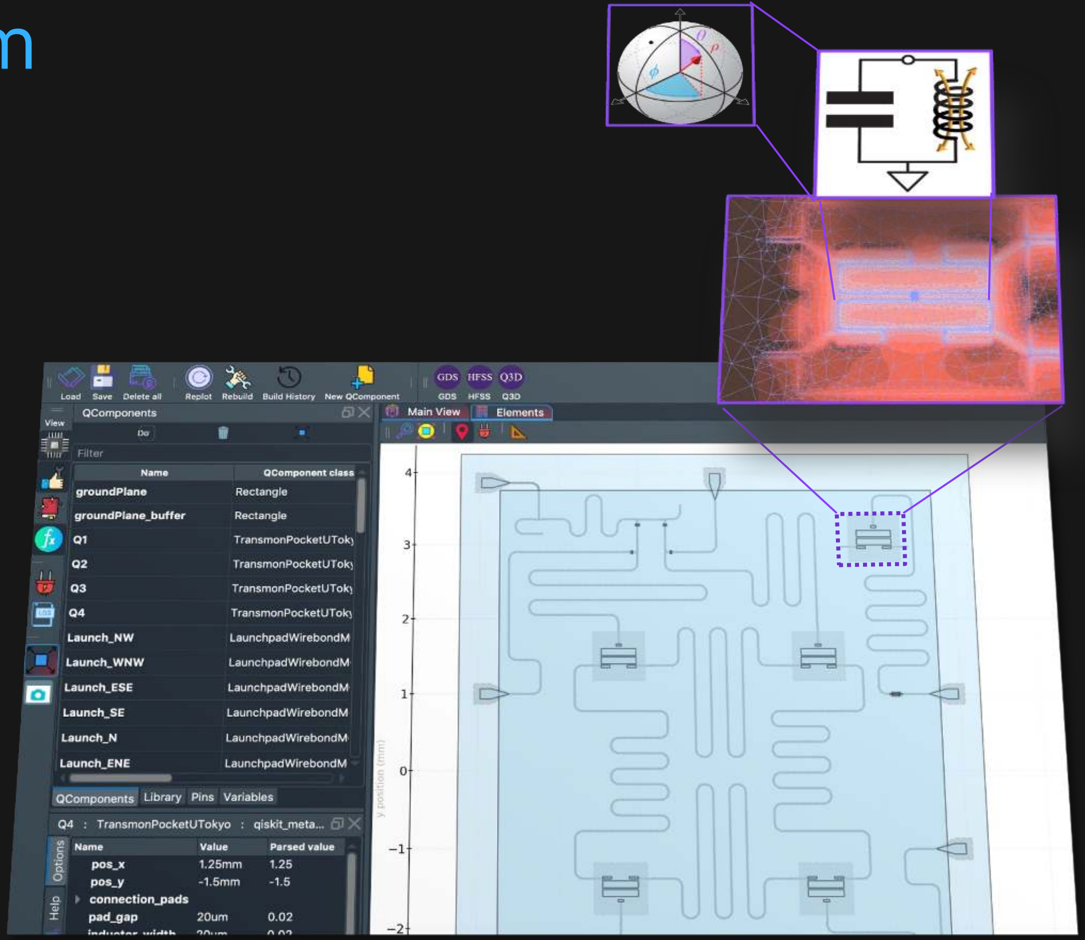
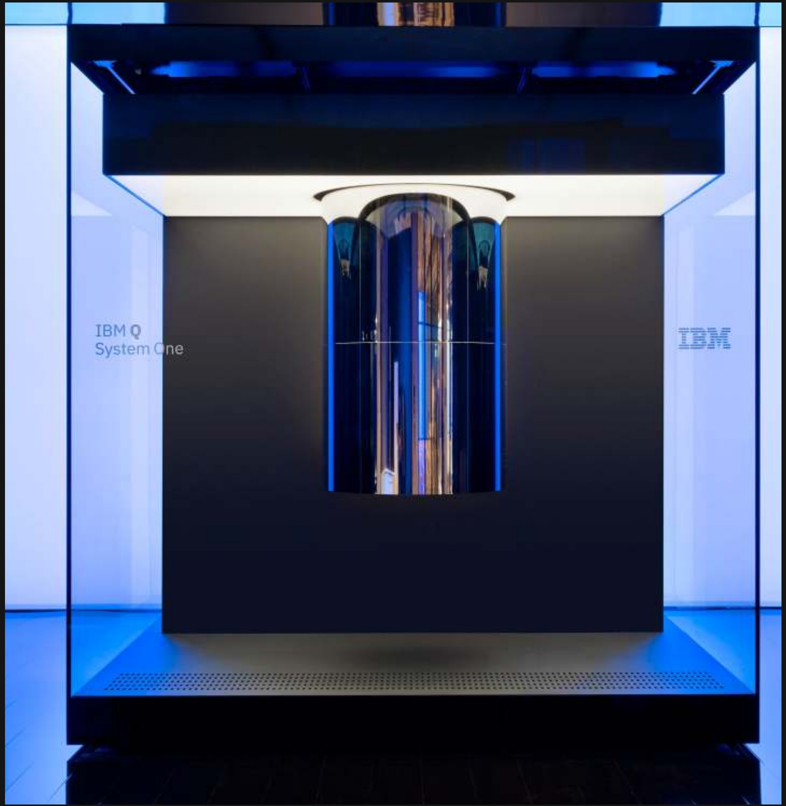
Qiskit Metal – Quantum Device Design and Analysis (Q-EDA)

