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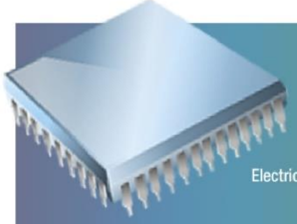

EEE Parts Bulletin

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Non-Hermetic and Plastic-Encapsulated Microcircuits, Part 2, [2] Revised on April 2021

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 for 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 of EEE parts selection presents new challenges for NASA, which—as always—holds the success of every mission paramount. In this second issue devoted to non-hermetic and plastic-encapsulated microcircuits, we discuss more manufacturers' PEMs flows, and introduce the AS6294/1 aerospace standard document on "Requirements for Plastic Encapsulated Microcircuits in Space Applications."

Aerospace Standard AS6294/1

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

In 2017, a subcommittee of SAE International's Group 12 (G12) was created to standardize a PEMs flow and to address a possible future extension of the Qualified Manufacturer List (QML) system to include PEMs for space. Considerable effort was put into developing a PEMs flow for space applications, documented in SAE Aerospace Standard AS6294/1, issued in November 2017, titled "Requirements for Plastic Encapsulated Microcircuits in Space Applications." The "/1" version was directed at space applications, the "/2" version at terrestrial applications. SAE AS6294/1 pulled information from many Marshall Space Flight Center (MSFC), Goddard Space Flight Center (GSFC), and SAE standards applicable to NASA—namely, MSFC-STD-3012, GSFC EEE-INST-002, GSFC PEMS-INST-001, and SAE SSB-001—as well as reviews of multiple industry practices.

AS6294/1 defines the requirements for screening, qualification, and lot-acceptance testing for use of PEMs in space flight applications. The level of testing is dependent on the risk approach, the application, and the reliability and radiation requirements of the mission. However, AS6294/1 contains only requirements that meet the highest known reliability for space applications. The document also addresses many concerns associated with PEMs, such as narrower operating temperature ranges and greater susceptibility to infant mortality and moisture absorption than space-grade products have [2].

AS6294/1 starts with device characterization for parts that don't meet space requirements. The

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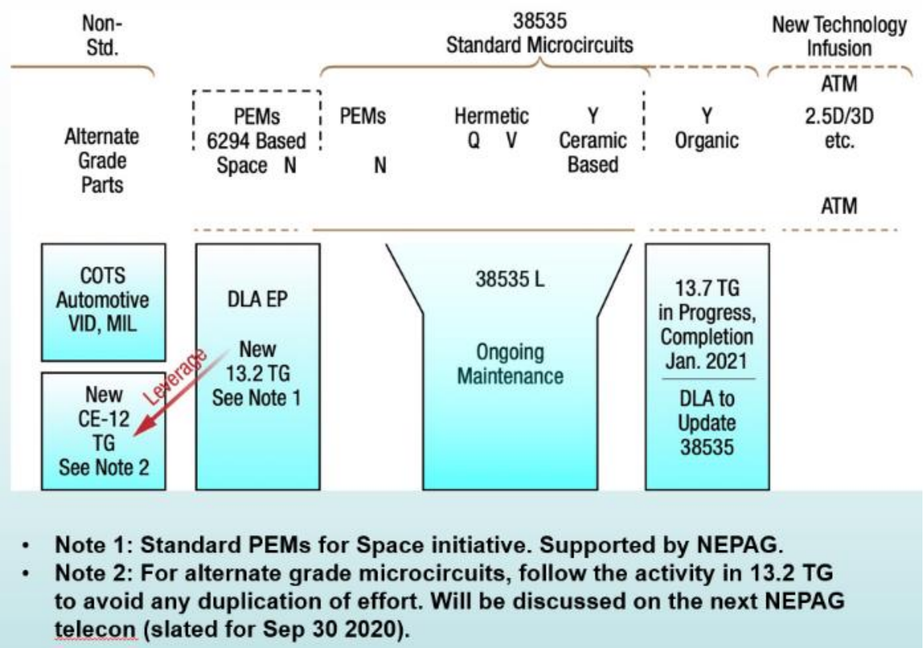
[1] This issue is a follow-on to Volume 11, Issue 1, released May 15, 2020: "Non-Hermetic and Plastic Encapsulated Microcircuits."

