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COTS FOR LONG-TERM MISSIONS

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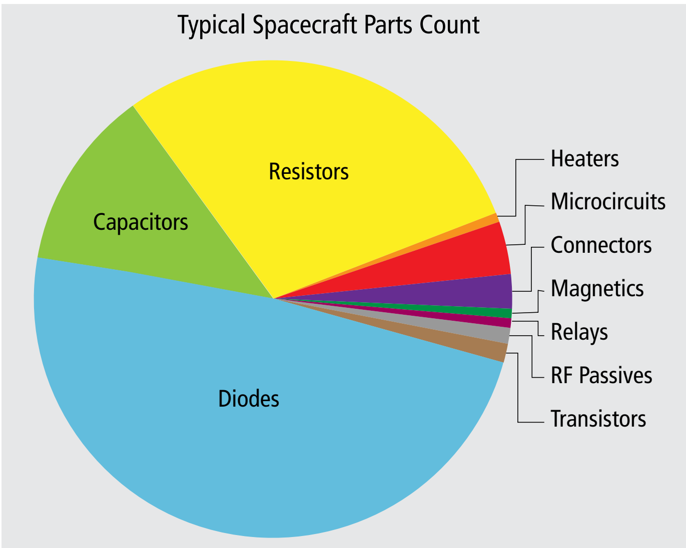
The commercial geostationary Earth orbit (GEO) communications satellite industry is robustly competitive on a global scale. Competition is keen and plays a crucial role in driving product innovation, robust quality, high reliability, and low cost. Exceptional long-term product performance and reliability have been achieved. SSL satellites meet a 15-year mission life requirement on orbit.

To achieve high reliability and long life, the highest quality military space-grade parts are used, including MIL-PRF-38535 level-V microcircuits, MIL-PRF-38534 class-K hybrids, JANS semiconductors, and ESA space-grade parts. It is an industry standard to use rad hard parts good to 100 krad(Si). Typical SSL spacecraft have >300,000 EEE parts.



SSL has investigated the suitability of using commercial off-the-shelf (COTS) parts for GEO long-term missions. We have focused on diodes, the simplest and most widely used EEE parts on our spacecraft (see pie chart). The diode is a simple, two-terminal device used for rectification: A current will flow only one way through a diode.

SSL embarked on an evaluation to determine if we could save cost and schedule without impacting reliability. For our first replacement evaluation, we selected our highest-volume diode, a simple rectifier, which is often used in a series/parallel manner. That is, any one diode could fail, be it open or short, and there would be no measurable impact at system level. We scoured the industry and found there was no COTS drop in replacement available. Every commercial diode offered on the marketplace differed in some aspect from our space-grade part. Therefore, we selected four COTS replacement candidates that were as close as we could find in terms of form, fit, and function for an applicability evaluation. Two of the candidates were sold as "automotive grade"; the other two were "commercial."

Two of the four failed this elementary evaluation/suitability step; they were close in size but just a tiny bit too small to fit reliably on the printed circuit boards without a re-layout of the printed wiring boards. This left us with one automotive-grade diode and one commercial-grade diode that physically fit without changing our mechanical design; both were close enough electrically that we were not concerned about any electrical performance issues.

We then began an extensive qualification program, duplicating the main tests required for JANS, except with larger sample sizes (up

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OFF THE SHELF AND INTO SPACE—BUT FIRST A TEST

By KATIE FEISTEL
The Aerospace Corporation

Competition in space launch is forcing providers to reduce the costs of their services. In 2015, TR-RS-2015-00011, *Parts, Materials, and Processes Control Program for Expendable Launch Vehicles*, was written to allow contractors the freedom to develop their own part selection criteria while still maintaining the required level of mission assurance to meet overall system reliability. Changes to the requirements allowed contractors to utilize nonmilitary-grade piece parts for redundant, flight-critical applications as standard piece parts. With these nonmilitary parts costing up to 90% less than the military-grade equivalent, substantial cost savings could be realized.

