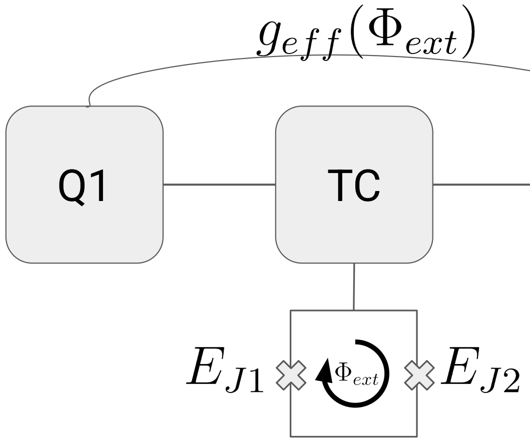
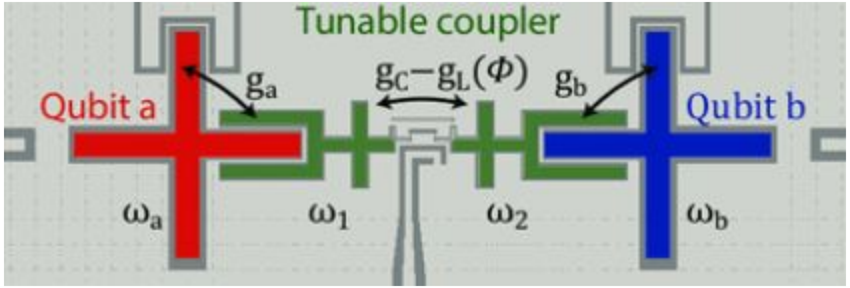
Two-qubit tunable couplers

Danilo Labranca

WP2 Meeting

Simple dc-squid transmon tunable coupler design

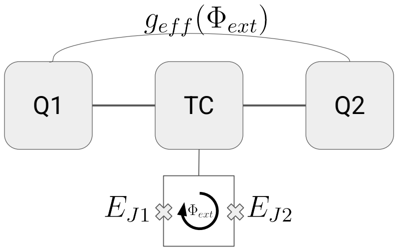




https://doi.org/10.1103/physrevapplied.19.064043

- Coupler's frequency is tunable with flux
- Also the effective coupling strength is tunable

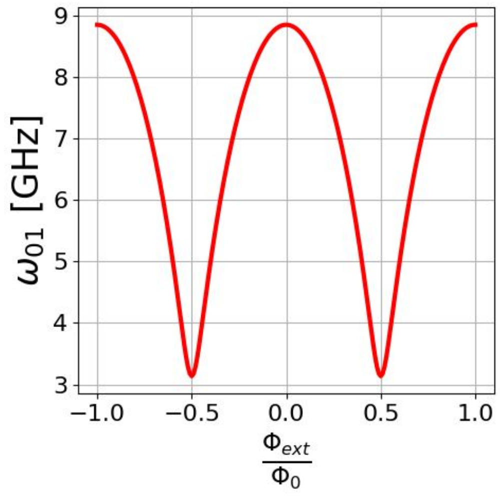
Simple dc-squid transmon tunable coupler

