

INTERFEROMETRIC MISSIONS USING SMALL SAT SAR SATELLITES

Guy Séguin, Ralph Girard

Canadian Space Agency, 6767 Route de l'Aéroport, St. Hubert, Qc, Canada, J3Y 8Y9
guy.seguin@space.gc.ca

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ABSTRACT:

The Canadian Space Agency (CSA) is currently involved in the development of active membrane antenna technology for SAR applications. To qualify this new technology, it is proposed to develop a small satellite L-band SAR demonstrator. Such a demonstrator could be placed on the same orbit than the ALOS satellite for a tandem interferometric mission. The paper describes the initial science objectives and mission definition based on the proposed concept.

1. INTRODUCTION

For sensors operating at L-band and even C-band, the mass and stowed volume of the SAR antenna are important drivers in the choice of the size of a spacecraft, as well as in the choice of a launcher. SAR satellites, such as RADARSAT-2, carry a SAR antenna with a mass exceeding 700 kg, which occupies a stowed envelope close to 7 cubic meters. The total mass of the satellite is 2,300 kg and a Delta-2 rocket is required to place the satellite in orbit.

By way of contrast, SAR antennas realized using a membrane construction can be much less massive and can stow much more compactly. Such substantial reductions can allow a smaller spacecraft to be selected for the mission. Furthermore, at low frequencies the membrane approach could be used to implement a SAR aperture whose dimensions exceed the largest values achievable with other approaches. The larger aperture provides system benefits such as wider coverage swaths and better image quality.

A 16-row L-band array design for a baseline of 12 m \times 3 m aperture antenna has been developed at EMS technology under funding by the CSA [1,2]. The design uses two non-deployable T/R modules per row, one per wing, located on or near the spacecraft bus, along the aperture mid-line. In this type of centralized architecture, the baseline 12m \times 3 m aperture antenna has 32 T/R modules, each with a RF peak power levels of the order of 200 W.

Current mass estimates for the SAR payload including the deployment mechanism as well as the spacecraft bus estimate of the satellite is 400 kg for the total mass, which places the mission in the small satellite category.

The membrane antenna and the T/R modules are both in breadboarding phase to complete a representative prototype by the end of 2002. The next step will be to fly an active membrane antenna in space to complete the qualification process. Given the risk involved with this new technology, it is planned to first develop a small-satellite technology demonstration (SSTD) mission.

The capabilities of a small satellite being limited, it is proposed to fly the instrument in tandem with the PALSAR radar on the Japanese ALOS satellite. Initial analysis presented in this document, shows that ALOS and SSTD mission would greatly benefit from a joint operation.

The choice of PALSAR is dictated by the fact that membrane antenna technology is easier to apply at L-band due to the lower density of elements. Current activities already focus on L-band for the development of the prototype membrane antennas.

Two joint missions are proposed that are detailed below:

- Interferometric mission for generating a digital elevation model (DEM) over polar region.
- Tandem mission for repeat-pass interferometry.

2. MEMBRANE ANTENNA

Membrane antenna technology has been under development since 1996 in Canada. Initial work concentrated on large passive structures to be used in reflection or as a lens. In the last three years, the CSA has concentrated on a direct radiating membrane antenna concept that is depicted in Fig.1.

The concept consists in three layers made of copper etched membranes: a radiating layer, a ground plane layer and a feed network layer. The radiating elements are connected to the feed layer through the ground plane using flexible interconnect elements.

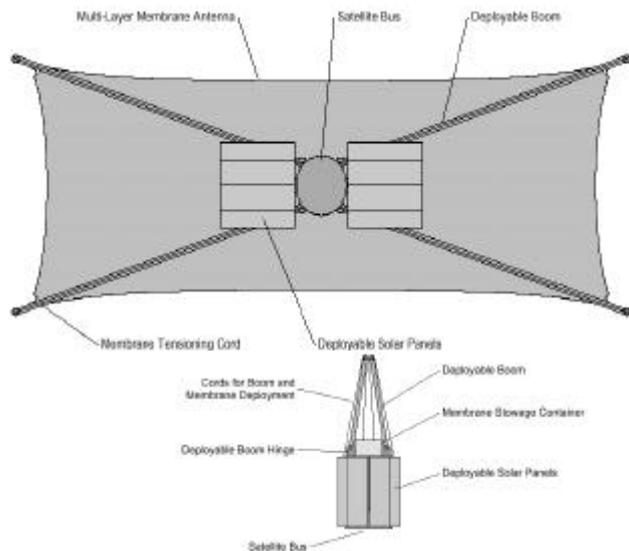


Fig. 1: A direct radiating membrane in stowed and deployed configuration.

