UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

Formation-Flying SAR as a Spaceborne Distributed Radar Based on a Microsatellite Cluster

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Outline of presentation

- FF-SAR Theoretical aspects
  - Definition
  - Monostatic SAR vs FF-SAR
  - Applications

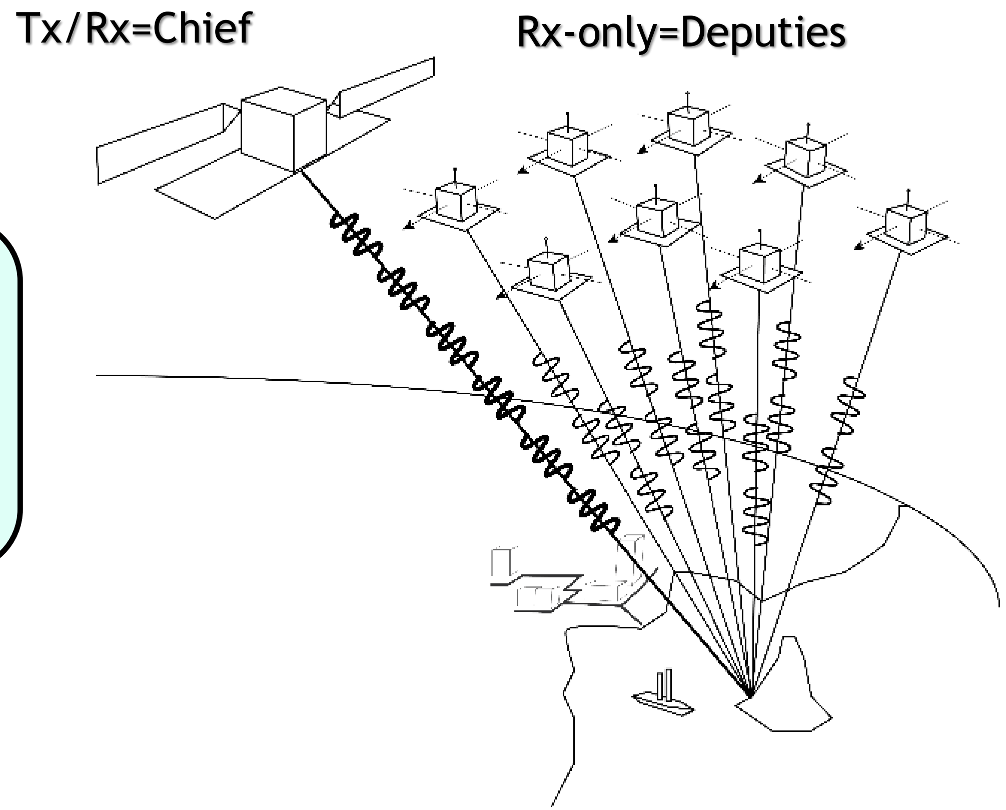
- End-to-end FF-SAR Mission concept
  - Satellite Design
  - Final budgets

