Technology Review

Loop Heat Pipes, 2010 to 2012

Qpedia continues its review of technologies developed for electronics cooling applications. We are presenting selected patents that were awarded to developers around the world to address cooling challenges. After reading the series, you will be more aware of both the historic developments and the latest breakthroughs in both product design and applications.

We are specifically focusing on patented technologies to show the breadth of development in thermal management product sectors. Please note that there are many patents within these areas. Limited by article space, we are presenting a small number to offer a representation of the entire field. You are encouraged to do your own patent investigation. Further, if you have been awarded a patent and would like to have it included in these reviews, please send us your patent number or patent application.

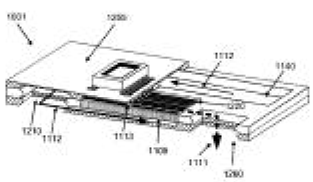
In this issue, our spotlight is on the Loop Heat Pipe. There is much discussion about its deployment in the electronics industry, and these patents show some of the salient features that are the focus of different inventors.

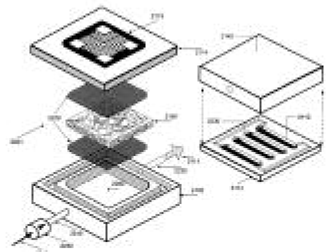
INTEGRATED THERMAL SYSTEMS
7,692,926 B2, Henderson, H. T., et al.

This invention generally relates to a MEMS based two phase LHP (loop heat pipe) and CPL (capillary pumped loop) using semiconductor grade silicon and micro lithographic/anisotropic etching techniques to achieve a planar configuration. The principal working material is silicon (and compatible borosilicate glass where necessary), particularly compatible with the cooling needs for electronic and computer chips and package cooling. The microloop heat pipes (μLHP^{TM}) utilize cutting edge microfabrication techniques. The device has no pump or moving parts, and is capable of moving heat at high power densities, using revolutionary coherent porous silicon (CPS) wicks. The CPS wick minimizes packaging thermal mismatch stress and improves strength to weight ratio. Also burst through pressures can be controlled as the diameter of the coherent pores can be controlled on a submicron scale. The two phase planar operation provides extremely low specific thermal resistance (2060 w/cm^2). The operation is dependent upon a unique micro patterned CPS wick which contains up to millions per square centimeter of stacked

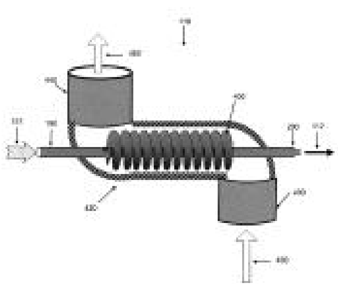
PATENT NUMBER	TITLE	INVENTORS	DATE OF AWARD
7,692,926 B2	INTEGRATED THERMAL SYSTEMS	Henderson, H. T., et al.	Apr. 6, 2010
0277967 AI	LIQUID COOLED CONDENSERS FOR LOOP HEAT PIPE LIKE ENCLOSURE COOLING	Fried, S.S., et. al.	Nov. 17, 2011
US 2012/0043060 AI	LOOP HEAT PIPE	Wang, et al.	Feb. 23, 2012

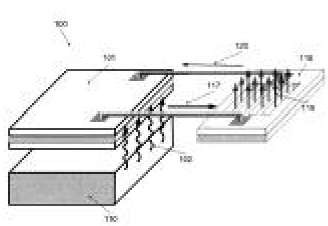
uniform micro through capillaries in semiconductor grade silicon, which serve as the capillary "engine," as opposed to the stochastic distribution of pores in the typical heat pipe wick. As with all heat pipes, cooling occurs by virtue of the extraction of heat by the latent heat of phase change of the operating fluid into vapor.





