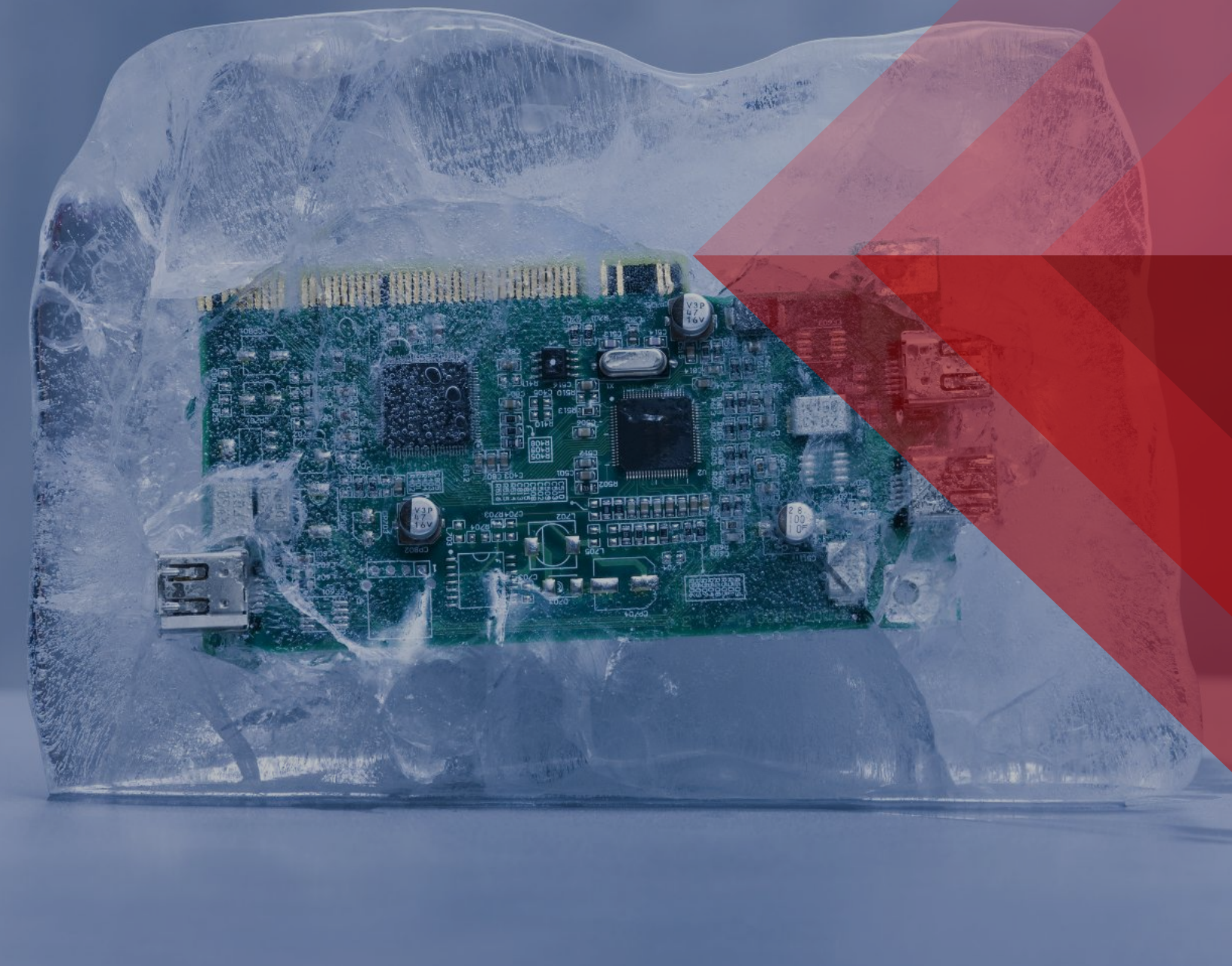
The Heat Is On

Why Thermal Management Is Crucial to Data Center and Telecom Performance



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Executive Summary

Thermal management—a small, silent vital enabler to network infrastructure—significantly affects network operational performance. That's because electronic components get hot—a problem exacerbated by heightened network demands for improved reliability, higher power density, and speed.

Thermal management has been limited by conventional thermal interface materials (TIMs) and traditional active-cooling methods. But impressive results can be achieved by using effective thermal management in hardware components such as circuit boards in active antenna units (AAUs) and line cards for routers and switches. Thermal management helps data centers and telecom operators to reach their target network performance metrics and to enable emerging technologies such as **5G, Wi-Fi 6, and supporting 400 GbE speeds.**

Perhaps it seems counterintuitive to start optimization at the integrated circuit level. However, data center and telecom infrastructures use components in mass quantities. One small uptick in thermal management at the integrated circuit level can create colossal, in-aggregate improvements.

