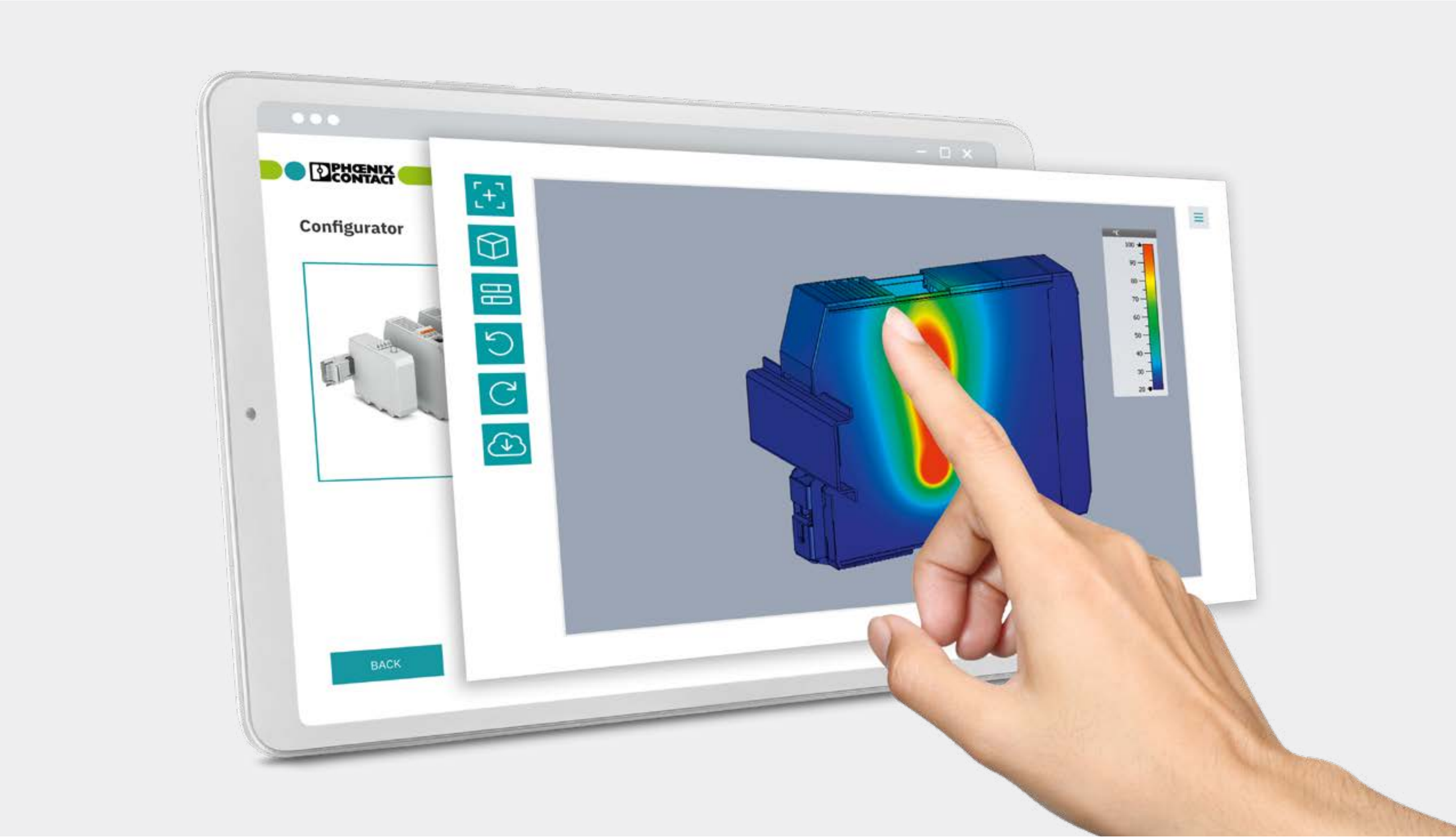

A guide to thermal management solutions for electronic enclosures

By Michael Wayde, Product Marketing Manager, Phoenix Contact USA

Key takeaways:

- As devices become smaller and power density continues to rise, effective thermal management during the design process is more important than ever
- To reduce heat, design engineers need to consider material selection, design style, construction methods, and other factors
- A vendor with simulation tools and consulting services can help designers balance the cost, performance, and availability needed for specific projects

Introduction

As Moore's law accurately predicted in 1965, the number of transistors in a dense integrated circuit (IC) doubles about every two years. The trend signifies that smaller, faster electronic devices are required to increase performance. The introduction of System on Module (SOM) boards accelerates the process of miniaturization and increases the packaging density.

