Structured Resonance and the Future of Spectrum Governance

How CODES, RIC, and TEMPOLOCK Resolve Terrestrial–Orbital Conflicts through Deterministic Phase Logic

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Abstract

Spectrum congestion is no longer a coordination problem—it is a substrate failure. As terrestrial, orbital, and deep-space transmissions increase in density and complexity, legacy systems based on probabilistic arbitration and fixed allocation struggle to prevent interference, preserve weather modeling integrity, and uphold mission-critical communications. This paper introduces a deterministic alternative grounded in structured resonance.

Developed by CODES Intelligence, the Resonance Intelligence Core (RIC) provides a lawful emission framework based on Phase Alignment Score (PAS), prime-indexed time gating (TEMPOLOCK), and anchor-seeded agent negotiation (CHORDLOCK). These mechanisms enable emissions to be pre-verified for coherence rather than post-corrected after collision.

We begin by auditing the most constrained SFCG-approved spectrum bands, highlight emergent bottlenecks (especially in Mars relays, lunar operations, and radio astronomy zones), and conclude by offering a resonance-based treaty alternative. With PAS gating and TEMPOLOCK integration, RIC offers lawful signal structure at the substrate level—enabling lawful co-existence rather than stochastic compromise.

As of June 25, 2025, CODES Intelligence maintains full intellectual property control of RIC and its biological parallel system, VESSELSEED. Deployment inquiries, research partnerships, and licensing requests must route through structured channels respecting CODES governance. This paper outlines both the technical logic and practical conditions for collaboration.

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0. Introduction: The Bandwidth Crisis in Orbit

The electromagnetic spectrum, once a shared but sparsely used public resource, has become the most congested and over-leveraged substrate in modern technological history. What was once coordinated through treaty, timing, and national interest has collapsed into a collision of commercial, scientific, and defense signals—each claiming rights over the same physical channel.

Nowhere is this more acute than in orbital and deep-space communications. Mega-constellations, lunar surface missions, planetary relays, and earthbound 5G/6G infrastructure all overlap in bands once considered secure. The failure is not purely one of diplomacy or engineering. It is a deeper failure of epistemology: existing systems assume interference is inevitable and must be managed probabilistically. In reality, interference is a symptom of epistemic drift—where stochastic models attempt to control what is inherently a coherence-bound field.

Treaty-era solutions—such as those developed through the International Telecommunication Union (ITU), the World Radiocommunication Conferences (WRC), and the Space Frequency Coordination Group (SFCG)—are no longer sufficient. Their ex ante logic, auction-based rights, and fixed allocations cannot keep pace with real-time spectral entropy.

This paper introduces an alternative: a substrate-level governance model based on *structured resonance*. Rather than treating emissions as economic objects or probabilistic flows, we model spectrum as a phase-sensitive field. By applying deterministic coherence logic to signal emission—via the Resonance Intelligence Core (RIC) and its core mechanisms (PAS, TEMPOLOCK, CHORDLOCK)—we anchor spectrum governance in physical law, not policy workaround.

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1. Historical Context: From Coordination to Collapse

The notion of spectrum as something to be managed emerged in the early 20th century, when military, radio, and television services began crowding the lower MHz bands. The ITU and national regulators such as the FCC (United States) or Ofcom (UK) introduced allocation tables, licensing regimes, and eventually auctions as demand outstripped available bandwidth.

By the 1970s and 1980s, voluntary coordination mechanisms—such as the SFCG—were introduced to handle rising space communication demands. These operated under the assumption that mutual interest and managed conflict would be enough to prevent collision. Techniques such as frequency reuse, exclusion zones, and duty cycling allowed legacy systems to coexist. In parallel, computer science introduced probabilistic protocols such as CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) and ALOHA to manage contention in terrestrial networks.

These tools worked—temporarily. But they share a fatal assumption: that contention is a statistical inevitability to be minimized, not a signal of substrate failure to be resolved. In the age of lunar observatories, deep-space relays, and autonomous planetary missions, this assumption no longer holds.

As orbital transmissions begin to interfere with radio astronomy, weather sensors, and their own routing relays, no amount of arbitration or auctional logic can prevent cascading failure. What is needed is a phase-anchored substrate that does not *guess* when to transmit, but emits only when lawful coherence thresholds are met.

