

FUTURE COOLING

Closed Loop Liquid Cooling for High Power Electronics

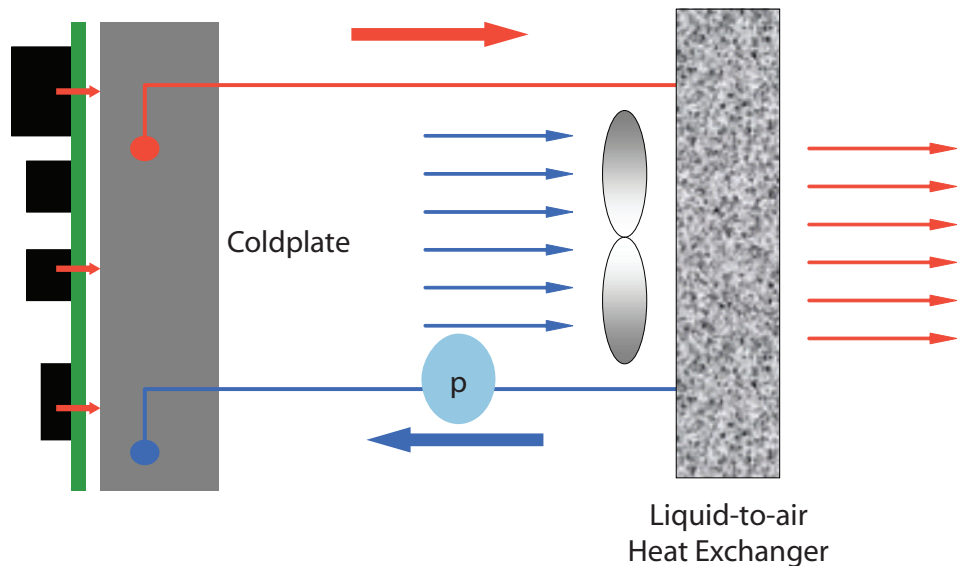


Figure 1. Schematic of a PCB Level CLLC and its Operating Components [1].

The successful operation of high power electronics requires cooling that is a departure from conventional air-cooled systems. Whether an IGBT, a CPU or an ASIC, its junction temperature must be maintained at the desired level for it to operate at the expected frequency. Therefore, the cooling system choice is a pivotal part of the system's design cycle, not only for thermal transport capabilities, but also from a system implementation stand point.

All issues associated with a cooling system's market acceptance, service and reliability are parameters that influence its design. Closed Loop Liquid Cooling (CLLC) is one system that is resurfacing in modern, high power electronics. The integral part of the CLLC is a coldplate that acts as a heat collector/spreader and plays a pivotal role in the operation of the cooling system. Figures 1 - 3, show levels of CLLC implementation: at the PCB, and external and internal to a high power device.

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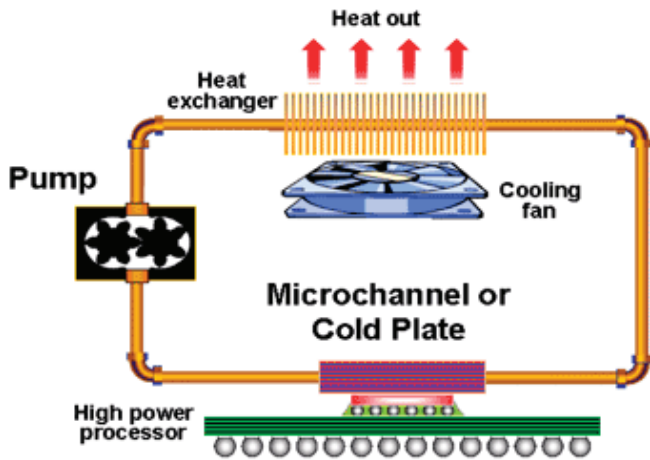


Figure 2. CLLC Implementation, External to Component [2].

