Passively Cooled Inlets: A Simple Solution to a Complex Challenge

Consumers demand fast charging for their electric vehicles so they can spend less time waiting and more time driving. But reducing charge times is a tremendous challenge, in no small part due to one key factor: heat.

The more electric current there is going through a conductor, the hotter the conductor will get — and there are regulations that limit the allowable temperature at the terminal contact interface. Actively cooled charging inlets leveraging liquid-cooling systems are the gold standard for bringing temperatures down, but they add cost and complexity.

Passively cooled systems are the natural alternative; they remove more heat than standard inlets do, though not as much as active-cooled systems. Some passive-cooled approaches offer more benefits than others — and it turns out that the best passive-cooled solution may be one of the simplest.

THE BEST, AT A COST

For maximum charging performance, actively cooled inlets cannot be beat. To pull heat away from an inlet, an active-cooling system uses a cold plate in close proximity to the high-voltage terminals, with coolant lines running from the cold plate to a heat exchanger. Usually, engineers will use the coolant supply from either the vehicle's power-electronics coolant loop or the battery pack coolant loop to feed the inlet.

The results can be profound. Aptiv's tests have shown that this technology can potentially limit the terminal pin's temperature rise to an acceptable increase over the coolant temperature at 500A — indefinitely. That allows the vehicle to continue to draw power at that high rate of current for as long as needed. The system also enables charging at higher amperages (800A or more) for shorter durations.

Those capabilities translate into benefits consumers will notice. Theoretically, a 100 kWh 400V battery pack on a high-performance EV could charge to 80 percent of capacity in as little as 30 minutes, using the best DC fast chargers in the market today running at 500A. In the future, with more advanced charging infrastructure possibly supplying 750A or more to vehicles with 800V architectures, that charge time could be slashed to about 10 minutes. Aptiv's actively cooled inlets enable excellent performance, even at these high currents, with their superior thermal management.

However, there are certain drawbacks to using an active-cooled system.

An obvious one is the coolant routing and management: The tubes that feed the inlet must be carefully routed through the body to a coolant loop, adding a level of complexity to the assembly process.

In addition, designers may have to take additional measures to ensure that the coolant temperature stays low enough by the time the coolant reaches the inlet. Regulations specify that the temperature at the terminal must not exceed 90º C, to protect anyone who might touch the terminal contacts. Depending on the coolant loop used, the coolant temperature might be operating at a temperature as high as 70º C, which does not leave a lot of headroom for the 90º C limit. To compensate, manufacturers might need to upsize the heat exchanger to remove heat from the system.

KEY FACTORS AFFECTING DC FAST CHARGING POWER

There are several factors that have the potential to limit how quickly a DC fast charging station can charge an electric vehicle:

- The charging infrastructure's performance
- The industry standard for DC pins (e.g., the 8 mm pin in the J1772 standard for North America, initially sized for about 200A)
- The standardized limit of 90º C for the inlet terminal temperature
- The transition from the inlet to the cable, via crimps, busbars, welds or bolts
- The cable or conductor size
- The charger temperature at a public charging station, especially on hot days or between charges
- The condition of the charger's female contacts, which could increase resistance if worn out

Then there is the added cost and complexity of adding the cooling system interface to the inlet, installing the coolant lines and upgrading to the potentially more powerful heat exchanger.

