bulgin

Design Considerations for Electronics Facing Extreme Temperature Environments

bulgin

The expanding number of evolving applications in Aerospace, Defense, Industrial, and Oil & Gas Exploration demand the highest level of thermal performance obtainable within budget.

One of the most profound aspects of an advanced connected electronically-oriented society is that device-based solutions must penetrate as many application spaces as possible to deliver the maximum benefit. However, this places relatively delicate hardware systems into situations they must be specially prepared for to deal with.

Most think of wet and dirty situations when harsh environments come to mind, and while correct that connection is incomplete. In addition to moisture, dirt, vibration, and shock, electronic systems intended for use in challenging environments must be able to handle thermal situations as well. Unfortunately too many think of thermal management after there has been a catastrophic thermal incident related to electronics (Figure 1).

In government-oriented application spaces such as military/aerospace equipment manufacturing, failure may not only include loss of human life, but may contribute to a significant diplomatic or strategic impact. Mission failure in such situations is completely unacceptable under any situations, existing or created by theater combat or

Figure 1: By the time a situation has reached catastrophic thermal runaway, it is too late to manage heat. (Orange County Sheriff's Department/National Transportation Safety Board via AP)

Figure 2: The oldest and most prevalent high-temp user space is the down-hole oil and gas industry.

exo-planetary conditions. Such situations demand not only the best solution available, but also one that is reliable in the field.

Thermal Challenges

There are three primary sources for thermal issues in an electronic system, and each, if unaddressed, can lead to failure, catastrophic or otherwise. These are, in no order of importance:

- Thermal inefficiency
- Thermal environment
- Thermal stress

Thermal inefficiency is a blanket term for all internal heat caused by the system. In electronics, this is primarily due to power-conversion losses in the circuitry. This can be complicated by thermal losses from friction or mechanical inefficiency in any electromechanical systems involved.

Thermal environment is what the system encounters in the field. This can be any external factor, from normal weather-based thermal challenges to situation-induced external thermal challenges such as from nearby operational combat weaponry or atmospheric friction.

Thermal stress comes from short-term challenges due to failure, accident, or mischief. This can be as simple as installing a wireless hub under an exhaust vent, to failure to compensate for motor failure or other short-circuit or arcing situations causing near-term high-level thermal shock.

Traditional means of addressing thermal management include active or passive cooling, with possible inclusion of physical thermal-transfer mechanisms such as fins or heat pipes. Another approach is to design the electronics with full derating in mind, or otherwise overengineer the solution to be able to cope with high temperature loads. With the advent of wide-bandgap semiconductors in power electronics, the latter approach is getting easier, but passives and magnetics are still challenged to keep up.

High-Temperature Applications

When it comes to high-temperature applications, many think military and aerospace, but in reality the oldest and most prevalent user space operating routinely at temperatures over 150°C is the down-hole oil and gas industry. Systems in this space face operating temperatures that can rise sharply, as the typical geothermal gradient is approximately 25°C/km. Temperatures in such hostile places can exceed 200°C, with pressures over 25 kpsi.

When drilling, electronics steer the drilling equipment, monitor its health, and acquire data about the surrounding geologic formations, including resistivity, radioactivity, acoustic travel time, magnetic resonance, and other properties. In addition, the systems monitor pressure, temperature, vibration, and flow, while actively controlling valves. Failed electronics miles underground can take up to a week to retrieve and replace, at costs that can exceed seven figures a day.

There are other applications, like avionics, that have always had to work with extremely high operating temperatures. However, in legacy applications such as aircraft, vehicle, and industrial, engines were mostly hydromechanical systems, with sensitive electronics and avionics usually confined to the operator and passenger spaces. Modern electronics-based distributed monitoring and control methodologies place controls and sensors closer to or inside the engine.

While this reduces complexity and weight while increasing reliability and performance, it requires said electronics to be able to operate under the temperature extremes involved. Again, as in down-hole systems, avionics and auto fossil-fuel engines can operate at temperatures up to 200°C, and must also be able to go in the other direction, down to as low as –55°C. Electronics cooling adds cost and weight to aircraft, and in any system, a cooling issue could lead to failure of the electronics controlling critical systems.

