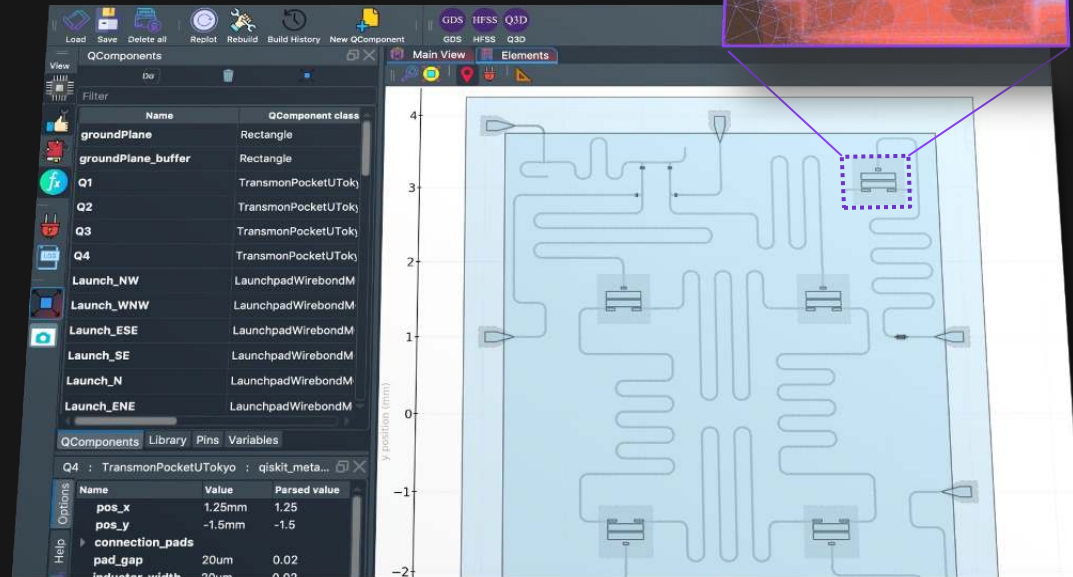


Qiskit Metal – Quantum Device Design and Analysis (Q-EDA)

Thomas G. McConkey, Zlatko Minev



A Quantum Computer

IBM Quantum



What needs to be designed?

junctions

qubit frequency,
anharmonicity, ...

qubit-qubit
coupling

readout
frequency/
coupling

spurious qubit
coupling

I-O
coupling

radiative dissipation
(Purcell limit)

