ETS-VIII Laser Retroreflector Array

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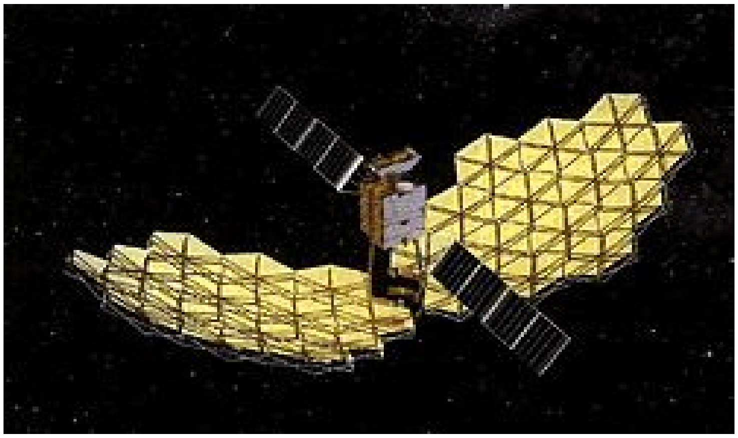
ETS-VIII Mission

- **Engineering Test Satellite-VIII**
- **Launch: 2003 (FY)**
- **Design Life: 3 years (mission)**
- **Geostationary Orbit**
  - **Altitude ~36,000 Km**
  - **Longitude 146° East ±0.1°**
  - **Latitude 0°±0.1°**
- **Attitude Control**
  - **3-Axis Stabilized**
  - **Roll/Pitch = ±0.05° (max)**
  - **Yaw = ±0.15° (max)**

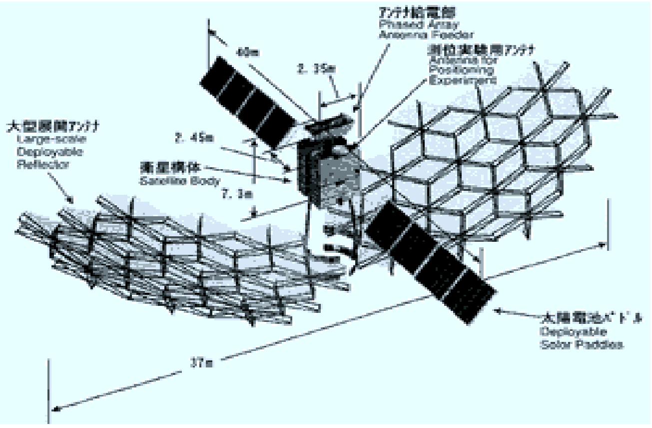


The ETS-VIII satellite, scheduled for launch in the summer of 2003, is being developed for the National Space Development Agency of Japan (NASDA). The ETS-VIII satellite will be placed into a Geosynchronous Earth Orbit (GEO) at a position of 146 degrees East (+/-0.1 degrees) longitude by 0 degrees (+/-0.1 degrees) latitude. Additional information may be obtained at the following Intranet sites:

http://www.nasda.go.jp/Home/Satellites/e/ets8_e.html
http://yyy.tksc.nasda.go.jp/Home/Projects/ETS-VIII/index_e.html

ETS-VIII Mission Objectives

- **An Advanced 3-ton-class Spacecraft Bus**
- **Large-scale Deployable Reflector (world’s largest)**
- **Mobile Satellite Communications System**
- **Mobile Satellite Multimedia Broadcasting System**
- **High Accuracy Clock (HAC) Subsystem For Satellite Positioning**



The ETS-VIII mission has multiple primary missions that include:

An advanced 3-ton-class spacecraft bus.

A large-scale deployable reflector that will be the world’s largest.

A mobile satellite communications system for audio and data communications with hand-held terminals.

A mobile satellite multimedia broadcast system for CD quality sound and image transmission.

A High Accuracy Clock subsystem for satellite positioning.

