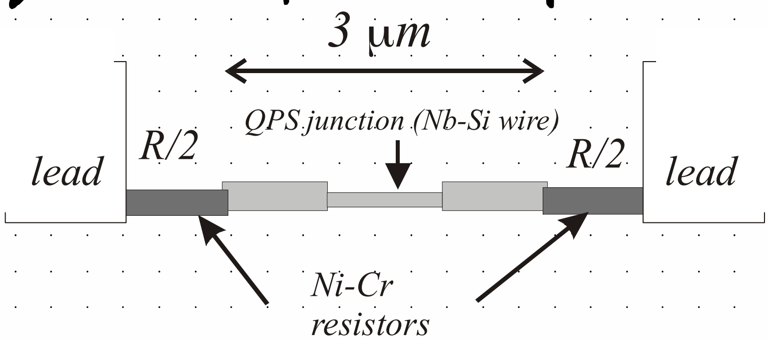
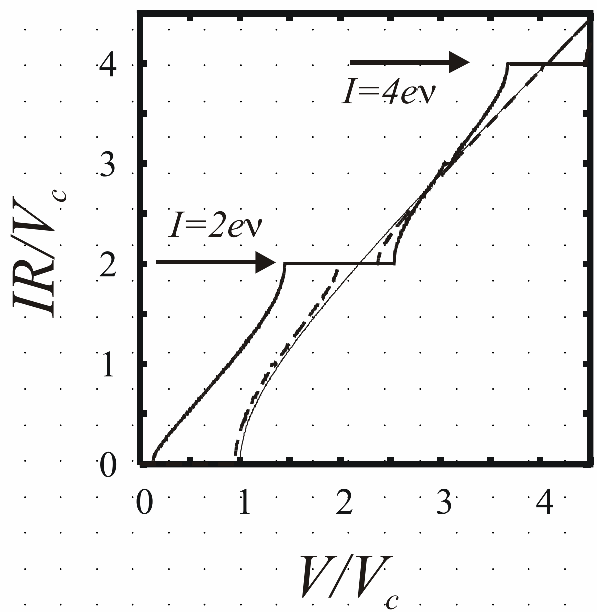
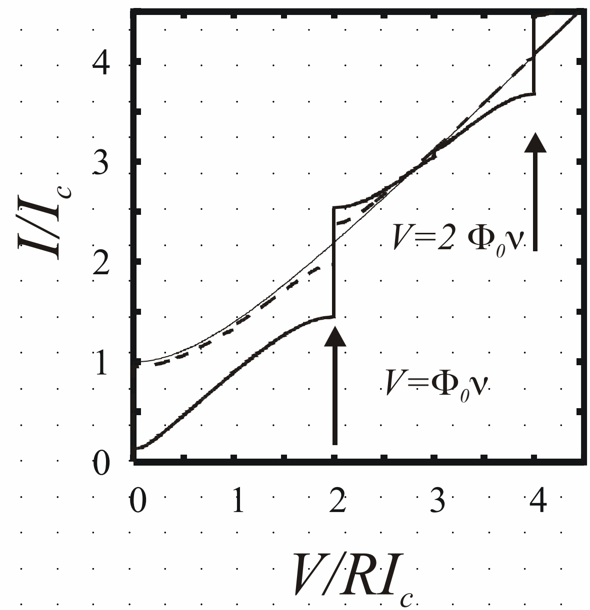
Quantum phase slips in double junction a current standart by gate modulation

Janis Erdmanis

What is a quantum phase slip?