- Conclusions

FF-SAR DEFINITION

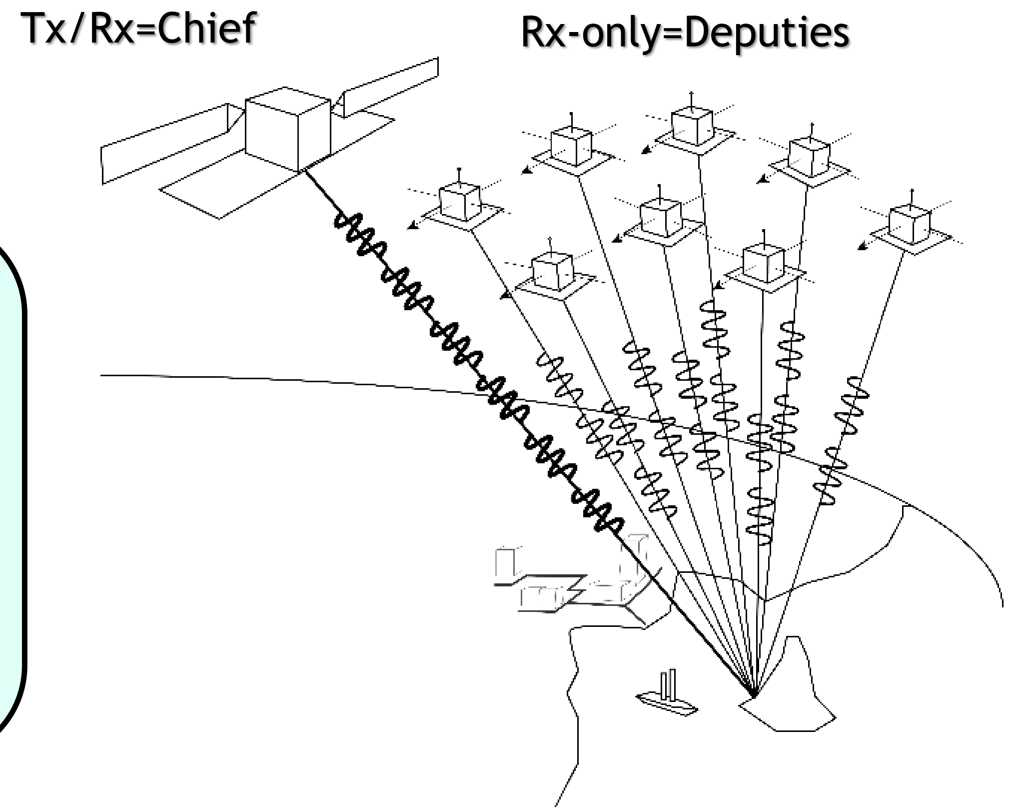
Formation-Flying SAR (FF-SAR)

Generalization of the conventional synthetic aperture radar principle and of standard interferometric SAR techniques



Formation-Flying SAR (FF-SAR)

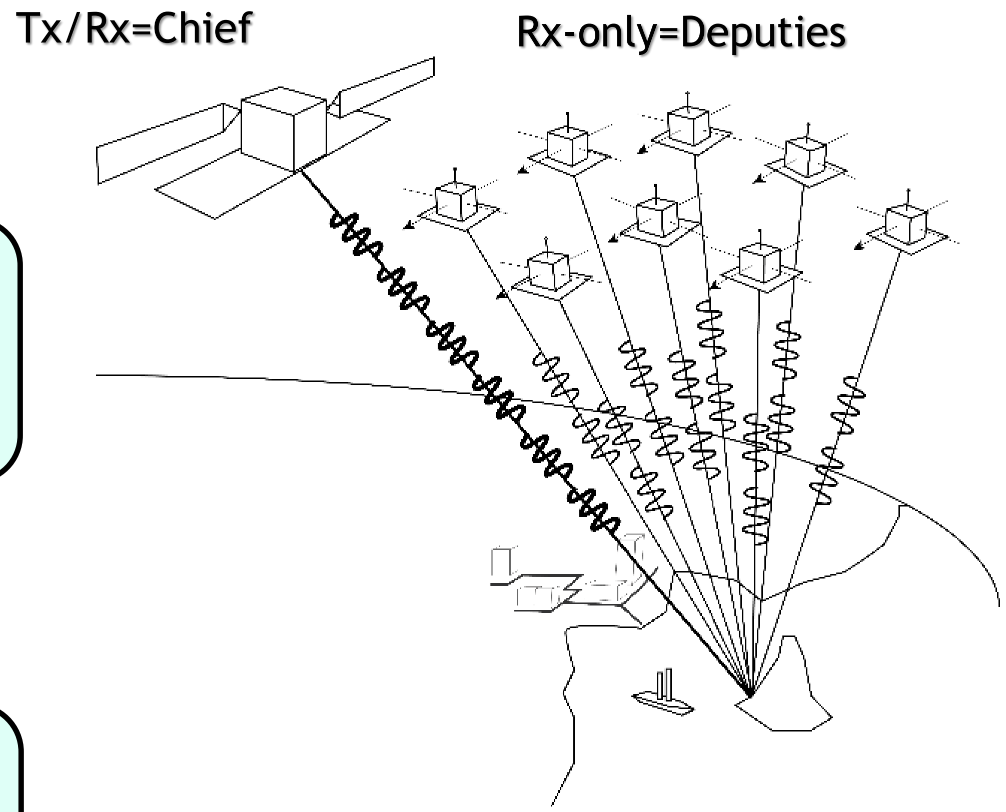
Many co-flying platforms cooperate with each other to implement new and complex SAR missions, otherwise impossible with the current monolithic systems



