S4Pro

Smart and Scalable Satellite High-Speed Processing chain

Synthetic Aperture Radar Missions, Requirements & Algorithms

Presenter: R. Scheiber

Contributors: F. Queiroz-Almeida, M. Martone, N. Gollin (DLR)

J. Naghmouchi (iTUBS)

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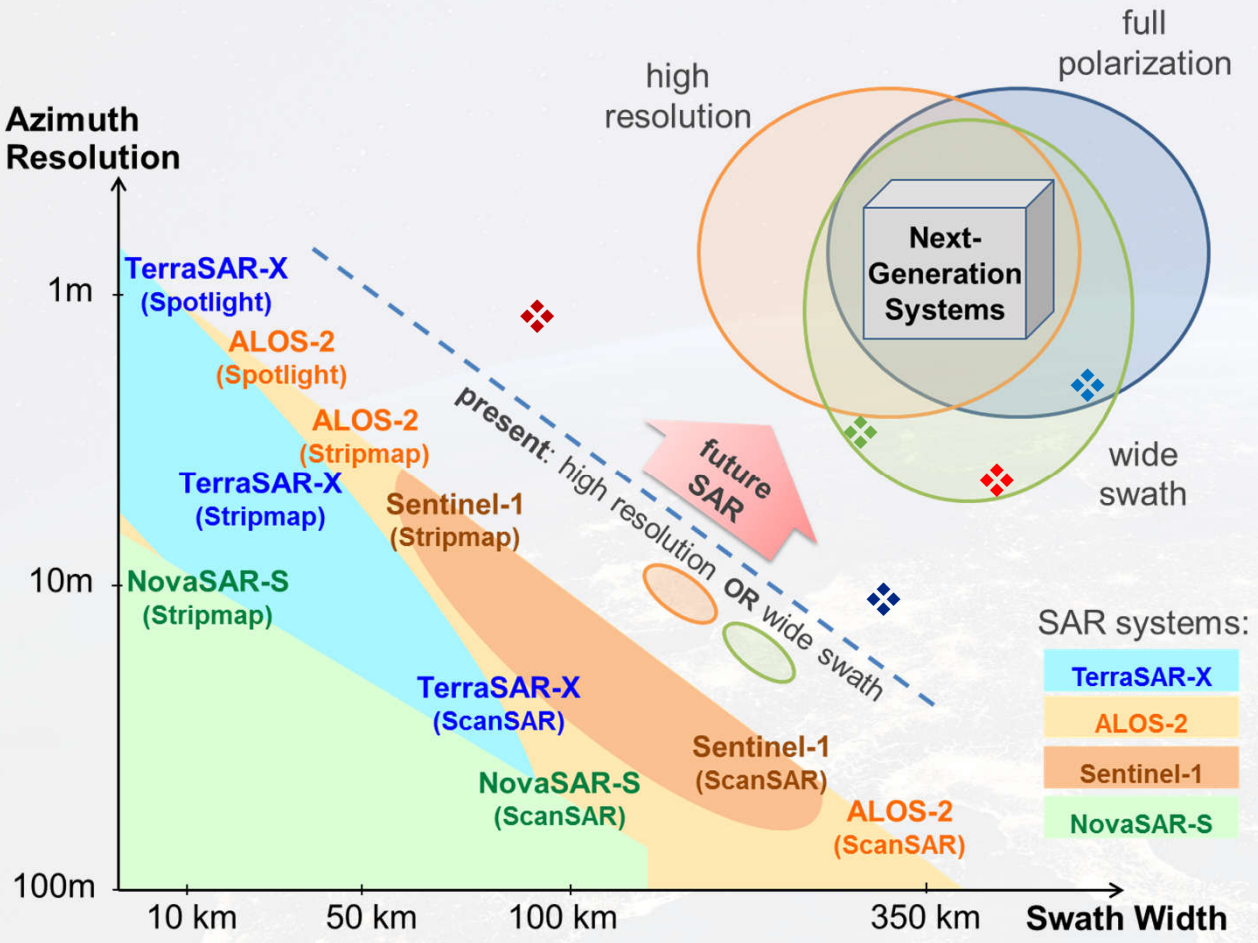
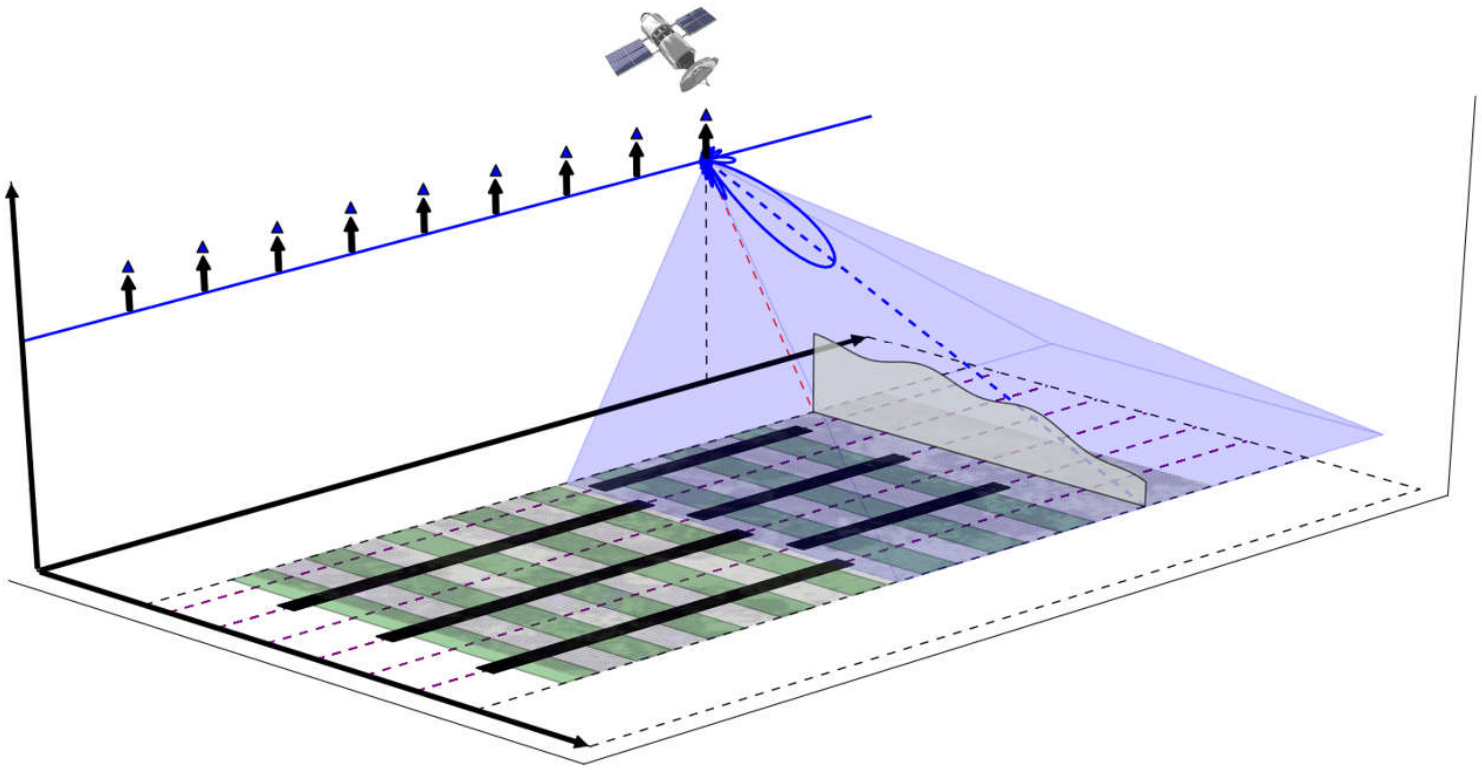
Future Spaceborne SAR Missions



