



AUBURN UNIVERSITY

SAMUEL GINN
COLLEGE OF ENGINEERING

3D MODELING OF DETACHED METAL WHISKERS

Auburn Team # 3
Metal Whiskers Team # 2

ORR

MANAGER: KURT KNUDSEN

SCRIBE: SHAWN EOM

CARSON REAMS

SPENCER HURST

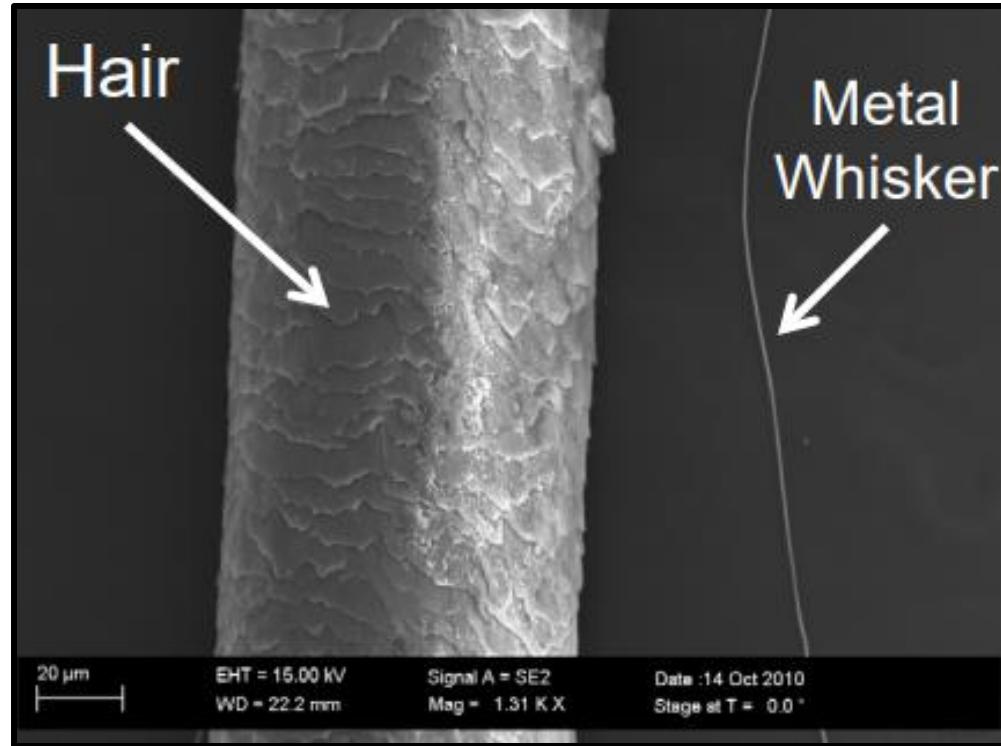
NATHAN NICHOLS

Abbreviations

2D	2-Dimensional
3D	3-Dimensional
CCA	Circuit Card Assembly
MCS	Monte Carlo Simulation
PCB	Printed Circuit Board
UI	User Interface
WP	Working Principle

Introduction

- What are metal whiskers?
 - Microscopic, metal hairs (Tin, Zinc, Cadmium) that
 - Grows from metal surfaces such as PCB
 - Length: A few microns to over 1cm (large magnitude variation)
 - Density: 1 whisker per cm^2 to >1000s of whiskers per cm^2
 - Width: 1/10 to 1/100 of a human hair (microns)
 - Time Frame
 - Incubation: hours to years
 - Growth Rate: Microns per month to millimeters per year



SEM comparison of Human Hair vs. Metal Whisker [1]

Failure Modes

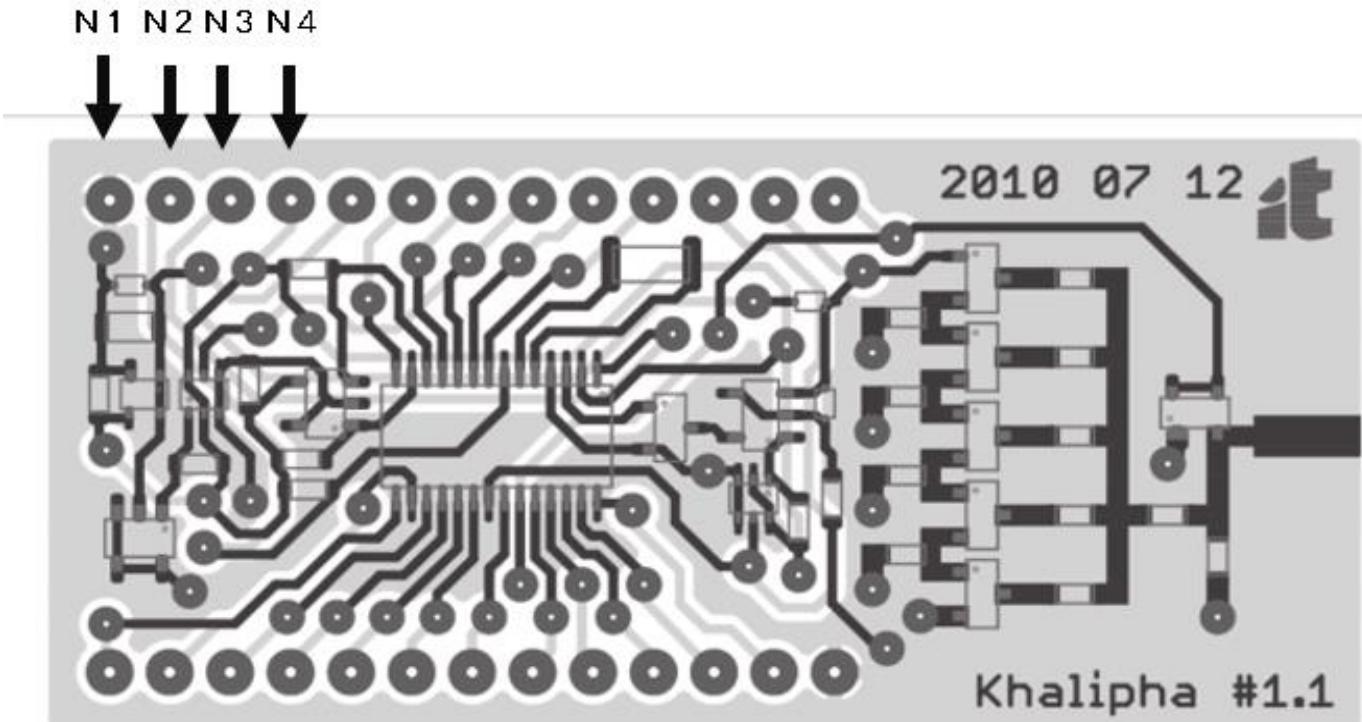
- Transient Short Circuits
 - Brief bridging
- Stable Short Circuits In Low Voltage
 - Continuous bridging
- Metal Vapor Arc
 - Vaporization Arc
- Various Glitches
 - Read data
 - Outputs



Induced Metal Whisker Causes Vapor Arc [2]

Problem Statement & Objectives

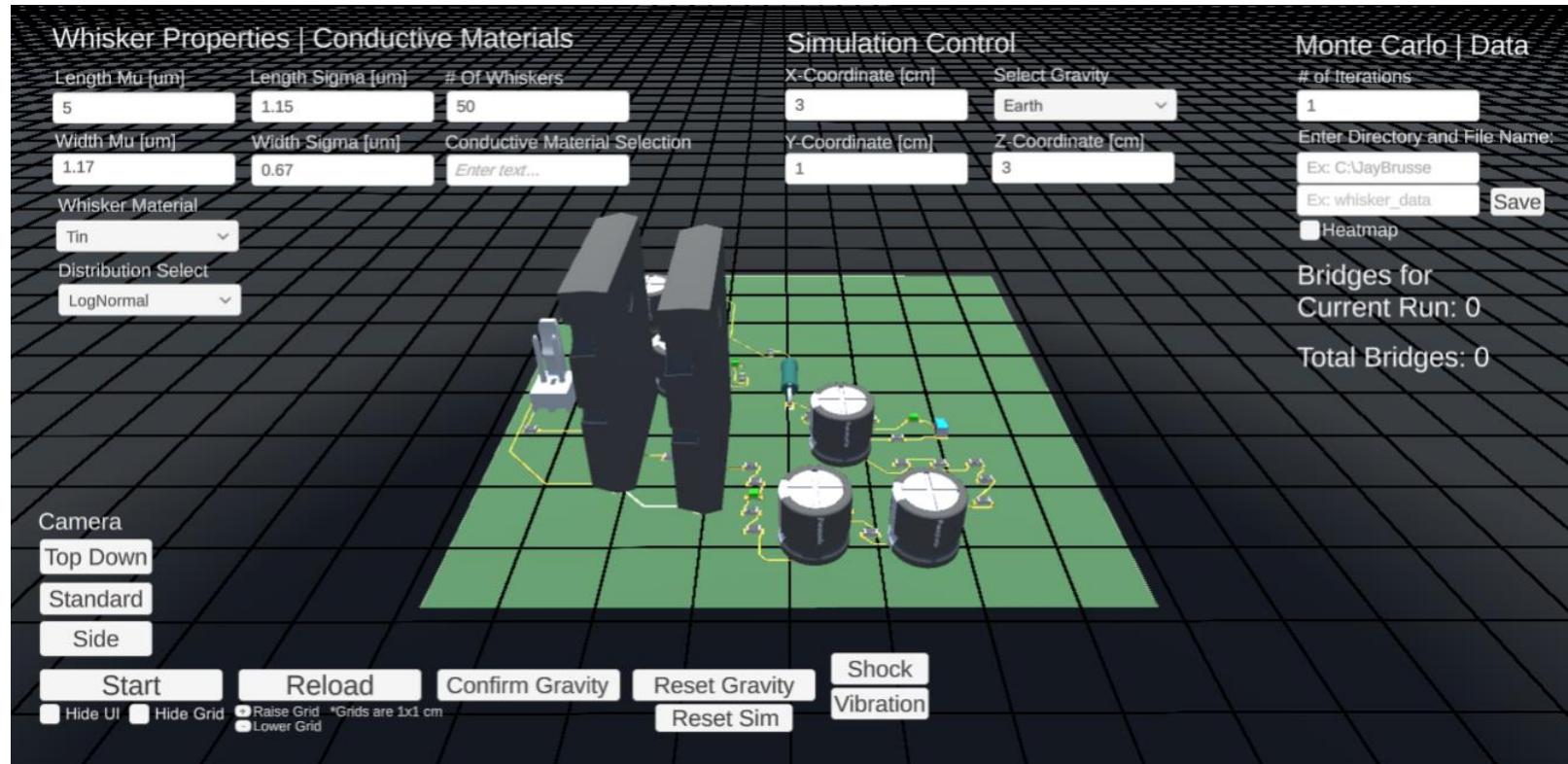
- Bridging risk-identification of detached whiskers
 - Statistical identification
 - Visual identification
- Revision
 - Improve UI
 - Improve Code
- Documentation



