USE CASE

CooliBlade **ULTIMA**

Efficient Cooling for High-Performance Power Electronics

Advanced Thermal Management
for
Power Converter Systems

Background

Modern power conversion systems have evolved dramatically to meet the increasing demands for efficiency, power density and reliability across industries, such as automotive and renewable energy sectors. The power electronics landscape encompasses both established technologies and emerging solutions, each with distinct advantages and thermal management requirements.

At the core of many existing power conversion systems are Insulated Gate Bipolar Transistors (IGBTs). These proven semiconductor devices continue to dominate medium to high-power applications (typically 1kW to several MW) due to their robust performance, established supply chains and cost-effectiveness. IGBT-based converters remain the backbone of industrial motor drives, grid-connected inverters and many traction applications, delivering reliable performance at switching frequencies typically ranging from 5-20 kHz.

Alongside these established solutions, wide-bandgap (WBG) semiconductor devices like Silicon Carbide (SiC) and Gallium Nitride (GaN) are gaining traction in specific applications. These technologies offer higher breakdown voltages, faster switching speeds and improved thermal conductivity, enabling operation at higher frequencies and power densities in applications where these characteristics justify their higher cost.

These advancements have enabled power converters to achieve significantly higher power densities exceeding 50W/cm³ in some applications, while maintaining or improving efficiency. However, this progress has created a critical engineering challenge as converters become more compact and powerful, thermal management becomes exponentially more complex.

The relationship between conversion efficiency, power density and thermal management now represents a fundamental design constraint across all power semiconductor technologies. Even with improvements in device efficiency, the concentration of power in smaller volumes creates significant thermal challenges. Effective heat dissipation has become essential not only for maintaining performance but also for ensuring long-term reliability and preventing premature component failure.

These thermal considerations influence every aspect of modern power converter design from semiconductor selection and circuit layout to mechanical packaging and cooling system integration. The challenge is particularly acute in space-constrained applications like electric vehicle powertrains, renewable energy inverters and industrial motor drives, where traditional cooling approaches often prove inadequate regardless of the semiconductor technology employed.

This technological diversity has transformed power converter design in several ways

- Varied switching frequencies (from 5-20 kHz for IGBTs, 50-500 kHz for SiC and up to several MHz for GaN) create different thermal profiles that require tailored cooling solutions
- Increasing power density across all technologies allows for more compact designs but creates challenging thermal hotspots that must be effectively managed
- Improved efficiency reduces overall heat generation but often concentrates remaining losses in smaller areas, requiring more sophisticated thermal solutions

The Challenge in PCS

Modern power conversion systems face increasingly complex thermal management challenges as they evolve to meet demands for higher efficiency, greater power density and enhanced reliability. These challenges stem from fundamental shifts in semiconductor technology, application requirements and design constraints that collectively create a complex thermal landscape requiring innovative cooling solutions.

Cooling as critical design factor

The drive toward compact, lightweight power conversion systems has significantly increased power density across all semiconductor technologies. Modern power converters generate substantial thermal loads concentrated in small areas, creating challenging hotspots that conventional cooling methods struggle to address effectively.

Research shows clear differences in achievable power densities based on cooling technology:

- Traditional air-cooled systems using basic aluminum heatsinks provide limited thermal performance, restricting power density
- Advanced air-cooled systems like CooliBlade NEOcore solutions deliver significantly higher power density, approaching some liquid-cooled systems while maintaining simplicity and reliability advantages
- Liquid-cooled systems achieve the highest absolute power densities but introduce additional complexity, maintenance requirements and reliability considerations

CooliBlade NEOcore solutions bridge the gap between traditional air cooling and liquid cooling by enabling higher power densities at a more reliable and lower cost level.

Power Density Evolution

The thermal management landscape in power electronics has evolved alongside semiconductor technology:

- IGBT-based systems typically operate at moderate switching frequencies (5-20 kHz) but handle high power levels, creating substantial heat loads that must be effectively dissipated. These systems often feature multiple power modules in parallel configurations, creating distributed thermal challenges across larger assemblies.
- SiC and GaN devices operate at significantly higher switching frequencies, reducing switching losses but concentrating thermal generation in extremely small areas. The higher thermal conductivity of SiC partially offsets this challenge, but the extreme power density still demands more sophisticated cooling solutions.

