Performance Evaluation of Quasi – Zenith Satellite System L5S Signal in the Asia-Oceania Region

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Motivation and Objective

The overall objective of this project is to develop an equipment to assess the real augmentation performance of QZSS L5S signal in the Asia-Oceania Region.

#QZS-2 IGSO : June 1, 2017

The first L5 SBAS signal (PRN196)

Acquire this new signal

The research objectives for the third year (from summer 2019 to spring 2020) are as follows.

- Analysis of the QZSS L5S signal characteristic
- Signal quality analysis of QZSS L5S signal

We have developed a software defined radio (SDR) receiver for all the necessary L5S signal processing techniques in the first and second year. The flow chart of the third year project is depicted below, that is, we first analyze the QZSS L5S signal frequency and modulation type. After the L5S signal is acquired and tracked successfully, we perform the analyses of the carrier frequency stability, code/carrier frequency coherence and code phase deviation.

Third year (2019~2020)

Reception of the QZSS L5S signal

- Analyze the QZSS L5S signal frequency and modulation type
- Analyze the carrier frequency stability
- Analyze the code/carrier frequency coherence
- Calculate the maximum code phase deviation

↓

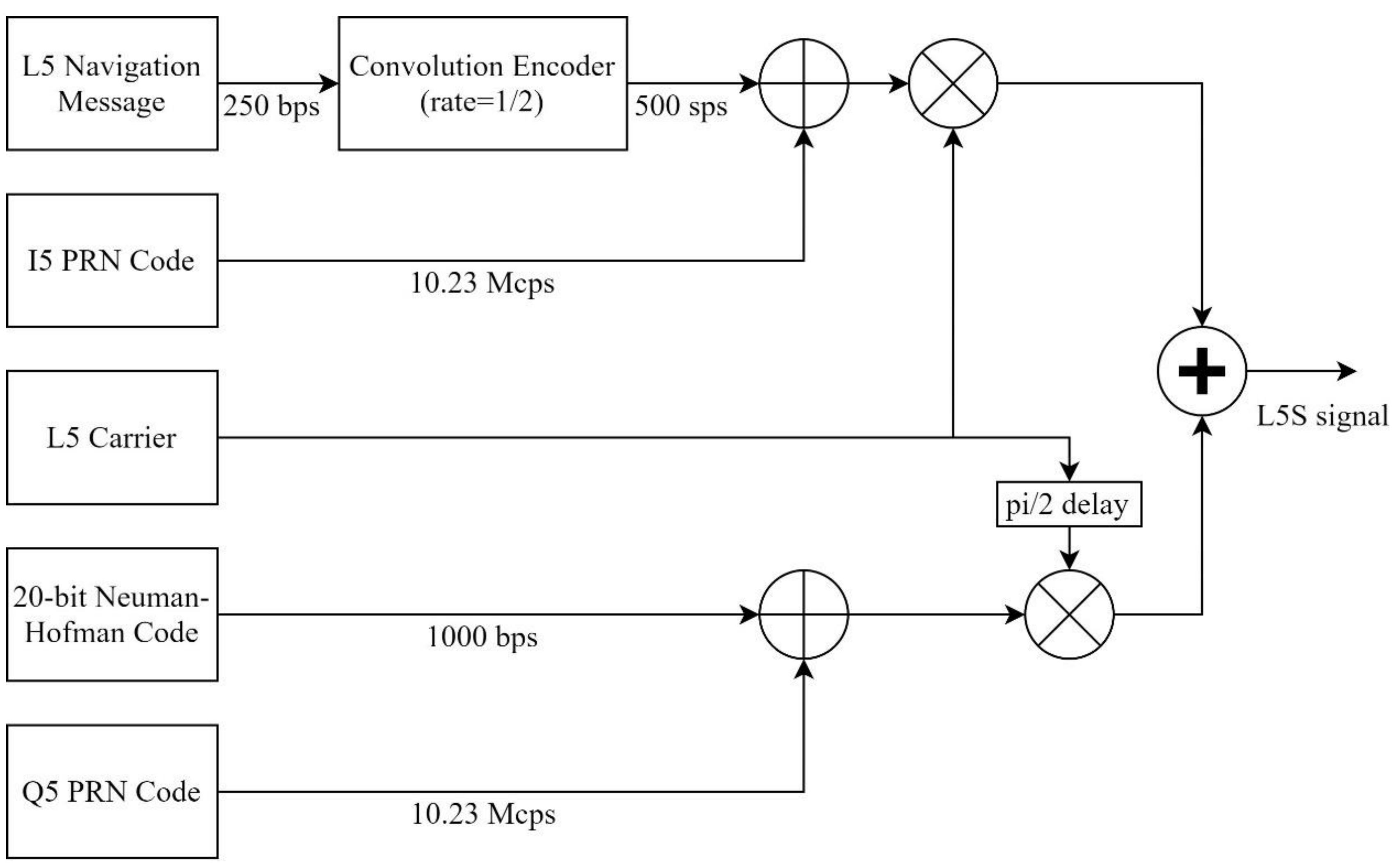
Signal Quality Analysis

- Compare the carrier-to-noise ratio of QZSS IGSO/GEO with GPS MEO
- Analyze the occurrence of carrier-to-noise ratio drop
- Analyze the L5S signal continuity and signal strength

