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Non-Hermetic and Plastic-Encapsulated Microcircuits

The mission assurance organizations at NASA have supported many large and small space missions and programs over the years. Today that spectrum has expanded, ranging from flagship missions such as Mars 2020 with its Perseverance Rover, Europa Clipper, and the proposed Europa Lander, to SmallSats/CubeSats such as the Temporal Experiment for Storms and Tropical Systems—Demonstration (TEMPEST-D) and Mars Cube One (MarCO). Plastic-encapsulated microcircuits (PEMs) have become more attractive since leading-edge alternatives are not available as space-qualified products. PEMs generally have smaller footprints and are lighter than the ceramic packages used in space-qualified products [1]. As the demand and use of non-hermetic and plastic-encapsulated microcircuits for space has increased, the scope of what future missions are capable of has also widened. This changing climate related to EEE parts selection presents new challenges for NASA, which—as always—holds the success of every mission paramount.

Growing Use of NASA SmallSats and CubeSats

Due to the need for low-cost communications satellites and new businesses evolving around Earth-observation services, there’s been an increased interest in the use of CubeSats and SmallSats. Many NASA centers have been involved in developing and flying CubeSats and SmallSats, working together with multiple universities and industry partners. These undertakings require new product solutions for smaller, lighter, and lower-cost spacecraft, which cannot be produced using traditional space-qualified electronic parts.

The reliability and radiation requirements for CubeSats and SmallSats are significantly lower than for larger spacecraft because these smaller satellites operate mainly in low Earth or geosynchronous orbits (LEO or GEO, as opposed to deep space) and for relatively short periods. Radiation-hardened, high-reliability, space-grade parts are often too expensive for such missions and do not match well with their requirements.

There are a few notable exceptions to the usual use of CubeSats, particularly MarCO-A and MarCO-B, which were the first CubeSats to fly to deep space, where they successfully supported the Interior Exploration Using Seismic Investigations, Geodesy, and Heat Transport (InSight) mission by relaying data to Earth from Mars during the entry, descent and landing stage (Figure 1). MarCO successfully demonstrated a "bring-your-own" communications-relay option for use by future Mars missions in the critical few minutes between Martian atmospheric entry and touchdown. Further, by verifying that CubeSats are a viable technology for interplanetary missions, and feasible on a short development timeline, this technology demonstration could lead to many other applications to explore and study our solar system.

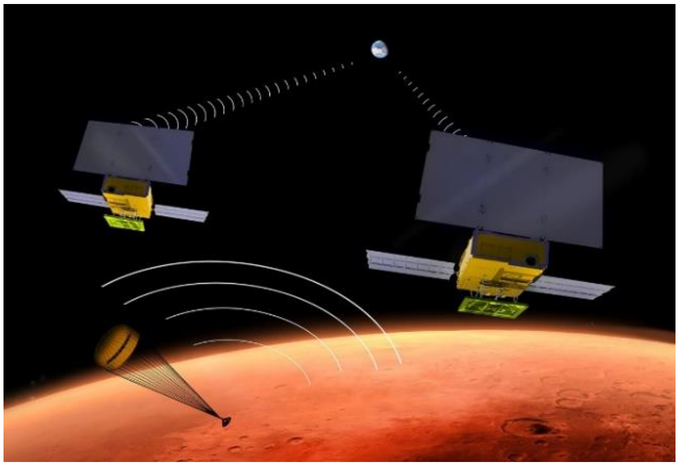

Figure 1. MarCO accompanying the InSight Mars lander and relaying data to Earth as it landed on Mars.

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[1] The EEE Parts Bulletin was not published in fiscal year 2019 (FY19). The two issues of Volume 10 were published in FY18.

Another interesting technology demonstration is the Mars Helicopter, Ingenuity, which is a small, autonomous aircraft that will be carried to the surface of the Red Planet attached to the belly of the Perseverance rover (Figure 2). In the months after landing, the helicopter will be placed on the surface to test—for the first time ever—powered flight in the thin Martian air. One of its key objectives is to demonstrate miniaturized flying technology, requiring shrinking down onboard computers, electronics, and other parts so that the helicopter is light enough to take off. Many parts used in the Mars Helicopter are non-hermetic, plastic parts, such as the Qualcomm Snapdragon 801 processor and a Texas Instruments (TI) TMS570LC43x microcontroller unit, together with commercial off-the-shelf (COTS) sensors [2].