[2] Revised on April 2nd 2021: Corrected the Microchip HP and SN flow descriptions on page 3.

characterization step includes the initial investigations needed to understand the details of the technology used in a PEM product [2]. This is crucial when the manufacturer has not evaluated the performance and reliability of a PEM in a space environment. Depending on the information available from the manufacturer, this step might include construction analysis, device evaluation, and/or radiation-hardness analysis. These tests provide important information regarding design, workmanship, and process defects related to a PEM manufacturer lot [2]. The data gathered can help inform the screening and lot-acceptance testing/qualification steps that follow.



- **Note 1: Standard PEMs for Space initiative. Supported by NEPAG.**
- **Note 2: For alternate grade microcircuits, follow the activity in 13.2 TG to avoid any duplication of effort. Will be discussed on the next NEPAG telecon (slated for Sep 30 2020).**

Figure 1. Options for standard, nonstandard, and new-technology microcircuits.

The screening step is applied to all flight parts in each lot. Testing and inspecting every sample proactively checks the reliability of the lot [2]. The screening test flow is described in detail in AS6294/1. After the final parametric and functional tests, a percent defective allowable (PDA) value is calculated with a passing condition of <5%.

Lot-acceptance tests are performed on parts that pass screening. The qualification step includes life-testing, electrical testing at three temperatures, temperature cycling, and more, followed by failure analysis for any failures that occur. Once PEMs have met all requirements specified in AS6294/1, they are cleared for flight.

AS6294/1, however, has never become a standard QML flow, and has not been immediately adopted in its entirety by commercial manufacturers, who offer their own parts flows similar to that in AS6294/1. With the recent increased interest in the use of standard plastic parts in space applications, the space community decided to revisit the document and take a renewed approach to implementing a standard PEMs flow for space. The issue was discussed in domestic and international NASA Electronic Parts Assurance Group (NEPAG) and Government Working Group (GWG) teleconferences. A vote to open a new task group was held during the JEDEC 2020 JC13.2 session, in which participants created the task group from industry partners, with NEPAG and GWG support. The task group (a CE-12 TG) is led by Samantha Williams of Texas Instruments and Rodrigo Deleon of Boeing.

Once the task group based on JC13.2 completes its work, a new proposed TG will be formed to support alternate-grade microcircuits. The work performed by the JC13.2 TG will be heavily leveraged in order to avoid any duplication of effort. See **Figure 1** for details on current and future options for nonstandard, standard, and new-technology microcircuits.

Manufacturer Solutions for Non-Hermetic and Plastic-Encapsulated Microcircuits

Historically, satellite programs have used space-grade, hermetically sealed, QML-V (space) and QML-Q (military) qualified components for enhanced reliability and radiation hardness. With the emergence of “commercial space,” there has been increased interest in using PEMs in space for a variety of reasons. Countering the concerns cited above—narrow operating temperature ranges and susceptibility to infant mortality and moisture absorption [2]—are certain advantages of PEMs over most space-grade hermetically sealed microcircuits: lower cost and weight, more advanced performance, lower power consumption, and smaller overall package size.

With this new growing trend in the market, an increasing number of suppliers now offer a wide range of enhanced plastic product solutions depending on quality, reliability, radiation, and cost. Not all of these product lines follow a consolidated test flow, and all depend on the specific tailoring that each manufacturer makes to them. Hopefully, in the near future, the industry will lean towards following a common flow that will be produced from the JEDEC JC13.2 TG.