Because of the increasing number of modules themselves, along with the power they require, there is an exponentially greater need for more sufficient heat dissipation within electronic enclosures (Figure 1). According to research conducted by the U.S. Air Force, high temperatures cause about 55% of all critical technical issues.

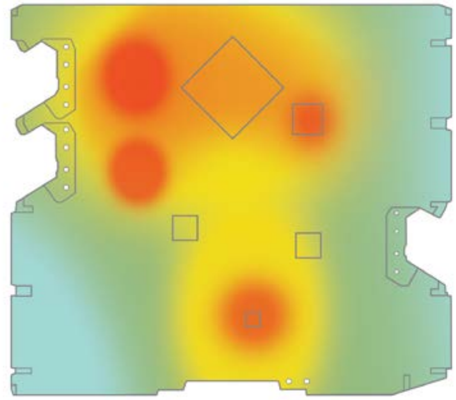

Figure 1: Many factors, including smaller enclosures and components, higher data requirements, elevated power levels, increased heat density, insufficient ventilation, and dust, are driving the need for thermal management in electronic enclosures.

Consequently, the global demand for heatsinks in electronic enclosures has been steadily increasing over the past five years. In fact, the market is expected to grow at a compounded annual growth rate (CAGR) of 6.5% by 2028. Driving the demand for thermal management strategies for device manufacturers is the push towards smaller profiles, miniaturized printed circuit board (PCB) components, higher data requirements, elevated power levels, increased heat density (which is watts per square centimeter), insufficient ventilation within the control cabinet, and added dust/dirt found in more demanding applications.

With these rising temperatures, electronics are exponentially at risk as well. Studies show that the service life of electronics is halved for every 10 degrees the system goes above the ideal thermal level (Figure 2).

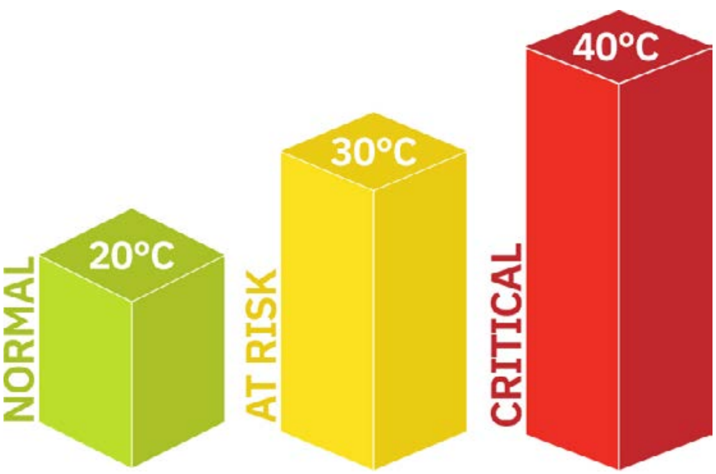

Figure 2: As temperatures rise, electronic devices become more likely to fail.

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Heat dissipation strategies

Not all applications require significant thermal mitigation solutions. In fact, customers have many options available to them to mitigate heat from their devices. The path to removing the necessary heat from a device is a sliding scale that should be considered as early as possible during the design cycle.

Component relocation

Relocating thermally demanding components higher within an enclosure will also more efficiently eliminate heat. If components are placed too low, their heat energy will flow over the entire PCB, raising the temperature of the entire module.

Component orientation

Orienting components to maximize the amount of surface area exposed to air is another inexpensive way to reduce heat within a system.

Passive heatsinks

When the addition of vents or simple adjustments to PCB components isn't enough to reduce heat within a module, heat spreaders and passive heatsinks can be integrated into modules to more efficiently transfer heat up and away from electronic components.

Active heatsinks

At the most extreme level, active heatsinks (fans) could be added to eliminate thermal loads that can't be handled with more traditional techniques.

Understanding heat transfer

When managing thermal loads within an enclosed space, it helps to understand the four common methods for moving heat.

1. **Conduction** is the transfer of heat from one metal surface to another. Heat spreaders and passive heatsinks are employed in conduction methods of heat transfer.
2. **Convection** is the process of moving heat by a fluid, such as water or air. Proper venting within an enclosure promotes better airflow and increases convection of heat up and out of a housing. Active heatsinks with fans are good examples of convection-style cooling.
3. **Radiation** is the transfer of heat in waves. This is the heat that radiates from the sides of an enclosure. Understanding the heat generated from adjoining modules upon a DIN rail aids in the techniques employed for proper thermal management.
4. Finally, there is **evaporative cooling**, which works like the compressed refrigerant lines within air conditioning and refrigeration systems.

