reliability. In particular, the system is composed of two main building blocks: the PanelSAT and the PanelSAR.

The panelSAT is a complete satellite included in a "panel" volume of 200x1000x1000 mm^3. An increment in performances and/or system expansion is achieved by adding more panel elements.

Figure 1 shows the high-level architecture of a PanelSAT based on a SAR mission.

From the mechanical point of view, each PanelSAT has an independent structure and each can be mounted on top of other modules, being another SATellite or SAR panel.

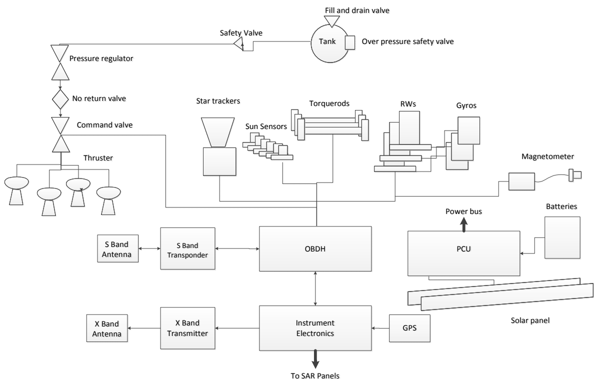

Figure 1: PanelSAT architecture

The same approach is followed for the instrument. The SAR instrument is composed of the so-called SAR panels, each having an identical design and implementation. A panel can be viewed as an independent SAR antenna and RF Front-end with maximum dimensions of 1000x1000 mm^2.

Several SAR panels can be used together to implement a specific instrument / mission or performance constraint. Each SAR panel performs RF <> Digital conversion and interfaces through industry standard SpaceWire and Wizardlink interfaces to the so-called Instrument Electronics through which the overall instrument configuration, control and status monitoring as well as high-speed data processing and mass-memory storage is implemented.

It is worth noting that to achieve a complete modularity of the system, each SAR panel is completely independent from an electrical point of view. Depending on the mission profile, a SAR panel can be directly connected to the spacecraft power bus or make use of an integrated power subsystem (batteries, solar panels).

More information regarding the PanelSAT concept is available from SSBV on request.

BACKGROUND AND CAPABILITIES OF THE miniSAR INSTRUMENT

The design and the architecture of the miniSAR is focused on modularity, flexibility and re-use, which allows for the implementation of different mission profiles and applications.

In fact, one of the unique aspects of the SSBV miniSAR is that, given its price-performance, it allows for the implementation of tailored missions that could otherwise not be covered in business cases that are typically linked to optimised orbits and/or high frequency revisits for example.

The first miniSAR is developed as an X-band instrument, allowing for high-resolution imaging and high-accuracy interferometry (inSAR).

One of the main technological differences of the miniSAR with respect to other space-borne SARs is the use of Frequency Modulated Continuous Wave (FMCW) techniques. The main benefit from this technique is related to the significant lower power that is required in comparison with traditional pulse/Doppler radar emitting short and high energy RF pulses. As implied by part of its name, an FMCW radar normally transmits and receives continuously, therefore requires a lot less RF power to be emitted in order to cover the same amount of energy over time, in comparison with a pulse-based radar, which has to emit this same amount of energy in a much shorter period of time.

The X-Band miniSAR is designed to operate in mono-static as well as bi-static mode. In the mono-static mode, operational aspects related to physical separation of the Transmit and Receive SAR panels are supported, as well as a special interrupted FMCW or extended pulse (iFMCW) mode using a Transmit/Receive capable SAR panel. The latter mode however requires more power than a full FMCW mode, but in comparison to other systems, still a factor of 3-5 less.

For bi-static operation of the instrument over more than one satellite, a proprietary solution to overcome the challenges of synchronisation and data-processing has been designed. The bi-static mode of operation, next to its (lowest) power consumption, also has the advantage of being able to implement a real-time observation and downlink system next to opening up the possibility to deploy a constellation of miniSARs implementing specific 3D-SAR, DEM and MTD applications.

For the in-orbit technology demonstration, a 3m long PanelSAR will be flown. During the mission both the iFMCW mode as well as some of the FMCW features of the instrument will be tested. The main performance characteristics of the instrument (without taking into account satellite agility) are:

- Stripmap : 12-15 km – 4m resolution
- ScanSAR: 60-65 km - 14-16m resolution
- Spotlight: 3-4 km - ~2m resolution

During the mission, SSBV will also demonstrate and validate a number of other next-generation subsystems that are used for the overall instrument and end-to -end mission implementation. This includes a GR712-based Instrument Controller (iOBC), On-Board Payload Data Processor (OPDP), GPS receiver, S-Band TTC transponder and X-Band Payload Data Transmitter.

FLIGHT DEMONSTRATION INSTRUMENT

The miniSAR will demonstrate its capabilities in a first in-orbit demonstration flight in 2015/2016. For this purpose, the instrument is considered a fully self-contained hosted-payload that will be operated in CCSDS / ECSS compatible TTC and PDT modes.

Figure 2 shows the high-level architecture of the flight demonstrator instrument.

