THERMAL AND OPTICAL CHARACTERIZATION OF A GNSS RETROREFLECTOR ARRAY AT THE SCF_LAB.

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Abstract. *INFN, in the framework of the R&D project ETRUSCO-2, designed and tested a full scale retroreflector array for GNSS applications, the GRA. This payload was designed in order to optimize the optical performance of retroreflectors in orbit, one of the fundamental step forward that the SLR techniques needs, in terms of both ground and space segment, to fulfill the benefits that could give to radio navigation satellites. We adopted the standard test procedure we developed and optimized for laser retroreflectors. We measured each retroreflector of the array in air and isothermal conditions, then we performed a default SCF-Test on representative CCRs of the array. Third we measured some CCRs on a simulated Galileo orbit in order to check the variation of performance, in terms of FFDP, in a more realistic illumination environment. This characterization process proved the good thermal insulation between CCRs and the array base and showed no optical performance degradation, within error, during the orbit test.*

1. Introduction

Present and upcoming radio navigation constellations have been equipped with Laser Retroreflector Arrays (LRAs) for laser tracking, in order to provide a precise, accurate, unambiguous and autonomous satellite positioning capability. During the last decade the Satellite Laser Ranging (SLR) community has many times addressed the importance of such technique to aid the classic MicroWave technique as a calibration mean (Urschl 2007) and to contribute to a combined orbit solution (Thaller 2011). The International Laser Ranging Service (ILRS) (Pearlman 2002) has however addressed some important ground and space improvements needed to support at best Global Navigation Satellite System (GNSS) satellites tracking (Pearlman 2009). Istituto Nazionale di Fisica Nucleare-Laboratori Nazionali di Frascati (INFN-LNF) with its work carried on since 2004 at the Satellite/luner/GNSS laser ranging altimetry and cube-microsat Characterization Facilities Laboratory (SCF_Lab)[1] provided an important contribution on the improvement of thermal and optical performance of LRAs in space through a combined design/simulation and laboratory testing activity. Measurements performed on some of the past and present Corner Cube Retroreflector (CCR) payloads (Dell'Agnello 2010, 2011) showed that in order to shorten the time needed for an efficient tracking and eventually increase the number of tracked satellites, an increase of the optical response of the space segment of SLR, retroreflector payloads is needed.

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[1] SCF_Lab website: www.lnf.infn.it/esperimenti/etrusco

With the ETRUSCO-2 project we designed and characterized a full size GNSS Retroreflector Array (GRA), with application to Galileo and GPS3 constellations. The design of the array was intended to:

- Keep the array lightweight
- Have the Far Field Diffraction Pattern (FFDP) of the LRA axial symmetric under design conditions
- Have target signature effects equal at different laser orientations
- Insulate CCRs from the base structure to keep the Optical Cross Section (OCS) of the array as constant as possible throughout an orbit.

In this work we are going to present the main results of the complete characterization carried out at the SCF_Lab intended to determine the performance of the LRA. Measurements comprise three steps; first a detailed FFDP characterization in air of each retroreflector of the array, then two successive tests in the realistic space environment of the SCF-G to determine the thermal inertia of the retroreflectors and probe critical thermal condition in a simulated orbital condition.

2. SCF-Test of the GRA at the SCF_Lab

The SCF-Test is a standard procedure that we developed at the SCF_Lab and applied in the course of time to many retroreflector payloads and revised and completed for the ETRUSCO-2 project (Dell'Agnello 2010, 2011).

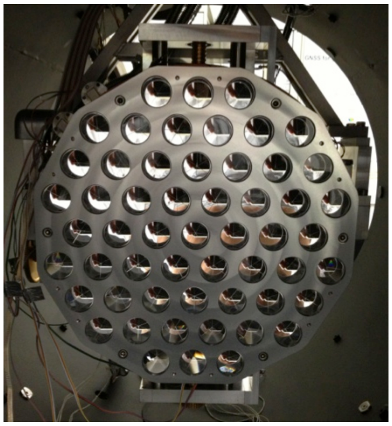

Figure 1 GRA inside the SCF-G facility

The detailed characterization of LRAs for satellite laser ranging comprises three phases:

1. FFDP measurements of all the retroreflectors of the array in air and isothermal conditions with the array installed inside the test facility, i.e. the cryostat. This test provides a reference intensity level for the successive FFDP measurements of the array in the space environment.
2. Default SCF-Test of some important CCRs at different temperatures of the base plate. This is done to measure their thermal inertia and output a thermal relaxation time.
3. Lab-simulated orbital SCF-Test. Inside the cryostat the varying irradiation conditions of a particular orbit are recreated. This is done to probe critical thermal conditions.

