Precise+®: Enabling reliable high-precision GNSS in challenging environments

Extending multipath suppression to carrier-phase observables for reliable high-precision positioning in challenging environments

FocalPoint

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— Focal Point Positioning

1 Introduction

High-precision GNSS applications — autonomous navigation, ADAS, surveying — demand centimetre-level accuracy, which requires carrier-phase (accumulated delta range, ADR) measurements. However, carrier-phase positioning is acutely vulnerable to multipath and signal blockage; in heavy foliage and deep urban canyons, these effects cause loss of lock and cycle slips that degrade both accuracy and availability.

Supercorrelation® is Focal Point Positioning's patented signal-processing replacement for the standard correlator, inherently suppressing multipath. It has already delivered major improvements in code-phase and Doppler quality in challenging environments [1][2]. This work extends Supercorrelation to carrier-phase for the first time in a new patented technology called Precise+®, which generates improved ADR observables that help bridge deep signal fading and prevent cycle slips leading to enhanced positioning performance.

We present a new software-defined receiver (FPP-SDR) implementing Precise+, validated through simulation and live data collection. Here we present results from a challenging dense foliage scenario.

2 FPP-SDR Implementation

The FPP-SDR is an in-house software-defined receiver originally developed under an ESA-funded project and independently extended for high-precision applications [1][2].

Precise+ relies on tight ME–PE coupling: the Measurement Engine (ME) correlators are steered using PVT fixes from the Positioning Engine (PE). Correlator outputs are clock- and motion-compensated, and combined into Supercorrelation (SC) outputs. Code, frequency, and carrier-phase errors are estimated, yielding pseudorange (PR), pseudorange-rate (PRR), and ADR observables. We present results for 100 ms and 1000 ms coherent integration intervals.

The PE fuses multi-constellation (GPS, Galileo, BeiDou, QZSS), multi-frequency GNSS observables with optional IMU data (results not presented here). Precise orbits and ionospheric corrections are provided from SP3 and IONEX files; tropospheric delays are calculated using the Saastamoinen model. The PE supports two modes:

- **Standard Precision (SP):** PRs + PRRs, metre-level real-time navigation
- **High-Precision (HP):** adds ADRs for PPP-like framework for centimetre-level accuracy

Both modes support optional integration of IMU data (not presented here). In HP mode, carrier-phase bias (CPB) states are estimated alongside position, velocity, clock, and inter-system biases.

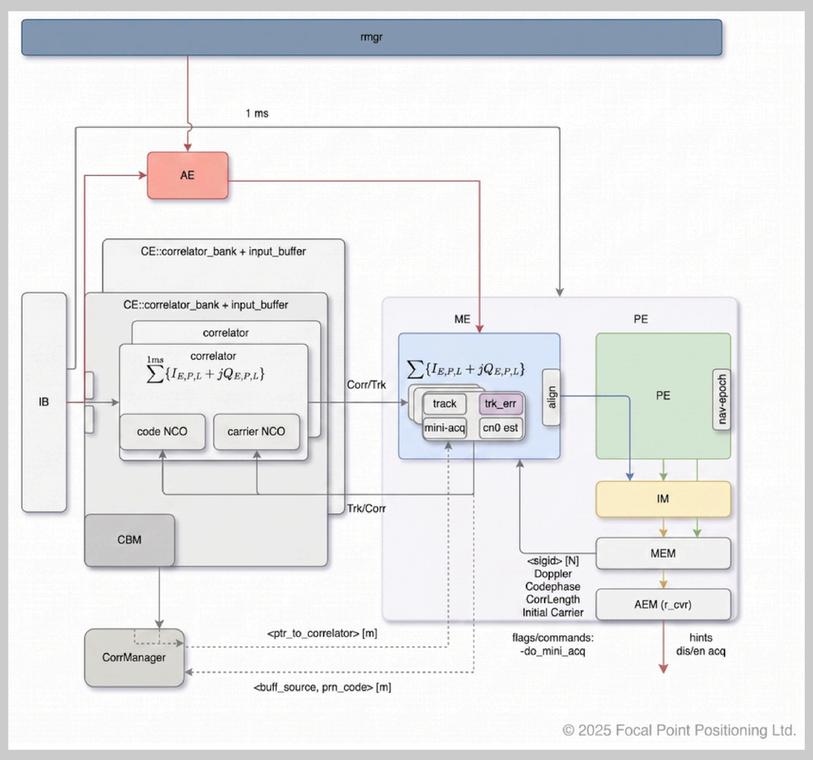

Fig.1: FPP-SDR Architecture

3 Trial Description

A live trial was run in Thetford Forest, Norfolk — dense coniferous canopy that severely attenuates and scatters GNSS signals.

