Quantum memcapacitance and thermometry with artificial two levels system

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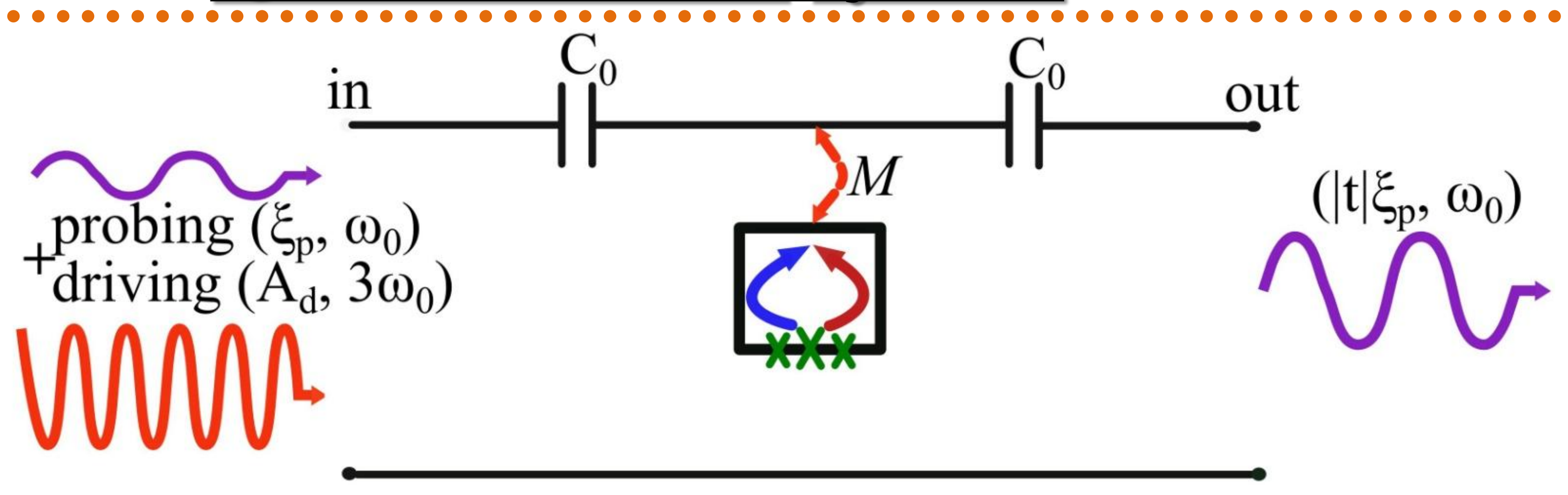
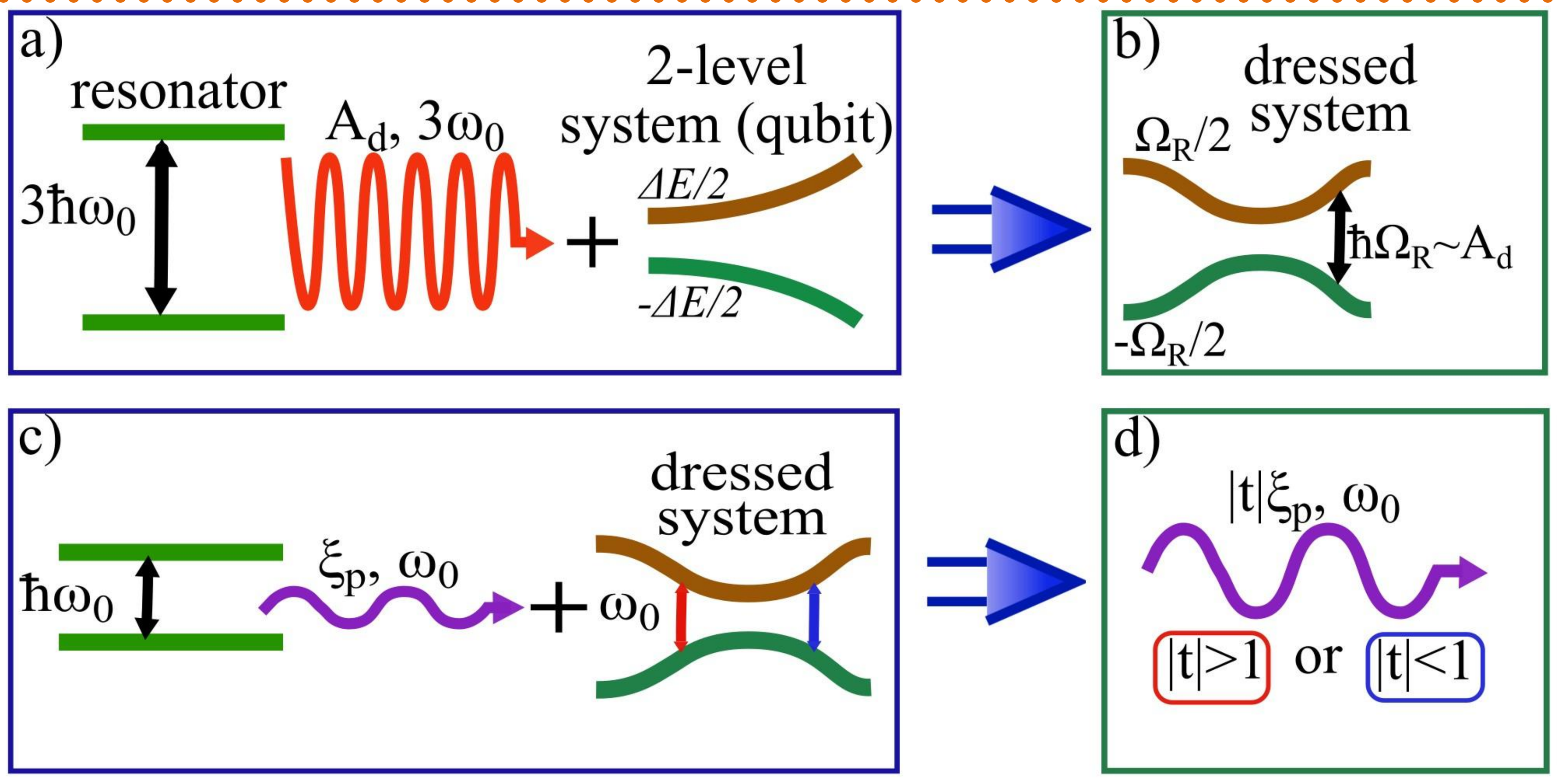
Qubit-resonator system



