National Aeronautics and Space Administration

NASA GSFC Code 300 SMA Perspective on Opportunities to Use Automotive Grade EEE Parts in Flight Applications

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SAFETY and MISSION ASSURANCE DIRECTORATE Code 300

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Outline

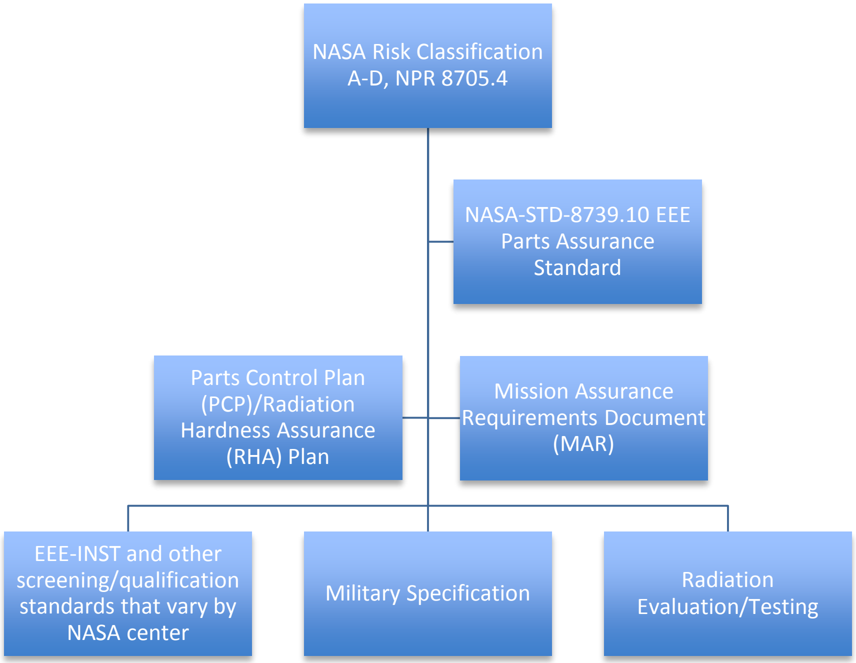
- EEE Part Suitability
- NASA's Traditional Approach to Suitability
- Why should NASA consider alternate EEE part approaches?
- Automotive Parts Approach to Reliability
- Automotive vs Military Specification
- NASA Evaluations of Automotive EEE Parts
  - NASA Electronics Parts and Packaging Program (NEPP)
  - NASA Engineering and Safety Center (NESC)
- Can we use automotive grade EEE parts in flight NASA missions?

What makes a EEE part suitable for a flight NASA mission?

Application

Manufacturability

NASA's Traditional Approach to EEE Part Suitability



- **Pros:**
  - EEE parts are qualified over broad end use applications
  - Established quality control system
  - Traceability
  - High success rate in flight applications

NASA's Traditional Approach to EEE Part Suitability (Continued)

- **Cons with traditional NASA approach:**
  - Cost prohibitive in some cases
  - Schedule prohibitive in some cases
  - Performance lags commercial options
  - Relatively low volume manufacturing which can enable quality escapes (Statistical Process Control)
  - Nebulous correlation with project risk posture
- **Takeaway:**
  - Project schedule and budget environments are becoming increasingly challenging and competitive
  - Any EEE part alternatives that can reduce cost and lead-time, and increase capability without compromising reliability should be thoroughly considered

Why Consider Automotive Grade Parts For Flight NASA Missions?