Formation-Flying SAR (FF-SAR)

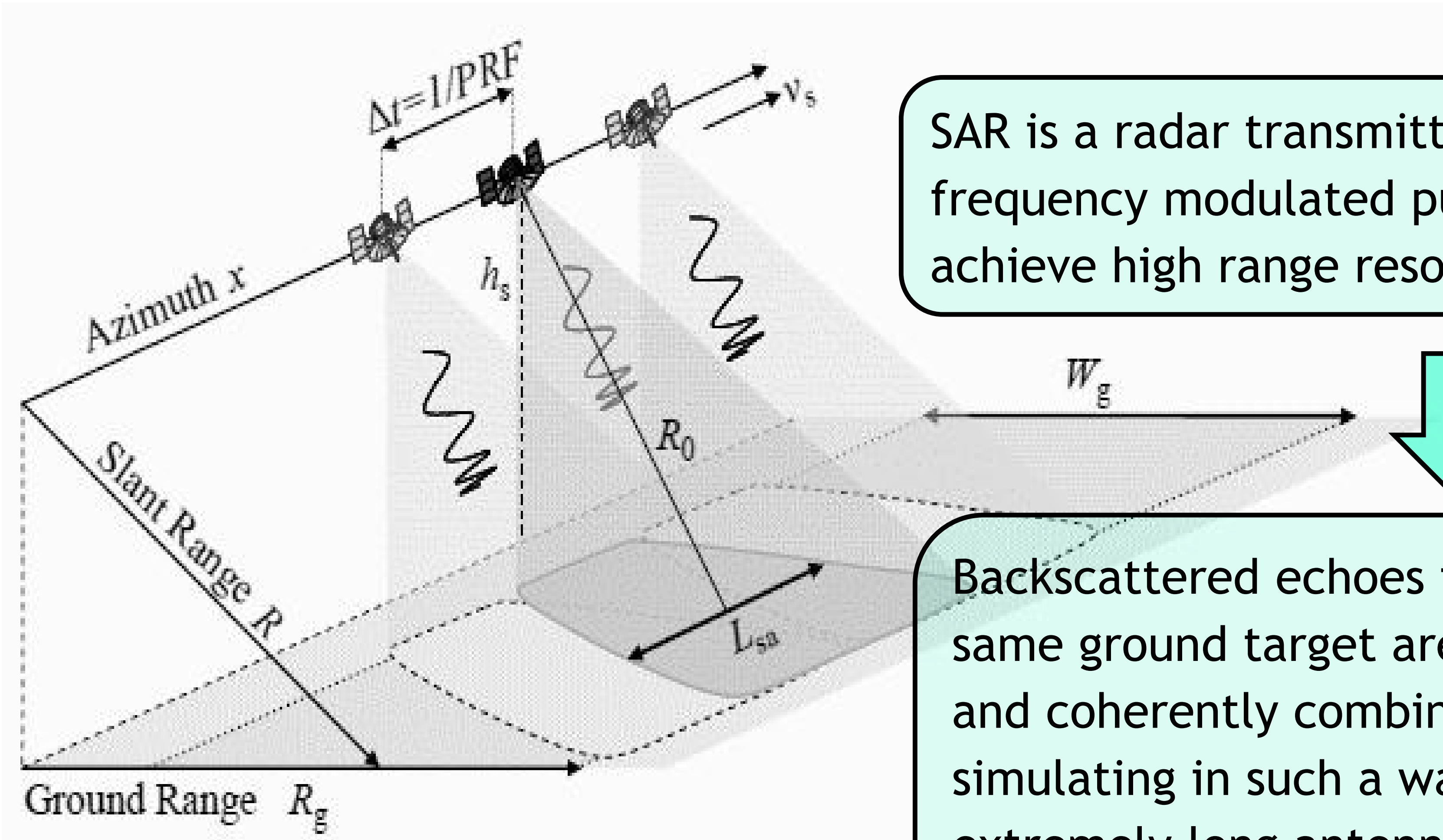
Highly flexible system able to implement a wide range of different working modes.

