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GRACE
Laser Retro Reflector
User Manual

Preparation/Review	Name
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Document Change Record

Issue	Date	Sheet	Description of Change
1.0	18.04.01	all	Final version
1.1	09.08.06	3	List of abbreviations added
		9, 10	More detailed description of LRR coordinates within S/C coordinate system, nadir view of GRACE S/C added

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List of abbreviations

CoG	Center of Gravity
GPS	Global Positioning system
GRACE	Gravity Recovery and Climate Experiment
LRR	Laser Retro Reflector
S/C	Spacecraft

1.1 Scope

The **Laser Retro Reflector** onboard GRACE shall be used to reflect short laser pulses (typically 35 ... 100 ps long) back to the transmitting ground station thus enabling to measure directly the two-way range between the ground station and the S/C with a single-shot accuracy of 1 ... 2 cm without any ambiguities. Because of the non-dispersive behaviour of the ionosphere to light waves, the negligible influence of tropospheric water vapor on the range correction and the easily predictable influence of other atmospheric parameters on the ranging results, the LRR is well-suited for

- Calibration of the on-board microwave orbit determination system (GPS)
- Precise orbit determination in connection with GPS for gravity field recovery
- Technological and basic research experiments (determination of atmospheric refraction models by two-colour ranging)

The **Laser Retro Reflector** consists of four optical cube corner reflectors which are optimized in their far-field reflection pattern to correct for the effect of relativistic aberration due to the relative motion between satellite and ground station to a high degree. The ranging signal from the transmitting ground station is reflected back to its origin independently from its angle of incidence as long as the cut-off entrance angle is not exceeded.

This document comprises the necessary

- handling aspects,
- integration and performance constraints,
- packing and storage descriptions as well as the
- identification of red-tagged and green-tagged items

for the GRACE **Laser Retro Reflector (LRR)**.

Considerations of the Range Correction (to be applied to laser range measurements from ground to the LRRs) are included as well.

1.2 Handling Aspects

In case of the Laser Retro Reflector, no specific handling items or handling constraints other than the ***usual precautions with optical precision equipment*** shall apply. The entrance apertures of the prisms shall be protected against dust and humidity by the delivered protecting caps as long as the LRR is not inspected or tested.

The integration personnel shall weare cotton gloves when dealing with the LRR. Any dust particles on the surfaces of the LRR shall be removed using pressurized dry air. Larger impurities (like fingerprints) may be cleaned cautiously by means of analytically pure organic solvents like acetone or ethanol.

1.3 Integration and Performance Constraints

The cube corner prisms of the LRR are made from fused quartz glass according to the specifications of Tab.1. The reflecting surfaces are aluminium coated. The uncoated front face is slightly spherical to increase the diameter of the two lobes of the reflection pattern. The splitting into two lobes is caused by a slight offset of one of the dihedral angles.

Table 1: Specifications of the cube corner prisms

Vertex length	28 mm
Clear aperture of the front face	38 mm
Dihedral angle offset	-3.8“ (smaller than 90 deg)
Radius of curvature of the front face	+500 m (convex)
Index of refraction @ 532nm	1.461
Nominal separation of the far field maxima	24“
Nominal width of the far field peaks (20% intensity of max.)	10“

The prisms are cemented using soft silicon rubber into mounting flanges which are screwed to the frame, a regular 45°- pyramid (Fig.1).

The cube corner prisms produce two-spot far field diffraction patterns. By proper orientation of the prisms it can be achieved that one of the lobes is directed to the apparent position of the station.

To ensure the proper orientation of the the prisms with respect to the GRACE satellite coordinate system, ***it is urgently required that***

> ***the double-arrow engraved into the LRR structure is oriented parallel with respect to the GRACE ± X-direction; a ±180°permutation is without any influence on the LRR performance (see Fig. 1; the arrow to the right marks the GRACE positive X-axis / flight direction).***

