TECHNICAL CASE STUDY
Thermal Management · CFD Optimization

CFD Optimization of a Ruggedized Electro-Optical Cooling Architecture

At a Glance

Advanced Thermal Solutions, Inc. (ATS) executed a baseline-to-optimized thermal design cycle for a ruggedized electro-optical module with mixed heat sources under elevated ambient conditions. The work focused on reducing thermal resistance and improving sensor temperature stability within tight packaging constraints.

CUSTOMER OVERVIEW

The customer was developing a ruggedized electro-optical module for portable threat detection. The design had to manage localized heat from laser thermoelectric coolers (TECs), an imaging sensor, and control electronics within a compact, field-ready package.

- Mixed heat-source architecture with TEC, sensor, and PCB dissipation
- Compact packaging with limited room for thermal hardware changes
- Sensor-region temperature stability critical to system performance

CHALLENGE

The customer needed better thermal performance at 40°C ambient while maintaining a compact, rugged, and manufacturable cooling architecture. The key challenge was reducing thermal resistance and improving temperature stability without increasing system size.

Key design targets:

- Ambient boundary condition: 40°C
- Total heat load: 27 W
- Heat sources distributed across laser TECs, imaging sensor, and PCB
- Compact axial fans with fan-forced convection
- Robust, manufacturable heat sink and heat spreading architecture

This required balancing airflow, heat sink selection, heat spreading strategy, and TEC coupling within strict packaging limits.

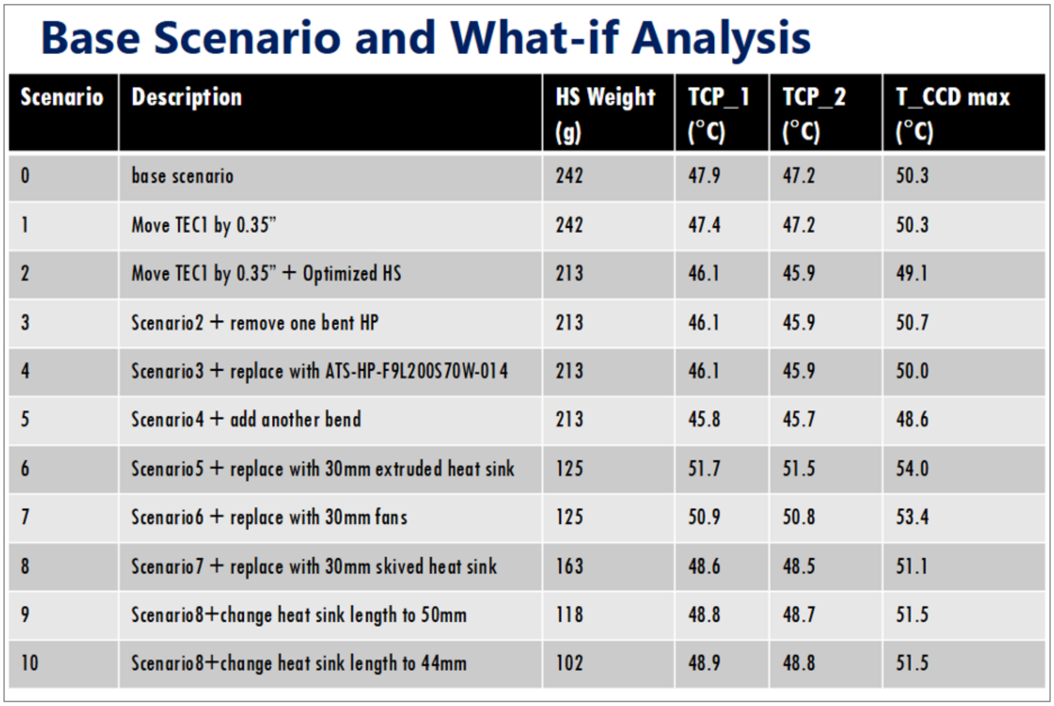
The design problem was not isolated to the heat sink alone. It depended on heat injection, spreading, airflow delivery, and fin-field utilization working together.

METHODOLOGY

ATS carried out a baseline-to-optimized CFD design cycle to identify the most effective changes for lowering thermal resistance in the cooling stack (Figure 1).

