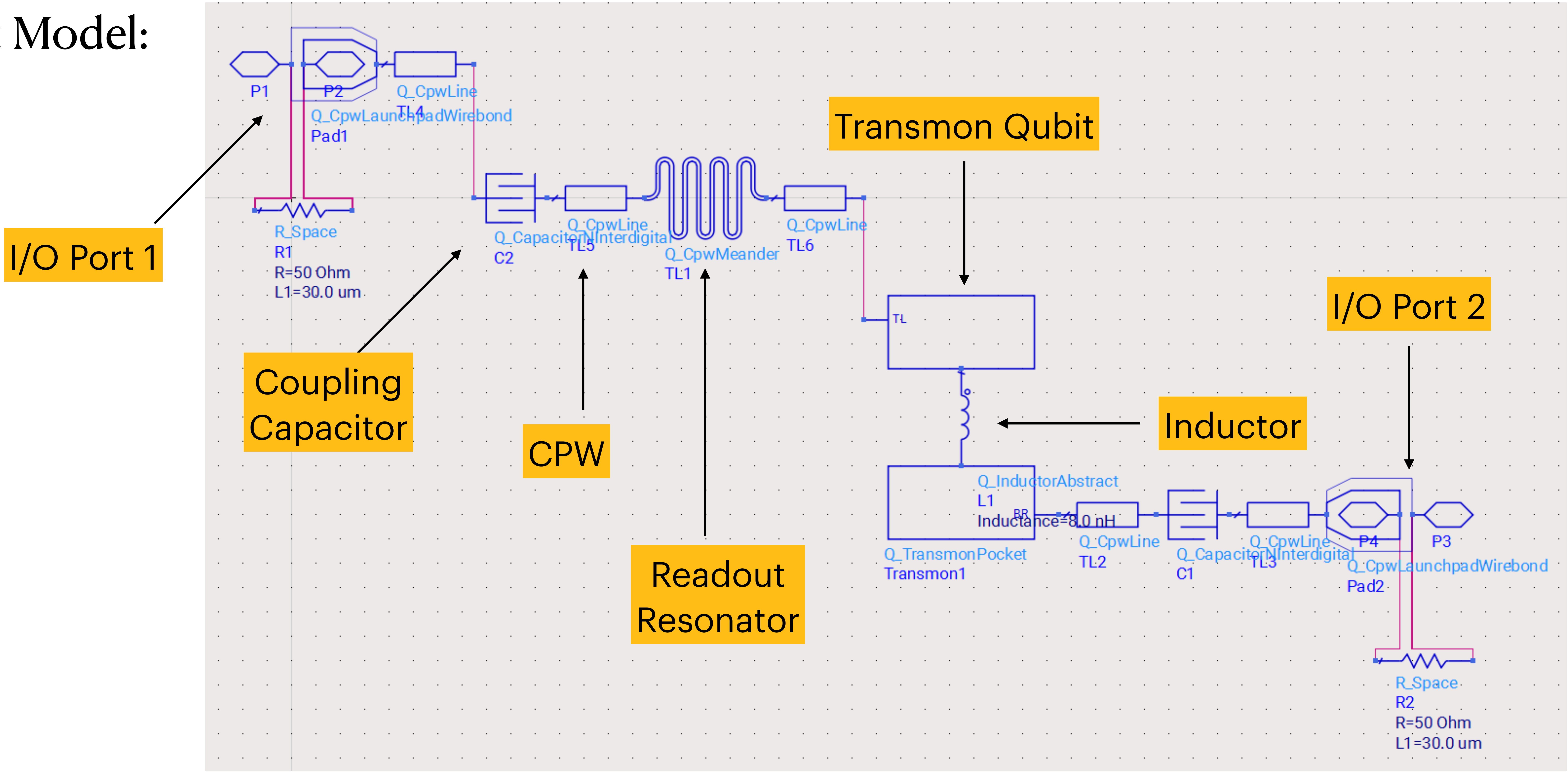
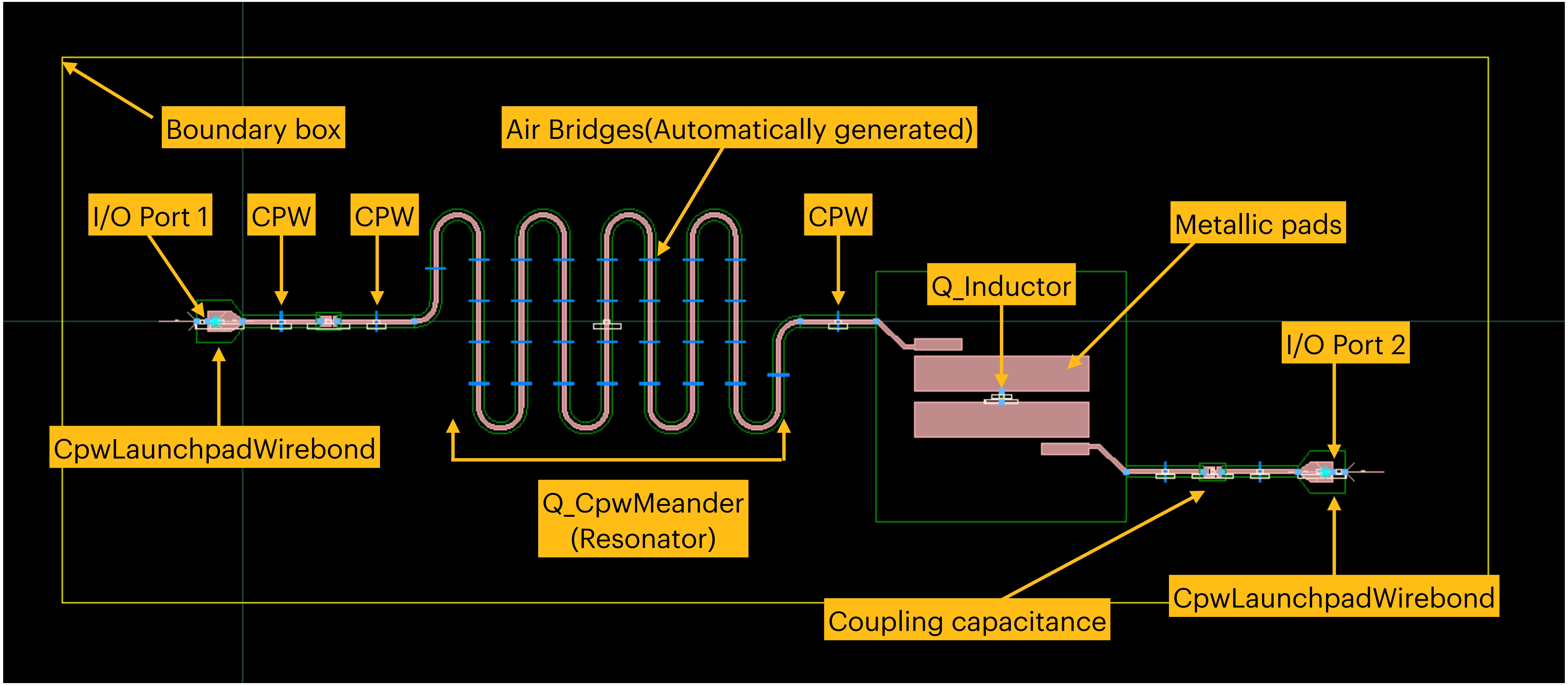
Single Superconducting Qubit

