LASER RETROREFLECTOR ARRAY OF GEOSTATIONARY SATELLITE, ETS-VIII

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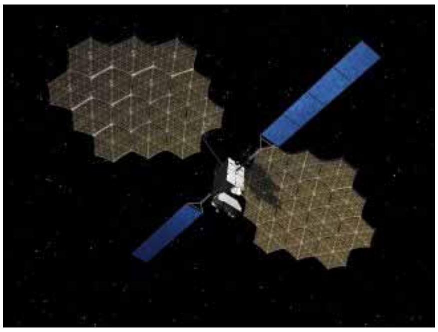
Abstruct
JAXA' Engineering Test Satellite-VIII (ETS-VIII) will conduct positioning experiments, combining the clock signals with GPS data, to study basic satellite positioning systems. It will be launched in 2006-2007 and located into the geostationary orbit at 146 degrees east. ETS-VIII will carry a high precise clock system, and also Laser Retroreflector Array (LRRA) that will be used for the evaluation of experiment results such as precise orbit determination and onboard clock estimation. The LRRA consists of 36 corner-cubes which are contained within an envelope of 26cm x 30cm x 5cm. Its approximate weight is three kilograms. SLR stations in the Asia-Pacific region will be able to Laser-track to the ETS-VIII.
We will present an overview of ETS-VIII, LRRA and result of link budget analysis.

1.ETS-VIII Mission Description
1.1 Outline

The ETS-VIII is an advanced satellite being developed primarily to establish and verify the world's largest-class geostationary satellite bus technology, which is necessary for space missions of the 21st century. The ETS-VIII will conduct orbital experiments on the Large-scale Deployable Reflector (for S-band), which is widely applicable to large-scale space structures, as well as the High-Power Transponder, and the On-Board Processor, which are all required to realize mobile satellite communications with hand-held terminals, similar to popular cellular phones.


Overview of ETS-VIII

Moreover, the ETS-VIII will carry the High Accuracy Clock (HAC) system and a Time Compare Equipment (TCE) system for the study of satellite positioning system. The SLR tracking data will be utilized in this study.
The ETS-VIII mission will carry out on the Geostationary Orbit (GEO) (Longitude 146degE (tentative)). Mission life is designed for 3 years. (The satellite bus is designed to have 10-year life.)

The orbit will be maintained within 0.1 degree range respectively toward the north, south, east and west direction.

1.2 Mission Objectives

The ETS-VIII is being developed to establish and verify the following technologies:

(1) An advanced 3-ton-class spacecraft bus
(2) Large-Scale Deployable Reflector
(3) Mobile satellite communication system technology that will enable audio/data communications with hand-held terminals
(4) Mobile satellite multimedia broadcasting system technology for CD-level sound and image transmission
(5) Satellite positioning using the High Accuracy Clock

1.3 Experiments plan using HAC system

JAXA will conduct the following positioning experiments, combining the clock signals with GPS data and SLR, to study basic satellite positioning systems using HAC system.

(1) AF (Atomic Frequency mode):

Positioning signal is generated by on-board CFS (Cesium Frequency Standards).

(2) BP (Bent Pipe mode):

Positioning signal in S-band (779fc/3) and pilot signal in S-band (260fc) are generated by HTS (HAC Transmission Station) and transmitted to ETS-VIII as left handed circular wave. Then, the carrier frequency of positioning signal is converted to L-band (156fc) and S-band (487fc/2) by using pilot signal. Pilot signal used in frequency conversion is selected by taking account of phase coherency of pilot signal and positioning signal. (i.e. The same Doppler effects and phase delay due to the common ionosphere.)

(3) TCE (Time comparing mode):

NICT (National Institute of Information and Communications technology) will carry out experiments for comparing the on-orbit CFS time and UTC(NICT) using bidirectional communication of navigation signal.