Spatial diversity for enhancing the overall system performance and the quality of the delivered products



FROM MONOSTATIC SAR TO FF-SAR

MONOSTATIC Synthetic Aperture Radar (SAR)

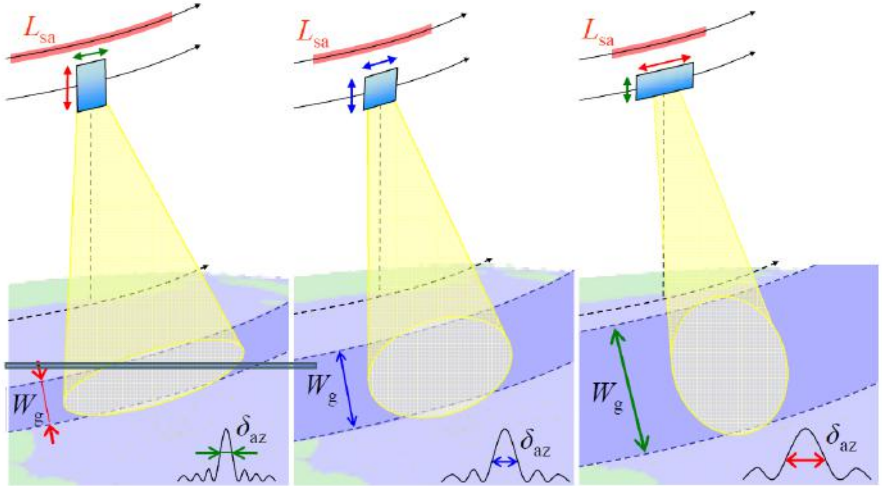


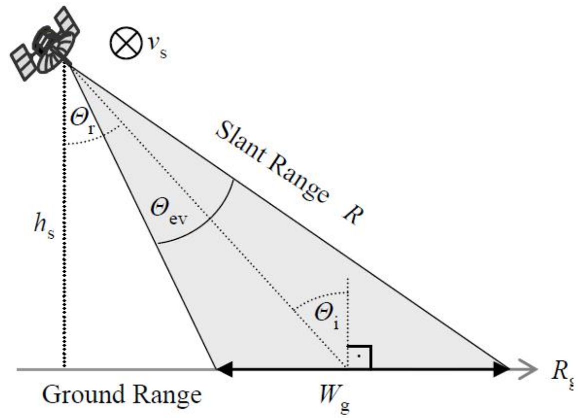
SAR is a radar transmitting short frequency modulated pulses to achieve high range resolution.

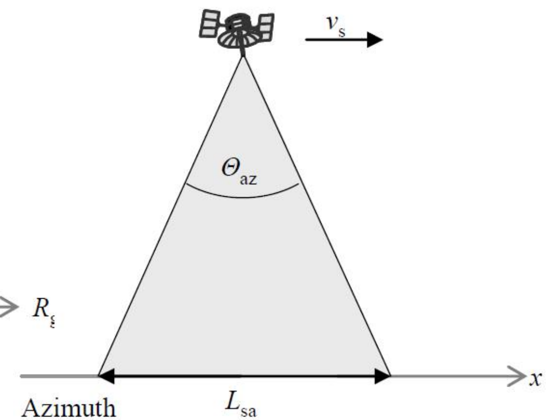
Backscattered echoes from the same ground target are collected and coherently combined, simulating in such a way an extremely long antenna.