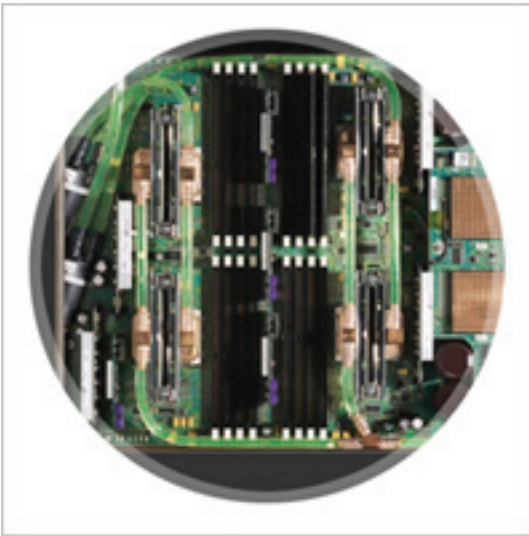


Figure 3. CLLC Implementation, Internal to Component [3].

CLLC has been used in modern electronics for several decades. As shown in Figure 4, part of a coldplate used in Apollo 11 is preserved and displayed by NASA.

Figure 4. Section of a Coldplate Used In Apollo 11, Courtesy Of NASA.



Typical CLLCs, schematically shown in Figure 1, are generally composed of a fluid (gas or liquid) loop, two heat exchangers, a pump and an air mover. CLLCs are used across the range of electronics, from consumer products to high power military electronic devices.

CLLCs have the following system components:

1. **Coldplate (liquid block)** – to absorb and transport heat from the source
2. **Pump** – to circulate the fluid within the CLLC
3. **Radiator (liquid to air) heat exchanger** – to transfer heat from the liquid to the air
4. **Liquid loop** – the plumbing connecting the heat source, coldplate and radiator
5. **Throttling or relief valve** – to regulate flow and relieve possible vapor, (system dependent, may not be used at all)
6. **Radiator fan** – to provide forced convection to remove heat in the liquid-to-air heat exchanger

Among these system components, the coldplate has received the broadest attention from the market place. The next section shows different coldplate designs developed by the community.

PCB Level

Because of the large surface involved, coldplate applications at the board level have been straight forward. Figure 5 shows some commonly encountered coldplates in which a liquid loop (copper pipe) is embedded in an aluminum conductor plate. This plate is then attached to a PCB or a large high power device.

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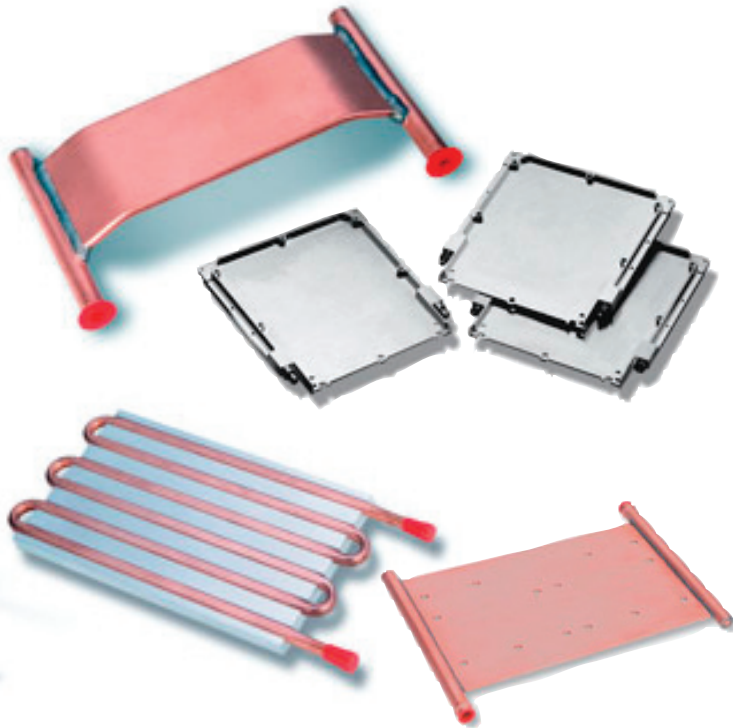


Figure 5. PCB and Large Component Level Coldplates [4].