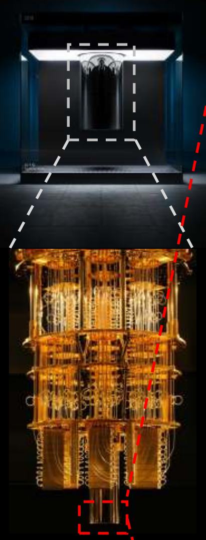
Thomas G. McConkey, Zlatko Minev

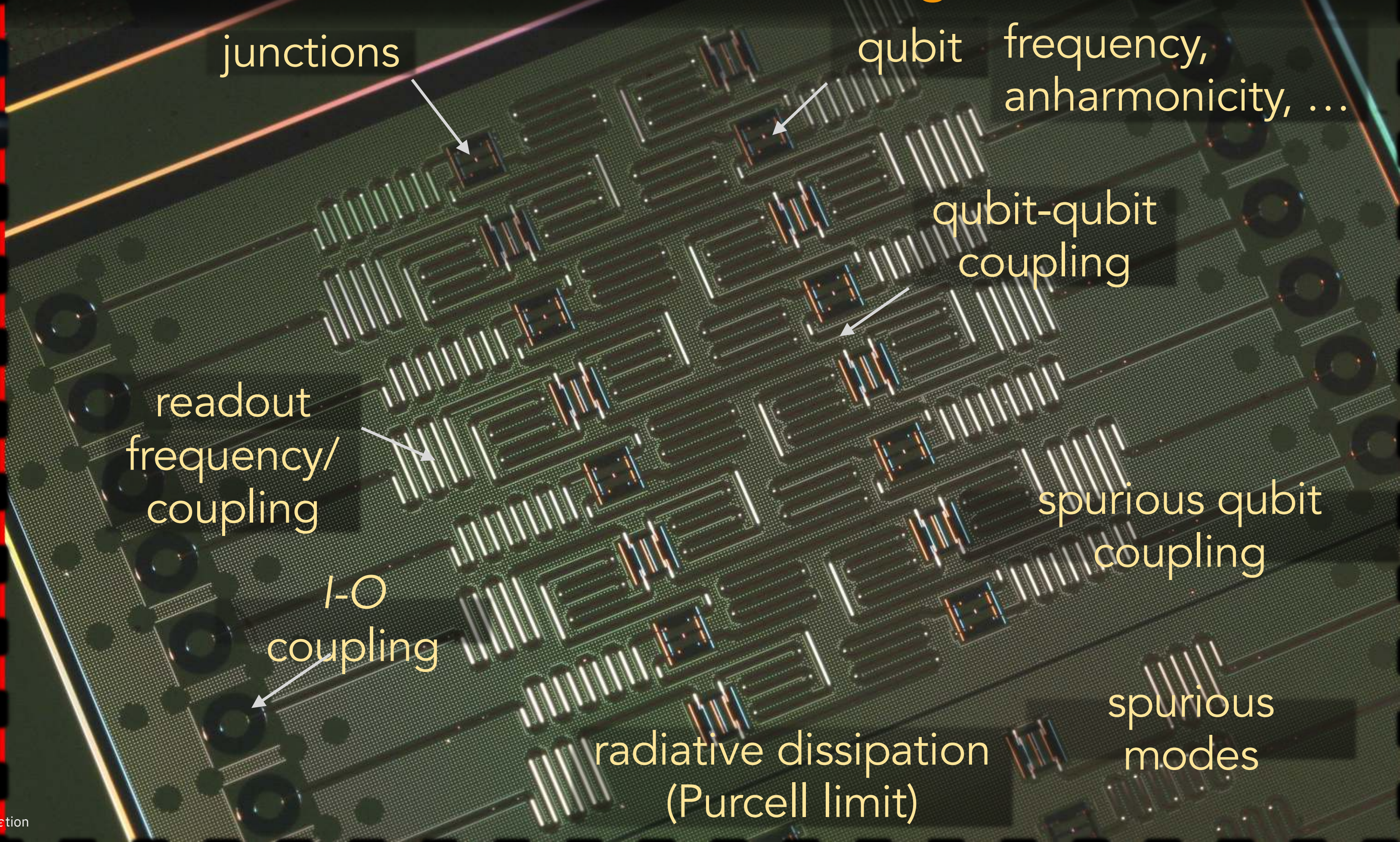


A Quantum Computer



What needs to be designed?





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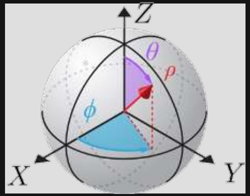
Quantum chip design flow

