Design and development of the Laser Retroreflector Array (LRA) for SARAL

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ABSTRACT

CNES (French spatial agency) will provide the AltiKa high-resolution altimeter, Doris instrument and the LRA (Laser Retro-reflector Array) for SARAL (Satellite with ARgos and Altika) in cooperation with ISRO. The paper presents the LRA, its design and its key performances. The nine corner cube reflectors have been manufactured with very stringent dihedral angle offset precision. The tests done will be described. Specific modelisation and analysis (thermal gradient), specific test (thermo-optical test) and optimizations will be described.

1. SARAL MISSION

The SARAL mission results from the common interest of both CNES (French space agency) and ISRO (Indian space agency) in studying ocean from space using altimetry system and in promoting maximum use of the ARGOS data collecting system. The SARAL mission is a joint mission conducted by CNES and ISRO. ISRO provides the platform, its launch and the on orbit operations. CNES provides the payload and ensures the data reception and processing. EUMETSAT ensures the data distribution to all the users except in India where ISRO is in charge of it. The payload is composed of an ARGOS-3 instrument for data collection and localisation, of AltiKa which provides altimetric measurements to study ocean circulation and sea surface elevation, of DORIS and a LRA (Laser Retro-reflector Array) for precise orbit determination.

2. LRA GENERALITIES

This paper presents the design and the optical performances of the LRA developed for SARAL. CNES with SOPHIA CONSEIL subcontractor was responsible for the design and the optical performances. SESO was in charge of the development and especially of the Corner Cubes (CC) manufacturing.
The LRA is a conventional device for altimetry satellites but constitutes a new development for CNES. It is used for calibration of the satellite altitude within few millimetres accuracy. The measurement principle is telemetry. The device is nadir-oriented and reflects laser shots from ground stations network. The analysis of the time delay of these laser shots permits to determine the orbit of the satellite.

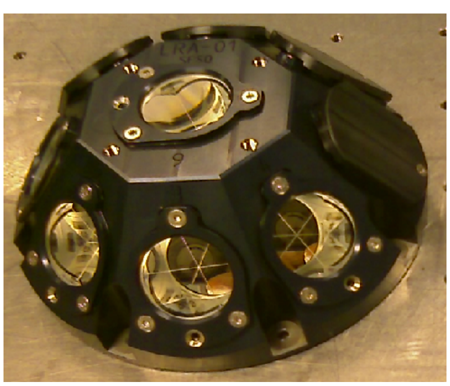

Figure 1. LRA with nine Corner Cubes.

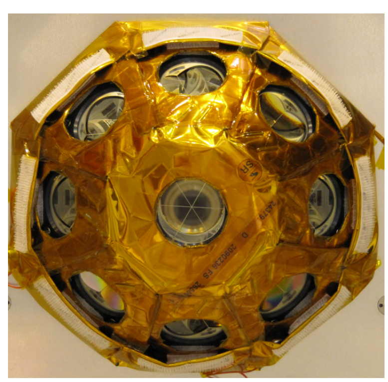

Figure 2. LRA equipped with MLI blanket.

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The LRA is an optomechanical device. As it is totally passive, no specific operational constraint and no calibration are needed. The Corner Cubes constitute the key elements for the optical performances of the LRA. The optical challenge is to determine and to manufacture the CC dihedral offset angle that spreads energy in relevant angular directions.

3. DESCRIPTION OF THE INSTRUMENT

The LRA for SARAL is a wide field reflecting system thanks to nine corner cubes. Cf. figure 1. It is an hexagonal array type with eight cubes all around the LRA and one at the top, nadir pointing. Such a design permits to position each Corner Cube on a common sphere. The center of this sphere constitutes the LRA phase center. The knowledge of the location of this center in the satellite frame is very important for accurate LRA corrections.
The CC are coated in order to make the LRA response homogeneous in the whole field of view. The following table gives the main characteristics of the LRA Instrument.

Table 1 : Main characteristics of the LRA.

Dimensions	Φ 165 mm x H 67 mm
Device mass	1,4 kg
Field of view	> 150°
for each CC, cone with optical performances	50°
Number of Corner Cubes (CC)	9
Clear aperture of the CC	30 mm

The LRA is covered by a MLI blanket made with eight petals and nine holes. The rear blanket is folded and fixed on the front face. The interface with the MLI of the payload is made with velcros. Cf. figure 2.

