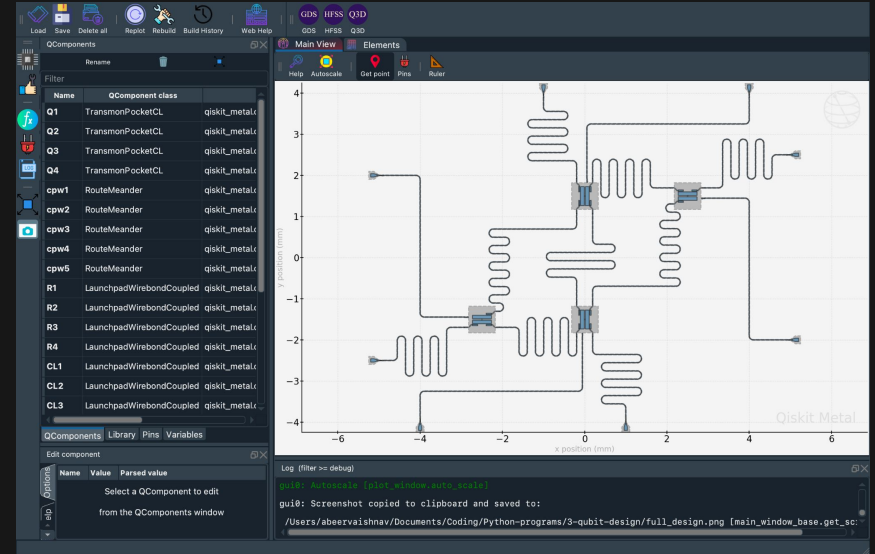
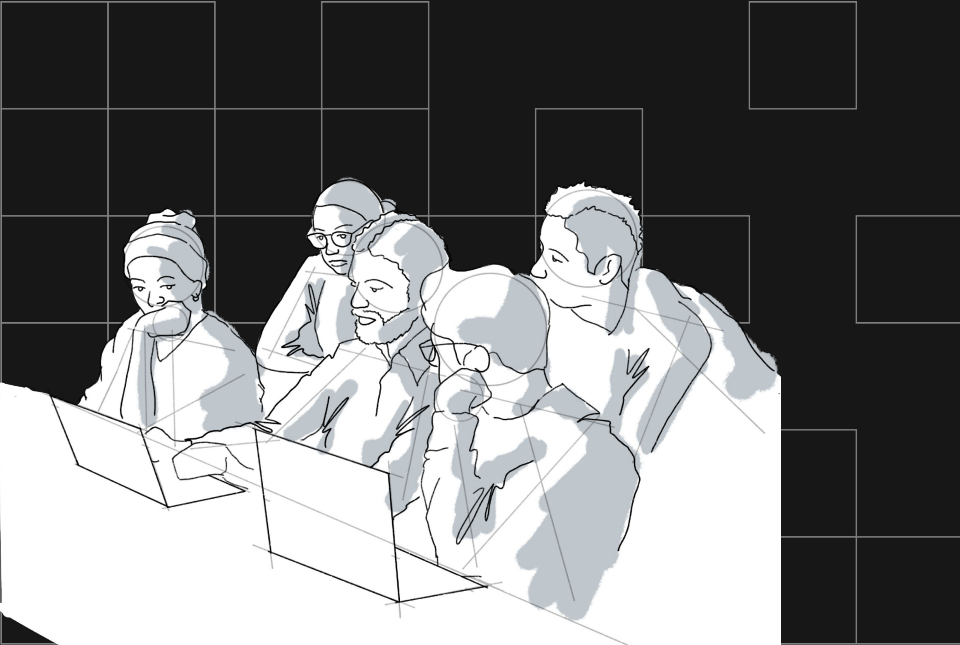


Designing a 4-qubit Superconducting Chip from Scratch



A bit about myself ...



