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Thermo-optical vacuum testing of Galileo In-Orbit Validation laser retroreflectors

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Abstract

The Galileo constellation is a space research and development program of the European Union to help navigate users all over the world. The Galileo IOV (In-Orbit Validation) are the first test satellites of the Galileo constellation and carry satellite laser retroreflectors as part of their payload systems for precision orbit determination and performance assessment. INFN-LNF SCF_Lab (Satellite/lunar/GNSS laser ranging/altimetry and Cube/microsat Characterization Facilities Laboratory) has been performing tests on a sample of the laser array segment under the **Thermo-optical vacuum testing of Galileo IOV laser retro-reflectors of Galileo IOV LRA** project, as defined in ESA-INFN Contract No. 4000108617/13/NL/PA. We will present the results of FFDP (Far Field Diffraction Pattern) and thermal relaxation times measurements in relevant space conditions of Galileo IOV CCRs (Cube Corner Retroreflectors) provided by ESA-ESTEC. A reference for the performance of laser ranging on Galileo satellites is the FFDP of a retroreflector in its design specifications and a Galileo retroreflector, in air and isothermal conditions, should have a minimum return intensity within the range $[0.55 \times 10^6\ m^2–2.14 \times 10^6\ m^2]$ (ESA-INFN, 2013). Measurements, performed in SCF_Lab facility, demonstrated that the 7 Galileo IOV laser retroreflectors under test were compliant with design performance expectations (Porcelli et al., 2015). The kind of tests carried out for this activity are the first performed on spare Galileo IOV hardware, made available after the launch of the four Galileo IOV satellites (2011 and 2012), which were the operational core of the constellation. The characterisation of the retroreflectors against their design requirements is important because LRAs (Laser Retroreflector Arrays) will be flown on all Galileo satellites.

Keywords: Satellite Laser Ranging; CCR; Retroreflectors; Laser Retroreflector Arrays; Galileo; IOV; GNSS

1. Introduction and test facility

1.1. Introduction

State of the art SLR (Satellite Laser Ranging) is the most accurate orbit measurement to the LRAs (Arnold, 2009; Pearlman, 2009), which are being integrated into the GNSS (Global Navigation Satellite System) constellations satellites (Bian et al., 2005; Fumin et al., 2008; Dow et al., 2009). SLR provides instantaneous range measurements at millimeter level precision, which can be compiled to give accurate orbits (Falcone et al., 2006; Weber and Springer, 2001; Willis et al., 1999). The two main characteristics of CCR operations are FFDP and OCS (Optical Cross Section). The FFDP is the reflector response, in terms of distribution of the return intensity, to an interrogating laser beam. FFDPs can be used to compute the incoherent

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OCS of the LRA. The OCS is an intrinsic feature of CCRs and LRAs (Degnan, 1993). In space, CCRs are subjected to strongly varying thermal conditions due to their exposure to solar radiation, and radiation from the Earth, Moon, and deep space. Consequently, CCR thermal gradients may develop, and they may translate into diffraction index gradients (Dell'Agnello et al., 2011a). Such an effect, if not properly understood, addressed and studied, can adversely affect the laser return to the ground laser ranging stations. For this reason, INFN-LNF put together and set up over the last 10 years infrastructures, instruments and procedures for thermo-optical vacuum testing and characterization of laser ranging reflectors in space under simulated orbital conditions. INFN-LNF has created the SCF-Test[1] and SCF_Lab, to make a standard for the ILRS (International Laser Ranging Service) community (Pearlman et al., 2002) by providing critical diagnostics, optimization and validation tools for SLR in all GNSS programs (Dell'Agnello et al., 2011a; Dell'Agnello et al., 2009).

The **Thermo-optical vacuum testing of Galileo IOV laser retro-reflectors of Galileo IOV LRA** project was conducted at the INFN-LNF's SCF_Lab to characterize thermal and optical performances of the Galileo IOV retroreflectors (Porcelli et al., 2015). The objectives of the test were to:

- Record the FFDP of each CCR of the sample LRA under investigation (see Section 2) in air and isothermal conditions. Such a set of FFDPs defines the baseline response of the CCRs (see Appendix).
- Determine the relaxation time constants of two selected CCRs of the test article at three reference temperatures of the array base plate during the 6 SCF-Tests (3 baseplate temperatures × 2 CCRs). The three reference temperatures were decided by ESA and INFN, based on ESA inputs, and became part of the contract (ESA-INFN, 2013).
- Determine the variation of the FFDP intensity of two selected CCRs of the test article at the VA (Velocity Aberration) of Galileo, in a realistic orbit.

The reason for the test was to verify that the Galileo IOV LRA performance was in accordance with specifications (ITN, 2012; ESA-INFN, 2013). The performance of a retroreflector is characterized by its FFDP, namely, one has to verify the average return intensity at the VA annulus (24 μrad) of the Galileo satellite. A Galileo retroreflector, in its design conditions and in-air and isothermal conditions, should have return intensity in between 0.55×10^6 m^2 and 2.14×10^6 m^2 (ITN, 2012; ESA-INFN, 2013) (in OCS intensity units). Due to the machining tolerances on the angles between the reflecting faces of any CCR (usually ±0.5 arcsec), return intensities may be subject to variations. In order to properly characterize the retroreflector behavior, for the in-air and isothermal case, each measured CCR was compared with the simulated performance of the same CCR using the DAOs (Dihedral Angle Offsets) as provided by the vendor.

1.2. Test facility

The SCF_Lab[2] was built and enhanced by INFN-LNF over the last 10 years, for carrying out space research programs. The laboratory is located inside an 85 m^2 class 10,000 clean room (ISO 7) and is operational with the SCF and the SCF-G OGSEs (Optical Ground Support Equipments). The laboratory has two separate entry areas for operators and equipment. The rest of the lab is divided in two working areas, one for the SCF and one for the SCF-G. Each single working area has the fundamental hardware to run the facility:

- Cryostat.
- Test article positioning/alignment system.
- Solar simulator.
- Optical table and imagers.
- Vacuum system.
- Thermal control system.
- Rack mounted control electronics.

The experimental innovation of the SCF_Lab is the capability of concurrent measurement and modeling of the optical FFDP and the temperature distribution of SLR payloads under realistically simulated space conditions, in terms of temperature, pressure and solar constant load. The SCF and the SCF-G are two sets of specialized instruments, which allow us to simulate a realistic space environment and to concurrently monitor temperature variations and optical behaviors of payloads under investigation. SCF_Lab was recently updated with Fizeau interferometry capabilities, in order to quantitatively measure optical systems and CCR DAOs.

2. Test article and test description

The test article is a 7 CCRs cluster, assembled on the EM (Engineering Model) LRA base plate in a hexagonal axial symmetric configuration. Galileo IOV CCRs have a vertex-face height of 23.3 mm with a hexagonal front face; the clear aperture of their front face has a diameter of 33 mm; CCRs are solid, made of Suprasil, front-face coated with ITO (Indium Tin Oxide) electrostatic discharge coat and enclosed in a 40-mm across mounting capsule (Attachments to (ESA-INFN, 2013)). The base plate, made of Anticorodal TA16 UNI 3571 avionics aluminium, was designed to allow for temperature control (ESA-INFN, 2013). The base plate had integrated radiators and was provided with thermal control system to simulate orbital transient conditions.

The EM LRA was instrumented with 7 probes to measure the temperature of the CCRs housing and was then

[1] Background intellectual property rights of INFN.

[2] www.lnf.infn.it/esperimenti/etrusco.