When is an RF SQUID in the Quantum Limit?

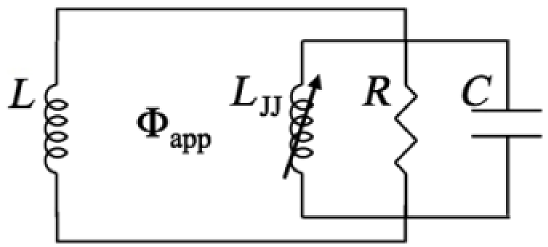
SQUID = Superconducting Quantum Interference Device

RF SQUID: a superconducting loop (inductance L) interrupted by a single Josephson junction

Magnetic flux Φ_{app} applied to the loop

Josephson junction contributes nonlinear and tunable inductance $L_{JJ} = \frac{\Phi_0}{2\pi I_c \cos\gamma}$

RCSJ model of JJ: shunt capacitance C and resistance R



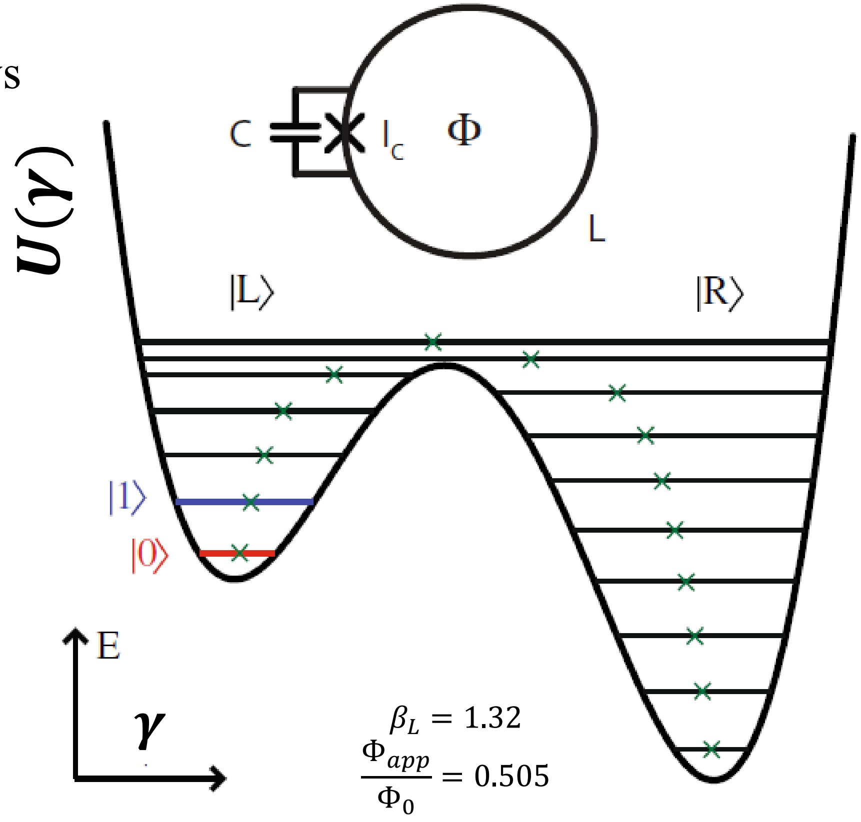
$$U(\gamma) = -\frac{1}{2L}\left(\frac{\Phi_0}{2\pi}\right)^2 \left(\gamma - 2\pi\frac{\Phi_{app}}{\Phi_0}\right)^2 - E_J \cos\gamma \qquad \text{with} \qquad E_J = \frac{\Phi_0 I_c}{2\pi}$$

Un-driven RF SQUID dynamics given by: $\frac{1}{2}C\left(\frac{\Phi_0}{2\pi}\right)^2 \dot{\gamma}^2 + U(\gamma) = 0$

When is the Problem Quantum as opposed to Classical?

Example of quantized energy levels in an RF SQUID near $\frac{\Phi_{app}}{\Phi_0} \approx \frac{1}{2}$

$\beta_L = \frac{2\pi L I_c}{\Phi_0} > 1$ shows two-well minima



D. A. Bennett, *et al.*, Quantum Info Process 8, 217 (2009)

1) Low temperature such that $\boldsymbol{k_B T \ll \hbar\omega_p}$

$$\omega_p = \frac{1}{\sqrt{\left(\frac{1}{L} + \frac{1}{L_{JJ}(T, \Phi_{app})}\right)^{-1} C}}$$

is the plasma frequency of a local well

2) To minimize the effects of loss we also require: $\boldsymbol{Q = \omega_p RC \gg 1}$, in the language of the RCSJ model

3) Intermediate $\beta_L \sim 1 - 3$ so that the potential supports 1 or 2 minima without too high a level density

4) Flux biasing near the half-quantum $\frac{\Phi_{app}}{\Phi_0} \approx \frac{1}{2}$ to create a symmetric double-well

This approach leads to a flux qubit