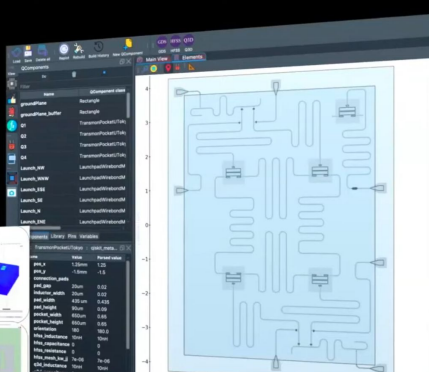
- Qiskit Advocate (2021 - Present)
- Duke University (MS, Electrical and Computer Engineering -- Quantum Hardware)
- Present Research: Superconducting and Trapped-ion hardware design and simulation
- Past Research: Quantum algorithms and circuit optimization for Near-term quantum computers
- Using Qiskit Metal for about 1 year
- IBM Quantum Intern - Summer 2022 (focusing on Qiskit Metal)

Our journey until now

Qiskit | quantum device design

Metal Tutorial 1 How to make your own quantum computer

Zlatko K. Minev



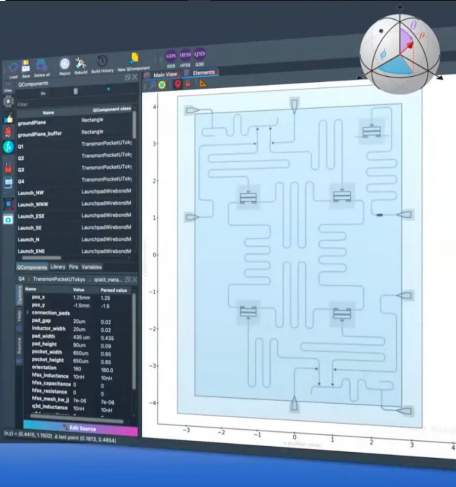
Qiskit | quantum device design

Qiskit Metal Tutorial Creating a Custom qcomponent


Thomas G. McConkey

Qiskit Metal™ Team
IBM Quantum

qiskit.org/metal Slack: #metal



SS



LP

AV

SS

Soyoung Shin (IBM)

Gyeonghun Kim (Extern)


Leonardo Placidi (Extern)

Abeer Vaishnav (Extern)

Shivam Sawarn (Extern)

Using QComponents for parametric design

Gyeonghun Kim
Qiskit Advocate / Seoul National University

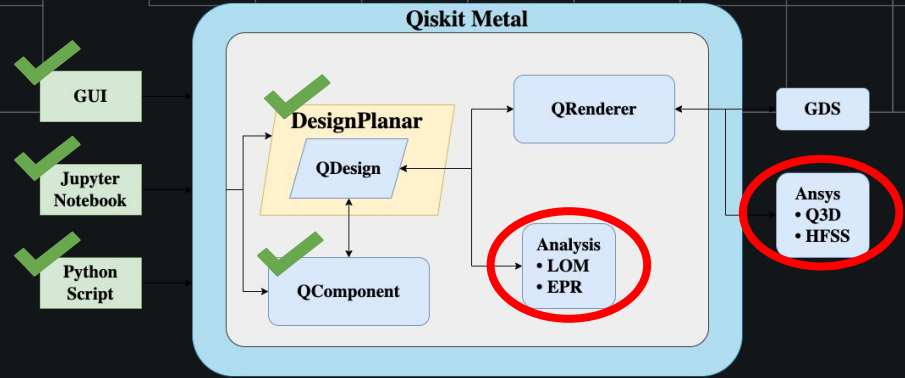


Our journey until now

- Qiskit Metal

- What?
- Why?
- How?

- Placing components in the Metal GUI
- Making the chip layout
- Making custom QComponents for flexibility and reproducibility



How do we make sure that our design works as expected?

