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Specification of Galileo and GIOVE Space Segment Properties Relevant for Satellite Laser Ranging

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A P P R O V A L

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Enclose information about positions of LRR, CoM, and phase centre, together with yaw steering, mass, and cross-section area for satellites GSTBV2/A and GSTBV2/B. Change structure of document to focus it on the different satellites.	2	1	10/10/2005
Corrected Z component of phase centre for GSTBV2/B. Rephrased attitude law description for both GSTBV2A and B.	2	2	01/11/2005
Update GSTB-V2 name to GIOVE. Provided revised and current information from GIOVE-A. Provided D-PDR information for IOV satellites LRR	3	0	03/07/2006

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Change GSTB-V2 to GIOVE	All document	
Added acronyms	Page 6	Section 1.3
Provided two new Reference Documents	Page 6	Section 1.2
Introduced the GIOVE name	Page 7	Section 2.2
Provided current GIOVE-A orbital parameters	Page 7	Section 2.2
Provided GIOVE-A LRR Optical Centre coordinates, and remove LRR CoM coordinates	Page 10	Section 3.2
Provided estimated current GIOVE-A Centre of Mass coordinates	Page 10	Section 3.2
Provided current GIOVE-A mass and SRP coefficient	Page 12	Section 3.4
Clarified use of LRR CoM for GIOVE-B	Page 13	Section 4.2
Provided IOV D-PDR specifications for LRR	Page 16	Section 5
Provided schematic drawings of LRR location on S/C and LRR top view	Pages 16 and 17	Section 5

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1 INTRODUCTION

1.1 Objectives and Scope

This document provides information about the relevant characteristics of the Galileo Spacecraft and orbits in order to allow an assessment by the International Laser Ranging Service of its capability to perform Satellite Laser Ranging support.

In addition, this document provides information (when available) about spacecraft properties crucial for precise orbit determination such as LRR position, centre of mass position, attitude law, navigation signal phase centre, etc. Some of these values are still subject to verification (for instance, during GIOVE-A QAR) and will be updated in following versions of this document.

The document applies both to the two experimental spacecraft flown as part of the Galileo System Test Bed V2, henceforth referred to as GIOVE-A and GIOVE-B, and to the operational Galileo spacecraft. For the latter, distinction is made between the In-Orbit Validation (IOV) and Full Operational Capability (FOC) phases.

1.2 Reference Documents

RD-1	Galileo Satellite Laser Ranging Retro-Reflector Specifications, ESA MEMO	-DEUI-NG-MEMO/01280, Issue 1.0, 6-8-2004	Issue 1.0 6-8-2004
RD-2	Galileo Global Component System Requirements Document		Issue 4.2 27-7-2004
RD-3	Space Segment Design and Justification	GSTBV2-SS-DD-SST-SC-0004	Issue 5 28/01/05
RD-4	Antenna ICD (Alenia)	GSTBV2-SS-DR-SST-SC-0005	Rev 1 D 03/05/05
RD-5	GSTBV2A Laser Retroreflector	01733-ITM (no ESA ref code)	Rev 2 03/07/04
RD-6	GSTBV2 - LASER REFLECTOR GSTBV2 LRR Technical note - Response to RID 4383	GSTBV2-SS-TN-SST-PL-0022	N/A
RD-7	Navigation Antenna Mechanical Design and Analysis	RPT-GT2-0025-ALS	Issue 3 16/02/05
RD-8	GSTBV2A RF Test Report	RPT-GT2-0040-ALS	Issue 1 18/02/05
RD-9	Propulsion Bay ICD	GSTBV2-SS-DR-SST-SC-0001	Rev B 10/02/05
RD-10	AOCS Design Description and	GSTBV2-SS-TN-SST-SC-	Issue 2

	Justification File	0016	22/02/05
RD-11	Space-Segment DDDJF	GSTBV2-DD-GAIN-0030	Issue 2A 29/11/04
RD-12	Mechanical Design Description	GSTBV2-DD-GAIN-0282	Issue 3 15/11/04
RD-13	Navigation Antenna PFM Design Verification and Compliance Matrix	GSTBV2-SS-CAS-ENG-13 B	Issue 5 19/01/05
RD-14	Navigation Antenna ICD PFM-FM	GSTBv2-SS-CAS-ENG-16-B	Issue 1 Rev 1 06/09/04
RD-15	Satellite Budgets	GSTBV2-BG-GAIN-0037	Issue 5 03/12/04
RD-16	Yaw Steering Guidance	TN_60_0023	Issue 1 17/10/03
RD-17	GSTBv2-A Technical Description Of the Laser Retroreflector Array	K01-Э170-00-00 TO	Rev 1 2004
RD-18	Laser Retroreflector Design Description and Justification File	GAL-DDJF-ASTD-LRR-R-0015	Issue:1.0 15/07/2005