spurious
modes

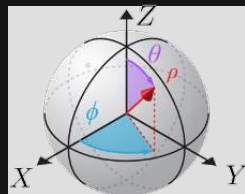
Quantum chip design flow

Complexity, Information, Accuracy
Risk, Cost, Time, Resources

Concept



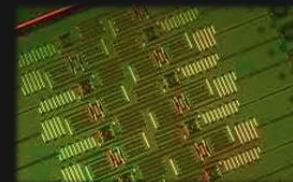
Hamiltonian



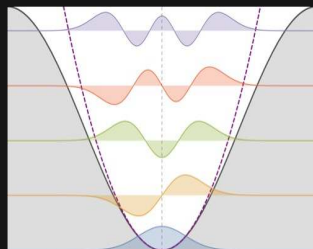
Layout



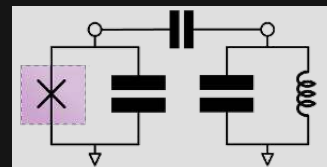
Fabrication



Quantum Analysis



Electromagnetic
Analysis



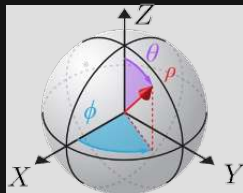
Quantum chip design flow

Complexity, Information, Accuracy
Risk, Cost, Time, Resources

Concept



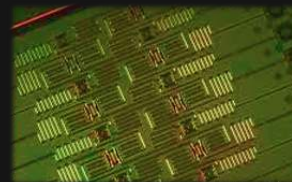
Hamiltonian



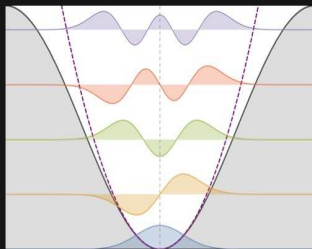
Layout



Fabrication



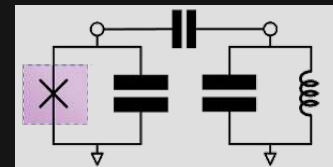
Quantum Analysis



Qiskit | quantum device
design



Electromagnetic
Analysis



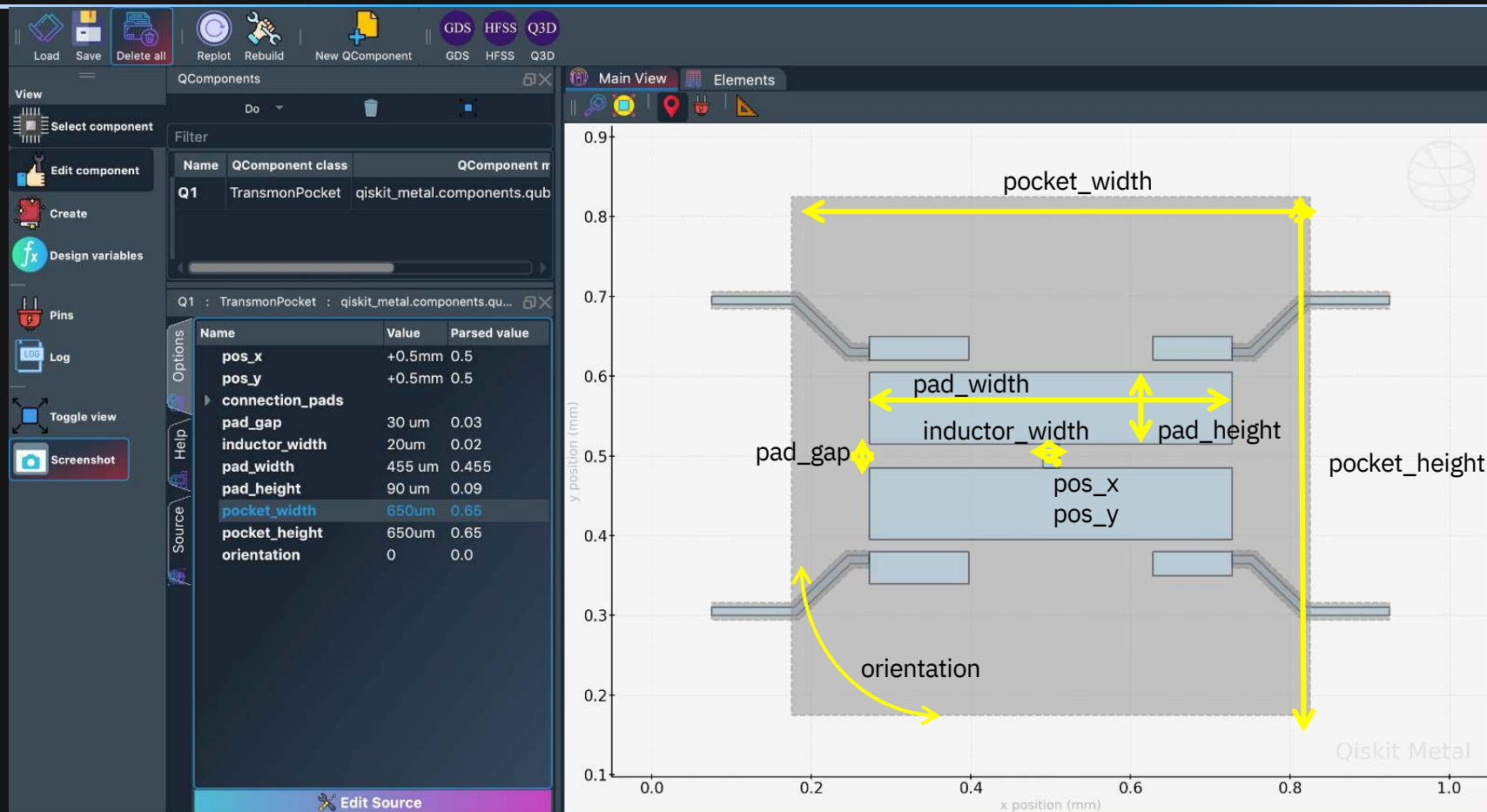
Qiskit Metal

qiskit.org/metal

What is Qiskit Metal?

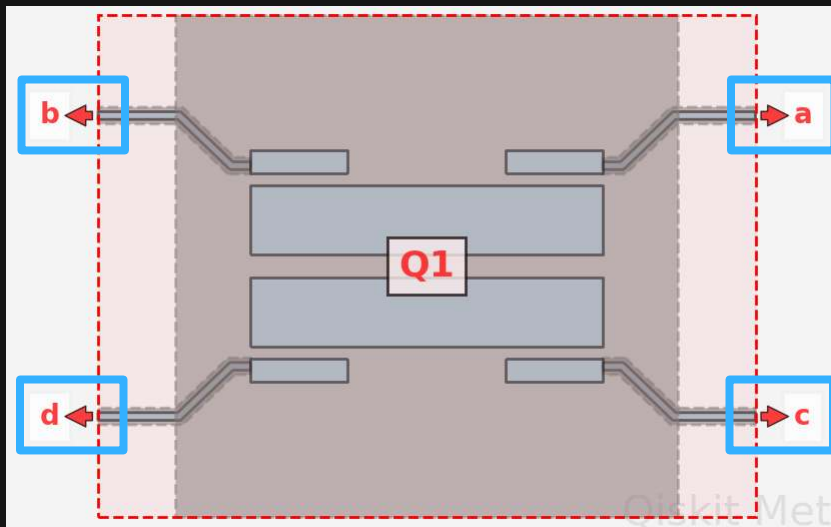
- A new open-source quantum-EDA tool from IBM
 - Written in python
 - Apache License 2.0
 - IBM claims no ownership or rights to any device or code
 - If you add code to the Metal database, it is open and free for everyone to use, but are under no obligation to ever contribute code.
 - Major contributions 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”



(x,y) = (0.7578, 0.4654) Δ last point (0.6510, -0.1140)