When surveying options for nonmilitary-grade piece parts, automotive-grade parts offered a bridge between commercial off-the-shelf (COTS) parts and their military equivalents (see Figure 1). Automotive parts are qualified to standards governed by the Automotive Engineering Council and have a standard qualification for each commodity type. One caveat is that each piece-part supplier self-certifies themselves and can take exceptions to the qualification standard while still proclaiming qualification. Hence, further

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CHIEF ENGINEER'S CORNER

Outrunning the Threat—Values Matter

By TODD NYGREN
Chief Engineer/General Manager
The Aerospace Corporation

As our nation faces a strategic challenge by near-peer adversaries, the national security space (NSS) leadership is committed to provide enterprise capabilities faster to stay ahead of and deter the threat.

The unstated value model that shaped much of the past 20 years in the NSS environment placed very high value on minimizing segment risks, maximizing performance, and balancing cost and schedule as third-tier elements.

There were good reasons for this. Several high-profile failures and the challenges in recapitalizing the NSS architecture pointed to the focused need for mission assurance. Resiliency, unless included as part of a program's requirement set, tended to be an afterthought.

As we look forward, the new value model that could guide our decisions places resilience and speed as top-tier attributes. The other elements such as segment performance, cost, or risk should be part of a dynamic tradespace to allow systems to deliver on time. The nation is investing more resources to ensure we can quickly field defendable capabilities.

Innovative approaches and different acquisition models appear almost daily—all built on delivering capability faster. Aerospace is excited to participate in this challenging new era and is strongly encouraging the entire space community to rise to this challenge.

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GOVERNMENT TEAM PURSUES DIGITAL TRANSFORMATION

By AL HOHEB and GAIL JOHNSON-ROTH
The Aerospace Corporation

"Government Transformation to Digital Engineering" was the theme of the Systems Engineering Forum hosted by The Aerospace Corporation (Aerospace) in Chantilly, Virginia, in May. Close to 250 attendees from more than 30 organizations participated, including members of civilian and military agencies, research centers, and direct support contractors. The forum examined a recent move by the Office of the Secretary of Defense (OSD) to apply model-based systems engineering (MBSE) beyond project implementation to enhance decisionmaking throughout the enterprise. The event was planned in collaboration with OSD and the SMC/AFSPC/NRO Enterprise Summit group.

Robert Gold, Director of Engineering Enterprise, Office of the Assistant Secretary of Defense, delivered the keynote address, "Transforming DOD to Digital Engineering." Gold noted that MBSE will help outpace threats, minimize risk of unnecessary human interaction, drive additive manufacturing to reduce part count, and generally "drive the engineering practice towards improved agility, quality, and efficiency, resulting in improvements in acquisition."

Robert Gold from the Office of the Assistant Secretary of Defense presents key benefits of MBSE.

The government panel, which included representatives from the DOD, civil space, and intelligence communities, provided insights on how to achieve the model-based enterprise vision. Panelists cited MBSE benefits including the potential for better enterprise interaction linking capabilities and cost/schedule implementation. The panel also cited MBSE as an enabler for better definition of implementation alternatives and faster technology adoption across the increasing complexity of enterprise interactions needed to address emerging threats.

Through a series of interactive tutorials, Aerospace presented MBSE and problem-framing approaches that set the stage for the technical presentations from different government organizations. The information sessions provided details about how to adopt an MBSE approach, while the active contributions of participants at parallel workshops further advanced the state of the practice. The sharing of unclassified and classified demonstrations provided exemplars of the implementation transformation.

Senior leaders demonstrated their commitment to instituting MBSE organizationally. Demonstrations of enterprise and program MBSE tools by

Marilee Wheaton (Aerospace), left, poses a question to Chi Lin (JPL) during the government panel discussion.

organizations that participated in previous forums underscored the importance of senior leadership follow-through for implementation success. The space community has come to realize that a lot of work remains to be done to unlock the potential of MBSE to achieve the enterprise-wide digital engineering vision.

