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Specification of Galileo and GSTB-V2 Space Segment Properties Relevant for Satellite Laser Ranging

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A P P R O V A L

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C H A N G E L O G

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Enclose information about positions of LRR, CoG, 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

C H A N G E R E C O R D

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	All Document	
Rephrased description of attitude law for GSTBV2A	Page 11	Section 3.3
Rephrased description of attitude law for GSTBV2B	Page14	Section 4.3

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Corrected Z component of phase centre for GSTBV2/B and reformat table	Page 14	Table is section 4.4

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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 GSTBV2/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 GSTB-V2/A and GSTB-V2/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

1.3 List of abbreviations

AOCS	Attitude and Orbit Control System
FOC	Full Operational Capability
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
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 GSTB-V2

GSTB-V2/A, built by Surrey Satellite Technology Ltd (SSTL) of the UK, is foreseen to be launched by the end of 2005. GSTB-V2/B, built by Galileo Industries (GaIn), is foreseen to be launched in the 2nd quarter of 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:

Semi-major axis:	29601 km
Eccentricity:	0.002
Inclination:	56º
Argument of perigee:	0º (TBC)
RA of ascending node:	182º for GSTBV2/A (TBC)

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 GSTB-V2 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 GSTB-V2/A (SSTL)

3.1 LRR Array Specifications

Originally, GSTB-V2/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 CoG positions

Coordinate of the Centre of gravity of 76 LRR array with respect satellite reference frame (RD-4 and RD-6):

X = -832 mm
Y = -654 mm
Z = 1489 mm

Coordinate of the S/C centre of gravity (beginning of life, deployed solar array configuration; communication by email from Paul Charman on 14 September 2005)

