QUART&T WP2 Meeting
18/11/2025

Ongoing activities in WP2 at INFN-BO

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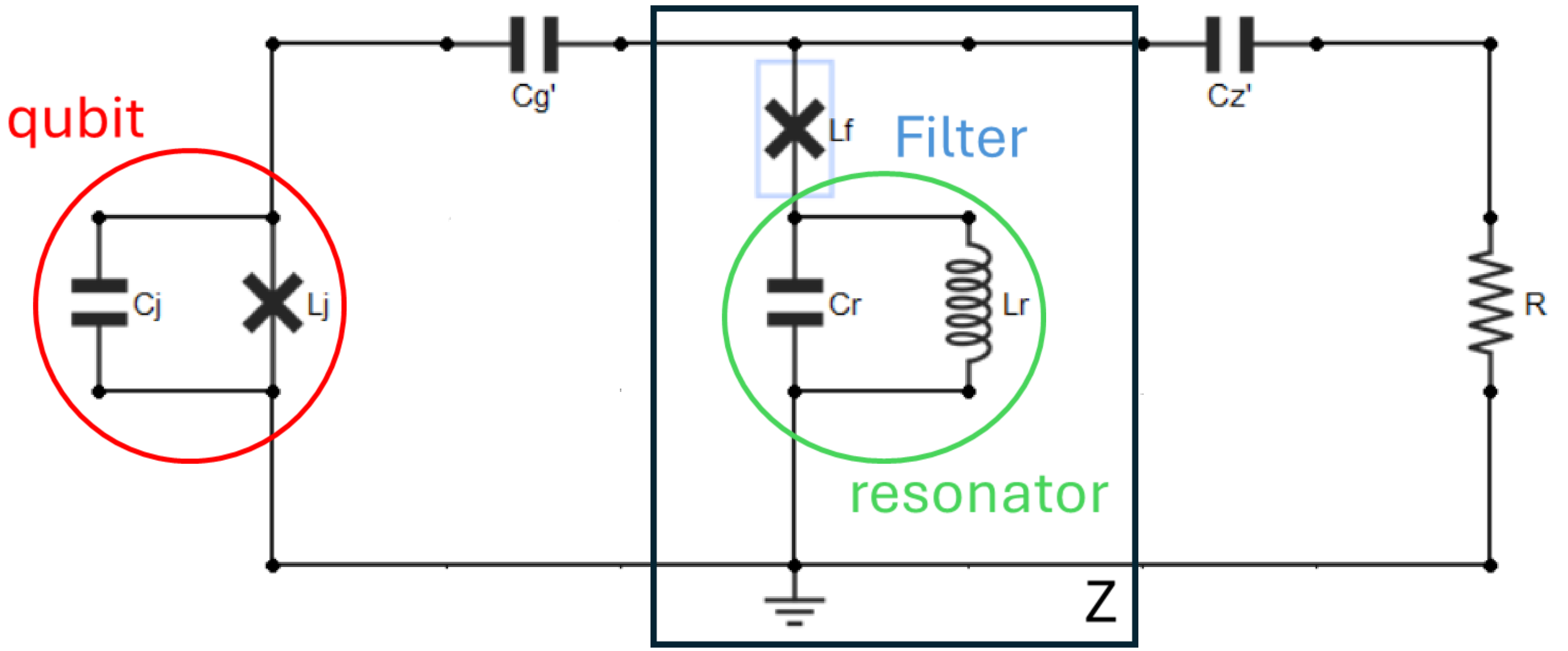
Outline

- Design of a notch Purcell filter
- Design for analog simulation of 1D Ising model for phase transition

Purcell filter design



- L_f implemented with JJ arrays
- Notch band very narrow:
  TUNING OF L_f REQUIRED !!

L_f is sized such that Z(ω_q)=0

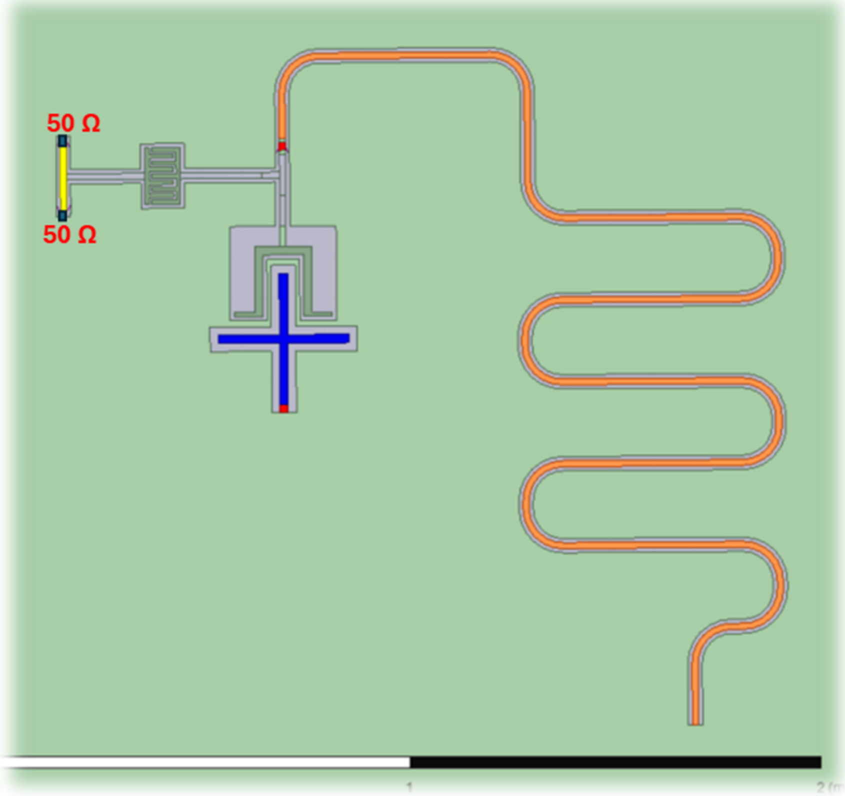
$$L_f = -\frac{L_r}{1-\frac{\omega_q^2}{\omega_r^2}}$$