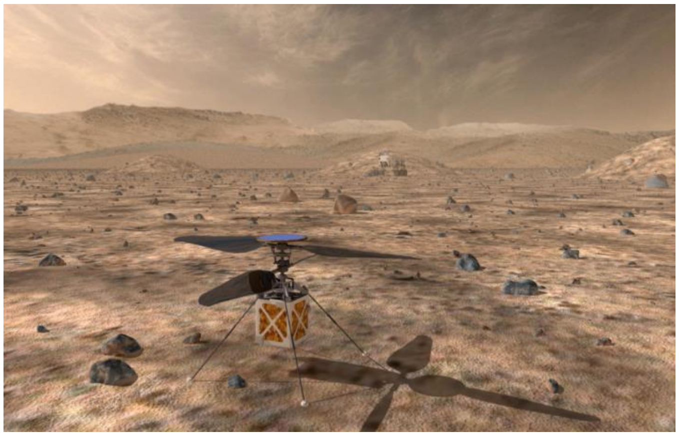


Figure 2. Artist's depiction of the Mars Helicopter that will be part of the Mars 2020 mission.

As astronauts explore the Moon during the Artemis program, they might need to make use of the resources that already exist on the lunar surface. Since water is an expensive resource to launch from Earth, our future explorers might have to seek out ice to mine. Once excavated, it can be melted and purified for drinking and used for rocket fuel. But how much water is there on the Moon, and where might we find it? NASA's Lunar Flashlight aims to detect naturally occurring surface ice believed to be at the bottom of craters on the Moon that have never seen sunlight (Figure 3).

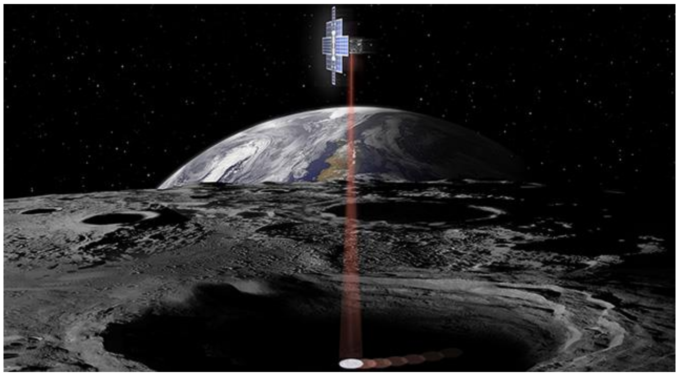


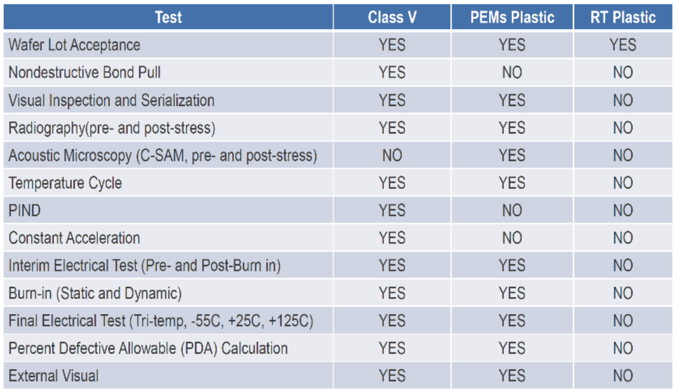
Figure 3. Lunar Flashlight, a CubeSat that will use lasers to look for water ice on the Moon.

Manufacturer Solutions for Non-Hermetic and Plastic-Encapsulated Microcircuits

Historically, satellite programs have used space-grade, hermetically sealed Qualified Manufacturers List (QML) V–certified electronics for enhanced reliability and radiation-hardness. With the emergence of commercial space, there has been more interest in using plastic-encapsulated microcircuits (PEMs) in spaceflight for a variety of reasons. "NewSpace" is a loosely defined term covering some of the trends in the space ecosystem, including the emerging commercial space industry, with both private and Government programs that have reduced requirements for reliability, lifetime, and radiation-tolerance [1]. The benefits of using PEMs or COTS parts in space-level applications are attractive: advanced technologies; higher levels of integration; higher performance; and more appropriate size, weight, and power specifications [3]. Users recognize that there are quality and reliability risks in using COTS products, with one of the biggest challenges being meeting the radiation goals.