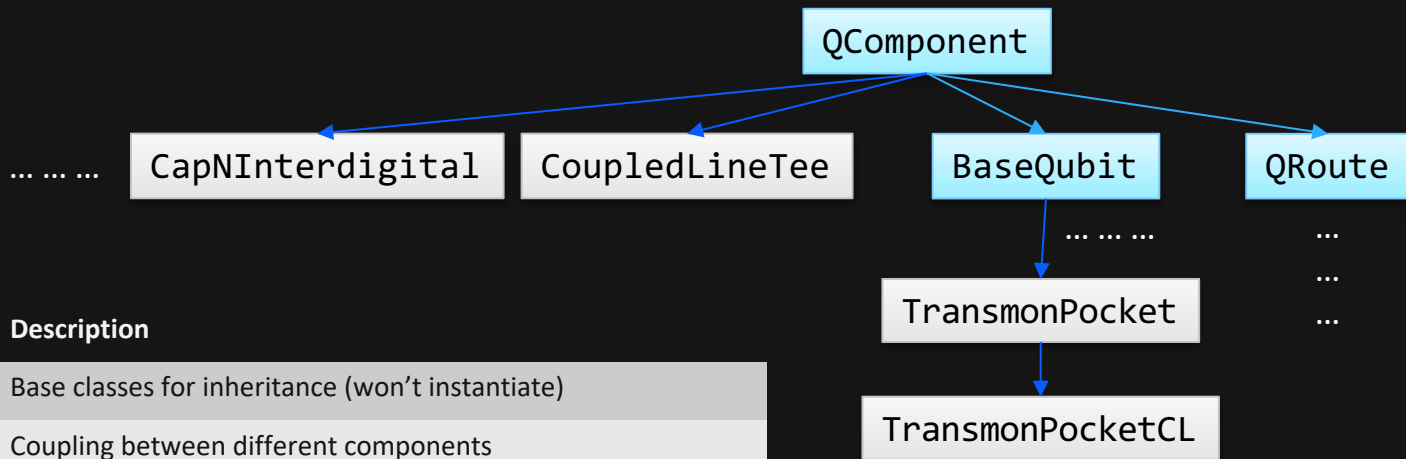
QComponents – “Super PCells”



```
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

QGeometry

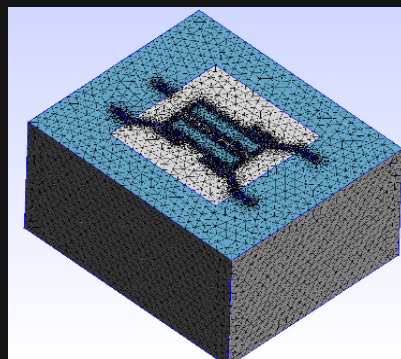
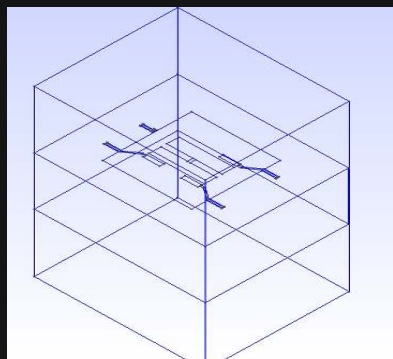
- The primitives of the Metal layout
 - Path, Poly and Junction
 - Includes additional parameters dependent on the renderers present

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	

Main View Elements													
Element type: junction		Filter: Component:	Layer:										
component	name	geometry	layer	subtract	helper	chip	width	hfss_inductance	hfss_capacitance	hfss_resistance	hfss_mesh		
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

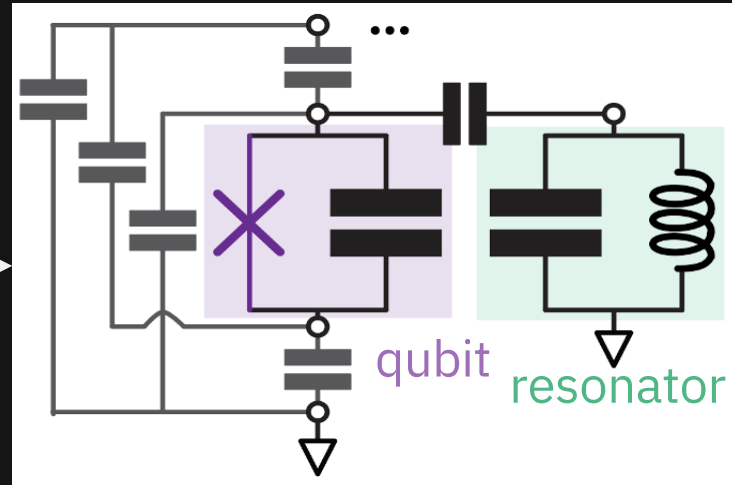
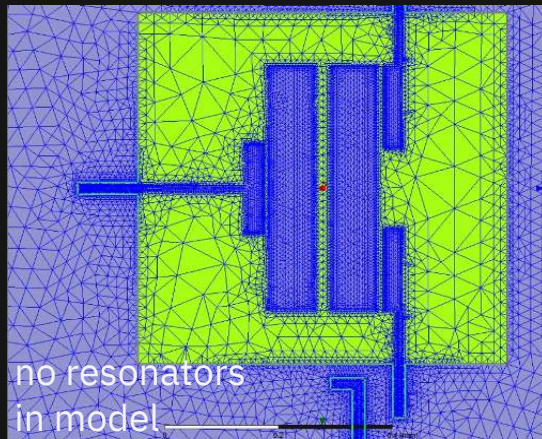
- The API translators between Metal layout/analysis and the classical simulation tools
 - To generate the layout natively for optimal simulation results
 - Extract results seamlessly into appropriate quantum analysis in Metal



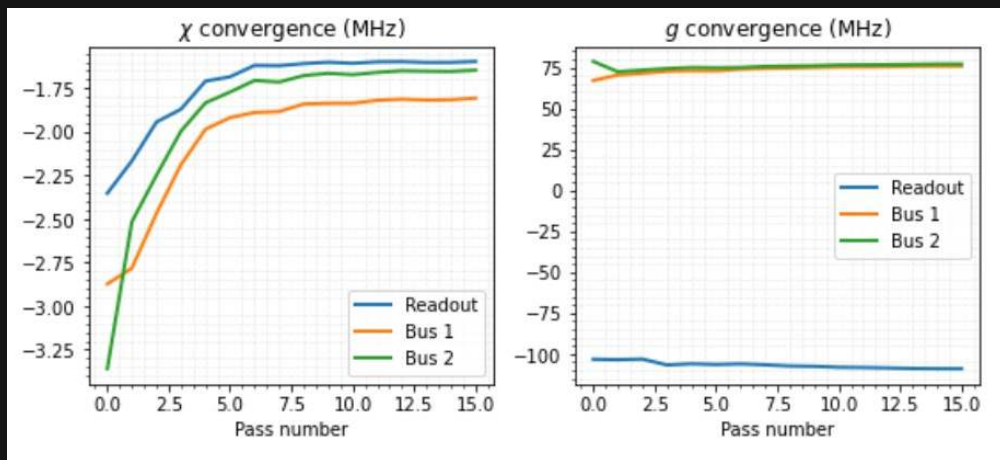
Quantum Analysis: LOM

- 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)

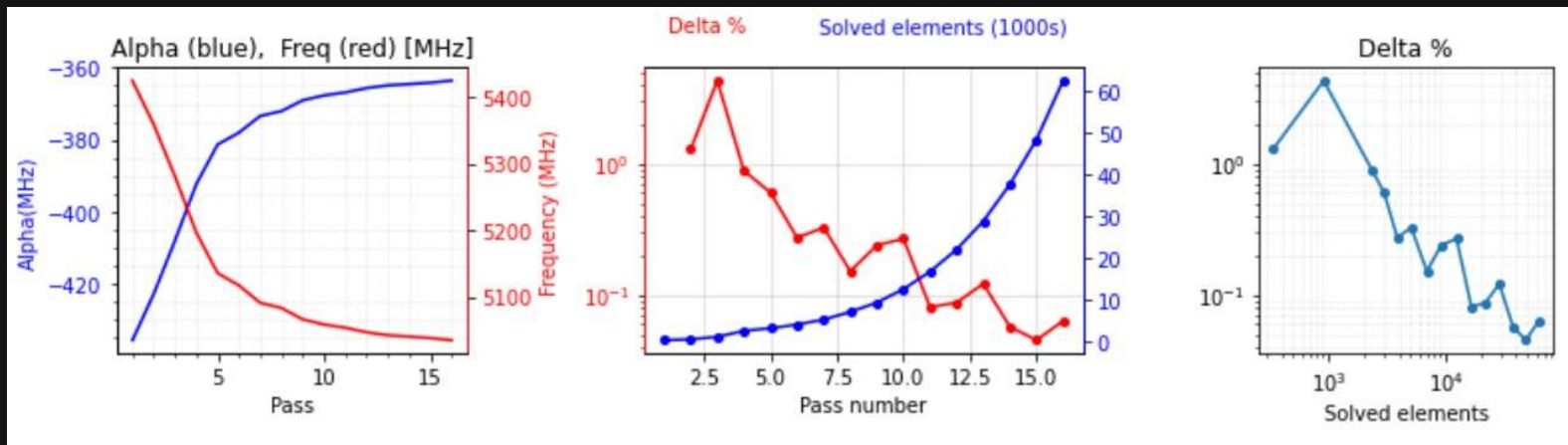
Quasi-static solver



Quantum Analysis: LOM