1.3 List of abbreviations

AOCS	Attitude and Orbit Control System
CoM	Centre of Mass
FOC	Full Operational Capability
GIOVE	Galileo In Orbit Validation Element
GSTB	Galileo System Test Bed
GTRF	Galileo Terrestrial Reference Frame
IOV	In-Orbit Validation
ITRF	International Terrestrial Reference Frame
LRR	Laser Retro-Reflector
MEO	Medium Earth Orbit
RA	Right Ascension
QAR	Qualification and Acceptance Review
S/C	Spacecraft
SLR	Satellite Laser Ranging
SSTL	Surrey Satellite Technology Ltd
TBC	To Be Confirmed

2 MISSION OBJECTIVES

2.1 General

This section specifies the mission objectives for the different S/C and operations phases, and includes the orbit parameters.

2.2 GIOVE

GIOVE-A , also known as GSTB-V2/A, built by Surrey Satellite Technology Ltd (SSTL) of the UK, was launched on 28th December 2005. GIOVE-B, also known as GSTB-V2/B, built by Galileo Industries (GaIn), is foreseen to be launched in the autumn 2006.

Both satellites missions have the same objectives:
- to secure the Galileo frequency allocations by providing a signal in space
- to allow early experimentation with critical hardware (Signal In Space and On-Board Clocks) and software systems
- to demonstrate navigation service
- to characterization of the MEO environment
- additional experimentation

Precise evaluation characterisation of the performance of the on-board atomic clocks, of antenna infrastructure, and of signal properties requires a precise orbit determination, in which SLR will play an important role. Both routine SLR tracking and occasional campaigns with higher-intensity tracking will be required.

The orbit defined for the operational test bed satellite is a near-circular ground track repeat orbit of 17 revolutions in (approximately) 10 sidereal days, with an inclination of 56º. The relevant orbit parameters are:

In particular, GIOVE-A has currently the keplerian elements described below (as of 26 May 2006, 00:00:00.000)

- Semi-major Axis (km): 29635.5
- Eccentricity: 0.000836
- Inclination (deg): 56.034
- RAAN (deg): 186.671
- Argument of Perigee (deg): 330.804
- Mean Anomaly (deg): 39.491

2.3 Galileo

The final constellation will consist of 27 operational spacecraft equipped with identical Laser Retro-Reflectors (LRR). The satellites will be evenly distributed over 3 orbit planes, in a

27/3/1 Walker constellation. That means that the R.A. of ascending nodes of the three planes are separated by 120º and the spacecraft in each plane are separated by 40º in-plane. The orbit is the same as for the GIOVE spacecraft, i.e. a 10-day ground-track repeat orbit with 17 revolutions and an inclination of 56º. Each plane will include an additional (inactive) spare satellite, for which no SLR tracking will be requested as long as it is inactive.

The relevant orbit parameters are:

Semi-major axis:	29601 km
Eccentricity:	0.002
Inclination:	56º
Argument of perigee:	0º (TBC)
RA of ascending node:	0º, 120º, 240º (TBC)

The (up to) four Galileo satellites used in IOV will be launched in the 4th quarter of 2007 for a foreseen IOV phase duration of 6 months (extendable to 1 year). They will be identical to the FOC S/C, and they will have the same orbit parameters - no change in semi-major axis or inclination between IOV and FOC is foreseen.

The IOV S/C will be collocated to allow simultaneous reception of the navigation signals, but the final decision whether all four S/C will be in one plane or subdivided over two planes, and whether they will also be separated by 40º, is not yet made.

The objectives of SLR during IOV are similar to those for the GSTBV2 mission: to characterise on-board instrument properties using precise orbit determination, both on a routine basis and in occasional campaigns with more intensive tracking.

During FOC, SLR data will contribute to the verification of the precise orbits based on microwave data and to the tie between the Galileo Terrestrial Reference Frame (GTRF) and ITRF.

3 GIOVE-A (SSTL)

3.1 LRR Array Specifications

Originally, GIOVE-A was planned to be equipped with a pair of identical LRR arrays separated by some distance on the nadir-facing side of the spacecraft. The final design deviates from this original approach, whereby the two patches have been co-located and form one integrated array of 76 coated cubes with a diameter of 27 mm each. The overall shape is trapezoidal.