Set-up: A vehicle-mounted roof box containing a LabSat 4 record-and-replay system, enabling post-processing of recorded RF data with the FPP-SDR, and several commercial receivers connected to live correction services for comparison. Ground truth: NovAtel SPAN ProPak7 (dual-antenna + IMU-100C), providing cm-level reference positioning throughout.

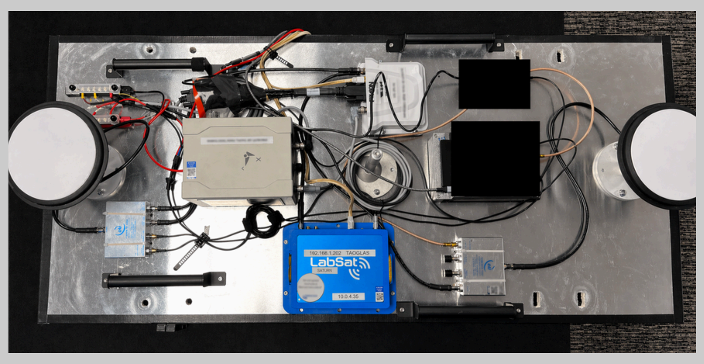

Fig.2: Roof-mounted data recording system setup

Fig.3: Roofbox mounted on test vehicle (Kia Ceed)

Trial: 13 November 2025, 11:17:53–12:21:17 UTC (~63 min). The route mixed environments:

Environment	Segments	Description
Static	2	Open-sky baseline
Urban	5	Moderate multipath, partial sky blockage
Highway	3	High dynamics, generally open sky
Foliage	4	Dense tree canopy, severe signal attenuation and multipath

Foliage dominated the route, giving extended and demanding testing of carrier-phase tracking under heavy canopy.

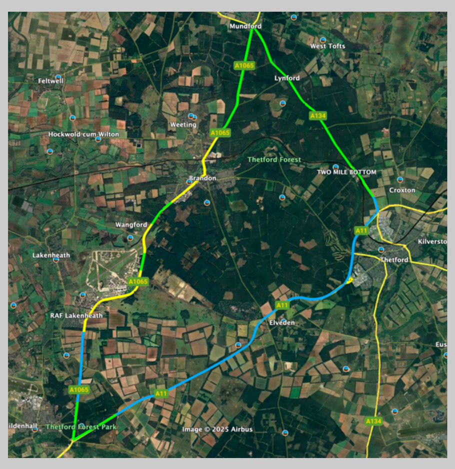

Fig.4: Trajectory map colour-coded by environment

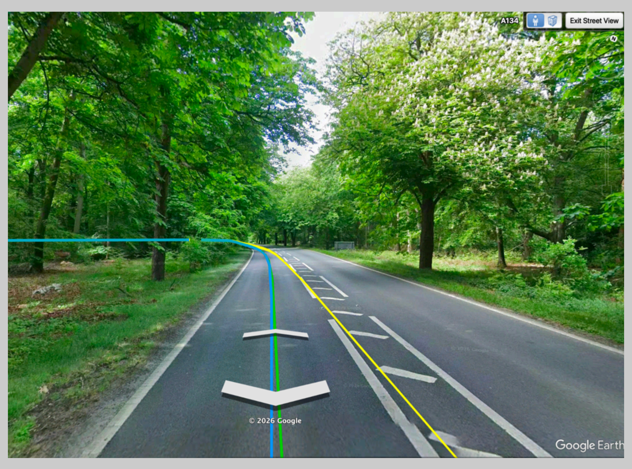

Fig.5: Typical forested section of road in Thetford Forest

4 Results

Measurement Domain Analysis

Observables were compared at three configurations — Standard (20 ms coherent integration), Precise+ 100 ms, Precise+ 1000 ms — against ground-truth-derived reference values. ADR errors use the Time-Differenced Carrier Phase (TDCP) method, isolating epoch-to-epoch range consistency independently of cycle slips.

