WHITE PAPER

Commercial Grade Electronics at High Temperatures

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ABSTRACT

Cooling electronics in harsh environments is a challenge especially as power densities of embedded electronics increase. The common objective of military and industry alike is to utilize the latest and greatest technology without significant cost by leveraging commercially available electronics. COTS electronics come in many ruggedization levels from commercial grade air-cooled to hardened conduction-cooled boards. Generally, the higher operational temperature specification of the electronics, the lower the performance will be. It is the inherent limitation of air and conduction-cooling that requires OEMs to limit the output of processors, FPGAs and other high heat flux components when exposed to high ambient temperatures. This paper provides an introduction to direct spray and will discuss how direst spray enables air-cooled electronics to operate at extreme temperatures while maintaining commercial component ratings.

Keywords: SprayCool, commercial electronics, high temperature, direct spray

BACKGROUND

For decades military platforms have included electronics for avionics, vehicle controls, radios, radar, sonar and fire control. Industrial applications include motor control, automation and communication. From a computational standpoint most of these systems could be accomplished with relatively low power devices. There have always been higher performance electronics for applications such as radar processing, Intelligence, Surveillance, and Reconnaissance (ISR) processing, and mission computing in the military and oil and gas exploration in the industrial sector; however, high performance electronics were traditionally relegated to stationary, benign environments. Due to bandwidth limitations of secure communications between command centers and front line troops or crews, trends to include these computationally intense applications on vehicles, aircraft and next to geological instrumentation exist. From airborne platforms such as U-2 Dragon Lady and Global Hawk operating up to 70,000 feet and -65°C or an artic oil field to a surface-to-air missile launcher mounted on a tank in a scorching +60°C desert, deployments of incredible performance in harsh environments. To enable mobility on vehicles or transportation to remote sites, the size, weight and power (SWaP) of the electronic systems are minimized to extend the range of airborne platforms or allow ground vehicle transport with a wider range of operation. Direct spray systems from SprayCool® are enabling these programs with minimal SWaP budgets and harsh environmental requirements to use lower cost, high performance and commercially available embedded electronics.

COOLING SYSTEM ARCHITECTURE

In practice, direct spray systems have the same building blocks. Figure 1 diagrams the common components found in direct spray enclosures. For all systems there are three fundamental functions of a cooling system: Heat acquisition, heat transport and heat rejection. Heat acquisition is accomplished by spraying a fine mist of non-conductive and non-corrosive coolant with atomizers (orifices) directly onto electronics or within a cold plate. As the coolant vaporizes, heat is transferred from the electronics to the fluid-vapor mixture. Transport occurs when the coolant vapor condenses on the enclosure walls collecting in the reservoir. System components are often connected by drip-less "quick disconnect" fluid connectors for ease of maintenance or reconfiguration. Finally, heat rejection is accomplished via the heat exchanger that rejects the thermal load to ambient air or platform fluid. Several fluid options for heat rejection on military vehicles include Polyalphaolefin (PAO), fuel, engine bleed air, an Ethylene Glycol and Water (EGW) mixture, or ram air. Ambient air is a common rejection medium in industrial applications. Spraying fluid warmed with heaters is effective at heating the electronics at cold ambient temperatures.