Figure 1 shows the GRA installed inside the SCF-G facility, on the rotation/positioning system, ready to start the measurements campaign.

2.1 FFDP in air and isothermal conditions

The first test that we performed was the FFDP measurement of each single CCR as they are mounted on the array. As described in (Boni 2013) CCRs are mounted on the array with different orientations to have the FFDP axial symmetric. We summed the 55 retroreflectors that compose the GRA to output the FFDP of the array, as an incoherent return. The FFDP from Figure 2 is not axial symmetric due to the obvious deviation of real manufactured retroreflectors from ideal conditions, ±0.5 arcsec of tolerance on Dihedral Angle Offset (DAO). The right plot of Figure 2 shows the OCS along a circle of 24 µrad of Velocity Aberration (VA) (the maximum VA at Galileo altitude); the average value along this circle is $127 \bullet 10^6$ m^2 which, within the error, is close to its design value of $113 \bullet 10^6$ m^2 (Boni 2013).

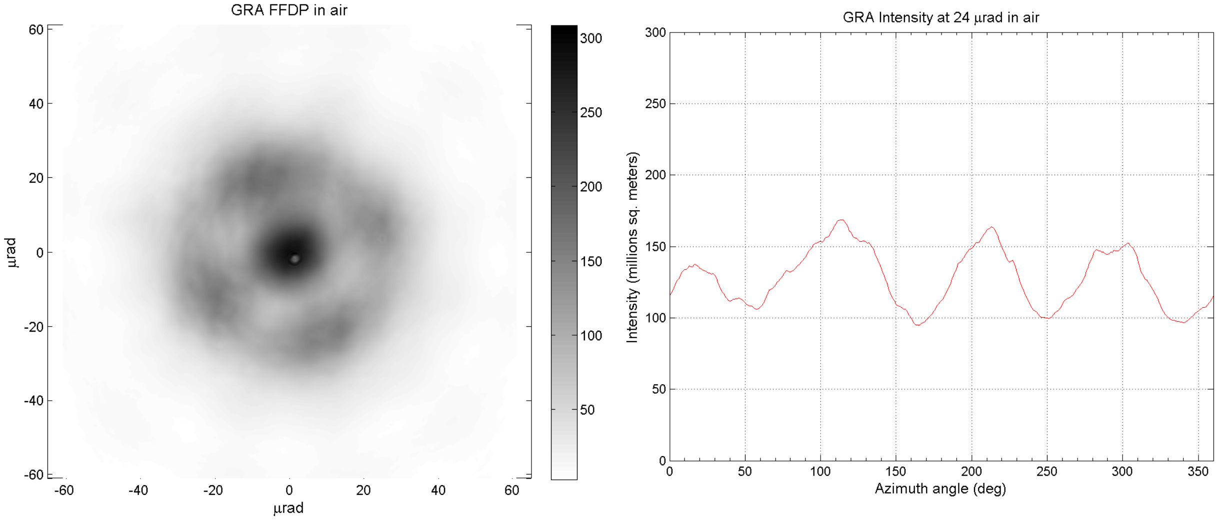

Figure 2 GRA FFDP and intensity at the maximum velocity aberration of Galileo. Intensity of FFDP is in millions square meters. Intensity value has a relative error of ±15%.

2.2 Default SCF-Test of the GRA

The default SCF-Test is a type of measurement in which we hold the array base structure at a fixed temperature while illuminating the LRA with our Solar Simulator (SS) for a fixed amount of time (varying according to the volume of CCRs) and let everything cool down, with the SS switched off, for the same amount of time. During this measurement we take IR pictures of the CCRs front face and FFDP, only during the cooling phase, with the optical table positioned on a side of the cryostat. The main outputs of the test are: thermal relaxation times of CCRs and optical intensity variation, in terms of OCS. Since retroreflectors can be optically tested one at a time, we focused on the concurrent thermal and optical measurement of two CCRs out of the 55 of the array. The default SCF-Test was then repeated with the array base plate held at three different temperatures. Following in Table 1 and Figure 4 we report the results of the thermal and optical measurements.

Table 1 Thermal relaxation times of the central 7 CCRs at different temperatures of the array base structure. The number is the average value between heating and cooling phase.