X = -4 mm
Y = 1 mm
Z = 788 mm

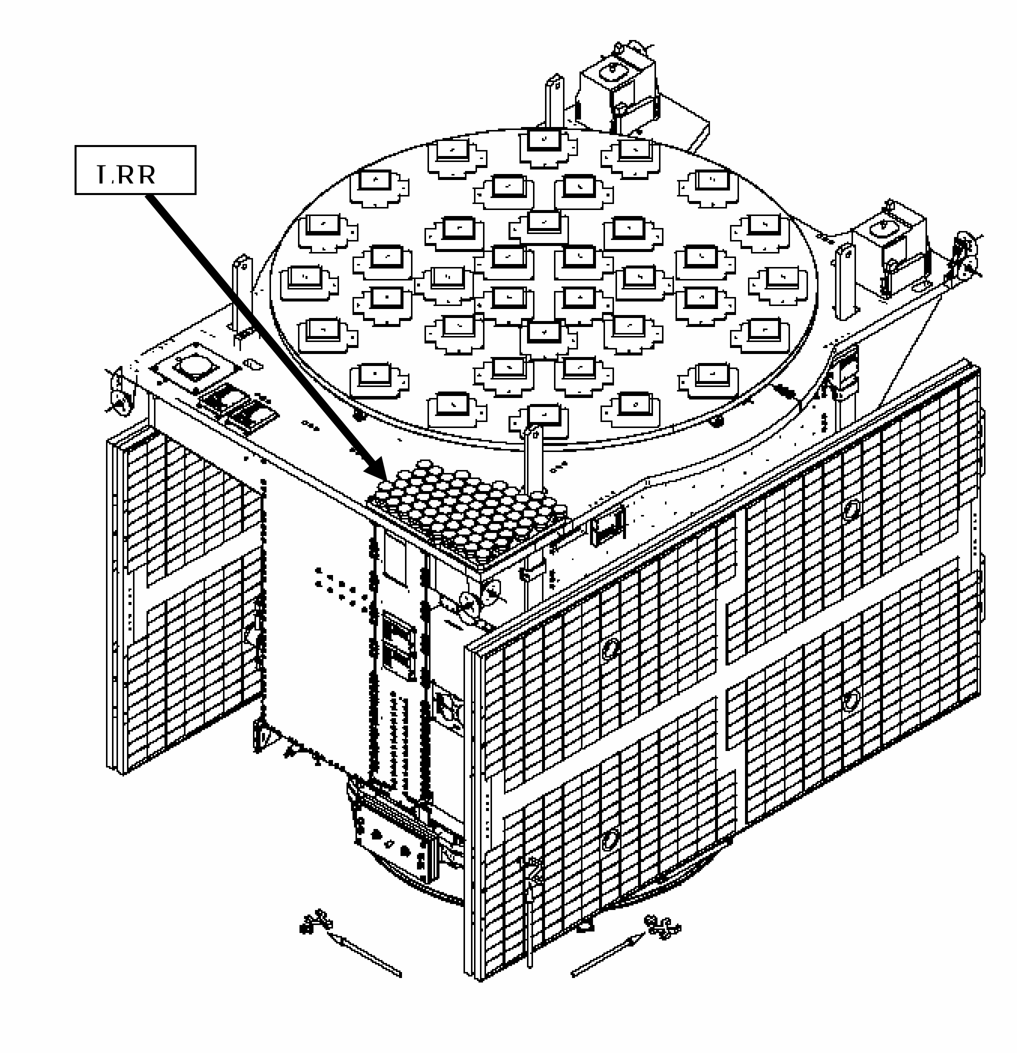


Fig 1. Position of the LRR in the GSTB2/A spacecraft.
Spacecraft is shown with solar array in stowed configuration

3.3 Attitude Law

The GSTB-V2/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 at launch will be 614 kg. The approximate cross-section Area is 9 squared metres.

4 GSTB-V2/B (GAIN)

4.1 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.

4.2 LRR and CoG positions

Coordinate of the Centre of gravity of the LRR array with respect satellite reference frame:

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

Coordinate of the S/C centre of gravity (beginning of life, deployed solar array configuration)

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

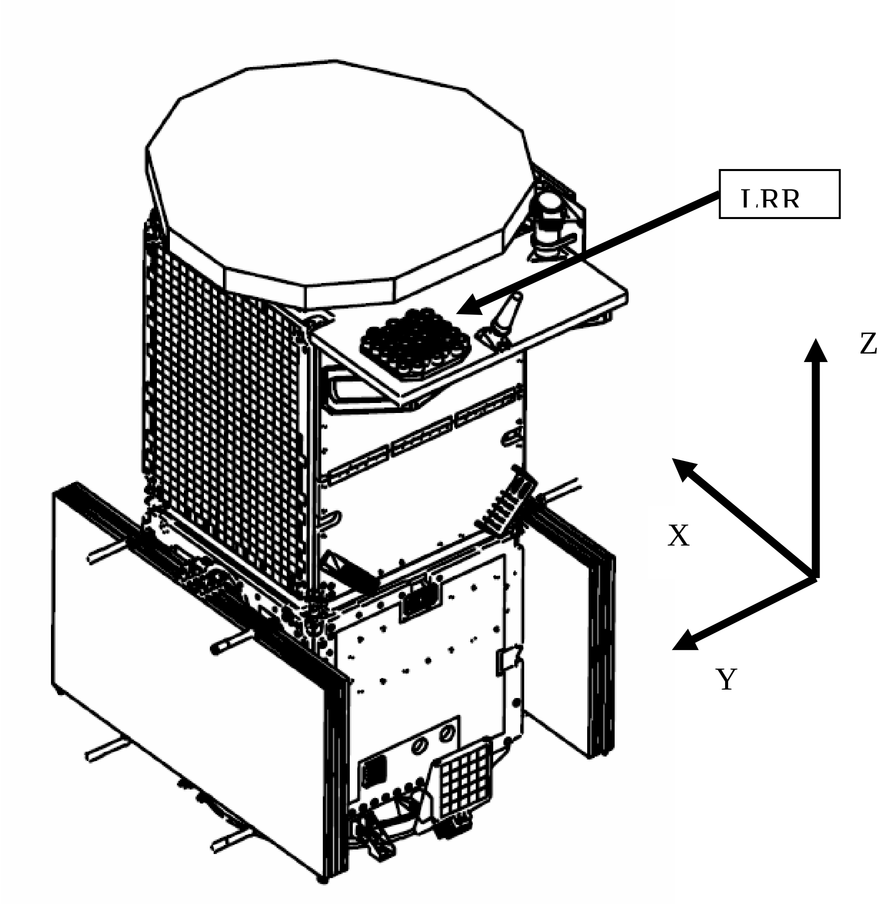


Fig 2. Position of LRR in GSTBV2/B.
Spacecraft is shown with solar array in stowed configuration

4.3 Attitude Law

GSTBV2/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 GSTBV2/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 other as GSTBV2/A.

