EDGE MICROWAVE

Triple-Band CRPA Solution

HEDGE-8008 & HEDGE-4008

Global Navigation Satellite Systems (GNSS) have become an indispensable component of modern civilian and defense platforms spanning autonomous vehicles, unmanned aerial systems (UAS), maritime navigation, telecommunications, critical infrastructure timing, and precision-guided technologies. However, the increasing dependency on GNSS positioning, navigation, and timing (PNT) has made these systems a strategic target for intentional radio-frequency (RF) interference, including both jamming and spoofing.

As the RF threat landscape evolves toward multi-band, wideband, and multi-source attacks, where conventional single-band anti-jam solutions may not be sufficient to guarantee robust and continuous PNT availability.

Controlled Reception Pattern Antennas (CRPAs) combined with adaptive digital beamforming represent the most effective physical-layer defense against RF interference in contested GNSS environments. By exploiting spatial discrimination using multi-element antenna arrays, CRPA-based systems can form deep adaptive nulls in the direction of interferers while preserving the desired satellite signals. However, many existing CRPA solutions remain limited to a single GNSS frequency band, leaving other valuable bands unused.

This white paper presents a **triple-band CRPA architecture** designed to provide simultaneous anti-jam protection across the **L1**, **L2**, and **L5** frequency bands.

1. System Overview

The proposed triple-band GNSS CRPA architecture is designed to provide simultaneous, independent spatial interference mitigation across the **L1**, **L2** and **L5** GNSS frequency bands, while maintaining full compatibility with a wide range of external all-band GNSS navigation receivers. The system achieves this by deploying two independent CRPA processing subsystems and three band-optimized spatial mitigation blocks (L1, L2, and L5), then combining their interference-mitigated RF outputs into a unified multi-band signal.

The RF outputs of both CRPA subsystems are coherently combined using a broadband RF combiner and delivered to a single external **multi-band GNSS receiver**, enabling seamless triple-band operation at the navigation engine level while preserving fully independent spatial interference mitigation on each band.

This architecture decouples **spatial anti-jam processing** from the **GNSS navigation receiver**, allowing the end-user to integrate any professional grade all-band GNSS receiver while immediately benefiting from multi-band adaptive nulling. The result is a scalable, multi-band, and platform-independent CRPA solution capable of maintaining GNSS availability under complex, multi-source jamming and spoofing scenarios.

Proposed triple-band GNSS CRPA solution has less than <575 g weight and 90x180x26mm total envelope.

A key architectural principle is the **strict separation of spatial interference mitigation per frequency band**. Each GNSS band is processed with fully independent RF paths, digitizers, and adaptive beamforming engines. This ensures that wideband, multi-source, or cross-band interference does not introduce algorithmic coupling or performance degradation between bands.

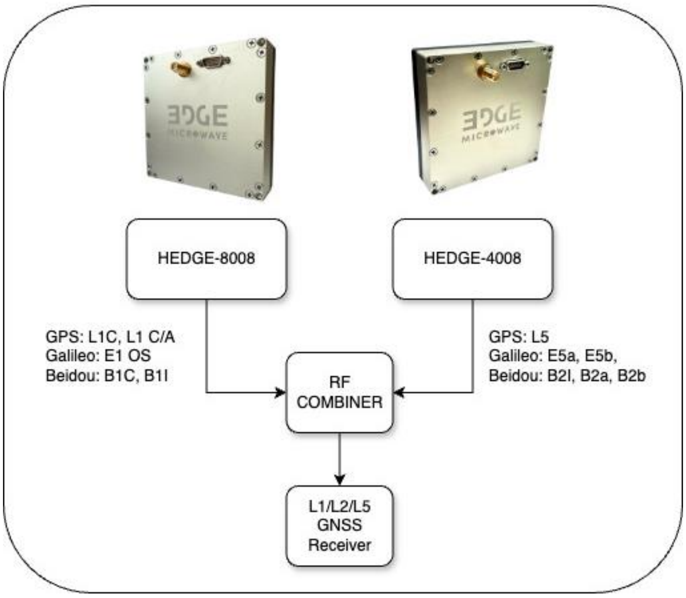

Figure 1. Triple-Band CRPA Solution

HEDGE-8008: 8-Channel Single Band CRPA (L1)
Optimized for high-order spatial nulling and dense interference environments.