Pseudorange (PR): 95th-percentile error drops from 9.30 m (Standard) to 4.77 m for Precise+ 100 ms (−49%) and 2.44 m for Precise+ 1000 ms (−74%). The 99th-percentile tail is reduced from 24.60 m to 5.29 m using Precise+ 1000 ms.

Pseudorange-rate (PRR): 95th-percentile falls from 1.24 m/s to 0.45 m/s (−64%) and 0.19 m/s (−85%) for Precise+ 100 ms and 1000 ms respectively — directly aiding velocity estimation and correlator steering.

Accumulated Delta Range (ADR): Aggregate 95th-percentile: 5.54 cm → 3.75 cm (Precise+ 100 ms, −32%) → 3.31 cm (Precise+ 1000 ms, −40%). Under foliage the gain is largest: 8.02 cm → 5.23 cm → 2.75 cm (−66%).

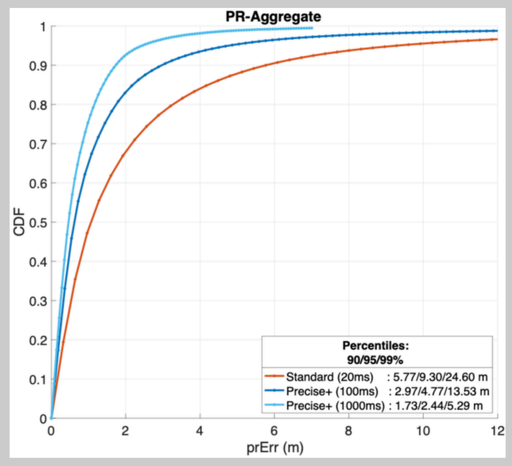

Fig.6: CDF of Pseudorange Errors

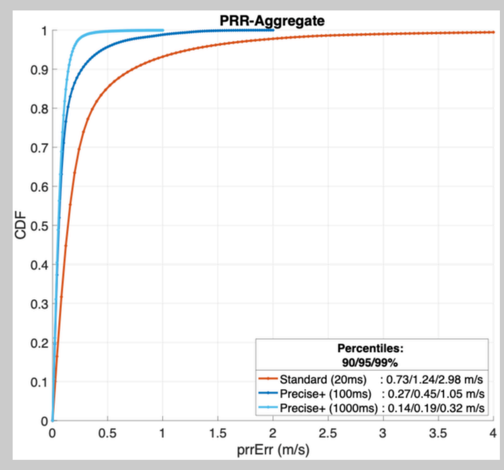

Fig.7: CDF of Pseudorange-rate Errors

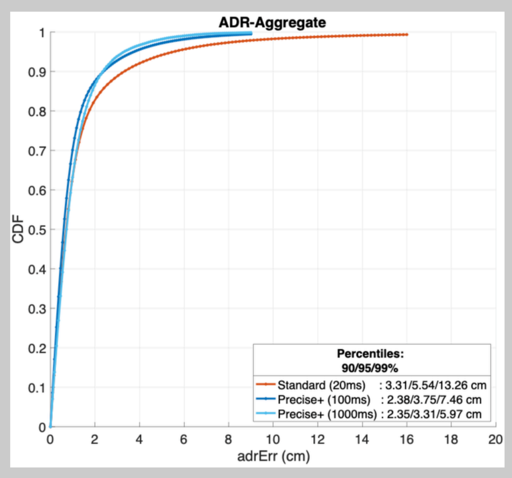

Fig.8: CDF of ADR Errors (Aggregate)

