# SprayCool Cooling Technology Applied to IGBT in High Power Applications

*Sept 2007 (Updated Jan 2009)*

**Brief description of our technology**
SprayCool technology provides a very efficient technique for extracting heat from a hot surface through the use of latent heat of vaporization of a liquid. The approach of evaporative spray cooling is to spray liquid droplets onto hot electronic components to create a thin film that results in the fluid boiling off quickly, thus removing excess heat. The resulting hot vapor can then be transported to a remote heat exchanger that rejects the heat to ambient and re-condenses the working fluid back into a liquid state. Thus, the system operates in a continuous closed-loop cycle and no fluid is consumed in the process. SprayCool uses 3M's Fluorinert as its primary fluid, an inert perfluorocarbon that is an electrically insulating dielectric typically used for electronics cooling. SprayCool technology enables all surfaces exposed to the liquid/vapor environment to remain very close to the saturation temperature of the fluid, resulting in an "isothermal" environment around the electronics. By keeping the components thermally stable it reduces the occurrence and severity of hot spots and thermal cycling found in most electronics systems. The resulting mechanical stresses induced by these problems are the primary causes of failure in electronic systems, and so SprayCool therefore can play a pivotal role in the design of high-reliability, high-performance, power electronics systems.

**How IGBTs are cooled today**
There are two primary ways to cool high-power IGBT modules:

**1. Air Cooling -** A conventional heatsink designed for forced or natural convection air-cooling is attached to the baseplate of the module. The excess heat from the module is transferred to the air and ultimately to the ambient air environment. Air cooling is most effective for lower-power and lower-power-density semiconductor components and can be a limiting factor in many high-density system packages.

**2. Liquid Cooling -** A coldplate designed for a single-phase fluid is attached to the base plate of the module. A mixture of ethylene glycol and water is the most common fluid used for liquid cooling. The excess heat from the module is transferred to the fluid in the coldplate and ultimately transferred to the ambient environment. Liquid cooling offers a reduced package size, quieter acoustics, and increased semiconductor life over air cooling.

Depending on the application, either approach to cooling is effective to a degree. Both approaches have been proven in military conditions; however, both are typically large and heavy.

**How SprayCool technology can be applied to IGBT cooling**

There are three ways to SprayCool power IGBT modules:

**1. Baseplate Direct Spray Cooling -** A spray plate designed for Fluorinert fluid is attached to the baseplate of the IGBT module. The excess heat from the module is transferred to the fluid from the baseplate and ultimately transferred to the ambient environment. Cooling with Fluorinert offers the advantages of liquid cooling with the additional benefit of smaller system components and the safety of using a nonconductive fluid in the event of a leak.

**2. Encasement of a Standard IGBT Module** – An enclosure is designed around a "standard" IGBT module (no encapsulant or cover) and SprayCool technology is applied to both the top and baseplate of the module. The excess heat from the module is transferred to the Fluorinert fluid in the enclosure and transferred to the ambient environment via a condenser. This method of cooling IGBTs is more effective, smaller, and lighter than current cooling methods.

**3. SprayCool Custom Package -** A custom package designed to allow both sides of a bare IGBT to be sprayed with Fluorinert fluid using SprayCool direct-spray technology. The excess heat from both sides of the die is transferred to the Fluorinert in a sealed enclosure and transferred to the ambient environment via a condenser. This is the best method of cooling IGBTs, and is the most effective, smallest, and lightest of all cooling methods.

SprayCool technology is smaller and lighter than conventional cooling methods. Advanced methods of SprayCool cooling of IGBTs have also been shown to improve electrical performance while reducing temperature cycling — resulting in substantial improvements in reliability.

**Comparison of SprayCool and conventional IGBT cooling**

| Performance Characteristic | Air Cooling Natural Convection[1,2] | Air Cooling Forced (Fan) Convection[1,2,3] | Ethylene Glycol / Water Coldplate | SprayCool Indirect SprayModule | SprayCool Encasement Module | SprayCool Custom Package |
|---|---|---|---|---|---|---|
| $R_{th(j-a)}$ | 1.24°C/W | 0.41°C/W | 0.138°C/W | 0.180°C/W | 0.060°C/W | 0.050°C/W |
| Additional Weight[6] | 2.4 lbs | 3.6 lbs | Plate 3.2 lbs<br>Cooler 44 lbs | Module 1 lbs<br>Cooler 5 lbs | Module 2 lbs<br>Cooler 20 lbs | Module 1 lbs<br>Cooler 25 lbs |
| Additional System Size[4,6] | 60 $in^3$ | 80 $in^3$ | Plate 41 $in^3$<br>Cooler 1400 $in^3$ | Module 8 $in^3$<br>Cooler 125 $in^3$ | Module 16 $in^3$<br>Cooler 500 $in^3$ | Module 12 $in^3$<br>Cooler 600 $in^3$ |
| Thermal Capacity[4,5] | 100 W | 300 W | 725 W | 550 W | 2000 W | 2550 W |
| Added Power Output[4,5] | 1x | 3x | 7x | 5.5x | 20x | 25.5x |
| Relative Noise Level[4] | 0dB | 60dB | 34dB | 28dB | 28dB | 28dB |

1. Natural and forced convection thermal resistances based on 6.000 in. length for profiles less than 8.000" wide.
2. Natural and forced convection thermal resistances based on12.000 in. length for profiles 8.000" wide and greater
3. Forced convection thermal resistance based on 500 LFM, shrouded, horizontal. Distributed heat load.
4. Based on the normal convection air –cooling at 1.24 C/W (BASELINE)
5. Based on 25°C ambient air (Ta) and a 125°C maximum Junction Temperature (Tj)

**Discussion**

From the numbers presented above, one can see that evaporative spray cooling technology has a substantial advantage over conventional IGBT cooling in terms of size, weight, and power required for cooling. Thermal and electrical performance is improved with the use of SprayCool technology for IGBT silicon and standard package modules. The improvement can be has high as 200% for standard packages and up to 300% for custom package designs. In addition, since SprayCool reduces temperature gradients and temperature cycling for the devices being cooled, the result is a significant reliability increase as compared to conventional plate cooling, enhancing the MTBF of the IGBT module.

A SprayCool system is smaller and lighter than conventional liquid cooling, resulting in a smaller power control footprint. Experience has shown that gains of 50% in terms of size, weight, power and noise reduction can be achieved over conventional liquid cooling for a given power capacity. This makes SprayCool ideal for small and/or high-heat flux surfaces (such as IGBT die) where the inherent advantages of the latent heat of vaporization can improve heat transfer by up to three times that of conventional EGW cooling.

While SprayCool technology has been in development since the late 1980s, in recent years the maturation of the technology, combined with the increasing power densities of electronics components, has driven its adoption in the defense industry. In particular, the size, weight, and power advantages of SprayCool have led to its incorporation in such programs as Northrop Grumman's Airborne Signal Intelligence Payload (ASIP), which is operating on the U-2 and Global Hawk. SprayCool technology can also be found in the Marine's Expeditionary Fighting Vehicle being developed by General Dynamics, and in data center applications such as the Top500 Supercomputer found at the Department of Energy's Pacific Northwest National Lab. These systems have been in operation for years and provide a wealth of past experience and data to draw from.

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