Design Goals: Simulating a quantum circuit comprising a transmon qubit and a readout resonator, each with distinct resonant frequencies, to extract key quantum parameters.

Circuit Model:



Layout:

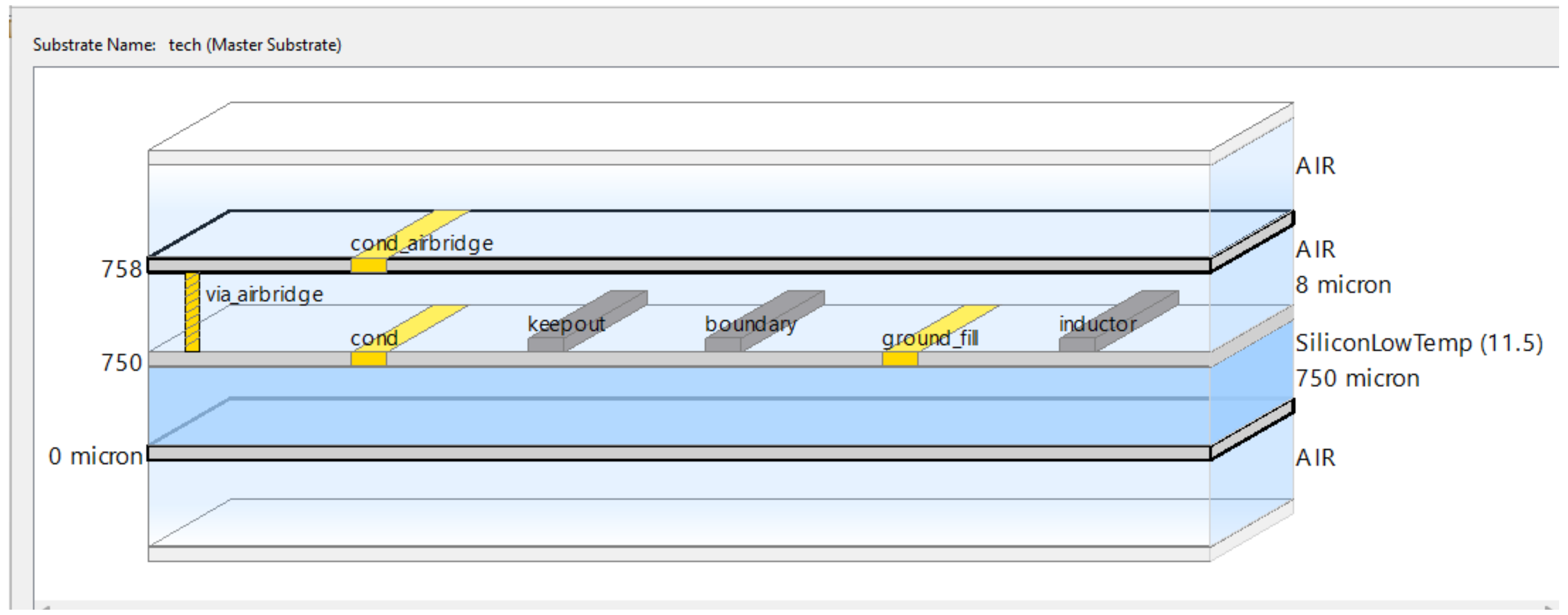


Boundary box
Air Bridges(Automatically generated)
I/O Port 1
CPW
CPW
CPW
Metallic pads
Q_Inductor
I/O Port 2
CpwLaunchpadWirebond
Q_CpwMeander
(Resonator)
Coupling capacitance
CpwLaunchpadWirebond

