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Cooligy™ Active Micro-Structure™ Cooling Offers Key to Advanced Processor Performance and Quieter Systems

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Cooligy™ Active Micro-Structure™ Cooling Offers Key to Advanced Processor Performance and Quieter Systems

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The thermal characteristics of new generation, high-power-density CPUs in today's high-end computing applications are rapidly outpacing the cooling capabilities of the best commercially available strategies. The problem lies in three compounding trends: higher total chip power, higher local heat flux in chip hotspots, and smaller system enclosures. Attacking the thermal needs of high power densities with conventional cooling systems poses a number of increasingly difficult challenges, including:

- Eliminating heat with high average heat density, above 100 W/cm^2;
- Maintaining consistent die temperature in the presence of local hot spot zones of 1-2 mm^2, with power densities of 500 W/cm^2 or above;
- Increased system noise due to high-volume air flow;
- Reduced system reliability due to increased numbers of high-speed fans.

Common solutions to the above challenges include multiple heat pipes, vapor chambers attached to fan heat sinks and optimized fan heat sinks with new designs. Of these solutions, none scales for higher heat flux in excess of 100W/cm^2, revealing an urgent need for a viable, alternative cooling solution.

Recent advances in pumped-liquid cooling system technology represent a promising alternative for cooling high power density processors. However, a successful implementation of this approach requires a high degree of innovation and careful attention to design details to optimally cool high heat flux chips within a targeted system volume. To address this problem, a revolutionary new Active Micro-Structure Cooling System has been developed by Emerson Network Power specifically for this application. Key system elements include (1) a micro-structure heat exchanger capable of high heat flux removal, (2) a reliable mechanical pump for delivering fluid with the required flow rate and pressure, and (3) an efficient liquid-air radiator heat exchanger.

Active Micro-Structure Cooling System Elements

The performance of any liquid-cooled system depends on several factors, including: a) physical dimensions of the heat-exchanger channels, b) liquid flow rate through the channels, c) radiator fin surface area and d) airflow available for heat rejection. Optimization of these system elements can result in very high thermal performance from low air-flow volume, which enables system fans to run at lower speeds and more quietly. Where fan noise is not a concern, higher airflow results in even better performance.

Figure 1 shows the schematic of a closed-loop Active Micro-Structure system for a typical single-CPU cooling application. In operation, cold liquid enters the micro-structure heat collector at a specific volumetric flow rate, driven by the mechanical pump. The liquid absorbs heat from the CPU, exits the heat exchanger, flows into a fan-cooled radiator, then repeats the process. As the liquid flows through the system, the pressure drop for the liquid flow through the system is managed by an appropriate fluid-delivery mechanism built into the design of the individual components. Although the system shown below represents a typical single-CPU application, the concept

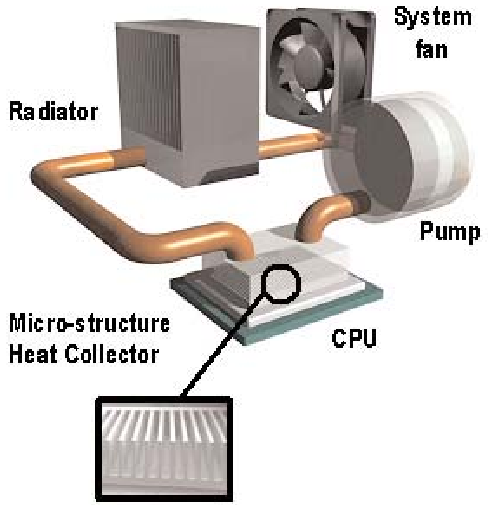

Figure 1: Schematic of the Cooligy closed-loop Active Micro-Structure Cooling System from Emerson Network Power

is easily adapted to other cooling uses, including multiple CPU configurations, racks, servers, graphics chips, high-output LEDs, and other high-heat-generating display devices. Additional applications include power modules like voltage regulators, isolated gate bipolar transistors (IGBTs), power semiconductors and field effect transistors (FETs), to name a few.

Thermal Performance Characteristics

Key performance factors to consider in specifying a liquid cooling system include:

- *Micro-structure heat exchanger design*
  The micro-structure heat exchanger should be optimally designed to accommodate the high heat flux of a high-performance microprocessor. Although cooling systems using micro-structure heat exchangers have been the object of considerable research over the past two decades, productizing them has been difficult due to several key technological advancements that had been lacking until now, including the ability to drive liquid through the microstructure heat exchanger itself.

Figure 2 shows the relationship of heat transfer efficiency and pressure drop on channel width. High performance is achievable with fine channel dimensions; however, the pressure drop is very high. To reduce pressure drop, patented fluid-delivery mechanisms have been developed that provide very low thermal resistance and high flow rates. The robust manufacturing techniques required to mass produce micro-structure heat exchangers with tightly controlled thermal performance characteristics posed a significant technical barrier—until recently. These technical and process development barriers have since been overcome with the successful volume production of the micro-structure heat exchangers described in this article.

