Smart On-Board Processing for Earth Observation Systems: the SOPHOS Project

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SOPHOS
Smart on-board processing for earth observation systems

Introduction

The ever-growing volume of data generated by spaceborne Earth observation missions will need new solutions to address the downlink bottleneck.

SOPHOS implements enabling technology up to TRL level 6, i.e. a more power efficient high-performance space processing chain for various Low-Earth Orbit (LEO) missions, with a focus on SAR.

SAR Use Cases & Requirements

Two important use cases are addressed in a multi-objective, multi-user SAR mission:

- **High-Quality** SAR products (incl. phase)
- **Low-Latency** SAR information products.

SAR Sensor Assumptions

Scene-level requirements regarding data volume and data rate for two scenarios:

SAR System Parameters	SOPHOS High End	SOPHOS Light
Center frequency	9.65 GHz	=
Bandwidths	600 MHz	150 MHz
Range sampl. freq.	660 MHz	165 MHz
Antenna length	3.2 m	=
Antenna width	0.4 m	=
Off-Nadir	30 deg	=
Pulse length	50 us	25us
Orbit height	560 km	=
Swath width & length	30 km / 50 km	50 km / 50 km
Ground resolution @ 30 deg incidence angle (rg/az)	0.5m / 3 m	2m / 6m

Operational Assumptions:

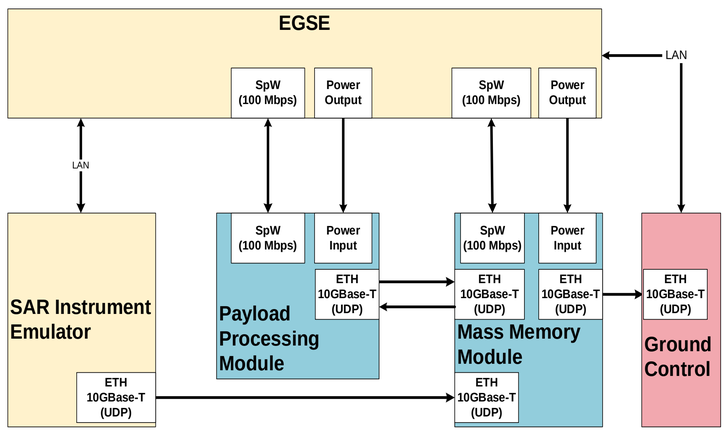
- Single-orbit timeline with 2 Ground Stations
- Effective downlink time is 2 x 10 min (no SAR data recording/processing).
- No on-board processing during active sensor operation
- Orbit duration is 90 minutes
- Orbit duty cycle between 1 % and 10 %

Derived Processing Time Requirements:

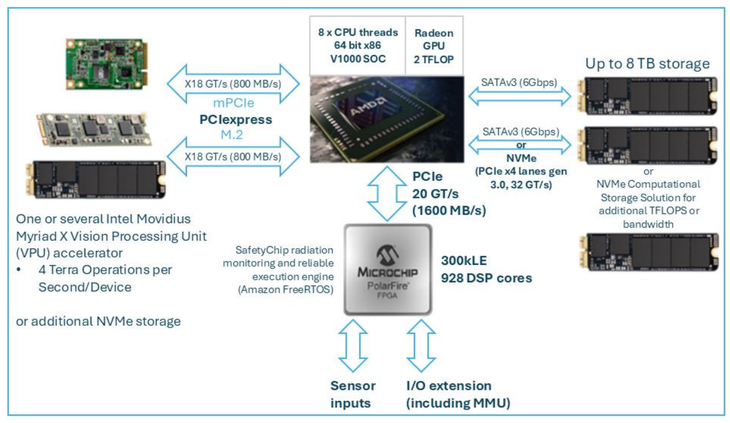
- 6-36 data takes per orbit (duty cycle)
- 61-69 minutes available for processing
- **100 s** (61 min / 36 scenes) for the 10% duty cycle scenario
- 660 s (69 min / 6 scenes) for 1% duty cycle

SOPHOS Demonstrator Concept

A flexible data path, using the routing capability of the Mass Memory Module, supports different mission scenarios.



SpaceCloud processing architectures available on iX10



Payload Processing Module

Unibap's SpaceCloud is a space-qualified heterogeneous compute solution:

- AMD GPU V1000 SoC compute node
- SpaceWire connected via PolarFire FPGA
- 10GB-Ethernet connected to AMD
- Intel Movidius MyriadX for AI applications
- Standard Linux for use of modern cloud-enabled development tools

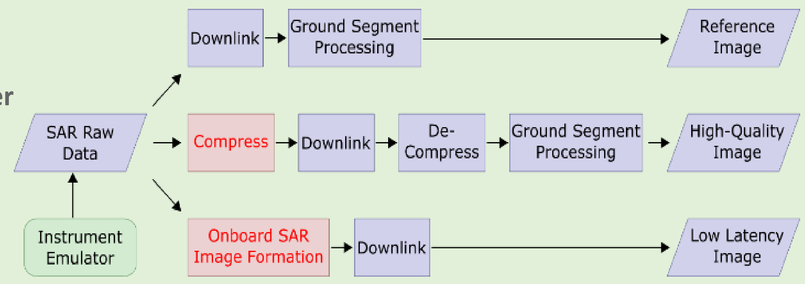
Mass Memory Module

3 interconnected PCBs: the Mass Memory Board (MMB), the Interface and Processing Board (IPB), the Power Supply Board (PSB).