(4) SLR (Satellite Laser Ranging):

ETS-VIII has also carries LRRA (Laser Retro-Reflector Array, $\sigma > 1x10^9 m^2$) and the SLR operation is planned. SLR operation can be performed without conflict for other operations.

JAXA will conduct the precise orbit determination of ETS-VIII using SLR and its result will be used for the evaluation of other experiment results such as precise orbit determination using navigation signal and onboard clock estimation.

(5) USR (User positioning experiment)

Effectiveness of overlaying ETS-VIII data and GPS data will be evaluated from the user's standpoint. USR mode is not ETS-VIII operation mode but just observation mode in ground. USR is a portable station, and will be placed at some location during mission period. Observed data by USR will be processed in 2 ways as follows:

- Applying user positioning algorithm to evaluate the usefulness of ETS-VIII overlay for users. The effect ETS-VIII overlay will be analyzed in off-line analysis for the case of adding ETS-VIII positioning signal, or introducing system state estimation.
- Using USR observed data for estimating system status as the data of 5 SMS in off-line analysis.

2. Overview of LRRA

2.1 General

The Laser RetroReflector Array (LRRA) is made of aluminum alloy and consists of 36 corner cubes mounted in a panel, which are 4.1 cm in diameter. The corner cubes are constrained to allow for differential thermal expansion of the structure and the quartz corner cubes. The array assembly weighs less than 3100 g. The array is 26 cm length, 30 cm width and 5.5 cm height.

Fig.2-1 ETS-VIII Retro-Reflector Array

2.2 Corner Cube Description

The 36 corner cubes are made of highly homogeneous fused silica, Suprasil-1(quartz). The individual corner cubes are 4.1 cm diameter and optimized for the velocity aberration of the satellite as well as for a wavelength of 5320 Angstroms. The surface flatness is 1/10 wavelength at 5320 Angstroms. The reflective coating external reflection is specified to exceed 75% at 5320 Angstroms.

The net optical efficiency of the prism is specified to exceed over 95% at 5320 Angstroms.

2.3 LRRA Specification Summary

Table 2-1 summarizes the LRRA specification.

Table 2-1 LRRA Specification Summary

Type	Reflector array
Wavelength	optimized for 532 nm
FOV (half angle)	10 deg
Optical Cross Section	1.63×10^8 m^2
Shape	Flat array
Size of Array	26×30×5.5 cm
Mass	< 3.1 kg
Reflector Number	36 corner cubes
Cube diameter	4.06 cm
Reflectivity	> 75 %
Beam divergence	20 μrad

2.4 LRRA Position

LRRA is installed on the top of ETS-VIII’s antenna-tower. (See Fig.2-2)

The attitude of ETS-VIII affects the position and the direction of LRRA. The performance of ETS-VIII attitude orbit control subsystem is as follows:

Attitude control error (3σ),

Roll	Pitch	Yaw
< ±0.05	< ±0.05	< ±0.15 (deg)

