Electronics for You
Extreme Temperatures Do Not Deter Modern Electronics
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Extreme Temperatures Do Not Deter Modern Electronics

Earlier active or passive air-conditioning and tough verification and qualification processes were needed to maintain electronics used in extreme environments such as mines, spacecrafts, engines and icy mountains. However, advancements in process technology, circuit design and layout techniques have now given rise to electronics that can withstand severe temperatures quite nonchalantly

JANANI GOPALAKRISHNAN VIKRAM

For ages, machines have been put to use in hazardous environments that intimidate humans, and these machines, more often than not, contain electronic components too. In the past, it was a huge challenge for engineers to make electronics work at temperatures too high or too low (say, less than -55°C or greater than +125°C). A lot of extra effort went into active and passive air-conditioning and ventilation systems, to keep the temperature in check, as well as complex verification, characterisation and qualification using lab ovens or freezers, to modify off-the-shelf components and test their behaviour under extreme temperatures. Despite all the efforts, the chances of the system functioning perfectly were still dismal.

"Traditionally, engineers had to rely on active or passive cooling when designing electronics that must function outside normal temperature ranges, but in some applications cooling may not be possible, or it might be more appealing for the electronics to operate hot to improve system reliability and reduce cost. The choice presents challenges that affect many aspects of the electronic system including silicon, packaging, qualification methodology and design techniques," says Somshubhro (Som) Pal Choudhury, managing director, Analog Devices India.

With advances in materials and process technology, circuit design and layout, chip-makers have developed electronic components that can work reliably under extreme-temperature conditions. In fact, players like Analog Devices (ADI) and Texas Instruments (TI) cover the whole signal chain, including sensors, amplifiers and microcontrollers, capable of operating under harsh conditions.

Traditional challenges

Operating electronics at low temperatures is less of a challenge compared to higher ranges. The performance of electronic components is known to be better at lower temperatures. Taking advantage of the same, Kryotech came up with the Cool Athlon range of cen-

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India Media Monitor

tral processing units (for desktops) that had an in-built refrigeration system to bring the system temperature down to -36°C, wherein the best performance was achieved.

It is only when temperatures drop beyond -230°C, such as in space applications, that the problem begins, as the properties of silicon start changing at that point. Since the applications are very niche, the problem is somehow overcome using insulation and heating systems, or special packaging and materials.

The bigger problem—with greater applications—that silicon makers are more concerned about today is extreme heat. We know how heat affects a laptop. In summers, we often end up having blowers or laptop coolers to bring down the temperature to avoid performance degradation. This is at temperatures in the range of 40°C-50°C. Imagine how temperatures in the range of 125°C or higher would affect electronic components!

If conventional electronics is to be used at extreme temperatures, it would require passive or active cooling, using refrigerators and heat sinks. Probes used for well-logging, for example, may be placed in vacuum-insulated vessels to protect them from the hot environment. In addition, the electronics may be thermally connected to a heat sink, which uses materials like water or bismuth alloy that can absorb large amount of heat without a substantial temperature increase. This is usually done by employing the material's phase change from solid to liquid, which absorbs a large amount of heat (the latent heat of fusion).

However, all such cooling techniques—both passive and active—have problems. Passive techniques have a limited lifetime, while active techniques require additional power and sub-systems. Active techniques may also be too disturbing to the environment because of the additional heat that is ejected from the system. All the techniques add weight, size and some degree of complexity—which is unacceptable because extreme-temperature applications are generally critical and space constrained.

Even if sufficient ventilation and cooling is incorporated into the system, electronic components still need to be extensively tested and validated using lab ovens, etc, to confirm whether they can withstand such temperatures. The component maker generally would not give any assurance or guarantee for the functioning of standard components at extreme temperatures; so deployment is at the user's own risk. Plus, even if the components per se work, sometimes the packaging might not be tolerant to very high temperatures, in which case the die has to be purchased and repackaged for the application. And, despite all this effort, there are chances that the component could fail due to other factors like vibration, interference or electro-migration in metal interconnects, which are very difficult to detect during testing.

All this gives rise to the need for special electronics that can withstand extreme temperatures, especially on the higher end.

Modern technologies

New materials, testing, qualification and packaging techniques have helped silicon makers to come up with customised silicon chains that can work in extreme temperatures with high reliability.

"Integrated circuit (IC) technology from companies like ADI has produced devices that can operate reliably at elevated temperatures with guaranteed datasheet specifications. Advances have been made in process technology, circuit design and layout techniques. Managing many key device characteristics is crucial for successful, high-performance operation at elevated temperatures. One of the most important and well-known challenges is posed by the increased

Tough weather, mate!

