

Liquid Cooling Systems

And Their Components

In its most basic form, the purpose of a liquid cooling system is to transport heat from a device to a remote heat exchanger. The liquid cooling system helps to reduce the thermal spreading resistance associated with the movement of heat from a small component to a larger surface. This reduction of spreading resistance is critical in applications with very high heat flux and limited space in the immediate area for heat dissipation. Examples include laptops, BGAs, IGBTs, traction motors and radar arrays.

With the ongoing increase in power dissipation, and tightening restriction on packaging, the need for more sophisticated and compact liquid cooling systems is clear. This paper will describe the classic setup of a liquid cooled loop, as well as several examples of novel designs.

The most basic liquid cooling loop is a gravity assisted thermosyphon, an example of which is shown in Figure 1. In this design, liquid in an evaporator block is attached to a component which transfers heat from the device into the working fluid. The heated fluid then rises in the loop, due to buoyancy effects, until it reaches the condenser (heat exchanger) where its thermal energy is transferred to the surroundings. At this point, the fluid is cooled and has a higher density so it travels down through the loop and back to the evaporator.

The advantage of this system is that there is no mechanical pump to circulate the fluid, which not only increases the life of the system, but also removes a potential area for leakage. The system does have a severe limitation, however; the

orientation of the system is critical for best performance due to the dependency on gravity. Care must also be taken not to exceed the maximum allowed power limit so as to avoid a situation known as “dry out”. Dry out is a failure mode of thermosyphons where all the working fluid is heated into vapor and no fluid exists in the evaporator to cool the component. Once the cooling system goes into a dry out phase, the system’s power and temperature must be reduced to allow for condensation to occur again.

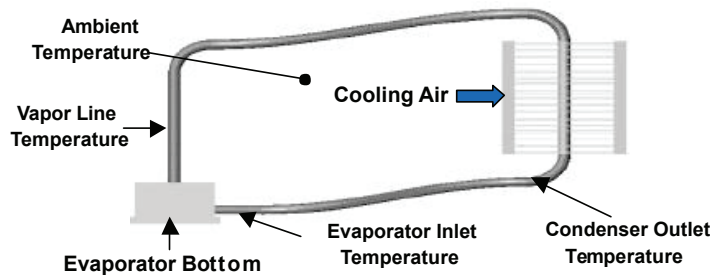


Figure 1. Basic Thermosyphon for Electronic Cooling [1].

To deal with the practical limits of a thermosyphon, a forced liquid loop can be used. This system differs from a thermosyphon, as it uses a mechanical pump to circulate the working fluid throughout the system instead of gravity. Typically, forced liquid loops contain several components as shown in Figure 2. A cold plate is attached to the device being cooled through which liquid is pumped under low pressure. The heated liquid is then pumped into a heat exchanger and is cooled by either natural or forced convection. Once the liquid is cooled, it then returns to the pump and the process is repeated. Because of the mechanical properties of the pump,

a reservoir may be needed to separate air trapped in the system to avoid cavitation and loss of pumping pressure.

The advantage of this system is greatly increased power dissipation limits afforded by the higher flow rate of the mechanical pump. The forced liquid cooled loop typically does not suffer from dry out conditions, as the fluid exists as a single phase flow. However, the reliability of the mechanical pump is a major point of concern, as well as potential leakage. Typically, the lifespan of a pump is less than that of a vane axial fan and thus is the limiting factor in MTBF for the system. The addition of a separate pump and reservoir also bring in additional plumbing connections which have the potential for leakage. Basic forced liquid loops can be a challenge from a packaging standpoint as they can be bulky.