"Leveraging MBSE Across the Enterprise" is the theme of the next forum, which will be hosted by Aerospace, February 12–14, 2019, in El Segundo, California. The Systems Engineering Forum, sponsored by Aerospace's Corporate Chief Engineer's Office, is a sequence of seminars and workshops designed to foster innovation in systems engineering. The next event will seek contributions to fulfill the digital engineering vision for mission success. Registration will be open to all enterprise stakeholders from government, industry, and the research community.

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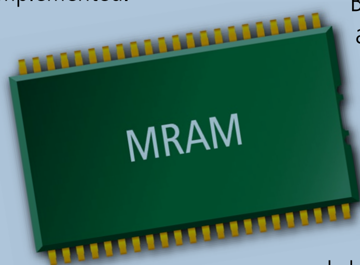
FIELD WORK: TAKING PRECAUTIONS, INITIATIVES, AND PERSONAL RESPONSIBILITY

By KEVIN HEFNER
Harris Space and Intelligence Systems

Joe Trevisani, senior component engineer at Harris Space and Intelligence Systems, deals with various types of high-tech components. When he learned that magnetoresistive random-access memory (MRAM) devices were headed to his facility, he recognized that they might be at risk unless new processes and procedures could be implemented.



"When a component is labeled 'magnetic sensitive,' damage can occur almost anywhere because stray magnetic fields are everywhere," said Trevisani. "Magnets are used in cell phones, credit cards, headphones, microphones, audiovisual equipment, and sometimes even key rings and lanyard clips. While these magnets are small and don't have a high field strength, direct contact between them and a component with even a low level of a magnetic field could cause inoperability."

Trevisani took the initiative to ensure that the production areas—which had not previously handled this type of device—were tested for stray magnetic fields. Because the site did not have the appropriate testing equipment on hand, he obtained a portable measuring tool and determined that, indeed, there was an issue.

As a result, new procedures were developed to protect the devices, and the production and shipping staff were educated on the requirements to keep the components safe from unintentional damage. These same safeguards were implemented at other sites where work is performed on similar components.

Trevisani's proactive approach helped avoid possible damage and saved program time and cost. "Because there is no method to test the device prior to production in our process, we would not have discovered damage until production was complete," he explained. "The time needed for troubleshooting and corrective action might have caused program delays. The processes our teams implemented addressed the issues and paved the way for future success."

Besides the central lesson learned about handling sensitive components, this example underlines the fact that mission success starts with someone taking personal responsibility for quality and mission assurance.

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OFF THE SHELF AND INTO SPACE—BUT FIRST A TEST

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analysis and review is required to ensure parts are indeed qualified. The Aerospace Corporation (Aerospace) worked with the Air Force, contractors, and automotive parts suppliers to adapt Aerospace's mission assurance approach to enable qualification of these parts for spaceflight. The new strategy implemented a tiered, risk-based approach to assess each supplier individually in accordance with knowledge of that supplier and their testing methods (see Figure 2). This approach leveraged Aerospace's unique position in the community and knowledge of electronic piece-part suppliers to focus verification efforts in the areas of highest risk instead of the blanket approach typically utilized. Tiering suppliers worked as a first-stage filter to sort out areas of risk. Next, a system-based approach was used to look at all testing that the piece parts would endure from the part level all the way up to system checkout. A trade was made by viewing part testing from a systems perspective: Piece-part failures could potentially be caught later in the flow, creating schedule risk, but robust unit and system testing with data trending lowered the technical risk of not catching failures prior to launch.