Missions in preparation:

- NISAR (USA/India)
  Launch 2022
- ROSE-L (EC)
  Launch 2027
- Tandem-L (D)
- Sentinel-1 NG (EC)
- X-band HRWS (D)
  Launch 202?

Multiple Beam Imaging with Constant PRI

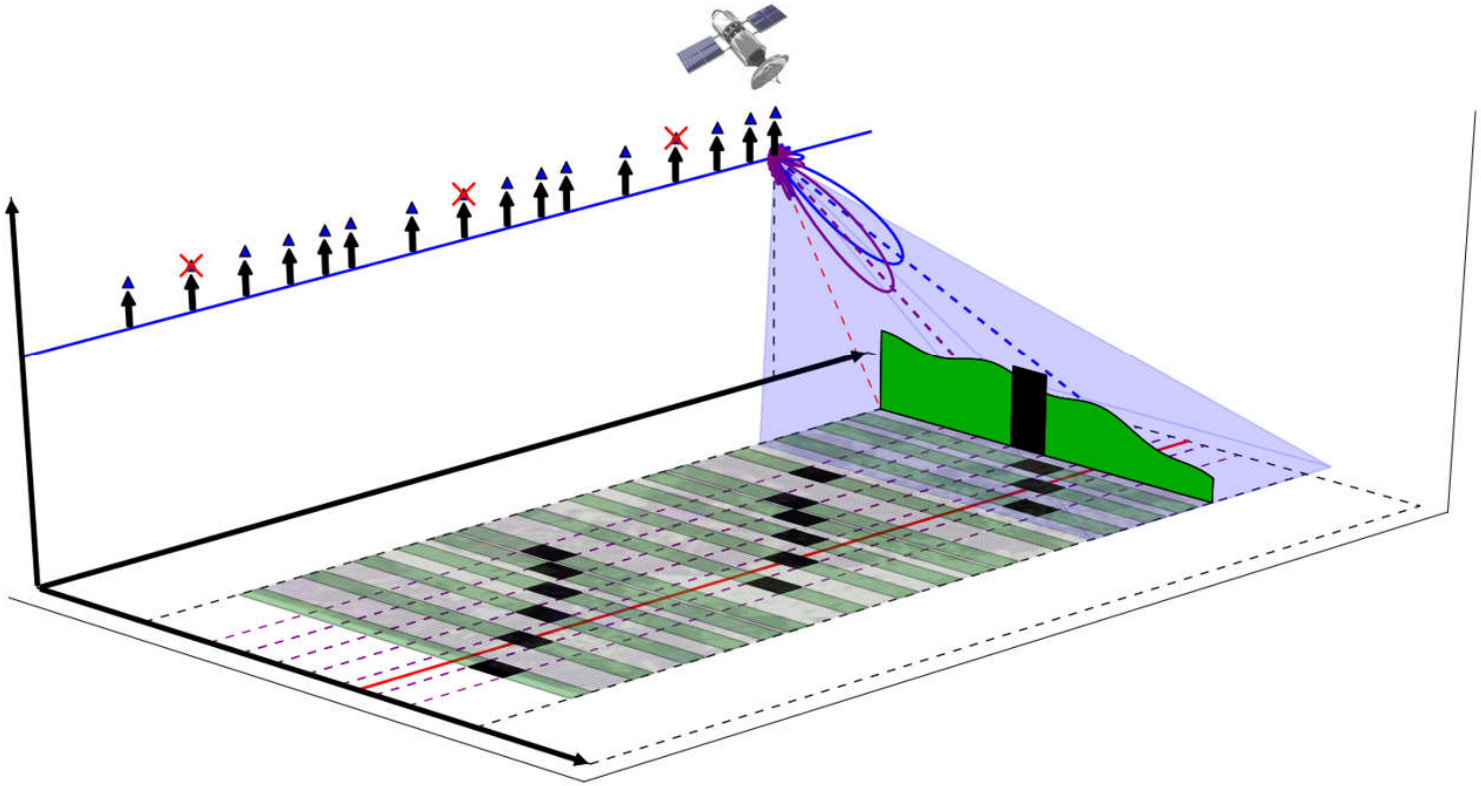


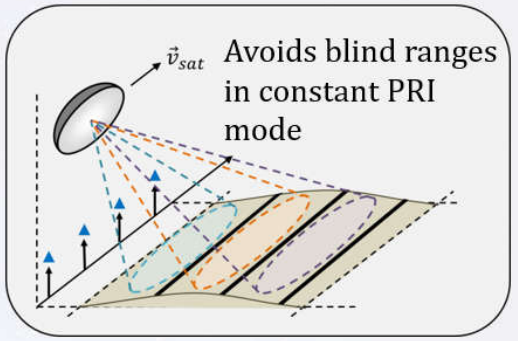
Transmission Events
(next pulse)
⇒ *Gaps in acquisition*

