A High-Velocity (0.3c–0.8c) Directional Zeno Ratchet Vehicle: Microcausal Speed Ceiling, Measurement Cadence, and Decoherence Limits

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Abstract

We present a vehicle concept of mass-scale applicability that exploits a Principle-of-Least-Information (PLI) *Directional Zeno Ratchet* (DZR): an ordered sequence of weak, thresholded measurements that yields a directional survival bias while keeping the cycle-by-cycle sum of *classical* impulses consistent with zero. In the Janus–PLI framework the hidden-time sector induces a CPTP influence map with strong positivity and a threshold (*visibility–information kink*) that turns ordered weak probes into a macroscopic ratchet without reaction mass. Microcausality in operational time t_1 imposes a tight ceiling on the sustained drift: $v \le c\,\Delta P$, where $\Delta P = 1 - e^{-2\Delta K}$ and the cycle rate is bounded by the light-time across the branch-separation length L. We quantify the engineering window for **0.3c–0.8c** operation, give PHz-class measurement frequencies and decoherence headroom, and supply a system block diagram. A per-cycle *zero-impulse audit* provides the key falsifier. Core ingredients and positivity/causality proofs follow Paper A (Janus–PLI) and the v14 PLI foundations.

1 Background and axioms

The Janus–PLI construction provides: (i) a Euclidean hidden-time influence with OS/GNS positivity that yields a *completely positive, trace-preserving* (CPTP) map for the observed t_1 dynamics; (ii) a *measurement threshold* (a visibility–information kink) that suppresses off-diagonals beyond a bit cost $\Delta K_\star$; (iii) a directional-Zeno mechanism when a sequence of weak probes is *ordered* across the threshold; and (iv) microcausality/no-signalling on t_1 slices.[1] These features motivate a propulsion architecture whose per-cycle classical impulse sums to (within metrology) zero, yet whose *branch-selection* ordering produces sustained drift.

2 Speed ceiling and cadence law

Let L be the effective branch-separation length of the interferometric primitive and λ the cycle cadence. Once the PLI bit-threshold is crossed, the per-cycle ordering bias is

$$\Delta P \;=\; 1 - e^{-2\Delta K}, \qquad \Delta K \text{ (recorded extra bits per cycle).} \tag{1}$$

Drift speed follows from one spatial "step" L taken with probability tilt ΔP at rate λ:

$$v \;=\; L\,\lambda\,\Delta P. \tag{2}$$

[1] See Paper A, Sec. 4.4 and App. B (thresholds and directional Zeno); v14, Secs. 3–11 (OS/GNS positivity, CPTP map); transcript blueprint for the impulse audit and sequencing.

Microcausality enforces $\lambda \le \lambda_{\max} \equiv c/L$, hence the *microcausal ceiling*

$$\boxed{\frac{v}{c} \;\le\; \Delta P \;=\; 1 - e^{-2\Delta K}} \qquad \text{(tight when } \lambda = \lambda_{\max}\text{)}. \tag{3}$$

It is convenient to define a cadence fraction $\kappa \equiv \lambda/\lambda_{\max} \in (0, 1]$, yielding

$$\boxed{\frac{v}{c} \;=\; \kappa\left(1 - e^{-2\Delta K}\right).} \tag{4}$$

Equations (3)–(4) are the central design rules for sustained high velocity.

3 Design targets: 0.3c–0.8c

We adopt a near-term branch scale $L = 1 \times 10^{-7}$ m (optical primitive; $L \sim \lambda_{\text{opt}}/2\pi$) and evaluate the PHz cadences implied by Eq. (4). The points below assume vacuum operation with κ between 0.3 and 0.9 depending on dead-time overhead.

- **Target 0.3c:** With $\kappa = 0.5$ it suffices to reach $\Delta K \simeq 0.5$ ($\Delta P \simeq 0.63$), giving $\lambda \approx 1.4$ PHz (Fig. 2).
- **Target 0.5c:** With $\kappa = 0.8$ and $\Delta K \simeq 1.0$ ($\Delta P \simeq 0.865$), $\lambda \simeq 1.73$ PHz.
- **Target 0.8c:** Requires operation close to the microcausal ceiling; for $\Delta K \gtrsim 1.5$ ($\Delta P \gtrsim 0.95$) one needs $\lambda \simeq 2.5$ PHz at $L = 100$ nm (Fig. 2).