Complexity, Information, Accuracy

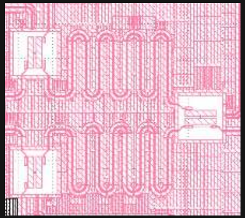
Risk, Cost, Time, Resources

Concept

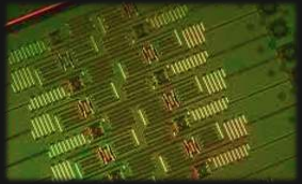
Hamiltonian



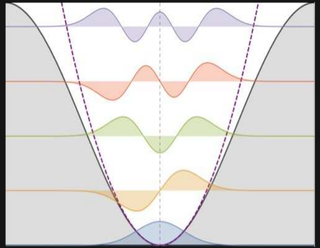
Layout



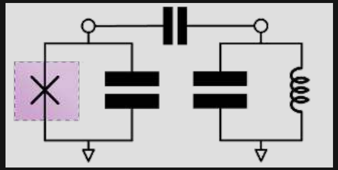
Fabrication



Quantum Analysis



Electromagnetic Analysis



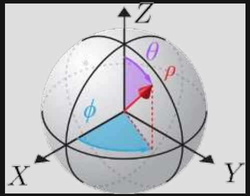
Quantum chip design flow

Complexity, Information, Accuracy

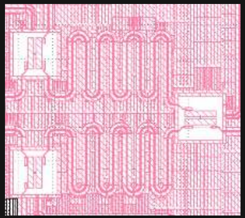
Risk, Cost, Time, Resources

Concept

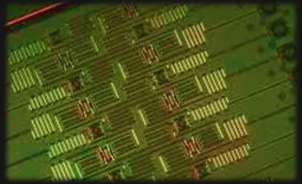
Hamiltonian



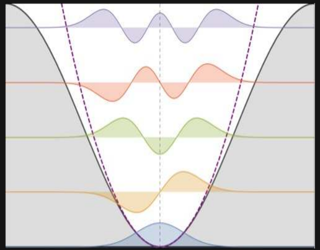
Layout



Fabrication

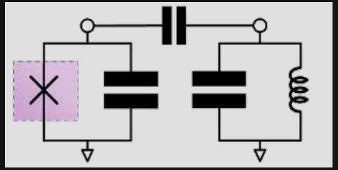


Quantum Analysis



Qiskit | quantum device design

Electromagnetic Analysis



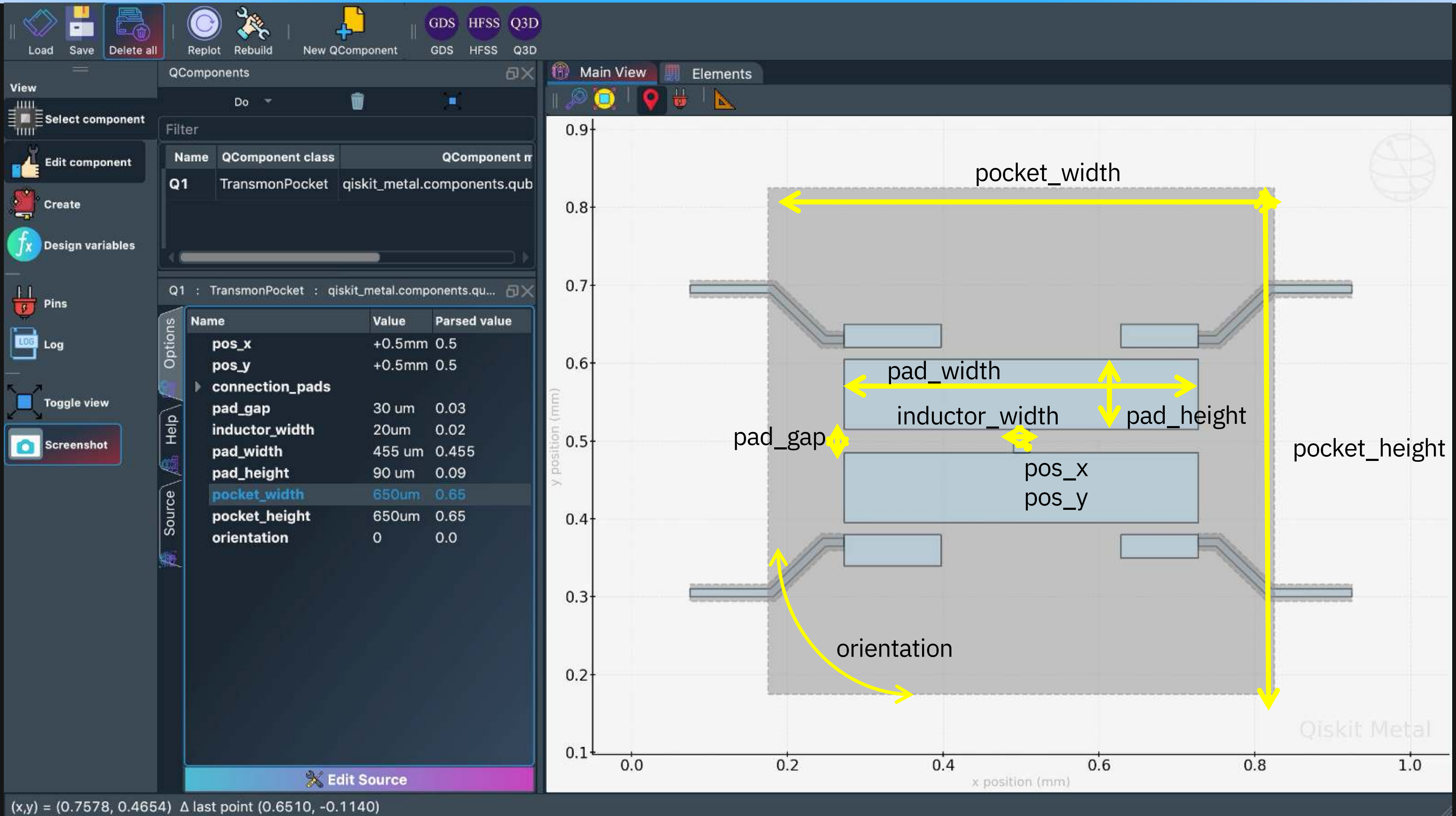
Qiskit Metal

qiskit.org/metal

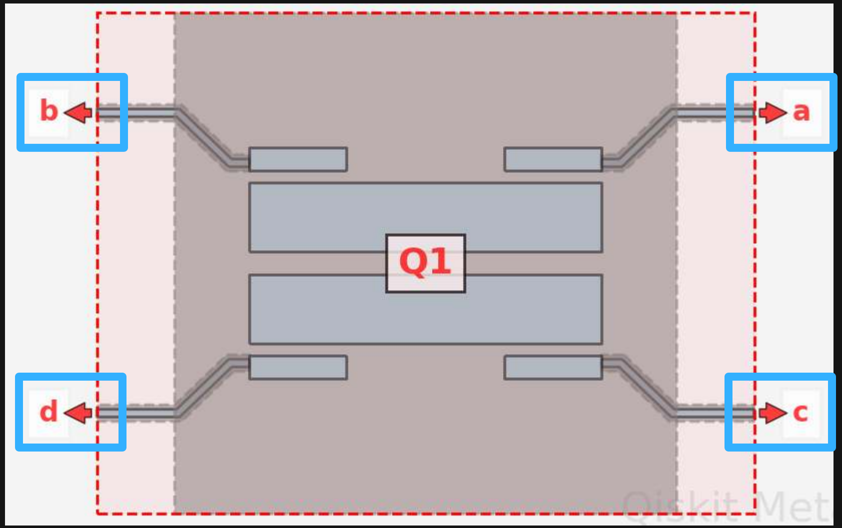
What is Qiskit Metal?

- A new open-source quantum-EDA tool from IBM
  - Written in python
  - Apache License 2.0
  - IBM claims no ownership or rights to any device or code
    - If you add code to the Metal database, it is open and free for everyone to use, but are under no obligation to ever contribute code.
    - Major contributions get authorship credit for citations.
- Follows a modular architecture
  - Qdesign is the primary instance for your circuit layout.
  - Qcomponents are the library of circuits, like “super” p-cells.
  - Renderers are the API interfaces between Metal and external software tools.
  - Analysis work with the returned data of renderers to determine quantum parameters.
  - Qgeometry is the internal database which allows your design to be generated natively in any external simulation software.

QComponents – "Super PCells"



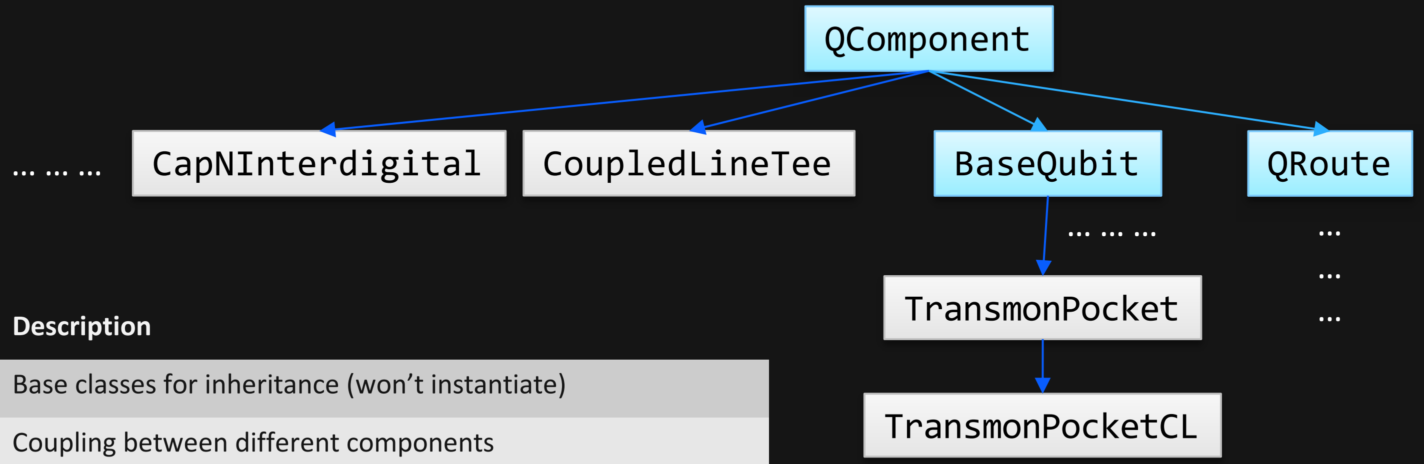
QComponents – "Super PCells"




```
self.add_pin(name, 2points, width)
```

- Represent the electrical/physical contact point between two QComponents
- Have position and direction (outwards)
- Routing algorithms use pins as start-end anchors
  - Non-routing component pins must be created before routing components
- Two pins can be "connected" thus establishing a net

Reuse and Extend the QLibrary



Folder	**Description**
Core	Base classes for inheritance (won't instantiate)
Couplers	Coupling between different components
Lumped	Capacitive/Inductive elements
Qubits	Contains josephson junctions
Sample Shapes	Geometries sand-box
Terminations	Single pin element (e.g. short to ground)
Tlines	Two pins transmission lines

Extensible horizontally and vertically

Simple plug-n-play custom QComponents

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QGeometry

- The primitives of the Metal layout
  - Path, Poly and Junction
  - Includes additional parameters dependent on the renderers present

Main View | Elements

Element type: path **Filter:** Component: Layer:

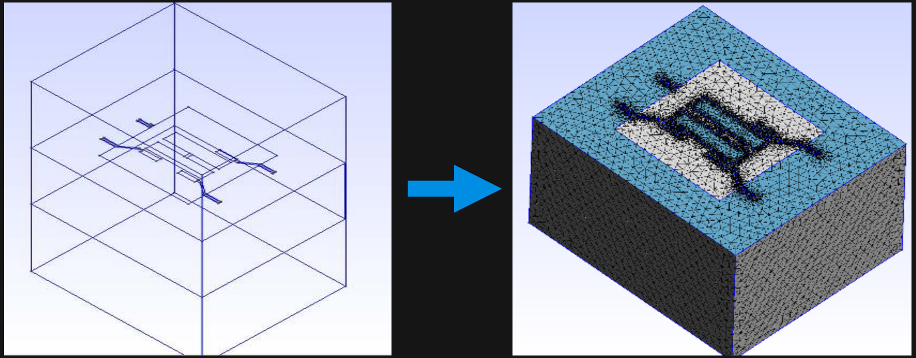
component	name	geometry	layer	subtract	helper	chip	width	fillet	hfss_wire_bonds	
1	readout_wire	LINESTRING (-1.25 0.685, -1.25 0.925)	1	False	False	main	0.01	nan	False	Fal
1	readout_wire_sub	LINESTRING (-1.25 0.685, -1.25 0.925)	1	True	False	main	0.022	nan	False	Fal
1	bus_01_wire	LINESTRING (-1.0375 0.38, -1.0125 0.38, ...	1	False	False	main	0.01	nan	False	Fal
1	bus_01_wire_sub	LINESTRING (-1.0375 0.38, -1.0125 0.38, ...	1	True	False	main	0.022	nan	False	Fal
1	bus_02_wire	LINESTRING (-1.4625 0.38, -1.4875 0.38, ...	1	False	False	main	0.01	nan	False	Fal
1	bus_02_wire_sub	LINESTRING (-1.4625 0.38, -1.4875 0.38, ...	1	True	False	main	0.022	nan	False	Fal
2	readout_wire	LINESTRING (1.25 0.685, 1.25 0.925)	1	False	False	main	0.01	nan	False	Fal
2	readout_wire_sub	LINESTRING (1.25 0.685, 1.25 0.925)	1	True	False	main	0.022	nan	False	Fal
2	bus_01_wire	LINESTRING (1.0375 0.38, 1.0125 0.38, 0.9...	1	False	False	main	0.01	nan	False	Fal