Electronic systems are often required to work in extremely harsh temperature conditions, beyond industrial or even military ranges. Here are some examples.

Down-hole oil and gas industry. This is one of the largest markets for extreme-temperature electronics. Well-loggers or probes sent into geothermal wells have sensors and signal processing equipment, which have to withstand temperatures as high as 300°C. The typical geothermal gradient is 25°C/km as you go closer to the centre of the Earth. So the deeper the underground well, the worse the operating temperatures.

Avionics. The distributed control systems used in modern aircrafts require engine control systems to be closer to the engine, to reduce complexity of interconnections and increase reliability. Since the electronic components are closer to the engine, these now have to sustain much higher temperatures.

Automotive. The electromechanical or mechatronic systems in modern automobiles require sensors, signal conditioning and control electronics to be located close to engines and heat sources. Electric and hybrid vehicles also require power electronics with high-energy density for converters, motor controls and charging circuits that are also associated with high temperatures.

Space exploration. A space probe that goes to Neptune should be able to operate at –230°C. On Venus, the temperature would be close to 500°C. When orbiting the Earth, the temperature might drop to –230°C near the lunar poles. Beyond tolerating such temperatures, the electronics should also be able to handle sudden or gradual changes in temperature along the path to its destination. Further, this complex industry requires not just temperature resistance but also radiation-hardened components that can withstand particle radiation and high-energy electromagnetic radiation.

Astrophysical equipment. Astrophysical equipment, such as bolometers and infrared space telescopes, require electronics that can withstand very low temperatures.

Medical equipment. Medical equipment that handle liquid nitrogen and other such compounds often need to handle very cold temperatures.

Surveillance. Sensors and signal processors used in military surveillance equipment must withstand very harsh weather conditions as they may be deployed anywhere.

LED lighting. LED lighting, especially centrally-managed lighting systems, require control systems, signal processors, etc that can withstand high temperatures generated by the light.

Other applications including undersea cabling and industrial use.

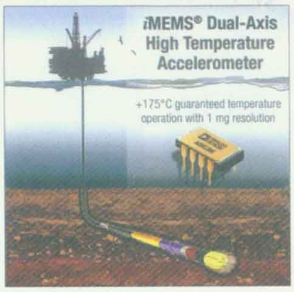
substrate leakage current. Some others are decreased carrier mobility, variation in device parameters such as threshold voltage, beta and saturation voltage, increased electro-migration of metal interconnects, and decreased dielectric breakdown strength," says Choudhury.

Let us look at how some of these problems are overcome in new technologies.

Handling substrate leakage. Although standard silicon can operate well beyond the military requirement of 125°C, leakage in standard silicon processes doubles for every 10°C increase in temperature, making it unacceptable for many precision applications. Trench isolation, silicon-on-insulator (SOI) and other variations to the standard silicon process help decrease leakage and enable high-performance operation at temperatures above 200°C. Use of wide-band-gap materials, such as silicon carbide (SiC), helps raise the limits even further, to as high as 600°C.

Testing and characterisation at high temperatures. Simulating extreme temperature environments in the lab to verify, qualify and characterise the components can be very challenging. Special materials, ovens and chambers are required to create the test platform, wherein the tests have to be done carefully without damaging the printed circuit board (PCB), by gradually increasing or decreasing the temperature. Specialised tools are available today, which can operate at such high temperatures to test and control electronic systems.

"Special industrial, aerospace and defence applications like monitoring oil and gas pipelines, and controlling heavy machinery and space vehicle test systems require control units and sensors that can function even at extreme conditions of temperature, pressure and vibration. These critical applications also demand extremely low failure rates. Testing the sensors and control systems thoroughly for all environmental conditions is necessary before they can be deployed in the field. Special test set-up with rugged



ADI ADXL206 accelerometer

control and measurement systems that can endure similar conditions are required to validate the functioning of these sensors and control units," says Ravichandran Raghavan, technical marketing engineer, National Instruments, India (NI). NI has solutions for design and test of extreme temperature components.

Packaging the die. While plastic packaging would withstand temperatures up to 175°C, other technologies would be needed beyond that. TI, for example, offers three types of packages to support high-temperature applications: plastic package for 175°C, ceramic and known good die (KGD) packaging for higher temperatures. Ceramic and KGD parts are characterised to 210°C, operate in an extended temperature range of -55°C to +210°C, and have a high-temperature operating life of 1000 hours. Even the plastic package is ruggedised using special techniques to improve reliability at high temperatures.