QZSS L5S Signal

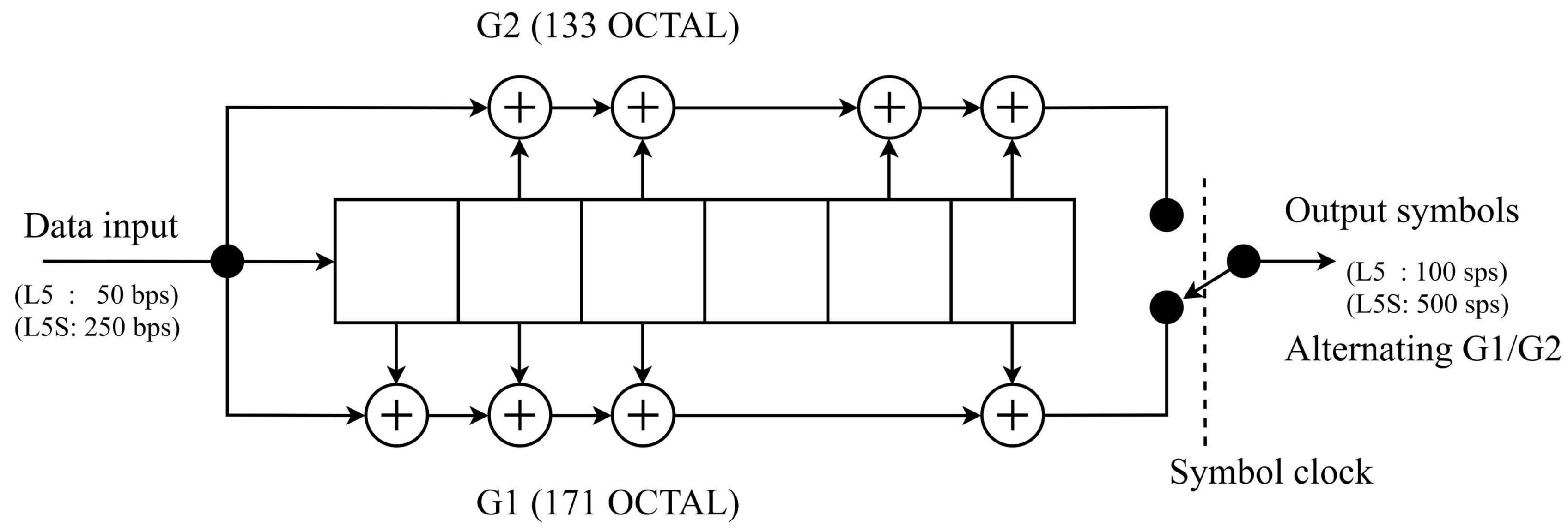
QZSS L5S Modulation

The L5S message is modulated with PRN code by exclusive OR (modulo 2 addition) with the I5 PRN code on the in-phase channel. The 20-bit NH code uses modulo-2 addition to modulate on the quadrature channel.



QZSS L5S signal modulation

Different from the L1 signal, the Forward Error Correction (FEC) is applied in the modernized CNAV message which contains higher precision representations and nominally more accurate data than the legacy L1 navigation message. The FEC is also applied in the L5S message. The L5S message bit streams are rate 1/2 convolution encoded with a FEC code. The convolution coding is constraint length 7, with a convolution encoder logic arrangement. The 250 bps L5S messages are extended to 500 sps.



Convolution encoder

Signal quality analysis

GNSS signals are continuously broadcast by satellites. Due to the free-space path loss and interference in the transmitting path, the user receives discontinuous and varying-strength signals from satellites. When the received signal power is below specified levels, the ranging error increases since the autocorrelation function causes errors in the code tracking loop. The carrier-to-noise density ratio (C/N_0) is used to show the signal strength and quality.

$$\frac{C}{N_0} = 10\log_{10}\left(\frac{(NA/2)^2}{2T_a\sigma_{IQ}^2}\right)$$

the cycle slip number for the carrier phase measurement for each satellite was used to analyze the signal continuity.

