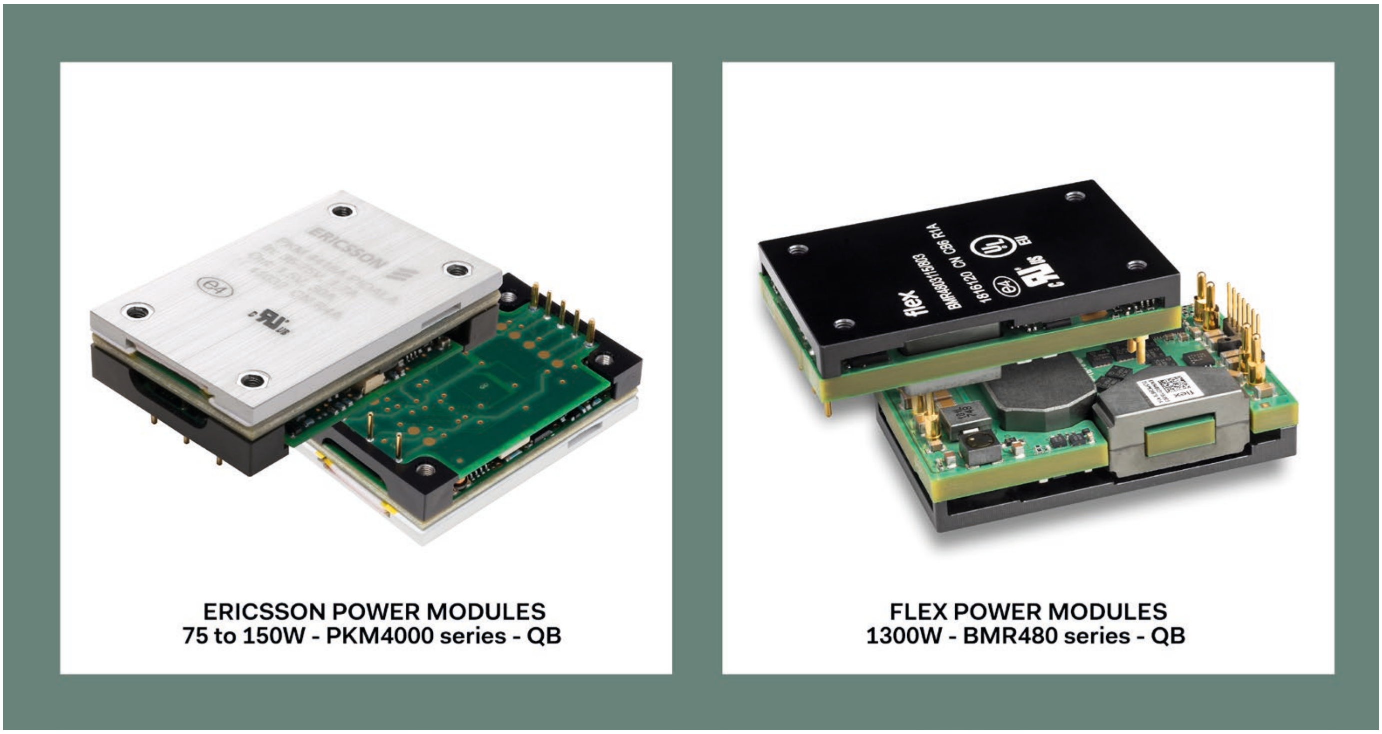
Convection and conduction cooling – what's next?

Ever since their introduction, keeping the temperature of a power supply down to a level that guarantees the highest levels of performance and safety has been a major concern for power designers. Considering the amazing increase in power densities that we have witnessed during the last 20 years; thermal management has become a preponderant part of the design process. Layout and mechanical design are now as important as efficiency topologies, and how to evacuate the calories out of modules has become an art!

The race to get greater power density!
Efficient thermal management has been one of the challenges that I faced in the early nineties when working for the microelectronics company Micro-Gisco. I took part in the design of a 100W DC/DC converter in a package size equivalent to what is today called a quarter-brick, for an application where the environmental temperature flirted with the junction temperature. At that time, the only technology available was to use thick film technology and chips bounding on a ceramic substrate. In such types of applications the only way to guarantee efficient cooling was through a base plate attached to a fluid refrigerant exchanger. There's no need to explain the importance of conduction cooling and efficient thermal management, that remains in every power designer's mind.