Figure 6 shows some fin enhancements developed for large aspect ratio coldplates.

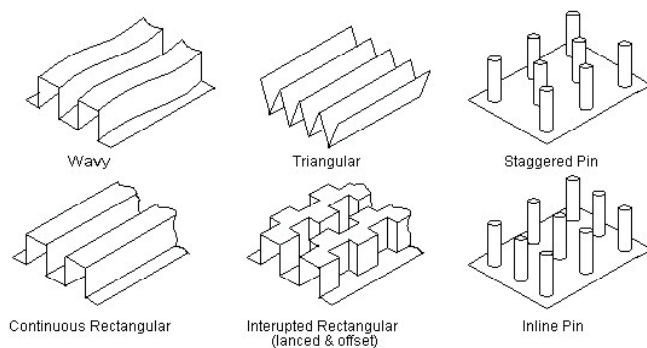


Figure 6. Fin Enhancements to Improve Heat Transfer Within Coldplates, [1].

Component Level

Design efforts for external coldplates to be used at the

component level have greatly exceeded those for PCB level coldplates. An Internet search reveals a diverse portfolio of these designs. Figure 7, shows examples of component-external coldplates with surface enhancements to increase the heat transfer coefficient.

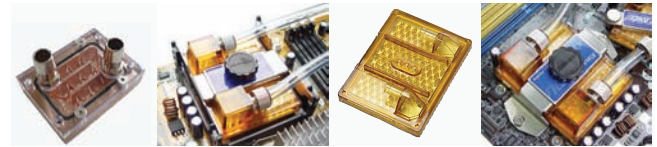


Figure 7. Different Coldplate Designs for External Attachment to High Power Devices, [1].

Figures 8a and 8b, show the use of fluid-jet(s) and normal-to-the-base flow delivery schemes to increase heat transfer within the coldplate attached to the exterior of the component.

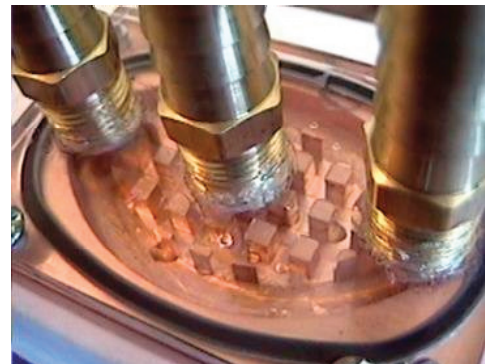


Figure 8a. Normal Flow Introduction Along with Surface Enhancement for Higher Cooling [1].



Figure 8b. Angular Introduction of Coolant with Central Return of the Heated Fluid [1].

Device Level

The placement of the coldplate at the device level is significantly more challenging than at the component and PCB levels. Efforts have focused on fabricating the coldplate from the silicon itself. This would allow the dispersion of heat on a larger surface and its direct removal from the die. Figure 9 shows the work by Wang, et. al., [2] for the following two configurations:

- Chip size = 2 x 6.5 cm, fabricated on a single crystal silicon.
- On the front side, the two Ts are the inlet and outlet manifolds.
- The effective cooling area is 4 cm².
- Each chip has 30-50 microchannels in parallel, as shown Figure 9.
- Each channel is 50-100 μm wide and 50 μm deep.

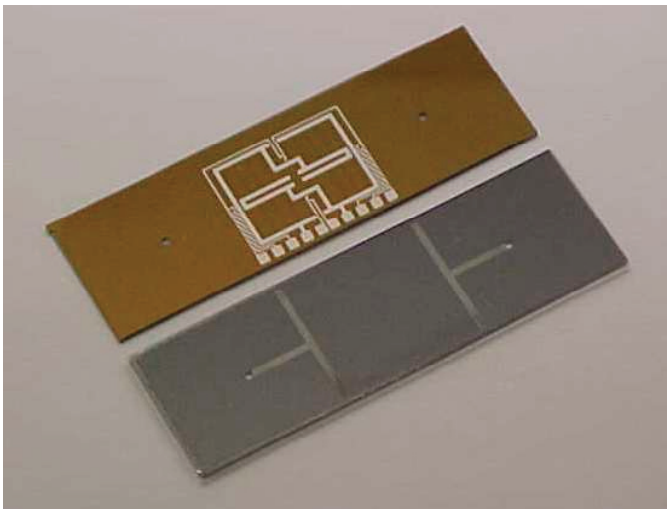


Figure 9. Microchannel Coldplate Made from the Silicon [1].

