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# A State of Art Review on The Thermal Management of Electronic Devices

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## ABSTRACT

Thermal management is necessary for all the electronic devices as well as circuits in order to optimise dependability and avoid premature failure. The lower the temperature of an electrical gadget, the less efficient it is. The performance of a machine decreases as the temperature rises. Heat loads generated by high-performance electronic components may cause excessive junction temperatures, shorten component lifespans, and even cause electronic devices to fail prematurely. As a consequence, it is necessary to reduce the temperature of electrical equipment and/or remove the heat from them. In the mobile device sector, this is a common problem to deal with. The capacity to keep the components cool is one of the most difficult tasks, since overheating significantly reduces the functioning life of a device as well as eventually leads to its failure. This paper presents a literature survey on several techniques being used as well as advances being made for the thermal management of the electronic devices.

**Keywords:** Thermal management, electronic devices, junction temperatures, Heat loads, overheating

## INTRODUCTION

Engineers as well as designers confront an ever-increasing issue as electronic devices reduce in size: how to keep up with the rising requirement to optimise processing performance inside a smaller form factor. Increased power consumption necessitates the generation of heat, which is a result of faster CPUs. The tools used to spread heat must be more compact to accommodate the reduced form factor. Systemic solutions, in which every aspect of the device's power equation is reviewed for the maximum optimisation, are now being considered by engineers as well as designers. The power equation dictates that a device's heat dissipation should be proportionate to its power dissipation, and this is the case across the board. How much energy a gadget uses in the process of discharging it is known as power discharging (capacitance of the logic parts, voltage swing, as well as operation frequency all affect the power dissipation). In today's small-footprint electronic devices, thick "printed circuit boards" (PCBs), greater heat density in the integrated circuit (IC) chips, the compactness of devices, as well as the mobility sought by users pose three key problems to regulating power dissipation.

Low power as well as low heat operation is the norm for most electronic components. Power transistors, CPU's, as well as power diodes are some of the technologies that generate substantial heat. Measures may be required to extend their service life and improve their dependability. Let's take a look at a heat-producing electrical component on its own. At some point during operation, its temperature rises until the heat generated inside the device equals the heat lost to the environment, at which point the device has achieved equilibrium. Because of the material's resistance to the movement of electrons, heat is created. Because of the renowned Joule's rule, which states that heat flow is proportional to current flow, $H=I^2Rt$ (H represents the heat generated, R represents the material's resistance, I represents the current flowing and t is the amount of time that the material is permitted to conduct current for). The material's resistance to current flow is the primary cause of heat creation (if I & t are taken to be controlled). Low heat production is achieved through reducing resistance and increasing conductivity. As a result, high-conductivity materials research is ongoing simultaneously.

## LITERATURE REVIEW

[1] (B. Xu et al., 2021) Developing a heat spreader with much higher "isotropic thermal conductivity" than copper (400 W/mK), which is currently the most widely employed heat dissipation material, is necessary to address the growing need for high efficiency in power electronics. In spite of its high "basal-plane thermal conductivity", graphite is constrained in its applicability due to its poor C–Axis thermal conductivity. Graphite may be made into an isotropic thermal conductor by creating a three-dimensional structure that efficiently routes heat. A double-decker structure with distinct oriented graphite layers is developed herein to provide "high heat dissipation" from the local heat source. High-temperature curing of graphite layers solves the key problem of securing the layers together. With a thermal conductivity of 900 W/mK, the graphite/Cu composite works as well as an isotropic conductor at dissipating heat.

[2] (Abo-Zahhad et al., 2021) The widespread usage of microelectronic devices as well as semiconductor devices in various applications, like the central processing units, illustrates the importance of these technologies. Because of the sensitivity of their functioning to operating temperature, these devices generate a significant quantity of heat which must be dispersed appropriately. When operating at high temperatures, thermal strains may cause physical damage to the components and increase the risk of component failures. To meet the required working conditions, these devices must have proper thermal management. As heat dissipation rises, the temperature of semiconductor components climbs linearly. This complicates even the most powerful single-phase liquid-cooling solution. As a result, the device's temperature might exceed the maximum limit. An advantage of two-phase flow boiling–cooling over single-phase flow is the uniform temperature distribution and high latent heat dissipation it may provide in terms of thermal management. Thus, flow boiling in the microscale devices is an efficient cooling method for high-density-power electronic components. The flow boiling in a microchannel device was studied using acetone, ethanol, and Novec-7000 coolants with a high, medium, as well as low boiling points, respectively. Experiments were conducted to examine the impact of volumetric flow rates and heat fluxes. Under boiling circumstances, a graphite sheet was employed as a "thermal interface material" (TIM) to further enhance heat dissipation. Extremely high heat flux circumstances proved to be ideal for the Novec-7000 coolant. A 0.62 percent increase in effective heat flux was seen for acetone as well as Novec-7000 when TIM was utilised. Flow boiling–cooling system performance is influenced by the boiling point, according to experimental data.