For most DIN rail and smaller field enclosures, conduction and convection methods are the most pragmatic and affordable options for moving heat. For this white paper, we will focus solely on these two techniques.

Thermal management design considerations

When starting on your thermal management journey, there are five heatsink decision elements that you should take into consideration: active versus passive, material selection, design, construction method, and vendor selection. In this white paper, we will dive into each consideration (Figure 3).

Figure 3: There are many things to consider when making decisions about thermal management.

If all other heat dissipation strategies have first been considered, and the decision to add a heatsink has been concluded, then the next decision that needs to be made is whether to utilize a passive or active heatsink. Passive heatsinks utilize conduction, convection, and radiation techniques to move heat out of a system with no moving parts. Conversely, active heatsinks are motor-driven fans that rely solely on convection technology to mitigate heat.

Overall, active heatsinks can handle a much higher thermal load compared to passive variants, but that increased productivity comes with accommodations and sacrifices.

- On larger applications, active heatsinks can be smaller and more compact than a passive heatsink. This isn't necessarily the case on smaller applications where heatsink fillers can be tailored to the exact size of specific hot spots, thereby reducing enclosure sizes.
- Active heatsinks contain a moving component, a motor-driven fan. For applications with connectivity restraints, designers may have to sacrifice a pole to accommodate power just for the fan motor.
- Introducing a fan requires filters to stop the ingress of dirt and dust. Those filters need annual cleaning and maintenance to make sure they are working properly.
- Most compact DIN rail housings are so small that fans are more expensive to introduce than a passive heatsink. The enclosure would likely need major modifications to accommodate the fan.

Unlike active heatsinks, passive heatsinks require no moving parts or power sources. They can be tailored to match the exact size needed for proper thermal management. They are far more affordable than their active heatsink equivalents. They don't require additional filters or annual maintenance to keep them running as installed. With no moving parts, they are quieter and easier to install than active heatsinks.

Material selection: Copper versus aluminum

If proceeding with a passive heatsink design, special consideration should be placed on material selection. The two most common materials are aluminum and copper. They each come with their own benefits and drawbacks. Other materials to consider are carbon nanotube designs or graphene-based coatings. Both are exciting, emerging technologies that could become more popular in the future, but for now, they are still widely experimental and more expensive. You would need a mission-critical design that has weight, size, and high thermal demands to warrant seriously considering these options.

Aluminum is the market leader for passive heatsink designs. It has relatively good thermal properties, is lighter than copper, and 50 percent cheaper than copper. Copper has far better thermal conductivity compared to aluminum, but its overall weight and cost are much higher. Some manufacturers will combine both aluminum and copper into designs to maximize performance.

Passive heatsink design style: Pin or fin?

The third consideration is whether to use a pin or fin style design. Certain construction methods, which will be discussed later in this white paper, will dictate the style that can be used. The major benefits of the pin-style design are its increased surface area and its ability to accommodate air flow from multiple directions. Conversely, fin style variants only allow for airflow to travel effectively in two different directions, which limits their flexibility in certain designs. Accommodations need to be made for optimum performance.

Once the material and design style have been chosen, the construction method can now be selected to accomplish the application's thermal goals. Each method should be considered, but different methods are better suited to handle certain materials and fin styles (Figure 4).

