Resolving photon number states in a superconducting circuit

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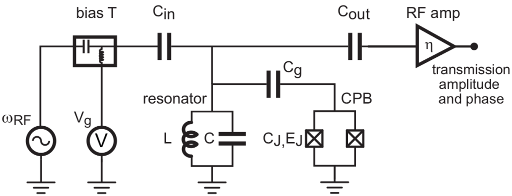
The paper

This is for paper [1]

Measurement

In the experiment, the transmitted amplitude at frequency ω_{rf} is the main observable. The exact way to measure it is not mentioned in this paper, but can be check in Schuster's thesis: [2].



- What we really measure is the expectation of the voltage, or electrical field $E \propto \langle a + a^{\dagger} \rangle$

Property of the cavity: Analytical

- Without the qubit, the cavity state is equivalently a damped harmonic oscillator with driving

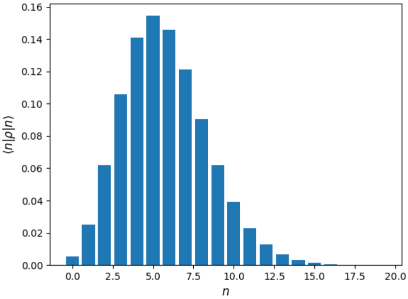
$$H = \delta a^\dagger a + \epsilon(a + a^\dagger)$$

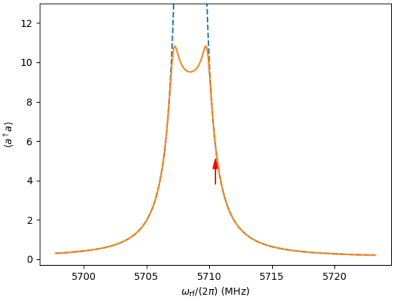
  Collapse operators: $\sqrt{\kappa(n_{\text{th}} + 1)}a$ and $\sqrt{\kappa n_{\text{th}}}a^\dagger$
- When it's off resonant, its steady state is not but approximately a coherent state
- Analytically the photon number expectation value is

$$\bar{n} = \frac{\epsilon^2}{\delta^2 + \kappa^2/4} + n_{\text{th}}$$

Property of the cavity: Numerical

- Numerically, a truncate on fork space is needed
- To check the validity of the truncate, we plot the photon distribution and frequency response of the cavity.

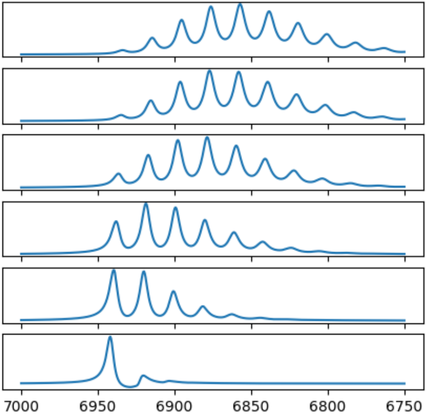


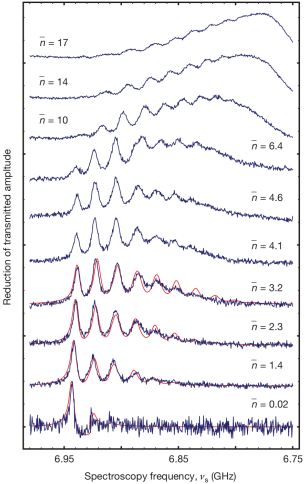


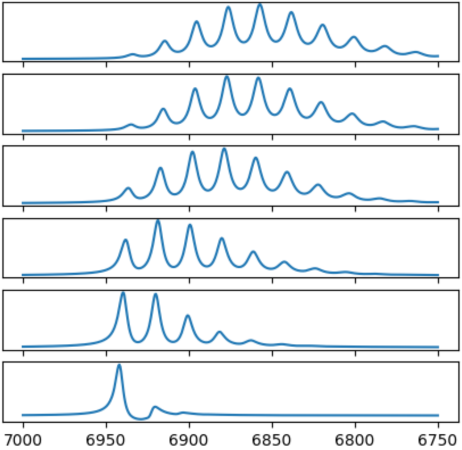
Direct spectroscopic observation of quantized cavity photon number

- For a fixed driving ϵ_{rf}, plot the $V_0 - \langle a^\dagger + a \rangle_{ss}$ v.s. ω_s.

