Phonon Pumping by Modulating the Ultrastrong Vacuum

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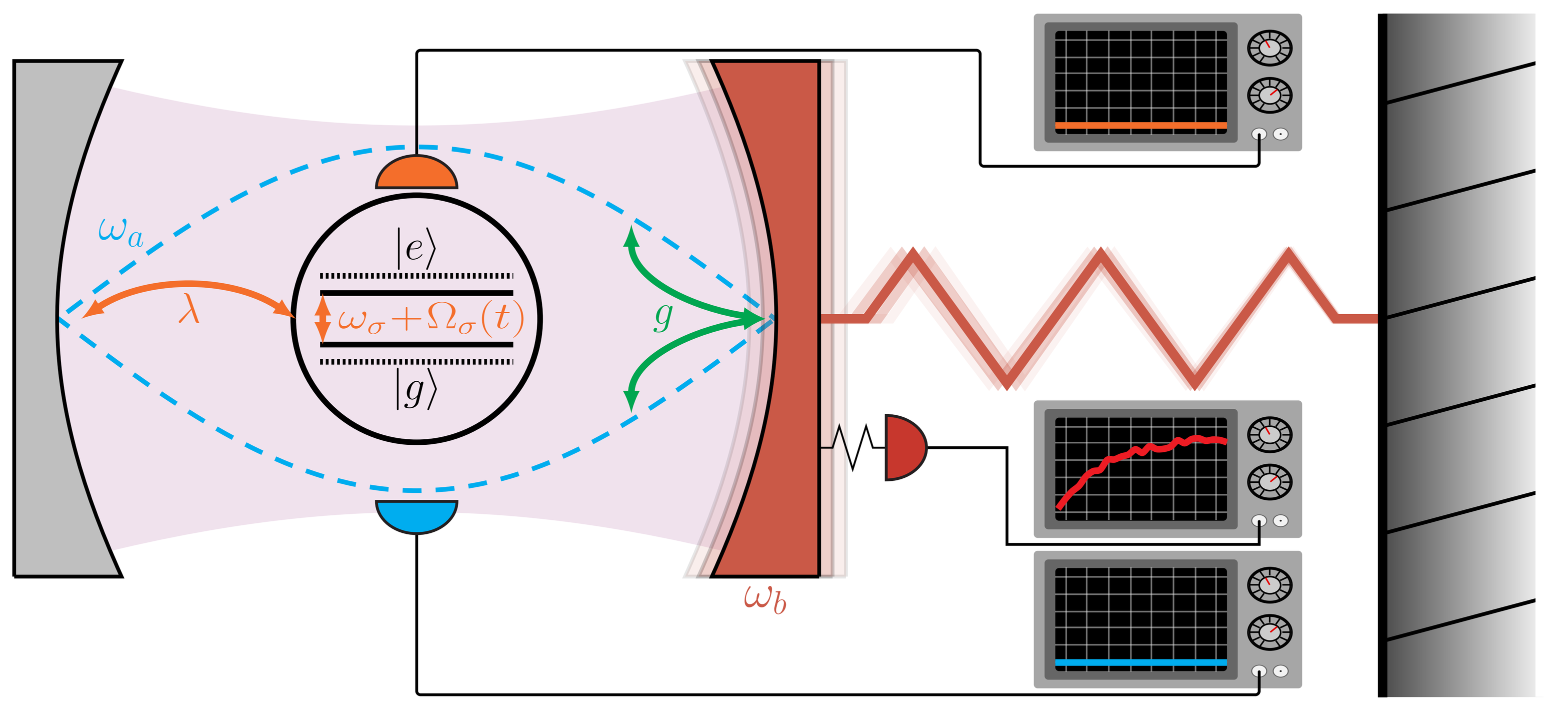
The System



A cavity of frequency ω_a and a qubit of frequency ω_σ, are in ultrastrong coupling (USC). The cavity also interacts with a mirror, whose vibration frequency is ω_b. The frequency of the qubit is adiabatically modulated, and the USC virtual photon population oscillates in time. This causes the mirror to oscillate. Collecting the emission of both the USC systems and of the vibrating mirror, only the latter will produce a signal.

