NUVATION ENGINEERING

WHITEPAPER

Important Design Considerations for Electronic Devices

Part 2: Operating in Harsh Environments

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Over the past two decades Nuvation Engineering has developed data acquisition systems for a wide range devices and market applications. Based on our experience performing hundreds of engineering design projects, our engineers have identified several key considerations that require special attention during the planning, design, and development of data acquisition systems.

Few products operate in clean, dust-free, temperature-controlled, vibration-free, laboratory-like environments. Your product is likely to be subjected to one or more of the following:

- Mechanical vibration/shock
- High or low pressures (e.g. high altitudes)
- Extreme temperatures
- Dirt/dust or other contaminations
- Humidity or moisture
- Ionizing radiation
- Electromagnetic interference (conducted or radiated)
- ESD and transients

Nuvation designed this 24-channel data acquisition board for use in a space satellite system.

Designing for Space

Products designed for space are exposed to the some of the harshest environments. They must operate reliably under intense vibration, mechanical shock, wide temperature swings, a vacuum environment, and exposure to ionizing radiation. This article will share some of the solutions Nuvation Engineering implemented for outer space environments when we designed a 24-channel data recorder module for a spacecraft built by Space Systems Loral (SSL).

Radiation

Radiation is one of the most challenging requirements for which to design. Products in space are bombarded with a wide variety of high energy particles and electromagnetic waves that originate from the sun and other stars. These sources of ionizing radiation cause short-term disturbances to electronics (such as bit flips and memory erasures), and cumulative damage to semiconductors. For long-term missions in space (typically about 15 years), the only option is to use radiation-hardened (a.k.a. "rad-hard") components. These components are relatively scarce compared to standard components. Rad-hard components can cost anywhere from ten to five hundred times more than their terrestrial equivalents!

For short-term space missions (one year or less), it is sometimes permissible to use standard commercial-off-the-shelf (a.k.a. "COTS") components in your design, subject to analysis and testing of their radiation tolerance. This can dramatically reduce the cost of designing space equipment and expand the selection of components available for the design.

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Nuvation's spacecraft design utilized mostly COTS components and included a few rad-hard parts for critical safety functions. We achieved this cost optimization in component selection by applying several design techniques in hardware and software to deal with the effects of radiation, such as:

- Since radiation can cause electrostatic charge build-up on isolated pieces of metal, the PCB design included the grounding of all stray metal islands.
- Our design engineers selected a special memory technology called "magnetoresistive memory", which is particularly tolerant to ionizing radiation.
- To avoid corruption of the code memory due to space radiation effects, the write-enable strobes for the code memory ICs were disconnected during flight (i.e. only connected when a ground testing harness was attached).
- In software, critical memory records were made redundant in 3 separate locations. The software continually scanned these three locations to determine if any errors appeared in one copy as compared to the other two. If an error appeared, the value was corrected based on the other two good copies. This same principle of data-triplication-and-compare was applied in several different contexts.
- Multiple levels of software and hardware watchdogs were employed to allow the system to recover from any type of unexpected processor glitch.
- The implementation of these design approaches in combination with the inclusion of a few rad-hard components dramatically reduced the potential risks associated with the effects of radiation damage.

Nuvation developed a control circuitry and software for transporting highly sensitive wafer-filled FOUPs down a conveyor.

Shock and Vibration

Spacecraft are subjected to high g-forces and vibration during ascent, and undergo violent shocks during each separation stage. Nuvation employed numerous design approaches to handle these conditions, including:

- The PCBA was contained in a machined aluminum housing that had many separate screw-down locations. Every screw was tightened to a prescribed torque and then reinforced with space-grade epoxy.
- All components on the PCB had to be considered with regard to their tolerance to shock and vibration. For example, since Class 2 ceramic capacitors are prone to piezoelectric effects (i.e. they generate an electric charge in response to mechanical stress), Nuvation's design engineers minimized their use in critical analog circuits.
- Large or heavy components soldered to the PCB were additionally bonded with epoxy.
- Extensive burn-in testing was required for each piece of equipment before it could be certified for flight. The burn-in test includes a 48-hour stress test with ten hot/

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cold temperature cycles, and four 2-minute vibration segments at an intensity of 30 Grms. The equipment had to remain powered and operate correctly throughout the entire 48-hour period. This extensive testing verified that the component choices and design approaches delivered a product that could withstand the extreme shock and vibration events of spacecraft stage separation.