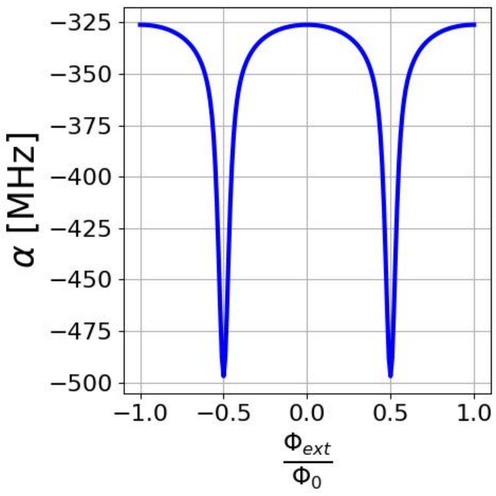


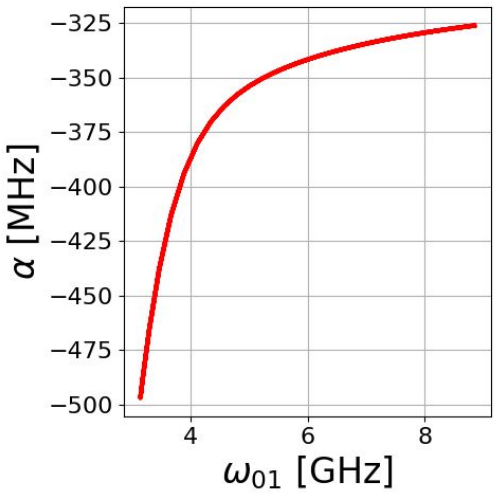
$$g_{eff}(\Phi_{ext}) = g_{1c}g_{2c}\left(\frac{1}{\Delta_{1c}(\Phi_{ext})} + \frac{1}{\Delta_{2c}(\Phi_{ext})} - \frac{1}{\Sigma_{1c}(\Phi_{ext})} - \frac{1}{\Sigma_{2c}(\Phi_{ext})}\right)$$

$$g_{ij} \approx \sqrt{\omega_i\omega_j} * \sqrt{\frac{C_c}{C_iC_j}} \qquad \Delta_{ic} = \omega_i - \omega_c \qquad \Sigma_{ic} = \omega_i + \omega_c$$

https://doi.org/10.1103/physrevapplied.10.054062







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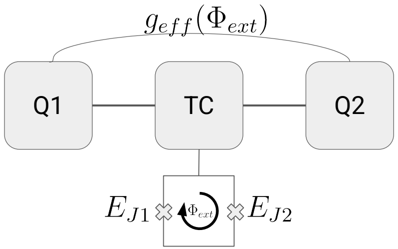

