Role of SLR on QZSS operation

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Outline

1. Role of SLR on QZSS Operation
2. Introduction to QZSS
3. SLR related requirements for QZSS
4. QZSS as a challenging target for SLR
5. Example of SLR data from QZS-1
6. LRA for QZS-2, 3 and 4
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GNSS Session A Questions (from ILRS workshop website)

- Who is analyzing the GNSS SLR data?
  - TBD (QSS(QZS System Service Inc.) and/or NEC)

- What products are being derived?
  - Precise QZSS Orbit
  - Precise QZSS Clock

- Is the ILRS satisfying their present requirements? Data volume? Data Accuracy? Data coverage? What are the short falls?
  - See Slides 6 and 19.

- What is the projection for future requirements? Timeframe?
  - Support for 4-satellite constellation starting April, 2018
  - Support for 7-satellite constellation in future (2023 and after)

- What do we see from SLR-GNSS co-location?
  - Very Important for QZSS: In QZS-1, SLR data used as reference for radial direction of orbit determination.

- Is SLR having an impact on GNSS products?
  - YES!
Role of SLR on QZSS operation

- Precise Orbit Determination for QZSS
- Acquisition of QZSS RF signal
- Routine Operation Daily
- Distributing QZSS Final Product
- Improvement in Orbit Determination by adding SLR data
- For further improvement
- SLR Tracking by ILRS Network
- SLR data in CRD format
Accuracy Evaluation of the post-processed precise orbit by SLR data

- Accuracy evaluation using SLR data has helped modeling and parameter tuning for QZS-1 Orbit Determination.
- Japan appreciates ILRS’ laser ranging activities and need continuous support for future QZSS mission.
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Introduction to QZSS

Quasi-Zenith Satellite System (QZSS)
- Regional Satellite Positioning System
- Service Area: Asia-Pacific region
- 1st satellite “MICHIBIKI” launched on 9/11/2010

- 3 more satellites under development for 4-satellite constellation
  - QZS-2 and QZS-4: Quasi-Zenith Orbit (inclined geo-synchronous orbit)
  - QZS-3: Geo-stationary orbit
- 7-satellite constellation officially decided by the Government of Japan
System Configuration

Quasi-Zenith Satellite System

Space Segment

3 QZO Satellites (Michibiki included)

1 Geostationary Satellite

Satellite bus

Payload (LRA included)

Satellite bus

Payload (LRA included)

Ground Segment

Master Ground Station

Telemetry command center

Monitor station

Public signal delivery center

Short message center

Messaging Service Center

Technology verification of positioning facility

※ QZO: Quasi-Zenith Orbit
# Deployment Schedule

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<tbody>
<tr>
<td>&quot;Michibiki&quot;</td>
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<td><img src="image" alt="Michibiki Replacement" /></td>
<td><img src="image" alt="Anticipated Launch" /></td>
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<tr>
<td></td>
<td>In-Operation since 2010</td>
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<td>4-Satellite Constellation</td>
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<td><img src="image" alt="Anticipated Launch" /></td>
<td><img src="image" alt="Service (15 yrs planned)" /></td>
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<td><img src="image" alt="Anticipated Launch" /></td>
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<tr>
<td>7-Satellite Constellation (details TBD)</td>
<td><img src="image" alt="Design/Development (Additional 3 Satellites)" /></td>
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<td><img src="image" alt="Design/Development (Additional 3 Satellites)" /></td>
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Anticipated Launch Date: one in 2016; two in 2017
Expected Mission Duration: 15+ years
Orbital Accuracy Required: TBD
Anticipated Orbital Parameters: See below

<table>
<thead>
<tr>
<th>QZS-2 and 4</th>
<th>QZS-3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Orbit type</strong></td>
<td>Inclined Geo-synchronous</td>
</tr>
<tr>
<td><strong>Semi-Major Axis</strong></td>
<td>a=42164km</td>
</tr>
<tr>
<td><strong>Eccentricity</strong></td>
<td>e=0.075+/−0.015</td>
</tr>
<tr>
<td><strong>Inclination</strong></td>
<td>40 degrees (nominal)</td>
</tr>
<tr>
<td><strong>Frequency of Orbital Maneuvers</strong></td>
<td>Twice a year (based on “Michibiki” operation)</td>
</tr>
<tr>
<td><strong>Mission Timeline</strong></td>
<td>2-3 months of IOT (Initial Orbit Test) followed by nominal operation.</td>
</tr>
</tbody>
</table>
SLR/LRA Related Requirements

1. Requirements for on-board LRA
   - LRA shall be prism-array type.
   - Wavelength of applied light shall be at 532nm.
   - Field of View shall be more than 10 degrees.
   - Reflection Coefficient (after 15 years on orbit) shall be more than 0.75.

2. SLR tracking requirement
   - Three SLR stations shall be for **primary use**: (NOT an exclusive list. More data, the better!)

<table>
<thead>
<tr>
<th>SLR station</th>
<th>Nominal Fire Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanegashima</td>
<td>GUTS</td>
</tr>
<tr>
<td>Yarragadee</td>
<td>Moblas-5</td>
</tr>
<tr>
<td>Mt. Stromlo</td>
<td>STR3</td>
</tr>
<tr>
<td></td>
<td>10 Hz</td>
</tr>
<tr>
<td></td>
<td>1 Hz</td>
</tr>
<tr>
<td></td>
<td>60 Hz</td>
</tr>
</tbody>
</table>

3. Operations Requirements
   - Normal Point Time Span: 300sec
   - **Expected number of photo-electron detected in NP shall be >15** (with mean waiting time of 60 seconds; with clear sky condition; during night; with target SLR stations listed above; for satellite elevation more than 20 degrees.)
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QZSS as SLR Target is challenging

QZS being challenging target

- Semi-major axis $\sim 42164\text{km}$
- Inclination $\sim 40$ degrees

- Slant Rang:
  - longer than GEO
  - Changes with time.
QZSS as SLR Target (2)

QZS being challenging target
- SLR stations that can track QZSS are limited.