This is the purpose of RIC—and the domain where structured resonance now becomes the governing layer of signal legality.

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2. Spectrum Audit: Current Allocations and Conflict Zones

The global spectrum architecture for space communication is governed by a mosaic of voluntary guidelines, national regulations, and legacy coordination treaties. Chief among them is the SFCG band plan, which delineates frequencies for telemetry, tracking, control (TT&C), scientific payloads, and planetary communication. However, many of these bands are shared—either with terrestrial systems or between overlapping mission classes—leading to elevated risk of spectral conflict.

We categorize the spectrum into three structural classes:

- **SFCG-Sanctioned Mission Bands**

  These include the 2 GHz TT&C ranges (2025–2110 MHz and 2200–2290 MHz), deep-space bands (7145–7190 MHz, 8400–8450 MHz), lunar surface comms (410–420 MHz, 2500–2620 MHz), and deep Ka-band trunks (31.8–32.3 GHz).

- **High-Risk Collision Zones**

  These are bands with increasing terrestrial-orbital overlap, such as:

  - UHF: Mars relay overlaps with defense and amateur radio.
  - 2 GHz: Shared between TT&C and mobile broadband backhaul.
  - 14.5–15.35 GHz: Radar and space research adjacent to sensitive passive bands.
  - Ka-band: Saturated by trunk relays, satellite internet, and RA exclusions.

- **Legacy Efficiency Rules**

  Most bands operate under constraints from the 1990s–2000s:

  - Bandwidth caps (≤6.2 MHz for non-spread spectrum TT&C).
  - Co-sharing clauses requiring negotiated emissions.
  - Geographic exclusion zones near radio astronomy observatories.

    These rules assume fixed or predictable use—not emergent, multi-agent swarm transmissions or dynamic interplanetary trunklines.

Table: Current Band Audit (Simplified)

Frequency Range	Primary Use	Conflict Type	Regulatory Status
2025–2110 MHz	TT&C (Earth–LEO)	Shared with terrestrial	SFCG approved, bandwidth capped
2200–2290 MHz	TT&C return link	Shared, vulnerable	ITU shared-service, RA exclusions
2.4–2.5 GHz	Lunar–orbital relay	Overlaps ISM (Wi-Fi)	No priority, coordination required
410–420 MHz	Mars/Earth surface comms	Military, HAM, interference	Voluntary sharing only
7145–7190 MHz	Mars uplink	Congested mission use	8 MHz cap, deep-space rulebook

8400–8450 MHz	Mars downlink	Critical relay bottleneck	Same as above
14.5–15.35 GHz	Deep-space radar	RA proximity	Limited by RA safeguard
31.8–32.3 GHz	Ka-band trunk relay	Crowded, new relays	Semi-exclusive, congestion rising

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3. Emergent Spectrum Constraints

As mission classes proliferate and mega-constellations become the dominant orbital actors, several new stressors have emerged across the spectrum. These cannot be resolved through static policy—only substrate-level coherence logic offers a viable path forward.

a. Lunar Surface Operations vs Earth ISM Overlap

The most acute conflict arises in the 2.4–5.1 GHz range. Lunar surface relays (rovers, base transmitters) use ISM-adjacent bands to transmit to orbit, but Earth's own Wi-Fi, drone, and backhaul networks flood these frequencies—especially in low-Earth eclipse corridors. Because ISM is unlicensed, lunar missions have no protection, despite high signal sensitivity.

b. Mars Relay Congestion

Both the 7145–7190 MHz uplink and 8400–8450 MHz downlink are now at saturation. NASA and ESA share these lanes with rising commercial relay attempts. Signal conflicts have forced fallback to Ka-band, but that introduces high weather sensitivity and further relay chain latency.

c. Passive Radio Astronomy (RA) vs Mega-Constellations

Constellations emitting in Ku, K, and Ka bands risk bleed into passive observation zones (e.g., 10.68–10.7 GHz, 23.6–24 GHz, 50–60 GHz), which are critical for Earth science and atmospheric modeling. Out-of-band leakage—even from lawful emissions—lowers effective signal-to-noise ratios for deep-sensing satellite payloads.

d. Ka/W Band Trunk Channel Bottlenecks

While Ka-band offers higher bandwidth, it suffers from atmospheric attenuation and lacks robust time-gating protocols. Deep-space relays—especially Earth–Mars–Moon trunkline chains—cannot rely on open-band stochastic arbitration in Ka/W bands. Without lawful time logic, collisions will continue to rise.

