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Cooligy™ Active Micro-Structure™ Liquid Cooling System for Gamer PC Applications

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Cooligy™ Active Micro-Structure™ Liquid Cooling System for Gamer PC Applications

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Recent technical advances in graphics processing units have accelerated the proliferation of GPUs in high-end gamer PC applications. Characterized by very high heat loads, this application is causing increasing numbers of OEMs to investigate alternative methods, such as liquid cooling, to achieve the level of thermal management needed for dramatically higher system power levels. Typical gamer PC platforms employ a dual-card configuration to support the operational requirements of extreme graphics computing. In this application, the power required by the GPU often exceeds that of the CPU itself, a trend that processor roadmaps predict will continue for the foreseeable future.

Traditional GPU cooling strategies, such as those combining a heat pipe, heat sink and fan, provide diminishing thermal performance at 120W per chip. Alternatively, the aggressive cooling requirements of gamer PCs and other high heat flux processor applications are proving to be fertile ground for "non-traditional" approaches that offer at least 25% better thermal performance, as typified by advanced liquid-cooling systems (LCS) like Emerson Network Power's Cooligy™ Active Micro-Structure™ Cooling System.

Another nettlesome technical issue in gamer PC applications is acoustical, having to do with system noise. Unlike conventional cooling strategies that require many fans to direct air to appropriate chassis hot spots, LCS provide the advantage of being able to physically pump the heat away from desired locations—resulting in significantly fewer system fans and extremely quiet operation. Advanced LCS are capable of a very high level of cooling performance as a result of the system fan being used more effectively for cooling the CPU.

This paper introduces a micro-structure liquid cooling system that was developed to cool one CPU and two GPU chips in a standard ATX chassis configuration featuring a top-mounted radiator installation. Simulation results as well as experimental work indicate that this liquid-cooling solution represents a viable, available-now alternative for meeting the high power needs of advanced processors used in gamer PC applications.

Features of the Micro-Structure Cooling System

Figure 1 shows the schematic of a closed-loop Active Micro-Structure liquid cooling system for a typical device cooling application. In operation, cold liquid driven by a mechanical pump enters the micro-structure heat exchanger at a specific volumetric flow rate. The liquid absorbs the heat from the processor before exiting the heat exchanger. The warm liquid then enters a fan-cooled radiator, which cools the liquid in preparation for repeating the cycle. The pressure drop as the liquid flows through the system is managed by an appropriate fluid-delivery mechanism built into the design of the individual components.

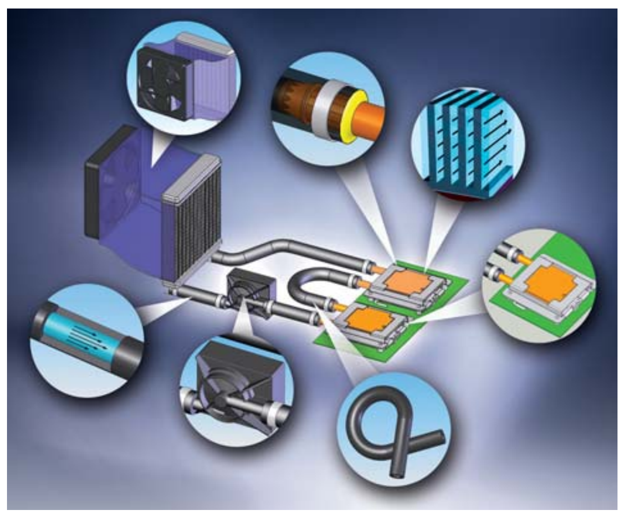

Figure 1: Schematic of micro-structure liquid cooling system loop

Superior Thermal Performance

Several factors contribute to the superior thermal performance of the micro-structure liquid cooling system including:

- *Micro-structure heat exchanger design*
  Although cooling systems using micro-structure heat exchangers have been a topic of considerable research in the past two decades, commercialization was not widespread, due to several technical issues that had yet to be resolved.
  The first technical hurdle involved thermal performance as a function of flow rate and the ability to drive flow through the micro-structure heat

exchanger. **Figure 2** shows the nature of the dependence 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 were recently developed that now enable high flow rates, thus providing very low thermal resistance.

Manufacturing processes themselves proved to be another problem. The fabrication techniques used to produce micro-structure heat exchangers in volume quantities proved incapable of also yielding tightly controlled thermal performance. However, these technical and process development barriers have since been overcome with the production of the micro-structure heat exchanger described in this paper.

- *Unique attachment mechanism*
  The liquid-cooling system described herein utilizes a patented heat-exchanger mounting mechanism that enables consistent thermal performance in a typical manufacturing set up.

- *High-efficiency radiator design*
  The system radiator is optimized to deliver the best performance at a given airflow. Numerical simulation techniques and analytical models were used throughout the design process. Experimental validation was performed using a thermal test vehicle consisting of a controlled heat input using a copper block, and controlled airflow using wind tunnels were instrumental elements of the optimization process.