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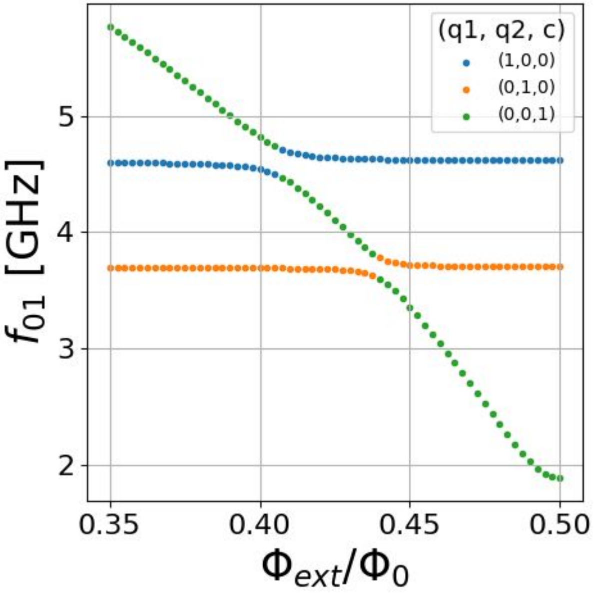
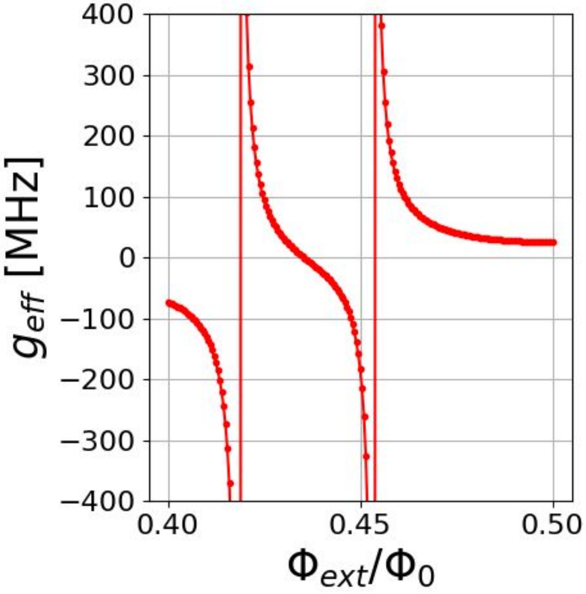
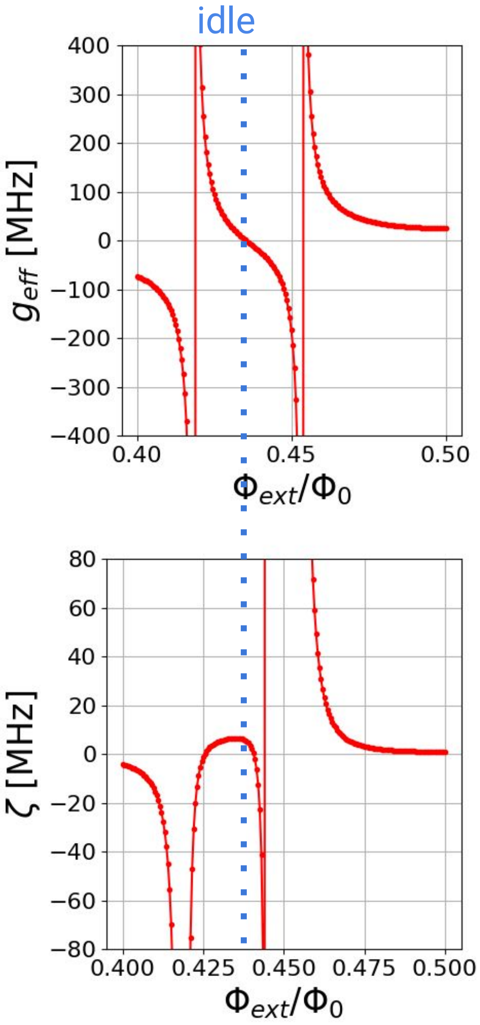