ETS-VIII High Accuracy Clock Subsystem

- **Combined CRL and NASDA Experiment**
- **Two Cesium Atomic Clocks & RF Positioning Equipment**
- **10-ps Two-way Time and Frequency Transfer**
- **Laser Retroreflector Array (LRRA)**

The High Accuracy Clock (HAC) subsystem will be used to conduct basic satellite positioning system experiments. The ETS-VIII Laser Retroreflector Array (LRRA), being provided by the HTSI LRRA Team, will be used as a part of the HAC mission to obtain Satellite Laser Ranging (SLR) data. This reference data will be used to evaluate the ranging of the HAC radio frequency (RF) positioning equipment. Additional information on the HAC can be obtained at the following Intranet site:

http://tycho.usno.navy.mil/ptti/ptti99/PTTI_1999_515.PDF

LRRA Mission Requirements

- **Orbit**
  - **Geostationary**
  - **Altitude ~36,000 Km**
  - **Longitude 146° East ±0.1°**
  - **Latitude 0°±0.1°**

- **SLR Operations**
  - **CRLLAS (Tokyo, Japan)**
  - **Hollas (Hawaii)**
  - **Moblas-5 (Western Australia)**

- **Wavelength**
  - **532 Nanometers**

- **Design Life**
  - **7 Years (including 4 years ground storage)**

The LRRA is being designed to support SLR operations at 532nm by a Japan based SLR system such as CRLLAS or Masuda, the Hollas system in Hawaii, and the Moblas-5 system in western Australia. The LRRA, consisting of 36 corner cubes, has a design life of 7 years, which includes 4 years ground storage and 3 years on orbit.

LRRA Support Station Parameters

Parameter	**CRLLAS ***	**Hollas (Hawaii)**	**Moblas-5 (Australia)**
Location Data			
Latitude	35.710081 N	20.7072034 N	29.04773064 S
Longitude	139.489130 E	203.7441046 E	115.3453279 E
Elevation	122.49 meters	3062.658 meters	274.068 meters
System Parameters			
Laser Energy	100 mJ	140 mJ	100 mJ
Pulse Width	150 ps	150-200 ps	200 ps
Beam Divergence	10 arcsec	4-30 arcsec	27.5 arcsec
Rcvr telescope dia.	1.5 meter	16 inch - 40 cm	30 inch – 76.2 cm
Detector QE	15%	15%	16%
Optical Efficiency Transmit / Receive	50% / 20%	~75% / ~60%	~94% / ~79%
Ranging Geometry			
Elevation Angle	47.9°	21.8°	42.3°
Satellite Range (km)	37,019	39,175	37,411
Incidence Angle on LRRA	5.8°	8.1°	6.4°

*** No longer supports Satellite Laser Ranging operations.**

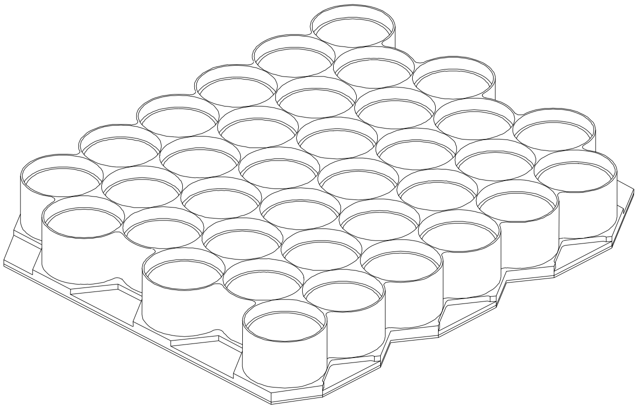
As I just mentioned, the ETS-VIII LRRA is designed to support SLR operations by CRLLAS in Tokyo, Japan; Hollas in Hawaii; and Moblas-5 in western Australia. Though the CRLLAS system is no longer operational, there are tentative plans to either refurbish this system or remodel the SLR station at the NASDA Masuda in Tanegashima:

Latitude:	30 deg. 33 min. North
Longitude:	131deg. 01 min. East

As can be seen, CRLLAS (or an alternative Japanese station), as well as Moblas-5, will both have a good view of the ETS-VIII satellite at almost 48 and over 42 degrees elevation angle, respectively. Hollas, with a view angle of just under 22 degrees elevation angle, has the capability of adjusting their beam divergence which can enhance their return signal level, when necessary.