	T=280K [sec]	T=300K [sec]	T=310K [sec]
CCR 1	1518±156	1973±58	1313±157
CCR 2	1555±233	1595±28	1355±208
CCR 3	1340±2	1632±29	1635±398
CCR 4	1437±32	1893±33	1379±325
CCR 5	1531±101	1719±31	1784±500
CCR 6	1425±61	1925±28	1548±292
CCR 7	1423±63	1732±35	1535±428

Numbers in table one are the result of an exponential fitting, using formula in (Dell'Agnello 2010) done on the average temperature of the front faces of the CCRs. These relaxation times are within 1313 and 1973 sec. showing a good insulation between the glass of the CCRs and the array base, if compared with previous measured retroreflectors of the same volume (Boni 2011); This fact means, from the optical point of view, that the reduction of intensity at the VA of Galileo is contained. In Figure 4 we present the result of the optical analysis of one of the CCRs tested at a temperature of the GRA of 300K. The red point at the very left of the plot is the intensity of the FFDP just before opening the shutter of the SS.

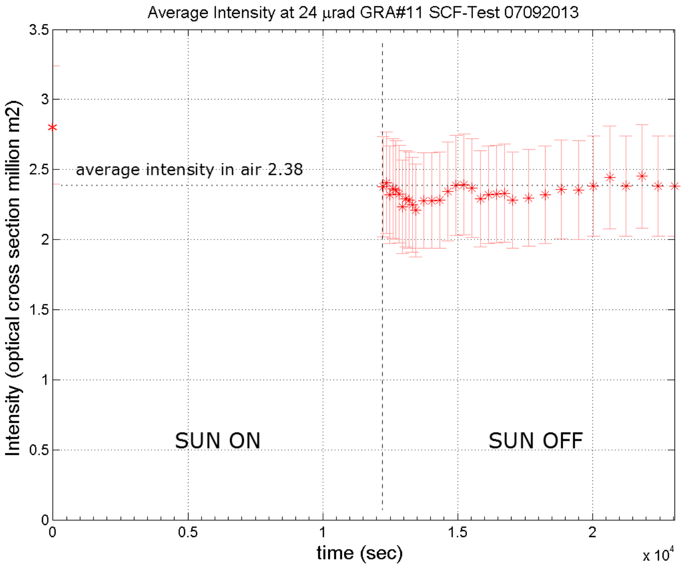

Figure 3 Example of Intensity variation at the VA of 24 µrad for one of the CCR tested. relative intensity error is ±15%.

There is a reduction of intensity of just ~8%. The test repeated at different temperature of the base structure did not show any particular difference in terms of thermal and optical performance.

2.3 Simulated Orbit Test (GNSS Critical half-Orbit)

With this test, exploiting the potentials of our rotation/translation positioning system, onto which payloads are mounted, we recreate the changing Sun radiation conditions of a simple orbit that we call GNSS Critical half-Orbit (GCO). At the beginning of the GCO test, the chamber environment was in space conditions, in terms of pressure and temperature, while the GRA base structure was controlled at 213K. As soon as all the parts of the prototype reached the equilibrium with the external environment, the test started. The temperature control of the array was switched off and we let the SS beam enter the chamber with the front face of the array parallel to it. The array was automatically rotated at discrete steps, with the same angular velocity of a Galileo satellite, lasting almost seven hours. Figure 4 shows the temperature variation of different parts of the payload during the GCO test.

