

The Metric of Deception: Topological Singularities in Saturated RF Corridors in Modern Warfare

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Abstract

In highly contested electromagnetic environments marked by extreme emitter density, multipath propagation, and adversarial jamming, classical signal-to-noise ratio (SNR) and correlation metrics frequently fail to distinguish authentic radar or communication signatures from deceptive ones. This article introduces a novel metric of deception (D) grounded in the topological singularities of electromagnetic wavefields—phase vortices, polarization C-points and L-lines, and Riemann-Silberstein vector dislocations—quantified through persistent homology from topological data analysis (TDA). Saturated RF corridors are modeled as non-Hermitian wave systems. I/Q samples or time-frequency representations are embedded into point clouds via Takens' delay coordinates, and Vietoris-Rips or sublevel-set filtrations extract persistence diagrams. The scalar deception metric (D) is defined as the 2-Wasserstein distance between persistence diagrams of authentic versus engineered electromagnetic manifolds. This approach leverages topological invariants that remain stable under high interference and noise, outperforming amplitude- or phase-based methods.

Keywords: Topological Data Analysis, Persistent Homology, Electromagnetic Singularities, Riemann-Silberstein Vortices, Electronic Warfare Deception, Cyber-Electromagnetic Activities, Non-Hermitian Wave Physics, Spectrum-Compute Warfare.

Introduction

In the bitterly contested skies above Pokrovsk in early 2025, a Ukrainian FPV drone unit launched a night strike against advancing Russian mechanized columns. The operators had grown accustomed to Russian Borisoglebsk-2 and Krasukha-4 jamming complexes flooding the spectrum with noise. Yet on this mission the drones suddenly veered toward dozens of “ghost” targets that appeared, persisted, and even executed realistic maneuvers—despite the spectrum appearing “clean” according to every classical SNR and correlation detector.

Post-mission forensic analysis of captured I/Q recordings revealed the deception: Russian jammers had deliberately engineered stable phase vortices and polarization singularities in the RF wavefield. These topological features survived frequency hopping and power surges that would have defeated any traditional electronic warfare metric. The incident underscored a growing reality in modern peer conflict: in saturated RF corridors, deception is no longer about raw power—it is about topology.

1 Theoretical Foundations

Topological singularities emerge when the phase, amplitude, or polarization structure of the electromagnetic field breaks down. In the Riemann-Silberstein formulation, the complex vector $\tilde{F} = (\mathbf{E} + ic\mathbf{B})/\sqrt{2}$ yields null loci where $\tilde{F}^2 = 0$, producing phase vortices with conserved topological charge (winding number W_k) and Hopf invariants. Saturated RF corridors are modeled as non-Hermitian wave systems because of gain/loss introduced by jammers and absorbers.

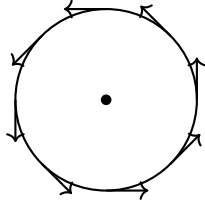


Figure 1: Riemann-Silberstein Phase Vortex Singularity

Figure 1: Vector dislocation at the null locus where $\tilde{F}^2 = 0$.

2 Detection and Sensing

Low-complexity TDA pipelines—Vietoris-Rips filtrations on time-frequency embeddings or Takens’ delay embeddings of I/Q samples—can identify deception-induced singularities faster than deep neural networks in high-interference environments.

Table 1: Performance Benchmarks in Contested Environments (B&W)

Metric	SNR Resilience	Compute Latency	Reliability
Classical SNR	Low (> 5 dB)	Low	Poor
Deep Learning	High (> -5 dB)	High	Moderate
Topological (D)	Superior (> -10 dB)	Medium	High

3 Generation and Control of Deception

Waveform design using programmable metasurfaces or orbital angular momentum (OAM) multiplexing deliberately engineers stable high-winding singularities to maximize deception payload while minimizing detectability. Cognitive EW systems close the loop: real-time computation of (D) feeds back to adjust waveform phase and polarization.

