Comparative verification of return rate on GNSS LRA

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ABSTRACT

Recently, GNSS mounted LRA for precise orbit determination, precise clock estimation, and precise orbit validation. As regional navigation satellite, JAXA has launched QZS-1 on September 2010. JAXA confirmed a return rate of LRA on QZS-1 as initial check out. As a result, LRA on QZS-1 works well as expected.

Moreover, we are interested in other GNSS LRA since there are some kind of GNSS LRA, for example, non coated or coated CCR. We focused on the return rate for each CCR. At this workshop, we have reported performance of each GNSS LRA, which based on actual tracking through ILRS network. As a result, there is no merit on coated CCR, since all return signal come from low incident angle, which mea\ns total inertial reflection.

1 QZSS LRA and Its Performance

2.1 About QZSS

The Quasi-Zenith Satellite System (QZSS) is a regional space-based positioning system. Typical orbital elements are shown in Table 1.1. Three satellites are in elliptical and inclined orbits in different orbital planes to pass over the same ground track. The QZSS is designed so that at least one satellite out of three satellites exists near zenith over Japan [Fig. 1.1].

The first satellite, which is called QZS-1, has launched in 11 September 2010. At preset, checkout for navigation service including ground system and tuning for QZS-1 orbit and clock synchronization are performed.

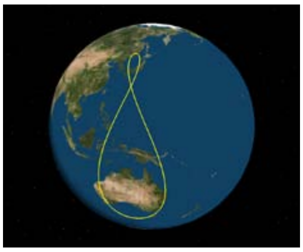


Fig.1.1 Image of Ground Track of QZS

Table 1.1 Orbit during QZS operation

Semimajor Axis	Eccentricity	Inclination	RAAN	Argument of Perigee	Center Longitude
42164.17km (ave)	0.075+/- 0.015	43 deg+/-4 deg	NA	270 deg+/-2 deg	135 degE+/- 5 deg

2.2 LRA on QZS-1

1.2.1 Reference LRA at GEO

Tanegashima (GMSL), Koganei (KOGC), Yaragadee (YARL), Changchun, and Mt. Stromlo (STL2) were success tracking for ETS-8. [Note that ETS-8 located 146 deg East longitude]. Tracking result is shown in Table 2.1.

Table 2.1 Summary of ETS-8 Tracking

Station Name	Return Rate	Note
Tanegashima	5% to 15 %	250mJ laser, 10Hz fire

Koganei	typically 1 %	50mJ laser, 20Hz fire
Yaragadee	1% to 3 %	100mJ laser, 5Hz fire
Changchun	0.1% to 1 %	150mJ laser, 20Hz
Mt. Stromlo	0.1 % to 1%	21mJ laser, 60Hz

1.2.2 Design for QZS-1 LRA

Though range for QZS-1 is farther than one for ETS-8, JAXA expects that QZS-1 LRA has same performance as ETS-8 even though farthest range of QZS-1. Here, we pay attention to the return rate from QZS-1. At tracking QZS-1, compared to ETS-8, the range between SLR station and QZS-1 is longer than ETS-8 case by 10%. According to the inverse four law, number of cube is calculated by

$$N = 36 \times \left(\frac{11}{10}\right)^4 = 52.7$$

Therefore, JAXA has designed LRA which has 56 (=7*8) CCRs, shape is shown in Fig1.2.2.

Fig.1.2.2 Shape of LRA for ETS-8 (up) and QZS-1 (down).

2.3 Performance of LRA on QZS-1

Obtained return rate, only typical case, is shown in Fig.1.2.3a. At Yaragadee, higher return rate corresponds to higher elevation angle, since higher elevation angle correspond to shorter range between SLR station and QZS-1. However, at Tanegashima, higher return rate is obtained at middle elevation angle.