Seeing this new growing trend in the market, major suppliers such as TI, Analog Devices, Cobham, STMicroelectronics and Renesas offer a wide range of enhanced plastic product solutions depending on quality, reliability, radiation, and cost. The plastic parts also offer size and weight advantages compared to hermetic ceramic packages.

A few years back, Renesas started developing space-grade products in plastic packaging. The first round of parts used rad-hard die and industrial-grade plastic-packaging techniques. Newer products use a mix of rad-hard and commercially developed products. This is part of Renesas's radiation-tolerant (RT) plastic flow, which is intended for LEO missions with an expected life cycle of about 5 years or less. In addition, Renesas is developing products on a newer flow, PEMs, outlined by Aerospace Standard AS6294/1. This PEMs flow essentially attempts to create a plastic "Class-V"-type flow and is intended for medium–Earth orbit (MEO) or GEO missions with an

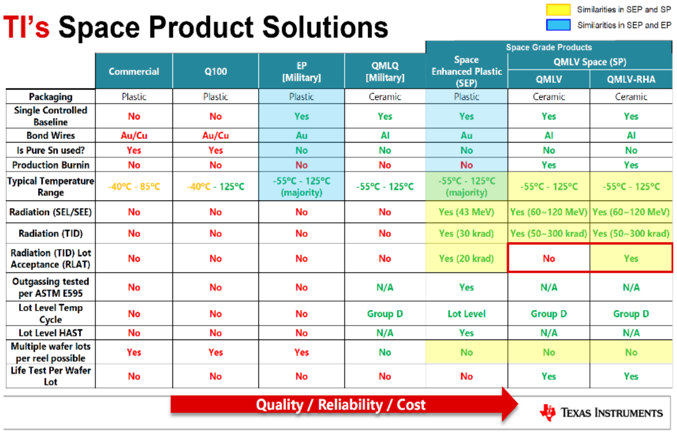


Test	Class V	PEMs Plastic	RT Plastic
Wafer Lot Acceptance	YES	YES	YES
Nondestructive Bond Pull	YES	NO	NO
Visual Inspection and Serialization	YES	YES	NO
Radiography(pre- and post-stress)	YES	YES	NO
Acoustic Microscopy (C-SAM, pre- and post-stress)	NO	YES	NO
Temperature Cycle	YES	YES	NO
PIND	YES	NO	NO
Constant Acceleration	YES	NO	NO
Interim Electrical Test (Pre- and Post-Burn in)	YES	YES	NO
Burn-in (Static and Dynamic)	YES	YES	NO
Final Electrical Test (Tri-temp, -55C, +25C, +125C)	YES	YES	NO
Percent Defective Allowable (PDA) Calculation	YES	YES	NO
External Visual	YES	YES	NO

Figure 4. A comparison of Renesas's PEM and RT plastic production flows (www.renesas.com).

expected life cycle of over 15 years. See Figure 4 for a flow comparison.

TI provides a space-enhanced plastic (SEP) solution focused on radiation-tolerant parts, used in short-duration missions with high-volume satellites. The SEP flow emphasizes traceability, reliability, and radiation-tolerance. TI SEP products are characterized for total-dose and single-event radiation performance. In many cases, different wafer fabrication processes or alternative die designs are used to achieve specified levels of radiation-tolerance. This is further ensured with a radiation lot-acceptance test (RLAT or Group E) performed on each SEP wafer lot. Figure 5 shows TI's space product solutions and comparisons among them in terms of quality, reliability, and cost.



