TestConX 2025

Advanced Thermal Management:
Enhancing Heat Sink Performance for Hand Socket Lids with Generative Design and Additive Manufacturing

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Keywords To Remember

Generative Design

Additive Manufacturing

Thermal Resistance

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- Introduction and Motivation
- Generative Design Framework
- Iterative Design Evolution
- Simulation-Driven Design and Experimental Validation
- Data-Driven Insights and Validation
- TPMS Structure and Flow Resistance
- Conclusion


Hand Socket Lids
5W
>300W
20W
100W
300W
TestConX
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4
2025

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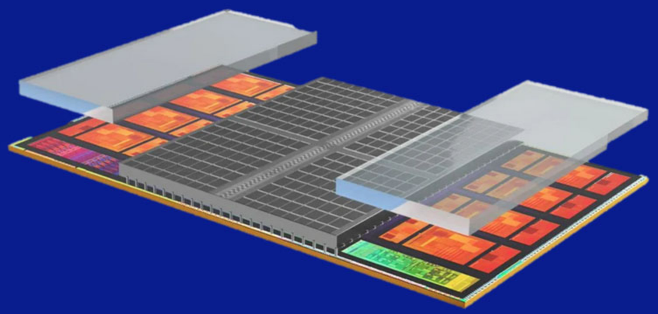
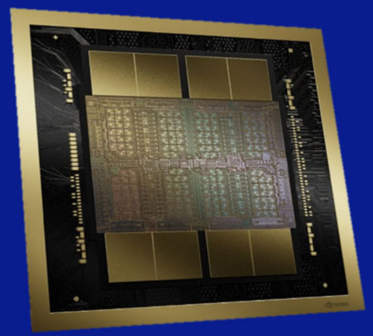
The Growing Heat Challenge in Modern Chips

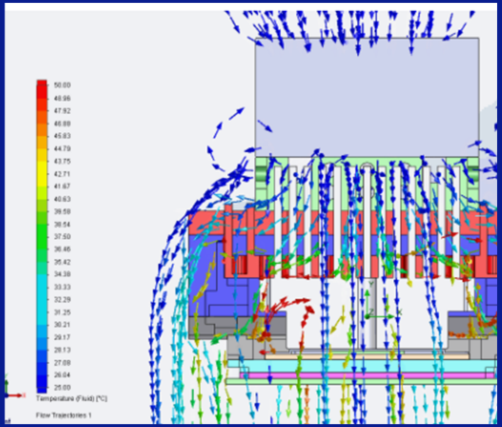
- Advancements in AI
- 3D chip stacking
- Miniaturization of components

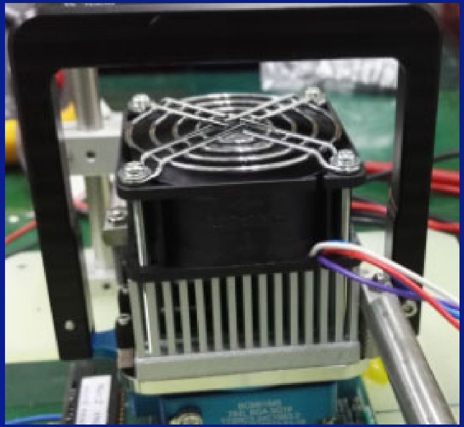




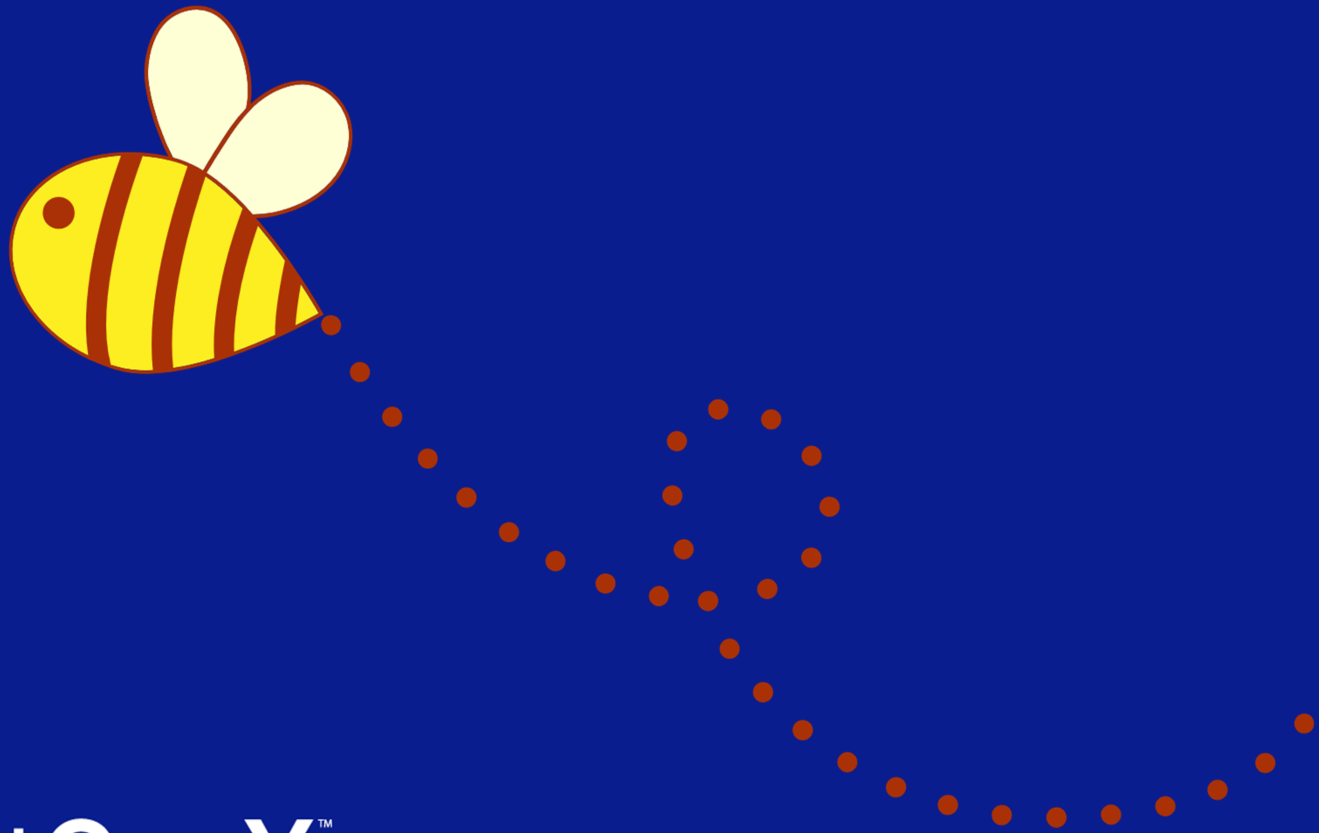
The Need for More Efficient Heat Sinks

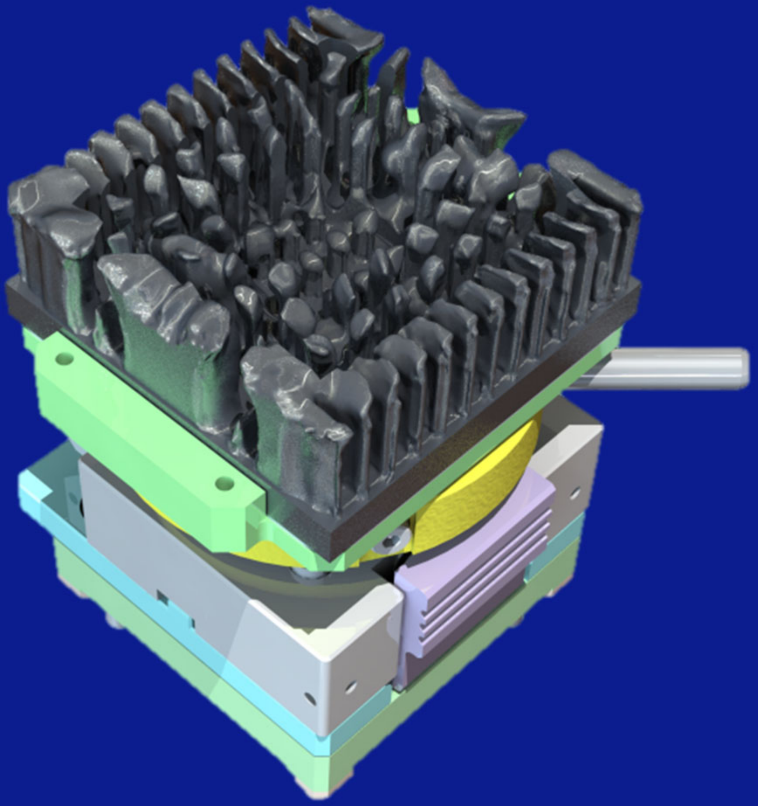
- Conventional heat sinks : < 150 W for a 100 mm² area
- Larger, noisy heat sinks are needed, but they’re not suitable for compact applications.





