CORRECTION AND SCOPE

A Proposal to Bound Timing-First Scalar Couplings with Reconfigurable Superconducting Arrays

Original title · A First Experimental Bound on Timing-First Scalar Couplings from Reconfigurable Superconducting Arrays

This manuscript proposes a measurement with reconfigurable superconducting arrays. It supplies a candidate coupling and an experimental design. A measured bound is still outstanding.

Manuscript · p. 1, abstract

Timing Before Force: A Quantitative Experimental Program for Scalar-First Geometry

Evidence · Scalar source/window residual audit

A First Experimental Bound on Timing-First Scalar Couplings from Reconfigurable Superconducting Arrays

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Abstract

We propose a first bound-setting experiment for the timing-first scalar-geometry program using an already existing medium class: reconfigurable superconducting circuit arrays with tunable couplers. The central observable is a graph-state–correlated fractional timing shift $\Delta y = \delta\omega/\omega$ measured while the array is cycled between distinct coupling topologies at fixed total mass. The proposal is deliberately conservative: it does not assume that superconducting arrays are the correct microscopic source medium, only that they provide a controlled weighted-graph platform on which to place the first empirical bounds on the effective parameters $(\alpha A, \mu, \Gamma)$ entering the scalar response law. We derive the screened and unscreened magnitude estimates, define topology-vs-mass and timing-vs-force discriminants, add a dynamical completion whose modal relaxation scales are tied to the graph Laplacian spectrum, and work through a concrete 20-node example (ring versus star graph) to show how the formalism generates an explicit target observable. We also address the two main practical constraints omitted in earlier drafts: the use of concrete hardware with documented switching and gate times, and the cryogenic environment as a confound whose thermal transients can imitate a timing signal unless monitored and bounded.

1 Introduction

The scalar-projection program is now strong enough on the theory side that the most important next step is not another general argument, but a severe first experiment. The objective is not to identify the final source medium. It is to ask whether a controllably reweighted graph medium can source any measurable timing perturbation at all.

The starting observable law is the same one used in the dimensional-selection and timing-first papers,

$$\omega_{\text{eff}}(x) = \frac{\omega}{1 + \alpha\Lambda(x)}, \qquad \frac{d\tau}{dt} = \frac{1}{1 + \alpha\Lambda(x)}, \tag{1}$$

with weak-load limit

$$\frac{\delta\omega}{\omega} \approx -\alpha\Lambda(x). \tag{2}$$

The practical question is whether one can place a nearby timing or phase-sensitive sensor adjacent to an already existing reconfigurable medium, cycle that medium through graph states that differ strongly in weighted connectivity, and either see a correlated signal or set the first empirical bound on the effective coupling parameters.

The medium chosen here is the tunable superconducting-coupler array. This is attractive not because it is known to instantiate QATNU microphysics, but because it already provides all of the following in real hardware: dynamically programmable couplings, graph-state switching

on nanosecond to sub-microsecond timescales, low total mass change under reconfiguration, and well-developed calibration and readout infrastructure [1, 2, 3].

2 Effective source model

We model the medium by a weighted graph $G = (V, E, w)$ with weighted Laplacian

$$L_w = D - W, \qquad D_{ii} = \sum_j w_{ij}. \tag{3}$$

The scalar load is taken to satisfy the lowest-order screened graph response

$$(\kappa L_w + \mu^2 I)\Lambda = A\rho, \tag{4}$$

with source profile ρ, stiffness $\kappa > 0$, screening scale $\mu \geq 0$, and source amplitude A. The static solution is

$$\Lambda = A(\kappa L_w + \mu^2 I)^{-1}\rho. \tag{5}$$

At a sensor location x outside the chip, the observable timing shift is

$$\Delta y(x) \equiv \frac{\delta\omega(x)}{\omega} \approx -\alpha\Lambda_x. \tag{6}$$