Meeting the Challenge

Internal hardware can be ruggedized to address thermal challenges in many ways. At the board level, this can mean applying a conformal thermal-transfer and/or insulation coating. Conformal coating can be a thin layer of a non-conductive, protective material such as silicon, acrylic, urethane, or paraxylene. In addition to increasing overall durability, coatings also protect from outside contaminants and dirt.

In systems operated above standard temperatures, one can add copper weight to the board, which can be used alongside conformal coating. Also, using a substrate with a higher glass transition temperature (Tg) will also make the board more durable at higher temperatures. These coatings and other insulation materials applied to the board can also ruggedize it against shock and vibration (Figure 3).

This enclose-and-protect approach extends to the packaging, which must be made of materials appropriate to the application as well as be resistant to temperature extremes. A device's enclosure not only encompasses the system, it also presents the user interface and I/O capabilities to the world. These buttons and ports must not only address form and function, but also harsh-environment and thermal resistance.

Any non-convection thermal management solutions involving cooling and/or heating must address issues such as the integrity of vents and fan protection from the environment as well. Gasketing and filtering are critical considerations, as they must not only protect against electromagnetic interference (EMI), dust, and moisture, they must also be able to handle temperature extremes.

When it comes to thermal management, it is best to test any solution created to ensure it can perform under any foreseen situations. Qualifying systems require testing in a lab oven, and it is difficult to speed testing because novel failure mechanisms may be encountered, resulting in another iteration of component selection and long-term test. In particular, IC process changes can result in unexpected failures at temperature extremes.

Many factors affect package integrity at temperature, so be attentive to aspects such as matching the coefficient of thermal expansion between the die, die-attach, and substrate—so that the die is not stressed or fractured over temperature cycles. Even slight mechanical stress on the die can cause unacceptable shifts to electrical parameters in precision applications.

Circuits that operate at high temperature must also account for changes in ICs and passive components, paying close attention to their behavior at or near derating limits to ensure circuit operation within target parameters. Examples include offset and input bias drift, gain errors, temperature coefficients, voltage ratings, power

Figure 3: Solutions that address heat can also otherwise ruggedize a system.

dissipation, board leakage, and intrinsic leakage of other discrete devices. In all cases, high-temperature operation exacerbates board issues caused by manufacturing such as solder flux, partial keystoning, and delamination.

The Critical Connection

No matter the sophistication of the system, unless the interconnections between the subsystems are as robust and rugged, usually more so, than the portions involved, the overall design will fail. Like a chain, any system is only as robust as the tolerances of its least-rugged aspect. That can be unavoidable things like ports and windows, or avoidable things like overlooking proper connection and cable integrity in the interconnects.

For example, MIL-DTL-83723F covers the general requirements for environment resisting, circular, electrical connectors and their associated contacts and accessories. Hermetic receptacles with nonremovable contacts must operate at a temperature range from -65°C to 200°C. The maximum operating temperature is the combination of the environment and current load.

