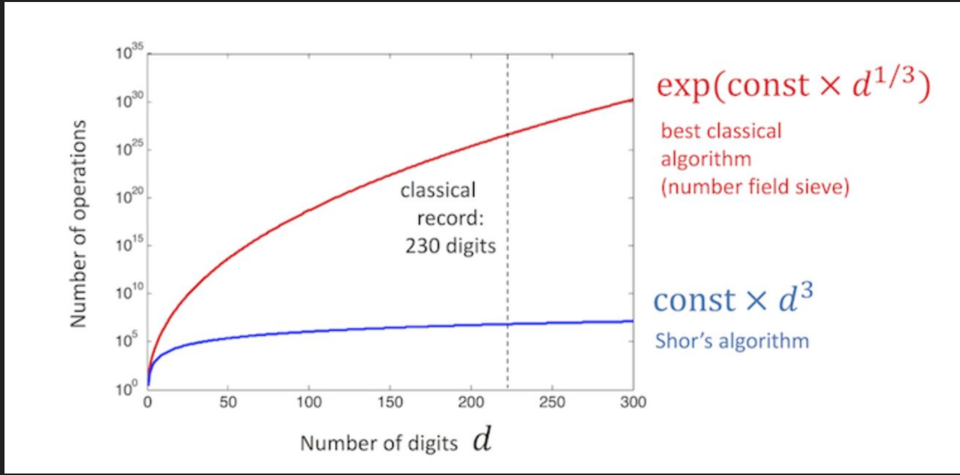
Gatemon Qubit Simulations in Qiskit Metal

Krishna Dindial

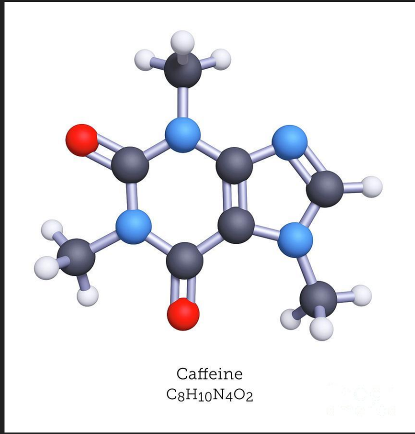
Advantages of a Quantum computer

- Can implement algorithms that take advantage of quantum mechanical effects such as entanglement, superposition and interference



- A 300 qubit computer can be in a superposition of 2^{300} states at once → larger than # atoms in universe

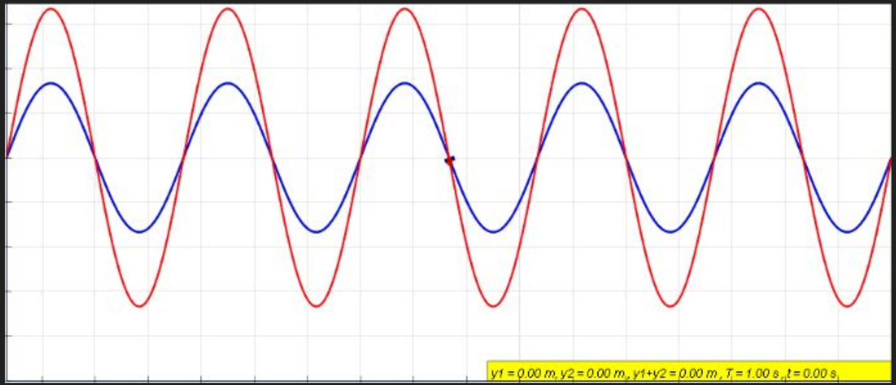
- Can simulate molecular structures that behave quantum mechanically



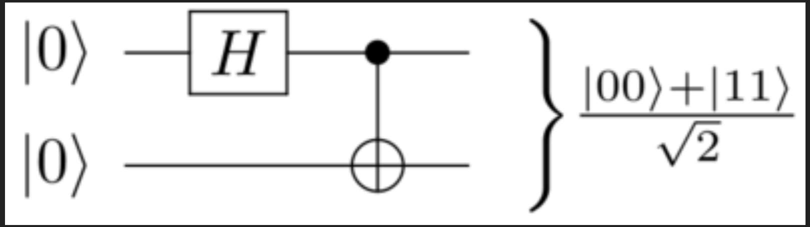
Qubits behave differently

- Can be in a superposition of 0 and 1
- Can interfere with each other
- Can become entangled with each other