PCB with Identified Pads / Nodes [3]

Project Start Point

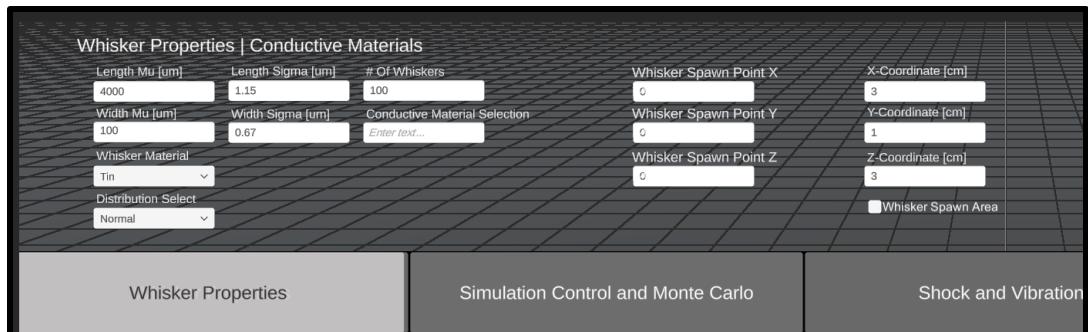
- Metal Whisker Team 1's UI
- Some external forces
- No end-user functionalities
- Specific bridged whisker visual analysis not possible
- Whisker spawning and board customization
- Better output data analysis



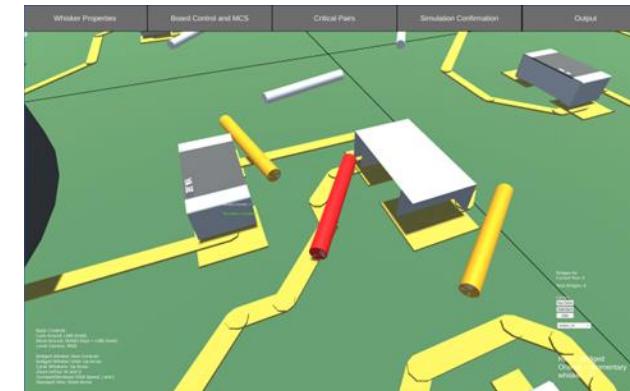
Team 1's UI

Post CDR Modifications

- UI Improvements
 - Changes made it easier for users to find functionality while keeping the screen clean.
 - Team 1's interface was functional but sometimes obstructed the simulation view.
 - Tabs were placed at the top of the screen and could be hidden.
 - The existing UI was sectioned into themed tabs for organization and usability.
- Better visual analysis
 - Improved analysis helps study whisker behavior under specific mission environments and identify areas on the circuit board prone to whiskers.
 - Enhancements can guide design changes to accommodate whisker behavior in mission environments.



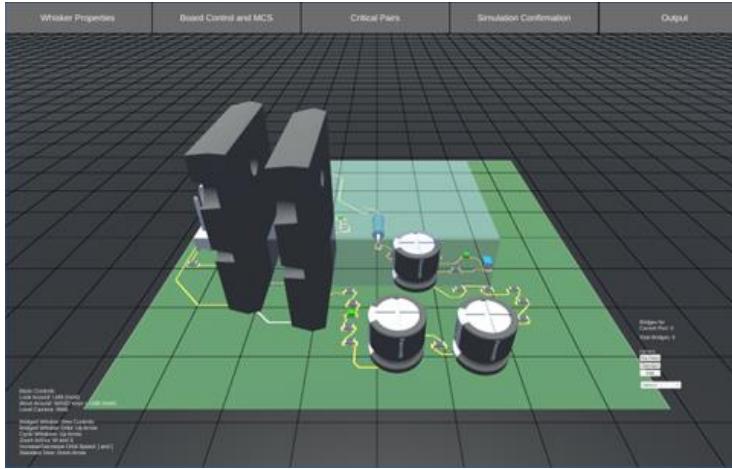
Revised UI



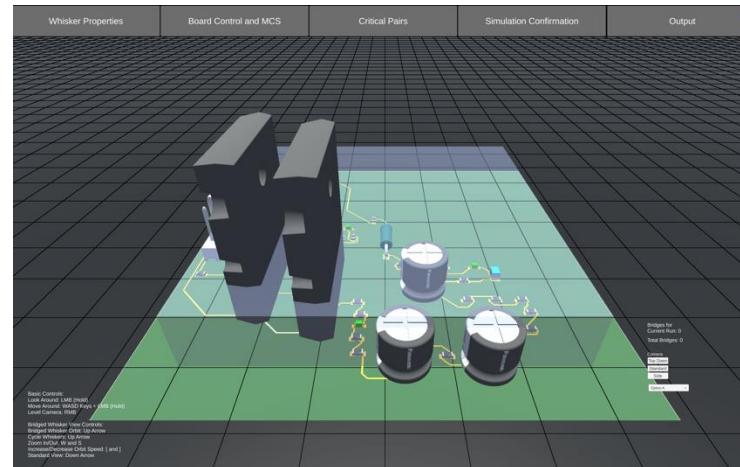
Bridged Whisker in Red

Post CDR Modifications

- Simulation Manipulation
 - Whiskers can now spawn in a custom location or within a custom area.
 - A toggleable whisker spawn area box allows users to make the spawn area visible or invisible.
 - The circuit board can be rotated and spun to simulate skewed or spinning conditions.
 - Users can input custom gravity settings to replicate heavy, low, or no-gravity environments.