Specifications (RD-5):

```
1. OVERALL ENVELOPE (WITH COVER): 308 x 408 x 48 mm (excluding heads of
   mounting screws)
   OVERALL ENVELOPE (WITH COVER): 308 x 408 x 54.5 mm (including heads of
   mounting screws)

      OVERALL ENVELOPE (WITHOUT COVER): 306.8 x 405.5 x 41.5 mm
      45 LRR ARRAY (WITHOUT COVER): 306.8 x 271.8 x 41.5 mm
      31 LRR ARRAY (WITHOUT COVER): 239.5 x 254 x 41.5 mm

2. TOTAL WEIGHT (WITHOUT COVER):          < 3.8 Kg
      45 LRR ARRAY (WITHOUT COVER): < 2.2 Kg
      31 LRR ARRAY (WITHOUT COVER): < 1.6 Kg

3. COORDINATES OF CENTRE OF GRAVITY OF 76 LRR ARRAY AS AN ASSEMBLY.
Xg=89 mm, Yg=176.8 mm, Zg=24.37 mm (Referred to reference hole)

4. CENTRE OF GRAVITY OF 45 LRR ARRAY:      Xg = 113.7 mm
  (Referred to reference hole)             Yg = 100.0 mm
                                           Zg = 24.5 mm

   CENTRE OF GRAVITY OF 31 LRR ARRAY:      Xg = 53.2 mm
   (Referred to reference hole)            Yg = 289.0 mm
                                           Zg = 24.2 mm

5. MOMENT OF INERTIA OF 76 LRR ARRAY:      Jx = 47964 Kg x mm^2
   (Referred to 76 LRR array CofG)
                                           Jy = 21881 Kg x mm^2
                                           Jz = 69038.6 Kg x mm^2

   MOMENT OF INERTIA OF 45 LRR ARRAY:      Jx = 8887.9 Kg x mm^2
  (Referred to 45 LRR array CofG)
                                           Jy = 15133.4 Kg x mm^2
                                           Jz = 23546.8 Kg x mm^2

  MOMENT OF INERTIA OF 31 LRR ARRAY:       Jx = 4319.5 Kg x mm^2
 (Referred to 31 LRR array CofG)
                                           Jy = 7261.8Kg x mm^2
                                           Jz = 11250.3 Kg x mm^2

6. MATERIAL (BASE AND RR HOLDER): ALUMINIUM ALLOY AMr6
```

7. MOUNTING SCREWS: 9 pcs. M5 x 20.0 mm LONG CAP HEAD, STAINLESS STEEL A2-70

8. MOUNTING WASHER: 9 pcs. DIA 5.3 мм, STAINLESS STEEL A2

9. CONTACT AREA (): 1,876.0 mm^2
   45 LRR ARRAY: 1061 mm^2
   31 LRR ARRAY: 815 mm^2

10. OVERALL MOUNTING SURFACE FLATNESS: < 0.2 mm
Actual flatness is 0.04 mm

11. FLATNESS FOR EACH FOOT: same as for item 10

12. MOUNTING SURFACE ROUGHNESS: Ra1.6

13. SURVIVAL TEMPERATURE RANGE: from -150°C to +125°C

A detailed drawing is attached as Annex A.

3.2 LRR and Satellite CoM positions

Coordinate of the Optical centre of 76 LRR array with respect satellite reference frame (RD-4, RD-6, RD-16):

X = -832 mm
Y = -654 mm
Z = 1476 mm

Coordinate of the S/C centre of gravity (valid as of March 2006)