- *Unique attachment mechanism*
  Processor-cooling applications employing conventional heat-sinks typically employ standard retention mechanisms like clips or screws to secure the heat sink to the processor package. The problem with retaining a massive heat sink in this way is that any variation in the assembly process will cause variations in the thickness of the thermal interface material (TIM), which in turn will notably affect thermal performance. Novel attachments are therefore needed to achieve consistent thermal interface material thickness. The liquid cooling system described in this article employs a patented heat exchanger mounting mechanism that enables consistent thermal performance with a high degree of manufacturability.

- *High-efficiency radiator design*
  Radiator performance is impacted by multiple variables, including liquid flow rate, fin surface area and tube attributes. The radiator design of the Active Micro-Structure Cooling System described in this article produced the best performance for a given airflow, as validated by laboratory experiments (see following application example). The test lab set-up incorporated a thermal test vehicle consisting of a controlled heat input using a copper block and controlled airflow using a wind tunnel. A variety of numerical simulation techniques and analytical models were used to validate the various design parameters that defined the optimized system.

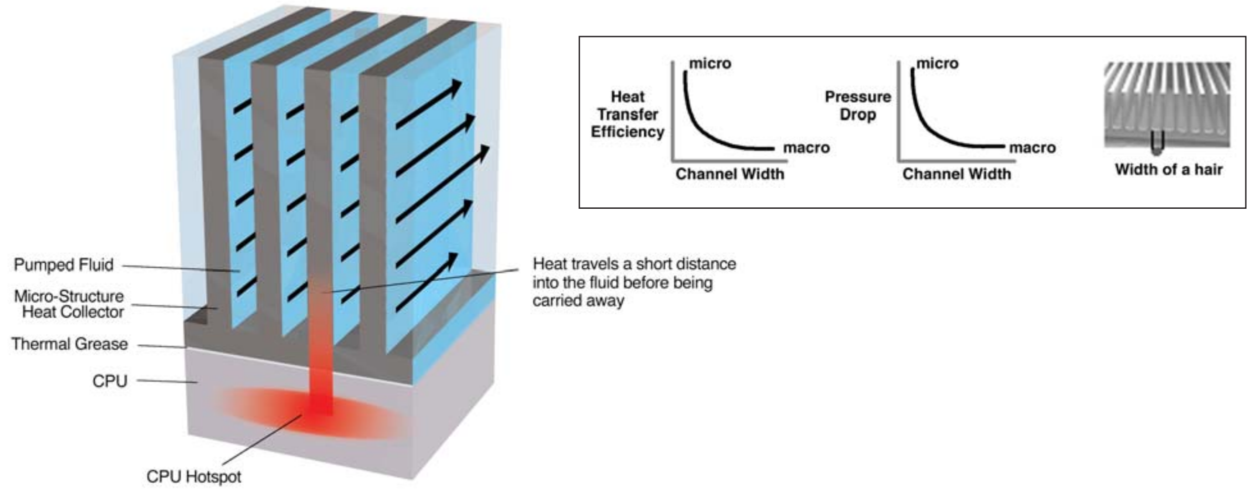

Figure 2: Dependence of thermal performance and pressure drop on channel width.

- *Optimized working fluid*
  The type of working fluid used in a liquid cooling system depends on the application. Typical liquid cooling systems on the market use an antifreeze type mixture of water and a significant percentage of propylene glycol. The water-based fluid used in this application provides much higher thermal conductivity and lower viscosity compared to water-glycol mixtures. Pure water has almost half the viscosity of a 30% propylene glycol / water mixture as well as higher thermal conductivity and heat capacity. The combined higher flow rate (due to lower viscosity), higher heat capacity and thermal conductivity of water resulted in markedly better thermal performance (see Table 1).

- *Mechanical pump*
  Liquid cooling system manufacturers like Emerson Network Power have demonstrated that high performance and reliability are possible using an Active Micro-Structure Cooling System with an electrokinetic pump. However, greater flow rates are now possible using compact mechanical pumps. In the past few years, significant design resources have been invested in making the liquid cooling system discussed in this article even more robust and reliable. A very high degree of reliability has now been attained through careful selection of materials, extra attention to system design details and implementing tight quality control techniques on the manufacturing floor.

- *Low-noise acoustics*
  The Active Micro-Structure Cooling System's performance advantage generates less cooling system noise, and allows system fans to run much slower while producing equivalent heat rejection at given performance levels. Also, in multiprocessor systems with high heat loads, the large number of fans typically required by conventional cooling solutions can be reduced considerably by using an Active Micro-Structure Cooling System of the type described in this article. An additional benefit of reducing the number of fans and using lower fan speeds is a significant gain in system reliability.