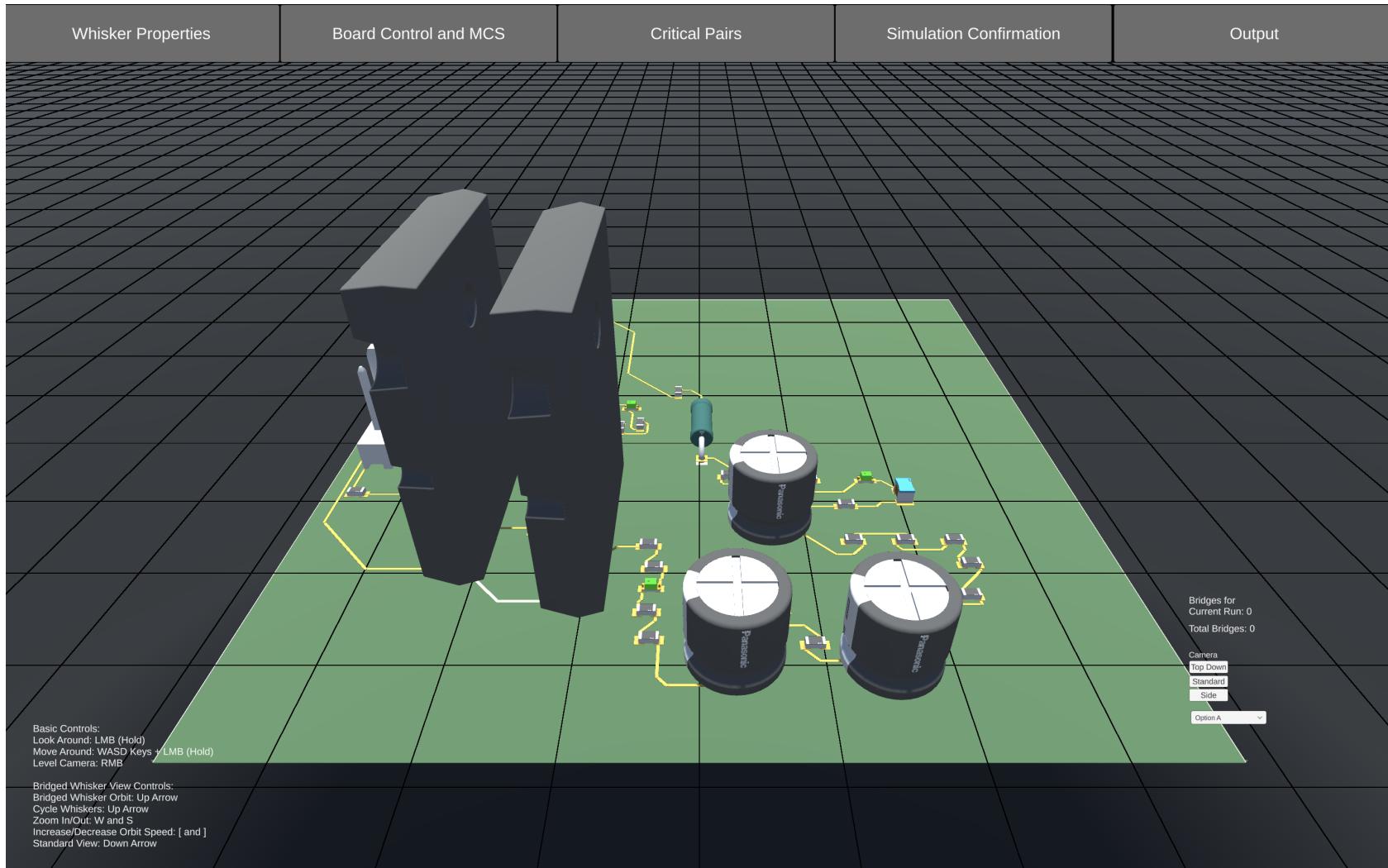
Default Spawn Area

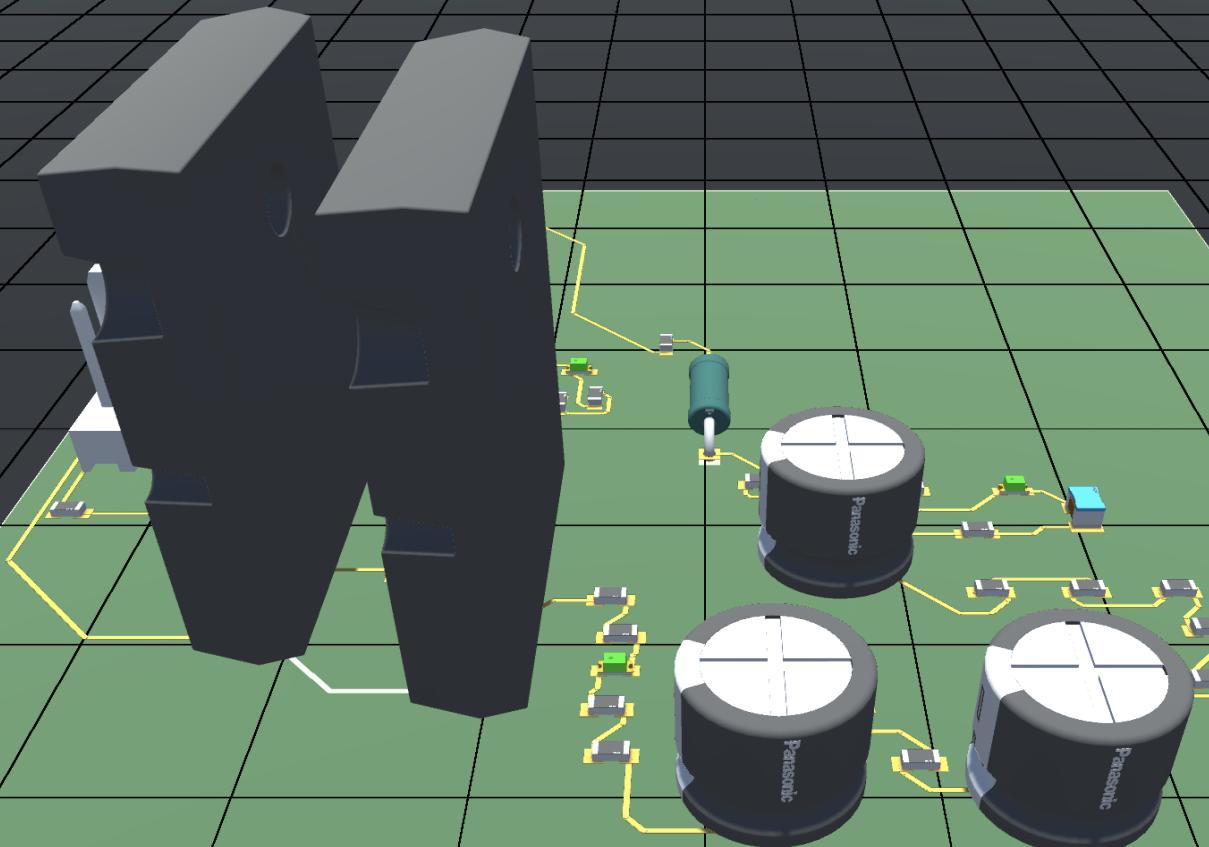


Custom Spawn Area

Method of Operations

Revised UI





Basic Controls:
Look Around: LMB (Hold)
Move Around: WASD Keys + LMB (Hold)
Level Camera: RMB

Bridged Whisker View Controls:
Bridged Whisker Orbit: Up Arrow
Cycle Whiskers: Up Arrow
Zoom In/Out: W and S
Increase/Decrease Orbit Speed: [and]
Standard View: Down Arrow

Bridges for
Current Run: 0
Total Bridges: 0

Camera
Top Down
Standard
Side
Option A

Whisker Properties | Conductive Materials

Length Mu [um]	Length Sigma [um]	# Of Whiskers
5	1.15	50
Width Mu [um]	Width Sigma [um]	Conductive Material Selection
1.17	0.67	<input type="text" value="Enter text..."/>
Whisker Material	<input type="button" value="Tin"/>	
Distribution Select	<input type="button" value="LogNormal"/>	

Whisker Spawn Point X	X-Coordinate [cm]
0	3
Whisker Spawn Point Y	Y-Coordinate [cm]
0	1
Whisker Spawn Point Z	Z-Coordinate [cm]
0	3
<input type="checkbox"/>	

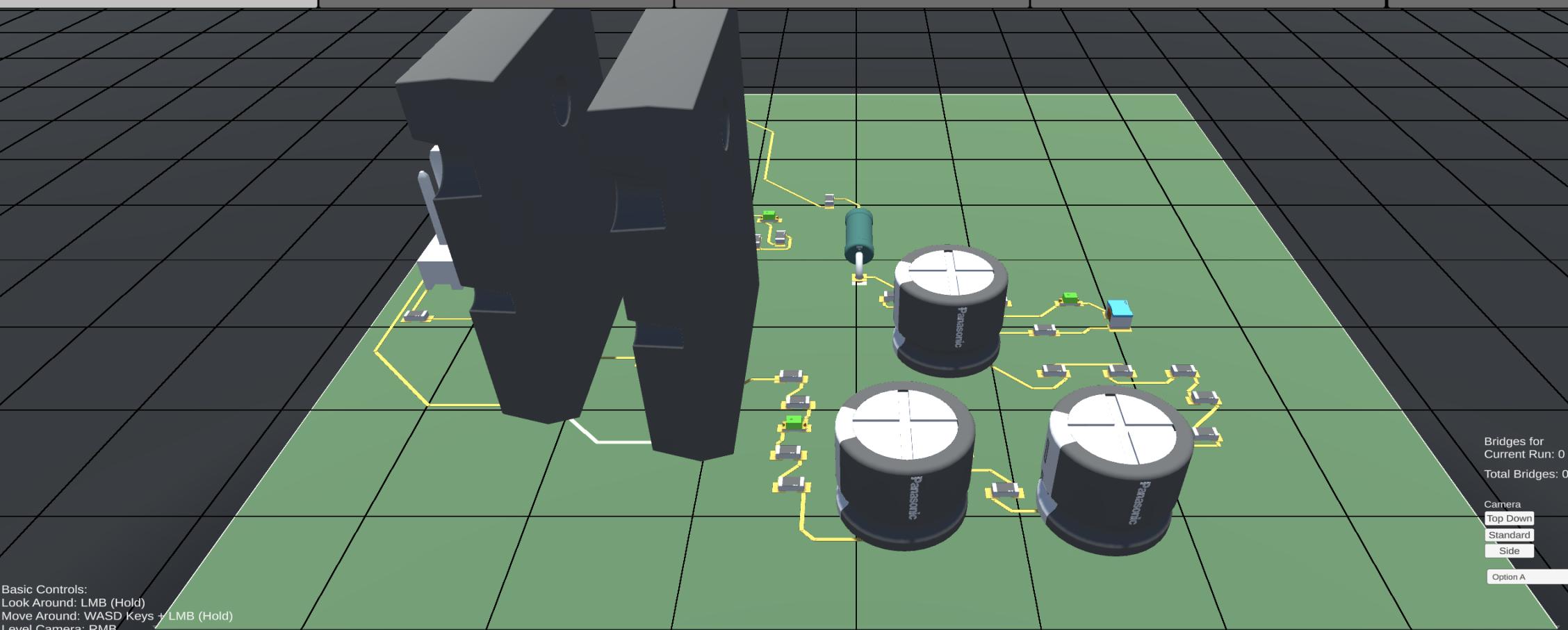
Whisker Properties

Board Control and MCS

Critical Pairs

Simulation Confirmation

Output



Basic Controls:
Look Around: LMB (Hold)
Move Around: WASD Keys + LMB (Hold)
Level Camera: RMB

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Bridged Whisker Orbit: Up Arrow
Cycle Whiskers: Up Arrow
Zoom In/Out: W and S
Increase/Decrease Orbit Speed: [and]
Standard View: Down Arrow

Simulation Control

Select Gravity
Earth

Monte Carlo | Data
of Iterations: 1
Save Inputs
Add Walls (mm)
Enter Directory and File Name:
Ex: C:\JayBrusse
Ex: whisker_data Save
 Heatmap

Wall Height
 Ceiling

Rotate Board X [degree]
 x Enter text...
Rotate Board Y [degree]
 y Enter text...
Rotate Board Z [degree]
 z Enter text...
 Reset Board

Spin Board X [deg/sec]
 x Enter text...
Spin Board Y [degree/sec]
 y Enter text...
Spin Board Z [degree/sec]
 z Enter text...
 Use in Simulation

Amplitude [N] Shock
 Enter text... Shock
 Use in Simulation Close

Vibration Amplitude [N] Frequency [Hz] Duration [s]
 Enter text... Enter text... Enter text...
 Use in Simulation Vibrate
 Close