This technological diversity requires thermal management solutions that can adapt to different heat profiles while maintaining optimal operating temperatures across all components.

Environmental Considerations

Power conversion systems operate in diverse and challenging environments:

- Industrial applications expose converters to contaminated air, vibration and high ambient conditions often exceeding 50°C in factory environments
- Outdoor installations subject power electronics to extreme weather conditions and direct solar radiation exposure that significantly increases thermal loads
- Renewable energy installations operate in remote locations with more limited maintenance resources

These environmental factors compound the thermal challenges of power conversion, requiring cooling solutions that remain effective under adverse conditions. Traditional forced-air cooling systems often prove inadequate due to higher maintenance requirements and vulnerability to contamination.

The thermal management landscape is further complicated by evolving regulatory requirements. Many refrigerants with high Global Warming Potential used in two-phase cooling systems face increasing restrictions under EU F-Gas Regulation and US EPA regulations, creating additional incentives for advanced air-cooling solutions that deliver high thermal performance without relying on environmentally problematic cooling fluids.

Design Constraints

Power conversion systems must operate within strict physical and operational limitations that directly impact thermal management approaches:

- Form factor limitations imposed by standardized enclosures or integration requirements restrict the available space for cooling solutions
- Weight restrictions affect overall system efficiency and installation flexibility, particularly in transportation and portable applications
- Acoustic performance requirements in noise-sensitive environments limit fan speeds and airflow rates in forced-air cooling systems
- Maintenance accessibility must be balanced against protection from environmental factors, often creating competing design priorities
- Cost considerations must be evaluated against performance and reliability, with cooling system design significantly impacting overall system cost

These constraints often conflict with optimal thermal management approaches, forcing engineers to make difficult trade-offs between competing requirements. Conventional cooling technologies frequently fail to resolve these conflicts, creating a need for innovative solutions that can balance thermal performance with practical design considerations while meeting increasingly stringent reliability and efficiency targets.

CooliBlade® NEOcore™ Thermal Management Solutions for Renewable Energy PCSs

Power converter applications demand thermal management solutions that balance high performance, reliability and practical implementation. As power densities continue to increase while form factors shrink, traditional cooling approaches face mounting limitations that impact system design flexibility and operational efficiency.

Advanced Thermal Architecture

CooliBlade NEOcore technology features a completely maintenance-free thermosiphon cooling system integrated into a pure aluminum structure. This advanced architecture eliminates the need for auxiliary cooling systems while providing superior thermal performance in confined spaces.

The NEOcore design leverages the natural physics of phase change heat transfer, efficiently moving heat from concentrated semiconductor hotspots to extended surface areas for dissipation. This approach is particularly effective for managing the thermal challenges of both IGBT and wide-bandgap semiconductor devices, where heat flux densities can exceed 100 W/cm² at junction points.

Performance Excellence

The CooliBlade NEOcore system is specifically engineered to handle the high thermal loads generated by modern power semiconductors, providing effective cooling for both IGBT based systems and advanced wide-bandgap devices.

The efficient thermal interface between power modules and control electronics ensures effective thermal transfer, critical for maintaining optimal operating temperatures in high-density converter implementations. This capability enables power electronics designers to fully utilize the performance potential of their semiconductor devices without thermal limitations.

The thermosiphon-based cooling system demonstrates particular effectiveness in managing multiple hot spots simultaneously, a crucial requirement for modern power converters. The compact form factor enables high power density designs while maintaining optimal thermal conditions across all critical components.

System Reliability

Installing liquid cooling to a power conversion system can get complicated, requiring careful attention to liquid circuit requirements, cooling distribution and balancing capacity. These systems also introduce additional failure modes that pose particular challenges for mission-critical applications.

The CooliBlade NEOcore system addresses these issues by providing a simpler, passive integrated structure that avoids traditional liquid cooling complexity. As a passive thermosiphon solution, it eliminates the infrastructure requirements that create reliability concerns in conventional systems. The sealed design prevents leak risks that create mental barriers to liquid cooling adoption due to concerns about liquid and electricity interaction, while maintaining liquid-based thermal performance without maintenance requirements.

Installation Benefits

The CooliBlade NEOcore system eliminates traditional liquid cooling complexity while providing superior thermal performance compared to air cooling. The system requires no pumps, external reservoirs or complex liquid circuits, significantly reducing potential failure points.