Switching between graph states (G_1, w_1, ρ_1) and (G_2, w_2, ρ_2) gives

$$\Delta y_{12}(x) \approx -\alpha\,\Delta\Lambda_{12}(x), \qquad \Delta\Lambda_{12}(x) = \Lambda_x(G_1, w_1, \rho_1) - \Lambda_x(G_2, w_2, \rho_2). \tag{7}$$

3 Why this medium class is a reasonable first target

Tunable-coupler superconducting hardware is no longer hypothetical. IBM's modified tunable-bus architecture for fixed-frequency transmons reported two-qubit fidelities up to 99.85% and calibration stability over a day [1]. NIST demonstrated a parametric-coupling architecture with 30-ns to 60-ns gate times and fidelities up to about 99.7% on shorter timescales [2]. Rigetti reported multichip tunable-coupler modules explicitly designed to preserve coupling control across chip boundaries [3]. These systems are therefore appropriate not only as quantum-computing hardware but as already-built weighted-graph media with rapid internal reconfiguration.

The experiment proposed here makes the weakest possible ontological commitment:

> *If any graph-structured medium sources timing-first scalar perturbations, then tunable superconducting arrays are a sensible early place to look for them.*

A null result is already valuable because it sets the first medium-class-specific bound on $(\alpha A, \mu, \Gamma)$.

4 Magnitude estimates and the role of screening

4.1 Static branch

For an effectively three-dimensional unscreened branch, the exterior scalar response is assumed to have the Green form

$$G_0(r) \sim \frac{1}{r}, \tag{8}$$

while a screened branch takes the Yukawa form

$$G_\mu(r) \sim \frac{e^{-\mu r}}{r}. \tag{9}$$

Then a vertical timing doublet with baseline $\Delta z \ll r$ has differential signal

$$|\Delta y| \approx \alpha A \frac{\Delta z}{r^2} \qquad (\mu = 0), \tag{10}$$

and

$$|\Delta y| \approx \alpha A \frac{\Delta z}{r^2}(1 + \mu r)e^{-\mu r} \qquad (\mu > 0). \tag{11}$$

The unscreened assumption is therefore doing real work. On tabletop baselines, if $\mu r \gtrsim 1$, the signal is exponentially suppressed. Measuring or bounding μ from the distance law is thus one of the earliest and most important experimental goals.

4.2 Topology versus mass

The topological contribution to the timing signal is

$$\Delta y_{\text{topo}} \sim -\alpha\, \Delta\Lambda_{\text{topo}}, \tag{12}$$

whereas an ordinary Newtonian nuisance from residual effective mass redistribution is of order

$$\Delta y_{\text{mass}} \sim \frac{G\, \Delta M_{\text{eff}}}{c^2 r}. \tag{13}$$

A useful control ratio is therefore

$$R_{\text{topo/mass}} \equiv \left| \frac{\Delta y_{\text{topo}}}{\Delta y_{\text{mass}}} \right| \sim \frac{\alpha c^2}{G} \frac{\delta A_\Lambda}{\delta M}\, f_{\text{topo}}(1 + \mu r)e^{-\mu r}. \tag{14}$$

The experiment is compelling only if its design and controls make a large lower bound on $R_{\text{topo/mass}}$ plausible.

A skeptic is entitled to ask: how do we know that any observed shift is not merely mass redistribution at the G/c^2 level? The answer must be quantitative. One therefore aims for graph-state pairs with nearly identical package geometry and measured power dissipation, while maximizing a graph-theoretic discriminator such as

$$\mathcal{D}(G_1, G_2) = \frac{\|L_{w_1} - L_{w_2}\|_F}{\|L_{w_1}\|_F + \|L_{w_2}\|_F}, \tag{15}$$

so that the internal weighted-graph change is known to be large while conventional mass and geometry changes remain bounded.

5 Sensors: near-term and stretch-goal architectures

The previous draft was too vague on the sensor side. There are really two distinct architectures.