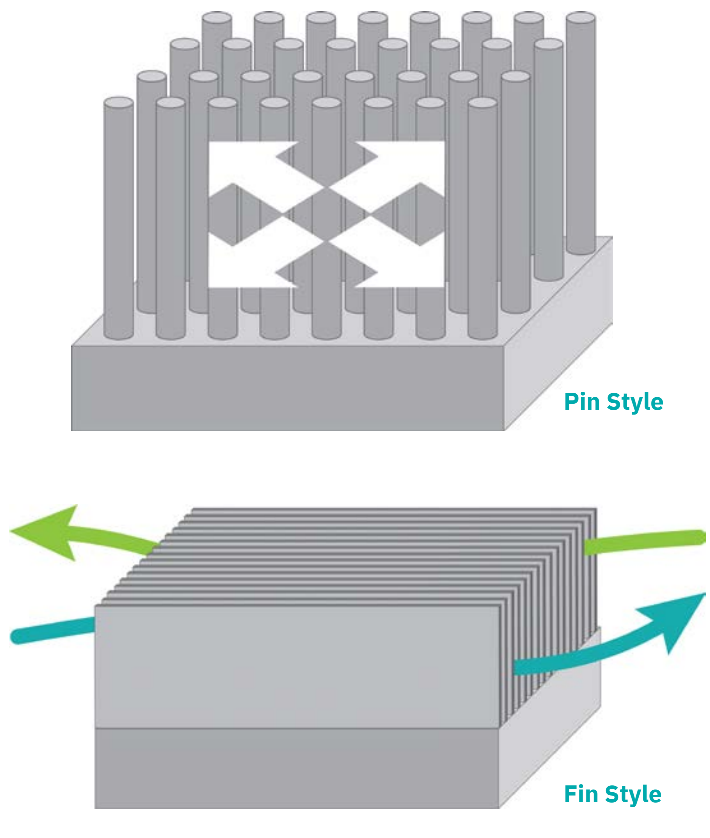
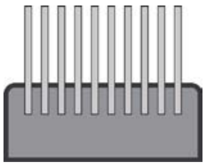


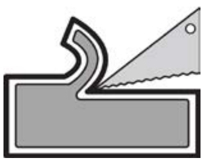
Figure 4: The two common heatsink designs are pin style (omnidirectional airflow) and fin style (bidirectional airflow).

Heatsink construction methods

Let's take a closer look at each method to better understand their benefits and drawbacks.

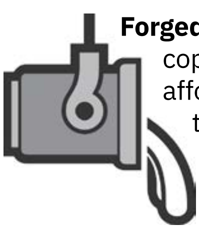


Bonded heatsinks are typically used in large applications. Typically, there are much larger designs than what you would need in most DIN-rail electronic enclosures. As the name implies, bonded heatsinks combine two metals, such as aluminum and copper together, into one form factor. The base and fins could be different materials, or the fins could be a mixture of two different materials. Both approaches can be considered to increase performance while reducing weight and cost. The drawbacks of this method include only a moderate thermal performance and high manufacturing cost.



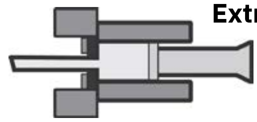
Skived-style heatsinks are made solely from one solid block of copper. Cutting tools slice thin sections of the copper into fins, which are bent up into place. This process can produce very high fin density designs, which increase the surface area for greater heat dissipation. Since copper is used, the drawbacks include a higher weight and higher price than aluminum designs. Because of the skiving process, these designs can only handle limited fin directions. Additional support structures need to be milled separately.

Stamped heatsinks have stamped fins soldered into place. As a result, they are typically only viable for low-power applications. While they can be produced at a very small cost, they only offer low thermal performance.



Forged heatsinks can be made out of copper or aluminum. They are reasonably affordable to produce. Fast production techniques mean high volumes can be realized with their pin-style design. We already discussed how advantageous this approach is for increased surface area and omnidirectional airflow. This method requires additional accommodations in enclosure designs for proper fit and extrusion, limiting their capabilities and thermal performance.

CNC-machined heatsinks are the ideal choice for complex designs with intricate geometries. They can obtain very high thermal performance and include very high fin density. The real drawback with this method is that they typically have longer lead times for design and production.



Extruded profile heatsinks are a commonly used method. These can be constructed of copper or aluminum. They are produced by pushing a billet of material through a die to create long lengths that can be cut down to appropriate sizes. They offer low manufacturing costs and are capable of low to high levels of performance, depending on their design. This style can easily accommodate custom specifications. They are limited in how they can be installed for proper airflow, and dimensions are limited to the width of the extrusion.

To determine which method is right for you, one should consider a variety of factors such as cost, performance, size, weight, design flexibility, fin density, directional sensitivity, and production time/availability.

For most, the ideal solution can be determined using the Triple Quality Constraint paradigm. Quality is a balance between three competing forces: time, budget, and scope. You can certainly have one of these...maybe even two out of the three, but it's highly doubtful that you can get all three. For the purposes of this white paper, I've translated that to Cost, Thermal Performance, and Availability (Figure 5). You can get a very high-performing heatsink, but you will likely sacrifice price or availability. Conversely, you can get a cheap heatsink that's easily available, but you will likely sacrifice thermal performance in the end.