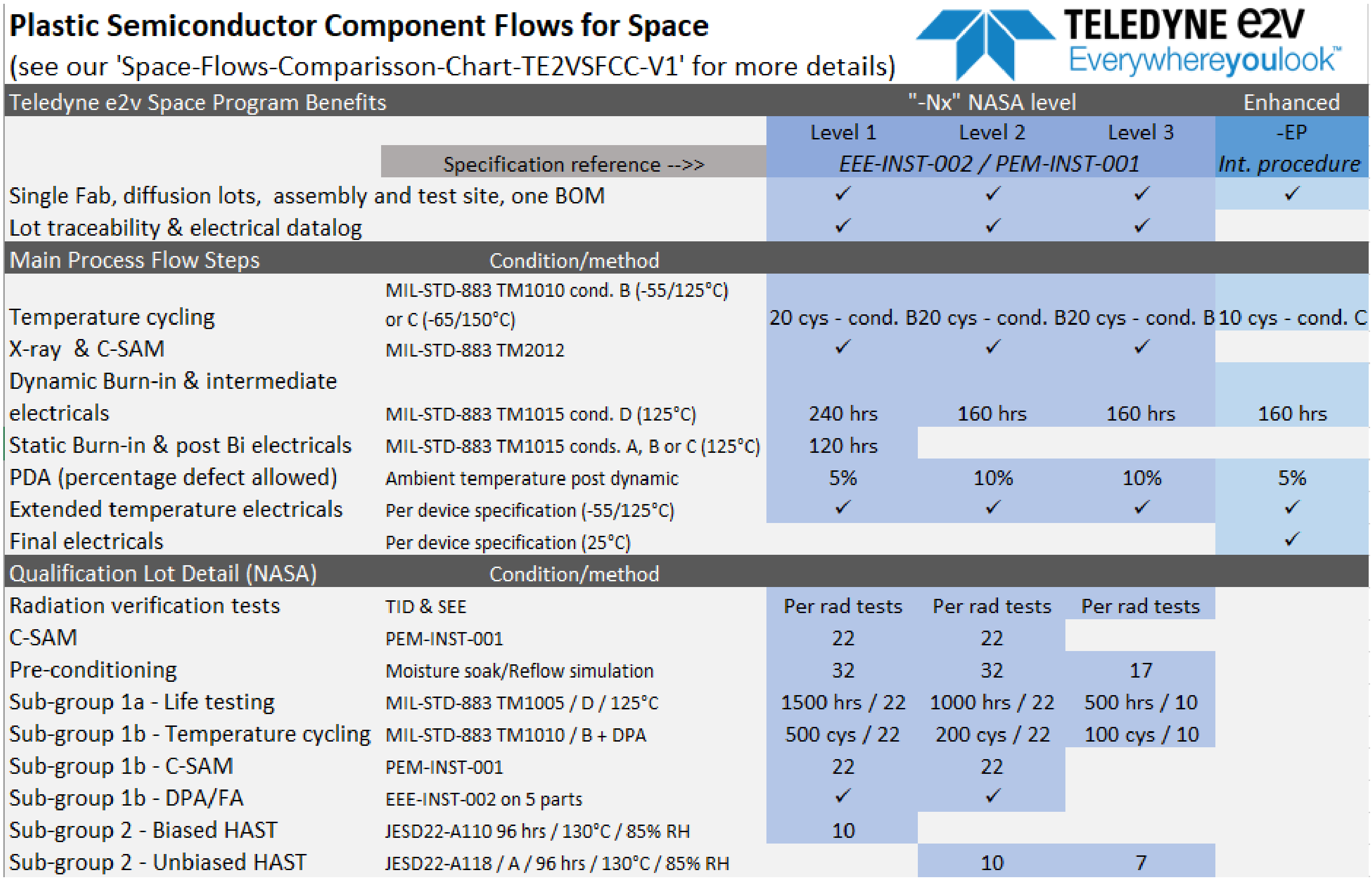
Teledyne e2v designs develops and manufactures systems and components for healthcare, life sciences, space, transportation, defense, security, and industrial markets. They offer both ceramic and plastic, hermetic and non-hermetic parts, tested to various flows, including QML-V, QML-Q, QML-Y (non-hermetic for space), enhanced, and more. **Table 1** shows Teledyne e2v's PEMs screening and qualification flows and the specification references they use [3].

Microchip provides, for space applications, sub-QML field-programmable gate arrays (FPGAs) aimed at bridging the gap between traditional QML components and commercial-off-the-shelf (COTS) components, the latter having little to no radiation or reliability data. For commercial space missions and constellations of small satellites with very stringent cost and schedule requirements, sub-QML FPGAs are the optimal solutions, combining the radiation tolerance of QML components with Microchip's spaceflight heritage, which permits reduced screening requirements, resulting in reduced cost and lead times.