Wikipedia: interference



Wikipedia: Entangled Bell State



Ideal Quantum Computer (DiVincenzo Criteria)

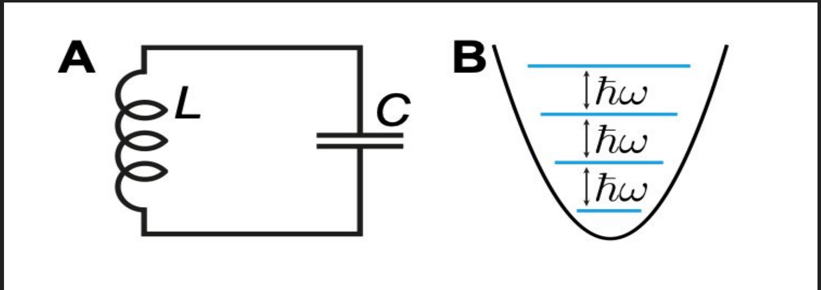
1. Scalable System
2. Long Coherence Times
3. Control
4. Readout
5. Reset

It is hard to achieve all of these things at once because quantum systems are fragile.

- Balancing act between isolating the qubit from its environment, but also being able to interact with it and measure it

LC Oscillator

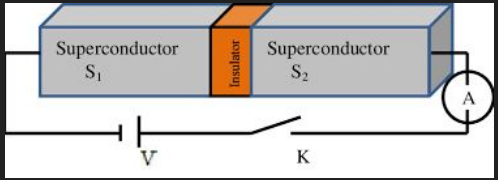
LC oscillator is a very common circuit, very familiar to physicists and electrical engineers

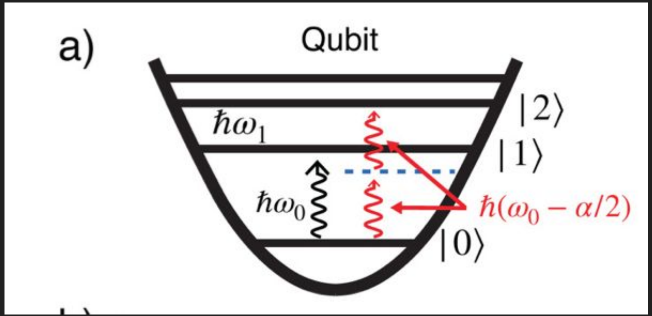


- Does not work as a qubit because energy levels are all evenly spaced out

Transmon Qubit

- By replacing an inductor with a josephson junction, the energy levels become uneven





Pros and cons of transmon

Pros:

- LC circuits are very familiar to physicists and electrical engineers
- Can be controlled and measured with photons microwave (5ghz) pulses

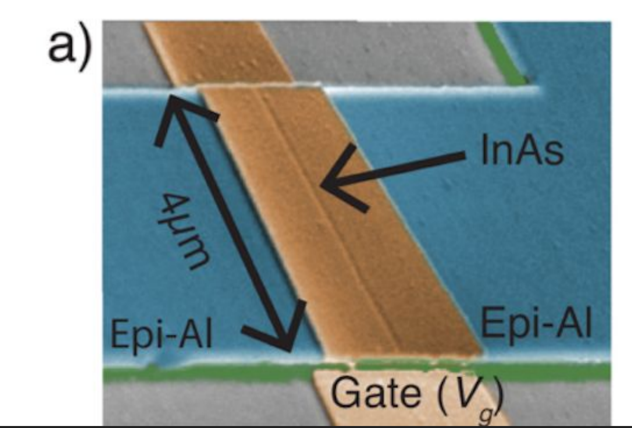
Cons:

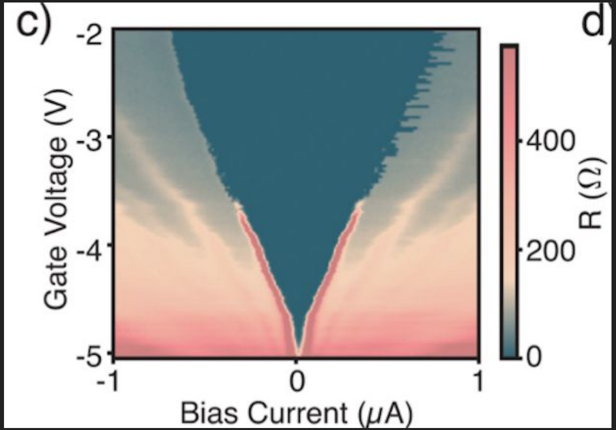
- susceptible to charge noise
- Must be kept in millikelvin fridge
- Cannot be tuned: the energy levels are fixed

Gatemon

- Rather than using a cubit with a fixed frequency, the gatemon uses a voltage tuneable semiconductor to “tune” the qubit to different frequencies

- Can tune qubits in and out of resonance with each-other





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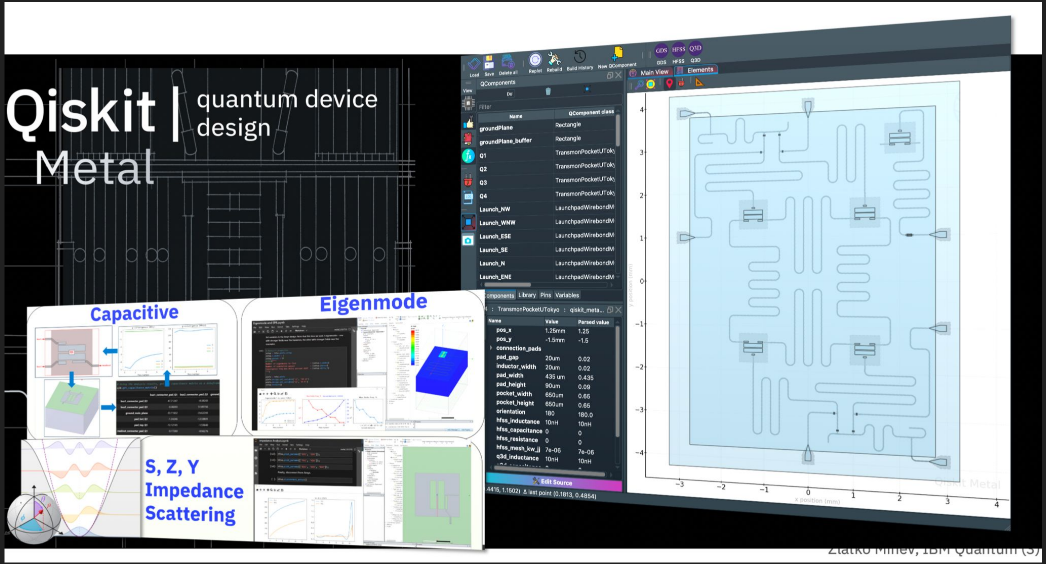
IBM Qiskit Metal

- It is expensive to fabricate tuneable junctions and new chip designs

- Qiskit metal lets us build and analyze new designs all on the computer saving time and money

- Once a worthwhile design is found we can fabricate it and test it



- LOM analysis *Minev et al 2021, arXiv: 2103.103344*

- EPR Analsyis analysis *Minev et al 2021, arXiv: 2010.00620*

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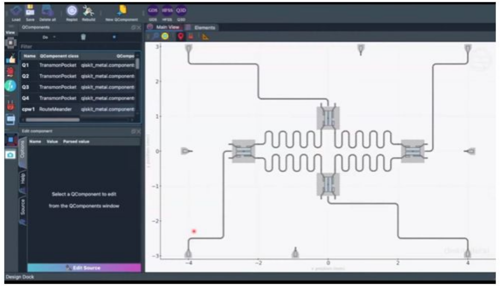
Qiskit-Metal Work Flow

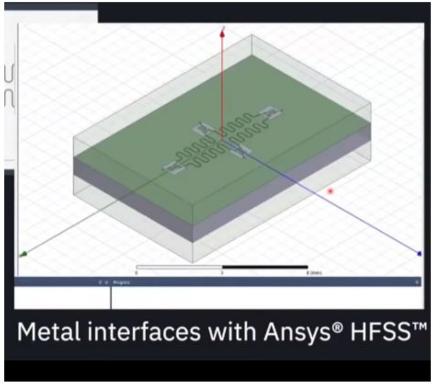
Step 0) Think of a design

Step 1)