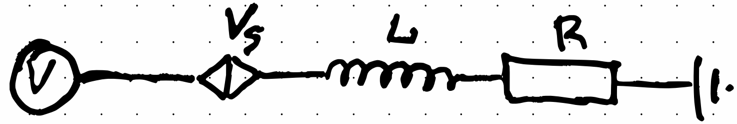






https://arxiv.org/ftp/cond-mat/papers/0511/0511535.pdf

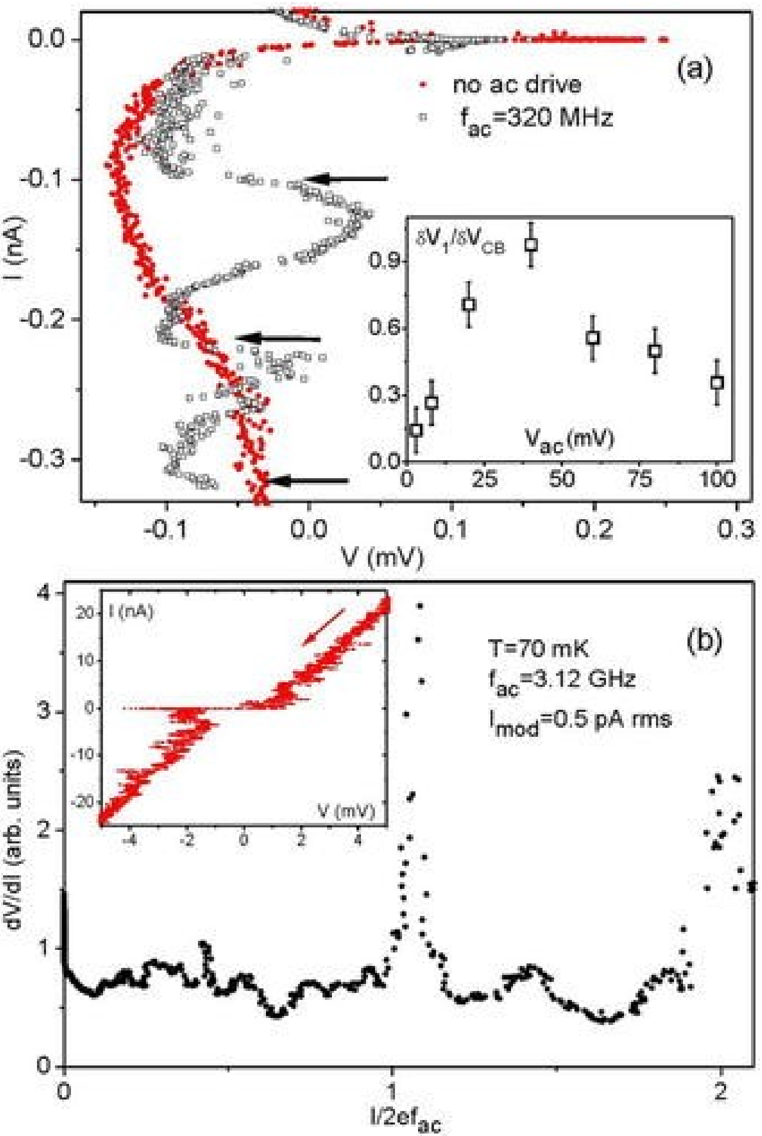
Measuring a phase slip



$$V(t) = V_s \sin\left(\frac{\pi}{e} q\right) + L\frac{d^2q}{dt^2} + R\frac{dq}{dt}$$

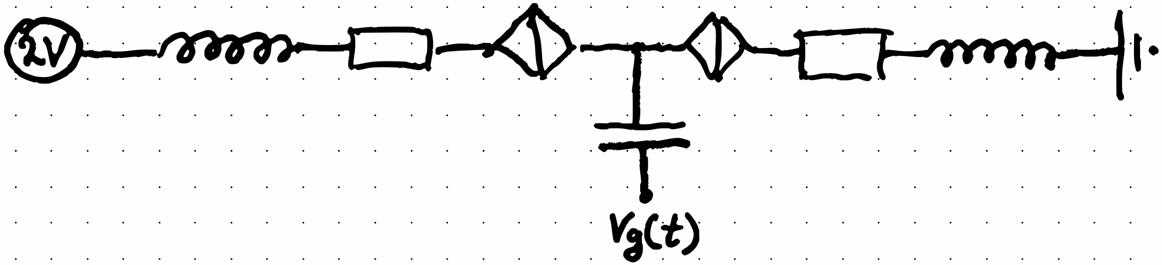
- $E_s \gg E_L$ for the charge to be a relevant quantum variable
- $R \gg L$ for non-hysteretic regime

$$\Rightarrow R = 60\,k\Omega \quad [1]$$



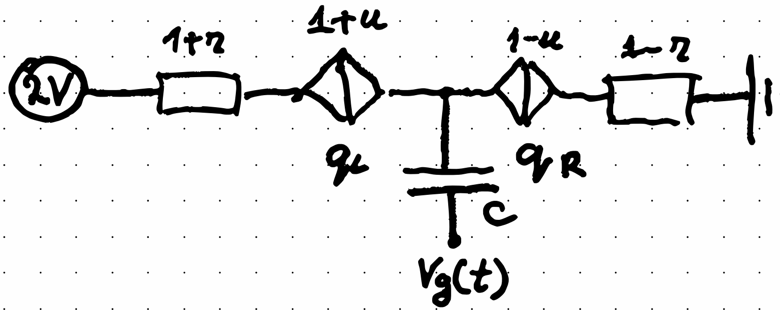
https://aip.scitation.org/doi/10.1063/1.5092271