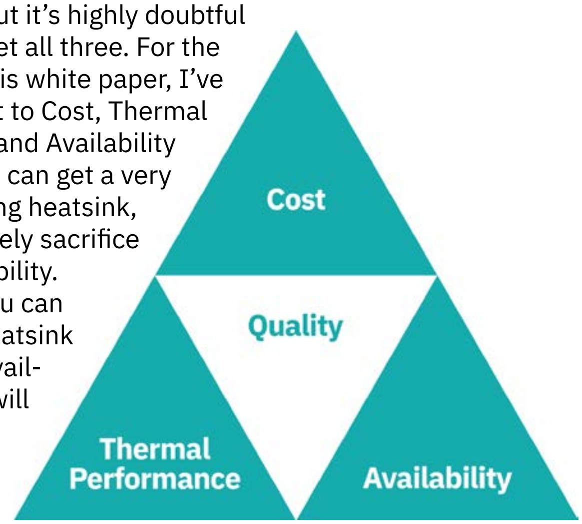


Figure 5: When it comes to thermal performance, quality is a balance between cost, thermal performance, and availability.

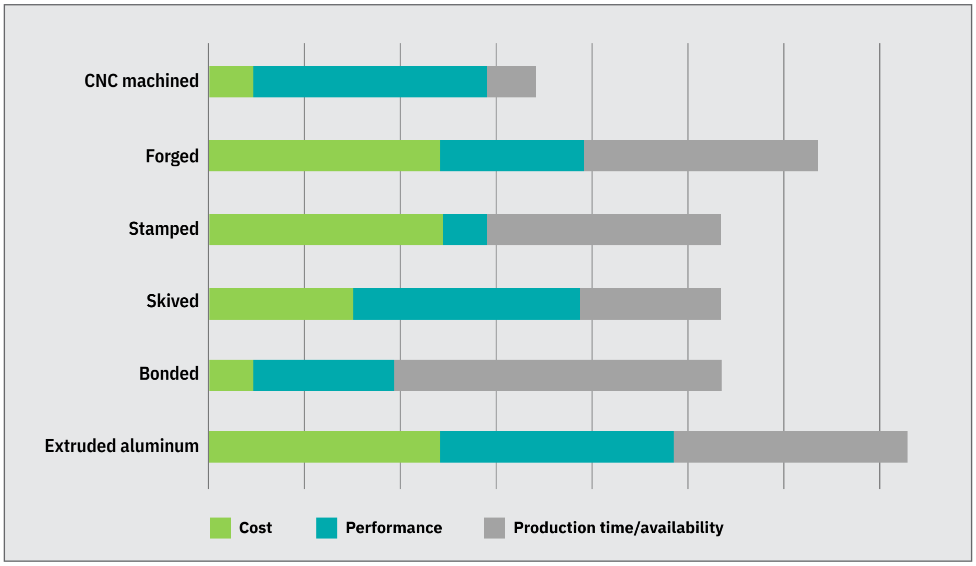


Figure 6: Different types of heatsinks have different advantages.

The above chart (Figure 6) visually depicts the six methods for how they rank on these three factors. Some are better on price, others on thermal performance. In the end, extruded aluminum ranks highest in the ability to meet client expectations for cost, performance, and availability.

Vendor selection

The final consideration on the journey is determining which vendor to use to handle your thermal management needs. Here, one must consider the triple quality constraint paradigm. The challenge with every new project is to deliver the best possible solution without sacrificing time or budget. You can choose an off-the-shelf heatsink solution to get fast delivery at the cheapest possible cost, but as you can imagine, this could mean less than ideal performance or even additional customization to try to fit into a housing.

The antithesis of that is a fully custom solution. This approach may have long lead times and high component costs. A holistic solution provider who offers both housings and integrated heatsinks can maintain a level of base heatsink parts that are designed to integrate seamlessly into housing platforms. In many cases, this is the most cost-effective approach. Stocked components can speed up availability, while still providing a high level of performance.

The Phoenix Contact thermal strategy

Phoenix Contact entered the heatsink market with the Industrial Case System (ICS) DIN rail enclosure portfolio in 2016. Since then, thermal management products have been released for the Building Case (BC) system, ME-IO platform, and the field or DIN rail-installed Universal Case System (UCS). To support customers in their thermal management journey, Phoenix Contact launched an online thermal management tool in 2020.

Phoenix Contact offers free thermal simulations during the development cycle to help reduce the risk to the design engineer (Figure 7). Other manufacturers on the market can only provide catalog values online for their enclosure platforms to show thermal characteristics for housings, headers, and/or connectors.

