SiC soars to meet demand for small, lightweight power solutions

Using SiC can improve both efficiency and reliability of aerospace applications. As the industry strives for lightweight, compact, high density efficient power, SiC is being propelled into the spotlight.

By **Alain Calmels, Design Engineer, Microchip Technology**

As is the case in other strategic sectors of electronics, the aerospace industry is rapidly moving toward lightweight, small, high efficiency and high density power solutions. As a matter of fact, the new size, weight, power, and cost paradigm poses tough and stringent requirements to designers struggling to meet the market demand while at the same time providing high efficiency power solutions.

Traditional inverters and DC/DC and DC/AC converters are proving inadequate or inefficient for the most critical and challenging applications, such as latest generation satellites, unmanned aerial vehicles or electric aircraft. To overcome these challenges, the approach to high density power modules proves to be an effective solution to deliver high reliability and power density as well as flexibility.

An unprecedented boost to the aerospace power applications industry is coming from the third generation of wide bandgap (WBG) semiconductors. Silicon carbide (SiC) is moving the aerospace power supply to a new era, characterised by more efficient, smaller, lighter power solutions.

SiC properties

While SiC properties have been known since the end of the 19th century, it is relatively recently that this WBG material has been used as a semiconductor. Compared with traditional silicon-based power devices, SiC MOSFETs feature a high breakdown electrical field (3 to 5MV/cm, which is almost 10 times higher than that of silicon) and a bandgap about three time higher than that of silicon (3.26eV versus 1.11eV). Thermal management is also improved thanks to the thermal conductivity of SiC, which is nearly three times higher than silicon (4.9W/cmK versus 1.5W/cmK), and its specific resistance, which is much lower than silicon (0.3mΩ/cm^2 versus 400mΩ/cm$^{\tilde{}}$ for a 1200V breakdown voltage at room temperature). The on-resistance, or RDS(on), of commercially available SiC power devices can be up to 400 times lower than that of an equivalent silicon-based device at the same breakdown voltage.

Compared with silicon counterparts, SiC MOSFETs can operate at higher switching frequencies with less conduction and power losses, allowing for smaller passive components in power systems and more compact and lighter power solutions. This, in turn, has enabled the replacement of current IGBT devices with SiC MOSFETs in high-power, volume-constrained applications such as aeronautics.

Aerospace applications

The gate driver circuit for SiC MOSFETs requires a high positive gate drive voltage (about 20V) and, depending on the specific application, a negative "off" gate voltage in the -2-V to -6-V range (for dV/dt immunity and for achieving the fastest turn-off speed). Combined with low output capacitance and low RDS(on), that makes SiC devices attractive for switching designs such as power supplies, three-phase inverters, amplifiers and voltage converters (AC/DC and DC/DC). The use of SiC devices also allows significant cost savings and a reduction in the size of the magnetic parts (transformers and inductors) used in many aerospace power applications.

In the aerospace industry, the concept of more electric aircraft (MEA) has become very popular. MEA aims to electrify auxiliary aircraft on-board systems, previously powered through mechanical, hydraulic and pneumatic means for efficiency improvement, cost reduction and increased reliability.

New power devices are being designed to meet MEA requirements, including AC and DC power systems, which need power electronic converters for operation.

Several power conversion functions required by an MEA power system are performed by DC/AC converters, such as engine starting, control of pumps and generators and flight control actuators.

To meet these challenging requirements, DC/AC converters with high power density and that can operate at high switching frequencies are needed. Efficiency is also a key factor, as it allows you to reduce both the size and weight of the converter, simplifying thermal management. Due to their reduced conduction and switching losses, SiC power devices are proposing themselves as a viable candidate to replace silicon-based IGBTs and MOSFETs in avionic power converters.

Clean and sustainable aviation

The aerospace industry is moving towards zero-emissions goals, developing new technologies able to reduce net greenhouse gas while promoting the usage of sustainable drop-in fuels.

In Europe, the Clean Sky Consortium, a partnership between the European Commission and the European aeronautics industry, aims to develop cleaner air transport technologies capable of reducing CO^2, NOx, and noise emissions. A similar initiative has been taken by the International Air Transport Association, which last October approved a resolution for the global air transport industry to achieve net zero carbon emissions by 2050.

To fulfill these challenging requirements, pneumatic and hydraulic control systems need to be progressively replaced with high efficiency electrical and electronic control systems. Higher efficiency is a key factor for reducing fuel consumption, weight, and size.

Microchip Technology has introduced a series of AC/DC and DC/DC low profile, low weight power modules that provide higher power conversion efficiency through the utilisation of SiC. Capable of delivering from 100W to up to 20kW of power, they have been developed in collaboration with the European Clean Sky Consortium to meet new, demanding, clean requirements for the aviation industry. That includes compliance with RTCA DO-160G testing procedure (Environmental Conditions and Test Procedures for Airborne Equipment, version G). A DO-160G–compliant device can deliver reliable and accurate operation in any flight condition.