[3] (Ferraro et al., 2021) It seems that nanopapers made from graphene as well as similar materials have a lot of promise for heat management applications. In the absence of a "high-temperature graphitization" stage, thermal interactions between conductive plates pose a bottleneck for the thermal conductivity of nanopapers. Thermal bridges between "graphite nanoplates" (GnP) are created using the "bifunctional polyaromatic" molecules, which are used to accelerate self-assembling of GnP and alleviate inefficient thermal connections. Because a defect-free sp2 structure is associated with high conductivity, non-covalent functionalization using bispyrene compounds produced specifically with the variable tethering chain length was used. UV-Vis, fluorescence, as well as Raman studies show that the graphene surface interacts strongly with the pyrene terminal groups, as illustrated. By controlling GnP orientation and organisation, bispyrene molecular connections between GnP were shown to significantly boost both cross-plane heat diffusion as well as thermal diffusivity inside the nanopaper. Ultimately, nanopapers were shown to be effective heat spreaders for electronic components, demonstrating equivalent or higher "thermal dissipation performance" than the standard Cu foil, while giving a weight reduction of more than 90 percent.

[4] (Cermak et al., 2020) In terms of heat sinks, "natural graphite sheet" (NGS) might be a viable option. Through–plane thermal conductivity may be improved using heat pipes, as we demonstrate. This NGS heat sink has the same thermal resistance as a geometrically similar aluminium one in the tested configuration. 37 percent of the weight was lost as a result of this treatment. Soft and compliant NGS does not need thermal grease at the contact between the heat source as well as the heat sink when the electrical insulation is not required. A drop in common mode conducted emissions is not caused by the poor electrical conductivity of NGS; nevertheless an analogy with antennas showed a reduction in radiated emissions of 12 to 97%. NGS heat sinks are not advised for the practical applications since they restrict the thermal performance, weight, as well as cost gains that may be achieved. An alternative method for determining the most effective heat sink shape involves utilising an optimization algorithm.

[5] (Cermak, 2020) Thermal performance, electromagnetic performance, dependability, energy efficiency, cost, as well as environmental effect are all examined in this thesis, which uses "natural graphite sheet" (NGS) as a heat sink. Weight-sensitive applications requiring heat sinks to be shielded from the environment may find that NGS heat sinks are an attractive solution. Because NGS is more resistant to corrosion than ordinary metals, it may be used in harsher conditions. The thermal diffusivity, thermal emissivity, thermal conductivity, electrical conductivity, co-efficient of

the thermal expansion, as well as compression behaviour are measured and provided in an easy-to-use manner to give the foundation for the design of the heat sink. NGS heat sinks embedded with heat pipes may ameliorate the low through–plane thermal conductivity of NGS heat sinks, according to an experiment conducted by researchers. NGS heat sinks cannot minimise the conducted common-mode electromagnetic emissions, but they have been shown to lower the radiated emissions by 12 to 97%. The replacement of traditional metal heat sinks with NGS heat sinks has complex ramifications for dependability. NGS heat sinks are expected to be twice as expensive as standard aluminium ones when made in large quantities. Environmental effect of NGS manufacture and end-of-life management is studied and compared to traditional heat sink materials in this study. In order to determine whether or not NGS heat sinks are practical, a case-specific strategy is advised, and the essential phases are detailed. When it comes to industrial r&d., this technology is ready.