Summary of Customized parameters

Part Name	Customized Parameters
Q_CpwMeander	• L = 7000.0 um • Radius = 50.0 um • XOffset = 1500.0um • BridgeGap = 150.0 um • LeadLength = 200.0 um
Q_TransmonPocket	• DrawBottomLeftPad = No • DrawTopRightPad = No • PadGapBottomRight = 50.0 um
C1 (Q_CapacitorNInterdigital)	• Fingers = 3 • InterdigitalGap = 30.0 um • FingerEndGap = 30.0 um
C2 (Q_CapacitorNInterdigital)	• Fingers = 3 • InterdigitalGap = 50.0 um • FingerEndGap = 50.0 um

Substrate



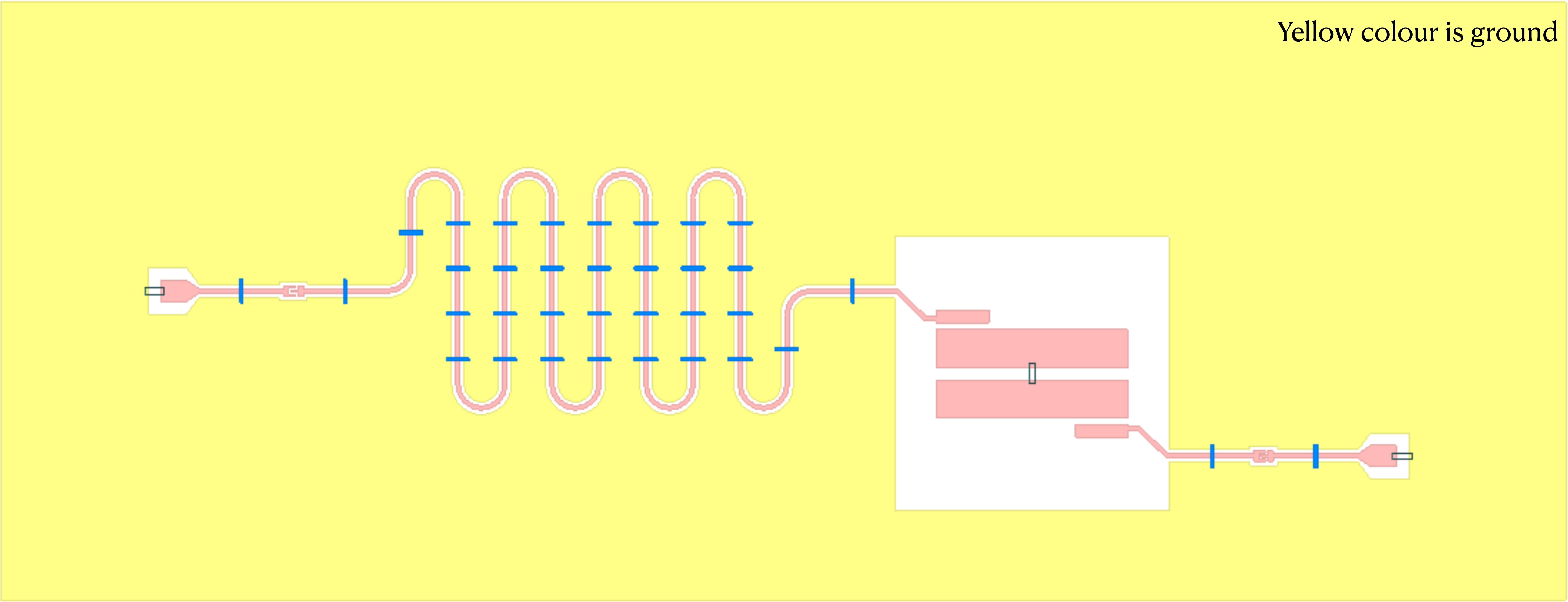
Substrate Layer Stackup

	Type	Name	Material	Thickness
	Dielectric		AIR	
1	Conductor Layer	cond_airbridge ...	PERFECT_CON...	200 nm
	Dielectric		AIR	8 um
2	Conductor Layer	cond (1)	PERFECT_CON...	200 nm
2	Other Layer	keepout (2)		200 nm
2	Other Layer	boundary (6)		200 nm
2	Conductor Layer	ground_fill (7)	PERFECT_CON...	200 nm
2	Other Layer	inductor (5)		200 nm
	Dielectric		SiliconLowTemp	750 um
	Dielectric		AIR	

A silicon substrate is used with a thickness of 750 um.
A dielectric constant of 11.5 and a loss tangent of 1e-5 are used to reflect the properties of silicon at low temperature.

Above and below the chip is air space. The airbridges require an 8 um thick air layer.