Single-platform monostatic SAR system limitation

Example- Spotlight







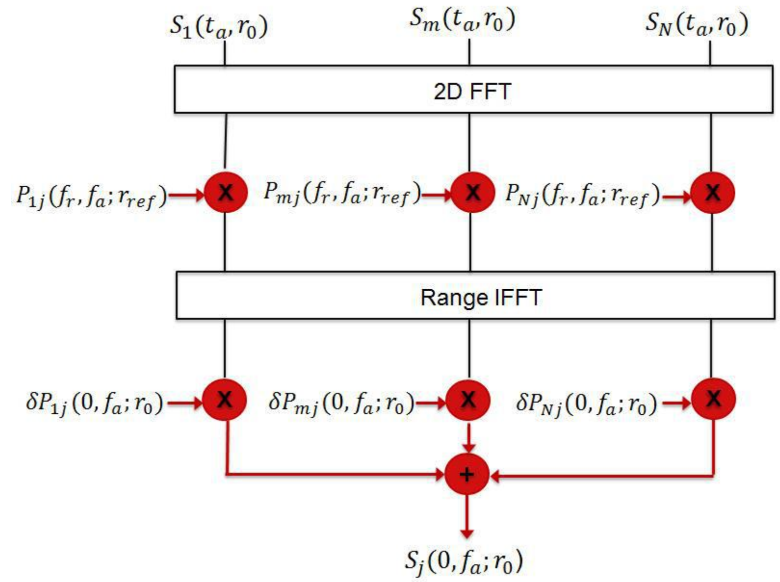
$$\frac{W_g}{\delta_{az}} < \frac{c}{2V}$$

Swath-to-azimuth resolution constraint for a monostatic platform system…

…as the swath width becomes larger azimuth resolution decreases

FF-SAR offers a feasible solution to the intrinsic limitation of a conventional SAR

Azimuth resolution can be decoupled from swath width by introducing multiple channels and applying **Digital Beamforming (DBF) techniques**



The coherent combination of the multiple receiving signals allows to reduce the *PRF* of transmitting signal by a factor of *N* (where *N* is the number of receivers), hence enabling to enlarge the width of the non-ambiguous swath on the ground, without arising of azimuth ambiguities

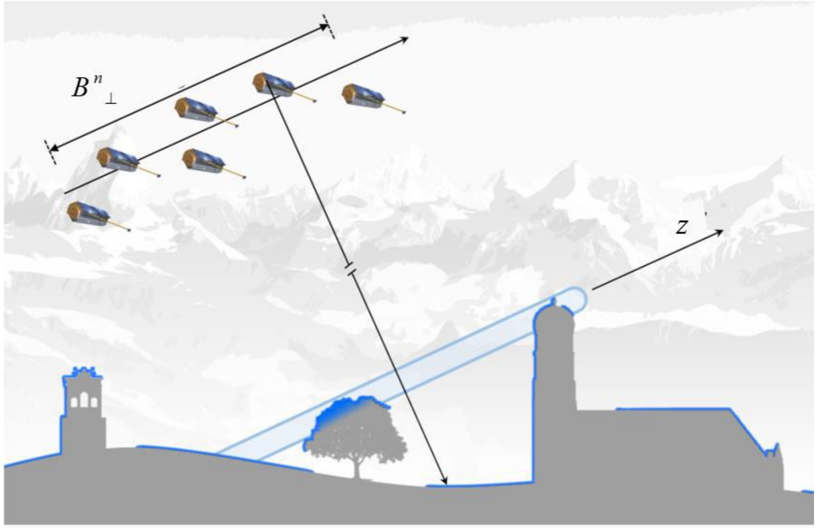
SAR interferometry issues related to the use of monostatic platform systems

- SAR interferometry obtains high accurate estimates of height and surface displacements by measuring the difference in phase of echoes scattered by the same targets and acquired by two different positions

With a monostatic platform only repeat-pass interferometry is possible, that suffers by **temporal decorrelation and atmospheric distortions.**