4. THERMAL AND MECHANICAL MODELS

With a Finite Element Assembly Model, SESO has validated that the design is compliant with no difficulty to the quasistatic and dynamic loads.

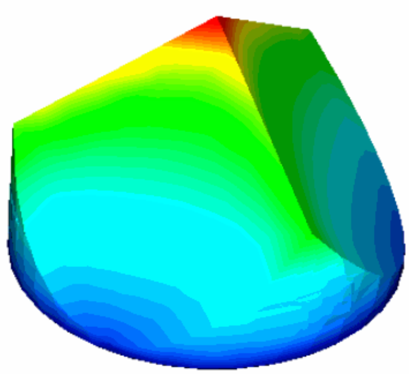


Figure 3. Corner Cube thermal gradient analysis.

For thermal analyses, SESO has developed a macroscopic LRA model and a local model for Corner Cubes. The aim of the macroscopic model was to determine the temperature excursion for the LRA. The CC modelisation is very simplified in this model. The external flux, the radiative effects, the internal conductivity and the interfaces properties are taken into account. Additional specific CC model is developed for relevant thermal analysis of the Corner Cubes. The need is to take into account the contribution of the optical flux, the conductive flux inside the cube, and radiative exchanges with the external environment (cold space for the front face and barrel environment for the coated surfaces). Cf. figure 3.

5. OPTICAL DESIGN

Because of velocity aberration, the return spot is not centered on the laser station. Considering the system in the frame of the satellite, the ground station is moving since the laser shot until the return signal detection. Each Corner Cube must spread the beam in order to compensate this velocity aberration effect. So, a dihedral offset angle is introduced. The prediction of the velocity aberration effect is very important for the optical performances of the LRA.

An optical ASAP (Advanced Systems Analysis Program) model has been developed by SOPHIA CONSEIL.
A parametric study has determined the aperture of the Corner Cubes and their dihedral offset angle. Both are coupled. Working with smaller aperture move away the diffraction rings. Increasing the dihedral offset angle also put energy away from the center of the spot as explained in [1]. A rigorous model calculation is needed to make a relevant coupled choice of aperture and dihedral offset angle.
Taking into account our satellite altitude and velocity, the working point chosen is an optical aperture of 30 mm and a dihedral offset angle of 1.5 arcsec. Figures 4 shows the nadir spot. Thanks to our dihedral offset angle, energy is put between the first and second diffraction ring.

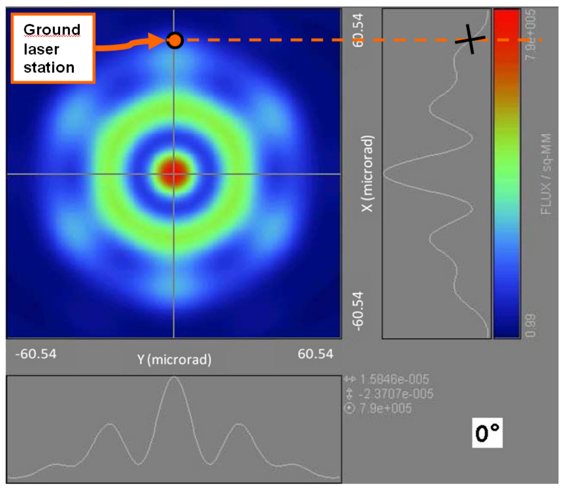


Figure 4. Far field diffraction pattern - nadir pointing.

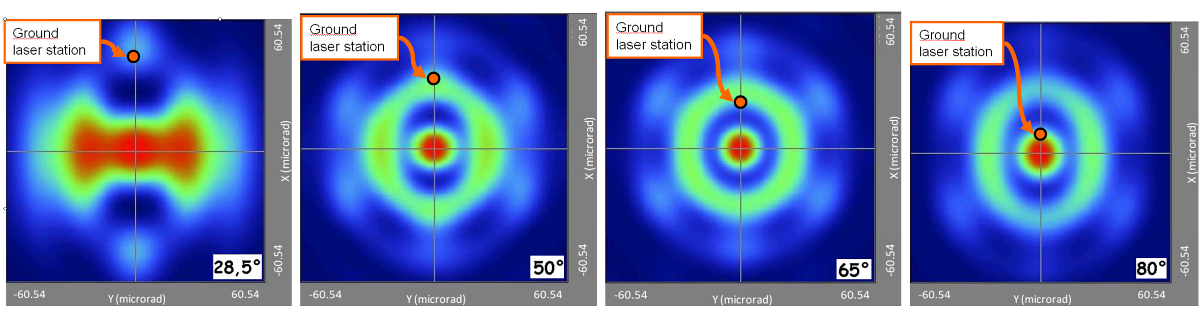


Figure 5. Far field diffraction patterns for 28.5°, 50°, 65° and 80° laser pointing direction.