Mitigation options investigated in S4Pro:

- Change of PRI
  -> **staggered SAR**
- **Frequency Scan** instead of multiple beams
  - High bandwidth sensors
  - Multiple azimuth channels

HIGH RESOLUTION WIDE SWATH IMAGING WITH STAGGERED SAR

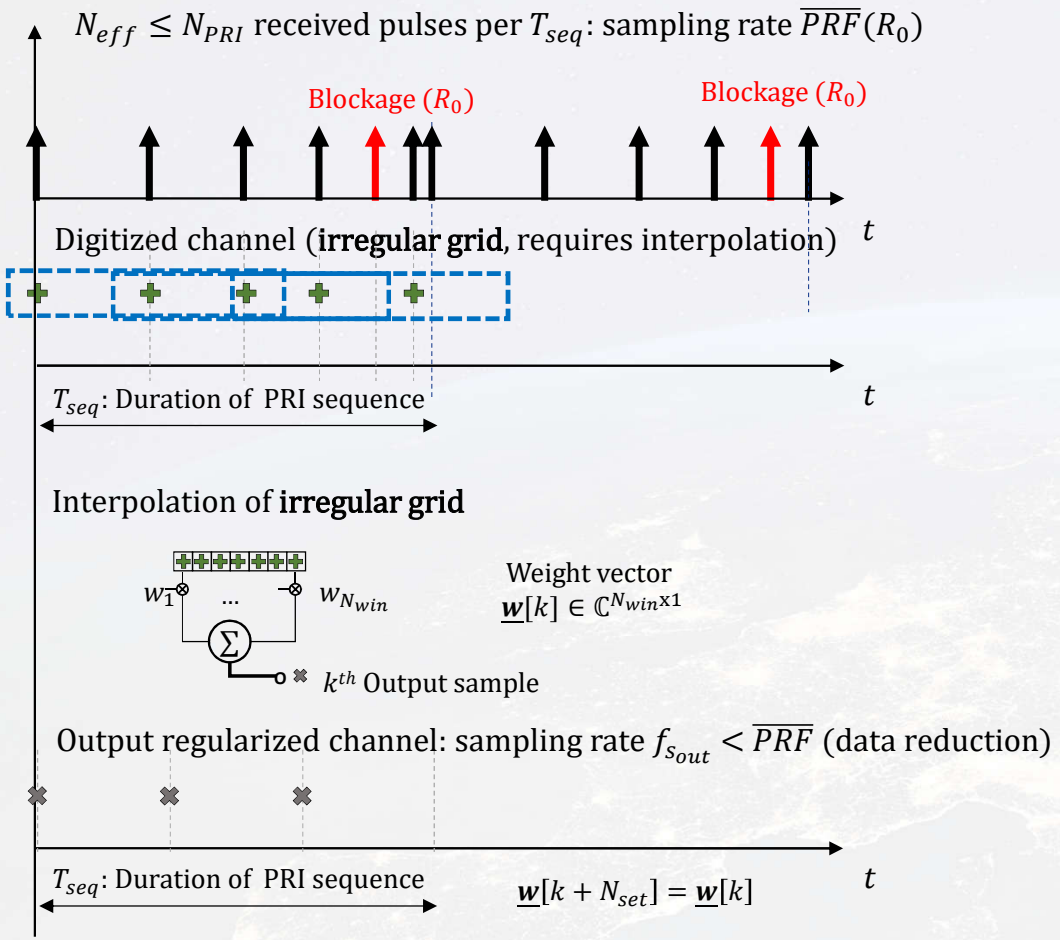


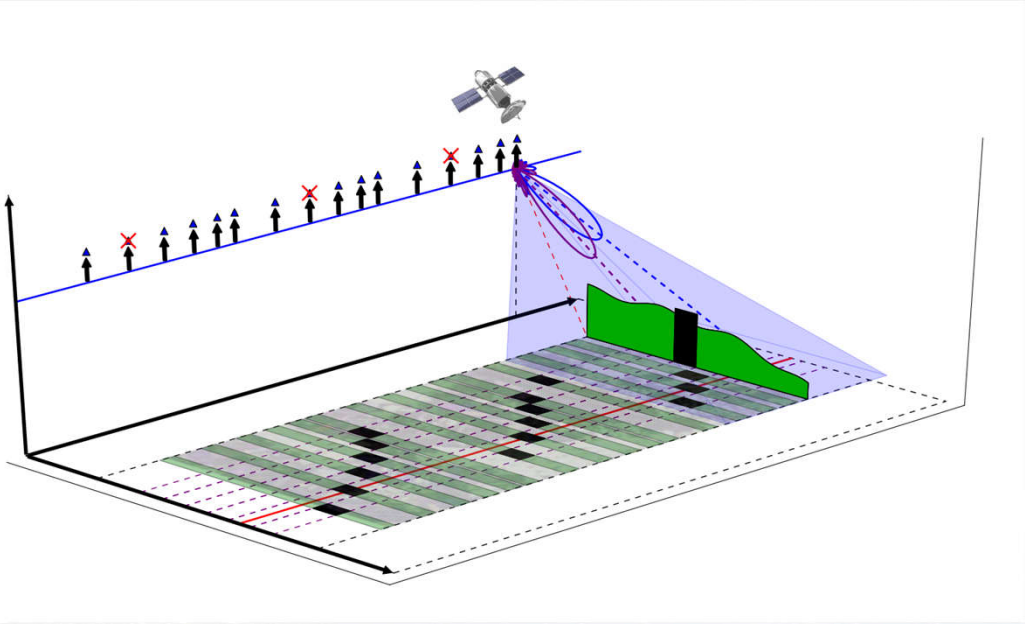


Interpolation over azimuth
⇒ *no gaps* over swath

[1] M. Villano, G. Krieger and A. Moreira: "Staggered SAR: High-Resolution Wide-Swath Imaging by Continuous PRI Variation", *IEEE Transactions on Geoscience and Remote Sensing*, vol. 52, no.7, pp.4462-4479, 2014.