Microchip also provides two space plastic flows: HP and SN^2. The HP flow is for low-cost and high-volume requirements, typically meeting low-Earth-orbit (LEO) constellations' needs. The SN flow provides a higher screening level, including wafer lot acceptance, serialization, 100% thermal cycling, 100% burn-in, and PDA. These flows apply to both rad-hard-by-design and rad-tolerant products. Products made to these flows (SN, HP) meet qualification levels compliant with automotive requirements (AEC-Q100), with the SN flow based on AS6294/1. See **Table 2** for more details on the screening and qualification flows for Microchip HP and SN devices [4].

Micross offers an extensive array of COTS components—both hermetic and plastic—including a wide selection of power modules and small-signal discretes. They also stock a wide range of upscreened plastic products, including an assortment of integrated PEM (iPEM) memory devices that have been tested to selected high-reliability performance levels. In their Retail+ products

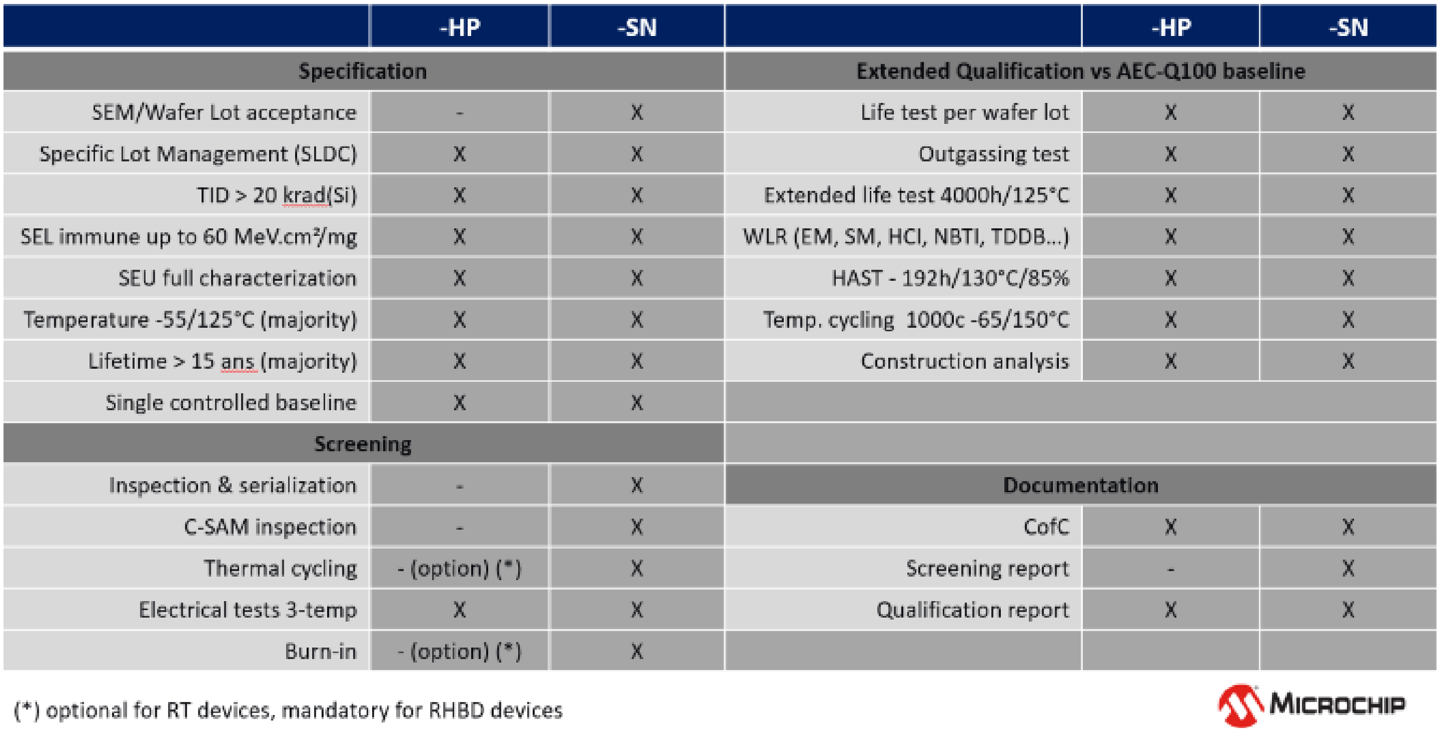
Table 1. Teledyne e2v has various plastic non-hermetic test flows.