As shown in figure 5, our choice allows optimised energy distribution for all the angular configurations. The angular pointing direction is the angle between the ground laser shot and the nadir direction. The laser shot is at the center of the diffracted pattern. The detected return beam is mentioned "Ground laser station". Energy distribution is relevant !

A detailed 3D-LRA model was developed in order to determine precisely the energy distribution as a function of the angular 3D configuration. The angular consideration is the relative position between laser station and satellite. Due to LRA symmetry, a 22.5° spinning symmetry is observed. Energy distribution calculation is given figures 6 and 7.

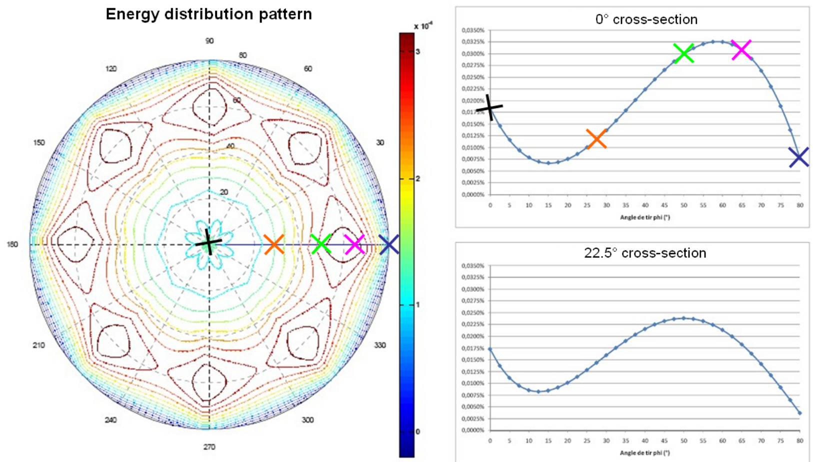


Figure 6. Energy distribution pattern.

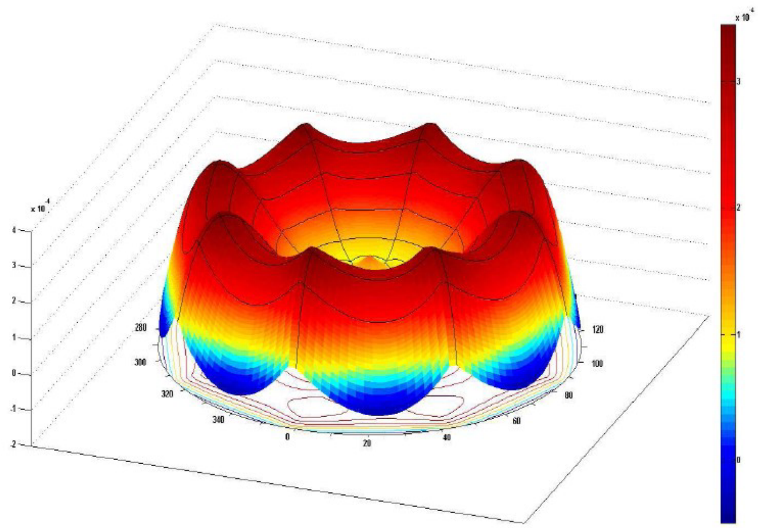


Figure 7. Energy 3D-distribution pattern.

6. CORNER CUBES

The key elements for LRA performances are the Corner Cubes (CC). SESO was in charge of their manufacture. See Figure 8. The table 2 gives the main characteristics of the CC.

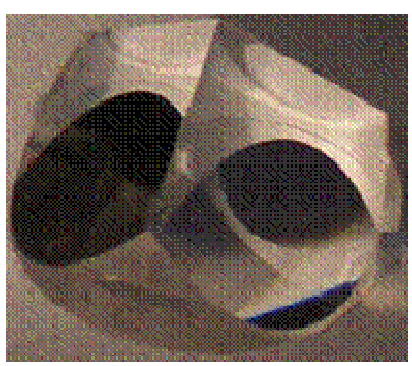


Figure 8. Corner Cube before coating.