STAGGERED SAR AZIMUTH FILTER - RESAMPLING





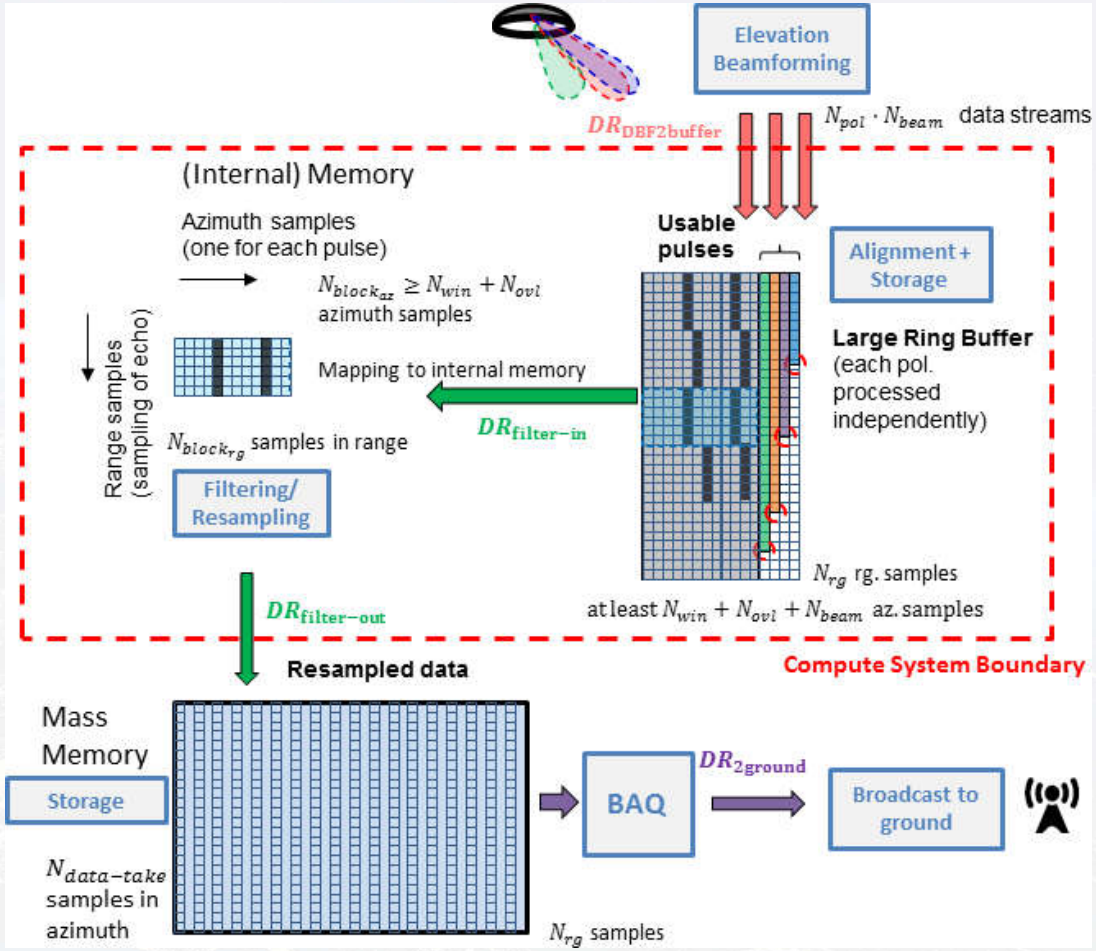
Challenge:

- Weight vector changes
  - periodically along azimuth
  - after certain number of range bins

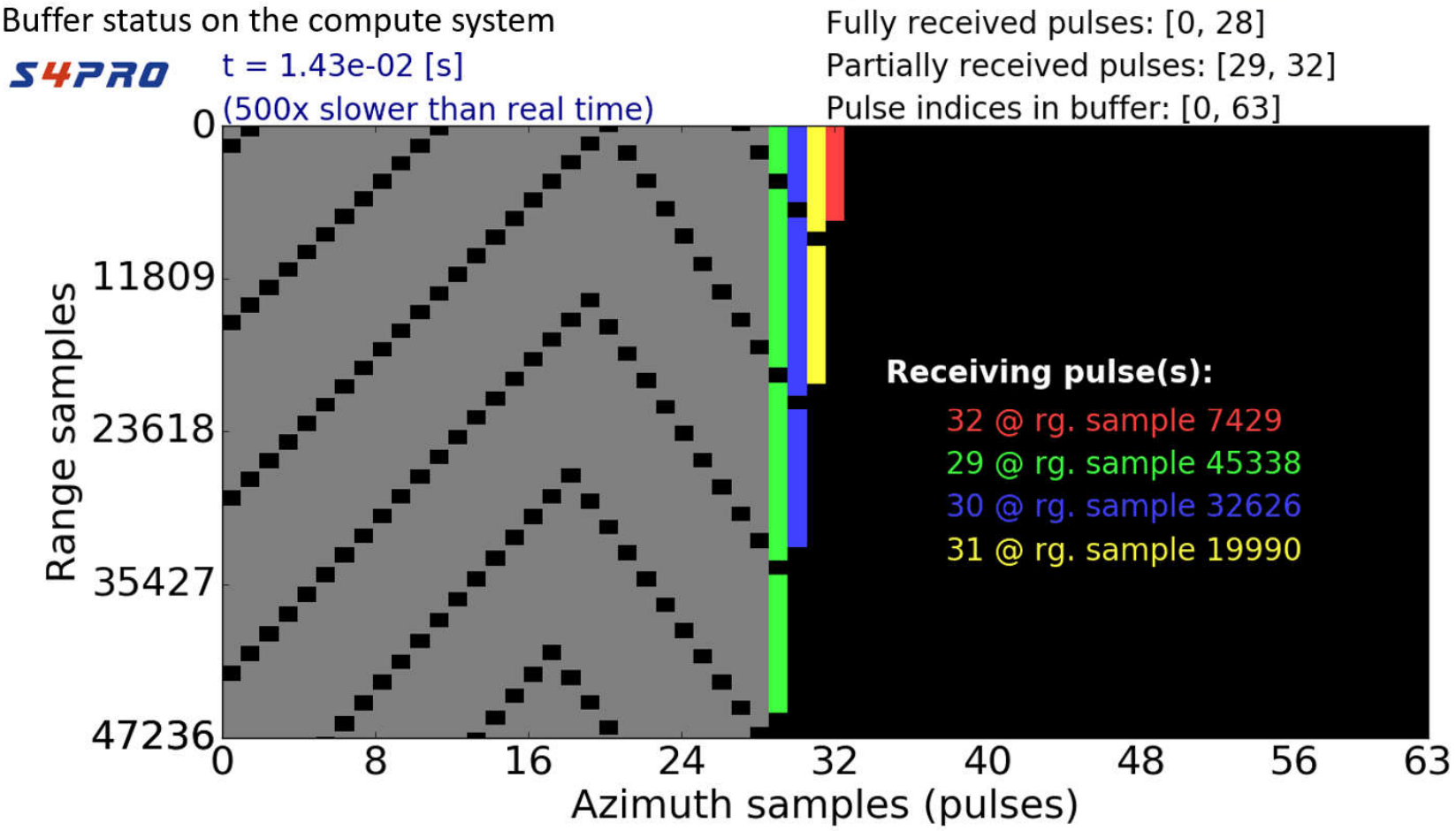
PROTOTYPE IMPLEMENTATION FOR THE S4PRO COMPUTE SYSTEM