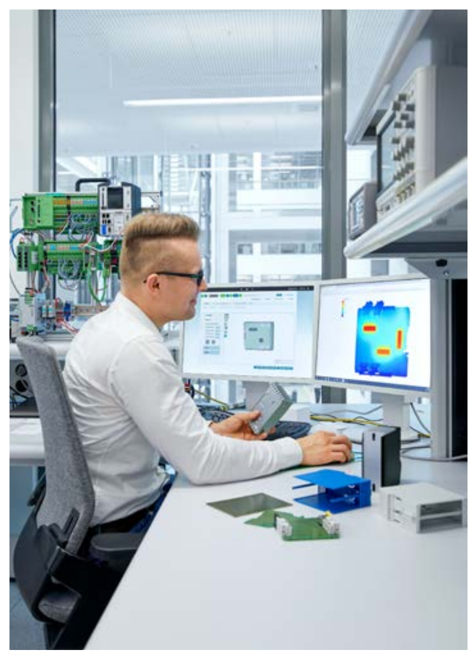


Figure 7: Phoenix Contact offers free thermal simulation during the development cycle.

Major redesigns can delay launch timetables, costing a company hundreds, or even thousands, in lost revenue. In a worst-case scenario, designs make it to market where catastrophic failures cost companies tens of thousands of dollars that could have been avoided if proper thermal management techniques were considered earlier in the development process. By adding additional thermal tools earlier in the development process, we can lower the cost of rework long before any lab test is performed. To reduce this customer blind spot, we now have the online thermal simulation tool, and a team of thermal experts who will create a free comprehensive thermal management report to guide recommendations.

Application in action: Solutions for single-board computers with high demands

As an example, we'll take a closer look at single-board computers (SBCs) (Figure 8). SBCs, such as Raspberry Pi computers and Arduino open-source microcontroller platforms, are an increasingly popular choice for new and developing applications. Historically, they have not satisfied the exacting requirements of industrial applications. This is changing rapidly, as are the requirements placed on SBCs in both industrial and private applications.

It all starts with the selection of a housing system and culminates in heat dissipation strategies for SBCs that are subject to high demands.

In the consumer sector, basic heatsink solutions are often simply stuck onto the processors to be cooled. The achievable reduction in processor temperature is therefore not particularly high. Heat dissipation concepts specifically tailored to the application are rarely found in the market.

The UCS (Universal Case System) housing from Phoenix Contact, developed specially for the installation of embedded systems and SBCs, can accommodate heat dissipation concepts. Integrable combinations of heatsinks and heat spreaders effectively cool highly stressed components and processors in a passive way. From a thermal point of view, optimally designed heatsinks, in conjunction with heat spreaders adapted to the application, ensure the best possible passive heat dissipation from local heat sources.

SBCs and electronics developed with high-clocking processors with associated thermal output require adaptable heat dissipation solutions. This could involve simply incorporating openings in the housing or a more targeted heat dissipation concept based on the specific application. Ideally designed to be passive so they don't impair reliability, current heatsink/heat spreader solutions for the UCS housing series can be included to reduce thermal load, thereby increasing the lifespan of an SBC.

Using plastic housings as part of a thermal optimization strategy offers many advantages. They are lightweight, have electrical insulation properties, and are simpler to process. They can be optimized to integrate heatsink/heat spreader solutions. In fact, some heatsink solutions can be as flexible as the entire housing system itself.

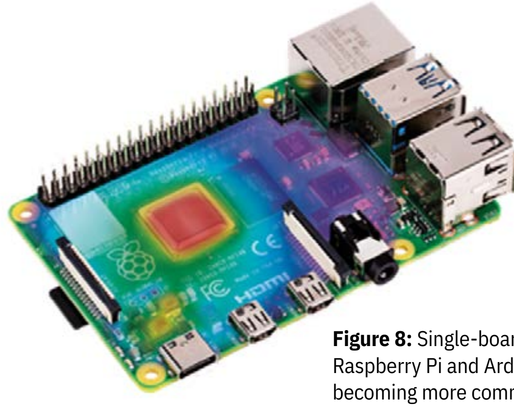


Figure 8: Single-board computers, like Raspberry Pi and Arduino platforms, are becoming more common in industrial applications.

SBC heat dissipation concept in detail

Heatsinks are specifically designed for the UCS housing system and the electronics typically installed in them (Figure 9). The solution offers a lightweight enclosure with an optimum thermal path. Its integrated heatsink/heat spreader solution, combined with the modularity of the housing system, features virtually no restrictions in combining the individual components of the system.