Electromagnetic Flow in QuantumPro

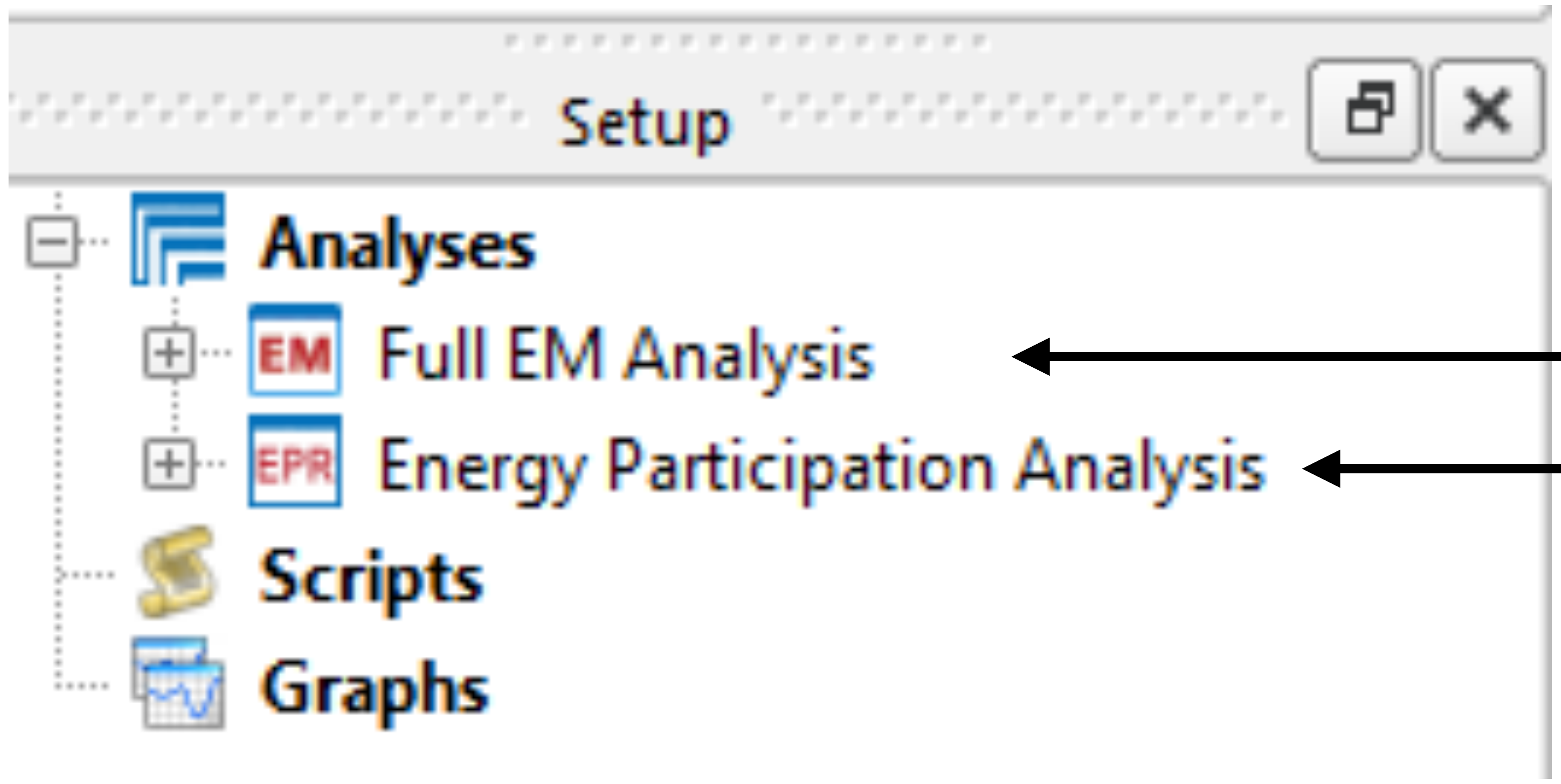


EM Analysis Types

In QuantumPro, two following types of analyses are supported:

Full EM Analysis allows for a frequency sweep of the circuits with the input and output ports. Therefore, this analysis requires placing pins to define the I/O ports. The output results return the S parameters, which can be converted into other formats such as Y parameters, Z parameters, a capacitance/inductance matrix, and others. The solvers supported for Full EM Analysis are FEM and MoM.

Energy Participation Analysis allows for finding the eigenmodes of the system. It does not require any external sources, and hence, no I/O ports are required. This analysis returns the eigenfrequencies of the system along with the electromagnetic field patterns supported by the modes. Only the FEM solver is supported for this analysis. It is worth noting that for eigenmode simulation the boundary condition is always set as Perfect Electric Conductor.