X = -4 mm
Y = 1 mm
Z = 796 mm

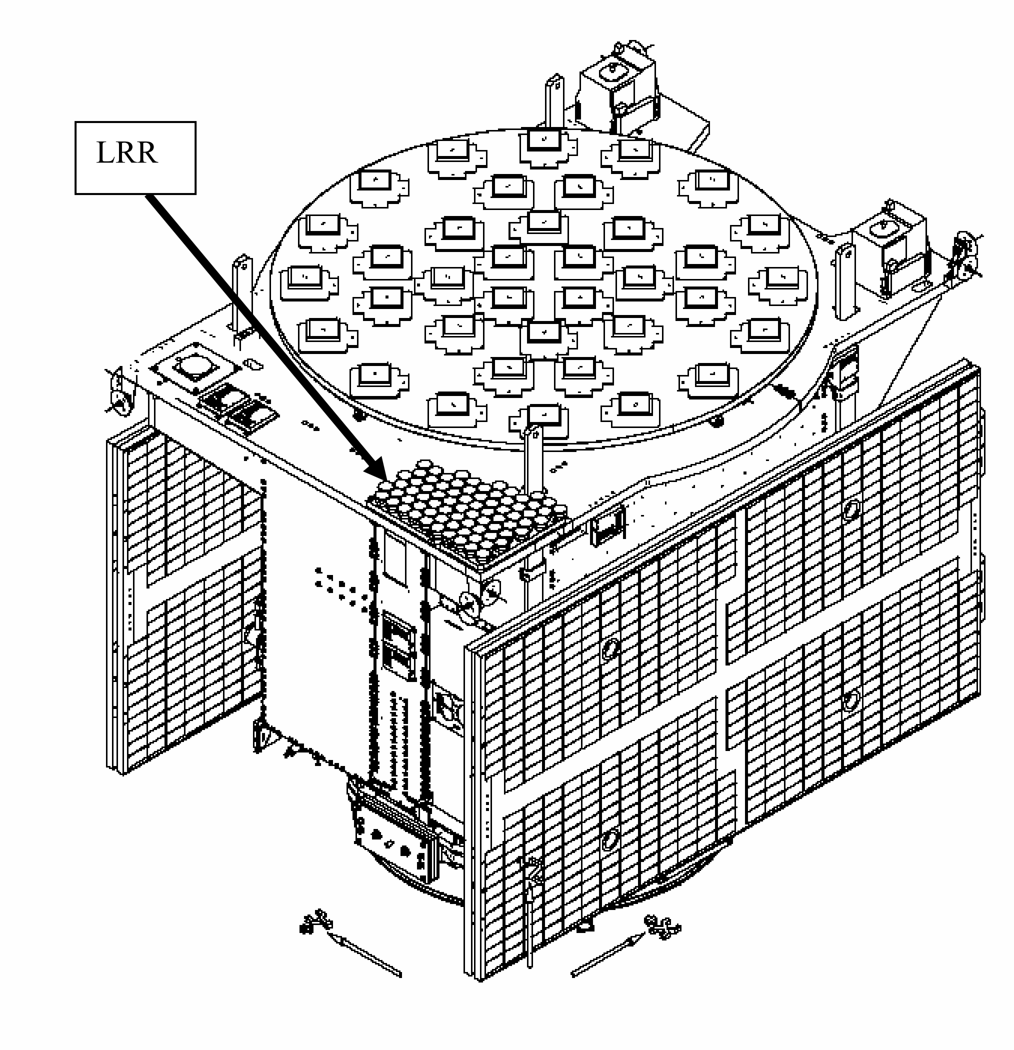

Fig 1. Position of the LRR in the GIOVE-A spacecraft.
Spacecraft is shown with solar array in stowed configuration

3.3 Attitude Law

The GIOVE-A AOCS Normal Mode must maintain the spacecraft attitude such that the payload line of sight (nominally aligned with the spacecraft +Z Body axis) is always nadir-pointing and the solar array panels (aligned with the spacecraft body Y axis) can always achieve normal solar incidence by a rotation of the solar panels around the body Y axis.
To be achieved this, the spacecraft follows an attitude profile that keeps the +Z body axis nadir-pointing and the spacecraft-Sun vector nominally in the spacecraft X-Z body plane by using only a spacecraft yaw rotation throughout the orbit. In practice there are two solutions which can be used to satisfy the requirements. The selected solution maintains the +X facet of the spacecraft in a deep-space pointing attitude.

It is foreseen that the theoretical attitude will not be achieved at times where the beta angle (angle between the sun and the orbital plane) is small, due to limitations in the reactions wheels and to poor yaw measurement (sun co-linearity). In addition, during eclipse, it is expected that the yaw error can reach values of up to 18 degrees.

3.4 Other navigation data

The phase centre for the navigation signal is provided here to complement the necessary information needed to perform precise orbit determination (RD-4, RD-7 and RD-8)

E5a + E5b	E6	E2/L1/E2
X = 0.0 mm Y = 0.0 mm Z = 1690.0 mm	X = 0.0 mm Y = 0.0 mm Z = 1665.0 mm	X = 0.0 mm Y = 0.0 mm Z = 1658.0 mm

The s/c mass is 582.8 Kg (valid as of March 2006). The approximate cross-section Area is 9 squared metres, with a C_{SRP} (Solar Pressure Radiation factor) equals 1.37 (assuming cannonball model, according to equation 1)

$$a = C_{SRP} \frac{AW}{m} \qquad \text{(Eq 1)}$$

A is cross-section Area, $W = 4.56 \cdot 10^{-6}$ N/m^2, m is satellite mass, R_{sun} is mean distance to Sun.