$$\bar{n} = n_{th} + \frac{\epsilon_{\text{rf}}^2}{\delta^2 + \kappa^2/4}$$



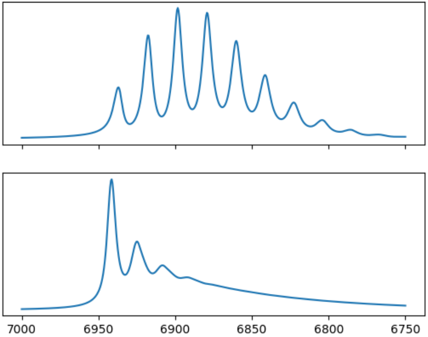


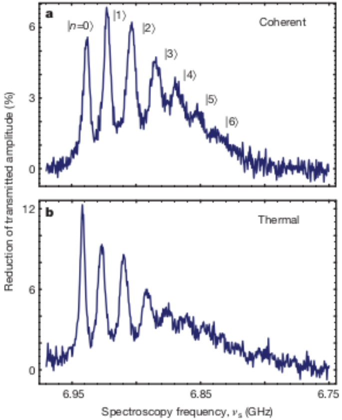


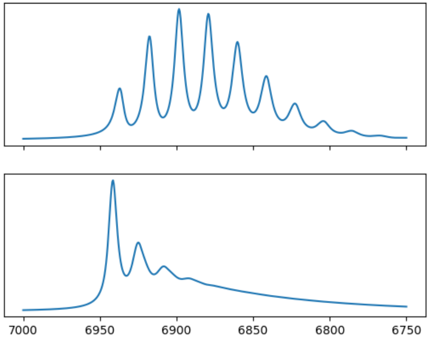
- The way $\bar{n}$ is defined is larger than ours.

Thermal Drive

- Thermal Drive is equivalent to setting n_{th} in collapse operator to the driving average, with small ϵ_{rf} to show the phase lock-in at the given frequency.







- Note that there's no thermal drive theory fitting. Our results tracks fewer peaks, but this depends on how they do the measurement, which is not mentioned in the paper.

Discussion: The picture of what happens

- The peaks shows discreteness in the photon state in the cavity.
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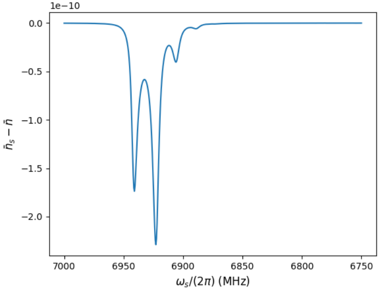
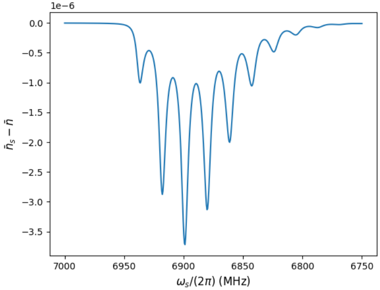
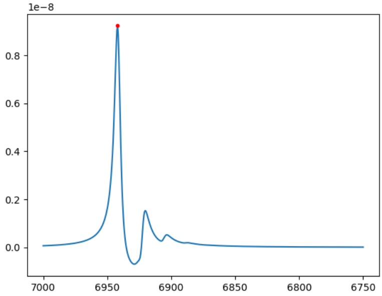
- Exciting the qubit making the cavity off-resonance, which results in the reduction? **NOT TRUE**
- Expected photon number increases at the peaks!

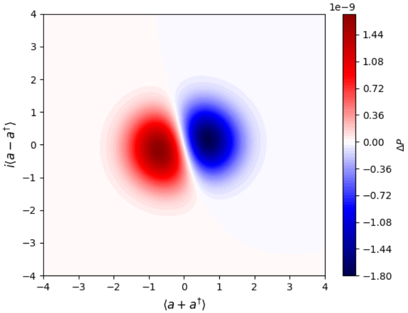




What happens

- Excitation of the qubit is not the dominant effect, but the polarization of the qubit, which twists the cavity photon state.
- This can be shown from the difference of the Wigner function (quasiprobability distribution on phase diagram) with/without the signal field.





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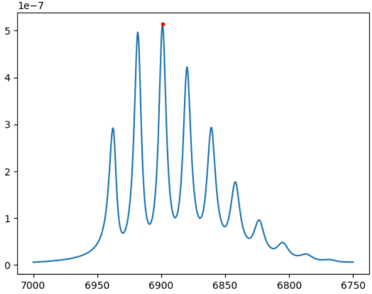

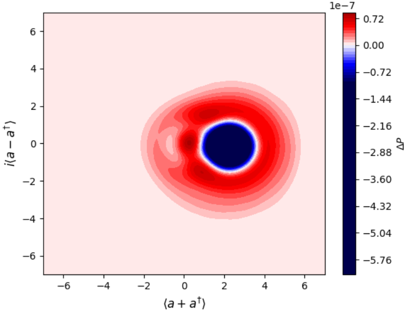

Reference I

DI Schuster, AA Houck, JA Schreier, A Wallraff, JM Gambetta, A Blais, L Frunzio, J Majer, B Johnson, MH Devoret, et al.
Resolving photon number states in a superconducting circuit.
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