Semiconductor makers have been struggling to find new ways to cool increasingly powerful chips. New chips generate more waste heat because of the increasing numbers of circuits being packed into the chips. As circuit dimensions shrink into the nanometer realm, waste heat becomes a significant problem. Increasing power densities, even with smaller switching potentials, causes the chips to warm to unacceptable temperatures. This condition has led to ever increasing space consumed by packaging schemes for heat transfer away from the chip-level electronics.



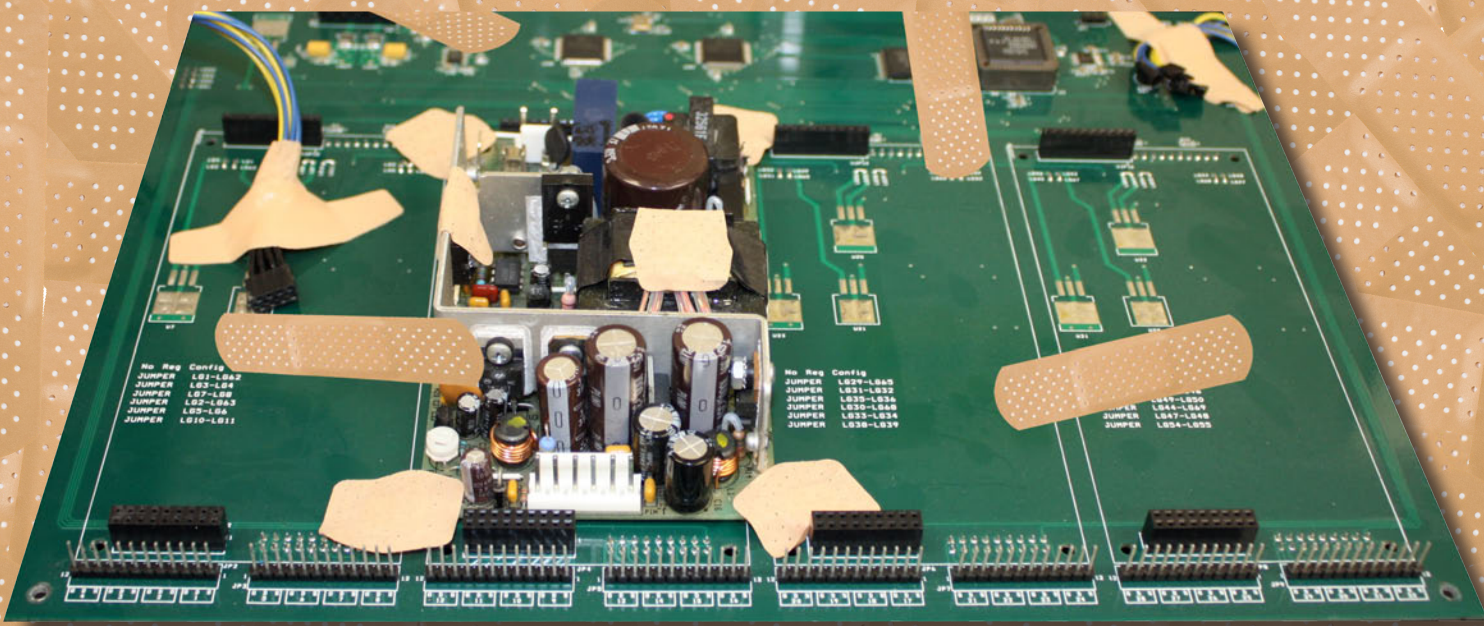


Heat sink and fan assemblies are large, which makes them less useful as the microelectronics industry moves towards thinner and smaller devices. For instance, while heat sink or fan assemblies are widely used in desktops, laptops cannot accommodate these components. Another disadvantage of these assemblies is their low convective heat transfer coefficients due to room temperature air acting as the cooling fluid. Air has low density, low thermal conductivity, and low specific heat, resulting in low heat load carrying capacity. The average convective heat transfer coefficient of forced air convection is typically in the range of 10200 W/m^2 K. In contrast, the use of two phase liquid cooling allows for heat transfer coefficients ranging from 10,000100,000 W/m^2 K.