Critical components for a direct radiating membrane have been breadboarded in 2001-2002. Space-qualified material has been selected and initial mechanical tests have been performed successfully. A membrane undergoing deformation tests is shown in Fig. 2.

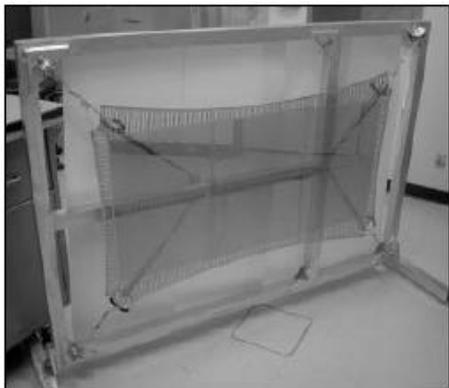


Fig. 2: A Kapton-E etched copper direct radiating membrane. The membrane is stretched for deformation tests.

Current activities for year 2002-2003 include breadboarding and testing of a small array in a representative environment. If the activities are successful, it is planned to develop a small-size antenna in the time frame 2004-5 and fly a prototype in 2006-7.

3. INTERFEROMETRIC MISSION DESCRIPTION

The SRTM mission that has flown in January 2000 has only covered the Earth's landmass over $\pm 60^\circ$ and no good DEM exists for polar region. A combined PALSAR/SSTD mission could complete the Earth coverage and generate a DEM over polar region with accuracy compliant to Digital Terrain Elevation Data (DTED) Level 2, which is the level achieved by the SRTM mission. This mission is made possible by the

fact that a bi-static mission could be proposed where PALSAR would be used as the main illuminator and the SSTD as a passive receiver system. The SSTD instrument would fly a few kilometers behind (or ahead of) PALSAR. Because the effective antenna beam width is that of the combined system and the SSTD would not transmit, it is possible to use a small satellite with low power consumption.

Moreover, the ALOS optically generated DEM data could serve as ground control points for the radar data. The concept is illustrated in Fig. 3.

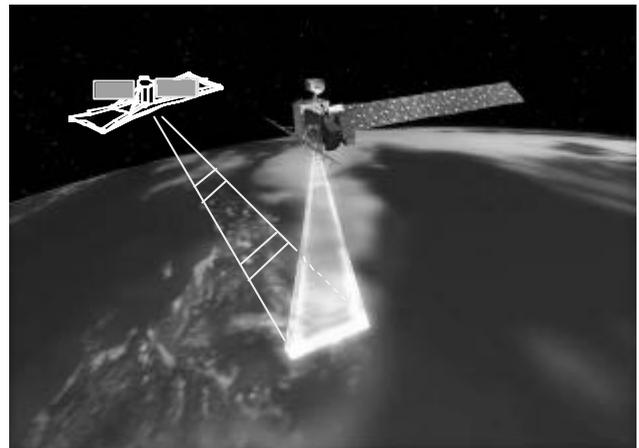


Fig. 3: A pictorial view of an interferometric mission between ALOS and SSTD.

The mission scenario assumes that ALOS is launched in 2004 and SSTD in 2006. The SSTD satellite would first be placed on an orbit close to ALOS but with a different right ascension for a period of validation and calibration. After validation, the SSTD satellite would be placed on an orbit close to ALOS for the polar interferometric mission.

DEM accuracy for a bi-static mission is discussed in detail in [3]. All radar parameters being fixed, the relative vertical accuracy is a strong function of the perpendicular baseline between the satellites. A large perpendicular baseline yields good accuracy. In principle, one could select a baseline up to a maximum value called the critical baseline where correlation between the signals received by the two radars drops to zero. For the tandem ALOS/SSTD, the critical baseline is around 20 km. However, in practice, the perpendicular is limited by the height of ambiguity, which is the height on the ground producing a phase difference of 2π on the radar interferogram. A small height of ambiguity would make phase unwrapping too difficult. Currently, the height of ambiguity is required to be higher than 40 m. In the along-track direction, it would be desirable for safety of operation to have a large separation. However, to maintain a good spectral overlap between the received Doppler spectra, it is necessary that the along-track separation is substantially smaller than the beam footprints on the ground. This constrains the along-track separation to be in the range 1 to 2 km.

