ETRUSCO-2: an ASI-INFN Project of Development and SCF-Test of GNSS Retroreflector Arrays (GRA) for Galileo and GPS-3

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ABSTRACT

The SCF-Test [1] is a new test procedure to characterize and model the detailed thermal behavior and optical performance of cube corner laser retroreflectors for the GNSS in laboratory-simulated space conditions, developed by INFN-LNF and in use by NASA, ESA and ASI. Under ASI-INFN Contract n. I/077/09/0 ETRUSCO-2 (Extra Terrestrial Ranging to Unified Satellite COnstellations-2) we are building a new experimental apparatus (our second), the "Satellite laser ranging (SLR) Characterization Facility optimized for Galileo and the GPS-3" (SCF-G) to characterize and model the detailed thermal behaviour and the optical performance of cube corner GNSS Retroreflector Arrays (GRAs). Galileo is Europe's flagship programme for GNSS (Global Navigation Satellite System). For the GPS-3, a collaborative effort with the US GNSS community is in preparation. ETRUSCO-2 goals will be achieved using the innovative test procedure described in [1], the SCF-Test, and its evolution and refinement outlined here, the SCF-Test/Revision-ETRUSCO-2. We are also developing an innovative prototype GRA of Hollow retroreflectors (GRA-H). Depending on the outcome of the GRA-H SCF-Test, a full-size GRA will be built using either the hollow or the solid fused silica technology.

Preliminary results of an integrated thermal and optical modelling of an uncoated retroreflector on a GNSS orbit, tuned to SCF-Test data of a selection of specific uncoated reflectors (LAGEOS and Galileo In-Orbit Validation, IOV), will be presented. Structural modelling of a specific hollow retroreflector provided by GSFC, tuned to its SCF-Test data, will also be reported. SCF-Testing, under a non-disclosure agreement (NDA) between INFN-LNF and ESA, of a prototype uncoated cube deployed on the 4 Galileo IOV satellites, is a major step forward and a successful application of the SCF. In fact, the IOVs are the first 4 of the 30 satellites of the Full Orbit Capability (FOC) Galileo constellation. Late breaking news: on August 30, 2011, ESA has authorized INFN-LNF to publish the results of the IOV prototype SCF-Test carried out in 2010.

1 The ETRUSCO-2 project

This project is the continuation of an INFN R&D experiment, ETRUSCO (Terrestrial Ranging to Unified Satellite COnstellations) carried out in 2006-2010, which concluded with a comprehensive, refereed publication [1], where the SCF-Test is fully described and the main experimental results are reported. The ILRS reference payload standard, LAGEOS, has also been SCF-Tested for the first time ever [2], using the LAGEOS "Sector" engineering model provided by NASA. While ETRUSCO-2 is a co-funded ASI-INFN project, the SCF-Test is background intellectual property of INFN.

INFN-LNF has built a new clean room, class ISO 7 or better, of 85 m^2, now operational, for the existing SCF (Satellite/lunar laser ranging Characterization Facility). Based on the experience made with the SCF, the SCF-G is being developed and will be operated in 2012 in the same clean room infrastructure. Additional, separate laboratory space is also in use. The SCF is being further optimized for Lunar Laser Ranging (LLR) [3] and for (inter)planetary applications with another dedicated INFN R&D experiment, MoonLIGHT-ILN (Moon Laser Instrumentation for General relativity High-accuracy Tests for the 'International Lunar Network' concept developed for a lunar geophysical network; see also http://iln.arc.nasa.gov/). The primary goal of these doubled and extended retroreflector metrology capabilities is to provide critical diagnostic, optimization and validation tools for SLR to all flagship GNSS programmes (not only Galileo and GPS-3) and for LLR. The capability will allow us to optimize GRA designs to maximize ranging efficiency, to improve signal-to-noise conditions in daylight, to provide pre-launch validation of retroreflector performance under accurately laboratory-simulated space conditions and/or characterize 'as-built' payloads. Implementation of optimized GRA designs will help to improve GNSS orbits, which will then increase the accuracy, stability, and distribution of the International Terrestrial Reference Frame (ITRF), to provide better definition of the geocenter (ITRF origin) and the scale (ITRF unit of length).