[6] (Wu, Fan, et al., 2019) Working performance has been limited by the difficulty of removing heat from high-power electronic gadgets. Even a little layer of "thermal interface material" may have a significant impact on the temperature increase throughout the whole heat dissipation route at ultrahigh heat flux densities. Current liquid cooling mainly considers cooling electronic devices/chips from the top, resulting in an underutilization of cooling capacity. Liquid cooling, an "impingement cooling device" with dispersed returns was developed, constructed, and tested in this article. It is possible to provide the body cooling for the "high-power electronic devices" using the suggested cooling mechanism, which involves immersing the chip in a coolant and having the coolant expelled from the impinging jets. Distribution returns were built up between neighbouring jets to eliminate jet interference, allowing coolant to depart the impingement zone without running through the surrounding jets. When the chip is powered by 550 watts and flows 1000 ml/min, the observed average temperature is 77.0 °C, where the effective heat flux is 110 W/cm2 as well as the coolant temperature is maintained at 40 °C at the intake of the chip At 800 W (160 W/cm2), the high-power chip's average temperature is 78.7 °C with a flow rate of 2000 ml/min. The most "effective heat transfer coefficient" was attained at 41,377 W/m2K. Electronics requiring ultrahigh heat flux densities will be able to utilise the current body cooling system because of its high heat removal capacity.

[7] (Mandrusiak et al., 2018) Reliability and operational life have a direct impact on transient performance of semiconductor devices with high available power ratings. "Liquid-cooled silicon carbide" (SiC) power devices are exposed to various unsteady electrical loads in this work to assess their transient thermal performance. Infrared thermography is used in the first section to investigate an observed asymmetrical device thermal time constant when current is increased and decreased step-by-step. Theoretically, this phenomenon may be explained by the fact that the ON-resistance of MOSFETs is temperature dependent. Three time constants for junction transient response are also identified: one for the die, one for the module, and a third for the cold plate. Using half sine-wave periodic excitations, the second phase of the transient thermal assessment is extended to mimic real-world operating circumstances. Thermal ripple rises as the excitation amplitude increases, but reduces as the excitation frequency increases. They also establish a link between the measured heat response and the time constants deduced from the step-change experiments. When designing the "power electronics cooling systems", it is critical to consider transient loads as well as the role electrical characteristics play in shaping the thermal response.

[8] (Patel & Zhao, 2017) Copper heat spreaders and vapour chambers (with and without graphite foam) were subjected to ANSYS numerical heat transfer simulations. The impacts of heat flow from the power electronics, "heat transfer coefficient" at the heat sink, vapour chamber thickness, and graphite foam on vapour chamber thermal performance were all examined. Ultra-thin vapour chambers with very "high effective thermal conductivities" were shown to have superior "heat transfer performance" than thicker ones with less effective thermal conductivity, according to the simulation tests. This is in contrast to other studies, which found that graphite foam had a considerable impact on thermal performance in thick vapour chambers. In the 5-mm thick vapour chamber, the GF might assist lower the junction temperature by 15-30%. For power electronics, a 250-400 W/cm2 local heat removal efficiency may be achieved by using a GF integrated vapour chamber.

## COOLING OF ELECTRONICS

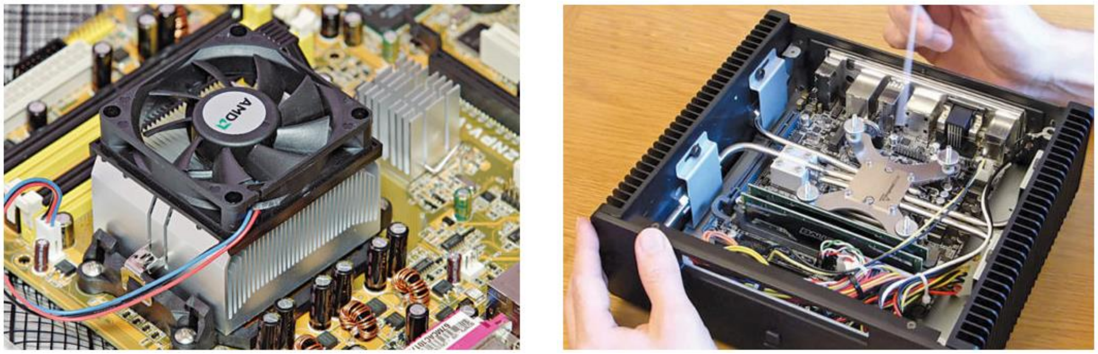
In general, Newton's Law of Cooling governs the pace at which a heated object loses heat. The rate at which heat is lost is proportional to the difference in temperature between the body as well as its surroundings, according to the rule. Heat loss increases in direct proportion to component temperature. Equilibrium temperature is reached when heat lost per second equals the heat generated per second in the component. An very high temperature may cause the component to fail or drastically limit its life span. When this occurs, it is necessary to use thermal management strategies.