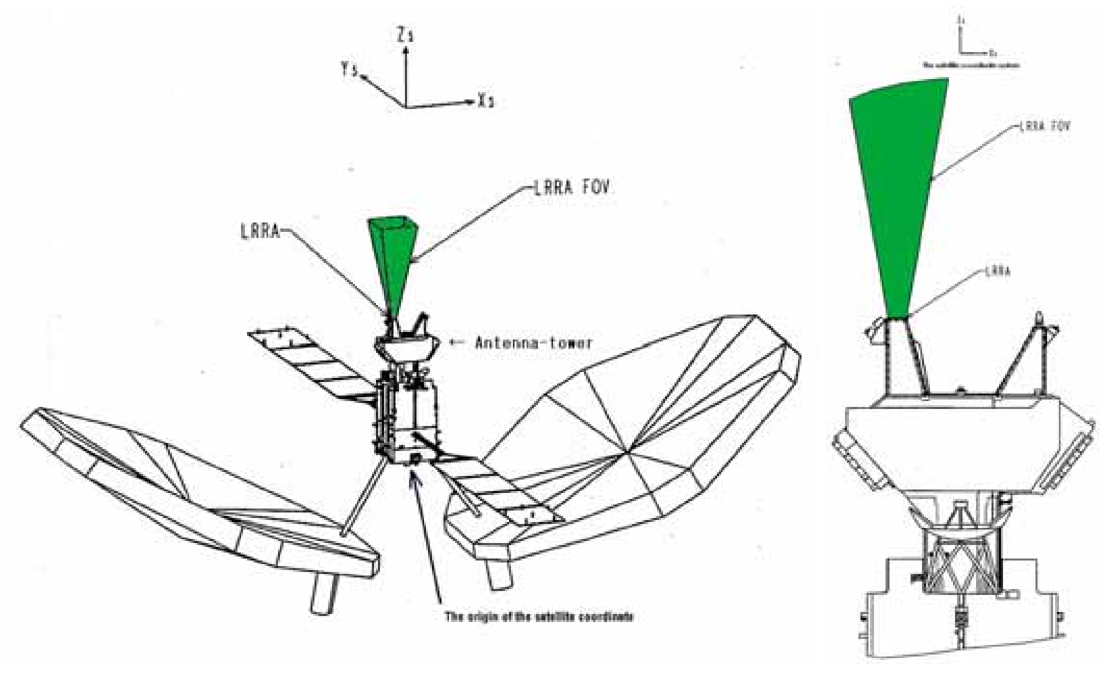


Fig.2-2 The satellite coordinate system of the ETS-VIII / LRRA installation position

3. Candidate SLR Station and Link Budget Analysis

3.1 Candidate SLR Station

The ETS-VIII will be carried into geostationary transfer orbit (Longitude 146 degrees East) by H-IIA launch vehicle from Tanegashima Space Center in Japan. Figure 3.1 shows the FOV (Field Of View) of the ETS-VIII LRRA and candidate SLR stations. Thus, SLR stations in the Asia-Pacific region will be able to track ETS-VIII.

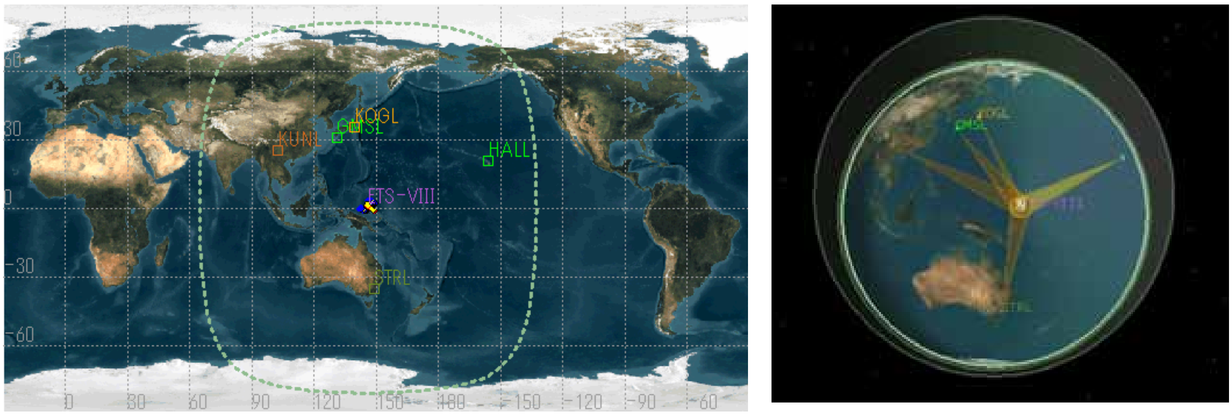


Fig3-1 FOV of the ETS-VIII LRRA and candidate SLR stations

3.2 SLR Link Budget Calculation

The example of link budget calculation result for each candidate station is shown in Table 3-1. We calculated link budget for each station based on the station site log on the ILRS web site.