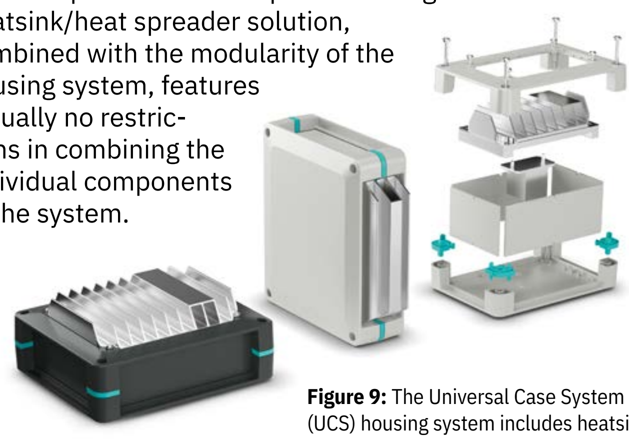


Figure 9: The Universal Case System (UCS) housing system includes heatsinks built into the design.

The complete heat dissipation system for the UCS housing family is based on the following components:

- Heatsink for use in the housing half-shell
- Heat spreaders for generating the optimal thermal path
- Heatsink designed as a side panel

The basic principle is that heatsinks can be integrated into several UCS housing sizes and positioned exactly where local hot spots occur. This means that the smaller UCS HS 145-125 heatsink for housing size 125-87 can also be used in all larger versions up to housing size 237-195. This also applies to the larger UCS HS 145-125 version. Both of these housings can be connected to one of the two heat spreaders. If there are several hot spots, these heat spreaders can, of course, be combined. The heat spreaders are calibrated to the application and individually positioned on the heatsink. This makes it possible to optimize the thermal properties of the device at any time.

To optimize the thermal path, pay particular attention to low thermal resistance. This enables optimum interaction between the heatsink, heat spreader, and thermal interface material (TIM). A low thermal resistance (Rth) means that the device can also operate in challenging thermal environments. The lower the thermal resistance, the larger the temperature range for operating the device – and the longer the service life (Figure 10).

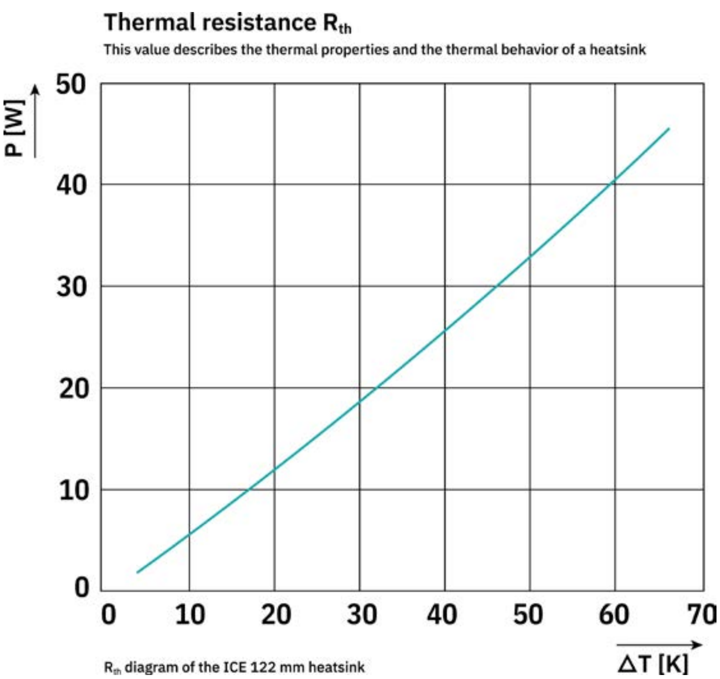


Figure 10: A low thermal resistance (Rth) means that the device can also operate in challenging thermal environments.

Thermally relevant areas on modern boards typically have different installed heights. Here, too, it is advantageous to use a UCS HSP heat spreader that can be individually adjusted in height (Figure 11). This is positioned individually and screwed onto the prepared contact surface of the UCS HS-HH heatsink. The heat spreaders are available in two sizes. The area available for contact with the hot spot is 22 mm x 22 mm or 50 mm x 50 mm. The height is adapted to the corresponding components.

The heatsink and heat spreader combination is connected to the PCB assembly via spacer bolts. This gives the combination the necessary contact pressure and thus thermal contact. The position of the spacer bolts determines the correct height. The available portfolio supports the optimal positioning and attachment of different PCBs.