From Dr. Nakamura’s presentation for QZS-1
QZSS Tracking Schedule

There are two stages of tracking planned.

1. IOT
   • Initial Orbit Test for 2-3 months after launch (planned)
   • Frequency of SLR: Every day preferred.
   • Candidate SLR stations: ILRS stations located at western pacific ocean i.e., Western Pacific Laser Tracking Network (WPLTN)

2. Nominal Operation
   • Purpose: To increase the accuracy of orbit determination during the nominal operation (i.e., 15+ years of on-orbit life)
   • Frequency of SLR: Every day preferred.
   • Candidate SLR stations: ILRS stations located at western pacific ocean i.e., Western Pacific Laser Tracking Network (WPLTN); including but not limited to Tanegashima, Yarragadee and Stromlo.
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Example of SLR data for QZS-1

- Data used: 2012 to 2014
- SLR station: Yarragadee (most difficult target station to satisfy requirement)

\[ \lambda > 15 \] requirement!

\( \lambda \): requirement for # of detected photo-electron detected in NP
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LRA for QZS-2, 3 and 4

With successful tracking record with QZS-1, QZS-2, 3 and 4 will be equipped with the same LRA as QZS-1.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
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<tbody>
<tr>
<td>LRA manufacturer</td>
<td>Honeywell Technology Solutions Inc.</td>
</tr>
<tr>
<td>Type of Array</td>
<td>Planar Array</td>
</tr>
<tr>
<td>Shape and size of each CCR</td>
<td>Circular 40.6 mm (1.60&quot;), Height - 29.7 mm (1.17&quot;)</td>
</tr>
<tr>
<td>Dihedral angle offset</td>
<td>0.8 +/- 0.3 arcsec</td>
</tr>
<tr>
<td>Flatness of cube’s surfaces</td>
<td>$\lambda/10$</td>
</tr>
<tr>
<td>Coating</td>
<td>Coated with MgF2 anti-reflective</td>
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<tr>
<td>Envelope</td>
<td>400mm x 400mm x 100mm</td>
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<tr>
<td>Number of CCR</td>
<td>56 (7 rows x 8 lines)</td>
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</tbody>
</table>
Backup Slides
# Orbit(s) of QZSS

## Quasi-Zenith Orbit Parameter and Tracking Range

<table>
<thead>
<tr>
<th>Orbit Parameter</th>
<th>Nominal Allocation</th>
<th>Tracking Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semimajor Axis (A)</td>
<td>42164km</td>
<td>-</td>
</tr>
<tr>
<td>Eccentricity (e)</td>
<td>0.075</td>
<td>0.075±0.015</td>
</tr>
<tr>
<td>Inclination (i)</td>
<td>40 degree</td>
<td>36 ~ 45 degree</td>
</tr>
<tr>
<td>Argument of Perigee (w)</td>
<td>270 degree</td>
<td>270±2.5 degree</td>
</tr>
<tr>
<td>RAAN (Ω)</td>
<td>Block I_Q: 117 degree Block II_Q: 117±130 degree</td>
<td>-</td>
</tr>
<tr>
<td>Central Longitude (λ)</td>
<td>136 degree</td>
<td>130~140 degree</td>
</tr>
</tbody>
</table>

RAAN: Right Ascension of the Ascending Node

## Geosynchronous Orbit Parameter and Tracking Range

<table>
<thead>
<tr>
<th>Orbit Parameter</th>
<th>Nominal Allocation</th>
<th>Tracking Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitude</td>
<td>E 127</td>
<td>127±0.1 degree</td>
</tr>
<tr>
<td>Latitude</td>
<td>0</td>
<td>0±0.1 degree</td>
</tr>
</tbody>
</table>
Benefit of QZSS for users

A Scene during the Experiment

J01: QZS-1
G##: GPS ##
(Grays: Blocked)
In Ginza, Tokyo

Need at least 4 satellites in sight.

× : GPS only
✓ : GPS+QZS
Positioning Signal of QZSS (as of Sept. 2015)

Positioning Signal of QZSS

Not only positioning complementation signal, but satellite orbit, time, and ionosphere correction information will be also transmitted as augment information.

<table>
<thead>
<tr>
<th></th>
<th>1st Satellite</th>
<th>2nd–4th Satellite</th>
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<tbody>
<tr>
<td></td>
<td>QZO</td>
<td>QZO</td>
</tr>
<tr>
<td>L1C/A</td>
<td></td>
<td></td>
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<tr>
<td>Positioning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>complement GPS</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>L1C</td>
<td>1575.42 MHz</td>
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<tr>
<td>Positioning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>complement GPS</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>L1S</td>
<td>Augmentation (SLAS)</td>
<td>○</td>
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<tr>
<td>Message Service</td>
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<tr>
<td>L2C</td>
<td>1227.60 MHz</td>
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<td>Positioning</td>
<td></td>
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<td>complement GPS</td>
<td>○</td>
<td>○</td>
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<tr>
<td>L5</td>
<td>1176.45 MHz</td>
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<td>Positioning</td>
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<td>complement GPS</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>L5S</td>
<td>Augmentation Experimental Use</td>
<td>–</td>
</tr>
<tr>
<td>L6</td>
<td>1278.75 MHz</td>
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<td>Augmentation (CLAS)</td>
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<tr>
<td>L1Sb</td>
<td>1575.42 MHz</td>
<td>Augmentation</td>
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(*) SBAS Service will be available from the beginning of 2020’s.