Application Note

Reduce the Risk in Low-Earth Orbit Missions with Space Enhanced Plastic Products

Kirby Kruckmeyer

ABSTRACT

Historically, satellite programs have used space grade, hermetically sealed, QML-V qualified components for enhanced reliability and radiation hardness. With the emergence continued growth in constellation and low-earth orbit satellite launches for new commercial and government programs, there is a growing need for smaller components that can meet strict budgets. As a result, there has been more interest in using plastic encapsulated microcircuits (PEM) in space for a variety of reasons. PEMs become more attractive because leading edge products are not available as space qualified products and PEMs generally have smaller footprints and are lighter than the ceramic packages used in space qualified products. It has been recognized that there is a quality and reliability risk in using commercial-off the shelf (COTS) products and some space programs have been investigating using automotive grade AEC-Q100 products with more stringent qualification requirements. However, the extra qualification steps in Q100 parts do not meet all the requirements of a space application, even for those space applications with reduced requirements. For instance, commercial low earth orbit (LEO) applications with a projected three year life still have to meet radiation goals that many PEM products do not survive. One of the biggest challenges for a satellite program is finding and then testing those products that meet the radiation goals.

Although radiation performance may be biggest obstacle to using some COTS or automotive products in space, there are a number of other risks and factors to consider, such as tin whiskers, copper bond wires, rated temperature range, and package outgassing. Finding a device that can withstand the harsh environments of space can prove to be time consuming and challenging.

In addition to Texas Instruments' full line of rad-hard QML-V products for normal and high risk space missions, TI has introduced the rad-tolerant Space Enhanced Plastic (Space EP) product family in PEM packaging to lower the risk of using PEMs for missions with reduced requirements. The Space EP products have the following features:

- Single Event Latch-up (SEL) immune to 43 MeV-cm^2/mg with some components such as power management having characterized additional destructive single event effects and single event transients. Each product is tested at maximum operating voltage and 125°C.
- ELDRS-free to 30 to 50 krad(Si). Every bipolar and BiCMOS product goes through ELDRS characterization at low dose rate (LDR) of 10 mrad(Si)/s.
- Radiation lot acceptance testing (RLAT) from 20 to 50 krad(Si). Every wafer lot is tested and qualified to 20 krad(Si) with an RLAT report available. Devices with higher TID characterization are typically assured with the same RLAT level.
- Some components also having Neutron Displacement Damage reports
- Military temperature range: –55°C to +125°C.
- No copper bond wires. All products have gold bond wires.
- No matte tin. Lead finish is NiPdAu or some other finish that does not have pure Sn.
- Enhanced mold compound for low outgassing.
- Extended qualification of each assembly lot including HAST and temperature cycling.
- 100% temperature cycling. Every unit receives temperature cycling or equivalent.
- Single production flow. One wafer fab and assembly site to minimize lot-to-lot variation.
- Long product life cycles.
- Each product has its own Vendor Item Drawing (VID) on DLA website.

The risks of using PEMs in space and how TI's Space EP products address these risks are discussed in this application note.

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Trademarks

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1 Radiation Challenges

Different semiconductor technologies have different inherent radiation tolerances (see TI's Radiation Handbook for Electronics for more details). At the same time, two products using the same process technology or node might have totally different radiation responses due to how the product is designed and which modules in the process are used. As a result, customers need to spend time and resources in order to evaluate the reliability and radiation performance of these devices. To enable shorter development times, Texas Instruments' Space EP products provide extensive radiation characterization to meet the requirements of LEO missions.

In addition, there are many generalities floating around about radiation tolerance that are not true for all cases. A 65-nm process is likely to be SEL immune, but only for the 1.1-V circuits. If a product uses higher voltage circuits, it is more likely to have SEL. Having an epi or SOI substrate does not necessarily mean that a CMOS product is SEL immune. For most CMOS products, the use of an epi substrate has no impact on SEL susceptibility and SOI only assures SEL immunity if the field oxide (STI) reaches all the way through the active layer down to the buried oxide.

A supplier such as TI has the knowledge of the process used on its products. Using this information, TI can choose products that have a high probability of being radiation tolerant and often uses a process or design change to meet the radiation goal. After choosing a part, TI then verifies the choice with heavy ion, neutron displacement damage (NDD), and total ionizing dose (TID) testing.