The system's compact and light-weight form-factor enables high power density designs while accommodating space constraints typical in modern power converter enclosures. The thermosiphon-based cooling adapts to various configurations, supporting both horizontal and vertical mounting orientations for different applications.

This passive approach is particularly advantageous for power converters in remote locations requiring high reliability. The efficient thermal management enables designers to fully utilize modern semiconductor performance, translating directly to enhanced reliability.

CooliBlade: Prepared to solve your cooling challenges

CooliBlade specializes in advanced thermal management solutions, delivering innovative cooling technologies for demanding applications such as telecommunications and other high-performance sectors. Our expertise in passive cooling systems enables us to provide reliable, energy-efficient solutions that address complex thermal challenges in modern infrastructure deployments.

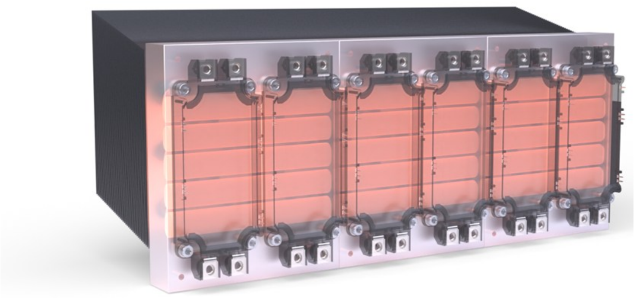
Value Proposition

- Superior thermal performance in confined spaces
- Zero maintenance requirements
- Silent operation
- No auxiliary cooling systems needed
- Lightweight yet robust structure
- Simple installation process
- Reduced total cost of ownership
- Extended lifespan of electronics
- Suitability for harsh outdoor environments
- Reliable long-term performance

CooliBlade®

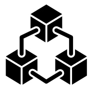
PRODUCT DATA

CooliBlade ULTIMA - Next Generation of Cooling in Power Converter Systems

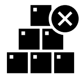


High performance

Cost-efficient



Easy-to-Integrate



Modular

CooliBlade® ULTIMA is built on patented **NEOcore™** technology, offering a leap forward in **power electronics cooling** performance for high-demand applications. NEOcore™ uses a phase-change thermosiphon process to transfer heat fast through an integrated thermal channel in the structure, delivering exceptional cooling capability without the complexity or maintenance of liquid systems.

In **power electronic converter** designs, the NEOcore™ thermal channels are formed between the baseplate and the condenser pipes, achieving internal thermal conductivity up to **1,000 times greater than aluminum**. By reducing the number of thermal interfaces, the integrated NEOcore™ structure provides outstanding heat transfer efficiency.

CooliBlade® ULTIMA provides design flexibility for both dimensional **optimization** and performance **scaling**, enabling superior results in the most demanding high voltage high current applications.

ULTIMA solution offers

- Superior thermal performance for IGBT and SiC cooling
- Reduced total cost of ownership through increased efficiency, lightweight structure and minimal maintenance
- Extended equipment lifespan thanks to stable operating temperatures and reduced thermal stress
- Lightweight structures following the trend of smaller and smaller applications
- Passive operation requireing no pumps or external power
- Maintenance freedom, ideal for remote locations
- Easy installation with minimal design modifications
- Small footprint (baseplate) for compact power electronics design in space-constrained environments
- Operational reliability
- Optimized airflow and low backpressure for efficient system integration
- Customer-specific adaptations to meet unique cooling requirements

By integrating CooliBlade® ULTIMA into power electronic converter systems, manufacturers can address the dual challenge of increasing **power density** and **ensuring long-term operational reliability** — particularly important in renewable energy cooling applications where maintenance access is limited and uptime is critical.

ULTIMA performance and possible lay-outs

ULTIMA platform – high performance cooling

The ULTIMA heat sink portfolio provides solutions for the most common IGBT and SiC module packages. The ULTIMA product range offers dedicated products for both horizontal and vertical installations. If the standard product offering does not directly fit to your needs, the ULTIMA product platform can be adapted to customer specific product designs and requirements, targeting the optimal cooling performance and desired form factor.

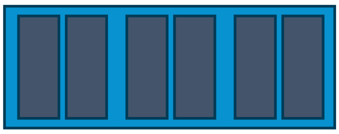
Customizable for demanding applications

ULTIMA products combines high cooling performance and a modular structure. CooliBlade can assist you by simulating the thermal performance of your own power electronic set-up. By accurate and fast simulation cycles, you save development time and resources by achieving fully optimized hardware architecture faster.