The modules (Figure 1) have a modified substrate, which results in a 40% reduction in weight and 10% in costs compared with standard solutions that incorporate metal baseplates and require a heatsink. In

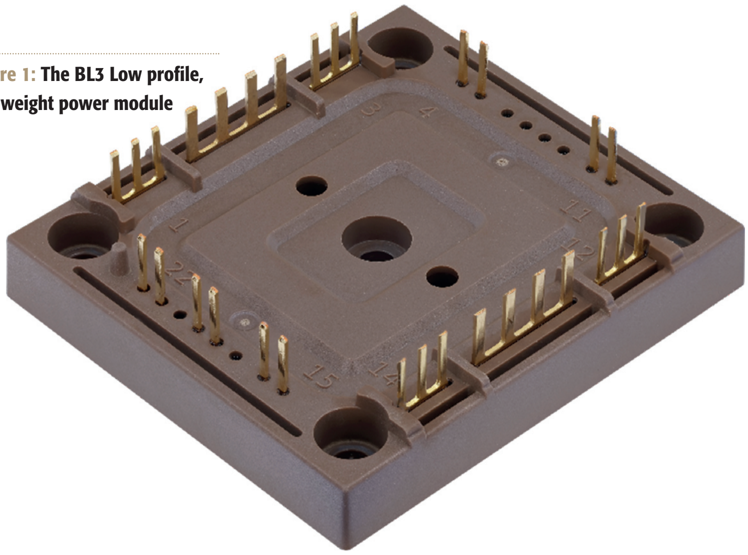

Figure 1: **The BL3 Low profile, low weight power module**

addition, the low-inductance and low-profile package can be soldered directly on the PCB, accelerating the development and increasing the reliability.

Believed to be the first aerospace-qualified low profile, low weight power module technology to serve aerospace applications, the family includes three sizes of power modules (BL1, BL2, and BL3). The standard configuration integrates 1.2kV full-SiC topologies, with or without freewheeling diodes. The modules are available as 75A and 145A SiC MOSFETs, 50A IGBTs and 90A rectifier diode outputs. IGBT-based and custom solutions containing devices with voltage ratings from 700V to 1,700V are also available. Depending on the specific version, different topologies are supported, such as full bridge, asymmetrical bridge, phase leg, dual common source, buck, and boost.

Figure 2 shows the phase leg topology supported by the BL1 power module (1200V, 79A, RDS(on) typical 25mΩ). The SiC power MOSFET features low RDS(on) and high switching frequency, while the SiC Schottky diode provides zero reverse- and forward-recovery and temperature-independent switching behaviour.

The full bridge topology, shown in Figure 3, is supported by both the BL2 and BL3 power modules. These modules feature a drain-source voltage of 1.2kV, continuous drain current up to 150A at ambient temperature (up to 300A of pulsed drain current), and drain-source on-resistance as low as 16mΩ. The SiC MOSFET features a Kelvin source for easy drive, and the SiC Schottky diodes also feature zero reverse- and forward-recoveries. Maximum power is 560W, while maximum gate-source voltage is -10V (off state) and 24V (on state).

Qualification tests

All of the BL1, BL2, and BL3 power modules have undergone qualification tests to demonstrate the ability to serve aerospace applications. The Acceptance Test Procedure, based on the conditions specified in RTCA DO-160G and in compliance with civil aircraft environmental conditions, included parametric test over the full voltage, current, and temperature range (–55°C, 25°C and 125°C), partial discharge test (10pC max at 1200V AC), hipot (3kV AC) and isolation resistance test (>100 MR at 500V DC).

The following tests have been performed:

- High temperature gate bias. The purpose of this test, performed at both VGS = 20V and VGS = -8V, is to verify that the device performance is not affected by high temperature gate bias. At a junction temperature of 175°C, the Vth measurements before and after 1,000 hours of high temperature gate bias stress show negligible variations.
- Temperature cycling. This test aims to assess the resistance of the device to extreme high and low temperatures. The X-rays and scanning electron microscopy analysis, performed after 1,000 cycles