EEE Part Pedigree	Cost	Lead time	Performance	Market Share (Statistical Process Control)
Automotive	X	X	X	X (>10X Mil/Aero)

*Attributes when compared to the traditional NASA approach

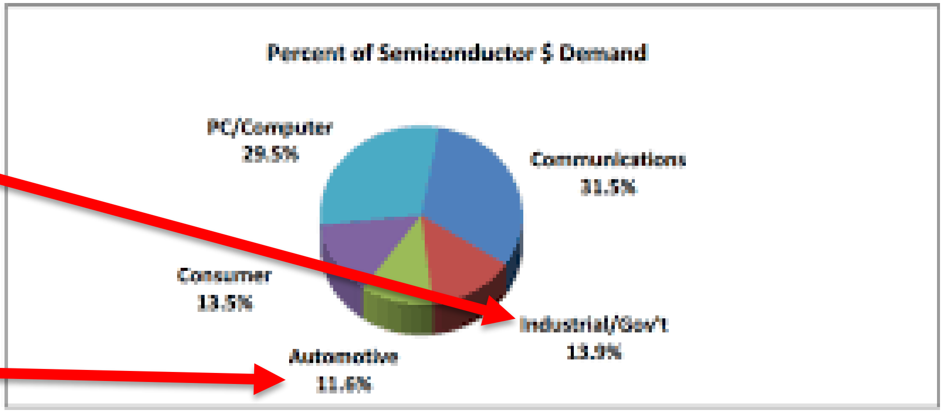
Semiconductor Demand Drivers: 2016 Growth

2016 Total Global Semiconductor Market $339 Billion $339 Billion

Industrial/Gov't **13.9%**.

*Military/Aerospace is included in this number but only account for **1%** of market share

Automotive **11.6%**



Source: WSTS End Use Report, 2016

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Note: Govt. includes military and is @ 1% of the industrial category.

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Can automotive EEE parts be used by NASA in space?

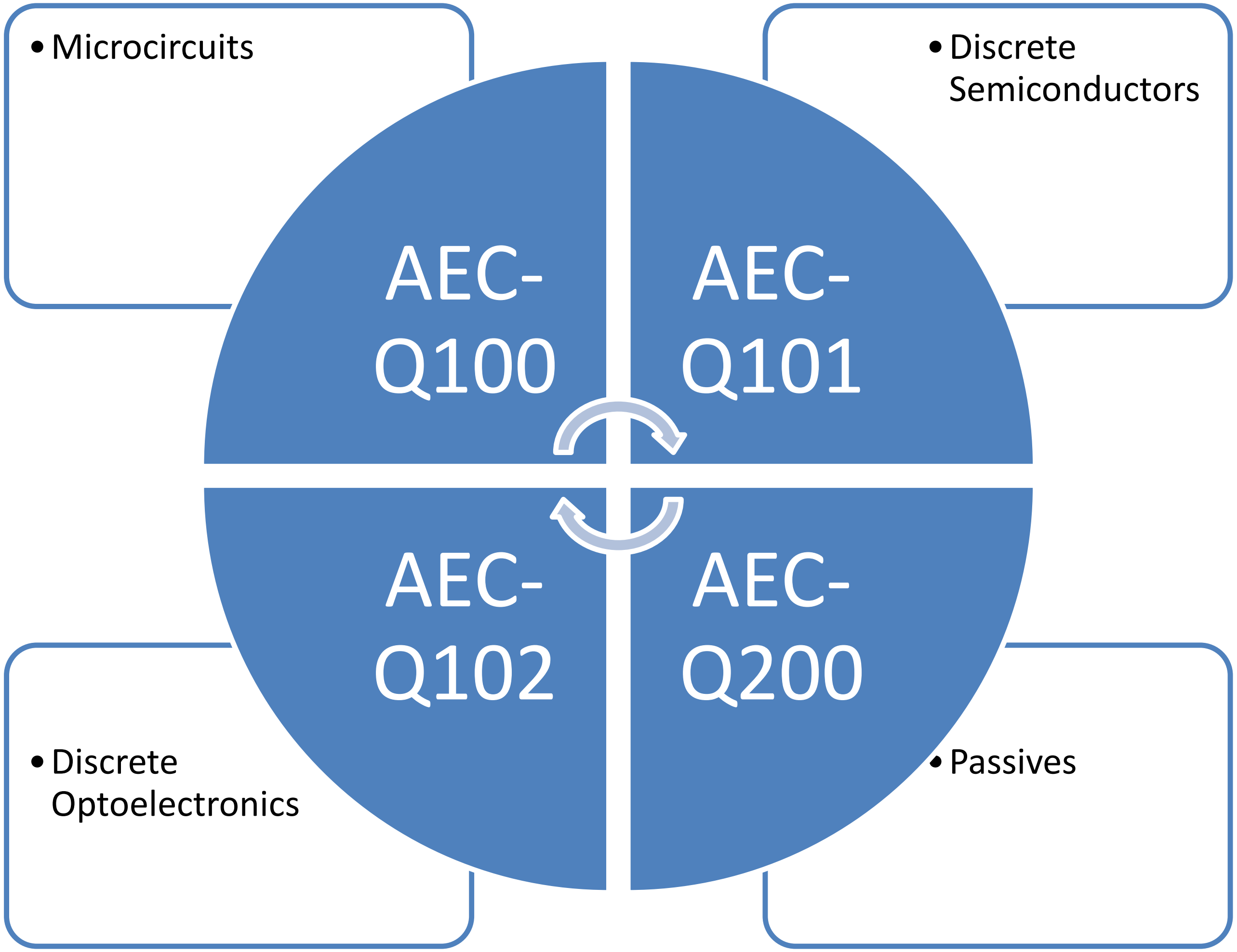
Automotive Approach to EEE Part Reliability- Automotive Electronics Council (AEC) [1]

