Multiclass Satellite Payload for SAR

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***Abstract*— Here we present a multiclass spaceborne Synthetic Aperture Radar (SAR) payload architecture developed by ARESYS to enable scalable and distributed Earth Observation missions based on NanoSat and SmallSat platforms. The architecture is designed to overcome the intrinsic limitations of small satellites in terms of mass, volume and power while supporting advanced mission concepts such as SIMO/MIMO operation, formation flying and onboard intelligent data handling. The proposed solution is centered on a compact and modular SAR Electronic Subsystem (SES) that can be deployed across different satellite classes and mission configurations operating either in standalone mode or as part of cooperative satellite swarms. X-band SAR performance is achieved with subsystem resources compatible with small satellite platforms. The architecture is currently being validated through the SATURN mission which serves as a representative in-orbit demonstration of the distributed MIMO SAR concept. The presented framework supports resilient, high-performance and cost-effective SAR missions in Low Earth Orbit.**

Keywords— Synthetic Aperture Radar (SAR); Small Satellites, Distributed SAR, MIMO SAR, SIMO SAR, SAR Payload; SAR Electronic Subsystem; X-band Radar; Deployable Antennas; Formation Flying; Cooperative Satellites; Earth Observation; On-Board Processing; AI-enabled SAR.

I. Introduction

The demand for high-performance spaceborne Synthetic Aperture Radar (SAR) data has steadily increased due to its unique capability to provide all-weather, day-and-night Earth Observation information. Traditionally, SAR missions have relied on large monolithic satellites to accommodate high peak transmitted power, large antennas and complex onboard electronics. While effective, this approach entails high development costs, long schedules and limited scalability. Recent advances in small satellite platforms, deployable antennas, RF electronics and onboard processing have enabled a new generation of compact SAR payloads suitable for NanoSat and SmallSat missions [1]. However, the intrinsic constraints of small platforms limited electrical power, volume and antenna size—still pose significant challenges to achieving mission-relevant SAR performance.

To address these limitations, ARESYS has developed a family of compact SAR payloads designed to support both standalone and distributed mission architectures and to serve agile SAR missions for specific applications needs (see Figure 1). These payloads enable flexible deployment across multiple satellite classes and allow performance scalability through cooperative operation. Within this broader development roadmap, distributed SAR concepts based on SIMO and MIMO techniques are used to decompose the classic monolithic SAR system into multiple coordinated units, improving robustness and scalability. The SATURN mission, developed within the ASI ALCOR programme, represents a concrete in-orbit application of this payload architecture and provides a relevant validation context for the distributed MIMO SAR concept [2][3][4]. In this paper, SATURN is therefore used as a representative example, while the focus remains on the general payload architecture and its applicability to a wider range of missions. The remainder of the paper is organized as follows. Section II introduces the distributed SAR concepts enabled by the proposed payload architecture. Section III describes the multiclass SAR payload and its adaptability across NanoSat and SmallSat platforms along its performance. Section IV addresses the conclusions of the paper.

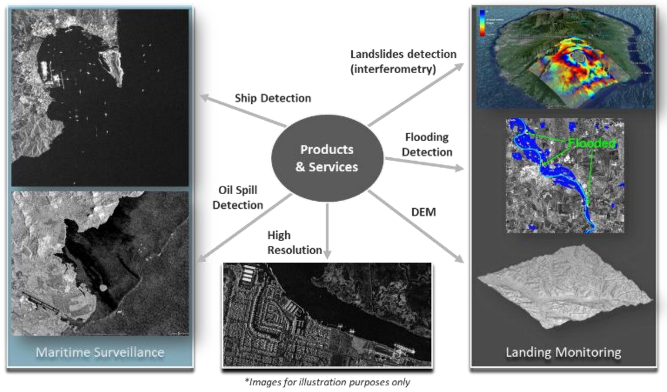

Figure 1 Examples of Mission Scenarios enabled by Aresys SAR payload.

II. Distributed SAR Concepts for Small Satellites

Distributed SAR represents a paradigm shift in spaceborne radar design in which the effective synthetic aperture is formed by the coordinated operation of multiple platforms rather than a single spacecraft. Each satellite contributes part of the overall system resources, such as transmitted power, receiving aperture or spatial diversity.

This approach provides several advantages particularly relevant to small satellite missions:

- scalability of imaging performance with the number of platforms,
- resilience to single-satellite failures,
- flexibility in mission design and reconfiguration,
- improved revisit time through multi orbit deployment.

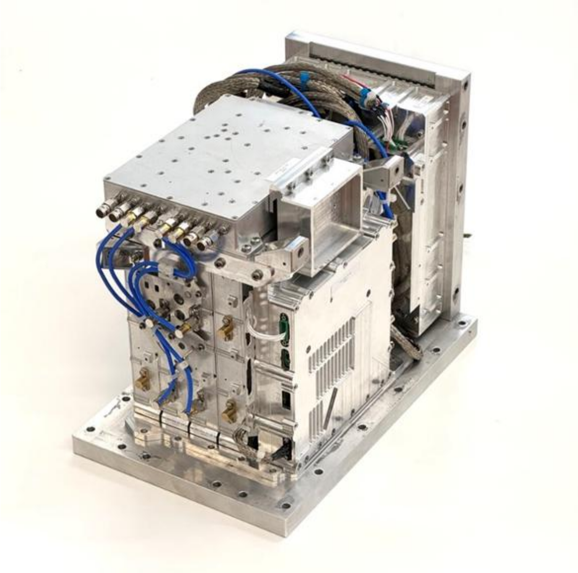

Figure 2 Aresys SAR Electronic Subsystem (SES)