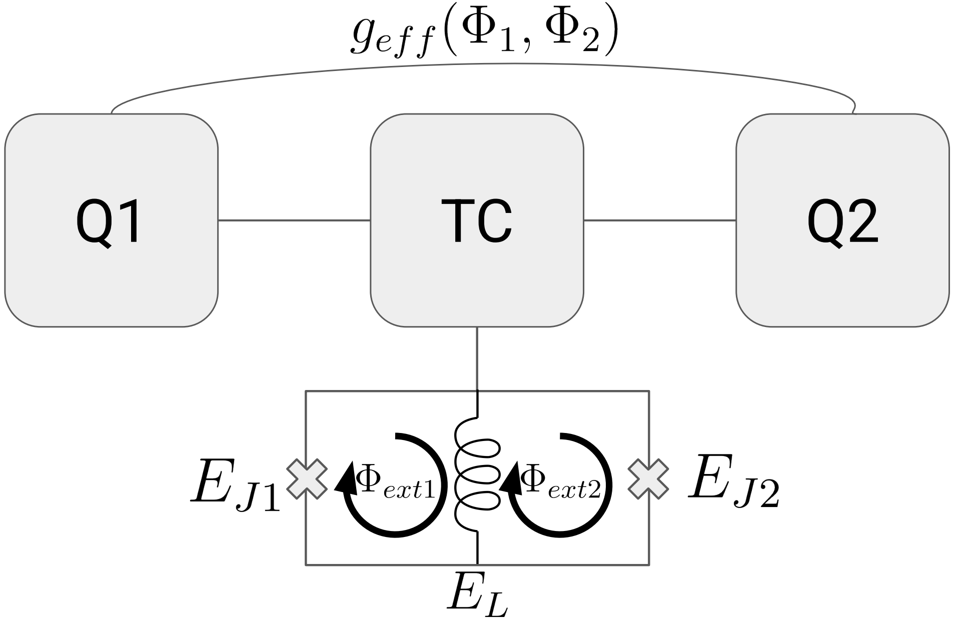
Residual ZZ-coupling

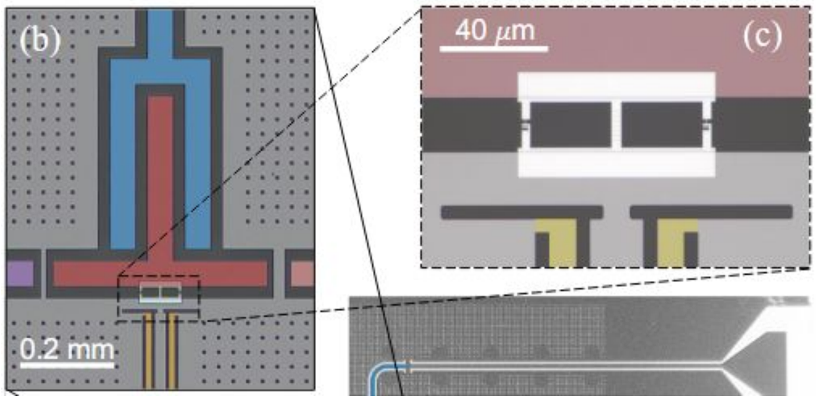
https://arxiv.org/pdf/1810.04182

$$\zeta = \frac{2g_{1c}^2 g_{2c}^2}{\Delta_{1c}+\Delta_{2c}+\alpha_c}\left(\frac{1}{\Delta_{1c}}+\frac{1}{\Delta_{2c}}\right)^2$$
$$+\left(\frac{g_{1c}g_{2c}}{\Delta_{1c}}\right)^2\left(\frac{2}{\Delta_{12}+\alpha_2}-\frac{1}{\Delta_{12}}\right)$$
$$+\left(\frac{g_{1c}g_{2c}}{\Delta_{2c}}\right)^2\left(\frac{2}{\Delta_{21}+\alpha_1}-\frac{1}{\Delta_{21}}\right)+$$
$$-\left(\frac{g_{1c}^2 g_{2c}^2}{\Delta_{1c}^2\Delta_{2c}}\right)-\left(\frac{g_{2c}^2 g_{1c}^2}{\Delta_{2c}^2\Delta_{1c}}\right)$$