Few materials master heat dissipation, but all networks need it. In router, switch, and circuit board design, effective thermal management is a notable competitive differentiator. Advanced thermal management materials include thermal gels, phase change materials, thermal GAP PAD® materials, and thin-film thermally conductive, dielectric coatings.

This paper explains how telecom operators and data center technologists can elevate network outcomes by improving thermal management at the electronic component level—and why it matters.

A Massive Lever

The heat is on for data center and telecom operations. Global demand for data, internet access, and bandwidth is skyrocketing. Network infrastructure spending has escalated to respond to the worldwide need.

A Massive Lever

One vital linchpin, however, holds the key to enabling expansion: thermal management. Networks need to operate integrated circuits at maximum processing power without overheating. As speed and component densities increase, however, so does the heat generated within those integrated circuits. Although active cooling assists with heat dissipation, it is expensive—and is reaching its limit.

Yet, those demands aren't letting up. New technology innovations—among them, 5G and Wi-Fi 6—and 400 GbE data transmission rates are dramatically increasing processing speeds, further elevating thermal management's importance as the gateway to future expansion.

Data centers rely on enormous scale and size to provide massive computing power. For example, a typical corporate data center may have 50,000 to 80,000 servers; hyperscale data centers have many more. In telecom, estimates suggest that there are over 4.1 million telecom towers globally.

The limiting factor to network size and operations is either power or cooling, both of which also represent a significant percentage of operating expense (OpEx).

It makes sense to minimize the aggregate heat generated by all that hardware. Thermal management is the gateway to future expansion, in part because of its domino effect on network performance. When it's successful, thermal management helps to maximize network performance, boost reliability, and enhance component life.

As a result, many electronic component manufacturers are motivated to improve thermal management at the source: the network infrastructure level within integrated circuits.

Akin to a powerful lever, the multiplier effect of a small heat dissipation improvement in the circuit boards comprising routers, switches, servers, and AAUs adds up to big outcomes. Thus, thermal management materials help to minimize the aggregate heat generated at the network infrastructure level. Among them: circuit boards, line cards for routers and switches, and printed circuit boards (PCBs). The PCBs often are used in AAUs and baseband units (BBUs, sometimes called active band units or ABUs).

Why is heat a problem?
Heat accelerates a component's performance degradation and reduces its life.

Electronic components are composed of semiconducting, conducting, and non-conducting materials. For any of them, the general rule of thumb is that the speed of chemical reactions doubles for each increase of 10° C. Electronic components need to be maintained at stable temperatures; otherwise, chemical reactions can break down or alter their materials.

Physical degradation can also occur. Thermal or power cycling can warp components when overheating occurs, such as when they run at maximum temperatures for extended periods of time.

As electronic devices become more powerful, they generate more heat. Thermal management materials play a pivotal role in network performance and mitigate risks of system reliability drops, product failures, and degradation over time. The good news is that it is possible to address these challenges with these exceptional thermal management materials—such as thermal gels, thermal GAP PAD® materials, phase change materials, and microTIMs—that are used in construction of the micro-sized electronic components.

Challenged by heightening demands for increasing reliability, density, processing power, and speed, thermal management is the pathway to data center and telecom performance, enabling 5G, Wi-Fi 6, 400 GbE data transmission rates, and other emerging innovations.

Turning Up the Heat

This isn't a minor matter. Data center and telecom trends underscore thermal management's crucial role.

Turning Up the Heat

Data Center

Cloud hyperscale data centers and their colossal computing power capabilities are working to meet the rising demands for data volume and speed. The world's largest data center operators—Amazon, Google, Facebook, and Microsoft—spent in excess of **$149 billion** (USD) from May 2020 to May 2021, according to Synergy Research Group. And the demand keeps rising. Per Cisco, network traffic within data centers is growing exponentially, exhibiting **a 27% CAGR during the last five years**, propelling investment and expenditures in data center networking to epic levels.

Data center OpEx, however, has reached a critical juncture, primarily due to cooling and power costs. Data centers are spending about 50% of their budgets on hardware and software, with a large percentage spent on ongoing maintenance. Typically, a large corporate data center spends $10–$25 million per year on OpEx, far outpacing the budgets allocated to cover those expenses.