This is how... Analyses

Lumped
Capacitive

***Old** LOM

Quasi
Lumped

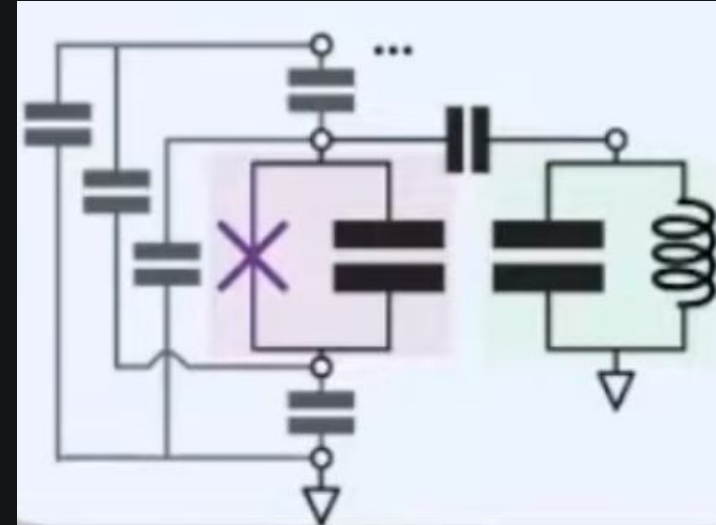
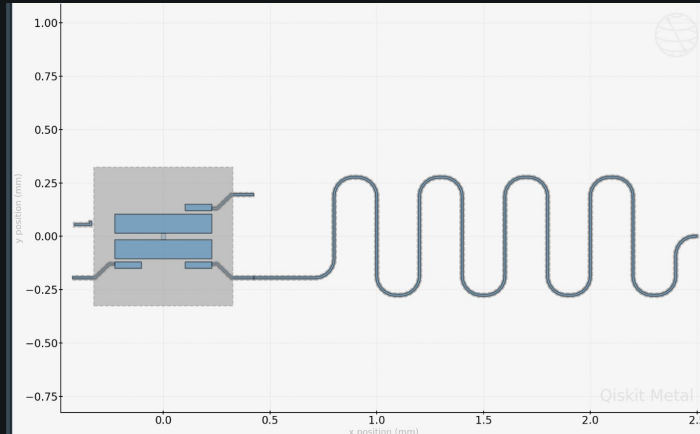
***New** LOM

Energy
Participation
Ratio

NOTE: Impedance or Black-Box Quantization Analysis is not covered in this lecture, but that is also another option available for analysis in Qiskit Metal.

Lumped Capacitive Analysis

Lumped Capacitive analysis method is the most computationally efficient method which makes an assumption of components being in the “lumped” regime and models the connections as **point capacitors** and **inductors**.

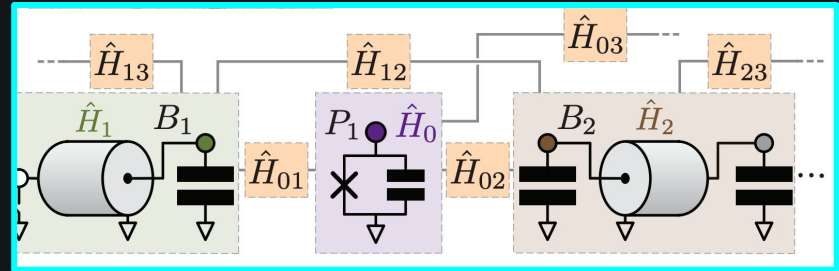
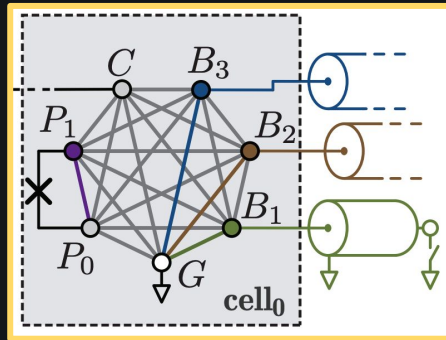
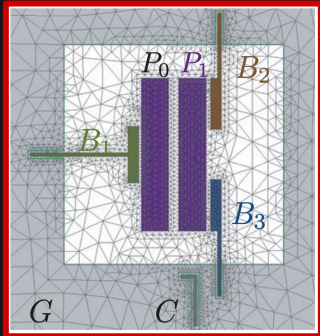
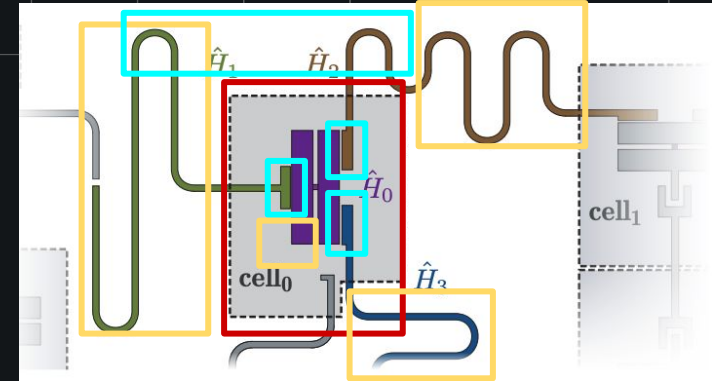