LRRA “As Designed” Configuration

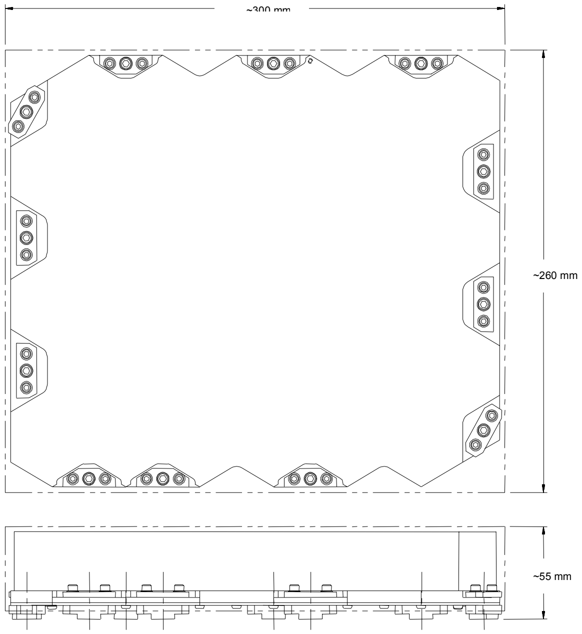
- **36 Quartz Corner Cubes**
- **Cube Diameter ~41 mm**
- **Envelope**
  - **(x) ~260 mm**
  - **(y) ~300 mm**
  - **(z) ~55 mm**
- **Mass <3 kg**
- **Optical Cross Section ~1.63 x108 m2**



The quartz used is a highly homogenous material with excellent thermal, optical, and radiation resistant characteristics/properties. The corner cube diameter of ~41 mm was chosen to maximize the optical cross section for the combined velocity aberration and earth rotation. The corner cubes arrangement has been chosen to maximize their optical characteristics of the array while minimizing the array envelope. Both the array envelope and mass meet the system requirements for the ETS-VIII mission. The optical cross section has been designed to meet the tracking capabilities of the Satellite Laser Ranging stations selected to support this mission.

LRRA Envelope

- **Envelope**
  - **(X) ~260 mm**
    (Y) ~300 mm
    (Z) ~55 mm
- **Height (z) Includes Thermal Isolation Spacers**



Shown here is the envelope footprint of the array, as designed, showing the approximate envelope size.

As you can see, we have incorporated many fasteners into our design. The reason for this is that the spacecraft system panel is constructed from a carbon-fiber composite that is weaker than the LRRA panel.

Therefore, we increased the number of fasteners in order to minimize the stresses on the spacecraft panel interface points.

LRRA Temperature Analysis

- **Spacecraft Interface**
  - **-80° to +65°C**
  - **MLI on System Panel**

- **Hot Case**

– Solar Flux	**1425 w/m2**
– Earth Albedo	**6 w/m2**
– Tmax	**-22° C**

- **Cold Case**

– Solar Flux	**1288 w/m2**
– Earth Albedo	**6 w/m2**
– Tmin	**-114° C**

Two primary concerns in designing the array were the thermal and optical properties. Thermally, it was necessary to perform an analysis to ensure the temperature gradients across the array as well as within an individual corner cube would not affect the optical characteristics or performance of the array.

Thermal gradients across the array were addressed both within the mechanical design of the array structure as well as by installing a thermal blanket fabricated of MLI (Multi Layer Insulation). Our thermal analysis assumed the above environment and resulted in the following results.

LRRA Thermal Results

- **Results**
  - **System Panel to LRRA <5 Watts**
  - **Temperature Gradients Across Corner Cubes <1.5° C**
  - **Gradients Across Array Panel <5.0° C**

- **Design Approach**
  - **Thermal Isolators Mount to System Panel**
  - **MLI Cover on LRRA Base**
  - **Cube Material and Array Design**

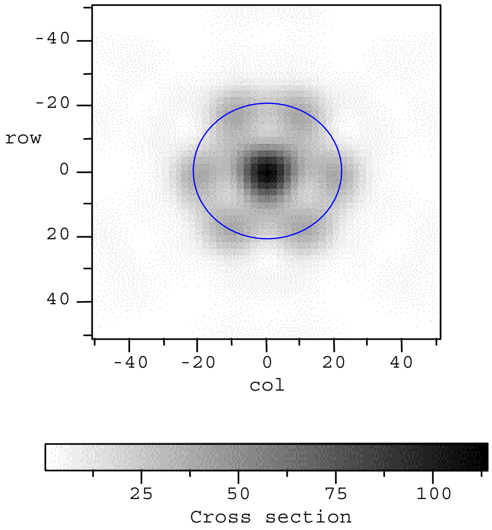
There will be less than 5 watts thermal transfer between the spacecraft system panel and the array panel. This was accomplished through the use of additional MLI between the two panels as well as by incorporating thermal isolators as a component of the array fastener.