4.4 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

5 GALILEO

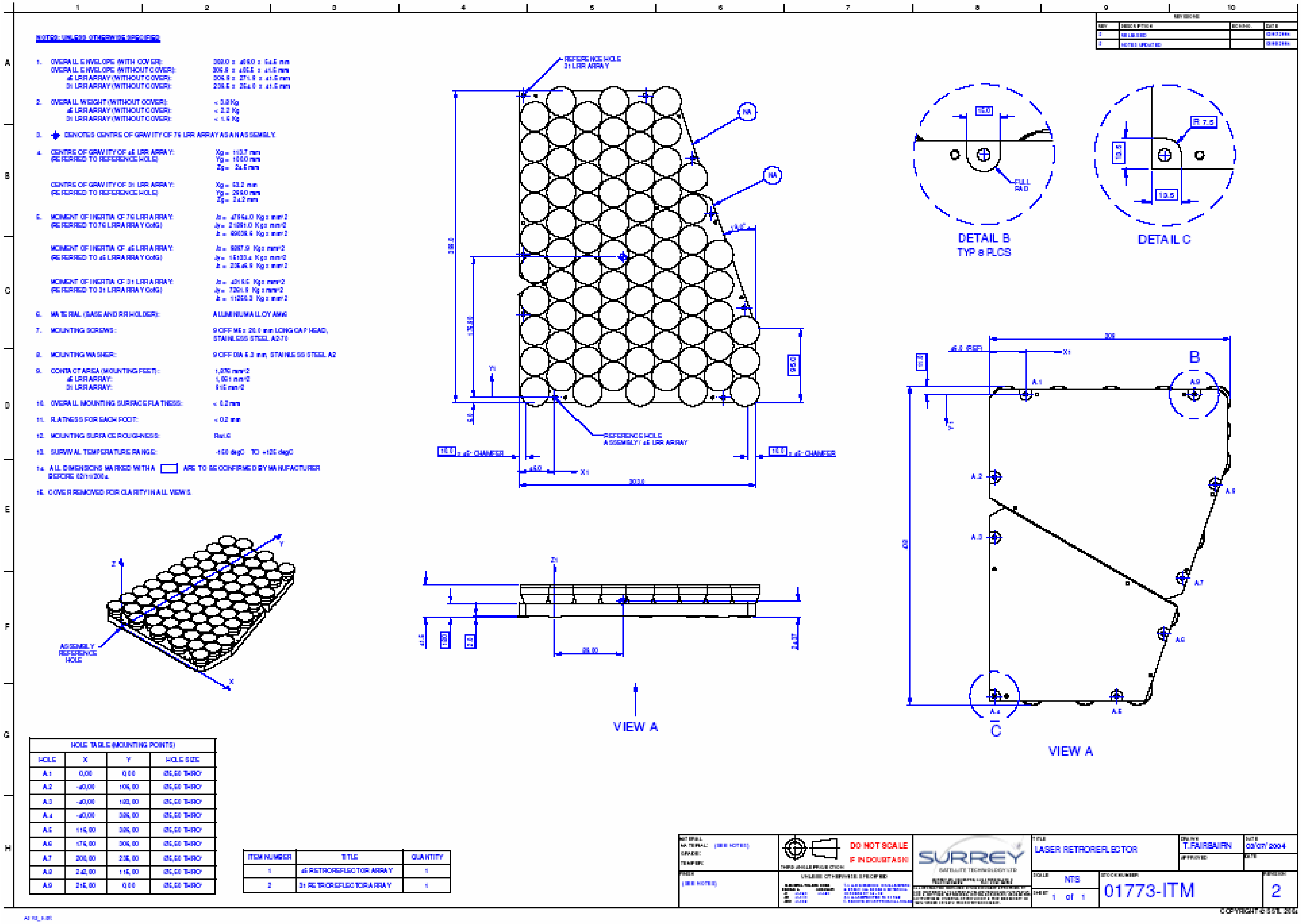
The current specifications by industry of the LRR size are extracted from industrial documentation and confirmed by D. Smith of Astrium on 27 August 2004. Source document used (for the purpose of traceability of the information) is Annex 1 to Space Segment and Satellite Design Description and Justification File, Doc-no: GAL-DD-ASTD-SS-R-0002, Issue 3, Rev. 1 draft. 31.07.2004.

```
Size: 435mm x 540mm x 53mm
Number of prisms: 100
Mass: 5 kg
Prism diameter, dihedral offset, or the choice: coated or uncoated are not
yet known.
```