Plastic Semiconductor Component Flows for Space
(see our 'Space-Flows-Comparisson-Chart-TE2VSFCC-V1' for more details)

Teledyne e2v Space Program Benefits		"-Nx" NASA level			Enhanced
		Level 1	Level 2	Level 3	-EP
	Specification reference -->>	*EEE-INST-002 / PEM-INST-001*			*Int. procedure*
Single Fab, diffusion lots, assembly and test site, one BOM		✓	✓	✓	✓
Lot traceability & electrical datalog		✓	✓	✓	
Main Process Flow Steps	**Condition/method**				
Temperature cycling	MIL-STD-883 TM1010 cond. B (-55/125°C) or C (-65/150°C)	20 cys - cond. B	20 cys - cond. B	20 cys - cond. B	10 cys - cond. C
X-ray & C-SAM	MIL-STD-883 TM2012	✓	✓	✓	
Dynamic Burn-in & intermediate electricals	MIL-STD-883 TM1015 cond. D (125°C)	240 hrs	160 hrs	160 hrs	160 hrs
Static Burn-in & post Bi electricals	MIL-STD-883 TM1015 conds. A, B or C (125°C)	120 hrs			
PDA (percentage defect allowed)	Ambient temperature post dynamic	5%	10%	10%	5%
Extended temperature electricals	Per device specification (-55/125°C)	✓	✓	✓	✓
Final electricals	Per device specification (25°C)				✓
Qualification Lot Detail (NASA)	**Condition/method**				
Radiation verification tests	TID & SEE	Per rad tests	Per rad tests	Per rad tests	
C-SAM	PEM-INST-001	22	22		
Pre-conditioning	Moisture soak/Reflow simulation	32	32	17	
Sub-group 1a - Life testing	MIL-STD-883 TM1005 / D / 125°C	1500 hrs / 22	1000 hrs / 22	500 hrs / 10	
Sub-group 1b - Temperature cycling	MIL-STD-883 TM1010 / B + DPA	500 cys / 22	200 cys / 22	100 cys / 10	
Sub-group 1b - C-SAM	PEM-INST-001	22	22		
Sub-group 1b - DPA/FA	EEE-INST-002 on 5 parts	✓	✓		
Sub-group 2 - Biased HAST	JESD22-A110 96 hrs / 130°C / 85% RH	10			
Sub-group 2 - Unbiased HAST	JESD22-A118 / A / 96 hrs / 130°C / 85% RH		10	7	

Table 2. A comparison of Microchip's HP and SN plastic quality flows for space.



	-HP	-SN		-HP	-SN
Specification			**Extended Qualification vs AEC-Q100 baseline**		
SEM/Wafer Lot acceptance	-	X	Life test per wafer lot	X	X
Specific Lot Management (SLDC)	X	X	Outgassing test	X	X
TID > 20 krad(Si)	X	X	Extended life test 4000h/125°C	X	X
SEL immune up to 60 MeV.cm^2/mg	X	X	WLR (EM, SM, HCI, NBTI, TDDB...)	X	X
SEU full characterization	X	X	HAST - 192h/130°C/85%	X	X
Temperature -55/125°C (majority)	X	X	Temp. cycling 1000c -65/150°C	X	X
Lifetime > 15 ans (majority)	X	X	Construction analysis	X	X
Single controlled baseline	X	X			
Screening					
Inspection & serialization	-	X	**Documentation**		
C-SAM inspection	-	X	CofC	X	X
Thermal cycling	- (option) (*)	X	Screening report	-	X
Electrical tests 3-temp	X	X	Qualification report	X	X
Burn-in	- (option) (*)	X			

(*) optional for RT devices, mandatory for RHBD devices

line, Micross provides customers with industry-leading COTS components that they have purchased and enhanced for use in high-reliability, long-life applications, including space missions [5].