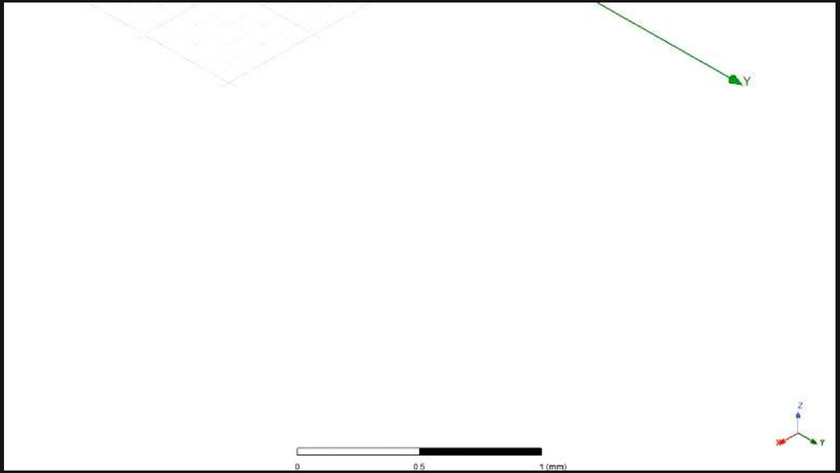
Element type: junction **Filter:** Component: Layer:

component	name	geometry	layer	subtract	helper	chip	width	hfss_inductance	hfss_capacitance	hfss_resistance	hfss_mesh_l
1	rect_jj	LINESTRING (-1.25 0.485, -1.25 0.515)	1	False	False	main	0.02	14nH	0	0	7e-06
2	rect_jj	LINESTRING (1.25 0.485, 1.25 0.515)	1	False	False	main	0.02	14nH	0	0	7e-06
3	rect_jj	LINESTRING (0 -1.365, 0 -1.335)	1	False	False	main	0.02	14nH	0	0	7e-06

Renderers

- The API translators between Metal layout/analysis and the classical simulation tools
  - To generate the layout natively for optimal simulation results
  - Extract results seamlessly into appropriate quantum analysis in Metal





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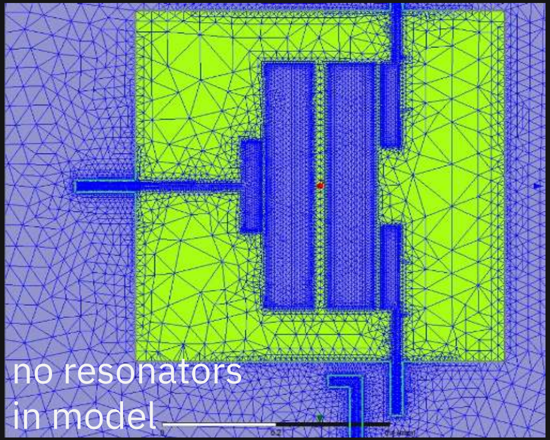
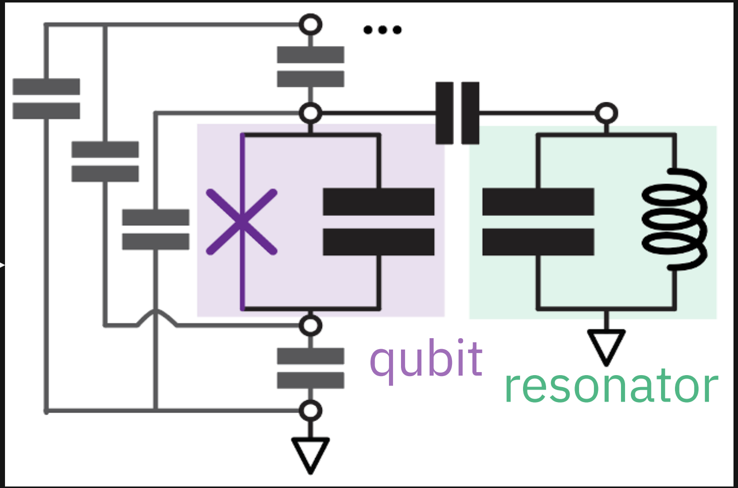
Quantum Analysis: LOM

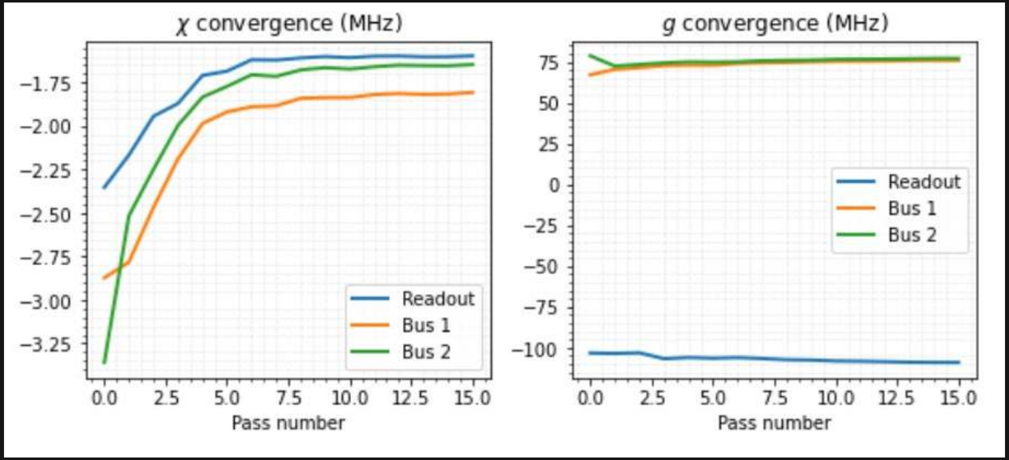
- From classical simulations, via the appropriate renderer, quantum analysis can extract several quantum values of interest, such as your qubit's anharmonicity or readout chi.
    - Lumped Oscillator Model (LOM)

Quasi-static solver

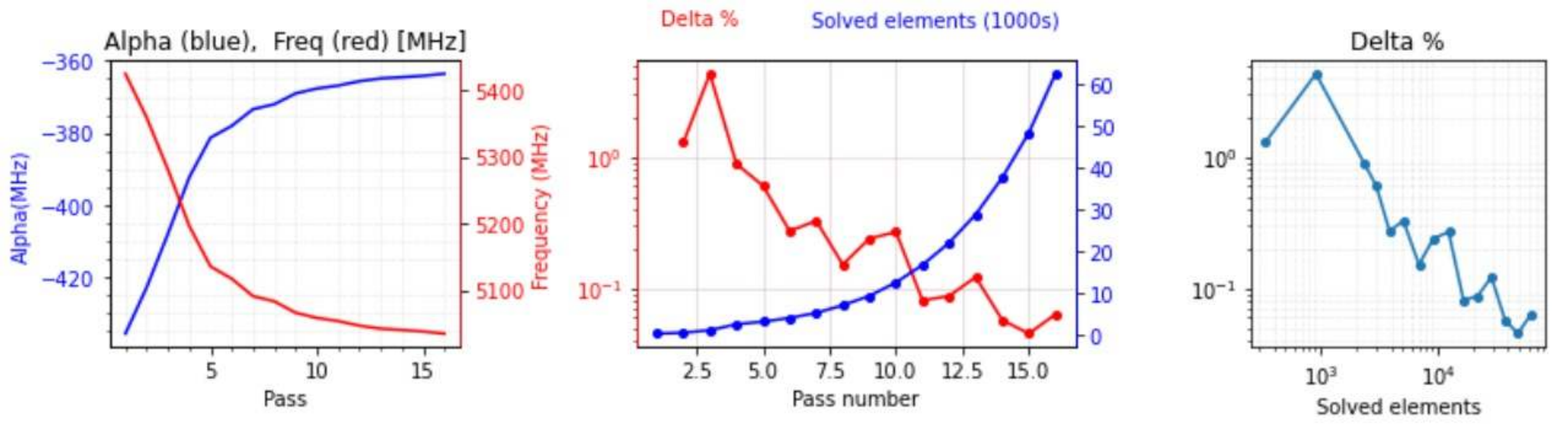




Quantum Analysis: LOM



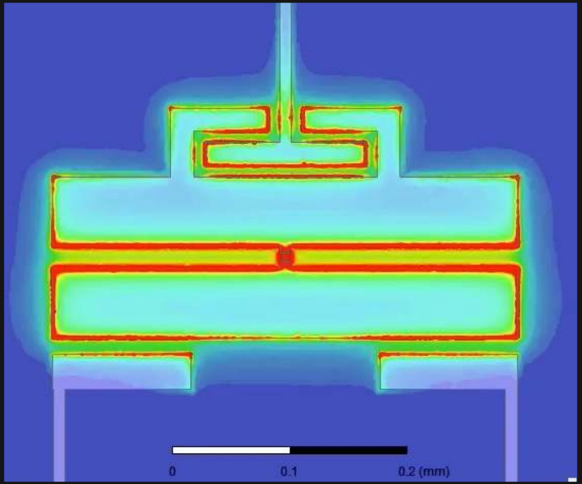

```
{'fQ': 4.787226695506869,
 'EC': 296.92044408559445,
 'EJ': 10.96614765930391,
 'alpha': -351.528599604318,
 'dispersion': 128.8753386135
 'gbus': array([-83.55898953,
 'chi_in_MHz': array([-1.0692
```