Baseline and Optimization Approach

- Baseline heat sink thermal resistance: approximately 0.22 °C/W
- Evaluation performed at 27 W total heat load and 40°C ambient
- Fan-forced convection using compact axial fans
- Optimization targeted reduced system thermal resistance



Base Scenario and What-if Analysis

Scenario	Description	HS Weight (g)	TCP_1 (°C)	TCP_2 (°C)	T_CCD max (°C)
0	base scenario	242	47.9	47.2	50.3
1	Move TEC1 by 0.35"	242	47.4	47.2	50.3
2	Move TEC1 by 0.35" + Optimized HS	213	46.1	45.9	49.1
3	Scenario2 + remove one bent HP	213	46.1	45.9	50.7
4	Scenario3 + replace with ATS-HP-F9L200S70W-014	213	46.1	45.9	50.0
5	Scenario4 + add another bend	213	45.8	45.7	48.6
6	Scenario5 + replace with 30mm extruded heat sink	125	51.7	51.5	54.0
7	Scenario6 + replace with 30mm fans	125	50.9	50.8	53.4
8	Scenario7 + replace with 30mm skived heat sink	163	48.6	48.5	51.1
9	Scenario8+change heat sink length to 50mm	118	48.8	48.7	51.5
10	Scenario8+change heat sink length to 44mm	102	48.9	48.8	51.5

Figure 1. ATS Completed a Range of Design Actions to Achieve and Improve on the Key Design Targets

Key Investigation Areas

- Heat spreading and heat pipe geometry and placement (Figures 2, 3, 4)
- TEC-to-spreader coupling effectiveness
- Fan operating point relative to system impedance
- Ducting strategy to increase useful flow through the fin field
- Alternative heat sink constructions for manufacturable performance

ATS used the CFD what-if analysis to isolate the design actions that delivered the strongest thermal gains while preserving manufacturability.

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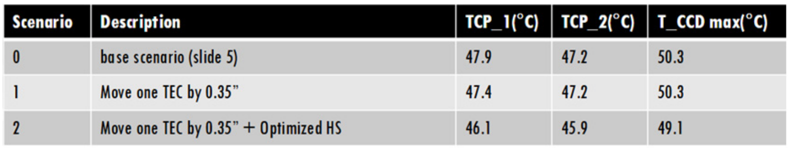


Scenario	Description	TCP_1(°C)	TCP_2(°C)	T_CCD max(°C)
0	base scenario (slide 5)	47.9	47.2	50.3
1	Move one TEC by 0.35"	47.4	47.2	50.3
2	Move one TEC by 0.35" + Optimized HS	46.1	45.9	49.1

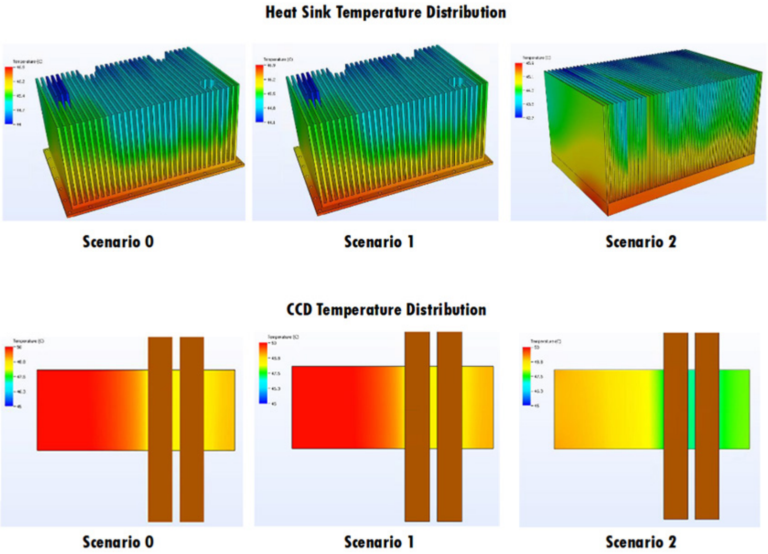
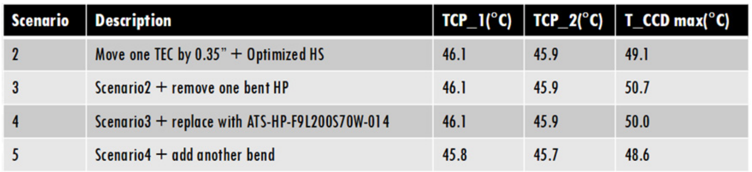