When the volumetric flow rate is $2.2 \times 10^{-7} \text{ m}^3/\text{s}$ and the pressure drop is 186 kPa, the thermal resistance for such a device is 1.4 °C/W. In a second design, jet impingement was used at the silicon level. Figure 10 shows the results of this jet impingement on the case when DI-water is used as the coolant, the microjet's diameter is 76 μm, and the flow rate is 2 mL/min.

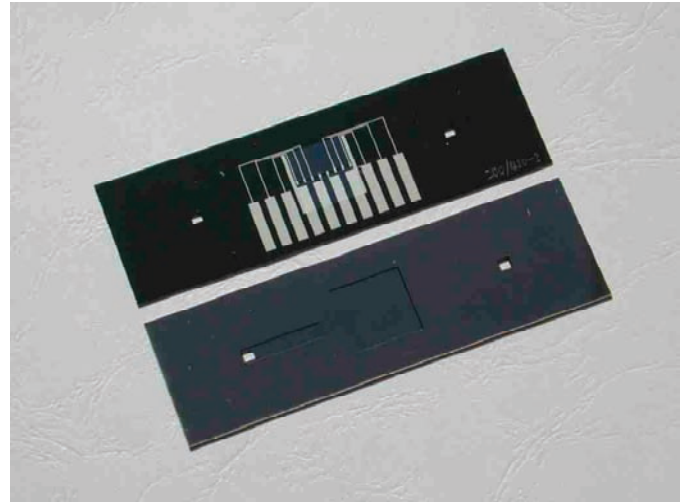


Figure 10. Microjet Impingement for a Die Level Coldplate [5].

It is worth noting that the temperature distribution is flat. It plateaus when the phase change occurs. This configuration resulted in a thermal resistance of 3.11 °C/W, as reported by the authors [2].

It is also important to note that in any CLLC system, the pressure drop in the system is a major point of contention. This pressure drop is exponentially dependent on the hydraulic diameter of the coldplate channels. The problem becomes acutely important as the coldplate reduces to a microchannel. The microchannel coldplate provides a large heat transfer coefficient. (For more information, refer to the definition of Nusselt number, $h = (k \cdot \text{Nu}) / D_{\text{hydraulic}}$.) But, for commercial applications, delivering the desired flow in such an array of small channels is a daunting task when the required pumping power and the impact of fouling are factored in.

When and Why a CLLC Should Be Used:

- After heat load and device temperature requirements are carefully established.
- Before lower technology options are considered and higher cost, high-capacity technologies are explored.
- If air cooling, including the system modifications to accommodate it, does not address the thermal design requirements.

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CLLC Design/Selection Procedures:

- Perform a thermal analysis to ensure that a CLLC is the only option.
- Review the system site and regulation requirements before considering a CLLC.
- Establish the design criterion by specifying the desired die, component case or PCB temperature.
- Specify the geometry, i.e. available space for the coldplate and the radiator in the CLLC loop.
- Specify the method for attaching the coldplate to the heat source; consider the thermal resistance of the interface and the spreading resistance.
- Identify the source of power and power consumption for coolant delivery, whether using liquid or compressed air.
- Identify the acoustic noise requirements.
- Perform a reliability analysis to ensure that the cooling system meets the expected life of the electronic equipment.

- Perform a cost analysis of the different cooling options on the system design, while including the cost of service/maintenance for the proposed CLLC.
- Ensure that the cooling system cost meets the budgeted requirement.

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