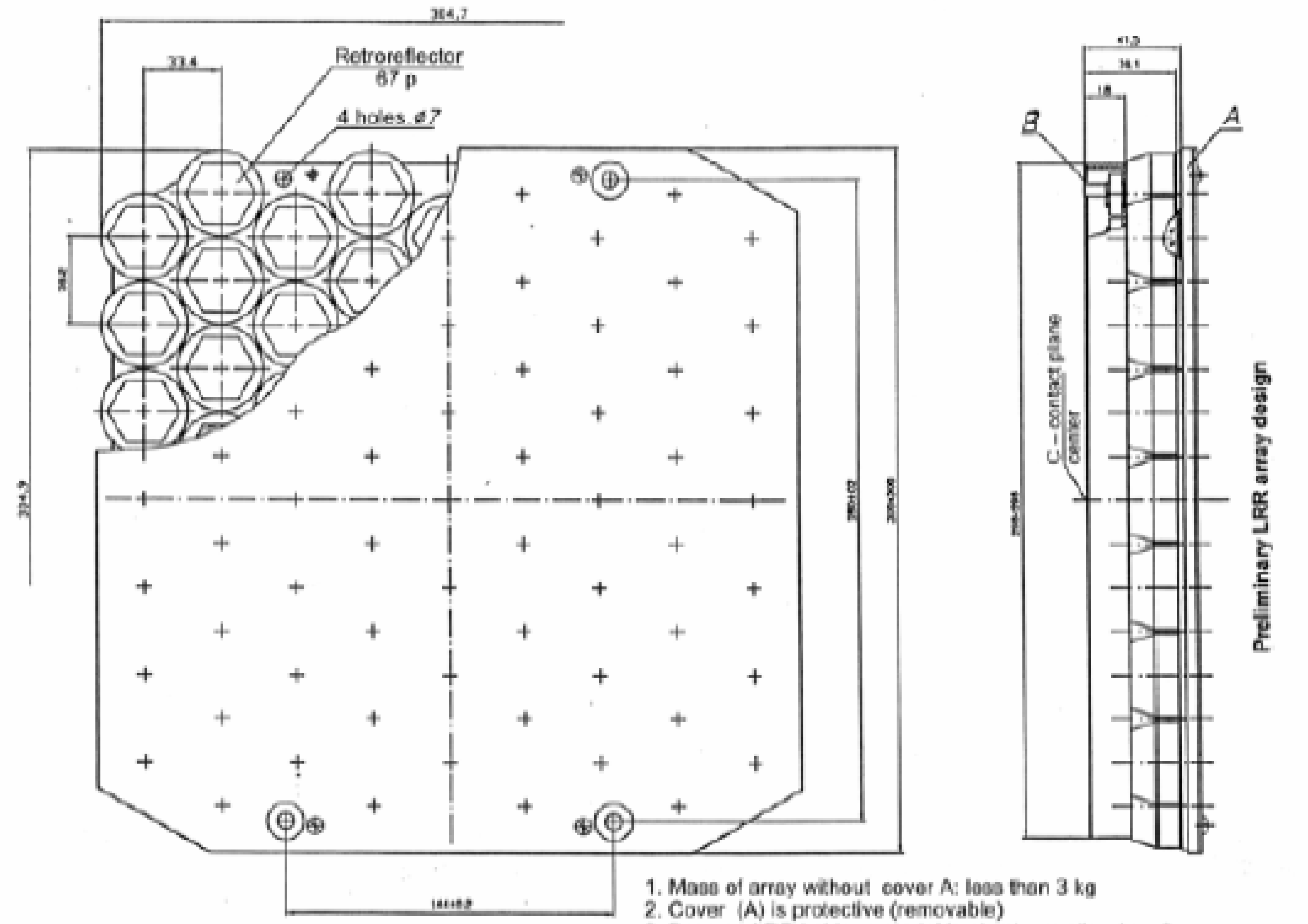
These values are now subject to change, since the Galileo System Requirements Document (RD-2) currently requires a minimum aggregate effective reflective LRR surface area of 660 square cm, viewed from any point on the Earth (i.e. assuming nominal S/C attitude).

END OF DOCUMENT

ANNEX A (RD-5)


DETAIL B
TYP 8 PLCS
DETAIL C
VIEW A
VIEW A
B
C
X
Y
Z
REFERENCE HOLE
ASSEMBLY REFERENCE HOLE
DO NOT SCALE
SURREY
SATELLITE TECHNOLOGY LTD
LASER RETROREFLECTOR
T.FAIRBAIRN
NTS
01773-ITM
2

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.