Exploring New Frontiers in Cooling

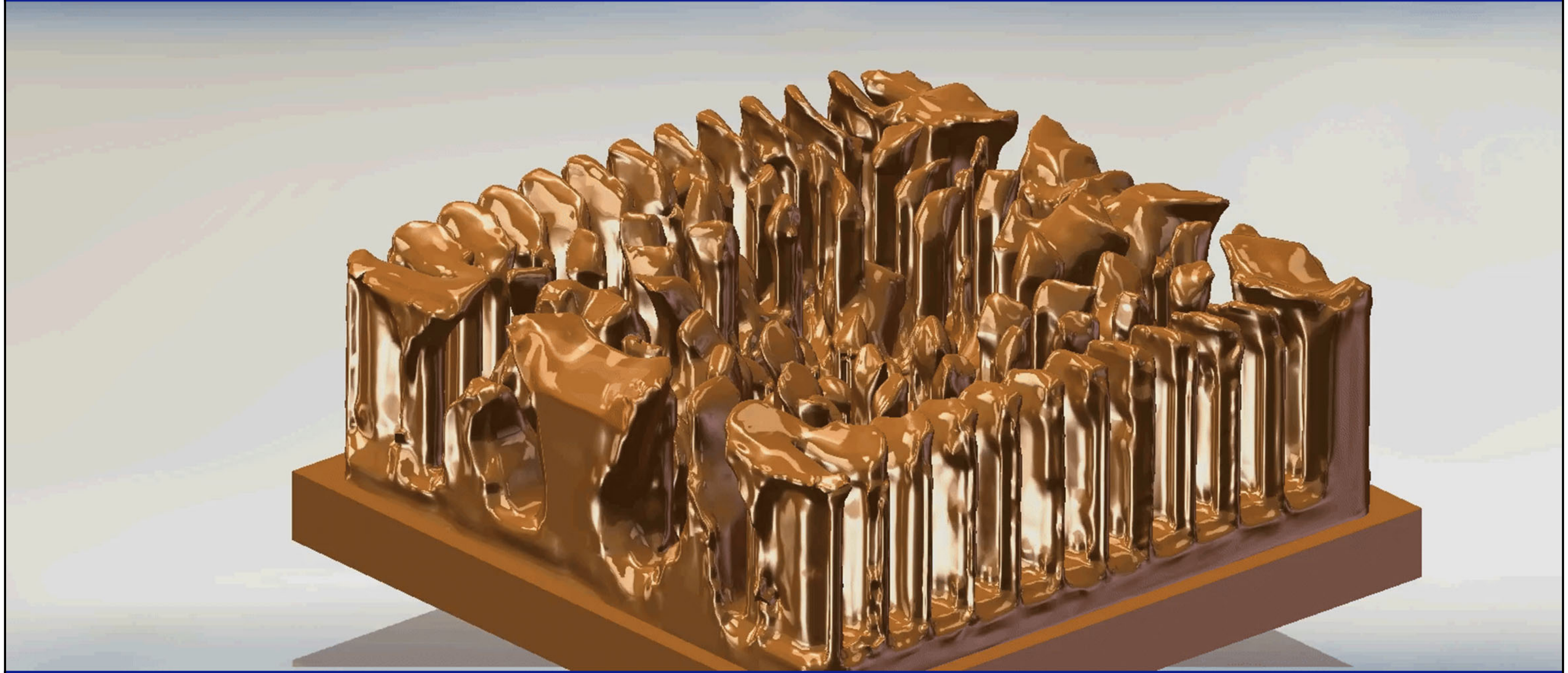




Neura Series

The Neura Series hand socket lids feature generative design-optimized heat sinks, engineered for exceptional thermal performance and efficiency.

Heat Sink 3D Model

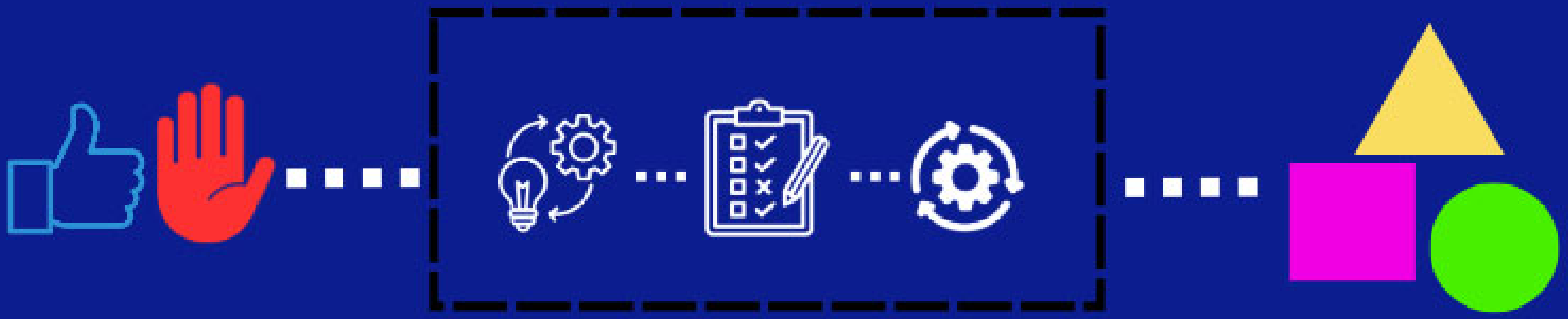


What is Generative Design?

Generative design is an advanced, algorithm-driven process, sometimes enabled by AI, used to explore a wide array of design possibilities that meet predefined criteria set by engineers or designers to produce an optimized design.

~Autodesk

What is Generative Design?



Step 1 :
Predefined criteria

Step 2 :
Algorithm-driven process

Step 3 :
Optimized Design

What is the difference?

- **Optimization Objectives**
  - Optimizes multiple objectives, including:
    - **Temperature minimization**
    - **Temperature Variance reduction**
  - Handles constraints like **pressure loss**.

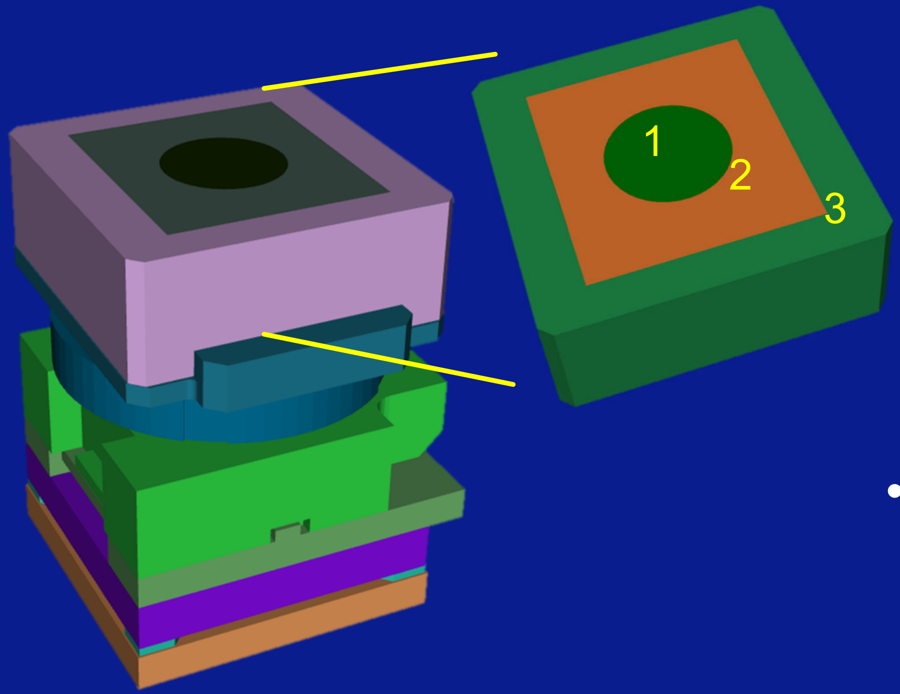
- **How is it different from Topology Optimization?**
  - Focuses mainly on material distribution within a space to achieve structural efficiency.