- MMB: Flash memory for non-volatile data storage with a capacity of up to 50Tbit EOL
- IPB: radiation-tolerant Microchip RT Polarfire FPGA and DDR4-SDRAM for data buffering
- Data interfaces: 4x 10GBase-R Ethernet with optical transceivers.

SAR Algorithms

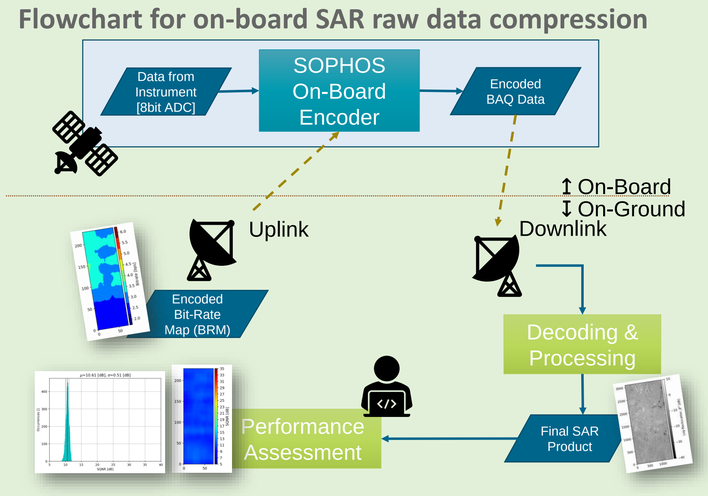
Proposed on-board processing algorithms (red). The upper line represents the state-of-the-art handling of present-day SAR mission data.



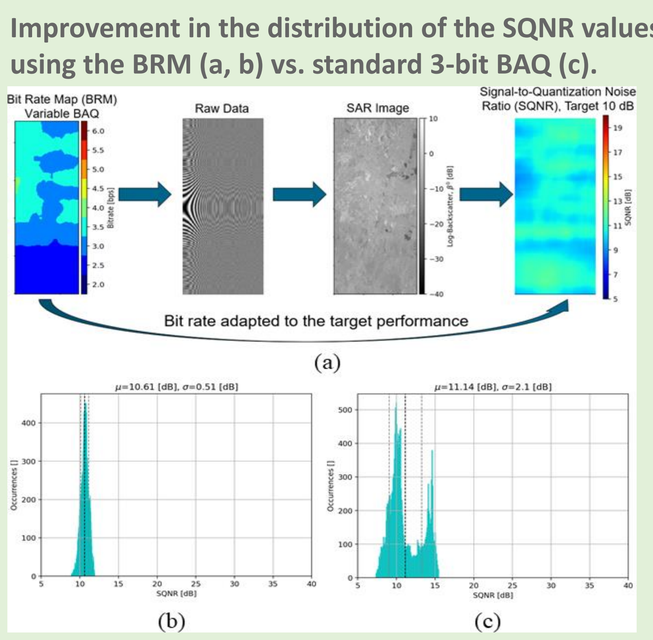
Performance-Optimized BAQ

Exploits *a priori* knowledge about the SAR backscatter statistics to implement variable bit-rates Block-Adaptive Quantization (BAQ) for SAR raw data compression.

Flowchart for on-board SAR raw data compression



Improvement in the distribution of the SQNR values using the BRM (a, b) vs. standard 3-bit BAQ (c).

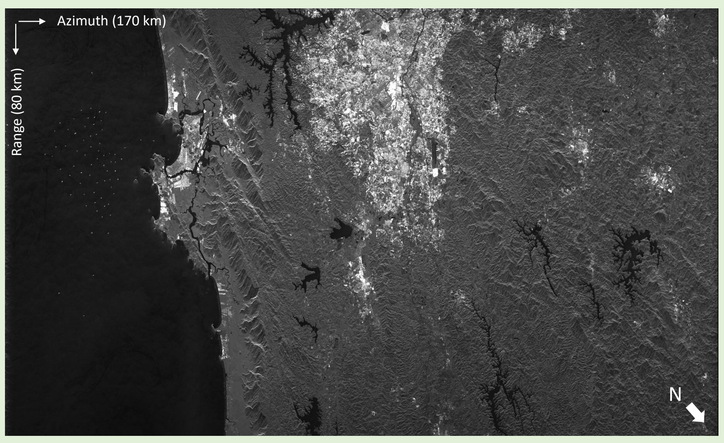


SAR Image Formation

- Stripmap ω-K algorithm (monochromatic)
- Multi-looking and detection
- Block processing

Parameter	SOPHOS High End	SOPHOS Light	Sentinel-1
Rows (range)	98,946	31,590	21,838
Colums (azimuth)	38,906	38,880	48,125
Low-Pass Dec. Factor	2	4	1
No of blocks	3	1	2
Acq. Time	7.5 s	7.5 s	25 s
Proc. Time (Python Prototype)	410 s	100 s	207 s
Proc. Time (optimized)	in progress		

Sentinel-1 Stripmap mode Sao Paolo data-take processed with the Python Prototype



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https://sophoshorizon.eu/

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