Table 2 : Main characteristics of the Corner Cubes.

Dimensions	Φ 30 mm x H 24 mm
Clear aperture of the CC	30 mm
Material	Suprasil
Index of refraction at lambda = 532 nm	1.461
Operational Dihedral offset angle	1.5 arcsec
Coating	Ag coating
Radius of curvature of front face surface	infinite
Wavefront error	< 40 nm RMS

Thermal study has pointed out that a 0.4°C thermal axial gradient is expected in the CC. An additional gradient is present if they are exposed to the sun. This term can't be compensated because it is very variable. The impact of a 0.4°C constant axial gradient is a deviation decrease of 0.5 arcsec. This is compensated by increasing the dihedral offset angle specification from 1.5 arcsec to 1.6 arcsec.
At ambient temperature, the measured dihedral angle errors are detailed in the following table. The manufacture of the CC is a great success. The mean error is 0.17 arcsec and the maximum error is 0.42 arcsec ! Due to this accuracy, the real optical pattern will be very close to the modelisation and the performances easily achieved.

Table 3 : Detailed dihedral offset angles of the Corner Cubes manufactured by SESO.

Corner Cube	Dihedral angle error	Corner Cube	Dihedral angle error	Corner Cube	Dihedral angle error
	1,553		1,508		1,696
CC1	1,44	CC4	1,74	CC7	1,18
	1,758		1,711		1,444
	1,309		2,019		1,294
CC2	1,26	CC5	1,74	CC8	1,64
	1,359		1,584		1,684
	1,5		1,445		1,607
CC3	1,53	CC6	1,68	CC9	1,45
	1,999		1,669		1,384

The optical performances are optimised for each CC by optimising its position and its specific orientation in the LRA frame. Considering the velocity aberration, three classes of Corner Cubes can be defined. The « Max », « medium » and « min » types respectively correspond to CC working with the maximum, medium and minimum angular deviation. The angular direction around which the CC are working, is respectively 50 µrad, 39 µrad and 25 µrad for « Max », « medium » and « min » class.

7. OPTICAL PERFORMANCES

An optical link budget has been studied by CNES. With typical hypothesis on the laser source (power 23 mJ and divergence of 7 arcsec) and on the detection system (aperture of collection 60 cm), the predicted collected photons are respectively 185 000, 82 000 and 1800 for a 0 (nadir), 50 and 75 degrees laser shot.

Experimental Point Spread Functions (PSF) have been characterized and analysed for each Corner Cube. This verification has permited to confirm their position and orientation.

Qualitative and quantitative verifications have been made by comparing measured PSFs and simulated ones. The figure 9 illustrates the analyses made. We have both demonstrated that the dihedral angle offset measurements are relevant and the energy is spread as expected.