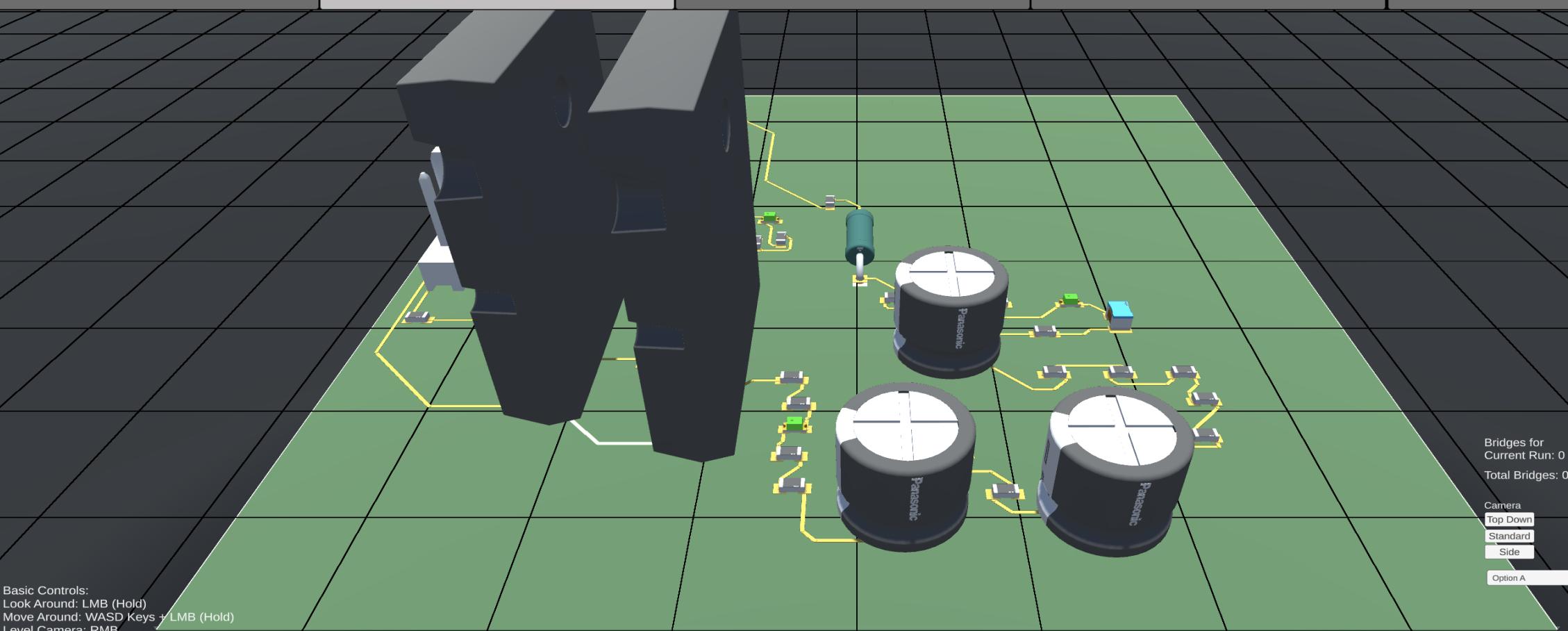
Whisker Properties

Board Control and MCS

Critical Pairs

Simulation Confirmation

Output



Basic Controls:
Look Around: LMB (Hold)
Move Around: WASD Keys + LMB (Hold)
Level Camera: RMB

Bridged Whisker View Controls:
Bridged Whisker Orbit: Up Arrow
Cycle Whiskers: Up Arrow
Zoom In/Out: W and S
Increase/Decrease Orbit Speed: [and]
Standard View: Down Arrow

Bridges for Current Run: 0
Total Bridges: 0

Camera
Top Down
Standard
Side
Option A

Conductor 1 Conductor 2

Refresh

Add Critical Pair

Remove Critical Pair

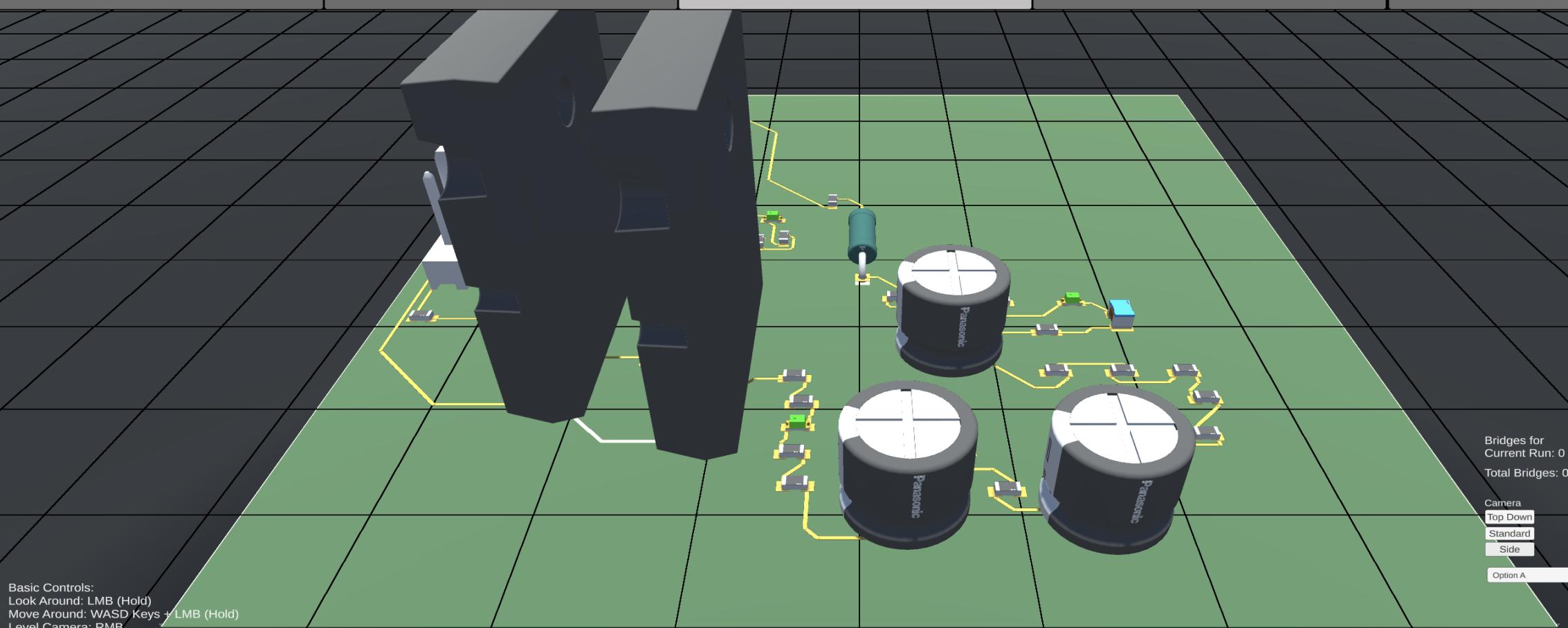
Whisker Properties

Board Control and MCS

Critical Pairs

Simulation Confirmation

Output



Basic Controls:

Look Around: LMB (Hold)

Move Around: WASD Keys + LMB (Hold)

Level Camera: RMB

Bridged Whisker View Controls:

Bridged Whisker Orbit: Up Arrow

Cycle Whiskers: Up Arrow

Zoom In/Out: W and S

Increase/Decrease Orbit Speed: [and]

Standard View: Down Arrow

Spawn whiskers Reload Reset Gravity Start Simulation
Reset Sim

Hide UI Screenshot
 Hide Grid Enable Automatic Screenshots
+ Raise Grid - Lower Grid
*Grids are 1x1 cm

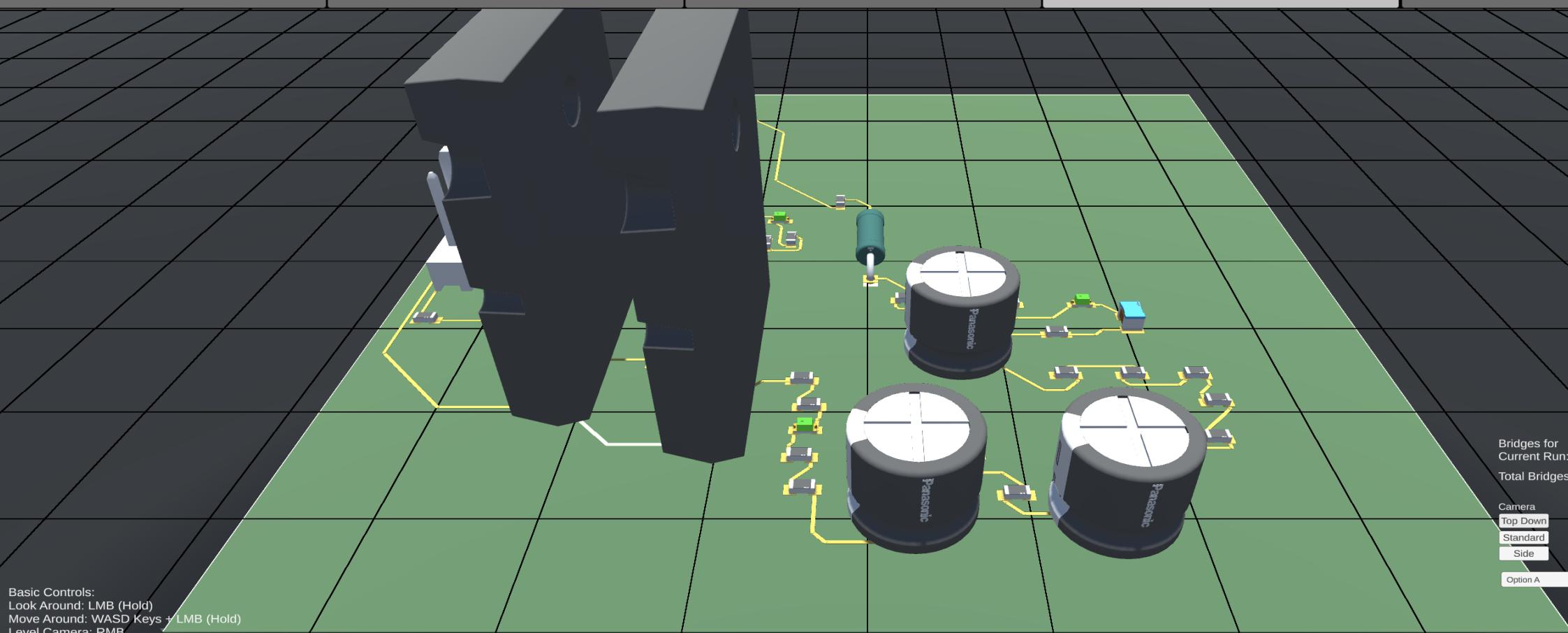
Whisker Properties

Board Control and MCS

Critical Pairs

Simulation Confirmation

Output



Spawn whiskers Reload Reset Gravity Start Simulation
Reset Sim

Hide UI Screenshot
Hide Grid Enable Automatic Screenshots
Raise Grid Lower Grid
*Grids are 1x1 cm