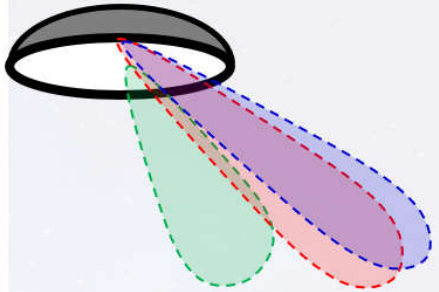
3 specific tasks:

- **Alignment and storage of the beams**
  - Handling high data rate
- **Filtering/Resampling**
  - Staggered SAR specific
  - Large computational burdon
  - Focus of S4Pro project
- **BAQ**
  - State-of-the-art



Multiple Beams: Alignment and Storage





Alignment simulation

- ROSE-L parameters
- 4 elevation beam HRWS system

PYTHON PROTOTYPE

Python Prototype

Algorithm description
Data type definition (int16, int64, float16)
Inputs (parameters, coefficient tables)

Example Scene (ROSE-L parametrisation)
Number of range samples: 47237
Slant range time: 5.04 - 6.02 ms
Swath extension: 260 km

Number of azimuth samples: 49860 (~277 cycles)
Azimuth time extension: 15.3 s

Staggered SAR PRI cycle:
Period: 55.4 ms
Number of distinct PRIs of a cycle: 180
PRIs: 307.7 – 362.5 ms (~3200 Hz)

[2] F. Queiroz de Almeida, M. Villano, R. Scheiber, G. Krieger, J. Naghmouchi: "*S4Pro: Prototype Implementation of Staggered SAR On-Board Processing*", *ARSI workshop*, November, 2019.

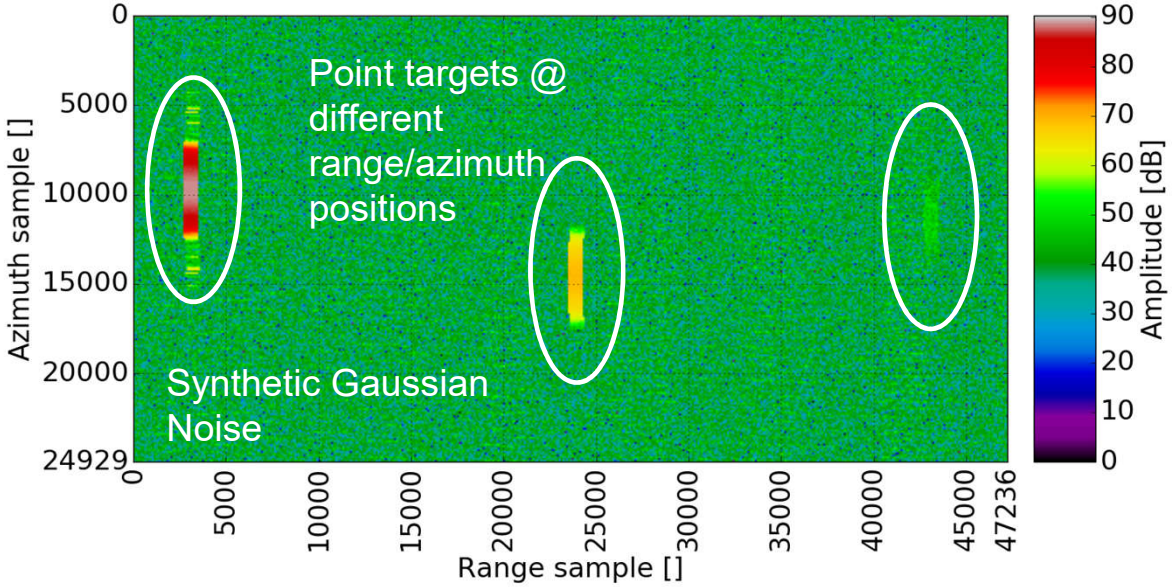
S4PRO Parameters	Value	S4PRO Parameters	Value
Echo window length [s]	990,0 E-6	Datatake duration [min]	50
Number of rg bins [ ]	54,5 E+3	Total data (no reduction) [GByte]	515
Simultaneous elevation beams [ ]	4	Total data (with reduction) [GByte]	265
ADC sampling rate [Hz]	55,0 E+6	Number of input samples per cycle	180
Mean PRF [Hz]	3,2 E+3	Number of output samples per cycle	90
Processed Doppler bandwidth [Hz]	1,4 E+3	Sampling rate of output [Hz]	1,6 E+3
Residual oversampling rate - azimuth	1,2	Size of filter window (number of taps)	15
Storage bits (for I or Q)	16	Number of real multiplications per output sample (I+Q)	30
Block Adaptive Quantization (BAQ) bits	4	Number of real additions per output sample (I+Q)	30
Data rates (average) [bit/s]		Number of floating point operations per output sample	60
from DBF to buffer	**7,0 E+9**	flop/s per range bin	97,2 E+3
from buffer to memory	5,5 E+9	flop/s due to azimuth filter (single-pol)	5,3 E+9
at filter input	5,5 E+9	additional flop/s due to BAQ (per range line)	499,4 E+3
at filter output	2,8 E+9	additional flop/s due to BAQ (rate of PRF)	809,0 E+6
to ground (no filter)	1,4 E+9	flop/s due to azimuth filter (single-pol)	**6,1 E+9**
to ground (with filter)	705,7 E+6		