"While packaging, care must be taken to match the coefficient of thermal expansion between die, die-attach and substrate, so that the die is not stressed or fractured over cycles of wide temperature span," suggests Choudhury.

Managing circuit design considerations: "Those designing circuits for high-temperature use must account for changes in IC parameters and passive components over a wide temperature range, paying close attention to their behaviour at the temperature extremes to ensure circuit operation within the target limits," says Choudhury. They must analyse offset and input bias drift, gain errors, temperature coefficients, voltage ratings, power dissipation, board leakage and intrinsic leakage of other discrete devices. Often, high-temperature operation worsens board leakages due to contaminants such as solder flux, dust or condensation. Designers usually overcome such problems by using a proper layout that ensures adequate spacing between sensitive nodes.

Being put to good use

Using special techniques and engineering skills as discussed above, chip makers now offer full extreme temperature silicon chains for various verticals. Several components are available today, which are guaranteed to withstand extreme temperatures. Examples include high-precision temperature sensors (ranging from 1 to 0.25-degree accuracy), low-voltage programmable thermostatic switches, airflow and liquid flow sensors, digitally-programmable sensor signal amplifiers, instrumentation amplifiers, high-G micro-electromechanical accelerometers and gyroscopes, microprocessor supervisory circuits, signal processors, power management and data conversion systems, test instrumentation, and more. Let us take a look at some of these products available in the market.

Accelerometers. High-temperature accelerometers are available for vibration, speed and gravity measurement in industrial applications, geological down-hole exploration, etc. One such example is ADI's ADXL206—a high-precision, low-power, dual-axis accelerometer that uses its integrated micro-electromechanical system (iMEMS) technology to integrate the sensor and signal-conditioned voltage outputs on a single, monolithic IC. It can measure both dynamic (vibration) and static acceleration (gravity) with an accuracy of 1mg resolution at 60 Hz. It is housed in an eight-lead side-brazed ceramic dual in-line package (SBDIP), and can stand operating temperatures of −40°C to +175°C, with a guaranteed 1000 hours life.

Instrumentation amplifiers. Companies like TI and ADI have high-temperature instrumentation amplifiers for various applications. ADI's AD8229 is an ultra-low noise instrumentation amplifier designed for measuring small signals in the presence of large common-mode voltages and at high temperatures in the range of 210°C. The process is dielectrically isolated to avoid leakage currents at high temperatures, and the design architecture compensates for the low base-emitter voltages at high temperatures.

Capable of measuring even tiny signals, the AD8229 is available in an eight-lead SBDIP. For space-constrained applications, there is also an eight-lead plastic standard small outline package (SOIC). It is used extensively for down-hole instrumentation, harsh-environment data acquisition, exhaust gas measurements and vibration analysis.

TI also has a range of high-temperature rated instrumentation amplifiers, such as the INA128-HT, INA129-HT and INA333-HT, which can operate from -55°C to +210°C. TI's high-temperature products utilise highly-optimised silicon (die) solutions with design and process enhancements to maximise performance over extended temperatures. The INA129 is available in an eight-pin ceramic dual inline package (DIP) and an eight-pin ceramic surface-mount package, specified for the −55°C to 210°C temperature range. The INA128 is available in an eight-pin small outline surface-mount package (SO8), specified for the −55°C to +175°C temperature range.

Flash memory. TI has introduced what it claims to be the industry's first high-temperature 4MB Flash memory device. TI's SM28VLT32-HT has an operating temperature ranging from -55°C up to +210°C, designed for data logging and firmware designs. It comes in a small ruggedised packaging—14-pin ceramic flat package and KGD.

SM28VLT32-HT 4MB Flash memory device by TI (Courtesy: http://newscenter-jp.ti.com)

Consumer products are also now featuring temperature-tolerant memories, although the range is much lower than for critical applications. SanDisk, for example, is now promoting its Extreme SDXC UHS-I card and Extreme Pro MicroSDHC UHS-I 16GB card for use in cameras, video recorders, etc, and the Cruzer Glide USB Flash drive, which can be used in cold and hot weather spanning -25°C to +85°C.

Applications processor. One example of a high-temperature applications processor is TI's OMAPL137-HT. It is a 300MHz dual-core (ARM926EJ-S and TMS320C674x DSP) applications processor designed for use from -55°C to +175°C, enabling harsh environment intelligent electronic processing. It runs a high-level, real-time operating system, and has robust 1.8V/3.3V peripherals (Ethernet MAC, EMIF 1/2, USB2.0 OTG, McASP). It comes in a 176-pin plastic quad-flat-pack package.