Per McKinsey, **significant data center OpEx is outstripping budgets**. That is making data center costs a boardroom issue and spurring the shift from private server solutions to cloud-based services via hyperscale data centers.

25%
Data centers comprise 25% of corporate IT budgets

20%
Costs to run data centers are increasing 20% per year

6%
IT budgets to cover those expenses are increasing 6% per year

The takeaway: Data center OpEx threatens profitability. Given that thermal management can help maximize data center output while minimizing OpEx, it's worth investigating.

Telecom

These changes aren't only in the data center. Concurrently, telecom infrastructure is growing rapidly. The telecom tower market was valued at **$39.47 billion** in 2018 and is projected to reach $114.06 billion by 2026. To fuel this growth, telecom operators are focused on controlling both capital expenditures (CapEx) and OpEx. According to a PwC survey, telecom operators indicate that **up to 20%, or $65 billion, per year in CapEx is wasted** due to under-optimized CapEx.

According to telecom operators, up to 20%—or $65 billion—is wasted per year in CapEx.

OpEx is also an ongoing challenge for telecom infrastructure. Mobile base stations and cell towers are always-on equipment and they generate rising levels of heat. Temperature and humidity fluctuations in outdoor environments are further burdens on remote telecom equipment that is equipped with limited active-cooling options.

Heat generated on the printed circuit boards used in base stations and cell towers can degrade equipment performance and reduce lifecycles. Because it costs so much to access and repair telecom towers, telecom operators need electronic components with maximum longevity and reliability. The operational target is near-zero failures and minimal maintenance. Telecom components can help achieve this goal by relying heavily on effective thermal management, using advanced materials applied to the printed circuit boards that power AAUs and BBUs.

Turning Up the Heat (cont.)

Emerging network enhancements

Everything is moving faster. 5G, Wi-Fi 6, and 400 GbE data transmission rates increase the need for effective thermal management in integrated circuits. Electronic components must respond to speed and component requirements and all the other demands that enable our global always-on connectivity.

10x

5G has 10 times faster data processing speeds than 4G

9.6 Gbps

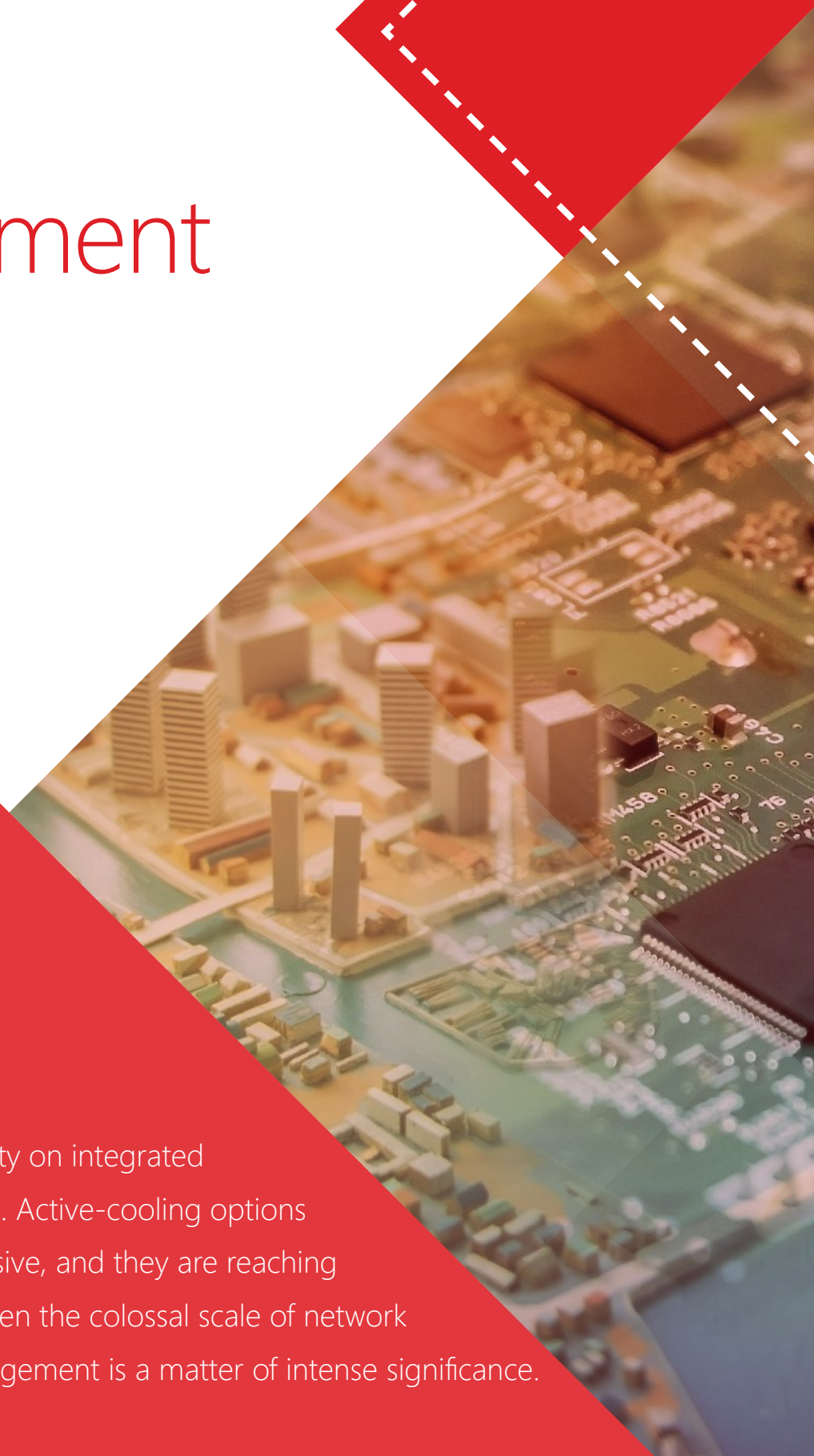
Wi-Fi 6 has the capacity for 9.6 Gbps, compared to 3.5 Gbps for Wi-Fi 5