```
{'fQ': 4.787226695506869,  
'EC': 296.92044408559445,  
'EJ': 10.966147659300391,  
'alpha': -351.528599604318,  
'dispersion': 128.8753386135,  
'gbus': array([-83.55898953,  
'chi_in_MHz': array([-1.0692
```

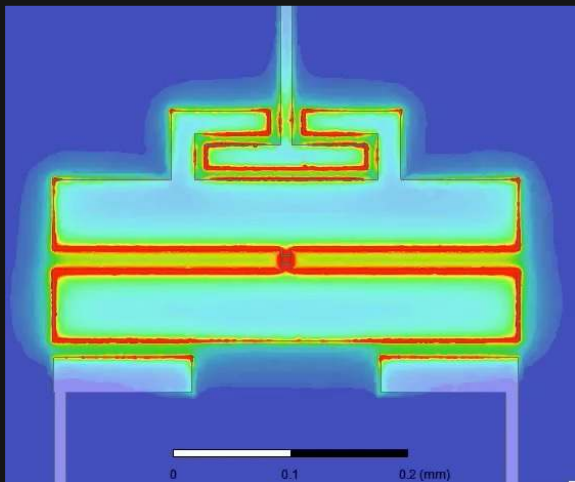


Quantum Analysis: EPR

- 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



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

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