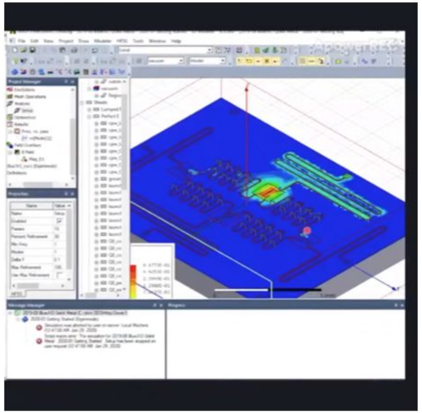
Draw design in Qiskit Metal

Step 2)



Render in HFSS Ansys

Step 3)



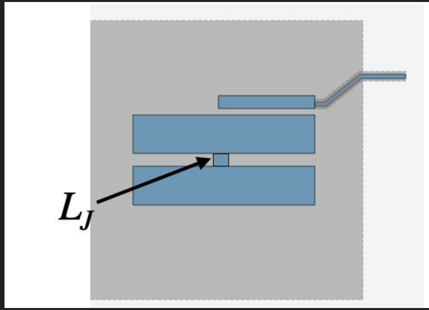
Simulate the circuit

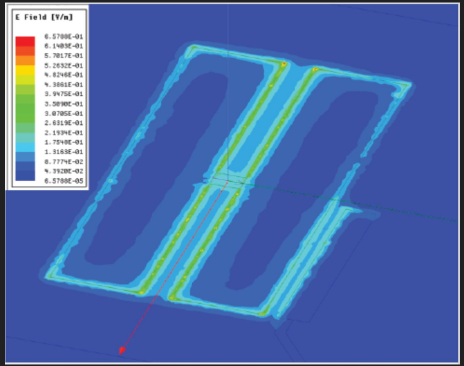
Youtube, Qiskit, “Qiskit Metal E05.1 - Analysis - Capacitance and Frequency Control”

What does the Simulation tell us?

- Qubit Frequency
  - The difference in energy levels between the 0 and 1 state.
- Anharmonicity
  - The difference between the first and second frequency levels
    - For Transmon this is about Ec, For gatemon this is about Ec/4
- Coupling Strength
  - Parameter that tells us how much interaction there is between two components in a chip
- Dispersive shift
  - How does the qubits energy change when you add new components to the chip

Simulating a Tuneable Transmon as a Gatemon





Design Parameters	Qubit Properties			
Josephson Inductance (nH)	Qubit Frequency (GHz)	Anharmonicity (MHz)	Coupling Strength (MHz)	Dispersive Shift (MHz)
10	6.152	370	125	11.3
20	4.241	402	105	1.1
30	3.389	440	95	0.6
40	2.878	477	88	0.5
50	2.527	496	84	0.4