Liquid cooling was first used in the 1960's to remove heat from bipolar junction transistor (BJT) based processors when air-cooling did not perform adequately. The introduction of complementary metal oxide semiconductor (CMOS) technology in the early 1990's reduced the necessity of liquid cooling because the material produces less excess heat. Due to the increased number of feature on CMOS based processors, liquid cooling is becoming useful again. In April 2005, IBM introduced a water cooled heat exchanger mounted to the back cover of a 19 inch server rack. The processors are cooled using a cooling distribution unit to supply the water, and the heat load is dissipated to the building's chilled water line. While not cutting edge technology, the use of this method signals the coming of a wide spread industry acceptance of liquid cooling solutions.

An increasingly common liquid cooling device, the heat pipe, is used extensively in cooling applications. Micro heat pipes use small ducts filled with a working fluid to transfer heat from high temperature devices to a remote heat sink. A typical heat pipe for semiconductor devices is a circular metal tube that has its interior wall coated with a wick structure. Evaporation and condensation of the fluid transfers heat through the duct. As heat from a device is applied, the fluid in the wick of the evaporator section of the device vaporizes, removing latent heat. The vapor travels through the channel to the cooled condenser region of the structure, where the latent heat is released by condensation of the vapor. The condensed vapor moves back to the evaporator region along the wick structure by capillary force along the interior wall of the heat pipe. Heat pipes are limited because they are mostly cylindrical, have vapor and liquid moving counter to one another in the same channel, and often cannot dissipate heat fluxes greater than 10 W/cm^2.

Stop trying to band-aid your thermal management problems



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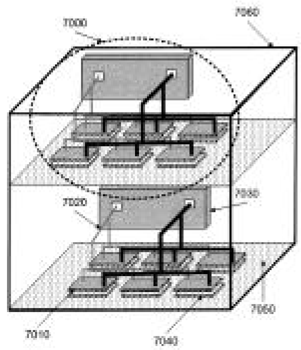
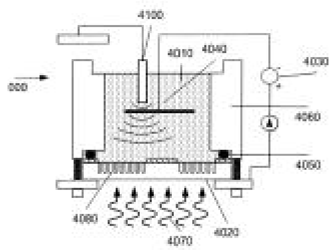
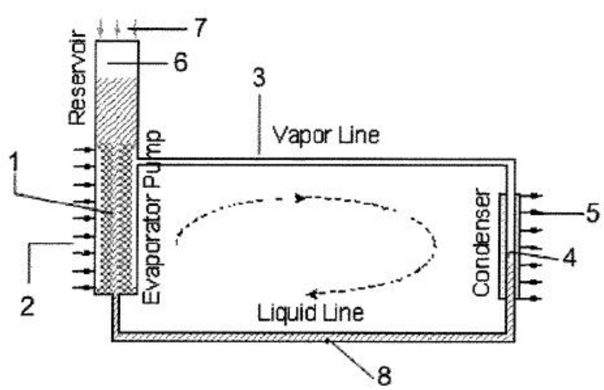




Recently, loop heat pipes (LHPs) have been utilized to remove heat from high density electronics and have been employed by the aerospace industry as well. The figure below is a schematic representation of a conventional LHP. In traditional devices, the cooling package or "evaporation pump" is normally a simple cylindrical metallic heat pipe, filled with a porous ceramic metallic oxide (sintered) that serves as the wick for the working fluid. When heat 2 is externally applied, the working fluid is evaporated from the wick surface. The vapor enters surface grooves extruded or cast on the wick surface, which direct the vapor into the vapor line 3. The vapor travels to the condenser 4, where the latent heat is extracted typically by cooling air, cooling liquid, or radiation to space. The condensed liquid returns to the reservoir 6 by virtue of the vapor pressure head in the lower line 8. The porous wick returns the working fluid through random pores by capillary action back to the hot surface to begin the process anew. In a similar device called a capillary pumped loop (CPL) heat pipe, the reservoir 6 is a separate ballast which may work by gravity or other forced feed 7.