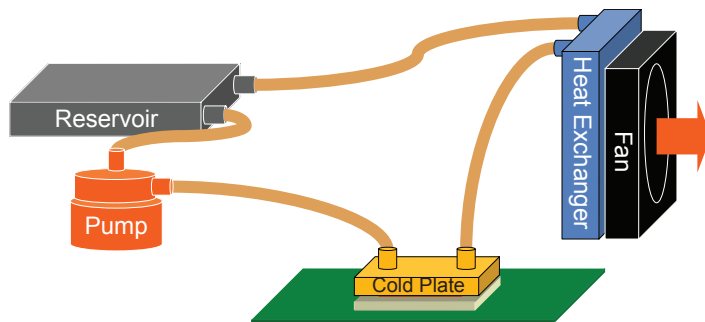


Figure 2. Classic Example of a Forced Liquid Cooling Loop [3].

In the past several years, the need for a liquid cooled system has increased, and many initiatives have been undertaken to reduce the associated disadvantages of these systems. The two main objectives of the designers have been to increase reliability and to reduce size. Several of the largest companies in the electronics and cooling industries have developed novel designs to meet these goals. Included in this paper are examples from Intel, Sanyo Denki and Dell.

Sanyo Denki is known as a fan and motor supplier for the electronics industry. They have applied this experience in developing a reliable pump based on existing motor technology. The self-contained cooling loop is shown in Figure 3. Sanyo Denki addresses several of the problems in typical cooling loops with its “SAN ACE MC” cooling system. In terms of packaging, Sanyo Denki has integrated components wherever possible to simplify installation and

reduce space. The liquid pump, heat exchanger, fan and reservoir have all been combined into a single assembly, with the cold plate as the only external component. To ease installation, the system is pre assembled and pressure checked at the factory. High reliability fittings are also used to reduce the risk of leakage.



Figure 3. Integrated Forced Liquid Cooling System Compared to an Air Cooled Solution [2].

Intel has also focused on integration, when developing its liquid cooled solution as a means to increase reliability, reduce cost and size. The approach taken by Intel was similar to Sanyo Denki's; however Intel combined the liquid pump and the cold plate into a single compact unit, Figure 4. This approach allows the heat exchanger to be mounted in a remote location with a minimum of plumbing connection points for increased reliability. Intel also claims that the primary need for a reservoir is to provide additional fluid to make up for migration losses through permeable plastic hoses. By using metal tubing, Intel has reduced the fluid losses to a point where a reservoir is no longer needed, Figure 5.

Along with the improvements that Intel has made to the liquid cooling assembly, they have also developed a testing procedure to ensure that the systems are leak free and reliable



Figure 5. Intel Integrated Liquid Cooling Loop [3].



Figure 4. Intel's Integrated Cold Plate and Liquid Pump Assembly [3].

from the factory. The flowchart showing this procedure is shown in Figure 6. The motor is first tested and the RPM is monitored under operation. Next a vacuum is pulled within the system to check for initial leakage. If the system can hold vacuum, then helium is introduced under pressure and a mass spectrometer is used to check for leakage from all components, hoses and connections. Finally, the system is filled with a precise amount of coolant and sealed.

The previous examples show the efforts being made to develop liquid cooling as a cost effective, reliable and compact cooling solution. Progress has been made in all areas, as

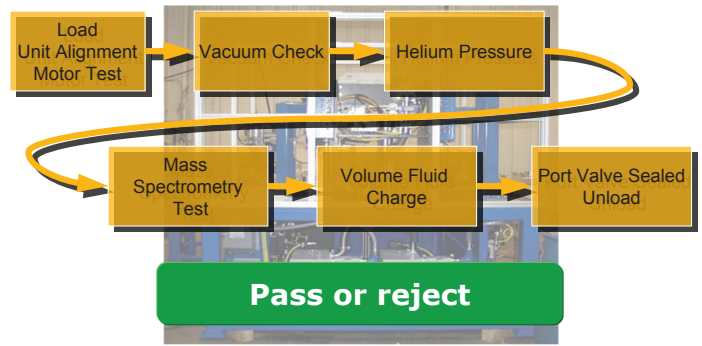


Figure 6. Intel Flowchart for Testing of Liquid Cooling Systems [3].

the market has driven the need for cooling solutions with increased reliability and reduced cost.