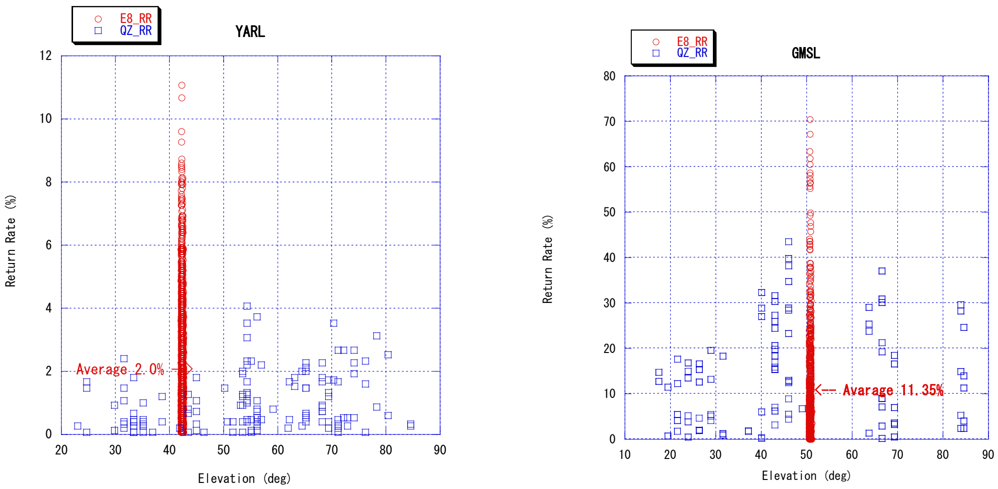
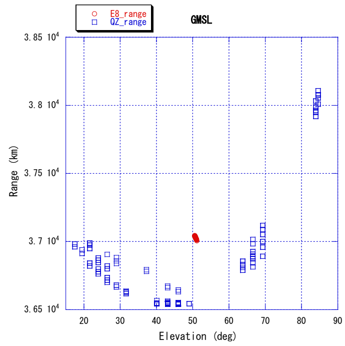
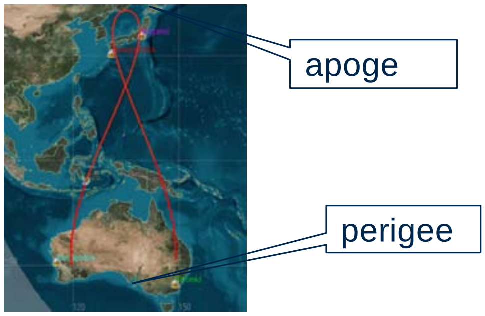


Fig.1.3-1. The return rate at Yaragadee (left) and Tanegashima (right). Horizontal axis and vertical axis denote elevation angle and the return rate, respectively.

From Fig.1.2.3b, minimum range is given at middle elevation angle, due to characteristic orbit of QZS-1, where apoge located north hemisphere. Therefore, generally speaking, SLR station at north hemisphere, higher return rate is observed at middle elevation angle. Since the elevation dependence of the return rate is interpreted from relation between range and elevation angle, as a result, LRA for QZS-1 is working well as we expected.





2 Comparative verification among GNSS LRA – coated & uncoated

2.1 LRA spec at high orbit

LRA at high orbit falls into two categories, Uncoating or Coating. Typical Satellites are listed in Table 2-1. In this section, by evaluating the return rate, we forcus on the fifference between coated and uncoated CCR.

	Sat Name	Altitude(Km)	LRA	Note
Un-Coat	ETS-8	36,000	36 CCRs diameter 40.6 mm	GEO JAXA
	QZS-1	32,000-40,000	56 CCRs diameter 40.6 mm	RNSS JAXA
	Compass-M1	21,500	42 CCRs diameter 33 mm	GNSS Chinese Defense Ministry
Coat	GPS36	20,030	32 CCRs diameter 28.6 mm	GNSS United States DOD
	GLONASS-102	19,140	396 CCRs hexagonal 28.3mm	GNSS Russian Federation
	GIOVE-B	23,916	67 CCRs diameter 27 mm	GNSS EU/ESA

Table. 2-1 List of LRA at high orbit.