Qubit in the resonator (example)

One of the most intriguing and counterintuitive phenomena in the fields of atomic physics and quantum optics is lasing. Recently there have been a number of experimental demonstrations of lasing and population inversion in superconducting systems. We study lasing in the strongly driven qubit-resonator system[1,2,3].

Processes in the system



The interaction of the qubit and the resonator can be considered as the interaction of the atom with a two-mode field.

A high-amplitude signal of the resonator interacts with the qubit. The dressed qubit can amplify or attenuate output signal.

Theoretical model

Lindblad equation

$$\dot{\rho} = -\frac{i}{\hbar}[H',\rho] + \kappa D[\sigma]\rho + \Gamma_1 D[\sigma]\rho + \frac{\Gamma_\phi}{2} D[\sigma_z]\rho,$$

$$H'/\hbar = (\delta\omega_r + \chi\hat{\sigma}_z)\hat{a}^\dagger\hat{a} + (\delta\omega_q + \chi)\hat{\sigma}_z/2 + \xi(\hat{a}^\dagger + \hat{a}) + \Omega(\hat{\sigma} + \hat{\sigma}^\dagger)/2,$$

$$D[B]\rho = (N_B + 1)\left(B\rho B^\dagger - \frac{1}{2}\{B^\dagger B, \rho\}\right) + N_B\left(B^\dagger \rho B - \frac{1}{2}\{BB^\dagger, \rho\}\right) \quad B = \sigma_z, \sigma, a$$