We confirmed the return energy from ETS-VIII for individual station by link budget calculation. The Lageos normalized signal level is approximate 0.01. According to this result, most candidate stations are possible to get return signals from ETS-VIII, but we need to re-calculate link budget using more detailed parameters and also to examine other parameters such as range gate, detecting method, etc.

Table 3-1 Link budget calculation result for each candidate station

	GMSL	KOGL	STRL	KUNL	YARL
Cirrus Cloud Transmission	1	1	1	1	1
Atmospheric Transmission	0.2	0.2	0.2	0.2	0.2
Longterm Beam Spread [1×10^{-6} rad]	5	5	5	5	5
Shortterm Beam Spread [1×10^{-6} rad]	20	20	20	20	20
Receive Efficiency	0.5	0.1	0.41	0.5	0.76
Satellite Backscattering Cross Section [1×10^{6} m^2]	168	168	168	168	168
Quantum Efficiency [%]	10.4	15	20	20	15.5
Receive Aperture [m^2]	0.78	1.76	0.44	0.88	0.4536
Satellite Height [km]	37000	37100	37100	38300	37100
Wavelength [1×10^{-6} m]	0.532	0.532	0.532	0.532	0.532
Transmit Efficiency	0.5	0.3	0.41	0.5	0.95
Pulse Energy [mJ]	300	50	50	120	100
Average signal level [p.e.]	6.551428	1.687381	0.787913	4.965641	5.407543
Lageos normalized signal level	0.016596	0.016418	0.016418	0.014455	0.016418

4. SLR Tracking Plan and Orbit Analysis

4.1 SLR Tracking Plan

HAC Experiment Ground System will conduct real-time orbit determination of ETS-VIII using navigation signal of ETS-VIII, 24 consecutive hours every 2 weeks. SLR data must be acquired at the same time.

The example of SLR data acquisition pattern is shown in Fig.4-1.

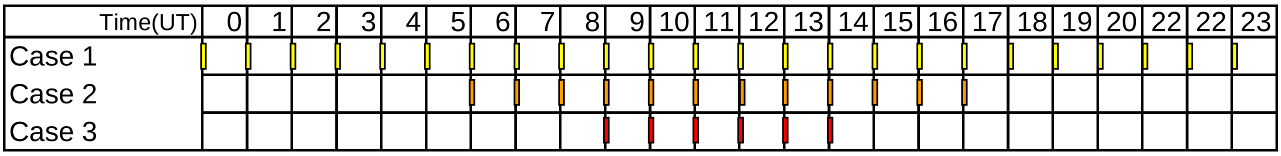


Fig. 4-1. SLR data acquisition pattern（sample）

Fig. 4-1 describes the SLR data acquisition cases of ETS-VIII. In Case 1, data are collected every pass of the satellite - every five minutes of every one hour - for 24 consecutive hours at each station at the same time. Case 2 and Case 3 are additional cases, in which acquisition times of data are shorter than Case 1, in order to reduce the workload of the stations. In principle, even if a data acquisition timing at one station is later than that of other stations due to the weather etc., data acquisition will be performed. Actual operation plan will be determined by the adjustment result with station and the analysis result.

4.2 Orbit Analysis Result

We carried out the analysis of orbital determination accuracy based on the operation case shown in the Section 4.1. Table4-2 shows the example case of orbit analysis. We analyzed the influence of orbit determination accuracy by changing the number of stations and data acquisition period. In Table4-2, (1) is an analysis case about the combination of station and (2) is an analysis case of observation conditions. Actually, we executed more cases by combining (1) with (2).