Sustaining Members

Technical, Associate and Guest Members

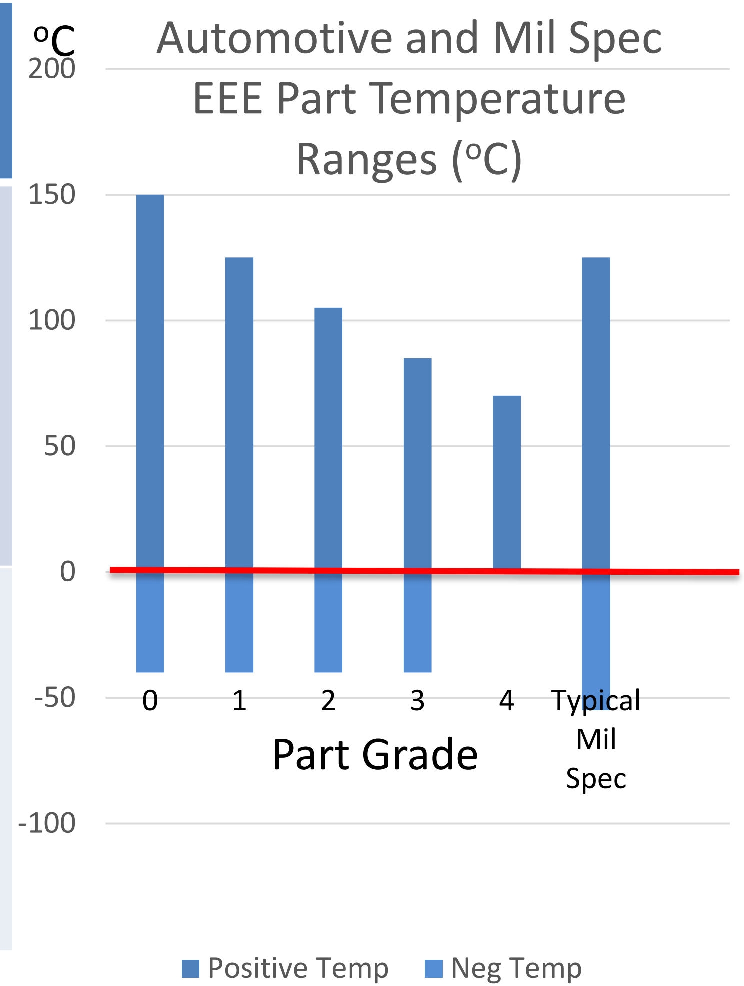
***Many listed members have delivered Flight parts for NASA missions**

Automotive Approach to EEE Part Reliability- AEC-Q Specifications



AEC-Q vs Military Specification

Specification Type	Grade	Screening	Qualification	Re-Qualification	Radiation Designator
AEC	Temp Range	Not Required	Device "Family"	Major changes	No
Military	Failure Rate/Test Level	Required	Each Device	Periodically (1-3 years)	Some have RHA Designators



AEC-Q vs Military Specification Construction Differences

- AEC-Q specification parts may contain materials typically prohibited in flight NASA missions (i.e. pure tin)
  - Mitigations such as solder dipping and conformal coating should be followed as necessary.