Generative Design Phase

Validation Phase

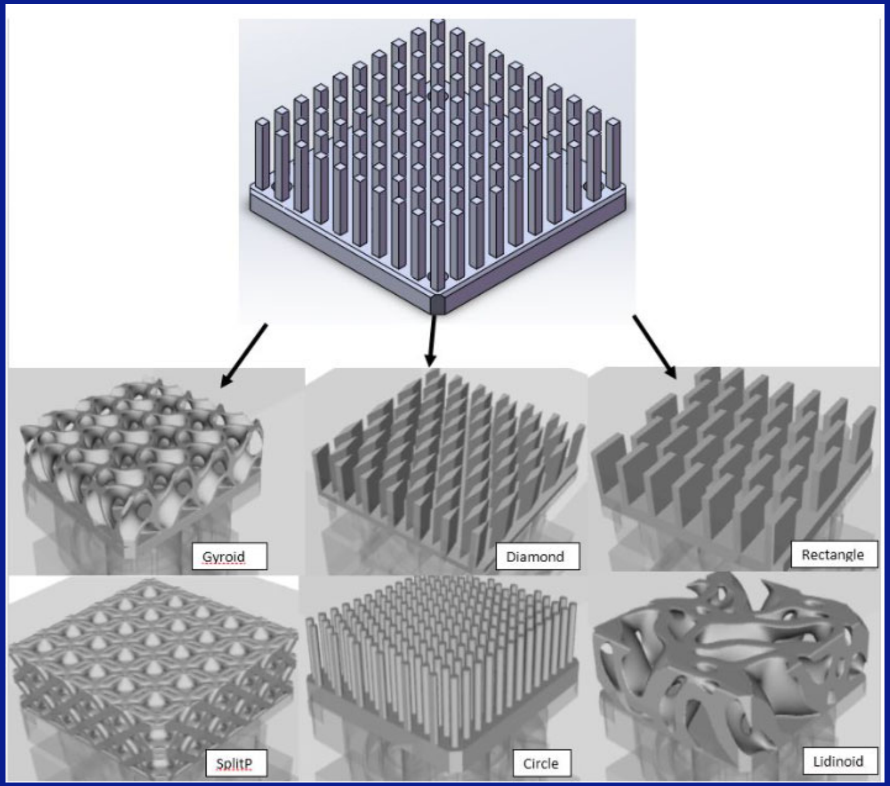
Generative Design Phase

Step 1 : Segmentation for Better Optimization



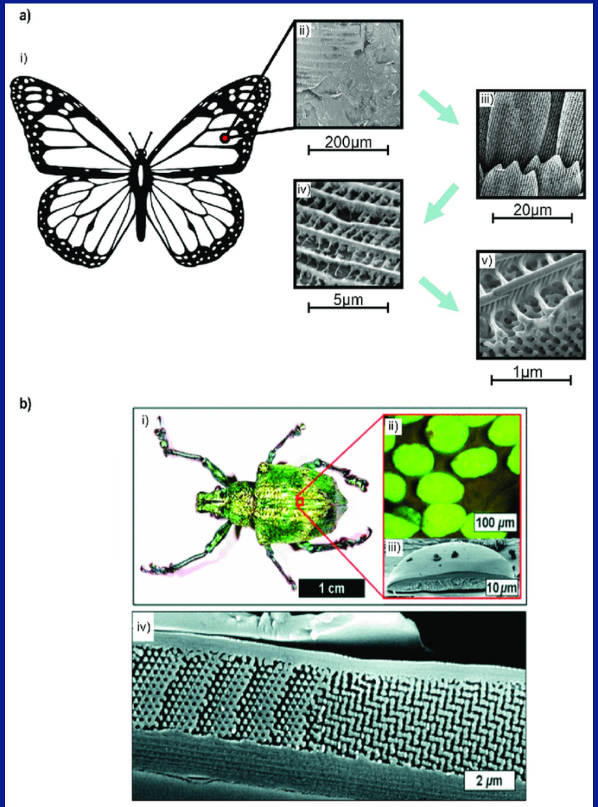
- **Segmentation for Enhanced Optimization**
  - The design space is divided into 3 distinct regions for targeted optimization.
  - Each region is optimized separately, aligning with airflow, pressure and thermal performance requirements.
- **Why This Approach?**
  - Provides the optimizer greater freedom to refine designs.

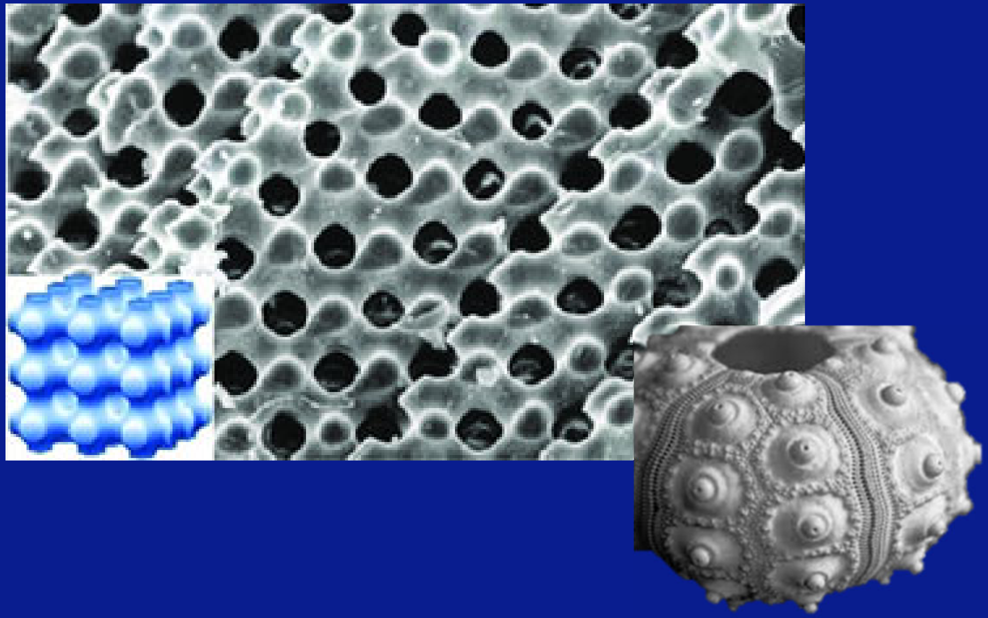
Step 2 : Design Selection



- **Pin Designs**
  Circular, Rectangular, Diamond
- **3D Lattice Structures**
  Gyroid, Schwarz, Diamond,Lidinoid, Sp
  P, Neovius

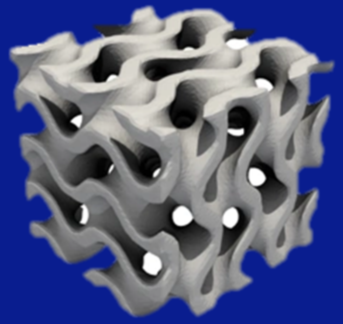
Fun Fact



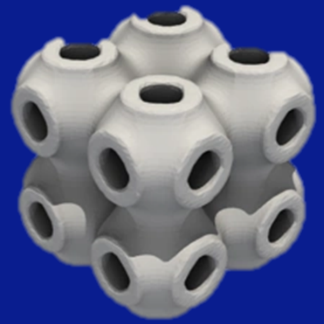


3D Lattice Structures

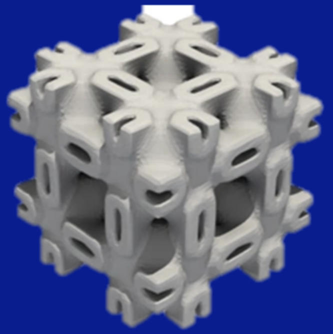
Triply Periodic Minimal Surface (TPMS)