Table 4-2 Orbit Analysis Case

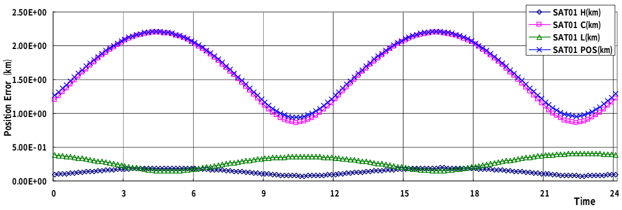
(1) Combination of Station

	GMSL	KOGL	STRL	KUNL
Case-1	○			
Case-2	○	○		
Case-3	○		○	
Case-4	○			○
Case-5	○	○	○	
Case-6	○	○		○
Case-7	○	○	○	○

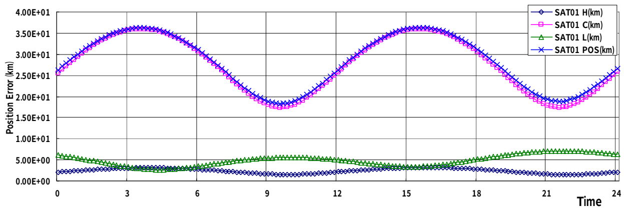
(2) Observation condition

	Orbit Arc(Hour)	Ranging Period
Case-A	24	5min/hour
Case-B	12	5min/hour
Case-C	6	5min/hour

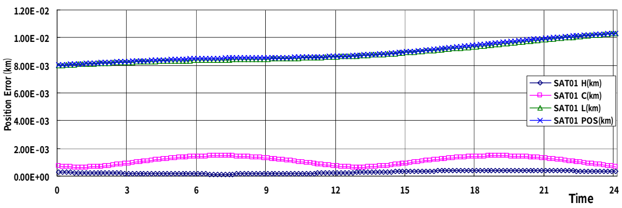
As the result, we verified that we could achieve target accuracy (~10m) by the combination of Mt. Stromlo station (STRL) and Tanegashima station (GMSL), but we need the support of NICT station (KOGL) and KUNMING station (KUNL) when considering weather conditions.



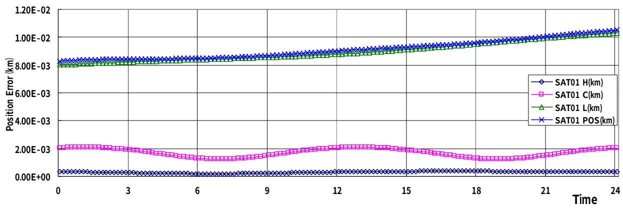
(a) Case1+CaseA (only GMSL, 24 hours)



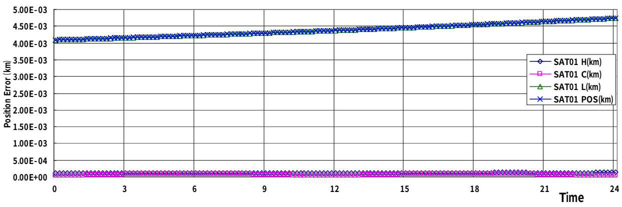
(b) Case1+CaseB (only GMSL, 12hours)



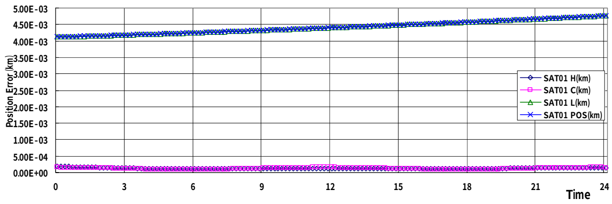
(c) Case2+CaseA (GMSL+KOGL,24 hours)



(d) Case2+CaseB (GMSL+KOGL,12 hours)



(e) Case3+CaseA (GMSL+STRL, 24 hours)



(f) Case3+CaseB (GMSL+STRL,12 hours)

Fig.4-2 Example of orbit determination analysis result

5. References

(1) Tomoichi Sato and Hiroyuki Noda, Introduction to fundamental experiment on satellite positioning system in ETS-VIII project, ISTS-2000-d-04

(2) Akinobu Suzuki, ETS-VIII SLR tracking Standards, QNX-030008