Semiconductor makers have been struggling to find new ways to cool their increasingly powerful chips. For example, Intel recently cancelled its 4-gigahertz Pentium 4 processor because of increasing heat dissipation problems. Intel has resorted to investigating dual core technologies which reduce waste heat by lower power consumption. However, the consortium between IBM, Toshiba, and Sony plans to use a 16 core processor in forthcoming products that will push the limits of processing power and waste heat mediation. While waste heat has been an industry-wide problem, cooling solutions will be of utmost importance as circuit dimensions shrink into the nanometer realm causing chips consume more power and give off more heat. The invention herein provides a solution to this and similar cooling problems.

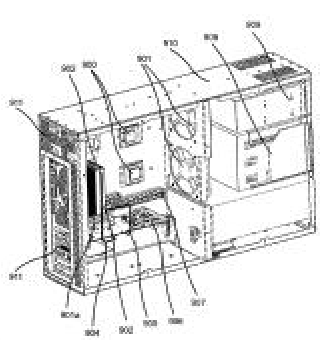
LIQUID COOLED CONDENSERS FOR LOOP HEAT PIPE LIKE ENCLOSURE COOLING

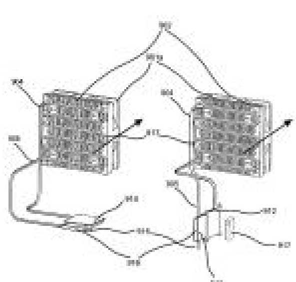
0277967, Al, Fried, S.S., et al.

A cooling device includes an enclosure, an external heat rejection device, and a primary cooling system including a loop heat pipe like device. The LHPL device includes an evaporator module, a condenser module, a vapor line, a liquid return line, and a working fluid having a liquid phase and a vapor phase. The evaporator module includes a component evaporator heat spreader, an evaporator body, and an evaporator- component clamping mean. The evaporator body includes an evaporator outer shell, a working fluid inlet port, a compensation chamber, a working fluid exit port, and an evaporator wick having vapor escape channels. The condenser module includes a condenser coolant inlet, a condenser coolant exit, a condenser condensation channel, a condensation channel working fluid inlet, a condensation channel working fluid exit, and a condensation channel-coolant thermal interface further comprises a coolant passageway. The secondary cooling system including a secondary coolant, the secondary cooling system cooling a secondary neat rejecting component, wherein the secondary heat rejecting component is one of the plurality of other components.

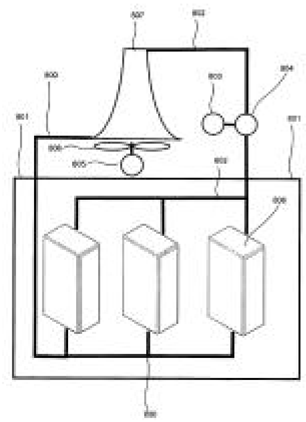
A cooling device includes an enclosure, an external heat rejection device, and a primary cooling system including a loop heat pipe like device. The LHPL device includes, an evaporator module, a condenser module, a vapor line, a liquid return line, and a working fluid having a liquid phase and a vapor
A way that maybe employed to efficiently cool data centers and electronics housed in electronics which employs Loop Heat Pipes and other passive technologies to cool the primary heat loads in such systems and which may employ a combination of other methods to cool the secondary heat loads.
The cooling of electronics housed in enclosures has for many years been dominated by methods that were much more concerned about getting the job done than the energy it took to get the job done.

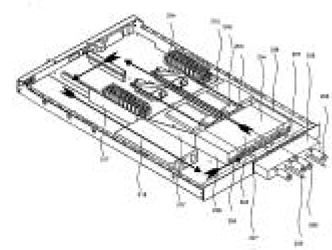
Methods for improving the efficiency of electronic cooling using passive heat transfer such as heat pipes have been available since at least the Manhattan project, yet have only become inexpensive with the advent of CPUs that rejected 40 or more Watts, and needed to extend the operating capabilities of finned heat sinks. This disclosure employs passive closed loop heat transfer devices that can dramatically improve not only the energy efficiency of electronic cooling but also makes it possible to cool devices that reject 500 or more Watts mounted on densely packed printed circuit boards and in the case of a data center reducing the energy required to cool it by 80% or more!





