radian
THERMAL PRODUCTS

White Paper:

Heat Pipes
& Vapor Chambers

November, 2014

Abstract:

This paper helps define basic characteristics of Copper Heat Pipes and Vapor Chambers used to assist in the cooling of heat generating devices (typically electronic components). We will focus on capillary structures, mechanical capabilities and limitations.

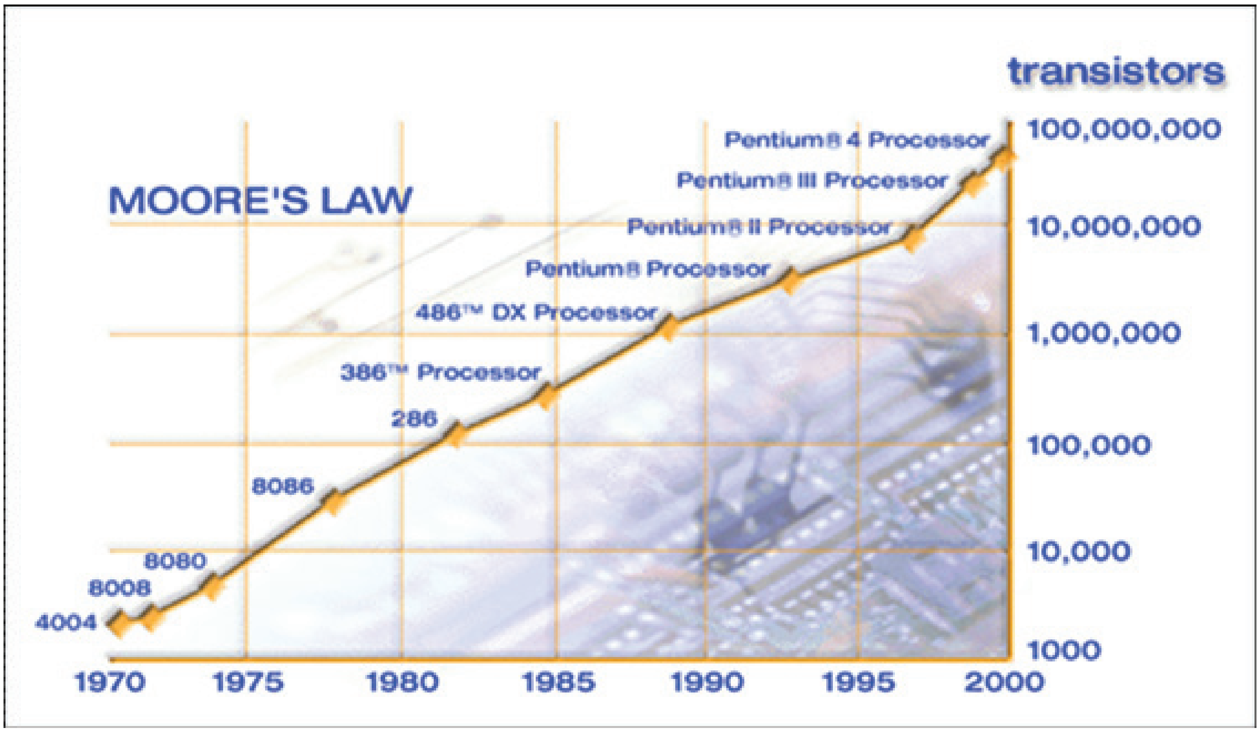
Key Words:

Heat Pipe, Vapor Chamber

The Increasing Challenge

Moore's Law is the observation that the number of transistors on a microchip doubles every two years. When Intel co-founder Gordon Moore issued his famous prediction 40 years ago, a chip could hold a few dozen transistors. Current technology allows almost 1 billion transistors on a single microchip.

Unfortunately, this level of density can cause issues as they generate more heat. The smaller the chips, the hotter they run. The heat created by so many transistors has pushed the thermal conductivity of the copper interconnects to their limit.