Quantum Analysis: EPR

- From classical simulations, via the appropriate renderer, quantum analysis can extract several quantum values of interest, such as your qubit's anharmonicity or readout chi.
  - Energy Participation Ratio (EPR)

Eigenmode Simulation



$$\hat{H}_{\text{full}} = \sum_{m} \boxed{(\omega'_m - i\kappa_m)} \hat{a}_m^\dagger \hat{a}_m + \sum_{\boldsymbol{\alpha},\boldsymbol{\beta}} \boxed{\mathcal{C}^p_{\boldsymbol{\alpha},\boldsymbol{\beta}}} \prod_{m,n} \hat{a}_m^{\dagger\beta_m} \hat{a}_n^{\alpha_n}$$

[Z. Minev et al., npj Quantum Inf, 2021]

```
*** Chi matrix O1 PT (MHz)
    Diag is anharmonicity, off
      286     0.559      5.88
    0.559       291      3.67
     5.88      3.67    0.0418

*** Chi matrix ND (MHz)
      329     -8.33      2.77
    -8.33       341      1.33
     2.77      1.33    0.0103

*** Frequencies O1 PT (MHz)
0    4784.895093
1    4990.716076
2    5896.840627
dtype: float64

*** Frequencies ND (MHz)
0    4763.813191
1    4972.265666
2    5898.088713
dtype: float64
```

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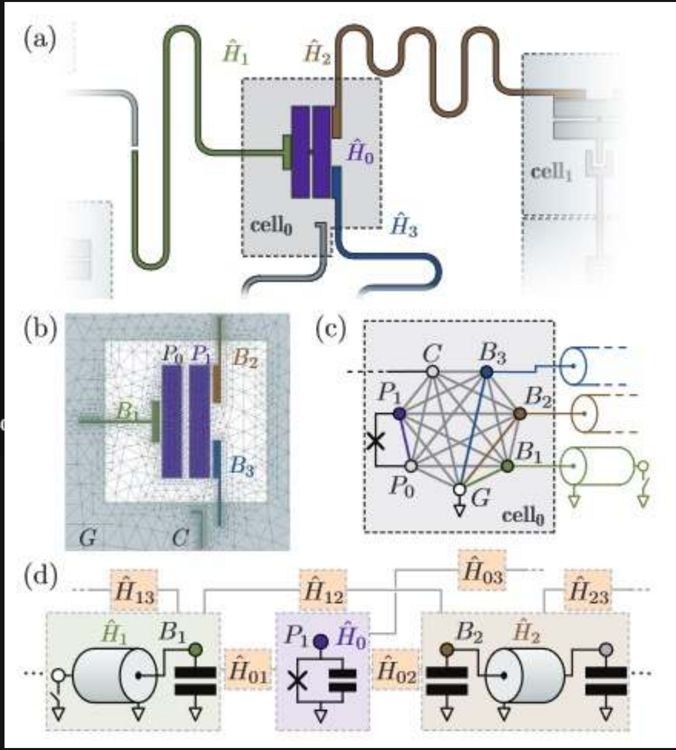
Quantum Analysis: LOM 2.0

- From classical simulations, via the appropriate renderer, quantum analysis can extract several quantum values of interest, such as your qubit’s anharmonicity or readout chi.
  - LOM 2.0

Quantum object: dims = [[10, 10, 3, 3], [10, 10, 3, 3]], shape = (900, 900), type = oper, isherm = True

$$\begin{pmatrix} -2.438\times10^{+04} & 0.108j & 0.0 & 0.127j & -0.436 & \cdots & 0.0 & 0.0 \\ -0.108j & -1.678\times10^{+04} & 0.153j & 0.436 & 0.127j & \cdots & 0.0 & 0.0 \\ 0.0 & -0.153j & -9.184\times10^{+03} & 0.0 & 0.617 & \cdots & 0.0 & 0.0 \\ -0.127j & 0.436 & 0.0 & -1.638\times10^{+04} & 0.108j & \cdots & 0.0 & 0.0 \\ -0.436 & -0.127j & 0.617 & -0.108j & -8.784\times10^{+03} & \cdots & -1.839\times10^{-08} & 0.0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0.0 & 0.0 & 0.0 & 0.0 & -1.839\times10^{-08} & \cdots & 7.287\times10^{+04} & 706.553j \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & \cdots & -706.553j & 8.047\times10^{+0} \end{pmatrix}$$



[Z. Minev et al., arXiv, 2021]

Quantum Analysis

- From classical simulations, via the appropriate renderer, quantum analysis can extract several quantum values of interest, such as your qubit’s anharmonicity or readout chi.
  - Lumped Oscillator Model (LOM) - https://youtu.be/rY7Os7B9sg0
  - Energy Participation Ratio (EPR) - https://youtu.be/wjryCzaK0wY
    - https://arxiv.org/abs/2010.00620
  - Quasi-Lumped Model for Composite Systems (LOM 2.0) - https://youtu.be/S8Wx2Lo2CxQ
    - https://arxiv.org/abs/2103.10344

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Export to GDS

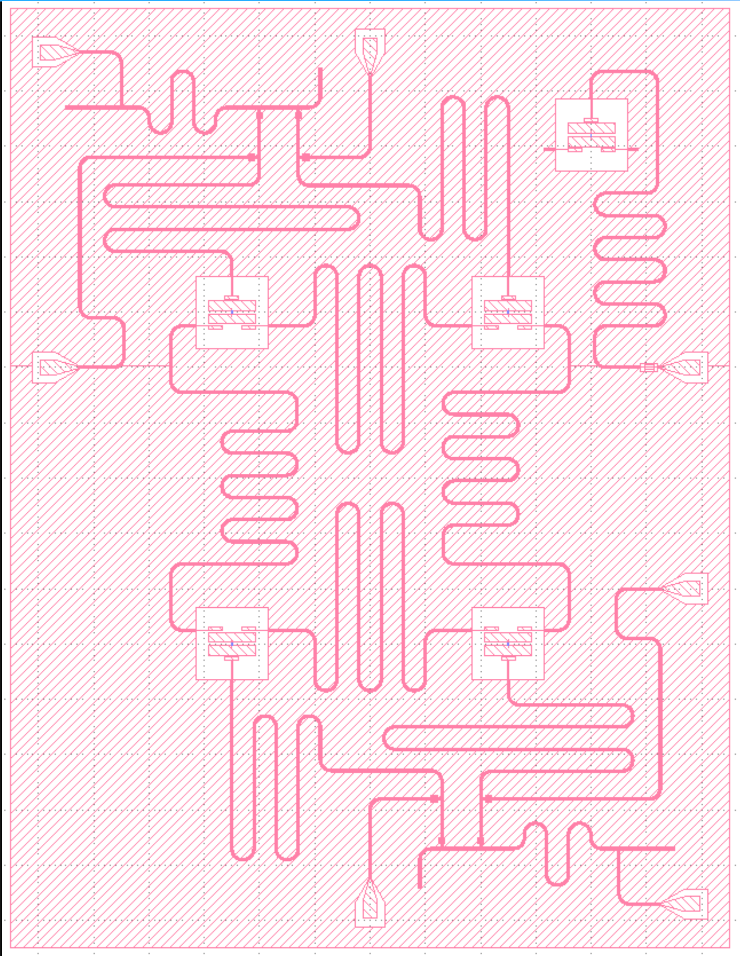
```
full_chip_gds = design.renderers.gds
```