- AEC-Q specification Plastic Encapsulated Microcircuits may contain copper bond wires
  - Reliability of copper bond wires is an ongoing study
    - Concerns about bond strength, corrosion, die cracking
    - NESC is in early phases of studying this issue
  - In 2015 the AEC established AEC-Q006: "Qualification Requirements for Components Using Copper Wire Interconnections to ensure reliability of EEE parts with copper wire bonds"

AEC-Q vs Popular Military Specifications- Qualification

Specification	Accelerated Environment Testing	Accelerated Lifetime Testing	Package Integrity Testing	Die Reliability Testing
AEC-Q100	X	X	X	X
Mil-Prf-38535	X	X	X	X
AEC-Q101	X	X	X	-
Mil-Prf-19500	X	X	X	-
AEC-Q200	X	X	X	N/A
Mil-Prf-55342	X	X	X	N/A
Mil-Prf-55681	X	X	X	N/A

Takeaway: AEC-Q and Military Specification qualification tests have similarities. AEC-Q specifications reference JEDEC test standards in many cases, Military Specifications typically reference Military Standards.

AEC-Q vs Military Specification- Data Package

- **Military Specification Data Package**
  - Lot specific screening results
  - Qualification results (lot specific or most recent)
  - Production traveler

- **AEC-Q Specification Data Package**
  - Expectation of certification to ISO 16949
  - ISO 16949 requires a Production Part Approval (PPAP) document
  - 18 elements
  - Depth of information varies by manufacturer and order size, customer oriented

NASA Evaluations of Automotive EEE Parts

NEPP Automotive EEE Part Goals

1. Determine exactly what: “automotive grade” does or does not entail.
2. Perform “snapshot” screening and testing on representative automotive grade electronic parts.
3. Parts selected for test were those available in automotive (AEC) grade that were closest in function to popular parts in current use
4. Develop Agency Assurance and Collaborative (U.S. Government, International Partners) Guidance

NEPP Automotive EEE Parts Test Results

Part Type	Manufacturers	Quantity Tested	Duration (hours)	Results
Ceramic Capacitors	6	597	10,000	All lots met typical requirements for MIL/Hi rel life test
Tantalum chip capacitors	1	160	2,000	No failures
Microcircuit	1	90	2,000	No failures
NPN Transistor	1	20	5,000	No failures
Diode	1	20	100	Strange behavior at elevated temperatures

Data as of August 2017. All devices met datasheet parameters.

NESC Test Flows On Selected Components

Environmental Testing

- Initial Electrical Measurements
- Moisture Pre-conditioning
- Solder Reflow Simulation
- Post Reflow Electrical Measurements
- Biased HAST/Thermal Cycle/Intermittent Operating Life
- Final Electrical Measurements
- DPA

Temperature Cycling

- Initial Electrical Measurements/Initial Pre-thermal DPA
- Thermal Cycle
- Final Electrical
- Post Thermal DPA

Radiation Testing

- Selected Single Event Effects (SEE) Test Evaluations

NESC Environmental Stress Testing Results

- Environmental Stress Testing Performed on 360 total parts
  - 6 part types, 60 each
  - N-Channel MOSFETs, P-Channel MOSFETs, Diodes
  - 5 of 6 part types had no anomalies in electrical measurements or DPA
  - 1 part type exhibited electrical failures [2/20] after Highly Accelerated Stress Testing (HAST)

NESC Temperature Cycling Results

- Temperature cycling performed on 120 total parts
  - 3 part types, 40 each
  - Ceramic capacitors, P-channel MOSFETs, N-Channel MOSFET's
  - No failures or degradation observed

NESC Radiation Test Results

- MOSFET's, Operational Amplifiers, and Diodes were tested
  - Various SEE's observed
  - 1 particular N-channel MOSFET showed high variability within same lot

Can automotive EEE parts be used by NASA in space?