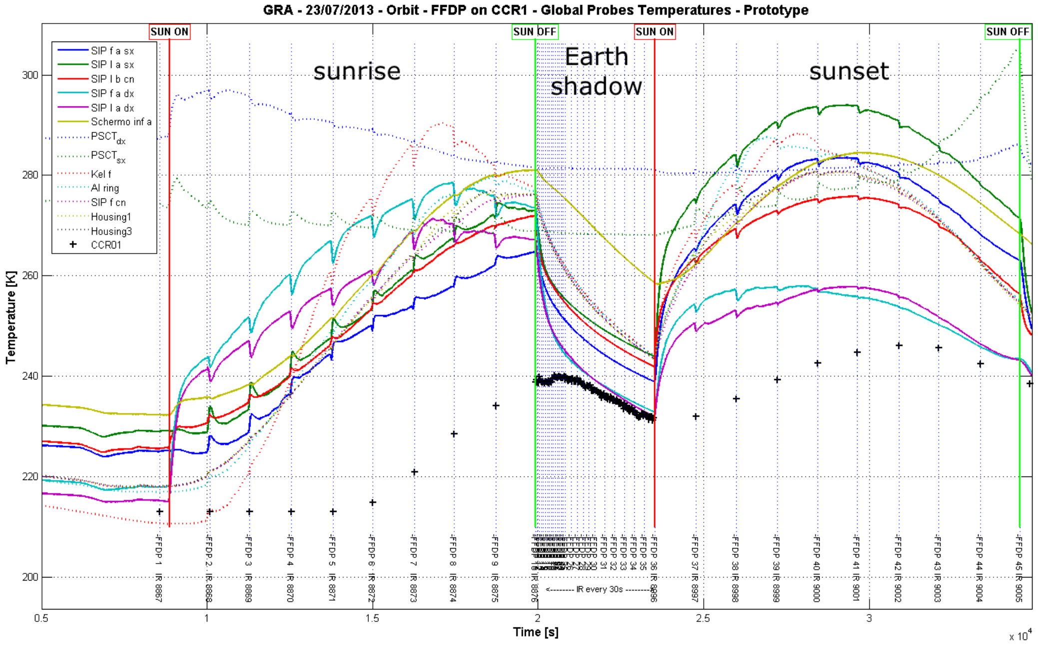

Figure 4 Temperature variation of GRA parts during GCO measurement. Black crosses are the temperatures of the CCR front face taken with InfraRed camera.

The measurement was repeated on 8 of the GRA CCRs, one for each orientation and, for each orientation, one inside and one at the edge of the array. Five CCRs of the GRA were realized with a different material, Suprasil 311, and two of the eight tested CCRs were made of this material. We gathered the results of these eight CCRs to extrapolate the OCS variation of a whole GRA during the orbit (see Figure 5).

The GRA shows, within ±15% error, no performance degradation during the test; this is a very remarkable result that proves the overall design of the array and the optimized CCR mounting system. A comparison among the two materials tested, Suprasil 1 and Suprasil 311, did not highlight any particular difference.

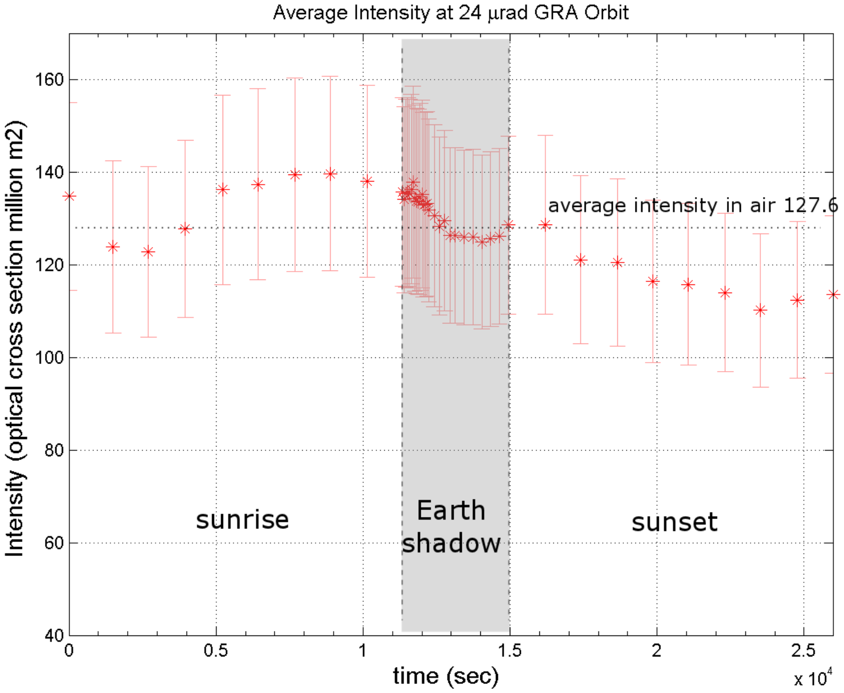

Figure 5 FFDP intensity of GRA during GCO test compared to the nominal performance in air and isothermal conditions.

3. Conclusions

The experience matured by the SCF_Lab in the characterization of LRAs for radio navigation satellites brought to a new design of a retroreflector array for next generation GNSS satellites, i.e. the GRA. The concept of this payload was intended to reduce as much as possible performance degradation due to thermal problems inside CCRs, induced by the space environment experienced in orbit. For the project ETRUSCO-2 we revised and integrated our SCF-Test and fully characterized the complete GRA.

Measurement showed a good agreement of the GRA with respect to its design performance, taken into account the tolerance on real manufactured DAOs. If we look together at the results of the default SCF-Test and the orbit test, measurements prove the overall design of the array and the optimized CCRs mounting system. Thermal relaxation times of retroreflectors are above 1000 sec. and the optical intensity, at Galileo VA, during the test has a contained reduction. The orbit measurement however told us something more. In a more realistic thermal load environment the GRA, within the quoted ±15% error, has no degradation of optical performance.

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