The double junction setup



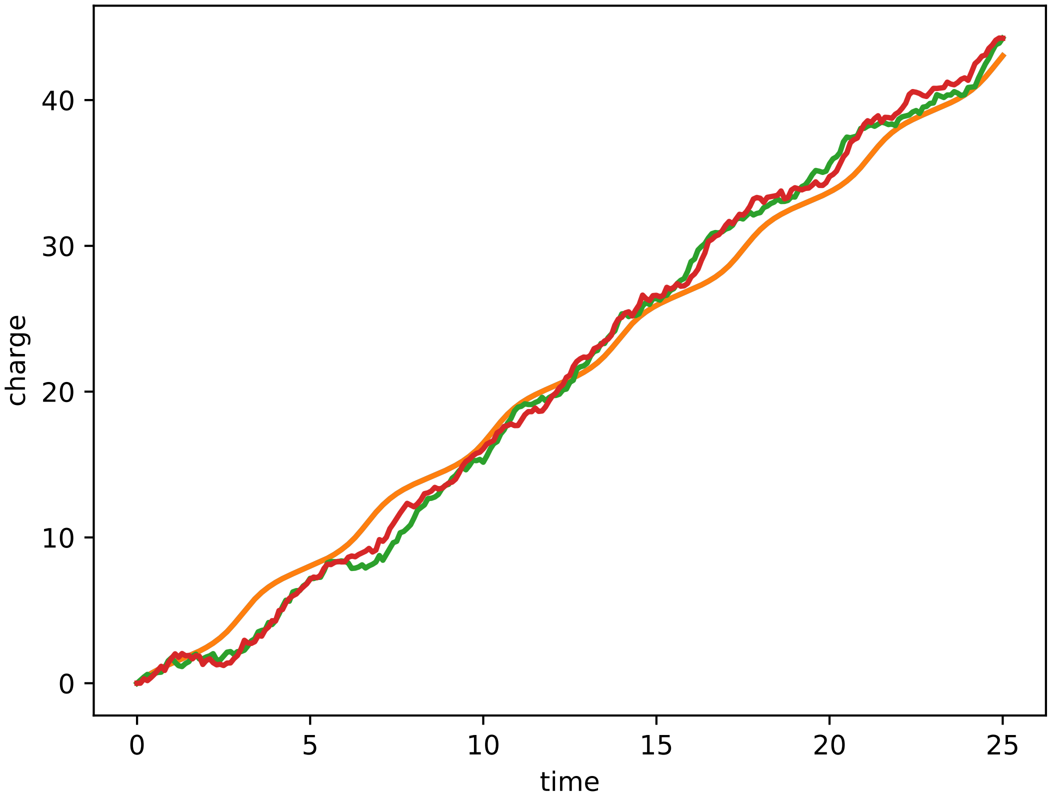
- Since V is constant we no longer need to fight inductivity with current
- The second phase slip allows us to alternate between constructive and destructive interference just by changing a gate voltage