GIOVE-B (GAIN)

3.5 LRR Array Specifications

Specifications have been extracted from industrial documentation. (RD-11)

```
Size: 305mm x 305mm x 42 mm
Number of prisms: 67
Prism diameter: 27 mm (light area)
Material: optical grade fused silica, aluminium-coated
Temperature range: from -125°C to +125°C
Field of view: 12 degrees (half-cone)
```

A detailed drawing is attached as Annex B.

3.6 LRR and Satellite CoM positions

At the time of writing, the coordinates of the Optical Centre were not available. This information will be included in future versions of this document as the information becomes available. The coordinates of the CoM of the LRR array with respect to the satellite reference frame:

```
X = -807.5 mm
Y =  297.5 mm
Z = 2267.0 mm
```

Coordinate of the S/C CoM (beginning of life, deployed solar array configuration) with respect to the satellite reference frame:

```
X =    0.0 mm
Y =    0.0 mm
Z =  940.6 mm
```

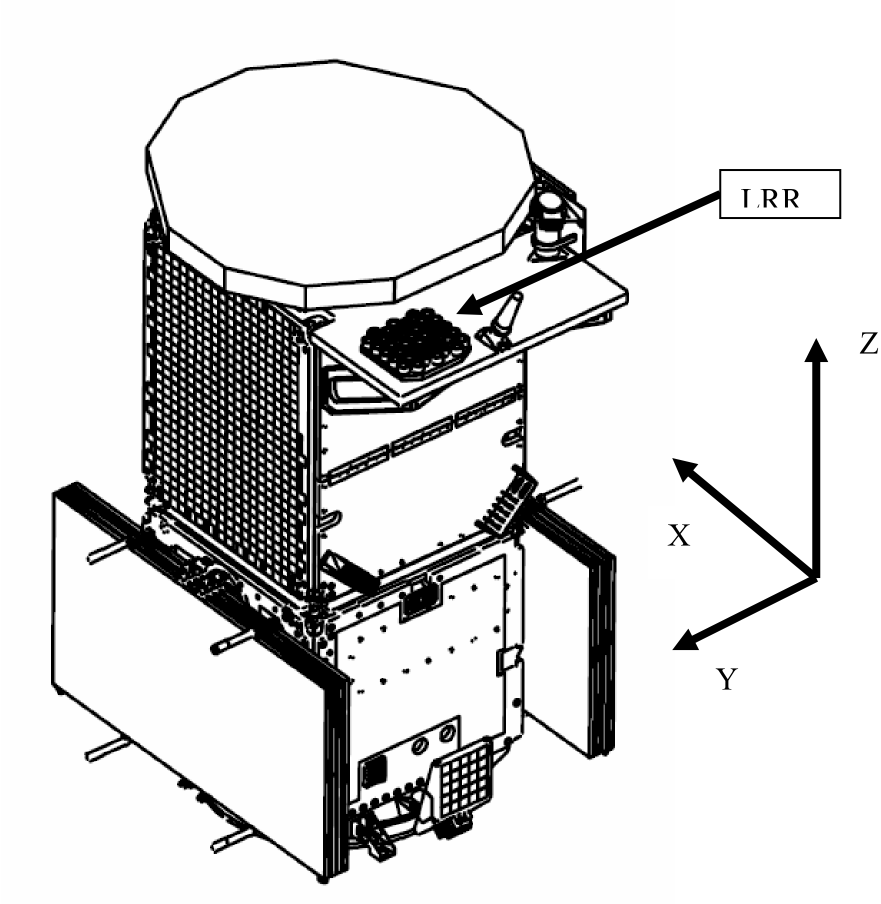

Fig 2. Position of LRR in GIOVE-B.
Spacecraft is shown with solar array in stowed configuration

3.7 Attitude Law

GIOVE-B follows a yaw steering law such that the body +Z axis points continuously to Nadir, together with a rotation performed around the Z axis that maintains the S/C Y axis perpendicular to the Sun. The +X spacecraft panel is maintained away from the sun. (RD-10).

As with GIOVE-A, it is foreseen that the theoretical attitude will not be achieved at times where the beta angle (angle between the sun and the orbital plane) is small, due to limitations in the reactions wheels and to poor yaw measurement (sun co-linearity). In addition, during eclipse, it is expected that the yaw error can reach values of the same order as GIOVE-A.

3.8 Other navigation data

L-band phase centres (RD-13 and RD-14)

E5a + E5b	E6	E2/L1/E2
X = 0.0 mm Y = 0.0 mm Z = 2288.7 mm	X = 0.0 mm Y = 0.0 mm Z = 2287.6 mm	X = 0.0 mm Y = 0.0 mm Z = 2289.15 mm

4 GALILEO

The current specifications by industry of the LRR size are extracted from industrial documentation (RD-18) at Delta Preliminary Design Review stage.