Simulating tunable resonator Cavities

CPW width: 10um
Fixed Resonator length: 3.10mm
Tuneable Resonator 3.13mm

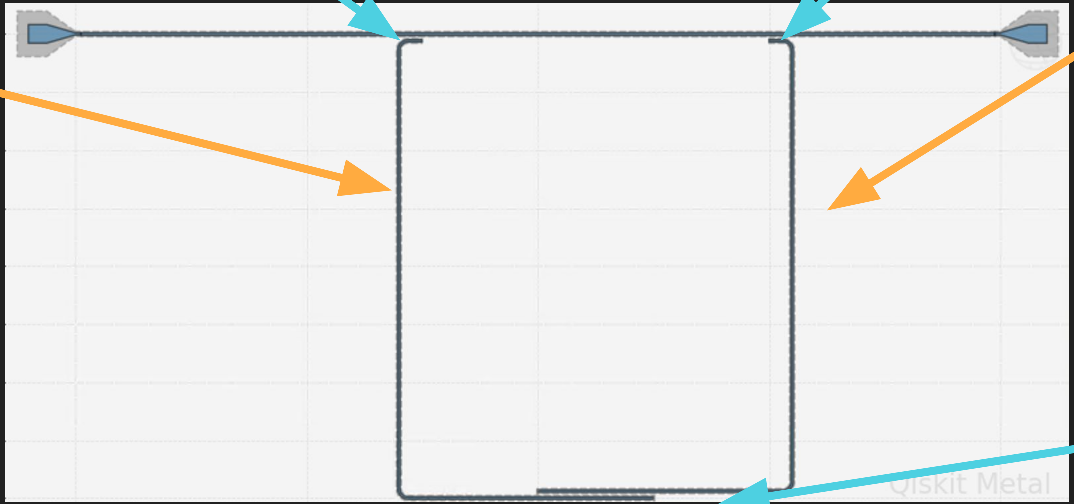
Can be Open or Closed

Closed to Ground

Fixed λ/4 Resonator

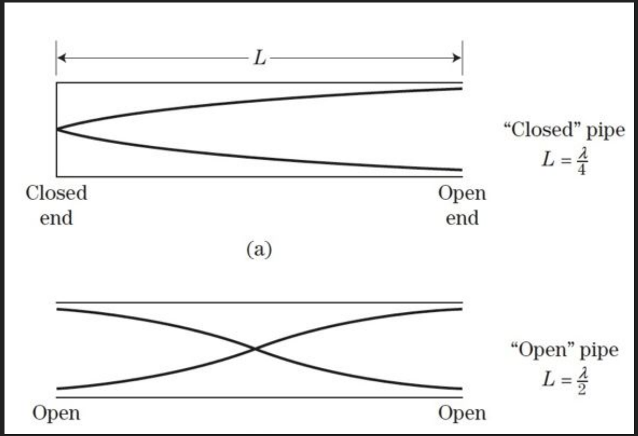
Tuneable Resonator:

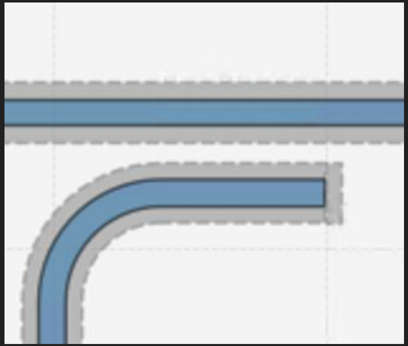
By opening or closing off one end it can can be a λ/4 or a λ/2 resonator