The equations for double junction

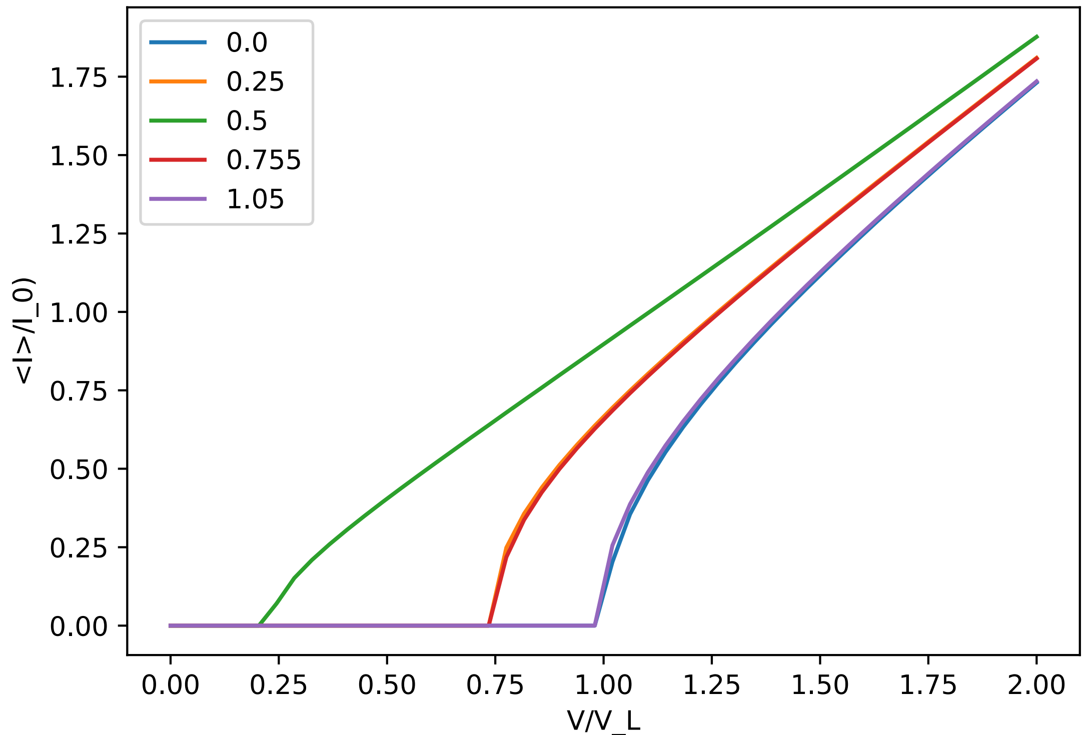


$$
\begin{cases}
\dot{q}_L = \dfrac{1}{1+r}\left(2V - (1+u)\sin q_L - \dfrac{1}{C}(q_L - q_R) - V_g(t)\right) + \text{Noise} \\
\dot{q}_R = \dfrac{1}{1-r}\left(-(1-u)\sin q_R + \dfrac{1}{C}(q_L - q_R) + V_g(t)\right) + \text{Noise}
\end{cases}
$$