```
*** Chi matrix O1 PT (MHz)
      Diag is anharmonicity, off d
      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
```

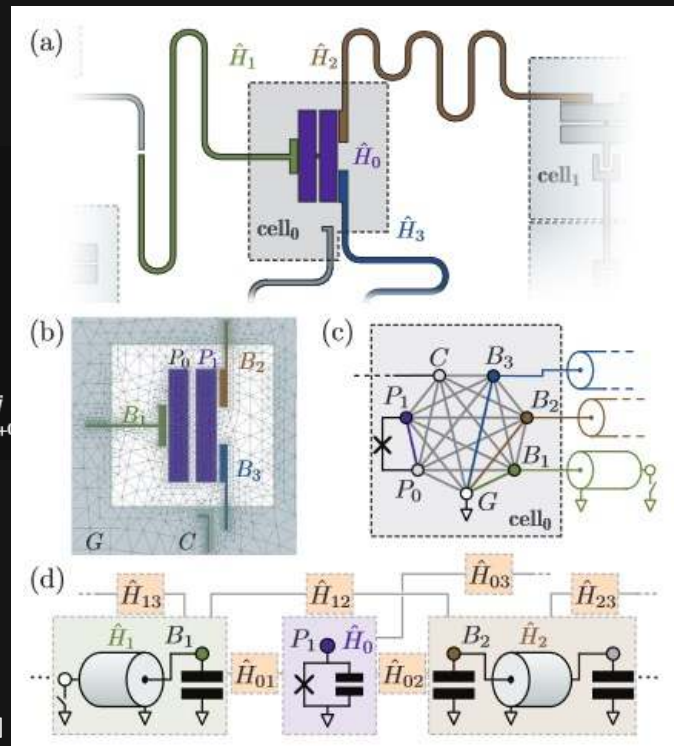
Quantum Analysis: LOM 2.0

- 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

$-2.438 \times 10^{+04}$	$0.108j$	0.0	$0.127j$	-0.436	...	0.0	0.0
$-0.108j$	$-1.678 \times 10^{+04}$	$0.153j$	0.436	$0.127j$...	0.0	0.0
0.0	$-0.153j$	$-9.184 \times 10^{+03}$	0.0	0.617	...	0.0	0.0
$-0.127j$	0.436	0.0	$-1.638 \times 10^{+04}$	$0.108j$...	0.0	0.0
-0.436	$-0.127j$	0.617	$-0.108j$	$-8.784 \times 10^{+03}$...	-1.839×10^{-08}	0.0
\vdots	\vdots	\vdots	\vdots	\vdots	\ddots	\vdots	\vdots
0.0	0.0	0.0	0.0	-1.839×10^{-08}	...	$7.287 \times 10^{+04}$	$706.553j$
0.0	0.0	0.0	0.0	0.0	...	$-706.553j$	$8.047 \times 10^{+4}$



[Z. Mineev 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>

Export to GDS

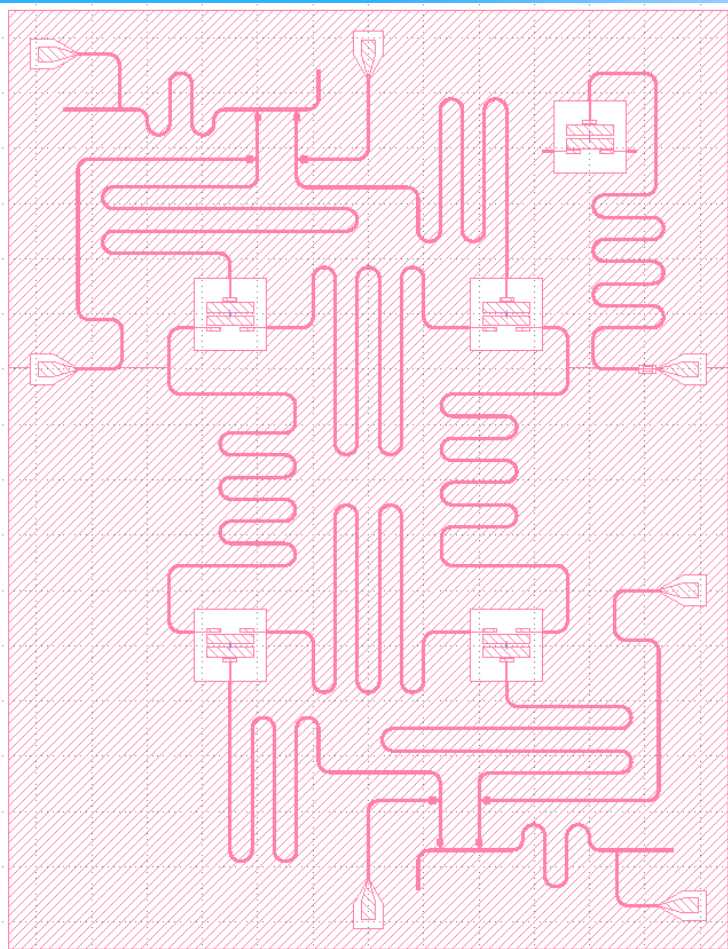
```
full_chip_gds = design.renderers.gds
```

...