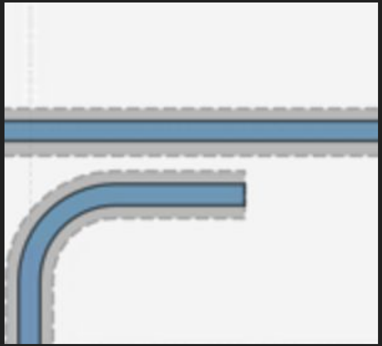
Open to Ground

Tuned Resonator Cavities





Closed End

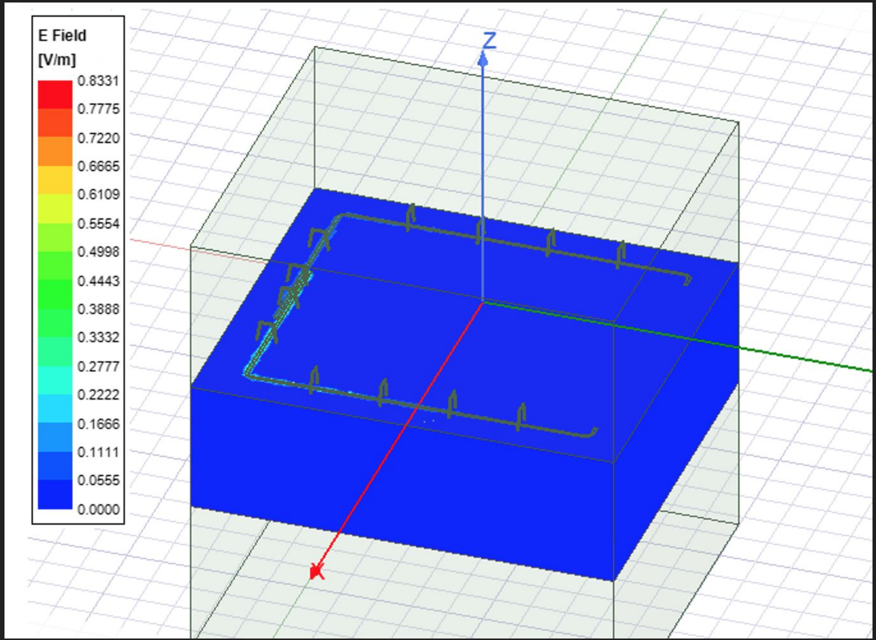


Open End

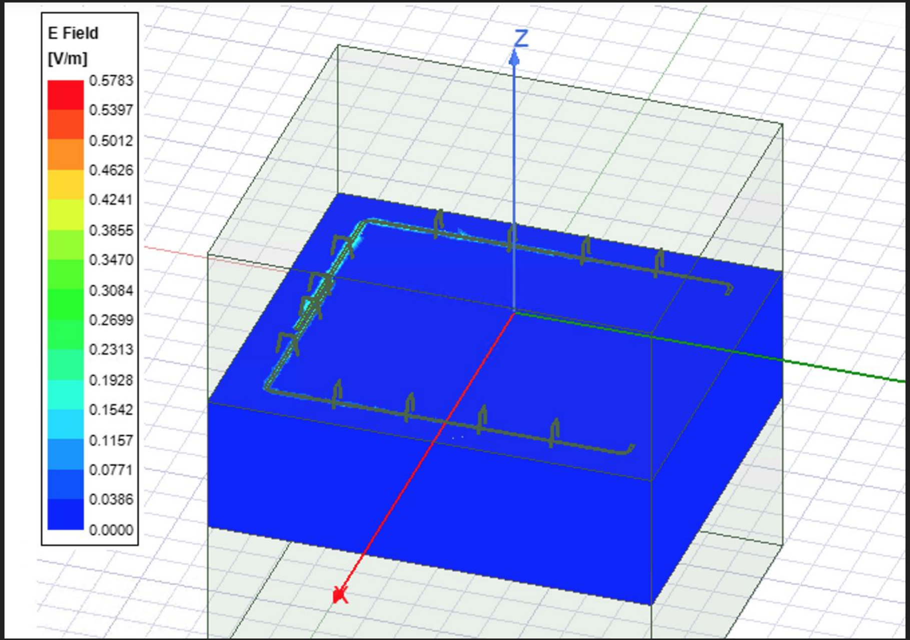
Two λ/4 Resonators

variation	mode	Freq. (GHz)
0	0	9.322328
	1	9.531701

Mode 0



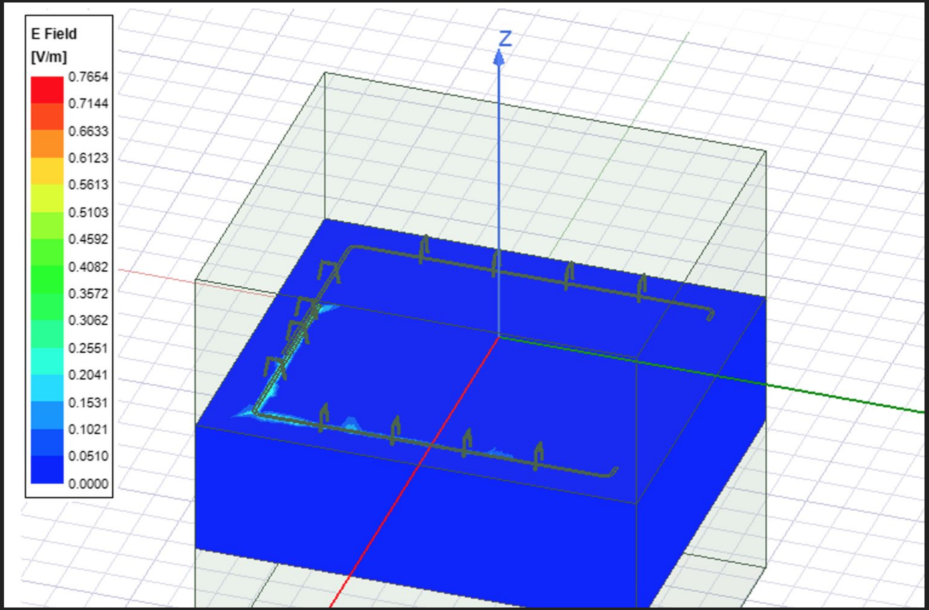
Mode 1



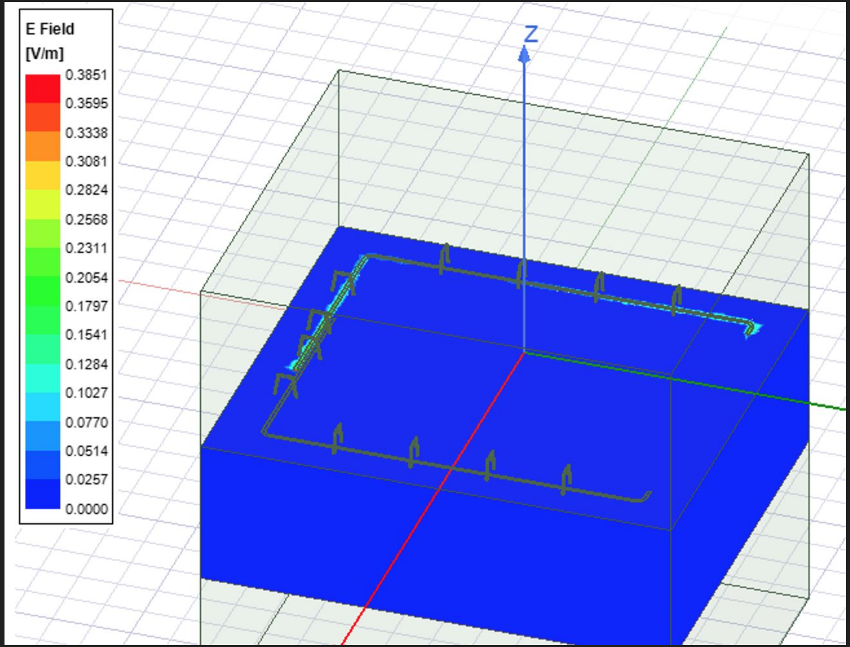
λ/2 Resonator and fixed λ/4 resonator

variation	mode	Freq. (GHz)
0	0	9.079696