Monostatic SAR vs FF-SAR

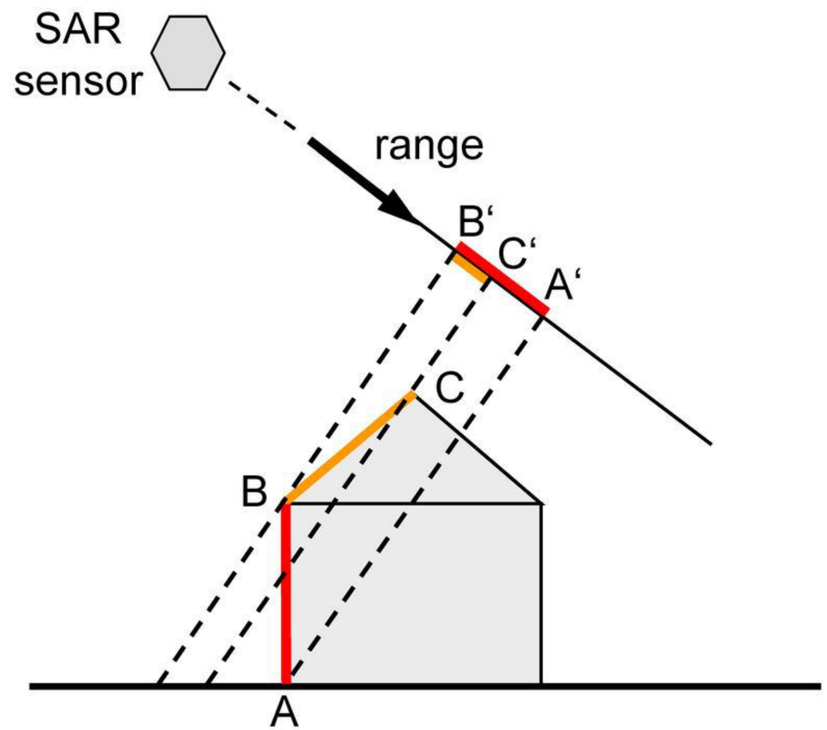
FF-SAR as a multistatic SAR system maps the scene without any significant time lag, thus giving the possibility to implement single-pass interferometry, thereby increasing the interferometric performance with respect to a single platform system



Multi-Baseline Single-Pass interferometry allows to drastically improve the DEM (Digital Elevation Model) accuracy

Monostatic SAR imaging effects due to geometric observation

SAR is able to measure the elevation of the imaged terrain by means of cross-track interferometry but has no resolving capability along this dimension



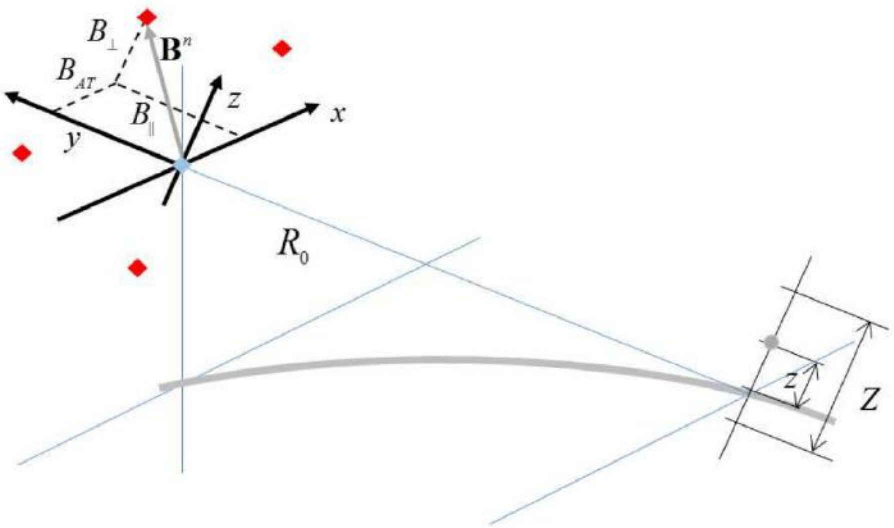
SAR images could be affected by the well-phenomenon of **LAYOVER**

If different terrain patches are at the same slant-range distances from the sensor, they will be mapped in the same range-azimuth resolution cell even if they are at different elevation angles in the SAR images

FF-SAR offers the capability to resolve multiple sources along the third dimension, i.e. a natural solution for the layover

Single-pass SAR tomography:

array processing of the sparse aperture formed by a formation flying cluster of multiple receivers displaced in the cross-track/vertical plane, i.e. thus realizing a baseline normal to the line of sight



Expected FF-SAR performance improvement and applications shall be

- Signal-to-Noise Ratio (SNR) improvement
- Coherent Resolution Enhancement (CRE)
- Pulse Repetition Frequency (PRF) reduction
- High-Resolution Wide-Swath (HRWS)
- 3D Imaging
- Ground Moving Target Indication (GMTI)