- Length: 522 mm
- Width: 424 mm
- Height: 45 mm
- 78 Non-coated fused silica mirrors
- Mass: 4.7 kg

LRR is specified to operate under inclination angles up to 15 ° (roll and pitch directions) with an overall effective reflecting area ≥ 660 cm2 as required from viewed from any point on the Earth (i.e. assuming nominal S/C attitude).

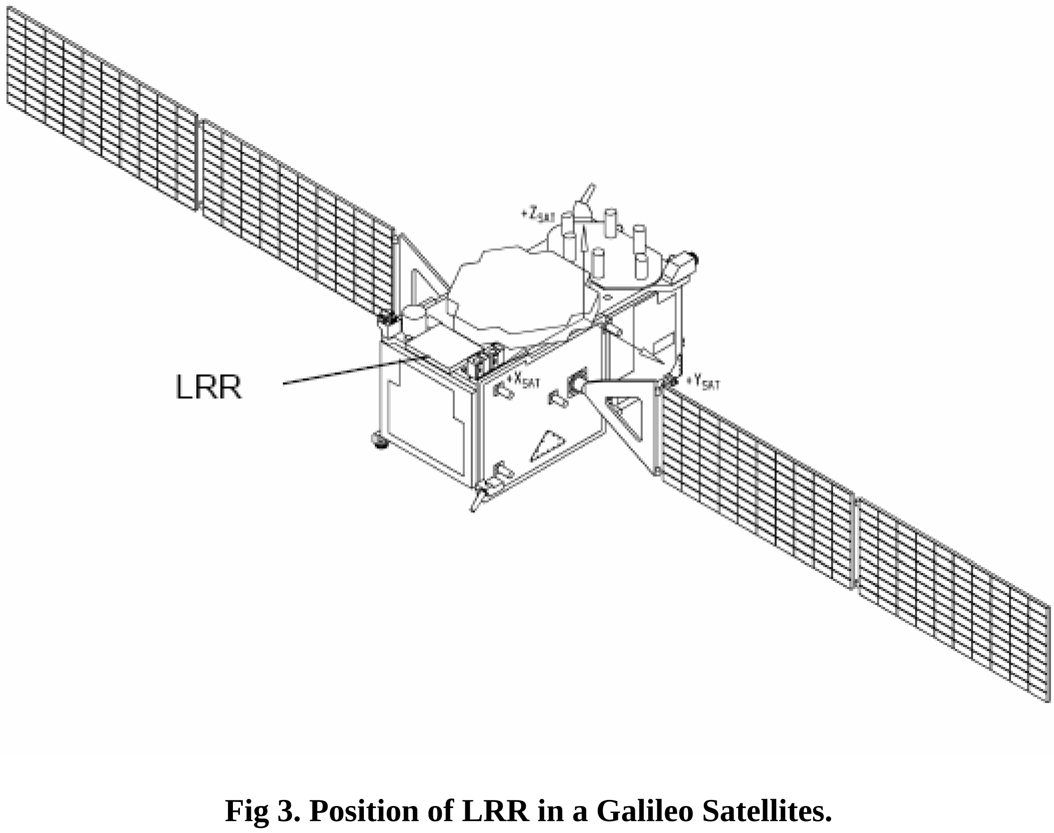

Fig 3. Position of LRR in a Galileo Satellites.