5.1 Near-term architecture: integrated cryogenic phase sensor

The most feasible near-term sensor is not a free-standing optical lattice clock perched above a dilution refrigerator. It is a cryogenic phase-sensitive proxy integrated into the same cryostat: for example, a spectator superconducting qubit operated in Ramsey mode, or a high-Q superconducting resonator whose phase/frequency is monitored relative to a stable external microwave reference. This uses the existing cryogenic control stack and avoids the immediate engineering problem of placing an optical reference within millimeters of a mK chip.

The merit of this architecture is feasibility. The drawback is that the sensor shares many cryogenic and electromagnetic systematics with the source medium. For that reason it is best treated as a first bound experiment, not as the final word.

5.2 Stretch-goal architecture: external optical timing probe

The cleaner but harder architecture uses an external clock-grade sensor referenced through fiber or free-space optics to a transportable optical clock. This is plausible in principle because transportable Yb optical lattice clocks now exist [5], and cryogenic optical lattice clocks have reached blackbody-shift uncertainties at the 1.7×10^{-20} level [4]. But integrating an optical probe close to a dilution refrigerator while controlling vibration, thermal radiation, and line-of-sight access is a substantial engineering project. It should be described as a follow-on experiment, not the first one.

6 Cryogenic environment as a confound

A serious weakness of any superconducting-medium experiment is the cryogenic environment itself. Switching couplers changes microwave field distributions, dissipates some energy, and can produce transient heating or nonequilibrium excitations. These effects can mimic a timing transient unless they are independently monitored and shown to have incompatible timescales or distance laws.

This is not a speculative concern. Recent work has shown that mechanical bursts and cryostat dynamics can induce correlated errors and nonequilibrium excitations in superconducting qubits on sub-millisecond scales [6]. Thermal engineering can also change reset and relaxation behavior on sub-microsecond to microsecond scales in superconducting circuits [7]. These are exactly the kinds of tails one must not confuse with a scalar-load transient.

The correct strategy is therefore differential. For every candidate timing channel, one runs in parallel:

1. a chip thermometry channel,
2. a microwave photon-noise/background channel,
3. a pulse-energy accounting channel,
4. and a mechanical/vibration monitor synchronized to the switching sequence.

If a residual timing or phase shift remains after regression against these nuisance channels, and if its relaxation spectrum follows the graph-modal form below rather than the measured thermal channels, the result becomes interesting.

7 Dynamical completion and temporal discriminants

The minimal time-dependent completion is

$$\partial_t \Lambda + \Gamma(\kappa L_w + \mu^2 I)\Lambda = \Gamma A \rho(t), \tag{16}$$

with modal time constants

$$\tau_n^{-1} = \Gamma(\kappa \lambda_n + \mu^2), \tag{17}$$

where

$$L_w \phi_n = \lambda_n \phi_n. \tag{18}$$

Thus graph switching need not produce an instantaneous step; it can produce a relaxation tail whose modal content is inherited from the Laplacian spectrum.

This is a useful extra discriminant because the thermal response of a cryogenic package is governed by entirely different operators: heat capacities, thermal boundary resistances, and phonon or microwave bath couplings. In practice, one compares the measured residual transient to both (i) a fitted thermal model and (ii) the graph-modal ansatz Eq. (17). A signal that fits neither should be discarded. A signal that fits only the thermal model is a nuisance. Only a residual that tracks graph-state changes and whose relaxation spectrum covaries with changes in the graph Laplacian is diagnostic of the scalar hypothesis.

8 Worked example: a 20-node ring versus star

To make the formalism concrete, consider a 20-node array reconfigured between two equal-mass graph states: an unweighted ring C_{20} and an unweighted star S_{20}.