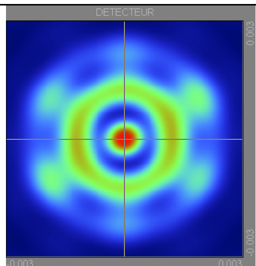
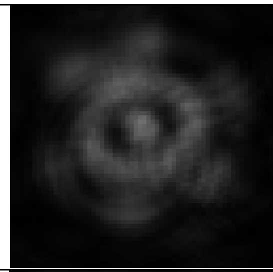
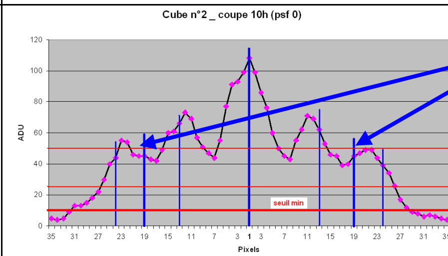
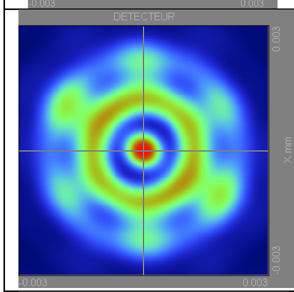
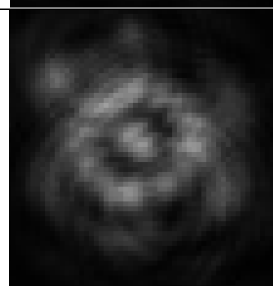
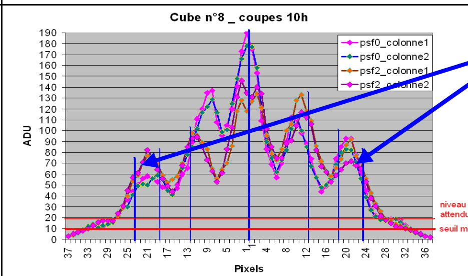
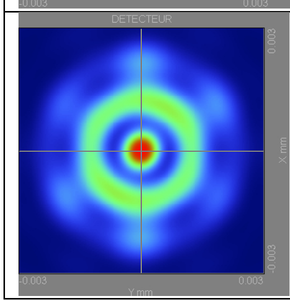
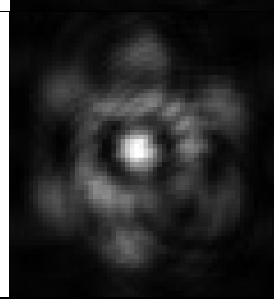
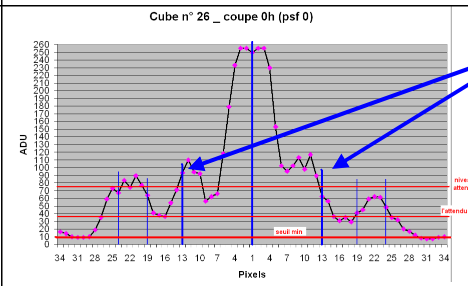
Simulated PSF	Measured PSF	Optimised position (class) and orientation	Class
			medium
			Max
			min

Figure 9. PSF measurements.

8. TESTS

A qualification model was developed for mechanical and thermal environment tests. LRA assembly has withstood SARAL mechanical loads and thermal cycling between -70°C and +40°C without any difficulty and without any change. Optical measurements (wave front error and geometrical verifications) reveal very little or no change.

A specific thermo-optical test has been run. The objective was to verify the thermal effects on the optical spot. The LRA assembly was put in a thermal chamber. Optical measurements were made in different configurations : homogenous temperature cases (+22°C, -8°C, -15°C, -30°C and -45°C) and one gradient case. The gradient case is a LRA's structure gradient. Figures 10 and 11 show the test configuration. The gradient is created with a thermal heater installed in a side of the LRA assembly.

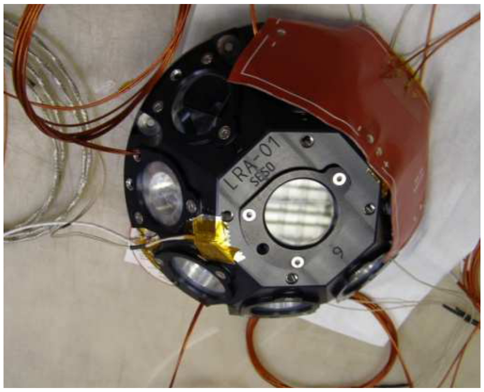


Figure 10. LRA equipped with its heater.

Figure 11. Thermo-optical test configuration.

Wave Front Error continuous measurements permit to characterize the thermal level effect and the gradient effect on the optical mean deviation. No change is observed nor expected with homogenous temperature changes. The gradient case is different. It generates a Corner Cube axial gradient and so changes the optical deviation.
A specific thermal calculation, taking into account convective exchanges, has predicted the nadir CC gradient due to the 8°C LRA transversal gradient. The expected inner CC axial gradient is 0.9°C and its induced deviation is 1.08 arcsec. The experimental subaperture measurements are 2.1 arcsec, 1.1 arcsec and 1.6 arcsec. This is very close to predicted.

9. CONCLUSION

The LRA development is a success with complementary contributions of CNES, SESO and SOPHIA CONSEIL. The LRA optical performances are compliant and have been verified by tests. A specific thermo-optical test confirmed the Corner Cube thermal gradient impact.
The delivery of the LRA flight model was done on december 2009. It has been integrated on the payload. SARAL Satellite launch is scheduled for the beginning of 2011.
For more information about SARAL mission and development: http://saral-mission.cnes.fr

REFERENCES

1. David A. Arnold, "Retroreflector Array Transfer Functions", ILRS Signal Processing Working Group, 2002.