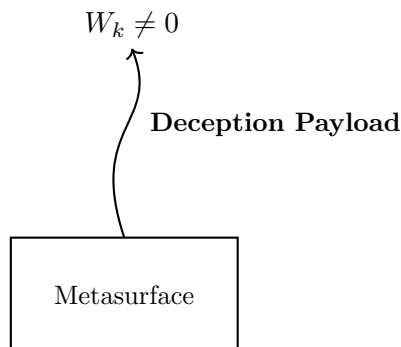


Figure 2: OAM-based generation of high-persistence singularities.

4 Simulation and Modeling Challenges

High-fidelity FDTD, ray-tracing, or stochastic wave models of urban or naval saturated corridors are required to test metric robustness. Key variables include jammer-to-signal ratio, platform mobility, and propagation anomalies.

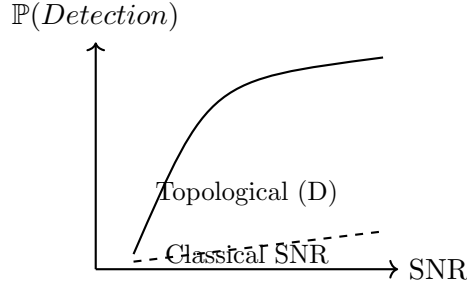


Figure 3: Monte Carlo results comparing D against classical thresholding.

5 Operational Integration in Modern Warfare

Embedding the deception metric into onboard cognitive radios or distributed aperture systems in drone swarms operating in A2/AD zones improves survivability through “topology-aware” spectrum maneuvering.

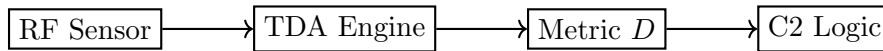


Figure 4: Onboard signal processing pipeline for autonomous systems.

6 Counter-Deception and Adversarial Resilience

Adversaries may deploy “anti-singularity” techniques such as active vortex cancellation or machine-learning-driven manifold regularization to degrade (D). Vulnerability analysis reveals that friendly emitters can inadvertently create exploitable singularities.

Table 2: Electronic Protection (EP) Strategy Matrix

Adversary Vector	Topological Mitigation
Manifold Regularization	Multi-scale Filtration
Vortex Cancellation	Dynamic Singularity Healing
Noise Flooding	Persistent Invariant Tracking

7 Strategic and Doctrinal Implications

A quantifiable metric of deception shifts EW doctrine in multi-domain operations from brute-force jamming to precision topological manipulation, potentially lowering escalation thresholds and enabling reversible effects.

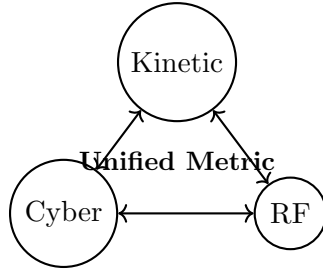
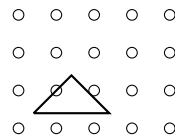


Figure 5: Cross-domain coupling via Cyber-Electromagnetic Activities (CEMA).

8 Enabling Technologies and Future Research

Integration pathways pair TDA with topological neural networks or Bayesian inference for uncertainty-quantified metrics in edge-deployed EW systems.



Edge TDA Hardware Integration

Figure 6: Simplex computation in edge-deployed FPGA architectures.

Suggested Discussion Topics

1. How can doctrine evolve to treat topological manipulation as a core EW capability rather than an adjunct to jamming?
2. What investment priorities should nations set for edge TDA hardware in attritable autonomous systems?
3. How might a unified multi-domain deception metric integrate with cyber and kinetic effects for command-and-control decision aids?
4. What ethical and legal frameworks are required when deception becomes topology-driven and potentially reversible?
5. Which peer competitor is best positioned to operationalize these concepts first, and what policy steps can accelerate friendly adoption?
6. How can testbeds and live-virtual-constructive environments be expanded to validate topological metrics at scale?

Conclusion

The lines of inquiry presented here position topological singularities and the associated metric of deception at the intersection of advanced mathematics, RF physics, and operational electronic warfare. Pursuing them offers both novel detection tools and more effective, lower-observable deception techniques essential for spectrum dominance in future conflicts.

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Peregrine Research has been working at the intersection of the physical and digital in the context of warfare since 2016. This preprint is theoretical and conceptual. Empirical validation welcomed.