At the same time, with the development of mobile telecommunications the increased demand for integrated power solutions contributed to the emergence of the so called 'bricks', and a race to package more power into smaller sizes began. The increases of power have been really impressive. One example is the increase in power density of the so called 'quarter-brick'. In March 2000, the power modules division of ERICSSON (EPM) launched a state of the art 100W quarter brick DC/DC converter, the PKM 4000 series. 20 years later FLEX Power Module (which acquired EPM in 2017) launched a 1300W quarter brick, the BMR480 (Picture 01).

Increasing the output power by a factor of more than 10 in less than 20 years is the result of a combination of more efficient topologies, digital control, new components,



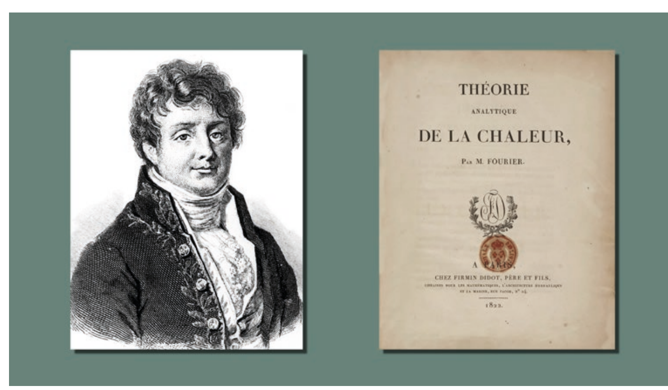
Picture 01 – In 20 years the quarter-brick output power increased by an average factor of more than 10x. (Credits: PRBX/FLEX Power Modules)

heavy-copper multilayer PCBs, integrated magnetics and outstanding layouts - but not only! - to guarantee full performance of such products, efficient cooling is a Must!

Keeping Fourier's Law in mind

Over the last 20 years power electronics engineers have improved products' efficiency to a high level, and we are all aiming to reach the magical figure of 99.99%. But until then we have to manage the heat generated by the power losses. A 1000W DC/DC converter with a typical efficiency of 97% will have to dissipate 31W [$P_d = P_{out} \times ((1-\eta) / \eta)$]. Considering an average ambient temperature in a telecom or industrial equipment of 55 degrees Celsius, efficient cooling will be required to guarantee the internal temperature of the module does not exceed the safety limit specified by the manufacturer e.g., +105 degrees C at specified test point.

As we all remember from school, in 1822 the French Physician Joseph Fourier (Picture 02) demonstrated that the time rate of heat transfer through a material is proportional to the negative gradient in the temperature and to the area.



Picture 02 – in 1822 the French Physician Joseph Fourier demonstrated that the time rate of heat transfer through a material is proportional to the negative gradient in the temperature and to the area. (credit: PRBX)

Fourier's laws (Picture 03) of thermal conduction governs the principle of heat exchange from the lowest level e.g., the semiconductor junction to ambient. Thermal resistance is the reciprocal of thermal conductance. Just as an electrical resistance is associated with the conduction of electricity, a thermal resistance may be associated with the conduction of heat. Making the thermal resistance as low as possible is a challenge for all power designers and that's where electronics meets thermodynamics.

$$\vec{q} = -k\nabla T$$

[1] q is the vector of local heat flux density [W.m^{-2}]
[2] k is the material conductivity [W.m^{-1}.K^{-1}]
[3] ∇T is the temperature gradient [K.m^{-1}]