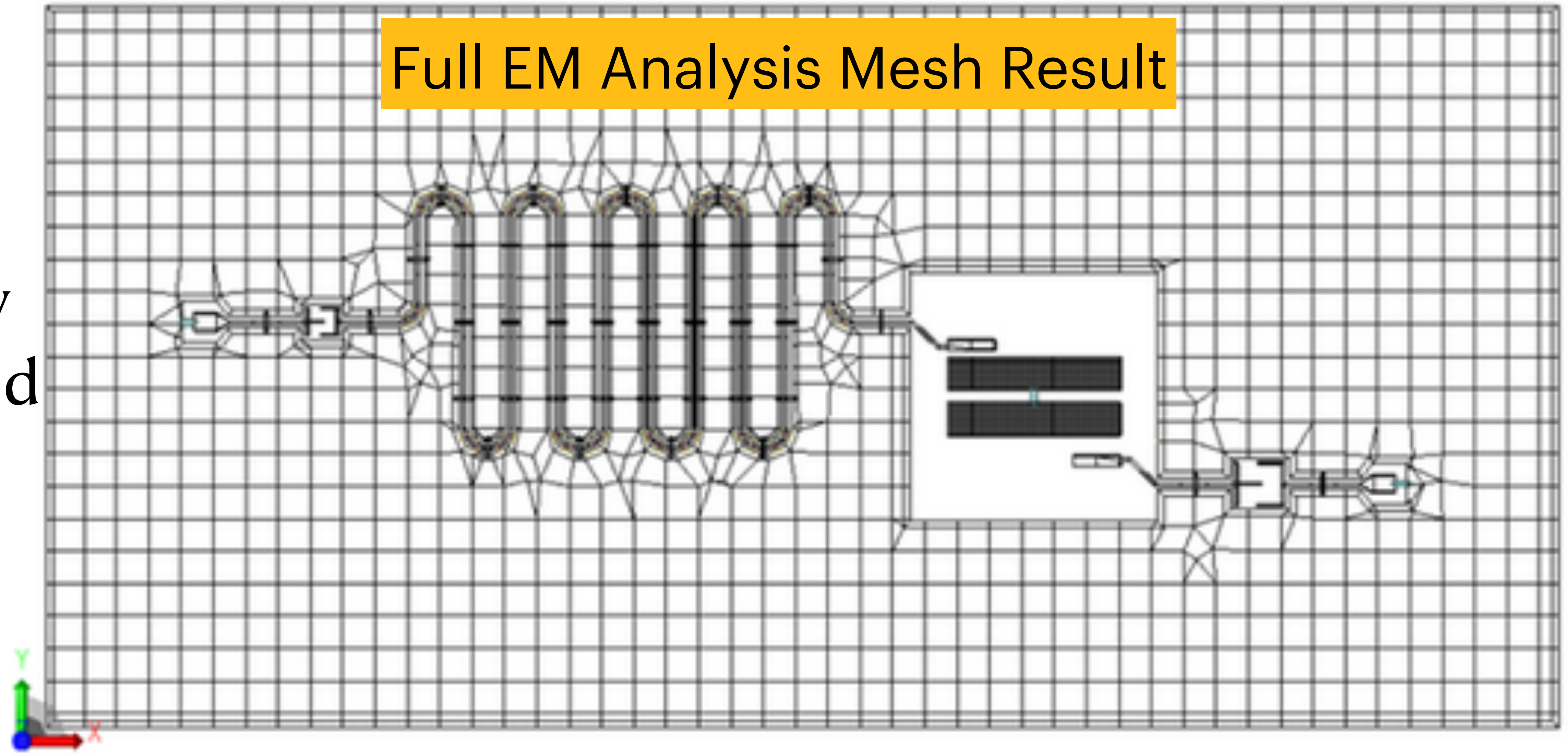


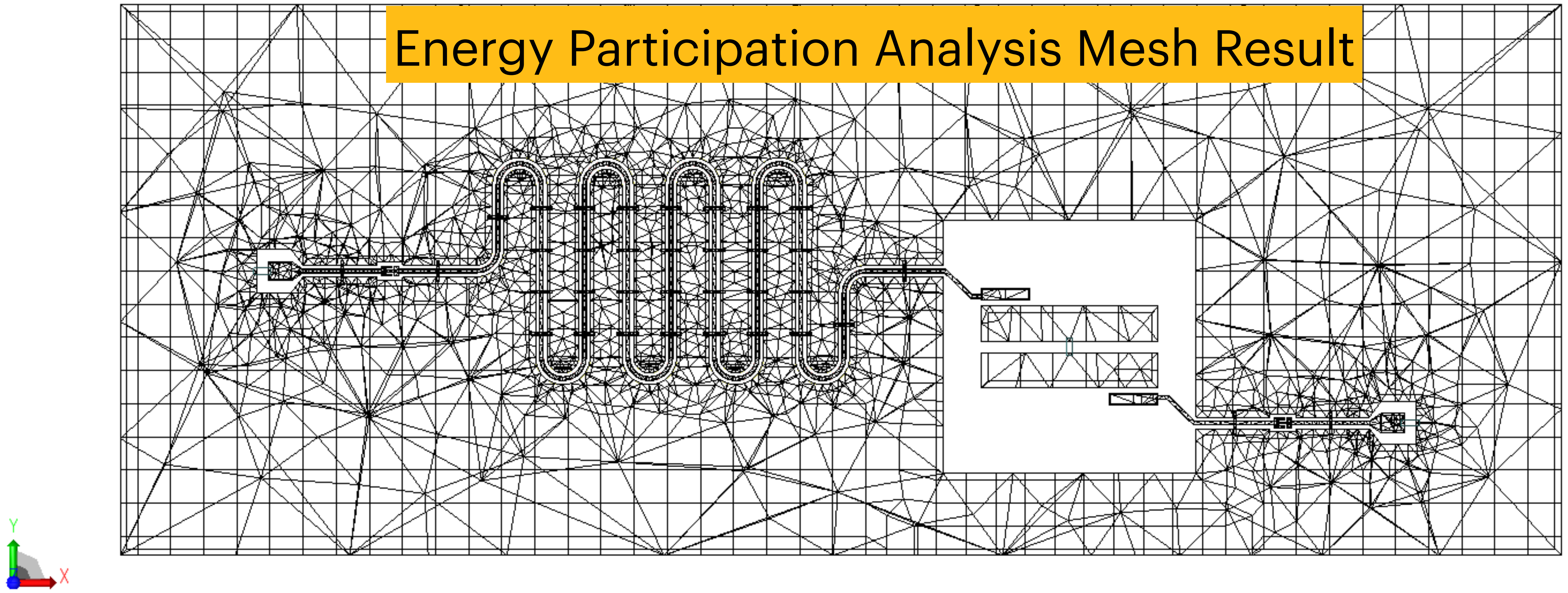
Full EM Analysis(Frequency Domain Solution)

Energy Participation Analysis(Eigenmode Domain solution)