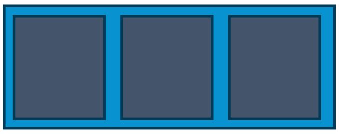
Design lay-outs

ULTIMA product platform offers flexibility to design several topologies for power electronics. Below you can find few examples. Together we can find the best and most powerful easy-to-scale air-cooling solution for your needs.

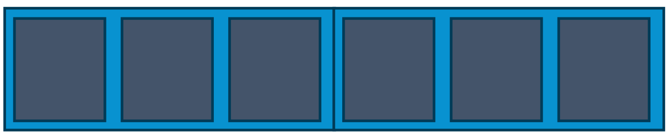
a) Six M1 modules



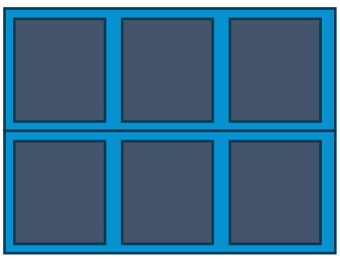
b) Three M2 modules



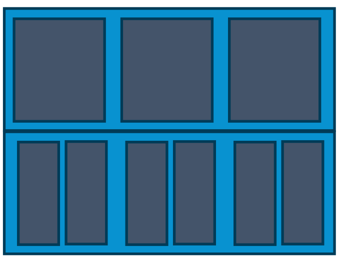
c) Six M2 modules



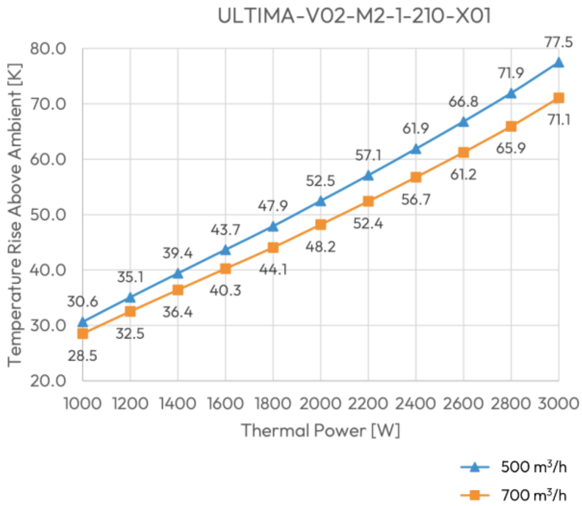
Six M2 modules



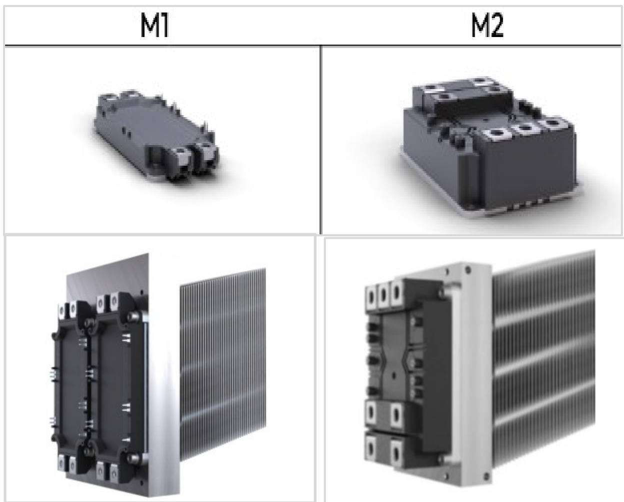
Three M1 and three M2 modules



Example of ULTIMA performance



*) Download the data sheet for further information
cooliblade.com/ultima-product-platform



Example performance (Z = 226 mm.)

Model	Air [m3/h]	Power	Delta T
a)	1050	9 kW	56.4 K
b)	2100	9 kW	71.1K
c)	4200	18 kW	71.1 K

CooliBlade®

REFERENCE CASE

Mega Watt Scale SiC Power Stack Cooling

Customer Challenge

A customer operating in the high-performance **power electronics design** sector previously relied on a massive 39 kg stacked-fin aluminum heatsink for cooling. While adequate for earlier power levels, this approach became insufficient when the customer sought to develop a next-generation higher power product for a power converter application. The power density of SiC modules set new challenges for the thermal management as well. The challenge was to improve thermal performance in limited space and find affordable price point for the use case.