The devices at the heart of this disclosure are Loop Heat Pipes, Capillary Pumped Loops and derivatives of Loop Heat Pipes that included devices like pumps in the condenser lines. We lump all these devices together into the category Loop Heat Pipe Like (LHPL).





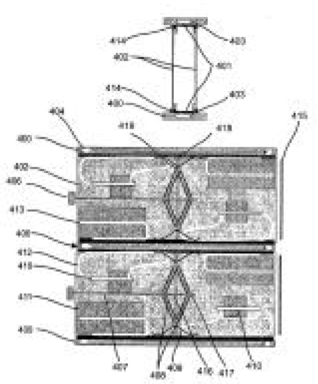
In general the LHPLs employed provide the best energy efficiency of any electronic cooling device ever invented. Not only are they passive, but their ability to reject heat to new locations is often measured in meters employing very small condenser pipes (often less than 3 mm) that make it possible for them to move heat out of tight spaces to condensers that can reject the heat over large heat transfer areas to secondary coolants such as air and water. And it is this ability to transport heat to new locations in a chassis or enclosure and then pass it through a reasonably long pipe in a condenser which distributes it over a reasonably large area, that makes it possible to efficiently transfer the heat being rejected by tiny hot spots to secondary coolants which in turn remove the heat to cooling loops which ultimately reject it to the outside world. And it is also this ability to distribute the primary heat load over large areas that makes it possible to create very efficient counter flow heat exchangers that retains the quality of the heat as well, that makes this technology so exciting. In fact, the secondary coolants that it heats up are produced with the highest delta T's of any technology we know of. It is the low total thermal resistances of these devices that make it.

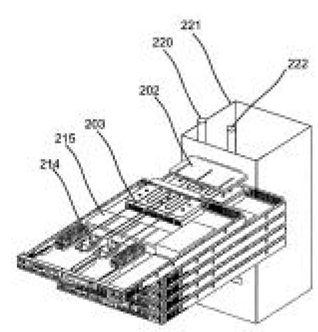
A cooling device includes an enclosure, an external heat rejection device, a primary cooling system including a loop heat pipe like device. The LHPL device includes, an evaporator module, a condenser module, a vapor line, a liquid return line, and a working fluid having a liquid phase and a vapor A way that maybe employed to efficiently cool data centers and electronics housed in electronics which employs Loop Heat Pipes and other passive technologies to cool the primary heat loads in such systems and which may employ a possible to produce LHPLs whose overall thermal resistance is only 0.15 °C/W. In the case of a 100 Watt CPU whose LHP condenser was cooled by water at 30 °C the output from the condenser turned out to be 47 °C with the CPU running at a heat spreader temperature of 59 °C. Translated into practical terms, employed in the 1 U rack mount chassis that dominate modern data centers, this device makes it possible to remove the heat directly from a server housed in a rack cabinet and move it directly back to the cooling tower in the data center.

In the process, the noisy fans in the racks that produce many points of failure and can consume as much as 30% of the energy being used by servers along with the main CRAC unit blowers and water chillers that consume 35% of the total power employed by the data center end up getting cut out of the cooling process. The temperature we chose to cool these LHPs with, 30 °C, was chosen based on ASHRAE tables, and the performance of commercially available evaporative cooling towers. This temperature turns out to be the temperature of the coolant that this type of cooling tower will produce running in Atlanta Ga. on the hottest and most humid day of the year.