Using an ATS instead of the dc-squid

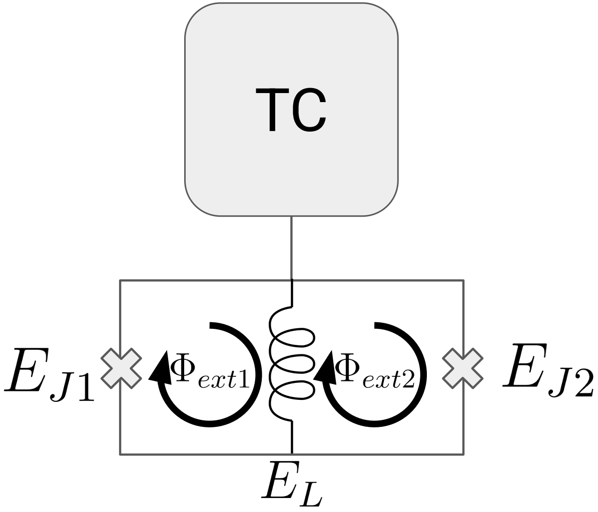


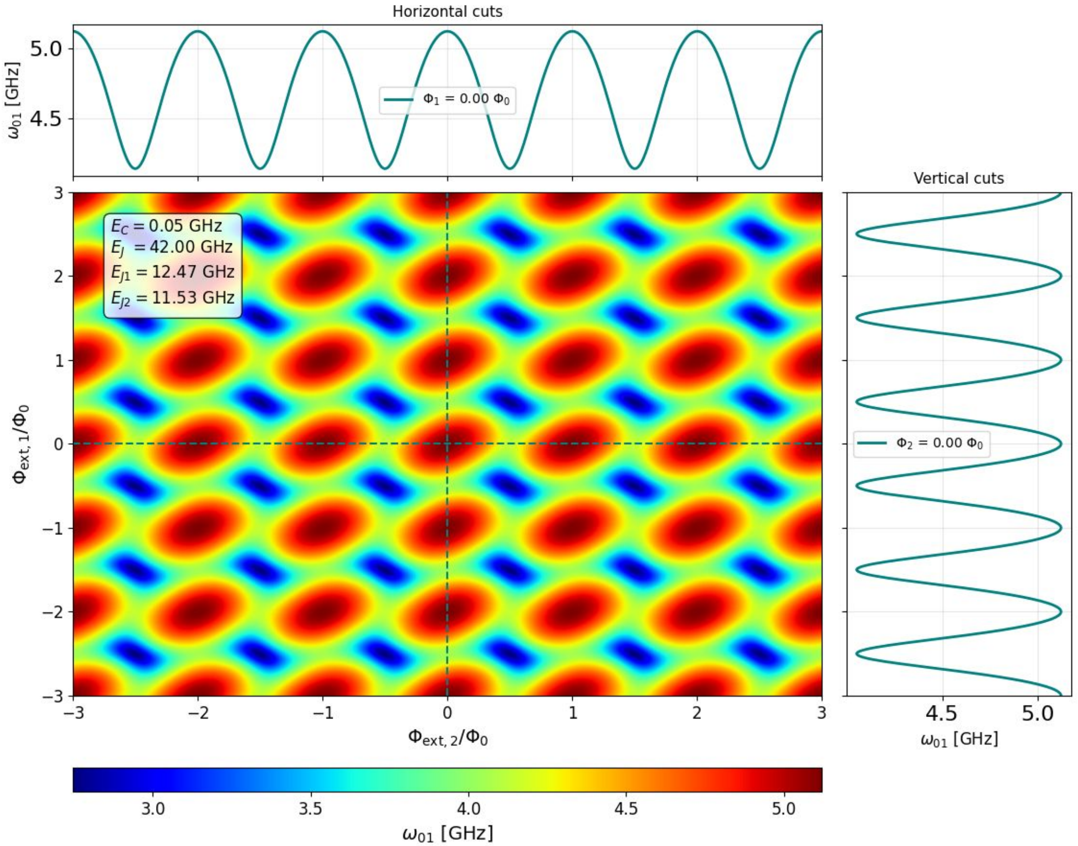


$$U(\varphi) = \frac{1}{2}E_{L,b}\varphi^2 - E_{J,1}\cos(\varphi + \varphi_{\mathrm{ext},1}) - E_{J,2}\cos(\varphi - \varphi_{\mathrm{ext},2})$$