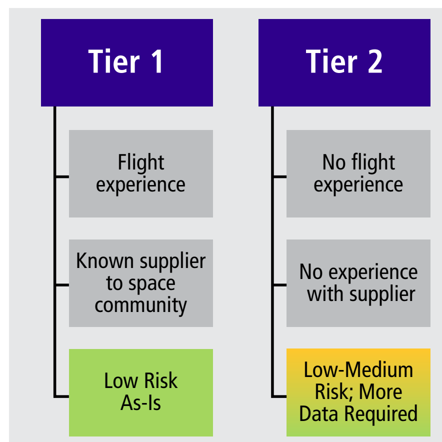

Figure 2: Risk-based categorizing of suppliers.

Because Aerospace was able to balance these mission assurance needs with the contractors' cost-reduction needs, the cost for new launch avionics systems was significantly reduced compared to the previous systems. As loss of influence in the electronics marketplace for space and military programs continues to grow and the market for automotive, industrial, and consumer electronics rapidly expands, the need to find ways to integrate these parts into high-reliability launch and space systems will also continue to grow.

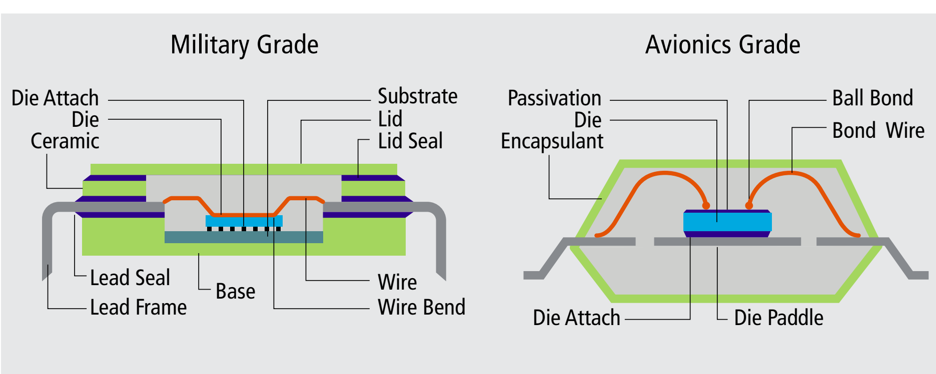

Figure 1: Typical military-grade piece part cavity devices are constructed of ceramic. Typical avionics-grade parts are plastic encapsulated.

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COTS FOR LONG-TERM MISSIONS

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to 800 pieces were tested) and longer-duration life tests. Our goal was to achieve enough part hours by test to demonstrate a failure-free part with a failure rate (based on zero failures at 60% confidence) less than that listed in MIL-HDBK-217F for a high-reliability diode.

In addition to the extended burn in and other typical semiconductor tests (such as thermal shock, resistance to soldering heat, and others), we performed additional tests only performed for nonhermetic devices, such as highly accelerated temperature/humidity stress testing (HAST), which is high temperature, pressure, and humidity, since commercial parts contain a finish of tin.

Testing confirmed that there was no tin whisker formation. To show suitability for spacecraft use, we then measured material outgassing properties, and these passed NASA requirements. We also performed total dose radiation testing, which verified performance parameters in excess of our 100 krad(Si) requirement. Finally, we chose the application with the most diode usage and performed highly accelerated life testing (HALT™) at the circuit card/electronic tray assembly level. HALT included high and low temperature, rapid thermal cycle, vibration, and combined environment (rapid thermal cycle with simultaneous vibration) stress testing.

Of the two types tested, only one proved suitable. The commercial part passed every test, with no failures at all. Electrically, we found the part to have a tighter distribution of key electrical parameters than the space-grade part it replaced. An unexpected benefit we also found was that the smaller, lighter commercial part saved us several kilograms of spacecraft mass. We were able to demonstrate a failure rate equal to or better than that of a space-grade part.

The COTS part was a winner in all categories and was incorporated into our standard product line, with no problems identified in any application. The use of COTS parts represents a major cost reduction, but to "upscreen" every part would negate the savings, as we have learned on other limited instances where we performed upgrades. Since we have found the quality to be excellent, we maintain cost savings by performing destructive physical analysis/constructional analysis on each reel in order to verify no changes, limiting quality conformance inspection on each reel, and not performing 100% burn in.