** Not very reliable, may have ~20% error compared to fabricated device.

Quasi-Lumped Analysis⁴

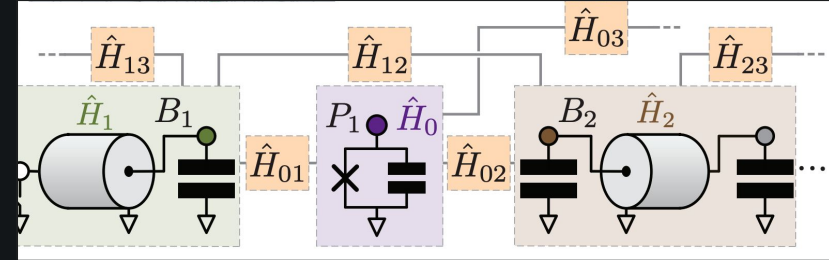
Quasi-Lumped analysis method is a computationally efficient process to solve for the Hamiltonian of an interacting quantum information processing system.

It partitions the composite system into **compact lumped** or **quasi-distributed cells**.

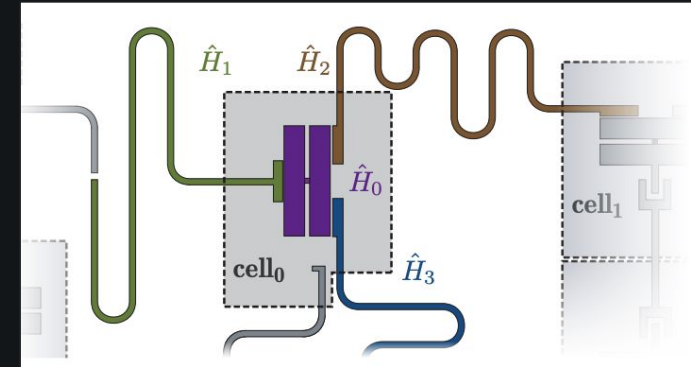


Quasi-Lumped Analysis⁴ - Steps

$$H_{full} = \hat{H}_0 + \sum_{n=1}^K \hat{H}_n + \sum_{n=0}^{K-1} \sum_{m=n+1}^K \hat{H}_{nm}$$