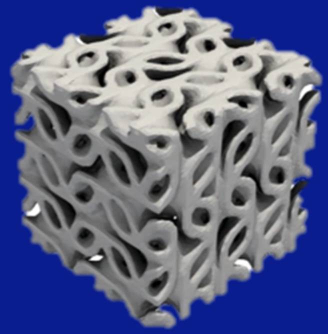
Gyroid



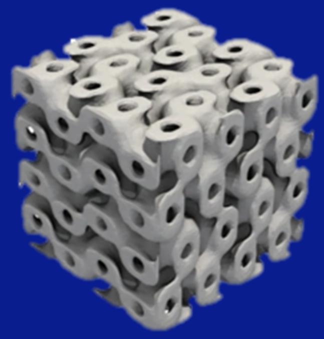
Schwarz



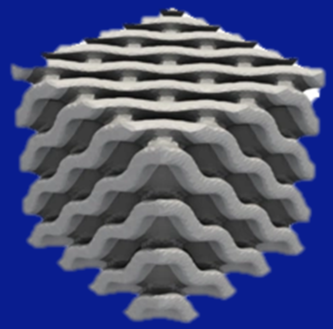
Neovius



Lidinoid

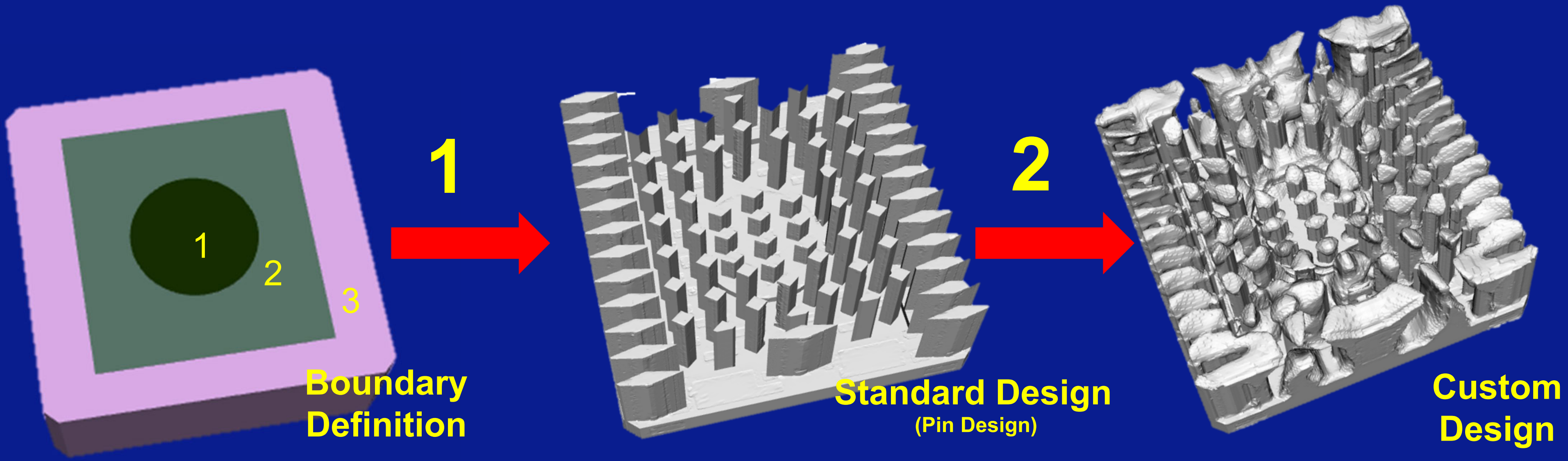


Split P



Diamond

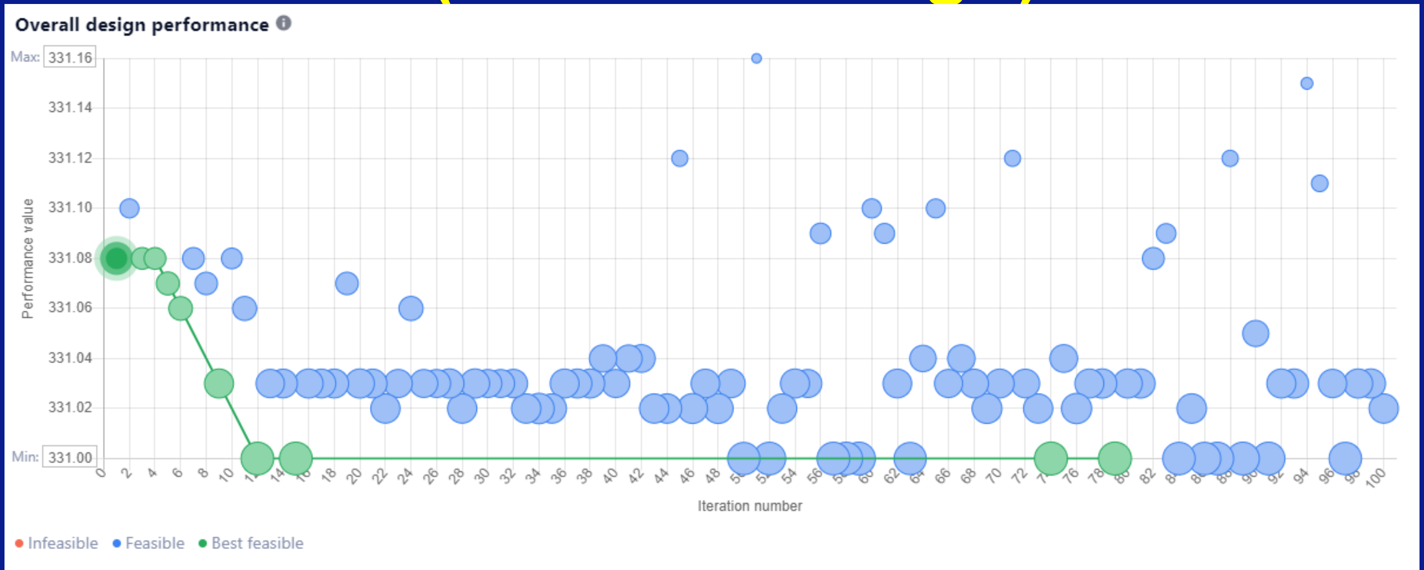
Step 3 : Algorithm-driven Process



Process1 : **Standard Design**: Optimized off-the-shelf heat sink as a baseline.

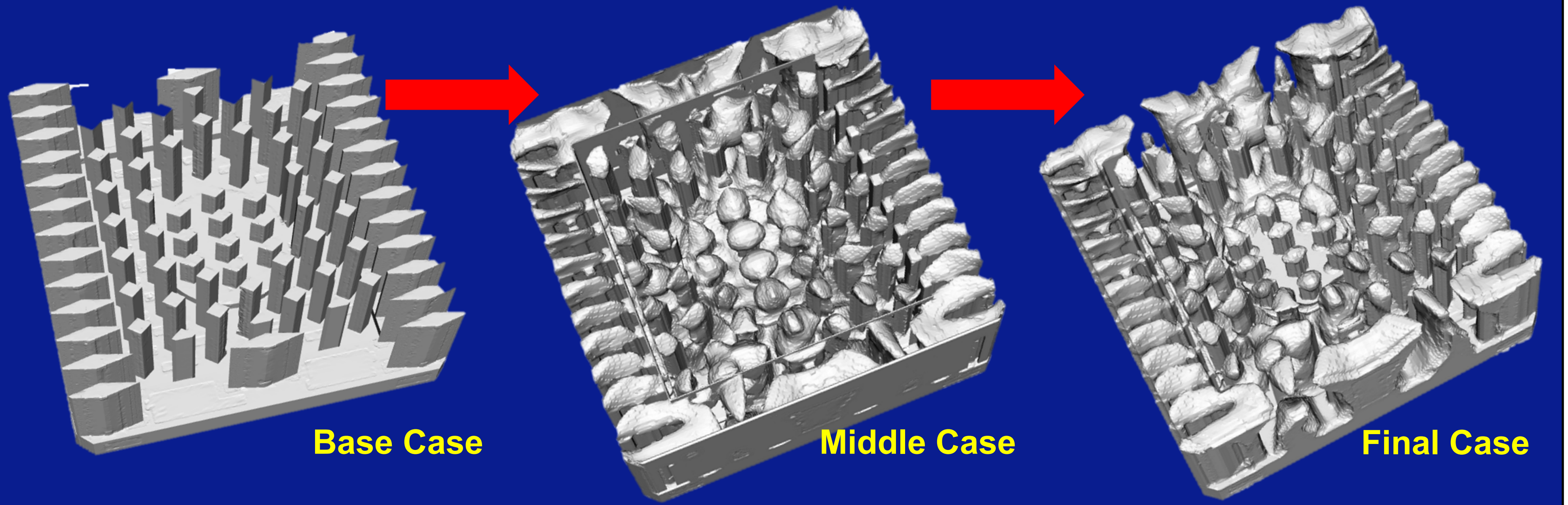
Process2 : **Custom Design**: Generative design creates a fully tailored solution, unrestricted by standard options

Design Iteration and Performance Evolution (Custom Design)



- The line chart illustrates the performance improvement across design iterations. Each dot represents a unique design iteration, showing how the optimization process evolves.
- ***Key Insight**: Smaller performance values indicate better overall performance, highlighting the effectiveness of iterative optimization.*

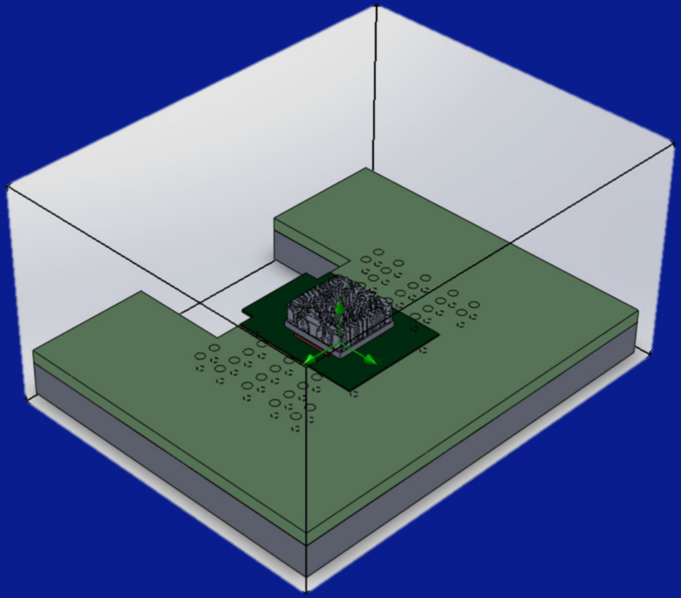
Inside the Algorithm



- Heat sink evolution through iterative optimization
- Improved structure and performance at each stage
- Final design: optimized for thermal efficiency

Validation Phase: Testing the Design

Simulation Parameters



Mesh Analysis :

Total Cell count : 1798540
Fluid Cells : 1373613
Solid Cells : 424927
Partial Cells : 245571

Thermodynamics Parameters:

Static Pressure : 101325 Pa
Ambient Temperature : 22°C

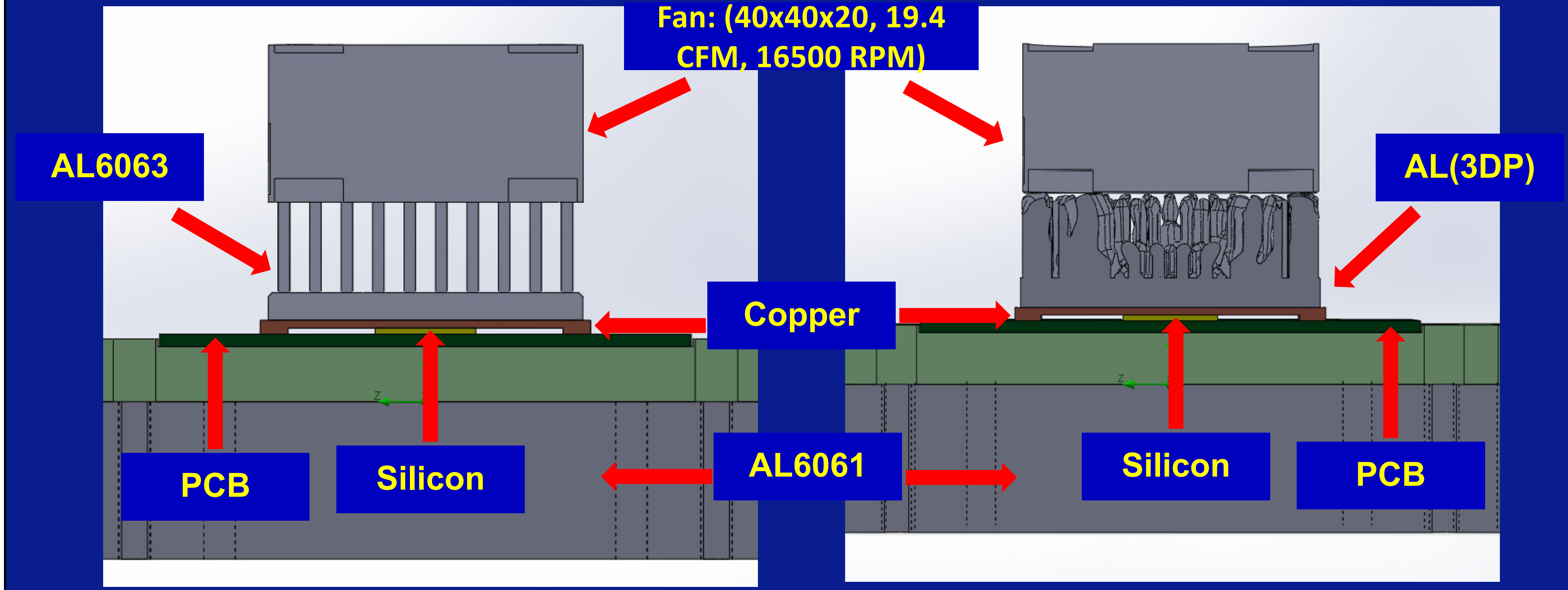
Boundary Conditions

Fan : (40x40x20 CUI)
Heat Source : 30W

Heat Transfer Analysis:

Heat conduction in solids: On
Flow Type : Laminar and turbulent
Time-Dependent Analysis: Off
Gravity: On
Humidity: 80.00 %

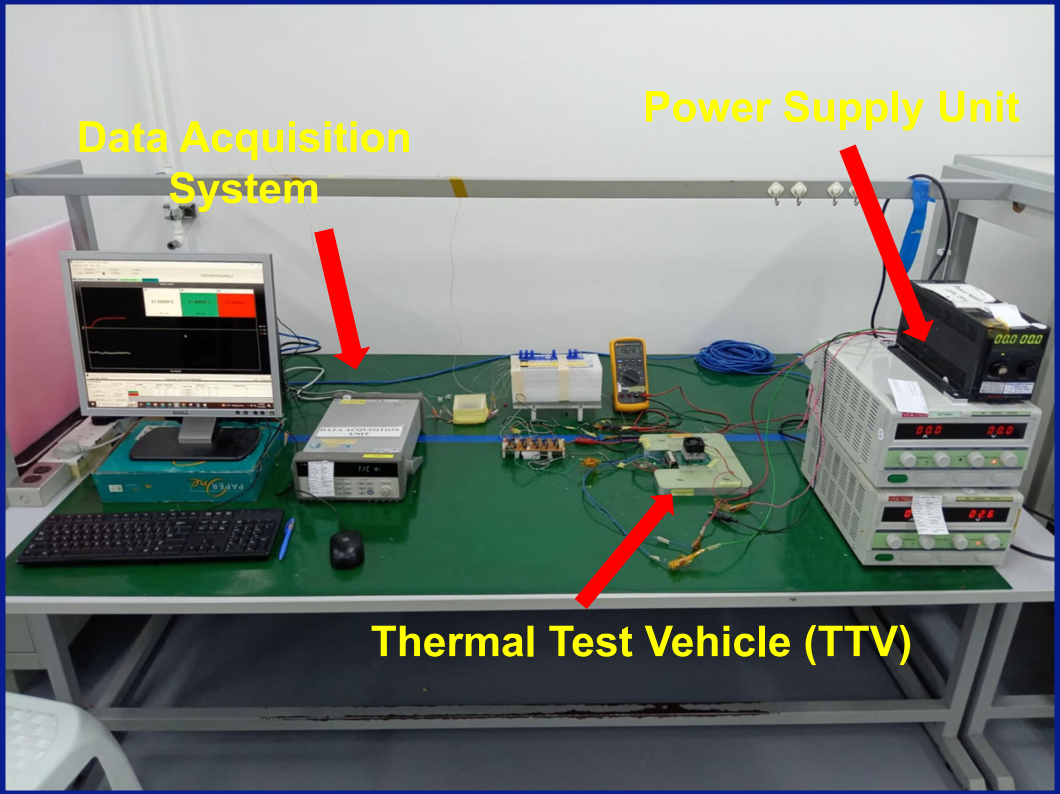
Simulation Material Setup

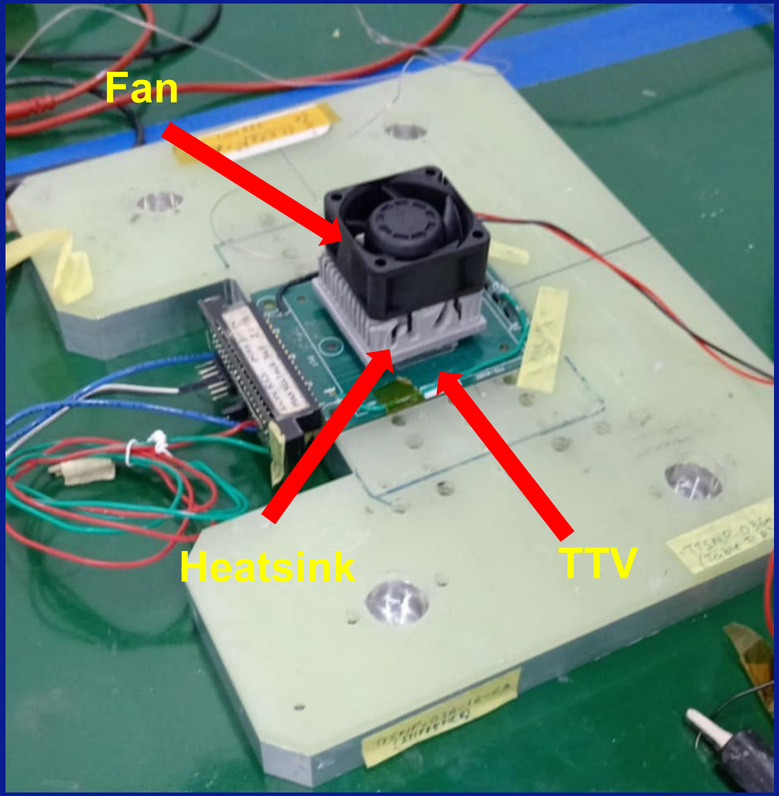


Pin Heat Sink (Traditional Heat Sink)