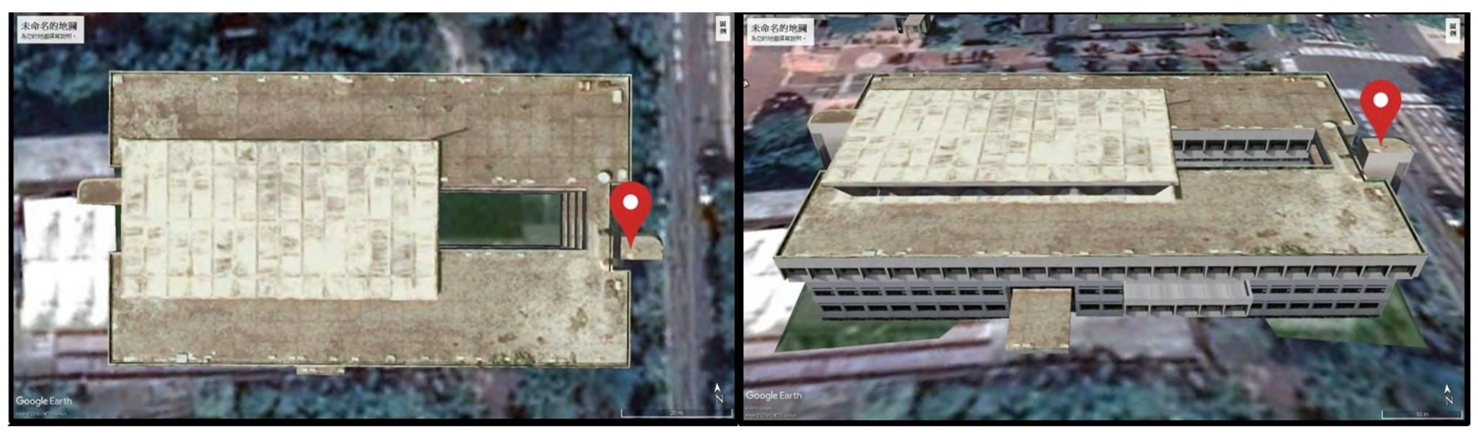
$$signal\ continuity = \frac{samples\ without\ cycle\ slips}{total\ samples} \times 100\%$$

Experimental Setup

The hardware of the developed SDR receiver consists of a NovAtel GPS-703-GGG triple-frequency antenna and the Universal Software Radio Peripheral (USRP) platform, which converts radio waves picked up by the antenna into digital copies. The software implementation of our SDR receiver includes the complete receiver's chain, namely, digital signal processing, signal acquisition and tracking of the available satellite signals and decoding navigation message.

QZSS L5S prototype receiver

The antenna was mounted on the roof of the Department of Aeronautics and Astronautics (DAA) building at National Cheng Kung University (NCKU). The experiment location is shown in below.

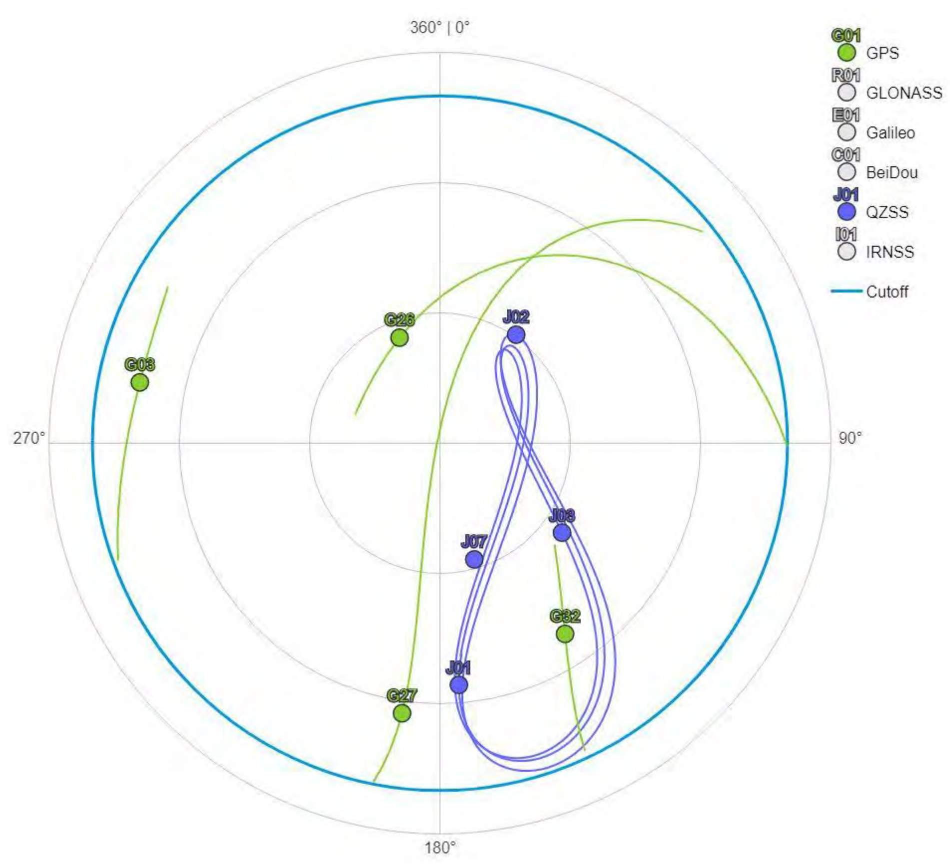


The experiment location on the roof of DAA building at NCKU, Taiwan

Experimental Results

The comparison of signal strength

The following results were received at 03:45 (local time) on July 24th, 2019. The visible satellites for the test are shown in below.