Hard Vacuum

An additional consideration for space is the need to operate in a hard vacuum. Although most COTS electronic components are not designed for use in a vacuum, many of them will work well as long as sufficient attention has been paid to thermal dissipation. However, since convective heat transfer will not occur in a vacuum, components must be cooled via conductive or radiative thermal transfer.

Nuvation Engineering designed the space PCBA to conductively channel all the heat from components into the aluminum heatsink/enclosure by implementing the following:

- Both sides of the PCBA surfaces were flooded with copper to aid in conduction.
- Hot components were placed close to the enclosure tie-down locations.
- Thermal epoxy was selectively applied to certain parts to improve their conductivity to the PCB.

A vacuum has a tendency to cause trapped gasses to leak from components or materials, an effect called outgassing. Since these gasses could interfere with other sensors or equipment on the spacecraft, all components on the PCBA had to be selected based on their outgassing potential. Nuvation's engineering team also coated the board with a special low-outgassing, space-rated conformal sealant, which provided the additional benefit of protecting the PCBA from contamination during ground operations.

Harsh Environments on Earth

Although space is a harsh environment, some of the harshest environments can be found right here on Earth. Every year, a number of Nuvation engineers contribute to the design and construction of an electric and autonomously driving mutant vehicle that is brought to the Nevada desert for one week. The daytime temperatures can reach 40°C (~104°F) and dip below freezing at night. The vehicle is exposed to high levels of vibration from the rough roads, and lack thereof. There are dust storms that coat everything in a thin layer of dirt. The electronics have to be designed to withstand wide

Nuvation designed battery control boards for this portable power system that can be continuously vibrating or emitting high electrical noise.

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temperature swings (including high temperatures generated by the vehicle itself) and high levels of vibration. Continuous reliable operation of the vehicle is critical given the remote location and dangerous conditions of any desert. Attention to design details, such as incorporating dust-proof connectors/enclosures to keep dust/water away from the electronics, contribute to ensuring reliability in the field.

It is important to realize that the end-users of your product may be exposing it to less-than-ideal conditions. When commissioning a battery management system for a grid-scale energy storage system, Nuvation engineers found that the radiated electrical noise from the power conversion system was significant enough to bring about the dreaded Blue Screen of Death on laptops that were simply in the same room as the noisy system.

Setting Design Requirements

Nuvation developed a custom imaging system for unmanned aerial vehicles.

One of the first steps in electronic design is to define the product requirements. Nuvation Engineering works with our customers to help capture these requirements in a Product Requirements Document (PRD). This document is used by the engineering team during the project as a reference when making key design decisions and performing validation. Documenting requirements at the start of the project helps avoid major architecture and design changes later on. Understanding requirements and constraints allows our engineers to provide optimal architecture and design implementation options. Getting these details flushed out early makes for more efficient and cost-effective project execution. It is important that the Product Requirements Document specifies the product's environmental requirements. Questions that should be answered in the PRD include:

- To what temperatures/humidity/pressures ranges will the product be exposed?
- To what levels of vibration/shock will the product be exposed?
- Is the product going to be exposed to high levels of electrical noise?
- Will the product be exposed to dirt, dust, or other contaminants?

