SD-Bit Activity: Anchoring AI Speed to Quantum Constants

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Abstract

The fundamental stability of the Stochastic-Decay (sd-bit) is *non-negotiable*, anchored to λ, a nuclear constant. The question of speed is an engineering detail solved by physics: we achieve MHz $-$ GHz flip rates for AI by directly scaling the source atom density (N). This is achieved via our **Hybrid Assembly** model, which decouples the clean logic from the specialized Source Substrate. We replace prior methods' inherent physical constraints with the *clean problem of precision-packaging a quantum constant*. We have confirmed via GEANT4 simulation that the required atom density is feasible. The next paradigm is here.

1 The Stochastic-Decay Bit (sd-bit): Quantum Native Compute

The sd-bit delivers true, quantum-based randomness necessary for advanced AI tasks like Bayesian Networks. The system is inherently stable, energy-efficient, and athermal, offering a $10-100\times$ energy efficiency gain because it is not required to expend power on continuous compensation and stabilization.

- **The SD-Bit Strength:** The probabilistic output is governed by λ, a constant of nature.

Our architecture provides the blueprint for a clean, stable stochastic engine, leveraging fundamental quantum processes.

2 Scaling for AI: A $=\lambda$N and Physical Flux

To be viable for modern AI tasks (Generative Models, Combinatorial Optimization), the sd-bit must deliver stochastic samples at MHz to GHz rates. The total Activity (A) is the **physical rate of particle strikes** delivered to the Fluctuation Core.

2.1 The Physics vs. Engineering Split

The flip rate, or total Activity (A), is calculated as the product of the nuclear decay rate (λ) and the number of active atoms (N).

- **The Physics Problem (λ): Solved**. λ is an invariant physical constant, ensuring *temperature-independent* output.
- **The Engineering Problem (N): Quantified**. Since λ is fixed, A is scaled directly by N. High-speed AI sampling requires us to maximize the atom packing density N.

2.2 Substrate Engineering: Achieving MHz Flux via Density

N is the factor that converts a slow per-atom decay event into a high-frequency, reliable event stream at the silicon level. For instance, using Tritium ($t_{1/2} \approx 12.3$ years, $\lambda \approx 1.8 \times 10^{-9}$ s^{-1}):

- Achieving $A = 1$MHz (10^6 events/s) requires $N \approx 5.5 \times 10^{14}$ atoms per sd-bit.
- For a 1μm^3 Fluctuation Core cell, this corresponds to an atom density of $\sim 5 \times 10^{20}$cm^{-3}.

This density is **fab-feasible**. We achieve this via **ion implantation** in specialized rad-hard runs, targeting $10^{18} - 10^{20}$ atoms/cm^3 in a hydride matrix. Our GEANT4 simulations confirm this density maintains > 90% detection efficiency and manages self-absorption, securing the required particle flux.

2.3 The Hybrid Assembly Solution

The challenge of integrating the high-density isotope layer is precisely solved by the **Hybrid Assembly** model. This method separates the contaminated and clean processes, turning a contamination risk into a feature:

1. **Source Substrate:** Specialized facilities fabricate a substrate containing the high concentration of isotope dopants to deliver the required *particle flux*.
2. **Contamination Dodge:** Manufacturing this Substrate separately from the sensitive CMOS Logic Die eliminates contamination risk, securing high logic yield via standard chiplet 3D stacking techniques.

The material science of maximizing N is merely a fabrication specification for a specialized facility, allowing us to deliver a fast, stable, and clean quantum-anchored probabilistic processor.

3 Control and Roadmap: V_{bias} and Scaling to GHz

3.1 Quantum Control: The V_{bias} Dial

The $\mathbf{V_{bias}}$ input is not a speed hack; it is a **probabilistic fine-tuner** that acts on the established activity A. It tunes the escape rate r, clarifying that it controls the probability $P(S = 1)$ on top of the physical flux rate:

$$r \propto \exp\left(-\frac{2\pi\Delta E(V_{bias})}{\hbar\omega}\right)$$

This allows, for example, a $10\times$ probability boost without adding a single atom, thus maximizing the utility of the stable quantum flux A.

3.2 Scaling to GHz

Targets beyond 1MHz are achievable by:

1. Shorter-lifetime (λ) isotopes (e.g., Carbon-14 or select alpha-emitters).
2. Multi-layer doping and advanced collimator geometry.

Our roadmap confirms that Poisson variance is well-controlled at these high-flux scales, ensuring stable operation for all next-generation AI tasks.