Meshing Results

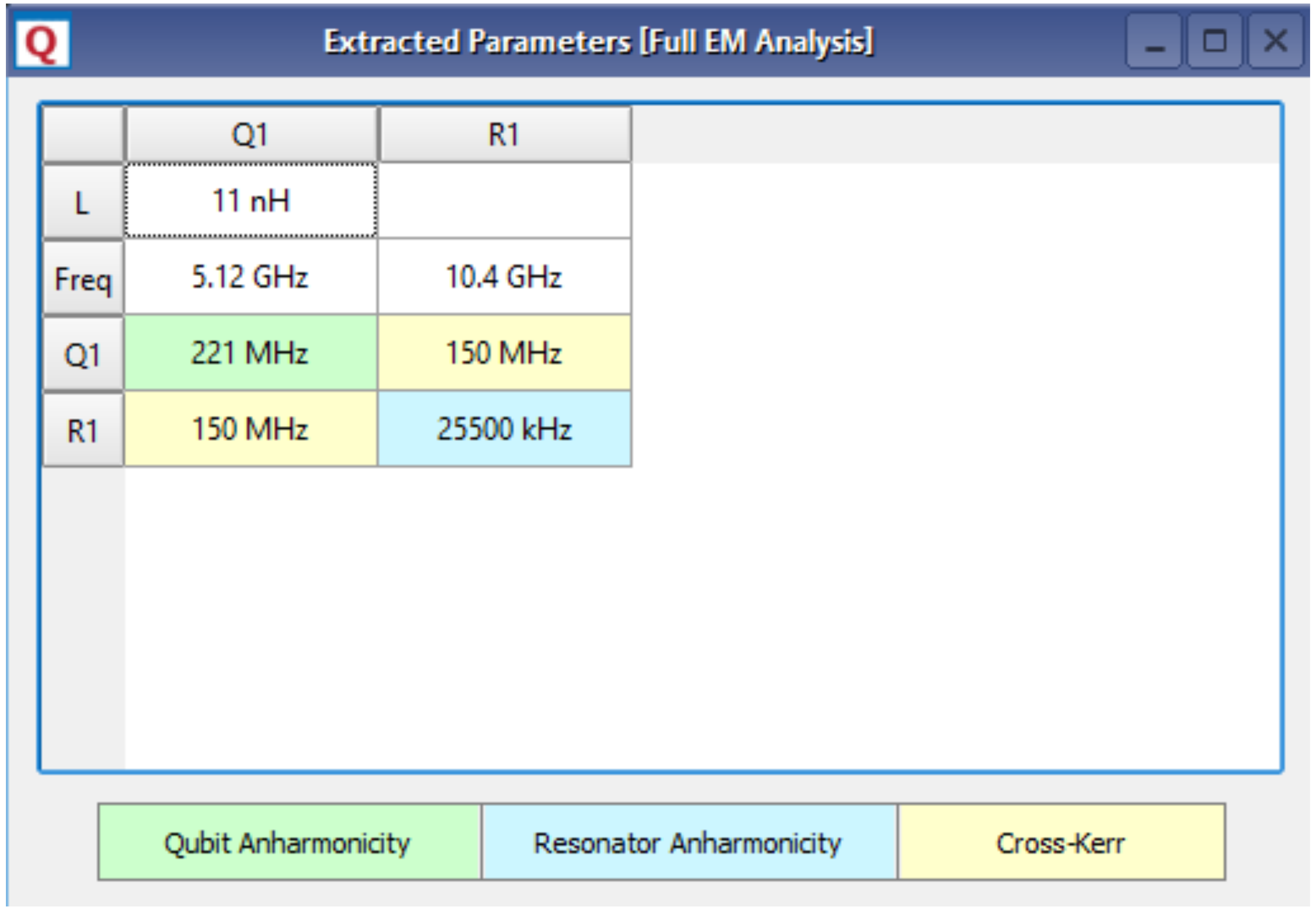
For the Full EM Analysis (MoM), the mesh grids are rather uniformly distributed, with a higher mesh density near the CPW conductor and the charge islands of the transmon qubit.