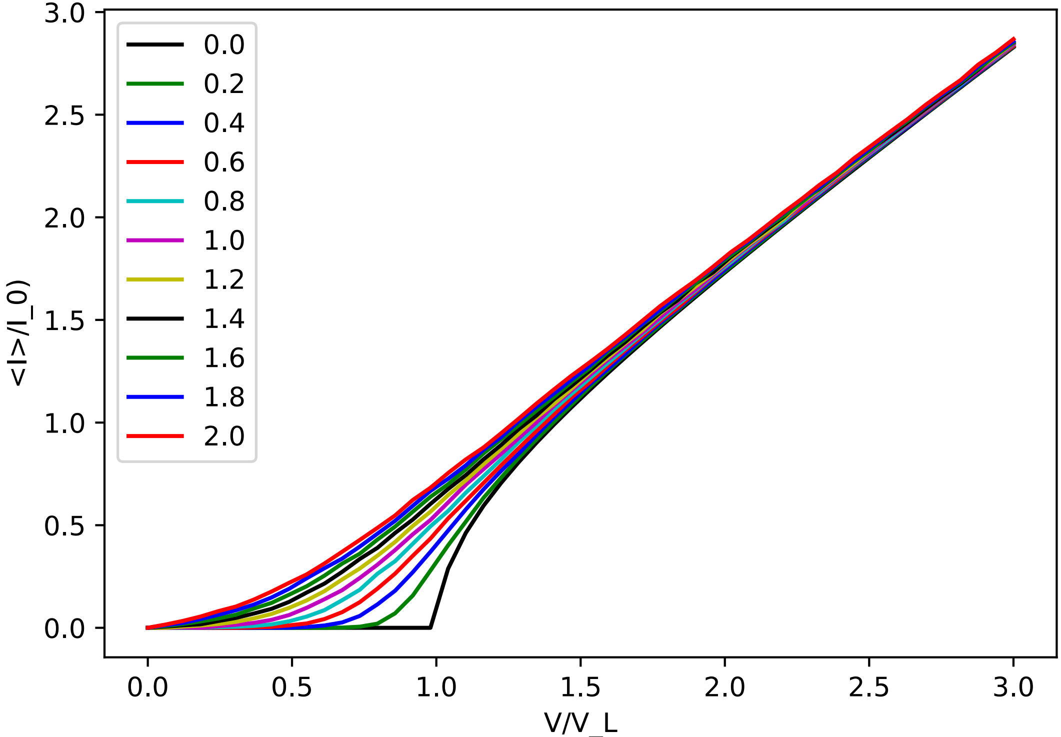
Numerical solution for charge



Average current as function of gate voltage

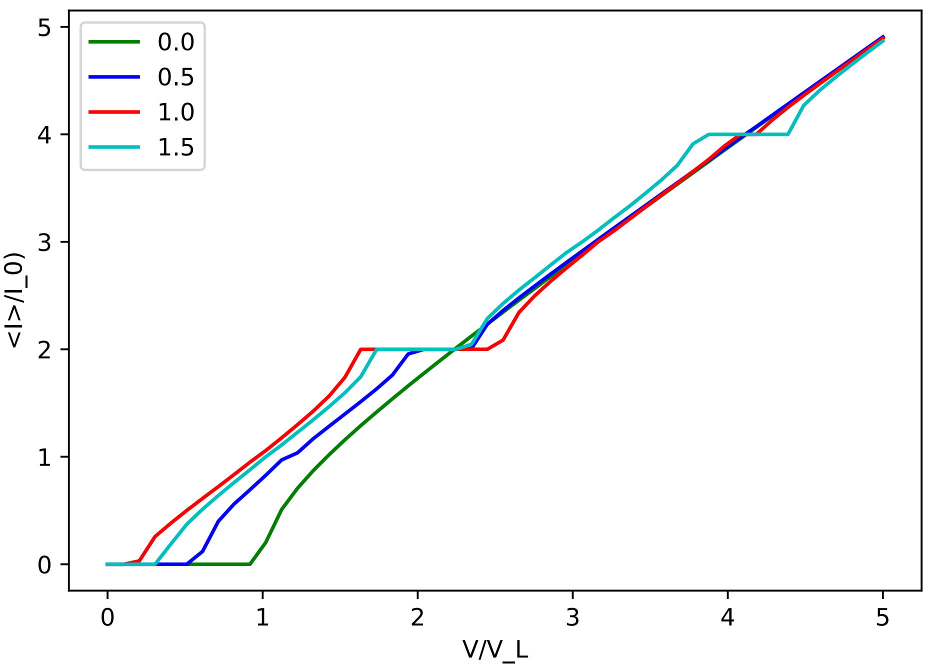


Effect of temperature on double phase slip system

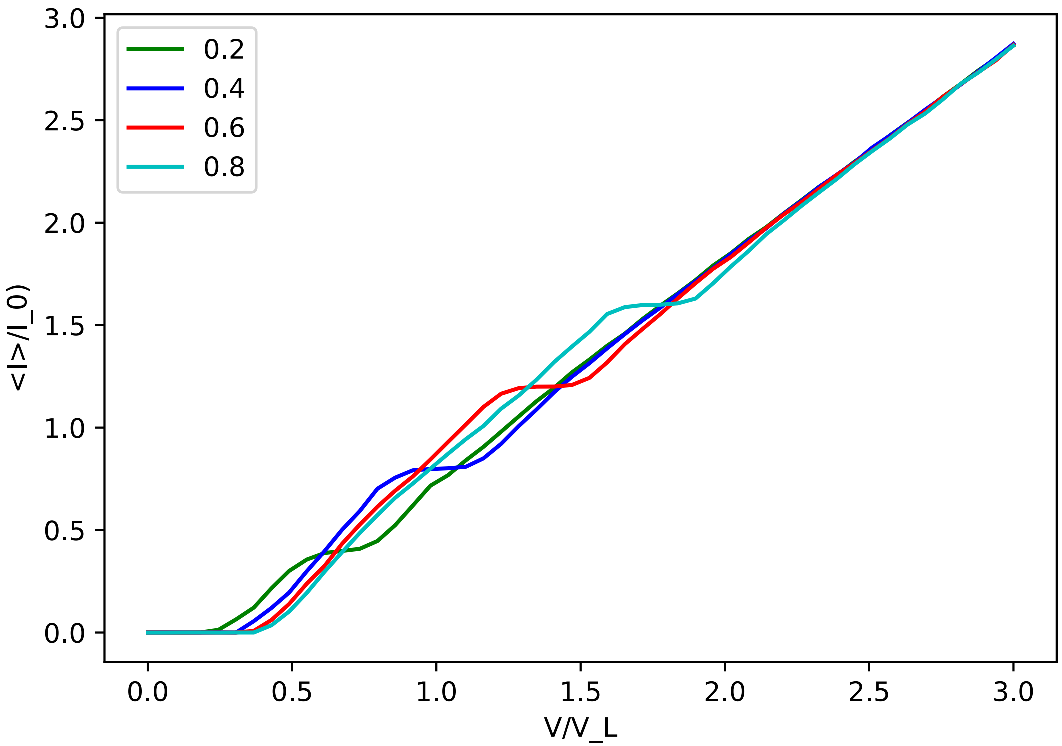


Harmonic modulation of gate voltage

Any nonlinear system with a limit cycle modulated with a signal gives rise to Shaphire steps



The step at finite temperature and difrerent frequencies



The rise of Shaphire steps (theory)

$$\begin{cases} \dot{q}_L = \frac{1}{1+r}\left(2V - (1+u)\sin q_L - \frac{1}{C}(q_L - q_R) - V_g(t)\right) \\ \dot{q}_R = \frac{1}{1-r}\left(-(1-u)\sin q_R + \frac{1}{C}(q_L - q_R) + V_g(t)\right) \end{cases}$$