Whisker #	Length (μm)	Diameter (μm)	Resistance (ohm)	Iteration	Conductor 1	Conductor 2
Whisker Properties						
83	21.38639	5.67823	0.09205516	1	R16	NetR8_1
170	293.9897	8.355381	0.5844349	2	Q1	GND
174	54.56393	4.537501	0.3677975	2	R17	NetC4_2
192	261.3305	0.7560071	63.45634	2	NetQ1_1	GND
70	424.4552	2.90998	6.956461	2	R35	NetR35_2
133	943.5942	0.6164488	344.6099	2	Q1	GND
128	365.3503	5.58126	1.627727	2	C6	NetC6_1
63	47.54796	3.763876	0.4657984	2	Q2	NetQ2_1
58	385.7464	2.157391	11.5022	3	C4	NetC4_1
77	610.6442	3.952015	5.426099	3	NetD2_1	R19
38	145.7424	4.973895	0.8175781	3	C1	NetC1_2
66	106.3897	2.005703	3.670313	3	Q1	GND
141	403.6245	4.826169	2.404967	3	Q1	GND



Basic Controls:
Look Around: LMB (Hold)
Move Around: WASD Keys / LMB (Hold)
Level Camera: RMB

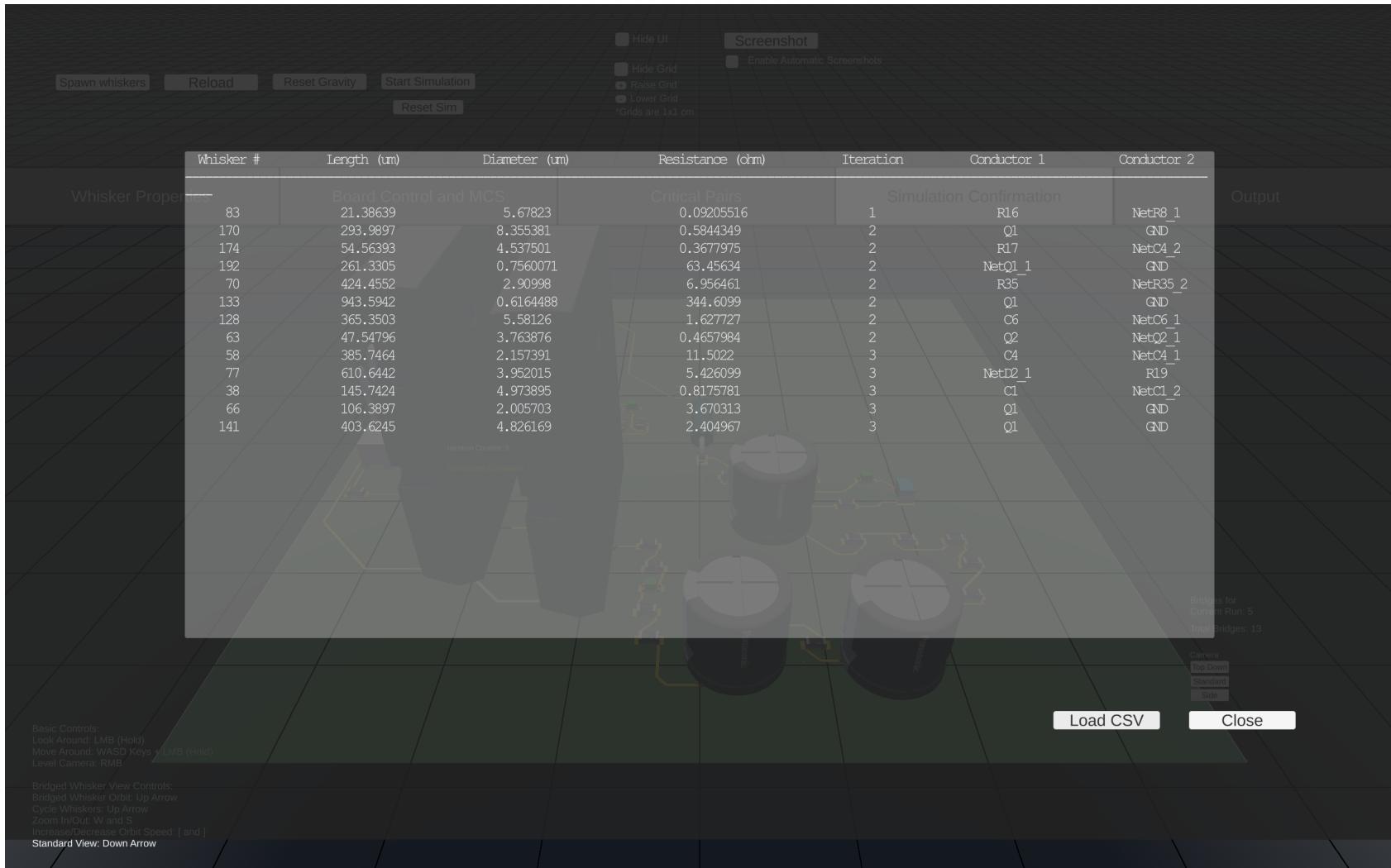
Bridged Whisker View Controls:
Bridged Whisker Orbit: Up Arrow
Cycle Whiskers: Up Arrow
Zoom In/Out: W and S
Increase/Decrease Orbit Speed: [and]
Standard View: Down Arrow