ARESYS SAR payloads are designed to natively support this paradigm through precise timing control, flexible waveform generation and coherent data handling.
The payload architecture supports both Single-Input Multiple-Output (SIMO) and Multiple-Input Multiple-Output (MIMO) SAR configurations.
In SIMO mode, one satellite transmits while multiple satellites receive the backscattered signal, improving signal-to-noise ratio and ambiguity rejection. In MIMO mode, multiple satellites transmit synchronized waveforms and receive echoes from a common illuminated area. When coherently combined on ground, the received signals provide performance gains that scale with the number and relative geometry of the participating nodes. Accurate synchronization between platforms is achieved through GNSS-disciplined oscillators and pulse-per-second timing references, enabling coherent processing of distributed SAR data.

III. Multiclass SAR Payload Architecture

The ARESYS SAR payload architecture is conceived as multiclass, meaning that the same core electronic design can be adapted to different satellite platforms with minimal changes. This approach maximizes reuse and allows mission designers to trade antenna size, transmitted power and swarm cardinality according to application needs. Two main platform classes are addressed:

- NanoSat class, including 16U and 16UXL CubeSat platforms, optimized for compactness;
- MicroSat class, with platform masses below 120 kg, allowing higher duty cycles and larger deployable antennas.

The SPAYDER® payload family integrates SAR acquisition, control and data handling functionalities in a compact form factor suitable for small satellites. It can operate as a standalone SAR instrument or as an element of a cooperative swarm. The payload supports a range of Earth Observation applications including maritime surveillance, flood mapping,

TABLE I. Reference Radar Instrument Parameters for MicroSat class

Parameter	Value
Carrier Frequency	9.6 GHz
Tx Bandwidth	Up to 325 MHz
Tx Peak Power	800 W
PRF	≃ 8650 Hz
Tx Duty Cycle	15%
Noise Figure	3 dB
Antenna Directivity	46 dBi
Antenna Az HPBW	≃0.7°
Antenna El HPBW	≃0.7°
Polarisation	HH
Total Loss	7.6 dB

TABLE II. Radar Instrument Performance

Altitude	500 Km	
Access Region	28° ÷ 40° incidence angle	
Operative Modes	Spotlight	Stripmap
Ground Swath	5 Km	5 Km
Azimuth Swath	5 Km	20 Km
Range Resolution (no multi-look)	1 m	1 m
Azimuth Resolution (no multi-look)	0.5 m	1.5 m

land monitoring, infrastructure change detection and emergency response.
Within this family, different configurations can be selected depending on mission objectives, while preserving a common electronic core and software framework. Example of reference radar instrument parameters of a baseline payload configuration for SmallSat and associated performance are summarized in Table I and Table II, respectively. The SAR Electronic Subsystem (SES) constitutes the core of the SPAYDER® payload and has been designed as a reusable building block. It integrates all SAR-specific electronic functions in a modular architecture, including:

- SAR Board Computer (SBC): responsible for instrument control, timing management, waveform generation, echo reception, calibration, raw data handling, compression and storage.
- High-Power Module (HPM): incorporating supercapacitor-based energy buffering and DC-DC conversion to supply peak RF power while reducing stress on the platform electrical power system.
- Up/Down Converter (UDC): providing frequency translation, filtering and low-noise amplification for both transmit and receive chains.
- Transmit–Receive Modules (TRMs): based on GaN solid-state power amplifiers to achieve high efficiency at X-band.
- Antenna Interfaces: supporting deployable reflector or reflectarray antenna

The SES achieves a total mass below 6 kg, a volume below 6 dm³ and a peak power consumption below 125 W during energy recharge phases. Energy consumption per acquisition is compatible with small satellite duty cycles. These characteristics allow integration on NanoSat and MicroSat platforms without requiring dedicated high-power spacecraft designs.

The SES configuration developed for the SATURN mission represents the first fully integrated and qualified instance of this architecture and is therefore used in this paper as a reference implementation. SAR imaging performance achieved by the proposed payload architecture scales with both the antenna configuration and the number of cooperating satellites. Even a minimal swarm of three satellites can achieve ground resolutions and swath widths comparable to much larger single-platform systems.

By increasing the number of nodes in a cooperative acquisition, the architecture enables:

- resolution enhancement,
- swath extension,
- improved radiometric sensitivity,
- support for interferometric and multi-baseline applications.

This scalability enables gradual mission evolution, starting from technology demonstration missions and progressing toward operational constellations with high revisit rates.

The payload architecture is designed to be compatible with onboard processing units capable of SAR pre-processing, data compression and AI based analytics. By moving part of the data exploitation chain onboard, mission efficiency can be increased through reduced downlink requirements and faster response times. Applications such as automatic target recognition, maritime object detection and tip-and-cue observation concepts can be supported by coupling the SAR payload with dedicated onboard processors.

IV. Conclusions

This paper has presented a multiclass SAR payload architecture developed by ARESYS to enable high-performance SAR imaging from NanoSat and SmallSat platforms. By combining compact modular electronics, deployable antennas and distributed SIMO/MIMO operation, the proposed solution overcomes the traditional limitations of small satellite SAR missions.

The architecture supports scalable performance and cost-efficient mission deployment. The SATURN mission serves as a representative example validating the approach, but the payload family is applicable to a wide range of future distributed SAR missions in Low Earth Orbit.

References

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