Using an ATS instead of the dc-squid

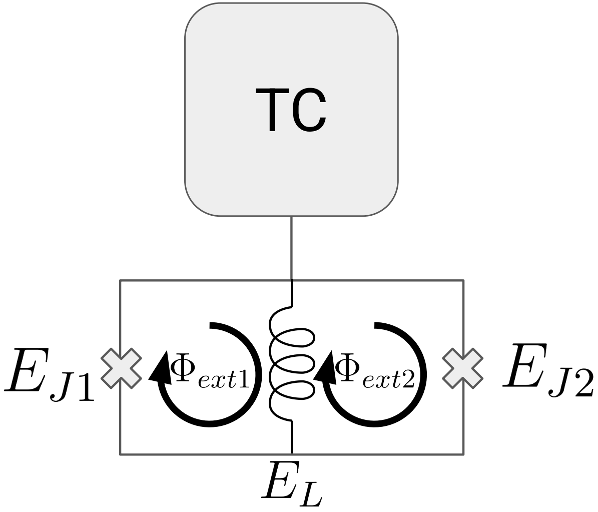
Frequency

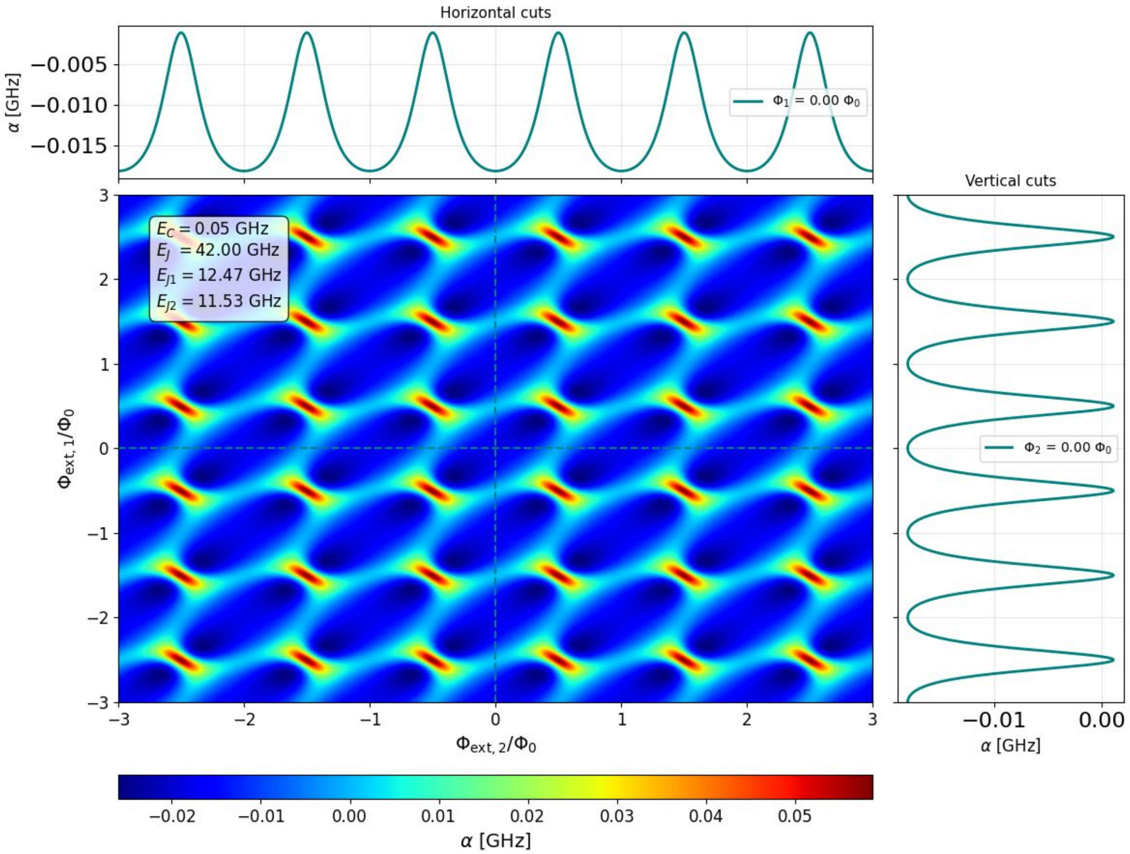




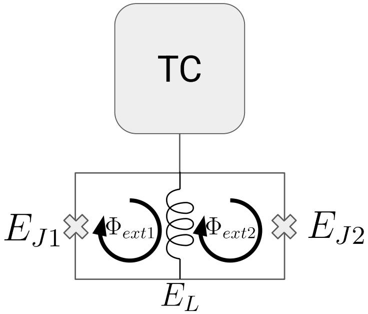
Using an ATS instead of the dc-squid

Anharmonicity



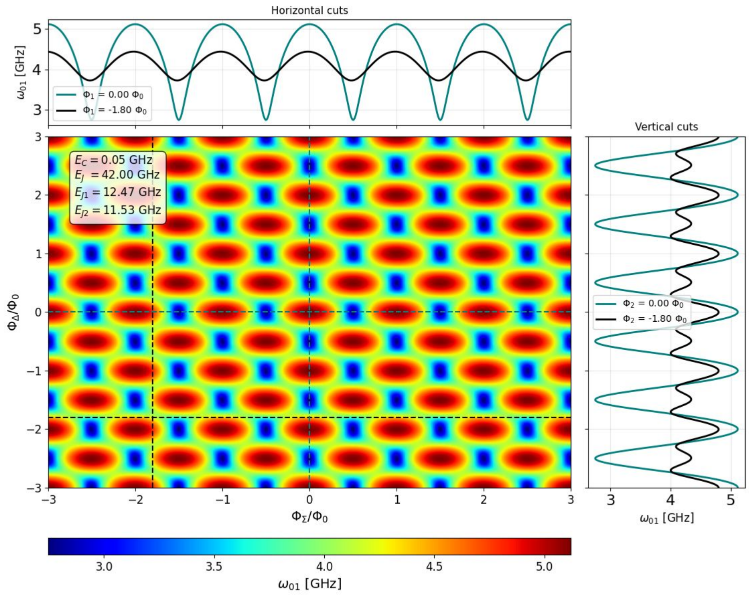


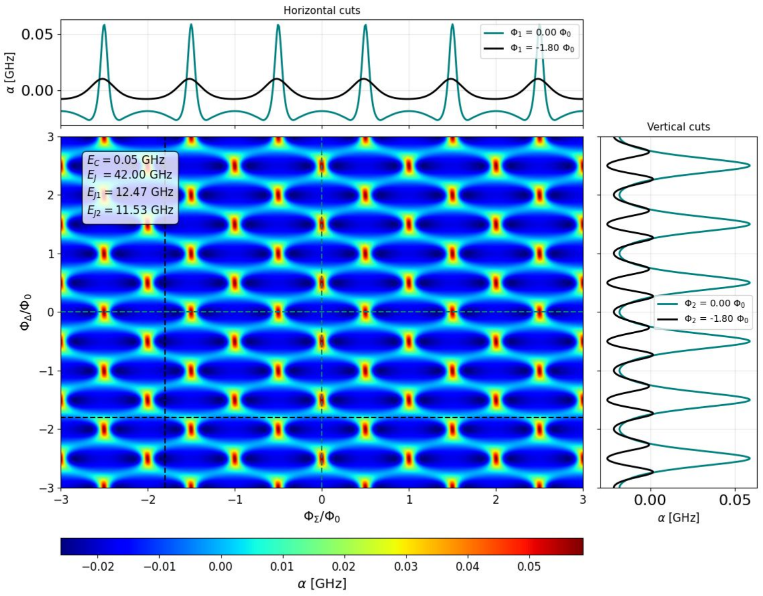
Redefining the coordinates



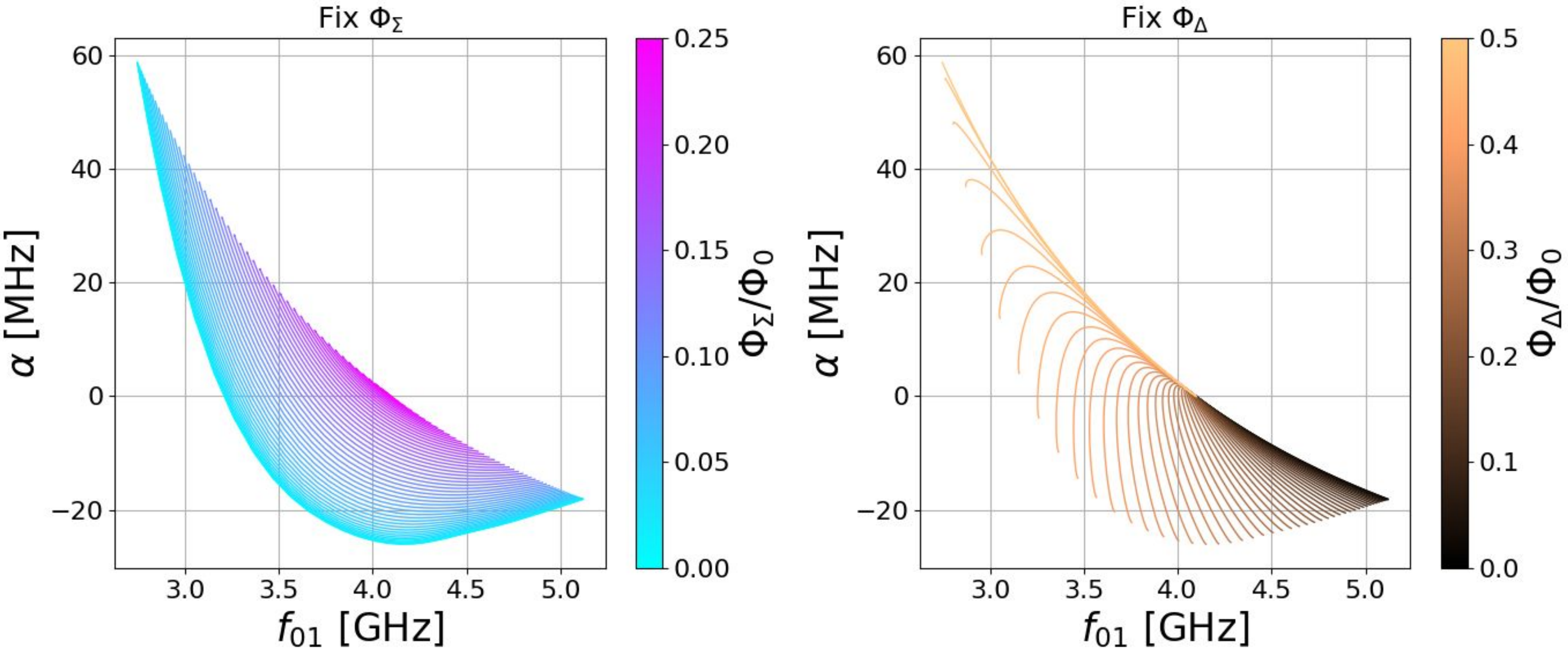
$$\Phi_\Sigma = \frac{\Phi_1 + \Phi_2}{2} \qquad \Phi_\Delta = \frac{\Phi_1 - \Phi_2}{2} \qquad \Delta E_J = E_{J1} - E_{J2}$$