The visible satellites at 03:45 on July 24th, 2019

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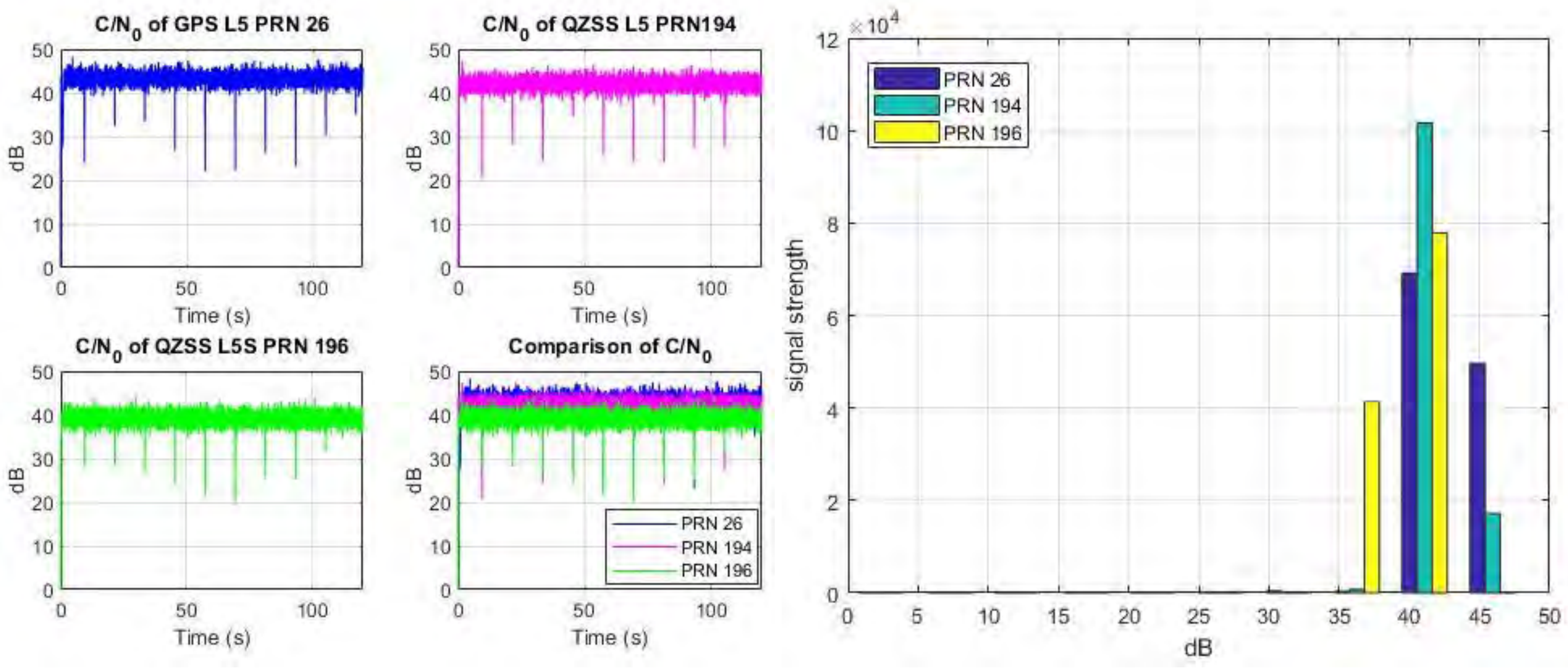
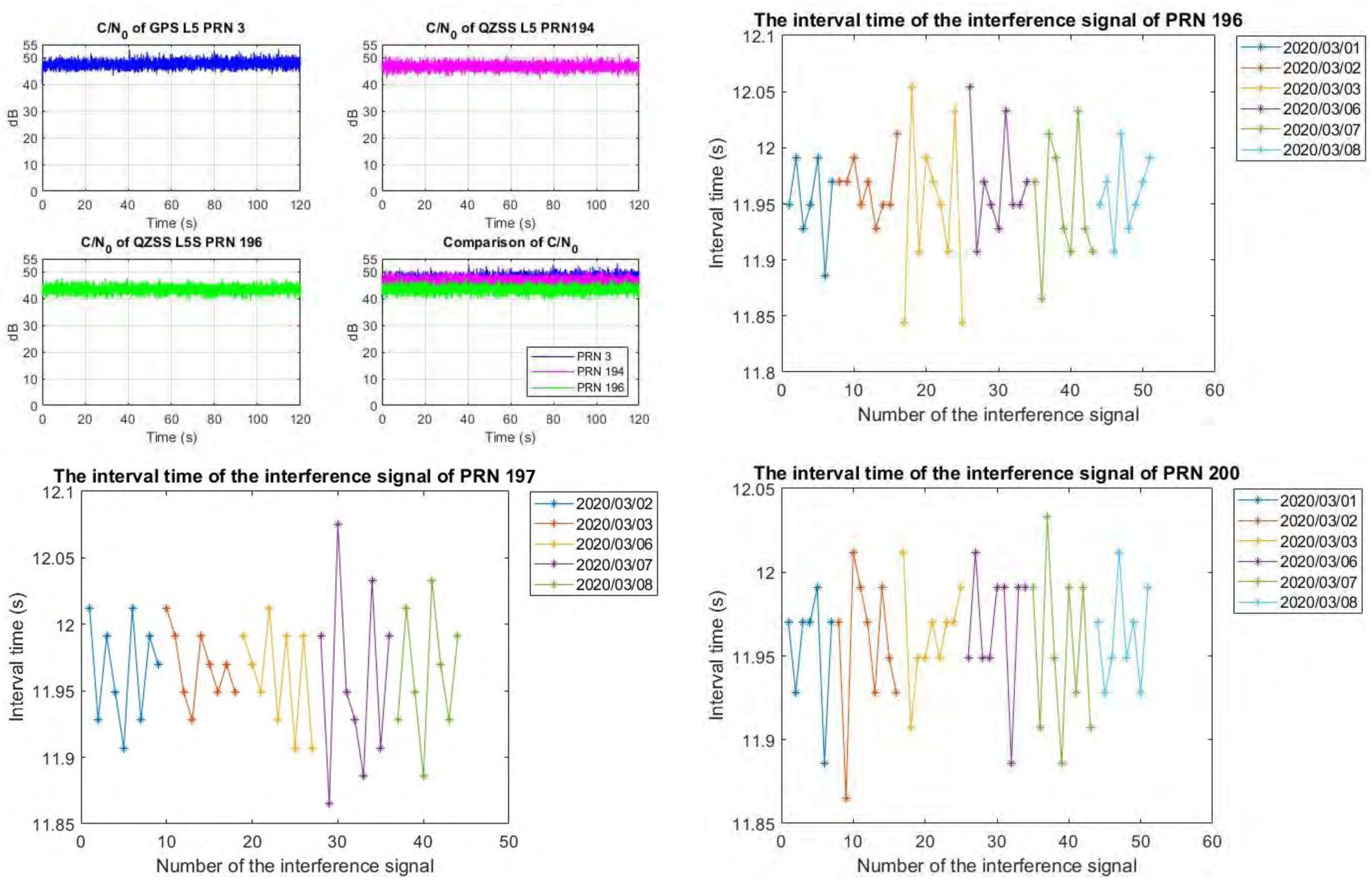
The GPS is stronger than the other signals. The strength of PRN 194 is approximately 2.9 dB stronger than PRN 196. In the figure, the analysis shows that dropped when the interference signal was received, which occurred about every 12 seconds. The histogram of the signal samples distribution shows most of samples are located between 40 dB and 45 dB.