1.1 SCF-Test/Revision-ETRUSCO-2 and thermal-optical modelling

This test evolution inherits from the old one the SLR/LLR Key Performance Indicators (KPIs): (1) the thermal relaxation time of reflectors (τ_{CCR}) and array mounting elements; (2) the reflector optical the Far Field Diffraction Pattern (FFDP), with Orthogonal Laser Polarizations (OLP) important for single, uncoated solid CCRs. The novel KPIs are: (3) the thermal-optical conditions experienced by reflectors during a GNSS Critical half-Orbit (GCO, see Fig. 1); (4) the reflector Wavefront Interferogram (WI) in space conditions. Optionally, we provide software modelling of the test data for KPIs 1) to 4), as shown below. The GCO test has been developed with ETRUSCO, WI for GNSS with ETRUSCO-2. The GCO is the orbit with the nodal line parallel to the Sun-Earth joining line. Orbit conditions are reproduced in laboratory rotating the GRA inside the cryostat, in quasi-real time, for the proper GCO duration: 7 hrs for Galileo, 6 hrs for GPS. Initially, the GRA and its reflectors are parallel to the solar simulator (SS) beam; then the GRA is gradually rotated experiencing sunrise, eclipse (simulated by obscuring temporarily the SS) and sunset. At the end of the GCO the GRA is reversed by 180 degrees. During the GCO, the GRA is periodically rotated towards the optical and infrared windows of the cryostat to take temperature and optical measurements of the reflectors, and rotated back to its progressing GCO orientation, all in a few seconds. This quick measurement rotation has a negligible influence on the thermal and optical behaviour of the GRA along the GCO. The GCO test has been successfully applied to a prototype Galileo IOV reflector, which INFN-LNF was provided with by ESA. These preliminary results can be published soon, since ESA has given INFN-LNF the necessary authorization on August 30, 2011.

Here we report a preliminary thermal and optical modelling of an uncoated retroreflector on a GCO tuned to SCF-Test data of a selection of specific uncoated reflectors types (LAGEOS and IOV prototypes). The reflector has 33 mm diameter, Dihedral Angle Offsets (DAOs) = 0.0 arcsec, mounting scheme taken from LAGEOS (which is different from Galileo IOV). The simulated temperature field inside the reflector and its time evolution (carried out with in-house and Thermal Desktop software by C&R Technologies) are the input to the optical simulation (CodeV by ORA Inc.), where the dependency of the refractive index from the temperature inside the fused silica is taken into account. The laser polarization is in the GCO plane, which in the IOV SCF-Test is horizontal. One physical edge of the cube corner is also oriented along the GCO plane (horizontal in the IOV SCF-Test) so that during sunrise in Fig. 1 and 2 there is no loss of total internal reflection (optical breakthrough), which occurs during sunset instead. Figure 2 shows the variation of FFDP average intensity at 24 μrad. During sunrise, sunrays heat up the reflector and the temperature difference between reflector tip inside the cavity (which is warmer) and the outer face increases thus reducing the FFDP intensity. When the reflector goes in the Earth shadow there is a sudden cooling of the outer face, which again involves FFDP intensity reduction (apparent discontinuities at entrance/exit of the shadow are an artifact due to lack of modelling of earth penumbra). Later on the temperature difference decreases and intensity goes up. At sunset, due to optical breakthrough, sunrays heat directly the cavity and consequently the retroreflector tip, thus reducing the FFDP intensity. Heating and cooling is convoluted with the (relatively) long LAGEOS-like τ_{CCR} (modelled after the SCF-Test of the LAGEOS Sector), which damps and delays in time thermal degradations.

2 Modelling the world-first SCF-Test of a Hollow reflector

The new GRA-H, made of 7 hollow cubes, one in the center and six in circle around it, has been built in 2011 and is now under test at the SCF. Depending on the behaviour of the GRA-H, a full-size GRA will be built with hollow or solid reflector technology. This GRA will be characterized with the SCF-G using the SCF-Test/Revision-ETRUSCO-2 described in the previous section. A major hollow reflector development that could benefit from an SCF-Test is reported in [4].

With ETRUSCO a hollow reflector prototype by NASA-GSFC has been tested in 2010 and result reported in [2]. Comparisons between these test measurements and thermo-structural simulations are reported in [5] and here. The GSFC hollow reflector is made by three Al-coated mirrors on pyrex substrates glued together; one of which is also glued to a holding structure (foot).