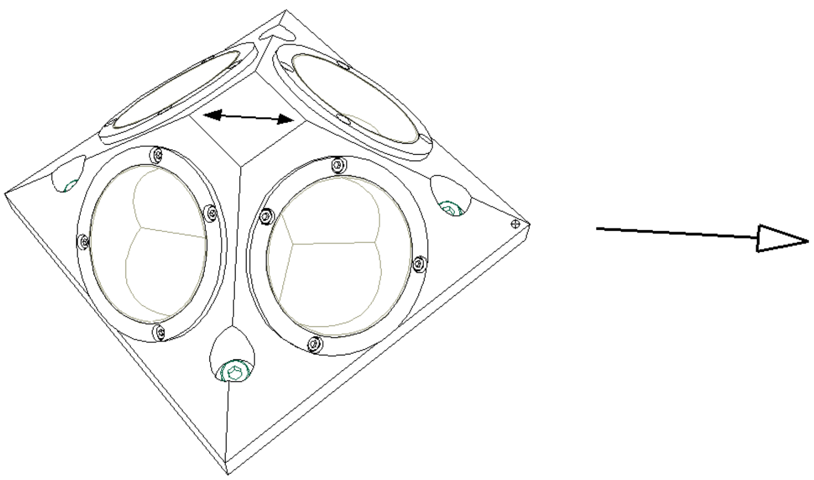


Figure 1 Required orientation of the LRR with respect to the GRACE ± X-axis

1.4 Packing and Storage Description

As long as the GRACE Laser Retro Reflector is not attached to the satellite for system level test or flight purposes, it shall be stored within the delivered vinyl box and secured in its position by 4 M5 screws (delivered).

The protective caps shall be attached to the prism apertures, and the box shall be closed to prevent contmination of the optical surfaces by dust.

1.5 Red-tagged / Green-tagged Items

1.5.1 Red-tagged Items:

The protective caps (made from red plastics) of all four prisms of the LRR have to be removed prior to flight. After removal of the caps, the LRR is ready for flight on GRACE.

1.5.2 Green-tagged items:

No green-tagged items are identified for the GRACE LRR.

1.6 Range Correction

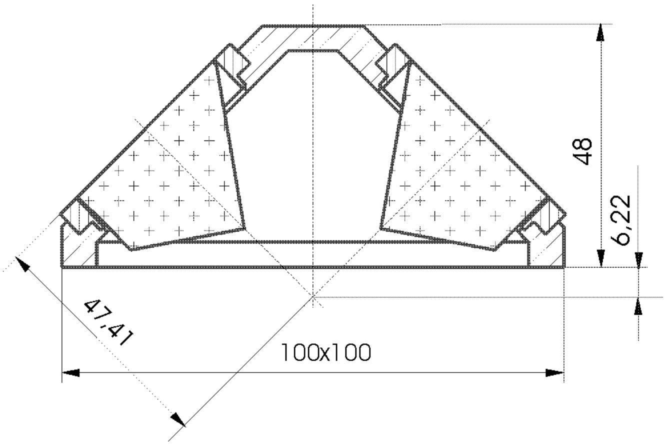


Figure 2: LRR sectional view showing the localization of the optical reference point

As a reference point of the array we are using the crossing point of the optical axes of the cube corner prisms. The range correction of a single cube corner refered to this point is given by the equation:

$$\Delta R = D \cdot \cos(\alpha) - L \cdot \sqrt{n^2 - \sin(\alpha)^2} \qquad \text{Eq.1}$$

where :

L: vertex length

D: distance of the prism front face from the reference point (D= 47.4 mm)

n: index of refraction

α: angle of incidence (relative to the normal to the front face)

The reference point is outside of the structure of the reflector with a distance of 6.2 mm from the mounting plane (cf. Fig.2).

The range correction **ΔR has to be added** to the measured range.

Eq.1 represents the ideal case if one prism is contributing to the signal. In the general case the weighted sum of the individual reflectors has to be computed:

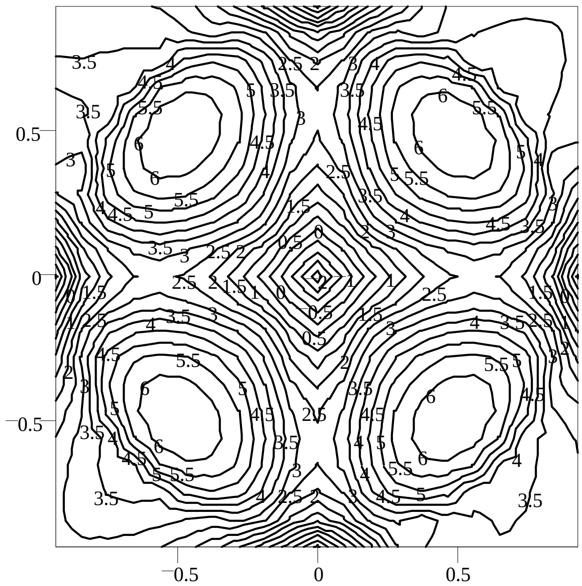
$$\overline{\Delta R} = \frac{\sum_k S_k \cdot \Delta R_k}{\sum_k S_k} \qquad \text{Eq.2}$$

where α_k is the angle of incidence for the prism No. k .