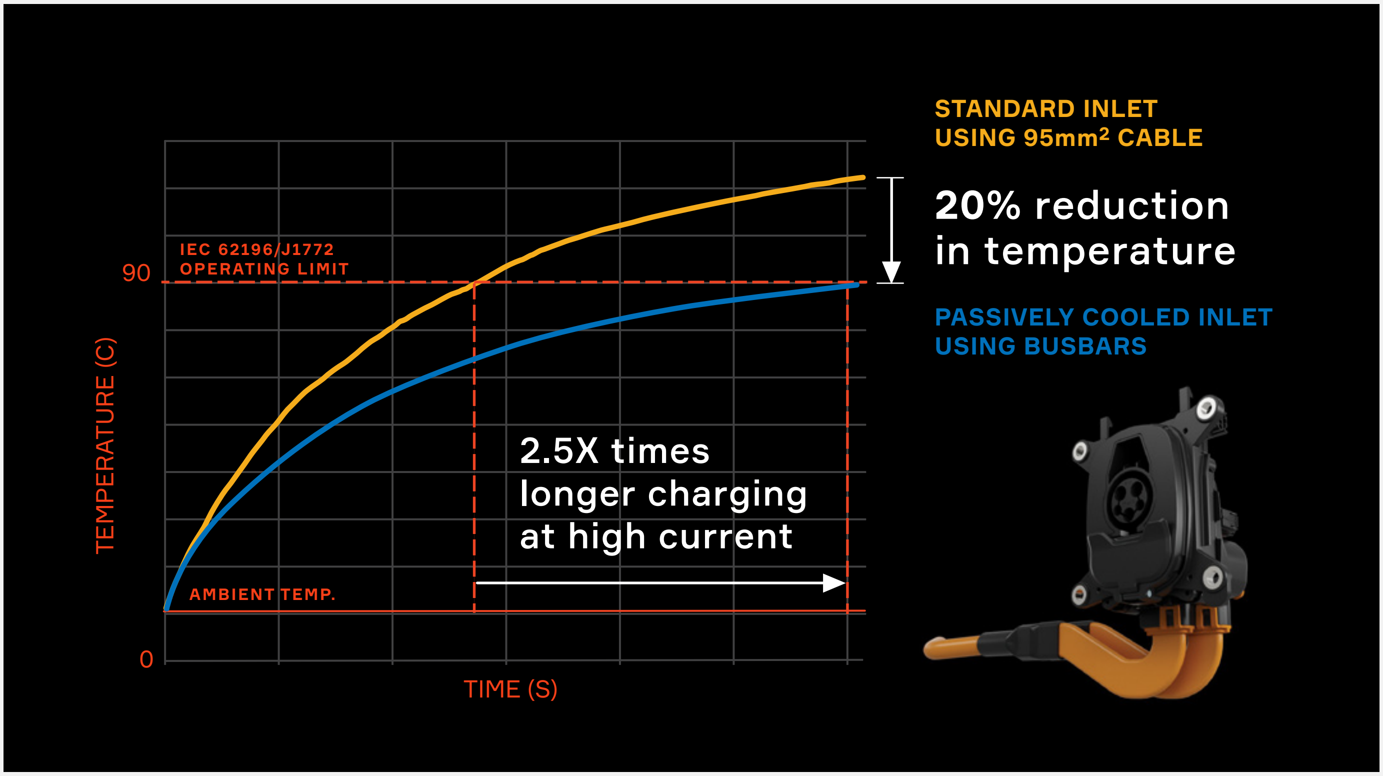
AGGRESSIVELY PASSIVE

Passive-cooling systems use special materials and certain component shapes to dissipate heat without using moving parts. For example, a finned heat sink could be attached to an inlet; the fins increase the surface area of the heated component, allowing the air around the heat sink to naturally pull away the heat.

Engineers could also use so-called potting material, a polyurethane- or epoxy-based thermally conductive material, around the power terminals to draw away heat. They could use conductive plastics, or even "phase change" material, which has a high latent heat capacity and pulls away heat as it moves from one physical state to another, such as from a solid to a liquid.

CHARGING AT HIGHER CURRENT FOR A LONGER TIME

When compared to a standard charging inlet using 95 mm² cables, a passively cooled inlet using larger cross-section busbars reduces temperatures by 20%. This allows charging to continue at 500A for 2.5 times as long.



In Aptiv's tests, using a combination of passive-cooling approaches — potting, conductive plastics and a finned heat sink — helped reduce inlet pin temperatures by about 15° C when charging at 400A continuously.

Still, these passive approaches do have limitations. One is that the potting material tends to stay hot after charging. After it absorbs the heat, the heat has nowhere to go, so the DC terminals take longer to cool. Plus, conductive plastics add significant cost without lowering temperatures significantly on their own. And, similar to an active-cooled solution, this approach does not allow for servicing. If there is a problem with the inlet, the potting requires that the entire wiring harness downstream also be replaced.

BUSBAR BALANCE

It turns out that a very good solution for a passively cooled approach is also a very simple one: Use busbars in place of round cables for the connection to the DC charge ports. Because busbars are flatter and wider than cables, they essentially act as an excellent heat sink, distributing the heat across a broader surface area so that it dissipates easily into the air around it.

Aptiv's tests found that using busbars instead of cables can significantly extend the time in which an inlet can receive a fast charge before hitting the 90° C threshold at the DC terminal. We compared inlets using 95 mm^2 cables with inlets using larger cross-section busbars, both connected to the same average-class-in-the-field charger at 500A. Naturally, performance may vary, and charging capability could be significantly improved or reduced based on the charger used. But the tests showed that an inlet using busbars could handle 500A for about 2.5 times longer before hitting 90° C.

SUPERIOR DESIGN

Aptiv maximizes charging performance by including several elements in our design:

- High-conductivity copper in busbars and terminals
- Bolted interfaces for low contact resistance
- No crimps on cable-to-cable transitions
- Busbars up to 200 mm^2

Furthermore, busbars are not required for the full length of the connection between the inlet and the battery to produce this benefit. Busbars extending from the inlet can connect to cables for the remainder of the distance to the battery.