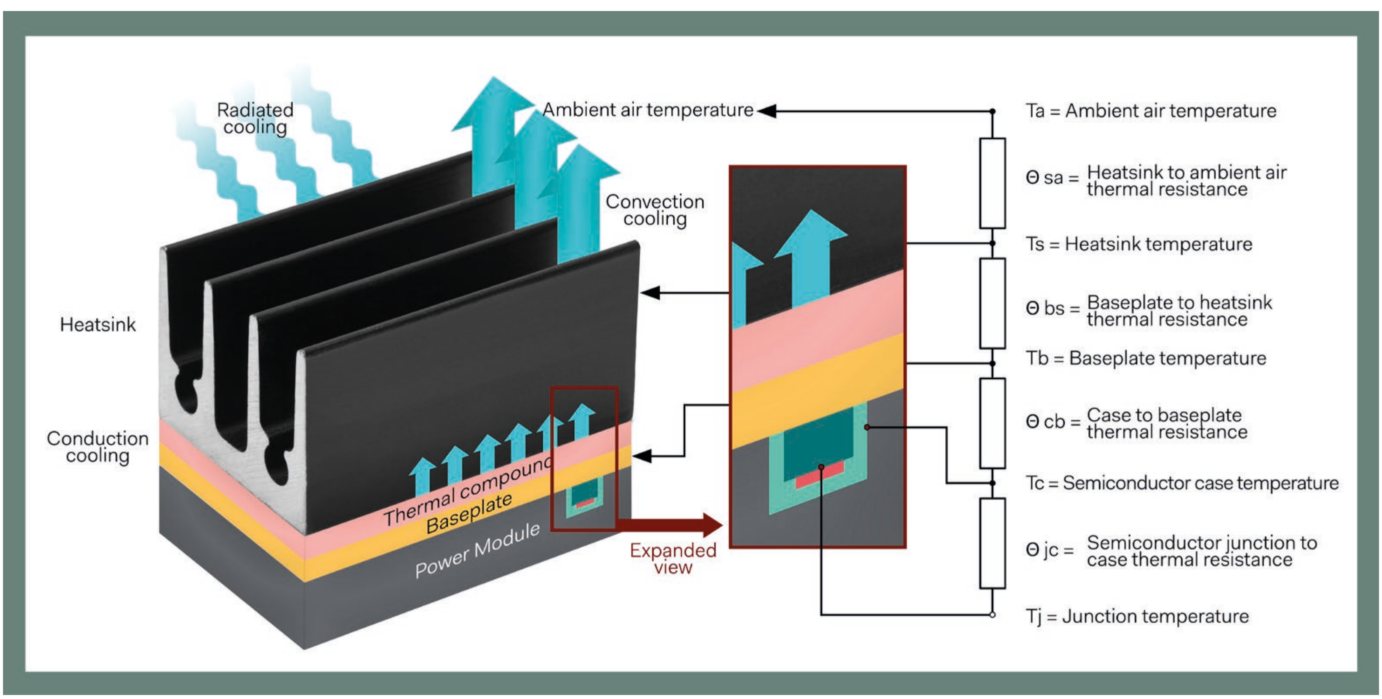
Picture 03 – Sweden / Mariestad ElectriVillage solar to hydrogen autonomous station (Source PRBX / Mariestad Municipality)

The building practices of AC/DC and DC/DC power modules are optimized to evacuate the heat through a conduction cooling mechanism from silicon to an exchanger surface e.g., aluminum baseplate. In most common applications a heatsink is attached to the baseplate and cooled by a flow of air, thus evacuating heat from the module (Picture 04). In telecom/datacom applications a 400 LFM (2 m/s) airflow circulating inside the rack to cool the overall system is very common, but some very high power density systems may require up to the double that (800 LFM (4 m/s), which is very noisy and reduces the life time of fans and cooling turbines.

Air forced cooling is the most common method to keep the temperature within safe limits though there are a number of applications where such cooling methods are not possible, and there are a growing number of concerns about reliability and sustainability related to that. Usually the air ventilated through datacenters and other high power equipment is exhausted outside the building, the calories are not converted into any usable resource, and in addition to that most of the datacenters requiring air-conditioning systems consume a lot of energy, which is a major concern.

When forced air cooling is not an option
There are a number of applications where it is not possible or even allowed to use active ventilation. In harsh environments or in applications where the required reliability level imposes the need to remove all possible risks of failure, fans and blowers are not allowed. Here are a few examples.

