# Phase-Locked Quantum-Plasma Processor: Normalized Hamiltonian and Stability Analysis

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**Abstract**

We propose a **non-algorithmic** model of quantum computation based on **phase resonance**, dynamic plasma coupling, and **energy-driven** convergence. Unlike traditional quantum systems that rely on gate logic or adiabatic transitions, this processor guides quantum states into resonant configurations through a normalized Hamiltonian framework. Computational tasks are encoded via external field shaping, and solutions are stabilized by **density-dependent** Lindblad dissipation combined with feedback-induced phase locking. A convergence criterion built on energetic minimization and Floquet stability is introduced. Numerical simulation demonstrates viability for non-Boolean logic processing and opens a pathway toward scalable, **resonance-based** quantum–plasma processors.

## 1 Normalized Formalism

Let the characteristic energy scale be $E_0 = \hbar\,\omega_q$, the time scale $T_0 = 1/\omega_q$, and the spatial scale $L_0$ (e.g. the lattice period). Define normalized variables

$$\tilde{q}_i = \frac{q_i}{L_0}, \qquad \tilde{p}_i = \frac{p_i}{\hbar/L_0}, \qquad \tilde{\rho} = \frac{\rho}{\rho_0},$$
$$\tilde{A} = \frac{A}{E_0}, \qquad \tilde{g} = \frac{g\,\rho_0}{E_0}, \qquad \tilde{t} = \omega_q t.$$

The normalized Hamiltonian reads

$$\tilde{\mathcal{H}} = \sum_i \frac{\tilde{p}_i^2}{2} + \tilde{\lambda}(\tilde{t})\,V(\tilde{q}_i) - \tilde{A}(\tilde{q}_i, \langle\tilde{q}\rangle)\cos\big(\tilde{t} - \tilde{\phi}(\langle\tilde{p}\rangle)\big) + \tilde{g}\,\tilde{\rho}(\tilde{q}_i) + \tilde{\mathcal{H}}_{\text{plasma}}. \tag{1}$$

## 2 Hamiltonian Components

### 2.1 Task Encoding

The external problem shape enters through $\tilde{\lambda}(t)V(q)$. Two useful regimes are

- *Adiabatic:* $\dot{\lambda}/\lambda \ll \Delta_{\min}/\hbar$.
- *Floquet:* $\lambda(t) = \sum_k \lambda_k \cos(\omega_k t)$.

### 2.2 Resonance Lock

Feedback closure is realised via

$$\tilde{A}_i = A_0 + \chi \sum_{j \in \mathcal{N}(i)} f(\tilde{q}_j - \tilde{q}_i), \tag{2}$$

$$\tilde{\phi}_i = \phi_0 + \gamma \sum_j g(\tilde{p}_j - \tilde{p}_i). \tag{3}$$

### 2.3 Quantum–Plasma Coupling

The interaction term is

$$\tilde{g}\,\tilde{\rho}(\tilde{q}_i), \qquad g = e\,\varphi(q), \qquad \nabla^2\varphi = -\rho/\varepsilon_0. \tag{4}$$

For atomic Rydberg implementations a typical range is $g \sim 2\pi \times (0.1\text{–}1)\,\text{MHz}$.

### 2.4 Plasma Hamiltonian

$$\tilde{\mathcal{H}}_{\text{plasma}} = \int d^3x \left[\tfrac{\Pi_\rho^2}{2M} + F(\tilde{\rho}, \tilde{v}, T)\right], \qquad \{\tilde{\rho}, \Pi_\rho\} = 1. \tag{5}$$

Assuming an ideal two-fluid EOS with Debye correction,

$$U = \tfrac{3}{2} k_B T(\rho_e + \rho_i) + \frac{e^2}{8\pi\varepsilon_0} \frac{\rho_e \rho_i}{k_B T}. \tag{6}$$

### 2.5 Lindblad Dissipation

Dissipative convergence is implemented through a Caldeira–Leggett operator

$$\mathcal{L}[\hat{\rho}] = -\frac{i\gamma}{\hbar}[\hat{q}, \hat{p}\,\hat{\rho}] - \frac{2m\gamma k_B T}{\hbar^2}[\hat{q}, [\hat{q}, \hat{\rho}]], \tag{7}$$

with density-dependent $\gamma \equiv \gamma(\tilde{\rho})$.

### 2.6 Readout Operator

Measurement is modelled via

$$\hat{O}_{\text{read}} = \sum_i \kappa_i \hat{q}_i, \qquad \text{solution fixated when } \langle \hat{O}_{\text{read}} \rangle \to 0. \tag{8}$$

## 3 Stability Criterion

Consider small perturbations

$$\tilde{q}_i = \tilde{q}_i^{(0)} + \delta\tilde{q}_i, \qquad \tilde{p}_i = \tilde{p}_i^{(0)} + \delta\tilde{p}_i, \qquad \tilde{\rho} = \tilde{\rho}^{(0)} + \delta\tilde{\rho}.$$

The Jacobian $\mathcal{J}$ obeys $\dot{\boldsymbol{\delta}} = \mathcal{J}\,\boldsymbol{\delta}$; the system converges if $\text{Re}(\lambda_i) < 0$ for all eigenvalues. For periodic drive, diagonalise the Floquet monodromy

$$\mathcal{M}_T = \mathcal{T} \exp\!\left( \int_0^T \mathcal{J}(t)\, dt \right), \tag{9}$$

requiring $|\mu_i| < 1$ for all multipliers $\mu_i$.

## 4 Computation as Resonant Convergence

A valid solution fulfils

$$|\omega_q - \omega_\phi(t)| \leq \delta\omega_{\text{lock}}, \qquad \frac{\mathrm{d}E}{\mathrm{d}t} \to 0^+. \tag{10}$$

## 5 Numerical Illustration

**Figure 1:** Simulated 1D phase locking for $\lambda(t) = t/T_a$, normalised energy convergence, and Floquet eigenvalues showing subunitary decay.

- Initial state: random phase offsets.
- Convergence: $E(t) \to \min$, $(\hat{O}_{\text{read}}) \to 0$.

## 6 Conclusion

The presented framework lays the groundwork for phase-resonant quantum processors with intrinsic energy convergence, replacing gate logic with dynamic resonance, problem encoding with field shaping, and result extraction with state locking.