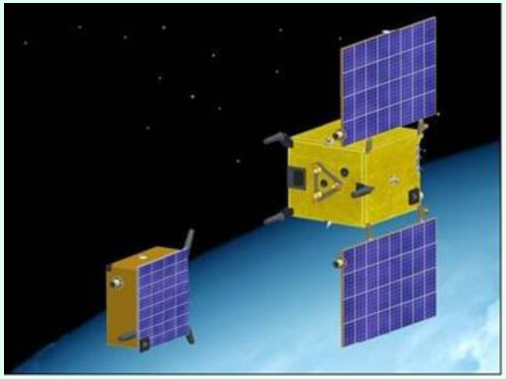
END-TO-END FF-SAR MISSION CONCEPT

Missions relying on two cooperative satellites successfully flown

- Space demonstration of distributed SAR concepts

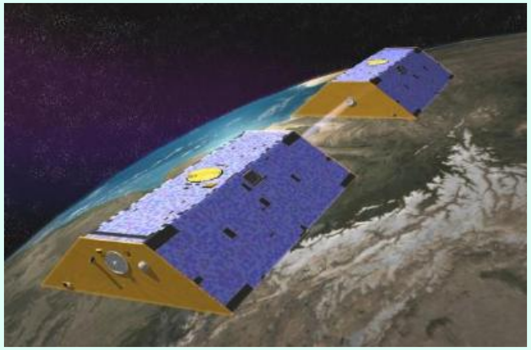
PRISMA

Tecnholgy demonstrator



GRACE

Aimed at gravimetry



TanDEM-X

High-resolution InSAR

…upcoming missions:

SESAME – STEREOID- HRWS DLR's Mission

All these missions are based on sub-500 kg class satellites !

WHY MICROSATELLITES?

The distributed system concept is naturally coupled with the use of **small space platforms**, for several advantages

- The system overall cost is lower
- The replacement of a failed satellite is easier and faster
- It is possible to gradually update on board technologies by incrementally replacing elements of the formation, which is generally an issue for large space systems.

Our work is aimed at..

In this framework, the design of an end-to-end space demonstrator concept was commissioned by DSO National Lab, Singapore, to the UniNa Aerospace Systems Team, to invetigate to investigate the feasibility of a distributed SAR system with micro-satellites

END-TO-END SPACE SYSTEM DEMONSTRATION CONCEPT

FF-SAR concept demonstrator mission is intended as a **reduced performance** space mission

Reduced Performance intended as

- **Limited duty cycle** per orbit
- Limited **life time**
- Limitations on **revisit time** and **coverage**
- Minimum DSAR redundancy, i.e. **just 3 satellites**

SPACE SEGMENT

Micro-satellite class (< 100 kg)

- 1 Tx/Rx, i.e. monostatic, satellite
- 2 Rx-only satellites
- X-band operations

FF-SAR DEMONSTRATION CONCEPT

Full demonstration of FF-SAR features at both:

- **System level ➔** distributed payload synchronization and formation flying
- **Product level ➔** SNR improvement, PRF reduction, HRWS, CRE, GMTI, 3D IMAGING

Starting from the design of monostatic platform, **targeted to achieve 8m x 8m resolution on ground, with -24 dB NESZ, from an orbit altitude of 550 km, and 20° inclination**

Imaging Requirements	Image Resolution	8 m x 8 m
	NESZ	- 24 dB
	Orbit altitude	550 km
Tx/Rx SAR Parameters	Antenna Size	0.7x4.9 m (7 tiles 0.7 m each)
	Chirp Bandwidth	Up to 100 MHz
	PRF	Up to 3.5 kHz
	Radar duty cycle	0.07 (at 3.5 kHz PRF)
	Incidence Angle	30°
	Swath width	35 km
	Peak Power	Up to 4 kW
	Data Rate	200 Mbps
	Orbit duty cycle	5% (about 5 min acquisition per orbit)
	Data Volume Per Orbit	7 GB

FF-SAR properties are exploited to demonstrate **performance improvement**

FF-SAR performance improvement

- ***Azimuth resolution enhancement***, *applying digital beamforming techniques*
- ***Ground-range resolution enhancement***, *by exploitation of Coherent Resolution Enhancement in Range*
- ***SAR tomography and Ground Moving Target indication testing***, *at the nominal 8m x 8m resolution*