Micross converts COTS products from lead-free to tin-lead–based metallurgies and uses established processes to increase their reliability for space applications. The PEM qualification flow followed is based on EEE-INST-002 and PEM-INST-001 and provides three levels of qualification, dependent on application risk:

- Level 1 for high-reliability/low-risk, 5+-year missions
- Level 2 for low-to-moderate-risk, 1- to 5-year missions
- Level 3 for high-risk, 1- to 2-year missions

A typical Micross PEMs qualification flow is shown in **Figure 2**.

VORAGO Technologies' plastic microcircuits flow leverages the cost and technology benefits of commercial high-volume manufacturing and adds qualification steps for space applications. Wafers are fabricated in a commercial high-volume process with additional processing steps for enhanced radiation performance. VORAGO Technologies' patented HARDSIL® technology enables radiation-hardening of integrated circuits before the PEMs flow has begun, creating a highly reliable space-grade product without an added cumbersome and costly flow (**Figure 3**). This is unique to VORAGO and all who license the HARDSIL® technology [6].

Due to the low volume and added rad-hard-by-process technology, radiation performance is currently characterized per lot up to 300 krad total ionizing dose, 100 MeV single-event-latchup threshold and <1e-12 uncorrectable errors/bit-day (geosynchronous orbit, solar minimum). Assembly is completed on an AEC-Q100 assembly line with a bill of materials qualified to 175°C. Additional qualification requirements include wafer lot traceability, lot-level steady-state life tests, tri-temp enhanced electrical test, and outgassing characterization per ASTM E595.

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 microcircuits and PEMs fit these requirements perfectly, a fact that has led to many manufacturers offering appropriate flows for these applications. Meeting the new challenges of qualifying these products for space is an important step towards the successful future of space exploration.