The other market-driven need is for increased thermal performance of liquid coolers. Dell has developed a liquid cooling system that targets performance, not cost or compactness, as its primary goal. Dell names their system H₂Ceramic and it is marketed towards high end users, such as graphics professionals and gamers. The liquid cooling system introduces cost and complexity in an effort to achieve maximum thermal performance. In addition to the normal liquid cooling components previously described, the H₂Ceramic system introduced a thermoelectric chilling assembly to sub cool the fluid below ambient temperatures, as shown in Figure 7.

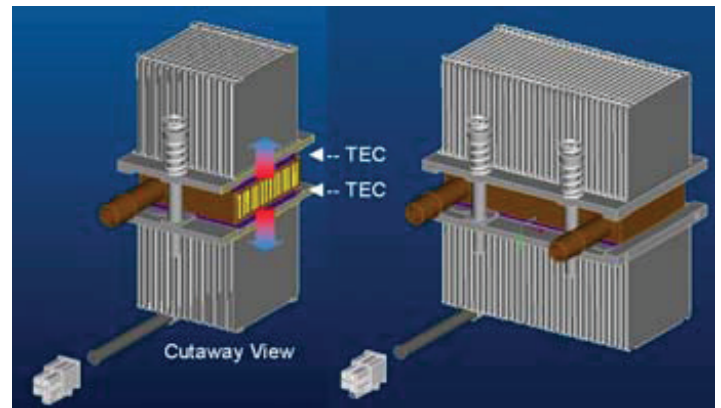


Figure 7. Thermoelectric Heat exchanger [4]

With the exception of the chilling assembly, the Dell system operates like a normal liquid cooling loop. The water is pumped through a cold plate with a mechanical pump. From the cold plate, the heated water is cooled with a

normal heat exchanger. This heat exchanger removes the majority of the heat from the liquid, but cannot reduce its temperature below that of room ambient. The partially cooled liquid would normally be routed back into the cold plate in a typical system. In the Dell system, however, the liquid is pumped into a second heat exchanger, which is cooled using thermoelectric chillers, which allow for sub ambient cooling of the liquid. By using liquid cooled below ambient, the component temperature can be reduced greatly over a typical system resulting in greater performance (over clocking) and longer life.

To achieve this performance, the Dell system needs a sophisticated control hardware to monitor the systems temperature and control the thermoelectric chillers, to avoid damaging condensation. This system also uses much more energy to run than a typical system, as the thermoelectric coolers are very power intensive. The complexity of the H2Ceramic system can also be seen in Figure 8 as compared to the previously discussed systems from Sanyo Denki and Intel.

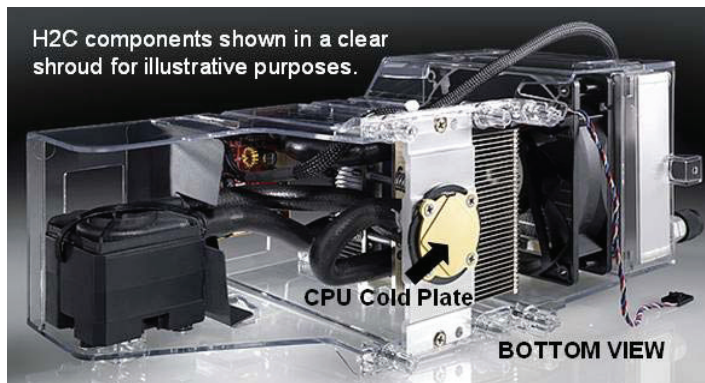


Figure 8. Dell XPS 710H2C Edition [4].

In conclusion, all liquid cooling loops operate according to a shared principal of using a coolant to transfer heat from a component to a remote heat exchanger. There are many methods of achieving the fluid flow and packaging of the system. Due to the market demands for increased thermal performance, research and development of liquid cooling systems will continue to yield more reliable, less expensive and higher performance solutions.

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