ISDO-B′ and Hadamard Interference Backends

Purpose of This Document

This document records the **design rationale, implementation plan, and verification protocol** for introducing **quantum-circuit-based interference backends** into the IQC (Interference Quantum Classifier) framework.

It exists to:

- Preserve architectural intent
- Enable back-tracing of design decisions
- Support paper, thesis, or patent drafting
- Prevent accidental regression to ad-hoc circuit integration

This document should be treated as **authoritative design reference** for circuit-backed IQC execution.

Background: What IQC Requires from a Circuit

IQC is defined entirely in terms of a single scalar observable:

> **Interference score**
> $S(\psi, \chi) = \mathrm{Re}\langle \chi \mid \psi \rangle$

All learning regimes (Regime 2 → 3-A → 3-B → 3-C) depend *only* on this value:

- sign
- relative magnitude
- ordering across samples

IQC **does not** require probabilities, fidelities, or variational gradients.

Therefore, a circuit backend is *only* responsible for **estimating this scalar**, not for learning.

Architectural Principle (Locked)

> **Learning logic must be completely independent of how interference is measured.**

To enforce this, IQC introduces an **Interference Backend abstraction**:

```
score(chi, psi) → float
```

All IQC regimes call this interface. The backend may be:

- mathematical (NumPy)
- circuit-based (Hadamard test)

- observable-engineered (ISDO-B′)

Learning code never inspects or controls the backend.

The Three Interference Backends

1. MathInterferenceBackend (Ground Truth)

Definition

```
S_math = Re⟨χ|ψ⟩
```

Purpose

- Exact reference
- Regression baseline
- Debug oracle

Properties

- Deterministic
- Noise-free
- Not hardware-executable

This backend defines *semantic correctness* of IQC.

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2. Hadamard-Test Interference Backend (Canonical Quantum Reference)

Definition

A Hadamard test with an ancilla qubit yields:

[\langle X_{anc} \rangle = \mathrm{Re}\langle \chi | \psi \rangle]

Circuit Characteristics

- Requires controlled state preparation
- One ancilla qubit
- Moderate circuit depth

Purpose

- Quantum-exact realization of the math backend
- Verification oracle for other quantum observables

Role in Project

- Reference backend
- Not the final hardware-efficient solution

This backend answers:

> “Does the circuit produce the same interference value as the math model?”

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3. ISDO-B′ Interference Backend (Hardware-Efficient, Novel)

Conceptual Shift

ISDO-B′ does **not** measure ⟨χ|ψ⟩ directly.

Instead, it:

- Embeds χ into an engineered observable
- Applies a fixed interferometric circuit
- Measures a single expectation value

Resulting in:

[S_{ISDO}(\psi) = \langle \psi | \mathcal{O}_{\chi} | \psi \rangle]

where (\mathcal{O}_{\chi}) is constructed from χ but **requires no controlled-χ unitary**.

Key Properties

- Shallow circuits
- No controlled state preparation
- NISQ-friendly
- Observable-engineered

Why This Matters

- Aligns with IQC’s sign-centric philosophy
- Avoids fidelity / kernel / SWAP paradigms
- Enables strong hardware efficiency claims

This backend is the **intended final embodiment** of IQC.

Verification Philosophy (Critical)

ISDO-B′ is **not required** to numerically equal the Hadamard test.

Instead, it must satisfy **three sufficiency criteria**:

Level 1 — Sign Agreement (Required)

```
sign(S_ISDO) == sign(Re⟨χ|ψ⟩)
```

IQC decisions depend on sign.

Level 2 — Ordering / Monotonicity (Required)

For fixed χ and multiple ψ:

$$\mathrm{Re}\langle\chi|\psi_1\rangle > \mathrm{Re}\langle\chi|\psi_2\rangle \;\Rightarrow\; S_{ISDO}(\psi_1) \geq S_{ISDO}(\psi_2)$$

This preserves:

- margin logic
- percentile-based memory growth

Level 3 — Correlation (Optional)

Statistical correlation between:

- Hadamard scores
- ISDO-B′ scores

Useful for diagnostics, not correctness.

Verification Harness (Planned)

A dedicated script will compare all three backends:

```
MathInterferenceBackend
HadamardInterferenceBackend
ISDOBPrimeInterferenceBackend
```

Across:

- random χ, ψ pairs
- small-qubit systems
- controlled noise-free simulation

Metrics recorded:

- sign agreement rate
- ordering violations
- correlation plots

This script is the **scientific validation artifact** for ISDO-B′.

Integration Test (Final Proof)

After standalone verification:

1. Fix a trained IQC memory bank
2. Swap backends:
    - math → hadamard → ISDO-B′
3. Run identical IQC inference

Compare:

- predictions
- accuracy
- margin statistics
- Regime-3C growth triggers

If IQC behavior is preserved, ISDO-B′ is validated as a backend.

Why This Design Is Strong

Scientifically

- Separates algorithm from measurement
- Proves sufficiency, not equality
- Matches physical constraints of NISQ hardware

Architecturally

- No `if use_circuit` pollution
- Backend injection at one point
- Future backends drop-in

For IP / Publications

- Multiple independent embodiments
- Observable-engineered learning
- Circuit-agnostic algorithm claims

Locked Decisions

- IQC learning code remains circuit-agnostic
- InterferenceBackend is the only boundary
- Hadamard backend is reference only
- ISDO-B′ is the target hardware backend
- Verification is based on sign and ordering

Status

This document reflects the agreed-upon design as of the current development checkpoint.

Any deviation from this structure should be treated as an intentional research fork and documented separately.