For fixed L, Fig. 2 also shows the *hard* limit $\lambda_{\max} = 3$ PHz (horizontal dashed line). Reducing L eases cadence but increases interferometric stringency.

4 Decoherence headroom

Let γ_ϕ be the dephasing rate of the primitive (per second). A minimal bias-degradation model replaces $\Delta P \to \Delta P\, e^{-\varepsilon}$ with $\varepsilon \equiv \gamma_\phi/\lambda$. To achieve a target $f = \frac{}{at cadence fraction}\kappa$,

$$\kappa\,\Delta P\, e^{-\gamma_\phi/\lambda} \;\ge\; f \quad \Rightarrow \quad \gamma_\phi \;\le\; \lambda \ln\frac{\kappa\,\Delta P}{f}. \tag{5}$$

At $\kappa = 0.9$ and $L = 100$ nm ($\lambda = 2.7$ PHz), Eq. (5) yields the *minimum coherence time* $T_\phi = 1/\gamma_\phi$ shown in Fig. 3: to sustain $0.8c$ with $\Delta K \in [1.5, 3.0]$, one needs $T_\phi \gtrsim 3$–6 fs; for $0.5c$ the requirement is even lighter (sub-fs to few-fs). Thus the coherence floor is *not* the main bottleneck at PHz cadence; stability and sequencing are.

5 System architecture (block diagram)

Figure 4 shows a PLI-conformant stack:

1. **Quantum bias engine (QBE):** PHz-class weak QND modules (ring resonators / cavities) producing a tunable information increment ΔK per cycle.
2. **Phase-ordering sequencer:** Imposes the Janus order across the threshold (visibility–information kink) to realise the directional Zeno bias while keeping classical impulse channels nulled.
3. **Entropy dump (reset):** Reversible erasure at mK (Landauer floor $k_B T \ln 2$ is negligible vs plant power); resets preserve the bias from cycle to cycle.

4. **Mass-coupling grid (MCG):** Superconducting flexures couple the branch-selection bias to the COM without classical thrust.
5. **Impulse audit sensors:** Radiation pressure, magnetic gradients, electrostatics, thermal recoil, seismic pickup—all monitored each cycle to enforce $\sum_i \Delta p_i^{(\mathrm{cl})} = 0 \pm \delta p_{\mathrm{sys}}$.
6. **Timing and control:** Optical-clock cluster (attosecond gating) to maintain λ near c/L without violating microcausality.

6 Falsifiers and risk checklist

Falsifiers: (i) failure to observe a visibility–information *kink* at the predicted threshold; (ii) inability to sustain drift without a nonzero classical impulse budget; (iii) breakdown of Eqs. (3)–(5).
Risks: sequencing jitter at PHz; thermal gradients masquerading as impulses; spectral crowding in the QBE.