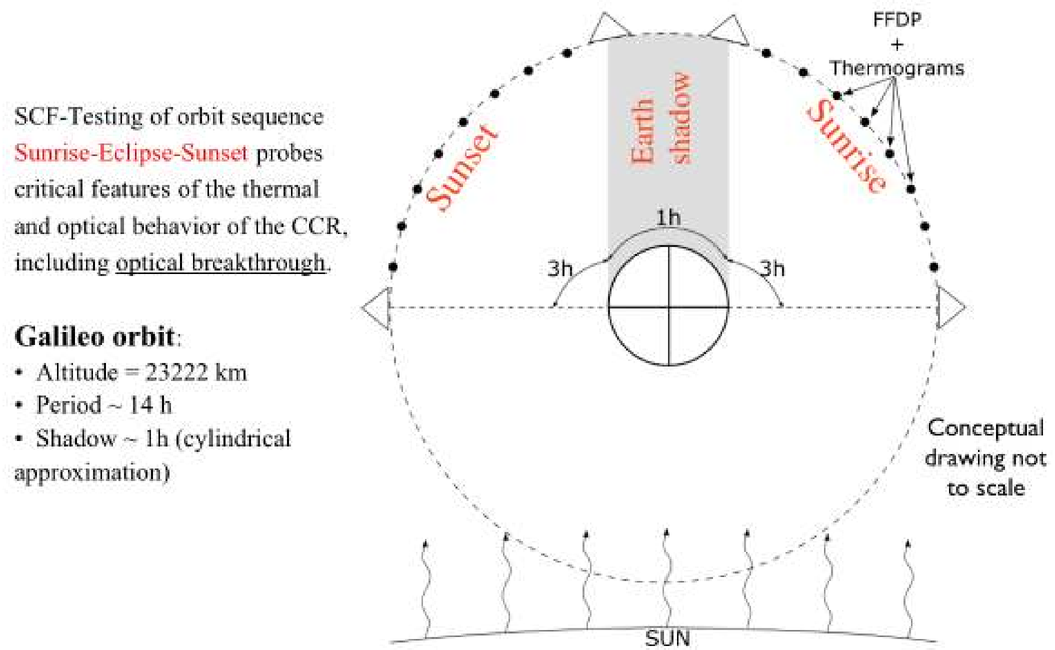

Figure 1 Conceptual drawing of the SCF-Test/Revision-ETRUSCO-2 and the GNSS Critical half-Orbit (GCO).