Figure 2. Temperature Results from Optimizing the Heat Sink and Moving the TEC



Scenario	Description	TCP_1(°C)	TCP_2(°C)	T_CCD max(°C)
2	Move one TEC by 0.35" + Optimized HS	46.1	45.9	49.1
3	Scenario2 + remove one bent HP	46.1	45.9	50.7
4	Scenario3 + replace with ATS-HP-F9L200S70W-014	46.1	45.9	50.0
5	Scenario4 + add another bend	45.8	45.7	48.6

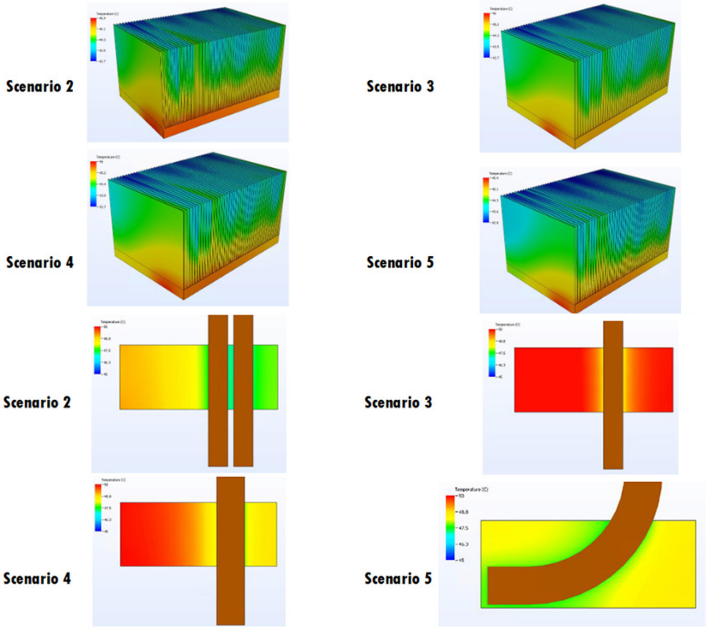
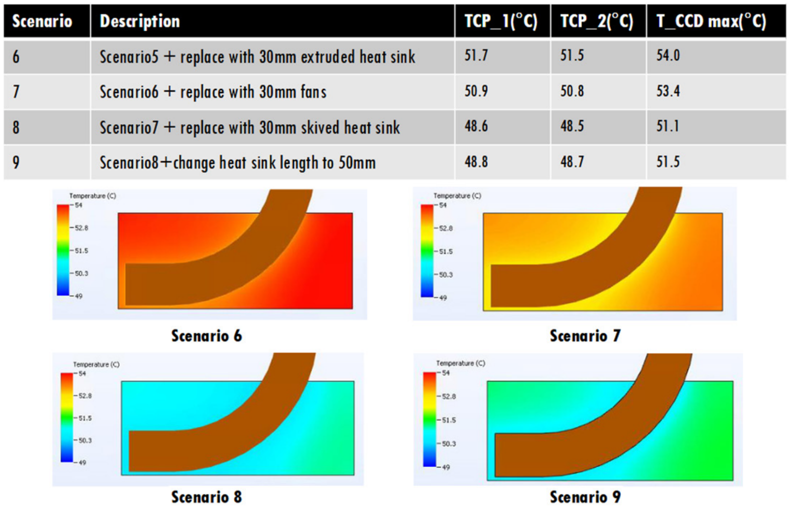


Figure 3. Temperature Results from Replacing the Heat Pipe and Adding Another HP Bend



Scenario	Description	TCP_1(°C)	TCP_2(°C)	T_CCD max(°C)
6	Scenario5 + replace with 30mm extruded heat sink	51.7	51.5	54.0
7	Scenario6 + replace with 30mm fans	50.9	50.8	53.4
8	Scenario7 + replace with 30mm skived heat sink	48.6	48.5	51.1
9	Scenario8+change heat sink length to 50mm	48.8	48.7	51.5

Figure 4. Temperature Results from Different Heat Sinks and Fans

SOLUTION

ATS optimized the cooling architecture by improving coupling between the heat sources and cooling hardware, refining the heat spreading path, and better matching airflow delivery to the fin field and pressure characteristics.