```
full_chip_gds.options
```

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

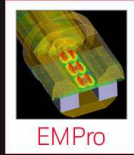
```
full_chip_gds.export_to_gds('Full_Chip_01.gds')
```



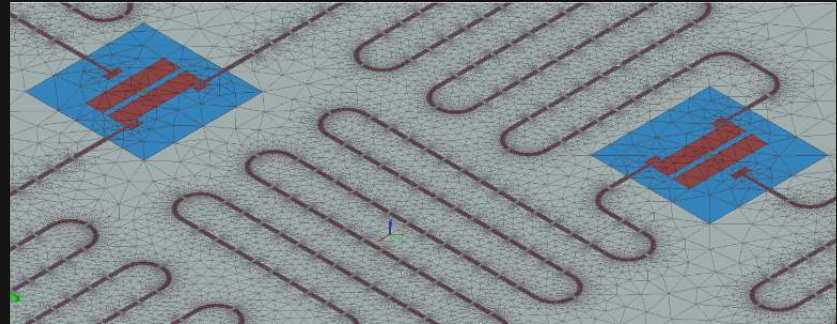
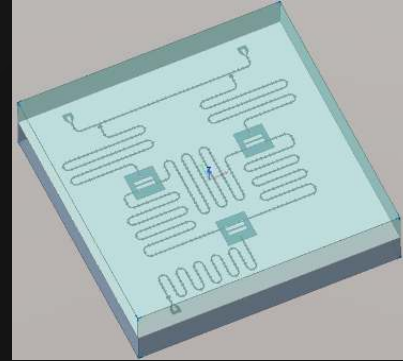
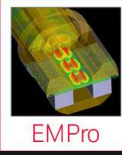
Current Metal Development

qiskit.org/metal

Keysight/EMPro Renderer

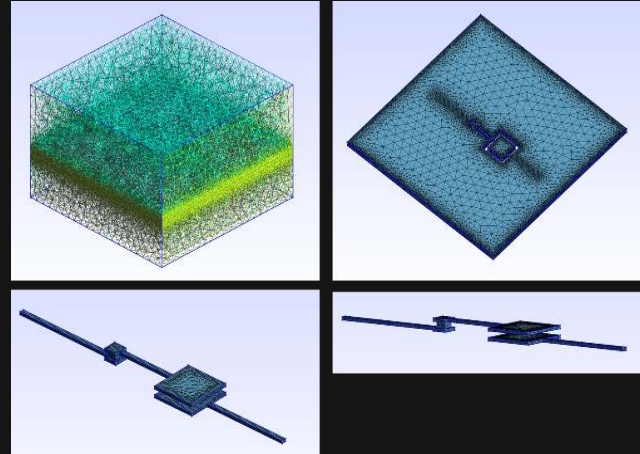
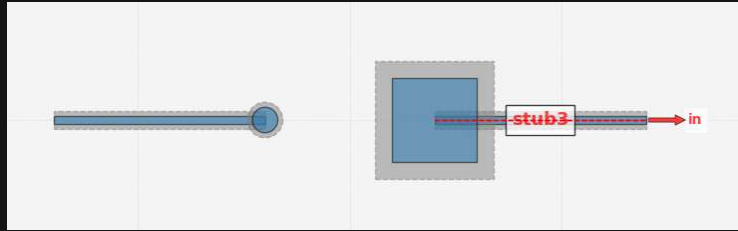
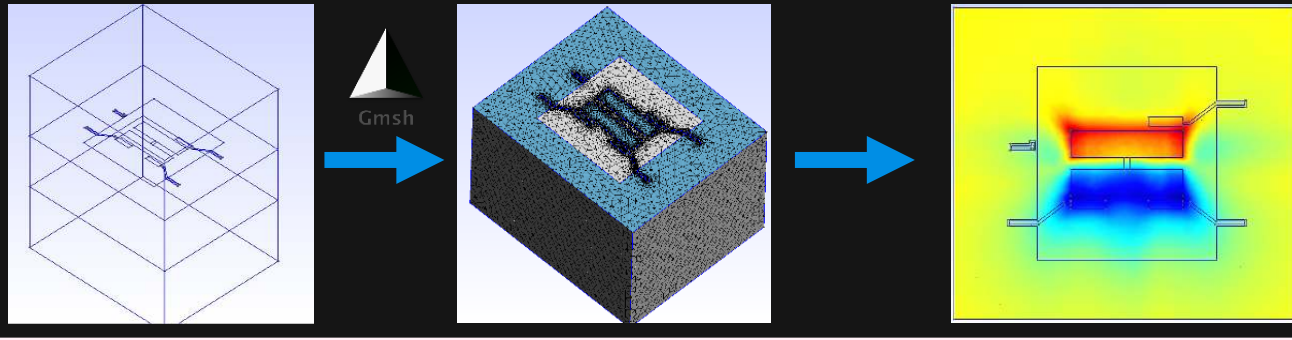


Renderer

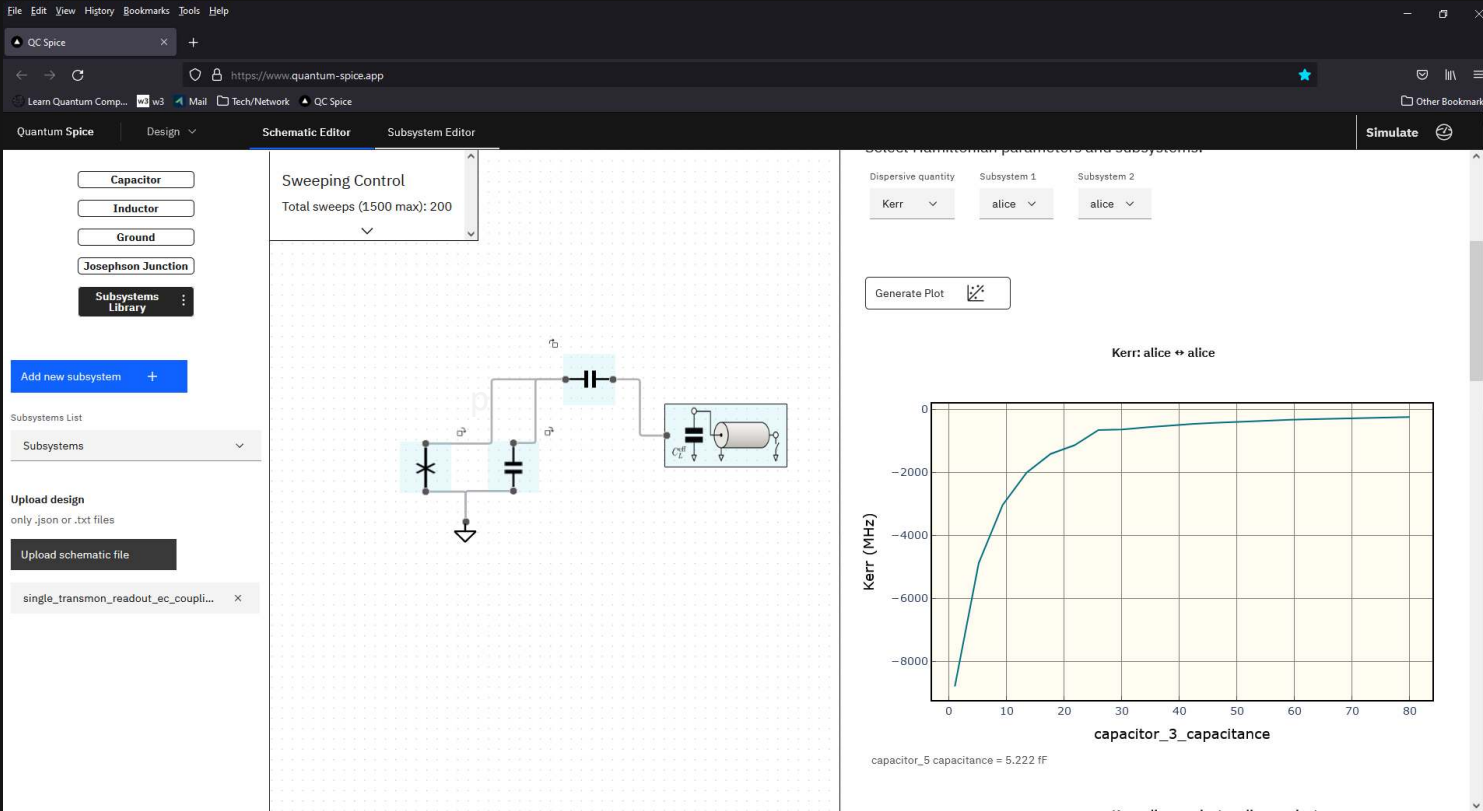


Open Source Renderers

- Gmsh Renderer -> Elmer simulation



Quantum Spice



NanoAcademics QTCad Renderer

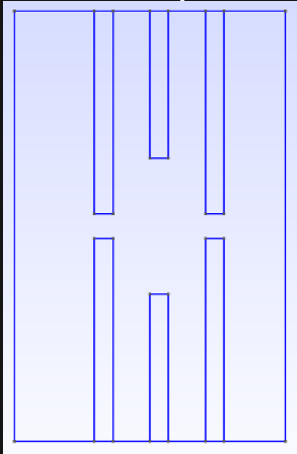


Metal

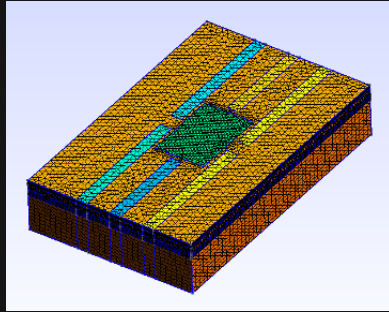


Gmsh

Renderer



devicegen



Cap

Barrier

n-doped layer

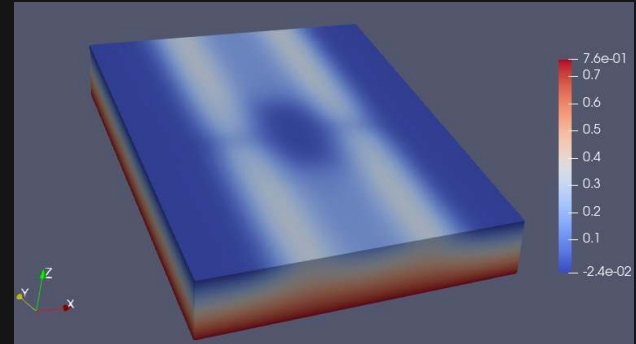
Spacer

2DEG

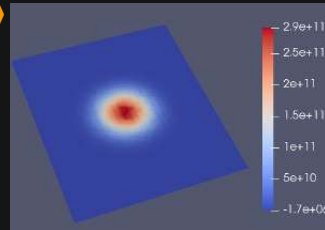
Substrate

NANOACADEMIC
TECHNOLOGIES
Coherent Modeling

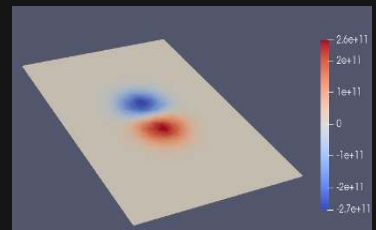
QTCAD



$|0\rangle$



$|1\rangle$

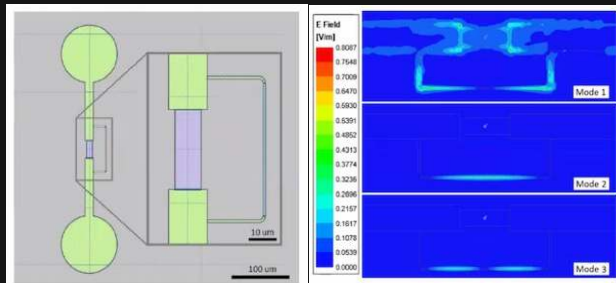


Metal Adoption

qiskit.org/metal

Research

TU Delft Fluxonium



Seoul National



University of Colorado
Boulder

NIST

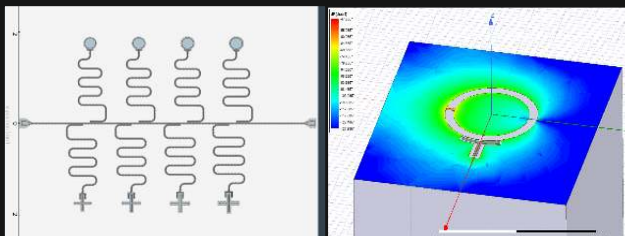
National Institute of
Standards and Technology
U.S. Department of Commerce

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

Chalmers 8Q



SUNG KYUN KWAN
UNIVERSITY

Value Creating University

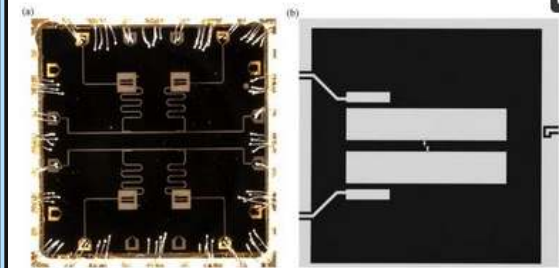
POSTECH
POHANG UNIVERSITY OF SCIENCE AND TECHNOLOGY



Article

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

Benzheng Yuan ^{*}, Weiliang Wang ^{*}, Fudong Liu ^{*}, Haoran He and Zheng Shan ^{*}