### 1. Heat-sinks

Components lose heat to the environment via their surfaces. The rate of heat loss rises with the component's surface area. The temperature rises faster for a 10 watt gadget than it does for a bigger one of the same power. Artificially increasing the surface area of a device may help restrict its temperature. By adding a metal heat-sink to the gadget, this is accomplished. It is possible to produce a heat sink through extrusion, stamping, or even by casting. The heat-sink must be a strong heat conductor, hence it is often made of copper or aluminium or alloys of these metals. In order to dissipate heat to the surroundings, the heat sinks often feature a finned construction. Heat sinks are more effective if the whole unit is adequately ventilated or, even better, if one or more fans are utilised to induce air flow through the heat sink. Heat sinks as well as other components cannot be manufactured with precisely smooth mating surfaces, so high areas rub against one another and a tiny air gap forms over most of the surface. A thermal barrier is created by the fact that air is a poor heat conductor. This reduces the device's ability to dissipate heat. The usage of heat transfer chemicals is necessary to counteract this. Synthetic diamond cooling-sinks have lately been studied for their potential to offer improved cooling. Phase-change materials, which may store a significant amount of energy owing to their high heat of fusion, are another option for heat sinks.

### 2. Heat spreaders

A heat spreader is another common cooling method. It is a metal plate or foil that is thermally conductive and is used to transfer and disperse heat. An intermediate thermal interface between the heat source as well as the secondary cooling device, such as an exhaust fan, is the most common usage for it. Conventional PCBs featuring heat-generating components are commonly supported by heat spreaders. In order to increase heat flow, thermal vias are inserted into the PCB, which connect each component package to the heat spreader. In certain PCB technologies, a metal core layer is directly integrated into the board, eliminating the need for an external heat spreader.



(a) (b)

**Figure-1 (a) Use of heat sink (b) Using heat pipes in electronics cooling**

### 3. Heat pipes

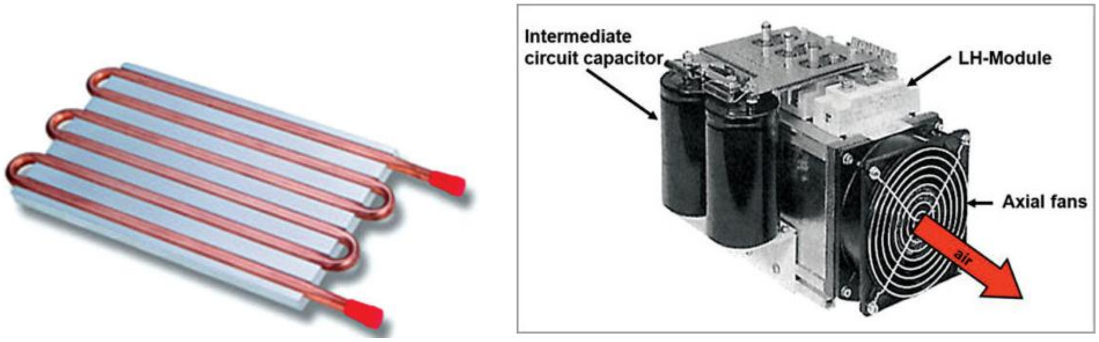
Using heat pipes, you may achieve a high level of thermal conduction efficiency. A liquid or coolant is contained inside a sealed, hollow tube in these devices. Two separate heat exchangers are connected by means of a tube, one at the source as well as the other at the destination. To cool the other end of a pipe, cold water is poured into it from the other end. The vapour condenses as well as returns to the heated end by capillary action or gravity. For the most part, thermally conductive metals are used to construct heat pipes, which may either be left flat or twisted into intricate designs. As a result, they're ideal for board designs with a restricted amount of area.

### 4. Thermal interface materials

In order to maximise heat transmission between a heat source as well as a cooling device (or two adjacent cooling devices), the thermal interface materials must be used. Some of these materials may be used in a number of ways since they are pre-made and can be applied in various ways. Adhesives and sealants are two examples of these. These are meant to fill up air gaps between the contact surfaces because of their ability to adhere to surface irregularities as well as defects. To maximise heat transmission, this guarantees that all of the available surface area is being used. With heat-generating electronics, potting inside a metal box, with or without connected cooling fins, using a "thermally-conductive potting compound" may be sufficient to assure temperature management. In order to lower the thermal resistance at the device-to-heat sink interface, special heat transfer materials have been developed. As a result, the device's working temperature is reduced and more heat is removed from the heat sink.