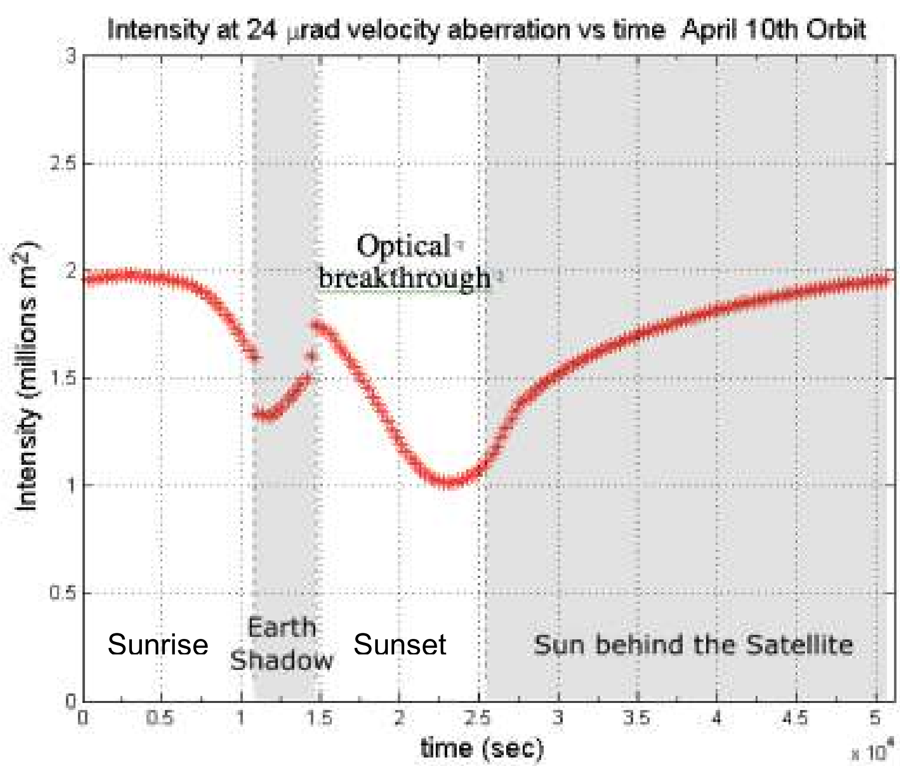

Figure 2 Thermal-optical modelling for the SCF-Test/Revision-ET-2 (preliminary): variation of the CCR average FFDP intensity at 24 μrad (velocity aberration for GNSS like satellites) along the GNSS Critical half-Orbit (GCO).

The reflector has been screwed inside an Al cavity, which is thermally controlled. One thermal probe was fixed in the center of every mirror substrate: the two substrates not connected to the foot showed almost coincident thermal behaviour. In the part of measurements reported here the reflector was irradiated by the SS for > 1.5 hr with a short sun-off interval of 2 min. Thermal simulations aim to find the best suitable values for thermal conduction among the mirrors through the glue and between the reflector and the cavity through the holding structure. When simulation results match satisfactorily measured temperatures, the temperature field (time dependent) becomes the input for structural simulation. Structural deformation data are post-processed to evaluate the parameters affecting the optical performance i.e. deviation from nominal mirror flatness, and nominal DAOs = (0.0 ± 0.5)″. At the beginning of Fig. 3, our simulation indicates that DAOs are beyond these limits and the measured FFDP, inset on the left, looks different from nominal; at the end DAOs are inside limits and measured FFDP, inset on the right, can be considered satisfactory, since it is close to the expected shape (an Airy pattern).

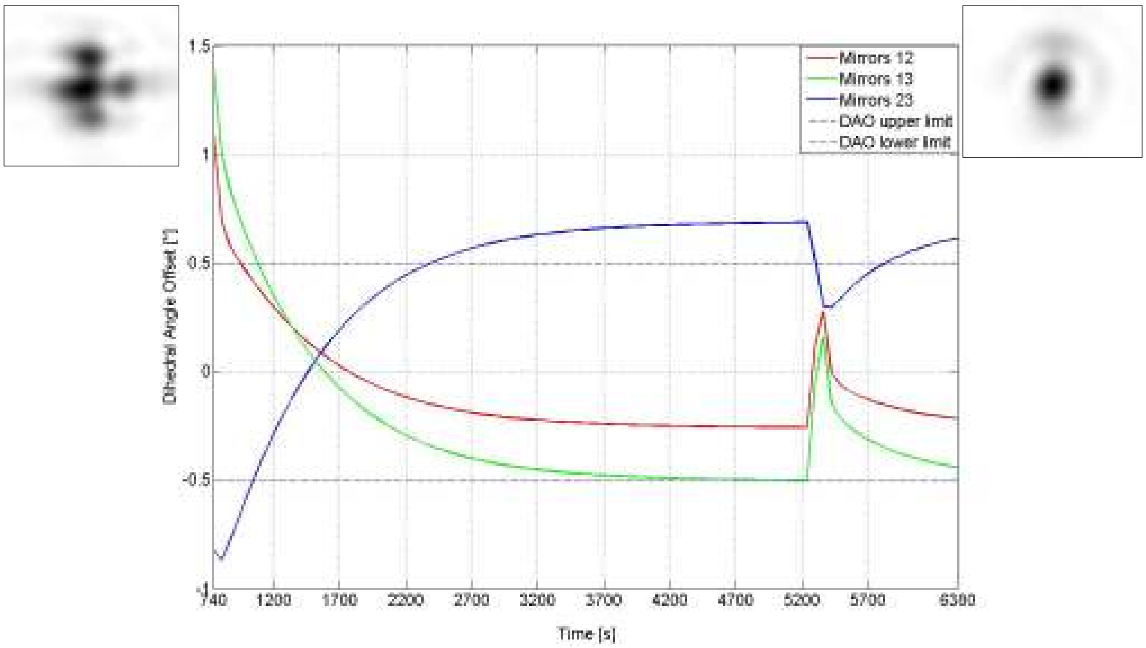

Figure 3 Modelling of the variation of DAOs between the mirrors. Dashed lines define specification limits. The plots at the top left and right of the main graph are the two FFDPs at the beginning and at the end of time span.

References

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