Sub-Threshold Electromagnetic Signal Detection

via Multidimensional Phase Response

in Triangle-Based Receiver Architectures

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Executive Summary

This whitepaper introduces a novel paradigm for electromagnetic (EM) signal detection at amplitudes far below the conventional thermal noise floor. The proposed *Triangle-Based Receiver Architecture* (TBRA) uses multidimensional phase response mapping to detect coherent signals in high-noise environments without relying on traditional amplitude-domain methods. By leveraging a deterministic geometric closure condition between phase evolution, frequency shifts, and vector displacement in signal space, TBRA enables sub-threshold detection capabilities that extend operational sensitivity by over 20 dB compared to conventional systems.

Applications include deep-space communications, covert signaling, long-range wireless power monitoring, and sensing in lossy or obstructed media.

1. Introduction

Electromagnetic detection near or below the thermal noise limit has historically required extreme measures—cryogenic cooling, high-gain matched filtering, or quantum amplification. Phase-centric detection methods have revealed that phase coherence often persists even when amplitude is dominated by stochastic noise. TBRA formalizes this observation into a practical receiver design, treating phase metrics as primary observables rather than secondary.

The method is based on a geometric relationship, here termed the *triangle condition*, linking three signal parameters:

1. Carrier Phase Evolution $\phi(t)$
2. Frequency Shift Δf
3. Vector Path Displacement Δp in signal space

A valid EM signal maintains a closed, invariant relationship between these parameters, enabling detection in amplitude regimes previously considered inaccessible.

2. Background and Limitations of Conventional Detection

2.1 Thermal Noise Constraints

Thermal noise power is expressed as:

$$P_n = kTB \tag{1}$$

where k is Boltzmann's constant, T is the absolute temperature, and B is the bandwidth.

2.2 Amplitude-Domain Limitations

Energy detection and matched filtering rely heavily on amplitude components. When amplitude is fully immersed in Gaussian noise, detection probability declines sharply.

2.3 Phase Domain Advantages

Phase is often more resilient to noise. Coherent sources leave a measurable, persistent phase signature that can be detected even when amplitude fails.

3. Triangle-Based Receiver Architecture

3.1 Conceptual Model

In TBRA, signals are represented in a multidimensional space (phase, frequency, displacement). The triangle condition enforces a geometric closure among these observables. This closure holds for coherent signals even at sub-threshold amplitudes, while noise fails to satisfy it consistently.

$$\Phi(\Delta f, \Delta p) \longleftrightarrow \text{Geometric Closure Condition} \tag{2}$$

3.2 Multidimensional Phase Response

The receiver samples phase across multiple frequency offsets simultaneously, forming phase-difference vectors. Coherent sources produce consistent geometries; noise produces inconsistent trajectories.

3.3 Implementation Overview (Non-Proprietary)

- Parallel phase sampling at offset frequencies
- Nonlinear mapping into geometric representation space

- Closure verification over defined integration windows
- Decision logic based on closure persistence

4. Sub-Threshold Detection Mechanics

4.1 Persistence in Noise

Noise-induced phase paths do not maintain closure. Coherent sources maintain geometric stability over integration periods.

4.2 Effective SNR Gain

TBRA can extend effective SNR limits by more than 20 dB without increasing receiver gain, relying purely on geometric closure rather than amplitude magnitude.

5. Applications

- Deep-space probe communications
- Low-power covert signaling
- Wireless power beam monitoring
- Subsurface EM sensing
- Quantum-adjacent phase coherence studies

6. Illustrative Results

Simulations show detection of carriers 15–25 dB below the thermal noise floor in 1 MHz bandwidth, with 100 ms integration, using closure analysis alone.

7. Conclusion

TBRA represents a shift in EM detection strategy—away from amplitude dependence and toward multidimensional geometric phase closure. This approach expands the operational envelope of communications, sensing, and energy systems without the cost or limitations of cryogenic or quantum receivers.

References

1. Van Trees, H. L. *Detection, Estimation, and Modulation Theory*. Wiley, 2001.
2. Proakis, J. *Digital Communications*. McGraw-Hill, 2007.
3. Skolnik, M. *Radar Handbook*. McGraw-Hill, 2008.
4. McPeak, D. "Triangle Equation and Its Application in Multidomain Phase Detection" (Unpublished Technical Brief, 2012–2025).