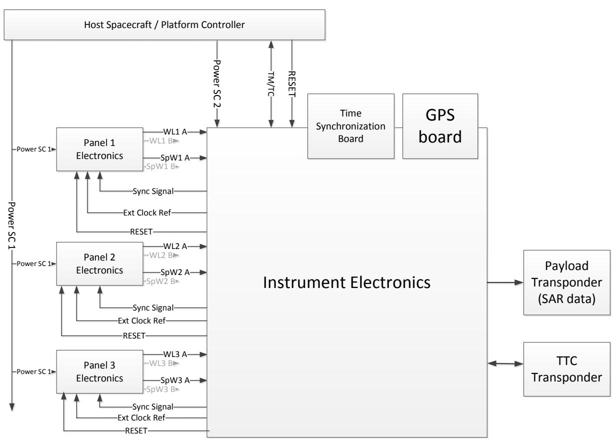

Figure 2: Flight demonstrator architecture

The system consists of 3 SAR panels, the instrument electronics (incl. GPS and Mass Memory) and an S-Band TTC transponder for TM/TC operations and an X-band Payload Data Transmitter for SAR data downlinking.

Main-bus power is provided by the hosting spacecraft and converted at SAR panel and electronics level. For safety reasons, power distribution (on/off) is controlled through the host spacecraft.

All nominal configuration and operations will be conducted through the TTC transponder link, with a back-up TM/TC link also available through the host spacecraft and its communication facilities.

As part of the standardisation approach, the miniSAR makes heavy use of standard yet modern interfaces, such as SpaceWire, WizardLink and CAN-bus / RS-485. Each of the main elements is also equipped with a GR712 Spacecraft Controller On a Chip (SCOC) to implement the distributed intelligence required for (independent) subsystem operation and high integration of the electronics including redundancy and support for re-configuration. This also aids to the standardisation and automation of the assembly and test activities, as well as early simulation and (pre) integration.

From a SAR and RF point of view, each SAR panel includes synchronisation, waveform generation and sampling, up/down conversion, RF signal combination/distribution, de-ramping and a fully programmable operation of the TRM modules. This includes enabling/disabling, phase-shifting, power setting, health monitoring and programmable yet synchronised phase steering. All interconnections from a SAR panel to the instrument electronics are based on the before mentioned SpaceWire and Wizardlink interfaces.

The antenna technology is based on a configurable array of so-called ‘antenna elements’, each consisting of a group of slotted-waveguides with a TRM module and associated electronics. The development of the antenna is performed in co-operation with TNO Space, whereas the material technology and manufacturing of the non-active antenna elements is done in co-operation with GTM Advanced Structures (Space division).

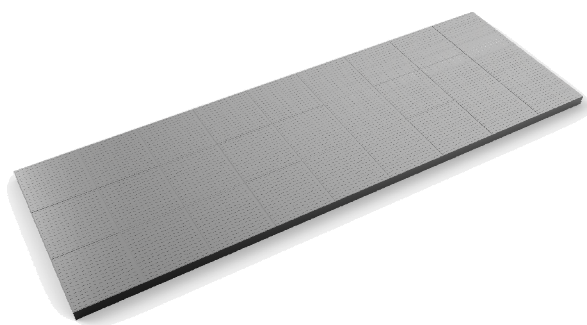

Figure 3: Integrated PanelSAR antenna

For the modelling of the antenna pattern, the precise test and calibration data that is available at TRM and panel level will be used. The resulting antenna configuration model will be verified during ground tests, as well as during the Cal/Val phase. From the model and the desired instrument operational mode, the ground- and space-based instrument controller(s) will be able to automatically generate the individual control data for the SAR panel / TRM modules in preparation for, or during, a data take.

The SAR configuration and data processing is heavily based on the re-use of the SAR Data Processor from MetaSensing, an SSBV Group company that is also responsible for the iFMCW and bi-static algorithm implementation.

Next to the iOBC-based Instrument Controller, the overall Instrument Electronics also includes:

- a SpaceWire and Wizardlink routing function;
- an On-board Payload Data Processing (OPDP) function using the ESA Fast Fourier Transform Co-Processor (FFTC) ASIC - this is based on a joint NLR/SSBV development;
- a (simple) Mass Memory Storage and replay function;
- a GPS receiver and time/signal synchronisation function.

The interface to the TTC transponder is based on SpaceWire, allowing packet-based data exchange rather than data/clock based interfaces.

The same applies to the X-band PDT that uses SpaceWire for control/monitoring and Wizardlink and/or parallel LVDS for high-speed data exchange. From a product point of view, both transponders also provide legacy data/clock interfaces, but these are not baselined for use by the miniSAR.

OPERATIONAL DEPLOYMENT AND COMMERCIALISATION ASPECTS

SSBV foresees that in parallel with the in-orbit technology demonstrator, the first smallsat miniSAR mission will also be developed, allowing the deployment of the instrument in a recurring configuration. This implies that recurring missions can be provided as of 2016.

For the development, assembly, integration, test and operation of the instrument and its foreseen platform, SSBV's experience of operating in the space business for 28 years, combined with a wide range of ground- and space-based building blocks, are readily available.

This, in combination with the 'new space' and partner approach, as well as the support from other stakeholders, provides a solid foundation and efficient approach to achieve a successful miniSAR implementation, demonstration and subsequent commercialisation.

From a commercialisation point of view, SSBV is open to a number of different business case approaches for the miniSAR which include: instrument provision, an integrated smallsat solution with corresponding ground infrastructure, as well as a full end-to-end solution including a commercial service model.