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

Danilo Labranca^{a,b}, Hervé Atsè Corti^{c,d}, Leonardo Banchi^{c,d}, Alessandro Cidronali^{f,d}, Simone Felicetti^g, Claudio Gatti^h, Andrea Giachero^{a,b}, Angelo Nucciotti^{a,b}

Education

Events



KAWASAKI
2022
QUANTUM
SUMMER CAMP

山崎市内の高校生限定！

Kawasaki Quantum Summer Camp 2022

あなたのアイデアが量子コンピューターの未来を創る

実施日：2022.8.1(金)～2022.8.4(金) 応募期限：2022.6.30(金)まで

受講費
無料

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

DENVER 2022

Superconducting Circuits and Qubits — Virtual Workshop

JULY 19-30, 2021

Learn how to design, fabricate, and test
your own superconducting circuits.

QUANTUM BC | QSciTech

We acknowledge the support of the Natural Sciences
and Engineering Research Council of Canada (NSERC).

NSERC
CRSNG

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QUANTIQUE
UNIVERSITY OF QUEBEC

Shrawan Bhushan
Quantum Matter Institute
BIOGRAPHIC

CMC
MICROELECTRONICS

D:WAVE
The Quantum Computing Company

University
of Victoria

Centre for
Advanced Materials
& Related Technology

IBM Q

USEQIP

Undergraduate School
on **Experimental Quantum**
Information Processing

Universities

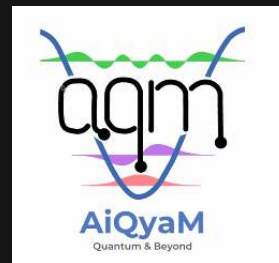
Value Creating University

POSTECH

POHANG UNIVERSITY OF SCIENCE AND TECHNOLOGY

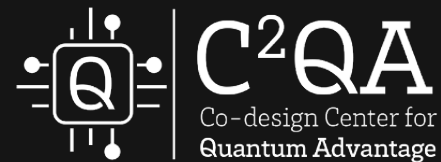


Organizations



aqm

AiQyam
Quantum & Beyond

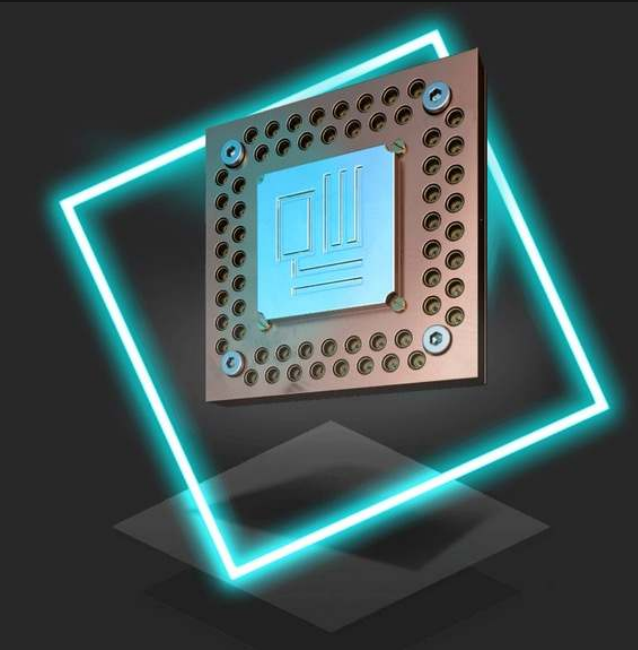


C²QA

Co-design Center for
Quantum Advantage

Commercial Foundries

QuantWare



MARKET LEADING TECHNOLOGY

QuantWare makes the best-in-industry fabrication technology available to third parties at affordable pricing.

Turn your design into reality with ease. With full support for [Qiskit Metal](#), making your own QPU becomes as simple as uploading a design.