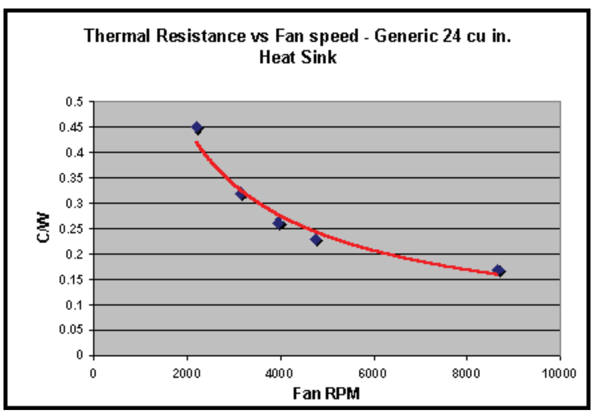


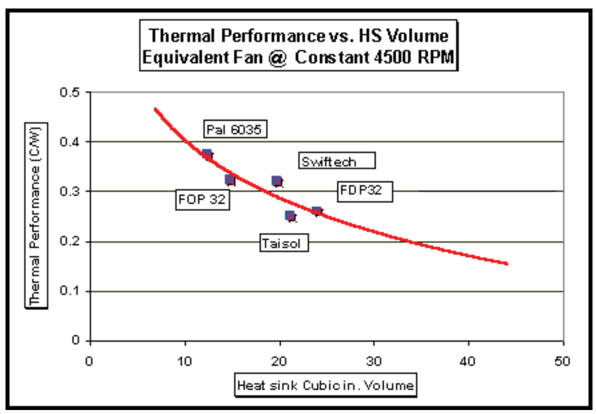
Limitations of Typical Cooling Devices

The typical methods for improving thermal performance have been increasing heatsink size or increasing airflow using fans or blowers. Thermal engineers are continually challenged to achieve better thermal performance using these methods within design constraints.

Most applications cannot accommodate large increases of heat sink size and weight. Various constraints such as board space availability, weight restrictions, and manufacturing cost can limit the size of a heatsink and the types of fans that can be used.

When design requirements allow, simply increasing heatsink size and airflow is not always a solution in real world applications. An oversized heatsink or very high airflow has limitations on the improvements of thermal performance. The graphs below illustrate the correlation between thermal performance to increased heatsink size and increased airflow. The first graph plots increasing airflow (fan rpm) versus heatsink thermal performance (thermal resistance, Celsius per Watt). As airflow increases, thermal resistance decreases as more airflow is able to remove more heat from the heatsink. But after about 6000 rpm, thermal resistance decreases at a slower rate. The second graph shows a similar trend. With an increase in heatsink size, thermal resistance decreases up to a point where the rate of decrease slows down and reaches a steady rate. When more thermal performance improvement is needed and the heatsink size and airflow have reached the limits, another form of cooling technology is needed.





**The graphs above assume using aluminum as the heatsink material.*

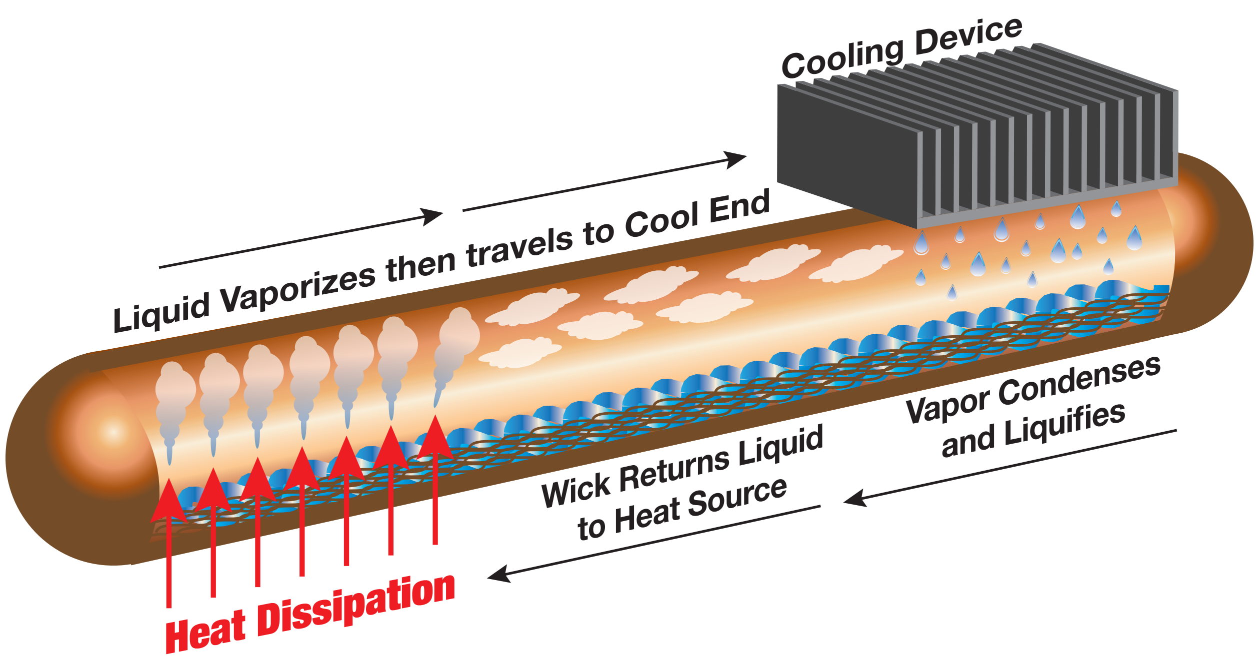
Moreover, other variables such as reduced air pressure at higher altitudes and reliability issues with motorized fans, support the need for other methods of cooling.