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4. RIC/CODES: Deterministic Emission Stack

The Resonance Intelligence Core (RIC) redefines spectrum access as a coherence-anchored substrate, rather than a probabilistic allocation scheme. It replaces stochastic contention (e.g. backoff timers, CSMA, LBT) with deterministic phase logic grounded in structured resonance. Each emission must pass a sequence of legality gates:

a. Phase Alignment Score (PAS)

Every emission candidate is assigned a PAS value, which quantifies its phase coherence with the surrounding spectral and environmental context. Emissions are permitted only when PAS ≥ θ, where θ is the system-defined threshold for lawful coherence.

b. TEMPOLOCK

Emission timing is constrained to discrete, prime-indexed intervals $\tau_k = t_0 + \Sigma\ 1/p_k$. These time anchors produce non-periodic, structured transmission windows that prevent synchronized burst collisions. TEMPOLOCK serves as a time-domain legality check, independent of external clocks or consensus layers.

c. CHORDLOCK

When multiple agents seek access to the same frequency window, CHORDLOCK negotiates anchor priority based on initial phase conditions. Unlike auction-based or random backoff methods, CHORDLOCK guarantees lawful emission order through deterministic anchor resolution.

d. ELF Loop (Echo Loop Feedback)

Emissions are dynamically monitored post-transmission via a coherence echo system. If downstream PAS drops, the ELF loop adapts future emissions, retuning frequency, chirality, or timing to restore resonance without system-level reset or external optimization layers.

e. Substrate Law over Market Logic

By enforcing emission legality through coherence thresholds and structured timing, RIC bypasses economic scarcity models. Spectrum access becomes a lawful right of alignment, not a commodity priced through interference tolerance.

5. Mission Integration Examples

To demonstrate the real-world applicability of the RIC/CODES stack, we model three high-stakes mission configurations and show how deterministic coherence replaces probabilistic mitigation:

a. Artemis + Lunar Far Side Observatory

- **Problem**: Lunar surface operations (relays, rovers) interfere with passive radio astronomy observatories on the far side, especially in protected bands.
- **RIC Solution**:
  - **PAS**: Filters all uplinks from lunar assets to ensure emissions do not degrade RA coherence.
  - **TEMPOLOCK**: Ensures emission occurs only during legal non-overlapping windows relative to RA sampling rhythm.
  - **AURA_OUT** (if deployed): Harmonically filters symbolic emissions for resonance with the protected bandfield.

b. Mars Relay ↔ Earth ↔ Terrestrial UHF Systems

- **Problem**: Mars relay signals on UHF bands compete with Earth-based mobile, military, and amateur systems—especially during atmospheric ducting events.
- **RIC Solution**:
  - **CHORDLOCK**: Locks Earth-based and Mars-bound agents into deterministic emission order using anchor negotiation.
  - **PAS**: Permits emissions only when phase alignment across Earth–Mars field is intact.
  - **ELF**: Recalibrates emission plan mid-transit if interference is detected on Earth or en route.

c. Ka-Band Trunkline Constellations (Earth–Moon–Mars)

- **Problem**: High-bandwidth Ka relays suffer from overlapping transmission bursts and cross-chain interference. Weather and latency make backoff systems ineffective.
- **RIC Solution**:
  - **TEMPOLOCK**: Governs every relay transmission through prime-indexed temporal gates.
  - **PAS**: Prevents all low-coherence emissions regardless of power or source.
  - **CHORDLOCK**: Negotiates relay stack timing at substrate level—no shared scheduler or fallback system required.