TI's Space EP flow also follows a single production flow and provides radiation lot acceptance testing (RLAT) in order to reduce the risk with lot-to-lot variation. Most wafer fabs do not have monitors or controls in place for radiation tolerance. Modern wafer fabs maintain very tight controls to ensure consistent electrical performance, but the parameters that are controlled are not the same ones that impact radiation tolerance. For instance, the stoichiometry and thickness of passivisation layers have little impact on electrical performance but can be huge variables in radiation tolerance. In an extreme case, there was a product where one lot passed 100 krad(Si) and a lot processed in the same wafer fab a month later only passed 10 krad(Si). That is why radiation lot acceptance testing (RLAT) is so important.

Customers can design with Texas Instruments' Space EP products to help bring new space systems faster to market and ensure these systems meet the radiation requirements for LEO missions. Each device is radiation tested up front and has TID, SEE and often NDD characterization provided in separate radiation reports available in the product folder. For enhanced radiation reliability, the Space EP products use only one production flow and each lot gets RLAT, eliminating the risks of lot-to-lot variations.

2 Temperature Range

Satellites often experience the extreme hot and cold temperature ranges in space. In order to ensure the reliability of circuit electrical performance in this environment, TI's Space EP products have a temperature range of -55°C to +125°C, with electrical parameters tested and guaranteed to operate over those conditions. The commercial grade temperature range is typically 0°C to +70°C. For automotive products, there are several specified temperature ranges with the most common being Grade 3 at –40°C to +85°C. While some COTS and automotive products may operate beyond the rated temperature, many others do not. It becomes necessary to test the products at the temperature extremes of the application to determine if a COTS or automotive product would work.

3 Tin Whiskers

Many commercial and automotive products now use pure tin (Sn) as the lead finish or as the main constituent of balls in ball grid arrays (BGA) for a low cost, ecologically friendly solution.

There is a risk that the matte Sn plating, now commonly used on COTS and AEC-Q100 PEMs, may grow whiskers under harsh conditions long enough to short between two metal leads. In addition, these whiskers can break off, resulting in electrical shorts in other places in a module. In order to reduce this risk of failure, TI's Space EP flow opts to not use any pure Sn terminations. Conformal coating is not a complete solution as it only partially retards whisker growth and the whiskers can still grow through coating. Numerous cases of satellite failures have been attributed to Sn whiskers.

TI's solution is to not use pure Sn terminations. The termination on TI's Space EP products is Sn63Pb37 solder dip, NiPdAu plating or similar finish without matte Sn. For BGAs, TI Space EP products use Sn63Pb37 solder balls.

4 Cu Wire Risks

Thermal cycling is especially prominent in LEO satellites which orbit the earth multiple times a day. TI's Space EP products use gold bond wires instead of classic copper (Cu) bond wires typically found in commercial and automotive AEC-Q100 products in order to reduce potential risks.

As a cost savings, more and more COTS products are switching from gold (Au) bond wires to copper (Cu) bond wires. Cu bond wires are now even permitted for automotive AEC-Q100 products. On some products, either Au or Cu bond wire could be used with the decision on which wire used is at the discretion of the supplier, but is usually based on available Cu wire bonding capacity. Many times, the customer does not know which bond wire material is used on any given lot.

While there has been continuous improvement in the Cu bonding process and Cu bond wire reliability, there are still potential risks, especially in harsh environment applications. Cu wire bonding requires much tighter process controls or bond integrity and reliability issues could result. Sporadic Cu wire corrosion has occurred from interaction with the plastic mold compound. There have been some cases where there has been corrosion at the Cu bond wire/lead frame interface when there has been package delamination. Perhaps of most concern for harsh environments is that Cu wire has a higher temperature coefficient than Au, making it more susceptible to bond neck breaks during thermal cycling. This could be critical in some LEO applications where a satellite might go through temperature cycle extremes several times per day.

5 Plastic Outgassing and Moisture Absorption

A common concern in using PEMs for space systems is that the packaging material is an organic mold compound that can absorb moisture and outgas organic compounds. Moisture absorption can result in reduced reliability and lifetime of a product. Outgassing constituents can condense on other components, contaminating them and impacting their performance. It is a major problem for sensors, such as imaging sensors.