Surprisingly, on the other hand, during our qualification, we had multiple failures of the automotive-grade part after 1000 hours of life test. We performed detailed failure analysis and determined the reason for the failures to be the construction of the device. So use of this automotive-grade part will not be pursued any further.

There were many lessons learned during our study:

1. "Drop in" replacements for space-grade parts are difficult to find. Extensive use of COTS would require redesign and requalification.
2. Some vendors produce very high-quality, high-reliability COTS parts that can be suitable for space and offer better affordability and lead times than space-grade equivalents.
3. On the other hand, due to low-cost construction techniques, some COTS parts may not be suitable for long-term use.
4. Automotive parts are not necessarily better than commercial.
5. Opportunities abound to provide more affordable systems, but it's important to do a full qualification to avoid reliability problems.

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ACRONYM KEY
AFSPC Air Force Space Command
DOD Department of Defense
EEE electronic electrical electromechanical
ESA European Space Agency
GEO geostationary Earth orbit
HALT highly accelerated life test/testing
HAST highly accelerated temperature/humidity stress test/testing
JANS Joint Army Navy Space
krad kilorad
MBSE model-based systems engineering
Mil-Hdbk Military Handbook
MIL-PRF Military Performance Specification
MIL-STD Military Standard
MRAM magnetoresistive random-access memory
NASA National Aeronautics and Space Administration
NRO National Reconnaissance Office
OSD Office of the Secretary of Defense
PMP parts, materials, and processes
Si silicon
SMC Space and Missile Systems Center
TOR technical operating report

SUMMER/FALL 2018 EVENTS

Jun 25–29 *10th AIAA Atmospheric and Space Environments Conference, Atlanta, GA*

Jun 26–28 *Spacecraft and Launch Vehicle Dynamic Environments Workshop, El Segundo, CA*

June 27 *MilSatCom USA 2018, Arlington, VA*

July 9–11 *AIAA Propulsion and Energy Forum and Exposition, Cincinnati, OH*

Aug 4–9 *Small Satellite Conference, Logan, UT*

August 7–8 *Intelligent Systems Workshop, El Segundo, CA*

September 17–19 *22nd AIAA International Space Planes and Hypersonic Systems and Technologies Conference, Orlando, FL*

October 9–11 *Satellite Innovation, Silicon Valley, CA*

October 22–25 *Aerospace Testing Seminar, Los Angeles, CA*

RECENT GUIDANCE AND RELATED MEDIA

Operational Aspects of Spacecraft Propellant Quality: Where, When, and Why of Sampling and How to Assess Issues by M. Mueller; ATR-2016-01393-Rev A; PR

Aerospace Additive Manufacturing Guidance Workshop by A. Hoheb; ATR-2018-00928; PR

Agile Fit Check Assessment Process by D. Harralson and V. Sather; TOR-2018-01369; USGC

Dead Bus Recovery Requirements for Earth Orbiting Spacecraft by D. Landis; TOR-2018-00316; USGC

Additive Manufacturing Standards Update by D. Witkin et al.; TOR-2018-00820; USGC

Introduction to MBSE from a Software Perspective by K. Rengarajan et al.; TOR-2018-00225; USGC

Tailoring for ANSI/AIAA S-120A-2015, Mass Properties Control for Space Systems: Space Vehicles by Y. Tam; TR-2018-01203; PR

Common Payload Interface Standard (CoPals) Industry Day by C. Sather; TOR-2018-01575; USGC

Stakeholder Review: Space and Launch Requirements Addendum to As9100d Quality Management Systems by R. Morehead et al.; TOR-2018-00016-Rev A; USGC

Cybersecurity Acquisition Oversight Risk Assessment Project by P. Naray; TOR-2016-01973; USGC

Mission Assurance for Satellite Bipropellant Thruster Usage on New Procurements by M. Mueller; TOR-2018-01544; USGC

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