For the ring,

$$\lambda_k^{\text{ring}} = 2 - 2\cos\left(\frac{2\pi k}{20}\right), \qquad k = 0, 1, \ldots, 19. \tag{19}$$

The smallest nonzero eigenvalue is

$$\lambda_1^{\text{ring}} \approx 0.0979. \tag{20}$$

For the star,

$$\text{spec}(L_{\text{star}}) = \{0, 1^{(18)}, 20\}. \tag{21}$$

So the slowest nontrivial mode has

$$\lambda_1^{\text{star}} = 1. \tag{22}$$

Even before assigning a microscopic source map, the dynamical model predicts that the slowest scalar relaxation times differ by roughly a factor of

$$\frac{\tau_1^{\text{ring}}}{\tau_1^{\text{star}}} \approx \frac{\kappa + \mu^2}{0.0979\,\kappa + \mu^2}. \tag{23}$$

In the unscreened or weakly screened regime this can be close to an order-of-magnitude effect. So the ring-to-star switch is not merely a symbolic graph change; it produces a concrete prediction for the transient channel.

For the static channel, let the effective source vector be uniform on vertices, $\rho_i = 1/20$, and define the external scalar proxy by a weighted sum

$$\Lambda_x(G) = B \sum_i \frac{u_i(G)}{r_i}, \qquad u(G) = (\kappa L_w + \mu^2 I)^{-1} \rho, \tag{24}$$

with geometric distances r_i from node i to the sensor and an overall exterior-coupling factor B. Then the formalism produces an explicit graph-pair prediction,

$$\Delta y_{\mathrm{ring-star}}(x) \approx -\alpha B \sum_i \frac{u_i(C_{20}) - u_i(S_{20})}{r_i}. \tag{25}$$

Even if αB is left symbolic, this is already a number once the chip geometry and sensor height are specified. That is enough for a first bound paper.

9 Systematic discriminants

A convincing first-attempt experiment should discriminate the target signal from known nuisances along at least five axes.

1. **Distance law.** The target branch should follow Eq. (11); pure thermal and electromagnetic leakage need not.
2. **Topology toggles at fixed mass.** The signal should correlate more strongly with graph reconfiguration than with monitored mass, power, or geometry changes.
3. **Force-null channel.** A timing residual without corresponding force-level or accelerometric signature distinguishes the hypothesis from standard weak-field GR.
4. **Temporal profile.** The residual transient should fit graph-modal timescales better than measured cryogenic thermal tails.
5. **Blind graph randomization.** Under blinded switching, any true signal should track the actual graph state rather than operator expectation.

10 How medium choice is further filtered by dimensional selection

The dimensional-selection paper identified several failure modes for the Gaussian scaling regime: strong anisotropy, heavy-tailed weight disorder, bottlenecks, near-tree sparsity, and small-world shortcuts. This matters here as an additional filter on medium choice. The best source medium is not merely one that can be reconfigured; it is one whose internal weighted graph plausibly supports an intermediate diffusion window in which a stable effective dimension can be diagnosed. Thus medium selection should be theory-filtered as follows:

> *Prefer media whose internal coupling graph is bounded-degree or effectively bounded-degree, moderately homogeneous under reconfiguration, and not dominated by weight disorder or shortcuts that destroy a clean Gaussian window.*

This links the present bound-setting proposal directly to the dimensional-selection program.

11 What a first bound should report

The point of the experiment is not to announce a new force. It is to report one of the following medium-specific bounds:

$$|\alpha A|_{\text{sc-array}} < \cdots, \tag{26}$$

$$\mu_{\text{sc-array}} > \cdots, \tag{27}$$

$$\Gamma_{\text{sc-array}} < \cdots \text{ or } > \cdots. \tag{28}$$

These should be accompanied by explicit nuisance budgets for heating, microwave background, vibration, and package drift. A null result is already useful, because it constrains the theory for a concrete medium class and guides the next medium-selection paper.

12 Conclusion

The next healthy step in the scalar-projection program is not to declare the correct material ontology. It is to run the first severe experiment on an already existing reconfigurable graph medium and learn from the result. Tunable superconducting arrays are appropriate for this because real hardware already provides programmable couplings, nanosecond to sub-microsecond switching/gate times, and well-developed cryogenic control and readout infrastructure [1, 2, 3]. The hardest remaining problem—identifying a medium whose internal dynamics map convincingly onto the weighted-Laplacian closure—should come after, not before, the first bound paper.

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