The semiconductor industry uses many different mold compounds depending upon the product type, package size and architecture, application, and available mold compounds at the assembly site. Different mold compounds have different moisture sensitivity levels and outgassing.

TI's Space EP products use enhanced mold compounds and go through extended qualification testing, beyond what is required for automotive products by AEC-Q100.

The mold compounds used on Space EP products exceed the NASA driven outgassing requirements in ASTM E-495 of Total Mass Loss (TML) of less than 1.0% and a Collected Volatile Condensable Material (CVCM) of less than 0.1%.

6 Harsh Environment Qualification

COTs and automotive products are not tested or qualified for the harsh conditions of space flight, such as the high G-forces during a launch or the temperature cycling to the temperature extremes experienced several times per day in a LEO mission.

Every TI Space EP assembly lot goes through an extended qualification. Assembly lot qualification tests include the highly accelerated stress test (HAST) at 130°C and 85% humidity for 192 hours, temperature cycling between –65°C to +150°C for 500 cycles and the moisture level sensitivity (MSL) preconditioning test followed by acoustic microscopy (CSAM). Sample inspections to ensure proper packaging include visual inspection after wire bonding prior to the mold process and visual and X-ray inspections post packaging.

After packaging, every Space EP unit receives temperature cycling (20 cycles) or a similar reflow stress prior to electrical testing. This extended qualification is to ensure the performance and reliability of the device in the harsh environments of space going beyond the qualification of typical commercial and automotive components.

7 Multiple Manufacturing Sites

To allow for manufacturing flexibility, a COTS product might be produced in several different wafer fabs. Each wafer fab can have slightly different equipment and processes. The difference in the wafer fabs would not impact a product's performance as long as the product is used within the parameters of the data sheet. These differences could impact how the part performs when operated outside rated parameters and could significantly impact the product's radiation performance.

Likewise, a COTS or automotive product could be assembled at multiple assembly sites, which could use different mold compounds and bond wires. As described earlier, these differences could have significant impact in product reliability when using the part in a harsh environment beyond the rated performance. Normally, a customer is not able to choose which manufacturing sites are used.

For the TI Space EP products, there is only one production flow, one wafer fab and one assembly site used for each product. This greatly reduces lot-to-lot variations.

8 Long Life Cycles

A risk of designing in COTS products is that some COTS products have a short life cycle and become obsolete and hard to get for future spacecraft builds.

Texas Instruments has a history of supporting the mil/aero industry with products that have a long life cycle. TI continues to supply military and space grade products that were first released over 50 years ago.

9 VID - Vendor Item Drawing

Each Space EP product has its own VID maintained by the US Department of Defense's Defense Logistics Agency (DLA) – Land and Maritime. The VIDs are available for download on the DLA website with unrestricted access. The VID is similar to the SMD used for QML-V space qualified products ensuring standardization of the manufacturing, qualification, and testing of the Space EP products. A link to the VID can be found in the TI data sheet and product page on ti.com.

10 Conclusions

The harsh environment in space require robust and reliable integrated circuits. While some COTS and Q100 devices may meet radiation requirements, it can prove to be costly and time consuming to qualify these devices. And although radiation reliability is the primary concern, there still exists many other risks and uncertainties when proving the reliability of a product in space.

TI has released the Space Enhanced Plastic (Space EP) family of products to eliminate the uncertainty and cost of upscreening and allow for much quicker design cycles. Customers can look to leverage the detailed radiation reports, and enhanced quality flow that Space EP provides and has shown to meet mission requirements for LEO satellites. Space EP products can be recognized on ti.com by the suffix "-SEP" on the product page and in the data sheet.

For higher risk space missions that require more stringent radiation and reliability requirements, TI still offers the fully qualified QMLV family of space products, with TID levels up to 300 krad(Si), SEL and SEFI immunity up to 120 MeVcm**2**/mg and comprehensive SEE characterization.

More information on TI's space product options can be found at any time by typing ti.com/space into your browser.

11 Revision History

Changes from Revision * (July 2019) to Revision A (September 2022)	**Page**
• Updated the numbering format for tables, figures, and cross-references throughout the document	1
• Deleted NewSpace	1
• Updated entire publication with new information	1

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265