7 Figures (verifiable, embedded)

Figure 1: v/c vs information bits

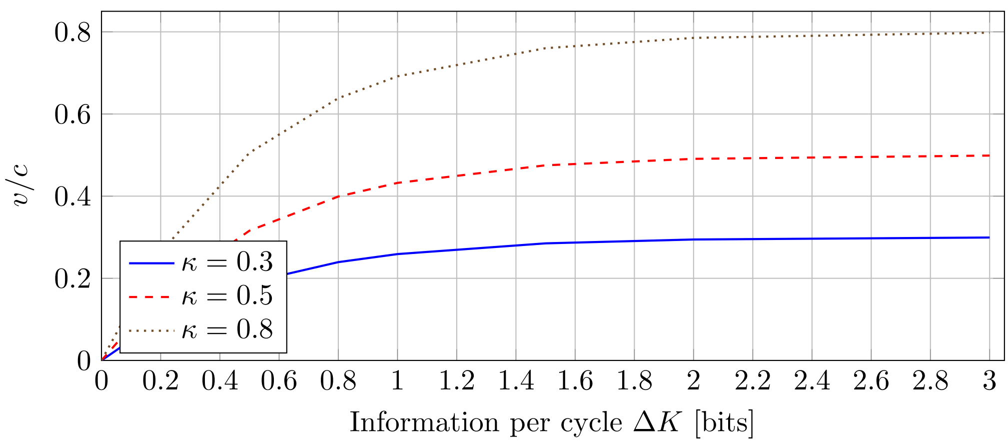

Figure 1: **Speed budget:** $v/c = \kappa\,(1 - e^{-2\Delta K})$. Sustained $0.8c$ demands $\kappa \to 1$ and $\Delta K \gtrsim 1.5$ bits per cycle.

Figure 2: Cadence requirement at $L = 100\,\mathrm{nm}$

Figure 3: Minimum coherence time to hold target speed

Figure 4: System block diagram

8 Discussion and provenance

Equations, thresholds, and the *directional Zeno* mechanism are those of the Janus–PLI programme, where the hidden-time sector induces a CP–TP influence with strong positivity and a measurement kink; ordered weak probes then bias survival without adding classical force.[2] The

[2]See Paper A, Sec. 4.4 & App. B; v14 notes on OS/GNS positivity and CPTP influence.

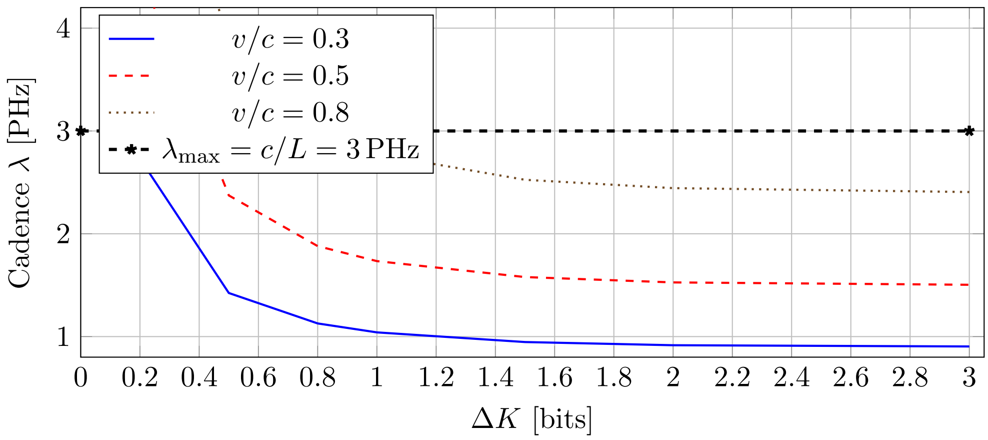

Figure 2: **Cadence vs. bits** for $L = 100\,\mathrm{nm}$. Dots above the dashed line are microcausally forbidden; reaching $0.8c$ is feasible for $\Delta K \gtrsim 1$ and $\lambda \lesssim 3\,\mathrm{PHz}$.