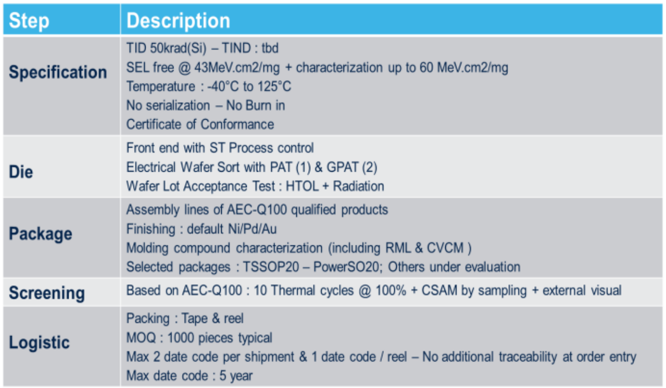
TI's Space Product Solutions

🟨 Similarities in SEP and SP
🟦 Similarities in SEP and EP

	Commercial	Q100	EP [Military]	QMLQ [Military]	Space Grade Products		
					Space Enhanced Plastic (SEP)	QMLV Space (SP)	
						QMLV	QMLV-RHA
Packaging	Plastic	Plastic	Plastic	Ceramic	Plastic	Ceramic	Ceramic
Single Controlled Baseline	No	No	Yes	Yes	Yes	Yes	Yes
Bond Wires	Au/Cu	Au/Cu	Au	Al	Au	Al	Al
Is Pure Sn used?	Yes	Yes	No	No	No	No	No
Production Burnin	No	No	No	No	No	Yes	Yes
Typical Temperature Range	-40°C - 85°C	-40°C - 125°C	-55°C - 125°C (majority)	-55°C - 125°C	-55°C - 125°C (majority)	-55°C - 125°C	-55°C - 125°C
Radiation (SEL/SEE)	No	No	No	No	Yes (43 MeV)	Yes (60~120 MeV)	Yes (60~120 MeV)
Radiation (TID)	No	No	No	No	Yes (30 krad)	Yes (50~300 krad)	Yes (50~300 krad)
Radiation (TID) Lot Acceptance (RLAT)	No	No	No	No	Yes (20 krad)	No	Yes
Outgassing tested per ASTM E595	No	No	No	N/A	Yes	N/A	N/A
Lot Level Temp Cycle	No	No	No	Group D	Lot Level	Group D	Group D
Lot Level HAST	No	No	No	N/A	Yes	N/A	N/A
Multiple wafer lots per reel possible	Yes	Yes	Yes	No	No	No	No
Life Test Per Wafer Lot	No	No	No	No	No	Yes	Yes

Figure 5. TI's various flows, comparing quality, reliability, and cost across products (www.ti.com) [4].

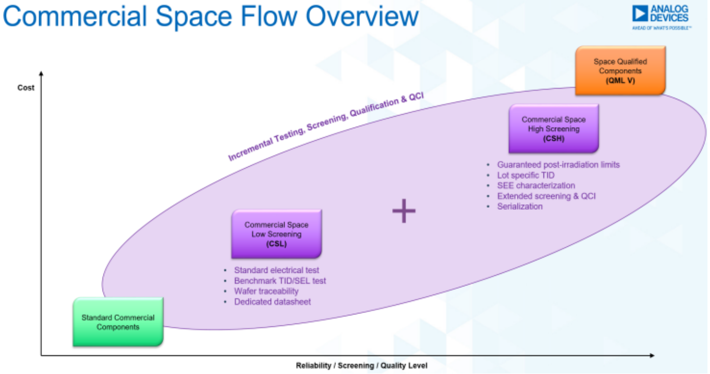
STMicroelectronics is working on creating a new product line for LEO applications. These new products will be plastic-packaged, with assembly in ST's high-volume back-end manufacturing sites, on assembly lines used for AEC-Q100-qualified products. The qualification of the LEO product line will be based on AEC-Q100 and will add by default 50 krad(Si) total ionizing dose (TID) and single-event latchup (SEL) immunity up to 43 MeV.cm2/mg, with a characterization up to 60 MeV.cm2/mg. (see Figure 6).