The same energy benefits that accrue to data center cooling also accrue to the general cooling of all electronic enclosures that are air cooled, but to a lesser extent, for the simple reason that air is a much poorer heat transport medium than the chilled water that gets employed to move heat from servers that are cooled with it back to the water chiller or in the best case cooling case we have run up against, the data center cooling tower. At the head of the list of benefits in addition to reduced energy costs are huge reductions in noise, the elimination of heat arriving at the walls of enclosures that can be so hot that it is almost possible to get burned touching them, the frequent failure of rotating cooling components including fans and pumps (in the case of pumped liquid cooling) which now occur so often that the systems that employ them have to mount them so that they can be easily swapped out without turning the machine off along with the ability to reject heat loads from devices that produced 500 or more Watts and to cool efficient devices such as CPUs and GPUs mounted in laptops where improved energy efficiency can improve battery life.

To appreciate the benefits of employing LHPLs to cool electronic enclosures, including air and water cooled electronic devices used to do everything from control the operation of space vehicles to reject heat to the cooling towers of data centers, it is first necessary to recite the goals of this disclosure, which were to efficiently cool electronic enclosures in which semiconductor devices that rejected large quantities of heat (greater than 200 Watts) mounted on densely packed PCBs along with devices that shared the same enclosures that rejected the balance of the heat but did not provide a dense source of heat.





In the case of air cooled enclosures housed in rack mounted chassis, we wanted to make the first goal achievable while at the same time improving the quality of heat being rejected to the data centers CRAC system. In cases where liquid cooling, including chilled water was available on the data center floor, our goal was to reject high quality heat all the way back to the data center cooling tower, on a year round basis in most localities in the world. To achieve these goals, we employed LHPLs, some of whose other outstanding properties in addition to the fact that they are passive devices, turns out to be that the eliminate most of the electric motors, fans, blowers, compressors and other rotating devices found in servers and throughout the data center that end up making noise, contribute to frequent server failures and cost money to maintain and operate.

These goals don't get met without skepticism from prior art and other technologies, so we will now address the advantages of our approach in detail, while at the same time laying out the critical items that need to be overcome to reach our goals.

There are a large number of technologies that have been recently investigated whose main purpose has been to improve the heat transfer capabilities of devices that can be used to cool semiconductor devices that reject large quantities of heat. LHPLs continue to remain as good as or better than these other devices. We will examine just a couple of the higher end sensibly cooled heat exchange technologies: microchannels and jet impingement. Microchannels require a liquid under pressure, usually pump driven and drive the liquid across a channel which extracts heat from the processors heat spreader. The contact areas that can be achieved with these devices is less than the wick areas provided by LHPLs which means to provide equivalent cooling, they need to make up for the fact that LHPLs absorb a factor of 100 as much heat per gram of coolant than they typically do.

As a consequence, they end up leaving the region of the device at higher velocities and at much colder temperatures. It is also very difficult for them to provide uniform cooling across the entire heat spreader for the simple reason that they do not uniformly expose the heat spreader to a uniform flow. Jet impingement, on the other hand does expose the surface to a more uniform flow, but because of a characteristics of the way in which jets interact with surfaces along with the fact that the heated water has to be quickly removed from the region of contact, a fair amount of mixing goes on, again reducing the temperature of the resulting effluent. The heat transfer coefficient of the LHPs employed in our experiments was $0.15^{o}C/Wcm^{2}$. This state of the art performance makes it possible to cool semiconductor dies whose are 2.5 cm squared and reject as much as a kilowatt. It is possible that jet impingement may be able to cool devices that reject more power, simply because of the energy that they can eject into the flow employing pumps. But, for now at least, what we have just demonstrated is that for all of the semiconductor devices that are available or likely to become available, this technology not only can reject as much energy as the competitors, but do it without requiring additional energy and at the same time producing effluents whose heat quality is excellent.