•••

```
full_chip_gds.options
```

```
full_chip_gds.options['path_filename'] ='../resources/Fake_Junctions.GDS'
full_chip_gds.options['no_cheese']['buffer']='50um'
```

```
full_chip_gds.export_to_gds('Full_Chip_01.gds')
```



Current Metal Development

qiskit.org/metal

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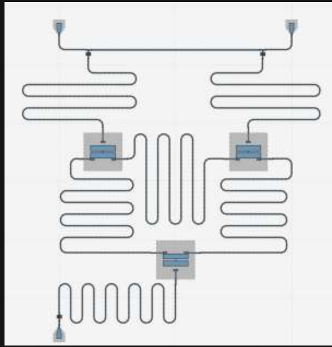
Keysight/EMPro Renderer

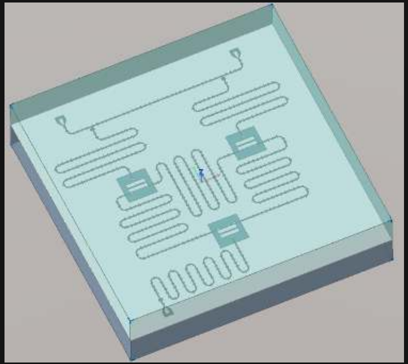
Metal

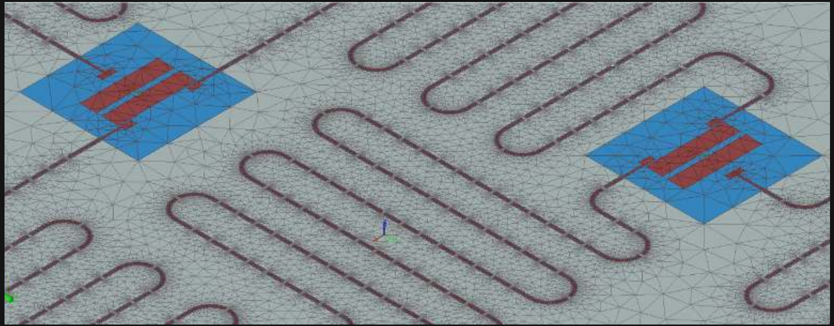


EMPro

Renderer

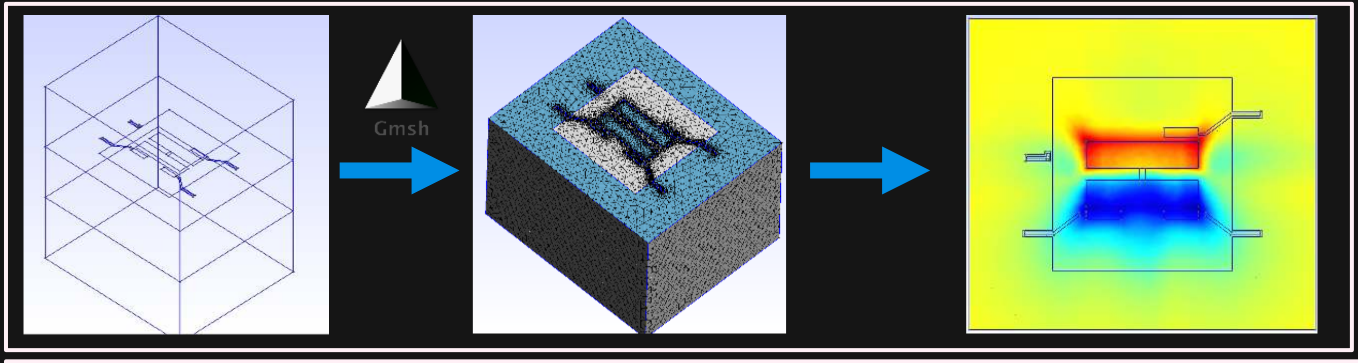
EMPro

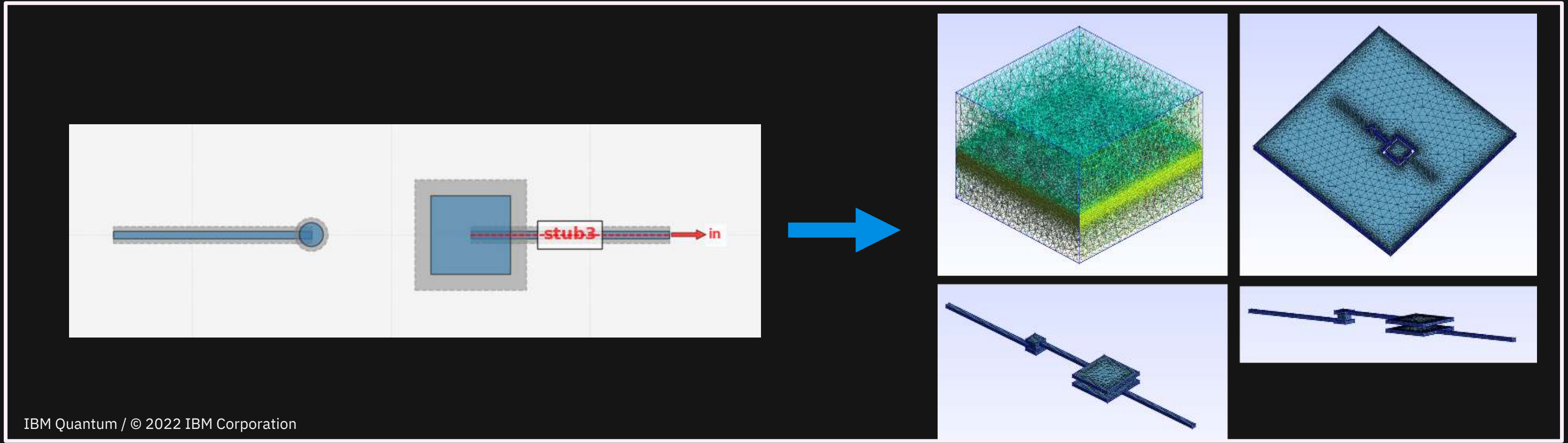




Open Source Renderers

- Gmsh Renderer -> Elmer simulation





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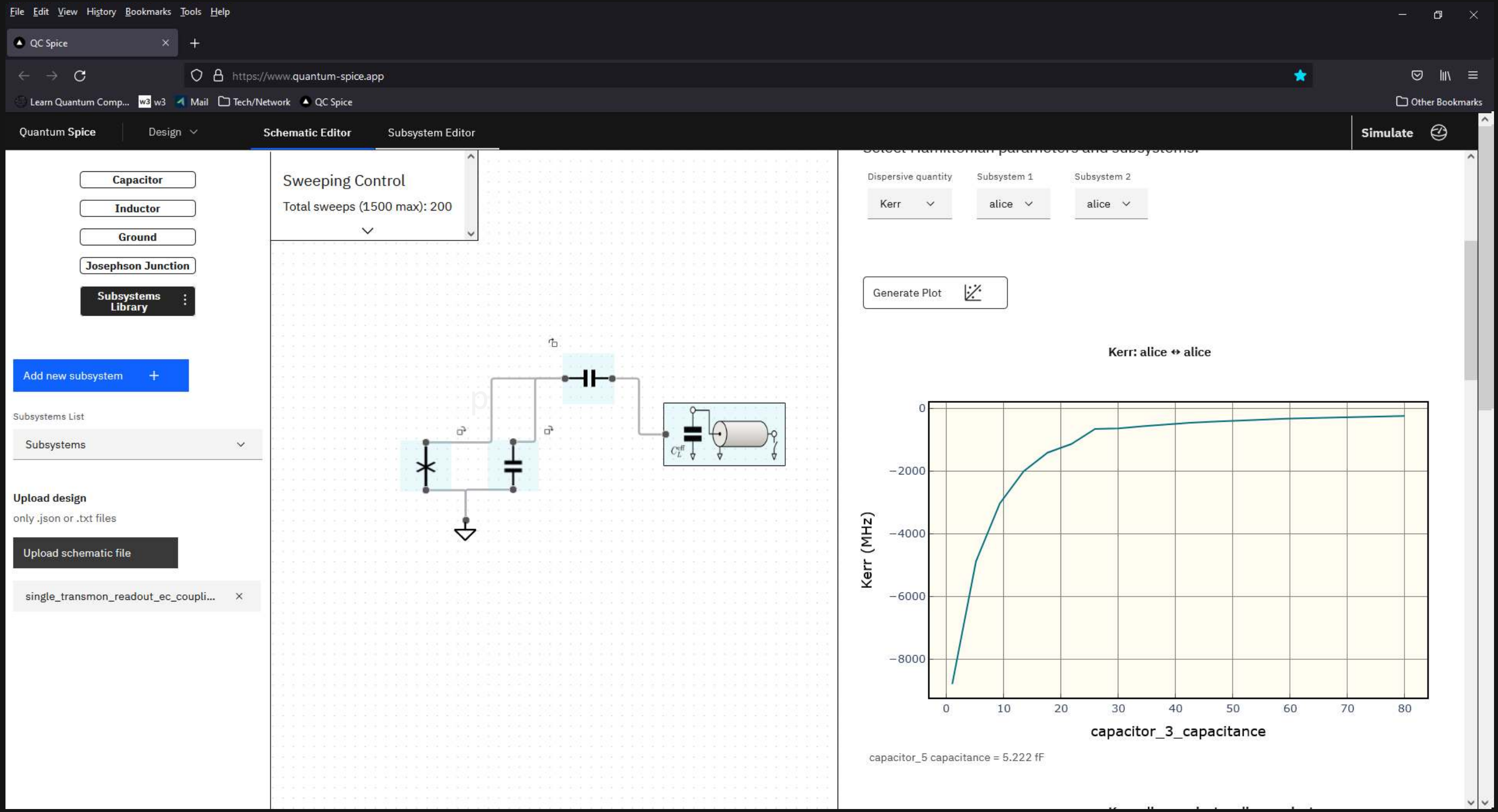
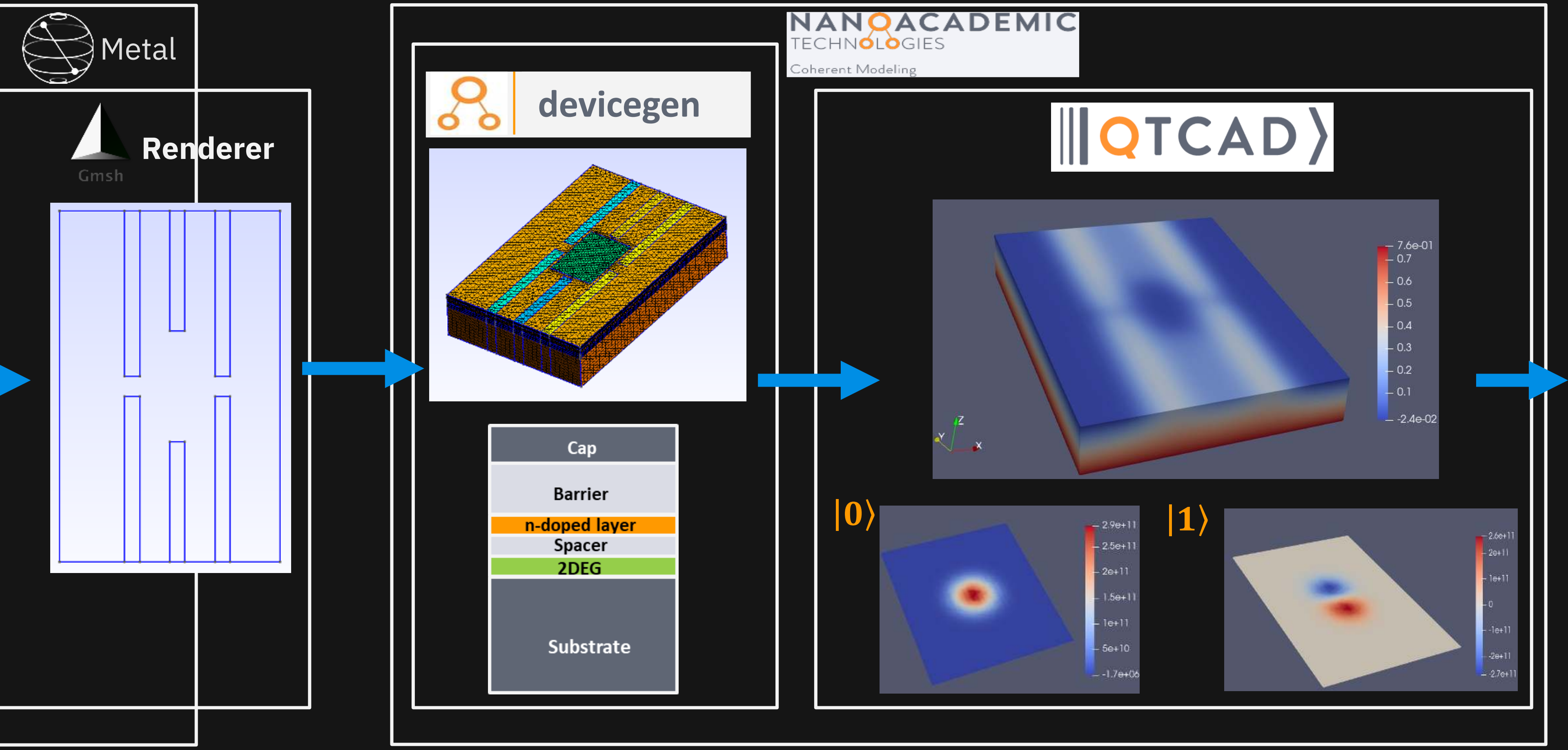
Quantum Spice



with scQubits

NanoAcademics QTCad Renderer



Metal Adoption

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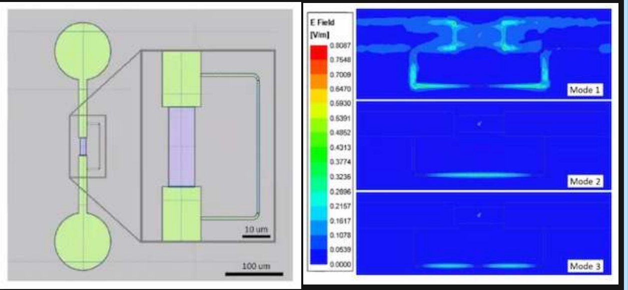
Research

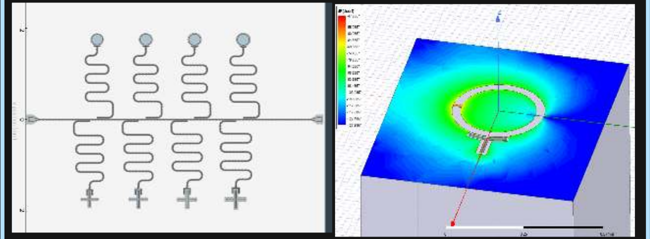
TU Delft Fluxonium



Seoul National University

VERI TAS LUX MEA