## 5. Cold plate

As a "heat transfer interface" between a heat source as well as a cold flowing fluid (or any other heat-sink), a thick metal plate, known as a cold plate, may increase the cooling performance. Instead of cooling in direct contact with the cooling fluid, the heat source is cooled behind the thick plate in such an arrangement. By carrying the heat current in an appropriate manner, a thick plate may considerably increase heat transfer between the heat source as well as the cooling fluids. The lack of increased pumping power as well as the lack of enhanced "heat transfer surface area" are two of this method's most appealing features. This is a departure from the fins (extended surfaces) in many ways.



(a) (b)

Figure-2 (a) Cold plate (b) Forced air cooling of electronics

## 6. Forced air

Forced air over a heat source is the most prevalent way of active cooling. With the help of a fan or blower, the flow of air may be increased immediately above a heat-producing equipment, like a heat-sink. The accelerated removal of hot air is made possible by the enhanced air flow. This greatly enhances the total heat dissipation of the device. It is possible to adjust flow rate by using fans of various sizes and designs as well as their suitable location and direction. Especially in an enclosed systems where warm air must be routed to an exhaust vent, this is critical. Using temperature sensors, more complicated systems may regulate both variables using electrical fan control. Pumped liquid cooling is another method of actively managing heat. A pump moves a circulating coolant via separate tubing to remove the heat from a heat source in this closed-loop system.

## 7. Solid-state heat pumps

Thermoelectric coolers are another name for these semiconductor devices (TECs). To speed up heat dissipation, they are often positioned between a heat source as well as a cooling fan. In order to create a temperature difference between the two sides of a TEC, voltage must be given to it. As a result, heat may be transferred by conduction. Heat may still be transferred via the use of thermal exchangers (TECs) even if they aren't as efficient as other heat transfer methods. Spot cooling and sub-ambient temperatures are appropriate for TEC applications. Heat transfer flow is reversed if the TEC current is reversed. As a result, the gadget now functions as a heater. This is a great option for situations that need very fine temperature control.

### 8. Electrostatic fluid acceleration

Without any mechanical elements, an "electrostatic fluid accelerator" (EFA) pumps a fluid, like air. EFAs employ an electric field to push electrically charged air molecules rather than revolving blades like traditional fans. To begin, the EFA must first produce some charged ions or molecules, because of the neutral charge of air molecules. Accelerating fluids is accomplished by ionising the air molecules, using those ions to propel more neutral molecules in an intended direction, and then neutralising the captured ions to remove any remaining charge. Fundamentally, we've known about the EFA concept for a while, but only recently have we seen improvements in the design and fabrication of EFA devices which may enable them to find practical and affordable uses, such as micro-cooling of the electronic components.

### 9. Role of nanotechnology

Using semiconductor nanostructures, a worldwide team of scientists lead by a researcher at the University of California, Riverside has altered the energy spectrum of the acoustic phonons, which are wave-like excitations of elements in crystalline materials. Thermal management of electrical gadgets will benefit from the findings. Using a method called "Brillouin-Mandelstam light scattering spectroscopy" (BMS) as well as semiconductor nanowires made from "gallium arsenide" (GaAs), the researchers in Finland studied the mobility of phonons in crystal formations. Researchers were able to adjust the dispersion of the acoustic phonons by altering the size as well as shape of GaAs nanostructures. Engineers face a huge obstacle in their efforts to shrink electronic devices by controlling the dispersion of phonons, which is critical to removing heat from nanoscale electronics. As a result, thermoelectric power production may be improved. Thermoelectric devices benefit from phonon-induced reductions in heat conductivity.

## CONCLUSION

Power electronics cooling thermal management has gotten more attention in recent years because of incorporation of the electrical systems. The widespread usage of microelectronic devices as well as semiconductor devices in various applications, like the central processing units, illustrates the importance of these technologies. Because of the sensitivity of their functioning to operating temperature, these devices generate a significant quantity of heat which must be dispersed appropriately. When operating at high temperatures, thermal strains may cause physical damage to the components and increase the risk of component failures. To meet the required working conditions, these devices must have proper thermal management. As heat dissipation rises, the temperature of semiconductor components climbs linearly. ) A heat sink made out of graphite film (GF) is believed to be the best option for thermal management. Nonetheless, the use of GF as a heat sink might be severely restricted if it has an ineffective thermal interface material (TIM).

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