The critical role that LHPLs perform in the removal of heat from hot semiconductors, is they make it possible to remove large quantities of it, using small devices that can be packed into small locations and while at the same time pro- viding rejection distances that make it possible to locate large efficient condensers that may employ counter-flow designs at locations in the electronic enclosure where that heat can be exchanged with either air or water. That being said, the next most important feature of the technology that this disclosure brings to the table is methods that make it possible to maintain the quality of that heat as long as possible, whether it be exchanger with air or a chilled liquid. This is a crucial part of the design approach to the heat transfer problem that we have taken.

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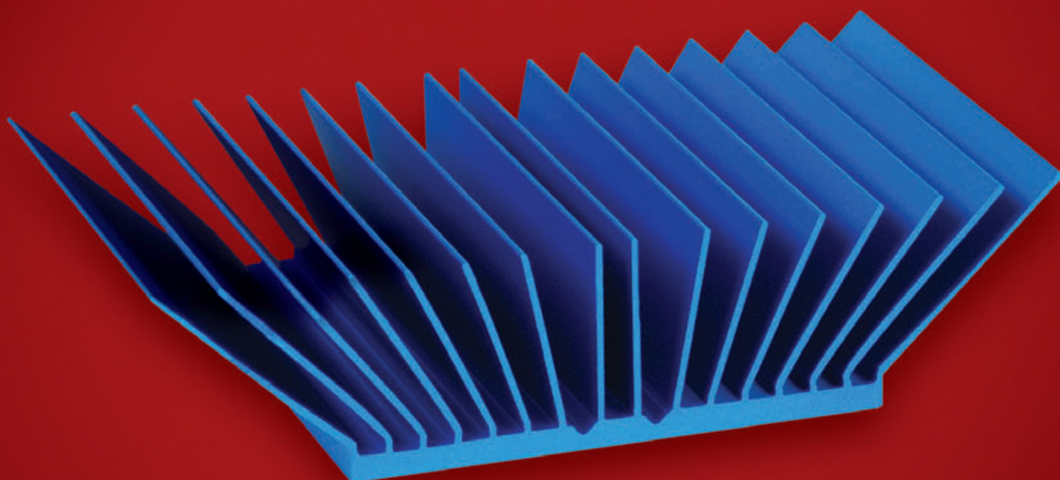

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In Summary, methods were disclosed which make it possible to employ Loop Heat Pipe, Capillary Pumped Loops and other passive closed loop heat transfer devices to cool electronic components housed in electronic enclosures, including rack mount chassis housed in rack cabinets, desktop computers, COTs computers, telecommunications equipment, electronics employed in vehicles and virtually any electronic enclosure one can imagine in which either air or a chilled liquid can be provided to cool the enclosure.

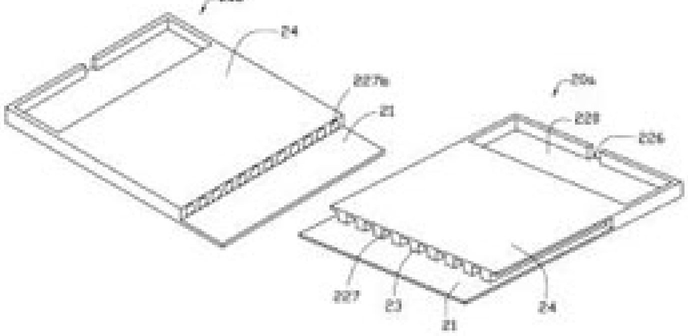
The resulting methods made dramatic reductions in the amount of energy employed to cool electronic components housed in electronic enclosures while at the same time making dramatic improvements in other operating characteristics, including reliability, the amount of heat being reject to the outside world, the amount of noise produced, the size of the power supplies needed to power units, the cost to build and operate data centers and last but not least, the ability to cool very hot electronic devices housed in electronic enclosures that are densely packed.

The embodiments included designs for LHPL condensers, including air and water cooled condensers that employed counter-flow techniques, LHPL CPU heat spreaders, sealed chassis and sealed air ducts, methods for controlling the vapor content of air within sealed chassis, methods for connecting chilled liquid sources to condensers including split condensers that eliminate the need for quick disconnects and quick disconnects that are shielded from the chassis being cooled by a duct.