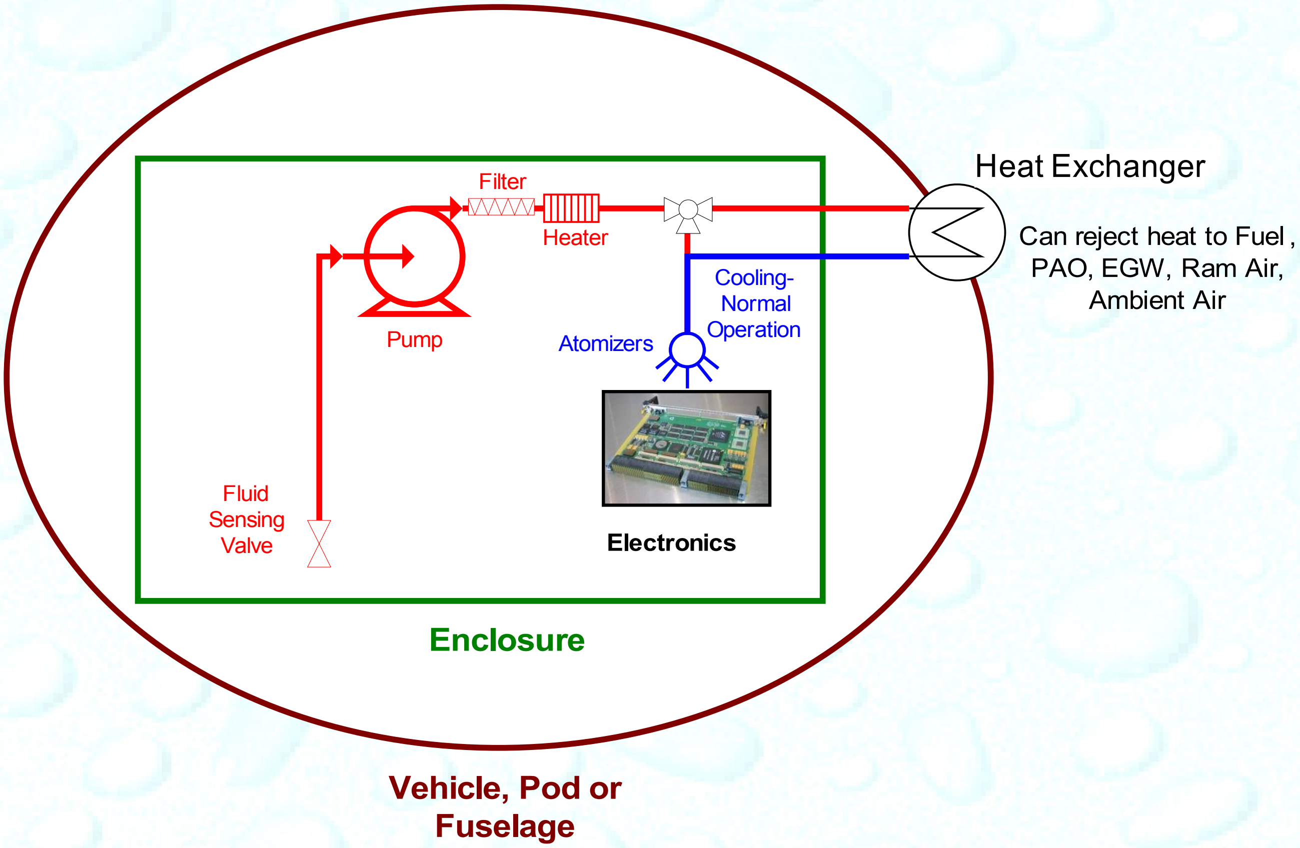


Figure 1 System diagram of direct spray enclosure

Filtration is built into the enclosure, pump and coolant delivery system to remove organic and chemical contamination. For mobile applications, valves are placed in the corners of the units to sense fluid and open when sufficient fluid is present. A controller is employed to operate the cooling system and provide cooling system status, user diagnostics, and warnings/shutdown notifications. Lastly, direct spray enclosures support cPCI, cPCIe, VME, VXS and VPX electronics in either conduction or lower cost air-cooled variants.

THERMAL CHARACTERISTICS

Direct spray enclosures apply dielectric perfluorocarbon fluid directly on the electronics by pumping fluid from the reservoir to the electronics. By wetting the electronics directly, energy is transferred between heat generating components and the fluid via forced convection (sensible heat), evaporation and nucleation (latent heat). The goal is to maximize the phase change from fluid to vapor because of the exceptional heat transfer capacity afforded by the latent heat of vaporization. Direct spray even outperforms boiling at higher temperature differences between the component surface and saturated fluid. This is primarily due to direct spray droplet velocity that reduces the boundary layer on component surfaces and breaks up bubbles created by nucleation. Cooling with single phase liquid has significantly less heat transfer capacity than either boiling or direct spray because there is no phase change.

To compare and contrast the cooling capability of direct spray to that of other cooling methods, Figure 2 describes a $1cm^2$ device that is 30°C higher than the heat transfer fluid (be it air or liquid). Typical heat transfer coefficients on the left side of the graphic determine the amount of power removed from the component (Q) shown on the right side. The differences in cooling capacity are easily explained with fluid properties. The specific heat of air and perfluorocarbon are very similar at 1 kJ/kg-°C and 1.1 kJ/kg-°C, respectively. However, when changing phase, the latent heat of FC-72 is 87.9 kJ/kg contributing to significant heat transfer rates. It is noteworthy that a 30°C temperature difference is difficult to achieve with liquid immersion as bubbles from vapor generation prevent fluid contact with the component surface resulting in a 'dry out' condition.