Step	Description
Specification	TID 50krad(Si) – TIND : tbd SEL free @ 43MeV.cm2/mg + characterization up to 60 MeV.cm2/mg Temperature : -40°C to 125°C No serialization – No Burn in Certificate of Conformance
Die	Front end with ST Process control Electrical Wafer Sort with PAT (1) & GPAT (2) Wafer Lot Acceptance Test : HTOL + Radiation
Package	Assembly lines of AEC-Q100 qualified products Finishing : default Ni/Pd/Au Molding compound characterization (including RML & CVCM) Selected packages : TSSOP20 – PowerSO20; Others under evaluation
Screening	Based on AEC-Q100 : 10 Thermal cycles @ 100% + CSAM by sampling + external visual
Logistic	Packing : Tape & reel MOQ : 1000 pieces typical Max 2 date code per shipment & 1 date code / reel – No additional traceability at order entry Max date code : 5 year

Figure 6. STMicroelectronics Rad-Hard LEO product line (plastic packaging) (www.st.com).

Analog Devices has established two commercial space product screening and qualification flows, namely Commercial Space Light (CSL), and High (CSH). The CSL flow is for low-cost, high-volume requirements, offering minimal testing and screening for LEO constellations. CSH provides the highest screening and qualification level, including 100% lot burn-in, Wafer Lot Acceptance Tests, burn-in deltas, and lot specific TID, targeted towards applications where no hermetic-package option is available (equivalent to QML V using SAE AS6294 as a guideline) (see Figure 7).



Commercial Space Flow Overview

Figure 7. Analog Devices commercial space flow grades (www.analog.com).

Cobham is also working on developing their new line of products called LeanREL. LeanREL products will aim to provide an optimized balance for reliability, performance, and affordability and serve satellites with a 3- to 7-year lifetime. These new products will provide a QML material pedigree, traceability, optimized test flows, and will be more affordable than QML parts.

Cobham also has an initiative to merge its quantified COTS (QCOTS) methodology with PEM-INST-001 (EEE-INST-002, Section M4). In an effort to retain some of the valuable features of the QCOTS methodology, such as single homogeneous wafer lots, traceability, restricted wire bonding, SEE and TID characterization per wafer lot, and more expansive electrical testing, Cobham has defined a PEMs+ methodology. Cobham also works with its assembly partners to widen the electrical test aperture, beginning with tri-temp testing of 100% of the production lots at the assembly house. Following production assembly, Cobham applies the PEM-INST-001 prescription for screening and qualification with the added services of addressing Pb-free lead finish concerns (e.g., adding eutectic solder balls), outgassing analysis, and thermomechanical and coefficient of thermal expansion (CTE) analysis. Finally, Cobham performs TID and single-event effect (SEE) characterization on a lot-by-wafer-lot basis to provide better radiation-hardness assurances and to monitor for unpredictable variations in the semiconductor fabrication process (Figure 8).

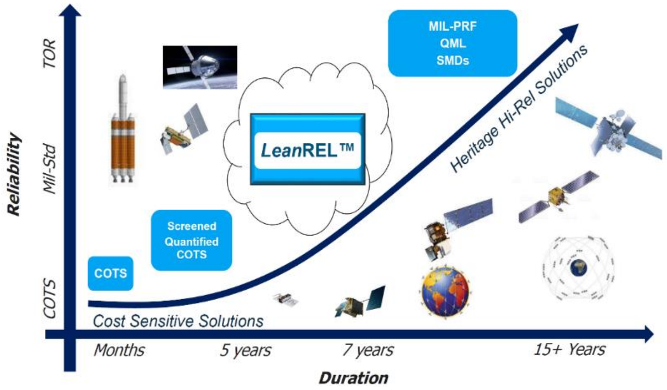


Figure 8. Cobham LeanREL product line (www.cobhamaes.com).

Class Y Initiatives for Advanced Devices

The Class Y effort was initiated to infuse a new technology into the QML system. Xilinx had introduced Virtex-4 and -5 field-programmable gate arrays (FPGAs) that were highly popular with hardware designers on space missions. However, these FPGAs couldn't be procured as standard Class-V products because of their non-hermetic construction.

The Xilinx FPGAs were system-on-a-chip (SOC), representing advances in packaging, feature size, and functional complexity. Packaging features included flip-chip construction, column grid arrays (CGAs) with 1752 pins, and vented packages for thermal management. After considerable discussion, the community decided that a new class was needed, Class Y (Figure 9).