How will NASA use automotive grade EEE parts on NASA missions?

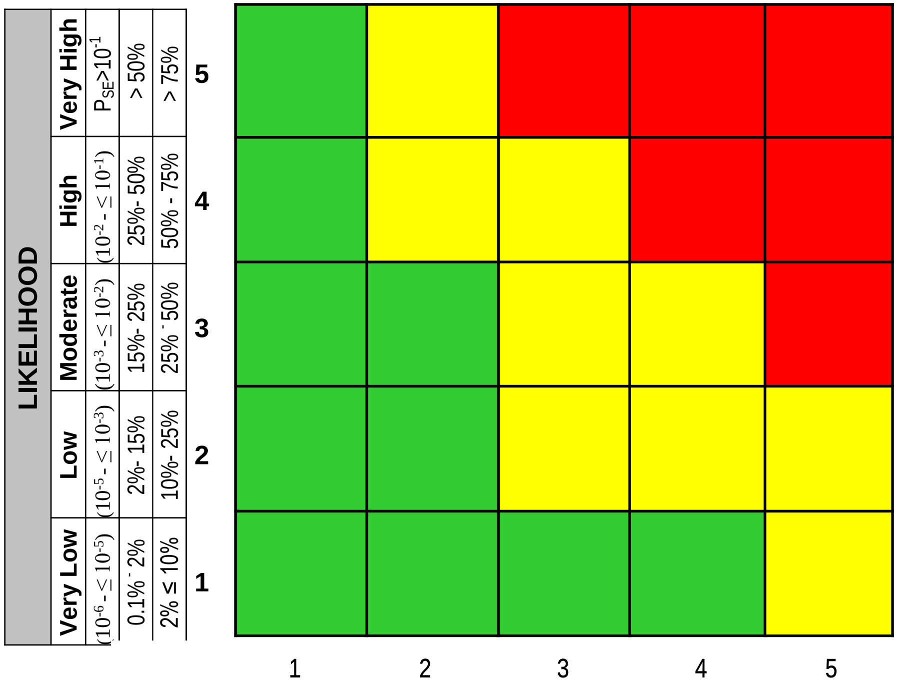
- Using the NASA paradigm of **YES, IF:**
  - Holistic ***risk based*** approach is used when selecting EEE parts
    - Mission specific risk trades are used to determine if automotive EEE parts are appropriate. *They may not be appropriate for all applications*
  - Good design, handling, and assembly practices and safe guards
  - Additional tests and inspections as necessary
  - Reputable vendors with proven processes

Holistic View

- Understand criticality of EEE parts to component and system (i.e. FMEA)
- EEE parts selection trades based on risk (likelihood and consequence)
- Understand correlation between project risk classification and EEE parts selection

Mission Specific Risk Trades

- NASA GSFC follows an approach where risks are classified by likelihood and consequence to the mission
  - Governed by GPR 8705.4
- For EEE parts likelihood is the likelihood of the part failing to meet specification. This is influenced by a number of factors i.e.:
  - Operating conditions
  - Mission duration
  - Part, Assembly and System level test profiles and results
- Consequence is impact to the mission i.e.:
  - Telemetry would have to be collected using secondary sources, negligible impact
  - Failure would result in loss of the instrument and subsequently loss of the mission