Auto-grade products. Companies like National Semiconductor, NXP, Altera and Bosch offer 'automotive-grade products,' which generally means that these adhere to Automotive Electronics Council (AEC) standards for humidity, temperature, stress and other factors. There are various levels of auto compliance such as Q100, Q200 and so on. NXP, for example, complies with AEC-Q100. Within AEC-Q100, there are five grades (0-5) for operating temperature, representing lower limits from -40°C to +150°C on the upper end. So when choosing an auto-grade product, one needs to check its compliance with the required standard/grading.

Test and measurement systems. When using electronics for critical applications, reliability is very important. In order to test and ensure non-failure, constant test and measurement is required, which means that the test system for such electronics should also be able to endure the same temperature conditions as the electronic components. NI's CompactRIO is designed for such applications in harsh environments and small places.

"Size, weight and I/O channel density are critical design requirements in many such embedded applications. Taking advantage of the performance and small size of FPGA devices, CompactRIO is able to deliver unprecedented control and acquisition capabilities in a compact, rugged package with extreme industrial certifications and ratings for operation in harsh industrial environments," says Raghavan.

With a variety of connectivity options, NI CompactRIO can be interfaced with most of the industrial sensors like pressure transducers, magnetic pickup sensors, digital encoders, temperature sensors, accelerometers, nuclear densitometers and magnetic flow meters. It is programmed with NI LabVIEW graphical programming tools. A bare-board version of the CompactRIO, the NI Single Board RIO, is also available.

"Korea Gas Corporation has used CompactRIO to develop a safety management system to monitor exposed city gas pipelines attached to bridges. Ventura Aerospace was able to develop an intelligent fire monitoring and suppression control system for FedEx Express using NI LabVIEW software and NI Single-Board RIO hardware to prevent catastrophic fires within freight aircraft and keep pilots, packages and planes safe from fires that may start in shipping containers. Similarly, Lime Instruments, LLC, built an advanced monitoring system that could be mounted directly on an oil well servicing pump in a rugged environment, to perform advanced analysis on sensor data," adds Raghavan.

Power equipment. Power equipment such as UPS are also available that can operate at extreme temperatures, when deployed in military outposts or industrial environments.

Sriram Ramakrishnan, CEO of Consul Consolidated, an Indian player in this space, says, "Consul offers UPS systems and inverters that can withstand extreme temperatures. These are custom designed and manufactured to meet the requirements of the order. Consul has supplied custom-built UPS for various defence applications to operate with defence equipment in extreme temperature conditions, as per JSS specifications."

All components used in defence applications meet MIL-grade specifications instead of commercial grade to operate in extreme temperature conditions. All the cables used in the cabinet are of shielded type for reducing the EMI and RFI interference.

Due to the need to operate in extreme conditions and other special needs, the cabinets are also constructed of higher-grade steel, with special surface treatment for conductivity. The layout of the internal components has also been changed to meet the RFI and EMI specifications.

"Apart from materials, you also need to consider self-contained cooling and ventilation for the UPS system to operate successfully," adds Ramakrishnan.

Consul has also worked closely with DRDO on some of DRDO's missile projects, and with the Brahmos team to create prototypes of UPS systems to be used in the early stages of the project. They have worked right from the design stage to the fabrication of prototypes and field testing of the UPS.

More to come

There are many more such extreme-temperature products available in the

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market today. There is also a lot of research happening across the world to understand and improve low- and high-temperature operation of electronics, hermetic packaging, cryogenic electronics, etc.

For example, in March 2013, Sandia National Laboratories (SNL) announced that it has developed a gold-silver-germanium alloy that is capable of withstanding high temperatures and pressures. The melting point of the alloy is around 450°C, making it suitable for use as a solder for electronics in high-temperature environments, such as those in geothermal wells. Current brazing processes occur at temperatures above 750°C, and the materials used are generally not suitable for electronics. Similarly, soldering occurs at temperatures below 350°C, which is also unsuitable for high-temperature electronics. Therefore SNL believes that its new alloy will fill a niche for high-temperature soldering.

Similarly, last year scientists at the University of Illinois, Urbana-Champaign, discovered the self-cooling effects of graphene transistors, which could do away with the need for heat sinks and other cooling mechanisms in high-temperature operating environments.

As electronics finds its way into more and more niche applications, there will be all the more need for it to work in cooler and hotter environments—and more scope to put specialised extreme-temperature electronics and research prototypes to good use! ●

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