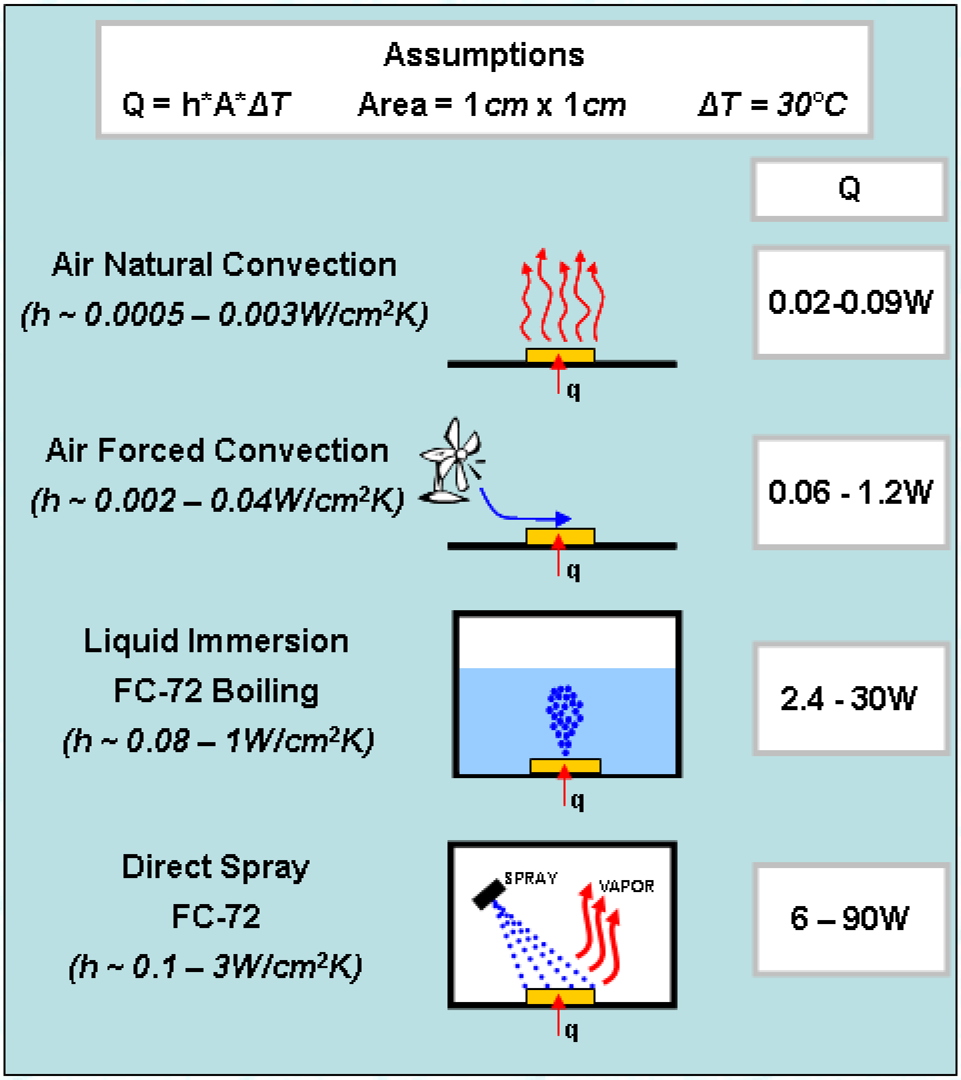
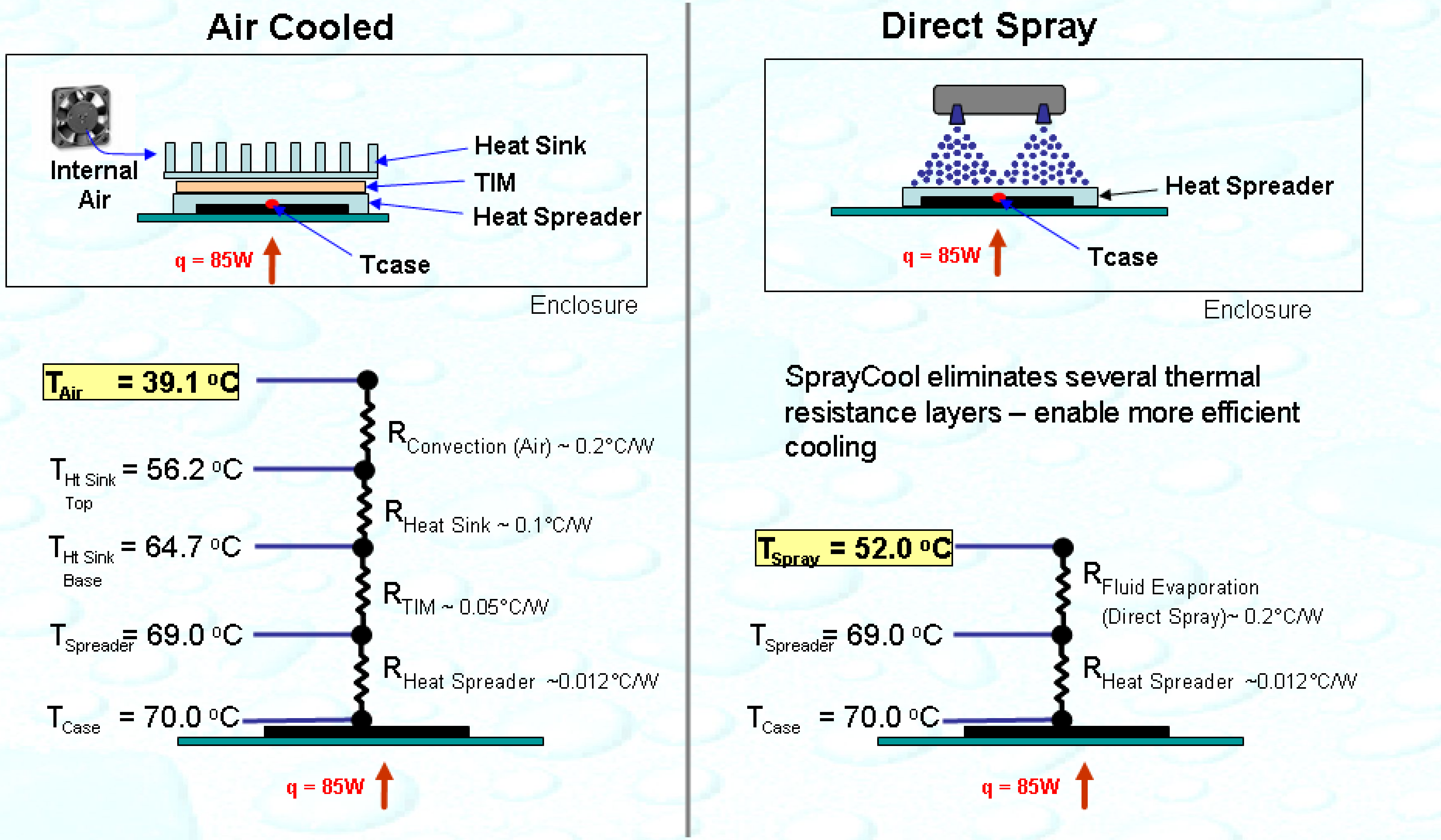