To demonstrate FF-SAR features, 3 test case scenarios has been investigated

Test case scenarios

Mode 1

- 3 satellites with dominant along-track separations (up to 200m)
- 8 m x 4 m resolution
- Ambiguities suppressed by digital beamforming in azimuth
- SNR improvement

Mode 2

- 3 satellites with dominant cross-track or vertical separations (up to 1km)
- 6 m x 6 m ground-range resolution
- CRE in range
- SNR improvement

Mode 3

- 8 m x 8 m resolution
- 3D imaging
- GMTI

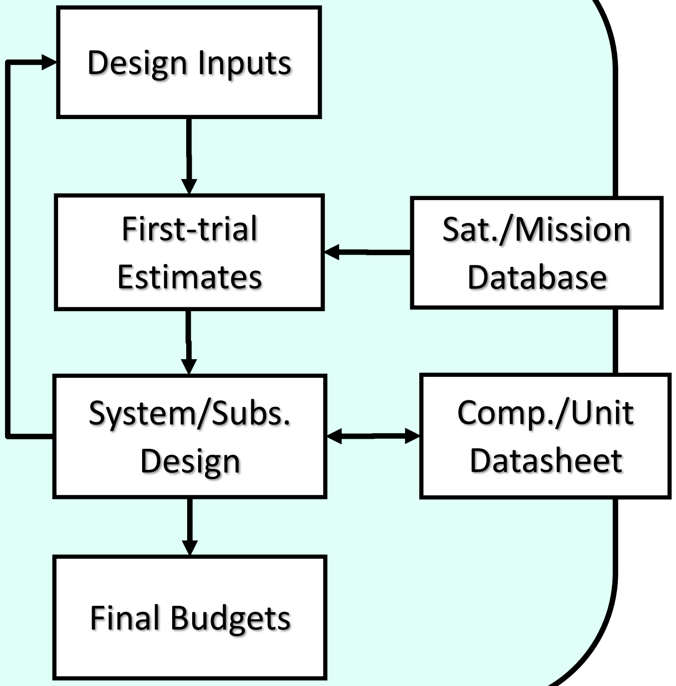
SATELLITE PRELIMINARY DESIGN

Satellite Preliminary Design: Approach

Goal is the preliminary design of Tx/Rx and Rx-only Satellites:

- 1-year demonstration mission
- limit size and mass while accommodating for SAR and FF operations

- At this stage, critical aspects investigated related to:
  - Electrical Power System (EPS)
  - Thermal Management (TM)
  - Attitude and Orbit Control System (AOCS)
  - FF maintenance
  - TT&C and PL data management
- First-trial mass estimate (used as reference):
  - 90/110 kg mass range and 1.14 m^3 volume for Tx/Rx Sat
  - 60/80 kg mass rage and 0.81 m^3 for Rx-only Sat



Signficant design choices that made possible the use of microsatellites are:

- No active control of the absolute trajectories (ΔV is low)
- The relative orbits are designed to be passively safe (they falls in the category of safe ellipses).
- SAR processing by means of Digital Beamforming allows one to relax formation control, i.e. the baseline could be also very different from the nominal values
- There is not an on-board synchronization system, thanks to autonomous calibration and GPS time referencing
- The antenna is not an active phased array, but a planar passive antenna. Mechanical beamsteering implemented by active maneuvers

Concluding Remarks: Final Budgets

- Final Budgets are in line with the initial rough estimates (Thermal Control & Structure can be estimated using typical percentages vs dry mass)
- It is remarked that computed values are only indicative of the satellite class

	Tx/Rx Satellite	Rx Satellite
Electrical Power System	10-22	3
Attitude & Orbit Determination and Control	5	5
Propulsion (wet mass)	11-13	9-11
TT&C and Data Handling	4-9	4-9
Thermal Control System & Structure	17-25	12-18
SAR Instrument	45	32
Total Wet Mass	92-119	65-78
Initial Rough Estimate (Dry)	90-110	60-80

- Final mass budgets indicate that the total mass is about 100 kg for the Tx/Rx satellite and less than 80 kg for Rx-only ones. Hence the results are in line with the use of microsatellites

- Simulation analysis confirmed the capability of the selected relative trajectory to support the demonstration of different working modes, such HRWS, CRE and 3D imaging.

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Thank you for your attention