When the constraints on baseline separation are taken into account, it is found that only a few orbit scenarios are possible for coverage over polar region. The first option is to use a large ascending node offset to create adequate spacecraft separation at high latitudes. The second option is to introduce an inclination offset between the orbits in order to create an

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across-track separation near the poles. The third option is to create a vertical spacecraft separation near the poles through an eccentricity offset. A fourth option is to create a vertical spacecraft separation through a combination of eccentricity offset and argument of perigee offset by taking advantage of the frozen orbit effect. The eccentricity and argument of perigee of a frozen orbit oscillate periodically around a pair of frozen values. If the orbits are initialized with orbital parameters separated by half the frozen orbit period, a vertical spacecraft separation is created with the point of maximum separation oscillating between +90 degrees and -90 degrees argument of latitude about the poles with a period equal to the frozen orbit period.

Each option has its advantage in terms of coverage efficiency and fuel consumption for orbit maintenance. For example, Fig. 4 gives the perpendicular baseline as a function of latitude for the second option. In this example, the orbit inclination of SSTD is chosen to differ by 0.02° from ALOS. This provides a separation that increases towards high latitude. On Fig. 4, the baseline over the polar region is found to be well within the minimum baseline to provide a 6 m vertical accuracy over an averaging area of 30 m x 30 m and the maximum baseline to satisfy the height ambiguity requirements. A lower inclination offset could be selected. Near equator, where the perpendicular baseline goes to zero, safety is provided by the 2.0 km along-track separation.

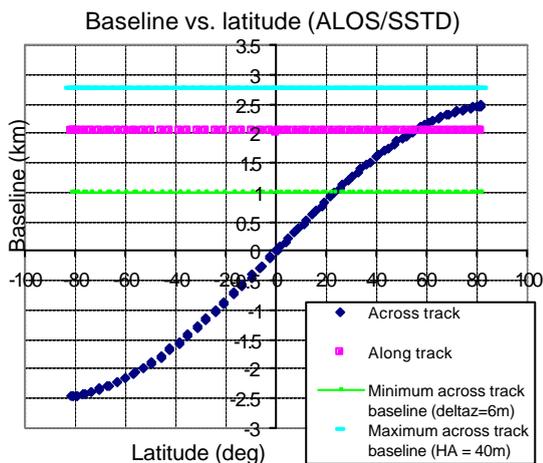


Fig. 4 Across-track baseline variation as a function of latitude for the SSTD/ALOS tandem with an inclination offset of 0.02° . The minimum and maximum values for the baseline are given for an incidence angle of 30° .

The disadvantage of option 2 is that the offset in the inclination causes a change in the drift rate of the ascending node, which makes the separation to increase with time. Fig. 5 gives the evolution of the maximum baseline as a function of time. After a few days, the maximum baseline is exceeded and an orbit correction manoeuvre must be applied.

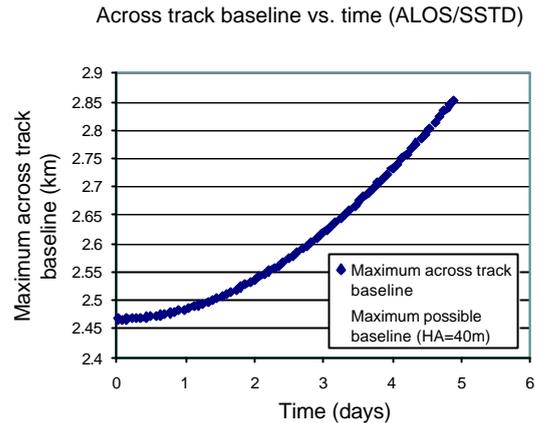


Fig. 5 Maximum across-track baseline variation as a function of time. An inclination offset causes a long-term drift in the variation of the ascending node causing the separation to increase beyond acceptable limits.

Detailed trade-off analysis will be performed to select the best orbit (or combination of orbits) option. Preliminary investigations indicate that all options are possible if the SSTD satellite carries 5% of its mass in fuel.