4x

400 GbE data transmission rates are four times the speed of today's 100 GbE

To keep up, thermal management capabilities must increase concurrently.

Thermal Management at Scale



The higher processing density on integrated circuits generates more heat. Active-cooling options do help, but they are expensive, and they are reaching their physical limitations. Given the colossal scale of network infrastructure, thermal management is a matter of intense significance.

Thermal Management at Scale

Data Center

Hyperscale data centers enabled an unprecedented evolution of cloud computing. In 2020, an estimated **61% of businesses migrated their workloads to the cloud** across all industries. To keep pace with this demand and the heat dissipation it requires, the data center cooling market for active cooling is forecast to **surpass $20 billion by 2024** as the public cloud computing market balloons to $800 billion by 2025. Advanced materials help tackle the operational challenge of heat dissipation with small, incremental improvements in thermal management—and it adds up to big network outcomes.

> The market for active cooling in data centers is forecast to surpass $20 billion by 2024.

Another factor impacting thermal management is higher processing densities. Five years ago, the racks with line cards in data centers handled around 100 GbE per pluggable optical module (POM). Since then, this number has quadrupled; it is poised to surpass 400 GbE speeds without any increase in rack size. More processing is required per board, and that elevates the heat generated in the electronic components.

Aggregate impact:
What 5° C means in data centers

Can 5° C really make a difference? With the transition to 400 GbE-capable modules, the power level per POM—which number as many as 32 per line card—can reach as high as 15 watts. Alternatively, advanced, innovative microTIMs enable more heat to dissipate from the module, which reduces operational temperature at a rate of 0.33° C per watt. For a 15-watt module, temperature reduction is upwards of 5° C, which is significant in aggregate across the line card.

Telecom

Telecom operators face a growing energy challenge, too, which puts more emphasis on innovative thermal management. According to industry estimates, **as 5G replaces 4G, each telecom site will require two to three times more power**. On average, energy costs account for 5–7% of OpEx. These rising costs squeeze margins and limit the growth potential of on-site active-cooling options, making thermal management a vital determinant for effective telecom operations.

> As 5G replaces 4G, each telecom site will require two to three times more power.