LOOP HEAT PIPE

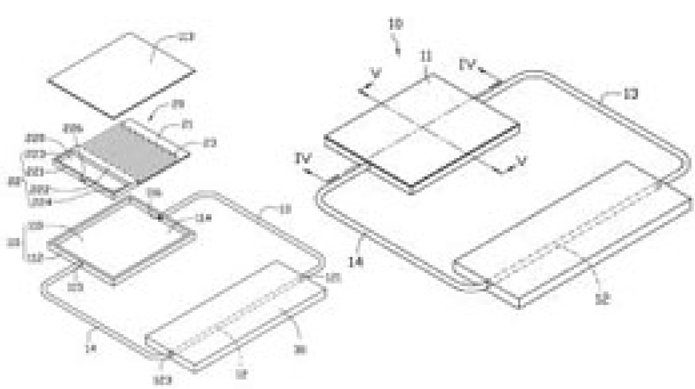
US 2012/0043060 Al, Wang, et al.

An exemplary loop heat pipe includes an evaporator, a condenser, a vapor line and a liquid line each connecting the evaporator with the condenser to form a closed loop. A working medium is contained in the closed loop. A wick structure is received in the evaporator, and includes a bottom wall contacting the bottom plate, a support wall

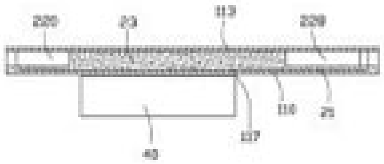


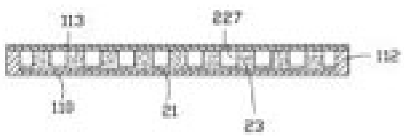
extending up from the bottom wall and contacting the cover plate, and guide walls extending out laterally from the support wall. The sup- port wall separates an interior of the evaporator into a liquid chamber adjacent to the liquid line and a vapor chamber adjacent to the vapor line. The guide walls are located in the vapor chamber. Guide channels are defined between the guide walls for guiding the working medium in a vapor state to flow from the vapor chamber through the vapor line to the condenser.

Loop heat pipes are widely used in various fields for heat dissipation purposes due to their excellent heat transfer performance. A commonly used loop heat pipe includes an evaporator thermally attached to a heat-generating electronic component, a condenser, and a vapor line and a liquid line respectively interconnected between the evaporator and the condenser. A predetermined quantity of bi-phase working medium is contained in the loop heat pipe. A wick structure, lining an inner surface of the evaporator, draws condensed working medium back to the evaporator after the working medium in vaporized form has condensed at the condenser.



In operation of the loop heat pipe, the working medium conveys heat from the evaporator to the condenser. More specifically, the working medium in a liquid state contained in the wick structure of the evaporator absorbs heat from the heat-generating electronic component and vaporizes to the vapor state. The working medium in the vapor state moves through the vapor line toward the condenser, carrying heat with it. At the condenser, the working medium in the vapor state dissipates the heat to the ambient environment and condenses back to the liquid state, and then flows back to the evaporator through the liquid line to start another heat transfer cycle.





If the wick structure of the evaporator is too thick, the working medium in the liquid state contained in the wick structure of the evaporator cannot be completely vaporized in a timely manner. Therefore, part of the working medium in the liquid state mixes with the working medium in the vapor state to form a number of bubbles in and on the wick structure of the evaporator. The bubbles tend to block the pores of the wick structure of the evaporator and decrease capillarity of the wick structure, to thereby retard the flow of the condensed working medium in the liquid state back into the evaporator. Thus, the amount of working medium in the liquid state contained in the wick structure of the evaporator is decreased, which may eventually result in overheating of the loop heat pipe.

On the other hand, if the wick structure of the evaporator is too thin, the working medium contained in the wick structure is liable to dry off altogether, whereupon the loop heat pipe is destroyed. What is needed, therefore, is a loop heat pipe which can overcome the described limitations.