2.2 Difference between coated and uncoated CCR

2.2.1 Range and Return Rate

The return rate from GNSS is shown in Fig.2-2. In Fig.2-2, green, red, blue and black dot correspond to GIOVE, Compass-M1, GPS and GLONASS, respectively. Horizontal axis and vertical axis denote range and the return rate, respectively. As well known, the return rate is decrease according to increase altitude. From Fig.2.2, there is no difference between coated and uncoated CCR.

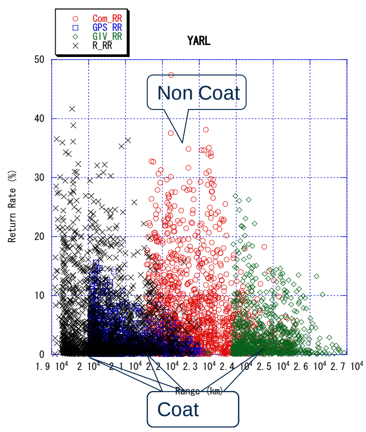


Fig. 2-2 The return rate from GNSS at Yaragadee.

2.2.2 Incident Angle and Return Rate

Uncoated CCR reflect laser pulse by a total internal reflection. This total internal reflection is arised for small incident angle, the threshold angle is called the critical angle which determined by refractive index of CCR. In order to overcome this restriction, uncoated CCR was adopted, we supposed. We made a assumption, that is, coated CCR had a advantage for high incident angle. In fact, through analysis for LAGIOS and AJISAI which installed uncoated CCR, there is no return signal over 18 degree, that is, cut off angle of uncoated CCR is about 18 degree (Otsubo and Graham 2003).

Obtained return rate with regard to incident angle at Yaragadee is shown in Fig.2.2.2. Horizontal axis and vertical axis denotes incident angle and the return rate, respectively. Left and right hand side express the return rate from uncoated CCR and coated CCR, respectively. On the left hand side, blue and red dot correspond to the return rate from Compass-M1 and QZS-1, respectively. On the right hand side, red, blue and green dot correspond to the return rate from GPS, GIOVE, and Glonass, respectively. What is important is all return signal come form less than 14 degree in incident angle for both graph in Fig. 2.2.2. It is impossible to find the merit of coated CCR, at least, for high orbit satellite.

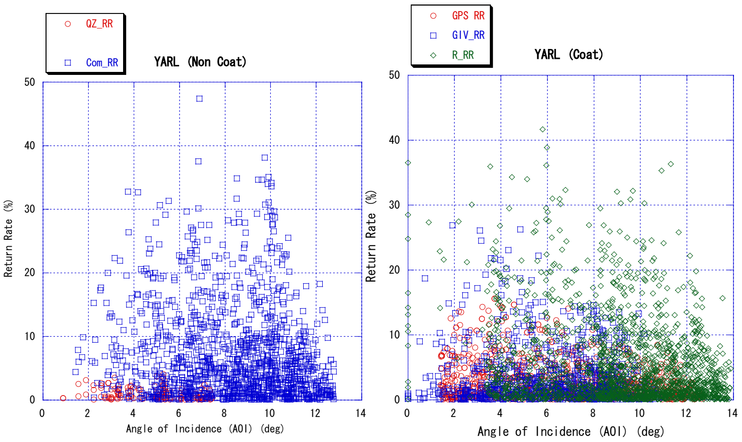


Fig.2.2-3 The return rate relation with regard to incident angle at Yaragadee.

2.3 Summary ~ from comparison return rate from coated with uncoated~

At least, when we evaluate LRA performance for GNSS (high orbit), there are no difference between coat and uncoat CCRs. At the view point of thermal control, coated CCR has more complexity than uncoated CCR. Through our study, focusing on the return rate and incident angle, there is no merit of coated CCR

Acknowledgements

My special thanks are due to Yaragadee, Mt. Stromlo, and Koganei SLR stations for providing us with the ranging data through ILRS network. I gratefully acknowledge helpful discussion with Dr. Matthew Wilkinson on several points in this paper.

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