Our standard fabrication process includes a base superconductor patterning, manhattan AlO_x Josephson junctions with I_c ranging between 1nA and 5mA, AirBridges and dicing. Material and design restrictions may apply (see below).

How To Get Involved!

qiskit.org/metal



image: pikpng

Docs & tutorials
qiskit.org/documentation/metal

Tutorial videos
[YouTube](#) – see docs

Slack
[#metal](#) (qiskit workspace)

Live tutorials

Open Source Collaboration

qiskit.org/metal

Qiskit

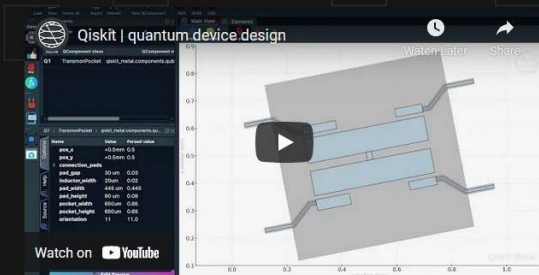
quantum device
design

Qiskit Metal | quantum device design is now open

Our vision is to develop a community-driven universal toolkit capable of orchestrating quantum chip development from concept to fabrication in a simple, scalable, and open framework.

A first-of-its-kind, open-source project for engineers and scientists to design superconducting quantum devices with ease: Qiskit Metal.

Get started now



The image shows a screenshot of the Qiskit/qiskit-metal GitHub repository page. The page header includes the repository name, public status, and statistics: 22 watches, 124 forks, and 186 stars. The main content area lists the repository's structure, including folders like .github, contributor_guidelines, docs, hooks, qiskit_metal, tools, and tutorials. It also shows a list of recent commits, including a fix for the FakeJunctionGDS error and a new tag for pip release. The right sidebar contains the 'About' section, which describes the project as an open-source framework for designing superconducting quantum devices, and lists the license (Apache-2.0) and the number of stars (186).

github.com/Qiskit/qiskit-metal