We shall change variables $q_{L,R} = q \pm \Delta q$ and consider a symmetric setup ($u, r = 0$)

$$\begin{cases} \dot{q} = V - \cos\Delta q \sin q \\ \Delta\dot{q} = \cos q \sin\Delta q - \frac{2}{C}(\Delta q - q_g(t)) \end{cases}$$

rescalled $V_g(t)$

If capacitance is small we can expect $\Delta q = q_g(t)$:

$$\dot{q} = V - \cos q_g(t) \sin q$$

Phase locking and equation for slowly varying phase

$$\dot{q}_* = \nu - w \cdot \sin q_*$$

The solution to this equation is time invariant and thus we have a degenerate solution

$$q_* = q_*\left(t + \frac{1}{\Omega}\varphi\right)$$

Now if we replace $w \to w(t)$ we break the symmetry. That manifests in a slowly varying phase thus

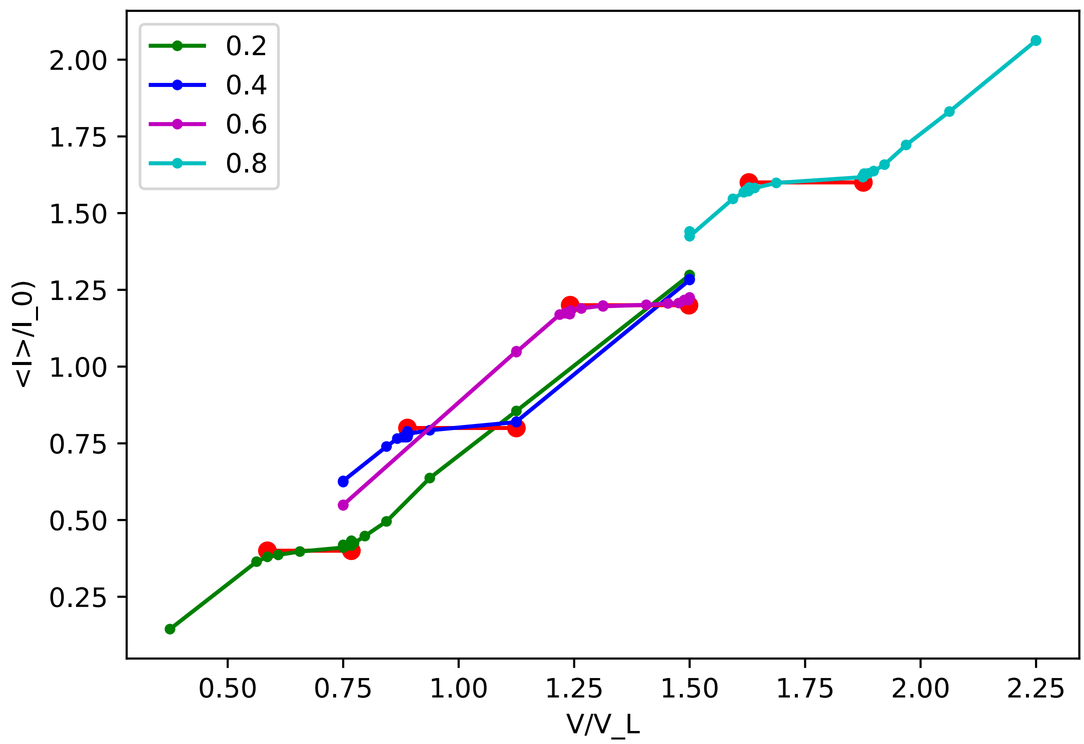
$$q(t) = q_*\left(t + \frac{1}{\Omega}\varphi(t)\right)$$

Plugging it in equation for $\dot{q}$ in case where $\omega = \Omega$ we derive:

$$\dot{\varphi} = \delta\nu + \frac{\Delta\nu}{2}\sin\varphi$$

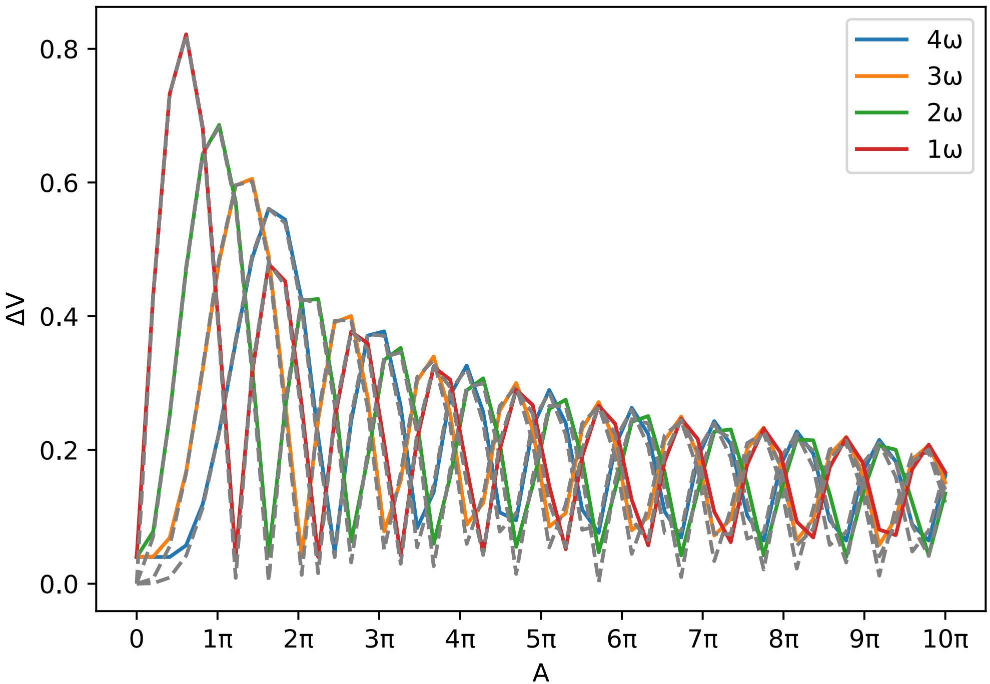
$$|\delta\nu| < \frac{\Delta\nu}{2} \implies \varphi = \varphi(\delta\nu)$$ a phase <u>locking</u>

The step extraction algorithm



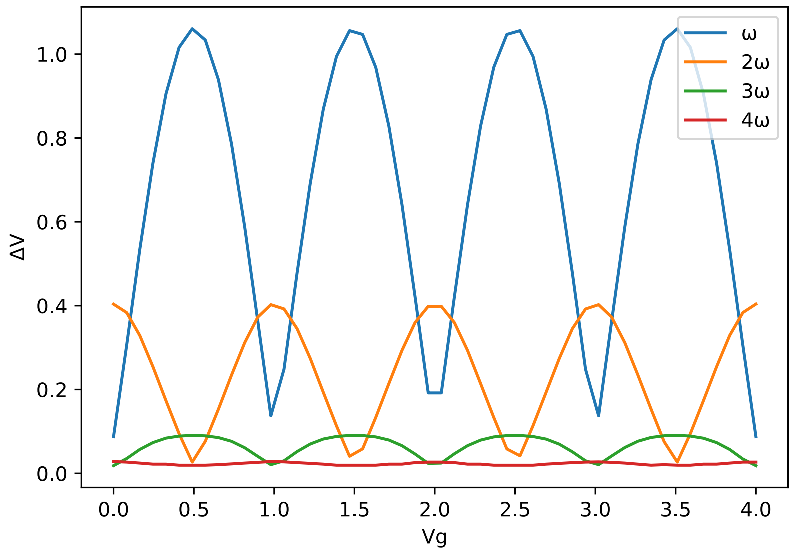
The step width as function of amplitude

$$\Delta V_\kappa = 2\, S_{\kappa\omega,\Omega}\, \mathcal{J}_\kappa(A) \begin{cases} |\cos\varphi_0| & \text{if } \kappa \text{ is even} \\ |\sin\varphi_0| & \text{if } \kappa \text{ is odd} \end{cases}$$



The step width as function of gate voltage

$$\Delta V_\kappa = 2\,\delta_{\kappa\omega,\Omega}\, \mathcal{J}_\kappa(A) \begin{cases} |\cos q_0| & \text{if } \kappa \text{ is even} \\ |\sin q_0| & \text{if } \kappa \text{ is odd} \end{cases}$$



For assymetric setup this dependance fades away

$$|\cos q_0| \to \sqrt{\cos^2 q_0 + u \sin^2 q_0} \qquad |\sin q_0| \to \sqrt{\sin^2 q_0 + u \cos^2 q_0}$$

The raise of fractional steps

$$\begin{cases} \dot{q} = V - \cos\Delta q \sin q \\ \Delta\dot{q} = \cos q \sin\Delta q - \frac{2}{C}(\Delta q - q_g(t)) \end{cases}$$

Previosly we assumed that $\Delta q = q_g(t)$. If capacitance is finite we shall consider correction $\Delta q = q_g(t) + q_c(t)$.