To represent the range correction according to Eq. 2 and Eq.3 graphically we introduce a satellite-fixed coordinate system, with the x-axis parallel to the nominal flight direction and the z-axis parallel to the nominal nadir direction. In the following contour plot the S_k and ΔR_k denote the relative intensities and range corrections of the individual reflectors respectively. The relative intensities S_k depend mainly on the active area of the cube corners and the apparent position of the station in the far field diffraction pattern. To get a rough estimate, we neglect the influence of aberration and diffraction using the active area as a measure of the relative signal. The angular dependence of the active area of a metal coated cube corner can be approximated by:

$$S_k = \left(1 - \frac{\alpha_k}{0.85}\right)^2 \qquad \text{Eq.3}$$

the independent variables X,Y are the components of the unit vector from the satellite to the station (direction of the reflected beam) whereas Z is the range correction. The maxima correspond to normal incidence to one of the prisms.



X, Y, Z

Figure 3:

Contour map of the effective range correction

The plotting range corresponds to a nadir distance from zero to 70°. The Z values are given in millimeters.

As can be seen the variation of the range correction is below 1 cm. For many purposes the range correction may be replaced by the constant value $\Delta R = (4 \pm 2)mm$

The next level of approximation would be to use the range correction of the dominating prism with smallest angle of incidence, neglecting any cross talk according to Eq.2. The error of such an approximation will be well below 1 mm.

To refer the measured range to the center of mass of the satellite one has further to add the scalar product of the vector from the mass center to the reference point with the unit vector of the light direction. For this, the attitude of the satellite has to be known to high accuracy. Because of the active attitude control of the GRACE satellites it might be necessary to introduce the orientation data which are measured by the star sensors.

The location of the LRR reference point on the GRACE satellites is given within the S/C coordinate system according to:

- X = - 600.0 mm
- Y = - 327.5 mm
- Z = + 217.8 mm

The S/C coordinate system is a right-handed orthogonal system defined as follows (cf. Fig. 4):

- Origin: satellite CoG, coinciding with the center of the accelerometer proof mass
- X-axis: positive through the center of the K-band horn, pointing along velocity and anti-velocity vector, respectively (depending on the orbital position of GRACE-A/-B as leading or trailing satellite)
- Z-axis: positive towards nadir
- Y-axis: completing the right-handed orthogonal system