References

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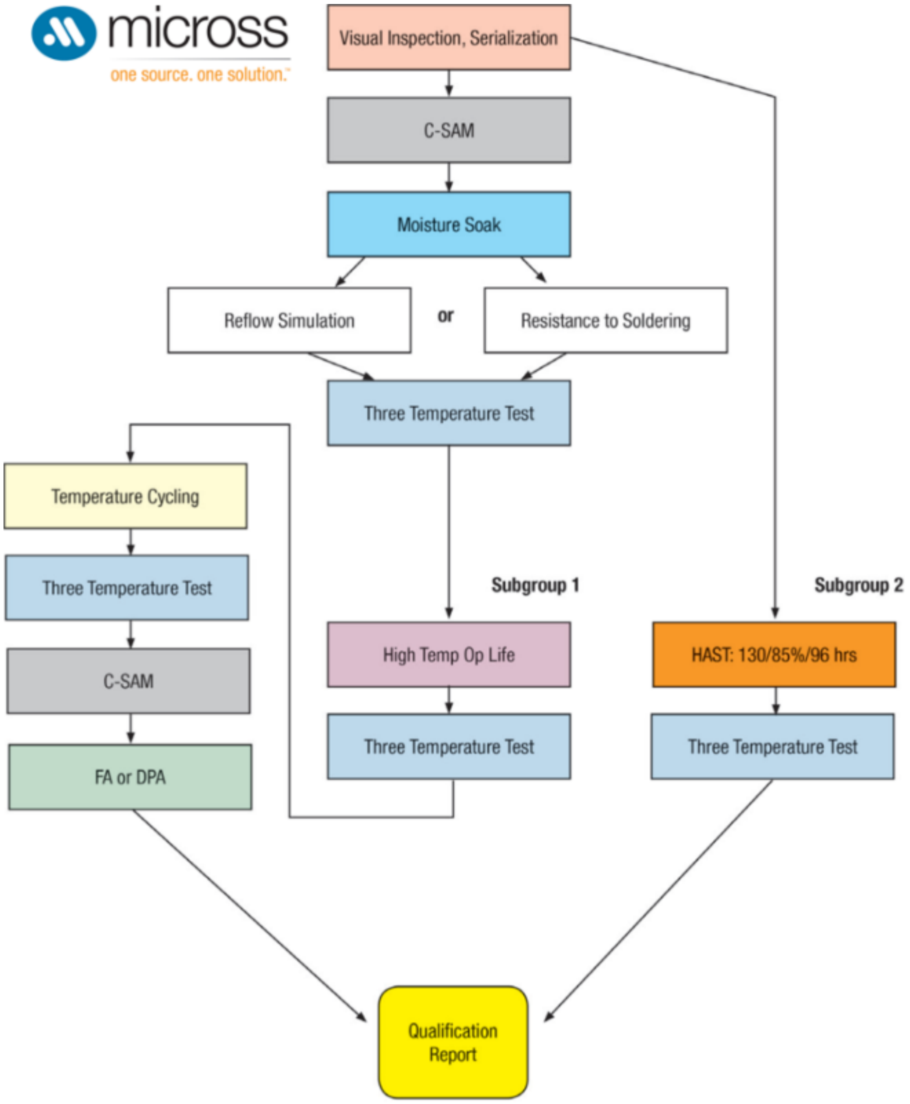
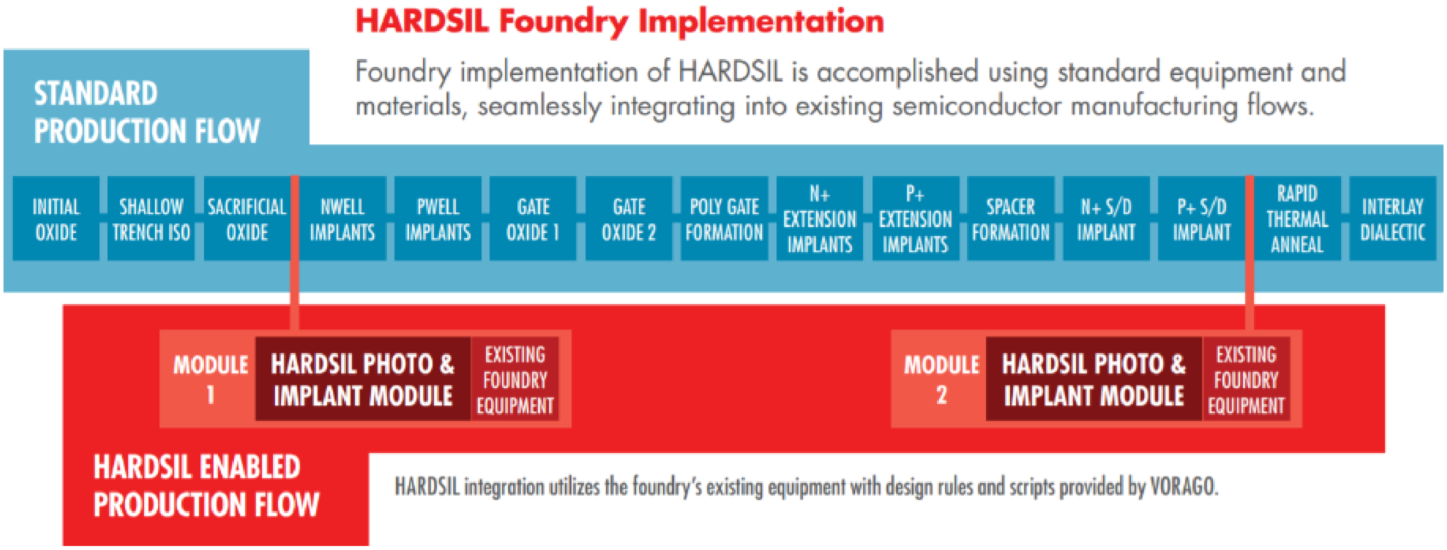


Figure 2. Micross's customizable PEMs qualification flow.



HARDSIL Foundry Implementation

Foundry implementation of HARDSIL is accomplished using standard equipment and materials, seamlessly integrating into existing semiconductor manufacturing flows.

HARDSIL integration utilizes the foundry's existing equipment with design rules and scripts provided by VORAGO.

Figure 3. VORAGO Technologies' HARDSIL®-enabled production flow insertion.

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