- Up to 7 independent nulls
- Single Band High Rejection
    - GPS: L1C, L1C/A
    - Galileo: E1 OS
    - BeiDou: B1C, B1I

HEDGE-4008: 4+4 Dual Band CRPA (L2 + L5)
Independent adaptive spatial processing on both wideband GNSS signals.

- Up to 3 independent nulls per band
- Multi-Band Signal Reception
    - GPS: L5
    - Galileo: E5a, E5b
    - BeiDou: B2I, B2a, B2b

2. Form Factor – Integration Envelope

One of the central design objectives of the proposed triple-band CRPA front-end is to deliver high-performance spatial interference mitigation within a **compact and lightweight mechanical envelope** suitable for airborne, ground, and unmanned platforms where size, weight, and power (SWaP) constraints dominate system selection. The complete assembly, including both CRPA units (HEDGE-8008 and HEDGE-4008 is designed to remain below:

- **Total mass:** < **575 g**
- **Mechanical envelope:** < **90 × 180 × 26 mm**

This physical footprint is significantly smaller than conventional multi-band CRPA systems, which often require physically separated antenna modules or bulky analog combining stages. By integrating all spatial processing and RF reconstruction hardware into a single enclosure, the system reduces platform-level wiring complexity, and supports rapid mechanical integration.

The low weight and compact geometry enable installation in environments where aerodynamic drag, payload limitations, or volume constraints would otherwise preclude multi-band anti-jam solutions. Representative integration targets include:

- Small and medium-size UAVs
- UGVs and compact ground vehicles
- Naval and airborne auxiliary sensors
- Portable GNSS timing and surveying units

The reduced form factor also improves system survivability by minimizing cross-sectional exposure and enabling embedment within radomes or platform skins without degrading antenna geometry.

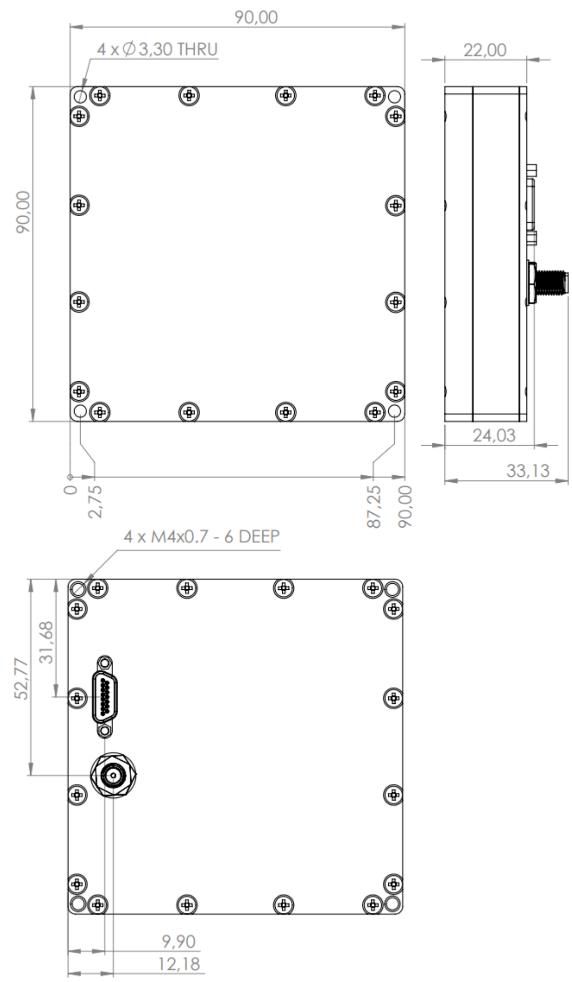

Figure 2. HEDGE-8008 Dimensions

This SWaP-focused design ensures that advanced multi-band CRPA protection can be deployed on platforms traditionally limited to single-band or low-performance anti-jam solutions, thereby expanding the operational envelope of GNSS-dependent systems operating in contested RF environments.