Chalmers 8Q



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POSTECH

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University of Colorado Boulder

NIST National Institute of Standards and Technology U.S. Department of Commerce

Simulation of Parametrically Coupled Qubits with Qiskit Metal and pyEPR

Zachary Parrott, X.Y. Jin, T. Noh, R. Simmonds

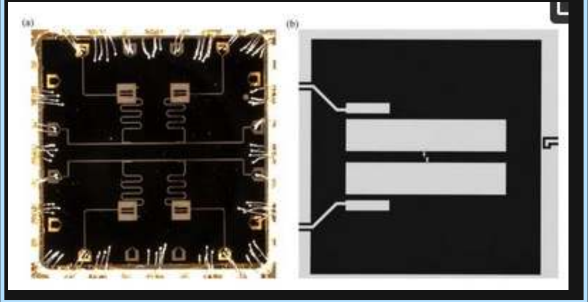
University of Colorado, Boulder & National Institute of Standards and Technology

entropy MDPI

Article

Comparison of Lumped Oscillator Model and Energy Participation Ratio Methods in Designing Two-Dimensional Superconducting Quantum Chips

Benzheng Yuan †, Weilong Wang †, Fudong Liu, Haoran He and Zheng Shan *



First design of a superconducting qubit for the QUB-IT experiment

Danilo Labranca[a,b], Hervè Atsè Corti[c,d], Leonardo Banchi[e,d], Alessandro Cidronali[f,d], Simone Felicetti[g], Claudio Gatti[h], Andrea Giachero[a,b], Angelo Nucciotti[a,b]

Education

Events

Qiskit Hackathon KOREA 2022

2022.02.07.(MON)~ 2022.02.10.(THU)

What is a hackathon?