The comparison and histogram distribution of C/N_0

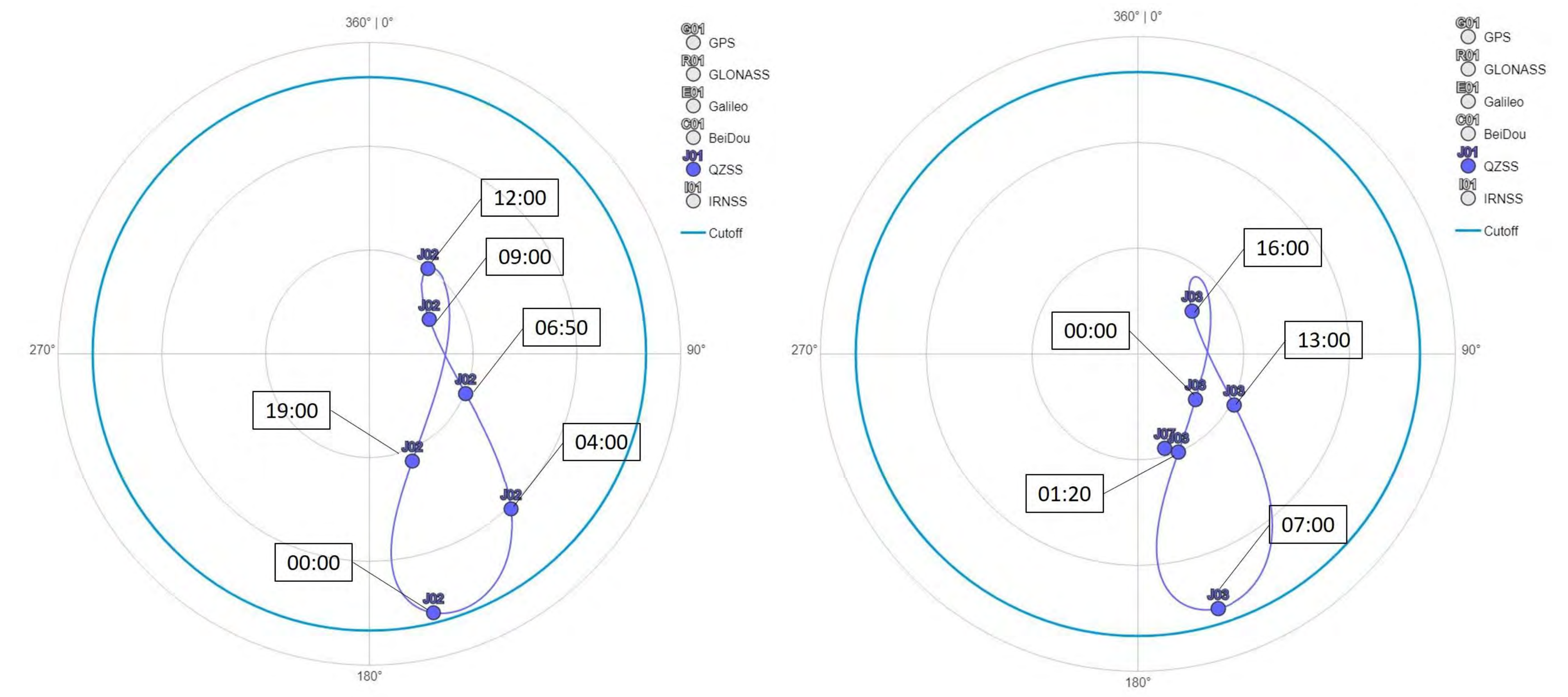
After receiving the 2-minute data every hour from March 1st to March 9th, 2020, The received data without the interference signal at 20:00 on March 6th, 2020 and there is no C/N0 drops. The following figure show the time interval of occurrence of the received interference signal. The signal was received at 12:00 (UTC+8) from March 1st to March 8th, 2020, and the elevation angle was 50 degrees. The time interval of receiving the interference signal was about 12 seconds.