Why Copper Heat Pipes / Vapor Chambers?

Using a copper heatsink instead of an aluminum one can improve thermal performance. Thermal conductivity of copper is about 2X higher than aluminum (thermal conductivity of copper is ~400 W/mK; thermal conductivity of aluminum is ~200 W/mK), but copper is about 3X heavier than aluminum (density of copper is ~9 g/cm^3; density of aluminum is ~3 g/cm^3). A copper heat pipe or vapor chamber can be used instead of a solid copper part to improve thermal performance without a large increase in weight.

The fundamentals of heat pipes and vapor chambers are the same. Both of them rely on phase change of liquid to significantly increase their thermal conductivity.

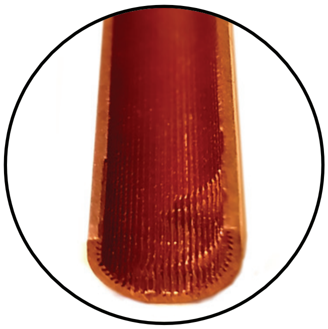
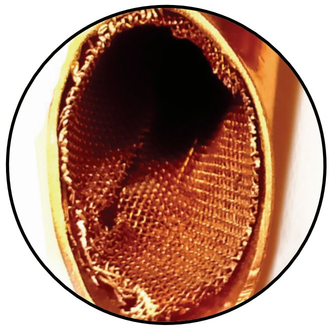
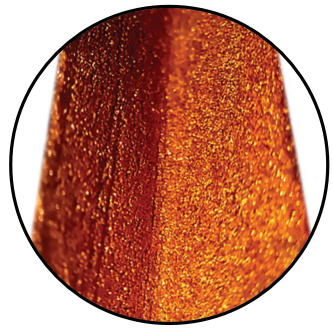
Heat Pipes / Vapor Chambers are vacuum sealed devices with liquid inside (typically water). The low pressure inside the chamber allows fluid to vaporize at a temperature much lower than normal boiling temperature. When heat is applied, the fluid near the hot location immediately vaporizes and rushes to fill the entire volume of the chamber (driven by pressure difference). When the vapor comes into contact with a cooler wall surface, it condenses. The condensed fluid returns to the heat source by capillary action of an internal wick structure.



Heat pipes have become commonplace in many of today's electronics systems. Computers, video games, network equipment all rely on heat pipes for thermal management.

What is a Copper Heat Pipe / Vapor Chamber? (continued)

The vacuum vessel is typically made of copper, and vacuum sealed under reduced air pressure. Many fluids can be used as the phase transition fluid within the vapor chambers. But in most applications, water is selected as the working fluid due to its high latent heat, surface tension, thermal conductivity and boiling temperature, not to mention the cost and environmental concerns. The internal wick can vary depending upon the application and orientation of the cooling device. The three most common methods are:

Grooved	Wire Mesh	Sintered
• Lowest cost • Lowest performance • Does not work well against gravity	• Most commonly used • Good performance • Works well against gravity	• Highest cost • Highest performance • Works best against gravity

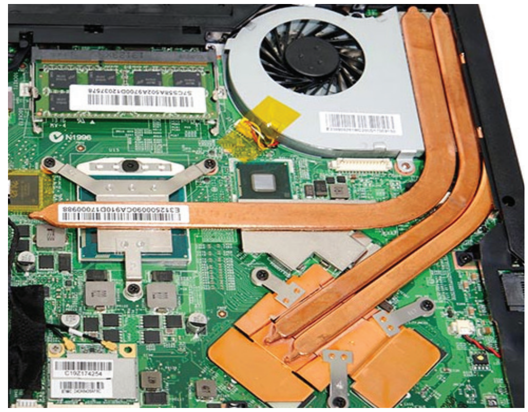
Reliability

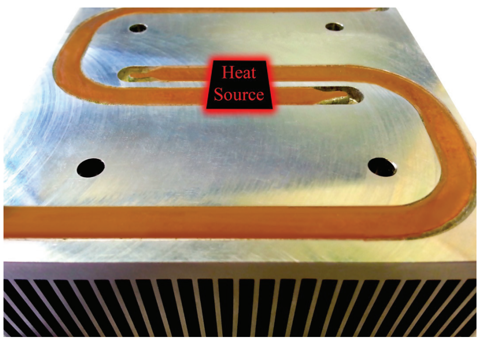
Heat pipes and vapor chambers are very reliable thermal devices. They do not have any moving parts or use any corrosive materials. The working fluid and wick structures are permanently encapsulated within a copper vessel. There is no mechanical or chemical degradation over time. The typical useful lifetime of a typical heatpipe is around 20 years, exceeding the typical lifetime of the systems they are cooling. Radian routinely performs the following tests to confirm the durability and reliability of its heat pipes and vapor chambers:

· Thermal Shock Test
· Cosmetic Degradation Test
· Burst Test
· Accelerated Life Test
· Freeze Thaw Test

Additional Advantages of Copper Heat Pipes:

Flexibility and spatial location: Heat pipes are flexible and can draw heat to a remote location where there is available space for related heatsinks and airflow. The image at right illustrates a laptop computer pcb. The chips requiring cooling are located on the center of the board. The heat pipes draw heat from the chips to a fan/blower at the end of the PCB to provide remote cooling.





Improve heat spreading at the heat sink base: You can improve heat dissipation by spreading the heat across the the base of a heatsink. Embedding heat pipes within the base of a heat sink is useful in cases where there is a small concentrated heat source versus a large heat sink base.

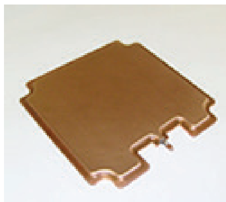
Improve heat-spreading at the heatsink fins: A heat pipe will improve heat sink efficiency by carrying heat to under-utilized areas of a heatsink. This is useful when heatsink fins are tall. Heat pipes can be used to effectively carry heat from the base of the heatsink to cooler parts of the fins.

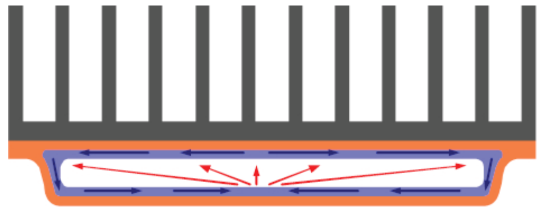
Summarizing the advantages of Copper Heat Pipes:

- Up to 90 times improved dissipation from copper alone (note: length, width, flattening and bending of heat pipes in combination with wick and liquid type effect dissipation performance)
- High Reliability / Lifetime of ≥20 Years - no moving parts
- Flexibility of location and Heat-Spreading

Advantages of Vapor Chambers

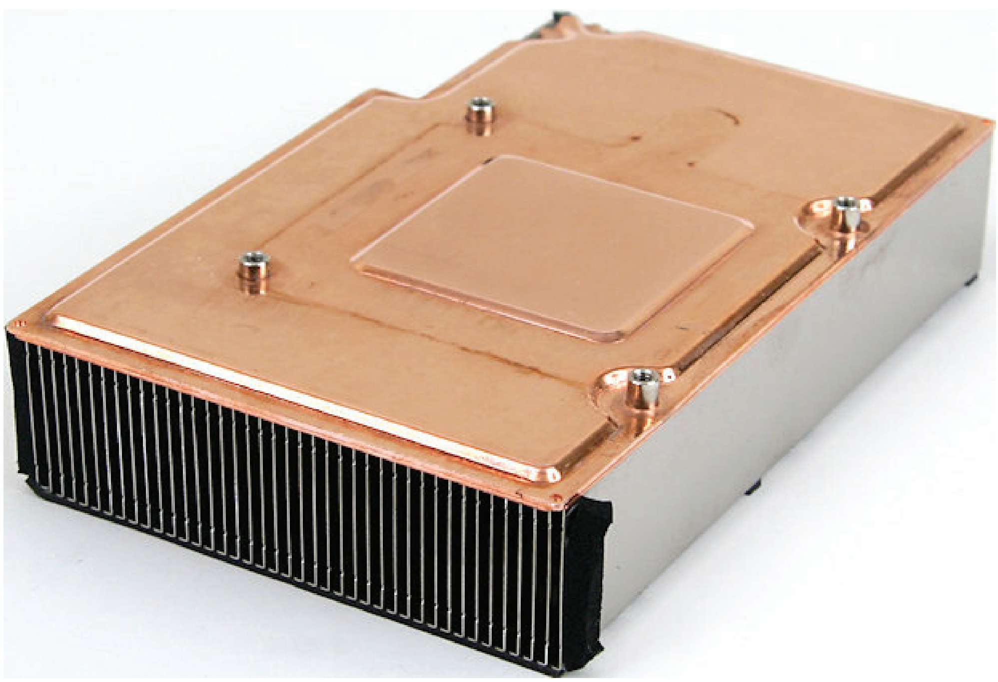
A vapor chamber is very similar to a heat pipe. The primary differences being an increased thermally connected surface area and heat can now spread in a 360˚ direction, versus the single direction offered by heat pipes. Vapor chambers are typically limited to 50~200mm^2 with a minimum thickness of 3mm.