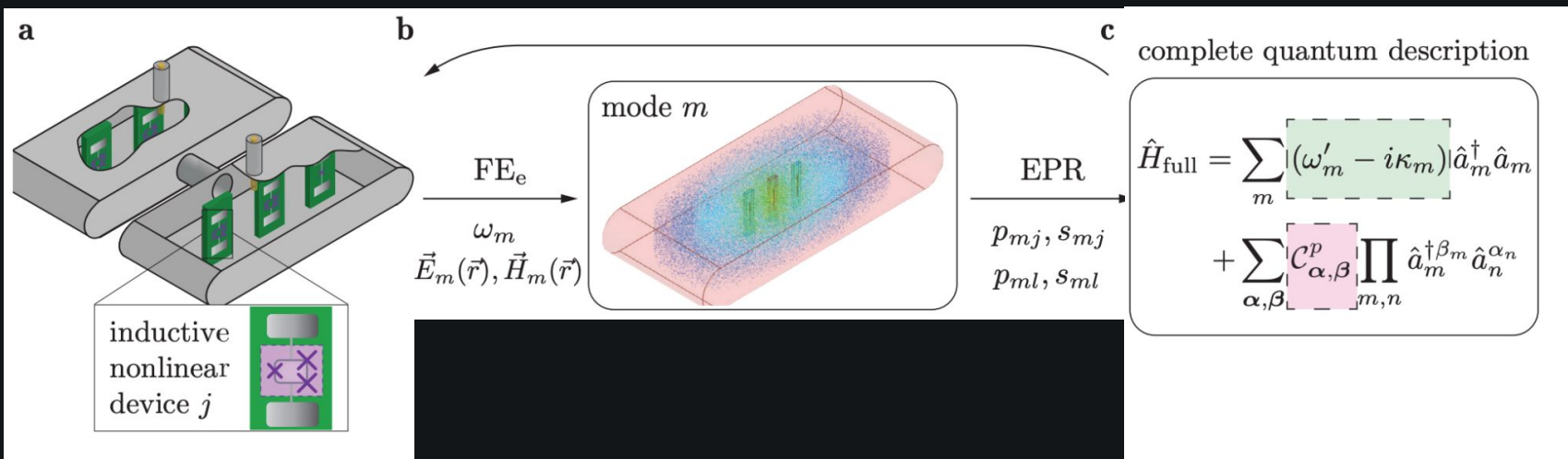
1. The qubit cell is taken and simulated in **Ansys Q3D Solver**. The output is a **capacitance matrix** between each component.
2. Capacitance matrix is used to solve for:
 - a. $E_j = \hbar I_c / 2e$
 - b. $E_c = e^2 / 2C$
 - c. Transmon energy levels (by diagonalizing the H)
3. Qubit-bus and bus-bus couplings are then calculated
4. Finally, we assume Q-factors and calculate T_1 value.



⁴Z. K. Minev et al.: [arXiv:2103.10344](https://arxiv.org/abs/2103.10344)

EPR Analysis³

Energy Participation Ratio analysis tries to answer a very simple question:
“What fraction of energy of mode ‘**m**’ is stored in element ‘**j**’?”



³Z. K. Mineev et al.: [arXiv:2010.00620](https://arxiv.org/abs/2010.00620)

EPR Analysis³ - Steps

$$\hat{H}_{full} = \hat{H}_{lin} + \hat{H}_{nl}$$

$$\hat{H}_{lin} = \hbar\omega_c \hat{a}_c^\dagger \hat{a}_c + \hbar\omega_q \hat{a}_q^\dagger \hat{a}_q$$

$$\hat{H}_{nl} = -E_J [\cos(\hat{\phi}_J) + \hat{\phi}_J^2/2]$$

$$\hat{\phi}_J = \varphi_q (\hat{a}_q + \hat{a}_q^\dagger) + \varphi_c (\hat{a}_c + \hat{a}_c^\dagger)$$

$$\varphi_c^2 = p_c \frac{\hbar\omega_c}{2E_J} \quad \text{and} \quad \varphi_q^2 = p_q \frac{\hbar\omega_q}{2E_J}$$

$$p_m = \frac{\text{inductive energy stored in the junction}}{\text{total inductive energy stored in mode } m}$$

Aim: To determine the non-linear part of H_{full} and reconstruct H_{full} .

1. Calculate quantum zero-point fluctuations using the participation of junction in the eigenfield solution.
2. Participation ratio for mode '**m**' is given by p_m . This is used to calculate the junction flux.
3. Now, we can reconstruct the full Hamiltonian and get the eigenstate energies (and frequencies), anharmonicities, and cross-Kerr couplings for the whole system.

³Z. K. Mineev et al.: [arXiv:2010.00620](https://arxiv.org/abs/2010.00620)

For a more in-depth overview ...