3. Multi-Band Signal Reception Performance

Modern GNSS constellations increasingly rely on wideband, high-power, and high-integrity signals such as **GPS L5**, **Galileo E5a/E5b**, and **BeiDou B2a/B2b**, which offer improved multipath resistance, enhanced ranging accuracy, and stronger interference resilience compared to legacy signals. The proposed triple-band CRPA architecture is designed not only to protect these signals through adaptive spatial filtering, but also to preserve their intrinsic modulation characteristics and wideband structure during reception.

4. Preservation of Modulation Fidelity

The lower-band subsystem (HEDGE-4008) processes the following wideband signals:

- **GPS L5 (1176.45 MHz)**: 10-MHz bandwidth, BPSK-modulated
- **Galileo E5a / E5b (1176.45 MHz / 1207.14 MHz)**: Total 20 MHz bandwidth – 10 MHz on each channel, BOC-modulated
- **BeiDou B2a / B2b / B2I (1176 MHz to 1207 MHz)**: Wideband BPSK/BOC signals across B2a/B2b and the narrower B2I channel

The system maintains **low group delay variation, and high linearity** within each band's RF and digital front-end. This fidelity is essential for receivers that exploit the advanced features of these signals, such as precise code-phase tracking, long coherent integrations, and dual-frequency ionospheric correction.

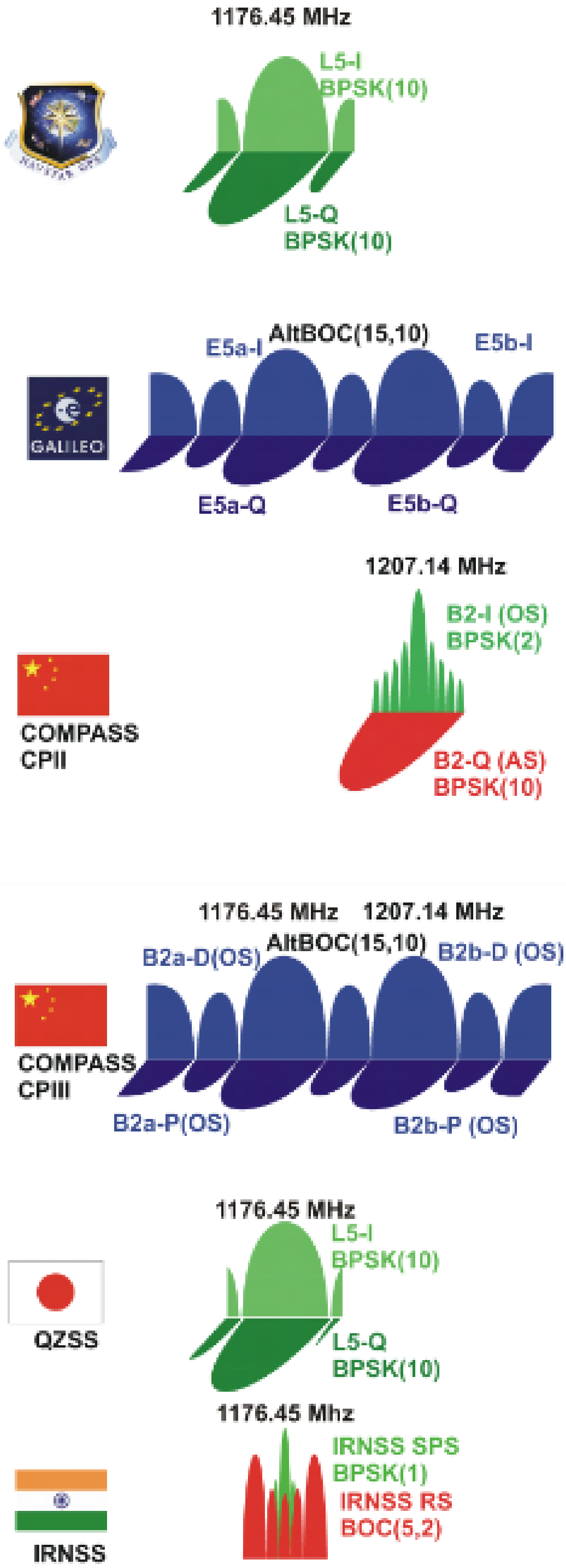

Figure 3. L5/L2 Received Signal Spectrum

5. GNSS Signal & Spectral Diversity

This section compares **L1 CRPA operation** against the proposed **triple-band L1+L2+L5 CRPA architecture**, focusing on signal availability and continuity of the position, velocity, and time (PVT) solution.