Figure 2 Comparison of cooling methods

It is evident from Figure 2 that direct spray enclosures offer tremendous thermal advantages. A resistance model is also instructive to quantify differences between cooling methods. Typical resistance values for heat spreader-to-internal air-cooling range from 0.3 to 0.5°C/W compared to direct spray resistances of 0.1 to 0.3°C/W for similar areas. Figure 3 illustrates an example of a processor with an 85 Watt Thermal Design Power (TDP) and a maximum junction temperature of 70°C. The resistances associated with each interface found in enclosures used to cool electronics are shown. Not only are the individual resistance values lower in direct spray, there are fewer of them. The resultant temperature difference between heat source and ultimate heat sink (such as ambient air) is 10-15°C higher with air-cooling than direct spray. This means the end user has the ability to either run at higher ambient temperatures, use higher power devices, or both without exceeding component temperature ratings.



SprayCool eliminates several thermal resistance layers – enable more efficient cooling

Figure 3 Quantitative thermal resistance models for air-cooled and direct spray

ALTERNATIVE COOLING APPROACHES

Commercially available embedded electronics are constantly increasing thermal loads because they employ the latest processors and FPGAs. The cost and performance density advantages of using less rugged electronics creates the demand for higher power electronics in harsh environments. This demand challenges system integrators to provide both cooling and performance.

Heat transfer rates and thermal resistances of a given cooling solution have a direct impact on the available options for fielding electronics in extreme conditions. For applications in controlled space (air conditioned/pressurized), air-cooled enclosures are a logical choice. Expensive conduction-cooled electronics are perfect for harsh operating environments, but not for high power devices. When high performance electronics must reside in unconditioned environments in small, lightweight form factors, direct spray offers a compelling alternative by enabling commercial grade electronics to operate at extreme temperatures.