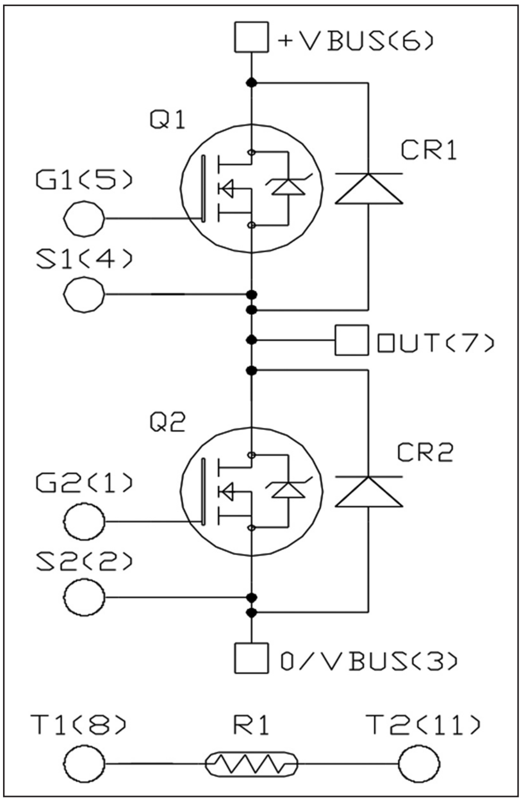

Figure 2: **Phase leg topology supported by the BL1 power module**

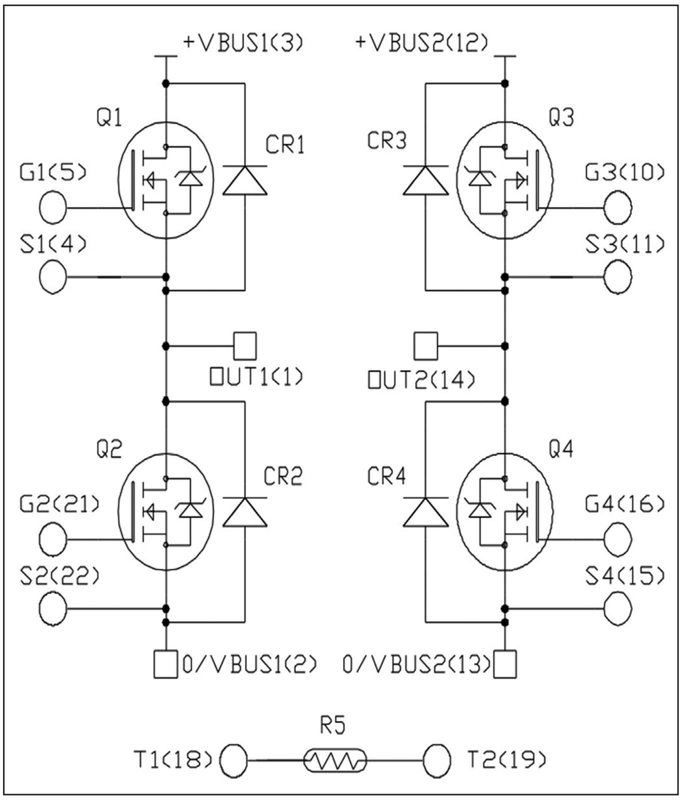

Figure 3: **Full bridge topology (dual phase leg) available in the BL2 and BL3 modules**