In the triple-band configuration:

- Each satellite can contribute multiple independent pseudorange and carrier-phase measurements.
- Dual/triple-frequency ionospheric corrections become available.
- Receiver tracking loops benefit from stronger pilot channels on L5/E5.

Figure 4. L1-Band Signal Reception

In comparison to single-band solution, the triple-band architecture simultaneously exploits signals across three spectrally separated bands. The increase in tracked signals directly improves measurement geometry, lowering dilution of precision (DOP) and enhancing solution stability.

L1-Band CRPA (Figure 4) shows a limited number of tracked satellites and usable signals, constrained to the upper GNSS band. In contrast, L1+L2+L5 CRPA (Figure 5) demonstrate a significantly higher aggregate signal count, with satellites contributing multiple measurements across different frequencies.

Figure 5. L1/L2/L5 Triple Band Signal Reception

6. GNSS Signal Reception Under Interference

While single-band GNSS systems operating exclusively on L1/E1/B1 have historically provided acceptable performance in benign RF environments, their limitations become evident under intentional interference. In an L1 CRPA configuration, the navigation solution relies on a single spectral region around 1560-1575 MHz. Although this band is widely supported across all GNSS constellations, it also represents the most heavily targeted frequency due to its legacy dominance and lower implementation complexity.

A critical advantage of the proposed architecture is its ability to ***maintain navigation continuity even under complete L1-band denial***.

- When L1 signals are fully jammed or suppressed:

  • A traditional L1-only system experiences immediate loss of PVT

  • Acquisition and tracking loops collapse simultaneously

  • Recovery requires jammer removal and full reacquisition

- In the triple-band CRPA system, however:

  • L2 and L5 signals remain spatially filtered and available

  • The external GNSS receiver continues operating using lower-band measurements

  • PVT continuity is preserved without requiring reacquisition on L1

As a result, the navigation engine maintains higher confidence in its PVT solution, even when individual bands experience degradation or intermittent interference.