A properly designed vapor chamber with heatsink can improve the thermal performance by as much as 30% over heat pipe based solutions. It not only lowers the temperature by a number of degrees, but may eliminate the need for fans, which improves the reliability of the system and eliminates noise.

A vapor chamber is typically integrated with heatsinks of either copper or aluminum material. Stamped fins are soldered to the vapor chamber and can accommodate various vapor chamber footprints.



Considerations

Vapor Chambers and Heat Pipes have limitations depending upon their size, wick structure, bending / flattening and working fluid. Exceeding the maximum heat capacity can cause “Dry Out”. Heat pipes no longer function properly if dry-out occurs.

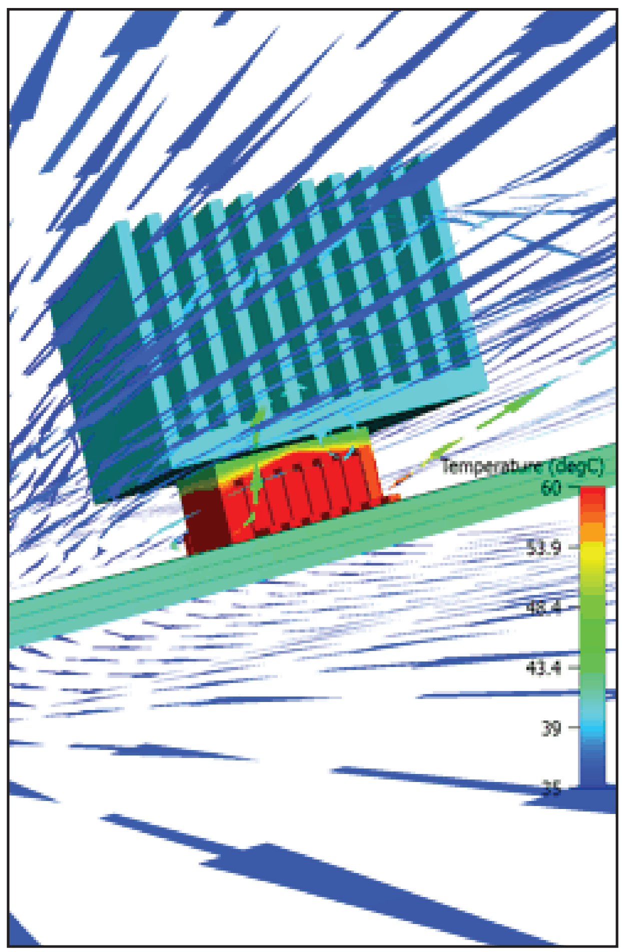
Design / Simulation

With >40 years of combined experience in thermal design and manufacturing for the electronics industry, Radian understands thermal design - and how to optimize manufacturing processes for any application. Understanding the performance characteristics of available topologies, process, and related costs allows Radian to develop thermal solutions that best fit the cost/performance requirements of OEM customers.

In regards to Heat Pipes and Vapor chambers, Radian's experience is critical. The numerous variables in regards to size, orientation, wick structure, flattening / bending and working liquid require advanced thermal engineering skill. Combining these technologies with other heatsink and air cooling devices at the component and system level only increases complexity.

Free Thermal Design with CFD Analysis / Simulation

Radian offers free engineering and detailed thermal analysis / validation services for OEM customers around the globe, ensuring delivery of the best and most cost effective thermal solutions to fit each unique requirement. Using powerful Computational Fluid Dynamics (CFD) and proprietary simulation packages, our thermal design engineers can asses your designs throughout the development cycle.



Radian's state-of-the-art design simulation system allows you to approximate a thermal solution to match your specific requirements - often within 24 hours, not days or weeks. Radian' simulations are generally within ±5% accuracy of actual tests.

Through our design simulations, a heatsink configuration can be pre-determined that will significantly streamline production implementation. Once an optimum heatsink model is reached, Radian can prototype the design using Rapid Prototyping technologies. Actual testing in a system can be enacted in a timely and cost-effective manner within weeks, not months.