Load CSV

Close

Method of Operations

Revised UI

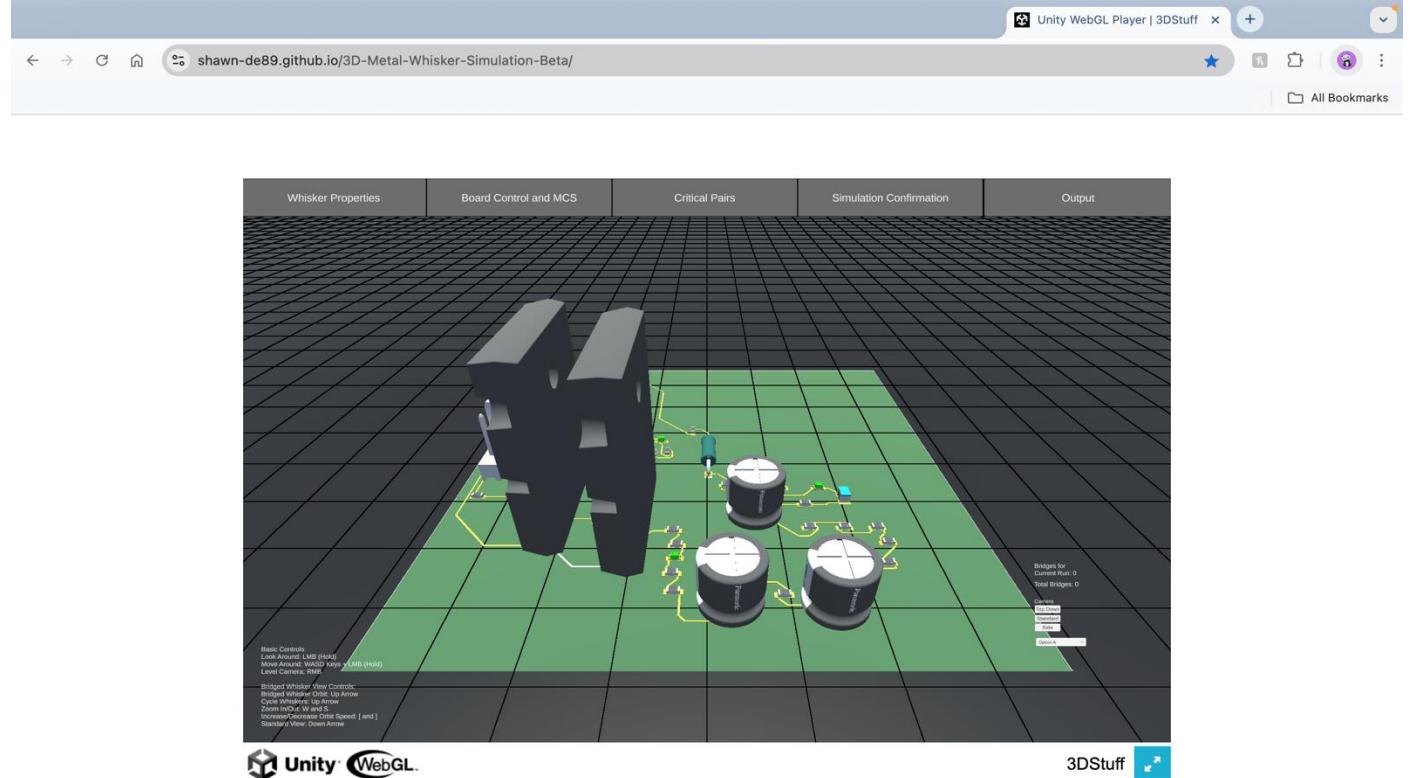


Method of Operations

Running the Beta Version in Web Browser

shawn-de89.github.io/3D-Metal-Whisker-Simulation-Beta/

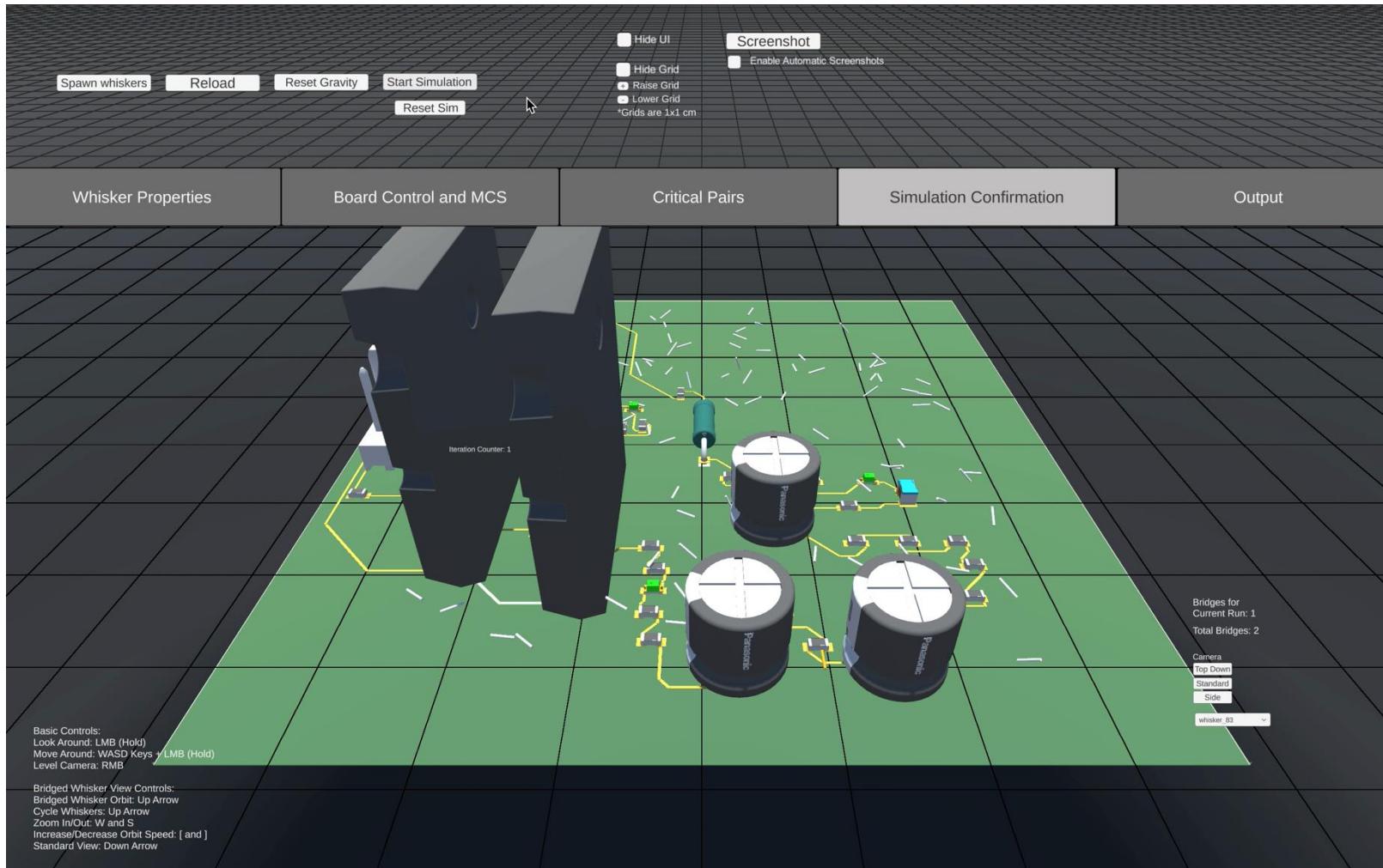
- Beta Version
 - Allowed for Quick Testing basic functions and revisions to code
 - Showed progress of the Project to customers and project technical advisors in real time
 - Allowed for Critiques and ideas from Project Tech Advisors on current states



Online Beta

Method of Operations

Running the Beta Version in Web Browser



Testing and Analysis

Critiques on Beta Version

- Technical Advisor and Customer Feedback
 - Enlarging the Beta to proper size of full screen
 - Did not have units properly displayed
 - Did not have access to output files
 - General UI visibility and ease of use
 - Add instructions for basic use of program
- Washington State Feedback/Status
 - UI elements are scattered
 - Cannot access results
 - Only able to run one MCS
 - Sim walls can't be removed
 - Spawn region ambiguous
 - Cannot load PCB into simulation



Testing and Analysis

Data Sheet

All Whiskers					
Whisker #	Length (um)	Width (um)	Resistance (ohm)	Iteration	
1	2921.423	57.96461	0.1206716	1	
2	5753.229	72.59191	0.1515206	1	
3	6390.803	52.62613	0.32025	1	
4	2826.367	45.6218	0.1884605	1	
5	2061.689	54.36802	0.09679941	1	
6	2657.678	62.38023	0.09478619	1	
7	1675.75	51.51289	0.08764234	1	
8	5369.641	60.25764	0.2052379	1	
9	6449.581	33.88324	0.7796476	1	
10	2589.204	66.38473	0.0815392	1	
11	2007.121	60.37473	0.0764187	1	
12	2974.402	32.73833	0.3851441	1	
13	1055.391	54.58115	0.04916594	1	
14	1913.361	55.89381	0.08499748	1	

List of All Whiskers in Excel®

Paste Inputs Below	
Simulation Inputs	
Parameter	Value
Length Mu	8
Length Sigma	0.5
Width Mu	4
Width Sigma	0.2
# Of Whiskers	400
Conductive Material Selection	copper
Whisker Material	Tin
Distribution Selection	LogNormal
Whisker Spawn Point X	0
Whisker Spawn Point Y	0
Whisker Spawn Point Z	0
X-Coord	3
Y-Coord	1
Z-Coord	3
Gravity	Earth
# of Iterations	30
Directory Path	C:\test
Save File Name	DemoDataLog2
Rotation-X	-90
Shock Active	N
Vibration Active	N

List of Simulation Inputs in Excel®

Testing and Analysis

Results and Analysis in Excel®

Bridged Whiskers

Whisker #	Length (um)	Width (um)	Resistance (ohm)	Iteration	Conductor 1	Conductor 2	Bridged Pair
318	3272.759	51.13706	0.1736917	1	GND	Q1	GND + Q1
352	4102.102	55.02091	0.1880561	1	GND	Q1	GND + Q1
26	4421.396	53.90409	0.2111799	1	Q1	GND	Q1 + GND
43	3747.569	56.62005	0.1622355	1	R28	NetD3_1	R28 + NetD3_1
56	2372.752	45.65566	0.1579791	1	C4	NetC4_1	C4 + NetC4_1
198	6977.418	59.15441	0.2767306	1	Q2	NetQ2_2	Q2 + NetQ2_2
117	6817.568	51.01569	0.3635453	1	GND	NetQ1_1	GND + NetQ1_1
9	6449.581	33.88324	0.7796476	1	NetR11_2	C2	NetR11_2 + C2
381	2518.593	63.03785	0.08796133	1	R30	NetR29_2	R30 + NetR29_2
368	1159.62	62.50555	0.04119219	1	R11	NetR11_2	R11 + NetR11_2
66	2761.829	66.48866	0.08670381	1	Q1	NetQ1_2	Q1 + NetQ1_2
274	3592.661	43.09268	0.268501	1	NetR11_2	R15	NetR11_2 + R15
260	3992.121	59.58002	0.156077	1	NetR7_2	NetC1_1	NetR7_2 + NetC1_1
240	2707.194	62.07954	0.09748974	1	R9	NetR8_2	R9 + NetR8_2

List of Bridged Whisker in Excel®

Critical Bridged Whiskers

Whisker #	Length (um)	Width (um)	Resistance (ohm)	Iteration	Conductor 1	Conductor 2	Bridged Pair
120	3336.264	91.95851	0.05475366	4	R35	R36	R35 + R36
271	4621.871	51.9052	0.2380853	4	C1	NetC1_1	C1 + NetC1_1
112	2761.398	60.62378	0.1042749	9	R35	R36	R35 + R36
167	6544.978	59.42219	0.2572453	14	R35	R36	R35 + R36
206	5232.003	46.96705	0.3291683	15	R35	R36	R35 + R36