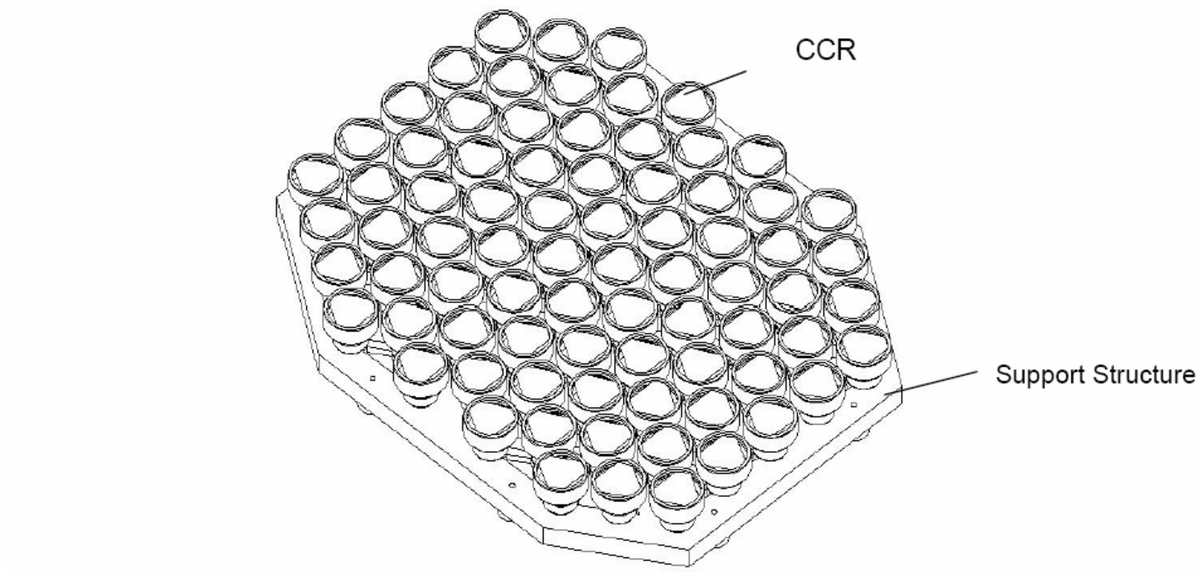

Fig 4. LRR top view

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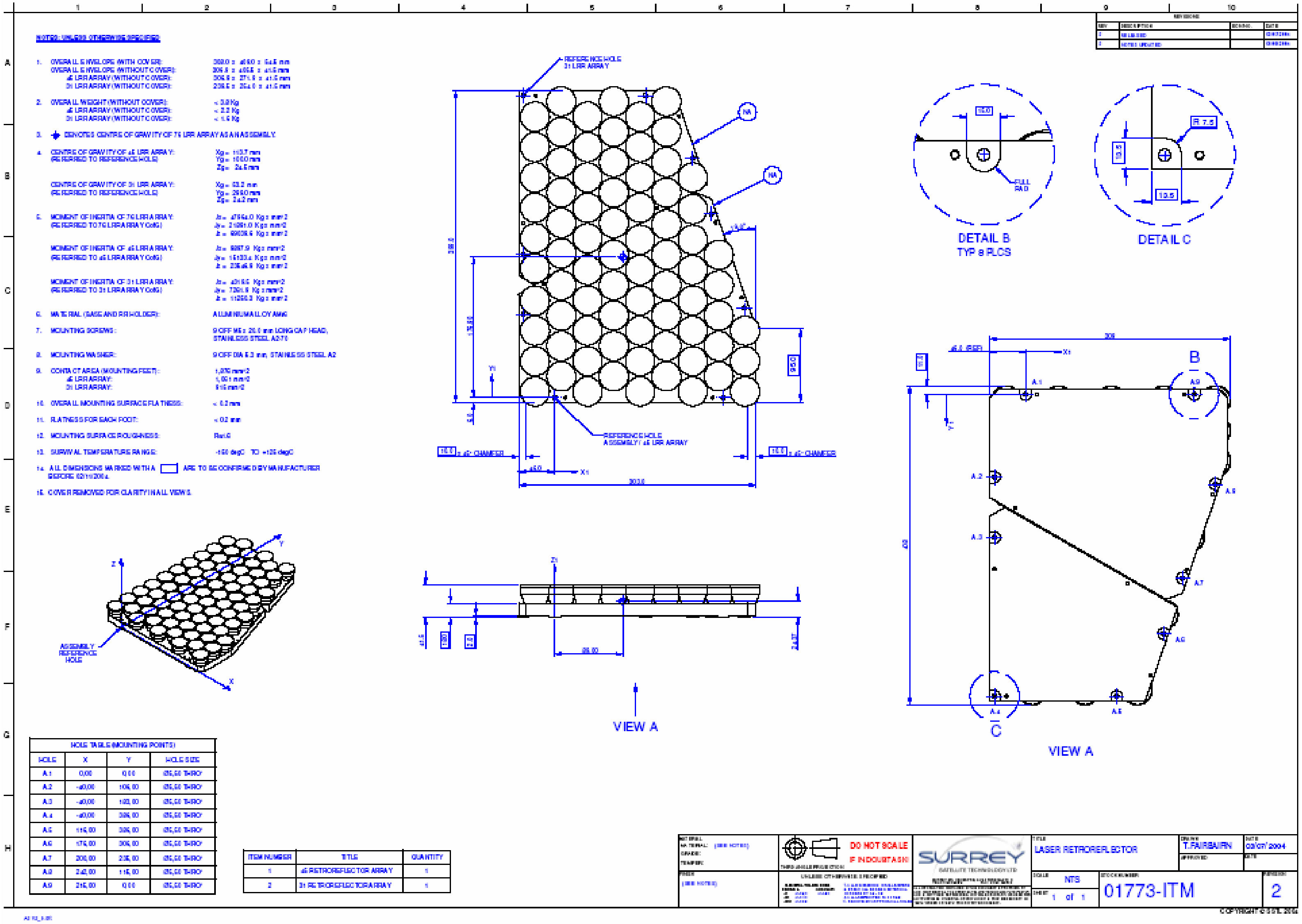
ANNEX A (RD-5)