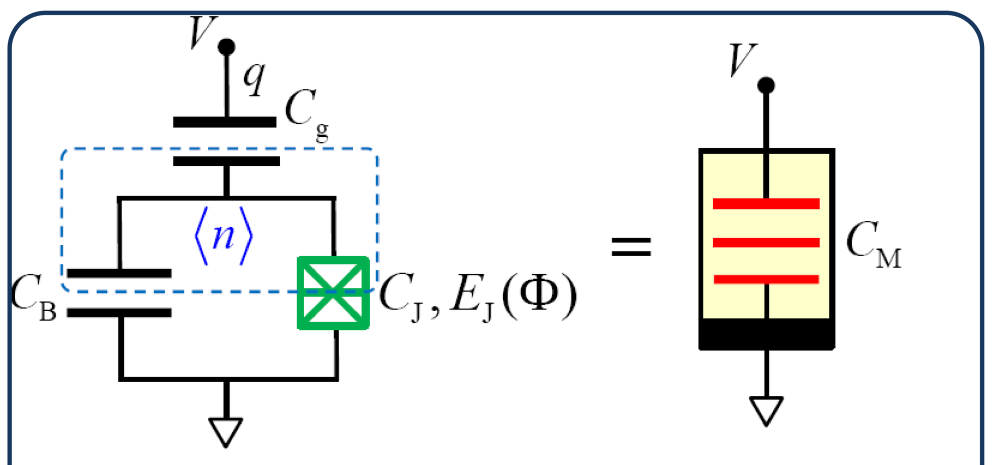
$$N_a = \left(\exp\left[\frac{\hbar\omega_r}{k_B T}\right] - 1\right)^{-1}, \quad N_{\sigma,\sigma_z} = \left(\exp\left[\frac{\hbar\omega_q}{k_B T}\right] - 1\right)^{-1}$$

Consider now the sensitivity of the system to the changes of temperature. ***How the behavior of the observables changes? Is this useful for a single-qubit thermometry?***

To respond to such questions, we describe below both dynamical and stationary behavior for non-zero temperature.

Transmission amplitude

$$A = \sqrt{I^2 + Q^2} = 2V_0 |\langle a \rangle|,$$
$$I = 2V_0 \,\mathrm{Re}\langle a \rangle, \quad Q = 2V_0 \,\mathrm{Im}\langle a \rangle$$



A transmon and a memcapacitor

For the transmon-resonator system:

$$V = \langle \hat{V} \rangle = V_{\rm rms}\langle a e^{-i\omega t} + a^\dagger e^{i\omega t}\rangle = 2V_{\rm rms}\mathrm{Re}\langle a e^{-i\omega t}\rangle$$

$$q = C_{\rm geom}V + \frac{C_g}{C_\Sigma}2e\langle n \rangle \equiv C_M V \qquad \langle n \rangle = const \times \langle \sigma_y \rangle.$$

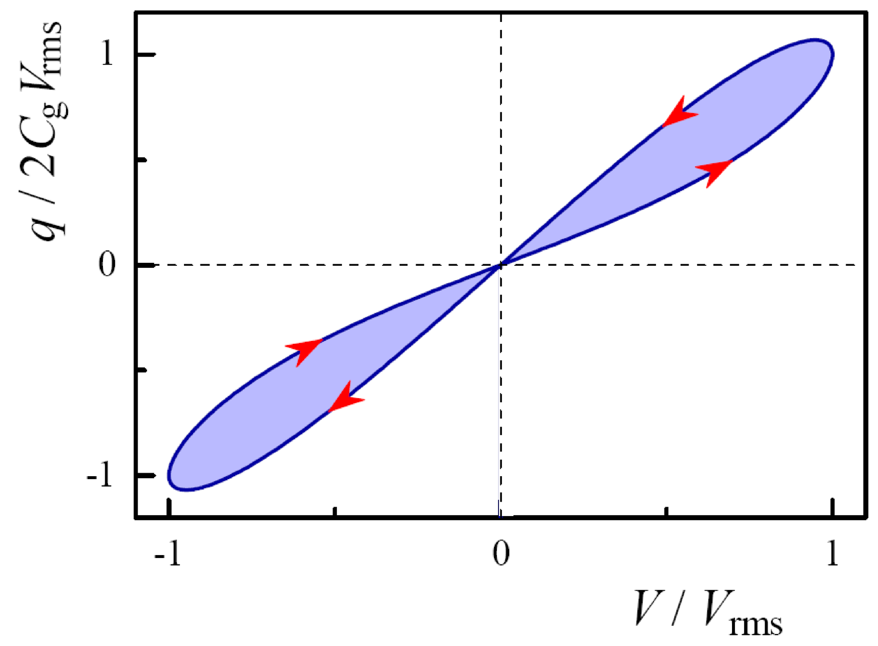
which corresponds to Eq. (1). In place of Eq. (2), we have the master (Lindblad) equation, which defines

Memcapacitor is described by the two relations:

$$q(t) = C_M(\mathbf{x}, V, t)\, V(t), \quad (1)$$
$$\dot{\mathbf{x}} = f(\mathbf{x}, V, t). \quad (2)$$

$$\bar{q} = \underbrace{\mathrm{Re}\langle a \rangle}_{I} \cos\omega t - \underbrace{\mathrm{Im}\langle a \rangle}_{Q} \sin\omega t + \lambda\langle \sigma_y \rangle,$$