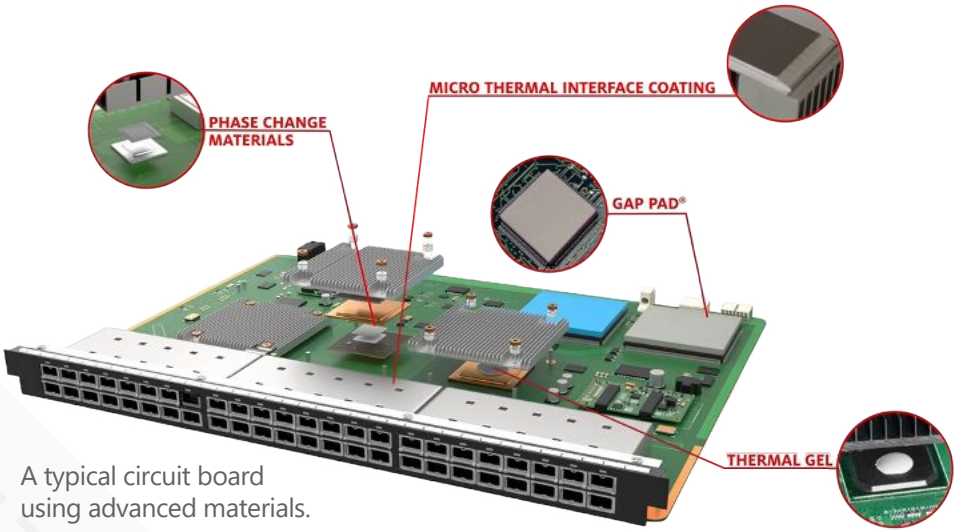
Electronic components are susceptible to constant in-operation stress. They also must contend with outdoor-related moisture and temperature fluctuations, which can lead to corrosion. Componentry is small, delicate, and temperature sensitive. It's important to avoid overheating printed circuit boards within telecom's AAUs and BBUs to sustain reliable operation and equipment life. 5G complicates this challenge; its higher switching and routing speeds increase heat generation at higher power densities.

Innovations in Advanced Materials

Innovations in Advanced Materials

Advanced materials—such as thermal gels, thermal GAP PAD® materials, phase change materials, and microTIMs—can make a huge difference when used in micro-sized electronic components.

It all starts with the circuit board, the primary source of heat generation. Circuit boards may use several thermal management materials, which in turn power a router, switch, server, AAU, or BBU. To better understand how to use thermal management, let's look at each of these robust heat-dissipating materials.



A typical circuit board using advanced materials.

Phase Change Materials

Phase change materials replace grease as the interface material between power devices and heat sinks. Thermal phase change compounds can form a thin bondline with low thermal resistance. Application is also simple, so the material can be integrated into fully automated processes, which supports mass production.

Thermal GAP PAD® Materials

Thermal GAP PAD® materials eliminate air space between hot components and heat sinks to manage the challenging thermal loads inherent with higher power densities. These are soft, high-compliance materials that conform to irregular surface shapes. They fill small gaps to enable interface wet-out and optimize thermal transfer. Thermal GAP PAD® materials minimize the adverse impacts of heat on device operation and lifetime across data center and telecom applications. Newer GAP PAD® materials, which help to address heat from 5G infrastructures, are rated at 12.0 W/m-K.

Micro Thermal Interface Coatings

MicroTIM is a durable, thermally conductive, thin film coating applied to networking line card heat sink s that come in contact with POMs. MicroTIMs enhance the thermal performance and durability of heat-generating devices—including POMs—and aluminum heat sink assemblies. MicroTIMs also provide additional resilience to POMs' repeated plug-and-pull action, and help lower networking line card heat.

Thermal Gels

Thermally conductive gels are conformable. They fill gaps across many different types of assemblies, where they provide low component stress, simple rework, process flexibility, in-application stability, and efficient thermal conductivity. Thermal gels often are used for stationary applications that require stability, a common requirement in the telecom sector. They are available in one-component liquid and curable formulations.

Network Infrastructure Outcomes

Network Infrastructure Outcomes

Advanced materials help with thermal management at the electronic component level to drive improved outcomes at the data center and telecom level.

The result	The root cause addressed
Efficiency	Better thermal management enables maximum operating power and maximum processing.
Less data latency	More heat dissipation lets facilities use higher power densities. That means more processing power and therefore lower latency.
Reliability	Components don't degrade as fast due to greater thermal efficiency.
Less downtime	Better component life expectancy and minimal repairs reduce maintenance costs.
Reduced hardware costs	With better hardware life expectancy, component replacement costs decrease.
Reduced cooling costs	Less need for additional cooling hardware and fans means less money spent on active or system cooling.

Hot Stuff: The Takeaway

Rising demand for data, internet access, and bandwidth has increased the need for thermal management. Advanced, innovative component materials provide next-level thermal management that helps organizations reach their goals of improved reliability, performance, and cost management. Tomorrow, they are the gateway to 5G, Wi-Fi 6, 400 GbE data transmission rates, and beyond.

Selecting the right materials for routers, switches, and circuit boards is essential for data center and telecom performance. We invite you to align with an innovative, advanced materials partner to source and, in some cases, co-innovate material development. Henkel stands ready to work with you toward that goal.