Heat Remains Enemy Number One

By **BARRY MANZ** *Editor*

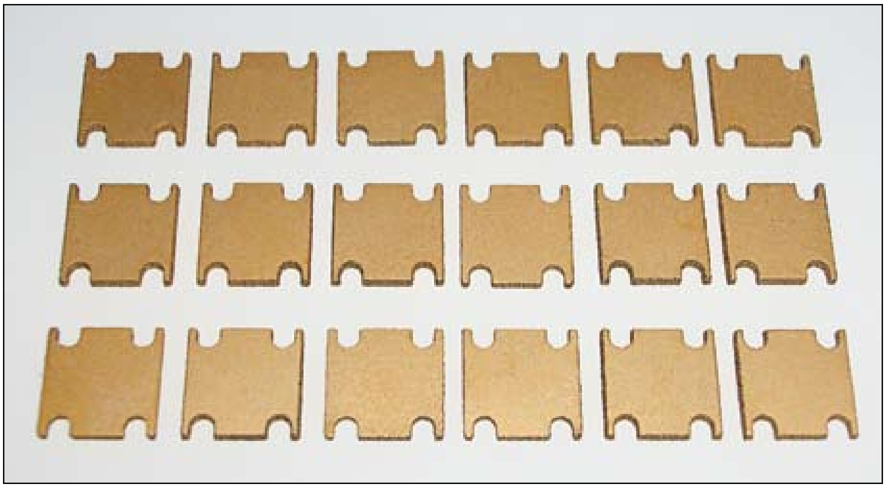
THE CONFLICTING requirements of delivering a defined set of increasingly complex functions within the confines of space-constrained environments has become a critical task for designers of defense communications, EW, and radar systems. Unmanned platforms make this any even more onerous challenge, as have portable systems either carried by or mounted on the warfighter.

A good example is the software defined radio (SDR), which has come into service and remains under intense development. These radios employ FPGAs for a wide array of functions including advanced waveforms, packet processing, and software communications architecture (SCA) middleware. Obviously, getting the immense capabilities of SDRs within small form factors places an emphasis on power management and thermal constraints, since many SDRs are hand-held devices.

This challenge is likely to increase in difficulty as the number and complexity of waveforms grows. The typical power consumption of hand-held SDRs is about 4 W and typical operating time on a charge is about 6 hr. Some of the considerations in their designs include the typical duty cycle experienced by users, generally considered to be about 10:1 standby to operational, which makes it essential that an absolute minimum of power is consumed when the radio is idle. Power management software typical of that employed in all types of wireless communication devices plays a large role in making this happen. Last but not least, the RF portion has its traditional place near or at the top of the power consumption list, at least when transmitting.

Traditional methods for removing heat from electronic systems include conduction, convection, and increasingly liquid cooling, a discipline that grows in importance every year. However, the circuits themselves (i.e., at the device level where the heat is generated) is another area of government and industry study. DSPs, FPGA, CPUs, and graphics processors employed in signal processing systems, as well RF power devices, generate large amounts of heat and have researchers seeking new ways to remove it. A trend rapidly gathering steam is the use of gallium nitride (GaN) transistors for RF power generation. One of the most appealing characteristics of GaN is its significantly greater power density, which allows it to achieve high RF output levels while taking up less space and using fewer devices. However, GaN devices (and all other RF power technologies for that matter) are responsible for large percentage of the heat generated by the host system.

Keeping devices cool has obvious benefits but less obvious ones as well, since heat is one of the greatest contributors to shortening the operating life of electronic components. Specifically, every 10° C increase in operating temperature produces a reduction in operating life of 50%. This is a major consideration for expensive RF power devices, so reducing their junction temperatures is essential and can potentially also allow the device to be driven harder to deliver more power at a specified junction temperature. Consequently, focusing on thermal management at the device level is highly desirable and the range of cooling methods being explored to address it range from traditional approaches to emerging technologies.



Nano Materials International's aluminum-diamond matrix composites have thermal conductivity greater than 500 W/m-K, compared with about 200 W/m-K for copper-tungsten or copper-moly-copper.

A key program in which these considerations are paramount is the US Navy's Next-Generation Jammer (NGJ), which is expected 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

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on other aircraft including the F-35 and UAVs. NGJ is expected to use solid-state RF power generation rather than the ALQ-99's Traveling Wave Tube Amplifiers (TWTAs). NGJ's use of solid-state RF power transistors and state-of-the-art signal processing hardware means fresh concepts for cooling are on the table.

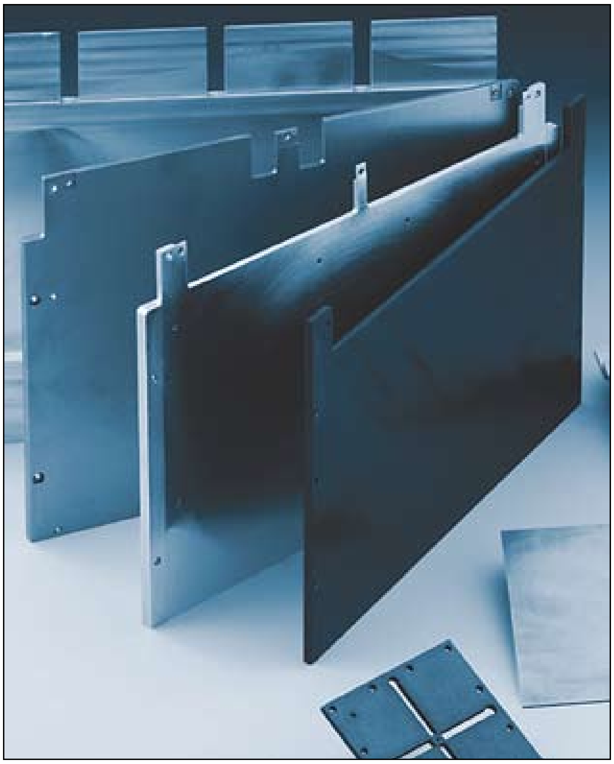
Works in Progress

A method for device cooling that has been "just around the corner" for many years is the use of aluminum diamond, which has been in various stages of development and dormancy since the first advances were made in the early 1990s. It 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), far better than other materials.

However, it has suffered from several 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, has been actively pursuing this technique and has developed aluminum diamond composites for packaging applications for the first time.

Diamond has the potential 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/cm^2 to 8000 W/cm^2."

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.



Momentive's called TC1050 material has high thermal conductivity, far higher than copper. TC1050 panels are typically mounted to PC boards placed in liquid-cooled chassis, providing a thermal short between the two.

"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 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."

Another technique in development at Pacific Northwest National Laboratory and Oregon State University employs nanoscale coatings to remove heat from semiconductors and other devices. The program, funded by the Army, has shown a ten times improvement in heat transfer coefficient with nanostructured surfaces over a bare aluminum substrate. The researchers also saw a four times improvement in critical heat flux. The coating method, called microreactor assistance nanomaterial deposition (MAND) deposits tiny grains of zinc oxide on bulk aluminum and copper, which allows heat to be transferred more efficiently.

One of the "thermal core"-type solu-

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