4. COVERAGE PERFORMANCE

Initial investigations of the coverage performance for the polar mission have been performed. PALSAR standard beam modes would be used to collect the data, which would produce a data rate of around 170 Mbps for SSTD. Assuming that SSTD carries a Solid State Recorder (SSR) with a capacity of 100 Gbits and that 3 stations supporting a channel capacity of 105 Mbps are used to downlink the data, it is found that 95% of the polar region can be imaged twice in a period of 6 months. Adding margins for operation, the polar mission could thus be completed in a one-year period.

After completion of the polar mission, the SSTD satellite would be placed on a transfer orbit and moved many nodes away to allow independent operation of the satellites.

5. REPEAT-PASS INTERFEROMETRY MISSION

One of the limitations of ALOS is its long revisit time. For change detection in critical areas, it would be desirable to have a shorter revisit period. A possible mission for the SSTD could be to complement ALOS in that aspect. The SSTD would be placed on the same orbit as ALOS but placed just in the middle of an ALOS 46-day cycle, such that the combined revisit time of the ALOS/SSTD pair is 23 days. Because the imaging capabilities of the SSTD are constrained, it would be limited to image over areas that have been previously flagged by ALOS as being subject to rapid changes. This combined operation would have little impact on the SSTD, allow for independent operation and double the effective revisit time of ALOS in critical areas.

The repeat-pass interferometry mission, as described above, would take place after the polar tandem mission and last for the remaining of SSTD lifetime. In case that a decision is

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made to not run the polar mission, then the repeat-pass mission could start immediately after the SSTD launch and commissioning period.

Table 1 gives the performance parameters for repeat-pass interferometry with the SSTD. The calculations are based on a baseline of 500 m, which is typical of the orbit control accuracy that one would require. A better performance could be achieved if a smaller baseline is used or if the target σ is higher. The calculations reported in Table 1 are for a look angle of 30°.

A better control of the SSTD orbit would be required to improve the repeat-pass capability of the system. For comparison, the JPL's LightSAR program had set a requirement for 2-5 mm accuracy.

Table 1: Repeat-Pass Interferometry Parameters

Parameter	Value	Comment
Across track baseline	500 m	Maximum Value
Height of ambiguities	200 m	
DTED-2 DEM error	12 m	Used for co-registration
Residual Topography phase	21.6°	
Thermal noise phase	13°	
Phase error	25.2°	
Displacement error	8 mm	Need to add any additional effect due to atmosphere and more generally temporal decorrelation.
Maximum displacement measurable	11.8 cm	

6. SCHEDULE

Fig. 6 gives a first idea of the SSTD mission schedule. Assuming that the SSTD mission can be developed for a launch in 2006, this would still leave about two years of operation with ALOS. Note that the Go-Ahead decision is not critical since much of the development activities leading to the payload are already on their way at the CSA. The important point is that with reasonable assumptions on the development of the technology demonstration mission, there exists a large window of opportunity for a tandem mission with ALOS.

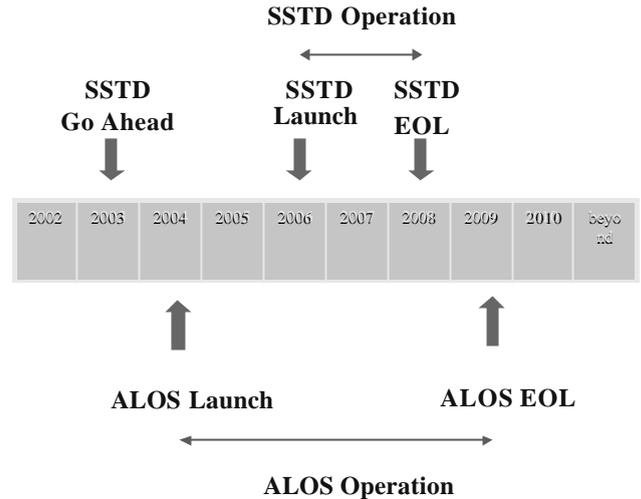


Fig. 6: Mission Timeline

7. CONCLUSION

A technology demonstration mission has been proposed to give flight heritage to new SAR technologies. In order to enhance the mission products, it is suggested to have a joint mission with the ALOS satellite that is slated for launch in 2004. Flying the satellites in tandem would allow generating unique interferometric data over polar region and more frequent repeat-pass Interferometric data in other regions.

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