Wired, thermally stressed components such as transistors can be optimally cooled with the UCS HS-SW side-panel heatsink. This has been specially developed for this purpose. The integrated support surface for the PCB supports the mechanical stability of the entire arrangement. The PCB is screwed directly to the heatsink with the support surface.

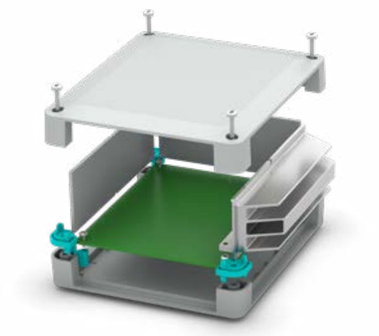


Figure 11: The UCS HSP heat spreader can be individually adjusted to the height that provides the best contact pressure and thermal contact.

The UCS modular system's well-known flexibility is also reflected in the heat dissipation solutions. The UCS offers countless solutions for the user. This modular system can make it easy to implement and customize many applications. This means that numerous applications and customizations can be implemented directly from the modular system. Customized printing on the housing parts, in combination with printing on the heatsinks on the surface provided, rounds out the system.

Various scalable options for heat dissipation are available. Options range from perforated or slotted housing elements to the additional use of aluminum side panels, as well as the integrative heatsink/heat spreader solution. The housing system offers a solution for almost every challenging thermal aspect.

Practical example

How does the system behave in practice? The heatsink/heat spreader combination was integrated into the simulation based on data from a commercially available SBC. Compared to standard plug-and-play solutions, the combination proved much more effective. The dissipation of heat loss could be increased by up to 100%. What became equally clear, however, was the influence of the orientation of the cooling fins. By utilizing natural convection, the cooling capacity could be increased by up to 60%. Users should consider behavior when selecting the housing and the associated heat dissipation system.

Comprehensive services

Users can access comprehensive services to optimize the housing systems in the UCS family. Starting with the comprehensive documentation, the different housing versions can be selected online.

Developers can use a configurator on the Phoenix Contact website to quickly select the correct housing. First, the housing is selected based on the following parameters: application, size, basic color, PCB preselection, and integrated heatsink. The preselection is based on the form factor or the dimensions. Next, the housing is moved from the preselection area to the display window via drag and drop. Once the PCB is positioned, the user can select additional accessories and choose component colors.

Once the basic configuration has been selected from the modular system, the individual connection technology is selected. The processing configurator is then used to select standard cutouts such as DSUB-9 or any other type of cutout.

Custom printing can also be specified at this point. The user can then open the resulting configuration in a 3D view and download it in various file formats. The developer can then use the solution ID generated for the configuration when requesting a solution that goes beyond the basic configuration in the Service Center.

In consultation, the solution is adapted to the thermal conditions, resulting in an optimal solution.

In addition to the aforementioned services, users also have access to a simulation service for the thermal analysis and optimization of an empty Phoenix Contact electronics housing, including connection technology and the customer-specific PCB. If the online simulation has already been used and rough thermal parameters have been clarified, the system will recommend a complete and highly detailed simulation. This can give the developer useful support when finalizing the PCB layout.

After providing relevant parameters and detailed PCB data, ideally in ODB++ format, conclusions regarding the thermal behavior can be made in the simulation. This means that different load cases under different ambient conditions can be considered in advance.

For the most accurate conclusion possible, the system will take into account all layout data for the PCB in the form of ODB++ data or other formats. The information will contain detailed information about the subsequent thermal behavior of the overall application. The simulator can then run the results through under different load cases and ambient conditions.

Conclusion

As devices become smaller and power density continues to rise, effective thermal management is essential for the reliability and longevity of modern electronic enclosures. Material selection, design style, and construction methods are just a few of the criteria that device designers need to consider to reduce heat.

Phoenix Contact's experience in thermal management can help engineers make informed decisions. With simulation tools and consulting services, our team can help designers balance the cost, performance, and availability needed for specific projects.

Learn more at https://www.phoenixcontact.com/en-us/products/customer-specific-solutions/configurators/configurators-electronics-housings.

About Phoenix Contact

Since 1923, Phoenix Contact has created products to connect, distribute, and control power and data flows. Our products are found in nearly all industrial markets. Sustainability and responsibility guide every action we take, and we are proud to collaborate with our customers to empower a smarter and better world for future generations. Together, we are creating a sustainable world based on our passion for technology and innovation.

For more information about Phoenix Contact or its products, visit **www.phoenixcontact.com**, call technical service at **800-322-3225**, or email **us-info@phoenixcontact.com**.

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