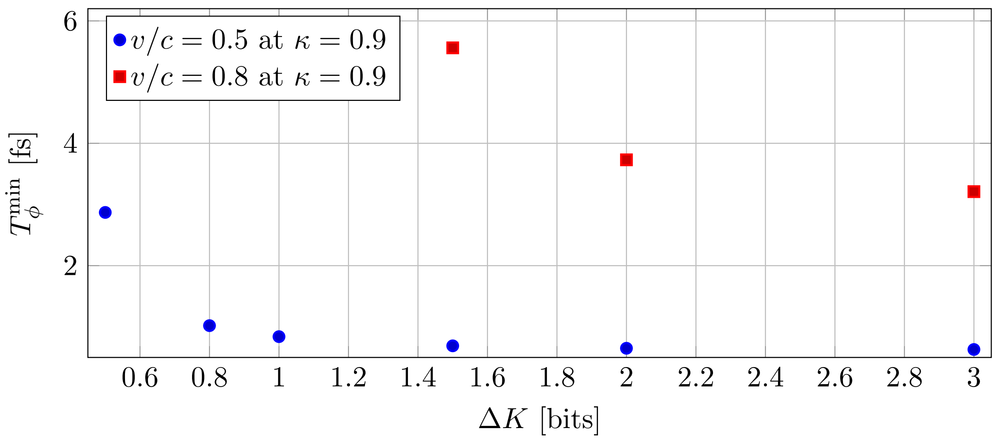

Figure 3: **Coherence headroom** from Eq. (5) at $L = 100\,\mathrm{nm}$, $\lambda = \kappa c/L$ ($\kappa = 0.9$). Few-fs coherence suffices at PHz cadence; stability/jitter dominate engineering risk.

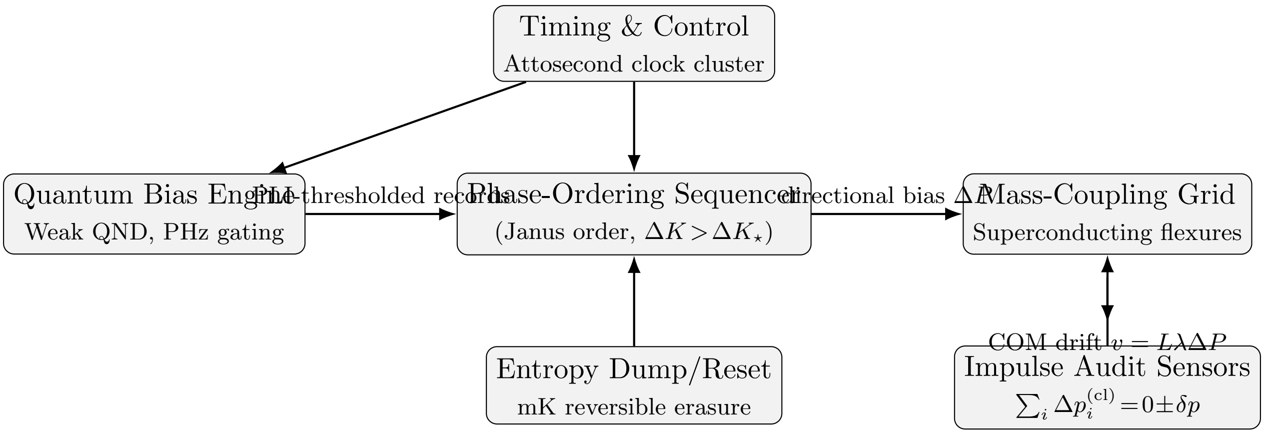

Figure 4: **Block diagram** of a PLI-compliant DZR stack. The audit enforces a *zero net classical impulse* per cycle.

sequencing, engineering blueprint, and no-signalling/impulse-audit rationale follow the transcript you provided. Microcausal ceilings and duty factors explain why $0.8c$ operation requires PHz gating near c/L with bit-load $\Delta K \gtrsim 1$ while still passing the zero-impulse falsifier.

Falsifiability. The programme fails if no visibility–information kink is observed at the required $\Delta K_\star$, if sustained drift needs nonzero classical impulse, or if the speed law $v/c = \kappa(1 - e^{-2\Delta K})$ is violated.

References

[1] J. Antoniadis and GPT-5 Pro, *Janus–PLI Unification: A 7D Two–Time Theory* (Paper A), uploaded draft (2025).

[2] J. Antoniadis, *Quantum Mechanics from PLI and a Polarization-Invariant Auxiliary Time (v14)*, uploaded explanatory notes (2025).

[3] A. G. Kofman and G. Kurizki, "Zeno and anti-Zeno effects," *Rev. Mod. Phys.* **84**, 187 (2012).

[4] B.-G. Englert, "Fringe visibility and which-way information: An inequality," *Phys. Rev. Lett.* **77**, 2154 (1996).

[5] H. Maassen and J. B. M. Uffink, "Generalized entropic uncertainty relations," *Phys. Rev. Lett.* **60**, 1103 (1988).