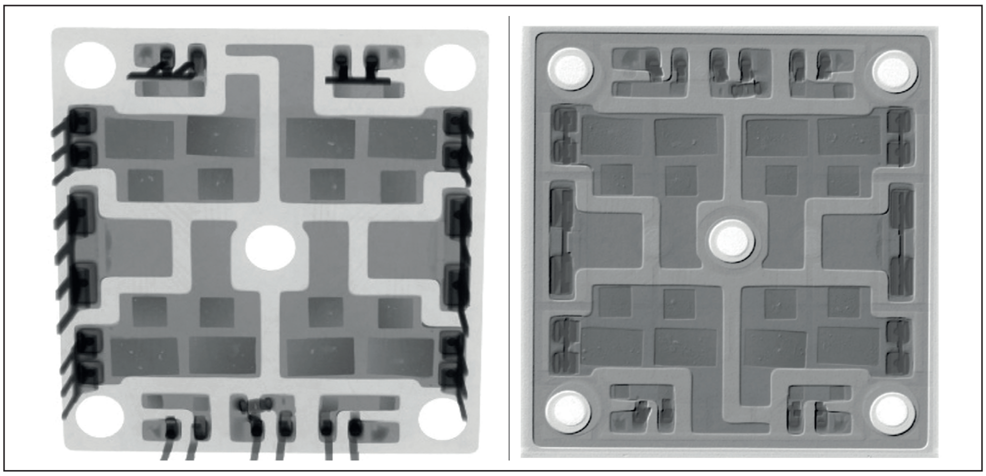

Figure 4: **X-ray analysis before and after 1,000 temperature cycles**

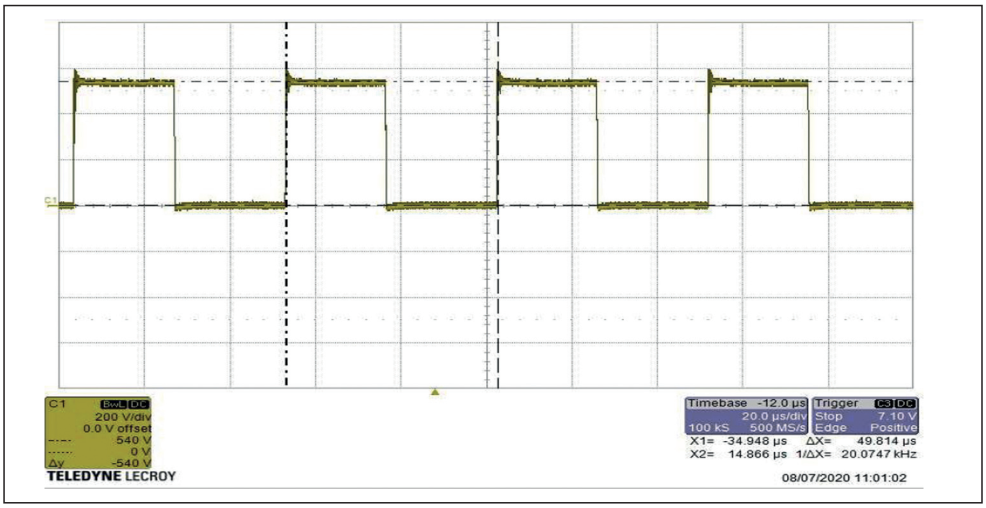

Figure 5: **CMB test plot**

(see Figure 4), do not show degradation at solder joint or substrate level capable of reducing the device performances.

- Vibration and shocks. After securing the power modules to a plate mounted on a vibration shaker, they were tested in three axes for vibration and shocks.
- Chopper mode bias (CMB). The purpose of this test is to verify the robustness of the device when it is operating in chopper mode at high temperature. Test conditions were the following: VGS = -5V, switching frequency = 20kHz, duty cycle = 0.5, T = 150˚C, test duration = 1,000 hours. Figure 5 shows the CMB test plot after 1,000 hours (200V/div).
- Partial discharge. This test aims to verify the insulation health of the DUT and is important for SiC power modules, which operate at high voltages and high dV/dt rates.
- Thermal simulations and measurements. Thermal simulation determines the DUT thermal resistance and thermal impedance values, while thermal measurement confirms the thermal resistance junction-to-heatsink calculated during the simulation. The switch under test, previously prepared with a modified package (Figure 6) was turned on, and a constant-current generator produced a junction temperature increase to calculate the thermal resistance. The results of the measurement confirmed the thermal simulations.

All tests were performed by Microchip. The company says passing these tests demonstrate reliability and prove this technology is qualified and suitable to serve ever more challenging aircraft applications.

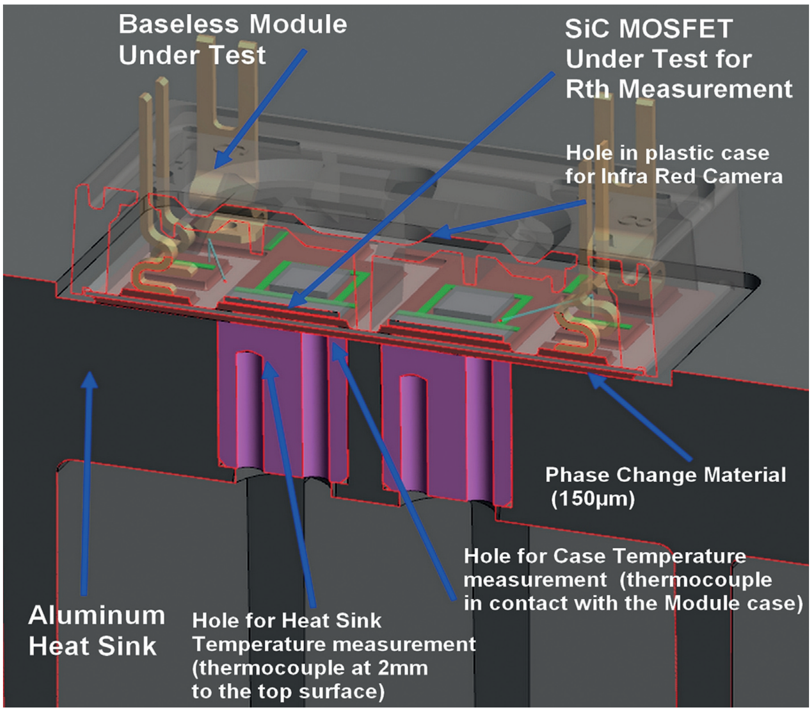

Figure 6: **Thermal measurement setup**