Qubit mode

$$\omega_r = 1/\sqrt{L_r \times C_r}$$

$$\omega_q > \omega_r$$

Purcell filter design



Parameter	Value
Qubit mode frequency f_q	6.45 GHz
Resonator mode frequency f_r	6.87 GHz
Filter mode frequency f_f	3.66 GHz
Dispersive shift χ_{qr}	12 MHz
Resonator self-Kerr α_r	0.5 MHz
Linewidth κ_r	10 MHz
Purcell-limited T_1	5 ms
Critical photon number n_{crit}	30

The simulations were performed using both Ansys HFSS, QuCAT and QuLTRA Python package.

Presented at SQA conference 2025 & published in IEEE-TAS
https://ieeexplore.ieee.org/document/11164455

1D Ising model for phase transition

Based on work proposed by prof. Ercolessi's presented on WP1

$$H = \frac{\hbar\omega_q^0}{2}\sum_{j=1}^{N}\sigma_z^{(j)} + \frac{\hbar J}{2}\sum_{j<k}\left(\sigma_x^{(j)}\sigma_x^{(k)} + \sigma_y^{(j)}\sigma_y^{(k)}\right)$$

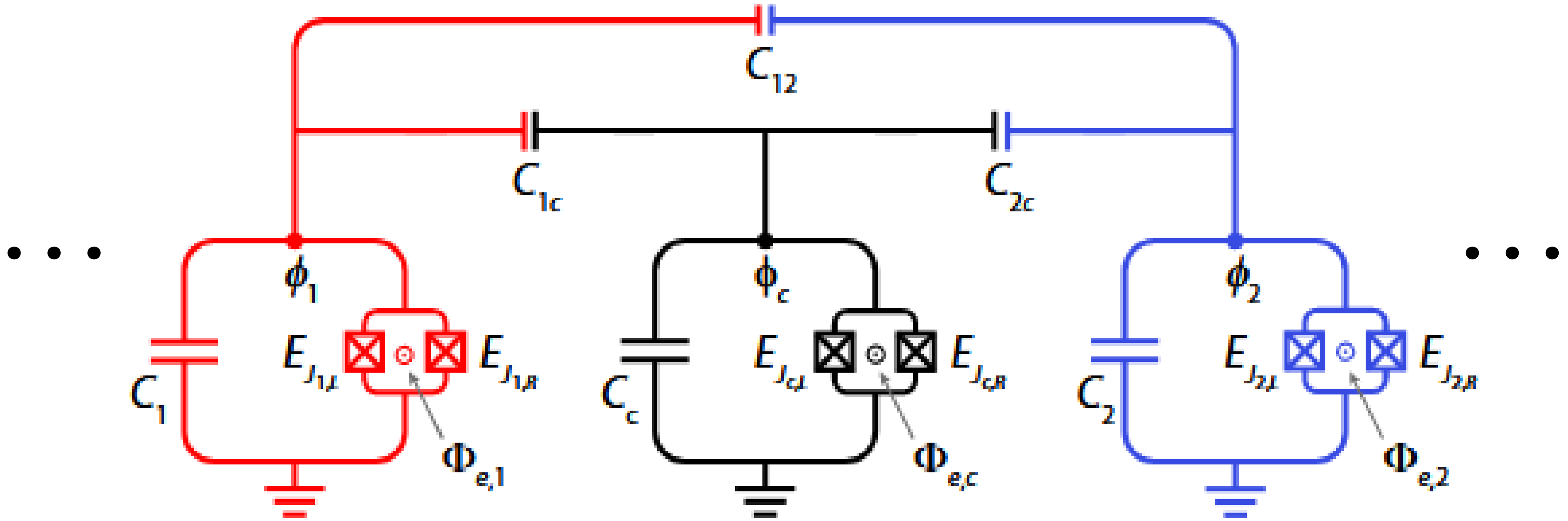
All qubits have same frequency

All coupling factors are the same

Two possible analog simulations:

- Simulation of the dynamics of the system
- Ground state calculation

Dynamics of the system



- Linear chain of qubits coupled through a tunable coupler
- We can perturb the system, let it evolve, and then measure it.