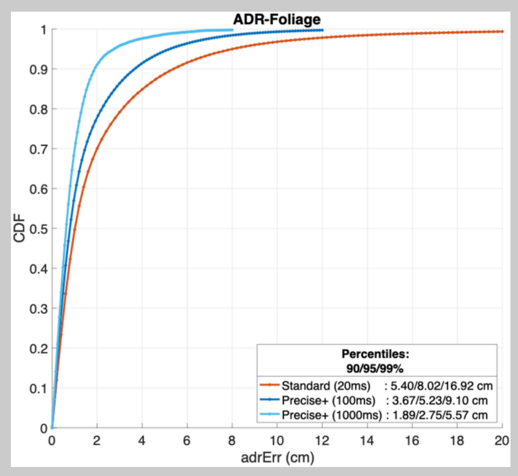

Fig.9: CDF of ADR Errors (Foliage only)

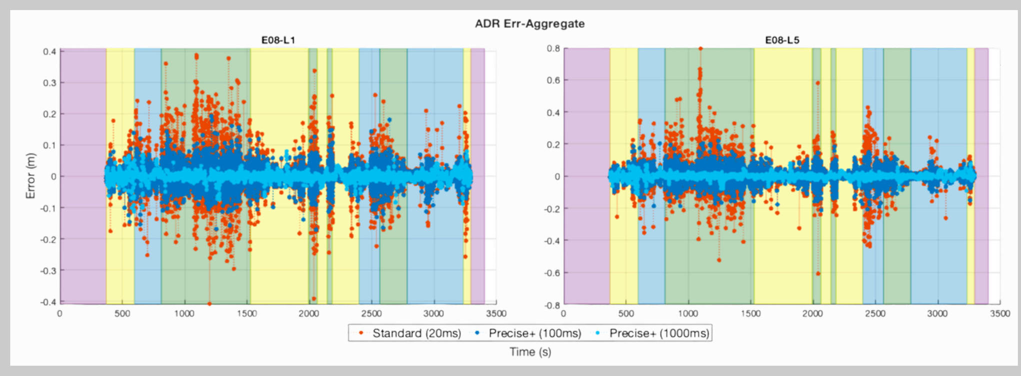

Fig.10: ADR error plots, L1 & L5

Positioning Domain Analysis

FPP-SDR was evaluated in HP mode using standard measurements and Precise+ 100 ms measurements against three commercial receivers: two state-of-the-art units with live corrections (without/with INS — REF RX 1 & 2) and one first-generation Supercorrelation-enabled receiver (an STMicroelectronics TeseoVI featuring FocalPoint's S-GNSS® Auto software).

Full trajectory, horizontal error (90th/95th/99th %ile):

- Precise+: **0.54 / 0.64 / 0.74 m**
- HP (standard): 0.64 / 0.74 / 1.12 m
- S-GNSS on TeseoVI: 1.41 / 1.54 / 1.93 m
- REF RX 1: 1.96 / 2.48 / 3.24 m
- REF RX 2: 1.72 / 2.44 / 3.54 m

Precise+ reduces 95th-percentile error by ~58% versus the best commercial alternative.

Foliage only:

- Precise+: **0.64 / 0.69 / 0.80 m** — sub-metre at the 99th %ile
- HP (standard): 0.73 / 1.04 / 1.33 m
- S-GNSS on TeseoVI: 1.50 / 1.64 / 1.97 m
- REF RX 1: 2.75 / 3.09 / 3.49 m
- REF RX 2: 2.36 / 2.71 / 3.32 m

Isolating the foliage sections, 95th-percentile error are reduced by 55% versus the best performing commercial receiver and 77% versus the worst. Precise+ fundamentally changes what is achievable under heavy foliage: consistent sub-metre positioning where state-of-the-art receivers with live corrections suffer multi-metre errors.