The received data without C/N_0 and time interval of the interference signal

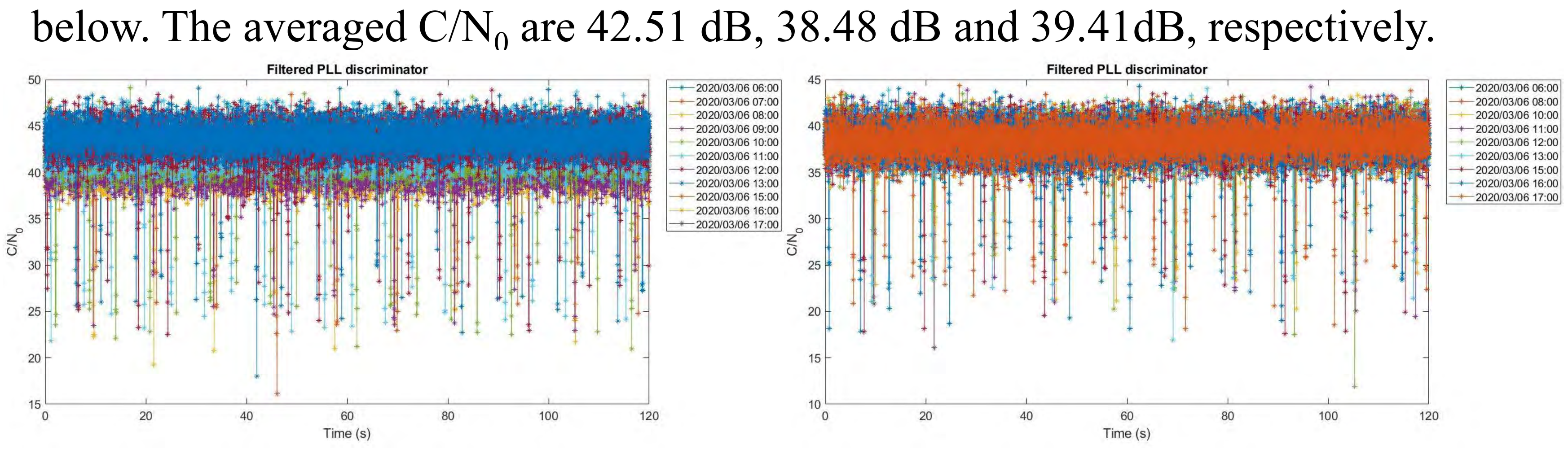
The signal strength of continuous data

The received data of QZSS PRN 196, 197 and 200 are shown in the below plots were from March 1st to March 9th, 2020. The orbit of QZSS PRN 196 (J02), PRN 197 (J07) and 200 (J03) from 0:00 to 23:00 on March 6th, 2020.