Busbars are already widely used within battery packs, and many manufacturers are expanding their use of busbars to inlets and other vehicle components with higher power requirements. Not only are the metal bars capable of carrying the required current, but their rigid structure also makes the assembly more automatable. For these reasons, busbars make sense for connecting inlets and rapidly bringing electricity into the vehicle from the DC charge ports.

Most of the charging infrastructure being built today does not support currents higher than 500A, so being able to take advantage of that high rate for longer will satisfy most requirements. Later, as the infrastructure is upgraded, manufacturers could choose from active or passive solutions, depending on their amperage requirements.

The busbar approach also maintains serviceability. If the inlet needs to be fixed or replaced, a technician can simply detach it from the busbars instead of pulling out the entire harness — sparing the consumer from a sizable repair charge.

Aptiv has a long history in developing innovations throughout the electrical/electronic system that deliver superior quality and performance while controlling costs, simplifying assembly, accommodating vehicle packaging challenges and preserving serviceability. Using our expertise and cutting-edge thermal simulation capabilities, we will continue to push the envelope to create charging inlet solutions that meet our customers' requirements today while positioning them well for the future.

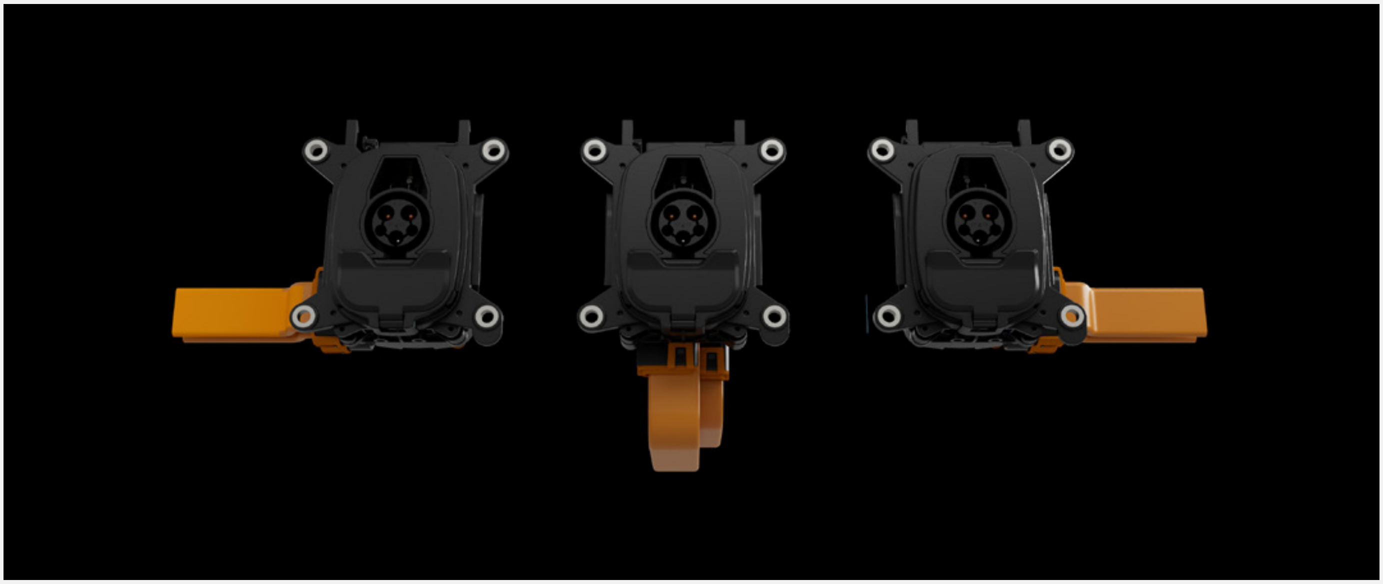
ALL IN ONE

Aptiv's capabilities for high-voltage electrification span a wide range of technologies, including:

- Inlets
- High-voltage interconnects
- Charge cords
- Power distribution units
- Battery disconnect units
- Cabling
- Busbars
- Wiring harnesses
- Cable management

FLEXIBLE DESIGN

A charging inlet should allow for multiple busbar orientations to adapt to the OEM's requirements.



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Thomas Mathews leads the development of high-voltage charging inlets at Aptiv. Thomas started his career at Aptiv in 2016 as a product development engineer working on high-voltage interconnects, before transitioning to focus on developing Aptiv's next-generation high-voltage inlets. The technology he has developed has led to several business awards and patents, garnering recognition by customers globally.

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