The Model

$$\hat{H}(t) = \hat{H}_{\mathrm{R}} + \hat{H}_{\mathrm{opt}} + \hat{H}_{\mathrm{M}}(t)$$

$$\hat{H}_{\mathrm{R}} = \omega_a \hat{a}^\dagger \hat{a} + \omega_\sigma \hat{\sigma}_+ \hat{\sigma}_- + \lambda(\hat{a} + \hat{a}^\dagger)(\hat{\sigma}_- + \hat{\sigma}_+),$$

$$\hat{H}_{\mathrm{opt}} = \omega_b \hat{b}^\dagger \hat{b} + \frac{g}{2}(\hat{a} + \hat{a}^\dagger)^2 (\hat{b}^\dagger + \hat{b})$$

$$\hat{H}_{\mathrm{M}}(t) = \frac{1}{2}\Delta_\omega \left[1 + \cos(\omega_d t)\right] \hat{\sigma}_+ \hat{\sigma}_- = \Omega_\sigma(t) \hat{\sigma}_+ \hat{\sigma}_-$$

The system evolves according to the Lindblad master equation

$$\dot{\hat{\rho}} = -i\left[\hat{H}(t), \hat{\rho}\right] + (1 + n_{\mathrm{th}})\gamma_b \mathcal{D}\left[\hat{b}\right]\hat{\rho} + n_{\mathrm{th}}\gamma_b \mathcal{D}\left[\hat{b}^\dagger\right]\hat{\rho} + \gamma_{\mathrm{D}} \mathcal{D}\left[\hat{b}^\dagger \hat{b}\right]\hat{\rho}$$

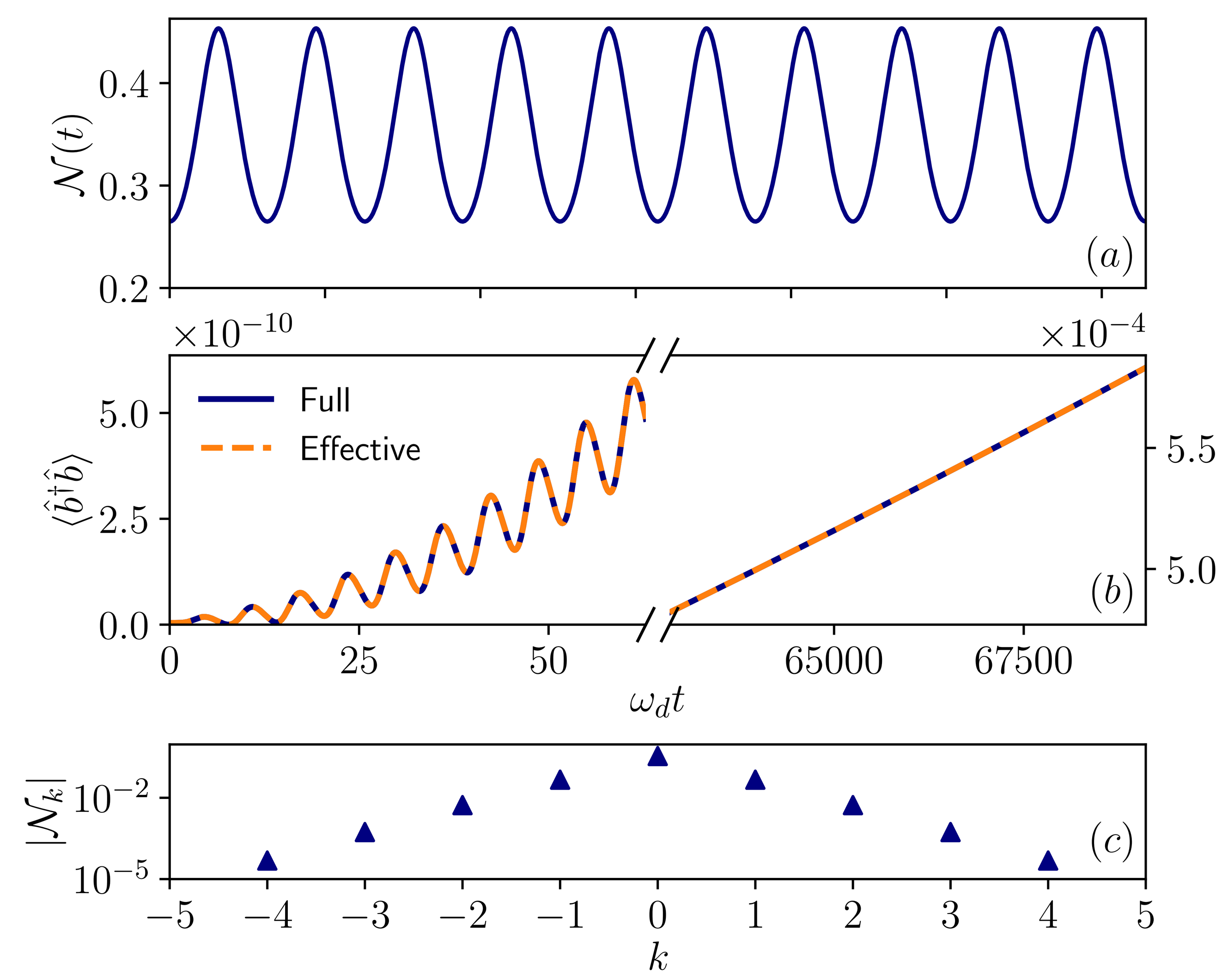
Dispersive Approximation

In the regime $g \ll \omega_d \simeq \omega_b \ll \omega_a \simeq \omega_\sigma$, the entanglement between the mechanical motion and the USC subsystem is negligible, and the state of the system can be factored as $|\Psi(t)\rangle \simeq |\psi(t)\rangle \otimes |\phi_b(t)\rangle$, where $|\psi(t)\rangle$ and $|\phi_b(t)\rangle$ are the USC and mirror states, respectively. The mechanical Hamiltonian becomes