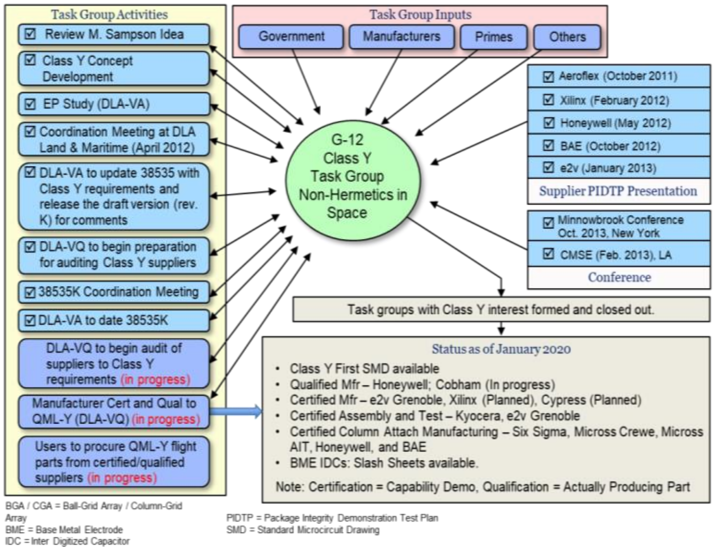
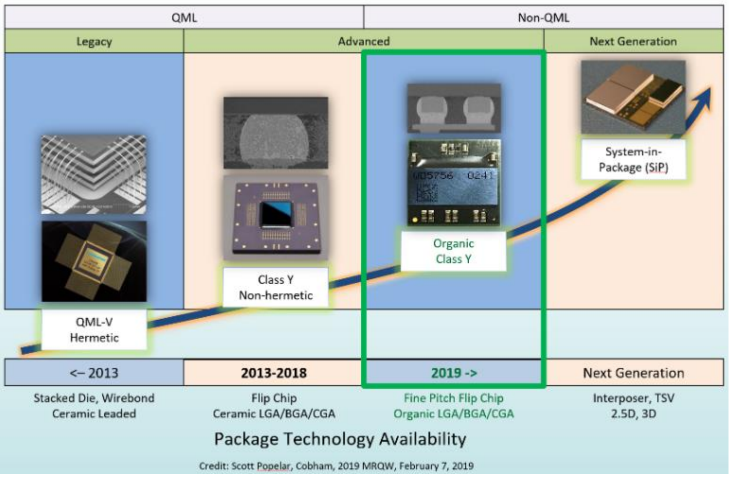


Figure 9. Class Y task group (non-hermetics in space).

NASA led a CE-12 Class Y initiative for infusing Xilinx FPGAs and other similar devices into military/space standards (Figure 10). New test methods were created, and existing standards were updated. The requirements for Class Y were included in MIL-PRF-38535, Revision K. Currently, the space community is developing requirements for organic Class Y.



Credit: Scott Popelar, Cobham, 2019 MRQW, February 7, 2019

Figure 10. Next-generation technology for space.

Conclusion

As space exploration initiatives grow and new businesses evolve around Earth-observation services and communications satellites, so does the need for lower-cost, lighter, cutting-edge electronic parts with advanced technologies, higher levels of integration, and higher performance. Non-hermetic and plastic-encapsulated microcircuits fit these requirements perfectly, a fact that has led many manufacturers to offer appropriate flows for these applications. These new products are a next step in the successful future of space exploration.

References

[1] Reduce the Risk in NewSpace with Space Enhanced Plastic Products. Kruckmeyer, Kirby. Texas Instruments, Application Report, SBOA344. July 2019. http://www.ti.com/lit/an/sboa344/sboa344.pdf?ts=1588374601862

[2] Mars Helicopter Technology Demonstrator. Balaram, Bob, et al. 2018 AIAA Atmospheric Flight Mechanics Conference. DOI:10.2514/6.2018-0023

[3] Analog Devices Commercial Space Level Products Program. Analog Devices. November 2019. https://www.analog.com/media/en/news-marketing-collateral/solutions-bulletins-brochures/ADI-Standard-Commercial-Space-Level-Products-Program.pdf

[4] Texas Instruments Aerospace & Defense Products. http://www.ti.com/applications/industrial/aerospace-defense/products.html

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