	1	18.377024

Mode 0

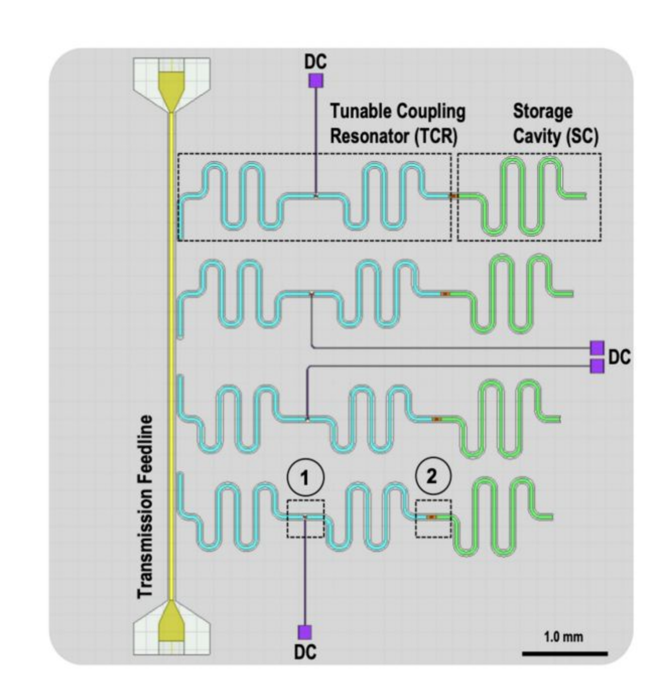


Mode 1



Next Steps

- Designing custom components in Qiskit metal
- Tuneable resonators coupled to tuneable qubits
- Multi qubit simulations
- Stay in Touch with Gatemon Team



K. Sardashti et al, "Voltage-Tunable Superconducting Resonators: A Platform for Random Access Quantum Memory," in *IEEE Transactions on Quantum Engineering*, vol. 1, pp. 1-7, 2020, Art no. 5502107