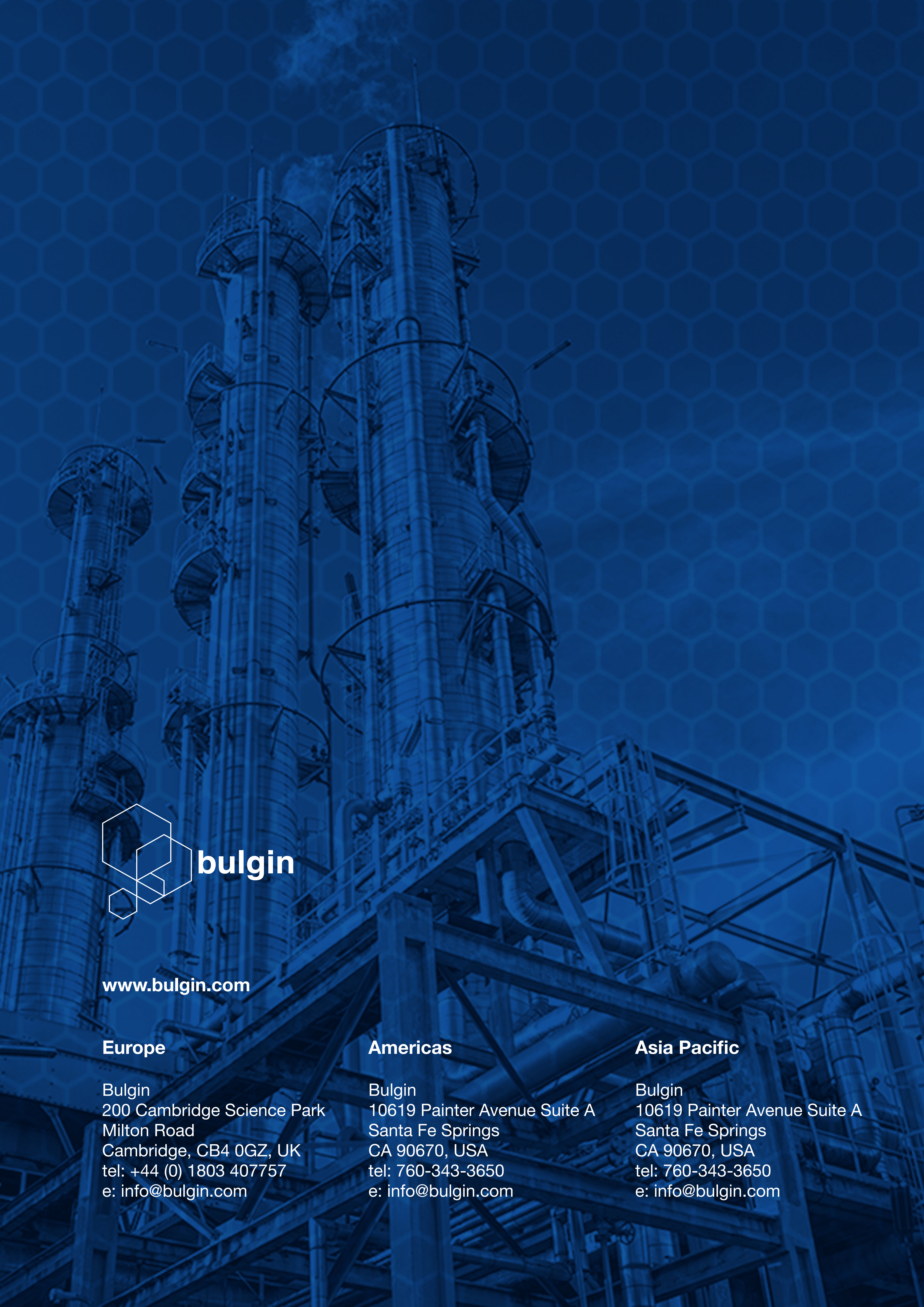
EN2997 is a related connector specification dedicated to applications in extreme environments such as engine aircraft applications where vibrations, EMI and high temperature issues are the most concerned. Compliant with the MIL-DTL-83723 standard, EN2997 are mainly used with high performance demands like aerospace and military.

Cables and connectors must have the same ability to withstand external environment extremes in temperature, pressure, and moisture as the systems they connect, and must also address issues such as flex, stretch, and user error. What the plug is made of directly impacts performance, and the use of high-grade, corrosion-resistant materials, and the use of specific plating and contact finishes, can ruggedize a connector, as well as encapsulation and gasketing. Plating options may need to create an electrically conductive finish, and some contacts' finish are in gold, due to both conductivity and corrosion resistance.

In places where systems are exposed to high pressures, for example in crewed or robotic vehicles submerged in water for extended periods, secure and waterproof electrical connections are as vital as thermally resistant. Assembly and maintenance are critical, as this is another area where connector design impacts performance, as poor termination haptics can increase user error, bypassing all intended thermal and environmental resistance.

Summary

Thermal issues, unless proactively addressed, can literally accumulate to the point of system failure. Thermal threats to operation can come from a variety of sources, from accumulated waste heat, to improperly managed external thermal loading, to heat from failure states like motor seizures and short circuits. Being able to address every kind of thermal threat to the system involved insures reliability, performance, and safety.



bulgin

www.bulgin.com

Europe

Bulgin
200 Cambridge Science Park
Milton Road
Cambridge, CB4 0GZ, UK
tel: +44 (0) 1803 407757
e: info@bulgin.com

Americas

Bulgin
10619 Painter Avenue Suite A
Santa Fe Springs
CA 90670, USA
tel: 760-343-3650
e: info@bulgin.com

Asia Pacific

Bulgin
10619 Painter Avenue Suite A
Santa Fe Springs
CA 90670, USA
tel: 760-343-3650
e: info@bulgin.com