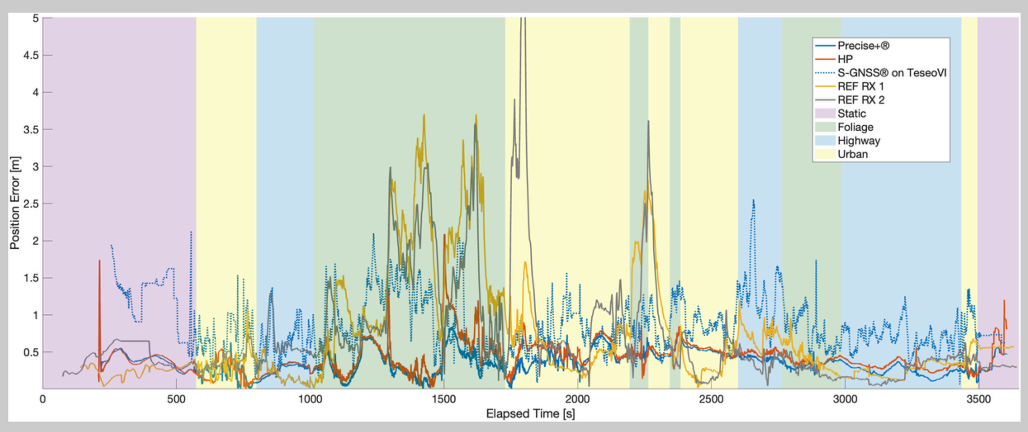

Fig.11: Horizontal position error over time, including environment types through trial

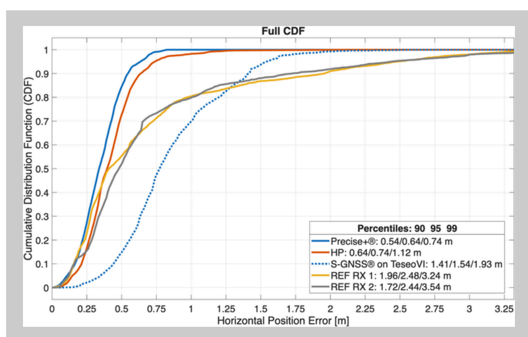

Fig.12: CDF of horizontal position error – Full trial

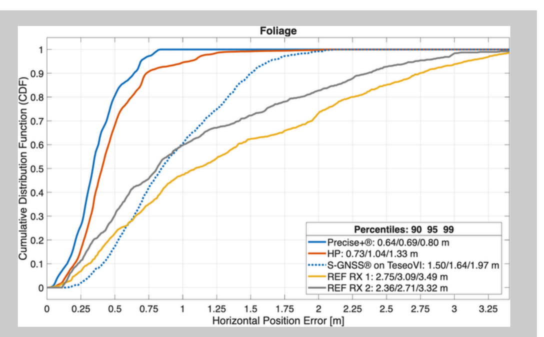

Fig.13: CDF of horizontal position error – Foliage sections only

6 Conclusions

Precise+ extends the benefits of Supercorrelation to high-precision GNSS positioning and has been demonstrated using a new software-defined receiver, FPP-SDR. In the measurement domain, Precise+ reduces 95th-percentile error by up to 74% (PR), 85% (PRR), and 66% (ADR) under foliage. In the position domain, Precise+ errors are less than 0.64 m (full trajectory) and 0.69 m (foliage sections) at the 95th percentile, and remain sub-metre at the 99th percentile in the most challenging regions — a 55–77% reduction over the best and worst performing commercial receivers with live corrections.

Precise+ delivers mass-market centimetre-level positioning as a **software upgrade, requiring no new silicon**. Commercial relevance spans autonomous vehicles, ADAS, and any application requiring reliable high-precision positioning across all environments.

7 References

[1] J. G. Garcia, J. R. van der Merwe, P. Esteves, D. Jamal, S. Benmendil, C. Higgins, R. Grey, E. Coetzee, and R. Faragher, "Development of a Custom GNSS Software Receiver Supporting Supercorrelation," Eng. Proc., vol. 54, no. 1, p. 9, 2023. doi: 10.3390/ENC2023-15423

[2] J. G. Garcia, J. R. van der Merwe, H. Mwenegoha, P. Esteves, S. Benmendil, E. Coetzee, J. Ellis, H. Eriksson-Martin, R. Grey, C. Higgins, D. Jamal, S. Kokradi, O. Kurt, R. Faragher, and M. Crockett, "Enhancing GNSS Robustness in Automotive Applications with Supercorrelation: Experimental Results in Urban Scenarios," Eng. Proc., vol. 88, no. 1, p. 75, 2025. doi: 10.3390/engproc2025088075