It is a programming marathon challenged by various people! Welcome to the Qiskit hackathons world, an open-source framework that enables developers around the world to write code for quantum computers!

EXPLORE THE PEAKS OF MICROWAVE ENGINEERING
DENVER2022

USEQIP
Undergraduate School on Experimental Quantum Information Processing

Universities

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POSTECH
POHANG UNIVERSITY OF SCIENCE AND TECHNOLOGY

SAN JOSÉ STATE UNIVERSITY
1857

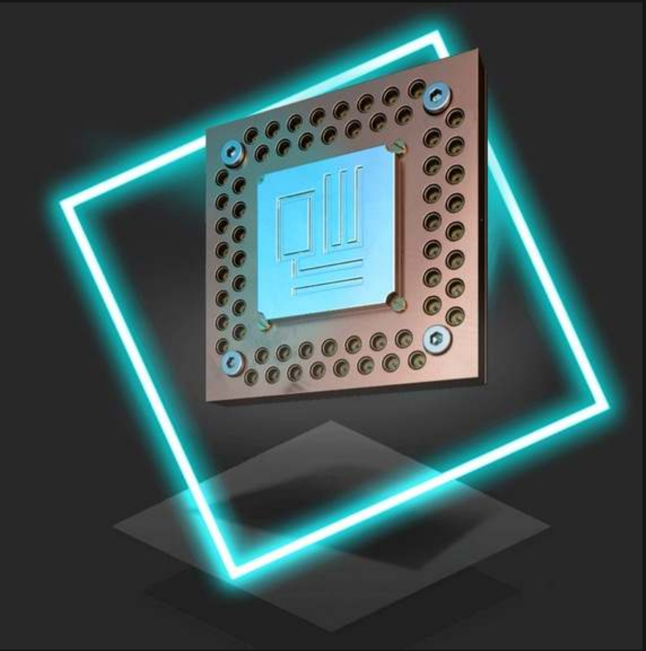
Organizations

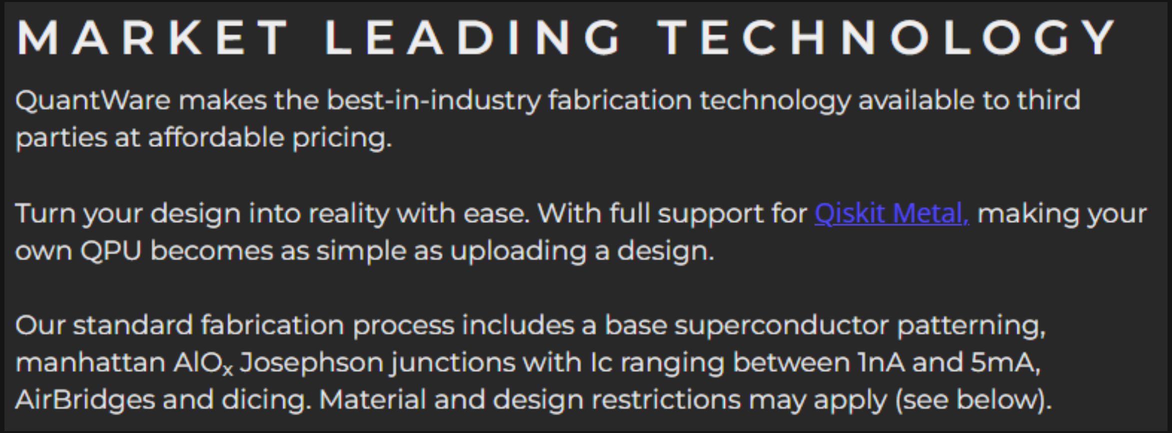
AiQyaM
Quantum & Beyond

C2QA
Co-design Center for Quantum Advantage

Commercial Foundries

QuantWare





How To Get Involved!

qiskit.org/metal

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image: *pikpng*

Docs & tutorials
qiskit.org/documentation/metal

Tutorial videos
YouTube – see docs

Slack
#metal (qiskit workspace)

Live tutorials

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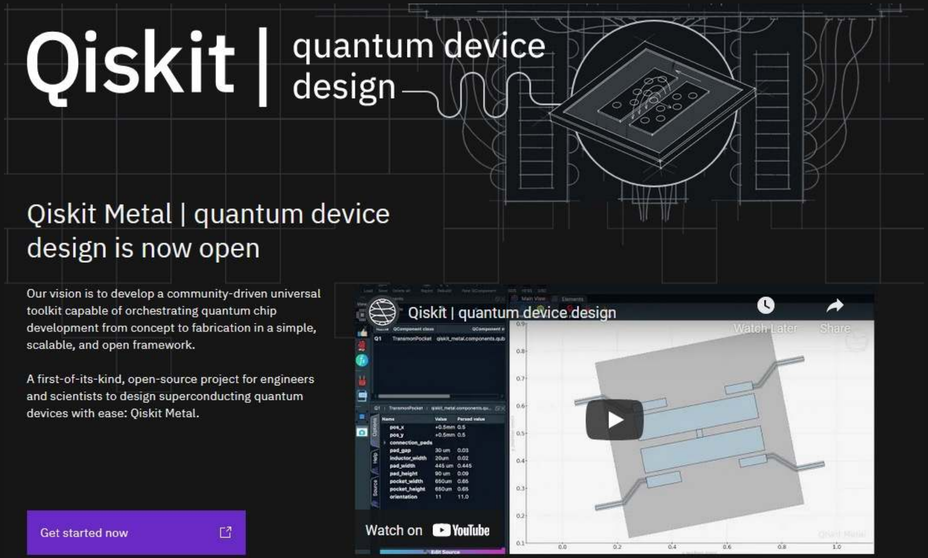
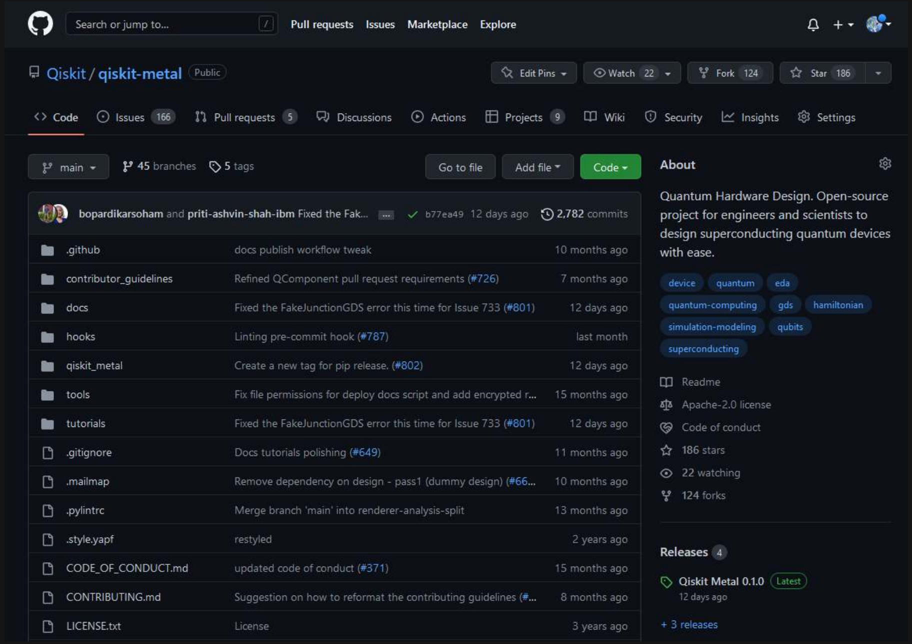
Open Source Collaboration

qiskit.org/metal





github.com/Qiskit/qiskit-metal

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