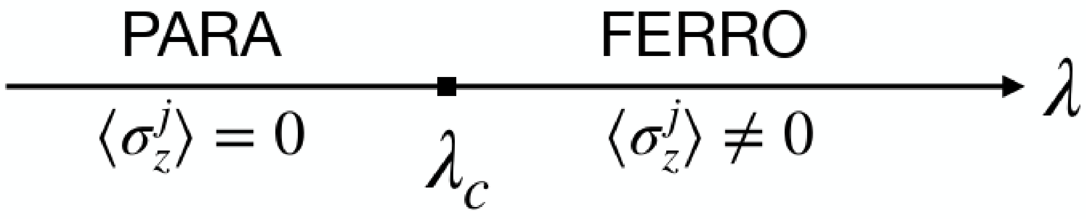
WARNING: Because of the tunable couplers, the total number of qubits increases.
Simulating a three-body Ising model requires five qubits !!

Ground state of the system

$$H = \frac{\hbar\omega_q^0}{2}\sum_{j=1}^{N}\sigma_z^{(j)} + \frac{\hbar J}{2}\sum_{j<k}\left(\sigma_x^{(j)}\sigma_x^{(k)} + \sigma_y^{(j)}\sigma_y^{(k)}\right)$$

Varying the parameter $\lambda \equiv \frac{\omega_q^0}{2J}$ the system can become paramagnetic

or ferromagnetic. The aim is to slowly vary λ and observe the ground state evolution of the system



Ground state of the system

ISSUE: The previously proposed architecture with transmon qubits does not yield strong qubit–qubit coupling.

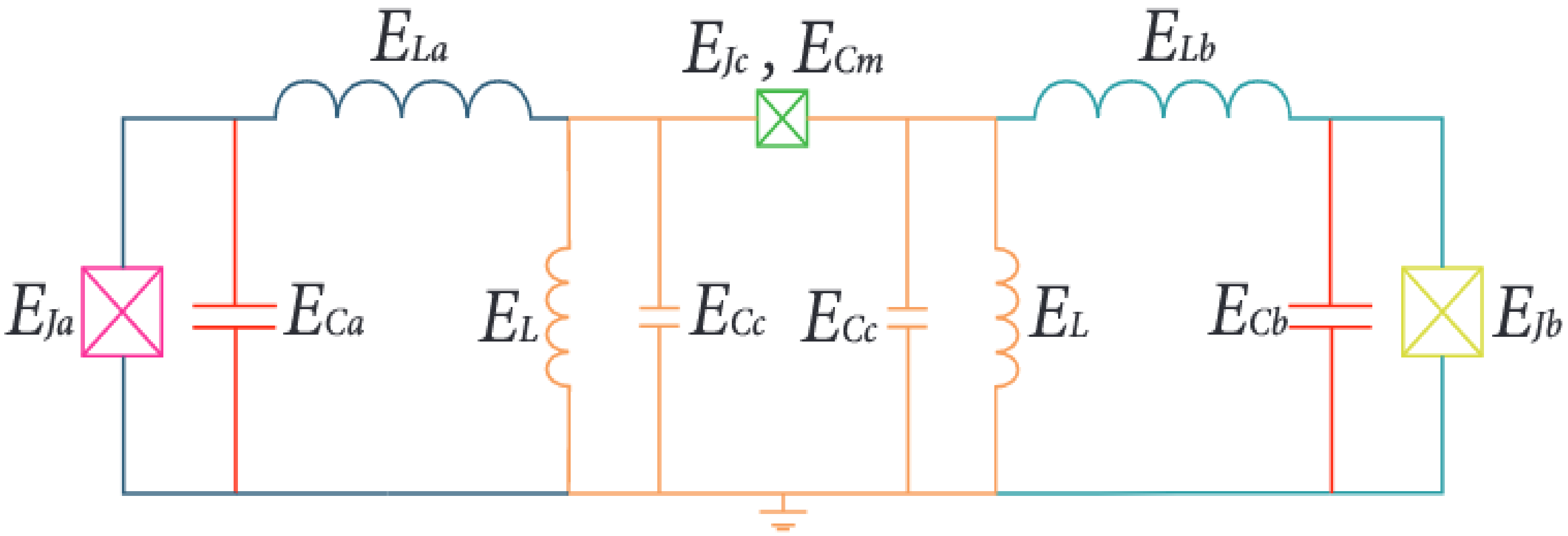
$\lambda < 1$ cannot be achieved, preventing the observation of the phase transition.

One possible solution is to use fluxonium qubits [1]

$$H_{\mathrm{eff}} = -\sum_{\mu=a,b} \frac{\omega_\mu}{2}\sigma_z^\mu - \Omega_\mu \sigma_x^\mu + J\sigma_x^a\sigma_x^b + \zeta\sigma_z^a\sigma_z^b$$

[1] https://arxiv.org/abs/2309.05720 **Tunable inductive coupler for high-fidelity gates between fluxonium qubits**

Ground state of the system



Structure under investigation through QuTip simulations

[1] https://arxiv.org/abs/2309.05720 **Tunable inductive coupler for high-fidelity gates between fluxonium qubits**