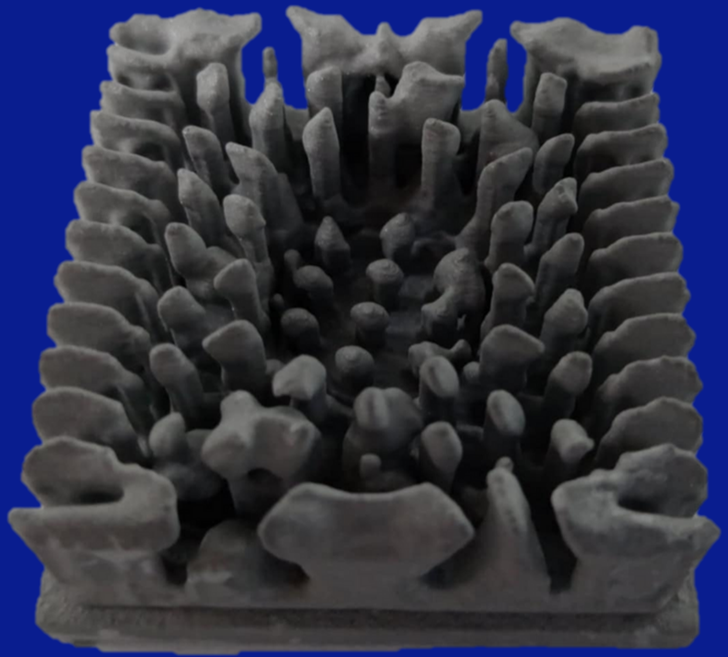
Optimized Heat Sink

Experimental Setup

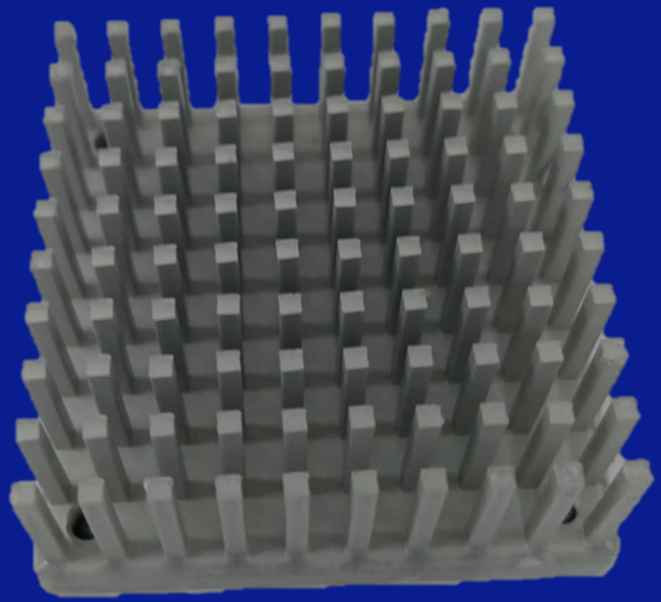




Fabricated Heat Sinks

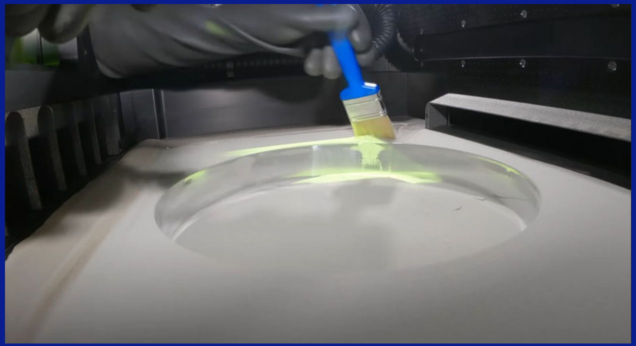


Optimized Heat Sink

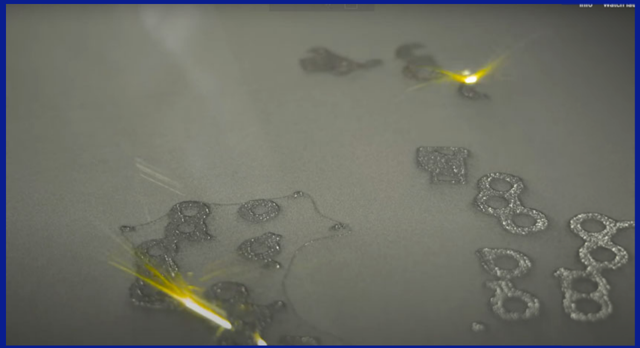


Pin Heat Sink
(Traditional Heat Sink)

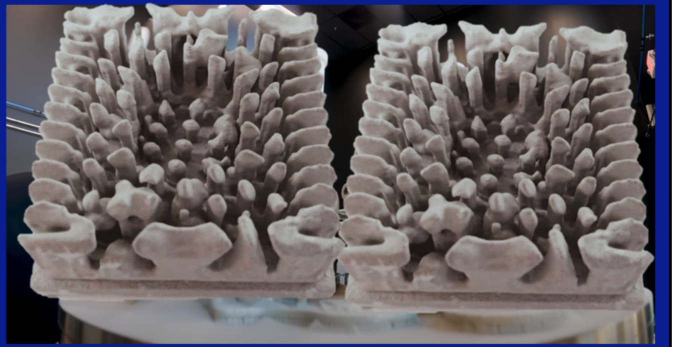
Additive Manufacturing Process



Spreading a layer of fine metal powder onto a build platform



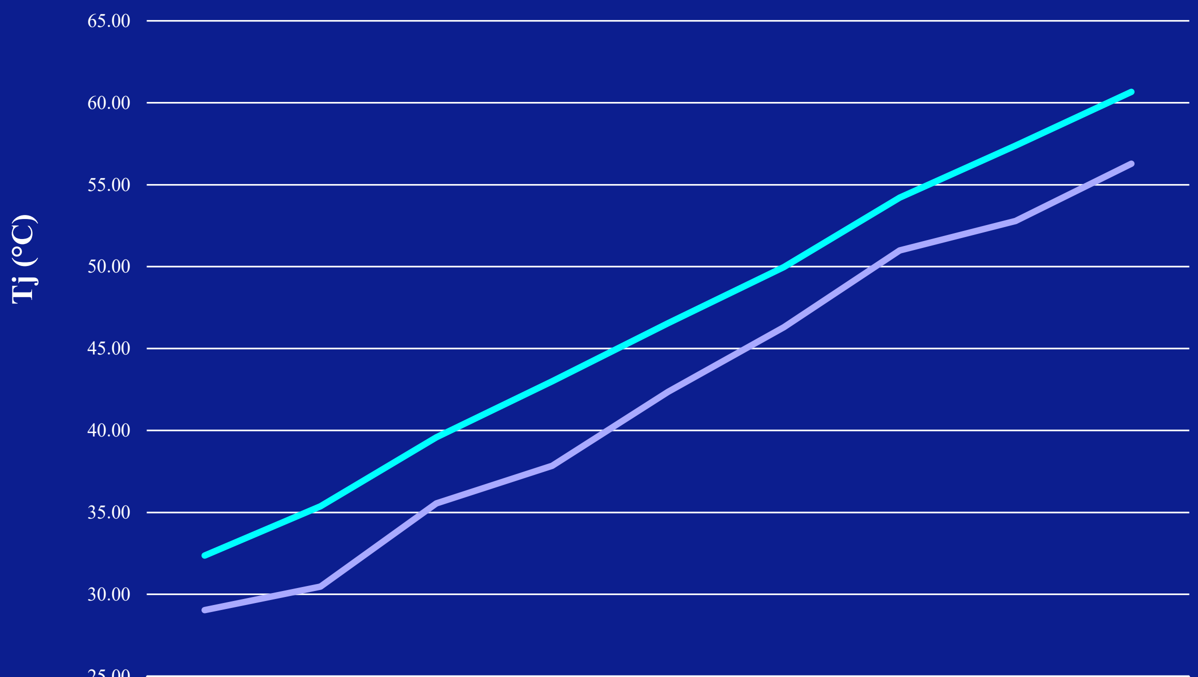
Laser or electron beam selectively melt and fuse the powder



3D part build

Test Results

Simulation Validation



	9.76	15.75	20.88	26.19	30.74	36.8	41.82	46.8	50.69
Optimized Heatsink Lab Test Tj (°C)	32.37	35.38	39.58	43.00	46.54	49.98	54.22	57.39	60.67
Simulated Optimized Heatsink Tj (°C)	29.03	30.47	35.55	37.85	42.35	46.30	50.99	52.79	56.28

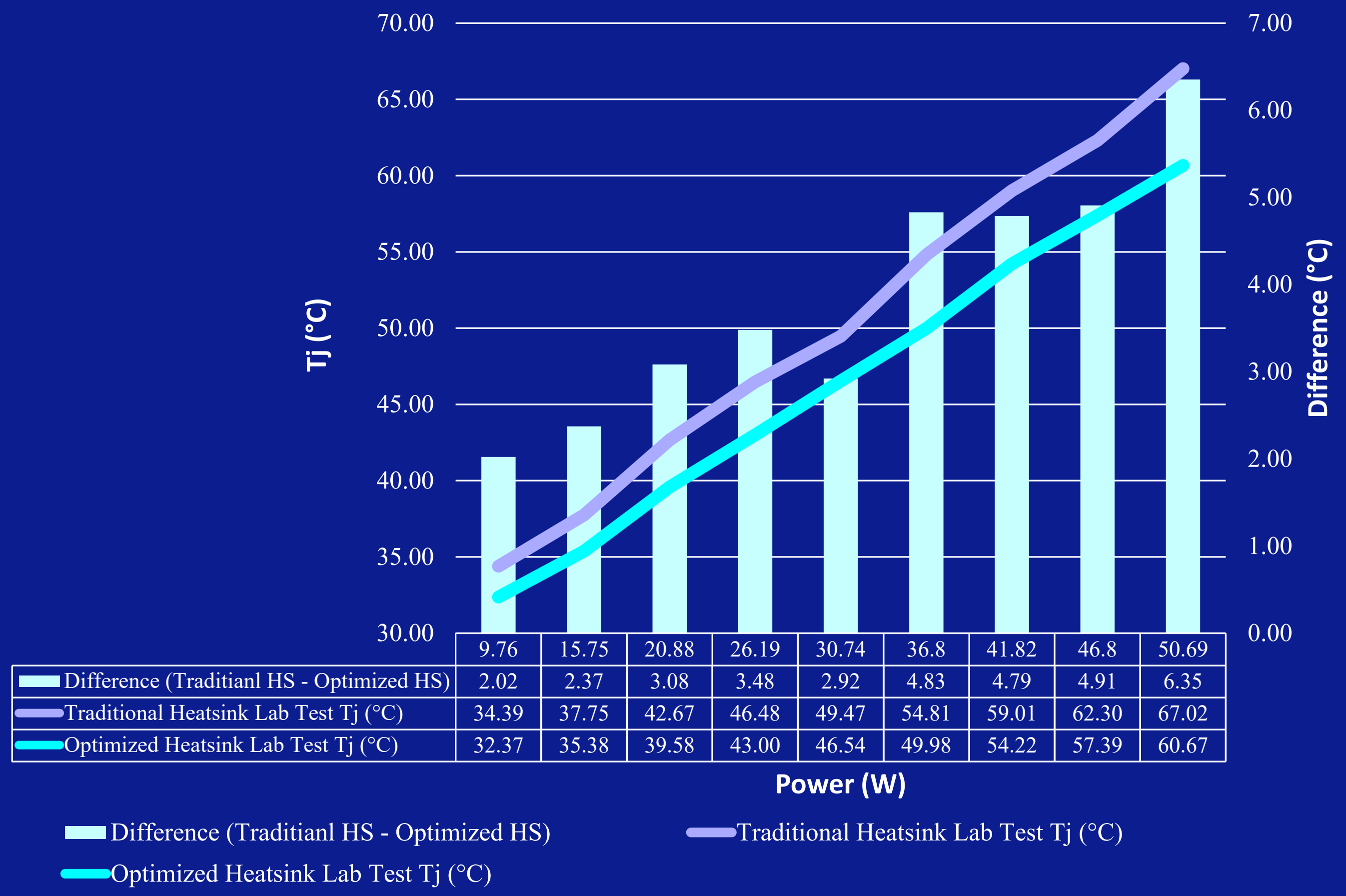
Power (W)