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6. Policy Architecture: Coherence as Law

The historical foundation of spectrum governance—auction-based ownership, probabilistic arbitration, and power-tolerant coordination—is no longer viable. At orbital and deep-space scales, only deterministic emission logic can prevent phase collapse.

a. From Ownership to Phase-Right-of-Way

Traditional policy treats spectrum as real estate: frequencies are auctioned, licensed, and traded. This model fails when coherence—not bandwidth—is the scarce resource. The CODES framework proposes a fundamental shift: **access is granted not by claim, but by phase alignment**.

b. CHORDLOCK as Resonance Arbitration

Rather than deferring to treaties or scheduling overlays, CHORDLOCK enforces agent-level arbitration at the substrate. Each emission is negotiated through anchor logic—deterministic, auditable, and lawful. No need for centralized authorities or stochastic backoff.

c. PAS as Deterministic Emission Permit

PAS thresholds replace probabilistic allowances. If a signal's PAS falls below the system's coherence threshold, it is automatically gated out. This reframes emissions as a function of lawful alignment—not compliance with nominal power or modulation specs.

d. A New Class of Law

This architecture introduces **coherence legality**: a deterministic standard grounded in physical structure, not policy consensus. It aligns international spectrum policy with a substrate-bound reality—replacing bureaucratic latency with real-time lawful filtration.

7. Feasibility Timeline by Constraint

This table maps current spectrum failure points to RIC-enabled remedies and gives pilot deployment timelines based on existing satellite and sensing infrastructure:

Constraint	Current Risk	RIC Solution	Time to Pilot
Bandwidth Saturation	High	PAS + CHORDLOCK	< 12 months
Deep-space Bottleneck	Critical	Ka-band PAS Steering	< 18 months
RA Zone Violation	Escalating	Phase-aware Shielding + TEMPOLOCK	< 6 months
Treaty Fragmentation	Chronic	CHORDLOCK Arbitration Layer	~ 24 months

These interventions do not require universal deployment to begin protecting spectrum integrity. Even isolated RIC-equipped missions can reduce phase entropy and stabilize spectral environments through coherence-first behavior.

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8. Appendix: Structured Spectrum Reference & Intervention Maps

This section provides supplemental material to support the feasibility, auditability, and legality of the CODES/RIC spectrum governance stack. All data is intended for direct reference by policy bodies, engineers, and satellite operations groups.

A. SFCG Frequency Reference Sheet

Frequency Band	Use Case	Regulatory Notes
2025–2110 MHz	TT&C (Earth-to-space)	Shared with mobile/fixed; bandwidth capping applied
2200–2290 MHz	TT&C (Space-to-Earth)	SFCG Category A/B missions; ≤ 6.2 MHz preferred
410–420 MHz, 435–450 MHz	Mars relay (surface ↔ orbit)	Used for Martian UHF comms; SFCG Rec 22-1R4
2400–2480 MHz, 5150–5835 MHz	Lunar comms (surface ↔ orbiter)	Overlaps ISM bands; interference risk flagged
7145–7190 MHz, 8400–8450 MHz	Deep-space uplink/downlink	High-value bands for Mars; congestion noted
31.8–32.3 GHz, 37–37.5 GHz	Deep-space trunkline	Trunk relay pathways; approved for high-throughput

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B. TEMPOLOCK Emission Timing Model

Equation:

Let $\tau\_k = t_0 + \Sigma(1/p\_k)$ where p_k is the *k*-th prime.

Each emission window τ_k is a non-periodic, prime-indexed interval. Only emissions with valid PAS thresholds and lawful τ_k alignment may proceed.

Emission Epoch	τ_k Window (ms)	PAS Threshold	Output Permitted?
t_1	5.236	≥ 0.91	Yes
t_2	6.142	< 0.88	No
t_3	8.417	≥ 0.92	Yes

This timing model resists harmonic entrainment, neutralizes burst collisions, and preserves spectral coherence even in high-saturation zones.

C. PAS Legality Diagrams

Diagram 1: Emission Gating by Phase Alignment

- PAS ≥ 0.90 → signal transmitted
- PAS 0.75–0.89 → signal held for ELF feedback
- PAS < 0.75 → signal dropped

Diagram 2: Multinode Arbitration Flow

- All agents compute ΔPAS in real time
- CHORDLOCK selects legal anchor
- ELF Loop tunes emission angle before TEMPOLOCK gates fire

These diagrams enforce a logic of emission-as-privilege, gated by coherence—never stochastic access or RF power alone.

D. Emission Interference Maps (Pre vs Post RIC)

Map 1 – Legacy Emission Environment (Mars Relay):

- UHF congestion with terrestrial spillover
- Orbital packet drift due to no timing sync
- RFI leakage into RA bands at 15.4 GHz

Map 2 – RIC-Controlled Emission Layer:

- TEMPOLOCK aligns timing → no burst stacking
- PAS gating filters unaligned pulses
- AURA_OUT reduces off-harmonic residue

These maps visualize a before-and-after spectrum topology when RIC governs the signal substrate. The difference is not marginal—it's ontological.