Key issues identified

- The existing aluminum heatsink could not manage the increased thermal load effectively
- The customer needed a plug & play thermal solution requiring minimal amount of modification
- Transitioning to liquid cooling would require a complete system redesign, adding complexity and lowering reliability
- Maintenance requirements for active liquid cooling systems were a concern, especially in remote installations

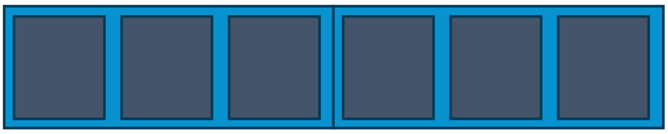
Our solution

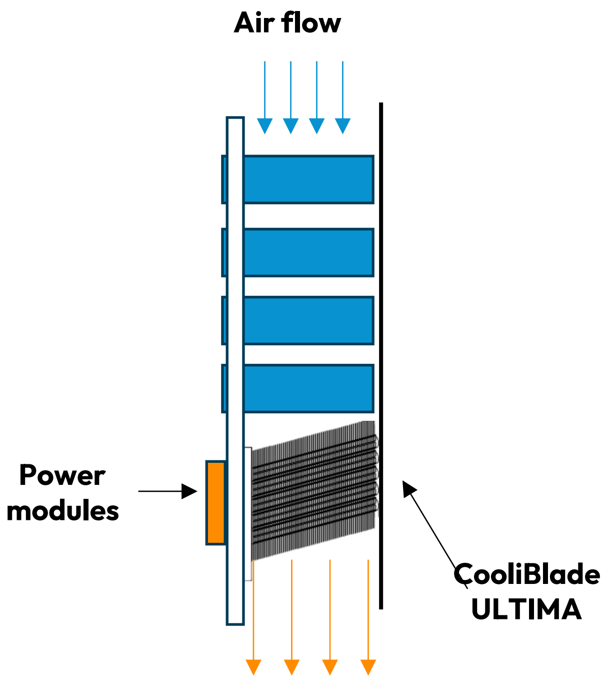
By implementing CooliBlade® ULTIMA heatsink (six modules), the customer achieved their higher target performance while maintaining the simplicity of their hardware architecture. The easy integration combined with significant thermal performance improvements, makes ULTIMA a highly attractive solution for power electronics industries where performance, reliability, weight savings and low maintenance costs are essential such as in renewable energy applications.

Customer value

- Superior cooling performance: 25 °C lower component temperature under comparable operating conditions
- 50% weight reduction (39 kg → 18.5 kg), reducing structural loads in HW architecture and simplifying installation in constrained spaces
- Lower noise levels due to passive heatsink operation
- Lower pressure drop for improved airflow efficiency
- Successful deployment of high-power variant without system redesign
- Improved system reliability in demanding conditions
- Compatibility with compact power electronics design layouts

Component lay-out of six M2 modules





Next Generation Air-Cooling for Demanding Applications

CooliBlade® specializes in advanced **cooling** solutions for **power electronics**, delivering innovative passive technologies for demanding applications for example in telecommunications, industrial drives, and **renewable energy** applications. Our expertise in **thermosiphon-based** cooling enables us to provide reliable, energy-efficient designs that solve complex thermal challenges in **power conversion systems** used across high-performance sectors.

Push the Limits of Your Power Electronics

Whether you are designing the next generation of **power conversion systems**, optimizing **IGBT** and **SiC** module **cooling** or building a more reliable **renewable energy system**, CooliBlade can help you to achieve higher power density, lower operating temperatures and longer equipment lifetime without the complexity of liquid cooling.

Our proven **NEOcore™** technology and **ULTIMA** solutions have delivered superior results in real-world customer cases, from industrial drives to MW-class power conversion systems.

Contact our engineering team today to discuss your thermal management challenges, request a performance assessment or explore a plug-in cooling upgrade for your existing systems. Let's turn the cooling bottlenecks into a competitive advantage.

Contact us here: https://cooliblade.com/contact-us

Read more about CooliBlade and NEOcore technology: https://cooliblade.com/