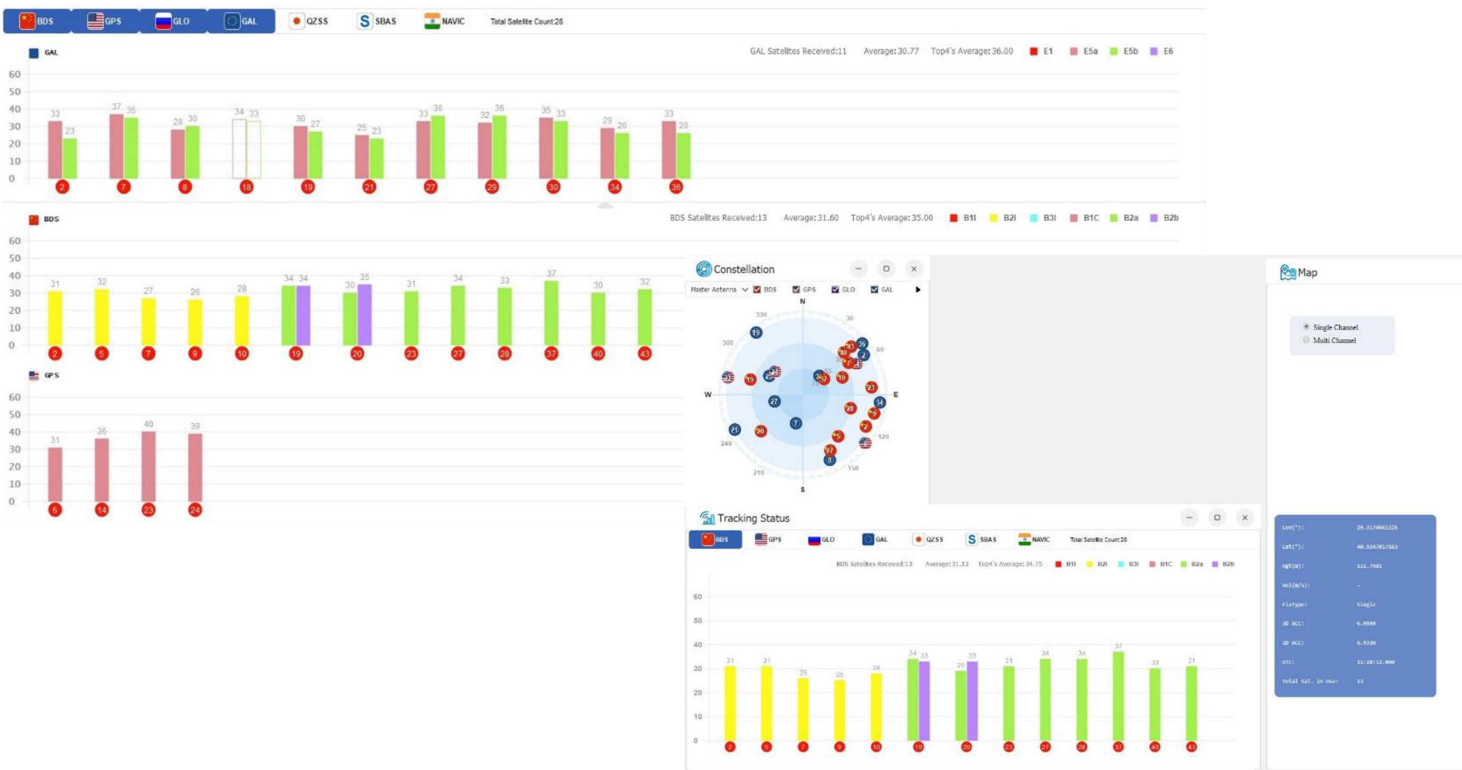

Figure 6. PVT Solution Under Completely Suppressed L1-Band

7. Conclusion

The triple-band CRPA GNSS front-end architecture presented in this document provides a comprehensive and scalable solution for ensuring reliable satellite navigation in contested, dynamic, and interference-dense RF environments. By combining an **8-channel L1 CRPA subsystem (HEDGE-8008)** with a **dual-band 4+4 channel L2/L5 CRPA subsystem (HEDGE-4008)**, the system delivers independent spatial interference mitigation across all major modern GNSS frequencies, including **GPS L1/L5**, **Galileo E1/E5a/E5b**, and **BeiDou B1/B2a/B2b/B2I**.

The architecture preserves the full spectral integrity of wideband safety-of-life signals such as GPS L5 and Galileo E5, while providing deep adaptive nulling against narrowband, wideband, and multi-source interferers. The resulting interference-clean RF outputs are recombined into a unified multi-band signal that can be consumed by any professional grade triple-band GNSS receiver without requiring modifications to its acquisition or tracking algorithms.

A defining advantage of the proposed triple-band CRPA architecture is its ability to **maintain PVT continuity under complete L1-band denial**. While L1-only GNSS systems experience immediate navigation outages when the upper band is jammed, the presented solution continues to operate using independently spatially filtered **L2 and L5 signals**, preserving satellite tracking and navigation output without interruption.

Despite its advanced spatial processing capabilities, the system remains highly compact and lightweight, with a total mass **below 575 g** and an overall envelope of **90 × 180 × 26 mm.** This enables deployment on SWaP-constrained platforms, including small UAVs, UGVs, and compact maritime assets.

By decoupling spatial anti-jam processing from the navigation engine itself, the proposed design provides long-term scalability, allowing future enhancements in beamforming algorithms, RF front-end design, or GNSS receiver technology without requiring structural changes to the system architecture. This modularity ensures compatibility with evolving GNSS constellations and emerging threat models while maintaining a stable integration interface.

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