	1	2	3	4	5
Safety (S)	Negligible or no impact	Could cause minor first aid treatment	May cause minor injury or occupational illness, minor property damage	May cause severe injury or occupational illness major property damage	May cause death or permanent injury or destruction of property
Technical (T)	No KPP impact / no tech required	Minor impact to KPP / mod to existing tech required	Moderate impact to KPP/ some new tech required	Significant impact to KPP/ mod new tech required	KPP cannot be met / major new tech required
Cost (C)	≤ 1% increase	≥ 1% but ≤2% increase	≥2% but ≤ 5% increase	≥5% but ≤8% increase	> 8% increase
Schedule (SC)	No slip	Non-critical slip 1-2 mo	Non-critical slip 2-3 mo	Non-critical slip 3-4 mo	Slip on critical path, launch date
CONSEQUENCES					

Good Design, Handling and Assembly Practices

- Derate (electrically, thermally, mechanically)
- Follow manufacturer recommendations
- Check for available data during design selection stage (i.e. radiation test results, screening and qualification results)
  - There are multiple industry efforts in motion to establish data sharing of alternate grade parts. NEPP is heavily involved in this effort
- Design tolerance
  - Including radiation tolerance when applicable/possible and avoid destructive effects
- Store parts in controlled environment (humidity and temperature)
- Assemble parts per recognized industry standards
- Tin whisker mitigation
  - Solder dip, conformal coat, etc

Additional Tests and Inspections

- Sample Destructive Physical Analysis (DPA) is a powerful tool
- Understand radiation concerns and test when project risk posture dictates necessary
- Screening tests can be performed as a tool to gain confidence that all infant mortality issues have been weeded out when project risk posture dictates necessary
- Board, component, and system level testing are essential
  - TVAC
  - Vibe
  - Test as you fly!
- Workmanship inspections at the piece part and assembly level

Reputable Vendors

- Perform common buys as much as possible
  - Buying power plays a major role in establishing relationship with vendors
- Certification to ISO 16949 a plus
  - Request and review PPAP. Can be challenging for small orders.
- Experience delivering EEE parts for high reliability programs
  - Bonus if they've delivered successfully for space programs
- Established Statistical Process Control (SPC)

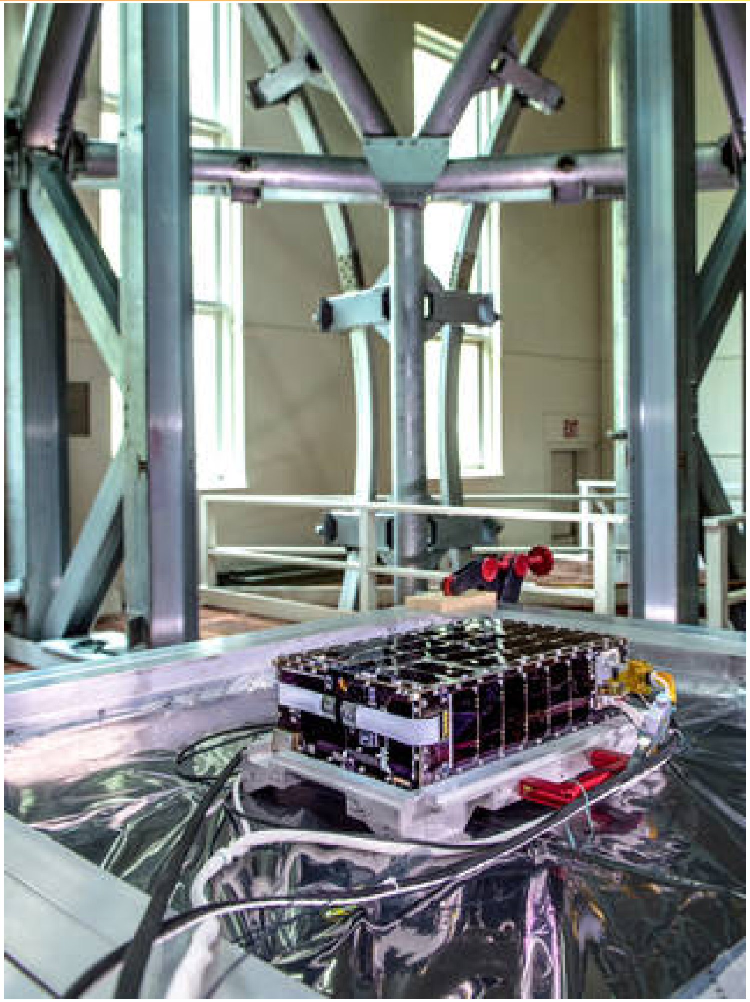
Conclusion

- Automotive EEE parts have an established quality system and are very reliable in automotive applications
  - Many automotive manufacturers require electrical parts failure rate of <10ppm/year [3] [4]