Optimized Heatsink Lab Test Tj (°C)   Simulated Optimized Heatsink Tj (°C)

Tj Comparison for Optimized Heat Sink (Lab Test VS Simulation)

- Simulation results aligns closely with lab results, with minimal differences between the die temperature (Tj) (~3-5.15°C), indicating accuracy in simulation.

Performance Comparison



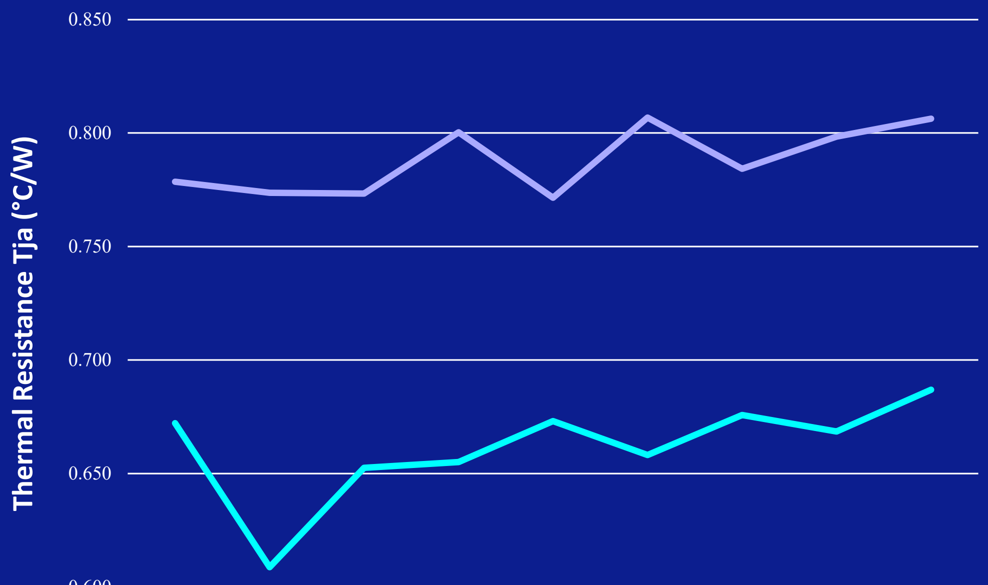
	9.76	15.75	20.88	26.19	30.74	36.8	41.82	46.8	50.69
Difference (Traditianl HS - Optimized HS)	2.02	2.37	3.08	3.48	2.92	4.83	4.79	4.91	6.35
Traditional Heatsink Lab Test Tj (°C)	34.39	37.75	42.67	46.48	49.47	54.81	59.01	62.30	67.02
Optimized Heatsink Lab Test Tj (°C)	32.37	35.38	39.58	43.00	46.54	49.98	54.22	57.39	60.67

Lab Test Results

Optimized Heat Sink vs Traditional Heat Sink (Die Temperature (Tj) Comparison):

- Optimized heat sink shows lower die temperatures compared to traditional heat sink at various power levels.
- Difference: Optimized heat sink consistently performs better (~2-6.35°C lower in die temperature).

Thermal Resistance Comparison



Power (W)	9.76	15.75	20.88	26.19	30.74	36.8	41.82	46.8	50.69
Optimized Heatsink Lab Test Thermal Resistance Tja (°C/W)	0.672	0.609	0.653	0.655	0.673	0.658	0.676	0.668	0.687
Traditional Heatsink Lab Test Tja (°C/W)	0.779	0.774	0.773	0.800	0.772	0.807	0.784	0.798	0.806

Power (W)

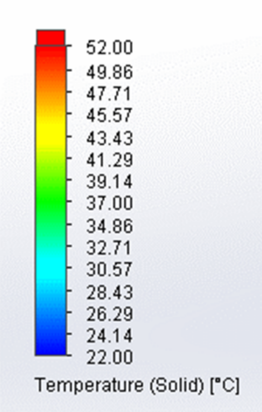
Optimized Heatsink Lab Test Thermal Resistance Tja (°C/W) Traditional Heatsink Lab Test Tja (°C/W)

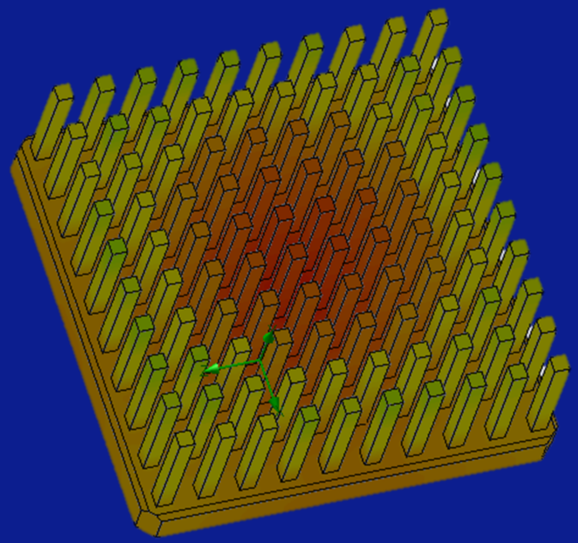
Lab Test Results

Optimized Heat Sink vs Traditional Heat Sink:

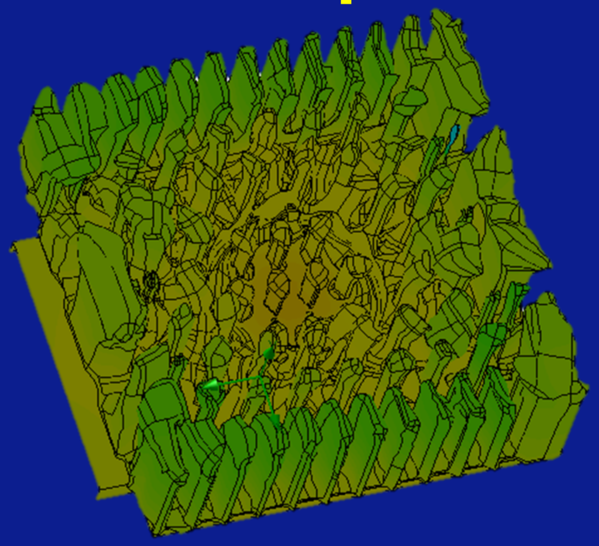
- Consistently show lower thermal resistance
- Percentage difference: 13.67% to 21.33% lower thermal resistance for optimized heat sink

Surface Temperature Plot Comparison





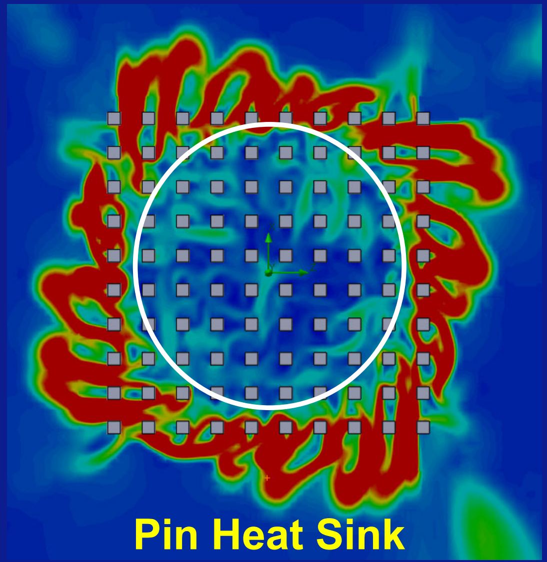
Pin Heat Sink
Max Surface Temperature : 51.45°C