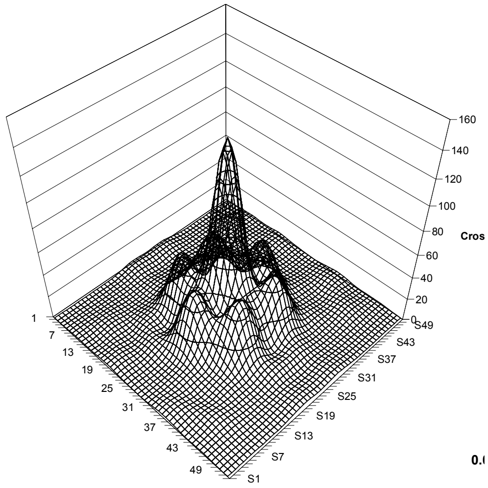
Temperature gradients across the corner cube will be less than 1.5 degrees C and the temperature gradient across the entire array will be less than 5.0 degrees C. This was accomplished by selecting the appropriate corner cube material and designing the array to minimize thermal absorption.

Corner Cube Optimization

Average Optical Cross Section σ (10^4 meters^2) for ~41mm Diameter Cube		
0 µrad	**18 µrad**	**20 µrad**
1,854.17	495.16	452.39

This chart shows the average optical cross section for a given far field divergence angle for a single, ~41 mm cube. This cube size was selected to maximize the optical cross section for the combined velocity aberration and the earth rotation.





Both of these graphs show the same far field diffraction pattern information for a single cube. The graph on the left shows a two dimensional representation of what would be seen if looking directly down at the graph on the right. The amplitude of the right diffraction pattern maxima are depicted in the left graph as intensity and represents the relative cross section for any given point within the diffraction pattern.

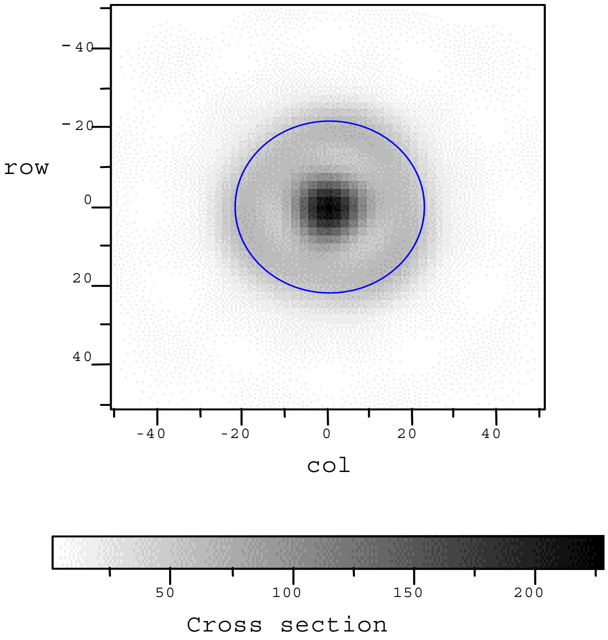
Smoothing The Pattern

Pattern shows multiple cubes arranged to provide a homogenous ring pattern.

Additional cubes have a cumulative effect.

The far field diffraction pattern shown here is a result of combining multiple corner cubes arranged to complement one another.

The addition of more corner cubes increases the homogeneity of the pattern as well as increases the optical cross section.



LRRA Manufacturing Testing

- **Interferometer Verification**
  - **Homogeneity**
  - **Dihedral Angles**
  - **Surface Finish**
  - **Diffraction Patterns**
  - **Wave Front Flatness**
  - **Reflectance Characteristics (532 nm)**

- **Vibration Testing**
  - **Sine**
  - **Random Vibration**

- **Temperature Cycle Testing**
  - **8 Cycles with 1 Hour Soak at Extremes**
  - **-129° C to +65° C**

To verify mission suitability, various tests and verifications were required. Individual verification measurements will be performed on each corner cube to ensure they all meet the levels of quality necessary to ensure a successful mission.

Vibration testing is performed to ensure the array could survive vibrations from the launch vehicle during insertion into orbit.

Temperature tests are performed to ensure the array will perform in the environmental extremes it is expected to encounter. This includes both here on earth as well as in orbit.