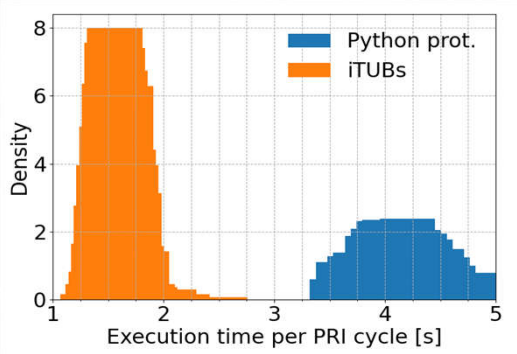
PROTOTYPES & TEST DATA & PERFORMANCE

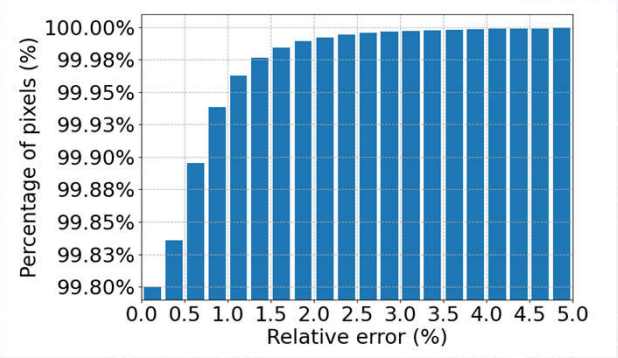
Optimized Python Prototype developed by DLR - 10x faster than very first implementation

Naive C-code implementation by iTUBS - 3x faster than Python prototype on Intel x86 CPU

Optimized C-code implementation by iTUBS - achieves more than 1.6 times the realtime performance on optimized compilation (i.e. ~ 8.4 sec processing time for 15.3 sec data acqusition)

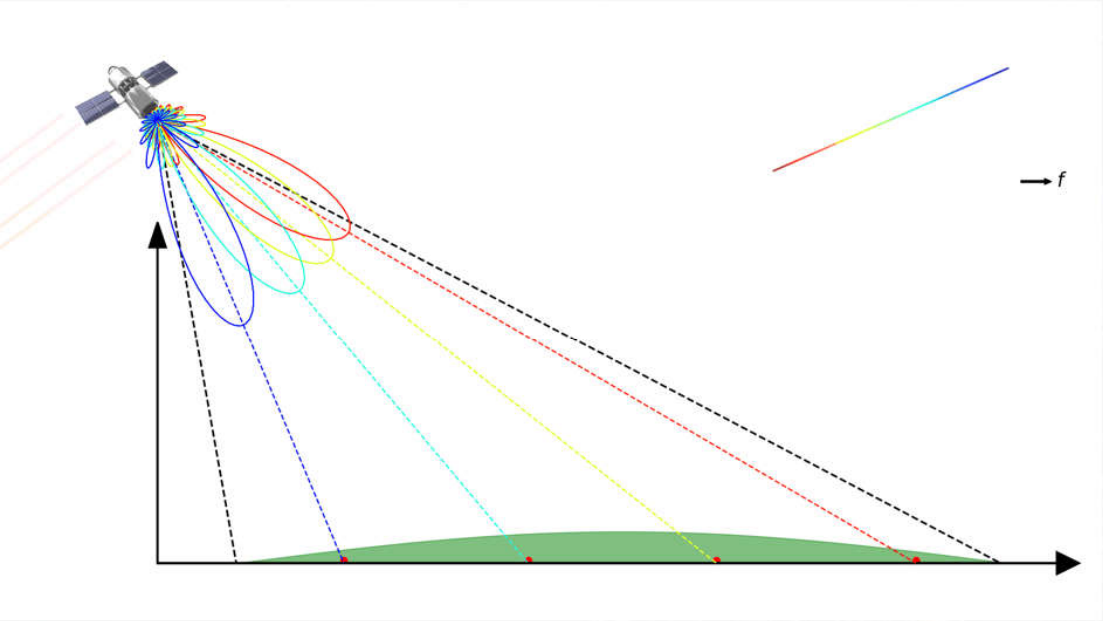






Accuracy: 99.8% less than 0.2%

HRWS IMAGING WITH FSCAN(*)



(*) Airbus DS concept as proposed by C. Römers, IGARSS 2017

FScan – Frequency Scanned Array Radar Antenna

Properties

- no DBF in elevation, single beam
- use of a wide-band radar system

  (e.g. X-band, B_w =1200 MHz)
- Antenna pointing changes as a function of frequency:
  - at f_0 antenna points to mid range
  - at $f_0 + \frac{B_w}{2}$ to near range
  - at $f_0 - \frac{B_w}{2}$ to far range
- Different parts of the swath are illuminated by different parts of the wide-band chirp.
- Echos arrive quasi simultaneously at the receiver