- Repositioned the TEC heat injection path to improve coupling into the heat spreader
- Evaluated larger and bent heat pipe options to reduce spreading resistance
- Compared alternative heat sink constructions to reduce thermal resistance
- Matched compact fan performance to system impedance for more useful airflow
- Supported ducted airflow integration to increase fin-field utilization

The resulting design direction improved temperature stability at critical sensor-relevant locations while preserving a rugged, manufacturable package (Figure 5).

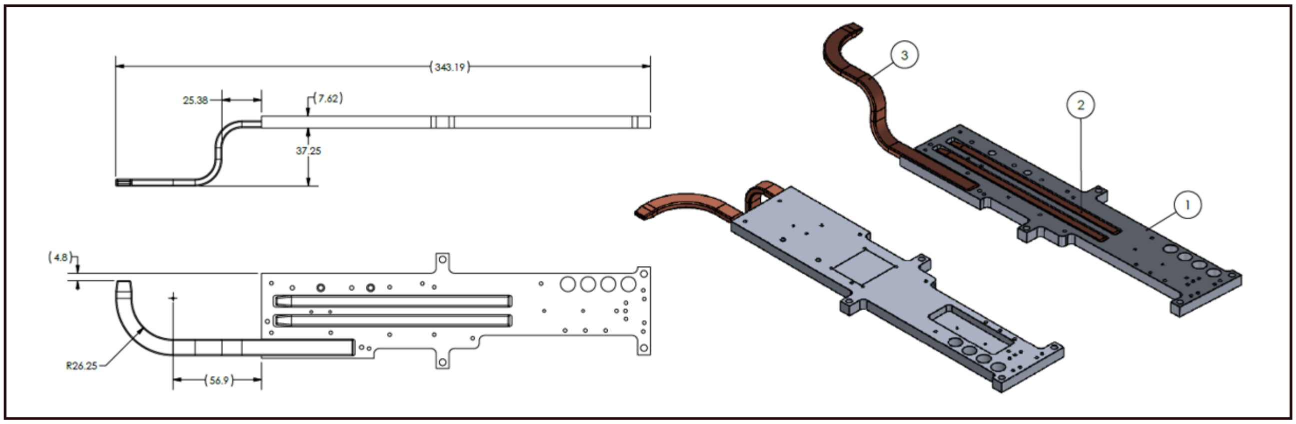


Figure 5. Base Plate and Heat Pipe Assembly – Scenario 5

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RESULTS & DATA

The optimized design reduced overall thermal resistance and improved performance under elevated ambient conditions.

Performance improvement:

- Baseline heat sink thermal resistance: approximately 0.22 °C/W
- Baseline temperature rise: approximately 5.94 °C at 27 W
- Optimized thermal resistance: approximately 0.16 °C/W
- Optimized temperature rise: approximately 4.32 °C at 27 W
- Overall thermal resistance reduction: approximately 27%

Beyond the numerical reduction, the optimization improved heat distribution into the cooling stack and airflow through the available fin area.

Thermal engineering outcomes:

- Improved TEC-to-spreader coupling
- Reduced spreading resistance through revised heat pipe architecture
- Better alignment of fan performance with system flow resistance
- Improved fin utilization and sensor-region temperature stability

ANALYSIS & CONCLUSION

This study shows that thermal optimization in compact electro-optical systems depends on the interaction between heat source placement, spreading resistance, airflow delivery, and manufacturable cooling architecture.

- Thermal performance improved by addressing the full cooling path rather than a single component
- Heat injection path and spreader coupling strongly influenced sensor thermal stability
- Heat pipe geometry and fan/ducting choices had a measurable effect on usable cooling capacity
- The optimized architecture delivered stronger thermal margin in a compact ruggedized package

ATS provided a practical, data-driven optimization strategy that improved thermal resistance and increased stability at critical locations without increasing overall system size.

Take control of your thermal performance with expert analysis and design services, contact ATS to speak with our engineers and start optimizing your system today.