Liquid Cooling Reliability

The micro-structure liquid cooling system presented in this paper is designed to pass stringent reliability qualification tests typical for OEMs. Several technological advances have been made in the last few years to make the micro-structure liquid cooling systems robust and reliable. The reliability is enhanced by attention to various factors as outlined below:

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

- *Water loss control*
  The Active Micro-Structure Cooling System provides a closed-loop design that completely eliminates water loss by means of super robust tubing joints that prevent leaks during shipment, storage and use. Several other design innovations were also employed, in addition to fine-tuning the manufacturing and assembly processes, to ensure long-term reliability of the completely sealed joints.

- *Freeze protection technology*
  Because the system's working fluid is water-based, it must withstand the volumetric expansion that will occur if the unit freezes during

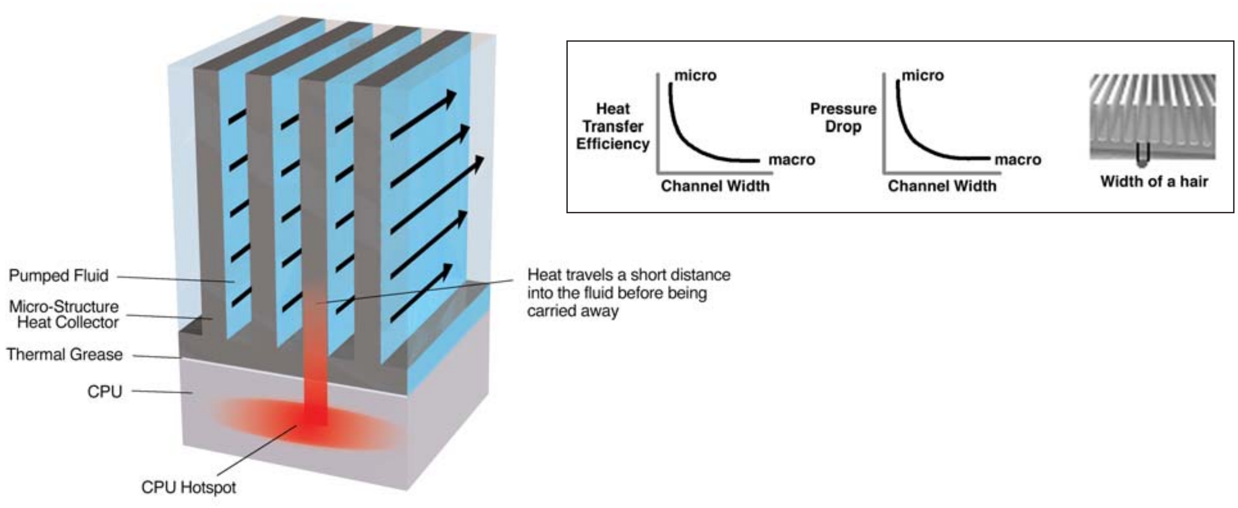

Figure 2: Dependence of thermal performance and pressure drop on channel width.

shipping or storage. To protect the system under these conditions, proprietary freeze-management features were designed into the cooling loop that allow the water to freeze without causing system damage or impacting thermal performance.

- *Material science control for long life*
  The materials used to construct the various Micro-Structure Cooling System components are critically important to ensure long life with minimum corrosion. All system components—micro-structure heat exchanger, radiator construction materials, tubing and working fluid—are designed to minimize corrosion and maximize long-term reliability. Extensive characterization was performed in the selection of the materials used to fabricate the cooling system.

Application Example: Active Micro-Structure Cooling System for a Gamer PC Platform

Figure 3 shows the schematic of the closed-loop liquid-cooling solution used in the gamer PC system prototype shown in **Figure 4**.

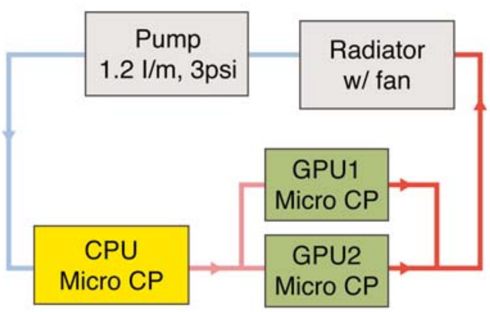

Figure 3: Schematic of a closed-loop micro-structure liquid cooling system for one CPU and two GPUs in a gamer PC application.

The cold water flows counter-clockwise into the CPU micro-coldplate at a specific volumetric flow rate driven by the mechanical pump, and exits the micro-structure heat exchanger after picking up the CPU heat. The warm water then enters the parallel network of GPU coldplates, absorbs heat from the two GPUs and flows into the radiator mounted atop the gamer PC chassis.

The radiator fins are cooled by a series of fans providing air flow at the ambient temperature. The cold water then continues through the loop back to the CPU micro-coldplate. The overall pressure drop of the liquid as it flows through the loop depends on the design of the micro-coldplates and the radiator. System components are carefully designed to operate within the pressure-drop capabilities of the pump for the required flow rate.