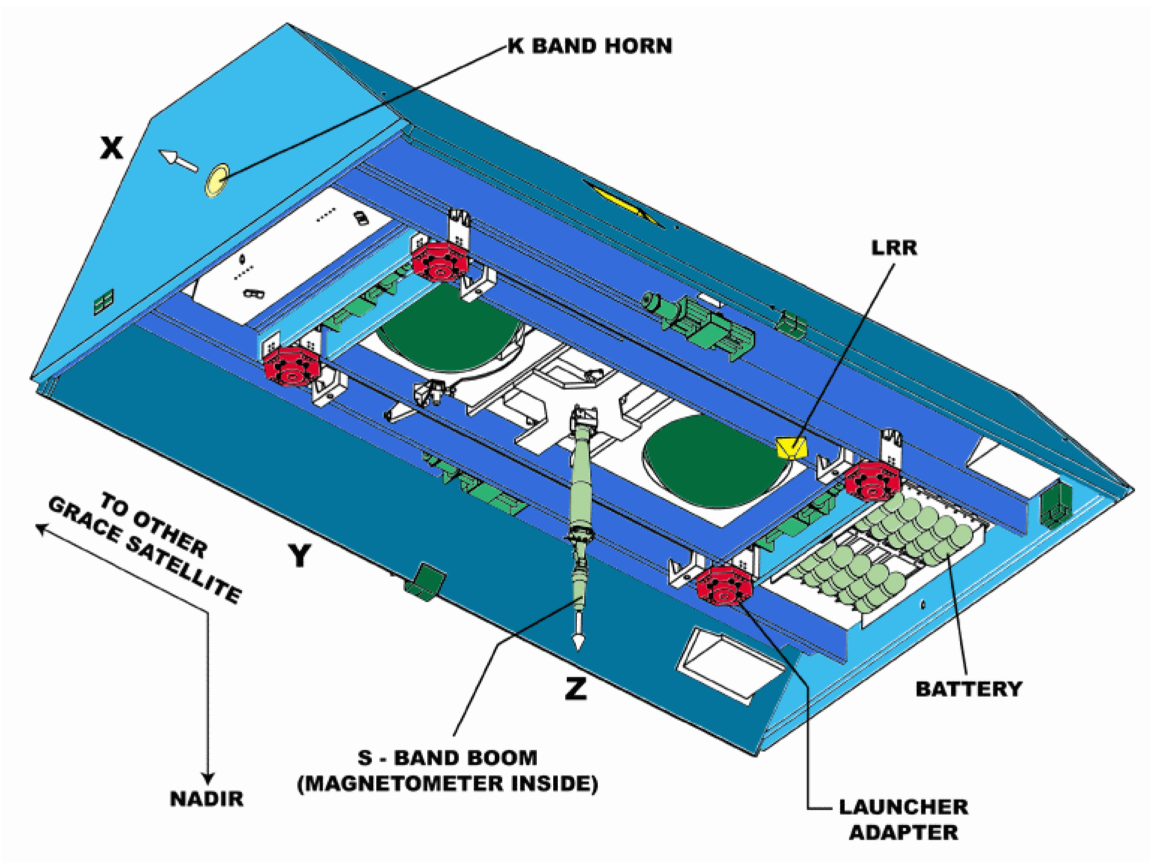


Figure 4: Nadir view of GRACE S/C, indicating the satellite coordinate system

The mounting bracket of the LRR is shown if Fig. 5. The length of the bracket itself is 220 mm from the S/C CoG, additionally a 4 mm thermal washer is used (the value of 7 mm in parentheses shall be omitted).

Taking into account the location of the optical reference point of the LRR (6.2 mm from the mounting plane, cf. Fig. 2) one obtains the z-coordinate of 217.8 mm.

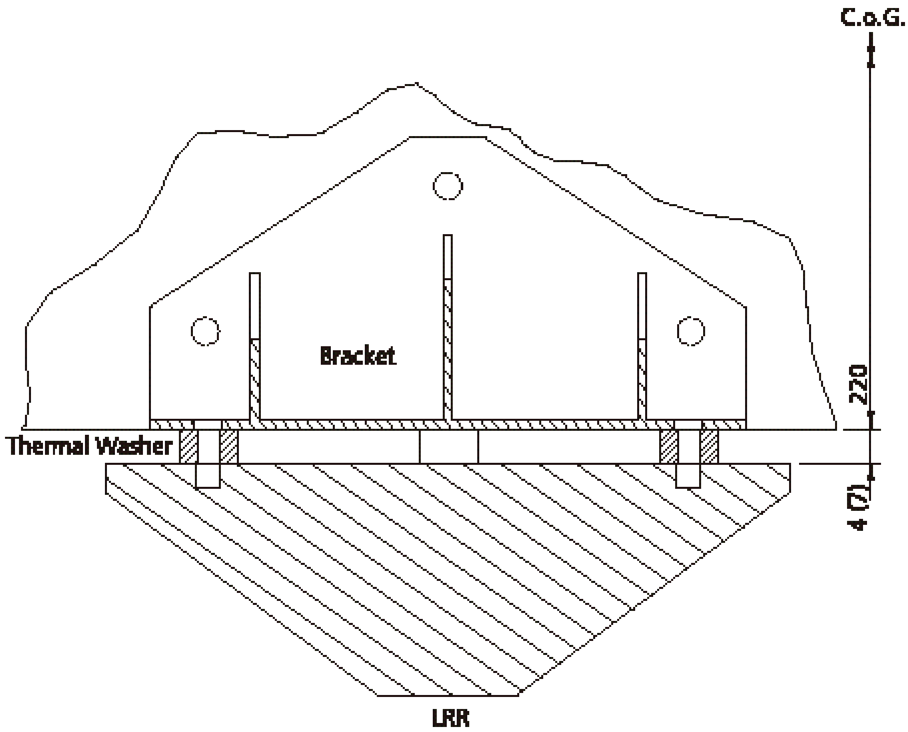


Figure 5: LRR mounting bracket