  -> **reduction of the echo window length.**

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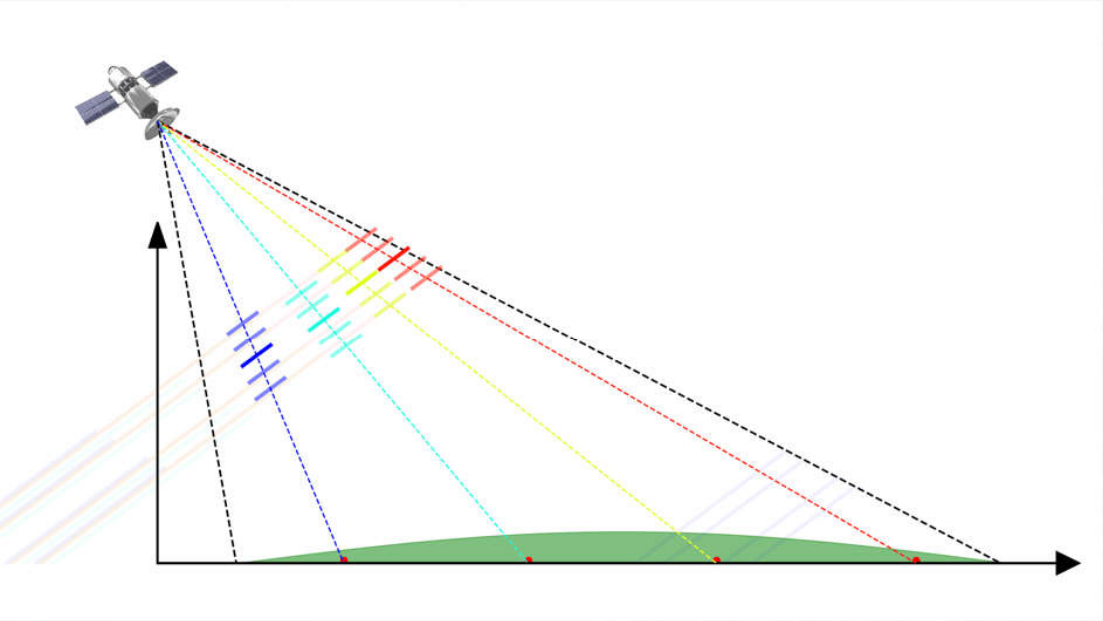

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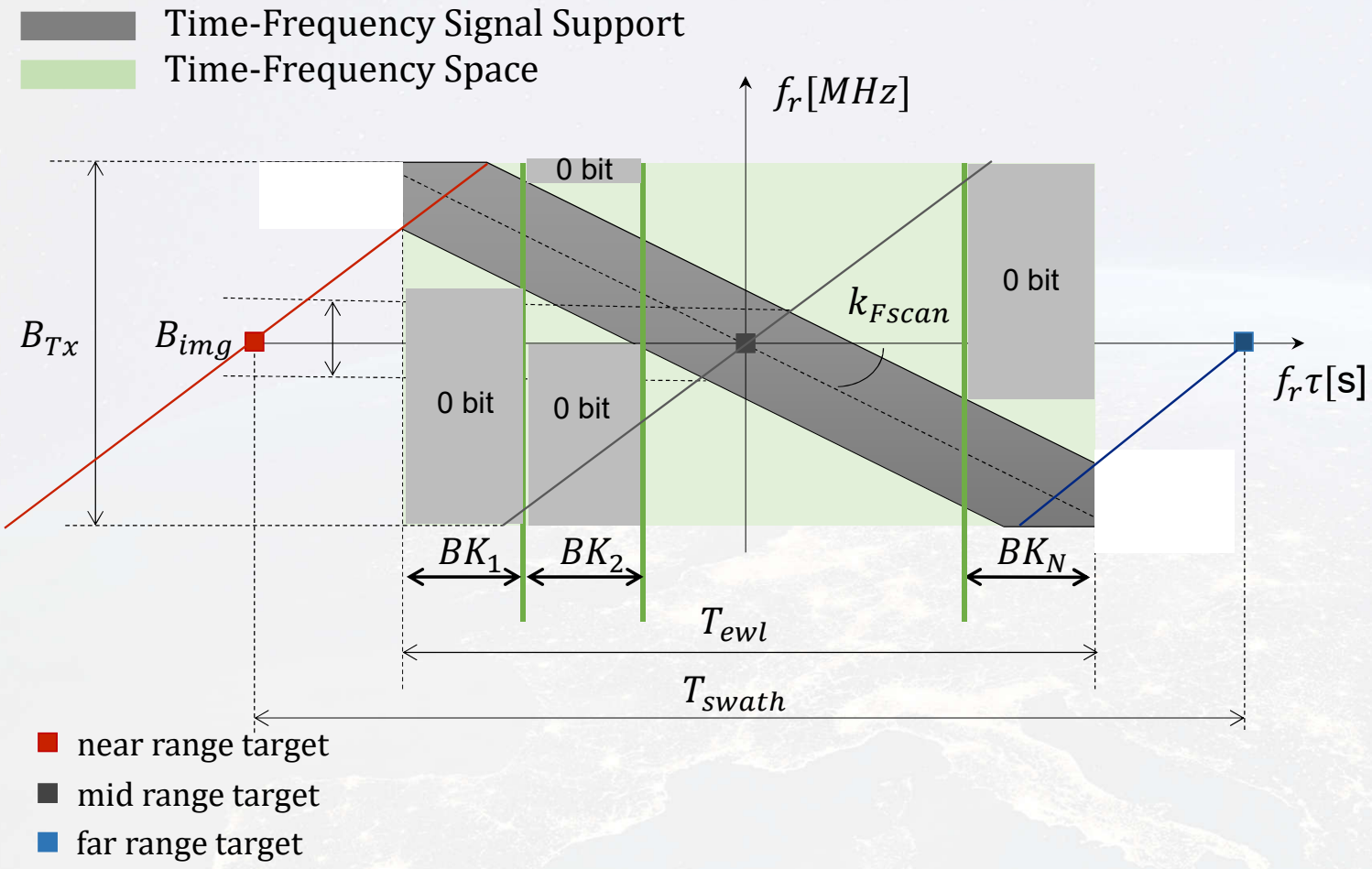
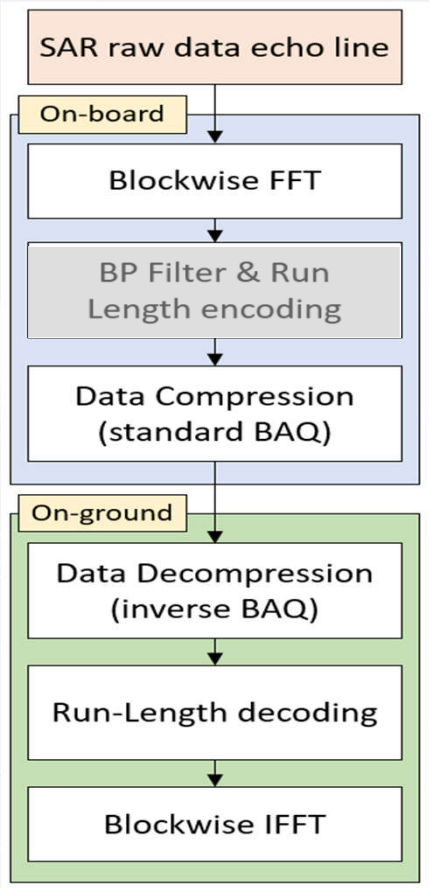
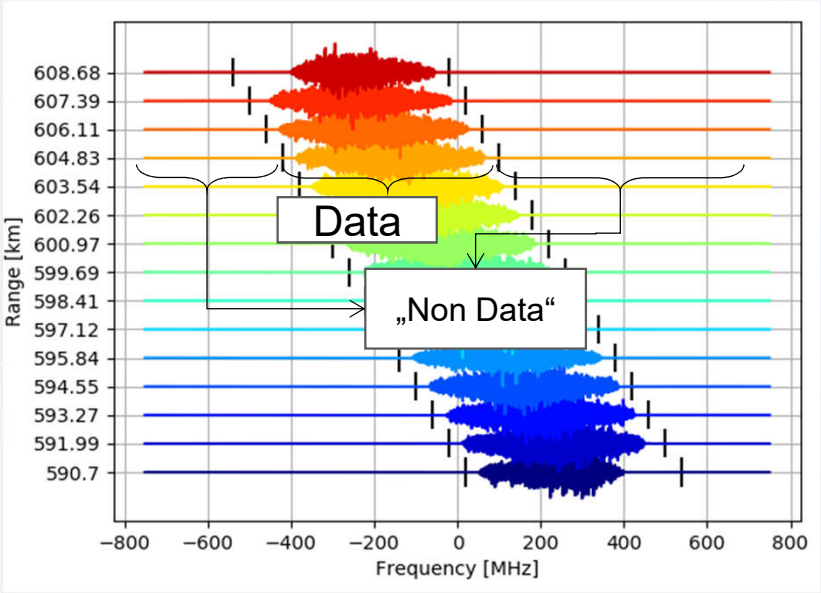
IMPROVED DATA COMPRESSION ALGORITHM FOR FSCAN