- Automotive EEE parts have benefits over traditionally selected NASA EEE parts
  - Cost, lead time, performance

- Automotive EEE parts have a different approach when compared to traditional NASA selected EEE parts (i.e. Mil spec, SCD)
  - No requirement for screening
  - No evaluation of space radiation effects
  - Qualification approach
  - Prohibited materials/Copper bond wires

- Despite these differences, automotive EEE parts ***can be successfully used in SOME flight NASA applications if proper practices are in place***
  - CubeSat community has successfully used automotive grade EEE parts for more than 20 years [5]



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References

1. Sampson, M. (2015, June 06). “Automotive Grade Electronics for In-Space Applications”
2. Label, K. (2017, October 23). “Electrical, Electronic and Electromechanical (EEE) Parts in the New Space Paradigm: When is Better the Enemy of Good Enough?”
3. Dallman, G. “0 ppm Failure Rate For Automotive Microelectronics-No Chance Without Extensive and Proactive Physical and Chemical Analysis”
4. Eckert, K. “What Automotive Quality Means and Why You Can’t Afford To Cut Corners”
5. Moe, M and Sullivan, E. “SmallSat Reliability Technology Interchange Meeting (TIM) Summary”
6. Keesey, L. (2017, August 06). “NASA Set to Launch Dellingr; CubeSat Purposely Designed to Improve Reliability of Small Satellites”
7. Yinug, F. (2017, May 12). “End-Use Products That Drove Semiconductor Sales in 2016”

Acknowledgements

- NASA GSFC Safety and Mission Assurance Directorate Code 300
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- NASA GSFC EEE Parts Branch and Parts Analysis (PA) Lab
- NASA GSFC Radiation Effects Branch
- NASA Electronics Parts and Packaging (NEPP) Program
- NASA Engineering and Safety Center (NESC)

BACK UP SLIDES

Automotive Grade “Family” Example - Microcircuits

- For AEC Q100 microcircuits a family is defined as having the same attributes:
  - Fab Process
    - Wafer Fab Technology (i.e. CMOS, NMOS, Bipolar, etc)
    - Wafer Fab Process (i.e. circuit element feature size, substrate, lithographic process etc)
    - Wafer Fab Site
  - Assembly Process (Plastic and Ceramic Parts Must Be Considered Separately)
    - Package Type
    - Assembly Process (i.e. leadframe base material, die attach material, wire bond material and diameter, etc)
    - Assembly Site

AEC-Q Qualification Example- AEC-Q-100 (Microcircuit)

- Qualification Tests
  - Accelerated Environment Stress Tests (Group A)
  - Accelerated Lifetime Simulation Tests (Group B)
  - Package Assembly Integrity Tests (Group C)
  - Die Fabrication Reliability Tests (Group D)
  - Electrical Verification Tests (Group E)
  - Defect Screening Tests (Group F) *Optional (not considered qualification)
  - Cavity Package Assembly Integrity Tests (Group G)

- These tests are **as stressful** and in some cases **more stressful** than military specification qualification tests

AEC-Q100 Accelerated Environment Stress Tests (Group A)

- Preconditioning (JEDEC J-STD-020 JESD22-A113)
- Unbiased and Biased Highly Accelerated Stress Test (JEDEC JESD22-A101, A110, A102, A118)
- Temperature Cycling (JEDEC JESD22-A104)
- Power Temperature Cycling (JEDEC JESD22-A105)
- High Temperature Storage Life (JEDEC JESD22-A103)

Gaps:

- Radiation is a concern for space applications and is not a part of the Automotive qualification process
  - TID radiation hardness indicators not apart of the Automotive grade part system
  - No mention of single event or other radiation parameter performance
- Mechanical tests are included in Group G (described below)

AEC-Q100 Accelerated Lifetime Simulation Tests (Group B)

- High Temperature Operating Life (JEDEC JESD22-A108)
- Early Life Failure Rate (AEC Q100-008)
- NVM Endurance, Data Retention, and Operational Life (AEC Q100-005)

AEC-Q100 Package Assembly Integrity Tests (Group C)

- Wire Bond Shear (AEC Q100-001)
- Wire Bond Pull (Mil-Std-883 Method 2011)
- Solderability (JEDEC JESD22-B102)
- Physical Dimensions (JEDEC JESD22-B100 and B108)
- Solder Ball Shear (AEC Q100-010)
- Lead Integrity (JEDEC JESD22-B105)

AEC-Q100 Die Fabrication Reliability Tests (Group D)

- Electromigration
- Time Dependent Dielectric Breakdown
- Hot Carrier Injection
- Negative Bias Temperature Instability
- Stress Migration

AEC-Q100 Electrical Verification Tests (Group E)

- Pre and Post Stress Function/Parameter (custom)
- ESD Human Body Model/Machine Model (AEC Q100-002/ Q100-003)
- ESD Charged Device Model (AEC Q100-011)
- Latch-up (AEC Q100-004); note: not related to radiation effects
- Electrical Distributions (AEC Q100-009)
- Fault Grading (AEC Q100-007)
- Characterization (AEC Q003)
- Electrothermally Induced Gate Leakage (AEC Q100-006)
- Electromagnetic Compatibility (SAE J1752/3)
- Short Circuit Characterization (AEC Q100-012)
- Soft Error Rate (JESD89-1 or JESD89-2/-3)

AEC-Q100 Cavity Package Assembly Integrity Tests (Group G)

- Mechanical Shock (JEDEC JESD22-B104)
- Variable Frequency Vibration (JEDEC JESD22-B103)
- Constant Acceleration (Mil-Std-883 Method 2001)
- Gross/Fine Leak (Mil-Std-883 Method 2014)
- Package Drop
- Lid Torque (Mil-Std-883 Method 2024)
- Die Shear (Mil-Std-883 Method 2019)
- Internal Water Vapor (Mil-Std-883 Method 1018)

AEC-Q100 Defect Screening Tests (Group F)

- Process Average Testing (AEC Q001)
- Statistical Bin/Yield Analysis (AEC Q002)
- 100% screening is not used.

Further Discussion on AEC-Q100 Defect Screening Tests (Group F)

- Another difference between mil spec and automotive parts is that mil spec parts require 100% screening and automotive parts do not require screening
- AEC Q100 spec states "it is highly desirable suppliers adopt these tests in their standard manufacturing operation"
- AEC Q001 is the screening specification called out in the AEC Q100
  - Purpose: "This guideline is intended to provide a general method for removing abnormal parts and thus improve the quality and reliability of parts supplied per AEC-Q100 and AEC-Q101."
  - Statistically based method for performing Part Average Testing (PAT)
- Static testing limits established using historical test data from 6 or more previous lots
- Dynamic test limits are established using the same approach as static but require data from the actual lot captured during static level testing
- Parts performing out of family are removed from the lot

Further Discussion on AEC-Q100 Defect Screening Tests (Group F) (Cont)

- *Required* Screening Tests for Microcircuits:
  - Pin leakage test (curve tracer or equivalent to verify junction characteristics)
  - Standby Power Supply Current (Idd or Icc)
  - IDDQ testing (if applicable)
  - Output breakdown voltage, Output leakage, Output current drive, Output voltage levels
    - Applicable to Linear and BiCMOS devices
  - Over-Voltage Stress Test
  - Low Level Input Current, High Level Input Current, Low Level Output Voltage, High Level Output Voltage
  - Propagation Delay or Output Response Time, Rise/Fall Times
- *Required only if vendor elects to follow procedure

NASA