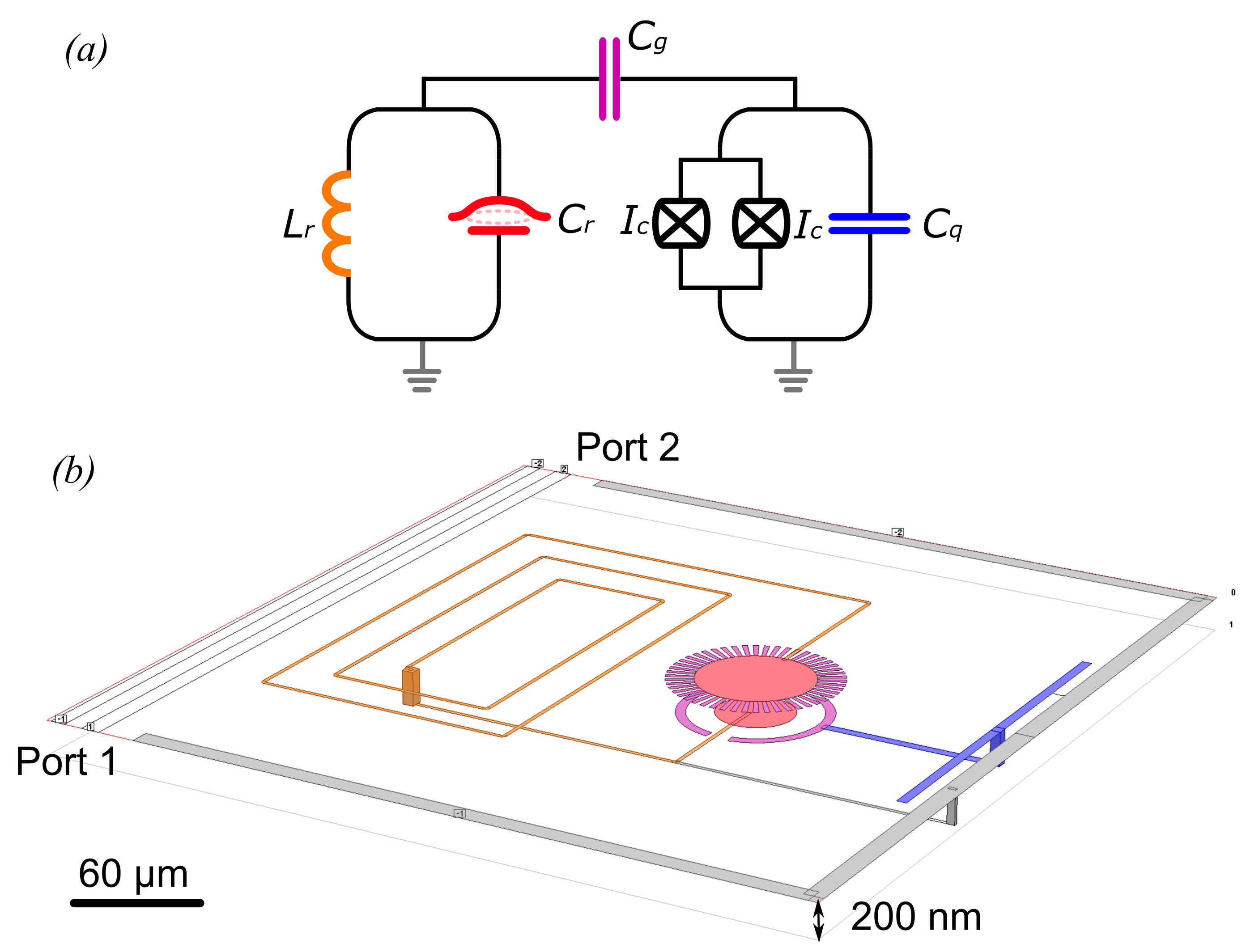
$$\hat{H}_b(t) = \langle \psi_0(t) | \hat{H}_{\mathrm{opt}} | \psi_0(t) \rangle = \omega_b \hat{b}^\dagger \hat{b} + \frac{g}{2} \mathcal{N}(t) \left(\hat{b} + \hat{b}^\dagger\right) ,$$

with $\boldsymbol{\mathcal{N}}(t) = \langle \psi_0(t) | 2\hat{a}^\dagger \hat{a} + \hat{a}^2 + \hat{a}^{\dagger 2} | \psi_0(t) \rangle$

Results



Experimental Proposal



References