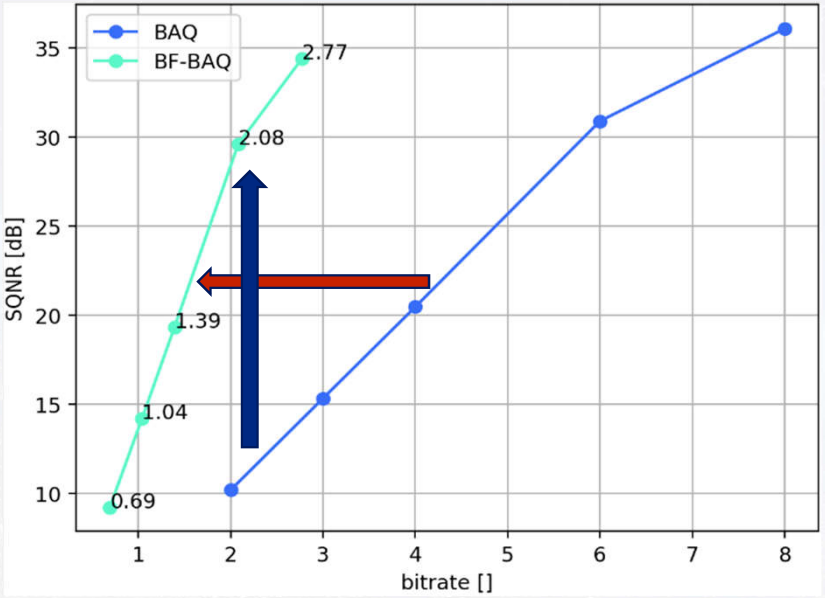


IMPROVED DATA COMPRESSION ALGORITHM FOR FSCAN (*)

Efficient Quantization in Frequency Domain



Benefits in SQNR and/or Effective Bit Rate



⬅ Run length coding (0 bit) of empty frequency spectrum allows data volume reduction by 60% wrt BAQ.

⬆ Alternatively, for same bit quantisation, the SQNR can be improved by ~18 dB.

[3] R. Scheiber, M. Martone and N. Gollin: "*Chirp Selection and Data Compression for Spaceborne Wide-Swath SAR in FScan-Mode*", *EUSAR Conference*, March 30 – April 1, 2021.

SUMMARY – S4PRO TECHNICAL PROGRESS

Staggered SAR azimuth filter

- Staggered SAR allows **HRWS imaging w/o gaps**; azimuth filter for data reduction by factor 2-3
- **Algorithm optimized** for efficient processing („Partial Sums“)
- Python Prototype transcoded to **C and optimized for the S4Pro Onboard Computer**
- **real-time** performance demonstrated for **ROSE-L parameters** -> **TRL level** raised **from 3 to 5**

SAR raw data compression for FScan mode

- **FScan** promises HRWS imaging with **short echo window length**
- Onboard Processing for **data volume reduction of up to 60%** in Fixed Chirp FScan mode
- **Variable bit FFT-BAQ** is proposed for improved compression performance

  -> ready for next step: dedicated prototyping within future HW breadboarding activities

THANK YOU

ANY QUESTIONS?

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