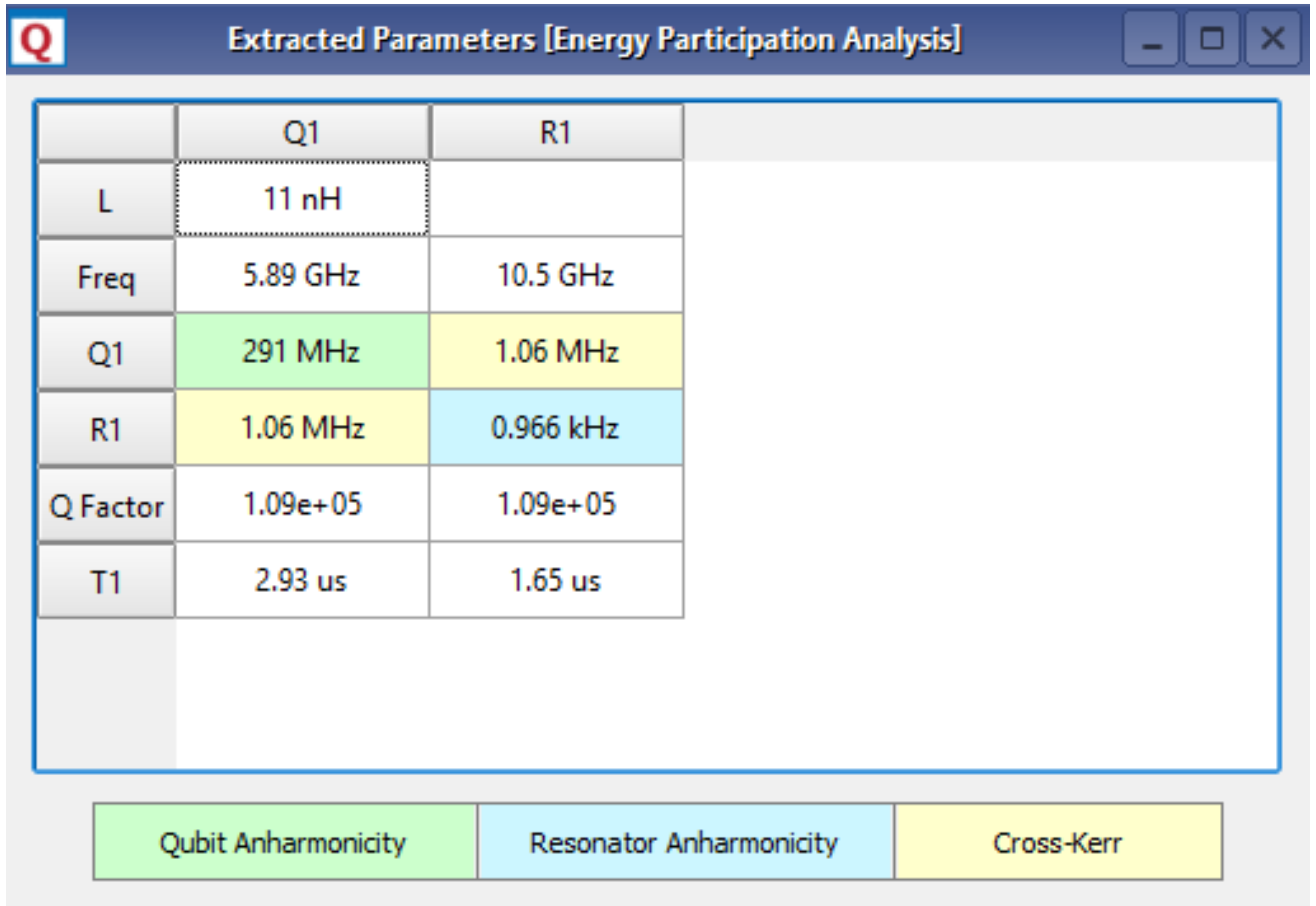


For the Energy Participation Analysis , mesh points are concentrated near the center conductor of the resonator, transmission lines, the pads, and the charge islands of the transmon qubit

Quantum Parameter Extraction



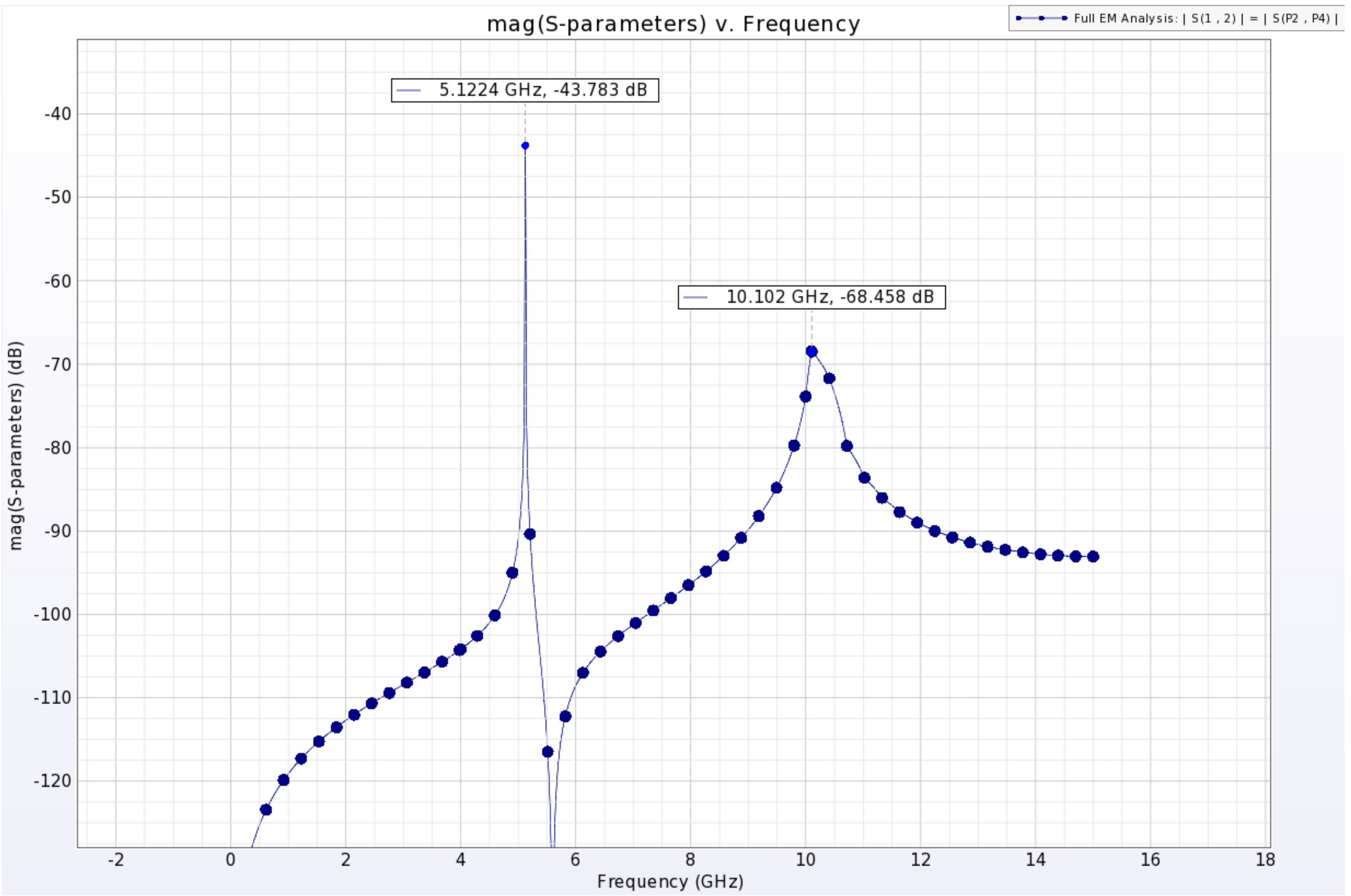
	Q1	R1
L	11 nH	
Freq	5.12 GHz	10.4 GHz
Q1	221 MHz	150 MHz
R1	150 MHz	25500 kHz

