How Cool is That?
Thermal Management in EW Systems

By Barry Manz

Reducing the size, weight and power of EW and SIGINT systems, while increasing overall performance, is a tall order. But trying to keep the system cool – even though its functional density is greater, it may use high-power-density gallium-nitride (GaN) or silicon carbide (SiC) transistors and it may reside in a size-, weight- and power- (SWaP) constrained environment (such as a UAV) – makes the job a lot tougher. Without question, it's time SWaP became SWaP™, holding thermal management on high, where it belongs.

In addition to removing heat at the chassis and system levels using conduction, convection and liquid cooling, designers are looking further into the box to remove heat at the device level where it is created. The target devices include traveling wave tube amplifiers (TWTAs) – the all-time heat-generating champion – and newer rivals for the title, such as dual- and quad-core processors, feverishly powerful graphics engines and most recently GaN and SiC transistors used for RF power generation and DC power, respectively. The latter devices bring unprecedented levels of power density to their intended applications – with a commensurate increase in heat dissipation.

STAY COOL, LIVE LONGER

High heat levels are recognized as the best (or worst) way to shorten the operating life of electronic systems from components on up the food chain, at a lifetime reduction rate of 50 percent per 10 degrees Celsius increase in operating temperature. An RF power transistor, for example, will not only live longer if its junction temperature is reduced, but it can potentially be driven harder to deliver more power at its specified junction temperature, as well. Consequently, focusing on thermal management at the device level makes sense, and the range of cooling methods being explored to address it range from the traditional approaches to emerging technologies.

Within the EW market, one of the leading drivers for this new-found interest in device-level cooling is the US Navy's Next-Generation Jammer (NGJ) program. The goal of the program is to replace the aging ALQ-99 tactical jammer developed in the 1960s and first deployed with the then-new EA-6B in 1971. NGJ will replace the ALQ-99 on the EA-6B Prowler and EA-18G Growler and possibly be deployed on other aircraft including the F-35 and UAVs. It will make extensive use of solid-state RF power generation rather than the ALQ-99's TWTAs. Not surprisingly, there is fierce competition among prime contractors for this program, because it potentially offers the winning contractor a strategic advantage in offering solid-state technology in future EW programs. NGJ's use of solid-state RF power devices, as well as its scalable, easily-reconfigurable, state-of-the-art signal processing system, translate into a need for new cooling requirements and fresh concepts for addressing them.

HOT NEW APPROACHES

One of the most promising methods for device-level cooling – aluminum diamond – is also one that might cause industry veterans to yawn. This technology seems to have been dormant ever since advances were announced in the early 1990s, and it then appeared to have great promise for device packaging as diamond's thermal conductivity is at least 900 W/m-K (Watts per Kelvin per meter).

The development of diamond as a packaging material has since claimed most of its champions thanks to the difficulty in solving the problems inherent in bringing it from scientific curiosity to viable commercial product. However, Nano Materials International Corp. (NMIC), a joint venture between Materials and Electrochemical Research (MER) Corp. (Tucson, AZ) and Mitsubishi Corp. of Japan, is not only still standing, but ready to introduce aluminum diamond composites for packaging applications for the first time.

The attention diamond has received is directly related to its ability (if made commercially viable) to reduce the problems associated with the increased heat generated by devices made with GaN and SiC (or GaN using SiC as a substrate material), creating a new standard for the thermal performance of transistor packaging. "We see our materials making inroads with manufacturers of MMICs and amplifiers for T/R modules," says Kevin Loutfy, NMIC's president, "because the introduction of SiC and GaN devices is increasing power density per unit area from 1500 W/cm2 to 8000 W/cm2."

The company's aluminum-diamond matrix composites have thermal conductivity greater than 500 W/m-K compared with the average of 200 W/m-K for conventional materials such as copper-tungsten or copper-moly-copper, which averages about 200 W/m-K). It can be used as a heat spreader that attaches to the die or to replace the base plate in the package. The composite encapsulates industrial-grade diamond particles in aluminum, the diamond providing exceptional thermal conductivity and the aluminum providing structure as well as a very smooth surface on the top and bottom that serves as the attach face.

"Some people might look at aluminum diamond and say 'I heard about this years ago, and they had the same roadmap in the '90s – so what's new?" says Dr. Raouf Loutfy, NMIC's chief technical officer. "Our answer is that over this time we worked on aluminum diamond for NASA, DOD and others and supplied samples, but there was always some problem like surface finish, cleanness of the edge or plating. It wasn't until 2007 when we formed the joint venture between MER and Mitsubishi to form NMIC that we could address real customer needs. We've made huge improvements since then and now that we have a production partner we're working to gain design wins with a production-ready technology."