Figure 4: Location and installation of the active micro-structure liquid cooling system elements in an ATX gamer PC chassis running one CPU and dual GPU chips,

The LCS described in this paper and shown in **Figure 4** is designed for an operating flow rate of around 1200 ml/min, a rate sufficient to achieve overall total cooling of 450W. 150W cooling capability for each of three processors—one CPU and two GPUs—is achieved as the fluid passes through the radiator accompanied by a fan-generated air flow of approximately 60 cfm. The radiator itself is a standard aluminum fin-tube type with an extruded-tubing micro-port for liquid flow and folded fins for airflow.

Micro-structure heat exchanger performance was modeled in the laboratory using IcepakTM, a leading computational fluid dynamics (CFD) software for simulating and analyzing fluid flow, heat and other design characteristics. The test LCS provided a water inlet temperature of 55C and a flow rate of 1200 ml/min. The die sizes assumed for the CPU coldplate and graphics heat source simulations were 16 x 12mm and 20 x 20mm, respectively. To minimize the number of components, the same coldplate design was used for both the CPU and GPUs

The micro-coldplate and radiator utilized a geometry optimized to deliver the required thermal performance of dissipating 150W from the CPU and 300W from the two GPUs, while keeping CPU spreader temperature below 63C. Cooling system performance, as shown in **Table 1**, indicates an overall case-to-ambient resistance (Rc-a) of 0.16C/W for the CPU and 0.21C/W for the GPUs.

Figure 5 shows the fluid temperature map of the radiator with an air flow of 60 cfm. The simulation of the micro-coldplates and radiator were carried out separately. The mean fluid exit temperature from the GPU micro-coldplate was used as the boundary condition for the incoming fluid in the radiator. The design of the micro-structure in the coldplate and the fluid channels in the radiator are very critical to optimum system performance.

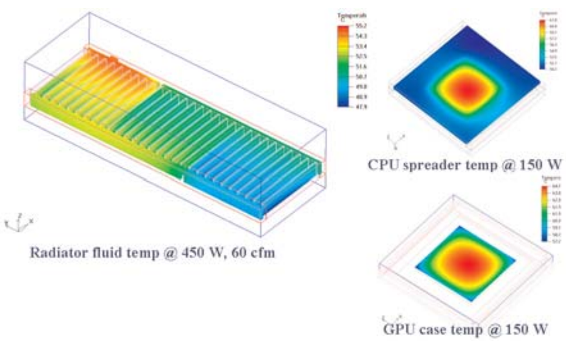

Figure 5: Temperature profile showing radiator fluid temperature at 60 cfm air flow (left), CPU spreader temperature at 150W (top right) and GPU case temperature at 150W (bottom right)

Benchmark Testing

The prototype liquid-cooling system was developed for a standard gamer PC configuration using one AMD CPU chip and two ATI GPU processors. Full performance testing was conducted using 3DMark®, a leading 3D game performance benchmarking tool that exercises the GPU and CPU at 100% and 90%, respectively. When monitored, the GPU indicated a case temperature of 37C at ambient room temperature. Compared to a normal air-cooling value of 70C, these results indicate that thermal performance may be significantly improved by means of micro-structure liquid-cooling technology.

Summary

This paper describes a closed-loop micro-structure cooling system for a single CPU and dual GPU-powered gamer PC platform. Simulation software results were discussed relative to the micro-coldplate and radiator used in the PC system. The LCS was shown to be capable of cooling up to 150W—each—for the CPU and two GPUs in parallel, for a total of 450W. Such outstanding thermal performance, augmented by extremely quiet fan operation, was obtained from a very low total air flow of only 60 cfm for all three system fans. The gamer PC demonstration prototype was constructed using a top-mounted radiator to cool the AMD CPU and two ATI graphics processors. Benchmark test results showed a GPU case temperature of only 37C at ambient room temperature—a significant thermal performance improvement over commercially available air-cooled solutions used in similarapplications.

Ambient Temperature:	35 C
CPU Power:	150 W
GPU Power:	150 W
Total Air Flow, LCS Radiator:	60 cfm
CPU TIM Resistance:	0.03 C/W
Total Rc-a CPU:	0.16 C/W
CPU Case Temperature:	59 C
CPU Case Temperature Spec:	63 C
GPU TIM Resistance:	0.03 C/W

Total Rc-a GPU:	0.21 C/W
GPU1 Case Temperature:	66.5 C
GPU2 Case Temperature:	66.5 C
GPU Case Temperature Spec:	90 C
Inlet Fluid Temp, CPU Radiator:	55 C
Exit Fluid Temp, CPU Radiator:	53 C
Inlet Fluid Temp, GPU Radiator:	53 C
Exit Fluid Temp, GPU Radiator:	49 C
Exit Air Temperature, Radiator:	<51 C

Table 1: Simulation results of micro-structure LCS performance in a gamer PC application

Keywords
Thermal Management, Micro-Structure Cooling, Micro-Channel Cooling, Liquid Cooling, LCS, Pumped Liquid Cooling, Active Cooling, Gamer PC Cooling.

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