# Development of GNSS Testbed with $C/N_0$ Simulation Capability

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***Abstract*—This paper presents the development of a GNSS testbed with Carrier-to-Noise Density Ratio ($C/N_0$) simulation capability, focusing on GPS L1 C/A signals. The testbed consists of a satellite simulator that precisely controls signal power according to satellite elevation and a receiver employing the Narrowband–Wideband Power Ratio (NWPR) method for $C/N_0$ estimation. Experiments confirm accurate $C/N_0$ generation and estimation, with mean errors of 0.38 dB-Hz above 45° elevation and 1.52 dB-Hz below 45°. This validates the testbed's utility for analyzing GNSS receiver performance under diverse operational scenarios.**

***Keywords*—Carrier-to-Noise ratio, $C/N_0$ Configuration, $C/N_0$ Estimation, GNSS Signal generator, Software Defined Receiver**

## I. Introduction

Global Navigation Satellite Systems (GNSS) provide Position, Velocity, and Time (PVT) information worldwide using satellite-broadcast radio signals. With GPS, Galileo, BDS, GLONASS, QZSS, NavIC, and KPS, new systems demand simulation environments capable of evaluating receiver robustness prior to deployment.

Among signal quality metrics, the Carrier-to-Noise Density Ratio ($C/N_0$) is particularly critical. It determines the stability of tracking loops and scales inversely with pseudorange error[1-2]. In practice, $C/N_0$ depends strongly on satellite elevation, as propagation loss and antenna gain vary. Accurate simulation of elevation-dependent $C/N_0$ is therefore essential in a testbed for realistic GNSS receiver evaluation.

This paper presents a GNSS testbed that generates and estimates $C/N_0$ as a function of satellite elevation, validating its accuracy and effectiveness for receiver performance evaluation.

## II. Background

Signal quality in GNSS is measured using $C/N_0$ rather than the traditional Signal-to-Noise Ratio (SNR). While SNR is defined as

$$SNR = 10\log_{10} P/N, \tag{1}$$

where $P$ is received power and $N$ is noise power within bandwidth $BW$, the $C/N_0$ metric isolates bandwidth effects. It is expressed as

$$\mathrm{C/N_0} = 10\log_{10}\left(\mathrm{C/N}\cdot BW\right), \tag{2}$$

where C is carrier power and $N_0$ is noise power density per unit bandwidth. Because it is independent of front-end filter bandwidth, $C/N_0$ enables direct comparison of receivers with different configurations.

In practice, $C/N_0$ is highly dependent on satellite elevation. Free-space path loss increases with distance, while antenna gain typically decreases at low elevations. This explains the characteristic pattern of higher $C/N_0$ at zenith and degraded values near the horizon. For accurate simulation, both propagation effects and antenna patterns must be incorporated.

## III. Proposed GNSS Testbed

The proposed testbed focuses on simulating GPS L1 C/A signals and estimating $C/N_0$ under realistic conditions. It is composed of two main modules: a Satellite Simulator and a Signal Receiver.

### A. Satellite Simulator

The Satellite Simulator generates GPS L1 C/A signals by constructing the navigation message, PRN code, and carrier according to ICD specifications. The carrier power $A$ is defined to achieve the target $C/N_0$ as

$$A = \sqrt{4\sigma^2\left(\mathrm{C/N_0}\right)/F_s} = 2\sqrt{\sigma^2\cdot 10^{(\mathrm{C/N_0})}/F_s}, \tag{3}$$

where $\sigma^2$ denotes the variance of white noise Gaussian noise and $F_s$ is the sampling rate. To reflect realistic conditions, the generated $C/N_0$ is further modified by incorporating free-space path loss, based on the ratio of the actual satellite–receiver distance to the mean MEO altitude, and by applying elevation-dependent antenna gain. Finally, Additive White Gaussian Noise (AWGN) is introduced, allowing the testbed to reproduce practical elevation-dependent $C/N_0$ variations for reliable GNSS performance evaluation.

### B. Signal Receiver

The Signal Receiver processes the synthesized IF signals through acquisition, tracking, and navigation modules, and estimates $C/N_0$ using the Narrowband–Wideband Power Ratio (NWPR) technique [3]. This method evaluates the ratio of narrowband to wideband power derived from correlator outputs, providing a bandwidth-independent estimate of $C/N_0$..

$$\left(\mathrm{C/N_0}\right)_i = 10\log_{10}\left(\frac{1}{T}\cdot\frac{\mu-1}{M-\mu}\right). \tag{4}$$

where $M$ denotes the number of correlator samples, $T$ is the accumulation interval, and $\mu$ if the average ratio of narrowband to wideband power. The averaging factor $\mu$ is obtained as