$$U(\varphi) = \frac{1}{2} E_{L,b}\varphi^2 - 2E_J \cos(\varphi_\Sigma) \underbrace{\cos(\varphi + \varphi_\Delta)}_{\text{Even terms}} + 2\Delta E_J \sin(\varphi_\Sigma) \underbrace{\sin(\varphi + \varphi_\Delta)}_{\text{Odd terms}}$$





Frequency and Anharmonicity relation



Next Steps

- dc-squid tunable coupler
  - Design device with two qubits with dc-squid tunable coupler
  - Optimize dc-squid coupler for optimal **on-off ratios** (minimizing ZZ-coupling)
  - Study **parametric interactions**
- ATS tunable coupler
  - Precise simulation and extraction of couplings
  - Investigate optimal parameters
  - Study **parametric interactions** (odd terms → **3-qubit gates**?)
- Investigate more complex coupling schemes (two couplers https://arxiv.org/pdf/1810.04182)

Backup slides

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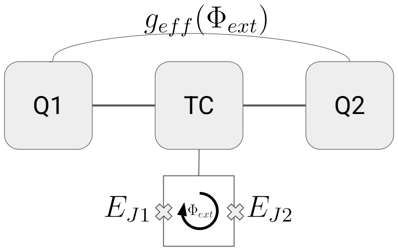

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