DETAIL B
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DETAIL C
VIEW A
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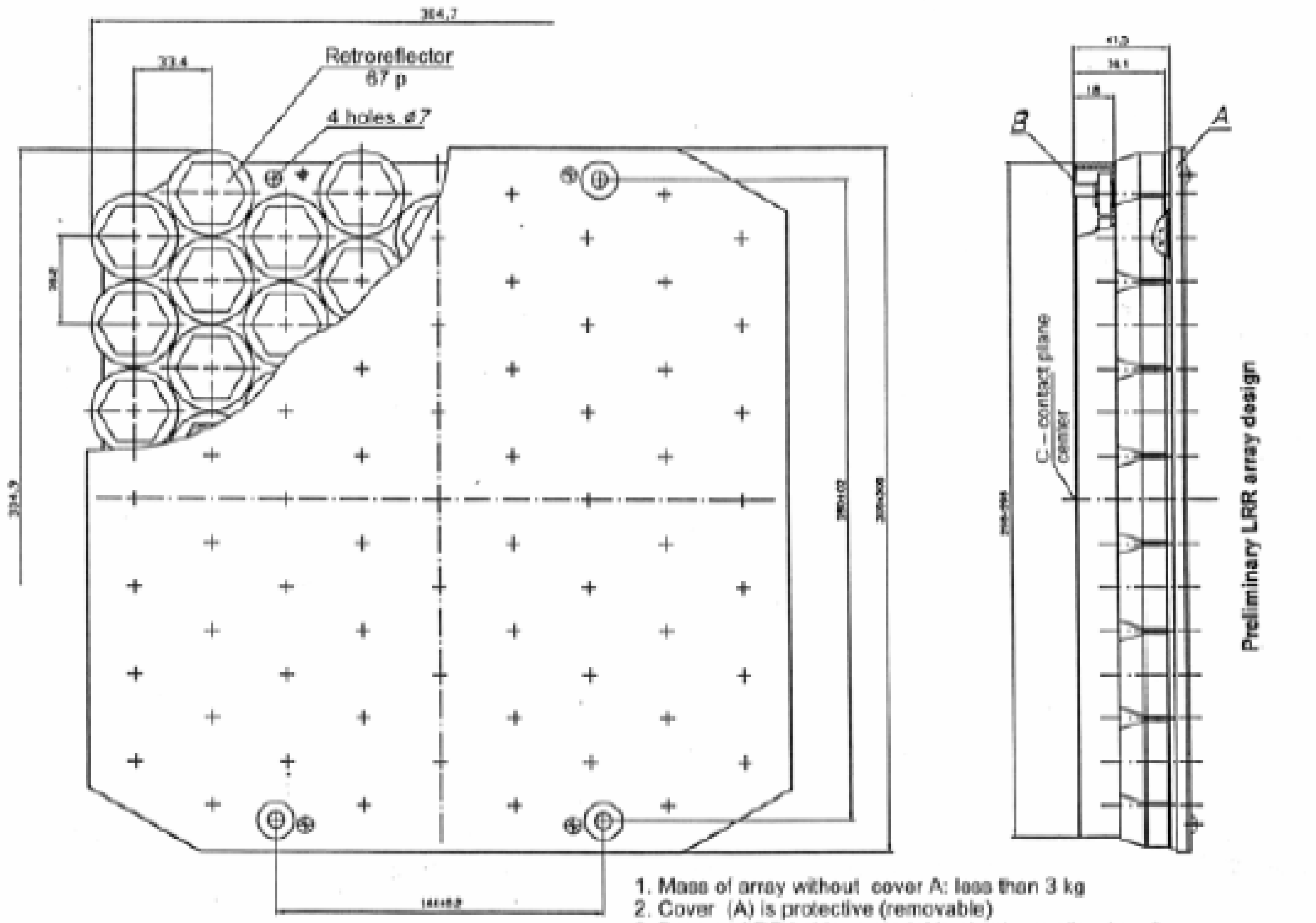
ANNEX B (RD-11)



1. Mass of array without cover A: less than 3 kg
2. Cover (A) is protective (removable)
3. Base and RR holder material is aluminum alloy Amg6.
4. Four holes Ж7 mm are designed for fastening of array by screw M6
5. Thermal contact between array and satellite body: through surfaces B.