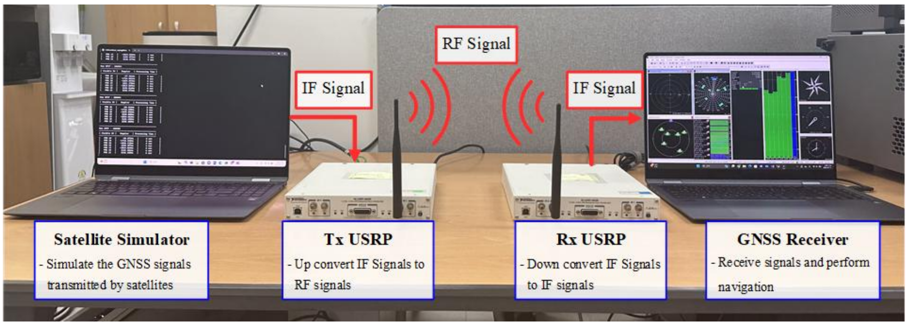


Fig. 1. Experimental environment

TABLE I. SUMMARY OF C/N₀ ERROR

| | Elevation Angle [◦] | True C/N$_0$ [dB-Hz] | Error C/N$_0$ [dB-Hz] |
|---|---|---|---|
| PRN 24 | 83.94 | 53.72 | 0.22 |
| PRN 23 | 60.85 | 50.24 | 0.39 |
| PRN 15 | 50.76 | 45.28 | 0.59 |
| PRN 18 | 45.50 | 46.73 | 0.32 |
| PRN 10 | 23.45 | 39.95 | 1.40 |
| PRN 13 | 17.88 | 38.95 | 1.43 |
| PRN 12 | 15.18 | 38.11 | 1.75 |
| Others | Invisible | NA | NA |

$$\mu = \frac{1}{K}\sum_{k=1}^{K}\frac{NBP_k}{WBP_k}, \tag{5}$$

where $K$ is the number of samples within the averaging interval. The wideband power $WBP_k$ and narrowband power measurement $NBP_k$ is are calculated from the in-phase($IP_m$) and quadrature ($QP_m$) correlator outputs as

$$WBP_k = \sum_{m=1}^{M}\left(IP_m^{\ 2} + QP_m^{\ 2}\right), \tag{6}$$

$$NBP_k = \left(\sum_{m=1}^{M} IP_m^{\ 2}\right)^2 + \left(\sum_{m=1}^{M} QP_m^{\ 2}\right)^2, \tag{7}$$

where $M$ is the number of correlator output samples used for power measurement.

## IV. EXPERIMENTAL RESULTS

The performance of the proposed testbed in generating and estimating C/N$_0$ was validated using the setup illustrated in Figure 1. A 100-second GPS L1 C/A signal sequence was generated and transmitted, after which the received signals were processed through the implemented receiver. This process enabled verification of both the signal generation fidelity and the accuracy of C/N$_0$ estimation.

The comparison between true and estimated C/N$_0$ values is summarized in Table 1, while Figure 2 presents the distribution of estimated C/N$_0$ across the visible satellites. Results demonstrate that for elevation angles above 45°, the mean estimation error was limited to 0.38 dB-Hz, whereas satellites below 45° exhibited a higher error of approximately 1.52 dB-Hz. These findings indicate that the testbed can reproduce realistic elevation-dependent C/N$_0$ variations and provide reliable estimation performance under diverse conditions.

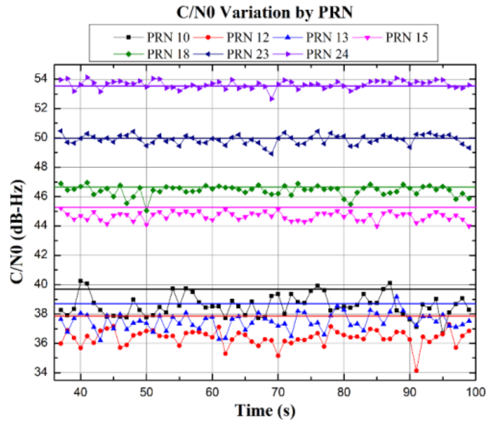


Fig. 2. C/N$_0$ estimation result

## V. CONCLUSION

This work introduced a GNSS testbed capable of simulating elevation-dependent variations in C/N$_0$ and validating them through receiver-based estimation. By adjusting signal power in the simulator and applying the NWPR method at the receiver, the testbed achieved accurate generation and estimation of C/N$_0$. Experimental validation confirmed estimation errors within 2 dB-Hz across all conditions, underscoring the testbed's reliability for signal quality analysis and receiver evaluation. Beyond baseline validation, the framework provides a foundation for further studies in interference environments such as multipath, jamming, and spoofing, where accurate C/N₀ modeling remains critical.

## ACKNOWLEDGMENT

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