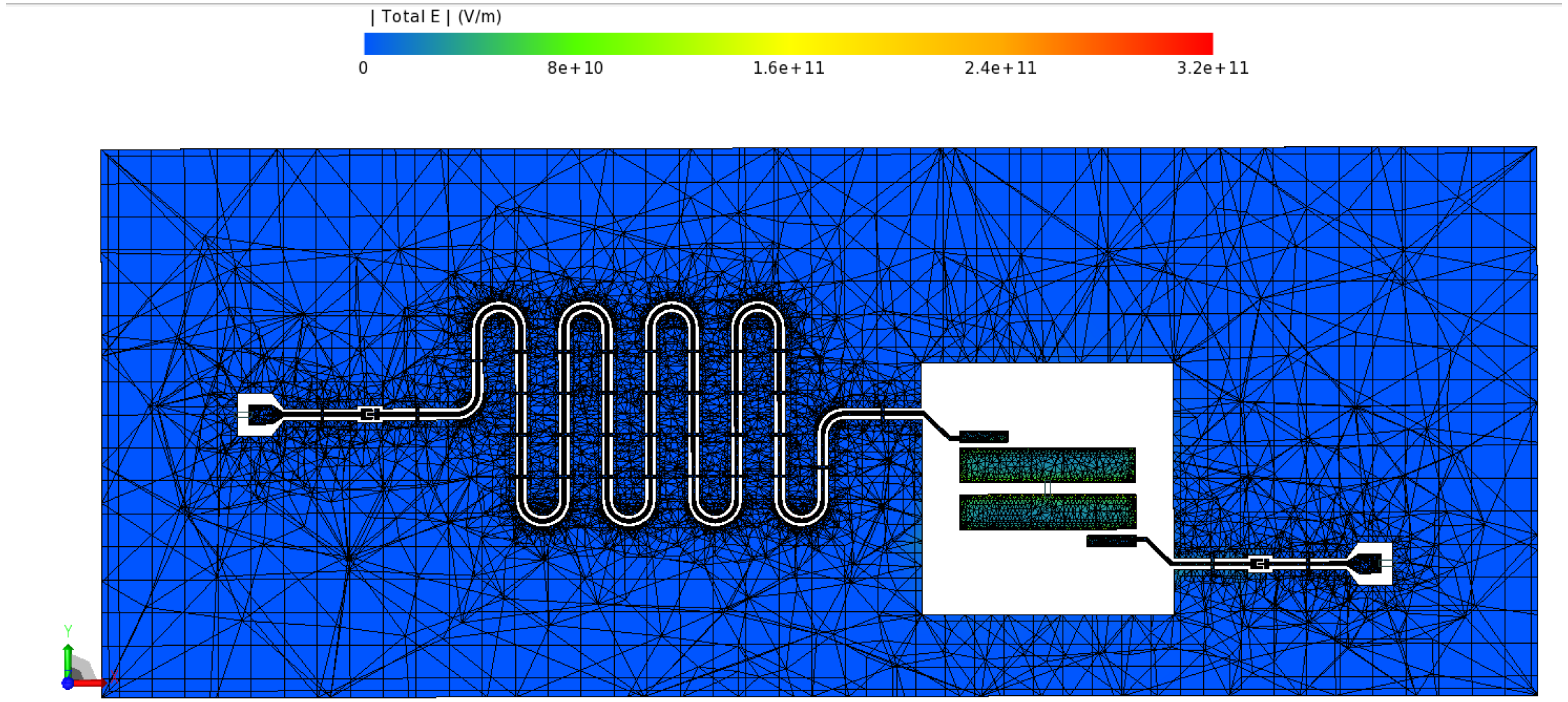


	Q1	R1
L	11 nH	
Freq	5.89 GHz	10.5 GHz
Q1	291 MHz	1.06 MHz
R1	1.06 MHz	0.966 kHz
Q Factor	1.09e+05	1.09e+05
T1	2.93 us	1.65 us

The quantum parameters in superconducting qubit circuits describe the qubit anharmonicities and the cross-Kerr values between the qubits and readout resonators.

Results





*The MoM and FEM studies allow for exploring the frequency response of the circuit (left) and the eigenmodes (right).

*The S-Parameter plot (left) from the Full EM Analysis shows the frequencies at which the transmission coefficient peaks, corresponding to the qubit and resonator resonant frequencies.

*We may visualize the field patterns for the resonance modes in the Energy Participation Analysis (right at 5.98 GHz).