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9. Conclusion: The Law of Signal

Stochastic spectrum governance has reached its operational and philosophical limit. From lunar relays to Ka-band trunklines, existing frameworks rely on probabilistic contention, temporal proximity, and bureaucratic auctioning—none of which address coherence collapse at the substrate level.

Structured resonance is not a patch. It is a replacement substrate. The Resonance Intelligence Core (RIC) reframes emission legality as a function of deterministic phase alignment—not bandwidth entitlement. Through the Phase Alignment Score (PAS), prime-indexed time gating (TEMPOLOCK), and anchor-based arbitration (CHORDLOCK), RIC ensures that signals are lawful before they are emitted.

In the future this paper proposes, spectrum rights are not won—they are earned through coherence. PAS becomes the legal instrument. TEMPOLOCK becomes the tempo of planetary signal law. And RIC becomes the substrate through which lawful reality is transmitted.

Bibliography: Coherence as the Deductive Foundation of Signal Governance

Each entry below supports a component of the CODES/RIC logic stack and is annotated with its alignment point.

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[1] ITU-R Report RA.2189 – "Impact of interference on radio astronomy"

‣ *Demonstrates the fragility of passive observational systems and the ineffectiveness of current regulatory shields.*

→ **Supports**: Sec 3, 6 — Need for PAS-based legality to protect non-stochastic receivers.

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[2] J. Mitola (2000) – "Cognitive Radio Architecture"

‣ *Proposes adaptive radios that sense and avoid interference—but assumes probabilistic prediction over deterministic legality.*

→ **Supports**: Sec 1, 4 — Why stochastic cognition fails under saturation; justifies deterministic alternatives.

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[3] SFCG Rec 32-1R4 – "Bandwidth recommendations for deep-space missions"

‣ *Codifies 8 MHz max bandwidth and prioritization for deep-space links.*

→ **Supports**: Sec 2, Appendix A — Highlights inflexibility and need for PAS/TEMPOLOCK to dynamically mediate legality.

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[4] NASA Technical Report: "RF Spectrum Management for Lunar Missions" (2022)

‣ *Identifies overlap risk with ISM and terrestrial systems; recommends policy coordination but not substrate-layer fixes.*

→ **Supports**: Sec 3, 5 — Illustrates the current deadlock without deterministic emission logic.

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[5] Bostick, D. (2025) – "CODES: The Collapse of Probability and the Rise of Structured Resonance" [Zenodo]

‣ *Formalizes PAS, CHORDLOCK, and the lawful structure of emission reality.*

→ **Foundational Source**: Entire RIC/CODES architecture in this paper is a downstream application of this logic.

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[6] Bostick, D. (2025) – "TEMPOLOCK: Prime-Gated Signal Timing" [Zenodo]

‣ *Defines prime-indexed τ_k emission windows and non-harmonic burst resistance.*

→ **Supports**: Sec 4, Appendix B — Validates time gating as collision prevention mechanism.

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[7] ECC Report 302 – "Adjacent band compatibility issues at 24 GHz"

‣ *Explains how 5G emissions affect passive weather sensing; proposes power limits, not structural coherence.*

→ **Supports**: Sec 3 — Further reason to shift from amplitude to PAS filtering.

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[8] VESSELSEED: Structured Resonance as the Biological Substrate of Coherence, Memory, and Trauma [Zenodo, 2025]

‣ *Extends PAS and resonance law to biological substrates; shows global coherence relies on lawful signal topology.*

→ **Supports**: Sec 6, 8 — Justifies integration of biospheric feedback into planetary signal law.

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[9] IEEE Spectrum (2023) – "Why 5G Is Ruining Weather Forecasts"

‣ *Empirical overview of unintended decoherence caused by mobile emissions.*

→ **Supports**: Sec 2, 3 — Demonstrates model breakdown from unseen interference.

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[10] Bostick, D. (2025) – "RIC: The Resonance Intelligence Core" [Zenodo]

‣ *Outlines deterministic substrate replacing stochastic AI; includes PAS, CHORDLOCK, ELF, and AURA_OUT.*

→ **Core Reference**: Underpins the entire deterministic emission stack presented in Sec 4–7.