List of Critical Bridged Whiskers in Excel®

Testing and Analysis

General Analysis Sheet

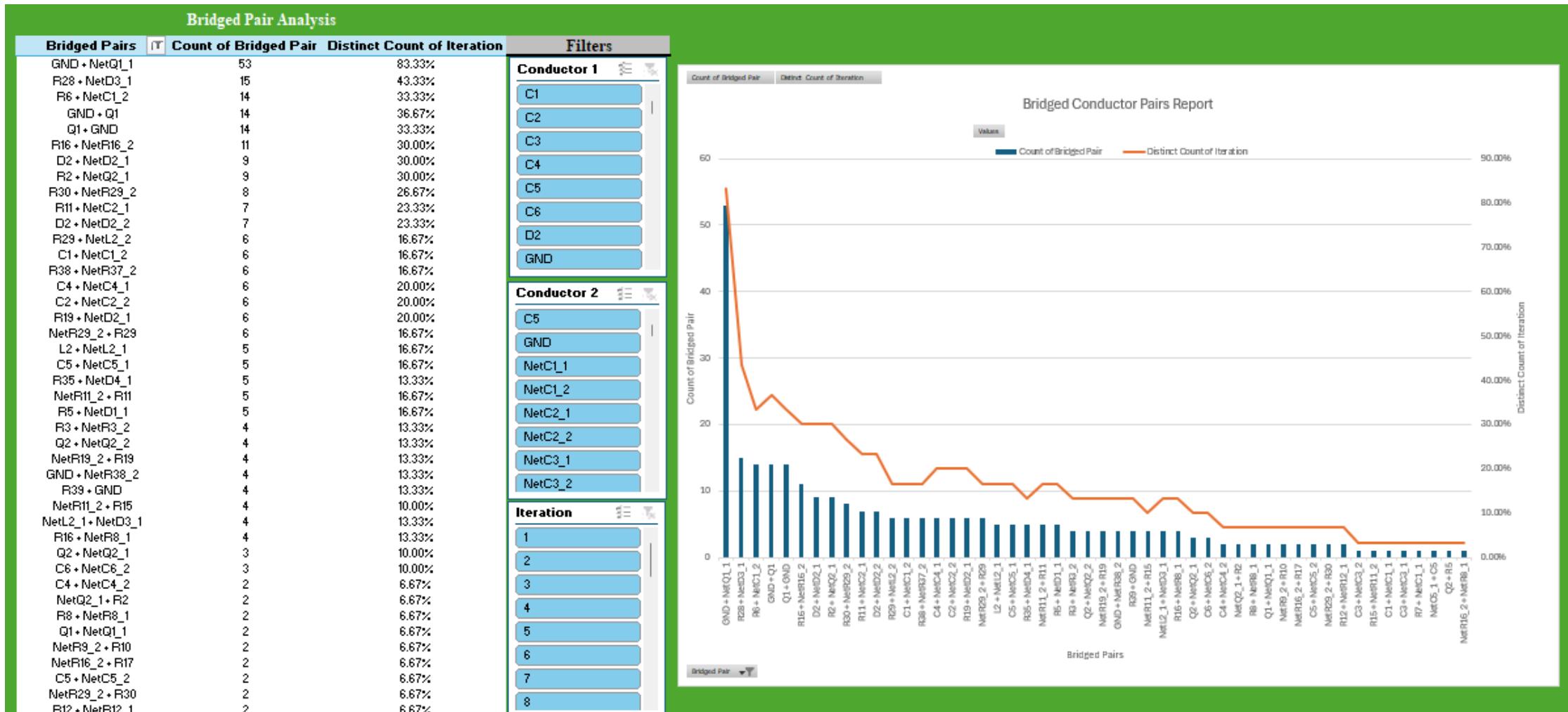
General Analysis Sheet

Bridged Probability*		Critical Bridged Probability*		Summary Statistics*			
Overall Probability*		Overall Probability*		All Whiskers		Bridged Whiskers	Critical Bridged Whiskers
100.00%		13.33%		Average Length (um)	3386.3	4190.6	4499.3
Individual Probability*		Individual Probability*		Average Width (um)	55.8	56.3	62.2
Iteration #	Probability	Iteration #	Probability	Average Resistance (ohm)	0.2	0.2	0.2
1	8.00%	4	0.50%	Maximum Length (um)	22522.4	22522.4	6545.0
2	6.25%	9	0.25%	Maximum Width (um)	112.9	99.8	92.0
3	8.25%	14	0.25%	Maximum Resistance (ohm)	1.5	1.4	0.3
4	5.50%	15	0.25%	Minimum Length (um)	426.7	1030.2	2761.4
5	7.50%			Minimum Width (um)	24.9	28.1	47.0
6	6.75%			Minimum Resistane (um)	0.0118	0.0217	0.0548
7	6.75%						
8	11.00%						
9	8.50%						
10	7.75%					Bridged Whiskers	Critical Bridged whiskers
11	6.75%			# of Iterations with 0 Bridges		0	26
12	7.50%			# of Iterations with at least 1 Bridge		30	4

List of Bridge Probability and Critical Bridge Probability and Summary Statistics