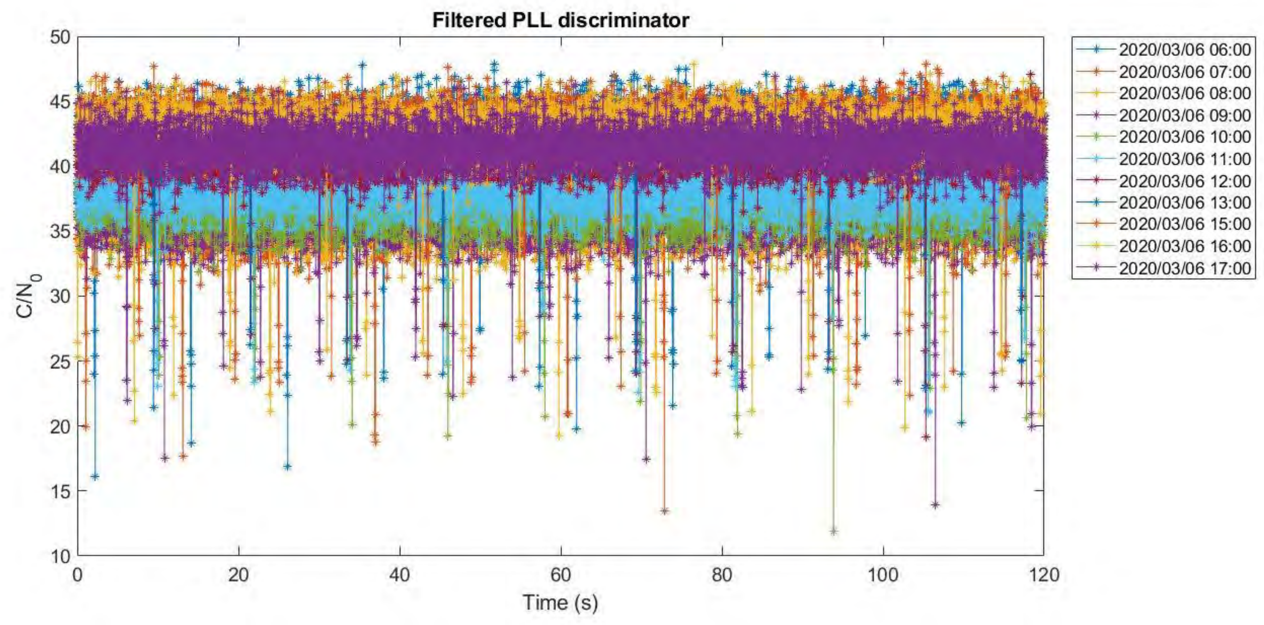


The orbit of QZSS satellites from 0:00 to 23:00 on March 6th, 2020.

The signal strength of PRN 196, 197 and 200 received on March 6th is shown in below. The averaged C/N_0 are 42.51 dB, 38.48 dB and 39.41dB, respectively.



The signal strength of QZSS L5S PRN 196 and 197 on March 6th, 2020

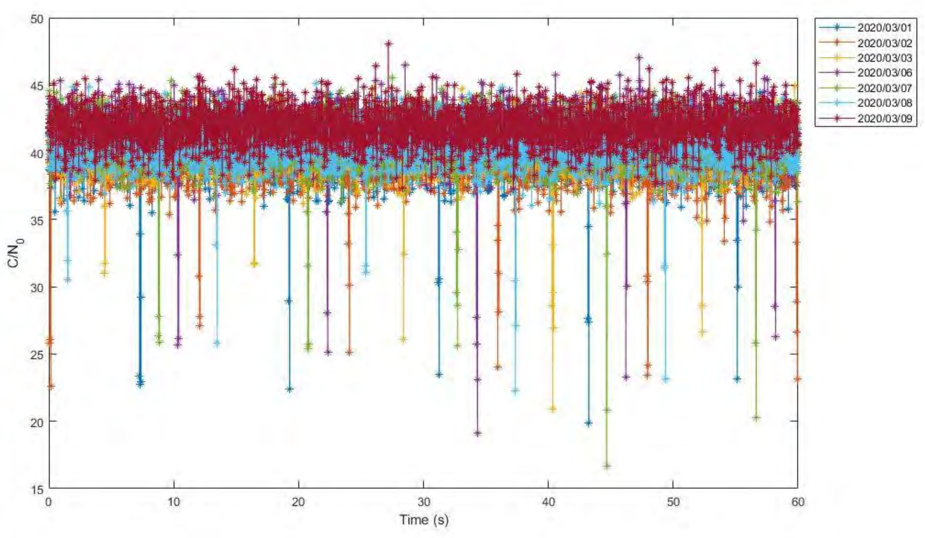


The signal strength of QZSS L5S PRN 200 on March 6th, 2020

Time	PRN 196 Mean (dB)	PRN 196 Std (dB)	PRN 197 Mean (dB)	PRN 197 Std (dB)	PRN 200 Mean (dB)	PRN 200 Std (dB)
06:00	43.2635	1.7699	38.7898	1.7849	36.3738	1.7641
07:00	43.9971	1.7736	-	-	36.4032	1.8223
08:00	43.8290	1.6910	38.5742	1.6778	36.4883	1.8100
09:00	43.4787	1.6787	-	-	37.0803	1.7874
10:00	42.2314	1.7051	38.4246	1.7025	38.3240	1.7856
11:00	40.1310	1.6855	38.4712	1.7480	41.2670	1.7657
12:00	40.2269	1.6408	38.4784	1.7112	42.8695	1.6564
13:00	41.6374	1.7161	38.3698	1.7407	42.9247	1.7727
15:00	42.2463	1.7510	38.4121	1.7827	42.6927	1.7929
16:00	42.9071	1.7217	38.3735	1.7708	41.4039	1.7369
17:00	43.6225	1.7051	38.4247	1.7193	37.7032	1.7000
Averaged	42.5064	1.7126	38.4798	1.7375	39.4119	1.7631

The signal strength of QZSS L5S on March 6th, 2020

The figure illustrate the signal data of PRN 200 received from March 1st to March 9th, 2020. The signal is received at 12:00 (UTC+8) every day to evaluate the signal strength and stability and the elevation angle is 50 degrees. The averaged mean of C/N_0 is 40.6320 dB and the averaged standard deviation was 1.6112 dB.