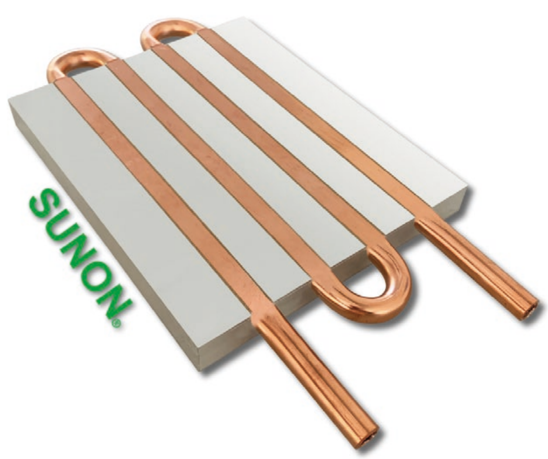
Industrial machinery such as laser cutting equipment that generates burnt particles, smoke, and steam have their monitoring and control boxes sealed to avoid contamination and the risk of damage as a result of the cutting process. In order to power the control system the



Picture 04 – Illustration of a typical Power Module being cooled by an attached heatsink. Just as an electrical resistance is associated with the conduction of electricity, a thermal resistance may be associated with the conduction of heat. (Credit: PRBX) power supply is enclosed in a sealed box, requiring the dissipated heat to be extracted by conduction from the chassis, or the need for it to be attached to a cold-wall. To make the cooling as efficient as possible the power supply is designed with a large base-plate to which all dissipating components are attached (Figure 05). In some equipment a liquid cooling is required to cool vital parts, e.g., a laser or plasma torch during operation.

Picture 05 – Example of a thermal conduction platform, optimized for conduction cooling, with all dissipating components attached to the baseplate. (Credit: PRBX)

In such applications the power supply benefits from the fluid circulation and the baseplate attached to a cooling element (Figure 06).



Picture 06 – In demanding applications, a liquid cooling element can be added to PSU baseplate to facilitate the evacuation of calories (Credit: PRBX/SUNON)

Industrial surveillance and safety equipment may be installed in remote places where exposure to extreme weather conditions is common, and where maintenance can become complicated. In such installations reliability is extremely important, and system designers need to exclude all possible causes of failure. Despite significant improvements in quality, fans and blowers are subject to mechanical failure and are not suitable for such applications. Again, as in the previous example, cooling can only be achieved through conduction to the outside of the sealed box and a passive heat exchanger.

When silence is golden

There is also a growing demand for equipment that is installed in supervisory rooms or even offices, that for the comfort and health of the employees, generated noise is simply not produced or very much limited.

One example is open-landscape offices where in some cases noise levels can be as high as 60 to 65 decibels. This may seem minor compared to say a busy highway that generates 85 decibels, but it can make cognitively demanding work difficult to undertake, with subsequent effects on health and safety. In fact a number of companies now require noise levels in open-landscape offices to be below 55 decibels and local regulations taking place.

Such situations include equipment installed in the room, and from computers to large displays e.g. as used in road or air traffic control office, noise levels must be reduced to the lowest level possible, and noisy forced air cooling is banned. In such conditions the power supply must be designed to be able to operate without ventilation, using a conduction cooling solution.

In conclusion:

Designing a power supply for conduction cooling requires power designers to work in very different ways compared to when designing a power supply that benefits from a high airflow and extensive cooling. Conduction cooled power supplies used to be considered as an anecdotic segment, though new environmental regulations may soon require a number of forced-air cooled applications to move to more environmentally friendly solutions and conduction cooling.

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FLEX Power Modules :
https://flexpowermodules.com/

About Powerbox
Founded in 1974, with headquarters in Sweden and operations in 15 countries across four continents, Powerbox serves customers all around the globe. The company focuses on four major markets - industrial, medical, transportation/railway and defense - for which it designs and markets premium quality power conversion systems for demanding applications. Powerbox's mission is to use its expertise to increase customers' competitiveness by meeting all of their power needs. Every aspect of the company's business is focused on that goal, from the design of advanced components that go into products, through to high levels of customer service. Powerbox is recognized for technical innovations that reduce energy consumption and its ability to manage full product lifecycles while minimizing environmental impact. Powerbox a Cosel Group Company.

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About the author
Chief Marketing and Communications Officer for Powerbox, Patrick Le Fèvre is an experienced, senior marketer and degree-qualified engineer with a 35-year track record of success in power electronics. He has pioneered the marketing of new technologies such as digital power and technical initiatives to reduce energy consumption. Le Fèvre has written and presented numerous white papers and articles at the world's leading international power electronics conferences. These have been published over 350 times in media throughout the world. He is also involved in several environmental forums, sharing his expertise and knowledge of clean energy.

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