Reliability Design Considerations

The Active Micro-Structure Cooling System described in this article has passed stringent reliability qualification tests typically required by OEMs. Several recent technological improvements have made the system more robust and reliable than ever before. In particular, these advances include the areas of:

- *Particle control*
  Particle control plays a crucial role in ensuring the reliable long-term performance of the liquid cooling system. The material/fluid combination has been optimized by careful analysis, testing and characterization. Material selection, along with refined assembly processes during manufacturing, significantly influences the reliability of the finished system.

- *Water loss control*
  Reliable, maintenance-free liquid cooling systems like Emerson Network Power's Cooligy Active Micro-Structure Cooling System provide a closed-loop system configuration that completely eliminates water loss by means of super robust tubing joints that prevent leaks during shipping, storage and use. To prevent fluid loss, several design solutions have been adopted in the Active Micro-Channel Cooling System. Again, the overall fabrication process, including assembly, has been fine-tuned to ensure long-term reliability of the completely sealed joints.

- *Freeze-protection technology*
  The cooling loop of the system employs proprietary freeze-management techniques that allow the system's water-based working fluid to expand without causing system damage or impacting thermal performance. This is especially important should freezing conditions be encountered during shipping or storage.

- *Material science control for long life*
  The materials used to manufacture the components of the Active Micro-Structure Cooling System are critically important to achieving long system service life without corrosion. The major system components—micro-structure heat exchanger, radiator construction materials, tubing and working fluid—are designed to eliminate corrosion and maximize long-term reliability. Extensive performance and reliability characterizations have been performed in the selection of all materials used in the fabrication of the cooling system.

- *Cost*
  One of the main hurdles facing adoption of the liquid cooling system is its higher cost versus solutions based on conventional air-cooling technologies. One solution now in practice has been to collaborate with strategic manufacturing partners in Asia, a move that ensures that the Active Micro-Structure Cooling System described in this article will continue to present a cost-effective answer for any OEM seeking a reliable, high-performance thermal solution.

Application Example: Cooligy Active Micro-Structure Cooling System

A processor cooling application involving in a high-performance workstation presented the challenge of removing heat from a bare die with high heat flux, keeping the junction temperature below 85 C. The average heat flux was nearly 150 W/cm^2, for a total power of nearly 220 W. The available system airflow was in the range of 30-35 cfm. To solve this problem, detailed simulations of the CPU power map were performed to optimize the micro-structure heat exchanger design, as well as the radiator design, to deliver the highest performance liquid cooling system. This was followed by extensive prototype testing and validation.

A thermal test vehicle (TTV) was built as a validation platform that included a fully instrumented copper heater block with a heat transfer area corresponding to the die size. The copper block was heated by cartridge heaters, and the heat flux was monitored using thermocouple measurements taken at fixed distances from the heat transfer surface. Thermal grease was applied at the heat transfer surface, and the heat exchanger was screw-mounted with a specified force. The test system was then placed in a wind tunnel, with measured airflow being driven by a 92 mm fan. The surface temperature of the copper block is calculated to estimate the die case temperature.

The thermal performance of the cooling system was measured to have a sink-to-ambient resistance (Rs-a) of less than 0.1 C/W from an air flow of around 30-35 cfm (the air pressure drop is roughly 0.1" water). The general operating specifications of the liquid cooling system are detailed in Table 1.

Summary

This article describes the basic elements and operational considerations of a closed-loop active micro-structure liquid cooling system that is currently shipping in volume for use in high heat flux processor cooling applications in high-end computers and workstations. The cooling system features a micro-structure heat exchanger, a reliable mechanical pump, and an efficient liquid-air heat exchanger (radiator). For a processor die size with an average power density of 250 W/cm^2, this cooling system has demonstrated a sink-to-ambient resistance of 0.1 deg C/W. In terms of heat mitigation, this represents the highest CPU cooling performance available in the industry today. The various design improvements enhancing system reliability have, in turn, enabled the speedy qualification of the Active Micro-Structure Cooling System for full commercial use as the most reliable, top performing liquid cooling system of its type currently on the market.

Keywords

Thermal Management, Micro-Structure Cooling, Micro-Channel Cooling, Liquid Cooling, Pumped Liquid Cooling, Active Cooling.

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Thermal Performance	
RS-a, °C/W:	0.1
Airflow:	32-35 cfm
Average Heat Flux:	150 W/cm^2
Power:	235 W
Peak Heat Flux:	250 W/cm^2
Ambient Temperature:	25 C
T_j Max:	< 85 C

Mechanical	
Radiator Volume:	90 x 140 x 40 mm
MCP Size:	35 x 25 x 20 mm
Pump Size:	60 x 60 x 80 mm
Storage:	-40 to 50 C
Acoustics:	< 45dB at 1 m
Reliability:	5 years

Table 1: Operational specifications of Emerson Network Power's Cooligy Active Micro-Structure Cooling System for a workstation processor cooling application.

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