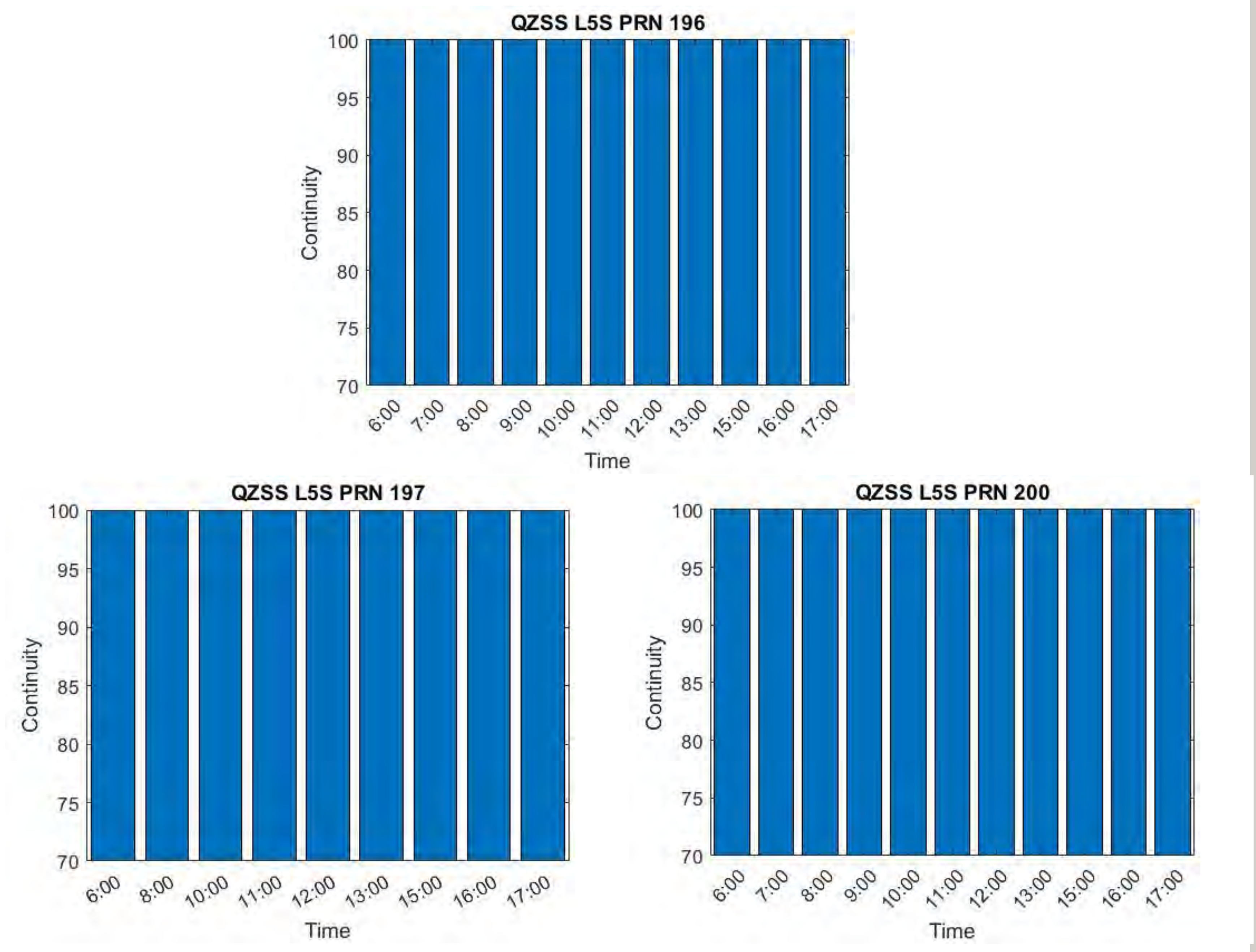


Date	Mean of C/N_0	Std of C/N_0
2020/03/01	39.9608	1.6965
2020/03/02	39.5932	1.7467
2020/03/03	40.4670	1.5435
2020/03/06	41.3511	1.6935
2020/03/07	40.6961	1.7329
2020/03/08	40.6003	1.5370
2020/03/09	41.8558	1.3280
Averaged	40.6320	1.6112

The signal strength of QZSS L5S PRN 200 for one week

Signal continuity

We calculate the cycle slip number for the carrier-phase measurement in the filtered PLL discriminator to analyze the signal continuity. The period for each signal collection was set at two minutes in the following results. The average continuity of PRN 196, 197 and 200 are 100 %, 100 % and 100 %.



Signal continuity of QZSS L5S on March 6th, 2020

Conclusions and Future Work

In the third year project, we analyzed the reception of QZSS L5S signal and applied the signal quality analysis. We developed the prototype equipment that can acquire, track and decode the new QZSS L5S signal. According to the QZSS L5S frequency and modulation type, the signal was required, tracked and decoded successfully. The one-week continuous data was received and the signal quality analysis was applied.