$$\Delta q: \quad \dot{q}_g + \dot{q}_c = -\cos q \sin(q_g + q_c) - \frac{2}{C} q_c$$

$$q_c = -\frac{C}{2}(\dot{q}_g + \sin q_g \cdot \cos q) + O(C^2)$$

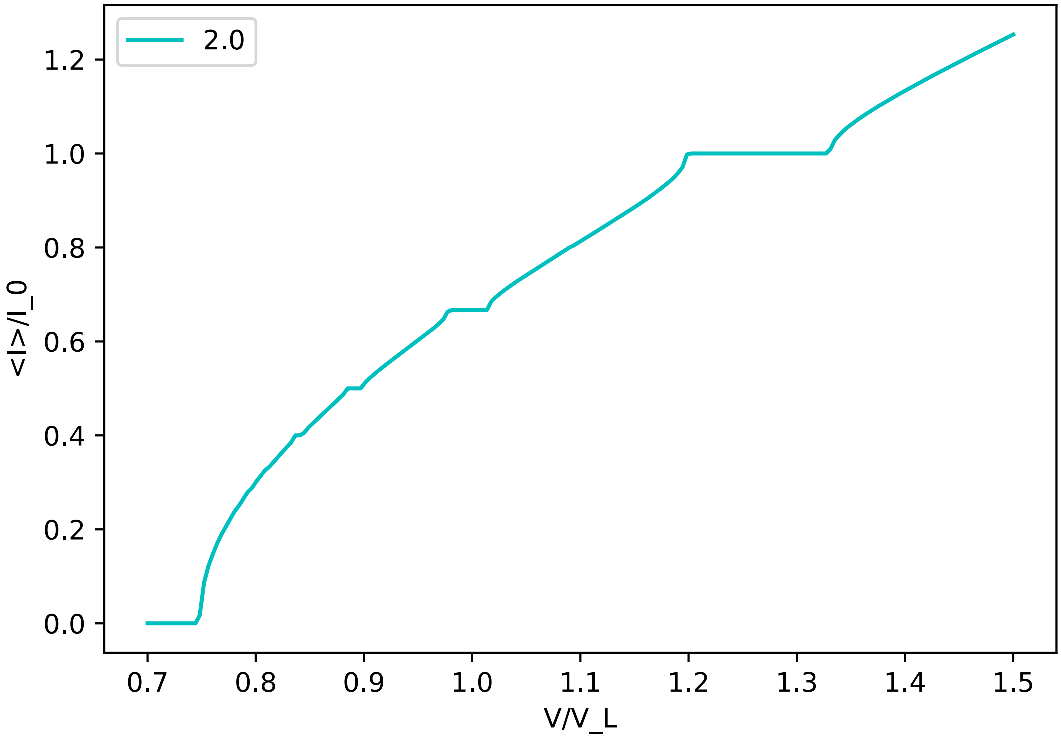
Putting that in equation for q gives us:

$$\dot{q} = V - \cos q_g(t) \cdot \sin q - \frac{C}{4}\sin^2 q_g(t) \cdot \sin 2q$$

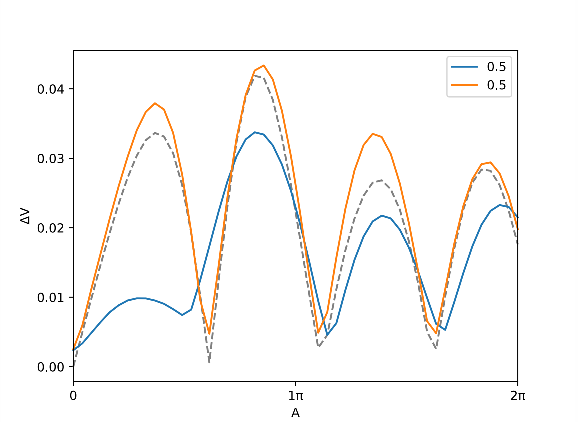
which makes equation for $\varphi(t)$ (if $N\Omega = M\omega$):

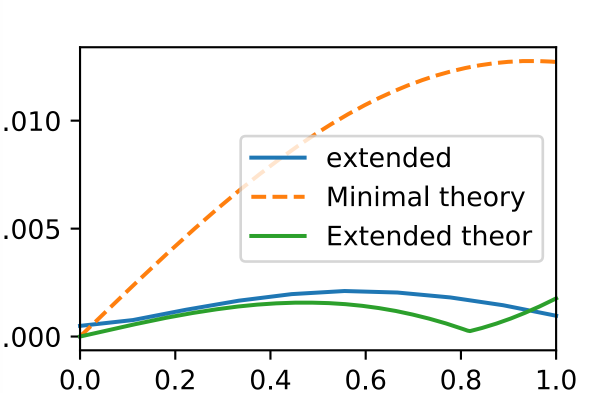
$$\dot{\varphi} = \delta V + \sum_n b_n e^{in\varphi}; \quad \Delta V = (\max_\varphi - \min_\varphi)\left(\sum_n b_n e^{in\varphi}\right)$$

The fractional steps in numerics



Ongoing research





- Finish deriving a formula for fractional steps
- Look into large capacitance limit.