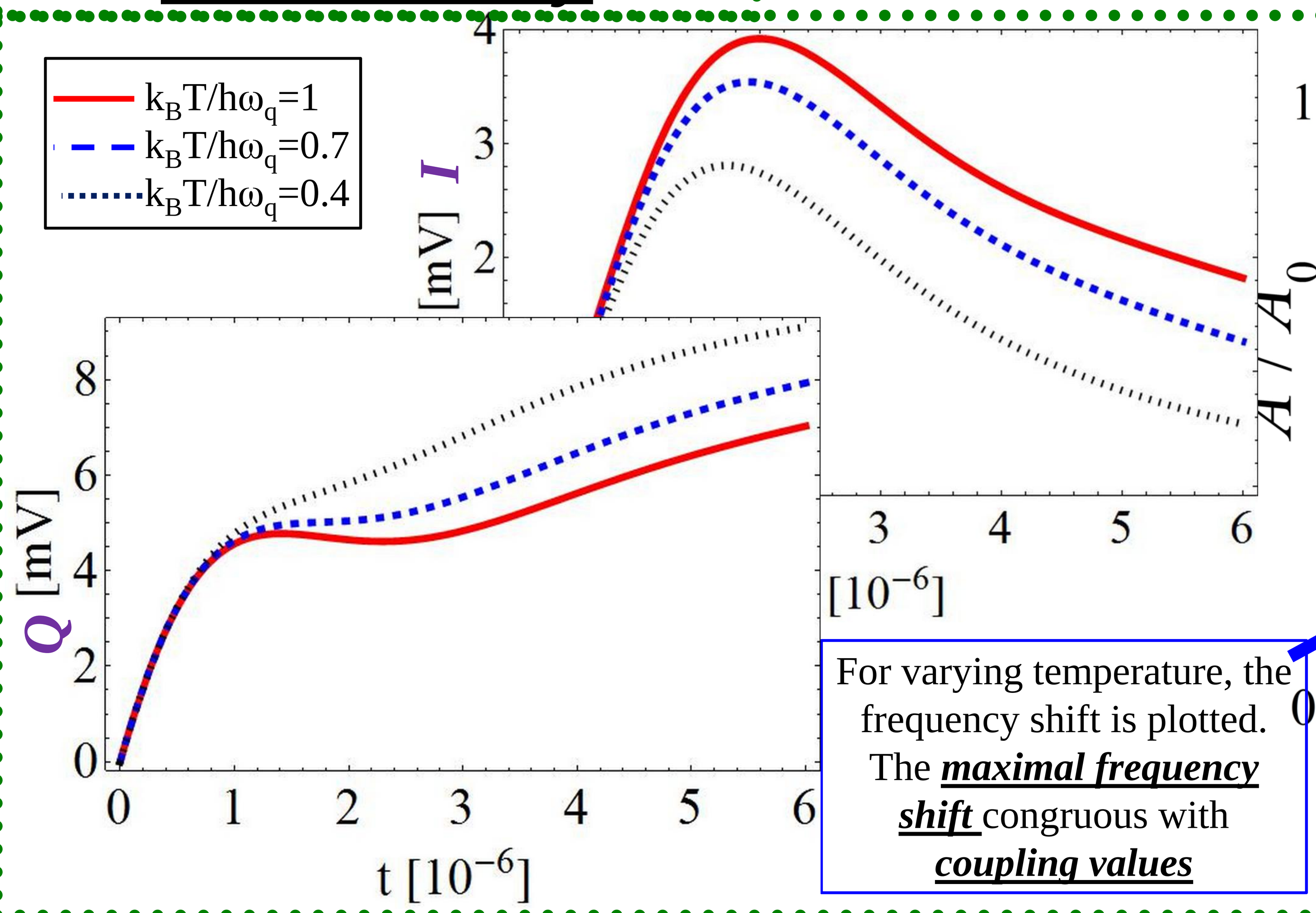
The memcapacitor's dynamics is defined by resonator and qubit, via $\langle a \rangle$ and $\langle \sigma_y \rangle$.