The problems with aluminum diamond have historically been related to the interface between the diamond and aluminum. Loufty and his team developed technology to convert the surface of the diamond to silicon carbide, which is what enabled the high levels of thermal conductivity to be achieved, according to Loutfy. "Adding a 'nano' layer of SiC matched the properties of aluminum so we patented it," says Loutfy. "In addition, when you add thermal-cycle diamond composites, its thermal conductivity decreases. We thought the interface between the matrix materials was breaking and might be the cause, and our conversion to SiC showed that no degradation of material occurs as you temperature cycle it. This is a big improvement over what has been done before."

GETTING TO THE CORE

One of the "thermal core"-type solutions that has been used for larger areas than required for device-level cooling is the Thermally-Annealed Pyrolytic Graphite (TPG) manufactured by Momentive Performance Materials (Albany, NY). TPG is similar in name only to the substance used in pencils, being created by thermally decomposing hydrocarbon gas in a high-temperature chemical vapor deposition process. The resulting deposit has a uniformly-aligned crystalline structure parallel "in plane," and thermal conductivity in this plane averages about 1500 W/m-K, in contrast to copper's 400 W/m-K, and aluminum's 250 W/m-K, making it an appealing heat-transfer medium.

However, to make it useful for defense radar and EW applications, the granular TPG must be diffusion-bonded to an aluminum shell and the enclosure is hermetically sealed to form a 3-mm sandwich that consists of 0.5-mm-thick aluminum plates on the top and bottom and 2 mm of TPG in the middle. This product, called TC1050, has lower thermal conductivity than the raw TPG (about 1050 W/m-K) but it is still far higher than copper. The TC1050 panels are typically mounted to PC boards placed in liquid-cooled chassis, providing a thermal short between the two.

Obvious applications for TC1050 include tower- or mast-top environments, where removing weight is paramount and the product can potentially solve a given heat-transfer problem using a fraction of the weight and material of a copper-base solution. A TC1050 panel also continues to function if damaged while heat pipes and other more complex cooling schemes will not.

With NGJ and other programs in mind, the company is looking hard at how to get TPG into form factors smaller than the transmit-receive module, where the company has had considerable success. Possibilities include encapsulating TPG into other materials that could potentially make the material viable for incorporation in and around packages.

REFOCUSING THE SPRAY

Ten years ago, "spray cooling" was relatively unknown, but today in many cases it is vying for "mainstream" status. SprayCool just became part of the Gas Turbine Fuel Systems Division of Parker Aerospace, which should not only remove any "small company" stigma but provide a nice complement to Parker's airframe manufacturer customer base, as SprayCool addresses the cooling of payloads rather than complete aircraft. EW is one of SprayCool's target markets going forward, according to Dan Kinney, director of business development. "We think there are benefits in cooling individual devices, such as T/R modules, EW amplifiers, and IGBTs for power electronics – the really high power density applications," says Kinney. "So we're targeting NGJ, where the benefit is to reject at least 65 kW of heat. On NGJ you need to both acquire the heat and reject it with ram air exchangers or skin heat exchangers where you can get the heat out through the skin of the pod. The closer you can get to where the heat is generated the better the SWaP."

"While we currently cool cards directly, we can also cool from the card edges as liquid is flowing through the sidewalls of the chassis," Kinney added. "Our job is to make the thermal management system in the pod much smaller, and the combined capabilities of SprayCool and Parker should offer an excellent solution."

Going deeper into the device domain, Kinney said that in addition to cooling signal processing cards, the company is cooling the devices in radars that generate the most power, primarily T/R modules and IGBTs in the power supplies. "We can spray devices directly within the enclosure or we can cool the enclosure through a cold plate to which the device is mounted. That is, spraying the plate where liquid is circulated to reach where the fluid is vaporizing to get the benefits of two-phase heat transfer – liquid to vapor and back to liquid."

KEEPING IT COOL

It seems unlikely there will be a day anytime soon when thermal management concerns have been satisfied, and EW system designers can breathe a sigh of relief. The increasing replacement of vacuum tubes with solid-state devices in the amplifiers of EW systems simply replaces one set of thermal management challenges with another. That is, high-voltage TWTAs may generate lots of heat, but so do massive banks of the lower-power GaN devices required to generate the same amount of power. Signal processing systems, general-purpose processors and graphics engines deliver spectacular computational ability – but they create lots and lots of heat to get the job done. And so on, generation after generation, as each new device operates at higher speeds, and has higher functional density.

The answer will in part be provided by looking at device-level heat generation more closely than ever and using multiple cooling technologies in more applications. The NGJ program alone provides the incentive for manufacturers to come to grips with the upcoming thermal management challenges presented by this system, which will probably be in service for a quarter century. Many other programs will benefit from the advances in cooling capabilities revealed in NGJ, and they won't come a moment too soon.