When in Doubt, do a Phase 0

The answers to the above questions are used to generate design requirements that will impact the success or failure of the product as much as (and in a harsh environment, perhaps even more than) application-level functionality. Trade-off decisions can usually be made that balance cost, functionality, operating range, and performance to yield a viable product that meets

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the desired price point. At Nuvation Engineering we refer to this level of up-front investigation as a Phase 0, a low-cost engineering investigation that enables the client to determine the viability and even desirability of the project effort before moving ahead. Often a slight modification to the product requirements (e.g. do you really need 4K video at 120 fps or is unit cost the higher priority) can alter the components and design requirements sufficiently to make the project more viable. Alternately, if the Phase 0 verifies that the product requirements are fully viable as-is, the documentation generated from that effort gets rolled into Phase 1 of the project planning documentation and can be referenced when generating the Bill of Materials (BOM) and design approach. For highly complex projects with technological risk (i.e. doing things that have never been done before, or in a way that has never been tried before), a Phase 0 provides engineering validation of viability and proposes design approaches the client can utilize to verify budgets and determine next steps.

Nuvation designed a 3-D camera system for use in military vehicles on the battlefield.

Making the Environment Friendlier

Generally, it is more effective to deal with a problem at the source. Unfortunately, this is not always possible. For example, when designing a circuit board for a given temperature range, there are a number of options for dealing with the temperature extremes:

A. Tighten the operating temperature rating of your product (your product may not need to be designed for temperatures up to +125°C if you specify to users that it must be operated below +85°C).
B. Choose whether heating circuitry, cooling circuitry, or both, are required to manage the temperature of the circuit board.
C. Design the circuit board with components that can withstand a wide temperature range.

A similar process could be used for working with a sensor with poor signal-to-noise ratio (SNR) characteristics. Options to consider can include:

A. Use a better sensor
B. Use hardware filtering
C. Use software filtering
D. Accept the poor performance

The right decision is very situation-dependent. Quite often, a decision matrix is used to determine the best design decision by rating the degree to which the design balances a range of

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factors such as cost, performance, reliability, operating range, etc. (see Figure 1).

		Better Sensor		Hardware Filtering		Software Filtering		Accept Poor Performance	
Criteria	**Weighting**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**
Material Cost	4	0	0	5	20	10	40	10	40
Performance	6	10	60	7	42	4	24	0	0
Design effort	2	8	16	4	8	2	4	10	20
Total			76		70		68		60

Figure 1: Decision Matrix

When creating the decision matrix's weight distribution (relative importance), Nuvation Engineering works with the client to prioritize the key drivers of design decisions. These factors typically include:

Summary

When designing a product for outer space, or for more terrestrial and mundane purposes, one must always factor into the design some level of resilience to harsh treatment or less than ideal environmental conditions. We have all dropped our TV remote on the floor (more than once!), used our cell phones in the rain, and perhaps even accidentally struck our smart watch on a doorknob. When these products survived it was because those scenarios were anticipated by the designers. In extreme harsh environments such as the cold vacuum of outer space or the heat and dust of the desert, design considerations become even more critical to a product's

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viability, and the solutions become more complex from a design perspective. Regardless of whether you're designing a TV remote or a satellite system component, the engineering planning effort revolves around the same planning decisions.

- Identify the types of abuse to which the product may be subjected.
- Define the range of environmental conditions in which the product must operate without failure.
- Make design decisions that ensure the product will survive its environment and the anticipated forces that will be brought to bear on it.
- Review the product requirements to find ways to balance cost against functionality and resilience.

- Explore creative ways to keep costs down without compromising functionality, such as our examples of designing in redundancy in software, grounding to prevent ESD, or utilizing a conformal sealant to protect components.

When employing an engineering services company to assist with your product development effort, the ability of the service provider to manage the points in the above list should be part of key selection criteria, in addition to technical capability. With over twenty years of experience and a thousand projects completed, the Nuvation Engineering team can provide you with a range of viable options to deliver a high quality product designed to withstand its target environment, at a production price point that supports your business case. If your requirements and target price point are too far apart, we will help you discover that before any engineering work has been done, and explore ways to refine your product requirements to bring them into the realm of possibility from a design, technology and business case perspective. Contact us today for a quote on how we can help design your next product to withstand harsh environments, or simply the harshness of everyday living.

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