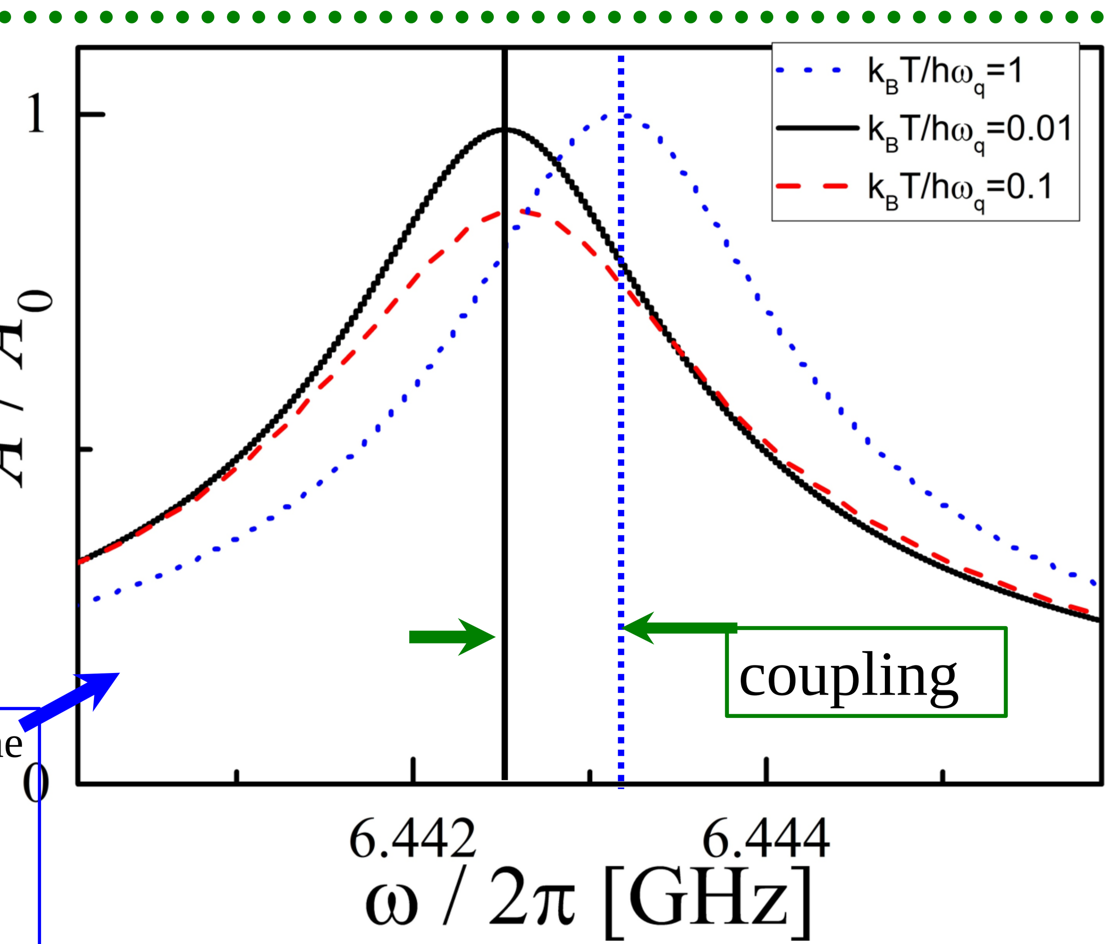
Pinched-hysteretic as a fingerprint of a memcapacitive behaviour

Quantum memcapacitance

Thermometry



For varying temperature, the frequency shift is plotted. The ***maximal frequency shift*** congruous with ***coupling values***



We plot the time evolution of the quadratures for the real parameters[4] take into account non-zero T. The figure demonstrates that both ***evolution and stationary values*** (at long times, independent of initial conditions) ***are strongly temperature dependent.***

[1] S.N. Shevchenko, G. Oelsner, Ya.S. Greenberg, P. Macha, D.S. Karpov, M. Grajcar, U. Hubner, A.N. Omelyanchouk, E. Il'ichev, Phys. Rev. B **89**, 184504 (2014).
[2] D. S. Karpov, G. Oelsner, S. N. Shevchenko, Ya. S. Greenberg, E. Ilichev, Low Temp. Phys. **42**, 189 (2016).
[3] P. Neilinger, S. N. Shevchenko, J. Bogár, M. Rehák, G. Oelsner, D. S. Karpov, U. Hübner, O. Astafiev, M. Grajcar, E. Il'ichev, Phys. Rev. B **94**, 094519 (2016).
[4] R. Bianchetti, S. Filipp, M. Baur, J. M. Fink, M. Göppl, P. J. Leek, L. Steen, A. Blais, and A. Wallraff, Phys. Rev. A **80**, 043840 (2009).

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