EPR:

<https://www.youtube.com/watch?v=iidYHZ0qxcY>

https://www.youtube.com/watch?v=ITCkKfjxcbc&list=PLOFEBzvs-VvqHl5ZqVmhB_FcSqmLufsib&index=8

Quasi-Lumped:

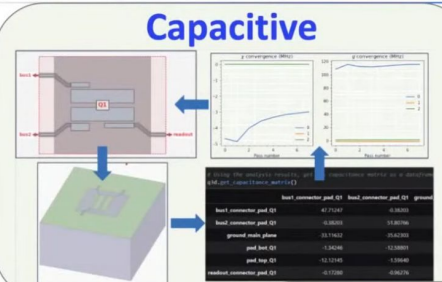
https://www.youtube.com/watch?v=S8Wx2Lo2CxQ&list=PLOFEBzvs-VvqHl5ZqVmhB_FcSqmLufsib&index=22

Quantum analysis library

arXiv: 2010.00620
arXiv: 1902.10355

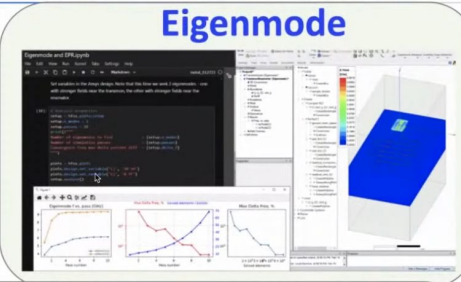
Qiskit Live

Capacitive




arXiv:2103.10344 ...

Eigenmode



S, Z, Y Impedance Scattering



arXiv:1204.0587 ...

29:30 / 1:17:17

Quantum Hardware Design: Energy, Circuits, and Metal | Qiskit Seminar Series with Zlatko Mineev

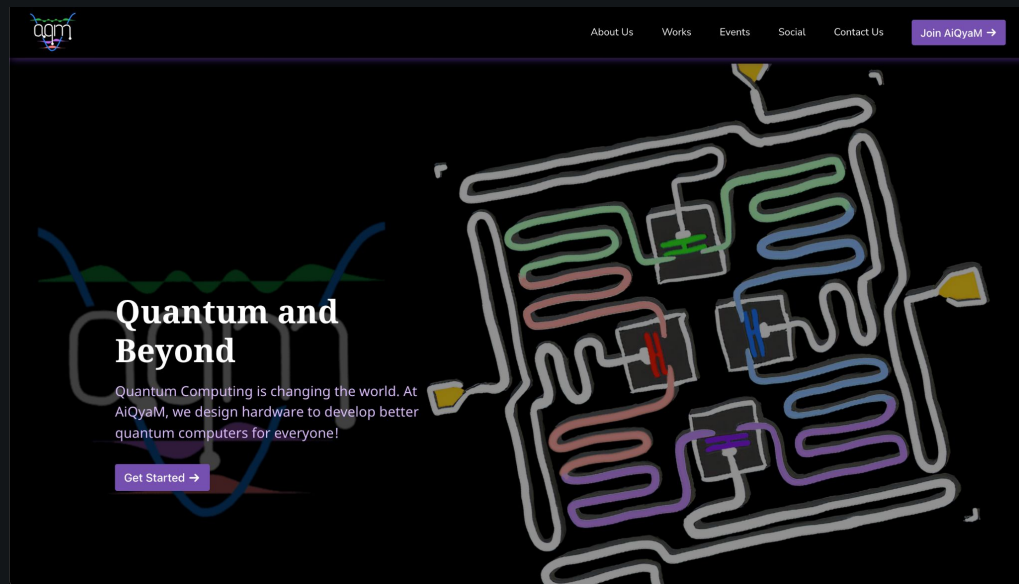
4,891 views • Streamed live on Jun 25, 2021

211 DISLIKE SHARE DOWNLOAD SAVE ...

Qiskit
57.4K subscribers

SUBSCRIBED

Thank You!



Explore our community at: <https://aiqyam.org>