Testing and Analysis

Bridged Whisker Analysis Sheet

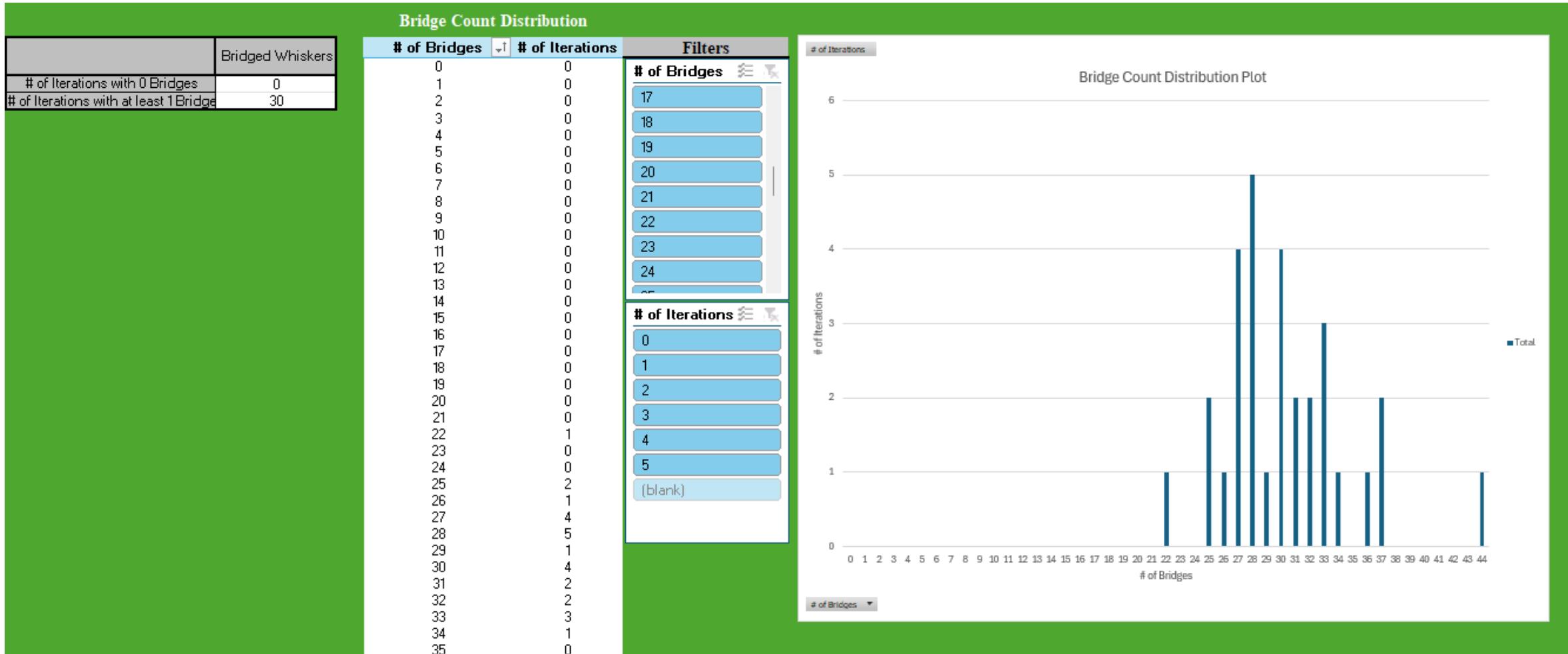


Bridged Pair Analysis, Filters, and Bridged Conductor Pairs report



Testing and Analysis

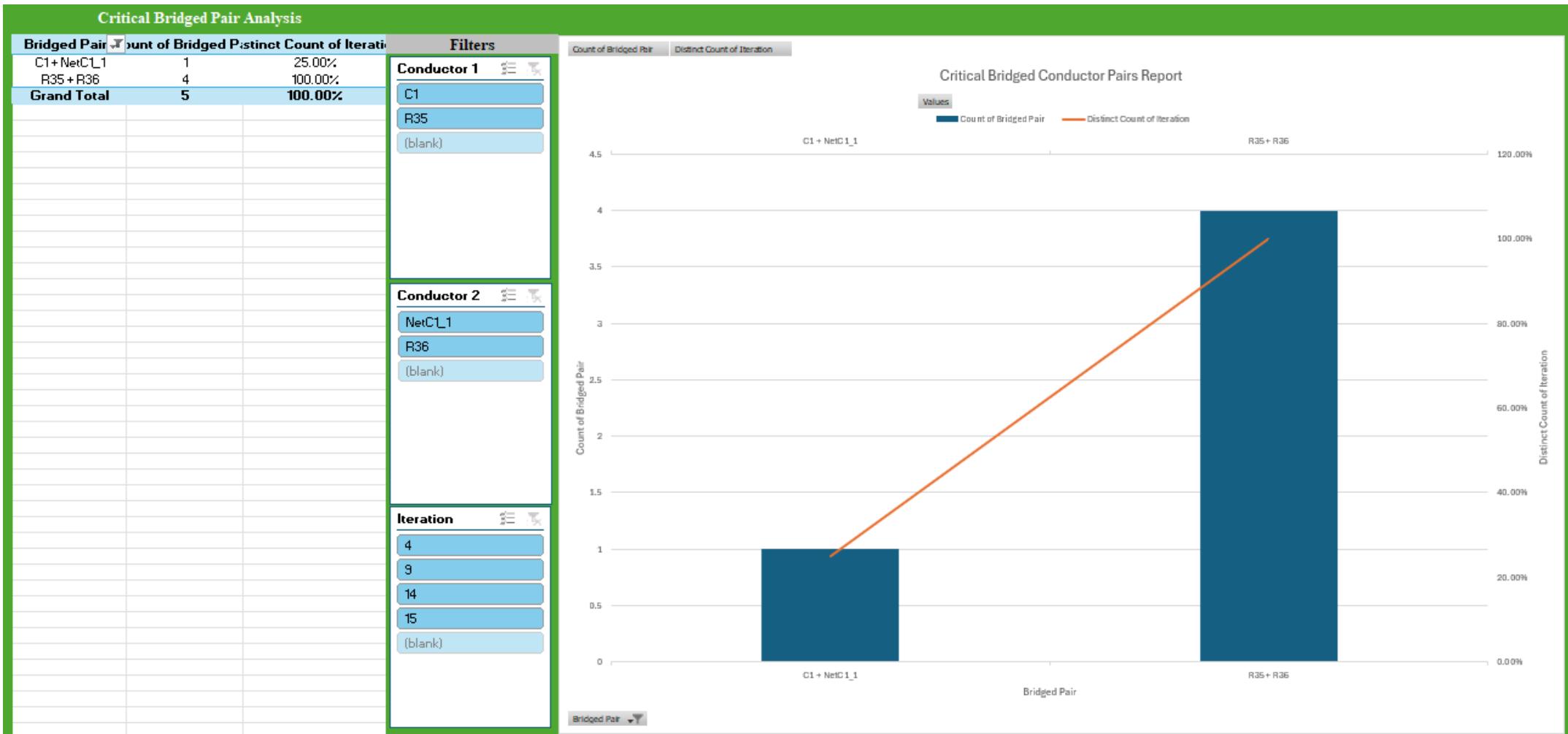
Bridged Whisker Analysis Sheet



Bridge Count Distribution, Filters, and Plot

Testing and Analysis

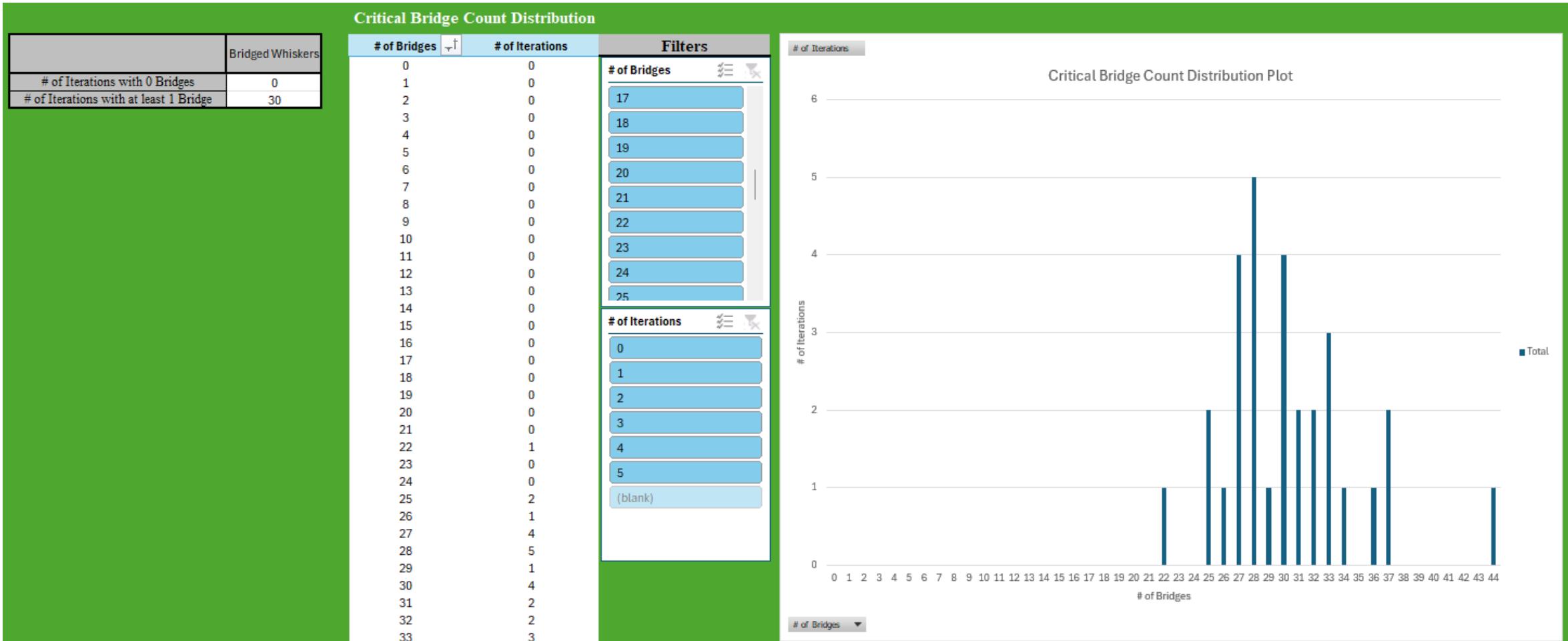
Critical Bridged Whisker Analysis



Critical Bridged Pair Analysis, Filters, and Critical Bridged Conductor Pairs report

Testing and Analysis

Critical Bridged Whisker Analysis



Bridge Count Distribution, Filters, and Plot

Further Development

- Unfinished Functionality
 - Screenshots saved to desktop with default sequential naming
 - Screenshot file name and directory pathing
- Screen Recording
 - Explored screen capture, but not implemented
 - Too processor-heavy, causing crashes
- Iteration Duration Control
 - Low priority, but simple
 - Modify "UIscript.cs" or create a new script
- PCB Upload Issues
 - Altium® and Unity® file compatibility issues
 - No pad or trace data stored in Altium® files (.step, .obj, .fbx)
 - Unity® material file limitations
 - Too time-consuming and ultimately abandoned.



ALTIUM
DESIGNER



Conclusion

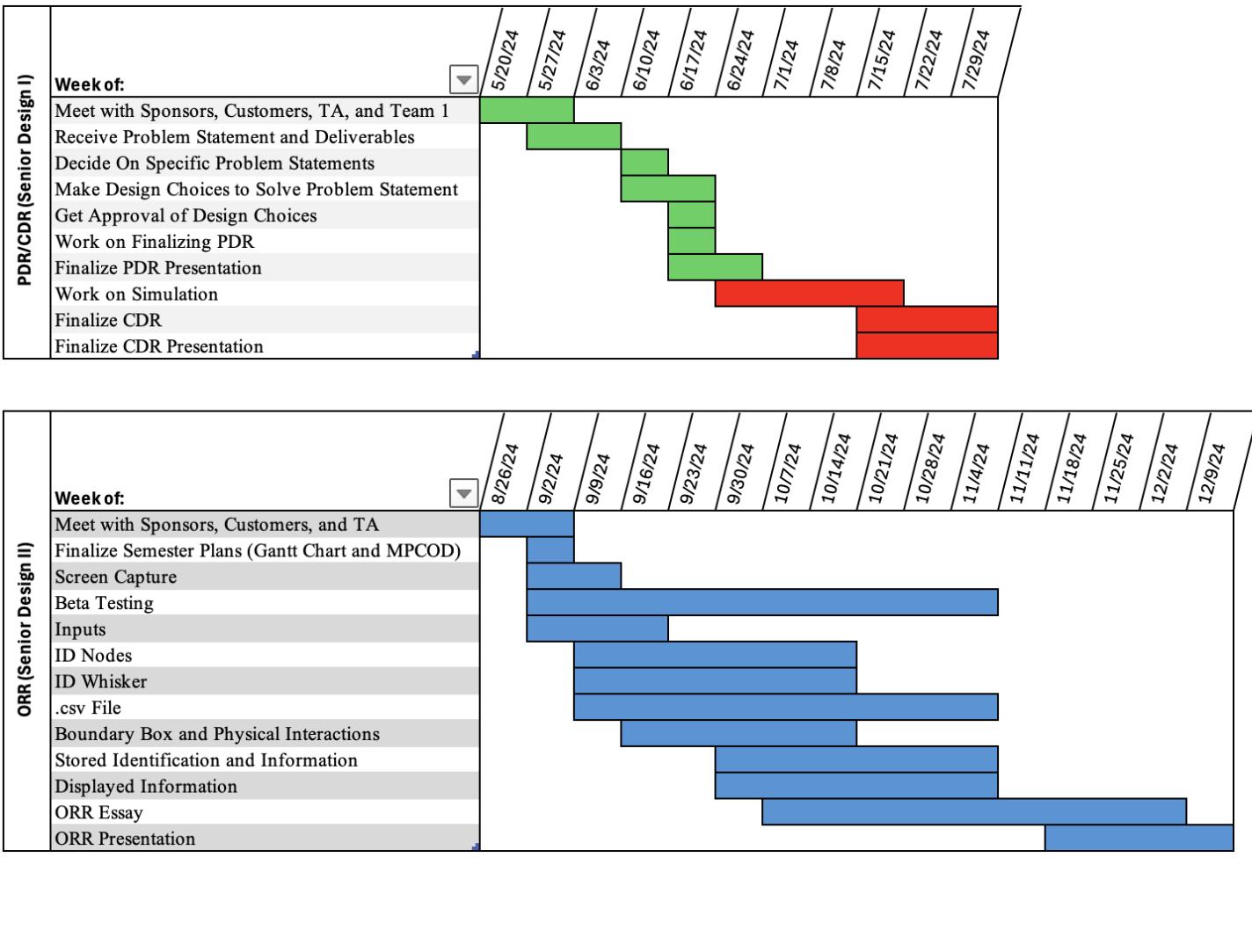
Design Specifications Met

- Location of whisker spawn
- System Container/ Boundary Box
- Physical Environment, specifically orientation and acceleration
- Identify and label node pairs
- Graphic Display
- Create ID number for each whisker generated
- Store whisker ID and pad ID of bridged nodes
- Storable results file
- Inputs: Store the initial parameters
- Screen capture

Continue Development and Continuation

- Look into .obj and .mtl files more and how they interact with Unity®
- Look into more PCB editors like KiCad® to see how to make traces interact with blender and unity more efficiently
- Mixed: A mixture of both free-floating and attached whiskers. The user may define the percentage of free-floating and attached whiskers created.
- Edit circuit: Add components, delete components, and modify the original circuit.

Gantt Chart

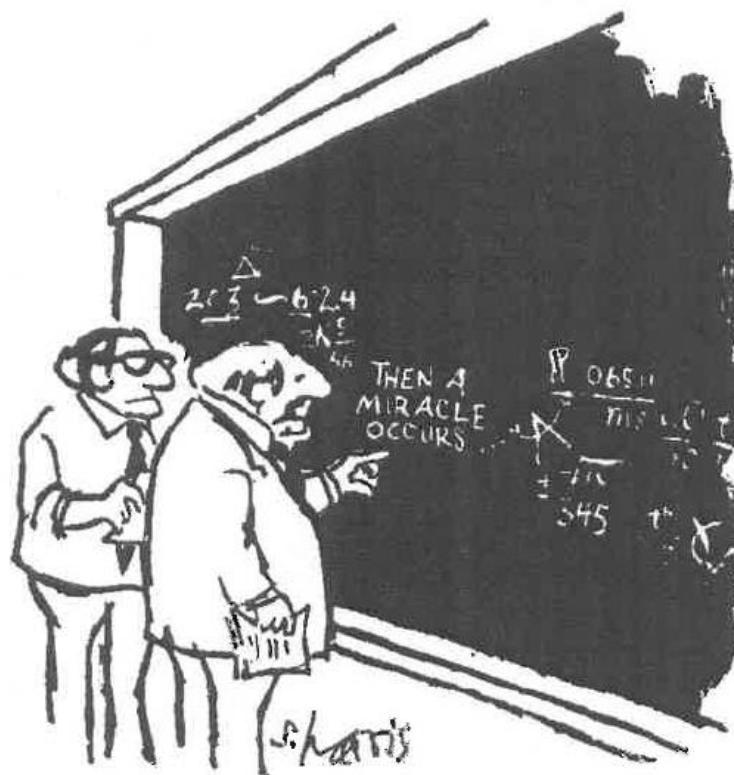


References

- [1] L. Panashchenko, “The Art of Metal Whisker Appreciation: A Practical Guide for Electronics Professionals,” 2012. Available: https://nepp.nasa.gov/WHISKER/reference/tech_papers/2012-Panashchenko-IPC-Art-of-Metal-Whisker-Appreciation.pdf [Accessed 17-Jun-2024.]
- [2] Center for Advanced Life Cycle Engineering, “CALCE Tin Whisker Induced Metal Vapor Arc 70 torr,” *YouTube*, Jul. 27, 2018. <https://www.youtube.com/watch?v=t38p2-sYkRE> [Accessed 17-Jun-2024.]
- [3] *Electronic Sensor Card Realized on PCB. / Download Scientific Diagram*, www.researchgate.net/figure/Electronic-sensor-card-realized-on-PCB_fig1_318330114 [Accessed 17-Jun-2024.]

Questions?

Tin Whisker Growth Mechanism



"I think you should be more explicit here in step two."