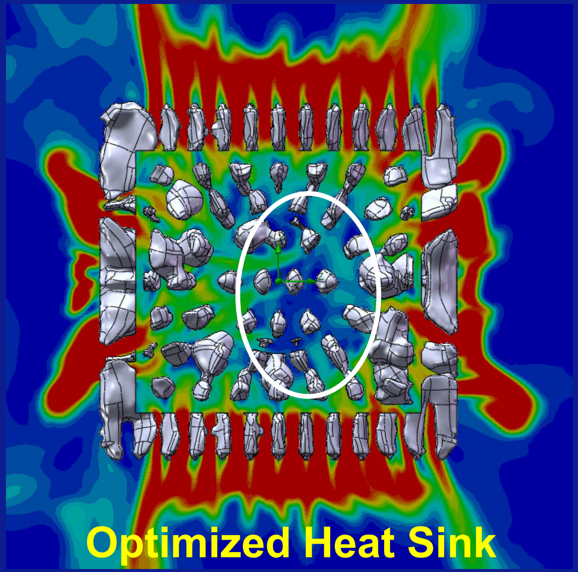


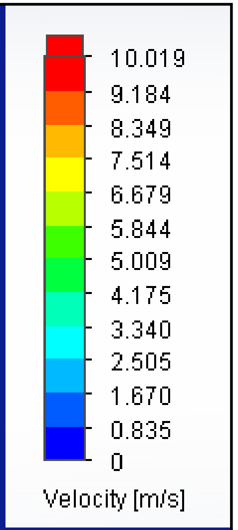
Optimized Heat Sink
Max Surface Temperature : 46.49°C

- Optimized heat sink reduce surface temperatures by ~9.64%
- Improved cooling and reduced heat buildup

Velocity Contour Comparison

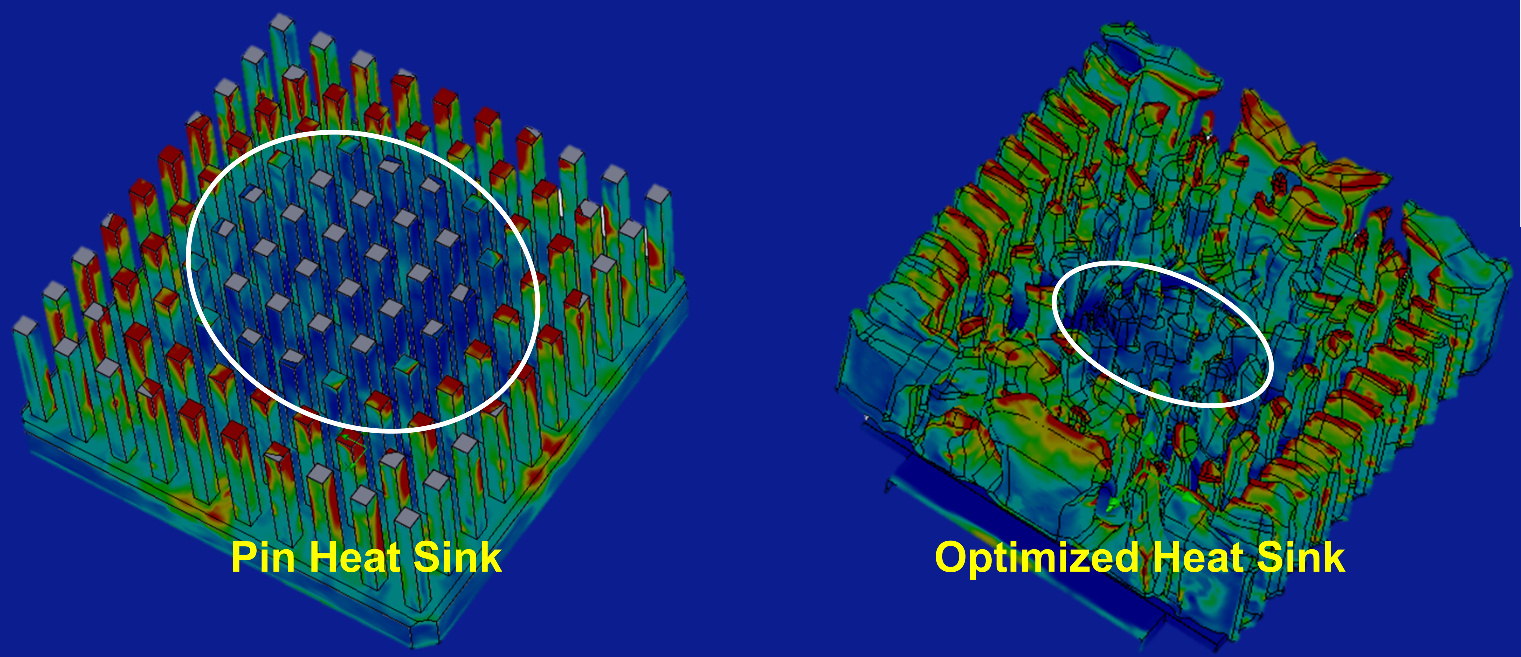


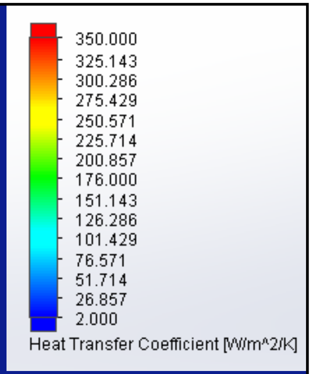




- Pin Heat Sink: Stagnant airflow, low max velocity (~13 m/s).
- Optimized Heat Sink: Uniform velocity distribution, higher max velocity (~19 m/s), better cooling performance.

Convective Heat Transfer Coefficient Comparison

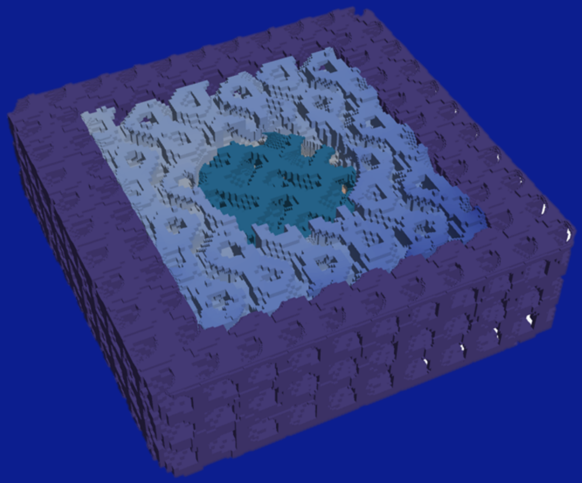




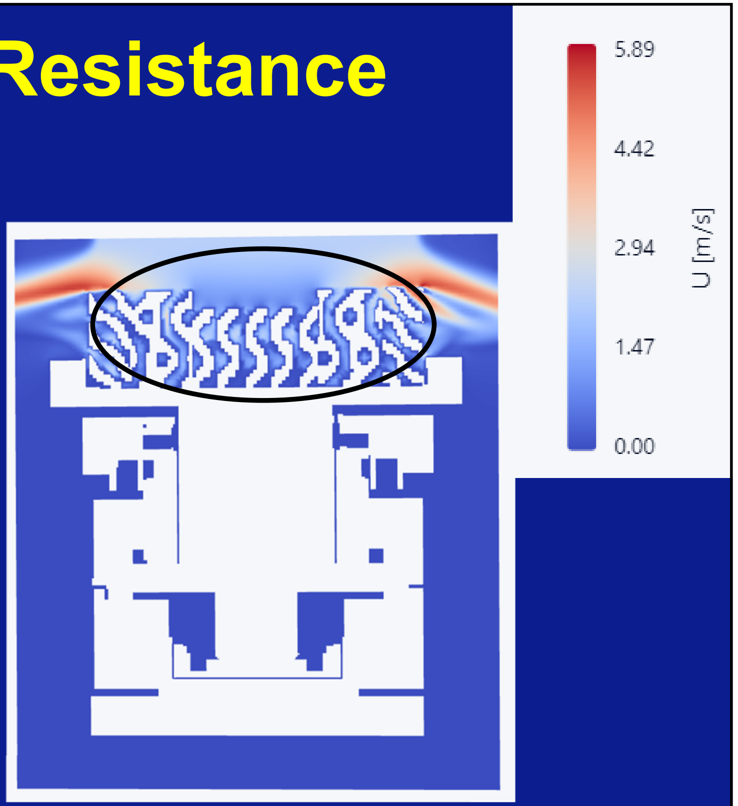
- Pin Heat Sink: Features larger blue regions, indicating lower convective heat transfer. This limits its ability to dissipate heat effectively.
- Optimized Heat Sink: Exhibits a more balanced distribution with fewer low-transfer areas, ensuring improved thermal performance through better heat dissipation.

TPMS Structure and Flow Resistance

- TPMS (Triply Periodic Minimal Surface) structures cause high flow resistance, as shown in the velocity contour plot.
- Flow Resistance: High resistance results in stagnant air areas, causing airflow to bypass the heatsink.
- Effect: Reduced convective heat transfer efficiency and less effective cooling performance.



TPMS Structure



Slice X

Conclusion

- Optimized heat sinks reduce thermal resistance by up to 20%.
- Generative design creates efficient, custom cooling solutions.

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